Welcome to ForestSAT 2018

The University of Maryland, NASA Goddard Space Flight Center and Science Committee warmly welcome you to ForestSAT 2018, the conference of the Association for Forest Spatial Analysis Technologies (ForestSAT). ForestSAT 2018 marks the eighth meeting of our biennial conference, with a goal of providing a vibrant and dynamic forum for discovery and discussion of the latest research in remote sensing and geomatics for forestry applications.

Echoing the theme of our conference, we are entering a new era in forest observation and analysis. New remote sensing missions, airborne and in-situ platforms, and the explosion in data fusion and cloud computing technologies are revolutionizing how we monitor and model forests around the world. At the same time, there is a new urgency among various scientific, governmental and NGO organizations to expand our understanding and use of forests with respect to ecosystem services, such as carbon storage, biodiversity, water quality, human livelihoods and others.

Both the University of Maryland and NASA GSFC provide important centers for the development and application of new technology for forestry. Likewise, Washington D.C. is a key center of activity, with its confluence of the US federal government, International, and non-profit organizations. We are thus especially pleased to be hosting ForestSAT 2018 here at the University of Maryland at such an important time.

We have organized a compelling program of keynote speakers, presentations and posters around our five themes: (1) Global Forest Observation; (2) New Approaches to Forest Ecosystem Modeling; (3) The Revolution in Remote Sensing Fusion; (4) Forest Mapping and Inventory, and; (5) Forest Management and Policy. We hope each of you find new insights, develop new connections with those you do not know and strengthen existing bonds with those you do. We encourage you to take full advantage of the amazing resources of the Washington D.C. area while you are here. Its monuments and memorials, eclectic neighborhoods, exceptional culinary opportunities, and rich cultural history have transformed what was once a staid and formal city to one of the great destinations in the world.

Lastly, ForestSAT 2018 would like to thank NASA's Terrestrial Ecology and Landcover programs, the Department of Geographical Sciences at the University of Maryland and the Biospheric Sciences Laboratory at NASA GSFC for their generous support of the conference.

TABLE OF CONTENTS

This program is best viewed in Firefox.

Please use bookmark menu in Adobe Reader to navigate between pages

ForestSAT 2018 Organizing Committee

Co-Chair: Ralph Dubayah, University of Maryland
Co-Chair: Jeffrey Masek, NASA Goddard Space Flight Center
Lead Conference Manager: Maureen Duane, Oregon State University
John Armston, University of Maryland
Shannon Corrigan, University of Maryland
Laura Duncanson, University of Maryland/NASA Goddard Space Flight Center

Conference Quick View

<table>
<tr><th></th><th colspan="4">MONDAY 1 OCTOBER</th></tr>
<tr><td>10:00-16:00</td><td colspan="4">Optional Excursion to National Arboretum</td></tr>
<tr><td>16:00-18:00</td><td colspan="4">FOYER A & B: Exhibitor and Poster set up</td></tr>
<tr><td>18:00-20:00</td><td colspan="4">FOYER A & B:
Registration and **Posters** (1st session) on display
Welcome Ice Breaker
Sponsored by ecometrica</td></tr>
<tr><th></th><th>TUESDAY</th><th>WEDNESDAY</th><th>THURSDAY</th><th>FRIDAY</th></tr>
<tr><td>8:00-9:00</td><td colspan="4">FOYER A & B: **Registration** and **Breakfast**</td></tr>
<tr><td rowspan="2">9:00 - 9:15</td><td colspan="4">CALVERT BALLROOM: **Welcome and Announcements**</td></tr>
<tr><td></td><td>SilviaTerra Forest Basemap for the US</td><td></td><td>Thomas Hilker Award Presentation</td></tr>
<tr><td rowspan="2">9:15 - 10:15</td><td colspan="4">CALVERT BALLROOM KEYNOTES:</td></tr>
<tr><td>**F Seymour**</td><td>**T Crowther & JF Bastin**</td><td>**Industry Panel**</td><td>**P Scarth & D Schimel**</td></tr>
<tr><td>10:15-10:30</td><td colspan="4">FOYER A & B: **Morning Break**</td></tr>
<tr><td>10:30-12:10</td><td colspan="4">SALONS E, F, G and TOP OF THE 7's BALLROOM:
Morning parallel sessions</td></tr>
<tr><td>12:10 - 13:30</td><td colspan="4">CALVERT BALLROOM: **Lunch**</td></tr>
<tr><td>13:30 - 15:10</td><td colspan="4">SALONS E, F, G and TOP OF THE 7's BALLROOM:
Afternoon parallel sessions 1</td></tr>
<tr><td>15:10 - 15:30</td><td colspan="4">FOYER A & B: **Afternoon Break**</td></tr>
<tr><td>15:30 - 17:10</td><td colspan="4">SALONS E, F, G, TOP OF THE 7'S and CALVERT BALLROOM (Thursday & Friday)
Afternoon parallel sessions 2</td></tr>
<tr><td>17:15 - 18:45</td><td>FOYER A & B:
Poster Reception #1</td><td>FOYER A & B:
Poster Reception #2</td><td>17:45 - Board bus to dinner
18:00 - Buses depart</td><td></td></tr>
<tr><td>18:45</td><td></td><td>Women of ForestSAT Reception (MilkBoy ArtHouse)</td><td>Conference Dinner Cruise</td><td></td></tr>
<tr><th></th><th colspan="4">SATURDAY 6 OCTOBER</th></tr>
<tr><td>10:00-17:00</td><td colspan="4">Optional Excursion to
Smithsonian Environmental Research Center</td></tr>
</table>

Conference Map

The Hotel at the University of Maryland

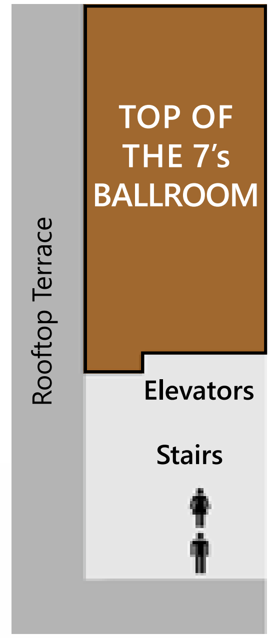
TOP OF THE 7'S BALLROOM – Sessions

CALVERT BALLROOM – Keynotes/Panel, Sessions, Lunch

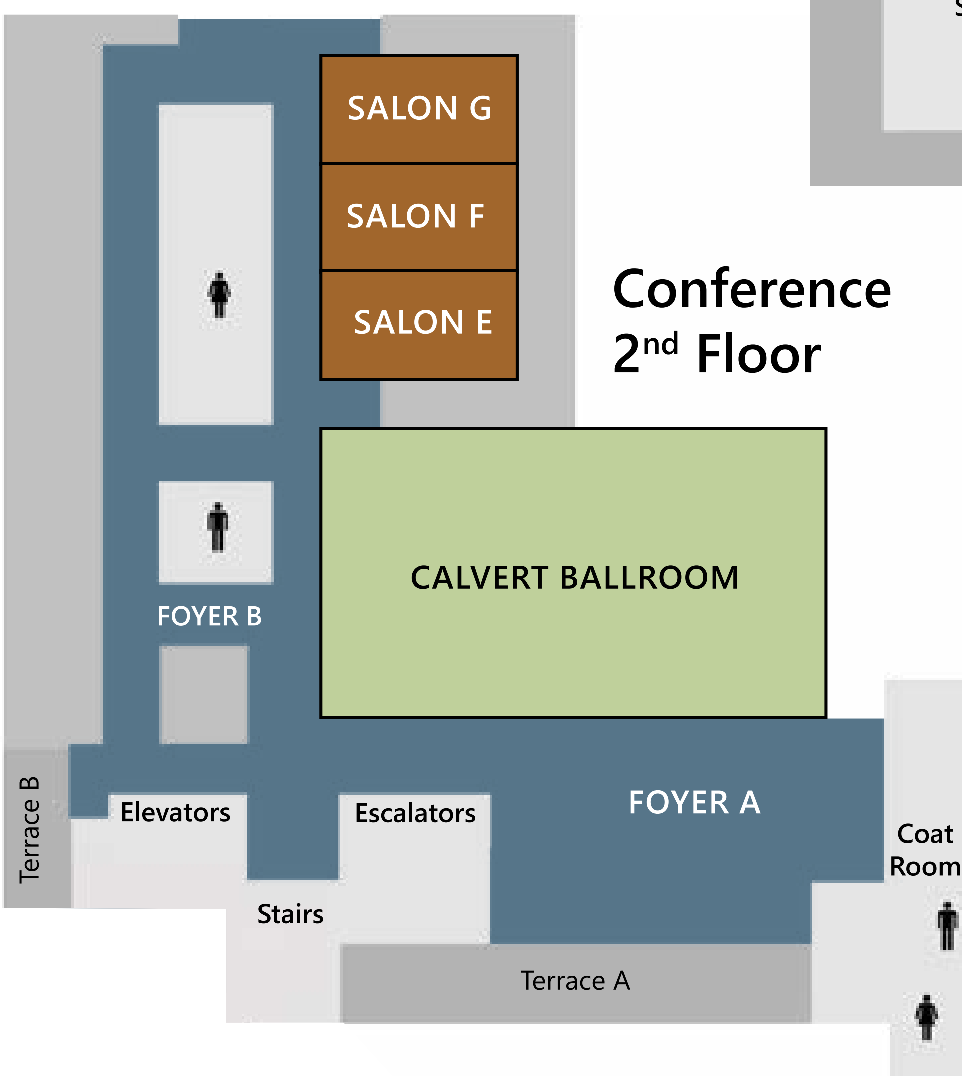
SALONS E, F, G – Sessions

FOYER A & B – Registration, Poster Sessions, Exhibitors, Breakfast/Breaks

Penthouse 10th Floor



Conference 2nd Floor



Times	Tuesday 2 October Event/Activity	
8:00-9:00	FOYER A&B Breakfast and Registration	
9:00-9:15	CALVERT BALLROOM: Welcome and Announcements	
9:15-10:15	CALVERT BALLROOM: Keynote: Frances Seymour	
10:15-10:30	FOYER A&B Mornng Break	
10:30-12:10	SALON E	SALON F

SALON E

Satellite Product Calibration and Validation

1. **Terrestrial Laser Scanning for calibration and validation of satellite image data products across Queensland, Australia** | N Goodwin, J Armston*, F Watson
2. **Validation of the GEDI simulator for pre-launch calibration and validation** | S Hancock*, J Armston, H Tang, M Hofton, JB Blair, S Luthcke, X Sun, JR Kellner, S Marselis, D Minor, S Healey, P Patterson, R Dubayah
3. **Influence of reference data accuracy in remote sensing studies** | HJ Persson*, G Ståhl, N Lindgren
4. **Validation of the operational SNPP VIIRS GVF product using high resolution Google Earth images in urban areas in U.S.** | Z Jiang*, Y Yu
5. ESA-NASA Multi-Mission Analysis Platform | A Whitehurst*, K Murphy, R Ramachandran, K Bugbee, H Laur, C Albinet

SALON F

Multi-Date Lidar Applications

1. **Monitoring adaptation to wind in Sitka spruce plantations using time-series analysis of airborne Lidar** | J Suarez*, R Manso
2. **Modelling top height growth and stand volume increment using repeated laser scanning data** | J Socha*, M Pierzchalski, K Stereńczak, P Hawryło, S Miścicki, G Krok
3. **Direct and indirect site index determination for Norway spruce and Scots pine using bitemporal airborne laser scanner data** | L Noordermeer*, OM Bollandsås, T Gobakken, E Næsset
4. **Canopy structural metrics for quantifying landscape level forest degradation** | G Parker*, A Anand, J Nagol
5. **Airborne Lidar detection of tropical forest degradation through simulations of selective logging disturbance using individual tree segmentation** | V Meyer*, S Saatchi, A Ferraz, M Longo, J Bastin, M Keller

SALON G

Large Area Mapping and Forest Management

1. **Comparison of single (C- and L-band) and multi-frequency satellite SAR-based tropical forest mapping in the Mai-Ndombe district in DRC** | J Haarpaintner*
2. **Climate Resilient Forest Management in Nepal** | V Chitale*, M Matin, S Thapa, S Adhikari
3. **Post-hoc change detection- making the best of point-in-time map products** | G Liknes*, S Bender
4. **Entering the Third Dimension, Can We Nationalize Tree Canopy Height?** | J Ellenwood*
5. **Comparison of Tree Canopy Cover Geospatial Datasets for the Conterminous United States** | S Bender, G Liknes*

TOP OF THE 7'S

Special Session: Forests in the Global Carbon Cycle 1: Connecting Remote Sensing and Forest Models

Rico Fischer & Andreas Huth, Session Chairs

1. **Beyond MRV: High-Resolution Forest Carbon Monitoring and Modeling at Regional-National scales** | G Hurtt*, E Campbell, K Dolan, R Dubayah, V Escobar, S Ganguly, W Huang, N Hultman, K Johnson, R Lamb, A Lister, L Ma, R Nemani, J O'Neill Dunne, D O'Leary, L Ott, B Poulter, R Sahajpal, E Sepulveda, H Tang, M Zhao
2. **Model-assisted estimation of tropical forest biomass change: a comparison of approaches** | N Knapp*, R Fischer, K Papathanassiou, A Huth
3. **Variability in canopy turnover and crown plasticity from repeat airborne Lidar** | D Morton*, B Cook, M Keller, M Alonzo, H Andersen, M Longo, R Meng, S Martinuzzi, D Lagomasino
4. **Assessing the contribution of forest disturbances to global forest dynamics and carbon cycling** | T Pugh*, A Arneth, M Kautz, B Poulter, B Smith
5. **Productivity and carbon fluxes of the Amazon rainforest: linking remote sensing and vegetation modeling** | A Huth*, E Rödig, F Taubert, A Rammig, M Cuntz, R Fischer

Times	Tuesday 2 October Event/Activity	
12:10 13:15	CALVERT BALLROOM: Lunch	
13:30-15:10	SALON E	SALON F

SALON E

Special Session: Plantation Management with High-Resolution Remote Sensing

Yong Pang, Session Chair

1. **Integrated use of time series satellite observations and field inventory data to monitor the life cycle of plantation forests** | C Huang*
2. **A case study on integration of aerial and ground observations in forested areas via object-based coregistration of backpack and UAV based Lidar Point Clouds** | W Yao, P Polewski*, L Cao
3. **Estimation of forest variables from VHSR Remotely Sensed Imagery** | J Yim*, J Park
4. **Forest biometrics with UAV Lidar, machine learning and Monte Carlo ray tracing simulations** | O Roberts*, P Bunting, A Hardy
5. **Larch plantation management monitoring using high resolution remote sensing data** | Y Pang*, W Jia, W Wang, J Li, Z Ma, L Si, Z Li, C Li, X Liang

SALON F

Airborne Laser Scanning Method Development

1. **Evaluating unmanned aerial vehicle based Lidar for the support of forest inventory** | M Sumnall*, C Hession, R Wynne, V Thomas
2. **Stand level estimates of forest attributes with different Lidar point densities** | F Mauro*, C Pascual, A Garcia-Abril, JA Manzanera, E Ayuga-Tellez, R Valbuena
3. **Towards high throughput assessment of canopy dynamics: the estimation of leaf area variation in Amazonian forests with multi-temporal multi-sensor discrete return Lidar** | G Shao*, S Stark, D Almeida
4. **Multispectral Lidar data for the prediction of forest stand attributes** | M Dalponte*, LT Ene, T Gobakken, E Næsset, D Gianelle
5. **Multispectral airborne Lidar data in the prediction of boreal tree species using area-based methods** | M Kukkonen*, M Maltamo, L Korhonen, P Packalen

SALON G

Forest Inventory and Decision Support

1. **Comparing airborne laser scanning and digital aerial photogrammetry for large scale operational forest management inventories** | T Gobakken*, HO Ørka, OM Bollandsås, E Næsset
2. **Value of airborne laser scanning and digital aerial photogrammetry data in forest decision making** | A Kangas*, T Gobakken, S Puliti, M Hauglin, E Næsset
3. **Transferability of ALS-derived Forest Resource Inventory Variables from Eastern to Western Mixedwoods in the Canadian Boreal Forest** | K van Ewijk*, P Tompalski, P Treitz, N Coops, M Woods, D Pitt
4. **Updating Lidar Forest Inventory Integrating Already Available Information** | J Esteban*, A Fernández-Landa, N Algeet-Abarquero, ML Guillen-Climent
5. **The Use of Deep Learning and Three-Dimensional Convolutional Neural Networks to Interpret Lidar Data for Forest Inventory** | E Ayrey*, D Hayes, A Weiskittel, S Fraver, J Kershaw, B Cook

TOP OF THE 7'S

Special Session: Forests in the Global Carbon Cycle 2: Connecting Remote Sensing and Forest Models

Rico Fischer & Andreas Huth, Session Chairs

1. **The challenge of detecting size and light environment structured forest dynamics: testing models with a multitemporal multisite Amazon forest dataset** | SC Stark*, G Shao, SM McMahon, DR Almeida, MN Smith
2. **Design and application of a next-generation forest biogeochemistry model, Sortie-BGC** | A Erickson*, N Strigul
3. **Global Patterns of Tropical Forest Fragmentation and its Impact on the Global Carbon Cycle** | R Fischer*, F Taubert, K Brinck, M Müller, J Groeneveld, S Lehmann, M Dantas De Paula, JO Sexton, D Song, T Wiegand, A Huth
4. **A Multi-scaled analysis of Forest Structure using Individual-Based Modeling in a Costa Rican Rainforest** | A Armstrong*, R Fischer, B Osmanoglu, G Sun, K Ranson, A Huth
5. **Spatio-temporal modelling of the light regime: tropical vs. temperate forest** | D Kükenbrink*, FD Schneider, A Hueni,ME Schaepman, F Morsdorf

15:10-15:30 — FOYER A & B: 15:10 - 15:30 **Afternoon Break**

15:30-17:10

SALON E

Agroforestry Applications

1. **Three Phase Forest Inventory Design with 1) wall-to-wall ALS, 2) very dense ALS on sample stripes and 3) fieldwork sample plots** | G Bronner*, M Hirschmugl, R Wack, B Jawecki
2. **Mapping Smallholder Forest Plantation Establishment in Andhra Pradesh** | R Wynne*, V Thomas, S More, P Williams
3. **Mapping forest management intensity and land use transitions in the southeastern US with multitemporal Landsat** | V Thomas*, R Wynne, J Kauffman, E Brooks, Q Thomas, L Chini, R Mei, D Wear
4. **Growing up on the frontier: assessing the impact of forest age and edge age on forest structure in the southeastern US** | M Fagan*, D Morton, B Cook, J Masek, F Zhao, C Huang, R Nelson
5. **Post-stratified estimation of harvest area by combining Global Forest Change and National Forest Inventory data** | J Breidenbach*, S Puliti, S Solberg, R Astrup

SALON F

Airborne Laser Scanning Applications

1. **Spatial variations of tree size-frequency distributions and 3D structure across elevations and soil type in a tropical rainforest** | A Ferraz, S Saatchi*, J Kellner, D Clark
2. **Effects of plot size, stand density, and scan density on the relationship between airborne laser scanning metrics and the Gini coefficient of tree size inequality** | S Adnan*, M Maltamo, D A. Coomes, R Valbuena
3. **Mapping tree clump and opening patterns following fire with airborne Lidar data** | B Bartl-Geller*, H Wiggins, J Kane, M North, V Kane
4. **Optimization of primary extraction routes prior to forest operations using Lidar data** | E Willén*, G Friberg, P Flisberg, M Frisk, M Rönnqvist
5. **Prediction of forest stand characteristics based on Airborne Laser Scanning data in the managed forests in Central Europe - Polish case study** | K Stereńczak*, S Miścicki, K Parkitna, G Krok, M Lisańczuk, P Rysiak, Ł Jełowicki, K Mitesztedt, P Mroczek, A Markiewicz

SALON G

Sampling and Statistical Inference

1. **Using remote sensing to support forest inventory in interior Alaska - demonstration of a two-phase, model-assisted sampling design** | H Andersen*, C Babcock, B Cook, D Morton, AQ Finley, M Alonzo, J Strunk
2. **Wall-to-wall spatial prediction of growing stock volume in Italy by coupling large-scale field sampling plots and remotely sensed data** | G Chirici*, F Giannetti, D Travaglini, RE McRoberts, F Maselli, M Chiesi, M Pecchi, P Corona
3. **FIESTA: A big party for small areas** | T Frescino*, G Moisen, C Toney
4. **Bamboo kNN: applications for national forest inventory with remote sensing imagery** | B Wilson*, G Meeden, R McRoberts, J Knight
5. **Estimators for Photo-Based Measurements** | P Patterson*, M Finco, K Tenneson, K Megown, S Bender, N Pugh

TOP OF THE 7'S

Special Session: Humid Tropical Forest Monitoring with Time-Series Landsat Data

Matt Hansen, Session Chair

1. **Sample-based assessment of forest loss trends and drivers in three major humid tropical forest regions using Landsat time-series data** | A Tyukavina*, M Hansen, S Stehman, P Potapov, D Parker, C Okpa, S Turubanova, I Kommareddy, A Tosiani, M Yazid, I Sari, T Kartika, R Firmansyah, Z Said, Z Kustiyo, A Wijaya, J Purwanto, S Nugroho
2. **Reconstructing Historical Land Use and Land Cover of the Amazon region with Earth Engine, Landsat Data Archive and Machine Learning** | C Souza Jr.*, AV Fonseca, JV Siqueira
3. **Integrating time-series multi-spectral Landsat and Lidar data in mapping tree height in DR Congo** | E Bongwele*, P Lola, P Potapov, M Hansen
4. Monitoring of Indonesia Tropical Rainforests and Land Cover Change using Time Series Landsat Data | A Wijaya*
5. **Annual monitoring of forest structure in the Lower Mekong region** | P Potapov*, A Tyukavina, S Turubanova, Y Talero, M Hansen, D Saah, A Aekakkararungroj, KS Aung, NH Quyen

17:15-18:45 — FOYER A & B: Poster Reception #1

Visit with authors of the posters on display in the 1st poster session. Meet with one of our many conference exhibitors.
Mingle and unwind. Light refreshment and beverages provided. .

Times	Wednesday 3 October Event/Activity
8:00-9:00	FOYER A&B Breakfast and Registration
9:00-9:15	CALVERT BALLROOM: **SilviaTerra Forest Basemap for the US - Zack Parisa**
9:15-10:15	CALVERT BALLROOM: **Keynotes: Tom Crowther and Jean-François Bastin**
10:15-10:30	FOYER A&B Mornng Break
10:30-12:10	SALON E / SALON F

SALON E

Special Session: Early Detection of Plant Stress

Juan Suarez, Session Chair

1. **Potential of Sentinel-1 Time Series to Detect Bark Beetle Outbreaks** | M Hollaus*, B Bauer-Marschallinger, M Löw, K Schadauer, W Wagner
2. **Monitoring and assessment of Mediterranean forest health using hyperspectral and thermal remote sensing imagery** | ML Guillen-Climent*, H Más, A Nur, F Alfredo, J Peñalver, I Etxebeste Larrañaga, D Gallego, P Zarco-Tejada, JL Tomé
3. **Leaf water content as a tree health indicator - Experiences from greenhouse and field** | S Junttila*, M Vastaranta, R Linnakoski, P Henttonen, M Holopainen, P Lyytikäinen-Saarenmaa, H Hyyppä
4. **Early detection of forest health stress through fusion of the Ecosystem Disturbance and Recovery Tracker system (eDaRT) and remotely sensed canopy water content** | M Slaton*, A Koltunov, C Ramirez, G Asner, E Haunreiter, T Kohler, P Brodrick
5. **Using time-varying sensitivity analysis to clarify the effects of two source energy balance model formulation on model behavior** | C Houser*

SALON F

SAR Interferometry, Tomography and Applications

1. **Forest structure monitoring by means of multi-baseline SAR configurations** | K Papathanassiou*, M Tello Alonso, V Cazcarra Bes, M Pardini, J Kim
2. Vegetation structure and biomass via spaceborne radar tomography: A case study using X-band over Indian forests | M Lavalle*, U Khati, G Shiroma, G Singh
3. **Spaceborne GEDI and TanDEM-X fusion for large-scale three-dimensional forest structure parameter retrieval** | S Lee*, T Fatoyinbo, W Qi, S Hancock, J Armston, R Dubayah
4. **GEDI-TanDEM-X fusion for enhanced forest structure observation: a comparison of InSAR height profiles and Lidar full waveforms** | C Choi, M Pardini*, K Papathanassiou
5. ~~**Potential of multi-tempo... LOS-2 PALSAR-2 ScanSAR data to est... forest parameters in tropical dry ar... forests** | M Urbazaev*, F Cremer, C Schmullius, ... Thiel~~ CANCELLED

SALON G

Large Area Observation Networks

1. **Forest-Observation-System.net - towards a global in-situ data repository for biomass datasets validation** | D Schepaschenko*, J Chave, O Phillips, S Davies, S Fritz, S Lewis, P Sist, M Réjou-Méchain, C Perger, C Dresel, K Scipal
2. **ForC: a global database characterizing carbon cycling in mature and regrowth forests** | K Anderson-Teixeira*, V Herrmann, J McGarvey, M Wang, N Kunert, B Bond-Lamberty, H Muller-Landau
3. **GLOBE Observer: citizen science in support of forest cover mapping and monitoring** | P Nelson*, B Campbell, H Kohl, D Overoye, MJ Hughes, J Braaten, R Kennedy
4. **Forest Inventory for the Entire Continental US - 1/20 acre resolution with DBH, Species, and Height** | Z Parisa*
5. **An open source HPC PYCUDA algorithm for processing waveform Lidar observations** | T Goulden*

TOP OF THE 7'S

Special Session: Advances in Satellite Fire Monitoring and Characterization 1

Louis Giglio, Chris Justice, David Roy & Krishna Vadrevu, Session Chairs

1. **Characterizing Mass Fire Events Using MODIS and VIIRS Hotspots - the British Columbia Fire Season of 2017** | C Stockdale*, P Englefield, N McLoughlin, M Parisien, D Perrakis
2. **Fire Detection, Characterization, and Monitoring with GOES-16/-17** | C Schmidt*
3. **Enhancing the GOES Early Fire Detection (GOES-EFD) algorithm prototype to assist wildfire response and management** | A Koltunov*, B Quayle, S Ustin
4. **Using the NASA polar orbiting fire product record to enhance and expand the Global Wildfire Information System (GWIS)** | L Boschetti*, D Roy, A Sparks
5. **The Use of Multi-temporal MODIS Satellite Data to Map Veld Fire Hazards in Limpopo Province, South Africa** | F Dondofema*, T Mudau, B Odhiambo

Times	Wednesday 3 October Event/Activity	
12:10 13:15	CALVERT BALLROOM: Lunch	
13:30-15:10	SALON E	SALON F

SALON E

Special Session: Forest Biodiversity Monitoring and Assessment from Remote Sensing 1

Gherardo Chirici & Ronald McRoberts, Session Chairs

1. **Long-term Landsat time series - a new opportunity for forest diversity monitoring** | W Graf*, C Kleinn, P Schall, T Nauss, F Detsch, P Magdon
2. **Comparing Sentinel-2 data and airborne imaging spectroscopy for mapping tree species diversity in Białowieża forest** | B Rombouts*, L Put, W De Keersmaecker, B Jaroszewicz, K Stereńczak, O Bouriaud, B Muys, B Somers
3. **Spatial analysis of remote sensing-based land cover data for assessing representativeness of biological inventories** | B Tavernia, M Nelson*, J Garner, C Perry
4. **Habitat mapping in a tropical dry forest through multispectral imagery** | AP Ochoa-Franco*, JR Valdez-Lazalde, HM de los Santos-Posadas, JL Hernandez-Stefanoni, JI Valdez-Hernández, G Ángeles-Pérez.
5. **The added value of multi-temporal Sentinel-2 data for tree species classification in the Wienerwald Biosphere Reserve** | M Immitzer*, M Neuwirth, S Böck, F Vuolo, H Brenner, C Atzberger

SALON F

Biomass Mapping

1. **Estimation of Tropical Forest Structure and Biomass Airborne P-band TomoSAR and Lidar Measurements** | S Saatchi*, A Ferraz, J Chave, S Tabaldini, S Quegan, T LeToan, P Dubois, K Papathanassiou, H Shugart
2. **Different sensitivity of X-band phase height to the vertical and horizontal dimensions of growing stock** | S Solberg*
3. **Benchmarked small area estimation of forest biomass change using stochastic optimization** | V Strimbu*, E Næsset
4. **Biomass mapping of deciduous forest over mountains areas using the penetration depth extracted by the fusion of spaceborne stereo imagery of leaf-on and leaf-off** | W Ni*, Z Zhang, G Sun
5. **OBI-WAN: Online Biomass Inference using Waveforms And iNventory** | S Healey*, P Patterson, S Saarela, Z Yang, N Gorelick, J Armston, L Duncanson, J Kellner, S Hancock, W Cohen, R Dubayah

SALON G

Near Real Time Monitoring

1. **Historical and Near-Real Time Forest Disturbance Detection Based on Full-Archive Data** | F Thonfeld*
2. **Monitoring land surface phenology in near-real-time: eMODIS, Forests, and NDVI** | C Schrader-Patton*, N Grulke
3. **Rapid Assessment of Forest Storm Damages with PlanetScope and Sentinel-2 Images in North-East Germany** | M Foerster*, A Clasen, K Juette
4. **Early warning system for the detection of changes in the native vegetation of Chile** | M Castro*, P Acevedo, V Sandoval, Y Martinez
5. **Near-real time forest disturbances detection in the Amazonian wet forest using Sentinel-1 images** | S Mermoz*, M Ballère, A Bouvet, T Koleck, C Lardeux, T Le Toan

TOP OF THE 7'S

Special Session: Advances in Satellite Fire Monitoring and Characterization 2

Louis Giglio, Chris Justice, David Roy & Krishna Vadrevu, Session Chairs

1. **Combined Landsat-8 and Sentinel-2 burned area mapping** | D Roy*, H Huang, H Zhang, L Yan, Z Li
2. **Forest Fire Disaster Assessment using ALOS 2 and Terrestrial Laser Scanner** | A Kato*, H Wakabayashi, A Osawa, M Watanabe, L Moskal, A Hudak
3. **L-band SAR sensitivity to prescribed burning effects in eucalypt forests of Western Australia** | A Fernandez-Carrillo*, L McCaw, MA Tanase
4. **Assessing economic damage of Wildland–Urban Interface (WUI) fires with economic model and high-resolution Planet Labs satellites constellation images** | Y Michael*, I Lensky, S Brenner, A Tchetchik, N Tessler, D Helman
5. **Remote sensing of live fuel moisture content in Mediterranean fire-prone shrubland: comparison of different satellite imagery and RTM simulations** | E Marino del Amo*, M Yebra, N Algeet, M Guillen-Climent, A Fernández, J Esteban, JL Tomé, C Hernando

15:10-15:30 — FOYER A & B: 15:10 - 15:30 **Afternoon Break**

15:30-17:10

SALON E

Special Session:
Forest Biodiversity Monitoring and Assessment from Remote Sensing 2

Gherardo Chirici & Ronald McRoberts, Session Chairs

1. **Essential Biodiversity Variables obtained from airborne and spaceborne Lidar** | R Valbuena*, B O'Connor, F Zellweger, F Morsdorf, P Vihervaara, W Simonson, M Maltamo, F Danks, G Chirici, N Coops, D Coomes
2. **Estimation of spatial indices for forest biodiversity from remote sensing** | H Häbel*, A Balázs, M Myllymäki
3. **Tree species classification using plant functional traits from Lidar and hyperspectral data** | Y Shi*, A K. Skidmore, T Wang, S Holzwarth, U Heiden, X Zhu, M Heurich
4. **Incorporating simulated GEDI Lidar into bird species distribution predictions for Sonoma County, CA, USA** | P Burns*, S Goetz, P Jantz, M Clark, L Salas, S Hancock
5. **Forest biodiversity estimated from remote sensing data through the new Rao's Q heterogeneity index: testing the Spectral Variation Hypothesis with a NDVI time-series derived from Landsat 8 and Sentinel 2, and the Height Variation Hypothesis with Lidar data** | M Torresani*, D Rocchini, R Sonnenschein, M Zebisch, G Tonon

SALON F

Forest Structure and Biomass

1. **A multi-scale remote sensing approach to derive a London-wide estimate of AGB** | P Wilkes*, M Disney, M Boni Vicari, K Calders, A Burt, O Baines
2. **The relationship between simulated and remotely sensed forest parameters** | B Osmanoglu, AH Armstrong*, G Sun, P Montesano, KJ Ranson
3. **Estimation of coniferous forest parameters by combining observations from optical and radar spaceborne sensors** | D Morin*, M Planells, D Guyon, S Mermoz, A Bouvet, L Villard, T Le Toan, G Dedieu
4. **Photogrammetrically Derived Forest Canopy Data to Assess and Monitor Forests Across States** | VR Kane*, T O'Mara, J Kane, J Strunk, P Gould, C Maki, D Churchill, LM Moskal
5. **Improving the performance of an area-based approach derived from DAP point clouds** | P Tompalski*, J White, N Coops, M Wulder

SALON G

Drought and Tree Mortality

1. **Assessment of Forest Response and Sensitivity to the Millennium Drought in Australia** | T Jiao, C Williams*
2. **Quantifying Impacts of Drought and Disturbance on Forest Water Use in North Carolina, USA Using Long-Term Daily ET Estimated with Multi-Satellite Data Fusion Method** | Y Yang*, M Anderson, F Gao, C Hain, W Kustas, A Noormets, G Sun, R Wynne, V Thomas
3. **Widespread tree mortality mapping suggests size-dependent risk for extreme drought stress** | A Stovall*, X Yang, H Shugart, A Khuu, J Smith
4. **Multiple years of monthly ground-based profiling Lidar data in the Amazon reveal seasonal and drought related changes in leaf area with surprising dependencies on height and light environment** | M Smith*, S Stark, T Taylor, T Woodcock, M Ferreira, E de Oliveira, L Alves, N Restrepo-Coupe, M Figueira, L Aragao, P de Camargo, R de Oliveira, D Falk, S McMahon, T Huxman, S Saleska
5. **Combining airborne and spaceborne optical, and Lidar datasets for tree mortality monitoring in the Polish part of Białowieża Forest** | K Stereńczak*, B Kraszewski, M Mielcarek, A Modzelewska, Ż Piasecka, M Białczak, R Sadkowski, A Kamińska, M Lisiewicz, R Wilkowska, S Miścicki, FE Fassnach

TOP OF THE 7'S

Special Session:
Near Real-Time Forest Monitoring

Johannes Reiche & Michele Martone
Session Chairs

1. **The SAR shadowing effect: a new indicator of forest disturbances for near-real time deforestation monitoring with Sentinel-1** | A Bouvet*, S Mermoz, M Ballère, T Koleck, T Le Toan
2. **Understanding user needs for Early Warning deforestation systems** | M Weisse*, B Mora, T Harvey, R Petersen
3. **The Dry Chaco Forest Near Real-Time Deforestation Detection System** | F Grings, E Roitberg*, V Barraza, P Perna, M Salvia
4. **Dense Sentinel-1 time series to support tropical forest cover loss alerting and characterization** | J Reiche*, E Hamunyela, J Verbesselt, M Herold, R Verhoeven, N Wielaard
5. **Fast Monitoring of Amazonas Deforestation by combining Sentinel-1 and TanDEM-X Interferometric SAR Data** | P Rizzoli, A Pulella, F Sica, J Bueso-Bello, M Martone*, M Zink

17:15-18:45 — FOYER A & B: Poster Reception #2

Visit with authors of the posters on display in the 2ndposter session. Meet with one of our many conference exhibitors. Mingle and unwind. Light refreshment and beverages provided. .

18:45-22:00

MilkBoy ArtHouse
7416 Baltimore Ave, College Park
Sponsored in part by

Women of ForestSAT: Mission to #STEMinism
Join us for an evening of networking, comradery and pushing the boundaries of STEMinism. All are welcome. Cash bar and light hors d'oeuvres provided.

Times | Thursday 4 October | Event/Activity

Times	Event/Activity	
8:00-9:00	FOYER A&B Breakfast and Registration	
9:00-9:15	CALVERT BALLROOM: Welcome and Announcements	
9:15-10:15	CALVERT BALLROOM: Industry Panel	
10:15-10:30	FOYER A&B Morning Break	
10:30-12:10	SALON E	SALON F

SALON E

Model-Data Integration

1. **An Integrated Framework for Greenhouse Gas Satellites and Forest Structure Remote Sensing to Estimate Emissions from Land Use, Land Use Change and Forestry (LULUCF)** | B Poulter*, L Calle
2. **Application of remote sensing and ecosystem modeling products to inform land-use decisions** | R Lamb*, G Hurtt
3. **Climate Benefits of Potential Avoided Emissions from Forest Conversion Diminished by Albedo Warming: Comprehensive, Data-Driven Assessment for the US and Beyond** | C Williams*, H Gu, T Jiao
4. **Using Landsat, Aerial Surveys, Weather Modeling, and Agent-based Models of Outbreak Insect Phenology and Migration to Explore the Topographic Concentration Hypothesis** | M Garcia*, B Sturtevant, J Régnière, Y Boulanger, R St-Amant, B Cooke,G Achtemeier, J Charney, P Townsend
5. **Combining high-resolution Lidar and forest modeling to improve predictions of future forest state across interior Alaska** | A Foster*, A Armstrong, J Shuman, KJ Ranson, H Shugart, BM Rogers, S Goetz

SALON F

UAVs for Forest Structure Mapping

1. **An extensible framework for small unmanned aerial system sensor integration with Lidar and satellite remote sensing** | D Krofcheck*, M Hurteau, H Zald
2. **DTM-independent variables to predict forest inventory variables using 3D UAV photogrammetric data** | F Giannetti*, G Chirici, T Gobakken, E Næsset, D Travaglini, S Puliti
3. **Combining UAV and Sentinel-2 auxiliary data for forest growing stock volume estimation through hierarchical model-based inference** | S Puliti*, S Saarela, T Gobakken, G Ståhl, E Næsset
4. **Technical and operational considerations for the implementation of UAVs for forest mapping and inventories and their role in the validation of satellite land products** | JP Arroyo-Mora*, M Kalacska, O Lucanus
5. **Assessment of below-canopy forest structure using UAV Structure from motion (SfM) Point Clouds** | S Hillman*, L Wallace, K Reinke, B Hally, S Jones, R Taneja

SALON G

Hurricanes and Mangroves

1. **Global and Regional patterns of mangrove forest structure** | M Simard*, L Fatoyinbo, C Smetanka, M Denbina, V Rivera-Monroy
2. **Greenness Trends and Carbon Stocks of Mangroves across Mexico** | A Vazquez-Lule*, R Colditz, J Herrera-Silveira, M Guevara, M Rodriguez-Zuniga, I Cruz, R Ressl, R Vargas
3. **Structural gradients of hurricane damage across the mangrove forests of South Florida** | D Lagomasino*
4. **Determining coarse woody debris in mangrove forest of the Florida Everglades after Hurricane Irma using airborne Lidar imagery** | S Chavez*, D Lagomasino, L Fatoyinbo, B Cook, D Morton, E Castaneda, R Moyer, K Radabaugh, JM Smoak
5. **Effects of Hurricanes Irma and Maria on the Puerto Rican forests measured by the NASA G-LiHT Airborne Imager** | S Martinuzzi*, B Cook, D Morton, L Corp, E Helmer, M Keller

TOP OF THE 7'S

Special Session: Next Generation Large Area Forest Monitoring 1: Context and Science

Mike Wulder & Sean Healey, Session Chairs

1. **Towards a satellite derived change, cover, and structure data cube: Satisfying large-area information needs for forest monitoring** | M Wulder*, J White, N Coops, T Hermosilla, G Hobart
2. **Trends and patterns of temperate forest disturbance dynamics in Europe from Landsat time series** | D Pflugmacher*, C Senf, Z Yang, J Knorn, J Sebald, R Seidl, P Hostert
3. **New opportunities for high-resolution countrywide tree species mapping** | L Waser*, B Price, N Rehush, D Small, M Rüetschi, C Straub
4. **LANDFIRE: Updating a national vegetation and fuels dataset using next-generation data** | B Peterson, K Nelson. S Sathyachandran*
5. **Monitoring Land Disturbance based on Landsat Time Series** | Z Zhu*, Z Yang

Times	Thursday 4 October Event/Activity	
12:10 13:15	CALVERT BALLROOM: Lunch	
13:30-15:10	SALON E	SALON F

SALON E

Data Fusion and Integration

1. **Multi-scale and multi-sensor detection and monitoring of invasive exotic tree species |** J Dash*, G Pearse, M Watt, T Paul, J Morgenroth
2. **Data assimilation of forest variables based on several remote sensing sources |** N Lindgren*, E Lindberg, A Grafström, S Saarela, M Nyström, HJ Persson, H Olsson, G Ståhl
3. **Space-series wavelet analysis and time-series of SAR data to characterise tropical forest |** EC De Grandi*, E Mitchard, D Hoekman, F De Grandi
4. **Bidirectional Mixing Effects of the Spectral Signal in Deciduous Forest Canopies |** A Clasen*, B Somers, S Itzerott, B Kleinschmit, M Foerster
5. **Updating Lidar-derived Forest Attributes with Sentinel-2 Data |** M Schardt*, J Deutscher, M Hirschmugl

SALON F

UAVs for Forest Monitoring

1. **Using Unmanned Aerial System (UAS) Lidar to characterise ecohydrological properties of eucalypt forests |** D Jaskierniak*, A Lucieer, G Kuczera, R Benyon, P Lane
2. **Assessing degraded forest structures using UAV and SAR remote sensing data |** C Bourgoin*, J Betbeder, P Couteron, L Blanc, N Baghdadi, L Reymondin, P Läderach, P Sist, V Gond
3. **Digital aerial photogrammetry and unmanned aerial systems for assessing forest regeneration |** T Goodbody*, N Coops, T Hermosilla, P Tompalski, A Hervieux, P Crawford
4. **Estimating the height of conifer seedlings in recovering linear disturbances with UAV photogrammetry |** G Castilla*, M Filiatrault, M Gartrell, MF Wu, G McDermid
5. **Measuring savanna structure using multi-sensor drone data to derive closure criteria for mine site revegetation |** R Bartolo*, P Erskine, T Whiteside, L Hernandez Santin, M Rudge, S Levick

SALON G

Land Cover and Land Use Change

1. **Characterizing Forty Years of Forest Change in Minnesota: Applications in Forest and Wildlife Science |** J Vogeler*, M Falkowski, R Slesak
2. **Extrapolating forest biomass dynamics through space and time using Landsat time series and inventory data |** T H.Nguyen*, S Jones, M Soto-Berelov, A Haywood, S Hislop
3. **Novel Map-to-Image Change Detection for Mapping Forest Change: Case Study for Wales, UK |** M Philip*, P Bunting, A Hardy, R Jensen
4. **Three Decades of Hyrcanian Forest Canopy Density Change in Iran |** M Taefi Feijani*, A Tavakoli, A Alimohammadi Sarab
5. **The Past and Future Land Use Footprint of Global Palm Oil |** I Collins, E Goldman*

TOP OF THE 7'S

Special Session:
Next Generation Large Area Forest Monitoring 2: Sensor Fusion

Mike Wulder & Sean Healey, Session Chairs

1. **Fusion of GEDI, ICESAT2 & NISAR data for above ground biomass mapping in California and Gabon |** L Duncanson*, A Neuenschwander, M Simard, N Thomas, S Hancock, J Armston, R Dubayah, M Hofton, S Marselis, S Saatchi, C Silva, L Fatoyinbo
2. **Cross-validation and transferability performance of GEDI footprint aboveground biomass models |** J Kellner*, J Armston, J Blair, L Duncanson, S Hancock, S Healey, M Hofton, S Luthcke, S Marselis, D Minor, P Patterson, H Tang, R Dubayah
3. **Generalized hierarchical model-based estimation for biomass assessment using GEDI and Landsat data |** S Saarela*, S Holm, SP Healey, H Petersson, W Prentius, PL Patterson, E Næsset, TG Gregoire, G Ståhl
4. **National-scale aboveground biomass geostatistical mapping with FIA inventory and GLAS data: Preparation for sparsely sampled Lidar assisted forest inventory |** C Babcock*, A Finley, H Andersen, D Morton, B Cook
5. **Early Spring Radiative Forcing Dynamics in North American Boreal Forests Using Albedo Products from Landsat and Sentinel-2 |** A Erb, Z Wang, B Rogers, S Healy, D Hall

15:10-15:30 — FOYER A & B: 15:10 - 15:30 **Afternoon Break**

15:30-17:10

SALON E

Ground-Based and Proximal Sensing

1. **Vegetation change in response to an extreme snowfall event using multitemporal terrestrial laser scanning |** J Greenberg*, Z Hou, R Hart, N Marchi, A Parra, R Tompkins, A Harpold, B Sullivan, P Weisberg, C Ramirez
2. **Rigorous assessment of sub-canopy structural dynamics in global savanna systems at landscape scales through long-range terrestrial laser scanning (LR-TLS) |** S Levick*, M Guderle, J Singh, G Cook, L Hutley, S Trumbore
3. **Using Zeb1, a highly-mobile terrestrial laser scanner, to assess and measure trees in an eastern hemlock-dominated forest |** D Crawford*, T Jovanovic, C Brack, A Stovall, D MacFarlane, J Frank, T Condon, A Strahler, C Schaaf, A Barker-Plotkin, D Orwig
4. **Quantifying forest structure, complexity, and biomass using the Leica BLK360 terrestrial laser scanner |** J Atkins*, A Stovall, G Clark, B Hardiman, C Gough
5. **Forest Inventory and Mapping with a Photo Point Cloud and FIA Plots for WA State |** J Strunk*, H Andersen, P Gould, C Maki, B McGaughey, D Gatziolis

SALON F

High Spatial Resolution Mapping

1. **Assessing the height and density of subarctic lichen woodlands using stereo measurements performed on WorldView 3 images |** B St-Onge*, S Grandin
2. **Canopy height models from very high resolution Pléiades stereo images over mountain regions |** L Piermattei*, M Marty, W Karel, M Hollaus, C Ginzler, N Pfeifer
3. **Classification of dominant forest tree species by multi-source very high spatial resolution remote sensing data |** B Del Perugia, D Travaglini*, A Barzagli, F Giannetti, S Nocentini, G Chirici
4. **D-SAR: A Novel Drone-Based SAR System for the Radar Characterisation of Forest Canopies |** K Morrison*, N Fox, L Bassett, P Minchinton
5. **Validating the Dynamics of JPSS VIIRS Green Vegetation Fraction (GVF) Product with High-Frequency Planet CubeSat Imagery |** F Zhao*, Z Jiang, M Chen, Y He, Y Yu, I Csiszar

SALON G

Forest Composition, Dynamics & Phenology

1. **Mapping forest species composition using FIA plot data and Landsat spectral-temporal features |** V Pasquarella*, J Thompson, L Morreale
2. **Tropical forest and land cover monitoring using optical and SAR data |** M Hirschmugl, C Sobe, J Deutscher, M Schardt*
3. **Is ground-based phenology of deciduous tree species consistent with the temporal pattern observed from Sentinel-2 time series? |** N Karasiak*, D Sheeren, J Dejoux, J Féret, J Willm, C Monteil, D Sheeren
4. **Monitoring Forest Degradation using Spectral Unmixing and Landsat Time Series Analysis in Rondonia, Brazil |** E Bullock*, C Woodcock, P Olofsson
5. **Wall to Wall Deforestation and Forest Degradation Detection: A Case Study in the Eastern Humid Forest Ecoregion of Madagascar |** N Algeet-Abarquero*, A Fernández-Landa, ML Guillen-Climent, J Esteban, P Rodríguez-Noriega, A Espejo

TOP OF THE 7'S

Special Session: Next Generation Large Area Forest Monitoring 3: Applications

Mike Wulder & Sean Healey, Session Chairs

1. **Opportunities for monitoring post-disturbance forest recovery over large areas |** J White*, M Wulder, T Hermosilla, N Coops, G Hobart
2. **Improving quality bands across Landsat sensors using convolutional neural networks |** MJ Hughes*, J Braaten, S Hooper, R Kennedy
3. **Monitoring Over a Decade of Carbon Flux in Pinyon-Juniper Woodlands |** M Falkowski, S Filippelli*, A Hudak, P Fekety
4. **Products of phenology, disturbance, and peak summer greenness for NASA's Arctic and Boreal Vulnerability Experiment |** C Woodcock*, S Chen, M Friedl, Y Zhang, E Melaas
5. **Annual estimates of forest biomass and forest cover for the continental U.S. |** R Kennedy*, MJ Hughes, J Braaten, S Hooper

CALVERT BALLROOM

Special Session: Mangroves: New Perspectives from Earth Observations

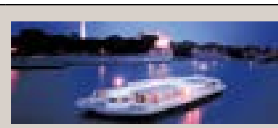
Richard Lucas & Kate Fickas, Session Chairs

1. **Ensuring a Long-Term Future for Mangroves: A Role for Remote Sensing** | R Lucas*
2. **The Global Mangrove Watch (GMW) |** P Bunting, A Rosenqvist, R Lucas*, A Hardy, N Thomas, L Hilarides, L Rebelo
3. **High-resolution 3-dimensional mapping of forest structure and aboveground biomass stocks in mangrove ecosystems in the Americas, Africa and South Asia** | L Fatoyinbo*, D Lagomasino
4. **Deciphering Mangrove Phenology: What, When and Where** | N Younes*, K Joyce, L Lymburner, S Maier
5. **EcoMap: An Interactive Early Warning System to Aid Global Mangrove Restoration and Policy** | L Goldberg*, D Lagomasino, L Fatoyinbo

17:45 -

DINNER CRUISE - Upscale dining with friends and colleagues, drifting past iconic D.C. landmarks on the Potomac River.

17:45 - Board buses in front of the hotel **18:00** - Buses depart



Sponsored by SILVIATERRA & Microsoft

Times	Friday 5 October	Event/Activity
8:00-9:00	FOYER A&B Breakfast and Registration	
9:00-9:15	CALVERT BALLROOM: **Thomas Hilker Award Presentation**	
9:15-10:15	CALVERT BALLROOM: **Keynote: Peter Scarth and David Schimel**	
10:15-10:30	FOYER A&B Mornng Break	
10:30-12:10	SALON E	SALON F

SALON E

Spaceborne Missions

1. **The BIOMASS mission: measuring forest height and above ground biomass from space** | K Scipal, S Quegan, T Le Toan, J Chave, J Dall, P Paillou, K Papathanassiou*, S Tebaldini, S Saatchi, H Shugart, L Ulander, M Williams
2. **Forest mapping with TanDEM-X: the global product and potentials for high-resolution classification** | M Martone*, P Rizzoli, C Gonzalez, J Bueso-Bello, F Sica, M Zink, G Krieger, A Moreira
3. **Understanding the Role of Ecosystem Structure in Carbon and Biodiversity: GEDI - The Global Ecosystem Dynamics Investigation** | R Dubayah*
4. **The development of vegetation Lidar mission 'MOLI'** | R Mitsuhashi*, J Murooka, D Sakaizawa, T Imai, T Kimura, M Hayashi, K Mizutani, Y Sawada, T Endo, K Kajiwara, Y Honda, K Asai
5. **Mapping global forests using data from NASA's ICESat-2 Mission** | A Neuenschwander*, L Magruder

SALON F

Habitat and Biodiversity

1. **Assessing habitat diversity in tropical forests using airborne Lidar scanning** | N Labrière*, S Tao, F Fischer, C Bedeau, G Vincent, J Chave
2. **Estimation of biodiversity relevant forest structure parameters using a multi-sensor and multi-scale remote sensing approach** | K Mulatu*, M Decuyper, B Brede, L Kooistra, B Mora, J Reiche, M Herold
3. **Combining 3D acoustic and Lidar data to assess biodiversity impacts of Amazon forest degradation** | D Rappaport*, A Royle, D Morton, R Dubayah
4. **Lessons Learned Identifying Wildlife Habitat Using Lidar** | J Kane*, V Kane, J Jenkins, D Lesmeister, M North, G Asner, LM Moskal
5. **Canadian Airborne Biodiversity Observatory** | M Kalacska*, JP Arroyo-Mora, E Laliberté, A Bruneau, M Vellend, N Coops

SALON G

Forest Disturbance and Degradation

1. **Comparison of Sentinel-1 and Sentinel-2 Time Series for Near-Real Time Deforestation and Forest Degradation Monitoring in Tropical Areas with Quasi-Permanent Cloud Coverage** | N Algeet Abarquero*, A Fernández-Landa, ML Guillén Climent, J Esteban, P Rodríguez-Noriega
2. **Using an ensemble approach with spatio-temporal variables from annual Landsat time series to detect forest disturbances and attribute driving agents in Myanmar** | K Shimizu*, T Ota, N Mizoue, S Yoshida
3. **Visual interpretation of the Landsat time series indicates that forest canopy decline represents heterogeneous forest structure and composition change** | D Bell*, M Reilly, W Cohen, A Gray, T Spies, Z Yang
4. **Mapping and monitoring fractional woody vegetation cover in the arid savannahs of northern Namibia using Lidar and SAR data** | K Wessels*, F van den Bergh, R Mathieu, R Main, L Naidoo, N Knox, K Steenkamp
5. **Using three decades worth of Landsat time series imagery to map disturbance dynamics across public forests in Victoria, Australia** | M Soto-Berelov*, J Simon, H Andrew, N Trung, H Samuel, S Ahmad, L Costello

TOP OF THE 7'S

Special Session: Using Remote Sensing-Based Maps in Compliance with IPCC Good Practices for Greenhouse Gas Inventories

Ronald McRoberts & Erik Næssat, Session Chairs

1. **On the impact of omission errors on area estimates of activity data** | P Olofsson*
2. **The Contribution of Reference Data Variability to the Total Variance of Forest Cover and Change Area Estimates** | S Stehman*, B Pengra, J Mousoupetros, R McRoberts, E Naesset, T Loveland
3. **Comparison of GREG versus Stratified estimator for reporting forest activity data for REDD+** | C Sannier*, R McRoberts, L Faucqueur, J Hugé, H Ghomsi
4. **Assessment of a global biomass map in miombo woodlands and rainforests in Tanzania** | E Næsset*, T Gobakken, RE McRoberts, S Saatchi, E Zahabu
5. **Using a finer resolution local biomass map as a source of reference data for assessing a coarser resolution regional biomass map** | RE McRoberts*, E Næsset, GC Liknes, S Saatchi, Q Chen, BF Walters

Times	Friday 5 October Event/Activity	
12:10 13:15	CALVERT BALLROOM: Lunch	
13:30-15:10	SALON E	SALON F

SALON E

Spaceborne Lidar

1. **Satellite-based Forest Inventory in Northwestern Canada** | G Castilla*, M Filiatrault, M Gartrell, R Skakun, R Hall, A Beaudoin, C Mahoney, L Smith, K Groenewegen
2. **Estimation of Forest Aboveground Biomass and Canopy Cover with Simulated ICESat-2 Data** | L Narine*, S Popescu, A Neuenschwander, T Zhou, S Srinivasan, K Walsh
3. **NASA ICESat-2 for Wildland Fire Applications** | S Delgado Arias*, B Peterson, N Glenn, W Ni-Meister, T Neumann, M Jasinski, M Brown,V Escobar
4. **Development of the Global Ecosystem Dynamics Investigation (GEDI) Lidar Canopy Cover and Vertical Profile Metrics Algorithm and Validation Results** | H Tang*, J Armston, S Hancock, S Marselis, S Luthcke, M Hofton, B Blair, R Dubayah
5. **Forest biomass estimation using large-footprint Lidar data for algorithm development of MOLI spaceborne Lidar** | M Hayashi*, R Mitsuhashi, J Murooka, D Sakaizawa, T Imai, T Kimura, K Mizutani, Y Sawada, T Endo, K Kajiwara, Y Honda, K Asai

SALON F

Multi- and Hyperspectral Applications

1. **Integration of NEON imaging spectroscopy and Lidar data for 3-dimensional canopy trait mapping** | A Chlus*, Z Wang, E Kruger, P Townsend
2. Differentiating FIA Forest Types with Hyperspectral and Lidar Data | C Shoot*, LM Moskal, H Andersen
3. **From pixels to function: Tree growth estimation from canopy hyperspectral reflectance | S Graves*, T Caughlin, S Marconi,S Bohlman**
4. **Foliar "trait space" from imaging spectroscopy** | P Townsend*, K Cawse-Nicholson, Z Wang, T Zheng, D Thompson, A Chlus, R Pavlick, F Schneider, D Schimel, E Kruger
5. **Mapping functional diversity of forests with remote sensing** | F Schneider*, F Morsdorf, B Schmid, O Petchey, A Hueni, D Schimel, M Schaepman

SALON G

Monitoring Forest Change & Deforestation

1. **Deforestation's Impacts on Fragmentation and Connectivity of Colombian Forests** | P Jantz*, S Goetz, A Hansen, J Watson, O Venter, M Hansen
2. **Dry Chaco Forest deforestation map by using Random Forest with Landsat dataset on Google Earth Engine** | V Barraza, P Perna, F Grings, E Roitberg*, M Salvia
3. **The potential of dense Landsat time series for deforestation monitoring in human-modified rainforests of Indonesia** | H Hadi*, A Krasovskii, V Maus, P Yowargana, S Pietsch, M Rautiainen
4. **The Benefits of Time: Characterizing the Landsat Spectral-Temporal Domain in Forested Ecosystems** | K Fickas*, V Pasquarella, P Arevalo, E Bullock, C Holden, P Olofsson, W Cohen, C Woodcock
5. **Monitoring direct drivers of deforestation in Indonesia** | K Austin*, Y Gu,P Kasibhatla, A Schwantes

TOP OF THE 7'S

Special Session: Terrestrial Laser Scanning 1: 3D Forest Measurements Structure, Function, and Satellite Cal/Val

Mathias Disney & Crystal Schaaf, Session Chairs

1. **Developing new biomass allometric equations based on terrestrial laser scanning** | K Calders*, M Disney, A Burt, N Origo, J Nightingale, Y Malhi, P Wilkes, P Raumonen, H Verbeeck
2. **Comparing Lidar-Derived Quantitative Structure Models (QSM) with Direct Measurements of Tree Structure, Volume, and Biomass | P Radtke*, A Barker-Plotkin, P Boucher, A Burt, K Calders, D Walker, J Frank, Z Li, D MacFarlane, D Orwig**, I Paynter, F Peri, P Raumonen, C Schaaf, A Stovall, A Strahler
3. **Savanna vegetation 3D models: defining disturbance and resource constraints at multiple-scales** | J Singh*, SR Levick, M Guderle, S Trumbore, C Schmullius
4. **Quantifying tree crown-filling using new 3D terrestrial laser scanning measurements** | M Disney*, L Bentley, A Burt, M Boni Vicari, K Calders, B Enquist, Y Malhi, P Wilkes
5. **The single tree and forest stand 4-D monitoring using point clouds comparison approach from multi-temporal and multi-station terrestrial laser scanning** | P Wezyk*, K Zieba-Kulawik, P Rysiak, M Starzyk

15:10-15:30 FOYER A & B: 15:10 - 15:30 **Afternoon Break**

15:30-17:10

SALON E

Fire, Burnt Area and Fuel Loads

1. **Characterising Vegetation and Fuel Structure in Mallee Woodlands using Terrestrial Laser Scanning** | L Wallace, S Hillman, R Taneja, K Reinke, B Hally*, S Jones
2. **Development of 3-dimensional burn severity metrics** | K Nelson, B Peterson*
3. **Detecting burnt forest through applied machine learning techniques on combined high resolution remote sensing data** | T de Conto*, GA Prata, LCE Rodriguez
4. **Small area estimation of forest attributes within fire perimeters** | G Moisen*, T Frescino, R Bush, K Megown, B Quayle, J Gregory, C Baker, C Toney
5. **Implications of Peat Burn Severity on C Emissions and Post-Fire Successional Trajectories in Boreal Northwest Territories Canada** | L Bourgeau-Chavez*, J Graham, M Battaglia, N French, E Kane, S Grelik

SALON F

Forest Cover Mapping

1. Boreal canopy surface estimates from spaceborne stereogrammetry | P Montesano*, C Neigh, W Wagner, M Wooten
2. How to apply forest definitions into multispectral imagery in the mountainous temperate forests? | E Grabska*, WS Keeton, B Price, P Tompalski, K Ostapowicz
3. A new tree extent and canopy height map for Bangladesh | N Thomas*, P Baltezar, D Lagomasino, S Lee, T Fatoyinbo, J Green, M Rahman
4. Multi-sensor data synthesis for forest classifications with the Bayesian Updating of Land Cover (BULC) algorithm | J Cardille*, M Crowley, X Giroux-Bougard, J Lee
5. Urban Tree Canopy Assessments | J O'Neil-Dunne*, M Grove, M Galvin, D Locke

SALON G

Forests and the Carbon Cycle

1. **A Spatial Carbon Budget Bookkeeping Model for Forest Disturbances** | W Gong*, F Zhao, C Huang, R Houghton, A Nassikas, K Schleeweis
2. **Implications of errors in remote sensing-based maps on models of carbon emissions in the Colombian Amazon** | P Arevalo*, C Woodcock, P Olofsson
3. **Using InSAR based Wall-to-Wall Forest Carbon Change Mapping for Estimating Forest Carbon Gain and Loss in all Protected Areas and buffer zones in Uganda : Implications to the Carbon Benefits of Conservation** | B Gizachew*, S Solberg, S Puliti
4. **Sentinel-1 and -2 Data for optimized Forest Cover Detection in European Temperate Forests and South African Savanna: Investigation of sensor fusion and the impact of spatial autocorrelation** | K Heckel*, M Urban, P Schratz, M Mahecha, C Schmullius
5. **Unravelling the effects of inundation dynamics on methane cycling in forested wetlands using spaceborne optical and radar data** | B DeVries, KL Hondula*, C Huang, CN Jones, MW Lang, MA Palmer

TOP OF THE 7'S

Special Session:
Terrestrial Laser Scanning 2: 3D Forest Measurements Structure, Function, and Satellite Cal/Val

Mathias Disney & Crystal Schaaf, Session Chairs

1. **Is UAS-Lidar the data acquisition method for future forest inventories?** | M Hollaus*, D Wang, M Wieser, N Pfeifer, G Bronner
2. **Investigating the above-ground competition effects of liana load on tree structure and allometry using TLS** | SM Krishna Moorthy*, K Calders, E Kearsley, H Verbeeck
3. **Application of a micro-TLS system to estimate woody shrub biomass** | J Batchelor*, LM Moskal, V Kane, A Kato
4. **Detecting tree-related microhabitats in TLS point clouds using machine learning** | N Rehush*, M Abegg, L Waser, U Brändli
5. **Benchmarking drone Lidar using TLS for landscape-scale sampling of individual tree structure in support of space-mission calibration and validation** | M Krůček*, K Cushman, J Trochta, K Král, J Kellner

CALVERT BALLROOM

Special Session: Forest Carbon MRV and Role in Future Climate Mitigation

Ben Poulter, George Hurtt, Neil Pederson & Thomas Pugh, Session Chairs

1. **Using NASA Carbon Monitoring System Data Products for Policy Applications in Maryland, USA** | E Campbell*, R Marks, G Hurtt
2. **Climate change will alter montane forests, but how fast? Fusing Landsat time series and spatially dynamic vegetation models to inform montane forest management** | J Foster*, A D'Amato
3. **A bottom-up, stakeholder-driven carbon monitoring system in the Northwestern USA** | A Hudak*, P Fekety, S Filippelli, M Falkowski, V Kane, G Domke, N Crookston, A Smith
4. **Satellite estimates of young North American boreal forest site-index for DGVMs** | C Neigh*, P Montesano, J Sexton, M Feng, S Channan, N Carvalhais, M Forkel, L Calle

On behalf of the ForestSAT 2018 Organizing Committee and the ForestSAT Board of Directors – THANK YOU!

Stay tuned to www.forestsat.com @ForestSAT2018 @ForestSAT2018 for announcements regarding ForestSAT 2020.

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Thomas Hilker
Early Career Scientist Award

This year at ForestSAT we are announcing a new award for young scientists, in honor of the late Dr. Thomas Hilker. Thomas was an incredibly special member of our community, embodying the best of what it is to be a scientist and a human. He was a joy to work with and know, and his humor and skills were matched by his humility.

Thomas obtained his Bachelor and MSC degrees in Germany and his PHD in Canada (UBC). Following a postdoctoral research fellowship at NASA Goddard Space Flight Center, he joined Oregon State University as an Assistant Professor. In 2016, he was about to commence a new position at the University of Southampton when he died unexpectedly at the age of 40. Thomas was a well-loved colleague of many remote sensing researchers world-wide. He built a network of collaborators in Canada, the US, Brazil, Europe and Australia. He approached environmental questions and challenges with vigor and zeal and had an enormous curiosity and passion for science. He was respectful of others' opinions, eager to share ideas and approaches, and recognized science was a collaborative endeavor. In his short career he was prolific, authoring many papers covering a wide range of research topics mirroring his broad interests in terrestrial Earth Observation.

By creating this award, the ForestSAT community chooses to recognize early career scientists undertaking challenging research and starting to publish groundbreaking science. We recognize innovative individuals who we believe will become global leaders in the field. More importantly, these individuals undertake science collaboratively, with humility, and boost the work and spirits of their colleagues as Thomas did

The award will be presented during the opening remarks on Friday, October 5th at 9:00 am.

Poster Session #1

Foyer A & B

**Indicates presenting author*

Posters in this session on display from 18:00 Monday (Oct 1) to 13:30 Wednesday (Oct 3). Posters in session #1 must be taken down after lunch on Wednesday (Oct 3).

Abstracts are grouped by 5's. Click on the abstract you want to read.

1. Forest health - using a multi-sensor UAV and satellite observations to monitor the state of UK forests and woodlands | E Cornforth*, M Williams, M Perks, E Mitchard
2. Constraints on the US forest carbon balance through the assimilation of above-ground biomass maps into CARDAMOM | AA Bloom*, S Saatchi, Y Yu, N Parazoo, M Williams, TL Smallman, J Exbrayat
3. Fusing GEDI lidar, TanDEM-X InSAR and Landsat data for improved forest structure mapping | W Qi*, P Wang, J Armston, R Dubayah
4. The Regional Scale Forest Aboveground Biomass Estimation of South Central Plains with the Calibrated Global Forest Canopy Height Map | N Ku, S Popescu*
5. A Comparison of Regression Techniques for Estimation of forest above ground biomass using Lidar and hyperspectral data | J Lv*, C Zhang
6. **Linking lidar and forest modeling to assess biomass estimation across scales and disturbance states** | N Knapp*, R Fischer, A Huth
7. **Estimating tree biomass using crown parameters derived from airborne lidar** | A Zielonka*, D Pflugmacher, K Ostapowicz
8. **Stand volume estimation using tree-level UAV based approach in mature boreal forest** | A Kuzmin*, L Korhonen, M Maltamo
9. **Moratoria on land acquisitions reduce tropical deforestation: Evidence from Indonesia** | B Chen*, C Kennedy, Y Jin, B Xu
10. **Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia** | S Turubanova*, P Potapov, A Tyukavina, M Hansen
11. **The use of Weibull coefficients as Lidar metrics to identify selective logging impacted areas in the Amazon** | C Reis, T Abib, E Görgens, A Melo, LC Rodriguez*
12. **Monitoring Black Wattle using GIS and Remote sensing techniques in Makhado Local Municipality, South Africa** | N Nethengwe*, F Dondofema, K Mavhungu
13. **Leaf- and stand-scale effects of age on canopy spectral signature dynamics in Chinese fir evergreen forests** | Q Wu*, J Song, C Song, J Wang, S Chen, B Yu
14. **Woody cover through the trees: How much woody cover are we overlooking in African savannas?** | R Nagelkirk*, K Dahlin
15. **Quantifying Forest Cover Loss based on Multi-Temporal L-Band SAR Intensity Value Representation** | IEW Rachmawan*, T Tadono, Y Kiyoki
16. **Estimation of Defoliation of Pine Trees by Using Single-scan Terrestrial Laser Scanning Data** | L Huo*, X Zhang, N Zhang, Y Wu
17. **Monitoring gap structure of plantation forests with high resolution remote sensing data** | S Li*, Q Liu
18. **Detecting of forest phenology and change trends for assessment of nature reserve in Tibetan Plateau during 2000-2016** | L Qian*, S Jinling
19. **Individual tree size and stand volume estimation of Teak plantation using UAV** | N Furuya*, W Himmapan, I Noda, G Hitsuma
20. **Explorative Study of Allometric Relationships of Forest Above-Ground Biomass to Small Footprint Lidar Data** | Q Wang*, Y Pang, Z Li, W Ni, E Chen, G Sun
21. **Deep Learning uNet Method for Forest Types Classification Based on high resolution optical Remote Sensing Data** | Y Guo*
22. **Mapping tree species spatial distribution using discrete aerial laser scanning data** | B Wu*, G Zheng

23. **VUX1-LR Lidar specifications for forest inventory in virtual reality environment** | B Del Perugia, D Travaglini*, G Chirici, S Gonzalez Aracil

24. **Inventorying forests in transformation to Continuous Cover Forestry using of-the-shelf UAVs** | MG Bennett*, DA Hardy, DP Bunting

25. **The development of an automated tree detection tool using UAV-based datasets** | AM Klein Hentz*, AP Dalla Corte, S Péllico Netto, M Strager, ER Schoeninger

26. **Lidar360 individual tree detection performance in forest plantations from UAV-derived point clouds** | AP Dalla Corte*, N Bonamichi Silva, M Klein Hentz, B Nascimento de Vasconcellos, MS Ruza

27. **Estimation of pine cone counts using small unmanned aerial system (UAS) imagery** | L Malambo*, S Popescu, B Bartlett, F Raley, T Byram, S Srinivasan

28. **A Multi-Sensor Fusion Approach to Landsat Time Series Fitting** | S Ghannam*, AL Abbott, ME Hussein, RH Wynne, VA Thomas

29. **Assessing the relationships between stand characteristics and Landsat-based aboveground forest biomass mapping uncertainty** | D Bell*, M Gregory, R Kennedy, D Saah, J Battles, B Collins, J Sanders

30. **Inter-annual variation in springtime phenology of North American temperate and boreal forests** | M Moon*, E Melaas, J Gray, M Friedl

31. **Landsat-based Upper Great Lakes Forest Phenoclimatology, 1984-2013** | M Garcia*, P Townsend

32. **Large-Scale trailcam networks enhance interpretation of satellite phenology for ecological studies** | N Liu*, J Clare, C Anhalt-Depies, B Zuckerberg, P Townsend

33. **Seasonal dynamics of forest albedo in European boreal region** | A Hovi*, E Lindberg, M Lang, T Arumäe, J Peuhkurinen, S Sirparanta, S Pyankov, M Rautiainen

34. **Customized web-based services to access the Daymet product: Analysis of user-based downloads provide insights into how scientists access large, complex data for their research needs** | M Thornton*, Y Wei, A Boyer, P Thornton, S Vannan

35. **Estimating clearcut area in Mediterranean forests on the basis of Landsat time series analysis** | G Chirici*, R Pegna, F Giannetti, RE McRoberts, E Mazza, D Travaglini

36. ~~**Potential of Sentinel-1 time series for deforestation and forest degradation mapping in temperate and tropical forests** | M Urbazaev*, F Cremer, C Schmullius, C Thiel~~ CANCELLED

37. **Validation and preliminary assessment of the Ecosystem Disturbance and Recovery Tracker (eDaRT) performance in forests of the Sierra Nevada, California** | E Haunreiter*, A Koltunov, C Ramirez, M Slaton, K Evans, T Kohler, L Young, S Ustin

38. **Time series data analysis for forest change-type attribution and applications for UK forest management and improving Hylobius abietis risk identification** | I Bye, J Suárez, M Payne, J Rosette*, Z Yang, W Cohen, D Plugmacher

39. **Structural Signatures of Forest Disturbance** | J Atkins*, R Fahey, B Hardiman, E Stuart-Haëntjens, B McNeil, D Orwig, L Turner, A Stovall, C Gough

40. **Integration of Landsat and simulated spaceborne Lidar data to estimate time since disturbance at the forest stand level** | N Sanchez-Lopez*, L Boschetti, AT Hudak

41. **Rapid Assessment of Post-Storm Windblow in Scotland using Sentinel-1** | S Fleming*, I Woodhouse, A Moyer, J Morel

42. **National Maps Attributing Forest Canopy Loss Activities 1986-2010** | K Schleeweis*, G Moisen, C Toney, E Freeman, T Schroeder, C Huang, J Dungan

43. **Mapping a changing fire frequency and carbon consumption in Alaskan black spruce forests** | E Hoy*, K Barret, T Loboda, M Turetsky, E Kasischke

44. **Advances of the identification and satellite monitoring system for forest fire danger zones (SIMPIF) originating from agricultural burning in southern Chile** | P Acevedo*, M Castro, C Soto, C Carrasco

45. **Variation in forest functional traits in tropical deciduous forests of India** | T Zheng*, A Singh, N Krishnayya, P Townsend
46. **Combining multi-temporal Sentinel-2 data and forest inventory plots to estimate the percent cover of tree species in a mixed European forest** | C Straub*, LT Waser
47. **Estimating the last disturbance year of forest stands in Coastal Georgia using all the available Landsat imagery with Google Earth Engine** | S Obata*, C Cieszewski, P Bettinger, R C. Lowe III, S Bernardes
48. **Identification of pine plantations with moderate management intensity using EWMA-CD on Landsat and harmonized Landsat-Sentinel (HLS) time series stacks** | MN House*, VA Thomas, EB Brooks, RH Wynne
49. **Global forest mapping through the integration of microwave and optical remote sensing** | X Xiao*, Y Qin, J Dong, J Wang, B Chen
50. **An Operational Remote Sensing Program for Conducting National Forest Health Surveys in the United States** | W Monahan, F Krist, F Sapio*
51. **Three-dimensional Mapping of Forest Canopy Water Content using Dual-wavelength Terrestrial Laser Scanning** | A Elsherif*, R Gaulton, J Mills
52. **Diurnal and seasonal cycles in leaf optical properties affect satellite-measured estimates of forest photosynthesis** | M Mõttus*, R Hernández-Clemente, V Markiet
53. **Mapping health status of chestnut forest stands using Sentinel-2 images** | V Chéret*, Y Hamrouni, M Goulard, JP Denux, H Poilvé, M Chartier
54. **Investigation of spectral and structural changes in Pinus contorta plantations following red band needle blight infection** | M Smigaj*, R Gaulton, S Barr, J Suarez
55. **Method analysis for early detection of spruce vitality loss with remote sensing data** | K Einzman, C Glas, C Atzberger, R Seitz, N Pinnel, M Immitzer*
56. **Fagus sylvatica L. presence and recent dynamics in its Spanish southernmost limit characterized with spectro-phenological traits captured by Landsat intra-annual time series** | C Gómez*, I Aulló-Maestro, P Alejandro, L Hernández, R Sánchez de Dios, H Sainz, F Montes
57. **Fusion of ALS and photogrammetric point cloud data in remote sensing of forest** | A Kaasinen*, T Luostari, P Packalen, A Seppänen
58. **Lidar collection methods compared through assessment and quantification of error in below-canopy forest structure characteristics in a fire-prone landscape** | J Donager*, T Sankey
59. **Classification of Tree Species and Oak Condition in a Mixed Broadleaf Forest Using Time Series of Hyperspatial Multispectral Unmanned Aerial System Imagery** | J Iglhaut*, J Rosette
60. **Processing PlanetScope time series images to detect post-fire regrowth** | N Leach*, N Obrknezev
61. **Establishing permanent large-scale forest dynamic plots of 100 ha at northeast China using UAV stereo imagery** | W Ni*, Q Wang, D Zhang, Z Zhang, G Sun
62. **A new approach to interpreting ICESat GLAS data for estimating canopy height in temperate woodlands in southwestern Australia** | P Lee*, J Jeong
63. **Estimation of growing stock volume of Scots pine stands using Sentinel-2 satellite imagery and airborne image-derived point clouds** | P Hawryło*, P Wężyk
64. **Characterizing Stem Volume in Mangrove Forests Using Terrestrial Lidar Scanning** | A Rouzbeh Kargar*, A Fafard, R MacKenzie, J Van Aardt
65. **Product generation for Calibration/Validation of the future NISAR mission biomass products** | V Meyer*, S Saatchi, B Chapman
66. **Accuracy of Plot-Level Forest Metrics from Terrestrial Photogrammetric Point Clouds** | L Piermattei*, W Karel, D Wang, M Wieser, P Surový, J Tomaštík, M Mokroš, M Hollaus, N Pfeifer

67. **Forest Biomass Retrieval Studies from Coupled Models and Data Fusion** | G Sun*, B Osmanoglu, AH Armstrong, KJ Ranson

68. **Estimating Effective Leaf Area Index (eLAI) in Heterogeneous Riparian Forest-Buffers: ALS vs. SfM** | LM Moskal*, T Axe

69. **Assessment of sustainable forest management of a mixed conifer-broadleaf forest by combinations of airborne Lidar and UAV observation** | N Furuya*, Y Hirata, T Owari, D Sakaue, S Inukai, Y Nakagawa, M Tokuni

70. **Mapping forest structure of Afromontane forest remnants by airborne laser scanning** | H Adhikari, J Heiskanen, R Valbuena, P Pellikka

71. **Comparing Sentinel-2 and Landsat 8 for detecting the invasive shrub species Ulex europaeus in South-Central Chile by using VHR UAV orthoimages** | T Schmidt*, M Förster, A Clasen, F Fassnacht, B Kleinschmit

72. **Individual Tree Mapping from Lidar point clouds based on topological tools** | X Xu*, F Luricich, L De Floriani

73. **Non-supervised individual trees segmentation of Lidar data in Amazonian forests with variable population densities** | DDA Papa*, PHK Millikan, TH Abib, SDP Chaves e Carvalho, LCE Rodriguez

74. **Detection of dead standing Eucalyptus camaldulensis without tree delineation for managing biodiversity in native Australian forest** | M Miltiadou*, ND Campbell, S Gonzalez Aracil, T Brown, M Grant

75. **Reuse of historical data in forest inventory** | AM de Lera Garrido*, HO Ørka, T Gobakken

76. **Potential of modern photogrammetry versus airborne laser scanning for estimating forest variables in a mountain environment** | S Ullah*, M Dees, P Datta, P Adler, B Koch

77. **Forest Field Inventories Through Terrestrial Point Cloud: Status And Outlook** | X Liang*, J Hyyppä, X Yu, Y Wang

78. **The accuracy of direct lidar-based estimation of forest canopy cover** | L Korhonen*, P Packalen, I Korpela

79. **Calibration of nationwide airborne laser scanning based stem volume models** | E Kotivuori*, M Maltamo, L Korhonen, P Packalen

80. **Predicting species-specific diameter distributions using a nearest neighbor imputation with various configurations - The effect of different ALS data** | J Räty*, P Packalen, M Maltamo

81. **Large Area Vegetation Mapping Using NASA's LVIS Facility** | M Hofton*, JB Blair, D Rabine

82. **Assessing the effects of multispectral aerial lidar viewing geometry on 3D and intensity features used for tree species identification** | BC Budei*, B St-Onge

83. **Feature standardization across areas of interest to optimize field sampling for individual tree species classification** | P Rana, B St-Onge*, J Prieur, BC Budei

84. **Evaluation of a method for yield forecasting produced using Lidar derived forest data and harvester data** | J Söderberg*, JJ Möller, E Willén

85. **The Integration of UAV and Backpack Lidar Systems for Forest Inventory** | Y Su*, T Hu, H Guan, J Liu, Q Guo

Ecometrica Booth. Forests 2020: Protecting and Restoring the World's Tropical Forests | N Moffat*, D Michelakis, P McGregor, S Middlemiss

Poster Session #2

Foyer A & B

**Indicates presenting author*

Posters in this session on display from 13:30 on Wednesday (Oct. 3) until end of conference in Foyer A & B.

Abstracts for Poster Session #2 can be found HERE

1. **A Semi-Automated Burned Area Mapping Methodology Using Sentinel-2 Imagery |** N Georgopoulos, D Stavrakoudis, IZ Gitas*
2. **Regional burned area mapping based on Google Earth Engine |** JA Anaya*, AM Rodríguez-Montellano, MI Cruz López, LDL Manzo Delgado, WF Sione, N Mari, G López-Saldaña, F Morelli, W Schroeder, JC Beltrán, A Bastarrika
3. **Fusion of multiple and temporally dense remotely sensed data sources for refined near-real-time burned-area mapping |** M Crowley*, J Cardille, M Wulder, J White
4. **Leveraging VIIRS active fire data from the Suomi NPP and NOAA-20 satellites for improved global fire monitoring |** I Csiszar*, M Tsidulko
5. **A Hybrid Hyrcanian Forest Fire Detection Algorithm |** M Rahim Zadegan, M Taefi Feijani*, M Zohary, A Tavakoli
6. **Detection of forest fires in Southeast Asia and western United Sates with optical and radar satellite observations |** M Humber*, K Lasko
7. **Combination of Sentinel-2 and Landsat 8 Data foMonitoring Wildfire Progression Using Google Earth Engine: The Case of the Massive Thomas Fire |** X Hu*, A Nascetti, Y Ban, M Wulder
8. **Monitoring Long-term Variation in Mediterranean Burnt Forests Using Sentinel 1-SAR Time Series. The case of Doñana National Park |** J Ruiz-Ramos*, A Marino, CP Boardman, R Diaz-Delgado, J Suarez
9. **Examining Fire Background Temperature - Methods for Estimation of Obscured Pixel Values |** B Hally*, L Wallace, C Engel, C Wickramasinghe, K Reinke, S Jones
10. **Burned area detection using Sentinel-1 data and locally adaptive algorithms |** MA Belenguer-Plomer*, MA Tanase, A Fernandez-Carrillo, E Chuvieco
11. **Predicting tree diversity with full-waveform Lidar data in Gabon |** S Marselis*, H Tang, J Armston, R Dubayah
12. **An ensemble classifier approach for urban tree species classification from ground-based spectral references |** J Aval*, S Fabre, E Zenou, D Sheeren, M Fauvel, B Xavier
13. **Identifying cerulean warbler habitat from forest structure using airborne laser scanning |** R Wasson*, P Treitz
14. **Forest biodiversity estimated from the space: testing the Spectral Variation Hypothesis comparing Landsat 8 and Sentinel 2 using a multi-temporal Rao Q |** M Torresani*, D Rocchini, R Sonnenschein, M Zebisch, G Tonon
15. **Non-Native Spathodea campanulata in Puerto Rico, Pre and Post 2017 Hurricane Season |** I Paynter*, B Cook, D Morton, S Martinuzzi, S Serbin
16. **The use of Cloud-Computing Approaches for Land Cover/Use Mapping to Support Ecosystem Accounting in West Africa using High Resolution Optical Data |** C Sousa*, T Fatoyinbo, C Neigh, M Honzák, T Wright, T Larsen
17. **Remote sensing of forest structural attributes in restoration plantings |** N Camarretta*, A Lucieer, PA Harrison, B Potts, N Davidson, M Hunt
18. **Integration of ForeStereo-Lidar data using Universal Kriging models: a geostatistical approach for forest inventories |** I Aulló Maestro*, C Gómez, A Vázquez, M Cabrera, F Montes
19. **Essential Biodiversity Variables obtained from airborne and spaceborne Lidar |** R Valbuena*, B O'Connor, F Zellweger, F Morsdorf, P Vihervaara, W Simonson, F Danks, G Chirici, N Coops, D Coomes
20. **Quantifying Multi-Source Carbon Cycle Model Uncertainties: Sensitivity Analysis, Perturbed Parameter Ensemble, and Uncertainty Attribution |** Y Zhou*, C Williams, H Gu
21. **Analysis of vegetative resilience and water use efficiency for the continental part of Ecuador using remote sensing and modelling |** JI Gamez-Badouin*, JM Madrigal-Gomez, GA Juarez Cansdales

22. **Assessing post-hurricane damage in mangrove forests of south Florida using repeat Lidar, Landsat imagery and U.S. Forest Service, Forest Inventory and Analysis (FIA) data |** T Schroeder*, M Brown, J Nowak, K Cummins, B Cook, C Giri

23. **Variations in mangrove canopy chlorophyll content with respect to species, submerged conditions and seasonality |** C Shi*, L Wang, X Cao

24. **Automated Quantification of Mangrove Change from Earth Observation Data, Matang Forest Mangrove Reserve, Malaysia |** R Lucas*, V Otero, R Van De Kerchove, B Satyanarayana, F Dahdouh-Guebas

25. **Mangrove forests of Ecuador: Extent, biomass and forty years of change |** N Thomas*, M Simard, S Howard, V Rivera-Monroy, E Castañeda-Moya, S Lee, T Fatoyinbo

26. **Mapping deforestation and forest structure deterioration: the potential of dense Sentinel-1 time series |** K Urban*, F von Poncet, L Fehrmann, M Freudenberg

27. **Validation of JICA-JAXA's deforestation monitoring system: JJ-FAST |** M Hayashi*, I Nagatani, T Watanabe, T Tadono, M Watanabe, C Koyama, M Shimada, T Ogawa, K Ishii, T Higashiuwatoko, M Miura, H Okonogi, T Morita

28. **Using Sentinel-2 satellite images for automated detection of forest changes |** T Pitkänen, A Kangas*, L Sirro, T Häme, L Häme

29. **Improving near real time tropical forest change monitoring with multiple data sources |** S Martin del Campo*, J Reiche, D Tuia, J Verbesselt, M Herold

30. **The Ecosystem Disturbance and Recovery Tracker system (eDaRT) for large-area multi-satellite monitoring of forest dynamics |** A Koltunov*, C Ramirez, S Ustin, M Slaton, E Haunreiter, ML Whiting

31. **Development of a fuel loading database for calculating and mapping fire emissions from wildland fires within the United States |** N French*, R Ottmar, S Prichard, M Billmire, M Kennedy, D McKenzie, E Kasischke, A Andreu, P Eagle, D Tanzer

32. **EPIC-simulated and MODIS-derived Leaf Area Index (LAI) comparisons across multiple spatial scales |** J Iiames*, E Cooter, A Pilant, Y Shao

33. **Mapping forest management |** D Schepaschenko*, F Kraxner, S Fuss, G Kindermann, M Dürauer, F Di Fulvio, A Krasovskii, M Lesiv

34. ~~**The value of fusing MOD**~~ CANCELLED ~~**nd Landsat data for analyzing phe**~~ ~~**gy and mapping forest tree specie**~~ ~~nej*, V Radeloff, F Gao, M Ozdog~~

35. **Sentinel-2 image time series analysis for forest classification: On the way to a Germany-wide tree species map |** S Preidl*, M Lange, D Doktor

36. **Large spatial variation of leaf angle distribution quantified by terrestrial Lidar in natural European Beech forests |** J Liu*, A Skidmore, T Wang, S Jones, M Heurich

37. **Retrieving forest canopy leaf area index using terrestrial laser scanning data |** L Ma*, G Zheng, W Ju

38. **What is the effect of varying wood density on Lidar-derived above-ground biomass? |** M Demol*, S Moorthy, K Calders, H Verbeeck, I Janssens, B Gielen

39. **Terrestrial laser scanning to derive non-destructive estimates of liana AGB |** SM Krishna Moorthy*, K Calders, H Verbeeck

40. **A New Method of Equiangular Sectorial Voxelization of Single-scan Terrestrial Laser Scanning Data and Its Applications on Forest Defoliation Estimation |** L Huo*, X Zhang

41. **Novel TLS Device with Excentric Automotiv Scanner to avoid occlusion in single stand-point scanning |** G Bronner*

42. **Seasonal structure-function interactions: fusing solar induced fluorescence and terrestrial Lidar for holistic ecosystem measurement |** A Stovall*, R Maini, R Nardacci, H Shi, H Shugart, X Yang

43. **Instrument-based Lidar point cloud modeling with DART |** T Yin, J Qi, B Cook*, J Gastellu-Etchegorry, S Wei, D Morton

44. **Quantifying Riparian Buffer Zones and Floodplain Vegetation Roughness using a Drone-based Lidar** | J Resop*, WC Hession

45. **The operational application of airborne Lidar technology for forest stand-level inventory in the South of China** | Y Pang*, C Li, H Dai, Z Li

46. **Mapping smallholder forest plantations in Andhra Pradesh, India using Sentinel 2** | PT Williams*, S More, SA Cerv, RH Wynne

47. **A review of field and laboratory spectral measurements of coniferous forest components** | M Rautiainen*, P Lukeš, L Homolová, A Hovi, J Pisek, M Mõttus

48. **Upscaling dorsiventral leaf optical properties in forest radiative transfer model** | P Lukeš*, E Neuwirthová, R Janoutová, Z Lhotáková, L Homolová, J Albrechtová

49. **A digital mapping method for linking high resolution remote sensing images to individual tree crowns** | S Graves*, S Bohlman

50. **Reforestation and Economic Security in a Developing World** | D Oetter*

51. **Multidecadal rates of arctic and boreal land cover change in ABoVE inferred from dense Landsat time series** | J Wang*, D Sulla-Menashe, C Woodcock, O Sonnentag, M Friedl

52. **Identifying and correcting biases in global tree cover products: a case study in Costa Rica** | D Cunningham*, M Fagan, P Cunningham

53. **Mapping human settlements and population density in the Democratic Republic of Congo using Landsat data** | P Lola Amani*, P Potapov, A Pickens, M Steininger, M Hansen

54. **Human-Guided v. Automated Classifications of Ponderosa Pine Plantations in the Willamette Valley, Oregon** | A Riddell*, B Strimbu

55. **Simulating Empirically Observed Forest Patterns Using a Hybrid Demand-Allocation Land Use Change Algorithm** | E Brooks*, J Coulston, K Riitters, D Wear

56. **Sentinel-1 CSAR Forest Land Cover Mapping of Troms County, Norway** | J Haarpaintner*, HA Tømmervik

57. **National wide CHM, deforestation areas and forest boundaries from airborne Lidar data in Estonia** | A Vain*, K Sepp, J Raet, M Villoslada Peciña, M Lang

58. **Forest mapping with machine learning methods** | R Boesch*

59. **Spatial prediction of old-growth forest fire refugia in the US Pacific Northwest** | G Meigs*, M Krawchuk

60. **Utilizing high-performance and data-rich cloud platforms for nearest neighbor imputation models: Bringing NN to the cloud** | M Gregory*, D Bell, N Gorelick, V Myroniuk

61. **The ICESat-2 Mission: an Overview** | A Neuenschwander*, S Popescu, T Neumann, L Magruder

62. **Mapping Forest Aboveground Biomass with Simulated ICESat-2 Data** | L Narine*, S Popescu, A Neuenschwander, S Srinivasan

63. **Leaf area density from airborne Lidar: Comparing sensors and resolutions in a temperate broadleaf forest ecosystem** | A Kamoske*, K Dahlin, S Stark, S Serbin

64. **Impact of PAD estimation method and of observation angles on the performance of forest structure classifications using Lidar derived PAD profiles** | F De Boissieu*, S Durrieu, A Piboule, A Munoz, J Bock, A Jolly, J Renaud

65. **VIIRS active fire products in different resolution in NOAA operations** | M Tsidulko*, I Csiszar, W Schroeder

66. **Using Window Regression to Repair Landsat ETM+ Data** | E Brooks*, R Wynne, V Thomas

67. **A Kalman Filter Approach to Estimate Leaf Index in Loblolly Pine Plantations in the Southeast United States using Ground Based Measurements and Satellite Data** | S Kinane*, C Montes

68. **Post-hurricane forest damege mapping in Bory Tucholskie (Poland) based on up-scaling approach of photogrammetry-point clouds and Sentinel-2 imagery** | P Wezyk*, P Hawrylo, M Brach, K Zieba-Kulawik, M Ratajczak, P Szymanski

69. **Variation in foliar functional traits from the NEON Airborne Observation Platform |** Z Wang*, A Chlus, T Zheng, A Singh, E Kruger, P Townsend

70. **Substituting spatial information for spectral resolution in multi-sensor time series |** MJ Hughes*, J Braaten, S Hooper, R Kennedy

71. **Spectral libraries for boreal forests |** A Hovi*, P Raitio, P Forsström, M Mõttus, M Rautiainen

72. **Deep learning to identify trees outside forests in Andhra Pradesh using Sentinel-2 and harmonized Landsat Sentinel data |** S More*, PT Williams, RH Wynne

73. **G-LiHT v2.0: NASA's Second-Generation, Multi-Sensor Airborne Remote Sensing System for Studying Ecosystem Form and Function |** BD Cook*, L Corp, D Morton, H Anderson, H Margolis

74. **The 2017 ABoVE airborne campaign |** E Hoy*, C Miller, P Griffith

75. **Testing the tree diversity - productivity and tree diversity - stability hypotheses in Białowieża forest using remote sensing time series |** B Rombouts*, L D'Haene, W De Keersmaecker, B Jaroszewicz, K Stereńczak, O Bouriaud, B Somers, B Muys

76. **Assessment of forest recovery using time series of satellite data and in-situ observations of ecosystem element budgets |** L Homolová*, M Švik, R Janoutová, O Brovkina, P Lukeš, F Oulehle

77. **Mining dense Landsat time series for secondary forest succession on abandoned agricultural lands mapping in heterogeneous mountainous landscapes |** K Ostapowicz*, E Grabska, A Zielonka

78. **The effects of sample size on accuracy estimates of burned areas in the Amazon |** A Fernandez-Carrillo*, MA Tanase, MA Belenguer-Plomer, E Chuvieco

79. **Bayesian Spatio-Temporal Models for Map Reconstruction and Forest Inventory Prediction |** A Chakraborty, K Khan, G Petris*, T Wilson

80. **Utilizing auxiliary information when designing field survey of National Forest Inventory |** M Räty, A Kangas*, J Heikkinen

81. **Modeling Tree Canopy Cover based on Crowdsourced Interpretations: A multi-scale bagging approach |** J Derwin*, V Thomas, R Wynne, SS Peery, J Coulston, K Luther

82. **Using RGB camera-mounted unmanned aerial vehicles to quantify individual tree-based leaf phenology in a tropical moist forest |** J Park*, H Muller-Landau, J Lichstein, S Rifai, J Dandois, S Bohlman

83. **Overview and Status of the CEOS Land Product Validation Subgroup |** J Nickeson, M Roman, F Camacho, L Duncanson*, J Armston

84. **Quality assessment of MODIS Vegetation Continuous Fields of Tree Cover over France |** D Sheeren*, V Thierion, P Herrault

85. **Sentinel-2 time series images analysis: a rapid and an accurate solution to map large-scale forest cover |** V Thierion*, A Vincent, J Inglada

86. **Using the new French Land Cover Map (OSO) as spatial inputs in forest ecological modeling |** P Herrault*, V Thierion, D Sheeren

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1A

SATELLITE PRODUCT CALIBRATION AND VALIDATION

Moderator: Andrew Hudak

1.(10:30) Terrestrial Laser Scanning for calibration and validation of satellite image data products across Queensland, Australia | *N Goodwin, J Armston*, F Watson*

The calibration and validation of large area vegetation fractional cover products across Queensland is challenging due to the logistics and costs involved in sampling such a wide range of vegetation, land use and soil types over a 1.9 million km2 area. In the past, densitometer point intercept measurements have been used to record the fractional cover of foliage and woody material at a network of sites across the state. However, further analysis has found that the lack of precision and measurement error between observers makes the data unsuitable for monitoring subtle changes in understorey and overstorey fractional cover. Airborne lidar has similarly been used in the calibration/validation of fractional cover but requires field measurements to account for sensor/survey properties and lacks temporal frequency for monitoring applications. These issues have made further improvements to reference datasets for calibration and validation of change products and derivation of new products difficult as it is unclear where the errors are originating from and whether new models are an improvement over previous models. As a result, we are exploring the use of Terrestrial Laser Scanner (TLS) to improve the accuracy and repeatability of site-based measurements for calibrating and validating statewide passive-optical image products (e.g. Landsat and Sentinel). Initially, we report on the findings of experimental datasets collected at five structurally different sites using a RIEGL VZ400 TLS that underpin a repeatability analysis framework for quantifying measurement errors and further improving our collective experience in the field and post-processing of TLS data. We then will provide details on our broader application including a sampling protocol for innovative field data collection with an emphasis on maximising the number of plots sampled.

2.(10:50) Validation of the GEDI simulator for pre-launch calibration and validation | *S Hancock*, J Armston, H Tang, M Hofton, JB Blair, S Luthcke, X Sun, JR Kellner, S Marselis, D Minor, S Healey, P Patterson, R Dubayah*

NASA's GEDI mission, due for launch in November 2018, will be the first spaceborne lidar mission optimised to measure forest structure. GEDI will deliver global data products of footprint and gridded aboveground biomass density (AGBD), leaf area index, foliage profiles, canopy cover and canopy height. The AGBD data products require statistical models to convert GEDI observables into AGBD estimates. To develop these models prior to GEDI launch, we have developed a simulator capable of producing waveforms for any large-footprint lidar instrument, using widely available airborne laser scanning (ALS) data. We used the waveform simulator to produce a large database of GEDI measurements at locations with coincident field observations.

We evaluated the accuracy of the waveform simulator by comparing simulated Land, Vegetation and Ice Sensor (LVIS) waveforms to recorded LVIS waveforms across a range of forest structures and ALS instruments. Sensitivity studies have revealed the minimum ALS data quality requirements to avoid bias and have quantified the uncertainty of the simulator. The ability of the simulator to predict measurement error was also assessed across the range of observed errors in LVIS. The simulator was found to have a mean bias in relative height (RH) metrics of 9 cm with a root mean squared error of 6 m and was able to explain 80% of observed measurement error. The simulator is considered accurate enough to use in GEDI's calibration.

The GEDI simulator was then coupled to the footprint and gridded AGBD models and orbital simulations of expected sampling density to create the GEDI performance tool. This allows errors to be propagated end-to-end through the GEDI processing chain to estimate global distributions of final product accuracies. Initial results from the performance tool are presented.

3.(11:10) Influence of reference data accuracy in remote sensing studies | *HJ Persson*, G Ståhl, N Lindgren*

The accuracy of remote sensing methods for forest inventory is commonly evaluated by comparing estimated values with the corresponding field inventoried references, which normally are considered to be true. However, these are also affected by different kinds of errors. In this project, we intend to clarify how different field data errors influence the results when evaluating the accuracy of remote sensing based inventory methods. In the past, the remote sensing data were typically of such low quality that minor errors in the field reference data did not make a difference in the evaluations. Today the situation is different, following technical improvements and high resolution techniques such as terrestrial laser scanning. Thus the need for accurate reference data, or methods to adjust for errors in reference data, are increasing. The error sources to be investigated in the project are measurement errors, modelling errors, positioning errors (mainly sample plots) and sampling errors. By assigning error sources a systematic or random nature, or a combination of the two, methods for quantifying the impact of reference data errors will be developed as well as (for some cases) methods to compensate for such errors in assessing the accuracy of estimates based on remote sensing data.

4.(11:30) Validation of the operational SNPP VIIRS GVF product using high resolution Google Earth images in urban areas in U.S. | *Z Jiang*, Y Yu*

Real-time Green Vegetation Fraction (GVF) is needed in the numeric weather, climate and hydrological models. Since August 2012, the Suomi National Polar-orbiting Partnership (SNPP) Visible Infrared Imager Radiometer Suite (VIIRS) GVF has been produced as a NOAA-Unique Product (NUP) for applications in numerical weather and seasonal climate prediction models at the National Centers for Environmental Prediction (NCEP). Validation is a key part of product development. The high (sub-meter) resolution Google Earth RGB imagery, along with its location and acquisition date information, is a valuable source of ground vegetation information. To validate the global 0.036-degree resolution VIIRS GVF product, Google Earth RGB images were used to derive the ground truth GVF. Google Earth images over VIIRS GVF pixels, areas of 0.036° by 0.036°, were downloaded from Google Earth over 50 urban areas in U.S.. A Green Color index (3G-2R-B) was used to measure the greenness of a pixel in the RGB images. Green pixels in the high resolution Google Earth images were identified if their Green Color index values are larger than a threshold value. GVF value of the Google Earth images were calculated by counting the percentage of green pixels, which then were compared with the corresponding VIIRS GVF values. It was found that the RMSE of the VIIRS GVF product is ~0.10.

5.(11:50) ESA-NASA Multi-Mission Analysis Platform | *A Whitehurst*, K Murphy, R Ramachandran, K Bugbee, H Laur, C Albinet*

With the launch of new satellite missions and growing understanding of the complexity of ecological processes, the scientific community is faced with a unique and immediate need for improved data sharing and collaboration. This is especially evident in the Earth sciences and carbon monitoring community with the launch of the NASA-ISRO SAR (NISAR) mission, the NASA Global Ecosystem Dynamics Investigation (GEDI) mission, and the ESA Biomass mission. These missions present data storing, processing and sharing challenges due to the quantities of data (mission as well as pre-launch airborne, field, and calibration/validation data and analyses), which can impede scientific progress. To address these issues, NASA and ESA are working collaboratively to develop the Multi-Mission Analysis Platform (MAP) to improve the understanding of global aboveground terrestrial carbon dynamics. The MAP will provide a common platform with computing capabilities co-located with data as well as a set of tools and algorithms developed to support this specific field of research. This will establish a collaboration framework between ESA and NASA to share data, science algorithms and compute resources in order to foster and accelerate scientific research conducted by NASA and ESA scientists.

The objectives of the MAP are to:

1) enable researchers to easily discover, process, visualize and analyze large volumes of data from both agencies
2) provide a wide variety of data in the same coordinate reference frame to enable comparison, analysis, data evaluation, and data generation
3) provide a version controlled science algorithm development environment that supports tools, co-located data and processing resources
4) address intellectual property and sharing issues related to collaborative algorithm development and sharing of data and algorithms.

This presentation will present the MAP to its potential user community as well as allow project managers to gain feedback from the aboveground biomass research community.

1B

MULTI-DATE LIDAR APPLICATIONS

Moderator: Jackie Rosette

1.(10:30) Monitoring adaptation to wind in Sitka spruce plantations using time-series analysis of airborne LiDAR | *J Suarez*, R Manso*

Background: Commercial softwood plantations are regularly affected by wind damage. As climate change is expected to further intensify wind-disturbance regimes, it is paramount to understand those impacts and the ecosystem responses. Monitoring and management has focused on structural damage. However, wind may have a detrimental effect on the functioning of surviving trees after a storm, which rarely has been accounted to date.

The aim of this work is to quantify the effect of wind on growth reduction using a combination of time-series analysis of

LiDAR acquisitions, maximum gust estimation using airflow models and field data collection.

Methodology: four LiDAR surveys covering ten growing seasons (2002-2012) were used to estimate growth in Sitka spruce (Picea sitkensis) plantation in Southwest Scotland. This area was affected by two catastrophic storms in 2006 and 2012. Reference anemometers were used to model wind climatology in WaSP at the time of the storm based on terrain and vegetation models derived from LiDAR. A cartography of damage was obtained by comparing reductions in fractional cover in between LiDAR acquisition. A hybrid method of analysis was used to produce an area-based analysis that estimated Top Height and Site Index variations. Areas of variable dimension were used in order to obtain the most representative metrics. A correction factor was used to homogenise point densities. Maximum gusts at the time of the storm were obtained with the ForestGALES model, which combined prevailing wind speed and directions across the study area with forest canopy.

Findings: growth reduction was observed in the vicinity (10 to 30 m distance) or adjacent to the larger windthrow gaps and in locations that suffered the largest gust values (as estimated by WaSP) but where no structural damage was observed. While top height continued to increase steadily among the surviving trees, Yield Class experienced substantial reductions of 3-7 cubic metres per ha per year. Yield reduction appeared in clusters and was not correlated to age, canopy height or Yield Classes, which suggests that trees either suffered damage in the root system or they changed their growing strategy in order to gain more stability. The proposed method provides estimations of timber volume loses as a result of catastrophic windthrow (normally recovered by salvaging operations), endemic damage (never recovered) and lost production due to Yield Class reductions.

2.(10:50) Modelling top height growth and stand volume increment using repeated laser scanning data | *J Socha*, M Pierzchalski, K Stereńczak, P Hawryło, S Miścicki, G Krok*

Forest site productivity, which is a quantitative estimate of the potential of a site to produce plant biomass, remains a fundamental variable in forestry, and embraces two concepts: the site potential and that part of the site potential realized by a given forest stand. The most commonly used and widely accepted method of evaluating potential site productivity is the site index. Therefore, the construction of site index models describing stand height growth with age remains a fundamental task for site productivity differentiation. Site potential realized by a given forest stand may be expressed by current stand volume increment. Three main data sources have been used for site index model development to date: 1) repeated measurements on permanent sample plots (PSP); 2) temporary sample plot (TSP) data from periodic inventories; and 3) stem analysis (SA) data. Stand volume increment has been estimated to date using PSP and TSP plots. Our study is a practical application of change detection using airborne laser scanning (ALS) for the development of top height growth models and estimation stand volume increment. We demonstrated how wall-to-wall multi temporal ALS data obtained for large forest areas can be used in developing stand height growth models for Scots pine that appropriately reflects site-specific growth trajectories. Height growth models were successfully captured by repeated ALS data from the 8-year period. During model development, we used raster plots with an area of 0.01, 0.09 and 0.25 ha and two methods of stand height estimation based on percentiles of point clouds and mean height of highest trees on each 0.01 ha obtained by segmentation of individual trees. Repeated ALS data may be recognized as a new, fully valuable data source for TH growth, site index and stand volume increment prediction. Repeated ALS observations can be a substitute for height growth data used in site index modelling and collected to-date from SA, PSP or TSP and enable quite precise estimation of stand volume increment. It could be expected that improving ALS technologies, decreasing costs of laser scanning acquisition and increasing data availability will result in improving the accuracy of forest growth estimates. Therefore, in the near future, both utility and increased predictive validity will lead to substantial increases in the importance of change detection using airborne laser scanning in forest growth prediction using the data from repeated ALS measurements.

3.(11:10) Direct and indirect site index determination for Norway spruce and Scots pine using bitemporal airborne laser scanner data | *L Noordermeer*, OM Bollandsås, T Gobakken, E Næsset*

Site index (SI) is a fundamental resource variable in forest management planning, as it is a quantitative measure of the production capacity of forest land. SI is usually derived from estimates of dominant height (Hdom) at a given reference age using empirical age-height curves. However, it is commonly quantified with large uncertainty in forest management inventories, resulting in economic losses due to incorrect management decisions. In this study, we used bitemporal airborne laser scanner (ALS) data acquired for a study area in southeastern Norway with a time interval of 15 years to estimate SI through the area-based approach. We present two practical methods for SI determination, i.e., the (1) direct and (2) indirect method. For the direct method, we regressed field observations of age-height SI against canopy height metrics derived from ALS data from the first point in time and changes in ALS metrics reflecting canopy height growth during the observation period. For the indirect method, we first modelled Hdom at the two points in time separately using the respective ALS metrics as predictors. We then derived SI from the initial Hdom, the estimated Hdom increment, and the length of the observation period using empirical SI curves. We used bitemporal field data collected from 80 georeferenced sample plots of size 232.9 m2 to fit species-specific regression models for SI and Hdom at both points in time. We then applied the models to an independent dataset comprising 42 georeferenced validation plots of size ~ 3700 m2 for which ground reference values were collected at both points in time to assess the accuracy of both methods. Both the proposed methods produced SI estimates with satisfactory precision. For the direct method, the independent validation revealed root mean squared errors (RMSE) of 1.78 and 1.08 m for Norway spruce and Scots pine, respectively, compared to 1.82 m obtained for both tree species using the indirect method. The indirect method can provide a suitable alternative to the direct method as field observations of SI are not required to calibrate the regression models.

4.(11:30) Canopy structural metrics for quantifying landscape level forest degradation | *G Parker*, A Anand, J Nagol*

Widely applicable, readily employed and mechanistically motivated metrics of forest structural conditions are critical for assessments of carbon stocks within multinational frameworks such as REDD+. However, a variety of issues have impeded the broad adoption of such needed measures. We present a suite of metrics based on the physical structure of forest canopies that could be useful for assessing carbon stocks and changes in carbon stocks in forested landscapes. Data for these metrics can be aquired from airborne or ground-based LIDAR, photogrammetric-derived canopy height models or with simple modifications of field stem surveys. Derived metrics include ground cover (gap fraction), canopy height and biomass, surface complexity and spatial variation. When used in conjunction with appropriate standards these can be used to provide quantitative measures of degradation extent. We illustrate this approach with examples using several sorts of data: multi-temporal ALS and profiling ground LIDAR and also stem surveys. We present a model of the impact of harvesting intensity on these metrics using data from a stem-mapped plot. We discuss some cautions and opportunities of this approach.

5.(11:50) Airborne Lidar detection of tropical forest degradation through simulations of selective logging disturbance using individual tree segmentation | *V Meyer*, S Saatchi, A Ferraz, M Longo, J Bastin, M Keller*

Forest degradation is recognized as a major source of carbon emissions, but it can be difficult to detect in complex tropical forests using remote sensing (RS) measurements. Unlike deforestation, forest degradation, in particular selective logging, does not result in large structural disturbance and biomass loss that can be easily detected even in high resolution imagery or Lidar data. Comparison of pre- and post-logging airborne Lidar data provides good estimates of change , but in many cases, Lidar data are only available for a single date, complicating detection of selective logging.

We simulated selective logging activities in an intact tropical forest of Panama using the individual tree crown (ITC) segmentation of small footprint (1 m) airborne Lidar data. We tested different scenarios of forest degradation, from low impact (ie. certified reduced impact logging (RIL)), to high intensity logging using typical examples reported in the literature for tropical forests. Parameters such as the number of harvested trees per ha, tree size, and directional felling were used to recreate various degradation scenarios. From simulated logging, we estimated biomass loss and assessed whether the forest degradation of each scenario could be detected using single date Lidar data, taking into account the natural variations of forest structure. The results from the simulations show that active logging events could be detected by Lidar due to the presence of logging roads, decks and skidding trails . However, the intensity of the logging activities was difficult to evaluate, unless a large number of trees have been removed. We found that the biomass loss due to RIL is mainly within the range of natural variability of the forest and is therefore difficult to detect using a single image. High intensity logging can be readily detected from single image through spatial association with logging roads and trails and statistically significant loss of large trees and biomass. The uncertainty in logging detection was also examined in the presence of post-logging regeneration to evaluate the applicability of the methodology and requirements for Lidar data acquisition. Our work represents a new methodological framework able to test virtually any kind of forest disturbance, and could potentially be applied to many case studies aiming to evaluate the impact of forest degradation.

1C

LARGE AREA MAPPING AND FOREST MANAGEMENT

Moderator: Johannes Reiche

1.(10:30) Comparison of single (C- and L-band) and multi-frequency satellite SAR-based tropical forest mapping in the Mai-Ndombe district in DRC. | *J Haarpaintner**

The Mai-Ndombe district in the Democratic Republic of Congo (DRC) is the focus area of the DRC's Emission Reductions Program. It has therefore attracted a lot of attention and also been the demonstration area in the ESA DUE Innovator III SAR for REDD project, focusing on the use of synthetic aperture radar (SAR) for tropical forest mapping for REDD/MRV.

Full multiyear coverage of the area with C- and L-band SAR satellite data were acquired with Sentinel-1 CSAR and ALOS-2 PALSAR-2, respectively, for the years 2015 to 2017 in addition to ALOS PALSAR 2007-2010 data and used for forest land cover mapping.

The overall approach is to take advantage of multi-observations of different seasons over the three years 2015-2107 in order to extract statistical parameters and seasonality on a pixel basis to improve forest/land cover (FLC) classification. The supervised classification differentiates into forest, swamp/inundated forest, savannahs, dry and wet grassland and river swamps. Several combinations of statistical parameters from both, single frequency and multi-frequency observation as multivariate features were used in a maximum likelihood classification. The FLC maps are reclassified into forest, savannah and grassland (FSG) super-classes which are then validated with a systematic sampling grid from manual interpretation of very high resolution optical satellite data from six Pleiades scenes acquired in 2016 and one SPOT-5 scenes from 2015. For the 3-class (FSG) validation overall accuracies of 84.4% and 89.1% were achieved for single frequency C- and L-band, respectively, and 90.0% by combining C-and L-band observations.

Resulting forest/non-forest maps with overall accuracies of 90.3%, 92.2% and 93.3%, for C-band, L-band and C/L-band combined, respectively, are then finally compared to global forest cover products from the Landsat-based Global Forest Change program and JAXA's ALOS-1&2 based global FNF maps that have accuracies of 88.9% and 87.7%, respectively. The highest accuracy 93.3% with a kappa value of 0.7988 was achieved by using 8 features, i.e. combining the 2015-2017 backscatter average and variance from the available SAR polarizations, i.e. VV and VH from Sentinel-1 and HH and HV from ALOS-2 PALSAR-2.

2.(10:50) Climate Resilient Forest Management in Nepal | *V Chitale*, M Matin, S Thapa, S Adhikari*

Forests play a vital role in combating climate change and mitigating its effects. In the Hindu Kush Himalaya (HKH), they are an important source of livelihood for the region's growing population. With forest degradation and deforestation increasing, it has become all the more necessary to have a reliable climate resilient forest management system. At present, lack of precise information on forest degradation and the impacts of climate change on forest ecosystems hinders the conservation, planning and management of forest ecosystems in Nepal. We attempt to tackle this issue in collaboration with Department of forest (DoF), Nepal, by providing scientific and reliable data on vulnerability of forests to anthropogenic factors and climate change using geospatial tools and techniques. We introduced a two-way multitier approach in Nepal to support the identification and implementation of adaptation and management strategies with special focus on forest ecosystems. It aims to reduce the vulnerability of forests to climate change and the degradation of forest ecosystems due to anthropogenic drivers. We used multispectral satellite datasets, data on climate trends and projections, and published data on extraction of forest resources in the study area. We conducted this study in 19 districts in Chitwan Annapurna Landscape (CHAL) that falls in Central Development Region in Nepal and covers an area of 32,057 km2 with altitudinal variation of 200-8800m. We assessed the forest degradation using following indicators based on the changes in forest cover, canopy density, forest fragmentation, and supply-demand dynamics of forest ecosystem services extracted by local communities. We then used data mining technique to quantify the influence of temperature and precipitation on functioning of forests by using MODIS data of net primary productivity, leaf area index, evapotranspiration and climatic trends and projections data. Finally, we overlayed the forest degradation map on forest climate sensitivity map to identify the hotspots of degradation and sensitivity needing immediate attention. These hotspots are defined as adaptation footprints, which help department of forest to prioritize their activities in the study area. These products are being actively taken up by Department of forest, Ministry of Forest and Soil Conservation, Government of Nepal and has helped improve their planning and management at district level.

3.(11:10) Post-hoc change detection- making the best of point-in-time map products | *G Liknes*, S Bender*

Landsat-based, multi-temporal change detection methods have greatly expanded since the opening of the Landsat archive. Disturbances to tree canopy cover can now be identified using all available scenes for a time-period of interest by exploiting information available in these dense time series. However, training and validation of these change models are ideally accomplished with repeat observations of either higher-resolution imagery or ground-based measurements, for a minimum of two points in time. If such data are not available, an alternative is to map tree canopy cover for two points in time with the best available training and validation data from independent locations, and the subsequent wall-to-wall change detection proceeds by some form of raster differencing. In this case study, we explore how best to determine change using two point-in-time, nationwide percent canopy datasets. The time 1 dataset nominally represents conditions across the conterminous United States for 2011 and was created using Landsat 5 TM imagery. The time 2 dataset represents conditions in 2016 and was created using Landsat 8 OLI imagery. Each dataset is accompanied by per-pixel estimates of model standard error. We adjusted confidence intervals around each per-pixel estimate of canopy cover by allowing a multiplier on the standard error (referred to hereafter m_z) to vary with time, initial canopy cover, and change type (gain or loss). Percent canopy cover estimates with non-overlapping confidence intervals were then considered to represent areas of likely change. Our objective was to empirically determine values for m_z that produce the optimal representation of canopy gains and losses. In our first exploration, we utilize area-based estimates of change from an ancillary national forest inventory (NFI) dataset and match the raster-differenced output to these estimates. In the second exploration, we use NFI plot observations from two points in time and an optimization approach to minimize pixel-level omission and commission errors. We found the optimal values of m_z to vary with time 1 and time 2, with location, and with change type. Holding m_z constant across the full range of percent canopy values suppresses changes in the middle range due to larger standard errors. In summary, analysis and application of standard errors associated with per-pixel canopy cover estimates, if carefully incorporated into an overall workflow, can contribute to a realistic change product.

4.(11:30) Entering the Third Dimension, Can We Nationalize Tree Canopy Height? | *J Ellenwood**

The US has a long history of ground based forest inventory supported by remotely sensed imagery. Today, high-resolution imagery is utilized for pre-field assessment of ground conditions and tactical decision-making while moderate resolution imagery is utilized for semi-automated change detection and post-stratified estimation of forest area, growing stock volume, and many other variables describing status and trends of forest land. Lidar and point clouds derived from stereo aerial imagery (Phodar) combined with new algorithms and enhanced computational power have opened new avenues for detailed characterization of forest vertical structure over broad areas. There is a high-level of interest among stakeholders in incorporating this information into the forest inventory process. Presented will be the current status of the US efforts in collecting Lidar and Phodar, the relationship with forest inventory and land status, a vision for incorporating this technology in the forest inventory program for the continental United States, and the potential implication for forest modeling.

5.(11:50) Comparison of Tree Canopy Cover Geospatial Datasets for the Conterminous United States | *S Bender, G Liknes**

The U.S. Forest Service (USFS) has been producing the tree canopy cover (TCC) component of the National Land Cover Database (NLCD) since the 2011 version. Several other TCC datasets are available, although the input data sources, methods, intended applications, and spatial extents differ. The USFS often receives inquiries from internal and external stakeholders regarding similarities and differences between USFS-produced TCC datasets (i.e., NLCD-TCC) and other datasets. To address these questions, we conducted a comparative analysis of several TCC datasets built by government, academic, and research organizations. We included datasets that are Landsat-based, as well as high-resolution (e.g., 1-m) tree datasets that we aggregated to a 30-m pixel prior to comparing with NLCD-TCC. Google Earth Engine was used to perform the analysis, which enabled common access to datasets and cloud computing for the authors who are located in different regions of the United States. Investigation into the tree cover datasets and their differences over the CONUS indicates a high amount of spatial variability. For example, the 2011 NLCD-TCC and the 2010 Landsat Tree Cover Continuous Fields data from the Global Land Cover Facility (GLCF) differ with root-mean-square-deviation (RMSD) of 2% to 39% (mean=17%, median=16%) on a regional basis, with large differences in the southeastern United States and in other regions with extensive tree cover. Comparison of 2011 NLCD-TCC data and aggregated high-resolution tree data from 2011 in the mid-Atlantic region indicates RMSD of approximately 20%, which is similar to the findings from the comparison of 2011 NLCD-TCC and the 2010 GLCF products. We also initiated comparisons of the 2016 NLCD-TCC provisional data with other datasets valid for a similar time period. In a comparison of the 2016 NLCD-TCC product and the 2015 GLCF product, the RMSD across northern New England is 22%, comparable to but slightly higher than the RMSD (18%) between the two products for 2011 and 2010. Results from our analysis will inform the USFS and its stakeholders as the next iteration of NLCD-TCC is developed.

1D

FORESTS IN THE GLOBAL CARBON CYCLE: CONNECTING REMOTE SENSING AND FOREST MODELS 1

Moderator: Rico Fisher & Andreas Huth

1.(10:30) Beyond MRV: High-Resolution Forest Carbon Monitoring and Modeling at Regional-National scales | *G Hurtt*, E Campbell, K Dolan, R Dubayah, V Escobar, S Ganguly, W Huang, N Hultman, K Johnson, R Lamb, A Lister, L Ma, R Nemani, J O'Neill Dunne, D O'Leary, L Ott, B Poulter, R Sahajpal, E Sepulveda, H Tang, M Zhao*

Local, national, and international programs have increasing need for precise and accurate estimates of both contemporary forest carbon and structure, and future estimates to support greenhouse gas reduction planning, climate mitigation initiatives, and other international climate treaty frameworks. To meet this need, we developed a robust, replicable framework to produce maps of high-resolution carbon stocks and future carbon sequestration potential. High-resolution (30m) maps of carbon stocks and uncertainty were produced by linking national 1m-resolution imagery and existing wall-to-wall airborne lidar to spatially explicit in-situ field observations such as the USFS Forest Inventory and Analysis (FIA) network. These same data, characterizing forest extent and vertical structure, were used to drive a prognostic ecosystem model to predict carbon fluxes and carbon sequestration potential at unprecedented spatial resolution and scale (90m), more than 100,000 times the spatial resolution of standard global models. Through project development, the domain of this research has expanded from two counties in MD, U.S.A. (2,181 km2), to the entire state (32,133 km2), to the tri-state region of MD, PA, and DE (157,868 km2), covering forests in four major USDA ecological providences (Eastern Broadleaf, Northeastern Mixed, Outer Coastal Plain, and Central Appalachian). Across the region, we estimate ~694 Tg C (14 DE, 113 MD, 567 PA) in above ground biomass, and estimate a carbon sequestration potential more than twice that amount. Empirical biomass products enhance existing approaches though high-resolution accounting for trees outside traditional forest maps. Modeling products move beyond traditional MRV, and map future afforestation and reforestation potential for carbon at local actionable spatial scales. Current work is expanding this spatial domain another order of magnitude encompassing an 11 state region, and a national scale prototype. These products are relevant to multiple stakeholder needs at multiple scales including the state of MD's Greenhouse Gas Reduction Act, the Regional Greenhouse Gas Initiative, and the U.S. The approach is scalable, and provides a prototype framework for application in other domains and for future spaceborne lidar missions including GEDI.

2.(10:50) Model-assisted estimation of tropical forest biomass change: a comparison of approaches | *N Knapp*, R Fischer, K Papathanassiou, A Huth*

Monitoring of changes in forest biomass requires accurate transfer functions between remote sensing derived changes in canopy height (ΔH) and the actual changes in aboveground biomass (ΔAGB). Different approaches can be used to accomplish this task: Direct approaches link ΔH directly to ΔAGB. Indirect approaches are based on deriving AGB stock estimates for two points in time and calculating the difference. In some studies direct approaches led to more accurate estimations, while in others indirect approaches led to more accurate estimations. It is unknown how each approach performs under different conditions and over the full range of possible changes. Here, we used a forest model (FORMIND) to generate a large dataset (> 28,000 ha) of natural and disturbed forest stands over time. Remote sensing of forest height was simulated on these stands to derive canopy height models for each time step. Three approaches for estimating ΔAGB were compared: 1) the direct approach, 2) the indirect approach and 3) an enhanced direct approach (dir+tex), using ΔH in combination with canopy texture. Total prediction accuracies of the three approaches measured as root mean squared errors were RMSEdirect = 18.7 t ha−1, RMSEindirect = 12.6 t ha−1 and RMSEdir+tex = 12.4 t ha−1. Further analyses revealed height-dependent biases in the ΔAGB estimates of the direct approach, which did not occur with the other approaches. Finally, the three approaches were applied on radar-derived (TanDEM-X) canopy height changes on Barro Colorado Island (Panama). The study demonstrates the potential of forest modeling for improving the interpretation of changes observed in remote sensing data and for comparing different methodologies.

3.(11:10) Variability in canopy turnover and crown plasticity from repeat airborne lidar | *D Morton*, B Cook, M Keller, M Alonzo, H Andersen, M Longo, R Meng, S Martinuzzi, D Lagomasino*

Fine-scale changes in forest structure from branch loss and tree fall events redistribute sunlight within the forest canopy and increase stocks of coarse woody debris. Representing the spatial and temporal variability in canopy tree mortality or sub-lethal losses of large branches in ecosystem models remains a challenge. Current models simplify the structural complexity of forested ecosystems, often through the use of large gaps to represent the total area of small disturbances or assumptions of forest plasticity to collapse three-dimensional heterogeneity in canopy structure into a one-dimensional profile of canopy leaf area. Here, we use repeat, high-density airborne lidar measurements from tropical, temperate, and boreal forests to evaluate latitudinal gradients in 1) canopy turnover from branch and tree fall events and 2) space-filling processes of forest recovery within and surrounding areas of recent canopy disturbance. Across all ecosystems, clustered canopy tree mortality events ≥400 m2 typically used to represent gaps in ecosystem models were rare. Instead, smaller changes in the canopy surface redistributed light to adjacent canopy trees or advanced regeneration. Rates of background canopy turnover and the size distributions of branch and tree fall events offer new constraints on the representation of forest succession in ecosystem models. For study sites with three or more lidar acquisitions, we evaluated the relative contributions from lateral growth of adjacent tree crowns or promotion from below to canopy closure. These findings offer a direct estimate of the degree of canopy tree plasticity across gradients of forest type, age, and height to advance the representation of forest disturbances in next-generation ecosystem models.

4.(11:30) Assessing the contribution of forest disturbances to global forest dynamics and carbon cycling | *T Pugh*, A Arneth, M Kautz, B Poulter, B Smith*

Stand-replacing disturbances, including fire, wind-throw, biotic outbreaks and harvest, are a cornerstone of forest dynamics, and their frequency is expected to change with climate. However, the variation in disturbance frequency across the world's forested biomes has remained poorly described, hindering quantification of their likely role in the global carbon cycle. New remote sensing observations of forest structure and dynamics will allow us to address a range of questions, for example: (i) Do such events dominate global carbon turnover, or are their effects highly regional? (ii) To what extent do they govern observed patterns of biomass variation? (iii) How sensitive is global terrestrial carbon exchange to realistic changes in the occurrence rate of such disturbances? Here we illustrate how combining satellite-based observations of forest loss and inventory-based observations of stand age can help infer the global distribution of disturbance return time. Using this information to drive a global dynamic vegetation model with a detailed representation of stand structure, we quantify the contribution of stand-replacing disturbances to global forest dynamics and resulting ecosystem stocks, and assess forest sensitivity to changes or uncertainties in disturbance return times. We find that the return interval of such disturbances varies from less than 50 years in heavily-managed temperate ecosystems to over 1000 years in tropical evergreen forests. Disturbances account for ca. 12% of annual vegetation-soil carbon transfer due to tree mortality globally, and over 60% in several regions. Inclusion of the observed rates substantially improves the accuracy of biomass simulation, but the substantial sensitivity of soil carbon stocks to assumptions regarding disturbance type emphasises the importance of attribution of disturbance agents. 45% of forested area demonstrates a high sensitivity of carbon stocks to changes in the frequency of disturbances, implying that relatively small shifts in disturbance frequency in these areas would have substantial consequences for the global carbon budget.

5.(11:50) Productivity and carbon fluxes of the Amazon rainforest: linking remote sensing and vegetation modelling | *A Huth*, E Rödig, F Taubert, A Rammig, M Cuntz, R Fischer*

Precise descriptions of forest productivity, biomass, and structure are essential for understanding ecosystem responses to climatic and anthropogenic changes. However, relations between these components are complex and rarely investigated, in particular for tropical forests.

We developed an approach to simulate carbon dynamics of around 410 billion individual trees within 7.8 Mio km2 of Amazon rainforest. We then integrated remote sensing observations from lidar (forest height map) in order to detect different forest states and structures caused by small-scale to large-scale natural and anthropogenic disturbances.

Under current conditions, we identified the Amazon rainforest as a carbon sink, gaining 0.56 Gt C per year. This carbon sink is driven by an estimated mean gross primary production of 25.1 tC ha-1 a-1, and a mean woody aboveground net primary production of 4.2 tC ha-1 a-1. We found that successional states play an important role for the relations between productivity and biomass. Forests in early to intermediate successional states are the most productive and carbon use efficiencies are non-linear. Simulated values can be compared to observed carbon fluxes at various spatial resolutions (individual to Amazon-wide scale). Notably, we found that our results match different observed patterns (e.g., MODIS GPP).

We conclude that forest structure has a substantial impact on productivity and biomass. It is an essential factor that should be taken into account when estimating current carbon budgets or analyzing climate change scenarios for the Amazon rainforest.

2A

PLANTATION MANAGEMENT WITH HIGH-RESOLUTION REMOTE SENSING

Moderator: Yong Pang

1.(13:30) Integrated use of time series satellite observations and field inventory data to monitor the life cycle of plantation forests | *C Huang**

Plantation forests offer vital socio-ecological services to the human society. Effective monitoring of these forests during key stages of their life cycle is required for valuation of the services they provide and for developing robust forest management approaches. Landsat has created an observational record of forests in many countries across the globe for over four decades. Opening of this record for no-cost access in 2008 led to rapid development of forest disturbance monitoring capabilities using time series approaches. Integration of time series Landsat observations with field measurements and other ancillary data sources provides viable approaches for assessing many important variables throughout the life cycle of plantation forests. In this study, we will first provide a brief review of time series approaches for forest disturbance mapping and then highlight recent studies demonstrating capabilities for determining disturbance type/agent, quantifying harvest intensity and timber output, and estimating forest age, structure, and growth through integrated use of Landsat time series with field measurements and other ancillary data sources. New opportunities offered by the Sentinel-2 and -1 satellites launched in recent years and forth coming optical (e.g. Landsat 9), lidar (e.g. ICESAT-2, GEDI), and radar (e.g. NISAR) missions to improve these capabilities will be discussed.

2.(13:50) A case study on integration of aerial and ground observations in forested areas via object-based coregistration of backpack and UAV based LiDAR Point Clouds | *W Yao, P Polewski*, L Cao*

In this work, we show a preliminary study on how to make use of the complementary strengths of the aerial and ground data sources by combining point clouds (PCs) to automatically enrich the unmanned aerial vehicle Laser Scanning PCs. Backpack Laser Scanning (BLS) is an emerging ground-based mobile mapping technology applicable for monitoring forested environments in unprecedented detail. For BLS the measured PCs based on SLAM techniques are stitched gradually and normally expressed in a less-accurate arbitrary coordinate system. Conversely, ULS PCs are acquired from above and usually georeferenced, yet the point density and penetrability near the ground may still suffer from dense overstory. Due to noticeably different platform characteristics and viewing angles, coregistration methods expecting a high geometric similarity between keypoints are inapplicable in this setting. Instead, our method focuses on single-tree level by constructing a tree descriptor which quantifies the 2D and vertical distances to other tree positions. These positions in both PCs are determined through 3D shape fitting and segmentation methods tailored to the PC density. Then, similarities between descriptor pairs form the basis for finding corresponding tree pairs (tietrees) using graph matching techniques. The tietrees yield the optimal transformation between the BLS and ULS coordinate systems. Our algorithm can handle different scales of the coregistered PCs. We evaluate our method on real test plots of ULS and BLS PCs involving diverse stem densities and tree species situated in the eastern coastal region of Jiangsu, China. Initial results show that the proposed tree descriptors are discriminative enough to find good correspondences. For the real plot data, up to 60% of detected trees can be matched and coregistered with an average positional deviation of 25 cm.

3.(14:10) Estimation of forest variables from VHSR Remotely Sensed Imagery | *J Yim*, J Park*

With the development of Remotely sensed technology, very high spatial resolution(VHSR) satellite imagery with ≤ 1m has been provided real information on forest resources at an individual tree level as well. In the forest inventory at the national and/or stand level, the data collection by surveyor is laborious and expensive. The forest information by VHSR imagery could be cost-efficiently provided.

This study was conducted to estimate forest variables including number of trees(NOTs), crown cover, the location information at a tree level, etc. with a VHSR image (GeoEye-1). For estimating the NOTs at an area of interest, tree crown by an individual tree was classified by watershed and object-based methods with different filter sizes. When applying the watershed method, the NOTs was decreased with increasing filter sizes. With a filter size of 9m, the NOTs are similar to that by field surveyor. With an object-based method, the NOTs increased with increasing of scale size for image segment. The Hybrid method by combining the watershed and object-based methods is provide more accurate NOTs compared to those by applying each method. The crown cover size by individual tree by surveyor and VHSR imagery will be compared to provide the NOTs and relationships between DBH and crown size. Finally, we will suggest the possibility of VHSR imagery for forest inventory at national and/or stand levels.

4.(14:30) Forest biometrics with UAV LiDAR, machine learning and Monte Carlo ray tracing simulations | *O Roberts*, P Bunting, A Hardy*

The generation of forest biometrics from airborne LiDAR typically requires a large quantity of forest inventory data for the calibration and validation of predictive models. Unfortunately, due to the financial and logistical costs of undertaking forest inventory over wide areas, forest managers have often developed regression models from numerically limited field measurements collected within a small sample of forest plots. The resulting empirical models tend to work well within the forests in which they are developed, however they often exhibit limited predictive accuracy (± 20% error) when applied in forests with contrasting biophysical properties.

This study explores whether forest attributes such as top height, standing volume and basal area can be determined more reliably through the application of machine learning and Monte Carlo ray tracing simulations. The Discrete Anisotropic Radiative Transfer (DART) model was used to simulate airborne discrete-return LiDAR over computer-generated forest plots with realistic tree allometrics and crown architectures. LiDAR simulations were compared to airborne LiDAR acquired over commercial Sitka spruce (Picea sitchensis Bong. Carrière) plantations in western Ireland. Comparisons demonstrated that DART simulations produced realistic point clouds with LiDAR metrics comparable to airborne LiDAR. Several machine learning algorithms were then calibrated using the simulated LiDAR metrics, resulting in improved estimates of standing volume, basal area and mean DBH. Preliminary results indicate that modern Monte Carlo ray tracing algorithms can generate reliable LiDAR data to supplement sparse forest inventory measurements for the estimation of forest biometrics in plantation forests. This novel approach shall be tested further in forthcoming UAV LiDAR surveys of Sitka spruce plantations throughout Wales, UK. Future work shall explore whether LiDAR simulations can also be applied to: (i) the estimation of forest biophysical attributes from historic LiDAR datasets where contemporaneous field measurements are lacking, and (ii) the segmentation and analysis of individual trees through the use of Convolutional Neural Networks.

5.(14:50) Larch plantation management monitoring using high resolution remote sensing data | *Y Pang*, W Jia, W Wang, J Li, Z Ma, L Si, Z Li, C Li, X Liang*

As a renewable resource, forest quantity and quality can be improved through management activities, especially for plantations. Larch is one of the most popular plantation species in the North Hemisphere. Larch plantation provides a variety of wood products, which include wood pulp, timber product and roundwood product. Different management plans are needed to maximize yields of different products. Geospatial technologies provide good support for these management plan and monitoring. We used airborne hyperspectral and lidar technologies to estimate individual tree and stand level parameters from larch plantation in the Northeast of China. The airborne hyperspectral data spanned 400 – 1000 nm. The larch plantation classification accuracy is of 93.1% using SVM classifier. The spectral clustering algorithm and a two-stage clustering algorithm were used to segment individual tree from point cloud data directly. The two-stage clustering algorithm was combined with region-growth and crown-profile analysis. The detection accuracies are of 58% and 86% separately. The individual tree height accuracies are of 0.69 and 0.86 for correlation coefficient, while 1.58 m and 3.2 m for RMSE. Based on these larch species reorganization and parameters, different management scenarios were analyzed for different management goals. We designed pruning and selective logging management activities based of age-group and tree density. Our first result showed good monitoring capability for pruning height monitoring. The logging management is still under-going, which will be monitored in the near future.

2B

AIRBORNE LASER SCANNING METHOD DEVELOPMENT

Moderator: Milto Miltiadou

1.(13:30) Evaluating unmanned aerial vehicle based LiDAR for the support of forest inventory | *M Sumnall*, C Hession, R Wynne, V Thomas*

Recent developments in unmanned aerial vehicle (UAV) and scanning LiDAR technology have allowed for widespread operational use within Forestry and at scales which may be prohibitive to conventional airborne LiDAR acquisition. The current study investigates the potential of UAV-based LIDAR for forest monitoring and to further explore methods for the delineation of individual trees. In the present study, high density (over 200ppm2) UAV-LiDAR data was collected for a two managed 10 year old Loblolly pine (Pinus taeda L.) plantation sites in 2017. One in Virginia and another in North Carolina, USA. Each site contained six different genetic types and three planting densities, which should represent a range of crown architectures. Height, crown dimensions and stem diameter were recorded by field measurements (n=6000). Individual tree crowns were delineated using a method applied directly to the LiDAR point-cloud. The returns corresponding to individual tree crowns were classified in an iterative approach. The first requirement was to find the highest unclassified return in the current field plot area, which was considered the tree center. The point-cloud surrounding the center was subset in 24 directions, where the upper surface was identified and horizontal break points identified using two height and distance from the center weight calculations based upon crown shape and proximity of potential neighbors. All returns falling in this horizontal extent were classified as part of the current crown. Existing methods such as raster-based marker segmentation and region growing algorithms were used in order to evaluate the current approach with UAV-based data. Given the high return density, for some of the individual trees, a proportion of the returns were from the main stem. The vertical extent or length of the crown was estimated using a voxel based approach. A method was developed using DBSCAN clustering to classify those returns most likely to be from the main stem in the vertical region below the crown. This classified returns were subset into discrete vertical regions and the horizontal distribution of these returns assessed. If groups of returns were found to approximate a parabolic distribution in horizontal space, they were considered to be from the main stem. Ellipsoids were then fit to these specific groups and used to estimate stem diameter within that height region. Results for stem dimeter were the assessed against corresponding field measurements.

2.(13:50) Stand level estimates of forest attributes with different LiDAR point densities | *F Mauro*, C Pascual, A Garcia-Abril, JA Manzanera, E Ayuga-Tellez, R Valbuena*

Forest management decisions are typically made considering stands or management units (MUs). Up to date information about forest structure attributes specific for MUs is required to make informed management decisions. Light detection and ranging (LiDAR) auxiliary information has been proved be highly correlated to structural attributes and it allows to obtain estimates of forest attributes with higher accuracy than field only methods. Prediction of forest attributes using LiDAR is typically made using models that relate LiDAR auxiliary information and forest attributes at a plot level. The influence of LiDAR point density in plot level predictions has been studied by several authors that found that increasing the LiDAR point density results in better estimates of plot level attributes. Accuracy of plot level models is related to the accuracy of estimates obtained for MUs using those models. However, the relation between explained variability of plot level models and the accuracy of MUs estimates is not obvious. In this study we analyzed the how increasing\reducing the LiDAR point density affected prediction of volume (V) and quadratic mean diameter (QMD) for MUs as they are the units that forest managers consider in their decision-making processes. The study area is a Mediterranean maritime pine forest located in Burgos (Central Spain) and contains 54 MUs. Estimates for MU and their corresponding measures of uncertainty were obtained using unit level empirical best linear unbiased predictors (EBLUPs) and LiDAR auxiliary information with point densities of 2, 1, 0.5 and 0.25 points per square meter. A set of 202 circular field plots was used to fit the models. Results showed that increasing the point density produced more accurate estimates at the stand level but differences between the highest and lowest point density was of very small (Differences in estimates and coefficients of variation for MU

3.(14:10) Towards high throughput assessment of canopy dynamics: the estimation of leaf area variation in Amazonian forests with multi-temporal multi-sensor discrete return lidar | *G Shao*, S Stark, D Almeida*

The Amazon forest plays a critical role in regulating Earth's climate system and carbon cycle, however, forest loss and degradation, including the impact of droughts, may be changing the region rapidly. Canopy properties are key indicators for degradation and ecological change. Specifically, the quantity and distribution of leaf area in the canopy influence light environments, forest productivity, and demographic processes. However, measurements of leaf area properties are challenging at regional scales and repeated measurements through time are required to capture structural changes. Airborne lidar (Light Detection and Ranging) is a promising source to quantify Leaf Area Density (LAD) variation, its vertical profile, and total (Leaf Area Index; LAI). Whether lidar can estimate these properties accurately in dense tropical forests, however, is still a critical question. Moreover, due to the diversity of available laser systems and varied campaign designs, airborne lidar surveys commonly utilize multiple laser devices with different collection parameters, which may introduce systematic bias and reduce comparability. In this study, we compared 16 pairs of repeat airborne lidar surveys with four different laser devices across Amazon forests. We asked whether leaf area estimates were stable across lidar sensors and survey parameters, particularly the density of laser pulse sampling, which is typically highly variable. Our study found significant effects of laser sensors on LAD estimation, which were consistent in pairwise comparison of laser systems and can be corrected as systematic bias. After correction, lidar-derived average LAI vertical profiles reveal canopy changes through time within sites, and structural variation between sites, which we confirmed through comparison with the high-certainty canopy surface characteristic, canopy height. Though limited to a comparison between just 4 devices, potential relationships between sensor-induced biases and lidar parameters suggest hypotheses for future enhancement of 3-D leaf area recovery. Our results show that lidar can quantify key characteristics of leaf area structural variation with acceptable accuracy and resolution over variable collections; however, when choice is possible, lidar device and collection parameters should be standardized to the greatest extent possible.

4.(14:30) Multispectral LiDAR data for the prediction of forest stand attributes | *M Dalponte*, LT Ene, T Gobakken, E Næsset, D Gianelle*

In this study, the potential of the Optech Titan multispectral LiDAR data to model and predict forest attributes at plot level is explored. In particular, we focus on three attributes: the aboveground biomass (AGB) per hectare (AGBha), the Gini coefficient of the diameter at breast height (GiniDBHs), and the Shannon diversity index of the tree species (SDI).

The study area is located in the Hadeland municipality in Southern Norway. The field data were collected on ten circular sample plots of size 1000 m2 and two circular sample plots of size 500 mq. In order to have a larger number of plots for the analysis the plots were split in 44 subplots of 250 mq. For each subplot AGB per hectare (AGBha), the Gini coefficient of DBHs (GiniDBH), the Shannon diversity index (SDI), and the number of trees per hectare (Nha) were computed.

LiDAR data were acquired with an Optech Titan sensor on the 27th of April 2016. Up to four echoes per pulse were recorded and the resulting density of single and first echoes was 38 pts/mq (14 pts/mq for the 1550 nm channel, 21 pts/mq for the 1064 nm channel, and 3 pts/mq for the 532 nm channel).

The normalized Z, i.e. heights above ground, was computed for the LiDAR data, and the intensity value of each LiDAR point was range calibrated. From each subplot variables (e.g. maximum, minimum, percentiles) were extracted from the point cloud, and five sets of variables were defined: i) TITAN: variables extracted considering the points altogether; ii) TITAN_1_2_3: variables extracted considering separately the points of the three LiDAR channels. In this way each variable was extracted three times; iii) TITAN_1: variables extracted only from the first channel (1550 nm); iv) TITAN_2: variables extracted only from the second channel (1064 nm); v) TITAN_3: variables extracted only from the third channel (532 nm). Multiple linear regression analysis was adopted.

The most accurate model for the AGBha prediction was the TITAN_1_2_3 ($R2 = 0.9$), for the GiniDBHs the TITAN_2 ($R2=0.79$), and for the SDI the TITAN ($R2=0.89$). The TITAN_3 model has always the lowest R2. Not all the channels provide the same amount of information, and the multispectral information is not always used. In particular, for the AGBha models it seems that the elevation information is much more useful. In contrast, the intensity information is frequently used for SDI. The 532 nm channel provided the weakest results for all the considered target variables.

5.(14:50) Multispectral airborne LiDAR data in the prediction of boreal tree species using area-based methods | *M Kukkonen*, M Maltamo, L Korhonen, P Packalen*

Light Detection and Ranging (LiDAR) has been established as the de facto airborne data source for modern remote sensing based forest inventory. Three dimensional information provides a platform to model total attributes, but species-specific information about forest resources are also required for many purposes. As means to provide better predictions at a tree species level, auxiliary information such as aerial images and satellite images has been used alongside LiDAR data. However, combining data from different sensors can result in errors due to different geometries and can be prohibitively expensive for some campaigns if it is impossible to capture all data in a single flight. Recent developments in LiDAR technology have led to a sensor capable of capturing pseudo-spectral airborne information alongside 3D observations from three wavelengths; 1550 nm, 1064 nm and 532 nm. It is suggested that the spectral information from the three channels of LiDAR would work analogous to information from aerial images. In this study, we compared multispectral airborne LiDAR sensor, Titan Optech, data with a traditional, unispectral, airborne LiDAR data and aerial images in the prediction of dominant tree species and tree species composition. Important features of both 3D and backscatter intensity were studied with a heuristic feature selection. A total of 479 circular field plots were measured in summer 2016 in the municipality of Liperi (62° 31′ N, 29° 23′ E), eastern Finland. The study area consists of managed boreal forests with different development classes and three main tree species classes: Scots pine (Pinus sylvestris), Norway spruce (Picea abies) and broadleaved trees (Betula pubsescens, Betula pendula). Multispectral LiDAR data was found to be comparable to use of unispectral LiDAR and aerial images in predicting the dominant tree species. Multispectral LiDAR mainly improved the prediction of the minority broadleaved tree species, as did the inclusion of aerial images to unispectral LiDAR data. Intensity features were important in predicting the dominant tree species with both unispectral and multispectral LiDAR data. Multispectral LiDAR decreased the prediction error of species composition in every tree species class compared to unispectral LiDAR, but was not comparable to aerial images and unispectral LiDAR.

2C

FOREST INVENTORY AND DECISION SUPPORT

Moderator: Chris Stockdale

1.(13:30) Comparing airborne laser scanning and digital aerial photogrammetry for large scale operational forest management inventories | *T Gobakken*, HO Ørka, OM Bollandsås, E Næsset*

Airborne laser scanning (ALS) has been the main source of auxiliary data for forest management planning during the last decade. Recently however, digital aerial photogrammetry (DAP) has emerged as an alternative to ALS data for three-dimensional characterization of forest structure. The accuracies obtained for estimates of biophysical forest characteristics using DAP have been similar to those obtained by using ALS, while the costs are markedly smaller. A prerequisite for using DAP is, however, that a terrain model already exists as a reference surface from a previous ALS acquisition. The accuracies of the most common biophysical forest characteristics estimated with both ALS and DAP have been assessed in a number of separate and relatively small studies in terms of geographical extent. Our objective was to compare the accuracies of DAP- and ALS-based inventories for large areas. Our study comprised data from five individual inventory projects (1693 km2), and by combining these data we were able to also assessed the project-specific effect on the models and the accuracies of the estimated biophysical forest characteristics. Only mature forest was considered and two strata were defined based on site productivity. In total, 594 sample plots of 250 m2 were measured. Stratum-specific non-linear regression models were fitted for the studied biophysical forest characteristics, i.e. volume, dominant height, and number of stems. The explanatory variables were various canopy height and canopy density metrics derived by means of photogrammetric matching of aerial images and small-footprint ALS data. Cross validation was used to assess the accuracy. For volume, dominant height, and number of stems, the root mean square error (RMSE) in percent of the mean ground reference value varied between 10-28%, 4-10%, and 25-38% for ALS and 16-32%, 5-11%, and 24-45% for DAP, respectively. Except for two of the 30 models, the results for ALS were better than for DAP. The results for ALS and DAP were most similar for dominant height. However, for number of stems larger differences were obtained. The differences between the projects were more pronounced for the low productivity forests compared to the high productivity forests. Furthermore, the differences between ALS and DAP were small, indicating that DAP data can be used for large scale operational forest inventories and providing estimates for biophysical forest characteristics with similar accuracy as for ALS.

2.(13:50) Value of airborne laser scanning and digital aerial photogrammetry data in forest decision making | *A Kangas*, T Gobakken, S Puliti, M Hauglin, E Næsset*

Airborne laser scanning (ALS) has been the main method for acquiring data for forest management planning in Finland and Norway in the last decade. Recently, digital aerial photogrammetry (DAP) has provided an interesting alternative, as the accuracy of stand-based estimates has been quite close to those of ALS while the costs are markedly smaller. Our objective was to find out whether the better accuracy of ALS is worth the higher costs for forest owners. In many recent studies, the value of forest inventory information in the harvest scheduling has been examined using cost-plus-loss analysis, where the losses due to inaccurate data are added to the inventory costs. In this study, the losses due to inaccuracies were calculated in monetary terms in the forest management planning context for both ALS and DAP methods at plot level. According to the results, the data produced using DAP are as good as data produced using ALS from a decision making point of view, even though ALS is slightly more accurate. ALS was better than DAP only if the data are to be used for more than 15 years before acquiring new data, and even then the difference is quite small. Thus, ALS and DAP data can be equally well recommended to the forest owners for management planning. With both methods, large underestimates of stand volume were the most severe errors for forest owner because of missed cutting possibilities, but overestimates had only a small impact. The results of the case study were compared to other studies. The properties of the case study areas and the relative RMSE of stand volume explained most of the differences between the case studies. On average, increasing the relative RMSE of volume by one per cent caused a 4.4€/ha increase in the losses.

3.(14:10) Transferability of ALS-derived Forest Resource Inventory Variables from Eastern to Western Mixedwoods in the Canadian Boreal Forest. | *K van Ewijk*, P Tompalski, P Treitz, N Coops, M Woods, D Pitt*

Over the last decades, the use of Airborne Laser Scanning (ALS) to predict a wide range of forest resource inventory (FRI) variables, such as timber volume (V), basal area (BA), quadratic mean dbh (QMD) and stem density (SD), has become more and more common practice. In most cases, these FRI variable models require locally collected field data for calibration and validation. The ability to expand the use of local predictive models within and between regions, i.e., to develop a model at one location and subsequently apply it to other locations, may have several advantages. First, such an approach may reduce the need and costs for additional extensive field data collections. Second, it may improve our understanding of how forest structure is related to these FRI variables. It may also improve our understanding of which ALS metrics, as proxies of forest structure, are more universally applicable in a variety of forest ecosystems and which are more site specific. The main objective of this research is to test the transferability of a suite of ALS-based FRI variable models from eastern to western boreal mixedwood forest sites. Mixedwoods are one of the most prevalent stand types within the Canadian boreal forest, however, different disturbances and species associations are seen in western compared to eastern boreal mixedwood forests. The impact of these differences on model predictions is an important aspect of this study. We use the Hearst Forest, northeastern Ontario as our eastern, and Slave Lake Forest, Alberta as our western study site. For both forests, ALS and forest mensuration data were acquired between 2004 and 2010. Based on the similarity of the ALS metric responses to the FRI variables in both sites and variable selection approaches, we build parametric and non-parametric models for each of the FRI variables. In addition, we test if model transferability improves if a combination of Hearst and Slave Lake Forest data are used for model calibration rather than using Hearst Forest data only. These models are then applied at Slave Lake Forest and compared to locally calibrated and validated Slave Lake Forest models. As expected our initial modeling results show that FRI variables directly related to tree height can be transferred easily to new locations with one or two-variable regression models. However, other FRI variables prove more difficult to transfer and may require more advanced approaches, e.g., Bayesian methods.

4.(14:30) Updating Lidar Forest Inventory Integrating Already Available Information | *J Esteban*, A Fernández-Landa, N Algeet-Abarquero, ML Guillen-Climent*

Within the framework of forest resources assessments, airborne LiDAR scanner (ALS) has emerged as a potential tool resulting in numerous sources for nationwide LiDAR availability. However, high acquisition costs hinder high frequency data updates making LiDAR data unusable in dynamic change areas. In this sense, Landsat time series may be an alternative to analyze dynamics of forest stands and to ensure the viability of LiDAR forest inventories results.

The purpose was to develop a methodology to update wall-to-wall volume estimates to current date through model-based inference using three sources of information Spanish National Forest Inventory (SNFI) plots, Landsat images and airborne LiDAR data. NDVI time series were analyzed using the Break for Additive Seasonal and Trend (BFAST) algorithm to detect abrupt and subtle changes on two different monitoring periods: between the dates of the 3rd and 4th NFIs (2005-2011) and after LiDAR data flight onwards (2012-2017). 3rd NFI volume estimates and a set of statistics derived from the magnitude of the detected breakpoint, within the first monitoring period, were used to predict volume estimates for the year of the 4th NFI. A set of metrics derived from ALS point cloud were selected as independent variables to provide volume estimates for 2012. Afterwards, these estimates together with the statistics from the magnitude of the second monitoring period were used to predict volume estimates to current date. A subset of plots from the 4th NFI and airborne LiDAR data from 2017 were used for residual uncertainty assessment.

Our results show that statistics derived from the magnitude of the breakpoints can be used as auxiliary information to update volume estimates yielding precise results. No statistically significant differences were found between the estimated volume with the proposed method and adjusting regression models with the most current LiDAR data. The methodology presented here has important implications for enhancing volume estimates, additionally; this approach poses an opportunity to decrease the cost of forest inventories since the interval between two LiDAR flights could be extended.

5.(14:50) The Use of Deep Learning and Three-Dimensional Convolutional Neural Networks to Interpret LiDAR Data for Forest Inventory. | *E Ayrey*, D Hayes, A Weiskittel, S Fraver, J Kershaw, B Cook*

As light detection and ranging (LiDAR) technology is increasingly available, it has become common to use these datasets to generate remotely sensed forest inventories across landscapes. Traditional methods for generating these inventories employ the use of height and proportion metrics to measure LiDAR returns and relate these measurements back to field data using predictive models. Unfortunately, these metrics fail to quantify horizontal canopy complexity, and can be subject to change between LiDAR acquisitions of varying parameters. This can make the transference of models between LiDAR datasets difficult.

Here we employ a three-dimensional convolutional neural network (CNN) to directly analyze the LiDAR point cloud and make area-based estimates of forest attributes (such as biomass and tree count). CNNs are a deep learning technique that operate by scanning and transforming the LiDAR using a series of moving windows. The values of each window are calibrated automatically as the model is trained to identify useful features for interpreting the LiDAR (such as tree crowns). Feature maps resulting from the window's transformations are then fed into a more traditional artificial neural network, which uses linear activators to filter important data and predict one or more desired forest attributes.

We demonstrate that several popular CNNs used for image recognition can outperform parametric and nonparametric models designed to predict aboveground biomass, tree number, and percent conifer species using traditional LiDAR height metrics. These results are found using LiDAR of similar acquisition parameters, as well as LiDAR of varying pulse density and phenology. We also discuss other potential ways that deep learning can be used to analyze LiDAR data, including segmenting individual tree crowns, classifying and filtering LiDAR point clouds, and projecting LiDAR forward in time.

2D

FORESTS IN THE GLOBAL CARBON CYCLE: CONNECTING REMOTE SENSING AND FOREST MODELS 2

Moderator: Rico Fisher & Andreas Huth

1.(13:30) The challenge of detecting size and light environment structured forest dynamics: testing models with a multitemporal multisite Amazon forest dataset | *SC Stark*, G Shao, SM McMahon, DR Almeida, MN Smith*

Forests play a critical role in regulating Earth's climate system and carbon cycle, however, detecting responses and feedbacks of forested systems to changing climate remains limited and controversial, especially at the scales that can inform Earth system models. Understanding how forests respond to changing environmental conditions, and determining which climate triggers might lead to forest die-offs will emerge from quantifying local-scale responses of individual trees. As remote-sensing platforms gain the power and resolution to detect individual fates, critical demographic information (how trees grow and survive) will need to be translated into the metrics of those observations. We use a large multisite, multitemporal dataset from the Amazon—the world's largest rainforest—to investigate whether an explicitly 3D lidar-based approach that fits a model unifying canopy and demographic structure to can meet this need by recovering forest demography with observations of canopy structure. We assess whether this approach can estimate tree crown light environment variation (over tree size) to improve upscaling of physiologically-based mechanisms of forest response. To monitor tree demographic processes through time, over important gradients, and with sufficient accuracy to identify subtle and emerging trends, we developed models that could use lidar remote sensing to link leaf area profiles with tree size distributions, comparing a model that included fine-scale 3D information about canopy surface height and light heterogeneity with a simpler model that was based on stand scale information. We found that a light environment-to-structure link was necessary to accurately simulate tree size distributions from canopy structure, while 3D light heterogeneity offered the advantage of information on crown condition variability, implicated recently as essential for production responses to environments. Our results showed acceptable predictions of small-to-mid size classes but higher uncertainties for larger classes at the ¼ ha plot scale, likely due to low densities and variation in height-diameter allometries, suggesting improvement with approaches tailored to large trees. While still maturing this lidar network based approach offers new capacity for high throughput size and light environment structured forest dynamics monitoring, a potentially transformative data stream to improve prediction of the consequences of climate change for forest atmosphere interactions.

2.(13:50) Design and application of a next-generation forest biogeochemistry model, Sortie-BGC | *A Erickson*, N Strigul*

Over the past two decades, a new generation of terrestrial biosphere models blended principles from physical 'big-leaf' models and individual-based 'gap' models into new hybrid models. This was done to reduce uncertainties in forests through explicit inclusion of vegetation dynamics. Early models along this line include HYBRID, LPJ-GUESS, and SEIB, which used sampling to reduce computational expense. Parallel research on the ED model approximated the first moment of a gap model using systems of partial differential equations. A more powerful model reduction technique followed in the Perfect Plasticity Approximation, or PPA. Inspired by the TASS tessellation scheme, this work showed that adding phototropism and crown plasticity to the Sortie gap model reduced variation in canopy join height to a negligible level. This observation allowed the reduction of individual-based dynamics to cohort-level interactions, improving computational efficiency and providing analytical tractability. Meanwhile, research on forest landscape models such as LANDIS-II followed the assumption that landscape patterns of disturbance and dispersal are key in shaping forests.

Despite reasonable fidelity to Moore's Law and a trend toward highly parallel processors, global application of individual-based models remains infeasible. Thus, we aim to extend Sortie-PPA by adding mechanistic representations of energetic and biogeochemical fluxes, and landscape disturbance dynamics, using hierarchical multiscale modeling, into the next-generation Sortie-NG model known. The model incorporates evolutionary optimality principles and allow for variation elsewhere in the trait space to represent phenotype plasticity and intraspecific genetic diversity. In doing so, we aim to bridge the divide between big-leaf, gap, and forest landscape models by integrating principles from each, focusing on salient dynamics for continental-scale biogeochemistry, demography, and diversity. Following the LM3-PPA model, we term this new class of hybrid models 'cohort-leaf' models for their partitioning of big-leaf model energy and biogeochemistry fluxes amongst dynamic vegetation cohorts. We discuss key aspects and limitations of model design and demonstrate application of an prototype of Sortie-NG at Harvard Forest, USA. We close by discussing planned future modifications to the model, including new machine learning-based processes intended to inspire the next generation of terrestrial biosphere models.

3.(14:10) Global Patterns of Tropical Forest Fragmentation and its Impact on the Global Carbon Cycle | *R Fischer*, F Taubert, K Brinck, M Müller, J Groeneveld, S Lehmann, M Dantas De Paula, JO Sexton, D Song, T Wiegand, A Huth*

Deforestation in the tropics is not only responsible for direct carbon emissions but also extends the forest edge wherein trees suffer increased mortality ('edge effects'). Here we combine high resolution (30 m) satellite maps of forest cover with estimates of edge effects from forest modeling and show that 19% of the remaining area of tropical forests lies within 100 m of a forest edge. Edge effects in tropical forests have caused an additional 10 Gt of carbon emissions, which translates into 0.3 Gt/year and represents 30% of the currently estimated annual carbon releases due to tropical deforestation. Fragmentation substantially augments carbon emissions from tropical forests and must be taken into account when analyzing the role of vegetation in the global carbon cycle. Above all, patterns of tropical forest fragmentation in three continents show surprisingly similar power-law size distributions as well as fractal dimensions. The principles of percolation theory provide one explanation for the observed patterns and suggest that forest fragmentation is close to the critical point of percolation.

4.(14:30) A Multi-scaled analysis of Forest Structure using Individual-Based Modeling in a Costa Rican Rainforest | *A Armstrong*, R Fischer, B Osmanoglu, G Sun, K Ranson, A Huth*

Consideration of scale is essential when examining structural relationships in forests. In this study, we present a parameterization of the FORMIND individual-based forest model for old growth Atlantic lowland rainforest in La Selva, Costa Rica. The model was successfully parameterized and calibrated for the study site; results show that the simulated forest reproduces the structural complexity of Costa Rican rainforest based on comparisons with CARBONO inventory plot data. Though the simulated stem numbers (378) slightly underestimated the plot data (418), particularly for canopy dominant intermediate shade tolerant trees and shade tolerant understory trees, overall there was a 90.3% agreement. Aboveground biomass (kg/ha) showed a 0.1% difference between the simulated forest and inventory plot dataset.

FORMIND can be used to further the capabilities of remote sensing through modeling applications aimed at drawing empirical relationships at scales that are too fine to be measured with sensors, but that could be scaled up to be applied in remote sensing studies. We used the Costa Rica FORMIND simulation to investigate the relationship between height (using three definitions) and aboveground biomass at different spatial scales (20x20m, 60x60m, 100mx100m). The results of our study can shed light on why forest height cannot predict aboveground biomass at coarser scales: we show that regardless of how height is defined, the empirical relationship breaks down when trees are scaled to 60-meter and

100-meter plots. In this presentation, we will present a comparison of remote sensing measurements at multiple scales (e.g. LVIS, UAVSAR/ECOSAR, Landsat) to FORMIND simulated forest, aggregated to matching scales.

5.(14:50) Spatio-temporal modelling of the light regime: tropical vs. temperate forest | *D Kükenbrink*, FD Schneider, A Hueni, ME Schaepman, F Morsdorf*

The complex three-dimensional (3D) structure of forests greatly influences the light distribution inside the canopy. Understanding light availability inside forest canopies is critical for assessing net ecosystem productivity. However, measuring the complex 3D light distribution in the canopy is a cumbersome and difficult task. Rapidly changing sky conditions, especially encountered in tropical forests, can further increase complexity of the measurement process. Spatio-temporal variations in light availability can be a cause for variability in net ecosystem productivity and could give explanations for species coexistence and light usage strategies.

In this study we analyse the 3D light extinction in the photosynthetically active radiation (PAR) regime for a tropical rain forest in Borneo, Malaysia and compare it with a temperate mixed deciduous forest in Switzerland. Modelling was performed using the Discrete Anisotropic Radiative Transfer model (DART). The 3D structure of the two 60x60 m2 large study areas were derived from terrestrial laser scanning measurements (TLS) from the ground, complemented by UAV based laser scanning and crane-based TLS to minimize occlusion within the upper parts of the canopy. The vegetation density distribution inside the forest canopy was derived from the merged point clouds using the AMAPVox software toolbox. Leaf optical properties (LOPs) were derived from field spectroradiometer (ASD FieldSpec Pro) measurements with a leaf clip. The 3D radiative budget output of DART was analysed in terms of light extinction through the canopy at a voxel resolution of 25 cm. Multiple solar angles for both study sites were simulated to analyse daily and seasonal variations in light availability within the canopies.

The modelled light distributions provide interesting insights on the relative importance of canopy structure and optical properties on spatio-temproal light availability within the canopy. First results indicate that the variations in light distribution between temperate and tropical forest canopies are driven mainly by the canopy structure, but also optical properties of leaves, bark and ground have been found to have an impact on the distribution of PAR. These findings will provide important insights into light-related mechanism driving species coexistence, competition and diversity in temperate and tropical forests.

3A

AGROFORESTRY APPLICATIONS

Moderator: Randolph Wynne

1.(15:30) Three Phase Forest Inventory Design with 1) wall-to-wall ALS, 2) very dense ALS on sample stripes and 3) fieldwork sample plots | *G Bronner*, M Hirschmugl, R Wack, B Jawecki*

Using airborne laserscanning (ALS) data has become a standard to support forest inventories in many regions of the world. However, field-measured sample plots are still needed to calibrate and evaluated the ALS-based results (two phase inventory). Existing sample plots for statistical inventories on forest areas are traditionally designed in a rectangular grid. One disadvantage of regular sample grids is the high probability of sample plots which consist of two or more forest types. As a consequence, the interpolation of inventory results by lidar-metrics becomes difficult and inaccurate from the statistical point of view. In an alternative (temporary) inventory design, we are using wall-to-wall ALS data (4P/m^2) and configure sample plots based on automated forest segmentation. Segmentation produces mini-stands of 0.2-0.5 hectares, which are homogeneous regarding tree height, density and structure. Forest segments are classified using lidar and image statistics. As potential sample plots we use the centroid points of segments after negative-buffering with the desired radius of sample plots. The high amount of potential sample plots is reduced to the desired per-class-quantity. This kind of inventory design was developed over the last years. As a current innovative development, we now fit a third phase between wall-to-wall ALS and fieldwork to enhance accuracy and efficiency. This third phase consists of intermediated ALS data of very high density. Our ALS provider is able to produce dense point clouds (100-200 echoes per m^2) with a tilted sensor platform to generate side looking scans, and alternatively, we can use UAV laser-scanning. Such data are too expensive for a wall-to-wall coverage and is therefore only recorded on a few corridors. The high density point clouds allow 3D single tree segmentation with tree coordinates, tree height, crown size and diameter estimation by allometric functions. Our fieldwork sample plots are placed on these corridors and can rely on pre-produced tree maps from single tree segmentation. Processing these data means first calibrating 3D-segmentation results on the corridors by means of field work assessment and then calibrating the wall-to-wall ALS data by means of corridor data. This approach will be tested on a heterogeneous alpine forest with 6000 ha, first results of this investigation are expected in Summer 2018. Ref: HIRSCHMUGL, GALLAUN, WACK, GRANICA, SCHARDT, 2013

2.(15:50) Mapping Smallholder Forest Plantation Establishment in Andhra Pradesh | *R Wynne*, V Thomas, S More, P Williams*

Forest cover in the Indian state of Andhra Pradesh has decreased in recent years, though in the same period there have been increases in forest plantation area, largely through conversion of existing agricultural land. The plantations are small (median of 2 ha), have a rapid harvest-regeneration cycle, and have spectral similarities to both agriculture and natural forest. As such, extant mapping efforts at both the national (e.g., Indian Space Resource Organization) and international (e.g., University of Maryland Global Forest Cover) scales have had difficulties in characterizing this important land cover and land use change. Our overall goal is to improve the accuracy and precision by which forest plantation establishment can be remotely-sensed using data from Sentinel 2, Landsat, harmonized Sentinel-Landsat data, and very high resolution datasets (both newly tasked and those available through the NASA National Geospatial-Intelligence Agency Commerical Data Access program). Local forest industry cooperators provided data on plantations (location, boundary, ownership, tree species, etc.) that supply wood to local mills. These data have been supplemented, through visual interpretation with points representing additional land cover classes, including additional forest plantation points, natural forest, agriculture, water, and sand. These are being verified by local cooperators. Analytical techniques include both classical machine learning (e.g., random forests) and deep learning (deep sequential artificial neural networks). Results to date using all available VNIR Sentinel 2 MSI data enable separation of plantation forest and natural forest from each other and from all other competing land uses (overall out-of-bag accuracy 85%; similar results were obtained using all available optical bands at 20 m spatial resolution). While overall results are promising, the resulting maps reveal good separation of plantation forests from natural forests, but too much fungibility between plantation forests and agriculture. Additionally, even Sentinel 2 VNIR data appear too coarse for many of these plantations, so the team is currently evaluating the role of very high resolution data in the classification protocol.

3.(16:10) Mapping forest management intensity and land use transitions in the southeastern US with multitemporal Landsat | *V Thomas*, R Wynne, J Kauffman, E Brooks, Q Thomas, L Chini, R Mei, D Wear*

In the southeastern United States, forest cover is dynamic and the planting/harvest cycle of pines is the dominant decadal signal. There are two major land change patterns in the region. The primary land use transitions are the conversion of forest and agricultural land to developed land (typically a permanent transition) and the dynamic transitions between forest and agriculture, which are largely determined by economic factors. In addition to land use transitions, there are also periodic land cover changes that reflect forest management decisions. These include the cycle of harvest and regeneration, as well as changes in forest density and composition as the result of a management intervention. Some authors have identified and mapped managed pines within the region (i.e., Fagan et al 2015), but there is no existing regional classification product that includes forest management intensity. Using thinning as a proxy for medium-intensity management, this study separates low and medium-intensity managed pines using all available data within multitemporal Landsat time series stacks. Results show that thinning is not fully captured by the National Land Cover Dataset (NLCD) (roughly 40% of thins not captured) or the combination of NLCD and the NLCD Change product (roughly 30% of thins not captured). The use of harmonic regression coefficients, which capture multitemporal Landsat information, enable the classification of harvests (88% accuracy) and thins (70% accuracy) even without stratifying by NLCD land cover. Within the NLCD coniferous class, thins are well captured by harmonic regression coefficients (92% accuracy). These data are being used to develop regionally-refined land-use transition matrices that include forest management.

4.(16:30) Growing up on the frontier: assessing the impact of forest age and edge age on forest structure in the southeastern US | *M Fagan*, D Morton, B Cook, J Masek, F Zhao, C Huang, R Nelson*

Exposure to edge environments is well known to influence the height and complexity of forest canopies (i.e., structure) through altered tree growth and mortality rates. However most studies of edge effects on forest structure and biomass have been conducted in mature forests. Because forest age strongly influences forest structure and composition, especially in the early stages of succession, edge effects may be weak in younger forests. Alternatively, because edge responses are often the most marked shortly after edge creation, edge effects in younger forests may be strong. The objective of this study was to elucidate how the age of forests and their associated edges influences canopy structure. We analyzed spatial changes in secondary forest canopy structure along aerial transects of LiDAR data (~3,000 km) in the southeastern U.S. To quantify forest stand age, edge age, and fragmentation, high-resolution (1 m) LiDAR data from Goddard's LiDAR, Hyperspectral, and Thermal Airborne Imager (G-LiHT) were combined with time series of Landsat imagery. Forest structural metrics (height, rugosity, and gap fraction) were examined across all large (>4 ha) fragments from the 8562 distinct forests measured during G-LiHT data collection in 2011. We hypothesized that 1) structural edge effects would not be detectable in the first two decades of forest succession, and 2) the effect of edge age on forest structure would increase with forest age. Although the relationship between edge exposure and forest structural metrics was highly variable, variability in height and gap fraction decreased away from an edge. Contrary to our first hypothesis, there were detectable edge effects on canopy structure in young forests, and these effects either increased (gap fraction) or decreased (tree height) with stand age. Edge age was a strong predictor of canopy structure in natural forests, but its effect did not increase with forest age. We found that canopy structure in our region is influenced by edge effects across all forest ages, and the particular impact of edges on structure is mediated by the ages of both the forest stand and the edge. Our results highlight the importance of forest fragmentation for the structure, biomass, and biodiversity of natural regeneration in the southeastern U.S.

5.(16:50) Post-stratified estimation of harvest area by combining Global Forest Change and National Forest Inventory data | *J Breidenbach*, S Puliti, S Solberg, R Astrup*

The utilization of timber from sustainably managed forests plays a substantial role in mitigating CO2 emissions from non-renewable sources, for example by substituting concrete and steel in construction works. At the same time, a harvest operation is a severe intervention in the forest ecosystem, which can have unwanted effects on different aspects such as biodiversity, hydrology, and tourism. In addition, sustainability requires that the clear cuts are regenerated. Therefore, monitoring harvest operations is important to control the adherence of measures, such as maximum harvest levels and replanting duties, to ensure a minimal impact. Due to long rotation periods in temperate to boreal conditions, harvests are relatively rare events in Norway, which are therefore difficult to monitor with field-based surveys. Consequently, estimating the area of clear cuts by field based sampling such as National Forest Inventories (NFIs) is challenging because the number of sample plots affected by harvests is relatively small. Due to the abrupt change in the spectral signature of harvested areas, detection based on optical satellites such as Hansen's Global Forest Change (GFC) data, may be an alternative or at least a supplement to purely field-based methods. When compared to Norway's NFI data, between 66% and 70% of different types of clear-cuts were correctly identified by GFC. Not unexpectedly, the detection rate for other harvest operations such as thinnings and selective harvests was lower – between 6% and 50%. Commission errors (false positive forest cover change) were close to 2%.

We employed GFC as auxiliary information with NFI field plots to estimate the area of clear cuts over a 5 year period using post-stratification. Google Earth Engine was used for raster calculations. The relative efficiency (ratio of the post-stratified variance and the SRS variance) suggested that approximately 10% and 20% as many field sample plots would have been needed to achieve the same precision for estimating harvest area and biomass loss, respectively.

3B

AIRBORNE LASER SCANNING APPLICATIONS

Moderator: Jeff Masek

1.(15:30) Spatial variations of tree size-frequency distributions and 3D structure across elevations and soil type in a tropical rainforest | *A Ferraz, S Saatchi*, J Kellner, D Clark*

Characterization of tropical forest trees has been limited to field-based measurements on tree bole diameter with large uncertainties associated in measuring 3D metrics such as tree height and crown size. Tropical trees often grow with irregular shapes that difficult their modeling using allometric equations. Adjacent patches of forests vary substantially in terms of density of trees of different sizes and thus in aboveground biomass and carbon stores. The knowledge of the tree size-frequency variability across time and space is crucial to understand the terrestrial carbon cycle and budget.

In this work, we examine the reliability of an airborne lidar-based technique to derive tree size-frequency distributions over the La Selva Biological Station in Costa Rica. We extract individual trees using a method called adaptive mean shift (AMS3D) to derive tree size-frequency distributions on tree height and crown area over 9 plots (1 ha). We estimate the diameter of the bole using the tree metrics derived from the lidar together with a local allometric equation. Results are compared with a field inventory composed of measurements on tree diameter, tree height and crown area. Our approach has a success rate of 97.3% with respect to the averaged tree density (diameter >10 cm) over the 9 plots. The size-frequency distribution on tree height compares with the field inventory indicating that our technique provides accurate estimates on tree density for different tree height classes across the spectrum. As for the results on crown size, the distributions follow a similar trend for the trees with a diameter larger than 20 cm with a significant underestimation of the crow size within the smaller trees. Finally, we study the spatial variations of tree density and tree size-frequency distributions across different soil types and topographic conditions. Our lidar-based approach provides a reliable characterization of tree size-frequency distributions that allows to characterize forest demographics and carbon storage variability over larger areas and to validate the spatial domain of the metabolic ecology theory.

2.(15:50) Effects of plot size, stand density, and scan density on the relationship between airborne laser scanning metrics and the Gini coefficient of tree size inequality | *S Adnan*, M Maltamo, D A. Coomes, R Valbuena*

Estimates of Gini Coefficient (GC) of tree sizes obtained from airborne laser scanning (ALS) provide wall-to-wall information useful for mapping forest structures across landscapes and further for sustainable forest management. A challenge arises in determining the optimal spatial resolution at which Gini Coefficient estimates are most stable and precise, which depends upon stand density and ALS scan density. We used two criteria: (1) stabilization of GC as field descriptor of a given forest community, and (2) maximizing the GC variability explained by ALS metrics for plot and sample size optimization. By random subsampling different plot sizes (1-15 m) within large field plots (20×20, 25×25,30×30 m) in Boreal managed forest in Finland, we calculated the GC values based on tree sizes, and metrics conventionally used in ALS-assisted inventories from the ALS returns in each subplot. We evaluated the impact of spatial resolution on Gini Coefficient estimation and found that plot size had greater effects than either stand density or ALS scan density in the relationship between Gini Coefficient and ALS metrics. Uncertainty in estimates decreased as the plot size increased. Very small subplots (1-5 m) and sample sizes (<15 trees) are unrepresentative of the total population, more sensitive to GC variations and produce unstable and unreliable GC estimations as compared to larger subplots which contain a more appropriate number of observations (sample size), produce stable and reliable GC estimates and represent the total population. However, when the GC reached stabilization under the first criterion, its correlation to ALS metrics remained consistent with increasing sample sizes and yielded a convex curve with maxima at 250-450 m^2 with increasing plot sizes, which, thus, was considered the optimal plot size / spatial resolution. By thinning the original ALS point density of 11.9 points.m^-2 to 0.50, 0.75, 1, 2, 3, 5, 7.5 and 10 points.m^-2, we deduced that at least 3 points·m^-2 are needed for reliable GC estimates. Many nationwide ALS scan densities are sparser than this, indicating that they are probably unreliable for estimation of Gini Coefficients. Our approach can be used to evaluate the optimal spatial resolution when estimating any forest attribute from remote sensing data.

3.(16:10) Mapping tree clump and opening patterns following fire with airborne LiDAR data | *B Bartl-Geller*, H Wiggins, J Kane, M North, V Kane*

Structure in historically fire-frequent coniferous forests in the western U.S. has diverged from historical patterns, becoming increasingly dense and homogenous as a result of altered fire regimes and management. This forest pattern exacerbates susceptibility to wildfire, drought, insect outbreak, and disease – all of which are expected to intensify with climate change. Individuals, Clumps, and Openings (ICO) is a framework for assessing fine-scale forest spatial pattern. Clump and opening patterns affect fire behavior and understory plant diversity, regeneration, pathogen/insect spread, and habitat use. We implemented ICO using Tree Approximate Objects (TAOs) derived from watershed segmentation of airborne LiDAR data to assess changes in clump and gap distributions in mixed-severity post-fire environments. TAOs were classified as individuals or as members of clumps using LiDAR-derived crown areas, allowing us to derive a suite of metrics including: median clump size; percent of canopy area in individual trees, small clumps (2-4 trees), and larger clumps (5-9 trees, 10+); and percent of TAOs in each clump size class. In addition, we identified canopy openings as areas within various distances from the nearest canopy edge and calculated percent total area in openings. We compared areas that burned recently (~ 5 yrs) for the first time in the modern fire record in managed (Tahoe National Forest; TNF) and wilderness (Yosemite National Park; YNP) landscapes with adjacent unburned areas and a reference region in YNP that exhibits wildfire resiliency. As expected, at both TNF and YNP high severity fire reduces clump sizes and increases area in gaps beyond that of the reference area. High severity fire was more destructive on the TNF compared to YNP. Low and moderate severity fire can shift clumps and gaps towards the reference condition, and were similarly effective in both YNP and TNF. Our results indicate that LiDAR-derived clump-gap methods can help us understand how mixed-severity fire affects the tree clump and opening patterns important to a number of ecological processes and management strategies.

4.(16:30) Optimization of primary extraction routes prior to forest operations using lidar data | *E Willén*, G Friberg, P Flisberg, M Frisk, M Rönnqvist*

In recent years, increasing attention has been drawn to improving productivity in logging while reducing negative impact on soil and water. In Sweden, some forest companies have introduced guarantees to minimise tracks during forest operations and efforts to reduce soil compaction are made by putting branches in the routes for the forest machines and passages built where streams are crossed. The position of primary extraction routes is crucial in these efforts as it has a huge impact on efficient and sustainable forwarder passages. The aim of this study was to validate primary extraction routes for forest machines planned prior to forest operations using lidar derived data in an optimization model. To minimise the total forwarding distance, but also to avoid steep terrain and impact on soil and water, an optimisation model was developed. The model comprises a detailed digital terrain model, depth-to-water maps and forest volume all derived from lidar data available nationwide. The information is supplemented with the extent of the stand, the position of the landing(s), nature and culture conservation sites, and any known unavoidable crossings in the terrain, e.g. streams. The model is a network design problem where arcs describes the routes and flows represent the number of loads the forwarder uses the arcs. A critical requirement of the model is fast solution times. Hence, a decomposition method based on Lagrangian relaxian is used to define subproblems that can be very efficiently solved by specifically designed subroutines. The primary extraction routes, resulting from the model, have been evaluated on 19 felling sites in operational conditions with experienced staff from a major forest company in southern Sweden. The results indicate a shorter driving distance, but also the potential to reduce the negative impact on soil and water. Among the conclusions are the useful suggestions for extraction routes as well as the possibility to increase the efficiency in planning by performing scenario analysis with different landing sites. Several other forest companies now start testing the model. Further research efforts include what sideway inclination to accept and the possibility to suggest landing sites prior to field visits.

5.(16:50) Prediction of forest stand characteristics based on Airborne Laser Scanning data in the managed forests in Central Europe - Polish case study | *K Stereńczak*, S Miścicki, K Parkitna, G Krok, M Lisańczuk, P Rysiak, Ł Jełowicki , K Mitesztedt, P Mroczek, A Markiewicz*

To support sustainable forest management and carry out a wide number of decisions, up to date forest inventories and accurate measurements of the tree and stands attributes are needed. In this work, we summarise our efforts in the implementation of ALS data in forest inventory for the managed forests in Poland.

Our research is based on 6 study areas spread over whole Poland. Apart from ALS data, 3800 sample plots of area 500 m2 were acquired with precise GNSS RTK position measurements. Additionally, 360 fully measured forest stands were used for cross-validation purposes. Based on point cloud data we created models of following forest characteristics: top heights, mean heights, mean heights of top layer trees, growing stock volumes (GSV), vertical structure and diameters at the breast height.

Growing stock volume was predicted using different area-based approaches and prediction models. The best results were achieved for ABA-PC and ABA-CHM approaches. Nevertheless, all models provided similar results. An additional goal of the research was to develop a global GSV prediction model which use ALS data and could be adopted for forest stands in Poland. First results show only small differences if compared to local GSV models and ground-reference data at the sample plot level. Additionally, auxiliary variables obtained from the state forest database like forest type or age class were added, which, to a certain level, have improved models' accuracy.

Top height, mean height, mean height of top layer tree, structure, and diameter at the breast height were predicted using various ALS based metrics. The results show a high compatibility with the field-based measurements both at the sample and the stand level, for all 6 study areas with R2 usually above 0.9. The final conclusion is that elaborated ALS data, with the current costs, can be an alternative for the field-based inventory of the most important variables in the managed forest stands in Poland.

3C

SAMPLING AND STATISTICAL INFERENCE

Moderator: Karen Schleeweis

1.(15:30) Using remote sensing to support forest inventory in interior Alaska - demonstration of a two-phase, model-assisted sampling design | *H Andersen*, C Babcock, B Cook, D Morton, AQ Finley, M Alonzo, J Strunk*

Two-phase, model-assisted sampling designs provide a means to incorporate auxiliary information in a forest inventory to increase the precision of estimates, while retaining the desirable properties of design-based inference. In this study, a relatively sparse sample of (104) field plots collected for the USFS Forest Inventory and Analysis (FIA) program in the Tanana valley of interior Alaska was augmented with high-resolution airborne remote sensing data collected with the NASA Goddard-Lidar-Hyperspectral-Thermal (G-LiHT) system in a strip sampling mode (9.2 km spacing between strips). G-LiHT is a portable, airborne imaging system that simultaneously maps the composition, structure, and function of terrestrial ecosystems using lidar, imaging spectroscopy, and thermal imaging. In this study, high-resolution forest structure and composition information derived from G-LiHT multi-sensor data, as well as NLCD-based wall-to-wall vegetation cover classification were both utilized as auxiliary information in a two-phase, model-assisted sampling design. Estimates of aboveground tree biomass by forest type, and with uncertainty, were obtained through application of this estimation framework. Results indicated that significant reduction (up to 50%) in the standard error of the biomass estimates (in comparison to the standard post-stratified estimator) can be achieved through the use of multiple sources of auxiliary information (high-resolution G-LiHT sampling and wall-to-wall GIS layers) in the estimation procedure.
The results from the two-phase, model-assisted estimator are compared with estimates obtained using standard FIA estimation procedures, and the statistical properties (bias, coverage probability of 95% confidence intervals) of the model-assisted estimators (and variance estimators) of total aboveground biomass are assessed via simulation. This approach indicates that the use of multiple sources of auxiliary (remote sensing) data, possibly collected at different resolutions and

in different sampling modes, can be effectively used to support operational forest inventory in remote regions such as interior Alaska.

2.(15:50) Wall-to-wall spatial prediction of growing stock volume in Italy by coupling large-scale field sampling plots and remotely sensed data | *G Chirici*, F Giannetti, D Travaglini, RE McRoberts, F Maselli, M Chiesi, M Pecchi, P Corona*

Spatial predictions of forest variables are required for supporting modern national and sub-national forest planning strategies, especially in the framework of a climate change scenario. Nowadays methods for constructing wall-to-wall maps and small-area estimates are becoming essential components of most advanced large-scale forest inventories, like the National Forest Inventory programs. Such methods are based on the assumption of a relationship between the forest variables to be predicted and predictor variables which are available for the entire forest area. Many commonly used predictors are produced by application of active or passive remote sensing technologies. Italy has almost 40% of its land area covered by forests. Because of the great diversity of Italian forests with respect to composition, structure, and management and underlying climatic, morphological and soil conditions, an interesting question is whether methods successfully used in more simplified European forests (mainly in boreal areas) may be applied successfully at country level in Italy.

For a study area of more than 65,000 km2 in central Italy (38% covered by forest), the study presents the results of a preliminary test regarding spatially explicit estimation of forest growing stock volume (GSV) based on field measurement of 1350 plots during the 2005 Italian NFI. For the same area we collected potential predictor variables which are available across the whole of Italy: cloud free mosaics of multispectral optical satellite imagery (Landsat 7 ETM+, SPOT HRG and IRS WiFS), microwave sensor data (JAXA PALSAR), and auxiliary variables from climate, temperature and precipitation maps, soil maps, and a digital terrain model.

Several parametric (e.g., multiple linear regression model, spatially (or geographically) weighted regression) and non-parametric (e.g., Random Forest, k-NN) prediction methods were tested to the accuracy of a spatial, wall-to-wall map of growing stock volume at 30 meters resolution and small area, municipality-level estimates. The accuracy of all the methods were compared in terms of percent root-main-square error using a leave-one-out procedure. Results were comparable to those available for other regions of Europe using similar predictor variables.

3.(16:10) FIESTA: A big party for small areas | *T Frescino*, G Moisen, C Toney*

FIESTA (Forest Inventory ESTimation for Analysis) is a user-friendly R package that produces a wide array of estimates and analyses for the Forest Inventory and Analysis (FIA) Program in the U.S. Because it is functional within the R environment, FIESTA provides an alternative data retrieval and reporting tool that allows customized applications and compatibility with other R-based analyses. In addition to producing standard forest inventory tables, the tool accommodates nonresponse in survey data, handles nuances of photo-based data, and uses remotely-sensed data to improve precision through numerous model-assisted estimators. Because of the growing need for forest land managers to understand forest characteristics within geographic areas too small to hold a sufficient number of inventory plots, a new FIESTA module now accommodates small area estimation methods. In this paper, we describe the automated data retrieval, summarization, and estimation processes that are now enabling rapid small area estimates for understanding effects of wildfire, making decisions over small management units, or characterizing forests within other small mapped units relevant to decision makers.

4.(16:30) Bamboo kNN: applications for national forest inventory with remote sensing imagery | *B Wilson*, G Meeden, R McRoberts, J Knight*

The Bamboo kNN algorithm is proposed for modeling continuous response variables from sample survey data with auxiliary population data and provides a unified framework for global optimization of kNN while simultaneously selecting feature variables and correcting for model bias. An empirical study was conducted to test the small area estimation performance of the proposed estimator using national forest inventory data with dense time series of Landsat imagery. Features were extracted from all Landsat scenes collected during the study timeframe 2009-2013 for one ecological unit in the state of Minnesota by means of harmonic regression. The locations of 1138 plots collected by the USFS Forest Inventory Analysis (FIA) program within the study area and timeframe were used to sample from a synthetic population of tree canopy cover (TCC).

Bamboo kNN, which stands for boosting and model-based optimization (MBO) of k-nearest neighbors, was used to construct and optimize a nonparametric model for predicting TCC using a feature space of estimated harmonic regression coefficients. The assumed but unknown bias of a kNN model is estimated by recursively fitting residuals, known as L2 boosting, with the kNN smoother used to make the initial predictions. The proposed MBO algorithm is a Markov chain Monte Carlo method for generating candidate solutions to the boosted kNN model using a parameterized probabilistic model for selecting values of k and subsets of feature variables from the solution space. This model is adaptively modified, using earlier candidate solutions, to concentrate the search in the most promising regions of the solution space. Guidelines are suggested for determining the appropriate order of recursion for boosting, as well as length of the chain.

At the end of the chain, a small sample of candidate solutions were drawn from the solution space using the updated probability weights. These candidate kNN models were used to construct predictive intervals for spatial domains over a range of sizes. Coverage tests were conducted by determining the proportion of spatial domains, for each domain size tested, whose predictive interval contained the actual TCC value observed in the synthetic population. The results showed that the coverage proportion approached the theoretical value when using a 4th-order boost, for spatial domains as small as the area represented by an FIA sample unit, with the unboosted model coverage proportion well below the theoretical value.

5.(16:50) Estimators for Photo-Based Measurements | *P Patterson*, M Finco, K Tenneson, K Megown, S Bender, N Pugh*

Aerial photography may be used to estimate population characteristics of a landscape. A current example is the Image-based Change Estimation of the US Forest Service, Forest Inventory and Analysis (FIA) program, which is an image-based approach for estimating land cover and land use changes. Another example is Collect Earth, which has been used for many photo-based surveys; such as the first global dryland survey which was conducted by the Food and Agriculture Organization of the United Nations. This involves establishing a sample of photo-plots and interpreting the characteristics of a grid of points within each of the photo-plots. Historically, the properties of estimators were based on the finite sampling paradigm. This approach has the theoretical difficulties of specifying what the population unit is and whether area is subdivided into distinct, non-overlapping population units. In the context of the infinite sampling paradigm and using the support region construct, these and other theoretical issues are be addressed. In this theoretical framework, an unbiased estimator for stratified sampling strategy can be constructed, the variance of the estimator derived, and an unbiased estimate of the variance given. Without going into the details of the proofs, we will outline the construction and properties of estimators and discussion implications for the data collection. The results of a simulation study that gives an empirical verification of the analytically-derived results will be presented. We present an extension of the variance and the estimated variance from the stratified sampling strategy to post-stratified sampling strategy.

3D

HUMID TROPICAL FOREST MONITORING WITH TIME-SERIES LANDSAT DATA

Moderator: Matt Hansen

1.(15:30) Sample-based assessment of forest loss trends and drivers in three major humid tropical forest regions using Landsat time-series data | *A Tyukavina*, M Hansen, S Stehman, P Potapov, D Parker, C Okpa, S Turubanova, I Kommareddy, A Tosiani, M Yazid, I Sari, T Kartika, R Firmansyah, Z Said, Z Kustiyo, A Wijaya, J Purwanto, S Nugroho*

Global and regional-scale tree cover loss maps provide spatially explicit information, vital for forest management and conservation. These maps, however, contain unknown biases, and often lack contextual information on the type of tree cover lost and disturbance drivers. Here we use sample-based approach to produce unbiased estimates of tree cover loss area, and attribute pre-disturbance forest types and disturbance drivers in Brazilian Legal Amazon (BLA), Congo Basin and Indonesia. Reference data for sample interpretation include all available Landsat observations and sub-meter optical data. Study area contains most of the remaining natural humid tropical forests, rich in biodiversity and providing essential ecosystem services, but threatened by industrial development and population pressure. Our findings indicate that since early 2000s primary forest clearing rates in BLA decreased, whereas in Indonesia and Congo Basin human encroachment into primary forests accelerated. The main driver of tree cover loss in BLA in 2000-2013 was large-scale agro-industrial clearing for pasture (63%); human clearing of primary forest in the region decreased dramatically after 2004 and in 2013 constituted less than 50% of tree cover loss area. Agro-industrial clearing for pasture, selective logging, fire and small-scale forest clearing were also significant drivers. Democratic Republic of the Congo (DRC) dominates Congo Basin in terms of tree cover and loss area, and total population. In DRC in 2000-2014 the main driver of tree cover loss was small-scale clearing for shifting cultivation (92%). Industrial selective logging contributed 10% to the Congo Basin tree cover loss area, being the major loss driver in Gabon (62%), and second largest after small-scale clearing for shifting cultivation in Republic of Congo (46%) and Cameroon (22%). In Indonesia, we analyzed changes in primary forest in 1990-2016. We found that most clearings were not used for agriculture or plantations immediately after the clearing, but were converted into oil palm plantations several years after. Smallholder clearing and timber plantations were important land use outcomes of forest conversion. Significant areas affected by escaped fires in Indonesia were not developed after disturbance. Similar methodology used in all three regional studies ensures adequate comparison of results among the regions, and provides the basis for the future sub-national assessments and driver-specific case studies.

2.(15:50) Reconstructing Historical Land Use and Land Cover of the Amazon region with Earth Engine, Landsat Data Archive and Machine Learning | *C Souza Jr.*, AV Fonseca, JV Siqueira*

We report our recent progress to reconstruct land-use and land cover change (LULCC) maps for the Brazilian Amazon from 2000 to 2016, and present the main results and challenges to consolidate this database. The Landsat Data Archive (LDA) in L1T Surface Reflectance format, available in the Google Earth Engine, was used to select Landsat scenes acquired from June 1st to October 31st, and a cloud mask algorithm was applied to each individual scene. Then, we estimated the median value of the unclouded pixel and ran a Spectral Mixture Analysis (SMA) to obtain fraction images of Green Vegetation (GV), Soil, Non-Photosynthetic Vegetation (NPV), Cloud (i.e., to detect residual clouds) and Shade. Training, validation, and test random samples were generated and further automatically classified based on reference maps available (TerraClass, GlobeLand30, Prodes, Global Forest Cover and ESA CCI), on the following classes: Forest, Savanna, Pastureland, Agriculture, Water, and Bare Lands. Finally, a random forest model was built to classify all annual temporal image mosaics using as input the training and validation samples. Initial accuracy assessment resulted in an overall accuracy of 82.6% (s = ± 1.5%). Average user,Äôs accuracy for Forest class was 87.3% (s = ± 2.4), and 85.7% (± 2.2%) for Water, 63.7% (± 3.3%) for Pastureland and 91.3% (± 8.65%) for Agriculture. Analysis of LULCC transitions made possible to derive consistent annual time-series of deforestation, compared to Prodes and other sources. We have also produced a novel forest regeneration time-series. Future developments include perfecting the random forest classification using the best annual pixel of LDA as inputs. Then, we will apply the new model to reconstruct 33 years (i.e., > 1985) of annual LULCC maps for the Amazon region and in other Brazilian biomes and South America countries in the scope of the MapBiomas project. However, improvements in the random forest algorithm running in Earth Engine are necessary to implement more robust statistical analysis relevant to machine learning, such as feature selection, and the use of very large feature dataset into the random forest classifier.

3.(16:10) Integrating time-series multi-spectral Landsat and lidar data in mapping tree height in DR Congo | *E Bongwele*, P Lola, P Potapov, M Hansen*

Integration of time-series multi-spectral imagery and lidar data enable improved large area characterization of forest structure. The presented of the Democratic Republic of the Congo employed canopy height information as training data to characterize annual time-series metrics from Landsat in the mapping of annual tree height over the record of Landsat TM, ETM+ and OLI. A total of 216 lidar samples of 2000 ha each were collected between October 2014 and February 2015 as part of a DRC forest carbon mapping project led by the World Wildlife Fund. The lidar samples were collected in a probability-based framework, primarily within the humid tropical forest ecosystem. Results illustrate the added value of height in discriminating primary versus secondary forest, terra firma versus wetland, and humid tropical forest versus dry tropical forests and woodlands, despite limited lidar collections over the dry tropics. The time-series of height capture the dominant land use change dynamic in Congo, that of shifting cultivation. Intensity of land use via the estimation of fallow periods is observed, with implications for assessing the sustainability of smallholder agricultural systems. Logging is also observed, but less robustly, as height estimation requires multiple looks and this requirement reduces the sensitivity of the method to detecting sub-pixel degradation dynamics. The primary challenge to generating a consistent record of forest height over the DRC is the paucity of Landsat data acquisitions pre-2000. Even after 2000, the seasonal acquisition strategy of ETM+ results in few cloud-free observations over dry tropical woodlands during the rainy season, when woodlands are not subject to fire and more readily characterized. Results are much better in the combined ETM+/OLI epoch, with a viable long-term monitoring application of the method subject to the continued provisioning of high cadence medium spatial resolution imagery. The forthcoming GEDI mission will enable improved calibration of the model with an unbiased collection of height information across all ecosystems of the Congo.

4.(16:30) Monitoring of Indonesia Tropical Rainforests and Land Cover Change using Time Series Landsat Data | *A Wijaya**

Monitoring of the forests of Indonesia is performed by the Ministry of Environment and Forestry (MoEF) in collaboration with the Indonesian Space Agency (LAPAN). The MoEF mapping method entails the visual interpretation of Landsat images in assigning 23 land cover classes (using a minimum mapping unit of 6.25 ha), with national-scale map products made from 1990 forward every three years, and annual updates since 2011. As part of the development of a national carbon accounting system, LAPAN developed a method for processing national-scale mosaics, which were used to prototype forest loss algorithms. The mosaics are now used as the primary reference for the MoEF map updates. The strategy has been to produce increasingly robust image inputs to the GIS-based mapping method. We assessed the accuracy of the MoEF time-series maps of forest cover and found a high accuracy for tracking primary and secondary forest loss. However, improving the efficiency and timely delivery of the annual update is now the primary focus of the

MoEF/LAPAN collaboration. A new spectral product that highlights areas of likely land change based on a spectral index and forest loss indication map are now used to help target analysts efforts in updating the annual map. The proposed method will improve on product latency. New value-added layers relevant to national forest monitoring objectives, such as burn scar mapping, will also be presented. This review of the national Indonesia forest monitoring system highlights 1) the strategic collaboration by operational and research agencies in improving the quality of the monitoring product, 2) the desire to maintain a consistent methodological framework, 3) and the recent improvements in product latency and accuracy.

5.(16:50) Annual monitoring of forest structure in the Lower Mekong region | *P Potapov*, A Tyukavina, S Turubanova, Y Talero, M Hansen, D Saah, A Aekakkararungroj, KS Aung, NH Quyen*

Forest structure metrics such as tree canopy cover, tree height, primary forest extent, and leaf longevity serve as important inputs for national and regional ecosystem services assessment. Time-series of structure metrics required for national carbon reporting, forest resources assessment, and for monitoring of conservation policy implementation. However, national monitoring agencies often lack the capacity for generating such data. Alternatively, forest structure data may be generated at the regional level and distributed to the national reporting agencies. National organizations will benefit from the availability of open, transparent, and timely data. Meanwhile, regionally consistent data sources may encourage cross-border collaboration, integration of monitoring efforts between agencies, and will ensure regional consistency of the reporting.

The integration of Landsat optical data with low spatial/high temporal resolution global datasets (MODIS) and active remote sensing products (vegetation structure metrics derived from spaceborne and airborne Lidar) using machine-learning algorithms was successfully implemented to produce spatially exhaustive maps of tree canopy cover, tree height, and leaf phenology. Landsat time-series data are ideal for regional-scale mapping of tree cover dynamics. However, integration of Landsat-derived forest structure and dynamics products may be challenging in tropical regions where cloud-free observation frequency is low, land cover changes are rapid, and vegetation disturbances are frequent. Mapping tree cover structure and composition requires phenology information collected over a growing season (or the entire year in the tropics) while detection of forest disturbance may require analysis of reflectance change over shorter time intervals. The annual forest monitoring methodology developed for the Lower Mekong region is based on the integration of annual forest disturbance datasets with the annual time-series of forest structure attributes. The integration is done through time-series analysis and modeling of vegetation structure metrics through time based on the disturbance history. We have demonstrated the use of annual products that are sensitive to land cover and land use change conversions while maintaining a consistent annual biophysical representation of the state of the theme. We show that directly mapped forest change integrated with annually mapped forest structure allows mapping ephemeral dynamics not otherwise

4A

EARLY DETECTION OF PLANT STRESS

Moderator: Juan Suarez

1.(10:30) Potential of Sentinel-1 Time Series to Detect Bark Beetle Outbreaks | *M Hollaus*, B Bauer-Marschallinger, M Löw, K Schadauer, W Wagner*

In the last decade, an increasing occurrence of European bark beetles (BB) is recognized. Due to the ability of the BB to spread quickly over large areas and the fact that they benefit from various environmental factors such as severe storms or droughts, an increasing number of heavy outbreaks in i.e. Norway spruce forests happened in several central European countries in the last years. These damages lead to considerable economic and ecological consequences and therefore the demand of an appropriate monitoring system emerges.

The freely available Copernicus data from the Sentinel-1 (S1) and Sentinel-2 (S2) satellites provide remote sensing data at a high spatial-temporal resolution. S1 provides Synthetic Aperture Radar (SAR) measurements at an unprecedented high spatial (i.e. 20 m) and temporal resolution (i.e. <4 days), and S2 delivers optical imagery of excellent quality at 10 m spatial resolution. This study analyses the potential of S1 data for identifying BB attacks in north-eastern Austria, where a severe BB attack struck the area in 2017.

As BB infests only coniferous forests, the region of interest is limited to this type of forests in a first step. S2 time series data are used for delineating potential coniferous forest stands by considering the phenological differences between coniferous and deciduous forests.

For the study area, S1 SAR data with VV- and VH polarizations are available for 2017, and for the previous years, when were much less bark beetle activity. After the pre-processing of the SAR data (e.g. geo-referencing, topographic correction, build up a time series data cube), a speckle reduction is done by applying spatial (homogenous forest areas) and temporal (monthly) averaging.

To study the potential of S1 data for recognizing the beginning of a BB infestation, homogenous areas with vital and affected forest stands are analyzed separately. These forest stands are derived from S2 time series by applying a change detection approach of several vegetation indices (NDVI, RGVI and green NDVI) to extract forest stands affected by BB.

Over the study area, 2825 km² was classified as coniferous forests, whereas 0.42% of this area was already harvested after BB attacks. The S1 time series analyses showed a clear difference of the backscatter coefficients between vital and infested forest stands of ~1 dB for both VV- and VH-polarized S1 data. The differences start in July, which corresponds well with the outbreak of the BB attacks.

2.(10:50) Monitoring and assessment of Mediterranean forest health using hyperspectral and thermal remote sensing imagery | *ML Guillen-Climent*, H Más, A Nur, F Alfredo, J Peñalver, I Etxebeste Larrañaga, D Gallego, P Zarco-Tejada, JL Tomé*

The increasing negative effects of climate change and invasive species on forests worldwide require the development innovative methods to monitor and measure quantitatively the change in forest health over vast regions. Such effects are already acute in the European Mediterranean area, where recurrent droughts result in increased damages due to populational bursts of otherwise secondary herbivores. Remote sensing technologies have been shown to provide the means for wide coverage measurements with reasonable accuracy. In particular, new spectral indices obtained from high-resolution hyperspectral and thermal imagery have been demonstrated as candidate indicators for the early detection of physiological changes linked with diseases. A pilot 95 ha Pinus halepensis stand in Comunitat Valenciana (Spain) has been used to develop a model to detect stressed trees, with Tomicus destruens induced attacks and girdling of different stages. The potential detection of changes at early stages using different spectral vegetation indices derived from high-resolution hyperspectral imagery and medium spatial resolution imagery from Sentinel 2 were compared. Concurrent with the image captures, attack and physiological stages of individual trees were surveyed in detail for the study area. Some of the indicators would also apply for the early detection of trees affected by the invasive Bursaphelenchus xylophilus, a very serious threat for European forestry. The results obtained in this study are discussed in the context of early detection system.

3.(11:10) Leaf water content as a tree health indicator - Experiences from greenhouse and field | *S Junttila*, M Vastaranta, R Linnakoski, P Henttonen, M Holopainen, P Lyytikäinen-Saarenmaa, H Hyyppä*

Leaf water content (LWC) has been identified as an early tree health indicator used for remote sensing based mapping of bark beetle damages and water deficiency. Accurate and early information on tree health is necessary for maintaining healthy forests that can provide a variety of ecosystem services for the society. The aim of this study was to evaluate the suitability of leaf water content as a tree health indicator with Norway spruce (Picea abies) in greenhouse and field environment.

Greenhouse data was collected in Southern Finland where five treatment groups of 2-year old Norway spruce seedlings (n = 145) were subjected to disturbance by inoculating a fungal pathogen, Endoconidiophora polonica, and limiting irrigation. The seedlings were destructively sampled at eight time intervals during 12 weeks by collecting needle samples to measure gravimetric water content (GWC) and equivalent water thickness (EWT). The seedlings inoculated with the pathogen showed a rapid decrease in both leaf water content metrics. The drought-treated seedlings showed resistance to lower irrigation and a strong decrease in GWC and EWT was apparent only after further reductions in the irrigation amount. GWC was highly correlated with EWT showing a Pearson's correlation coefficient of 0.94.

Field data was collected in SE Finland where Norway spruce-dominated forest has been damaged by Ips typographus. Needle samples (n = 68) were collected from two heights from 34 mature trees to measure GWC and EWT. The health of the sample trees was classified in the field according to crown and bark condition. Discoloration, defoliation and bark condition moderately explained the variation in GWC with coefficient of determinations (R2) of 0.52, 0.41, and 0.28, respectively. A regression model with all the three variables explained 65% of the variation in GWC. However, tree health explained only a minor part of the variation in EWT. Bark condition and defoliation were the most significant explanatory variables with R2 of 0.14 and 0.13, respectively. EWT highly correlated with leaf mass per area (LMA), decreasing the correlation between GWC and EWT. LMA explained 89% of the variation in EWT of all the samples, and 96% of the EWT of green crowns (n = 40). The results showed that due to large variation of LMA in natural environment, EWT is not a good indicator of tree health in Norway spruce, hindering the use of EWT as an indicator in detecting bark beetle damage using remote sensing.

4.(11:30) Early detection of forest health stress through fusion of the Ecosystem Disturbance and Recovery Tracker system (eDaRT) and remotely sensed canopy water content | *M Slaton*, A Koltunov, C Ramirez, G Asner, E Haunreiter, T Kohler, P Brodrick*

Land managers seek to increase the pace and scale of forest restoration to enhance forest resilience and support economic sustainability in the face of recent global-scale decline in forest health. Monitoring has traditionally relied upon airborne campaigns and limited site inspection to assess forest health status and vulnerability to disease and drought, often overlooking the very early stages of physiological stress, especially when drought-related, and when evidence of biological disease or pathogens is absent.

We describe the capability of two remote sensing systems to detect early manifestations of forest health impairment in California, and data fusion methods that enhance our understanding of the temporal sequencing, seasonality, and relative magnitude of recent declines in physiological water status and fractional canopy cover loss.

The first method applies the Ecosystem Disturbance and Recovery Tracker (eDaRT), a Landsat-based dense image time series algorithm that detects statistical anomalies in forest conditions. The second method measures canopy water content (CWC) through the use of high-fidelity imaging spectroscopy (HiFIS). Between 2015 and 2017, the Carnegie Airborne Observatory (CAO) performed a series of aerial surveys to collect both HiFIS and light detection and ranging (LiDAR) data, from which CWC measurements were calculated. A deep learning model was then used to derive relationships between a suite of satellite and terrain data and the CAO CWC measurements, which allowed for wall-to-wall mapping of CWC throughout California.

Combining the eDaRT capability of detecting disturbance at sub-annual scales with the CAO annual CWC estimates, we attempted to answer the following questions: How is canopy water loss related to the occurrence and timing of subsequent tree mortality? What levels of CWC loss can be detected consistently by eDaRT to best discern early stress?

The connection of observable change to physiological status creates the opportunity to conduct near real-time monitoring and enable same-year vegetation management action. We report on continued progress in fusing these approaches to better monitor health at sufficient scale and frequency to meet an ever-increasing demand to detect forests at risk.

5.(11:50) Using time-varying sensitivity analysis to clarify the effects of two source energy balance model formulation on model behavior | *C Houser**

Evapotranspiration (ET), which includes evaporation and vegetation transpiration, is an important component of the earth's energy balance that influences water availability and energy partitioning at the land surface. Two-source energy balance (TSEB) models are widely used for estimating ET, however selecting an appropriate modeling scheme often depends on the understanding of the system, data availability, and modeling objectives. Therefore, understanding how the development of TSEB models influences their process-level behavior is a necessary next step to advance the field. To this end, I develop a comprehensive exploration of the dominant parameters in the TSEB model structure. Model controls are isolated using time-varying Sobol' Sensitivity analysis over time series data accounting for spatial and temporal variability in vegetation structure and hydroclimatic conditions in order to asses the time-dependent nature of parameter sensitivity. Sensitivity indices are visualized along hydroclimatic and surface structural gradients to identify key behavioral differences between TSEB models and to connect these back to the models underlying assumptions. The results highlight model differences in performance controls. Understanding the links between model formulation and behavior can be an important diagnostic approach in applications where dominate model controls change over time.

4B

SAR INTERFEROMETRY, TOMOGRAPHY AND APPLICATIONS

Moderator: Iain Woodhouse

1.(10:30) Forest structure monitoring by means of multi-baseline SAR configurations | *K Papathanassiou*, M Tello Alonso, V Cazcarra Bes, M Pardini, J Kim*

The penetration capability of microwaves into and through vegetation layers allows scattering interactions across the whole vertical vegetation extend. This, combined with the ability of multi-baseline Synthetic Aperture Radar (SAR) techniques to reconstruct the 3D radar reflectivity opens the door to the use of air- and space-borne SAR configurations to explore and map forest structure parameters on large (global) scales with high spatial and temporal resolution.

In this paper we discuss the potential of multi-baseline SAR configurations to estimate (or map) physical forest structure parameters. For this, first the link between 3D radar reflectivity and 3D forest structure has to be established. Accordingly, a framework for qualitative and quantitative forest structure interpretation and estimation from 3D radar reflectivity reconstructed by multi-baseline SAR measurements is introduced, reviewed and validated against experimental data (including Lidar and inventory meassurements) acquired over/in different temperate and tropical forest conditions. The role of system frequency, implementation and spatial resolution is discussed. The dependency of the obtained / possible structure estimates on the spatial scales is addressed and through the analysis on real and simulated data it is demonstrated that a single (spatial) scale does not always ensure a complete characterization of forest structure. The potential of multi-baseline SAR configurations to monitor dynamic effects as the temporal variations of forest structure induced by natural or anthropogenic changes is considered. Results achieved in the framework of actual air-borne SAR (F-SAR) temperate and tropical forest campaigns and/or experiments at different frequencies and/or configurations are critically discussed.

Finally, the role of future multibaseline SAR spaceborne configurations / missions as Tandem-L in the context of global forest structure and structure change mapping is discussed.

2.(10:50) Vegetation structure and biomass via spaceborne radar tomography: A case study using X-band over Indian forests | *M Lavalle*, U Khati, G Shiroma, G Singh*

Forest 3D structure is a fundamental component of terrestrial ecosystems as it provides a proxy for forest health and above-ground biomass (AGB). Radar tomography (TomoSAR) has emerged as a complementary technique to lidar remote sensing for mapping fine-scale vegetation structure. TomoSAR algorithms employs multiple radar passes with slightly different look angles to deliver radar tomograms, which can be thought as the equivalent of lidar waveforms. Experiments have shown that spaceborne TanDEM-X data enable generation of high-quality tomograms. The sensitivity of these tomograms to forest species and the ability to extract biomass from tomogram metrics, however, remain largely understudied.

The objectives of this work are to (1) assess TanDEM-X-derived structure product over Indian forests using an end-to-end processing chain developed at JPL; (2) compare multi-polarimetric tomograms and field data for three forest species; and (3) develop algorithms for extracting biomass from tomogram metrics and validate them using field-derived biomass. Out test site is a managed forest in the Haldwani forest range (Uttarakhand, India). The forest is moderately dense and it is divided into mono-species compartments. Here we will focus on Teak, Eucalyptus and Gutel species, which vary in their phenology and canopy and leaf structure.

A field survey was carried out during November-December 2015 to measure tree-level height, stand height H100, breast height diameter and AGB in 100 field plots measuring 0.1ha. The survey indicates that H100 varies between 11.3m and 27.8m with a mean of 20.7m, while AGB varies between 10 Mg/ha and 350 Mg/ha. Spaceborne TanDEM-X data were acquired from December 2014 to March 2015. Nine ascending pairs (0-0.6 rad/m vertical wavenumber) were calibrated, resampled into a stack and corrected for topographic phase effects using a new JPL processing chain. The 12-m WorldDEM was used in the processing.

We were able to generate successfully TanDEM-X tomograms in three linear and two Pauli polarimetric channels. An analysis of multi-polarimetric tomograms reveled that polarimetric diversity helps resolve different scattering locations within the canopy. Field height H100 and our tomograms were found in excellent agreement. We are currently comparing tomograms for the Teak, Eucalyptus and Gutel species and developing algorithms to extract AGB from tomogram metrics, which will be then validated using field-derived biomass.

3.(11:10) Spaceborne GEDI and TanDEM-X fusion for large-scale three-dimensional forest structure parameter retrieval | *S Lee*, T Fatoyinbo, W Qi, S Hancock, J Armston, R Dubayah*

Three-dimensional (3-D) forest structure parameters are fundamental components for understanding of the global forest carbon storage and cycle, as well as climate changes. Active remote sensing sensors, for example, SAR and waveform lidar, have been successfully used for extracting 3-D forest structure profiles by means of both SAR and lidar airborne systems, but individually. Fusing both SAR and lidar over forested areas and developing new merging algorithms are critical to measure global forest biomass and to understand terrestrial carbon dynamics.

The upcoming spaceborne waveform lidar mission, GEDI (Global Ecosystem Dynamics Investigation) will operate on the International Space Station (ISS) and laser ranging measurements for 3-D structure of the Earth from November 2018. The GEDI instrument will not provide continuously imaging on the ground resulting in gaps between ground tracks and adjacent swath at the footprint level. In order to provide wall-to-wall mapping of 3D forest structure while maintaining the fine resolution measurement of each footprint, the GEDI data will be combined with spaceborne remote sensing data.

TanDEM-X (TDX) is an innovative satellite SAR mission that is flying twin X-band SAR satellite sensors in order to generate a consistent global DEM (digital elevation model) with high resolution and accuracy. It also makes possible to estimate 3-D forest parameters using the Pol-InSAR inversion techniques, when dual-/full polarization data or airborne lidar digital elevation models (DTMs) are available. However, globally available single-pol (HH) TDX data limits conventional Pol-InSAR inversion approaches because of unbalance between the single observable and unknown parameters in the Pol-InSAR model.

The fusion approach from GEDI and TanDEM-X indicates a great possibility for generating global-scale forest map and biomass maps (where the GEDI data will be available) with unprecedented spatial resolution. In this study, GEDI data have been first simulated from LVIS airborne waveform lidar data using GEDI system configuration and ISS orbit information. The interpolated GEDI DTM was merged with TDX DEM at 12 m resolution using the wavelet transformation technique. The proposed fusion approach has provided high-resolution DTM that is directly related to a ground phase in the forest height inversion. It provided a great possibility to apply Pol-InSAR inversion techniques to globally available single-pol TDX SAR data.

4.(11:30) GEDI-TanDEM-X fusion for enhanced forest structure observation: a comparison of InSAR height profiles and lidar full waveforms | *C Choi, M Pardini*, K Papathanassiou*

The NASA's Global Ecosystem Dynamics Investigation (GEDI) lidar mission will record full waveform returns on 25 m footprints, globally and at a high spatial sampling density never reached before. Focused on tropical and temperate forests, the full waveforms will be used to provide global and high-resolution observations of forest vertical structure (< 500-1000 m), canopy height and (under canopy) surface elevation. Towards enhanced products, GEDI is expected to use data of present and future space borne synthetic aperture radar (SAR) missions for instance to fill the gaps in its coverage, increase its product resolution, and gain from different ways to calibrate and estimate biomass. In this framework, the possibility of fusing GEDI waveforms and TanDEM-X single-pass X-band interferometric (InSAR) coherences is currently being investigated. TanDEM-X InSAR coherences, which are available globally and without gaps, have already been widely demonstrated not only to contain information about the Earth surface topography, but also to enable e.g. the estimation of forest height and biomass, and of their changes.

The relationship between TanDEM-X InSAR coherences and lidar full waveforms is not understood yet. Coherences are related to vertical profiles of the radar backscattered power, which cannot be estimated from a single interferometric measurement as normally available with TanDEM-X. A way to partially circumvent this limitation is to create height profiles from (high resolution) digital elevation models estimated from the InSAR coherences. Thus, the purpose of this work is to compare InSAR height profiles and lidar full waveforms in order to characterize their commonalities and differences in terms of forest structure. Given the limited X-band penetration capabilities, it has been found that the TanDEM-X InSAR height profiles clearly contain information about the horizontal spatial heterogeneity of the top canopy layer. Such heterogeneity can be quantified by using appropriate metrics calculated within a unit scale, and a correlation has been observed with the same metrics calculated by using the lidar waveforms. Experimental results will be presented on tropical and temperate forest sites. Comparisons will be carried out also with field inventory data to understand not only the relevance of the employed profile metrics in terms of physical forest structure, but also their shortcomings and ambiguities depending on the used profiles.

CANCELLED

5.(11:50) Potential of multi-temporal ALOS-2 PALSAR-2 ScanSAR data to estimate forest parameters in tropical dry and wet for[illegible] *M Urbazaev*, F Cremer, C Schmullius, C Thiel*

In this study we est[illegible]ed forest parameters (tree height, percentage tree cover, aboveground biomass (AGB)) using multi-tempo[illegible] [illegible]OS-2 PALSAR-2 ScanSAR backscatter images. These data were collected between 2014 and 2018 comprising 30 dual-polarized L band acquisitions. Compared to the Stripmap mode, the ScanSAR data possess five times wider swath (70 km vs. 350 km) resulting in a higher repetition rate over large areas. The spatial resolution of the dual polarized ScanSAR data is 50 m, which is commonly sufficient for forest parameter maps at a large scale. The aim of the study was to analyze the benefit of multi-temporal data for estimation of forest parameters compared to the annual global L band mosaics. Accordingly, we estimated forest parameters using 1) multi-temporal ScanSAR data and 2) two annual global L-band mosaics. The study area was located in the Yucatan peninsula covered by tropical dry and wet forests. For AGB estimation national forest inventory (NFI) data collected by the Mexican Forestry Commission (CONAFOR) were used to calibrate statistical models as well as to validate the AGB products. To derive tree height and percentage tree cover products very high resolution airborne LiDAR data collected by NASA were used for model calibration and product validation. We applied a non-parametric machine learning algorithm (Random Forests) to estimate the above mentioned forest parameters with multi-temporal ScanSAR data and annual global L band mosaics. The validation results showed a better performance of multi-temporal data compared to the global mosaics for estimation of all three forest parameters (e.g., R^2 increased from 0.33 to 0.79 for tree height, from 0.57 to 0.79 for percentage tree cover, and from 0.21 to 0.42 for AGB estimation). The results of this study indicated that using of multi temporal SAR data can potentially mitigate saturation effects in the dense tropical forests. It is important to mention that these multi-temporal ScanSAR data are available for vast regions of the globe and thus can be used for mapping of forest parameters at continental or inter-continental scales.

4C

LARGE AREA OBSERVATION NETWORKS

Moderator: Laura Duncanson

1.(10:30) Forest-Observation-System.net - towards a global in-situ data repository for biomass datasets validation | *D Schepaschenko*, J Chave, O Phillips, S Davies, S Fritz, S Lewis, P Sist, M Réjou-Méchain, C Perger, C Dresel, K Scipal*

Forest monitoring is high on the scientific and political agenda. Global measurements of forest height, biomass and how they change with time are urgently needed as essential climate and ecosystem variables. The Forest Observation System – FOS (http://forest-observation-system.net/) is an international cooperation to establish a global in-situ forest biomass database to support earth observation and to encourage investment in relevant field-based observations and science. FOS aims to link the Remote Sensing (RS) community with ecologists who measure forest biomass and estimating biodiversity in the field for a common benefit. The benefit of FOS for the RS community is the partnering of the most established teams and networks that manage permanent forest plots globally; to overcome data sharing issues and introduce a standard biomass data flow from tree level measurement to the plot level aggregation served in the most suitable form for the RS community. Ecologists benefit from the FOS with improved access to global biomass information, data standards, gap identification and potential improved funding opportunities to address the known gaps and deficiencies in the data. FOS closely collaborate with the Center for Tropical Forest Science – CTFS-ForestGEO, the ForestPlots.net (incl. RAINFOR, AfriTRON and T-FORCES), AusCover, Tropical managed Forests Observatory and the IIASA network. FOS is an open initiative with other networks and teams most welcome to join. The online database provides open access for both metadata (e.g. who conducted the measurements, where and which parameters) and actual data for a subset of plots where the authors have granted access. A minimum set of database values include: principal investigator and institution, plot coordinates, number of trees, forest type and tree species composition, wood density, canopy height and above ground biomass of trees. Plot size is 0.25 ha or large. The database will be essential for validating and calibrating satellite observations and various models. Comparison of plot biomass data with available global and regional maps (incl. IIASA global biomass map by Kindermann et al., 2013; Boreal and temperate forest by Thurner et al., 2013; NASA tropical by Saatchi et al., 2011; WHRC tropical by Baccini et al., 2012; WUR pan-tropical by Avitabile et al., 2015; IB-CAS global map by Hu et al., 2016) shows wide range of uncertainties associated with biomass estimation.

2.(10:50) ForC: a global database characterizing carbon cycling in mature and regrowth forests | *K Anderson-Teixeira*, V Herrmann, J McGarvey, M Wang, N Kunert, B Bond-Lamberty, H Muller-Landau*

Forests play an influential role in the global carbon (C) cycle. They store roughly half of terrestrial C, annually fix ~5.5 times more CO2 than is released through human activities, and offset ~1/3 of anthropogenic emissions through biomass growth. With the fate of Earth's climate closely linked to forests, a better understanding of their C cycles is urgently needed to constrain model estimates of forest feedbacks to climate change and to more accurately quantify the influence of land use decisions on climate. We present a dynamic open-access database of forest C stocks and fluxes, ForC (github.com/forc-db/forc), and draw upon it to provide a macroscopic overview of C cycling in the world's forests. ForC currently contains >17,000 previously published field-based measurements of ecosystem-level C stocks and annual fluxes representing >2,700 plots in >800 geographically distinct areas, along with disturbance history and methodological information. We draw upon these data to characterize ensemble C budgets for four broad forest types (tropical broadleaf evergreen, temperate broadleaf, temperate conifer, and taiga), including both age trends and mature forest averages. The rate of C cycling generally increased from boreal to tropical regions, whereas C stocks showed less directional variation. Relative to differences across biomes, age differences in fluxes were relatively small. Our results represent by far the most comprehensive analysis of C cycling in global forests. Moving forward, we expect that ForC will prove useful for macroecological analyses of forest C cycling, for evaluation of model predictions or remote sensing products, for quantifying the contribution of forests to the global C cycle, and for supporting international efforts to inventory forest carbon and greenhouse gas exchange. A dynamic version of ForC is maintained on GitHub (https://GitHub.com/forc-db), and we encourage the research community to collaborate in updating, correcting, expanding, and utilizing this database.

3.(11:10) GLOBE Observer: citizen science in support of forest cover mapping and monitoring | *P Nelson*, B Campbell, H Kohl, D Overoye, MJ Hughes, J Braaten, R Kennedy*

The science community has easy access to remote sensing satellite data but limited resources for acquiring ground reference photographs to verify land cover or forest type maps. GLOBE Observer is an international citizen science initiative to understand our global environment. Using this mobile app to capture location, photos, and text, citizen scientists help track changes in global forest types, conditions, and sky observations. Here, we will introduce the newest data collection protocol, 'Land Cover', and share observations from 'Cloud Observer' that include information such as forest leaf phenology. The goal of the new Land Cover (Adopt a Pixel) protocol is to acquire ground-based photographs to improve satellite data interpretation for operational and research science. Photographs from volunteers provide scientists with ground-based landscape data that would be too expensive or time consuming to acquire by other means. In addition, students of all ages are able to do real scientific research as part of the NASA-led Global Observations to Benefit the Environment (GLOBE) Program. The vision of which includes a worldwide community of students, teachers, scientists, and citizens working together to better understand, sustain, and improve Earth's environment at local, regional, and global scales. This new crowd-sourced land cover and tree height dataset will add to the approximate 7,300 land cover and 22,000 forest biometry measurements that have been collected since the program began in 1995. Research scientists can use this open-source data to verify satellite data and improve their models, including the important cloud identification and masking process. Finally, plans to use citizen scientists to help calibrate and validate the Ice, Cloud, and land Elevation Satellite 2 (ICESat-2) tree height data will be discussed.

4.(11:30) Forest Inventory for the Entire Continental US - 1/20 acre resolution with DBH, Species, and Height | *Z Parisa**

SilviaTerra is opening up access to a high-resolution forest inventory data layer for the entire continental US. Using a combination of publicly available remote sensing data, FIA plot information, and a custom-built cloud-computing system, SILVIATERRA and Microsoft AI for Earth have created a 15 meter resolution map including DBH, species, and height for each stem. By sampling to correct, the precision for individual stands can be improved with a small number of additional plots. This forest basemap is enabling new possibilities in forest management. Rather than managing the average, foresters can use this data to adjust their management at the sub-stand scale. Small landowners will benefit from the availability of low-cost, instantly available information about their property – enabling them to participate in both timber markets and in emerging ecosystem service markets. In this talk, SILVIATERRA president Zack Parisa will discuss how this basemap will transform the dynamics of forest markets and what it means for the future of forestry.

5.(11:50) An open source HPC PYCUDA algorithm for processing waveform lidar observations | *T Goulden**

The National Ecological Observatory Network (NEON) is a continental-scale ecological observation platform designed to collect and disseminate data that contributes to understanding and forecasting the impacts of climate change, land use change, and invasive species on ecology. NEON will collect in-situ and airborne data over 81 sites across the US, including Alaska, Hawaii, and Puerto Rico over a 30-year operational period. One of the main sub-systems of the NEON is the Airborne Observation Platform (AOP). The AOP is an aerial sensor suite that includes an imaging spectrometer, RGB camera and a waveform lidar. NEON will be one of the first organizations that provides open access to waveform lidar data collected at a variety of forest ecosystems with annual temporal resolution. Currently, there are limited open source tools available to process raw lidar waveforms, which has hampered the adoption of AOP waveform lidar.
This presentation details a waveform processing algorithm written in Python that reads data from the Pulsewaves file format, performs a peak detection, and coordinates discrete targets through Gaussian decomposition. Gaussian decomposition is performed with a constrained Levenburg-Marquedt least-squares curve-fitting algorithm (LM). The algorithm was coded with three different implementations of LM: 1) an open-source implementation written as standard Python function, 2) an open source HPC implementation using PyCUDA, which leverages a GPU, 3) a non-open source implementation using AGLIB, used to verify the accuracy of the open source implementations. Results show that the AGLIB implementation performs with marginally higher accuracy, with sum of squares of Gaussian Decomposition fits typically 0-0.5% lower than both the standard Python and PyCUDA implementation. The improvement of sum of squares of the AGLIB implementation lead to negligible improvements in derived coordinates. The AGLIB implementation was the least efficient, processing approximately 1 million waveforms per 120 min, while the open-source Python implementation processed approximately 1 million points per 60 min, both parallelized across all cores of an Intel XEON E5-2667 CPU. The PyCUDA implementation was the most efficient, processing 1 million waveforms per 120 seconds. The source code for all implementations is available through the NEON project along with several test datasets to allow for continued community development of open source waveform lidar processing tools.

4D

ADVANCES IN SATELLITE FIRE MONITORING AND CHARACTERIZATION 1

Moderator: Louis Giglio, Chris Justice, David Roy & Krishna Vadrevu

1.(10:30) Characterizing Mass Fire Events Using MODIS and VIIRS Hotspots - the British Columbia Fire Season of 2017 | *C Stockdale*, P Englefield, N McLoughlin, M Parisien, D Perrakis*

Considerable disagreement exists as to whether wildfires have higher rates of spread, and burn more intensely in landscapes that have been attacked by Mountain Pine Beetle (MPB). Some recent studies have shown that there may be short-term increases in wildfire extent, severity, and probability of ignition following MPB attack, however other studies show no change in wildfire risk. In general, previous studies have been hampered due to a paucity of fires that have burned in MPB-killed landscapes, however the 2017 wildfire season in British Columbia (BC) burned more than 1.2M ha, with much of this occurring in MPB-killed areas. Using VIIRS and MODIS hotspot data, we reconstructed the 2017 fire season in central British Columbia to determine whether or not areas with heavy MPB infestation influenced wildfire behavior such as rate of spread, area burned, and spotting. We examined roughly 150 fires and developed methods to derive rate of spread from more than 9,000 fire spread events. To determine the influence of MPB-kill on the rate of spread, size of fires, and spotting we related each spread event to the fuel conditions present at the time of fire. Fuel conditions were determined using BC Aerial Overview Survey data to develop a beetle-severity index that accounted for the presence/absence, level of severity, and time since attack of MPB across the landscape. We found evidence that indeed fires spread faster, created more spot fires, and burned more area if MPB had attacked stands. However, we found significant effects related to the severity of beetle attack and the time since infestation.

2.(10:50) Fire Detection, Characterization, and Monitoring with GOES-16/-17 | *C Schmidt**

Fire detection and characterization has been operationally available from geostationary satellites since 2002 when the Wildfire Automated Biomass Burning Algorithm (WFABBA) went into Operations for the GOES series at NOAA/NESDIS. The WFABBA was later adapted for the Meteosat Second Generation series of satellites, MTSAT-1R/-2, and Korea's COMS in support of GOFC/GOLD efforts to produce geostationary fire products with a globally consistent algorithm. The Fire Detection and Characterization Algorithm (FDCA), the WFABBA for Advanced Baseline Imager (ABI) class sensors, was a day 1 product for GOES-16. Like the WFABBA it provides six categories of detection and for the highest confidence categories it supplies fire radiative power (FRP), fire size, and fire temperature for the Contiguous United States (CONUS) and full disk (FD) ABI scans. The FDCA has been undergoing extended validation since data begin flowing in January 2017 as algorithm performance has been assessed against high resolution satellite data such as from LANDSAT, as well as VIIRS on JPSS and MODIS on Terra and Aqua. Results of the validation work, including assessments of commission and omission error rates in various scenarios and inter-comparisons of satellite derived fire radiative power, will be presented, as will case studies highlighting both strengths and weaknesses of detection and characterization with the FDCA using ABI-class sensors. Pathways forward for algorithm improvements will also be outlined.

3.(11:10) Enhancing the GOES Early Fire Detection (GOES-EFD) algorithm prototype to assist wildfire response and management | *A Koltunov*, B Quayle, S Ustin*

The recent launch of the new generation of geostationary satellites, GOES-R/S series, offers great potential to dramatically improve wildfire early warning capabilities of satellite remote sensing in the continental US, which previously were considered unattainable, except in remote, sparsely populated areas. An obstacle on this road is the lack of reliable automated algorithms that are optimized toward the earliest possible initial detection, as opposed to the priorities of the NOAA operational geostationary fire algorithm. To address the problem and complement existing fire monitoring assets, University of California-Davis and US Forest Service (at GTAC) have been developing the GOES Early Fire Detection (GOES-EFD) system that detects ignitions using an ensemble of novel time-series techniques. In the early small-scale experiments with GOES-NOP data in California GOES-EFD previously demonstrated its potential to shorten the time to initial detection.

We will present a recently completed round of GOES-EFD development, including algorithm enhancements and a large scale test during 2014 wildfire season in Western US. This test used the legacy GOES-15 images spanning seven states and tens of thousands of cross-checked and validated fire records from state and federal sources. These developments and experiments, along with the universality of the GOES-EFD core algorithms, elevate the system readiness and argue for accelerating its transition to the new GOES-R/S Advanced Baseline Imager data in which fires provide much stronger and more frequent signals than in the legacy GOES. Although not every incident can be detected early by GOES-EFD and not every early detected incident can be contained, an operational low-cost fire discovery tool, such as GOES-EFD, could reduce preventable losses of lives, property, ecosystems, and agency resources due to tomorrow's megafires.

4.(11:30) Using the NASA polar orbiting fire product record to enhance and expand the Global Wildfire Information System (GWIS) | *L Boschetti*, D Roy, A Sparks*

The Global Wildfire Information System (GWIS), hosted by the European Commission Joint Research Center and developed under the Work Program of the intergovernmental Group on Earth Observations (GEO), provides an internet based portal and repository of fire information with the goal of enabling a comprehensive view and evaluation of fire regimes and fire effects in support of policy making and national resource management. Currently the GWIS is a beta-version with limited content. The 18+ year MODIS fire product record is the longest systematically generated science quality global coverage fire record, and has been widely used in science and applications. To date however there is no service for the systematic generation of metrics and statistics that are accessible to non-technical users. Software to generate scientifically accepted, reproducible fire information, documented for non-technical users in easily accessible formats, will be developed that describe fire activity over different spatial regions and temporal periods, fire seasonality and fire size metrics. The information will be based on the global MODIS Collection 6 fire products. This presentation will highlight the GWIS improvements and showcase on-demand statistics, and tabular and graphical information, at state/regional, national, sub-continental, continental, and global spatial scales, for monthly, seasonal and annual time periods.

5.(11:50) The Use of Multi-temporal MODIS Satellite Data to Map Veld Fire Hazards in Limpopo Province, South Africa | *F Dondofema*, T Mudau, B Odhiambo*

Veld fire is an essential natural hazard in South Africa, fires can be a resultant of nature or anthropogenic activities. This study assesses and maps veld fire hazards on the environment in Limpopo Province, South Africa. The study employed GIS and remote sensing techniques on MODIS satellite data to produce veld fire risk maps in Limpopo Province. Enhanced Vegetation Index (EVI) and Land Surface Temperature (LST) variables were used as a surrogate to determine vegetation attributes, behavior and conditions, estimating the Fuel Moisture Content (FMC) using regression analysis and facilitate the classification of fuel types. The estimated FMC was used to generate the veld fire risk maps using Improved Fire Susceptibility Index (IFSI) in ArcGIS 10x—. The MODIS satellite images were used to map the burnt areas using the Maximum Likelihood Classifier (MLC) and to estimate the burn severity using difference Normalized Burn Ratio (dNBR). For this reason, the study used Uni-temporal and bi-temporal approach to discriminate severity levels of veld fires in the study area. The classical multiplicative model of time series analysis was used to analyse the veld fire trend from 2002 – 2017 and make a forecast of one year into the future (2018). Based on the results, EVI is strongly related to LST and showed an inverse relationship in the study area. Fuel type 1, fuel type 2, fuel type 5 and no fuel were classified. EVI and LST positively estimated the FMC of each classified fuel type. The burnt areas and burn severity were spatially distributed in the study area across slopes facing Northeast (22.5 – 67.5) and Southeast (112.5 – 157.5) characterized by fuel type 1 and fuel type 2. The regression output between IFSI and historical fire data in the study area a significance F of 0.079 indicating a probability of 7.9% that the correlation between IFSI and historical fire data is a random occurrence. The time series analysis showed a decreasing trend of veld fires since 2002.

5A

FOREST BIODIVERSITY MONITORING AND ASSESSMENT FROM REMOTE SENSING 1

Moderator: Gherardo Chirici & Ronald McRoberts

1.(13:30) Long-term Landsat time series - a new opportunity for forest diversity monitoring | *W Graf*, C Kleinn, P Schall, T Nauss, F Detsch, P Magdon*

Long-term Landsat time series offer the opportunity to study vegetation dynamics and management operations over several decades. These dynamics, here termed ecosystem history, have an impact on herb layer plant diversity in temperate forests. However, analyses of long-term Landsat time series have not been used yet for better understanding and monitoring forest plant diversity.

We used Landsat time series over 31 years of the USGS and ESA archives to investigate disturbance regimes and forest dynamics in German temperate forests and related the ecosystem history to the herb layer plant diversity. The study plots cover forests from low to high management intensity, quantified here by a management intensity index.

We applied two approaches to study the ecosystem history: i) We used break point analysis to detect changes in trends and disturbances and ii) differences in time series dynamics of seven forest types were analyzed with hierarchical cluster analysis of time series dissimilarity measures. Differences in the Simpson's diversity index of the herb layer plant species were tested between plots with and without detected break points in the time series and between the clusters.

To investigate the benefit of time series in describing plant diversity patterns, we compared the time series cluster analysis to the clustering based on the median NDVI of only one growing season in 2015.

The detected break points were e.g. linked to severe weather events or large-area management operations. However, we could not identify small changes, caused by small-area management activities, common in German forestry.

We found significant differences in the Simpson's diversity index between time series clusters for five forest types. These clusters also significantly differed in the management intensity for two forest types. By contrast, the clusters based on the median NDVI of 2015 of six forest types could not explain differences in the diversity index.

Our study suggests that Landsat time series, describing elements of historic dynamics, may improve understanding current forest diversity patterns. The time series clustering approach is promising to study the relationship of ecosystem history and herb layer diversity. To our best knowledge, this is the first study to show the benefit of Landsat time series in context of plant species diversity assessment in temperate forests. In further analyses we will focus on different temporal and spatial resolutions.

2.(13:50) Comparing Sentinel-2 data and airborne imaging spectroscopy for mapping tree species diversity in Białowieża forest | *B Rombouts*, L Put, W De Keersmaecker, B Jaroszewicz, K Stereńczak, O Bouriaud, B Muys, B Somers*

Mapping tree species diversity is essential for planning forest management and highlighting diversity hotspots for nature conservation. However, creating these maps based on field data is labour intensive, hard to repeat yearly and field work results in non-spatially explicit data. Remote sensing has been long suggested as an alternative. Yet the limited spectral and spatial resolution of readily available spaceborne remote sensing products from e.g. MODIS and Landsat products have always been a limiting factor for the quality of the outputs. The Sentinel-2 products coming from the ESA Copernicus program and upcoming hyperspectral satellite platforms such as PRISMA and EnMAP offer new possibilities. In this study both Sentinel-2 data and aerial hyperspectral data are used to create tree diversity maps based on the spectral diversity hypothesis. This hypothesis assumes higher diversity with increased spectral variance. Here, the coefficient of variation (CV) is calculated at different kernel sizes to quantify spectral variance. The study site is the Polish part of the primeval Białowieża forest. Since this forest contains both managed and strictly protected parts, also the effect of forest management on the performance of the spectral variation hypothesis can be tested. Field data (for calibration and validation) consists of a set of forest plots following a diversity gradient in both managed and unmanaged parts of the forest. Spectra were obtained from a fusion of Sentinel-2 before and after the growing season and from an aerial hyperspectral flight in the middle of the growing season. For both dataset the growing season 2017 was used. Based on the spectra, the coefficients of variation are calculated. These are afterwards combined with the calibration field data to create tree diversity maps for the different remote sensing datasets. First results show the potential of Sentinel-2 data to map tree species richness with a RMSE of 1.5 species while the tree species richness ranges from one to eight. Since clear-cuts and roads highly influence the results, the potential of LiDAR fusion will be investigated to enhance results. Currently, similar analysis are performed for the hyperspectral data after which the results will be compared.

3.(14:10) Spatial analysis of remote sensing-based land cover data for assessing representativeness of biological inventories | *B Tavernia, M Nelson*, J Garner, C Perry*

Biological diversity monitoring of terrestrial vertebrates typically is grounded on field inventories, providing estimates for various indices of diversity which are assumed to be representative of national or regional populations or distributions. However, some field inventories like the American woodcock (Scolopax minor) Singing Ground Survey (SGS) employ sample designs that constrain samples to roadside locations accessible to observers, introducing potential bias. Independent biological inventory data rarely are available to test assumptions of sample representativeness. Remote sensing-based datasets portray characteristics associated with species-specific habitat requirements which may be used as a surrogate for assessing the representativeness of biological surveys. We tested whether SGS routes in Minnesota, USA represented land covers statewide and within local landscapes defined using simulated 10-minute blocks surrounding individual SGS routes. We used Landsat time series stacks and a vegetation-change-tracker algorithm to model time since a canopy-clearing disturbance between 1990 and 2009, from which we inferred stand age. We mapped early successional forest (< 20 years) by assigning age classes to deciduous, evergreen, mixed, and woody wetland forest classes and shrub-scrub classes within a land cover map. When assessing local representativeness the grand mean absolute difference (MAD) between route buffer and block cover classes was 3.78 percentage points. Twenty-two of eighty-one route (27%) buffers had MAD values >5 percentage points. Within Minnesota, more of these routes (19 of 22) occurred in the northern portion of Minnesota than in the southern portion. Linear regression of percent covers in route buffers against percent covers in corresponding blocks revealed differences due to: 1) both systematic and unsystematic error, 2) only systematic error, 3) only unsystematic error, and 4) neither systematic nor unsystematic error. When routes where compared in aggregate to Minnesota, the range of percentage point differences for individual covers did not exceed 5, except for open water, suggesting that SGS routes well represent land covers within Minnesota. Our results illustrate the utility of remote sensing products for assessing representativeness of biological inventories at multiple scales.

4.(14:30) Habitat mapping in a tropical dry forest through multispectral imagery | *AP Ochoa-Franco, JR Valdez-Lazalde*, HM de los Santos-Posadas, JL Hernandez-Stefanoni, JI Valdez-Hernández, G Ángeles-Pérez.*

Habitat characterization is a prerequisite for assessing ecological niche definition, base for animal or vegetation population studies and forest management planning, besides being a national and international priority goal.

Nowadays the Mexican government is promoting biodiversity conservation based on habitat management as an incentive for timber management certification, but soon, habitat characterization and mapping could became an official requirement for approval of all timber management plans regardless of their type and extent.

Despite the publication of an official guide for habitat characterization, there is a general environment of uncertainty regarding the most effective way to operationalize habitat characterization and mapping.

In this project, we classified 900 ha of a semi evergreen tropical dry forest in the Mayan Zone of central Quintana Roo, using a multiresolution segmentation algorithm. Image objects were created over a RapidEye image, considering the global intra-segment and inter-segment heterogeneity measures and ground experience opinion for choosing iteratively parameters (image layer weights, scale parameters, shape and compactness).

To assess if the object based classification was supported by vegetation structure and composition we used data from a ground forest survey carried out in 2013. We calculated attributes of stand structure including basal area, stem density, tree diversity, canopy cover, and above ground biomass using specific allometric equations. For each sampling unit and diametric class, we calculated mean, mode, and 50, 75 and 90 percentiles of the structural attributes. For the specific structural relevance we calculated the Importance Value of every specie as well as taxonomic diversity metrics based on species number, Shannon-Weaver and Fisher indices.

The stand structural differences between classes were tested by a Permutational Multivariate Analysis of Variance based on distance measures. The possible effect of species composition underlying the object based classification was illustrated by non-metric multidimensional scaling (NMDS, meta-MDS function in vegan) based on Bray–Curtis distances.

We concluded that RapidEye multispectral imagery could be a valuable tool for habitat mapping, as it allows identifying differently structured habitat units, coherent with land management history and tree species composition.

5.(14:50) The added value of multi-temporal Sentinel-2 data for tree species classification in the Wienerwald Biosphere Reserve | *M Immitzer*, M Neuwirth, S Böck, F Vuolo, H Brenner, C Atzberger*

Detailed knowledge about tree species composition is of great importance and the potential of multi-spectral earth observation (EO) data for tree species mapping is well known. Until recently, most research focused on spectral and spatial resolutions. However, the temporal resolution can decisively influence the ability to distinguish between individual species. In 2015, the European Space Agency (ESA) launched its first Sentinel-2 satellite (S2A). Together with its twin satellite launched in 2017 (S2B), EO data are now provided with unprecedented spectral, spatial and temporal resolution. Here, we investigate the potential benefits of using high temporal resolution data for classification of five coniferous and seven broadleaved tree species in a highly mixed and diverse Central Europe. To run the Random Forest (RF) classification, 18 cloud-free S2 acquisitions between August 2015 and October 2017 were analyzed in a 2-step approach. The available scenes were first used to partition the study area into six broad land-cover classes (Coniferous Forest, Broadleaved Forest, Grassland, Agriculture, Urban Areas and Waterbodies). Subsequently, additional RF classification models were created separately for the coniferous and the broadleaved class, taking into account all 262,143 possible permutations of the 18 S2 scenes. Each model includes a stepwise recursive feature elimination. The model quality was assessed in terms of out-of-bag overall accuracy (OOB-OA). Individual mono-temporal tree species accuracies range from 48.1% (January 2017) to 78.6% (June 2017). Compared to the best mono-temporal result, the multi-temporal analysis approach improves the OOB-OA by 11 and 12 percentage points for the coniferous and the broadleaved tree species, respectively. Remarkably, a combination of 6-7 scenes achieves a model quality equally high as the model based on all data; images from April until August proved most important. The classes European Beech and European Larch attain the highest user's accuracies of 96.3% and 95.9%, respectively. The most important spectral variables to distinguish between tree species are located in the red (conifers) and SWIR bands (deciduous), respectively. Overall, the study highlights the potential of multi-temporal S2 data for species-level classifications in middle European forests. In a next step, the modeling approach will be extended to cover larger areas and include higher resolution data.

5B

BIOMASS MAPPING

Moderator: Sylvia Wilson

1.(13:30) Estimation of Tropical Forest Structure and Biomass Airborne P-band TomoSAR and Lidar Measurements | *S Saatchi*, A Ferraz, J Chave, S Tabaldini, S Quegan, T LeToan, P Dubois, K Papathanassiou, H Shugart*

The BIOMASS mission of the European Space Agency (ESA), to be launched in 2021-2022 will provide, for the first time, synthetic aperture radar tomographical (TomoSAR) imaging capability to quantify forest structure and above ground biomass. TomoSAR imaging is based on the multibaseline interferometric measurements along N parallel tracks that allows quantifying the reflectivity of the vegetation along a vertical dimension derived from the Fourier transform of the SAR images along the baseline dimensions. The result of this TomoSAR image processing is a profile of reflectance that relates to the forest structure and its density of scattering components such as leaves, branches, and stems within the SAR footprint or resolution. However, the interpretation of the TomoSAR data compared to actual structure of the forest depend of a variety of parameters such as the geometry of observation (off-nadir incidence angles), large wavelength of observation and sensitivity to forest structural components, and multiple scattering characteristics of the SAR reflectivity complicating the effective location of the reflectivity along the vertical access. Here, we use P-band TomoSAR data acquired during the AfriSAR campaign over tropical forests of Gabon along with the airborne Lidar and ground measurements of forest structure to examine the relationship of TomoSAR vertical profile with Lidar and ground observations across multiple spatial scales. By using a SAR scattering model based on ground and Lidar data to simulate the TomoSAR observations, we will address: 1) To what extent the TomoSAR observations can separate the ground and vegetation reflectivity across spatial scales and slope gradients? 2) What are the main contributions from the forest components to SAR reflectivity at different heights above ground? 3) How do TomoSAR observations relate to aboveground biomass and why? Specifically, we examine why TomoSAR reflectivity at a certain height above ground (e.g. ~ 30 m) show a strong sensitivity to the total above ground biomass over old-growth undisturbed tropical forests with the aid of Lidar vertical profiles aggregated to the same spatial scales. The results of our study will provide the mechanisms TomoSAR data can be explored alone or along with lidar observations for global mapping and monitoring of forest structure and biomass.

2.(13:50) Different sensitivity of X-band phase height to the vertical and horizontal dimensions of growing stock | *S Solberg**

Aims/objectives

The objective of this study was to investigate the sensitivity of X-band phase height to the horizontal and vertical dimension of volume (growing stock).

Materials and methods

The volume of a tree trunk is the product of the basal area, height and form factor. I here let basal area (b) represent the horizontal component of the volume, and the product of height (h) and form factor (f), i.e. form height, to represent the vertical dimension. While this is well-defined for a tree, I adapt this to the plot level by summing up basal area (b), by using basal-area weighted height (h) and a volume weighted form factor (f). In order to analyze the sensitivity of the phase height (InSAR height) to the horizontal and vertical components I introduce an H/V-ratio, being the basal area (b) divided by the form height (fh).

A TanDEM-X stripmap data set was acquired over the study area in a spruce dominated forest in south Norway, and phase height was derived from the ground corrected complex coherence. Phase height was derived for a set of 250 m2 field inventory plots, with measurements of basal area, Lorey's height and stem volume.

The effect of the H/V-ratio on the relationship between plot volume and phase height was investigated with a regression model, and residual analyses.

Summary of key findings

A scatterplot of volume against phase height showed a residual scattering around a fitted no-intercept regression line, V = 27PH, where PH is the phase height. The RMSE was 93 t/ha (46% of the mean volume). The residuals were largely attributable to H/V-ratios. Plots having many small trees had underestimated volumes based on the regression, while plots with few and tall trees had overestimated volumes. Phase height is more sensitive to the vertical dimension of volume than to the horizontal dimension. When plots were assigned to four classes of H/V-ratios, separate no-intercept regression models were fitted having slope parameters of 8.5; 22.9; 29.4 and 36.9 t/ha/m, respectively. This different sensitivity to horizontal and vertical dimension of volume results in errors in estimation of volume as well as above-ground biomass for single plots and single pixels. For estimation of temporal change the errors will vary with the category of change, i.e. how it affects the H/V-ratio. Errors in aggregated values for large-scale studies can only be avoided if the plots used for model calibration is a representative sample for the area.

3.(14:10) Benchmarked small area estimation of forest biomass change using stochastic optimization | *V Strimbu*, E Næsset*

When aggregated, small area estimates do not correspond to a large area estimate which is precise and may have an official status. This type of consistency is an important aspect when there is some dependency in how the local and global information are being used. For instance small area estimates of forest change may support local decisions that must be in agreement with national goals.

In this study we propose a flexible benchmarking method to adjust small area estimates to satisfy complex aggregation requirements. Composite estimators are often used in small area estimation to compromise between the possible bias of a model based (MB) estimator and the instability of a design based (DB) estimator when the sample size is small. The proposed benchmarking method optimizes the contribution of each estimator to the composite estimate in order to minimize the difference between aggregated small area estimates and prescribed large area values.

The benchmarking method was tested under simulated sampling (Norwegian NFI design) on artificially generated data resembling five municipalities in Hedmark County, Norway. Five different land cover classes cut across the five administrative divisions, with the small areas of interest being defined as the 25 regions of intersection. Four aggregation schemes of increasing complexity were tested: overall aggregation of total biomass change (A), aggregation at the municipality level (B), cover class (C) level, and by municipality and cover class simultaneously (D). Stochastic optimization was used in each case. The benchmarked estimators were compared to the MB and DB estimators and assessed with respect to bias, RMSE and how well the aggregation requirement was achieved.

The main findings were:

1. The benchmarked estimators RMSEs were in general larger than the MB RMSEs but always smaller than the DB RMSEs,
2. The biases of the benchmarked estimators were smaller than the biases of the MB estimator
3. Benchmarking (A) always satisfied the aggregation requirement. Benchmarking (B), (C), and (D) didn't always find the optimum solution but always substantially ameliorated the aggregation agreement.
4. (14:30) Biomass mapping of deciduous forest over mountains areas using the penetration depth extracted by the fusion of spaceborne stereo imagery of leaf-on and leaf-off | W Ni*, Z zhang, G sun

1. ObjectivesForest biomass mapping over large area is essential for the research on global climate changes and carbon cycles. Direct measurement of forest spatial structures is important for the estimation of forest biomass, which is the reason for the booming of LiDAR and PolInSAR in recent years. LiDAR could directly measure the three-dimensional distribution of tree components by recording the pose, position of laser sensor and the traveling time of laser between sensor and reflectors. PolInSAR makes use of the separation of scattering phase center of different polarizations. Besides LiDAR and PolInSAR, stereo imagery could also be used to measure the spatial distribution of terrain objects using the parallax information extracted from at least two images acquired from different looking angles. However, the direct measurement extracted from stereo imagery is dominated by ground elevations. The biggest challenge is how to separate the information of forest spatial structure with the elevation of ground surface. This study will report our recent works on the extraction of forest spatial structures through the fusion of spaceborne stereo imagery acquired at leaf-on and leaf-off seasons, and its contribution on the mapping of deciduous forest biomass.

2.Materials and methodsThe stereo imagery used is acquired by Chinese ZY-3 surveying satellite launched on January 9, 2012. The panchromatic sensor onboard is composed of three telescopes pointing at forward, backward and nadir angles. The inclination angles of forward and backward telescope are ±23.5° from nadir to realize a base-to-height ratio of 0.87. Three sets of point cloud are firstly derived from the stereo image pair of any two of the three view angles. The system errors between different DSMs, which are caused by satellite platform jitter, are removed. Then three point clouds are merged to form the final one with the highest point density. The two point clouds from stereo images of leaf-on and leaf-off were analyzed against the LiDAR point cloud. The forest biomass was mapped and evaluated using that from LiDAR point cloud.

3. Summary Result showed that the point cloud of leaf-on mainly located on forest canopy top while that of leaf-off is dominated by the points on ground surface. The difference between them could remove the terrain elevation while keep the forest spatial structures. The extracted forest spatial structures have good performance on the estimation of forest biomass.

5.(14:50) OBI-WAN: Online Biomass Inference using Waveforms And iNventory | *S Healey*, P Patterson, S Saarela, Z Yang, N Gorelick, J Armston, L Duncanson, J Kellner, S Hancock, W Cohen, R Dubayah*

NASA's GEDI (Global Ecosystem Dynamics Investigation) mission will mount an innovative lidar instrument on the International Space Station, providing unprecedented detail about the structure of Earth's forests. The number, quality, and international consistency of GEDI's tree height measurements represent a matchless global tool for describing how much carbon our forests store and how that storage is affected by ecological change. GEDI will produce a 1 km grid of mean biomass estimates, with accompanying standard errors. While there are important science applications for this grid, many scientists, landowners, and government agencies would benefit from easy access to GEDI-based biomass estimates over more flexible spatial domains.

An online tool called OBI-WAN is being developed to meet this need. OBI-WAN will access GEDI's database of waveform data and waveform-to-biomass models to provide carbon reports tailored to forest managers'areas of interest. GEDI's high-quality, but discontinuous, lidar data will be supplemented by wall-to-wall reflectance and disturbance history information from the Landsat platform. GEDI-to-Landsat models will be automatically calibrated locally for the area of interest, and a generalized version of Hierarchical Model-Based (HMB) estimation within model-based inference will be used to generate estimates of both mean biomass and uncertainty. It is expected that this fusion of GEDI and Landsat data will improve local estimate precision, and will enable production of high-quality, Landsat-resolution biomass maps for the area of interest as an ancillary benefit. By pairing an easy-to-use interface with statistically sound inference, OBI-WAN is intended to maximize the value of GEDI's unique dataset in forest carbon accounting applications.

5C

NEAR REAL TIME MONITORING

Moderator: Peder Nelson

1.(13:30) Historical and Near-Real Time Forest Disturbance Detection Based on Full-Archive Data | *F Thonfeld**

Time series of satellite data are a valuable source to detect forest disturbance pattern in time and space. Several approaches exist to explore satellite time series: The generation of annual or multi-annual artifact-free composites, temporal segmentation, and breakpoint detection are common techniques to characterize forest dynamics. Currently, only very few methods exist that generate time series of all artifact-free observations rather than reducing them to a series of optimal dates. Recent approaches also make use of compositing approaches or multitemporal metrics. Here, we use time series of all available Landsat observations to explore earth observation data for forest disturbance monitoring over a test site on Vancouver Island, British Columbia, Canada. We calculated the disturbance index (DI) for each image and applied a break detection method to identify clear-cut events in time and space. For each pixel, we apply support vector machine (SVM) regression to estimate the DI value for any given date. By subtracting the DI value of real observations (e.g. cloud-free images) from the predicted values, we are able to detect recent changes, i.e. new clear-cuts. Our results demonstrate applicability of DI to reveal forest dynamics at very high temporal resolution. The method results in maps of clear-cut timing at virtually daily resolution and regrowth trends. Validation of historical changes showed high conformity with existing maps. The results of the detection of very recent changes are reasonable. The new approach allows using the full capacity of dense time series data allowing for better understanding of forest processes and phenology and near-real time change detection. The growing archive of Landsat-like and Sentinel data will widen the field of its application in future since the presented approach is not restricted to a specific data source.

2.(13:50) Monitoring land surface phenology in near-real-time: eMODIS, Forests, and NDVI | *C Schrader-Patton*, N Grulke*

Vegetation phenology is an amalgamation of a plant's response to environmental conditions and key transition points such as the start of spring have received considerable attention from the research community in recent years. The driver here is the use of these phenological metrics to assess the effects of a changing climate, which are not uniform across time and space. Land surface phenology (LSP - phenology at the level of a remotely sensed pixel) studies have gained importance as tools to estimate these metrics across landscapes, especially as the record of remotely sensed data grows. Field Validation of these LSP studies remains elusive as it requires pixel-level field measurements at regular intervals for a long period. Here we describe our efforts to validate eMODIS NDVI weekly composites using the PhenoCam network of in-situ digital cameras (https://phenocam.sr.unh.edu/). The PhenoCam network is maintained by the University of New Hampshire and has grown to over 500 sites globally since its inception in 2007. The eMODIS 7-day NDVI composites are a key product in PhenoMap, our near-real-time (weekly) phenology monitoring web map designed to aid managers in decision making. We correlated eMODIS NDVI with the green chromatic coordinate derived from PhenoCam images on

25 forested sites across CONUS. Results indicate a strong relationship on deciduous broadleaf and mixed forest sites, but a poor one for needleleaf sites. This is not surprising considering that phenological development (shoot elongation, bud burst) in evergreen needleleaf trees is a relatively small component of the overall biomass present at spring onset. When using PhenoCam data for validation of remote sensing products, issues such as field of view and pixel extent must be considered on site-by-site basis. As the period of record for some forest sites extends beyond ten years and newer cameras are equipped with IR band capability, forest remote sensing scientists should consider PhenoCam as a dataset to augment and validate their modeling efforts.

3.(14:10) Rapid Assessment of Forest Storm Damages with PlanetScope and Sentinel-2 Images in North-East Germany | *M Foerster*, A Clasen, K Juette*

Forestry has been suffering increasing economic damage from windthrows since the 1990s. This events are due to more frequent storms with high wind speeds. As similar extreme weather conditions are to be expected increasingly against the background of climate change, the forest administration needs timely information on the quantity and location of wind damage.

The autumn storms Xavier and Herwart, which hit the north-east of Germany on 5 October 2017 and on 29 October 2017, caused considerable damage to the forests in this region. In the ground softened by prolonged rainfall, large-crowned trees were unable to withstand the storm, especially as most deciduous trees were still densely foliated. In this study we analyzed the potential of two recent satellite missions (Sentinel-2 & PlanetScope) to implement a rapid assessment of the impact of the two storm events.

For the study area (approx. 8000 km2) nearly cloud free images shortly before the storm, after the first event, and after the second event were processed. For Sentinel-2 (10/20 m at 13 spectral bands) we acquired two L2A images on 7 September and 6 November. For PlanetScope (3.7 m at RGB and NIR) we acquired two L2A images on 18 September, 8 October, and 30 October. Moreover, 800 field survey reference areas are available. Additionally to the input spectral bands a number of vegetation indices and difference indices between the dates were used as predictor variables.

For the classification and feature selection of the windthrow events we used the Random Forest (RF) classifier and utilized the reference data-set (70 % cal. / 30 % val.) for windthrow and non-windthrow areas. The results can be used to detect true and false positive and negatives as well as to evaluate to most contributing layers within the two sensors.

Mainly because of the higher spatial resolution and the higher temporal resolution, the PlanetScope classifications resulted in much higher detection of true positives. Moreover, the before event image was more closer to the date of the event, which resulted in a more comparable spectral response between the images. Additionally, the higher spatial resolution of PlanetScope made it possible to detect smaller spots of windthrow. However, it has to be highlighted that Sentinel images are free data with a high radiometric standard, while PlanetScope data for operational applications would be a matter of financial resources.

4.(14:30) Early warning system for the detection of changes in the native vegetation of Chile. | *M Castro*, P Acevedo, V Sandoval, Y Martinez*

Changes brought on by man in forested areas (deforestation, reforestation) and forest condition (forest degradation) are of great interest in the processes of national and international politics. The magnitude and the spatial distribution of these activities vary within a country and are difficult to monitor, particularly in large areas. Remote sensing, thanks to synoptic vision, is a great source of information that can be used to identify these activities over extensive surfaces and in shorter time intervals.

In Chile, the principal use of native forests as private property is firewood and other types of wood. The monitoring and identification of such unplanned or illegal interventions are currently a high priority for the National Forest Corporation of Chile (CONAF). Currently the loss of native forests caused by illegal logging is high, and is only detected and quantified every 4 years upon updating national land use.

The objective of this study was to establish a system for the early detection of vegetational loss, and the evaluation of forest management plans. More specifically, a user-friendly monitoring process that would produce enough reliable information about the changes in national forests, with a high periodicity and localization of illegal logging in a reduced time period.

For the development of the early detection system LandSat-8 data and DEM de Aster were used. Different vegetation indexes (VI) were evaluated such as NDVI, NDII, and EVI, and subsequently the ΔVI was created. Together with the aforementioned, shadow masks were created for relief, cloud shadow, cloud, and snow. The evaluation of the percentage of extraction was realized in the field. A methodology of analysis of change called mobile year was implemented in order to determine the period in which the illegal logging occurred with greater accuracy, as well as create a solution for the low periodicity of the detection of illegal logging due to the high cloudiness in southern Chile. Four levels of extraction were determined: 0-25%, 26-50%, 51-75%, and 76-100%.

The evaluation of the percentage of extraction was performed in the field, obtaining a success of 80%, 77%, 98% and 100% for the four aforementioned levels. Currently the methodology is applied using LandSat-8 and Sentinel 2 data.

5.(14:50) Near-real time forest disturbances detection in the Amazonian wet forest using Sentinel-1 images | *S Mermoz*, M Ballère, A Bouvet, T Koleck, C Lardeux, T Le Toan*

Satellite based monitoring systems are the primary tools for providing information on newly deforested areas in vast and inaccessible tropical forests. Hansen et al. (2016) demonstrated the potential for and constraints of operational Landsat based tropical deforestation alerts for the humid tropics. The major limitation of Landsat based deforestation alerts is the limited availability of cloud-free observations. Incorporating Sentinel-2 data would increase data richness and improve detection of change within local rainy seasons. Synthetic Aperture Radar (SAR) is another option.

In fact, SAR is one of the most promising remote sensing tools for the near-real time mapping of forest disturbances in the tropics, in all weather conditions at any time of day or night. Nevertheless, the use of SAR data in forest disturbances mapping has not been well developed so far compared to optical data, and thus its operational application has not yet been realized (Reiche et al., 2015). A new era started since 2014 with the launch of the Sentinel satellites developed by the European Space Agency, providing a large and unprecedented amount of free data for the operational needs of the Copernicus program. With such temporal series of SAR data, new methods for forest disturbances monitoring are being developed.

In this study, we apply the method developed by Bouvet et al. (2018, submitted to Remote Sensing; see also the abstract from Bouvet et al.submitted to ForestSat 2018) based on Sentinel-1 data time series to mapping forest disturbances from beginning of 2017 over the whole Amazonian wet forest. The method is based on a new indicator of deforestation that relies on a geometric artifact that appears when forest logging happens, in the form of a shadowing effect at the border of the deforested patch. Sentinel-1 images are processed using the CNES Orfeo ToolBox (OTB), an open-source project for state-of-the-art remote sensing running on the cluster of CESBIO. Results are validated using very high resolution optical images, reference plots from field trips in Brasil and French Guyana, and using Sentinel-2 images acquired over Brasil, French Guyana, Peru, Suriname, and Bolivia, processed at level 2A by the Theia land data services centre (http://www.theia-land.fr). The first maps and quantitative results will be presented, and the complementarity between our SAR-based product and the optical-based forest alerts from Hansen et al. (2016) discussed.

5D

ADVANCES IN SATELLITE FIRE MONITORING AND CHARACTERIZATION 2

Moderator: Louis Giglio, Chris Justice, David Roy & Krishna

Vadrevu

1.(13:30) Combined Landsat-8 and Sentinel-2 burned area mapping | *D Roy*, H Huang, H Zhang, L Yan, Z Li*

There is a long established recognition that Landsat data capture small and spatially fragmented burned areas that are not seen in coarser spatial resolution satellite data. The free-availability of global coverage Landsat-8 and Sentinel-2 data marks the beginning of a new near-daily medium resolution global observation era. This paper presents recent NASA funded research to develop a combined Landsat-8 Sentinel-2 burned area mapping algorithm. The algorithm is automated and applied on a multi-temporal per-pixel basis with a heritage from the MODIS burned area algorithms. Seamless integration of the different sensor data is achieved through a random forest change regression, parameterized with synthetic training data, that models reflective wavelength change considering the different sensor spectral response functions. Temporal consistency checks are used to reduce commission errors. The data handling is based on the global Web Enabled Landsat Data (WELD) code and integrating our recent research on Landsat-8 and Sentinel-2 pre-processing to generate registered, surface nadir BRDF-adjusted reflectance (NBAR) sensor time series that are used as an input to the algorithm. Burned areas results for Africa are shown and the results compared with contemporaneous MODIS burned area and active fire detection products to gain insights into their spatial and temporal reporting differences.

2.(13:50) Forest Fire Disaster Assessment using ALOS 2 and Terrestrial Laser Scanner | A *Kato*, H Wakabayashi, A Osawa, M Watanabe, L Moskal, A Hudak*

A large size of forest change has been caused by forest fire. Detecting and monitoring forest fire becomes an important issue in increasing forest fire due to the recent dramatic climate change and the carbon loss from the fire under the frame of REDD plus. The forest biomass loss is more directly related with structural change rather than spectral change. Satellite based radar and Terrestrial Laser Scanner (TLS) are more fitted to this aim to detect the structural change. The purpose of this study is to develop a method to detect the structural change from forest disaster. The wide coverage of forest fire is achieved by ALOS 2 radar image and the satellite-based result is validated by the volume loss of TLS based 3D data before and after the fire. Our study area is Wood Buffalo National Park, NWT, Canada, where frequent natural fire happens during summer. To validate and conduct wall-to-wall analysis, we set up 2 wide experimental plots in 50m x 50m at the fire site and the total 30 small circle plots with 10m radius in various condition of forest fire sites.

To identify structural change from radar image, coherence change has been used to detect the change between two different time of radar images. ALOS 2 radar has more solid orbit navigation system and the coherence value became stable. The wide coverage TLS scanner of RIEGL VZ 400 has been conducted to cover all trees within 50m x 50m plot. The voxel size was set to 0.25m to quantify the structural loss from forest fire. And 6.25m grids were determined by radar pixel size and generated over TLS scanning site to take the wall-to-wall comparison between the coherence value from ALOS 2 and the voxel volume loss from TLS 3D data before and after the fire. Voxel representation of 3D data has been used to remove duplicated points from different scanning sensor locations and quantify the voxel volume loss before and after the fire.

As a result, there is R2 value of 0.66 between radar coherence value and lost voxel of TLS. It means that coherence change from radar analysis has a good detection power to indicate the volume lost on the ground. In practice, this technique is very useful to assess the intensity of forest fire and the quantified fire intensity is good information for the insurance.

3.(14:10) L-band SAR sensitivity to prescribed burning effects in eucalypt forests of Western Australia | *A Fernandez-Carrillo*, L McCaw, MA Tanase*

Prescribed burning is a technique applied to control fire risk in fire-prone environments and it has been used in the forests of Western Australia since the 1960s. Synthetic Aperture Radar (SAR) data are sensitive to vegetation structural changes (such as those induced by prescribed burns) and may be sensitive to understory vegetation particularly when the upper forest canopy remains largely unaffected, as is often the case for prescribed burns.

In this study, the ability of the Radar Burn Ratio (RBR), a SAR index that measures the degree of change between pre- and post-event radar backscatter, to appraise fire efficiency in prescribed burns was assessed. Data acquired by the L-band PALSAR-2 sensor, onboard the ALOS-2 satellite, were analysed to study the relationship between radar backscatter coefficient and prescribed burns carried out in eucalypt forests in Western Australia. A previously proposed framework was adapted to evaluate burn impacts in different environmental conditions (dry, wet and mean) using HV and HH polarizations as well as the RFDI (Radar Forest Degradation Index).

A linear relationship between RBR and fire severity was found for HV polarization and RFDI confirming previous results observed for wildfires. RBRHV in dry environmental conditions yielded the most accurate estimates of fire impact (OA = 77.8 %; k = 0.67). RBRHH showed higher ability to differentiate between severity classes in wet conditions while the RBRRFDI showed an intermediate behavior being less susceptible to varying environmental conditions. HH polarization and RFDI showed special ability for burn area detection in wet conditions. The results showed that it is possible to estimate the impact of prescribed burns using SAR data. As such, SAR data could contribute to monitor and assess the effectiveness of fire policy in Western Australia and similar environments.

4.(14:30) Assessing economic damage of Wildland–Urban Interface (WUI) fires with economic model and high-resolution Planet Labs satellites constellation images | *Y Michael*, I Lensky, S Brenner, A Tchetchik, N Tessler, D Helman*

Wildland-urban interface (WUI), the area where wildland vegetation and urban buildings meet, is at a greater risk of fire to occur due to extended human activity. In recent years, there is an increase in reported cases of large WUI fires while this trend is likely to continue due to projected warming and ongoing urban expansion in many regions. Accurate information regarding the spatial distribution and level of damage (e.g. burnt severity) following WUI fires is therefore required to allocate economic resources and prioritizing proper treatment actions. Remote sensing has been a major tool in monitoring and assessing wildland fires. However, because of the trade-off between the spatial and temporal resolutions of satellites images, monitoring fires at the WUI becomes a challenging task. Here, we take advantage of the new Planet Doves satellites constellation to overcome the spatio-temporal drawback and assess WUI fire at the Mediterranean city of Haifa, Israel, which occurred at the end of 2016. First, time series of NDVI from Planet Doves where compared with MODIS (at the MODIS spatial resolution) to extract the proper images that corresponds mainly to the woody vegetation in the burnt area. We used for that purpose a discrimination method of subpixel separation to distinguish between woody and herbaceous vegetation in the WUI area. Then, burnt severity was determined using Planet-derived NDVI of the woody vegetation and information acquired through a field survey in the burnt area. High-resolution (3-m) maps of stand density and woody biomass prior to the WUI fire were generated together with a burn severity map to assess the level of damage at the WUI. Finally, and after validating the maps with ground truth data, we used these maps with a combination of an economical model to assess the economic damage of the WUI fire. As far as we know, this is a first attempt to assess economic damage of wildfires at the WUI. Using methods developed in this study with high spatial resolution and frequent images from Planet Doves has a great potential in future WUI fire economic assessment elsewhere.

5.(14:50) Remote sensing of live fuel moisture content in Mediterranean fire-prone shrubland: comparison of different satellite imagery and RTM simulations | *E Marino del Amo*, M Yebra, N Algeet, M Guillen-Climent, A Fernández, J Esteban, JL Tomé, C Hernando*

Live fuel moisture content is a major driver of wildfire behavior, and a key component in fire danger rating systems. Due to climate change, Mediterranean countries are suffering more frequent extreme weather conditions and an extension of fire season along the year. Therefore, public administrations in Spain are investing important amounts of resources to monitor vegetation moisture content. Fire managers need up-to-date and reliable information on moisture content of the main fuel types for wildfire prevention and suppression planning. However field sampling is expensive and time-consuming, implying also a delay time until moisture data are available. Previous research highlights the ability of remote sensing imagery for fire risk analysis at different spatial and temporal resolutions. However, accurate live fuel moisture content estimation is still a challenge for operational integration on pre-alert systems. The aim of the present research was to assess the potential for live fuel moisture content estimation from satellite images in Cistus ladanifer shrubland, a fire-prone species commonly found in Mediterranean shrubland areas which is used by fire management services as an indicator species for wildfire risk assessment. We assess the performance of satellite images with different spatial, spectral and temporal resolutions, and simulations from a radiative transfer model (RTM) to drive fuel moisture estimates. Spectral information was derived from MODIS and Sentinel-2 products. Regression analysis was used to obtain empirical models for live fuel moisture content prediction based on vegetation indices. MODIS images were also used to simulate vegetation moisture from a RTM model calibrated with C.ladanifer field data. Observed moisture values are compared with predicted values derived from empirical models and RTM simulations. Our findings showed that reflectance data from both MODIS and Sentinel-2 images provide valuable information for live fuel moisture content estimation in C.ladanifer shrubland. RTM simulations were also useful to retrieve temporal variability of C.ladanifer moisture. This study could help in the development of tools for the improvement of near real-time live fuel moisture content estimation based on remote sensing data.

6A

FOREST BIODIVERSITY MONITORING AND ASSESSMENT FROM REMOTE SENSING 2

Moderator: Gherardo Chirici & Ronald McRoberts

1.(15:30) Essential Biodiversity Variables obtained from airborne and spaceborne LIDAR | *R Valbuena*, B O'Connor, F Zellweger, F Morsdorf, P Vihervaara, W Simonson, M Maltamo, F Danks, G Chirici, N Coops, D Coomes*

Harmonisation of observations for biodiversity assessment necessitate a set of Essential Biodiversity Variables (EBVs) that aims to capture the multidimensionality of biodiversity. Regular monitoring of these EBVs can help identifying where conservation efforts are needed and evaluate their efficacy. The Group on Earth Observations within the Biodiversity Observation Network (GEO BON) has been refining this list of EBVs according to those that can be reliably observed using remote sensing. Light detection and ranging (LIDAR), an active form of remote sensing, provides accurate measurements of vegetation structure at very high spatial resolution. In this contribution we review the potential and limitations of LIDAR for monitoring EBVs in terms of feasibility, global validity and sensitivity to change. We identify two pathways through which LIDAR technology can inform EBVs: (i) derivation of morphological traits of species, communities and ecosystems, directly from LIDAR and (ii) prediction of variables using LIDAR plus ancillary data for calibration. Over the past decade there has been convergence on which morphological traits can be directly evaluated from LIDAR, including: (1) vegetation height, (2) vegetation density, and (3) vertical vegetation structure, all of which can be derived from both airborne and spaceborne sensors. Spatio-temporal changes in these morphological traits can be linked to local changes in species community composition (i.e alpha diversity), as well as changes between communities or ecosystems (i.e. beta diversity). Airborne LIDAR (a.k.a. ALS) provides spatially continuous coverages of these traits, giving opportunities to derive landscape scale assessments of habitat extent, horizontal structure, connectivity and fragmentation. Spaceborne LIDAR will provide the added advantage of consistent global assessments. But gaps in spatial coverage between laser pulses from space means that deriving continuous maps will require sampling-based approaches, coupling satellite LIDAR with other remote sensing sources, among which ALS will play an important role. We challenge the widespread notion that ALS is unfeasible at continental scales due to high cost, given the availability of public whole-country surveys, useful both for monitoring EBVs and as a key source of ground-truth for calibrating spaceborne data. Additionally, coupling LIDAR with ancillary data can provide EBV estimates with higher accuracy than other feasible alternatives.

2.(15:50) Estimation of spatial indices for forest biodiversity from remote sensing | *H Häbel*, A Balázs, M Myllymäki*

Introduction and aims: Forest biodiversity can be divided into three major aspects, namely spatial distribution, species diversity, and variation in attributes. Biodiversity has been assessed by considering indices independent or dependent on distances between neighboring trees at stand-level. Examples are Pielou's segregation index and the species mingling index. With recent developments in remote sensing technologies, it becomes intriguing to study to what extent biodiversity indices can be estimated from remote sensing data. Here, we focus on distance-dependent characteristics for the spatial biodiversity. Our main aim is to classify forests into aggregated, random, or regular patterns of tree locations based on airborne laser scanning (ALS) data. A further aim is to even draw conclusions on species and size biodiversity.

Materials and methods: We present how summary characteristics from spatial statistics can be useful for a spatial analysis in two ways. First, we suggest new spatial indices of which some can also take tree attributes such as size and species into account. Second, we present how these indices can be estimated from ALS data. For this purpose, we extract open areas and patches of vegetation at a number of height layers using a canopy height model applied to the ALS data. This is not a completely new idea; however, we introduce a novel way of how to integrate the information from thresholded canopy height models into an ALS-assisted spatial analysis. In particular, we summarize the spatial structure of trees using the so-called L- and empty space function from spatial statistics and we predict these spatial summaries employing, in addition to commonly used remote sensing features, the proposed new spatial features in the well-known k-nn estimation method. We use the statistical software R for all computations and present the methodology on the example of Finnish forests. Belonging to the southern and middle boreal vegetation zone, the forests are mainly coniferous.

Summary of key findings: We found that the new spatial features can be used to predict the spatial structure of trees from ALS data. It also appears that the new features can be useful in estimating other forest characteristics such as diameter distribution and other biodiversity indices. Furthermore, our proposed spatial field indices were estimated more robustly with respect to different forest structures than other commonly used indices.

3.(16:10) Tree species classification using plant functional traits from LiDAR and hyperspectral data | *Y Shi*, A K. Skidmore, T Wang, S Holzwarth, U Heiden, X Zhu, M Heurich*

Plant functional traits have been extensively used to describe, rank and discriminate species according to their variability between species in classical plant taxonomy. However, the utility of plant functional traits for tree species classification from remote sensing data in natural forests has not been clearly established. In this study, we integrated three selected plant functional traits (i.e. equivalent water thickness (Cw), leaf mass per area (Cm) and leaf chlorophyll (Cab)) retrieved from hyperspectral data with hyperspectral derived spectral features and airborne LiDAR derived metrics for mapping five tree species in a natural forest in Germany. Our results showed that when plant functional traits were combined with spectral features and LiDAR metrics, an overall accuracy of 83.7% was obtained, which was statistically significantly higher than using LiDAR (65.1%) or hyperspectral (69.3%) data alone. The results of our study demonstrate that plant functional traits retrieved from hyperspectral data using radiative transfer models can be used in conjunction with hyperspectral features and LiDAR metrics to further improve individual tree species classification in a mixed temperate forest.

4.(16:30) Incorporating simulated GEDI Lidar into bird species distribution predictions for Sonoma County, CA, USA | *P Burns*, S Goetz, P Jantz, M Clark, L Salas, S Hancock*

The Global Ecosystem Dynamics Investigation (GEDI) Lidar instrument is scheduled for launch and installation on the International Space Station in November 2018. This full waveform instrument is expected to receive approximately 11 billion returns between 52S and 52N over the course of its mission. With a vertical resolution of approximately 15cm, GEDI Lidar is capable of accurately profiling forest canopy structure within its 25m footprint diameter. Previously field observations and airborne lidar data have been used to examine the relationship between forest canopy structure and faunal biodiversity, most commonly bird species. GEDI's latitudinal coverage will permit these types of demonstrative analyses over the vast majority of the Earth's forests. To examine the potential of GEDI for increasing our understanding of forest structure and habitat prior to launch we focus on Sonoma County, CA, an area with high quality airborne lidar and a multitude of bird species observations. We simulate GEDI observations in Sonoma County for a range of mission lifetime scenarios (1, 2, 3 years corresponding to water years 2014-2016) and then aggregate the footprints to estimate expected return density within various grid sizes (250m, 500m, and 1000m). For the species distribution modeling we will rely on GEDI level 3 products in which bayesian kriging is used to aggregate GEDI metrics to the grid sizes listed above. We incorporate the following GEDI metrics when predicting the presence of 20 forest bird species: ground height, canopy cover, relative height (RH) 2, RH25, RH50, RH75, RH98, foliage height diversity, and biomass. We also incorporate optical satellite predictors such as MODIS median and maximum NDVI, NDVI difference between the dry and wet season, and dynamic habitat indices derived from NDVI and EVI. The last set of predictors come from the USGS Basin Characterization Model for the state of California: minimum Temperature, maximum Temperature, mean Temperature, precipitation, climate water deficit, and actual evapotranspiration. We combine four models (Random Forests, Boosted Decision Trees, Boosted Regression Trees, and Support Vector Machine) into an ensemble framework, weighted by RMSE, to predict the probability that a particular species will be present within a given grid cell. Variable importance is used to assess the relative impact of GEDI metrics compared to optical satellite and climate predictors.

5.(16:50) Forest biodiversity estimated from remote sensing data through the new Rao's Q heterogeneity index: testing the Spectral Variation Hypothesis with a NDVI time-series derived from Landsat 8 and Sentinel 2, and the Height Variation Hypothesis with LiDAR data. | *M Torresani*, D Rocchini, R Sonnenschein, M Zebisch, G Tonon*

Forest is the most biodiverse ecosystem, covering 30% of earth surface, providing a wide range of ecosystem services underpinned by its biodiversity and important to human well-being. The assessment of biodiversity is therefore an important and essential goal to achieve, that however, if estimated through field data, results difficult, time consuming and expensive. Remote sensing is one of the more objective and most cost-effective approaches to better verify biodiversity, covering broad surfaces with high quality and standardized data.

One of the methods used to estimate biodiversity from remote sensing data is based on the Spectral Variation Hypothesis (SVH); the assumption of this approach is that the higher the spectral variation of an image, the higher the environmental heterogeneity and the species diversity of the considered area. SVH has been teste using different indexes and measures; recently in literature, the Rao's Q index, applied to remote sensing data has been theoretically proposed as a new and innovative spectral variation measure.

In this research the SVH through the Rao's Q index has been tested and compared with

other two well-known heterogeneity indexes, the Coefficient of Variation (CV) and the Shannon's H using a NDVI time-series (for both the years 2016 and 2017) derived from the Sentinel 2 (with a spatial resolution of 10m) and Landsat 8 satellites (spatial resolution of 30m). The data of Spectral Variation have been compared with data of species diversity (through the Shannon's H) collected in 20 plots in a coniferous forest.

For both the sensors and years, the Rao's Q performed better than the other two considered indexes, showing that the correlation with the field data had the same tendency as the NDVI trend, reaching the highest R2 value in June (R2=0.70 for the year 2017), when the NDVI was at its peak.

The Rao's Q has been also used to test the concept of Height Variation Hypothesis (HVH) stating that, the higher is the variation of the height of the trees (Canopy Height derived from LiDAR), the higher is the species diversity of that area.

The HVH showed excellent results: the correlation with field data reached values of R2=0.74 with Canopy Height with spatial resolution (SR) of 2.5m, showing a decrease of correlation with the decrease of the resolution (SR 5m R2=0.73; SR 10m R2=0.62; SR 20m R2= 0.15) underling that also the HVH is scale dependent

6B

FOREST STRUCTURE AND BIOMASS

Moderator: Lars Waser

1.(15:30) A multi-scale remote sensing approach to derive a London-wide estimate of AGB | *P Wilkes*, M Disney, M Boni Vicari, K Calders, A Burt, O Baines*

Global populations are becoming increasingly urbanised resulting in unprecedented urban expansion. Green infrastructure plays a vital role in improving the lives of these new urbanites, for example, improving air quality, reducing heat stress as well as other health and well-being benefits. Urban vegetation also plays an (increasingly) important role in reducing the carbon burden of Earth's expanding population, yet until recently, this has been mostly overlooked in carbon accounting terms. Reasons for this could include the difficulty in measuring urban tree demographics owing to high species diversity, atypical crown shapes and, from a remote sensing perspective, highly heterogeneous and dynamic land cover. In an attempt to overcome these challenges we present a new multi-scale remote sensing approach to quantify above ground biomass (AGB) sequestered in the street trees and parklands of Greater London (1,569 km2). Terrestrial laser scanning (TLS) was used to estimate the volume and AGB of 385 trees across the London Borough of Camden. Using these tree models, new allometry was derived to estimate stem volume from projected crown area and canopy height (r2 = 0.94). This was subsequently applied to tree crowns extracted from the UK Environment Agencies open-access airborne LiDAR dataset (covering ~15% of the Greater London area). Tree density and AGB estimates were then scaled to the whole Greater London area by training a random forest model with Sentinel 1 and 2 bands as predictor variables; computation was done using Google Earth Engine. Early results indicate that there are ~9M trees in the Greater London area and that small pockets of urban forest have a carbon density similar to temperate and tropical forests.

2.(15:50) The relationship between simulated and remotely sensed forest parameters | *B Osmanoglu, AH Armstrong*, G Sun, P Montesano, KJ Ranson*

Howland research forest covers an area of 550 acres and has been studied extensively over the past two decades. The forest is also home to old-growth spruce and hemlock providing habitat for many species. In this project we parameterized a spatially explicit version of SIBBORK individual-based gap model for the old-growth section of the Howland forest. SIBBORK simulations were conducted over a 300x300m domain with sub-plot sizes of 10x10m within which each tree was positioned to a specific location. The parameterization was calibrated using field data for the study site and results show that the simulated forest reproduces the structural complexity of Howland old growth forest, based on comparisons of key variables including, aboveground biomass, forest height and basal area. The model was initialized using a stem map data from 1989. Afterwards the model was advanced 26 years and results were compared to the 2015 stem map.

We will present the relationship between the simulated forest parameters (e.g. tree height) and their comparison to available remote sensing data (e.g. lidar and stereogrammetry-based tree heights). Data from G-LiHT, a portable airborne imaging system that combines hi-resolution imagery, lidar, imaging spectroscopy and thermal mapping, will be used; as well as imagery from commercially available high-resolution satellite imagery. Furthermore, we will provide an outlook to the observational capabilities that will be available in the near future, like the two LiDAR (NASA's GEDI and ICESAT 2) and two SAR (NASA's ISRO NiSAR and ESA's Biomass) systems to be launch within the next 4 years.

3.(16:10) Estimation of coniferous forest parameters by combining observations from optical and radar spaceborne sensors | *D Morin*, M Planells, D Guyon, S Mermoz, A Bouvet, L Villard, T Le Toan, G Dedieu*

Forests provide several ecosystem services such as carbon storage, climate regulation, biodiversity and wood production. The use of wood fuel as a source of renewable energy constitutes an important part of the objectives for 2020-2030 in European energy and environmental policies.

The current trend to meet growing need for spatialized forest inventories is to use spaceborne remote sensing data: The Sentinel-1&2 images every 6 days, the SPOT6/7 images, together with the ALOS L-band SAR mosaic constitute a great asset to monitor forests over large territories. For forest monitoring, most studies consist in evaluating separately this data. The aim of our study is to evaluate the synergy between these different data sources and the improvement when combining their measurements for estimating major forest variables generally used in forest monitoring. The perspective is to develop a generic semi-automatic method to be applied over large areas.

For coniferous forests, our test site is located in south France within the Landes de Gascogne forest. This forest is the largest European pine forest and is characterized by a flat topography and even-aged stands. The remote sensing data consists of multi-temporal Sentinel-1 data, one mosaic ALOS PalSAR data, 2 dates of Sentinel-2 and 1 date of SPOT in 2016. Ground data were collected over 84 stands of maritime pine (Pinus Pinaster Ait.) from 3 to 72 years old. Several dendrometric parameters were measured: tree number density, DBH, and heights. AGB was estimated using allometric equations.

Radar data as well as several spectral and textural indexes from optical data were used. Several algorithms were tested: best estimates were obtained using Support Vector Regression. Random Forest was also tested but needs larger dataset to be really efficient and Multi-linear Regression provided the worst estimations. The regression can work with all the input features, however, we built an automated selection method to reduce their number and improve results.

The best relative RMSEs obtained on AGB, DBH, density and height were respectively 25%, 19.6%, 24.6% and 13.8%. The results indicate that multi-temporal Sentinel-1 is the best data source to estimate the forest variables on even-aged stands. Furthermore, combining spectral and textural optical indexes with Sentinel-1 and ALOS data improves the accuracy by 5-10% compared to SAR data only. A processing chain is developed and is currently tested in other forests in France.

4.(16:30) Photogrammetrically Derived Forest Canopy Data to Assess and Monitor Forests Across States | *VR Kane*, T O'Mara, J Kane, J Strunk, P Gould, C Maki, D Churchill, LM Moskal*

Objectives: A new option is emerging for measuring and monitoring forests structure for the contiguous United States. The vendors that collect nation-wide imagery to support the National Agriculture Imagery Program (NAIP) acquire 40 cm resolution stereo images through the Hexagon Imagery Program (HxIP). These images can be used to generate photogrammetrically-derived digital surface models (DSM) and top of surface point data (hereafter referred to as PhoDAR) using photogrammetric autocorrelation/pixel-matching techniques (structure from motion). Because these image sets are collected every two to three years over entire states, they provide an unprecedented option to inexpensively measure forests at high resolution across large areas and through time. While the use of autocorrelation techniques to create canopy surface models from aerial imagery is becoming more common, the Hexagon image-derived surface models have unique characteristics. The sensor arrays are pushbroom with a single stereo coverage coming from a nadir and rear-viewing imaging array. In this study, we compare these PhoDAR measures of forests both to field measurements and to airborne lidar measurements.

Materials and methods: We used field plot data, airborne lidar data, and PhoDAR data created from HxIP imagery over the Colville National forest in north central Washington state, USA. This study compared the ability of the field, lidar, and PhoDAR data to distinguish forest structural complexity across a diverse landscape of forest types, management histories, and fire histories. We also compared the accuracy of models derived from the lidar and PhoDAR data to estimate common forest inventory metrics such as basal area and volume derived from the field data.

Key findings: Compared to lidar-derived canopy surface models, the PhoDAR DSMs have substantially less detail with the profiles of individual trees and smaller gaps often obscured. Over the area of several trees, however, statistical descriptors of the PhoDAR and lidar data were correlated. We were able to detect areas of change using the PhoDAR data when either stand-alone large trees or clumps of trees were removed by harvest or fire. Regressions for model inventory metrics using the PhoDAR surface models generally explained about 10% less variation than when the airborne lidar data was used.

5.(16:50) Improving the performance of an area-based approach derived from DAP point clouds | *P Tompalski*, J White, N Coops, M Wulder*

Recent developments in digital aerial photogrammetry (DAP) demonstrates the use of these data as an alternative data source to airborne laser scanning (ALS) for characterizing forest structure. The similarities between DAP and ALS enable the use of DAP-based metrics as predictors to develop stand attribute models using the area-based approach (ABA). Although image matching algorithms allow for the creation of point clouds and true-orthophotos, in most cases only the point cloud-based metrics are incorporated in an ABA. In addition, because the DAP point clouds characterize only the top of the canopy, an auxiliary source of terrain elevation is required to normalize DAP point elevations to canopy heights.

Focusing on highly productive coastal temperate rainforest in British Columbia, we characterize the improvement gained using spectral-based metrics on the accuracy of five predicted forest stand attributes: Lorey's height (HL), quadratic mean diameter (QMD), basal area per ha (BA), total volume per ha (V), and stem density (N). The predictive models were based on different sets of metrics derived using combinations of point cloud- and spectral-based data. Point clouds were normalized using ALS-based terrain model. Three different sets of metrics were used: those derived using DAP point cloud data only, DAP spectral data only, and a combination of DAP point cloud and spectral data. Spectral-based predictors consisted of a number of spectral indices and metrics characterizing image texture.

Results showed that the highest prediction accuracy was achieved for models based on the integrated point cloud and spectral metrics, although the accuracy of models that did not incorporate spectral information was only slightly lower (e.g. R2 for V was 0.71 and 0.70, respectively). Models that only utilized DAP spectral metrics had the lowest R2 and highest RMSE value. We conclude that the most important and informative metrics were those derived from the DAP point clouds, and that the spectral metrics resulted in only small improvements in estimation accuracy. This improvement was consistent for all modelled stand attributes except stem density.

6C

DROUGHT & TREE MORTALITY

Moderator: John Armston

1.(15:30) Assessment of Forest Response and Sensitivity to the Millennium Drought in Australia | *T Jiao, C Williams**

During the period from 1997 to 2009, Australia experienced one of the most severe and persistent drought known as the Millennium Drought (MD). Large-area tree dieback and decline were observed across the Australian continent during and post this drought event. Given the projection of hotter and drier conditions for much of the continent, it is critical to analyze the impacts of climate extremes like MD as an indicator of possible impacts of future trends. This paper aimed to provide a comprehensive and quantitative assessment of the impacts of MD on forest ecosystems in Australia. Multi-source remote sensing datasets and an event-based drought assessment method were employed to quantify the magnitude and sensitivity of forests response to drought. Key vegetation properties including leaf area, canopy cover and density, upper canopy water content and structure, and aboveground carbon stock were respectively examined using AVHRR fraction of photosynthetically absorbed radiation (Fpar), MODIS photosynthetic vegetation cover (PVC), vegetation optical depth (VOD) derived from passive microwave data, QuikSCAT backscatter, and VOD-translated aboveground biomass carbon (ABC). Drought indicators were calculated based on precipitation and potential evapotranspiration. Results show that forest ecosystems in the north and east of New South Wales experienced the largest drought impacts in spite of moderate drought exposure during the MD period. ABC declines were greatest in the most humid settings, while canopy responses declined most in semi-arid or semi-humid regions. Among all native forest ecosystems, eucalypt forests and woodlands demonstrate the highest drought sensitivity in aboveground biomass and upper canopy water content but lowest sensitivities in canopy density. High drought sensitivity of aboveground biomass carbon in eucalypt ecosystems indicates a sizable risk of carbon release to the atmosphere with future droughts.

2.(15:50) Quantifying Impacts of Drought and Disturbance on Forest Water Use in North Carolina, USA Using Long-Term Daily ET Estimated with Multi-Satellite Data Fusion Method | *Y Yang*, M Anderson, F Gao, C Hain, W Kustas, A Noormets, G Sun, R Wynne, V Thomas*

Forests in the United States are increasingly stressed due to disturbances associated with climate change and land use change. Disturbance includes harvest, thinning, wind throw, fire and insect damage. Drought can serve as a modulator of forest disturbances. For example, drought can make forest more susceptible to insect attack and wildfire, while prolonged drought can directly cause tree mortality. Hence, improved understanding of the impacts of disturbance and drought on forests at stand-scale is important for forest management. One important parameter used to monitor forest health and regional water use is evapotranspiration (ET), which can be estimated using surface energy balance models based on thermal infrared (TIR) imagery. The need for both high spatial and temporal resolution imagery limits the use of TIR remote sensing for monitoring applications. Landsat TIR data can provide high spatial resolution (~100 m) but having a long revisiting time (>16 days). Moderate Resolution Imaging Spectroradiometer (MODIS) TIR data can provide daily information but only at relatively coarse scale (1-km resolution). To get daily Landsat-scale ET data, Landsat and MODIS retrieved ET was estimated using ALEXI/DisALEXI and then fused using the Spatial and Temporal Adaptive Reflectance Fusion Model. In this study, we estimated daily 30 m ET from 2006 to 2012 over a forested landscape (~900km2) in North Carolina. The research site experienced a 100-yr drought event from the summer of 2007 to the end of 2008. The model results were evaluated at two pine plantations (2 and 15 years old, classified in Ameriflux database as US-NC1 and US-NC2, respectively). The simulated long-term ET shows good agreement with observed fluxes. Transpiration and a moisture stress metric defined as the actual-to-reference ET ratio (fRET) were also estimated in the model and used to investigate changes in water use patterns in response to land cover type, forest stand age, climatic forcing and disturbance. Analyses show differential response to extreme drought events from different land cover types, with young plantations and short vegetation showing larger impacts than mature pine plantations with presumably deeper rooting systems. Time series maps of fRET anomalies at 30 m resolution capture signals of drought, disturbance, and the subsequent recovery after clearcut at the stand-scale, and may be an effective indicator for water use change detection and monitoring in forested landscapes.

3.(16:10) Widespread tree mortality mapping suggests size-dependent risk for extreme drought stress | *A Stovall*, X Yang, H Shugart, A Khuu, J Smith*

Forest ecosystems are one of the single greatest global contributors to ecosystem services and wildlife habitat, but uncertainty about future climate brings these benefits under threat. Drought poses a serious risk to forested ecosystems by disrupting water availability, reducing photosynthetic rates and increasing leaf mortality. Overtime, tree death propagates through ecosystems as trees succumb to pests that take advantage of the weakened individual, resulting in widespread tree mortality. Large trees in forests provide the most benefits to humans and wildlife, but may be the most vulnerable. The U.S. Forest Service estimates that over 66 million trees have died off in California since the severe 2010 drought. The future of forests in this region is unclear, presenting the need for a more thorough understanding of which trees are experiencing high mortality and what might be the landscape-scale drivers of this trend. We investigated whether larger trees have higher mortality in the dry forested areas of the Sierra Nevada near the NEON site, Soaproot Saddle. We used LiDAR to detect single tree crowns and measured height of over 68,000 individuals. NAIP imagery provided the basis for crown-level mortality mapping, with a validated accuracy of over 80%. Over half of all measured trees in this study were dead and taller on average than the live population ($p < 0.001$). Dead trees clustered in valley bottoms and mountain slopes had a higher proportion of living trees. Our findings add robust landscape-scale evidence for the higher risk of large individuals in dry forest ecosystems and a method for future monitoring of size-dependent tree mortality for improved management.

4.(16:30) Multiple years of monthly ground-based profiling lidar data in the Amazon reveal seasonal and drought related changes in leaf area with surprising dependencies on height and light environment | *M Smith*, S Stark, T Taylor, T Woodcock, M Ferreira, E de Oliveira, L Alves, N Restrepo-Coupe, M Figueira, L Aragao, P de Camargo, R de Oliveira, D Falk, S McMahon, T Huxman, S Saleska*

Given the importance of tropical forests to the global climate system, understanding controls on their seasonal productivity now, and under projected drier climates, is a high priority. In evergreen tropical forests, total leaf area index (LAI) exhibits modest seasonal variation, while productivity tends to increase through the dry season, contrary to model predictions. One recent study identified strong seasonal dynamics of the vertical distribution of LAI, a potentially important factor influencing productivity. Tang & Dubayah (2017) analysed satellite lidar across Amazonia and found that seasonal changes in LAI of lower and upper canopy layers were strongly anti-correlated, potentially implicating the upper canopy as the primary control on the lower canopy via light limitation. However, large-footprint data cannot capture fine-scale variation in canopy structure that may be critical to understanding the mechanisms behind seasonal dynamics, especially in the lower canopy where light environments are most spatially variable.

To investigate the local dynamics of vertically distributed leaf area in response to seasonality and drought in unprecedented resolution, we conducted monthly ground-based lidar surveys over four years, including an El Niño-induced drought, at an evergreen tropical forest in Brazil. We analysed temporal changes in vertically structured LAI along axes of both canopy height and light environments, estimated by distance from the canopy surface.

Upper canopy LAI increased during the dry season, while lower canopy LAI decreased. Our light environment analysis revealed that much of the lower canopy comprises canopy surface leaves of smaller trees in gaps, not understory vegetation, at this structurally heterogeneous site. Hence, the reduction in lower canopy LAI was actually driven by loss of leaves from the canopy surface of small trees, not the understory. In contrast, understory LAI increased in the dry season, concurrent with the upper canopy. These trends were amplified during a severe drought. Thus, canopy surface leaves of smaller trees appear most sensitive to seasonal dry periods and drought, exhibiting behaviour more consistent with water- than light-limitation, and with acquisitive early- to mid-successional tree functional type physiologies. Together, these vertical and environmentally structured patterns place new emphasis on understanding the influence of canopy surface heterogeneity on ecosystem function in the Amazon.

5.(16:50) Combining airborne and spaceborne optical, and lidar datasets for tree mortality monitoring in the Polish part of Białowieża Forest | *K Stereńczak*, B Kraszewski, M Mielcarek, A Modzelewska, Ż Piasecka, M Białczak, R Sadkowski, A Kamińska, M Lisiewicz, R Wilkowska, S Miścicki, FE Fassnacht*

Forest disturbances are increasingly occurring in forested areas worldwide. Many disturbance events result in high tree mortality. Therefore, it can be expected that an increasing number of forest stands will have a notable portion of dead tree coverage in the future. This will have a notable influence on ecosystem services as well as forest management strategies. Up-to-date and repeated maps of the current spread of dead trees are hence important to trace the tree mortality and to better understand the disturbance processes which is necessary for efficient management decisions. This task can be achieved with remote sensing (RS) data but the multi-temporal integration of various RS data is a challenging topic, especially for areas of wide spatial extent.This study presents results related to the integration of various remote sensing and field data for tree mortality monitoring in the Polish part of the Białowieża Forest. We applied Airborne Laser Scanner (ALS) data, multispectral satellite and aerial images, as well as hyperspectral aerial data in combination with 685 field samples plots (500 m2). The main objective was to map tree mortality at single tree level on a regional scale and for multiple dates by integrating above-mentioned data.At the beginning, single tree detection was carried out using an ALS based Canopy Height Model (CHM). The resulting tree segments were classified to Spruce, Pine, and deciduous, dead or alive classes based on multitemporal ALS data and aerial images. Next, we mapped annual tree mortality dynamics across the whole BF for the time period between 2015 and 2017. Since species information was available, we were able to map relations between tree species and mortality dynamics. The paper will present the results of the workflow described above and discuss some of the challenges occurring when integrating multi temporal and multi platform remote sensing data.

6D

NEAR REAL-TIME FOREST MONITORING

Moderator: Johannes Reiche & Michele Martone

1.(15:30) The SAR shadowing effect: a new indicator of forest disturbances for near-real time deforestation monitoring with Sentinel-1 | *A Bouvet*, S Mermoz, M Ballère, T Koleck, T Le Toan*

Satellite imagery is the primary source for providing information on newly deforested areas. An optical time series approach has been developed by the UMD-GLAD laboratory to exploit Landsat data and provide forest alerts in near-real time (NRT): the UMD-GLAD Forest Alert dataset (Hansen et al. 2016). The major limitation of optical-based tropical deforestation alerts is the limited availability of cloud-free observations, which could be overcome by exploiting Synthetic Aperture Radar (SAR) imagery. However, the use of SAR data has not been well developed so far compared to optical data (Reiche et al. 2016). Reiche et al. (2018) developed methods combining optical and SAR sensors. However, these methods suffer from a crucial flaw: assuming that disturbances are necessarily characterized by a decrease in backscatter within the disturbed area, which is not always the case, depending on the post-disturbance management practices and environmental conditions.

In this study, we introduce a new indicator of deforestation obtained from SAR images, which relies on a geometric artifact that appears when forest logging happens, in the form of a shadowing effect at the border of the deforested patch. Thanks to its purely geometrical nature, this indicator is not sensitive to the post-disturbance conditions and is therefore more robust than the detection of a backscatter decrease. The conditions for the appearance of these shadows are discussed, as well as the methods that can be employed to exploit it to detect deforestation. Two steps are needed: 1) detection of new shadow areas; 2) reconstruction of the deforested patch around the shadow.

With the launch of Sentinel-1, the availability of free-of-charge high resolution SAR data with a global coverage and a high temporal repetitivity allows testing this approach for the first time. We assessed the potential of the method in a 600 000 ha test site in the Peruvian Amazon. The method was found to perform better than the UMD-GLAD Forest Alert dataset both in terms of spatial and temporal detection: the detection rates of reference samples larger than 0.4ha is 91% with the S1-based approach, compared to 79% only for the UMD-GLAD dataset, and the samples are detected 41.6 ± 34.7 days earlier. This demonstrates the sensitivity of the approach, which was also observed in other test sites (Vietnam, Brazil, Indonesia), and which can be exploited in large-scale operational applications (see abstract by Mermoz et al.).

2.(15:50) Understanding user needs for Early Warning deforestation systems | *M Weisse*, B Mora, T Harvey, R Petersen*

Technological advancements make it possible to detect forest disturbances more quickly than ever. Operational, near-real-time forest monitoring, or Early Warning (EW) systems, present opportunities for rapid responses to suspected illegal or unsustainable forest clearing. Countries like Brazil and Peru have successfully developed their own EW systems and use EW data to guide law enforcement efforts. Though significant research and investment has gone into developing EW systems, there has been little effort to systematically understand how EW systems are used, document user requirements, or share best practices around the use of these systems.

To address these gaps, an informal EW working group was established in September 2017 with core partners including the Global Forest Observation Initiative office, the World Resources Institute, the Japan Aerospace Exploration Agency, the US Forest Service, Wageningen University, the Committee on Earth Observation Satellites, FAO, and Norway's International Forest and Climate Initiative. The working group has undertaken three key phases of work related to EW systems: 1) authoring a User Needs Assessment (UNA), 2) organizing a multi-stakeholder forum, and 3) identifying opportunities to improve and support implementation of EW systems in tropical countries.

The UNA consists of surveys and interviews of EW users and producers, focusing on experiences in tropical forest countries. The final report, delivered in June 2018, identifies the current state of play for the countries and institutions represented, as well as their biggest challenges. The multi-stakeholder forum, held in July 2018, brought together the users and producers of EW systems for a discussion on best practices, standards around EW systems, and exploration of existing solutions.

This talk will present results from the UNA and multi-stakeholder forum, as well as suggested next steps. This work underscores the strong level of interest in EW among tropical countries, as well as the fact that several countries are already making good use of EW. Technical limitations for EW systems include blockage of alert detection by cloud cover, lack of systems operating for dry or mountainous forests, and an over-abundance of alerts. However, non-technical factors limit the application of EW systems even where these systems work well, including related to lack of funding for field actions, lack of coordination, and safety concerns. Understanding the end use of EW systems can help EW data and tool providers create systems that will be useful for enabling better management of forests.

3.(16:10) The Dry Chaco Forest Near Real-Time Deforestation Detection System | *F Grings, E Roitberg*, V Barraza, P Perna, M Salvia*

The Dry Chaco region (DCF) has the highest absolute deforestation rates of all Argentinian forests. The most recent report indicates a current deforestation rate of 200,000 Ha year−1 (0.85 % year−1). In order to better monitor this process, DCF was chosen to implement an early warning program for illegal deforestation. To fulfil the requirements, we chose to develop several near real time change detection models to identify abrupt changes in vegetation dynamics associated with deforestation events. The Near Real-Time Deforestation Detection System takes as input MODIS 16-day enhanced vegetation index (EVI) and/or 8-day land surface temperature (LST), with 250 m and 1 km of spatial resolution, respectively, enabling an early warning system to support surveillance and control of deforestation. Three models were developed: i) a temporal pattern classification model based on convolutional neural networks, ii) a bayesian change point detection model and , iii) a statistical model based on EVI and LST historical values for each pixel. The model (i) is based on the supervised classification of “time series segments”, in order to estimate change point detection date using both previous and current values of EVI (2 month window period). Model (ii) is based on the identification of abrupt changes in the generative parameters of sequential data. Based on Bayes’ theorem, we can compute the posterior distribution to make online predictions robust to underlying changes in the time series. The time series was modeled as a set of 23 uniformly distributed and correlated random variables corresponding to each of the 16-day period of the year for EVI. The model is trained using historical data, in which data that are accepted are included in order to further refine the model. The last model (iii) relies on a semiempirical approach based on the fact that a deforestation event should produce a lower value than the historical value of EVI and a larger value than the historical LST. Incoming values of EVI and LST are compared with their historical values and marked using a decision rule in order to be flagged as potential deforestation. Finally, the three models are combined using a simple voting approach. Results shows that deforestation was detected with a F-score of 0.78, and with a mean time lag not higher than 30 days combining all models.

4.(16:30) Dense Sentinel-1 time series to support tropical forest cover loss alerting and characterization | *J Reiche*, E Hamunyela, J Verbesselt, M Herold, R Verhoeven, N Wielaard*

Here we use dense Sentinel-1 time series to support tropical forest cover loss alerting and characterization in the Province of Riau, Indonesia. We first applied a pixel-wise time series method to detect forest cover loss in near real-time in Sentinel-1 time series. Results showed that dense Sentinel-1 data allow for confident and timely forest cover loss detection in natural and plantation forest with user’s and producer’s accuracy above 95%. Forest cover loss was detected and confirmed within 22 days in natural forest and within 15 days in plantation forest, a difference that can primarily be related to different change processes and dynamics in natural and plantation forest. We improved the precision of the reference data derived from the multi-sensor satellite time series, which enabled a more robust estimation of the temporal accuracy. We quantified how the near real-time deforestation detection is associated with a trade-off between the confidence in detection and the temporal accuracy. We showed that the trade-off affects the choice on how to use the near-real time data for different applications such as fast alerting with high temporal accuracy but lower confidence versus accurate detection at lower temporal detail.

Next, we combined near real-time Sentinel-1 based forest cover information with VIIRS (Visible Infrared Imaging Radiometer Suite) active fire alerts, and for the first time characterized the temporal relationship between fires and tropical forest cover loss at high temporal detail and medium spatial scale. Fire use for forest management is wide spread in tropical natural and plantation forest causing major environmental and economic damage. Recent studies combining active fire alerts with annual forest cover loss information well identified fire-related forest cover loss areas, but do not provide detailed understanding on how fires and forest cover loss are temporally related. For the period between 2016/01/01 and 2017/06/31, fire-related forest cover loss accounted for about one third of the natural forest cover loss, while in plantation forest less than ten percent of the forest cover loss was fire-related. We found clear spatial patterns of fires predating, coinciding or postdating forest cover loss patches. Only the minority of fires in natural and plantation forest temporally coincided with forest cover loss (~ 15%) and can thus be confidently attributed as direct cause of forest cover loss. The majority of the fires predated (~ 60%) or postdated forest cover loss (~ 25%), may be attributed to other causes and/or fire management practices. Detailed and timely information on how fires and forest cover loss are temporally related can support forest management and policy enforcement to reduce unsustainable and illegal fire use in the tropics.

5.(16:50) Fast Monitoring of Amazonas Deforestation by combining Sentinel-1 and TanDEM-X Interferometric SAR Data | *P Rizzoli, A Pulella, F Sica, J Bueso-Bello, M Martone*, M Zink*

In the last decades, illegal deforestation in the Amazon rainforest has drastically increased, threatening its delicate ecosystems and strongly influencing climate changes. An up-to-date and fast assessment and monitoring of forest resources is therefore of crucial importance. Given the huge extend of the Amazon basin, spaceborne remote sensing represents a unique instrument for providing consistent, timely, and high-resolution products at a global scale, without need for on ground activities. Moreover, rainforests are almost completely hidden from optical sensors by a consistent clouds coverage during the wet season, which can last up to six months per year. Synthetic aperture radar (SAR), with its capability to acquire data independently from weather or day-light conditions, is therefore the most suitable technique to achieve such a high demanding task. In this paper, we present a novel approach to monitor the evolution of deforested areas in the Amazon rainforest, by combining Sentinel-1 and TanDEM-X interferometric SAR data. The idea is firstly to exploit the large coverage and short revisit time provided by the constellation of Sentinel-1 satellites in order to cover the entire arch of deforestation at regular temporal intervals. The goal is here to discriminate forest/non-forest by exploiting C-band backscatter signatures in dual polarization and the evolution in time of the interferometric coherence, in order to identify the so-called deforestation hot-spots: local areas characterized by a significant amount of on-going deforestation activities. Secondly, high-resolution time series of bistatic TanDEM-X data can be acquired over these hot spots with a revisit time of 11 days, and used to track fast changes at small scales, aiming at identifying specific on-going deforestation activities. In this case, the unique ability of TanDEM-X to generate interferometric coherences, which are temporal decorrelation-free, allows for an accurate isolation of the decorrelation contribution caused by volume scattering, which is a stable and reliable indicator of the presence of vegetation on ground.

The preliminary results are very encouraging, and aim at verifying the feasibility of the development of a semiautomatic tool for a reliable monitoring of on-going deforestation, which could support governmental authorities in stopping illegal deforestation activities. In the present paper, we intent to present the acquisition concept and the developed algorithms.

7A

MODEL-DATA INTEGRATION

Moderator: Davide Travaglini

1.(10:30) An Integrated Framework for Greenhouse Gas Satellites and Forest Structure Remote Sensing to Estimate Emissions from Land Use, Land Use Change and Forestry (LULUCF) | *B Poulter*, L Calle*

Land use, land use change and forestry (LULUCF) activities are a large source of carbon dioxide, methane and nitrous oxide to the atmosphere. Because LULUCF is associated with complex socioeconomic, biogeochemical and ecological processes, emission estimates are one of the largest sources of uncertainty in bottom-up greenhouse gas inventories. The current generation of 'bookkeeping' and land-surface modeling tools represent a variety of LULUCF fluxes that include deforestation, afforestation and forest regrowth, wood harvest, agriculture, and pasture management. These estimates rely mainly on statistics reported by countries to the United Nations Global Forest Resource Assessment every five years, resulting in time lags, and an accumulation of uncertainties from different methodologies, definitions etc. New remote sensing missions have the potential to help inform, constrain and reduce emission estimates from LULUCF by providing a top-down perspective. Existing greenhouse gas satellite missions include OCO-2, GOSAT and TROPOMI, and will soon be joined by several others to provide a global, time series and column trace gas concentrations. Forest structure remote sensing is also gaining traction with advances in using Vegetation Optical Depth to estimate biomass accompanied by the upcoming launches of ICESAT-2, GEDI, BIOMASS. Here we demonstrate the utility of an integrated framework of greenhouse gas and forest structure remote sensing and evaluate the potential for such a system to 1) detect emission enhancements, 2) assimilation of multiple greenhouse gases as a LULUCF constraint, 3) combined measurements for land-surface model initialization, and 4) providing land-surface model evaluation and benchmarking.

2.(10:50) Application of remote sensing and ecosystem modeling products to inform land-use decisions | *R Lamb*, G Hurtt*

Afforestation has the potential to provide effective climate mitigation through forest carbon sequestration. However, strategic afforestation activities, which account for both carbon sequestration potential (CSP) as well as a range of co-benefits, such as biodiversity protection, access to green space, and riparian management, can provide particularly attractive options for policy-makers who must manage competing social and environmental goals. In this paper, we conduct a case-study in the State of Maryland using Hurtt et al.'s high-resolution carbon monitoring and modeling product. This NASA and University of Maryland product estimates high-resolution carbon stocks and dynamics and future CSP using remote sensing and ecosystem modeling linked with existing field observation systems such as the USFS Forest Inventory and Analysis Program. We couple the product's localized (30m) estimations of CSP with other social and ecological co-benefits of interest to identify target areas for afforestation or reforestation across Maryland given various policy priorities. We also couple localized estimates of CSP with an economic model to determine how current land uses may be displaced under various carbon pricing schemes. This research considers the multi-purpose goals of Maryland's Greenhouse Gas Emissions Reduction Act Plan, and how the State's emissions goals may be met, exceeded or accelerated by following a co-benefits and linked-systems approach. This methodological approach may be useful for other States or regional climate initiatives, interested in including a spatially-explicit co-benefits approach in their climate policies and planning.

3.(11:10) Climate Benefits of Potential Avoided Emissions from Forest Conversion Diminished by Albedo Warming: Comprehensive, Data-Driven Assessment for the US and Beyond | *C Williams*, H Gu, T Jiao*

Avoided deforestation is a leading pathway for climate change mitigation, featuring prominently in many country's Intended Nationally Determined Contributions, but its climate benefits remain contested, in part because of reports of large offsetting effects in some regions of the world. It is well known that avoiding forest to non-forest conversion prevents forest carbon release, and sustains forest carbon uptake, but also increases albedo thus diminishing the potency of this mitigation strategy. While the mechanisms are known, their relative importance and the resulting climate benefit remain unclear. This is in part due to a lack of quantitative assessments documenting geographic variation in rates of forest conversion, associated carbon emissions, resulting radiative forcing, and the magnitude of simultaneous albedo offsets. This study (i) quantifies the current rate of forest conversion and carbon release in the United States with Landsat remote sensing and a carbon assessment framework, and (ii) compares this to quantitative estimates of the radiative forcing from the corresponding albedo change. Albedo radiative forcing is assessed with a recently-generated, global atlas of land-cover-specific albedos derived from a fusion of MODIS and Landsat reflectances, combined with snow cover and solar radiation datasets. We document the degree to which albedo warming offsets carbon cooling from contemporary forest conversions taking place in different regions of the United States and identify the underlying drivers of spatial variability. We then extend this to other regions of the world where forests are under threat and where avoided deforestation is viewed as a primary tool for climate mitigation. Results shed light on the, at times contentious, debate about the efficacy of forest protection as a mitigation mechanism.

4.(11:30) Using Landsat, Aerial Surveys, Weather Modeling, and Agent-based Models of Outbreak Insect Phenology and Migration to Explore the Topographic Concentration Hypothesis. | *M Garcia*, B Sturtevant, J Régnière, Y Boulanger, R St-Amant, B Cooke, G Achtemeier, J Charney, P Townsend*

We present ongoing work investigating topographic effects on the concentration and spatiotemporal patterns of the growing eastern spruce budworm [Choristoneura fumiferana (Clem.)] outbreak in eastern Canada. Spruce budworm moths tend to migrate in discrete, but sometimes massive, nocturnal flight events over several weeks each summer. Moths from an outbreak area may supplement distant locations to boost endemic populations to outbreak levels the following spring. The spruce budworm outbreak event on the north shore of the Gulf of St. Lawrence in Quebec has recently crossed the Gulf to the south shore and now threatens forests in New Brunswick and Maine. Past work [Pedgley, 1990] and recent studies [Bouchard and Auger, 2014; Bouchard et al., 2017] suggest that outbreak epicenters are associated with topographic valleys. We hypothesize that night-migrating insects may become concentrated by near-surface wind patterns in topographic valleys, where egg deposition and favorable climate can lead to a persistent source of migrating insects along with host forest defoliation (and eventual mortality) in subsequent years. We are exploring the validity of this topographic concentration hypothesis using an agent-based model of insect phenology and migratory flights. Spatially explicit spruce budworm phenology is modeled using the BioSIM framework [Nealis and Régnière, 2014], where data regarding the likelihood of adult moth migration readiness are provided to an Atmospheric Transport Model (ATM) derived from prior work [Sturtevant et al., 2013]. This ATM component uses Weather Research and Forecasting (WRF) model results on a 1-km grid to simulate the flights of individual moths. We used high-performance and high-throughput computing systems at the University of Wisconsin–Madison to perform WRF and ATM simulations of migration flight events in July 2013 for calibration and validation against Val d'Irène weather radar observations in southern Québec [Boulanger et al., 2017]. We then compared model-based maps of egg deposition during migration events in a given year with aerial surveys and Landsat-based analyses of host species defoliation and mortality in subsequent years. The fusion of these modeling methods and data sources provides insight into the patterns and dynamics of the current spruce budworm outbreak behavior in Québec and may be applicable to other species outbreaks in locations where such information is available.

5.(11:50) Combining high-resolution LiDAR and forest modeling to improve predictions of future forest state across interior Alaska | *A Foster*, A Armstrong, J Shuman, KJ Ranson, H Shugart, BM Rogers, S Goetz*

The boreal zone of Alaska is highly influenced by climate and by climate-driven disturbances such as wildfire. Future climate change is likely to cause changes in both the climate and disturbance regimes of interior Alaska, carrying with it the potential to affect the species composition, biomass, and forest structure of the boreal zone. We utilize an individual tree-based vegetation model and high-resolution airborne LiDAR data to provide estimates of current and future forest conditions across the Yukon River Basin in interior Alaska. The University of Virginia Forest Model Enhanced (UVAFME) is an individual-based gap model that has been updated for application within interior Alaska, with improved simulation of permafrost dynamics, litter decay and nutrient dynamics, and fire mortality and post-fire regrowth. Canopy height derived from 2014 G-LiHT flight lines over the Tanana Valley, as well as species composition and diameter at breast height distributions from the Cooperative Alaska Forest Inventory database is used to initialize UVAFME to current forest conditions within the Tanana Valley. At locations where resampling has taken place, UVAFME is initialized using the earliest sample data and run until the date of subsequent sampling. Comparisons between model-simulated data and the resampled inventory/LiDAR data show good agreement between UVAFME output and ground-truth data, and highlight the importance of initialization to current conditions. Several different scenarios involving interacting climate change and fire are then simulated, first at the initialization sites within the Tanana Valley, and then across the entire Alaskan Yukon River Basin in a gridded fashion at 2 km cell resolution. Climate change is modeled using projected temperature and precipitation from a five-model average taken from the CMIP5 AR5 for the RCP4.5 and RCP8.5 scenarios. Results from these simulations show that climate change and the associated impacts on wildfire and permafrost dynamics will result in shifts in biomass and species composition across the region, with potential for further feedback to the climate-vegetation-disturbance system. These simulations advance our understanding of the possible futures for the Alaskan boreal forest, which is a valuable part of the global carbon budget.

7B

UAVS FOR FOREST STRUCTURE MAPPING

Moderator: Guillermo Castilla

1.(10:30) An extensible framework for small unmanned aerial system sensor integration with lidar and satellite remote sensing. | *D Krofcheck*, M Hurteau, H Zald*

Recent technological advances coupled with decreasing costs are driving widespread small footprint image acquisition using small, unmanned aerial systems (sUAS). These platforms provide the scientific community with the opportunity to inexpensively incorporate an on-demand remote sensing component to existing research programs, or design sampling schemes around this technology. However, between rapidly decreasing costs and relative ease of use, the proliferation of studies using sUAS to acquire data appear haphazard when viewed as a body of work because there is little methodological overlap between studies and it is often limited to the software used to generate a surface model.

We propose that sUAS are uniquely positioned to provide the foundation for sensor integration and remote sensing driven knowledge production across a range of spatial and temporal scales. However, the capability of sUAS as a flexible data collection and research tool is both enhanced and made more applicable to current and subsequent research efforts by leveraging existing remote sensing and field collected data products and integrating them in a data fusion context.

Here we describe an extensible framework for the integration of sUAS collected structure from motion data with airborne lidar and satellite passive optical remote sensing. This combination of data sets affords the fusion of structural and spectral data generation at frequencies that are ecologically relevant, and when coupled with a modeling component allows for knowledge production in natural systems at scales and frequencies that facilitate doing science in novel ways. Specifically, the high-resolution mapping capabilities of sUAS when combined with structure from motion provides a unique description of natural systems at the scale of plots and transects. By integrating these data with ground-based observations, methods of abstraction (e.g., classification) can be used to create models of vegetation and ecosystem function. We use a time series of sUAS acquired imagery collected in a mountainous area, coupled with aerial lidar and passive optical satellite data to demonstrate the role of sUAS in knowledge production in ecological contexts. In this example we investigated the role of surface fuel on vegetation survivorship post-prescribed fire, using the sUAS data as the foundation for creating a simple yet extensible model, driven using combinations of freely available satellite and aerial lidar data sets.

2.(10:50) DTM-independent variables to predict forest inventory variables using 3D UAV photogrammetric data | *F Giannetti*, G Chirici, T Gobakken, E Næsset, D Travaglini, S Puliti*

This study presents a novel approach for the extraction of a new set of explanatory variables from 3D UAV photogrammetric data without the need of any digital terrain model (DTM) to normalize the data, i.e., to obtain relative heights above ground. The set of DTM-independent variables was used to predict five forest inventory variables: growing stock volume, basal area, stem number, Lorey's height, and dominant height. To gain further insights in the applicability of the approach across different regions, the assessment of the DTM-independent variables was performed across two different forest types, namely a temperate mixed forest in Italy and a boreal forest in Norway. The use of DTM-independent variables was compared against two more traditional sets of variables: (i) statistical height and density variables from UAV photogrammetric data normalized using an airborne laser scanning (ALS) DTM (Image-DTMALS) and (ii) statistical height and density variables from normalized ALS echoes (ALS variables). Multivariate linear regression models were fitted with the forest inventory variables as response and the three different sets as explanatory variables, i.e., (i) DTM-independent variables, (ii) Image-DTMALS variables, and (iii) ALS variables. The average root mean square error in percent of the mean (RMSE%) across all the studied forest inventory variables found for the models using the DTM-independent variables was 19.6%, which was similar to the RMSE% found for the other sets of explanatory variables (19.7% - 21.6%). Interestingly, as the terrain and forest structure complexity increased (mixed forests) the DTM-independent variables yielded smaller average RMSE% (19.1%) than ALS (23.2%). Our results suggest that 3D UAV photogrammetric data may be used effectively for forest inventories even when high resolution DTMs are not available.

3.(11:10) Combining UAV and Sentinel-2 auxiliary data for forest growing stock volume estimation through hierarchical model-based inference | *S Puliti*, S Saarela, T Gobakken, G Ståhl, E Næsset*

The increased availability of remotely sensed (RS) data at multiple levels of resolution, from coarse satellite imagery (e.g. Sentinel-2) to highly detailed 3D data from unmanned aerial vehicles (UAVs), offers new possibility to estimate and map forest resources cost-effectively. The development of new statistically estimation frameworks allow the estimation of forest resource parameters using multiple auxiliary RS data while ensuring a rigorous reporting of the uncertainty of the resulting estimates. In this study, growing stock was estimated and its variance assessed using a combination of field, UAV, and Sentinel-2 data in a hierarchical model-based (HMB) inferential framework. The main objective of this study was to compare the precision of the HMB estimates against three alternative cases, namely (1) a model-based estimation based on field data and wall-to-wall airborne laser scanning (ALS) data (MB-ALS) or (2) Sentinel-2 data (MB-S2), and (3) a hybrid inference using field data and of partial-coverage UAV data (HYB). Furthermore, the study investigated the possibility of reducing the number of UAV samples and its effect on the precision of the estimates of HMB and HYB. The results indicated that the precision in terms of standard error (SE; m3 ha-1) of the proposed HMB case was of similar magnitude (7.7) compared to the MB-ALS (8.3) and HYB (8.1) cases. In contrast, the SE nearly doubled (13.1) for case MB-S2 where only Sentinel-2 multispectral data were used as auxiliary data. The results also revealed a greater decrease in precision for the HYB case compared to the HMB when reducing the UAV sampling intensity. In particular, the precision of the HMB when including only 9% of the total number of UAV samples (55) was of similar magnitude to that of the HYB case with all the UAV samples. The findings of this study are encouraging for further application of the proposed HMB application, especially in light of the potential cost reductions due to the reduced need of UAV samples. A key advantages of the proposed methodology is that it does not assume probabilistic properties of any of the samples (the field data and the UAV data). It can therefore be adopted even when UAV data are acquired purposely and not according to probabilistic sampling designs. On the other hand, it relies on the assumption that the models connecting the different levels of data are correctly specified for the area of application for the estimators to be approximately unbiased.

4.(11:30) Technical and operational considerations for the implementation of UAVs for forest mapping and inventories and their role in the validation of satellite land products | *JP Arroyo-Mora*, M Kalacska, O Lucanus*

The current availability of small (< 25 kg) and relatively inexpensive unmanned aerial vehicles (UAVs) presents a new exciting tool for forest mapping and inventory applications in many ecosystems, from boreal to tropical forests. By reviewing the significant increase in literature on the use of UAVs for environmental applications, our presentation focuses on the utilization of this novel platform for forest mapping and inventories. We complement our review by presenting examples of work carried out using various UAV platforms of relatively low cost (US$1500-20,000). Furthermore, we cover fundamental methodological considerations necessary to carry out field campaigns with both RGB camera systems for determining forest structure, as well as more advanced hyperspectral systems for tree species mapping identification. Our case study from a boreal forest in Quebec, Canada illustrates the utility of multi-temporal 3D forest structure reconstruction from Structure from Motion (SfM) photogrammetry (i.e. including both leaf-off and leaf-on acquisition). We examine the primary characteristics of camera systems (e.g. ISO, shutter speed, resolution, data compression) and flight parameters (e.g. altitude, overlap, GPS quality with and without D-RTK) contributing to data quality. We also describe the implementation of the micro-CASI hyperspectral imagery on a UAV platform, and present examples of UAV-based hyperspectral imagery to complement the multi-temporal 3D SfM results for biodiversity estimation and tree species identification, in the context of forest inventories. Finally, we discuss the potential challenges for the use of UAV-derived biophysical variables for the validation of satellite products (e.g. phenology, species richness, LAI).

5.(11:50) Assessment of below-canopy forest structure using UAV Structure from motion (SfM) Point Clouds | *S Hillman*, L Wallace, K Reinke, B Hally, S Jones, R Taneja*

Unmanned Aerial Vehicles (UAV) equipped with consumer grade cameras are increasingly used to capture information describing the world's forests. Pioneering studies in this field have shown that high resolution images captured from these platforms, when passed through structure from motion (SfM) workflows, provide detailed information describing the dominant canopy tree elements. However, to date, these studies have not explored the information content contained within the point clouds describing the arrangement of vegetation elements below the canopy. Estimates of below canopy vegetation have been identified as an important metric for carbon accounting, wildlife habitat diversity, precision forestry, fire and fuel hazard modelling and understorey forest competition dynamics.

This paper explores the use of image based point clouds generated from UAV platforms for describing forest structural properties within the surface and near-surface layers. Airborne imagery was captured at 5 sites in Australia and and Chile using a DJI S1000 platform equipped with RGB and a NIR altered sony A6000 cameras and a DJI Phantom 4pro. Landscapes captured in the study include Mallee woodland and schlerophyll forest in Australia and plantation and robe-rauli-coigu forest in Chile. These sites were selected to represent a range of structural complexity in both canopy vegetation and below canopy vegetation density.

Images were captured using various flight plan and camera viewing angle configurations, and processed to produce a dense point cloud. The results were compared to Terrestrial Laser Scanner data and field based measures of height and cover. Results suggest that canopy density and height along with camera overlap, spectral properties and pointing angle are important factors in capturing below canopy vegetation structure. In the Mallee landscape, which consists of sparse low Eucalypt trees, below canopy vegetation, including branching of the overstorey trees could be resolved; in environments with greater canopy cover (native forests) information describing the composition of below canopy layers was minimal.

This research demonstrates that image-based point clouds captured from a UAV are a viable method of assessing below-canopy structure. The accurate assessment of vegetation height and coverage coupled with the advantages of UAV platforms provide policy makers with the information required to make informed decisions about the existing and future management strategies.

7C

HURRICANES AND MANGROVES

Moderator: Kate Fickas

1.(10:30) Global and Regional patterns of mangrove forest structure | *M Simard*, L Fatoyinbo, C Smetanka, M Denbina, V Rivera-Monroy*

Mangrove forests thrive within the intertidal zones of tropical coasts providing critical ecosystem services such as protecting coastlines and sequestering disproportionate amounts of carbon. However, these ecosystems are squeezed between rising seas and anthropogenic activity. These threats are imminent and baseline measurements are required. Recent advances in remote sensing capabilities and free access to data have enabled the development of large scale mapping of mangrove extent, structure and change. The ability to produce large-scale maps provide a powerful tool for analysis of global trends in structure and change, and their relationships to geophysical and climatic parameters.

Using elevation measurements from radar interferometry, calibrated with laser altimetry and validated with in situ field data, we examine the spatial patterns of mangrove forest structure at regional and global scales to discover its environmental and geophysical drivers. The global datasets include Shuttle Radar Topography Mission (SRTM), TanDEM-X, ICESAT/GLAS, and Landsat-derived mangrove maps. On the regional to local scales, we used UAVSAR interferometric data and Laser Vegetation Imaging Sensor (LVIS) to provide fine resolution measurement of canopy height and extent with high accuracy.

Our large in situ dataset has revealed strong differences in tree density between continental regions. in particular, the east coast of Africa exhibited the highest tree densities leading to significant variability in allometry relating mangrove forest canopy height and above ground biomass. The global maps show mangrove forests reach their full structural potential, as defined by maximum canopy height, close to the equator in areas sheltered from seaward storm events. It is also evident that forest structure varies strongly with local geophysical setting and local environmental gradients.

2.(10:50) Greenness Trends and Carbon Stocks of Mangroves across Mexico | *A Vazquez-Lule*, R Colditz, J Herrera-Silveira, M Guevara, M Rodriguez-Zuniga, I Cruz, R Ressl, R Vargas*

Mangroves cover less than 0.1% of Earth's surface, store large amounts of carbon per unit area, but are threatened by global environmental change. The capacity of mangroves to cycle carbon could be characterized by their greenness, however greenness has not been tested at regional scale for mangrove forests. Here, we analyzed time series of Normalized Difference Vegetation Index (NDVI), mean air temperature and total precipitation between 2001 and 2015 to quantify greenness and climate variability trends for mangroves not influenced by land use/land cover change (LULCC) across Mexico. During the study period persistent mangrove forests covered 432,800 ha, it represents 57% of the current mangrove area in the country. We found a greenness increase between 0.001[0-0.002] to 0.004[0.002-0.005] yr-1 (NDVI values) along the 14 years for mangroves with surface water input as main source of freshwater. Mangroves developed over carbonate platforms and interior water as main source of freshwater did not show a significant greenness trend. Mangroves with surface water input showed above ground carbon stocks (AGC) between 37.7 to 169.5 Mg C ha-1 and soil organic carbon stock at first 30 cm of depth (SOC) between 92.4 to 123.1 Mg C ha-1. Mangroves with interior water input showed an AGC of 12.7 Mg C ha-1 and a SOC of 219.0 Mg C ha-1. Average greenness and climate variables values were better related with AGC ($0.21< r2 <0.50$) rather than SOC ($r2 <0.21$). This study represents a country-level effort to identify greenness trends and their relationship with carbon stocks and how they are influenced by climate variability. Our findings are useful to provide baselines for regional monitoring programs and they could be tested across other mangrove forests around the world.

3.(11:10) Structural gradients of hurricane damage across the mangrove forests of South Florida | *D Lagomasino**

Hurricanes epitomize large scale, pulsed disturbances that can drastically change the structure and composition of coastal ecosystems. However, there are few studies that capture the full extent of structural damage across large coastal regions. Hurricane Irma, one of the strongest hurricanes ever recorded in the Atlantic basin, first made landfall in the Florida Keys archipelago before coming ashore in southwestern Florida on September 9th and 10th of 2017. Strong winds in excess of 225 km/h and a 3 m storm surge impacted a 100+ km stretch of the southern Florida Gulf Coast, resulting in extensive damages to coastal and inland ecosystems. In response to the hurricane, a rapid response airborne campaign was conducted to collect repeat imagery from Goddard's Lidar, Hyperspectral, and Thermal airborne instruments (G-LiHT) over southwest Florida to directly quantify mangrove forest damage and coastal erosion from Hurricane Irma using pre and post-storm data. Rapid assessment of storm impacts was critical to characterize sedimentation, erosion, changes in forest canopy structure. After the storm, Ten Thousand Islands, the area directly in the path of Irma's landfall, was most impacted with a loss of nearly 20% of the forest volume with a lower rate of recovery relative to other impacted areas. The average change in mean canopy height ranged from 0 m in areas least impacted by the storm, and up to 1.5 m in mangrove areas most heavily damaged. Mangrove canopy damage and the opening of gaps were more prevalent in areas where the forest canopy was taller than 7 m.. These findings provide new insights into the significant role of hurricanes in shaping mangrove structural patterns that drive the resilience and vulnerability within these coastal forested wetlands.

4.(11:30) Determining coarse woody debris in mangrove forest of the Florida Everglades after Hurricane Irma using airborne lidar imagery | *S Chavez*, D Lagomasino, L Fatoyinbo, B Cook, D Morton, E Castaneda, R Moyer, K Radabaugh, JM Smoak*

Mangroves have been shown to have potential benefits in protecting coastal areas from natural disasters, such as hurricanes. Hurricane Irma hit the coast of southwest Florida in September of 2017, impacting large swaths of mangrove forests. A combination of strong winds and high storm surge were extensive across the area resulting defoliation, broken branches, and downed trees. As a result, large volumes of Coarse Woody Debris (CWD), in the form of downed branches and trees fell to the forest floor. This material is a significant input of carbon and nutrients to the pool that contributes to nutrient recycling and provides food and new habitat for other organisms. Unique airborne imagery collected by NASA Goddard's Lidar, Hyperspectral and Thermal imager (G-LiHT) before and after Hurricane Irma provides new opportunities to estimate the volume of coarse woody debris deposited during the storm. We developed novel metrics derived from the high-resolution lidar points clouds to determine the amount of standing live woody volume in the canopy before the storm and CWD on the ground after the storm. Estimates of CWD were calibrated and validated against field collected data collected during post-storm surveys. We then applied the CWD models to mangrove forest were G-LiHT data was collected to identify regional patterns of disturbance along the gradient of storm surge and wind velocities. The extent and distribution of CWD can not only identify regions of major disturbance across south Florida, but also help to model the future effects on these systems as carbon and nutrients are released as CWD decomposes over the next few years.

5.(11:50) Effects of Hurricanes Irma and Maria on the Puerto Rican forests measured by the NASA G-LiHT Airborne Imager | *S Martinuzzi*, B Cook, D Morton, L Corp, E Helmer, M Keller*

In 2017, strong Hurricanes Irma and Maria transformed the lush green forests of Puerto Rico to a leafless tangle of damaged and downed trees. We present preliminary results of a repeated airborne remote sensing campaign in Puerto Rico aimed at quantifying the effects of Hurricanes Irma and Maria on the island forests. We collected high-resolution (1m) data using NASA Goddard's Lidar, Hyperspectral, and Thermal (G-LiHT) Airborne Imager across Puerto Rico in March 2017, six months before the hurricanes, and then conducted a repeated airborne mission covering the same flight lines in April-May 2018, about eight months after the hurricanes. We covered gradients of soil fertility, topography, climate, forest age, and distances to the Hurricanes path, providing an unprecedented detailed data set to understand forest structural damage across the landscape. In addition, because vegetation recovery and leaf-out had already begun by the post-hurricane sensing campaign, we evaluated tree survival and recovery. We present examples of changes in forest canopy height and canopy cover from the repeated G-LiHT lidar data across the island forests, and discuss the effects of environmental conditions on forest damage. The remote sensing data collected provides key information to guide forest restoration efforts in Puerto Rico, and to increase our understanding of the effects of natural disturbances on tropical forests in general.

7D

NEXT GENERATION LARGE AREA FOREST MONITORING 1: CONTEXT AND SCIENCE

Moderator: Mike Wulder & Sean Healey

1.(10:30) Towards a satellite derived change, cover, and structure data cube: Satisfying large-area information needs for forest monitoring | *M Wulder*, J White, N Coops, T Hermosilla, G Hobart*

Governments are responsible for stewardship of natural resources, from development of policy and regulatory frameworks, allocation of timber licences and fire suppression resources, through to subsequent monitoring and reporting. The monitoring and reporting aspects are implemented to document the nature and dynamics of forest resources, over a range of scales, in order to inform regional, national, and international programs. Remote sensing offers an information source that is synoptic and spatially explicit, and that can be generated in a transparent, systematic, and increasingly timely fashion. Common to most forest inventory and carbon-focused monitoring and reporting programs are a set of basic attributes, many of which can be measured or modeled with remotely sensed data, including forest change, structural attribution (e.g., biomass, volume, stand height), and land cover.

Open data, high performance computing, and modeling now offer operationally viable capacity for forest monitoring and reporting over large areas. Monitoring requires the capture of change over time, in order to characterize trends. The Landsat archive provides an analysis ready source of more than three decades of data for use with novel, time series informed, processing techniques to meet forest monitoring and reporting information needs at a level of spatial detail that allows for the capture of anthropogenic activity. In this presentation, we share insights regarding opportunities, outcomes, and directions for the generation of forest change, structure and land cover for the 650 million hectare forested area of Canada. Initial determination of disturbance characteristics (e.g., type, magnitude, persistence) allows for the incorporation of successional information into land cover mapping (e.g., to ensure logical and correctly timed transitions). Likewise, knowledge of time since disturbance and samples of airborne lidar strengthens models of forest structure. The spatial-temporal information content of satellite time series in combination with high performance computing and modeling, has resulted in an increasingly dynamic and flexible means for monitoring and reporting of forests over large areas.

2.(10:50) Trends and patterns of temperate forest disturbance dynamics in Europe from Landsat time series | *D Pflugmacher*, C Senf, Z Yang, J Knorn, J Sebald, R Seidl, P Hostert*

Forest disturbances have increased in Europe over the last decades and are likely to continue to increase in the future. To successfully adapt management and policy to these future challenges will require improved monitoring of forest disturbances and their impacts on ecosystem structure and function, building historic baselines and generating knowledge for developing predictive models. Yet, existing large-scale mapping approaches are rare, especially in the complex systems of Europe. The objective of this study consequently is to map and characterize annual forest disturbance rates and patterns in temperate forests of Europe using medium resolution sensor data from the Landsat satellites. By combining a statistical sample of 24,000 photo-interpretation plots distributed across six countries, trajectory-based change detection and cloud computing, we mapped partial and stand-replacing forest changes between 1985 and 2016. Preliminary results using an ensemble of multi-spectral trajectories show an 80% detection accuracy if balancing omission and commission errors. Annual disturbance rates increased consistently across the region, although temporal and spatial patterns varied by country and biogeographic region. This study contributes to on-going European-wide efforts, in line with the Copernicus Land Monitoring Service, to harmonize and operationalize forest monitoring for climate change mitigation and adaptation, sustainable forest management, and environmental protection.

3.(11:10) New opportunities for high-resolution countrywide tree species mapping | *L Waser*, B Price, N Rehush, D Small, M Rüetschi, C Straub*

Precise and regularly updated information on the state, change and distribution of tree types is essential for the forestry sector and beyond. Wall-to-wall tree type maps are fundamental inputs for the changing requirements of regional and national forest inventories (NFIs). While repeated and routinely acquired digital aerial images have been incorporated into operational NFIs, limitations of optical data remain particularly in complex terrain, such as the European Alps. In their pioneer work of a high-resolution countrywide tree type mapping approach, Waser et al. (2017) showed that such limitations resulted in an overestimation of coniferous trees.

In the present study, a novel approach is introduced that minimizes these limitations and allows to generate repeatable and objective tree type maps (broadleaved, coniferous) and a further distinction of 5 tree species with a spatial resolution of 10m for the whole of Switzerland (41,285km2). It incorporates a Random Forest classifier, explanatory variables from Sentinel-1/-2 data, a DTM from a countywide ALS data set, training data, and independent validation data from NFI surveys. The single usage of multi-temporal Sentinel-2 imagery partly enabled to reduce previous overestimations of conifers but results were still unsatisfactory in areas with complex topography. Combining both Sentinel-1/-2 time series and training the classification models in the specific problem areas with Sentinel-1 SAR backscatter data finally minimized overestimations of conifers. 10-fold-cross-validation showed high overall model accuracies (95-98%) with small variations between different regions. A comparison with independent NFI plot data revealed differences in the range of 5-8%. The presented approach is currently being extended by applying convolutional neural networks for the classification of 5 main tree species. First results are very promising and the whole of Switzerland will be calculated within the next few months.

The tree type map of Switzerland is superior to existing products due to its national coverage and high level of detail. The usage of R and free available basis remote sensing data sets guarantee a flexible adapting of the approach, regular updating and the possibility to apply it for other countries.

Both the tree type and species maps are potentially useful for optimizing forest management and planning activities and are also a valuable information source for applications beyond the forestry sector.

4.(11:30) LANDFIRE: Updating a national vegetation and fuels dataset using next-generation data | *B Peterson, K Nelson. S Sathyachandran**

The LANDFIRE product suite represents a critical default data source to the wildland fire management and research community. The first LANDFIRE baseline products, representing the circa 2001 era and informed predominantly by Landsat imagery, were incrementally released between 2006 and 2009. Since then, to keep products relatively current, a series of biennial updates have been released. The production of these geospatial layers has continued to be been driven by the availability of Landsat data as well as the application of state and transition models that provide a reasonable process for representing change on the landscape with the program constraints. Currently, LANDFIRE has initiated a Remap effort to generate new baseline products representing the circa 2016 era. LANDFIRE Remap draws upon the Landsat archive and big data processing capabilities to refine mapping and gain production efficiencies. Yet, even as LANDFIRE Remap production has commenced and users anticipate the release of new products, the LANDFIRE program must already consider post-Remap update needs. A common request from the LANDFIRE user community is for more frequent updates. For the post-Remap era an initial target of annual updates is planned. Program researchers are exploring methods for leveraging data from both legacy (i.e., Landsat, MODIS) and new (e.g., Sentinel-2, VIIRS, ATLAS, and GEDI) sensors. The goal is to develop a system to leverage a tiered, multi-sensor approach to monitor the landscape and capture change closer to real time and then generate corresponding vegetation and fuels layers that are used operationally for strategic and tactical wildland fire management decisions, among myriad other applications. Additionally, the program seeks to incorporate spaceborne lidar at the national scale to provide a consistent baseline of vegetation structure and canopy fuels assessments. LANDFIRE will build on experience gained using GLAS data to map canopy height and cover in Alaska and testing simulated ATLAS data for the derivation of vegetation structure. This previous work has demonstrated that the integration of spaceborne lidar will aid in the generation of consistent vegetation structure products that meet or exceed current user requirements. The combination of these approaches will move the program away from a static set of maps based on application of abstract rulesets for updating to a more dynamic data delivery with maps tied more closely to actual observations.

5.(11:50) Monitoring Land Disturbance based on Landsat Time Series | *Z Zhu*, Z Yang*

We developed a new algorithm for monitoring land disturbance based on Landsat time series. All available Collection 1 Landsat data (Tier 1 from Landsats 4-7 and Tiers 1/2 from Landsat 8) were used for our analysis. We first extracted all potential land disturbance based on the breaks identified by the Continuous Change Detection and Classification (CCDC) algorithm. Next, we used the 7,200 reference samples interpreted by TimeSync across the Conterminous United States (CONUS) to calibrate the CCDC algorithm to extract real land disturbance from all the potential CCDC breaks. In this calibration process, we will optimize CCDC threshold for better identifying all potential land disturbance and develop methodology to separate false positive breaks and vegetation regrowth breaks out from breaks that are caused by real land disturbance. Meanwhile, we will evaluate the impacts of input data on monitoring land disturbance, which including data from different processing levels such as Top of Atmosphere (TOA) reflectance and surface reflectance, and data with different temporal frequencies such as time series observations from a single Landsat scene or from multiple Landsat scenes (including overlap areas).

8A

DATA FUSION AND INTEGRATION

Moderator: L. Monika Moskal

1.(13:30) Multi-scale and multi-sensor detection and monitoring of invasive exotic tree species | *J Dash*, G Pearse, M Watt, T Paul, J Morgenroth*

Exotic conifers are the cornerstone of the forestry sector in New Zealand and provide significant benefits. However, in some environments several species have become locally invasive and are becoming dominant. The area infested is currently estimated at 1.8 M ha and it is thought to be increasing at 6 % per annum. This has significant ecological and economic consequences and there is a growing consensus that this impact is unacceptable. Robust detection is required to inform targeted control and eradication of invasive conifers and to protect valuable environments. Our research aims to deliver methods for detection and mapping of invasive conifers throughout New Zealand's varied landscapes and across a range of ecosystems.

Four study sites representing an ecological gradient of risk prone sites in New Zealand have been established. The terrain and vegetation structure in these sites varies considerably. We are undertaking comprehensive field surveys to provide ground truth for the remote detection. In some instances our field surveys include a total census of all trees and seedlings in an invasion event. Across all sites multi-scale remote sensing data has been acquired from UAV (ALS and spectral), manned aircraft (ALS and spectral), and satellite (WV3, Sentinel-2) platforms. A key objective of this research is the development of data fusion methods that enhance the detection of invasive conifers. In this manner we develop datasets that have greater utility than their component parts and can cover larger areas. Through a comprehensive examination of analysis techniques across all sites we seek to define the detection threshold for various sensors in many environments.

We present results from several study sites. We have developed methods to fuse ALS data with multispectral imagery for invasive conifer detection. By colouring the point cloud data we found that the inclusion of near-infrared data improved detection. A classifier based on the random forest algorithm was used to classify each colourised laser return and produced accurate classification models (kappa = 0.837). To explore data capture settings we thinned the ALS data from its initial density of 21 pls/m2 down to 1 pls/m2. The classification models were invariant to pulse density. However, the probability of sampling target trees was significantly affected by pulse density. We explored the relationship between pulse density and canopy size to guide acquisition settings for detection.

2.(13:50) Data assimilation of forest variables based on several remote sensing sources | *N Lindgren*, E Lindberg, A Grafström, S Saarela, M Nyström, HJ Persson, H Olsson, G Ståhl*

An increased supply of remote sensing data gives opportunities for predictions of key forest variables, such as growing stock volume and basal area. In addition, the increased availability of time series data from several types of sensors provides new opportunities to keep forest data up-to-date and accurate. In remote sensing of forests, the most accurate predictions are made from data that are costly and thus can be acquired only at certain intervals. Therefore, filling the gap between the accurate predictions with other data sources is of high interest. Data assimilation provides a framework for combining time series of predictions and growth forecasts. Previous studies using time series data from a single sensor type have shown promising results but also identified challenges that need to be addressed (Nyström et al., 2015; Lindgren et al., 2017; Ehlers et al., 2018).

In the present study, different sensors are combined in an effort to obtain more accurate and up-to-date forest variable predictions. It has been shown in previous studies (Ehlers et al., 2018, Lindgren et al., 2017) that the prediction errors will contain a component that depends on the combination of the sensor used and of the forest type. This component causes the prediction errors to be correlated as described in Ehlers et al. (2018). Since different sensors measure the forest in different ways, combining sensors could be an opportunity to address this problem, which reduces the efficiency of data assimilation.

The study is conducted at the Remningstorp test site in southern Sweden (Lat. 58°30' N, Long. 13°40'). Here several acquisitions of airborne LiDAR, optical satellite data, digital photogrammetry and TanDEM-X InSAR data are available providing a rare opportunity to study how to combine different data sources in data assimilation in an efficient way. As reference data repeatedly measured sample plots with 10m radius were used for predictive modelling.

Preliminary results show that RMSEs of volume predictions, estimated using cross validation, were lower when different sensors were combined, compared to using time series data from a single sensor

3.(14:10) Space-series wavelet analysis and time-series of SAR data to characterise tropical forest | *EC De Grandi*, E Mitchard, D Hoekman, F De Grandi*

Statistical measures of forest structure dynamics are of importance in the thematic context of tropical forest degradation. Spatial information on forest structure can be derived from canopy height models (CHMs) provided by airborne LiDAR and, in principle, also from InSAR digital surface models (DSMs), these being approximations of the top of the vegetation layer. However, InSAR DSMs result from the superposition of a terrain topographic component and a vegetation layer height component. Therefore, the information of interest about the forest structure could be affected by topography.

In this study, we address this issue by considering wavelet statistics of space-series of coincident LiDAR and TanDEM-X DEMs. Wavelet variance analysis reveals that information on vegetation structure can still be detected in the TanDEM-X DSM, because it happens at a different scale range. Wavelet flatness (normalized fourth moment) indicates that intermittency information in the TanDEM-X DSM is not affected by topography. However, the DSM provides a different measure of the forest intermittency with respect to LiDAR CHM, this being due to several causes, mainly spatial resolution and the physics governing the canopy height estimation.

4.(14:30) Bidirectional Mixing Effects of the Spectral Signal in Deciduous Forest Canopies | *A Clasen*, B Somers, S Itzerott, B Kleinschmit, M Foerster*

We investigated the bidirectional effects of forest reflectance by means of two different methods for the quantification of green vegetation fraction: (i) Unmixing and (ii) Vegetation Indices (VIs) as a measure of green vegetation. Instead of solely considering the effects induced by illumination and viewing angles, this study is explicitly taking into account the angle-dependent change in the actual visibility of the individual components from different angles.

Based on a tower slewing crane situated in a temperate forest in northern Germany, nadir and off-nadir measurements were acquired with a field spectrometer. All measurements were arranged in transects over two deciduous tree species, alder and beech. A very detailed validation data set on the fractional abundances of canopy components was derived from RGB-images taken synchronously to the spectrometer measurements. The fractions were quantified semi automatically for each viewing angle.

The endmember measurements for the unmixing were also taken in field at different viewing angles. The visible fractional abundances of the canopy components 'leaf', 'bark' and 'non-photosynthetic vegetation'(NPV) were unmixed at five different viewing angles in the principle plane using the multiple endmember spectral mixture analysis (MESMA). With an average unmixing error of around 10 %, best unmixing results were clearly found in the viewing angles, which capture the backscatter of the sunlit canopy sides. Accuracies in the commonly used nadir viewing angle were already considerably lower with a tendency to further underestimations towards the larger off-nadir angles capturing the forward scatter of the shaded sides of the canopy.

As an alternative to spectral unmixing, 18 different VIs that can be interpreted as a measure of green vegetation were calculated and examined regarding their bidirectional patterns. Relevant anisotropic dynamics were found for most VIs. The main drivers were found to be the illumination conditions and visible crown component fractions. Which of the two influences is the dominant one was mainly determined by the structure of the mathematical formula of the VIs and the choice of involved wavelength domains. Only if the VI equation has no direct additive factors and the chosen wavelengths are relatively stable against anisotropic effects, multiangular evaluations of vertical vegetation structure are made feasible without being mixed with anisotropic effects.

5.(14:50) Updating Lidar-Derived Forest Attributes With Sentinel-2 Data | *M Schardt*, J Deutscher, M Hirschmug***l**

Forests are continuously subjected to damages caused by natural as well as anthropogenic influences. Catastrophic storms, the resultant and lasting problem of bark beetle calamities, and global climatic changes result in a reduction of forest crown cover density. Crown cover density is defined as the proportion of the forest floor covered by the vertical projection of the tree crowns. Another consequence of the influences mentioned above is an increasing number of forest gaps. Both effects weaken the resilience of alpine forests and, consequently, diminish their protection function against landslides and avalanches. Local or regional authorities thus require detailed and georeferenced information on the degradation status of their forests to be able to take appropriate countermeasures against the aftermaths of forest damage and to ensure sustainable forest management.

With remote sensing, crown cover density and the distribution of forest gaps can be derived from the spectral information of optical satellite imagery or from a normalized digital surface model. LiDAR data which show a high spatial resolution and take into account the vegetation height provide the most accurate results, but LiDAR campaigns are expensive and, thus, available data is often outdated. At our test sites in Styria (Austria), data from only one state-wide LiDAR campaign is available. In some locations of Styria, LiDAR data acquisitions are more than 8 years old and thus no longer present the current state of the forest. It is therefore of high interest to forest managers to obtain updates of LiDAR-derived crown cover density products based on auxiliary data sets, such as optical satellite imagery.

We propose a new method to update LiDAR-derived crown density products and to map forest change. The method is based on Sentinel-2 data available to all users free of charge and an outdated LiDAR nDSM used to train a kNN classifier. Crown cover density products based on these data sets can therefore be provided at low costs and at short time intervals. Crown cover density estimations are derived for two tests sites in the Alps and the Alpine foothills of Austria. Results are compared with the LiDAR derived crown cover density information in unchanged forests and with the latest tree cover density product of the European Copernicus High Resolution Layers. Results demonstrate the operability of the workflow. User accuracies for forest change detection are very high with 87.3% and 94.8%.

8B

UAVS FOR FOREST MONITORING

Moderator: Samuli Junttila

1.(13:30) Using Unmanned Aerial System (UAS) LiDAR to characterise ecohydrological properties of eucalypt forests | *D Jaskierniak*, A Lucieer, G Kuczera, R Benyon, P Lane*

Forest growth dynamics within water supply basins dominated by eucalypt forests influence streamflow with changes in actual evapotranspiration (AET) during forest regeneration. We present a forest hydrology modelling framework that uses spatiotemporal forest growth models to explain vegetation-induced trends in streamflow arising from wildfire and logging. Aerial LIDAR derived forest stocking density (N), and basal area (BA) were coupled with forest inventory data from Permanent Growth Plots to estimate spatiotemporal forest growth. Relationships between field measured N, BA and sapwood area (SA) were developed to quantify spatiotemporal SA, a surrogate for annual AET. By subtracting SA derived AET from rainfall estimates, we estimated seasonal streamflow for three large water basins totally 915 km2 with Nash Sutcliffe efficiencies of 0.85, 0.87, and 0.91.

To date the spatiotemporal estimates of forest growth have been derived for the more dominant Ash forests (Eucalyptus regnans). For lower-rainfall basins with a more complex forest structure in Mixed Species Eucalypt Forest (MSEF) we use Unmanned Aerial Systems (UAS) LiDAR to scale plot-level measured SA. We captured UAS LIDAR data across 53 sites, with each flight consisting of approx. 3,000 points m-2 across 3 ha of forest. The surveyed MSEF is possibly the most detailed existing measure of forest structure in Australia.

To characterise MSEF a tree detection algorithm for UAS LiDAR is developed. We first isolated the over-storey stems in the UAS LiDAR with a vegetation profile analyses of vertical gaps to remove understorey and over-storey canopy. The retained LIDAR was segmented into tree stems using: a voxel method to remove mid-storey leaf-area surrounding over-storey stems; a morphological open/close procedure to identify cluster centroids within incrementally sliced horizontal planes of LiDAR up the height profile; and density-based clustering (DBSCAN) procedure to cluster the cluster centroids identified in the morphological procedure. Visual inspection of ultra-high resolution UAS LiDAR demonstrates over-storey trees being correctly identified in almost all cases when algorithm was calibrated to a flight. Heterogeneity in forest structure meant that using one set of parameters between all flights produced substantially poorer results. Using a measure of variability in UAS LiDAR point density distribution, a parameterisation procedure that scales parameter values between-flights is proposed.

2.(13:50) Assessing degraded forest structures using UAV and SAR remote sensing data | *C Bourgoin*, J Betbeder, P Couteron, L Blanc, N Baghdadi, L Reymondin, P Läderach, P Sist, V Gond*

Forest degradation accounts for 68.9% of overall forest carbon losses and changes forest structure. Due to the diversity (nature, intensity and frequency) of anthropogenic disturbances, multiple forest structures can be observed within the forest landscape mosaic. Remote sensing offers a unique opportunity to identify and characterize these structures. Very High Spatial Resolution (VHRS) optical imagery has the capacity to model forest canopy. SAR VHSR data which are independent of visibility conditions are capable to retrieve forest biomass, depending on the radar frequency and forest density. However, optical and SAR images have rarely been combined to study degraded forest structure.

The aim of this study is i) to characterize the structure of a wide range of degraded forests types using optical UAV imagery and ii) to evaluate the potential of VHSR SAR imagery for scaling up.

The investigated area is located in the human-dominated landscape of Paragominas municipality (Para state, Brazil).

52 UAV images of 25 ha (10 cm resolution) were acquired in September 2017 along the whole forest degradation gradient (from undisturbed to logged and/or burned forests) and to derive Digital Elevation Models. Four TerraSAR-X images were acquired in October 2017 (1.5m resolution) with different incident angles and polarizations.

Three textural indexes based on the spatial variation in pixel radiance were derived from VHSR images (Fourier Transform Textural Ordination spectrum, the lacunarity and the skewness indexes) within different window sizes (from 50 to 200m). Generalized Linear Models were established between the UAV and SAR derived indexes and the forest canopy heights. Models and robustness were assessed by calculating the coefficient of determination (R-squared), the Akaike information criterion (AIC) and the root mean square error (RMSE).

The combination of the three textural indexes from UAV images were able to capture the full gradient of canopy crown size distribution and canopy gaps and show a positive relation with the opening and lowering of the canopy. TerraSar X derived indexes showed most accurate results with the 26° incidence angle and HH-HV polarization.

This quantification is highly informative for forested land use planning and policy makers to better understand and characterize degraded forests status from local to regional scale.

3.(14:10) Digital aerial photogrammetry and unmanned aerial systems for assessing forest regeneration | *T Goodbody*, N Coops, T Hermosilla, P Tompalski, A Hervieux, P Crawford*

Accurate, reliable, and cost effective methods of evaluating forest regeneration success are needed to improve forest inventories and silvicultural operations. Traditional silviculture surveys are conducted on over 1 million hectares of forest in British Columbia annually, requiring substantial operational and logistical planning. To improve the efficiency and utility of forest regeneration inventories we propose a multi-temporal monitoring methodology to improve knowledge on the rates and characteristics of vegetative succession, while providing a means to evaluate the economic and operational success of management actions on public land. In this study we evaluate the potential of utilizing Unmanned Aerial System (UAS) acquired very high spatial resolution (~ 3 cm) imagery to provide spatial, spectral, and structural information on forest regeneration in previously clear-cut stands near Nakusp and Quesnel, British Columbia, Canada. Three stands approximately 5, 10, and 15 years since planting were chosen at both sites. Using wall-to-wall UAS acquired RGB imagery, dense Digital Aerial Photogrammetric (DAP) point clouds were produced to provide forest structure information, while spectral data in the form of Visible Vegetation Indices (VVI) were computed from ortho-imagery. Spectral and structural information from the VVI and DAP were combined to perform Object Based Image Analyses (OBIA) facilitating supervised classifications of forest cover into conifer, deciduous, and ground classes. Independent classifications were performed on each stand, yielding accuracies of up to 95 %. Spectral and structural differences amongst classes and ages were analyzed. Height and area coverage of conifers was found to increase with years since planting in both sites (0.7 2.7 m for Nakusp; 0.3 2.2 m for Quesnel), while VVI metrics were shown to be successful at differentiating forest cover through time. The results of this study indicate that UAS acquired imagery has a potential niche for quickly, accurately, and reliably providing highly detailed spatial, spectral, and structural information on forest regeneration. Methodology and data products from this study show promise for benefiting silvicultural monitoring and operations while improving multi-temporal forest inventory knowledge.

4.(14:30) Estimating the height of conifer seedlings in recovering linear disturbances with UAV photogrammetry | *G Castilla*, M Filiatrault, M Gartrell, MF Wu, G McDermid*

Seismic lines (narrow corridors used to transport and deploy geophysical survey equipment for oil and gas exploration) have a prominent indirect role in the decline of threatened woodland caribou. If this decline persists, Canadian federal law contemplates temporary prohibitions of industrial activity in the affected ranges. Hence seismic line restoration is a top priority for industry and governments alike, who need information on the number and condition of conifer seedlings growing on them. Unmanned Aerial Vehicles (UAVs, aka drones) can add substantial value to monitoring efforts by providing low cost, very high-resolution 2D and 3D data. With an inexpensive UAV, it is possible to capture geolocated, above-canopy digital photographs that can then be automatically aligned using a Structure from Motion workflow to create a 3D model that has orders of magnitude more points than the typical airborne LiDAR acquisition. These dense point clouds, and their associated orthophotos, can be used for a variety of forest applications, including restoration. The goal of this study is to assess to what degree it is possible to monitor seismic line vegetation recovery using UAV-based Digital Aerial Photogrammetry (DAP). We measured from the ground the height and precise location of hundreds of conifer seedlings growing on seismic lines within the Cold Lake Caribou Range in Alberta. Then we flew the lines with a UAV carrying a gimbaled digital camera. We derived DAP point clouds from several acquisitions at different altitudes above ground level, both leaf-on (August) and leaf-off (October). Finally, we estimated the height of the seedlings using different combinations of point cloud metrics. Preliminary results suggest there is a sufficiently strong linear relation between seedling height and metrics derived from photogrammetric point clouds as to estimate the former from the latter. Furthermore, as both spatial resolution and point density decrease with higher altitude flights, the coefficient of determination (R2) hardly decreases, and the root mean square error (RMSE) hardly increases; however, the underestimation bias grows more pronouncedly.

5.(14:50) Measuring savanna structure using multi-sensor drone data to derive closure criteria for mine site revegetation | *R Bartolo*, P Erskine, T Whiteside, L Hernandez Santin, M Rudge, S Levick*

The Ranger uranium mine, surrounded by the World Heritage listed, Kakadu National Park, in northern Australia, is closing in 2026. It is expected that rehabilitation of the site to agreed closure criteria for flora (revegetation) will take decades. These closure criteria for revegetation are currently being refined and will ultimately represent measures of savanna community structure and vegetation architecture at-scale (>400 ha) to meet the Environmental Requirements with which the mine must comply.

Over the last few decades, a considerable amount of work has been conducted within the region to assess reference savanna communities. Surveys have generally focused on areas close, or adjacent, to the mine lease areas and have been conducted by a number of different teams. Not surprisingly there has also been a range of approaches to the design, replication, plot size and strata selected for the survey of vegetation. Understory components were not typically measured. These inherent differences make these datasets difficult to use together for the goal of setting quantitative mine site closure criteria.

The main aims of the project are: 1) to select and establish appropriate scale vegetation analogue plots in the surrounding environment; 2) to measure floristic species composition, relative abundance and structure to refine existing closure criteria; and 3) to develop drone- based methods for measuring species composition, relative abundance and structure at-scale. A key sub-aim is to develop drone-based methods to characterise and assess understory flora.

During October 2017 and March 2018, 8 x 1ha plots were established and surveyed using the AusPlots method (1000 intercept-points). Using both fixed-wing and multi-rotor drone platforms, LiDAR, hyperspectral and 5-band multispectral data were collected over the plots in March 2018. The drone-based LiDAR was also compared to ground-based terrestrial laser scanning (TLS) in one plot to determine how much of the understory structure can be recorded by the drone-based LiDAR. Further surveys are planned for September - October 2018 and March 2019 to capture dynamics in phenology and increase our ability to identify species using remote sensing methods.

The findings of this study show that drone-based measurements provide us with the ability to collect savanna community structure information at-scale in a manner not previously possible (including accounting for seasonal differences).

8C

LAND COVER AND LAND USE CHANGE

Moderator: Randolph Wynne

1.(13:30) Characterizing Forty Years of Forest Change in Minnesota: Applications in Forest and Wildlife Science | *J Vogeler*, M Falkowski, R Slesak*

Forest disturbance dynamics (arising from harvest, fire, wind, land conversion, etc.) play a fundamental role in the health and resilience of multiple forest resources including water quality, wildlife habitat, and wood resources, among others. Our research utilizes the full value of the long running Landsat archive by harmonizing and incorporating imagery dating back to 1972 to provide >40 years of comparable inter-annual trends in forest dynamics across the Laurentian mixed forest province of Minnesota. Our approach combines the LandsatLinkr R package for harmonizing spectral indices across all Landsat sensors with the LandTrendr segmentation algorithm to reduce annual noise through trend fitting, resulting in the creation of smoothed spectral indices for annual forest change detection. We further classified the annual disturbance patches by the agent of change (e.g. harvest vs. wind-throw), for which we calculated classification error rates from independent validation assessments. We demonstrate the utility of these annual maps of forest change for quantifying trends in forest disturbance agents across the time period of the study, along with applications for habitat change assessments for wildlife species of management and conservation interest.

2.(13:50) Extrapolating forest biomass dynamics through space and time using Landsat time series and inventory data | *T H.Nguyen*, S Jones, M Soto-Berelov, A Haywood, S Hislop*

Wall-to-wall predictions of forest biomass over time are important to forest monitoring and reporting systems. These can be achieved by integrating data from field plots with a time series of satellite imagery, in particular data from the Landsat archive. Previous studies have demonstrated methods for estimating forest biomass variables for a single-date that mostly coincides with the date of field measurement. In this study, we propose an imputation approach for extrapolating forest biomass variables (total above ground biomass (AGBtotal), above ground biomass of live (AGBlive) and above ground biomass of dead-standing trees (AGBdead)) across large areas and long time periods (1987-2016). We tested our method over seven million hectares of public forests in Victoria, Australia. We developed imputation models to relate plot-level biomass response variables to spatial predictor variables of spectral properties, and topographic and climatic conditions using the Random Forest based k-Nearest Neighbor algorithm. Spectral predictors included range of indices and change metrics derived from the analysis of Landsat TM/ETM+ annual composites. We validated the accuracy of our models in estimating forest biomass and its change using a withheld remeasured inventory plots. Our model assessments reported that R2 values were 0.59, 0.60 and 0.46 for AGBtotal, AGBlive, AGBdead, respectively. Validations of biomass change obtained the R2 values of 0.57, 0.52 and 0.19 for AGBtotal, AGBlive, AGBdead, respectively. Spatial and temporal predictions of biomass showed coherent trends in relation to the patterns of forest disturbance and recovery history, indicating the ability of our models in capturing ecological processes occurring in forests. These findings suggest that forest biomass dynamics can be effectively extrapolated through space and time using imputation methods and Landsat time-series. This work can support land managers and researchers in their forest monitoring practices at the landscape scale.

3.(14:10) Novel Map-to-Image Change Detection for Mapping Forest Change: Case Study for Wales, UK | *M Philp*, P Bunting, A Hardy, R Jensen*

Forest monitoring is crucial for maintaining for biodiversity, forest health, management and resources. Earth observation data is an established tool for providing high temporal resolution data of large or inaccessible forests. Freely available consolidated archives and decreases in revisit periods have increased monitoring potential dramatically. However, current change detection approaches are not always well-equipped to generate high temporal resolution land cover maps, handle a cloud-contaminated archive or form a monitoring system. The novel 'map-to-image' approach uses contemporary satellite imagery to identify change in relation to a baseline map, thereby providing an updated thematic map and generating a time series of classifications. The method assumes that the area of the change features is small compared to the whole. Change is identified using statistical deviations of land cover subsets. Two change methods are investigated: optimised skew and kurtosis threshold of a parametric histogram and fuzzy-rough logic. The map-to-image approach is applied to coniferous forest cover in Wales, UK (1990 - 2017) using 119 Landsat (TM, ETM+ and OLI) and 57 Sentinel 2 scenes (178 total). An accuracy assessment (70,000 points) of the parametric histogram threshold approach produced an overall accuracy of 93.6% and a kappa of 0.92. A comparison of change detection accuracy using fuzzy-rough logic is expected to show improved accuracies and remove the assumption of a normal distribution. Currently, results illustrate that the map-to-image change detection approach provides a novel, robust and accurate way of analysing both historical change and continuous monitoring of forest cover. With further work and when combined with the increasing volume of Earth Observation data it represents a tractable, scalable solution for generating a 'living map' of forest and other land cover data.

4.(14:30) Three Decades of Hyrcanian Forest Canopy Density Change in Iran | *M Taefi Feijani*, A Tavakoli, A Alimohammadi Sarab*

Forest canopy density (FCD) of seventeen protected areas of the Caspian hyrcanian mixed forest are studied here. A modified version of FCD mapper based on spectral band fusion and customized threshold calibration that is optimized for hyrcanian forests is used for this purpose.

FCD is a critical parameter in the planning and implementation of forest rehabilitation programs. A biophysical analysis model (FCD Mapper) is used that utilizes LANDSAT TM and ETM images to generate the four components of the FCD model of vegetation, bare soil, thermal and shadow indices.

In order to achieve a higher classification precision, the Spectral Response and Smoothing Filter Based Intensity Modulation (SFIM) fusion algorithms that emphasize on conserving the spectral characteristics and radiometric values of the bands are used. Then, using the new images with smaller pixel size, the FCD model was applied.

The methodology was validated by comparing the results with the Haraz watershed FCD maps that were based on visual interpretation of aerial photos and field surveying that were provided by Forest, region and watershed organization of Iran (FRWO). An overall accuracy of 81.59 percent and kappa coefficient of 0.65 was achieved.

The total 195356 ha of these seventeen protected areas were analyzed by this methodology from 1987 to 2017 in five year intervals. Considering that these forests were declared as protected areas in 1992, the following was concluded. Prior to this date, a declining trend in FCD is observed. Afterward, from 1992 to 1997, due to natural forest regeneration and less human intervention, a slight increase in FCD is noticed. Since the Department of Environment (DOE) did not take any serious protective measurement other than posting signs indicating that these areas are protected, gradually human intervention returned back again and thus, a gradual decrease in FCD from 1997 up to this date is detected.

5.(14:50) The Past and Future Land Use Footprint of Global Palm Oil | *I Collins, E Goldman**

Palm oil is traded globally through complex supply chains, with 54% of the global supply coming from Indonesia. While an important part of Indonesia's GDP, palm oil is also one of the world's leading deforestation drivers and contributes to global greenhouse gas emissions. To meet sustainability goals, companies that source palm oil for their products need accurate benchmarks for palm oil's past impact on deforestation and associated emissions, as well as concrete options for how to reduce their land use and carbon footprints going forward. Here we present a global map of the deforestation and emissions associated with the palm oil industry's expanding land use footprint over the past 25 years. We delineated a global supply shed for palm oil using locations of palm oil mills and the network analyst tool in ArcGIS to generate road network buffers around mills. Within these areas, we calculated net emissions from oil palm plantation expansion, including biomass loss, as well as peat drainage and burning, to determine a baseline of emissions from deforestation due to palm oil. These results can be used by companies and governments as a benchmark for assessing progress towards achieving sustainability in the sector overall. Next, we examined the potential future impacts of 23 individual oil palm permits planned for the Indonesian province of Papua, home to some of Southeast Asia's last remaining intact forest landscapes that are critically important for carbon, biodiversity and local livelihoods. Primary forests and peatlands inside Papua's oil palm concession boundaries were analyzed for possible emissions from biomass loss if the land was cleared over the next several years based on current rates of land use change. We conclude that the planned expansion of oil palm concessions into Papua poses a threat both to corporate sustainability goals as well as to the Indonesian government's Paris Agreement pledge to reduce national emissions by 29 to 41 percent by 2030.

8D

NEXT GENERATION LARGE AREA FOREST MONITORING 2: SENSOR FUSION

Moderator: Mike Wulder & Sean Healey

1.(13:30) Fusion of GEDI, ICESAT2 & NISAR data for above ground biomass mapping in California and Gabon | *L Duncanson*, A Neuenschwander, M Simard, N Thomas, S Hancock, J Armston, R Dubayah, M Hofton, S Marselis, S Saatchi, C Silva, L Fatoyinbo*

Several upcoming NASA missions will collect data sensitive to forest structure (GEDI, ICESAT-2 & NISAR). The LiDAR and SAR data collected by these missions will be used in coming years to map forest aboveground biomass at various resolutions. This research focuses on developing and testing multi-sensor data fusion approaches in advance of these missions in both temperate forests (Sonoma County, California) and tropical forests (Gabon, Africa). We aim to a) understand errors from the three missions with respect to forest height, slope, and % canopy cover, b) quantify expected errors from each mission independently and c) test data fusion approaches for wall-to-wall biomass SAR mapping calibrated with lidar structure.

GEDI and ICESat-2 data are simulated from discrete return lidar collected over Sonoma County, California, and Mondah National Park in Gabon. Both sites also have airborne UAVSAR L-band data that is filtered to approximate expected NISAR L-band backscatter. Reference biomass maps are generated through regionally calibrated discrete return lidar datasets based on random forest models that predict field estimated biomass as a function of lidar percentile height metrics. These 25 m biomass maps are then rescaled to the nominal expected resolution of the GEDI, NISAR and ICESat-2 products to evaluate errors at the native resolution of each sensor.

Biomass models for GEDI and ICESat-2 are developed using GEDI's global calibration/validation database of linked field and airborne lidar datasets, while NISAR biomass estimates are based on locally calibrating L-band backscatter with the discrete return lidar biomass maps. Biomass residuals for each mission, and for fusion approaches, are calculated with respect to this airborne lidar map.

NISAR estimates of biomass are most heavily influenced by canopy cover and slope, and errors increase substantially after ~100 Mg/ha, as expected. ICESat-2 models developed using GEDI's calibration equations overestimate biomass in areas of dense canopy cover, because height metrics gleaned from simulated ICESat-2 are biased high due to the relatively small proportion of photons that penetrate to the ground. This research demonstrates the utility of airborne lidar as a multi-scale validation tool for global biomass validation either for individual mission products or fusion-derived biomass maps.

2.(13:50) Cross-validation and transferability performance of GEDI footprint aboveground biomass models | *J Kellner*, J Armston, J Blair, L Duncanson, S Hancock, S Healey, M Hofton, S Luthcke, S Marselis, D Minor, P Patterson, H Tang, R Dubayah*

The Global Ecosystem Dynamics Investigation will place a multi-beam waveform lidar instrument on the International Space Station. GEDI data will provide globally representative measurements of vertical height profiles (waveforms) and estimates of aboveground carbon stocks. Here we describe the algorithm theoretical basis for the L4A footprint aboveground biomass data product, and benchmark the performance of candidate statistical models using a comprehensive global dataset. The L4A data product is aboveground biomass density (AGBD, Mg · ha-1) at the scale of individual GEDI footprints (22 m). Footprint AGBD is derived from statistical models that relate waveform height metrics to field-estimated aboveground biomass. We used a waveform simulator to generate simulated GEDI waveforms from discrete-return airborne lidar data. We associated height metrics from simulated waveforms with field-estimated aboveground biomass at sites in temperate and tropical regions of North and South America, Europe, Africa, Asia and Australia. We evaluated the ability of empirical and physically-based regression and machine learning models to predict AGBD at the footprint level, and characterize these models in terms of the percentage root mean squared error (RMSE) and bias. Our analysis demonstrates that empirical, physically-based and machine learning models can produce RMSE that meets GEDI requirements. We discuss tradeoffs in complexity and performance among the set of models that produces unbiased predictions.

3.(14:10) Generalized hierarchical model-based estimation for biomass assessment using GEDI and Landsat data | *S Saarela*, S Holm, SP Healey, H Petersson, W Prentius, PL Patterson, E Næsset, TG Gregoire, G Ståhl*

Recent developments in remote sensing technology make it apparent that several sources of auxiliary data nowadays are available to support forest inventories. Thus, a pertinent question is how different sources of remotely sensed (RS) data should be combined with field data to make inventories cost-efficient. Hierarchical model-based estimation has been proposed as a promising way of combining non-expensive wall-to-wall RS data with a sample of expensive RS data and a sparse sample of field data. Data from both of latter sources usually are strongly correlated with the target attribute to be estimated. Model predictions based on the expensive RS data source are used for estimating a model linking the target quantity with non-expensive wall-to-wall RS data. Basing the inference on the latter model, uncertainties due to the both modelling steps must be accounted for to obtain reliable variance estimates of estimated population parameters, such as totals or means.

Here, we generalize previously existing estimators for hierarchical model-based estimation so that the technique can be used also in cases with clustered data and when the models have non-homogenous variance. This is an important generalization, since many samples of field and RS data are clustered in practical surveys. We apply the new estimation framework to case studies that mimic the data that will be available from the Global Ecosystem Dynamics Investigation (GEDI) mission and compare the proposed estimation framework with an existing method based on two-stage least squares theory. The proposed method is of interest especially in cases when field data are sparse and accurate models can be estimated to link field data with sample RS data. In our case studies aboveground biomass was the target variable, Landsat data were available wall-to-wall, and sample RS data were obtained from an airborne lidar campaign that produced simulated GEDI waveforms. The results show that generalized hierarchical model-based estimation has a potential to yield more precise estimates than approaches utilizing only one source of RS data, such as model-based and hybrid inferential approaches.

4.(14:30) National-scale aboveground biomass geostatistical mapping with FIA inventory and GLAS data: Preparation for sparsely sampled lidar assisted forest inventory | *C Babcock*, A Finley, H Andersen, D Morton, B Cook*

Upcoming satellite lidar missions, such as GEDI and IceSat-2, are designed to collect laser altimetry data from space for narrow bands along orbital tracts. As a result lidar metric sets derived from these sources will not be of complete spatial coverage. This lack of complete coverage, or sparsity, means traditional regression approaches that consider lidar metrics as explanatory variables (without error) cannot be used to generate wall-to-wall maps of forest inventory variables. We implement a coregionalization framework to jointly model sparsely sampled lidar information and point-referenced forest aboveground biomass (AGB) to create wall-to-wall maps with full probabilistic uncertainty quantification of all inputs. We inform the model with USFS Forest Inventory and Analysis (FIA) in-situ forest measurements, G-LiHT airborne and GLAS spaceborne lidar to spatially predict AGB across the contiguous US. We cast our model within a Bayesian hierarchical framework to better model complex space-varying correlation structures among the lidar metrics and FIA data, which yields improved prediction and uncertainty assessment. To circumvent computational difficulties that arise when fitting complex geostatistical models to massive datasets, we use a Nearest Neighbor Gaussian process (NNGP) prior. Results indicate that a coregionalization modeling approach to leveraging sampled lidar data to improve AGB estimation is effective. Further, fitting the coregionalization model within a Bayesian mode of inference allows for AGB quantification across scales ranging from individual pixel estimates of AGB density to total AGB for the continental US with uncertainty. The coregionalization framework examined here is directly applicable to future spaceborne lidar acquisitions from GEDI and IceSat-2. Pairing these lidar sources with the extensive FIA forest monitoring plot network using a joint prediction framework, such as the coregionalization model explored here, offers the potential to improve forest AGB accounting certainty and provide maps for analysis of the spatial distribution of AGB.

5.(14:50) Early Spring Radiative Forcing Dynamics in North American Boreal Forests Using Albedo Products from Landsat and Sentinel-2 | *A Erb, Z Wang, B Rogers, S Healy, D Hall*

Land surface albedo plays an important role in the surface energy budget and surface shortwave radiative forcing by determining the proportion of absorbed incoming solar radiation available to drive photosynthesis and surface heating. In northern biomes, albedo is particularly sensitive to land cover and land use change and modeling efforts have shown it to be the primary driver of effective surface shortwave radiative forcing from the biogeophysical effects of land cover change. In forests over mid- and high-latitudinal areas, the effects of these changes are further complicated by changing snow covers during the early spring when the presence or absence of highly reflective snow coupled with an increase in solar insolation can serve as the primary driver of seasonal surface shortwave forcing. As such, it is critical to understanding the magnitude and persistence of these disturbances and their interactions with snow covers with regard to radiative forcing dynamics across spatial and temporal scales.

The albedo products used in this study couple 30m and 20m surface reflectances, respectively from Landsat and Sentinel-2 sensors, with concurrent 500m-gridded Bidirectional Reflectance Distribution Functions (BRDF) Products from the MODerate resolution Imaging Spectroradiometer (MODIS). The improved temporal and spatial resolution made available through the combination of Landsat and Sentinel-2 imagery provides a better record of high-quality and unsaturated albedo values through rapid and dynamic seasonal changes. Recent work on the early spring albedo of fire scars has illustrated significant post-disturbance spatial heterogeneity of burn severity at the landscape scale and highlights the need for a finer spatial resolution albedo record.

This work aims to identify and track early spring albedo trends across a latitudinal gradient in forests over the northern latitudes using high resolution Landsat and Sentinel-2 derived albedo products. The impact of disturbance and vegetation shifts across the boreal forest on the surface albedo and hence the surface energy budget are examined. We will present how changes in the early spring albedo of recent forest disturbance and land cover change in northern latitudes affect landscape-scale surface shortwave radiative forcing.

9A

GROUND-BASED AND PROXIMAL SENSING

Moderator: John Armston

1.(15:30) Vegetation change in response to an extreme snowfall event using multitemporal terrestrial laser scanning | *J Greenberg*, Z Hou, R Hart, N Marchi, A Parra, R Tompkins, A Harpold, B Sullivan, P Weisberg, C Ramirez*

The Sierra Nevada Mountains experienced record-breaking snowfall during the 2016-2017 winter after a prolonged period of drought. We hypothesized that at lower elevations, the increased snowmelt would result in a significant increase in biomass across vegetation strata, but at higher elevations, the prolonged snowpack would result in a diminished growing season, and yield a suppression of growth rates particularly in the understory vegetation. To test these hypotheses, we using a terrestrial laser scanner to sample sites across the Plumas National Forest and Lake Tahoe Basin (CA/NV) in the early growing season, and then rescanned these sites in the late growing season. Herein, we present results from a voxel-based change detection as it relates to site microclimate and soil moisture.

2.(15:50) Rigorous assessment of sub-canopy structural dynamics in global savanna systems at landscape scales through long-range terrestrial laser scanning (LR-TLS) | *S Levick*, M Guderle, J Singh, G Cook, L Hutley, S Trumbore*

Quantifying spatial-temporal patterns of ecosystem dynamics is essential for landscape management and biodiversity conservation. Rapid assessment of vegetation structure in savannas at fine scales (individual branch) over large scales (hillslopes to catchments) is challenging as: i) field-based plot measures cannot capture the heterogeneity inherent in savanna ecosystems; and ii) most remote sensing techniques cannot capture subtle changes in three-dimensional structure. Repeat airborne LiDAR has provided unique insight into large tree dynamics in savanna ecosystems, but we still lack understanding of sub-canopy scale dynamics and rates of growth - which require measurements with even higher resolution, accuracy and precision. Recent advances in long-range terrestrial laser scanning (LR-TLS) have opened the door to large scale, fine resolution repeat surveying of vegetation structure. We used a LR-TLS (Riegl VZ-2000) to sample 300-500 ha landscape plots in southern African and northern Australia savannas in 2015, 2016 and 2017. Here, we present data illustrating how LR-TLS can provide valuable spatio-temporal information at scales not feasible from traditional TLS and ALS sampling. We our time-series of LR-TLS data to quantify rates of growth and mortality over broad landscapes. We reveal different rates of large tree turnover in African and Australia savannas (6 % and 2 % respectively), and illustrate the dynamic nature of the recruitment later - with some saplings gaining 1 m in height per year with no increase in DBH. These results are important for constraining rates of change in global dynamic vegetation models, and highlight the need to move to 3D metrics of vegetation growth. Our findings also provide insight into ecosystem dynamics that need to be taken into account when propagating uncertainty in the upscaling of field-plot data to landscapes and regions via global satellite platforms.

3.(16:10) Using Zeb1, a highly-mobile terrestrial laser scanner, to assess and measure trees in an eastern hemlock-dominated forest | *D Crawford*, T Jovanovic, C Brack, A Stovall, D MacFarlane, J Frank, T Condon, A Strahler, C Schaaf, A Barker-Plotkin, D Orwig*

In August 2017, a collaborative terrestrial lidar scanning exercise took place in Harvard Forest (HF), Petersham, Massachusetts, USA. A number of fixed and mobile TLS instruments were employed in the activity. This paper reports the preliminary results of analysis of scans from a highly mobile TLS, the GeoSLAM Ltd Zeb1. The instrument has a single-laser wavelength of 905 nm and an outdoor scanning distance of up to ~15 m. Data is readily collected by slowly walking through the environment of interest.

A 50 x 50 m forest plot dominated by eastern hemlock (Tsuga canadensis (L.) Carriere) was measured as part of the HF activity. From over 300 plot trees, 16 were identified for destructive sampling to obtain detailed measurements to compare to the scans. The entire plot was covered by four scans with the Zeb1, each taking 15-20 minutes. Using the free computer software CloudCompare and 3D Forest, point clouds of the harvested trees were identified and extracted. Point clouds of approximately 45-50 more trees in each scan were also extracted. Linear regression analysis of the point cloud-estimated diameter at breast height (DBH) versus manual field measured DBH for 196 trees had an R2 of 0.975 and an RMSE of 2.03 cm. For the 16 harvest trees there was good agreement between the point cloud estimates and harvest data for stem diameter at ~1.2 m intervals up to about 6 m, indicating that the Zeb1 scans provide useful information on lower stem form and taper. Although the Zeb1 scans were unable to reach the tree tops (25+ m), the lower stem information obtained is important for informing tree models. We explore how the Zeb1 point clouds can be used for producing stem models and biomass estimations.

4.(16:30) Quantifying forest structure, complexity, and biomass using the Leica BLK360 terrestrial laser scanner | *J Atkins*, A Stovall, G Clark, B Hardiman, C Gough*

More precise and better constrained estimates of forest structure, complexity, and biomass are important to inform earth system models and for carbon accounting. Terrestrial laser scanning (TLS) provides a non-destructive means to accomplish this goal, but the high-cost of TLS units has been, in part, a reason this methodology has not been embraced more broadly. Using a new, lower-cost TLS 3-D LiDAR unit, the BLK360 from Leica Geosystems, we scanned forests of varying structure to evaluate the BLK360's performance and precision in quantifying forest biomass, complexity, and structure. At Observatory Hill, a mixed-forest in central Virginia, structure and biomass data derived from the BLK360 were compared with those from the Faro FOCUS, a well-established and validated TLS unit. Results indicate a slight positive bias in both stem diameter and tree volume for the BLK360 over the FOCUS, while tree height shows no difference. During the summer of 2018, the BLK360 will be used to quantify forest structure and complexity across a secondary forest successional gradient at the Blandy Experimental Farm in northern Virginia, encompassing stands from 20 to 100 years in age. Along this successional gradient, the BLK360 will be compared with the portable canopy LiDAR (PCL) to test the ability of the BLK360 to estimate forest structure and complexity. These data will also be validated by ground-truth data (e.g. diameter at breast height, tree height, leaf area index, etc.). The successional gradient allows for a useful comparison across widely variant structure and age classes under similar climate conditions. If lower-cost systems such as the BLK360 provide reasonable estimates of forest structure, complexity, and biomass, the bar of entry for this technology has been lowered, creating new opportunities for both research and application.

5.(16:50) Forest Inventory and Mapping with a Photo Point Cloud and FIA Plots for WA State | *J Strunk*, H Andersen, P Gould, C Maki, B McGaughey, D Gatziolis*

Objectives:

The data collected by the Forest Inventory and Analysis (FIA) program is a powerful tool for inferences about forest conditions across the USA. While the grid of approximately 1 plot / 6000 acres is designed for county level estimation, there are many cases where finer resolution and improved precision are desired. One strategy for improved resolution and precision is to leverage auxiliary data for mapping and estimation. There is, however, a need to acquire auxiliary information which is consistent across large areas, affordable, and able to sufficiently explain variation in attributes measured by FIA, such as volume, to merit the effort.

One promising candidate source of auxiliary information is forest height derived from stereo imagery, specifically the pushbroom stereo imagery which is collected to support the National Agricultural Imagery Program (NAIP). Obtaining forest height from stereo imagery also requires a ground elevation model, for example a lidar-derived ground model or the USGS ground model. Desirable characteristics of NAIP imagery include that the data are collected consistently across the entire contiguous USA, and that they are collected frequently (every 2-3 years).

The objective of our study is to evaluate improvements in precision and resolution that are feasible by combining FIA plots with a NAIP imagery derived canopy height information for Washington State. We also investigate the effects of plot coordinate precision, and source of ground model on modeling and estimation.

Methods:

The analysis was conducted for WA State using 2015 FIA field plot measurements on forest lands, and a digital surface model generated from 2015 40 cm pushbroom imagery for NAIP and the hexagon imagery program. Plot locations were precisely geo-reference in the field using high-end resource grade GNSS receivers. Performances were evaluated using estimated efficiency (inverse design effect), model performance (coefficient of determination and scatter plots), and with visual demonstrations of feasible resolutions for inference.

Key findings:

We found that 4 to 6 fold improvements in efficiency for cubic foot volume were feasible when using auxiliary height information and regression models for volume were able to explain up to 70% of variation (R-squared). In addition, inclusion of auxiliary height information increases the resolution of inference that is feasible with FIA data from county level to at least 20m pixels, although county level es

9B

HIGH SPATIAL RESOLUTION MAPPING

Moderator: Erik Willén

1.(15:30) Assessing the height and density of subarctic lichen woodlands using stereo measurements performed on WorldView 3 images | *B St-Onge*, S Grandin*

Lichen woodlands (LW) occupy vast portions of the circumpolar subarctic boreal forest. In Canada, LW covers 2 million km2. They are characterized by sparse and short trees (< 10 m) having very narrow crowns. Basal area is generally below 10 m2ha-1. The evolution of LW under climate change is not well documented. Gathering information on the structure of LW is made difficult by their remoteness and the scarcity of roads and airports. Medium and low resolution imagery from space only provides very approximate values for structural attributes. Airborne surveys are logistically difficult and expensive. Airborne laser scanning is not well adapted to these forests as many crowns are so narrow that some fall between scan lines. For these reason, we have assessed the accuracy of stereo measurements performed on 31 cm resolution WorldView-3 (WV3) images to assess the height and density of LW. The goal is to evaluate if this could be used to create virtual plots, as a sampling strategy that would not require field work or airborne surveys. Such plots could also be used to calibrate ICESAT-2 based methods. A stereo-pair of WV3 was acquired on July 7 2017 over a 102 km2 region (centred on 78.7o W, 53.7o N) and tied to 8 ground control points. 18 plots of 400 m2 were intensely measured (including the height of all trees >= 2 m) in the field and reconstructed in 3D using UAV images. The height (H) and position of 212 trees visible on both WV3 images was measured using manual stereo pinpointing of the tree tops and ground on the WV3 pair. On average, the r2 between WV3 and field H was 0.84, with a RMSE of 1.27 m and a negative bias of 0.83 m. Based on confrontation with field and UAV data, the bias could be mostly attributed to the underestimation of tree top height, although the ground elevations were also slightly underestimated. In stereo, the detection rate of trees having H>= 2 m was rather low, at 25%. However, the detection rate or trees having H>= 4 m was much higher, at 42%, and the r2 against field counts per plot was 0.41. At this stage, H from stereo WV3 images can be accurately assessed after bias correction (residual RMSE of 0.96 m), and the number of trees can be predicted with moderate uncertainty. This opens the possibility of estimating basal area, and eventually biomass. Future research will be directed toward using monoscopic approaches for detecting trees on each of the images forming a stereo-pair, as a complement to the current methodology.

2.(15:50) Canopy height models from very high resolution Pléiades stereo images over mountain regions. | *L Piermattei*, M Marty, W Karel, M Hollaus, C Ginzler, N Pfeifer*

Forest canopy height describes the top of the vegetated canopy and it is an important input for the estimation of forest structure parameters and for retrieving forest resources. For deriving current data on canopy height at wide spatial coverage i.e. at landscape scale, remote sensing observations with high temporal and spatial resolutions are required. In comparison with airborne remote sensing, very high resolution (VHR) stereo satellite imagery has the benefit of worldwide availability without any access restrictions and large area coverage from local to regional scale. Furthermore, satellites have the potential of high temporal resolutions of a few days only. Among the available VHR satellites, here we consider canopy height models (CHMs) derived from the Pléiades system to test its operational feasibility for forest monitoring. This system has a great agility to steer acquisitions of a specific area of interest. Moreover, it is designed to acquire along track Stereo (forward-, backward-views) and Tristereo (forward-, nadir-, backward- views) images with daily revisit capability. This work investigates the potential of using 4-band pan-sharpened Tristereo Pléiades imagery with 0.70 m resolution to calculate the CHM over a forested mountain region. The study area of around 120 km2 is located in the Alpine region of Ticino (Switzerland). We compare the accuracies of Pléiades Tristereo and Stereo CHMs and the impact of topographic characteristics like slope, aspect and shadow on them. We use a CHM derived from aerial images as reference for evaluating the accuracies and the agreement with CHMs from Pléiades data. From the Pléiades and aerial CHMs, we extract the same forest height metrics (i.e. median, 95 quantile and maximum height) within raster cells of 10 by 10 m and compare the results. With respect to the aerial forest metrics, the maximum Pléiades CHM has a median negative systematic shift of 90 cm and 65 cm for Tristereo and Stereo, respectively. However, over young trees (< 5 m), the maximum Pléiades canopy height is higher than the aerial CHM, with a positive median of about 0.60 m. Additionally, the median error in maximum height is 1 m larger on steep terrain (> 50°) for both Pléiades CHMs and that the error increases in shadow areas. By contrast, the aspect does not affect the accuracy of the CHMs. We conclude that stereo Pléiades satellite imagery provides a sufficient alternative to airborne remote sensing for canopy height monitoring over large mountain areas with high temporal resolution.

3.(16:10) Classification of dominant forest tree species by multi-source very high spatial resolution remote sensing data | *B Del Perugia, D Travaglini*, A Barzagli, F Giannetti, S Nocentini, G Chirici*

Information on forest tree species composition is required for forest management planning and to assess indicators for Sustainable Forest Management. Forest tree species composition is classified using subjective methods based on ground-based visual observations. Remote sensing platforms equipped with multispectral and/or laser scanning sensors provide very high spatial resolution data useful for forest classification, and small-unmanned aerial vehicle (UAV) is a rapidly evolving technology which offers new opportunities to such end.

In this study we compared the use of multispectral and point cloud based data taken from conventional (helicopter) and unconventional (UAV) remote sensing platforms to classify dominant forest tree species in Mediterranean environments. The study was carried out in the Apennine Mountain, central Italy. The study area was 270 ha large and hosted forest stands dominated by seven tree species, both conifers and broadleaf, plus two mixed formations, for a total of nine classes.

Airborne laser scanning data with a point density of 10 pts/m2 and multispectral data (RGB and NIR) with 20 cm spatial resolution were taken using an Eurocopter. RGB and NIR data with 10 cm spatial resolution were also acquired using a fixed wing UAV. 3D point clouds with a point density of 20-40 pts/m2 were derived from UAV images. We divided the study area into a grid of quadrats of side 23 m and each quadrat was assigned to a dominant forest tree species class by visual inspection of remote sensing data. For each quadrat, helicopter and UAV's data were used to extract both multispectral features and point cloud-derived metrics. For classification purposes, the quadrats were divided into training sites (35%) and test sites (65%). Two supervised classifiers were tested: Random Forest (RF) and k-NN. Several combinations of data sources were adopted for both helicopter and UAV data: RGB, NIR, NDVI and point cloud alone, and all data sources. The accuracy of the supervised classifications was assessed against the visual one.

Our results show that the best accuracy of dominant forest tree species was obtained with RF using all data sources, achieving an overall accuracy (OA) of 0.705 and a KIA of 0.628. OA and KIA increased by 29% and 50%, respectively, when helicopter instead of UAV data were used. OA and KIA increased up to 0.834 and 0.777, respectively, when forest categories (conifers, broadleaf and mixed) instead of forest tree species were considered.

4.(16:30) D-SAR: A Novel Drone-Based SAR System for the Radar Characterisation of Forest Canopies | *K Morrison*, N Fox, L Bassett, P Minchinton*

The work concerns the development of D-SAR, a drone-based synthetic aperture radar (SAR) imaging system. It is a joint venture between the University of Reading and the UK's National Physics Laboratory. It has as its goal the radar characterisation of Wytham Woods, a tract of semi-natural woodland which has been the focus of numerous long-term monitoring projects. The drone is based around a programmable, free-flying hexacopter carrying a stepped-frequency CW radar. The work will commence with a C-band study, although the flexibility of the radar allows future operation anywhere over the range 0.03-18GHz. A principal issue in SAR imaging performance is positional accuracy and stability of the drone. The process utilizes a coherent summation, where each subsequent sweep is offset from the previous one by a fixed distance along an image transect. Irregular movement between measurements will lead to image degradation from blurring. In addition, the sweep time at each measurement position could be as long as several seconds, during which time positional stability must be maintained. Data collection will consist of a series of horizontal linear transects collected above a canopy, typically tens of metres in length. Image processing uses a SAR scheme known as tomographic profiling (TP), developed specifically for examination of the internal structure of semi-transparent media such as forest canopies and snow packs. With conventional SAR processing the canopy would appear pancaked flat, obfuscating separation even between canopy and ground returns. In contrast, TP presents a succession of overlapping vertical slices along a transect to produce a continuous 2D wall of the vertical backscatter through the canopy. It provides an image in which pixels are all viewed at the same incidence angle, which is important to avoid unwanted geometrical effects. In addition, from a single transect pass, a whole series of TP images can be reconstructed at different incidence angles by post-measurement beam steering. The resolution will be as good as 4cm, allowing us to see the details of the interaction of a radar wave within a canopy in incredible detail. The presentation will detail drone characteristics, performance, and modes of operation. It will use experimental results and simulations to quantify image quality performance against drone operation and weather (wind) conditions. Early imaging results from the field may be available in time for the conference.

5.(16:50) Validating the Dynamics of JPSS VIIRS Green Vegetation Fraction (GVF) Product with High-Frequency Planet CubeSat Imagery | *F Zhao*, Z Jiang, M Chen, Y He, Y Yu, I Csiszar*

Green Vegetation Fraction (GVF) is a critical input to numerical weather prediction models, seasonal climate prediction models, climate variability models and hydrological models as it determines the partition of surface sensible and latent heat fluxes. As such, the current NOAA operational GVF product, as part of the NOAA SNPP Data Exploration (NDE) program, has been derived and produced since 2015 to provide for science community. Validation of the dynamics of GVF product is very challenging because long term in-situ observations are only available in a limited number of sites (i.e., PhenoCam network) and those sites are located primarily in North America and Europe.

The Planet cubesat constellation is a developing earth observation constellation, that is and will continue to sense the whole earth surface on a daily scale at high resolution (3 meter). In this study, we will exploit high frequency of Planet CubeSat imagery in support of the validation of the global 1km GVF product produced from Visible Infrared Imaging Radiometer Suite (VIIRS) instrument. Specifically two steps will be required to validate the dynamics of GVF at EOS core validation sites. First, we classify the Planet CubeSat data into vegetation and nonvegetation using the classification approach at sample Earth Observing System (EOS) Land Validation Core Sites. Based on the classification maps, the daily GVF value at VIIRS GVF product scale will be retrieved. Second, we compare the dynamics of VIIRS GVF against those from high-frequency of Planet imagery.

9C

FOREST COMPOSITION, DYNAMICS AND PHENOLOGY

Moderator: Ty Wilson

1.(15:30) Mapping forest species composition using FIA plot data and Landsat spectral-temporal features | *V Pasquarella*, J Thompson, L Morreale*

Accurate maps of forest composition and the distributions of individual tree species are highly desired by researchers and resource managers alike. Remotely sensed imagery is widely used to map forest attributes. However, characterizing the mixed deciduous forests of the Northeastern US has been particularly challenging. Most regional and national efforts have relied on data from MODIS and AVHRR, which have the high temporal resolution needed to characterize forest phenology, but the coarse spatial resolution of these sensors can result in highly mixed pixels. With the opening of the Landsat archive and continued advances in image processing, there are new opportunities to use time series of 30-meter Landsat imagery to improve mapping of forest composition over large spatial extents. In this study, we combine Forest Inventory Analysis (FIA) plot data with spectral-temporal features (STFs) calculated from dense time series of Landsat observations to map forest composition in the Northeast. Unlike more conventional spectral features, which typically represent reflectance values at discrete points in time, STFs are calculated from the complete observation record, providing a more robust characterization of spectral dynamics. We aim to (1) use forest census data from FIA plots to explore relationships between STFs and forest attributes and (2) generate maps of dominant species and the distributions of individual species that are locally accurate and include measures of uncertainty. The Continuous Change Detection and Classification (CCDC) algorithm was used to identify relatively stable time segments from time series of all high-quality Landsat observations. From these segments, two types of STFs were calculated: harmonic metrics, which characterize mean annual and seasonal variability in reflectance, and phenological metrics, which quantify the timing of seasonal events. These STFs are used in combination with other environmental predictors and training data from FIA plots to generate a series of map products. Three mapping approaches are currently being tested: classification, regression, and imputation. We compare the quality of map products using both quantitative statistics and qualitative stakeholder evaluations. Not surprisingly, mapped results vary significantly depending on the choice of FIA training sites and feature inputs. Therefore, our final product will be an ensemble that integrates these various representations of the forested landscape.

2.(15:50) Tropical forest and land cover monitoring using optical and SAR data | *M Hirschmugl, C Sobe, J Deutscher, M Schardt**

Tropical forest monitoring is currently in a transition phase from annual mapping updates to automated near real-time applications that rely on full time-series analysis and from single sensor applications to integrated optical & SAR monitoring systems. The research aim of the Horizon2020 project EOMonDIS is to assess the benefit of a joint use of high resolution optical and SAR time series data for cost-efficient and accurate tropical forest monitoring. We evaluate forest monitoring methods that combine optical Landsat-8 and Sentinel-2 data with SAR Sentinel-1 data. We compare two different methods for data integration: first, a Random Forest classification based on a combination of pre-processed SAR and optical data, and second, a result-based fusion of separate optical and SAR classification results using Bayesian combination. For result-based fusion, Maximum Likelihood and thresholding procedures are used to classify the optical data and backscatter trend and variation analyses are used to classify the SAR data. The final products are high resolution forest and land use maps as well as deforestation and forest disturbance maps. We present the classification results for four diverse forest monitoring test sites in Africa and Latin America that cover both humid and dry tropical forests. The accuracies of the results vary strongly among test sites and products. We analyze the influencing factors that lead to the strong variance in classification accuracies in order to better understand existing inter-dependencies. The main influencing factors are

i) Forest type: dry vs. humid;
ii) cloud frequency;
iii) topographic effects;
iv) type and properties of the requested output products;
v) change drivers, e.g. selective logging, plantations, agriculture, fire) and
vi) type and size of typical LU and/or disturbance patterns.

For areas with frequent cloud cover and for large deforestation plots, SAR data gives a significant added value in terms of detection timeliness and classification accuracy. However, the added value of integrating SAR data in the processing chain for small structured changes (forest degradation) is only marginal; SAR data integration can even cause additional errors. We also obtained some unexpected results: In Malawi, the use of SAR time series data in combination with a mono-temporal optical image achieved comparable LU classification accuracies than the results based on the full optical time series data classification.

3.(16:10) Is ground-based phenology of deciduous tree species consistent with the temporal pattern observed from Sentinel-2 time series? | *N Karasiak*, D Sheeren, J Dejoux, J Féret, J Willm, C Monteil, D Sheeren*

Characterizing green-leaf phenology from satellite imagery is crucial for many ecological applications. This information can also help to better discriminate tree species in forests taking into account the variations of leaf flush and coloring among species. Substantial advances in the assessment of phenological traits from satellite data have been made recently. However, a large part of the previous works was based on products of moderate spatial resolution (such as MODIS) or with, possibly cloudy, images with a limited temporal resolution (such as Landsat). The new optical Sentinel-2 (S2) image time series providing data every 5 days with a high spatial resolution offer new opportunities to address phenological studies. Dense observations increase the probability to get cloud-free images which can help to better classify tree species and to derive more accurate phenological metrics.

In this study, we investigate the potentialities of dense S2 time series to (i) discriminate tree species in temperate forests and (ii) determine if the seasonal variations of spectral bands in the time series is related to phenological events observed in situ. To address this analysis, we conducted field observations of phenology every 10 days during the senescence and green-up periods (autumn 2017 and spring 2018 respectively). Field observations, based on a standard protocol, were carried out on a study site of 20 km x 25 km located in southwest France. Phenological events were collected in two distinct plots of 100 mÂ² for 7 deciduous tree species (Oak, Red oak, Silver birch, Black locust, European ash, Aspen and Willow). Canopy closure was also measured from hemispherical photographs, in addition to chlorophyll content and the presence of understory vegetation, which may influence the seasonal reflectance. In parallel, a supervised classification of the time series was carried out to discriminate the major coniferous and deciduous tree species existing in the study area. This classification was based on the SVM algorithm with a spatial leave-one-out (SLOO) cross-validation procedure to deal with autocorrelation in the field-collected reference plots (n>1,200 pixels; 14 tree species).

The first analysis of the spectro-temporal profiles show consistent patterns with the in situ phenological observations. However, a significant effect of the understory vegetation composed of evergreen species (e.g. Ruscus aculeatus, rubus fructicosus) is also observed in some stands.

4.(16:30) Monitoring Forest Degradation using Spectral Unmixing and Landsat Time Series Analysis in Rondonia, Brazil | *E Bullock*, C Woodcock, P Olofsson*

Tropical forest loss currently contributes 5 to 15% of anthropogenic carbon emissions to the atmosphere. The large uncertainty in emissions estimates is a consequence of many factors, including differences in definitions of forests and deforestation, as well as estimation methodologies. However, a primary factor driving uncertainty is an inability to properly account for forest degradation. While remote sensing offers the only practical way of monitoring forest disturbances over large areas, and despite recent improvements in data quality and quantity and processing techniques, remote sensing approaches are still limited in their ability to detect forest degradation. In this research, a system is demonstrated that uses dense Landsat time series and spectral mixture analysis to detect both degradation and deforestation in forested landscapes. All Landsat images are transformed into spectral endmember fractions and are used to calculate the Normalized Degradation Fraction Index (NDFI; Souza et al., 2005). The spectrally unmixed data are then used for disturbance monitoring and land cover classification using methods from time series analysis. Maps of deforestation and degradation were used to stratify the study area for collection of sample data to which unbiased estimators were applied to produce area estimates of degradation and deforestation from 1990 to 2013. The approach extends previous research in spectral mixture analysis for identifying forest degradation to the temporal domain. The method was applied using the Google Earth Engine (GEE) and tested in the Brazilian state of RondÃ´nia. Degradation and deforestation were mapped with 88.0% and 93.3% User's Accuracy, and 68.1% and 85.3% Producer's Accuracy, and area estimates of degradation and deforestation with margin of errors of 13.88% and 5.26% respectively over the 24 year time period. Yearly areas of disturbances are also calculated. These results indicate that, for RondÃ´nia, a decreasing trend in deforestation after 2004 corresponded to an increase in degradation during the same time period. The demonstrated approach is open source, easy to apply over large areas using the GEE, and capable of producing information on areas of disturbance with high precision.

5.(16:50) Wall To Wall Deforestation And Forest Degradation Detection: A Case Study In The Eastern Humid Forest Ecoregion Of Madagascar | *N Algeet-Abarquero*, A Fernández-Landa, ML Guillen-Climent, J Esteban, P Rodríguez-Noriega, A Espejo*

Spatially explicit deforestation and forest degradation information are essential for the establishment of the Forest Reference Emission Levels, the definition of the Emission Reduction Program and the design of the Forest Monitoring Systems in the REDD+ framework. Recent scientific researches are developing advance methods for detecting both sudden and subtle changes in forests based on satellite image time series analysis. These methods offer an opportunity to improve the available information of deforestation, forest degradation, enhancement and recovery in REDD+ countries.

The aim of this study was to obtain a wall to wall mapping of deforestation, forest degradation and forest regrowth/ recovery in the eastern humid forest ecoregion of Madagascar in the historical reference period of 2005-2016. The methodological approach, developed in the framework of the Forest Carbon Partnership Facility (FCPF) Emission Reduction Program, consisted on an open source software workflow. This workflow applies annual mosaic generation, time series analysis, IRMAD change detection algorithm (Canty and Nielsen, 2008) and decision tree and Random Forest (RF) classifiers over historical time series of vegetation indexes (NDVI and NBR) obtained from Landsat imagery.

Annual metrics of vegetation indices were computed from all the Landsat imagery available per year. Forest degradation monitoring was based on trend analysis estimations over mean annual NDVI data with Greenbrown algorithm (Forkel et al., 2013). Deforestation is mapped annually, by the calibration of the mean annual NBR index threshold values. Forest regrowth/recovery was classified from IRMAD bands and annual vegetation indices (NBR and NDVI) metrics. IRMAD algorithm was applied over the annual Landsat mosaics of the first and last year of the reference period (2005 - 2016) which were created based on the best available pixel selected from maximum annual NDVI values.

The final map for the reference period integrates: i) stable primary and modified natural forests, ii) deforested areas, iii) degraded forests, iv) new secondary forests, and stable non-forest areas. The proposed methodology provides a forest monitoring system at suitable temporal and spatial resolutions for REDD+ program requirements.

9D

NEXT GENERATION LARGE AREA FOREST MONITORING 3: APPLICATIONS

Moderator: Mike Wulder & Sean Healey

1.(15:30) Opportunities for monitoring post-disturbance forest recovery over large areas | *J White*, M Wulder, T Hermosilla, N Coops, G Hobart*

Forest recovery is a long-term process that is challenging to measure or quantify over large areas using ground plot data alone. Time series of analysis-ready data from the Landsat archive have enabled large-area characterizations of post-disturbance spectral recovery. Mapping of spectral recovery provides a spatially-explicit framework for understanding variations in the rate of forest recovery relative to disturbance type and other biotic and abiotic characteristics.
Using a Landsat time series representing 1984 - 2012 for the 650 Mha of Canada's forested ecosystems and the Composite2Change (C2C) algorithm, we generated a national assessment of forest recovery using both short- and long-term measures of spectral recovery. We found that disturbance type was important for distinguishing recovery trends, with harvested areas recovering more rapidly over time relative to areas disturbed by wildfire: 78.6% of harvested areas required ≤ 10 years to recover, compared to only 35.5% of wildfire areas. Regional differences in post-disturbance recovery were observed; however, less than 1% of the areas disturbed by wildfire and harvest were identified as non-recovering. Our subsequent research has used measures of forest height and cover derived from airborne laser scanning data to corroborate the use of spectral recovery metrics to provide a standardized, objective assessment of relative recovery over large forest areas. Such assessments can be spatially exhaustive and retrospective, providing important baseline data at a level of spatial detail that is relevant for forest monitoring. Moreover, quantifying recovery is useful for evaluating sustainable forest management practices and for refining projections of forest carbon.

2.(15:50) Improving quality bands across Landsat sensors using convolutional neural networks | *MJ Hughes*, J Braaten, S Hooper, R Kennedy*

The Landsat record represents an amazing resource for detecting landcover change and forest disturbance. But making the most use of the available data, including extending views back into the early 1970s using MSS, requires robust identification of cloud, cloud-shadow, and other obstructions of clear views. Currently, different information is available for different sensors, or is available but generated with low-accuracy algorithms, which impedes integration of data. Products derived from imagery where humans do not manually check the quality of this screening - which is necessarily the case for modern, automated approaches to global, long-term monitoring, are contaminated by missed obstructions, leading to incorrect classifications and estimates.

We developed a suite of convolutional neural network (CNN)-driven algorithms to identify clouds, cloud-shadows, water, snow/ice, and flooding in MSS, TM, ETM+, and OLI imagery from Landsat satellites. CNNs are deep-learning algorithms that extract spectral and spatial information to generate semantic information and underpin the recent advances in image recognition and computer vision, but are relatively under-utilized in remote sensing.

We compared our estimates of cloud and cloud-shadow in OLI imagery to C-FMask, the algorithm that generates quality masks distributed with USGS products. Our algorithms performed consistently better, missing approximately half as many clouded pixels on average and approximately an eighth the cloud-shadows, with very high variance between images. However, due to the increased computational complexity, our algorithms are over an order of magnitude slower than an unoptimized implementation of FMask. And though we expect timings to decrease with improved technology, they are currently best suited for users with substantial computing resources and a strong need to reduce masking error, such as those performing automated time series analyses over large spatial extents with minimal human oversight.

3.(16:10) Monitoring Over a Decade of Carbon Flux in Pinyon-Juniper Woodlands | *M Falkowski, S Filippelli*, A Hudak, P Fekety*

Pinyon-juniper (PJ) forests and woodlands are the third largest vegetation type in the United States, representing 40% of the total forest and woodland area in the Intermountain West. Although the density of carbon stored in these ecosystems is relatively low compared to other forest types, the vast area of short stature forests and woodlands (both nationally and globally) make them critical components of regional, national, and global carbon budgets. The goal of this research is to develop a carbon monitoring, reporting, and verification (MRV) system for characterizing total aboveground biomass stocks and flux across the PJ vegetation gradient in the western United States. We achieve this by applying cover-based allometrics to canopy cover maps derived from high resolution aerial imagery to map aboveground biomass across 500,000 km2 in the Western US for a single time. Unlike most forests which require measurements of canopy height to reasonably estimate aboveground biomass, accurate biomass estimates can be produced for PJ woodlands solely from canopy cover due to their short stature. The high-resolution maps of aboveground biomass then serve as training data to predict biomass flux for this ecosystem over more than a decade. We produce stable estimates of aboveground biomass through time by utilizing temporally segmented Landsat time-series data produced by the LandTrendr algorithm implemented in Google Earth Engine. This technique allows us to capture trends such as PJ encroachment into shrublands and major disturbances while minimizing year-to-year noise. Maps of aboveground biomass are validated at multiple time periods with in situ forest measurements from the SageStep project and Forest Inventory and Analysis Program. The results from this research highlight the potential in mapping biomass stocks and flux in open forests and woodlands, and could be easily adopted into an MRV framework.

4.(16:30) Products of phenology, disturbance, and peak summer greenness for NASA's Arctic and Boreal Vulnerability Experiment | *C Woodcock*, S Chen, M Friedl, Y Zhang, E Melaas*

We are developing a suite of products based on time series analysis of Landsat for the entire study area of NASA's Arctic and Boreal Vulnerability Experiment, which includes a large portion of Canada and Alaska. These products are based on newly tiled Landsat data, such that each observations for a single pixel is stacked in support of time series analysis. The entire archive of Landsats 4,5 and 7 are being used. The following annual products are being developed: (1) synthetic imagery for the middle of the growing season; (2) timing of greenup and onset of senesence as well as the timing of peak summer greenness; (3) land cover change and changes within land covers (such as periods of growth or decline); and Landsat values of peak summer greenness in support of studies on the effect of climate change on ecosystems. Challenges include the sheer volume of data involved, validation of datasets, and representation of results.

5.(16:50) Annual estimates of forest biomass and forest cover for the continental U.S. | *R Kennedy*, MJ Hughes, J Braaten, S Hooper*

Forest biomass and projected forest cover are essential descriptors of forest condition. Because of their importance, maps of both variables for the conterminous U.S. (CONUS) have been developed either by federal agencies or by federally-supported research teams. Because of the effort involved in creating such maps, they have traditionally been limited to single-year or discrete interval maps. To understand forest dynamics more fully, however, forest biomass and cover must be tracked over time, capturing the spatial and temporal dimensions of both forest growth and forest removal. Such understanding of forest dynamics can inform management decisions and act as a benchmark for carbon modeling. Here, we report on results of a NASA-supported modeling effort to parley existing CONUS-wide maps of forest biomass and forest cover into annual maps for the period 1990 to 2017. Our approach combines temporal segmentation of Landsat imagery using the LandTrendr algorithms with a spatial statistical modeling approach that allows geographic variation in the underlying statistical relationships. For the core temporal segmentation, we utilize Google Earth Engine technology, allowing testing of a range of spectral indices and temporal windows for modeling. We find that forest cover estimation can be mimicked more robustly than forest biomass, but that overall agreement for both variables is sufficient to allow exploration of forest biomass dynamics. We then report on specific examples of forest loss and gain, including impacts of harvest, fire, insects, and regrowth on cover and biomass.

9E

MANGROVES: NEW PERSPECTIVES FROM EARTH OBSERVATIONS

Moderator: Richard Lucas & Kate Fickas

1.(15:30) Ensuring a Long-Term Future for Mangroves: A Role for Remote Sensing | *R Lucas**

Across their range and particularly in recent decades, mangroves have experienced significant loss and degradation through human activities (e.g., clearance or degradation) and induced climate change. These changes and the impacts on the coastal environment are particularly noticeable in time-series of remote sensing data, which reveal varying foci of impacts across the globe, both spatially and temporally. The remote sensing community has reported on such changes at varying scales, from the local to the global, and using a diverse range of sensors (primarily optical, radar and lidar). However, despite alerting communities at all levels to such changes, mangroves continue to be lost or degraded to the point that there are now large sections of coastline with very little of this ecosystem remaining. Such losses are devastating to both floral and faunal diversity and significantly compromise the integrity and functioning of coastal environments. Moreover, there are significant impacts on societies living close to or relying on mangroves and also local to national economies. For this reason, this situation needs to be reversed. Without earth observations, there is no doubt that the community would be far less aware of the changes in mangroves that have occurred and the extent of damage inflicted. However, we can do more but this involves action by the whole community to engage and collaborate in a way that ensures that local to international policymakers, land managers and communities are provided with robust datasets that routinely capture and can be used to report, on a timely and regularly basis, the states and dynamics of mangroves at local to global scales. In particular, we advocate that: a) Global efforts at characterizing, mapping and monitoring mangroves are fully coordinated such that the various datasets generated build on and align with each other, particularly in terms of mapped extent, class taxonomies and biophysical attributes; b) Supportive in situ (field) and airborne (including drone) sensor data are collated or acquired (including through national and international collaboration) and made freely available through centralized portals; c) Local communities, particularly in tropical and subtropical regions, are made aware of and provided with the remote sensing data and derived products such that they can observe and respond to the changes that are occurring and review mangrove use and management strategies.

2.(15:50) The Global Mangrove Watch (GMW) | *P Bunting, A Rosenqvist, R Lucas*, A Hardy, N Thomas, L Hilarides, L Rebelo*

Globally mangrove forests have witnessed a considerable amount of change over the past 30 years, with clearing (e.g., for aquaculture), erosion, sedimentation events and dieback making this environment one of the most dynamic of any ecosystem. Mangroves are also at the forefront of climate change with changing sea levels and temperatures providing new opportunities for mangroves but also making some areas uninhabitable. The time lag between these events and the mangrove response is also short, it can be only a few months. Little information is known on the overall extent of mangroves and how this extent and condition has been changing on a global scale. This study has therefore created the first global monitoring system for mangrove forests.

The system came out of the JAXA Kyoto & Carbon (K&C) initiative and has therefore focused on the application of JAXA ALOS PALSAR, ALOS-2 PALSAR-2 and JERS-1 data with the augmentation of Landsat to aid the definition of a new 2010 mangrove global mangrove baseline. Change products (from the 2010 baseline) were produced for 1996 using JERS-1, 2007, 2008 and 2009 using ALOS PALSAR, and 2015 and 2016 using ALOS-2 PALSAR-2. The baseline classification was created using an automated machine learning approach based on random forests algorithm while the change products were produced using a new innovative map-to-image change detection approach.

The baseline was assessed to have an overall accuracy of 95.25 % with 2.5 % omission and 6 % commission based on 53,800 visually accessed random points from 20 regions. Globally, mangrove change has been estimated at a rate of -0.29 % per year, i.e., a loss of 5.8 % in mangrove extent from 1996 to 2016. This is not equally distributed with Indonesia, having the largest area of mangroves within a single country, having lost almost 20 % of mangrove extent from 1996 to 2016.

3.(16:10) High-resolution 3-dimensional mapping of forest structure and aboveground biomass stocks in mangrove ecosystems in the Americas, Africa and South Asia | *L Fatoyinbo*, D Lagomasino*

Mangroves and tropical peat forests have the highest carbon (C) density among terrestrial ecosystems ecosystems with most C stocks found within soils (Donato et al., 2011, Murray et al., 2011). Although they only represent between 3-5% of the total forest area, C stocks from mangroves and tropical peatlands constitute significant proportions of total tropical forest carbon stocks (Page et al., 2011, Donato et al., 2011, Dargie et al., 2017, and Siikamaki et al., 2012). These forests are under significant threat from anthropogenic activity such as urbanization and agriculture as well as sea level rise (Alongi, 2002). In fact, it is estimated that over 60% of mangrove forests and tropical peatland forests have been destroyed (Bouillon et al., 2008). The high Carbon sequestration coupled with the high risk of destruction has made mangroves and freshwater peatlands a prime candidate for Payment for Ecosystem Services (PES) initiatives.

One of the main challenges to implementing PES projects is measuring carbon, efficiently, effectively, and safely. In mangroves especially, the extreme difficulty of the terrain has hindered the establishment of sufficient field plots needed to accurately measure carbon on the scale necessary to relate remotely sensed measurements with field measurements at accuracies of 10% to 20% as required for PES. Furthermore, most intensive mangrove sites are established in South-East Asia, Australia and Latin America, with a large gap in knowledge in African mangrove ecosystems (Hutchison et al., 2014).

Here we present our efforts to measure total (above and belowground) carbon stocks in East and Central Africa using in situ, high resolution stereo (Worldview, Digital Globe), airborne lidar and Interferometric SAR data from SRTM, UAVSAR and TanDEM-X. We generated Mangrove extent and change maps and canopy height estimates for the 2000 and 2015 eras that were used as input to field plot samples of Total Carbon stocks in, Tanzania, Mozambique and Gabon. By combining the field measurements and remotely sensed data, we estimated countrywide mangrove total carbon stocks and emissions. Uncertainties of estimates associated with different remote sensing input data were also calculated and will be presented. Our presentation describes CMS data products and uses, including recently collected airborne Lidar and Radar from the AfriSAR campaign in Gabon.

4.(16:30) Deciphering Mangrove Phenology: What, When And Where. | *N Younes*, K Joyce, L Lymburner, S Maier*

Mangrove phenology is believed to be influenced by temperature, rainfall and sea level, however broad scale measurements of these interactions are close to non-existent. Mangrove phenology is often studied in situ and provides limited information at the landscape level. This research aims to describe mangrove phenology at the landscape level using all available Landsat imagery (n=2157) across two Australian bioregions. We use the Landsat 30 year time series to: 1) describe the phenology (i.e. start, end and duration of growing season) of mangrove forests in the Cairns and Darwin regions; 2) assess how mangrove phenology has changed over the past 30 years; and 3) compare phenological drivers across bioregions. Digital Earth Australia provided the imagery and high-performance computing capabilities for data processing and visualization. We used Generalized Additive Models (GAMs) of five spectral indices (NDVI, SAVI, EVI, NDWI and Tasselled Cap Greenness) to compare annual and decadal changes in phenology and how mangroves react to changes in three environmental drivers (temperature, rainfall and sea level altimetry). Our preliminary results suggest: 1) mangroves in northern Australia follow a six-monthly phenological cycle with maximum growth from May through September and minimum growth between October and April; 2) in (relatively) undisturbed mangroves, there is a long-term positive trend in index values, potentially indicating an increase in fractional vegetation cover; and 3) mangrove phenology is site dependent and varies across bioregions. We expect our results to inform conservation policy and modelling efforts both in Australia and overseas.

5.(16:50) EcoMap: An Interactive Early Warning System to Aid Global Mangrove Restoration and Policy | *L Goldberg*, D Lagomasino, L Fatoyinbo*

Mangrove forests hold high ecological and economic value in coastal communities worldwide; mangrove stressors pose a threat to both the health of the ecosystems and the wellbeing of nearby communities that rely on their ecosystem services. The Electronic Coastal Monitoring and Assessment Program (EcoMap) seeks to address the need for a unified, global risk management system for mangrove loss and vulnerability. Long-term Earth observations from Landsat, MODIS, and TRMM are used to monitor extreme change in greenness, land surface temperature, and precipitation using designated thresholds. Natural risks such as erosion and degradation are evaluated through an analysis of NDVI time series trends from calendar year 1984 through 2018. Additional risk maps also incorporate anthropogenic pressures such as urbanization, population growth, and expansion of agriculture and aquaculture through rice, rubber, shrimp, and oil palm farming. These natural and human-driven risk factors are aggregated to generate a cumulative estimate for total mangrove vulnerability in each region. Based on varying conditions on the ground, users of the platform can adjust the weight of each loss driver when calculating total vulnerability in accordance with the resilience of local mangroves. By calculating the total area under high vulnerability, EcoMap also determines the total carbon stocks under risk in each mangrove-holding nation. This interactive modeling tool has the potential to enable decision-makers at the regional, national, and international levels to identify areas best suited for mangrove restoration measures, allowing governments and local communities to address a wide range of Sustainable Development Goals and implement sustainable management planning in coastal regions.

10A

SPACEBORNE MISSIONS

Moderator: Mike Falkowski

1.(10:30) The BIOMASS mission: measuring forest height and above ground biomass from space | *K Scipal, S Quegan, T Le Toan, J Chave, J Dall, P Paillou, K Papathanassiou*, S Tebaldini, S Saatchi, H Shugart, L Ulander, M Williams*

BIOMASS is the 7th mission of the European Space Agency Earth Explorer Programme. The mission was selected in 2015 for implementation with a foreseen launch in 2022.

The primary objective of the BIOMASS mission is to determine, for the first time wall-to-wall and in a consistent manner, the worldwide distribution of forest above-ground biomass (AGB) in order to reduce the major uncertainties in calculations of carbon stocks and fluxes associated with the terrestrial biosphere, including carbon fluxes associated with Land Use Change, forest degradation and forest regrowth.

To address these objectives BIOMASS will provide following products wall-to-wall, over the mission lifetime of 5 years

1. Above-ground forest biomass (AGB), defined as dry weight of woody matter, expressed in t ha-1, at 4 ha (200 x 200 m2) resolution every 7.2 month.
2. Forest height, defined as upper canopy height according to the H100 standard used in forestry expressed in m, at

4 ha (200 x 200 m2) resolution every 7.2 month.

3. Severe disturbance, defined as an area where an intact patch of forest has been cleared, expressed as a binary classification of intact vs deforested or logged areas, with detection of forest loss being fixed at a given level of statistical significance at 0.25 ha (50 x 50 m2) resolution every 7.2 month.

Although BIOMASS aims at full global coverage, it will at least cover forested areas between 75° N and 56° S, subject to US Department of Defense Space Object Tracking Radar (SOTR) restrictions. These restrictions do not allow BIOMASS to operate within line-of-sight of the SOTR radars and mainly exclude the North American continent and Europe.

BIOMASS will be implemented as a single platform fully-polarimetric SAR mission operating at P-band (centre frequency 435 MHz) with 6 MHz bandwidth. The satellite will be operated in a 3 days repeat pass orbit during two distinct mission phases. During the first year the mission will operate a tomographic mission phase, which will collect 7 subsequent images over each location. During the remaining mission life time the mission will operate in an interferometric mission phase, which will collect 3 subsequent images over each location.

This paper will provide an overview of the mission, the retrieval concept and characteristics of its products and its implementation status.

2.(10:50) Forest mapping with TanDEM-X: the global product and potentials for high-resolution classification | *M Martone*, P Rizzoli, C Gonzalez, J Bueso-Bello, F Sica, M Zink, G Krieger, A Moreira*

Forests cover about 30% of the Earth's landmasses, play an essential role in many dynamic processes of our planet, and are of extreme importance for all living species, allowing for the existence and preservation of biodiversity and healthy ecosystems. However, severe loss and degradation of forests is nowadays occurring at an alarming rate, hence putting this delicate balance in serious danger. For these reasons, an up-to-date assessment of the forest resource state becomes of crucial importance. In this context, spaceborne SAR represents a very attractive solution for regular mapping and monitoring of forested areas. Indeed, thanks to its weather and daylight independence and large coverage capabilities, spaceborne SAR is able to provide timely, high-resolution imaging at local, as well as regional and up to global scale.

In this paper we present the new global Forest/Non-Forest classification map from TanDEM-X interferometric SAR data (InSAR) at X band, at a spatial resolution of 50 meters. The TanDEM-X mission comprises the two twin satellites TerraSAR-X and TanDEM-X, which fly in closed-controlled formation acting as a flexible single-pass radar interferometer. Among the different factors affecting the quality of InSAR data, the so-called volume correlation factor describes the coherence loss due to volume scattering effects, which typically occur in presence of vegetation. Therefore, the volume correlation factor is used as main indicator for the discrimination of forested from non-forested areas. The proposed classification method, the product validation with external reference data, and the comparison with existing land cover maps are presented. The global TanDEM-X classification mosaics will be released to the scientific community for free download and usage.

In a second part of the paper the potentials of TanDEM-X data for high-resolution forest mapping are addressed. We present forest/non-forest classification mosaics of the State of Pennsylvania, USA, from TanDEM-X data processed at ground resolutions down to 6 m. For coherence estimation, both standard boxcar and nonlocal filtering methods have been considered, and a performance comparison verifies that nonlocal filters, thanks to their outstanding performance in terms of noise reduction capabilities and spatial features preservation, represent a promising approach to achieve a reliable classification at such fine resolutions.

3.(11:10) Understanding the Role of Ecosystem Structure in Carbon and Biodiversity: GEDI - The Global Ecosystem Dynamics Investigation | *R Dubayah**

For over 50 years NASA, along with other international space agencies, has supported important scientific and policy issues related to the present and future states of the Earth's carbon and water cycles, its climate, its habitat suitability, and other ecosystem services using a constellation of Earth orbiting satellites. Vegetation three-dimensional structure and its above-ground carbon content (biomass) continue to be the most crucial information missing from the observational archive. The most direct and accurate way of obtaining this detailed vertical structure at the resolution and accuracy required is through lidar remote sensing.

To fill this ongoing gap, the Global Ecosystem Dynamics Investigation (GEDI) was proposed and selected as part of NASA's Earth System Science Pathfinder (ESSP) Earth Ventures competition. Scheduled for launch to the International Space Station (ISS) in late 2018, GEDI will provide over 12 billion observations of vegetation vertical structure over the Earth's temperate and tropical forests. GEDI lidar observations are used to create data sets on canopy height, canopy profiles, topography, and biomass, among others. These are the first set of spaceborne measurements from an instrument specifically designed to measure vegetation structure and form the basis of much anticipated reference data sets. GEDI data will be used by the scientific community for far ranging applications, by themselves, and in fusion with other existing and planned missions, that together should deepen our understanding of ecosystem structure, function, and composition.

In this talk we provide an overview and current status of the GEDI mission. I first discuss its scientific goals and objectives, and explain its rationale within a context of the scientific importance of ecosystem structure for the main application areas of GEDI: carbon balance and biodiversity. I next describe the GEDI lidar instrument, including its specifications and measurement capabilities. Next, I describe how GEDI measurements are used to produce its science products, including algorithm development and calibration and validation. With this background, I then discuss how GEDI data are applied to answer it main science questions. Lastly, I show how GEDI data may be used in fusion with other sensors, and how, collectively, this ensemble of land surface observations positions us at the forefront of a new era in ecological inquiry.

4.(11:30) The development of vegetation LIDAR mission 'MOLI' | *R Mitsuhashi*, J Murooka, D Sakaizawa, T Imai, T Kimura, M Hayashi, K Mizutani, Y Sawada, T Endo, K Kajiwara, Y Honda, K Asai*

Information on precise forest biomass is important to evaluate its contribution as a CO2 absorption source to the global carbon cycle. Regarding the assessment of forest biomass as a CO2 absorption source, information on both the volume and forest area must be observed. However, it is unrealistic to conduct ground observation in all areas as a method of assessing the volume of global forests.Given this situation, the Japan Aerospace Exploration Agency (JAXA) has developed spaceborne vegetation LIDAR named the "Multi-footprint Observation LIDAR and Imager (MOLI). The unique points of MOLI are the dual beams with enough small and close footprints (called Multi-footprint) to determine inclination of the ground surface. This is useful for correcting estimation errors of canopy height due to a difference in height of the ground in the footprints.

Another unique point is the 3-band imager adopted to use the determination of LIDAR-measured positions and observe the vegetation index at the same time as LIDAR observation . Concurrently with these developments, we conducted an observation experiment using airborne LIDAR to evaluate the validity of the observation method using Multi-footprint. Full LIDAR waves were acquired from this experience in broadleaf and conifer forests . These waves were analyzed to calculate footprint coordinates and estimate canopy heights.

We validated the canopy height directly to verify the observation results at two sites in December 2016. Here we report MOLI's overview and preliminary results of the airborne LIDAR experiment.This paper presents an overview of MOLI and reports the preliminary results of our airborne LIDAR experiment.

5.(11:50) Mapping global forests using data from NASA's ICESat-2 Mission | *A Neuenschwander*, L Magruder*

NASA plans to launch the ICESat-2 (Ice, Cloud, and land Elevation Satellite-2) laser altimeter in September 2018. While the primary mission goal of ICESat-2 is to monitor elevation changes in the cryosphere, it will also collect data over much of the Earth's terrestrial surfaces. A science objective for the mission is to produce elevation measurements that enable the independent determination of vegetation height. The Advanced Topographic Laser Altimeter System (ATLAS) instrument on-board ICESat-2 is a lidar system with detection sensitivities at the photon level and operates at the 532 nm wavelength. The laser repetition rate of ATLAS (10 kHz) combined with a laser footprint diameter of 13 m results in a 70 cm separation for each laser shot on the surface. Due to the high laser pulse repetition rate and smaller footprint size, there is potential to tease out vegetation photons from ground photons, even in areas of high relief an improvement from ICESat/GLAS where the topographic signal was convolved with the vegetation signal. The ICESat-2 geophysical data product characterizing heights over land and vegetation is known as ATL08. The methodology to produce the ATL08 data product requires the accurate identification of both the canopy and ground surfaces for all ecosystems. Terrain height, canopy height, canopy cover, and other canopy metrics will be reported at a 100 m resolution in the satellite along-track direction. Due to the fact that ATLAS is sensitive at the photon level, there will be ambiguity from where within the vertical column of vegetation that a photon will be reflected. That is, the ICESat-2 canopy height may not reflect the true top canopy height. Although ICESat-2 will under-estimate the true maximum canopy height, results indicate ICESat-2 derived heights are correlated to relative canopy height metrics (e.g. RH75 or RH95). For a simulation ICESat-2 data set over Sonoma County, CA, the ATL08 canopy height had the highest correlation with the ideal RH75 height metric from the airborne lidar data ($R2 = 0.9$ and RMSE of 1.32 m). This correlation lends to the potential of ATL08 canopy heights being used for global biomass estimation for models that utilize RH metrics in the allometry. Such products will complement NASA's GEDI mission that is designed to capture forest structure in densely canopy cover regions.

10B

HABITAT AND BIODIVERSITY

Moderator: Michael Foerster

1.(10:30) Assessing habitat diversity in tropical forests using airborne lidar scanning | *N Labrière*, S Tao, F Fischer, C Bedeau, G Vincent, J Chave*

Tropical forests have complex canopies with sharp gradients in light, moisture and temperature. Animal species use these habitats to shelter and forage for resources, and vertical stratification is one of the causes of the great diversity in the tropics. Airborne lidar scanning of the vegetation is becoming increasingly available over extended forested areas, opening up new avenues for the study of canopies as habitats of animals. We used airborne lidar coverages (2012-2016) of over 85,300 ha of tropical forest in French Guiana, to detect 'natural' discrete clusters representing biologically-relevant habitat types. Point density ranged from ca. 10 to 36 pt m-2. We constructed 1m-binned height distributions of point clouds over 20'—20m pixels and performed a non-supervised clustering of these pixels using the Infomap software. We found 6 clusters which we interpreted as being different forest structures. We replicated this study using only, for each of the 20'—20m pixels, top-of-canopy height values from a 1m-resolution canopy height model. Both approaches were consistent. We finally tested whether the different clusters harbored a distinctive large fauna using long-term fauna inventories. Our results confirm the relevance of wall-to-wall lidar coverage to assist the prioritization of protected areas at national scale is discussed.

2.(10:50) Estimation of biodiversity relevant forest structure parameters using a multi-sensor and multi-scale remote sensing approach | *K Mulatu*, M Decuyper, B Brede, L Kooistra, B Mora, J Reiche, M Herold*

Background: The role of forest structure on regulating the microclimate, thus the biological diversity of tropical forest environments is proven essential. However, accurate estimates of forest structure and their impact on biodiversity has been challenging to assess due to the complex nature of tropical forests.

Aim: Our study aims to assess the variation of biodiversity relevant forest structure parameters along four forest management practices, and to derive satellite remote sensing (SRS) based predictors to estimate field measured structural parameters

Methods: We used a combination of conventional forest inventory (CFI) measures and Terrestrial Laser Scanning (TLS) to estimate the impact of management practices on forest structural parameters in tropical montane cloud forest in Kafa, Ethiopia. For estimating plot measurement with SRS derived predictors, the in situ structural parameters from TLS and CFI were linked to forest structure proxies derived from optical bands of Landsat 8, Sentinel 2, and PlanetScope images; as well as SAR bands from ALOS PALSAR and Sentinel 1. Vegetation indices were developed from optical images, while backscatter intensity values were obtained from SAR data.

Key findings: Using TLS it was possible to capture the forest structure variation along four management practices. The results followed our assumptions with intact forest having the highest biomass values, silvopasture having the largest canopy gaps, and plantations having the lowest canopy openness. Contrary to our expectations, coffee forest had higher canopy openness and similar biomass to silvopasture, indicating a heavy impact on forest structure. Trends in the relation between in situ and satellite derived parameters showed that the optical SRS derived parameters showed a significantly high correlation with canopy gap related parameters, while the SAR backscatter intensity parameters were found to be more sensitive to Plant Area Volume Density and tree density parameters. Models from the combination of SRS derived structural parameters were used to assess their ability towards estimating field measured forest structure parameters. Above ground biomass, total basal area, maximum gap, and canopy openness were among the best predicted field measured parameter. Our results demonstrate that accounting of biodiversity relevant forest structural parameters at multiple scales require integration of multi-sensor remote sensing approaches.

3.(11:10) Combining 3D acoustic and lidar data to assess biodiversity impacts of Amazon forest degradation | *D Rappaport*, A Royle, D Morton, R Dubayah*

Amazon forest degradation from logging and fire has altered the structure and composition of frontier forests, yet the impacts of forest degradation on biodiversity remain poorly quantified. This work demonstrates the potential to combine acoustic remote sensing and airborne lidar within an innovative hierarchical occupancy modeling framework to characterize biodiversity across a diversity of degraded forest types. Acoustic remote sensing, or bioacoustics, represents a novel avenue for directly observing the animal community. The acoustic space is a limited resource partitioned by the animal community to maximize the transmission of auditory signals necessary for survival. The 3D partitioning of acoustic space (time, frequency, amplitude) is strongly associated with animal diversity within range of acoustic recording equipment. Further, given that species diversity and sound attenuation in forested environments closely correspond to forest structure, there are natural synergies between bioacoustics and lidar-derived measurements of forest structure. The use of bioacoustics has traditionally been limited by the availability of specialists capable of identifying the sounds of individual species. By modeling the occupancy of acoustic space at the site level, we propose a means to bypass species identification altogether. In this work, thousands of hours of acoustic recordings were acquired for study locations with coincident airborne lidar coverage to sample gradients of Amazon forest degradation. Acoustic data were converted into three-dimensional renderings of acoustic space configuration. We developed a hierarchical occupancy modeling framework to investigate the occupancy of acoustic space and transmission of acoustic signals as a function of lidar-derived covariates. We derived a synthetic measure of community diversity to characterize the biodiversity response to forest degradation in a space-for-time sampling approach. The results illustrate the role of degradation history in shaping both habitat structure and habitat use in frontier Amazon forests, and the unparalleled capacity of fire to erode canopy structure and transform wildlife communities. This work paves the way for more integrated research applications of remote sensing and spatial analysis methods that can support rapid, operational biodiversity assessments.

4.(11:30) Lessons Learned Identifying Wildlife Habitat Using Lidar | *J Kane*, V Kane, J Jenkins, D Lesmeister, M North, G Asner, LM Moskal*

Objectives: Aerial lidar is increasingly being used to quantify and distinguish the habitat of species of interest in forested areas. However, the realities of what lidar can and can't measure play a large role in whether such studies are successful. It is important to consider the biology and behavior of the species in question before deciding whether lidar is an appropriate tool for habitat identification.

Methods: We performed three lidar habitat studies with California spotted owls, northern spotted owls, barred owls and Pacific fishers. In two of those three studies, we performed tree segmentation over large study areas (420000 total hectares) and used the heights of those segments to estimate the percentage of canopy in trees of different heights. By comparing these values at various distances from dens and nests, we were able to statistically measure the degree of selection for trees of different sizes, and the size of area over which this selection occurs. In the third study, we compared the effects of metrics describing canopy height variation, cover, and vertical forest complexity using multivariate conditional availability models of foraging resource use within seasonal territories by 2 sympatric competitors (northern spotted owls and barred owls) and uncovered evidence for differences in use based on sub-canopy forest complexity.

Key results: We were able to successfully distinguish nesting areas or selection within territories of all three owls from the surrounding landscape, and were the first to distinguish northern spotted owl from barred owl habitat based on vegetative structure. We were unable to distinguish fisher denning areas from the surrounding forest. We believe these results are explainable from an examination of the limitations of lidar and the biology of the species in question. Fishers appear to select for structures such as tree cavities which are not detectable with lidar and do not correlate well with lidar metrics. We believe when owls fly and look down at the forest, they get a similar view to the lidar instrument, and thus that the characteristics they select for correlate more strongly with lidar measurements.

5.(11:50) Canadian Airborne Biodiversity Observatory | M Kalacska*, JP Arroyo-Mora, E Laliberté, A Bruneau, M Vellend, N Coops

The Canadian Airborne Biodiversity Observatory (CABO), is a new, highly innovative, transdisciplinary, and multi-scale initiative at the nexus of biodiversity and remote sensing science. Land-use change, climate change, biotic invasions and altered biogeochemical cycles are profoundly and rapidly transforming biodiversity across the globe. Yet our ability to monitor, understand and predict how biosystems will adapt to these pressures at regional to continental scales is severely constrained by the small spatial extent at which high-resolution biodiversity data are acquired. Through the integration of multi-scale remote sensed data form leaf to satellite, the overall objective of CABO is to understand and forecast how Canadian biosystems adapt to global change drivers, using a spectranomics approach. CABO studies the four most important global drivers of biodiversity changes affecting terrestrial ecosystems: land-use change, climate change, nitrogen deposition, and biotic invasions. We study these drivers and their effects at focal sites selected to represent a wide range of Canadian terrestrial ecosystems, each exposed to different threats. CABO is comprised of five modules that work jointly to forecast how Canadian biosystems adapt to environmental changes across spatial scales. In Module 1 we use high-fidelity spectroscopy to measure foliar spectra of Canadian plants in situ, using standardised protocols. These data provide the foundational upon which all other modules depend and allow us to determine how spectral signatures discriminate plant species across Canadian ecosystems. Module 2 examines chemometrics and functional traits capturing variation in foliar biochemistry and structure. Module 3 provides detailed, plot-based biodiversity field surveys to determine the ability of remotely-sensed data to quantify plant community properties and determine how selected Canadian biosystems have responded major environmental changes. Module 4 uses UAV and airborne (manned aircraft) hyperspectral imagery to assess plant taxonomic and functional diversity at high spatial and spectral resolutions. Finally, the satellite data fusion and mining in Module 5 provides CABO mechanisms to scale up to the continental scale. Through case studies we illustrate a first look at examples of boreal forest tree biodiversity and peatland vegetation biodiversity mapping from UAV and manned aircraft based hyperspectral imagery.

10C

FOREST DISTURBANCE AND DEGRADATION

Moderator: Lars Waser, Christoph Straub

1.(10:30) Comparison Of Sentinel-1 And Sentinel-2 Time Series For Near-Real Time Deforestation And Forest Degradation Monitoring In Tropical Areas With Quasi-Permanent Cloud Coverage | *N Algeet Abarquero*, A Fernández-Landa, ML Guillén Climent, J Esteban, P Rodríguez-Noriega*

The implementation of robust and cost-efficient forest monitoring systems for evaluating the performance of REDD+ actions in reducing deforestation and forest degradation is a key part of the agenda of REDD+ countries.This monitoring systems need to be based in near-real time automated mapping methods of forest change detection. Although some methods based on optical imagery are already available, the use of synthetic aperture radar (SAR) satellite products can be an alternative source of periodic information for implementing this successful near-real time forest monitoring. This is especially important in tropical areas where cloud and their shadows affect optical imagery availability during most part of the year. Traditionally, long wavelength SAR products have been used to assess forest status although their integration in monitoring system is constrained due to the low data availability. SAR products of short wavelength such as Sentinel-1 are generally less useful for forest studies because their lower penetration depth and its rapid saturation of the signal over forests. However, the unprecedented SAR data availability from Sentinel-1, opens the opportunity of evaluating new methodologies for forest monitoring apart from biomass monitoring form backscatter techniques that would make it possible to include this products in a forest monitoring scheme.

The objective of this research is to assess the performance of Sentinel-1 time series for forest monitoring. We explore the performance of backscatter and coherence methodologies over Sentinel-1 products in comparison with optical Sentinel 2 time series to detect deforestation and forest degradation as part of a near-real time monitoring system for the Humid Tropics of the Nicaragua Caribbean Region.

2.(10:50) Using an ensemble approach with spatio-temporal variables from annual Landsat time series to detect forest disturbances and attribute driving agents in Myanmar | *K Shimizu*, T Ota, N Mizoue, S Yoshida*

Detecting forest disturbances over large area at frequent time step is crucial for an assessment of carbon stocks and biodiversity. Free access policy of Landsat data archive made significant advancement in techniques for investigating decades of disturbance history and their driving agents across large scale extent, even in regions with sparse ground data in the past. While some change detection algorithms require threshold parameters to extract disturbance events from temporal noise in trajectories of single spectral index, other approaches such as enhancing machine learning algorithms based on various spectral indices are not fully investigated. In addition, attribution of driving agents in ensemble learning at the same time as disturbance detection might provide clear insights into error assessment in comparison to usual process where attribution is conducted for detected disturbances. Here, we investigated an ensemble learning based approach to detect forest disturbances and directly attribute their driving agents with spatio-temporal information derived from trajectory-based time series segmentation. Landsat images acquired from 2000 to 2018 were used to construct annual time series composites covering whole study area in Myanmar. After image preprocessing, a LandTrendr algorithm was run to acquire a set of time series segmentation for trajectories of tasseled cap and other spectral indices. A random forest classification was conducted to detect forest disturbances and directly attribute disturbance agents (e.g. logging, shifting cultivation and plantation expansion) based on variables derived from vertices of temporal segments and spectral values at the given year both for target and adjacent pixels. As key findings, our study showed that the ensemble learning approach improved performance of detecting and attributing disturbances compared with results of the approach using threshold of single spectral index. Our study also indicated that variables derived from adjacent pixels were helpful for reducing false change detection such as caused by salt-and-pepper effect, implying that the value of spatial information as well as temporal information in disturbance detection.

3.(11:10) Visual interpretation of the Landsat time series indicates that forest canopy decline represents heterogeneous forest structure and composition change | *D Bell*, M Reilly, W Cohen, A Gray, T Spies, Z Yang*

Remotely sensed observations of forest canopy decline highlight increasingly common forest changes driven by insects, disease, and drought that range from subtle (e.g., temporary foliage loss) to obvious (e.g., major canopy cover losses). Both the drivers and consequences of forest canopy decline may be variable, depending on the current status of the forest. The aim of this research was to assess how forest structure and composition affected forest canopy decline dynamics, particularly (1) the occurrence of forest canopy decline events and (2) their consequences for tree growth, tree mortality, and species turnover. We assessed forest canopy decline at 500 forest inventory plots measured from 1993 - 2013 in California, Oregon, and Washington, USA. We used the TimeSync tool to visually interpret the Landsat time series (1984-2015), identifying the year, duration, and magnitude of forest canopy decline events. We modeled the probability of forest canopy decline event occurrence as a function of forest status (i.e., structure and composition) and abiotic environment (topography and climate). Additionally, we modeled changes in basal area and relative abundance for 11 tree species related to forest status and the duration and magnitude of forest decline events.

Regional fluctuations in the frequency of decline events occurred early in the record (1984-1995), followed by a quadrupling (1996-2001) and a steady reduction for the remainder of the study period (2002-2013). Forest canopy declines were preceded by multiple years of increasingly hot and dry conditions, though this varied somewhat as a function of tree species. Both tree mortality and reductions in the relative abundance of tree species were related to the duration and magnitude of forest canopy decline events. However, these changes depended on initial tree basal area and size, indicating that the structural and compositional consequences of forest canopy declines depended on the local tree community. By examining the role of local factors in altering forest canopy decline occurrences and consequences, this research highlights the likely complex spatial patterns of landscape change and a potential for forest compositional shifts in the future. Furthermore, our results indicate that users of remotely sensed disturbance and tree mortality maps should be cautious as the causes and consequences of forest canopy decline vary substantially as a function of the forest landscape being examined.

4.(11:30) Mapping and monitoring fractional woody vegetation cover in the arid savannahs of northern Namibia using LiDAR and SAR data | *K Wessels*, F van den Bergh, R Mathieu, R Main, L Naidoo, N Knox, K Steenkamp*

Globally savannahs are experiencing an increase in woody vegetation with diverse environmental and socio-economic impacts. Although Namibia is a very arid country, it has experienced significant bush encroachment which has decreased livestock productivity, but presented new opportunities for biomass-based energy production. Therefore it is essential to monitor bush encroachment and widespread debushing activities. Literature on the remote sensing of vegetation structure mainly focuses on the high biomass tropics, with limited studies located in the arid savannas. The aim of study was to develop a system which can accurately map and monitor fractional woody cover (FWC) in arid savannas, at national scales using SAR satellite data (ALOS PALSAR annual global mosaics, 2009, 2010, 2015, 2016), using machine learning models that are trained using diverse airborne LiDAR acquisitions (244032 ha, 2008-2014). Innovative methods were applied to process LiDAR data with highly variable point density to unbiased estimates of FWC. The average R2 across all the years with the same ancillary data sets were 0.64, 0.75 and 0.76 at 25m, 50m and 75m respectively. This average absolute errors on FWC estimation at 25m, 50m and 75m were, 0.168, 0.14 and 0.135. All the models overestimated by an average of 10% FWC at the lower cover values (10-20% and 20-30%) and underestimated by an average of 15-20% FWC at high cover values (70-80% and 80-90%). Very limited bias in the FWC estimation was evident in middle ranges of FWC (40-50%). When focussing on 50m results only, the addition of ancillary variables, elevation, rainfall and both, increased the average R2 to 0.75, 0.74 and 0.79 respectively. The regional maps of FWC reflected spatial patterns related to rainfall gradients, vegetation type and structure. However, the inclusion of ancillary data sets resulted in anomalies in the FWC maps in areas with insufficient LiDAR training data coverage. The pair-wise annual FWC change maps displayed detailed local patterns related to debushing activities, wildfires and subsequent increases in FWC. Increases in FWC of 0.2-0.3 occurred over 3-7% of the surface area of Dense Shrublands and Woodlands between 2009 and 2016. However, there is no independent data to verify if this increase in FWC represents bush encroachment or error. The study demonstrated the potential of monitoring woody vegetation structure in arid savannahs with l-band SAR and limited LiDAR data, and provided essential insight into to challenges of using this approach at operational scales.

5.(11:50) Using three decades worth of Landsat time series imagery to map disturbance dynamics across public forests in Victoria, Australia | *M Soto-Berelov*, J Simon, H Andrew, N Trung, H Samuel, S Ahmad, L Costello*

Time series satellite imagery can be used to map trends and changes occurring in forests over time. This can support reporting and decision making in the land management and policy areas and quantify the annual impacts of land management decisions and land use land cover change (LULCC). This study uses dense time series Landsat imagery to map and examine disturbance events impacting 8.2 million hectares of forests in public land across Victoria, Australia. Public forests include state and national forests, parks and reserves. They have been managed for a variety of land-uses, and have experienced a range of natural (e.g., wildfire, drought) and anthropogenic disturbances (e.g., logging, planned burning). We downloaded all available Landsat TM imagery (1988-2016) for southern hemisphere summer months and created annual composites of various vegetation indices (using LandsatLinkR) across 19 WRS Landsat tiles. We extracted the spectral trajectory of each annual composite on a per pixel basis over a 28 year period, and used LandTrendR (Kennedy et al., 2010) to fit a trend and characterise disturbance-recovery dynamics on forests. A reference dataset consisting of nearly 8,000 reference pixels was then created to attribute disturbance events using a multiple lines of evidence approach. This was used to train a classifier (Random Forest) and map disturbance according to meaningful agents: logging (clear fell and selective logging), fire (wildfire and prescribed burning), low severity disturbance including pests, flooding, drought and disease. Results, which achieved a 67% overall accuracy, clearly show annualised abrupt disturbance events such as logging and wildfire, but are less clear with regards to gradual changes such as drought and disease. About a quarter of public forests across the state were impacted by med or high severity fire, while logging was detected in certain parts of the state (mostly in state forests). Our study demonstrates the successful application of dense time series for large area disturbance mapping according to meaningful agents for the first time in Australia. This can be used by land managers to support a range of forest monitoring and reporting activities.

10D

USING REMOTE SENSING-BASED MAPS IN COMPLIANCE WITH IPCC GOOD PRACTICES FOR GREENHOUSE GAS INVENTORIES

Moderator: Ronald McRoberts & Erik Næssat

1.(10:30) On the impact of omission errors on area estimates of activity data | *P Olofsson**

In recent years, the remote sensing community has recognized the importance of approaches to estimation of areas of land change categories -- referred to as activity data in the IPCC documentation -- from sample data rather than by counting pixels in maps. The recognition of the importance of estimation is driven by that fact that classification errors are inevitable when creating maps from remote sensing data, and that the impact of such errors on mapped areas can be severe. Further, IPCC Good Practices stipulate estimation of activity data and uncertainty assessment; pixel-counted areas are not compliant with IPCC guidelines. One type of classification error has proven particularly important: when using a map to stratify the study area in a sampling-based approach to area estimation, sample units in the often large forest stratum identified as activity data in the reference data, i.e. omission errors, often carry a large area weight. The critical impact of such errors has been documented in UNFCCC/REDD+ related work. In this talk, an overview of the underlying reasons for the impact of errors, REDD+ case studies and potential solutions are presented. In essence, if substrata in the forest stratum can be identified that are less likely to contain omissions of activities, the impact of omission errors can be contained. Approaches to efficiently splitting large forest strata are presented but examples in the literature on the use of such approaches are rare. More research is needed before further recommendations can be provided on how to contain, mitigate and potentially eliminate the impact of omissions errors.

2.(10:50) The Contribution of Reference Data Variability to the Total Variance of Forest Cover and Change Area Estimates | *S Stehman*, B Pengra, J Mousoupetros, R McRoberts, E Naesset, T Loveland*

Estimates of the proportion of area of forest cover or forest cover change can be produced from sample data obtained in conjunction with an accuracy assessment of a map. These area estimates are based on the reference classification of each sample unit, where the reference classification is defined as the best available assessment of the true ground condition. In many studies the reference class is determined by human interpreters examining satellite imagery, and thus these interpretations vary among interpreters. This interpreter variability has usually not been considered in the overall uncertainty characterization of area estimates and may have a considerable impact on the overall variance of sample-based forest cover and forest cover change area estimates. One approach to addressing the variance introduced by interpreter inconsistency is to apply a measurement error model, where measurement error is defined as a deviation between the recorded value and the true value of a sampled element. Such measurement error models have long been in use in survey sampling practice. These models express the total variance of an estimator as having components attributable to the sampling design (i.e., the usual variability of design-based inference) and to measurement error, where a model is used to characterize the measurement process.

The objectives of this study are to illustrate two methods, repeated measurements and interpenetrating subsampling, that yield unbiased estimators of total variance, and to quantify the contribution to total variance attributable to interpreter variability. Case study data from the Puget Sound ecoregion of the USA are used. These data are from a simple random sample and include up to seven interpreters for each sample location. Proportion of forest area and forest cover change estimates are examined. Interpreter variability contributed as much as 50% of the estimated total variance of the area estimates. The standard variance estimator for proportion of area underestimated the total variance by up to 40%. Interpenetrating subsampling generally produced smaller estimates of total variance than repeated measurements. However, the variance of both of these total variance estimators was substantial. Because the repeated measurements method for estimating total variance is simpler to implement, it is recommended for use to account for the considerable contribution of measurement variance to the total variance of area estimators.

3.(11:10) Comparison of GREG versus Stratified estimator for reporting forest activity data for REDD+ | *C Sannier*, R McRoberts, L Faucqueur, J Hugé, H Ghomsi*

Developing countries wishing to implement REDD+ need to develop a national forest reference emission level as part of the process. Reference levels are expressed as tonnes of CO2 equivalent per year for a reference period. Reference level serves as a benchmark for assessing a country's performance in implementing REDD+ activities. According to IPCC guidance, emission level is calculated based on the multiplication of activity data which is the total area affected by changes during the reference period considered and emission factor which is expressed in tonnes of CO2 equivalent per unit area for the particular activity. Several countries in the Congo basin have expressed their commitment in the REDD+ process and are in the process of submitting their forest reference emission levels. However, the levels of deforestation currently observed in those countries tend to be relatively small compared to other regions. This makes it particularly challenging to define suitable methods to estimate activity data with a small level of uncertainty. Design-based activity data estimation often relies on a probability sample of reference data that is obtained from the visual interpretation of satellite imagery. Several estimation methods exist either based on using a forest change map in a stratified estimation or a model assisted approach. Both methods were implemented for the Cameroon and Republic of Congo. Initial results for the Republic of Congo indicate that the two methods lead to equivalent results, but the level of uncertainty still appears relatively large despite following the guidelines suggested in the relevant literature. This is primarily due to the difficulty in appropriately characterizing the changed areas in the maps used. This is because deforestation tends to be related to small patches scattered over the entire study areas. Potential improvements are being implemented in relation to (i) improving the quality of the change strata and (ii) combining the stratified with model assisted estimation.

4.(11:30) Assessment of a global biomass map in miombo woodlands and rainforests in Tanzania | E Næsset*, T Gobakken, RE McRoberts, S Saatchi, E Zahabu

Around 9% of the land surface of the African continent is occupied by miombo woodlands a dry forest type with generally small biomass values. The miombo woodlands are subject to severe deforestation and degradation in many African countries, and so also in Tanzania where the miombo accounts for more than 90% of the forest land. In contrast, Tanzania also hosts some of the planets biodiversity hotspots centered at the sub-montane rainforests scattered around the country. These areas often have steep slopes with very large biomass values. Tanzania has submitted its forest reference emission level to the UNFCCC. The country is determined to establish greenhouse gas inventories in full compliance with the IPCC guidelines as recommended by the Conference of the Parties to the UNFCCC. Although Tanzania has a recently established national forest inventory (NFI) consisting of more than 30 000 ground plots, use of biomass maps may enhance the precision of the estimates of emissions and removals of greenhouse gases. In design-based and model-assisted estimation and inference, maps may be used in their original form to enhance estimates regardless of how well the map is calibrated to local conditions. Estimates will be fully compliant with the IPCC guidelines even in cases where the map may be of low quality. The price to pay for a poor map relative to a map of greater quality is larger uncertainty. However, if the map is used to support model-dependent estimation and inference, it is a crucial assumption that the method or model used to create the map is correctly specified for the geographical area of application. It is of particular importance that there are no systematic differences between the map and the reality.

In this study, we used a probability sample consisting of 513 ground plots of the NFI collected in a 15 000 km2 district with mainly miombo woodlands with small biomass values to evaluate the contribution of a global biomass map to enhance precision of biomass estimates. A model-assisted estimator was used, which also offered an opportunity to estimate the magnitude of the local bias adjustment. Another probability sample of 153 ground plots in a rainforest with large biomass values was used for the same purpose. The two study sites together span much of the range in biomass values found in Africa, and the contrasting results of the analysis which will be presented, illustrates the properties of the map in various biomass situations.

5.(11:50) Using a finer resolution local biomass map as a source of reference data for assessing a coarser resolution regional biomass map | *RE McRoberts*, E Næsset, GC Liknes, S Saatchi, Q Chen, BF Walters*

For greenhouse gas inventories, forest carbon stocks and emissions are often estimated by converting biomass or biomass change estimates to carbon. Conventional inventory methods for estimating biomass typically require acquisition of reference data in the form of ground observations, a potentially difficult task when forests are remote and/or inaccessible. An alternative is to use a regional map as a source of biomass information. However, regardless of the source, the IPCC good practice guidance requires that all estimates comply with statistically rigorous uncertainty criteria. To accommodate these criteria, a biomass map must be assessed using reference data that are of greater quality than the map data relative to attributes such as accuracy and resolution. If ground sampling is not feasible, a local finer resolution map may be considered as the source of reference data. With this approach, a two-stage sampling design can be used with the coarser resolution map units serving as the primary sampling units and the finer resolution map units serving as the secondary sampling units. IPCC compliant uncertainty estimation requires a hybrid approach to inference whereby the effects of sampling variability are estimated using design-based estimators and the effects of uncertainty in the finer resolution map unit values are estimated using model-based estimators. Using this approach, a 100-m x 100-m radar-based map and a 250-m x 250-m MODIS-based map were assessed using a 13-m x 13-m lidar-based map as the source of reference data. The primary results were that for the design-based component greater first-stage sample sizes reduced standard errors more than greater second-stage sample sizes, and for the model-based component the effects of spatial correlation, while non-negligible, were relatively small.

11A

SPACEBORNE LIDAR

Moderator: Rubén Valbuena

1.(13:30) Satellite-based Forest Inventory in Northwestern Canada | *G Castilla*, M Filiatrault, M Gartrell, R Skakun, R Hall, A Beaudoin, C Mahoney, L Smith, K Groenewegen*

The nearly half a million sq. km of forests in the Northwest Territories (NWT), Canada, is a widely distributed area, generally inaccessible and costly to survey. The existing Government of NWT (GNWT) Forest Vegetation Inventory (FVI) is available for less than 10% of these forests, creating the need for an inventory that could extend beyond the FVI. The only other full-coverage information regarding the location and composition of these forests was the c.2000 Landsat-based Earth Observation for Sustainable Development of Forests (EOSD) land cover map, but it does not contain detailed forest structure information. The goal of this work was to generate local information about forest structure in an area covering 80% of NWT forests, using an updated EOSD land cover map as a base. First,a multisource data set was created consisting of field inventory plots, samples of airborne LiDAR, and satellite LiDAR data from the Geoscience Laser Altimeter System (GLAS) aboard the IceSAT-1 satellite. These data sets were related through statistical models to generate estimates of stand height, crown closure, stand volume, and above ground biomass for selected GLAS footprints from forested areas. These estimates were then used as reference dataset to spatially impute the forest attributes across the landscape using the k-nearest neighbor algorithm, with predictors comprising Landsat data, a L-band dual-polarization PALSAR mosaic, and physiographic and climatic variables. The resulting continuous raster layers were also integrated with the limited coverage of the existing FVI into a vector layer called the Multisource Vegetation Inventory (MVI). The accuracy of the output suite of rasters is being assessed using independent ground plot data from the National Forest Inventory, and independent airborne LiDAR data acquired across the study area, and results will be reported in this communication. The MVI product will: (1) serve as input to the CFS spatially explicit Carbon Budget Model (gCBM); (2) be used by GNWT to identify areas for salvage logging after fire and potential timber harvesting; (3) used by GNWT to further stratify the land base by height, density and volume thereby enhancing the NWT Ecological Land Classification; and (4) be used in conjunction with the updated EOSD product to inform habitat suitability mapping and analysis. The methodology developed provides a framework that can be replicated in other poorly inventoried boreal forests.

2.(13:50) Estimation of Forest Aboveground Biomass and Canopy Cover with Simulated ICESat-2 Data | *L Narine*, S Popescu, A Neuenschwander, T Zhou, S Srinivasan, K Walsh*

The Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) is scheduled for launch in September 2018 and this mission will offer an extraordinary opportunity to contribute to an assessment of forest resources at multiple spatial scales. This study served to develop a methodology for utilizing data that will be collected by ICESat-2 over vegetated areas, for estimating forest aboveground biomass (AGB) and canopy cover. Using existing airborne lidar data for Sam Houston National Forest (SHNF) in Texas and known ICESat-2 track locations, photon counting lidar (PCL) data were simulated. Expected noise associated with daytime and night time operation times of ICESat-2 were added to the simulated data these datasets were processed using noise filtering and photon classification algorithms to derive forest canopy heights. Segments measuring 100 m along the proposed ICESat-2 tracks were then used to extract simulated PCL metrics, which provides similar data to the expected ICESat-2 vegetation canopy product. Linear regression models were developed to relate simulated PCL height metrics for 100 m segments along ICESat2 tracks for daytime and night time scenarios, to spatially coincident AGB and canopy cover derived from airborne lidar data. Findings from this study demonstrate the potential of ICESat-2 for estimating forest parameters under temperate forest settings, given the photon detection rate anticipated by ICESat-2, and especially in the data format provided by prospective standard ICESat-2 data vegetation products.

3.(14:10) NASA ICESat-2 for Wildland Fire Applications | *S Delgado Arias*, B Peterson, N Glenn, W Ni-Meister, T Neumann, M Jasinski, M Brown, V Escobar*

In September 2018, the NASA Ice, Cloud and land Elevation Satellite (ICESat-2) mission, will launch into its 500 km orbit to provide us with spatially dense and fine precision global measurements of our earth's surface elevation. The highly anticipated altimetry measurements are expected to improve decision processes needed to advance applications ranging from operational sea ice forecasting for Arctic shipping to monitoring global flood risk to improving fire fuel mapping. In this poster, we highlight pre-launch research that explores the use of ICESat-2 for wildland fire applications. This includes Early Adopter (EA) work on the potential use of ICESat-2 to improve fuel assessments that inform decision processes related to long-term land management, fire hazards, ecosystem restoration and national strategic planning.

Among its science objectives, ICESat-2 will measure global vegetation height as a basis for estimating large-scale biomass change. The single micro-pulse, multi-beam ATLAS instrument onboard ICESat-2 will take along-track measurements approximately every 70 cm and provide global terrain elevation, global canopy heights, and global canopy cover at 100-m resolution. In preparation for this new data, ICESat-2 EAs have been investigating the potential of ICESat-2, either independently or with data fusion, to (1) quantify aboveground biomass of semiarid ecosystem vegetation to quantify fuel loads regionally; (2) refine vegetation structure information for fire fuel mapping nationally; and (3) expand spatial coverage (regional-to-national) of fire-relevant canopy structure and fuel metrics for operational wildfire fuels mapping.

Latency, spatial and temporal resolutions are key data characteristics uniquely inherent to individual decision processes and operations. The ICESat-2 Applications Program facilitates the necessary feedback loops between the mission and EAs to clarify these characteristics for particular applications and to help identify the paths for how the mission products can become actively relevant. EAs are groups or individuals who have a clearly defined need for ICESat-2 data products and volunteer their own resources to demonstrate the utility of ICESat-2 data for their specific application or decision-making activity. Our poster will highlight this EA research, its preliminary results, and include a discussion on the requirements needed to effectively synthesize the ICESat-2 observations to inform wildland fire applications.

4.(14:30) Development of the Global Ecosystem Dynamics Investigation (GEDI) Lidar Canopy Cover and Vertical Profile Metrics Algorithm and Validation Results | *H Tang*, J Armston, S Hancock, S Marselis, S Luthcke, M Hofton, B Blair, R Dubayah*

NASA's Global Ecosystem Dynamics Investigation (GEDI) is scheduled for launch in November 2018, and will be the first spaceborne lidar mission optimized to measure global vertical forest structure and aboveground biomass. By the end of its nominal 2-year mission, GEDI will have delivered multiple scientific data products at both footprint (~22 m) and gridded (1 km) level. Here we describe the algorithm theoretical basis for the Level 2B footprint canopy cover and vertical profile metrics product and their gridding globally for the Level 3 product. The Level 2B data product consists of Canopy Cover Fraction (CCF), Plant Area Index (PAI), and their vertical profiles. These variables will be derived from individual lidar waveforms using a physically-based gap probability model under moderate assumptions, and the Level 3 gridding of these variables will be undertaken using Bayesian Kriging. The model efficacy for large footprint lidar has been evaluated across different biomes using data products from GEDI's airborne prototype (LVIS) and a preceding spaceborne lidar (ICESat/GLAS) in combination with in situ measurements including equivalent retrievals using Terrestrial Laser Scanning (TLS). We present examples of how GEDI lidar data can complement current satellite observations by providing new information on biophysical stratification and change in vertical canopy structure for dense tropical rainforests. We anticipate that the dense spatial sampling of GEDI over a two year mission period will greatly advance our understanding of global forest ecology and biodiversity.

5.(14:50) Forest biomass estimation using large-footprint LiDAR data for algorithm development of MOLI spaceborne LiDAR | *M Hayashi*, R Mitsuhashi, J Murooka, D Sakaizawa, T Imai, T Kimura, K Mizutani, Y Sawada, T Endo, K Kajiwara, Y Honda, K Asai*

Global-scale forest biomass mapping is essential for the progress of carbon cycle research aimed at climate change mitigation. Spaceborne LiDAR can measure forest biomass with high accuracy, therefore, it meets that demand. In this context, JAXA is developing a vegetation LiDAR of MOLI (Multi-footprint Observation Lidar and Imager), which will be installed at the International Space Station in 2021. MOLI has two unique features: (1) to transmit two laser beams closely for measuring ground slope accurately, (2) to load an optical imager simultaneously. We conducted airborne LiDAR experiment to develop algorithms to estimate canopy height and above-ground biomass from MOLI waveform data, and to verify its estimation ability. In the experiment, we installed a large-footprint LiDAR system developed by National Institute of Information and Communications Technology (NICT) in a small aircraft, and observed four forested areas in central Japan in November 2016. Its footprint has 25 m diameter and is located continuously in two lines of 40 m apart. As a result, we acquired a large amount of LiDAR waveform data over the forested areas. Then, we collected calibration and validation data by field survey in order to develop algorithms for the canopy height and above-ground biomass estimation. The survey was conducted in the Ise Shrine forest from January to March 2018. We accessed to 45 points, where corresponded with footprints of the airborne LiDAR observation, and conducted every-tree measurements within 12 m radius. As a result, The tree species were mainly cypress, average canopy height was 19.3 ± 3.1 m, and average above-ground biomass was 191.2 ± 84.4 Mg ha-1. We used this field survey data to develop algorithms for MOLI in this study. MOLI is expected to provide valuable information on the forest carbon stocks distribution.

11B

MULTI- AND HYPERSPECTRAL APPLICATIONS

Moderator: Robert Kennedy

1.(13:30) Integration of NEON imaging spectroscopy and LiDAR data for 3-dimensional canopy trait mapping | *A Chlus*, Z Wang, E Kruger, P Townsend*

Imaging spectroscopy has been demonstrated as a valuable tool for mapping biochemical traits in forested ecosystems at broad scales. However, most efforts to date have involved two-dimensional mapping of traits, typically representing top-of-canopy conditions. In reality, traits and their associated biological functions vary through the vertical profile of a canopy, such that incorporating information about vertical patterns may improve modeling of ecosystem processes like primary productivity. In 2016 and 2017, we collected extensive field data in forests in Domain 5 (Great Lakes) of the National Ecological Observatory Network (NEON) to characterize the vertical variation in a range of foliar traits (e.g., nitrogen, leaf mass per area [LMA], pigments, calcium) important to ecosystem functioning. Fieldwork was coincident with NEON Airborne Observation Platform (AOP) overflights which collected imaging spectroscopy and full waveform and discrete LiDAR data. Here we demonstrate the capabilities of hyperspectral remote sensing to estimate top-of-canopy biochemical traits and LiDAR to model canopy environmental conditions related to variation in traits (i.e., light transmittance) to extend functional trait estimates through the canopy in broadleaf species. A regression model considering top-of-canopy LMA, LiDAR-derived metrics of transmittance and height accurately estimated LMA at discrete heights throughout the canopy across all species (R2 = 0.72; RMSE: 9.1 g/m2; PRMSE: 11.5%). This model was then used to generate 3-dimensional maps of LMA across the study area. Other traits, including chlorophyll A content, showed strong species-specific relationships between vertical patterns and LiDAR-derived transmittance and top-of-canopy trait estimates.

2.(13:50) Differentiating FIA Forest Types with Hyperspectral and LiDAR Data | *C Shoot*, LM Moskal, H Andersen*

In this study we develop a methodology for classifying United States Forest Service (USFS) Forest Inventory and Analysis (FIA) defined forest type across the Tanana Inventory Unit (TIU) using a fusion of hyperspectral and LiDAR data. The hyperspectral and LiDAR data used in this study were collected as part of the 2014 acquisition with the NASA Goddard's LiDAR, Hyperspectral & Thermal Imager (G-LiHT). In order to determine the best classification method, we tested 5 classification algorithms: Gaussian Maximum Likelihood, K-Nearest Neighbor, Multinomial Logistic Regression, Support Vector Machine, and Random Forests. Each model was trained and validated using the forest type corresponding to each FIA subplot, alongside raw hyperspectral band data (114 in total), hyperspectral vegetation indices, and selected LiDAR-derived canopy height and topography metrics. Six different combinations of this input data were tested to determine the most accurate classification algorithm and model inputs. A 3-fold cross validation was performed in order to ensure that all data was included in both training and validation, but never within the same model. Of the five models and six model input combinations tested, we found random forest with hyperspectral vegetation indices as well as topography and canopy height metrics as model inputs had the highest accuracy at 77.53% overall. With the completion of this work, we hope to use this best model to classify forest types across the Tanana Inventory Unit in central inland Alaska where there is GLiHT coverage.

3.(14:10) From pixels to function: Tree growth estimation from canopy hyperspectral reflectance | *S Graves*, T Caughlin, S Marconi, S Bohlman*

Measuring forest demographic rates at large scales is important for understanding forest response to change. Advanced remote sensors and platforms enables ecologists to quantify forest characteristics on the scale of individual trees and species. This scale is valuable because it is an individual's demographic response (rates of growth, death, and fecundity) to the environment that drives forest composition and dynamics.

Time series remote sensing is used to measure tree mortality and changes in tree height and crown size. Growth measurements are challenging because changes are subtle and requires precise alignment of images between years. Hyperspectral remote sensing offers a different approach to measuring growth because of the relationships between spectral reflectance, foliar properties (functional traits), and tree performance.

Our objective is to predict tree stem growth rate from a single acquisition of hyperspectral reflectance. We focus on two research areas to quantify patterns across biomes (neotropical vs. temperate forests), forest types (even-aged plot vs. mature natural forest) and spatial scales (individual and plot). We matched field measurements of trees to pixels in high spatial resolution (1-2 m) airborne hyperspectral images. For the same trees we measured stem growth rate via tree inventories or growth ring analysis, and measured foliar traits and leaf reflectance. We quantified the strength of the relationships among reflectance, foliar traits, and tree growth.

Direct predictions of growth from hyperspectral reflectance was possible at the leaf and crown scale. In a tropical plantation, 63% of the variation in growth was explained by leaf reflectance alone, and 53% with canopy reflectance and elevation. In a temperate forest, canopy reflectance explained 53% of the variation in growth. Our results support the idea that the spectral-growth relationship is partly driven by foliar traits. In a temperate forest, canopy reflectance explained 71, 71, and 54% of variation in N, LMA, and P, respectively. In the tropical plantation, leaf reflectance explained 93, 94, and 63% of variation in N, LMA, and phenolic compounds, respectively. Two spectrally-derived traits (phenolic compounds and LMA) explained 49% of the variation in growth rate. Overall our results demonstrate the potential to derive forest function from remote sensing by predicting an important demographic parameter of tree stem growth rate.

4.(14:30) Foliar trait space from imaging spectroscopy | *P Townsend*, K Cawse-Nicholson, Z Wang, T Zheng, D Thompson, A Chlus, R Pavlick, F Schneider, D Schimel, E Kruger*

An increasing number of studies in recent years have demonstrated that imaging spectroscopy (hyperspectral) data can be used to map foliar biochemical and functional traits such as nitrogen and chlorophyll concentration, leaf mass per area, lignin and many others. Collectively, these parameters define a multi-dimensional trait space, and one of the major arguments for a global imaging spectroscopy mission is the potential for imaging spectroscopy to fill in gaps in our knowledge of how traits vary spatially and temporally between and within ecosystems globally. This is especially important for locations that are logistically difficult or expensive to sample on the ground. Using data from several studies, we present two sets of results looking at trait variation in forested ecosystems. First, we compare trait variation derived from imaging spectroscopy and trait variation derived from field data and show that image-derived trait space in ecosystems appears to be considerably broader than trait space inferred from field measurements. This confirms that imaging spectroscopy has the potential to provide information on trait variability that is not currently conveyed in trait databases or from other sources (e.g., Jetz et al. 2015, Schimel et al. 2015). Second, we compare the dimensionality of image-derived trait data to the dimensionality of hyperspectral images themselves, and find that there is a considerable amount of coherent residual variation in the spectral data of forests that is not fully characterized by the traits we have measured. In addition to laying the groundwork for future research (are there additional traits represented by the unexplained variation?), these results provide evidence that spectral diversity provides information content on multiple measures of diversity in ecosystems, most notably functional diversity.

5.(14:50) Mapping functional diversity of forests with remote sensing | *F Schneider*, F Morsdorf, B Schmid, O Petchey, A Hueni, D Schimel, M Schaepman*

Biodiversity is a key driver of productivity in a wide range of taxa and ecosystems, including forests accounting for the majority of terrestrial biomass and gross primary production on Earth. With the recent recognition of the importance of trait-based biodiversity assessments, a way to map, monitor and predict changes in plant functional diversity is needed. Therefore, we present a method to study spatial patterns of forest functional diversity with remote sensing, and its implication on ecosystem functioning.

We retrieved three physiological traits (leaf chlorophylls, carotenoids and water content) and three morphological traits (canopy height, layering and density) from airborne imaging spectroscopy and airborne laser scanning data, respectively, over 900 ha of a temperate mixed forest. The airborne trait retrieval was successfully validated with field data using a modeling approach to overcome temporal and spatial scale mismatches.

Based on the trait maps we applied a continuous mapping approach, having the advantage to include intra-specific diversity and to be independent of any predefined vegetation units, species or plant functional types. Results show clear spatial patterns of functional diversity following an environmental gradient, consistent between morphological and physiological diversity. Lower diversity on steeper, rockier and more exposed slopes could indicate reduced resource availability and resource-use efficiency, potentially leading to lower ecosystem functioning and stability. Besides detecting these matches between plant functional diversity and the environment, we were able to describe the scale dependency of the patterns and the functional diversity–area relationship of the forest. We found higher diversity within species and communities and a lower diversity between communities than expected from established species richnes–area relationships.

This is the first study addressing the mapping of functional diversity with remote sensing without the need of ground calibration, which is an important step forward from previous approaches. The approach is scalable and widely applicable, being only dependent on sensor resolution. With the integration of our results into dynamic vegetation models, it should be possible to establish the link from functional traits and diversity to ecosystem functioning and services. Ultimately, this will improve predictive ecology.

11C

MONITORING FOREST CHANGE & DEFORESTATION

Moderator: Jörg Haarpaintner

1.(13:30) Deforestation's Impacts on Fragmentation and Connectivity of Colombian Forests | *P Jantz*, S Goetz, A Hansen, J Watson, O Venter, M Hansen*

Connectivity of forest ecosystems contributes to maintenance of biodiversity and ecosystem processes. Decades of deforestation have progressively isolated humid tropical forests. Depending on its location and magnitude, deforestation has different effects on forest fragmentation and connectivity loss. Combining landscape pattern analysis and connectivity algorithms can provide detailed information on the effects of both the location and magnitude of deforestation. Using global forest change data with morphological spatial pattern analysis and corridor mapping algorithms, we quantify the impacts of deforestation on forest fragmentation and on structural connectivity change in the early 2000's between large, core forest areas in Colombia. Results show extensive loss of core forest area as well as increased isolation of core forest due to deforestation in landscapes between core forests. Deforestation contributed to loss of both along- and between-cordillera connectivity in the Andes. Core forests on the Pacific coast and in the Colombian Amazon were eroded and fragmented while deforestation effectively increased the distance between remaining core forests. Deforestation also decreased the effectiveness of the protected area system as protected core forests became more isolated. Our results highlight parts of the landscape that are strategically important for maintaining connectivity between core forest and, critically, for maintaining connectivity between core forests in protected areas. These results can be used to assess the relative vulnerability of strategic connectivity areas to continued forest loss. And, when considered in concert with other conservation targets, such as protected areas, maintaining populations of threatened and endangered species, and mitigating effects of climate change, they provide a basis for prioritizing conservation actions that can help maintain critical ecosystem functions in humid tropical forests.

2.(13:50) Dry Chaco Forest deforestation map by using Random Forest with Landsat dataset on Google Earth Engine | *V Barraza, P Perna, F Grings, E Roitberg*, M Salvia*

Semi-arid forest ecosystems play an important role in seasonal carbon cycle dynamics; however these ecosystems are prone to heavy degradation. In this research, we assess the potential to use Random Forest (RF) algorithm with the Landsat dataset on Google Earth Engine to detect cover change over the dry chaco forest (DCF), Argentina. In subtropical Argentina, the Chaco region has the highest absolute deforestation rates the country (200.000 ha/ year), and at the same time, is the least represented ecoregion in the national protected areas system. There is a critical need for methods that enable the analysis of satellite image time series to detect forest disturbances, especially in developing countries (e.g. Argentina). The unit of forest management (UMSEF) from Argentina provided an annual deforestation map based on visual inspection of Landsat images (Landsat 5 TM, Landsat 7 ETM+ and Landsat 8 OLI), taking large time of processing and the intensive and coordinated participation of many human resources. Here, we propose a RF model that automatically selects the training dataset using forest service (UMSEF) annual deforestation maps as a benchmark during 2007 to 2009. The RF training was based on 50 sample pixels for the sites in crops and another 50 over forest areas, each month from 2007 to 2009. The objective was to capture the seasonal variability of the predictor variables due to the seasonal behaviour of forest and crops. Using the monthly classification we combine the results annually with the objective of reducing false positive related to clouds, aerosols, etc. These composition were carried out using python tool development ad-hoc which assigns the most suitable class to each pixel based on measure of classification quality (CQ). These composition reduces the gaps produced by clouds and cloud shadows by assigning the correct class. The final annual product provides a nominal 30 m deforestation map over the DCF of Argentina using Landsat 7 and 8 datasets for 2007-2014. Two different metrics, derived from the confusion matrix approach (2000 independent validation samples were used per year), were selected for the accuracy assessment: the overall accuracy (OA) and the F-SCORE. In general, the global overall accuracy (OA) and F-SCORE was higher than 70% and 0.65, respectively, with a producer's accuracy and user accuracy higher than 70%.

3.(14:10) The potential of dense Landsat time series for deforestation monitoring in human-modified rainforests of Indonesia | *H Hadi*, A Krasovskii, V Maus, P Yowargana, S Pietsch, M Rautiainen*

The tropical region of insular South East Asia, notably the country of Indonesia, is a well-known global hotspot of deforestation. We demonstrated, for the first time, the potential of using Landsat Time Series (LTS) data and data-driven dense time series algorithms for deforestation monitoring in tropical rainforests of Kalimantan, Indonesia, at sub-annual time scales. We investigated three algorithms for deforestation detection, namely 1) Algorithm 1: the standard BFAST (Breaks for Additive Season and Trend) Monitor, 2) Algorithm 2: BFAST Monitor applied with consecutive anomalies criterion (CAC), and 3) Algorithm 3: an algorithm based on CAC and an alternative decision boundary. An accuracy assessment in spatial (user's (UA) and producer's accuracy (PA) of deforestation class; overall accuracy (OA)) and temporal (median temporal lag (MTL)) domain was conducted using 435 high-confidence reference sample pixels interpreted from multi-temporal very high spatial resolution (VHSR) image series.

Our results show, firstly, in terms of data availability, combining data from all Landsat sensors provided on average 4-8 (during 1999-2012 period) and 4-12 (during 2013-2016 period) cloud-free observations per year for most area in the Kalimantan mega-island. This indicates the feasibility for sub-annual deforestation mapping and monitoring in the region. Secondly, in terms of deforestation detection, Algorithm 1 was found to be prone to commission errors (67.4%) due to noise in LTS caused by un-screened clouds, providing UA: 32.6%, PA: 100.0%, and OA: 43.0%. Application of CAC in Algorithm 2 improved the spatial accuracy as compared to Algorithm 1, providing UA: 41.3%, PA: 99.3%, and OA: 53.3%. Algorithm 3 on the other hand dramatically improved spatial accuracy, providing UA: 94.5%, PA: 93.2%, and OA: 93.8% when three consecutive anomalies were required to confirm a deforestation event. When we decreased the required number of consecutive anomalies from three to two, the spatial accuracy decreased (UA: 87.0%, PA: 89.9%, OA: 88.7%), but the temporal accuracy improved from MTL: 112 days (2 observations) to MTL: 40 days (1 observation). Owing to the simple, generic nature of the optimal Algorithm 3, we provided a recommendation on tuning the algorithm for different operational use cases within the context of satisfying REDD+ requirements, depending on whether spatial accuracy or temporal accuracy needs to be optimized.

4.(14:30) The Benefits of Time: Characterizing the Landsat Spectral-Temporal Domain in Forested Ecosystems | *K Fickas*, V Pasquarella, P Arevalo, E Bullock, C Holden, P Olofsson, W Cohen, C Woodcock*

The use of Landsat data has historically been constrained to spectral and spatial information derived from a carefully selected image or set of images. However, free and open access to Landsat imagery combined with advances in data storage and computing are revolutionizing how the Landsat temporal domain is used to map and monitor land surface properties and land cover change. Since the opening of the USGS archives in 2008, many different time series analysis approaches have been developed without a unified framework for characterizing information extracted from dense time series of Landsat imagery.

Like spectral indices, Spectral-Temporal Features (STFs) represent a transformation of the original image data and can provide new information about land surface properties and other biophysical parameters. STFs offer a number of improvements over conventional spectral or spatial inputs, including seamless coverage over large extents, more consistent and stable feature sets for classification through time, and new information on both spectral and temporal variability in reflectance that can be related to biophysical parameters.

To demonstrate how STFs can be applied in practice, we present a series of case studies spanning a range of geographic locations within different forested ecosystem types, and study objectives. These case studies illustrate relationships between different STFs and various biophysical parameters and yield insight into the specific ecological metrics that can be discovered and characterized with the spectral-temporal domain.

With the release of collection-style Landsat products and continued advances in pre-processing algorithms , as well as availability of tiled Analysis Ready Data and improved access to cloud- and cluster-based computing resources such as

Google Earth Engine, the Australian Data Cube, and Sentinel Hub, time series approaches are becoming increasingly prevalent. We argue that STFs provide new information on both spectral and temporal variability in reflectance in forested ecosystems that can be related to biophysical parameters. Thus, there is a critical need to continue to review and standardize the discussion and application of STFs for locally-accurate mapping and monitoring of forested ecosystem dynamics.

5.(14:50) Monitoring direct drivers of deforestation in Indonesia | *K Austin*, Y Gu, P Kasibhatla, A Schwantes*

Policy interventions aimed at slowing deforestation should be based on up-to-date and spatially explicit information on the drivers of tree cover loss. In this analysis we improve understanding of the proximate drivers of deforestation in Indonesia, which has the highest rate of primary natural forest loss in the tropics, between 2000 and 2015. The causes of forest loss in the country have not been systematically characterized over time, limiting the development of effective policy solutions. We use high resolution imagery from Google Earth to characterize the drivers underlying a random selection of deforestation events, drawing from a global forest change product from Hansen et al. We find that small scale agriculture, including grasslands and fallow lands, comprises the largest single driver of forest loss, responsible for over one-third of national deforestation. Although notorious for causing environmental degradation, large scale oil palm plantations contributed less than one-fifth of nationwide deforestation over our study period. Logging roads were responsible for a declining share of deforestation 2000 - 2015, whereas mining, oil and gas activities were responsible for an increasing share. Direct drivers of forest loss in Indonesia are both spatially and temporally dynamic, suggesting the need for policy responses tailored at the subnational level, and new methods for tracking drivers over time.

11D

TERRESTRIAL LASER SCANNING 1: 3D FOREST MEASUREMENTS STRUCTURE, FUNCTION, AND SATELLITE CAL/VAL

Moderator: Mathias Disney & Crystal Schaaf

1.(13:30) Developing new biomass allometric equations based on terrestrial laser scanning | *K Calders*, M Disney, A Burt, N Origo, J Nightingale, Y Malhi, P Wilkes, P Raumonen, H Verbeeck*

Measuring forest structure - the size and location of leaves, branches and trunks - allows us to estimate the amount of above-ground biomass (AGB) stored in a forest. Forest structure is a key property as it indicates the (potential) size and variability of forests as a store and flux of atmospheric CO2. Our current best estimates of AGB are based on empirical extrapolations (i.e. allometric equations) of the masses of a small number of trees that have been destructively harvested. Due to the difficulty of weighing trees, these destructive measurements are also heavily biased towards smaller trees. As a result, estimates of forest AGB are highly uncertain, which is problematic for the calibration and validation of large-scale or global AGB maps derived from airborne or satellite data. We will show how measurements with 3D terrestrial laser scanning (TLS) are providing new insights into plot-scale estimates of AGB. We will show results from Wytham Woods, a deciduous forest in the UK that is dominated by Acer pseudoplatanus, Fraxinus excelsior and Corylus avellana. LiDAR scans were done in leaf-off conditions to assure the highest quality data. More than 1000 trees from within a two-hectare area were extracted from the point cloud. These trees were linked to traditional census data for comparison and species detection (to apply species-specific wood density). We will demonstrate the differences in AGB estimates using the traditional allometric equations vs. the AGB estimates through TLS volume estimates. We will develop a new, improved set of species-specific allometric equations based on the TLS data. Using the insights from our study area, we will illustrate the potential impact on carbon estimates for UK woodlands.

2.(13:50) Comparing Lidar-Derived Quantitative Structure Models (QSM) with Direct Measurements of Tree Structure, Volume, and Biomass | *P Radtke*, A Barker-Plotkin, P Boucher, A Burt, K Calders, D Walker, J Frank, Z Li, D MacFarlane, D Orwig, I Paynter, F Peri, P Raumonen, C Schaaf, A Stovall, A Strahler*

Terrestrial lidar-derived quantitative structural models (QSM) show great promise as tools for modeling tree structural attributes, including the volume of stems and branches along with their biomass contents. Recent results have demonstrated the potential for superior accuracy of biomass predictions from QSM models compared to those derived from allometric equations. An important question remaining – the one being studied here – is how well QSMs compare to direct measurements of volume or biomass for use in allometric model development.

In August 2017, the NSF RCN Coordinating the Development of Terrestrial Lidar Scanning for Aboveground Biomass and Ecological Applications hosted an international calibration activity at Harvard Forest, an experimental forest and LTER site in Petersham, MA, USA. The goal of this activity was to directly observe detailed structural measurements on standing trees, including stem and branch geometry in 3D, followed by destructive sampling for biomass determination in order to validate lidar-derived QSM results. A number of different terrestrial lidar instruments and scanning methods were employed. Results allowed for the comparison of not only whole-tree volume and biomass estimates, but also QSM characterizations of more detailed attributes, such as the volumes of main stems as well as first and second order branch architecture. Although considerable effort is required to collect such detailed measurements, they provide an important means of demonstrating the accuracy of QSM results and make progress toward a point in time when terrestrial laser scanning may nearly obviate the need for effort-intensive felled tree studies.

3.(14:10) Savanna vegetation 3D models: defining disturbance and resource constraints at multiple-scales | *J Singh*, SR Levick, M Guderle, S Trumbore, C Schmullius*

The varied spatial combinations and proportions of woody and herbaceous vegetation in savannas make them one of the most structurally complex ecosystems in the world. The structural intricacy is often attributed to the stochastic interactions between disturbance-regimes (fire and herbivory) and resources (rainfall and geology), acting at various spatio-temporal scales. Much has been learnt about the drivers of savanna vegetation heterogeneity from the plot-scale field measurements, but multi-scale structural inventories that characterize the synergy between fire, resources and vegetation structure are sparse. In response, we assessed fine scale woody tree structure and three-dimensional canopy arrangements at local and landscape scale across Kruger National Park, South Africa with the Riegl VZ 2000 terrestrial laser scanner. At local scale, we evaluated the effect of fire regimes and rainfall across a 63 year old fire manipulation experiment. We reveal that the vegetation 3D structure-fire relationships are context dependent, and are strongly influenced by rainfall. To enable the quantification of vegetation structure at landscape scale, we collected 106 long-range scans (> 2000 m) from topographic vantage points and hill-slopes across the entire KNP. In order to validate the accuracy of long-range scanning in large area monitoring, a canopy height and cover change matrix with respect to increasing distance from the scanner was produced. For this, we used 30 m x 30 m multi-scan plots in the footprint of long-range scans. The relationships were highly significant ($R2 = 0.80$), and displayed a low RMSE of 1.0 m up until 600 m from the long-range scan. Furthermore, despite the decreasing point density, canopy cover metrics from long-range scans were comparable to those reported from the field plots ($R2 = 0.71$). The high correlation of biophysical attributes derived from long-range scans allowed us to trace the trajectories of woody vegetation structure at landscape scale under diverse ecological settings. These findings highlight the huge potential of this rapid and accurate approach for regional scale vegetation monitoring in the context of changing global climate and land-use.

4.(14:30) Quantifying tree crown-filling using new 3D terrestrial laser scanning measurements | *M Disney*, L Bentley, A Burt, M Boni Vicari, K Calders, B Enquist, Y Malhi, P Wilkes*

Tree morphology is an often complex interplay of long-term evolutionary (genetic) response to selection pressure, and shorter-term phenotypic plasticity in the face of more immediate environmental constraints (climate, resources, competition, disturbance etc). This leads to interesting questions about what constrains or determines tree size and shape, and how this manifests response to their environment: what constrains tree height? What limits crown and branch size? What are the physiological advantages of long v short branches, wide v narrow crowns, fast v slow growth etc? There are a number of intriguing hypotheses relating tree size and shape to function, the so-called metabolic theory of ecology (MTE). One aspect of MTE concerns the space-filling nature of tree branching within the crown. This area has seemingly been relatively neglected (compared to overall height and mass) due to the difficulty of measuring branching size and volume accurately. Here, we analyse the space-filling (fractal) dimensions of tree crowns, based on terrestrial laser scanning (TLS) measurements across a range of tropical and temperate forests, and compare these estimates with theoretical predictions. We show that some truly extraordinary figures emerge when considering the length of branching within tree crowns, exceeding 35 km of branches in a single 35 m tall tree for example. We have measured some of the tallest and heaviest trees in the world, in tropical (Borneo) and temperate forests (coastal redwoods in California). Yet these extremely large trees have nowhere near the length or crown-filling volume of branches. These results are rather unexpected and have never been explored in this way before. Our results raise a number of interesting questions: what are the limits on such space-filling branching? Where and what species is the 'largest' tree in this crown-filling sense? How do environmental and genetic constraints control crown-filling? New highly-detailed 3D structural measurements provided by TLS are opening up new avenues of exploring tree structure and form, and we discuss the implications for this in terms of tree crown-filling and the wider ecosystem properties of forests.

5.(14:50) The single tree and forest stand 4-D monitoring using point clouds comparison approach from multi-temporal and multi-station terrestrial laser scanning | *P Wezyk*, K Zieba-Kulawik, P Rysiak, M Starzyk*

The 3-D precise TLS observations conducted regularly allow to describe dynamics of changes happening in horizontal and vertical structure of the forests. The volumetric changes of tree parts and whole forest stand (biomass) taking place over time enable conducting the 4-D monitoring. Three case studies will be presented: 1- the single tree; 2- the old-growth forest stand and 3-Norway spruce stand in forest decay stage.

The aim of the first case study project was the 4-D monitoring based on multi-temporal comparison of point clouds captured with Terrestrial Laser Scanning (TLS). The historical data from year 1829 showed that the 800 years old Oak Bartek was 23,5m high. In the same year, DBH (1.3m) equal to 2.52 m and the registered trunk perimeter was 7.92 m. First TLS data collections were performed during the Leaf-OFF (04.2013) and in Leaf-ON period (07.2013) using FARO FOCUS 3D, RIEGL VZ-400, LEICA C10 and RevScan (HandyScan).

The results showed some differences. The height (H) of the tree differed approx. 0.41 cm using altimeter Vertex (HaglÃ¶f; H = 29.31 m) and TLS point cloud (28.49 m). Trunk circumference (L) was 9.80 m much shorter then adjacent along the shape of bark (LT = 13.70 m). The TLS point cloud-based measurements showed 9.97 m and Handy-scanner LRevScan = 13.54 m. The second case study was the old growth forest located in the Reserve Lipowka Niepolomice Primeval Forest. The first TLS point cloud was collected in 2006 and the last one in 2016 using FARO LS 880 and FARO FOCUS 3D respectively. Throughout the 10 year analyzed period, the volume of dead wood increased by over 60%, from 31,7 m3 to 51,8 m3. The 8 old-growth trees died and fell over in the analyzed 10 year period. The last case study was located in Gorce National Park in total reserve zone where the forest decay of Norway spruce stand is observed since last two decades. The 4-station TLS scanning was performed in years 2012, 2016 and 2018 as well. The high dynamic changes were observed like broken of dead trees, falling of logs and destruction of the wood. In the same time we observed the natural regeneration of the forest resulted as the inflow of a significant amount of sun light. Conducted research demonstrates usefulness of TLS technology application in observation of natural processes taking place in natural forests ecosystems.

12A

FIRE, BURNT AREA AND FUEL LOADS

Moderator: Chris Stockdale

1.(15:30) Characterising Vegetation and Fuel Structure in Mallee Woodlands using Terrestrial Laser Scanning | *L Wallace, S Hillman*, R Taneja, K Reinke, B Hally, S Jones*

Australia's Mallee woodlands occur in the semi-arid areas of southern Australia. The overstorey vegetation consists of eucalypts, with trees being multi-branched from ground level and rarely exceeding 6m in height interspersed with other tree species (tea-tree and Cypress pine). Understorey species and density vary between regions and includes hummock grasses and shrubs. Mallee woodlands are significant for their plant biodiversity and maintain diverse populations of vertebrate and invertebrate species. They are also highly flammable with large wildfires capable of burning a high proportion of remnant vegetation and causing the local extinguishment of certain species. As such, vegetation structural information in Mallee Woodlands is critical for environmental monitoring and wildfire risk mitigation in these areas. The decreasing cost and increasing ease of use suggest the high quality structural information inherent in Terrestrial Laser Scanning point clouds can provide this information.

This studies objective was to evaluate the ability of TLS scanning to capture Mallee woodland environments primarily for assessing fuel hazard. In order to account for factors such as scan density, sampling efficiency and occlusion a dense set of 24 scans spaced at 10 m intervals across 50 x 30 m plot were collected. The sample approach was undertaken at 6 plots of varying fuel age and understorey composition. Current environmental models in Mallee woodlands consider tree height and cover and near-surface load as key variables. The TLS data was assessed for its accuracy in determining these metrics across the plot scale at varied sampling densities (all scans, single scan and every second scan). Other metrics such as individual branch diameter and fuel fineness (surface area to volume ratio) were also calculated. Where possible, metrics were assessed against field measures for accuracy.

The results of this study suggest that Mallee woodlands present an interesting case for TLS technology. The low height and sparse canopy make the retrieval of tree height and canopy cover relatively easy and accurate. However, the low diameter of multiple branches/stems combined with a high amount of hanging bark mean that for highly accurate information describing individual trees, dense scans surrounding each tree are required. In recently burnt areas, where leafs are present, ground level occlusion presents significant issues for characterising plots and for scan to scan matching.

2.(15:50) Development of 3-dimensional burn severity metrics | *K Nelson, B Peterson**

Remote sensing based estimates of post-wildfire burn severity have been operationally produced for many years. Typically, vegetation indices such as the Normalized Burn Ratio (NBR) are calculated from pre-fire and post-fire imagery, then differenced to show the degree of change after a fire. NBR is sensitive to changes in vegetation cover and soil properties related to fire. However, 2-dimensional imagery does not inherently capture changes in vegetation structure at various levels that also occur during wildfires. With the increasing availability of data from active remote sensing systems, new research is underway to develop a more complete accounting of ecosystem change following wildfire.

The applicability of lidar data for characterizing forest structure is well established. Many studies have used lidar for quantifying fuel profiles and stand characteristics for modeling fire behavior and fire effects. Few studies, however, have utilized lidar collections from before and after fire to quantify the structural changes caused by the fire. This is one of the goals of the USGS EROS fire science team. Using a terrestrial lidar system to capture very detailed structural profiles and relating them to aerial lidar surveys, we are working to develop a robust measure of three dimensional burn severity. With the advent of UAS-based lidar, near real-time pre- and post-fire data collection is becoming possible.

Another potential data source for characterizing three dimensional burn severity is SAR. While these data are less intuitive than lidar, they are, nonetheless, sensitive to vegetation structure. SAR data have been used previously for fire mapping, though experimentally. With newer missions such as Sentinel-1 and NISAR either already accessible or coming in the next few years, the availability of SAR data is significantly increasing. Research is underway to develop methods for operational burn severity mapping by combining optical, lidar, and SAR data. The goal is to develop a robust capability for mapping three dimensional burn severity using the best available data.

3.(16:10) Detecting burnt forest through applied machine learning techniques on combined high resolution remote sensing data | *T de Conto*, GA Prata, LCE Rodriguez*

Data acquisition through aerial/orbital platforms have become easily accessible. Aerial and satellite images can be taken at short, regular intervals, providing high resolution, multispectral data of the top layers of the land cover. Airborne LiDAR data can reach even higher resolution than spectral data, with the advantage of being able to penetrate the top layers of forested land, reaching the soil and providing better and more detailed structural description of the vegetation, but with the current draw back of lacking multispectral data. By combining close to synchronous data surveys from different sensors, with proper field or visual validation, powerful supervised, state of the art algorithms can be trained for specific forest monitoring tasks, such as detecting forest fires accurately. Our aim in this study is to combine Airborne Laser Scanning data with Rapid Eye imagery to build a reliable model for detecting burnt areas within a native forest and eucalypt plantation mosaic. Based on LiDAR derived metrics on the vertical forest structure, the Rapid Eye coarse bands and a few color filters we trained the Random Forests and Support Vector Machines (SVM – using a polynomial kernel) algorithms for detecting burnt areas in the forest mosaic. Accuracy of the techniques was assessed by cross validation and reached up to 96% assertiveness on both tested algorithms. The most important variables on the final trained models were related to the red and near infra red bands of the rapid eye images, as well as canopy cover and canopy density metrics derived from the LiDAR datasets. Such an approach has shown to be a reliable way of automating the detection of burnt areas on high resolution remote sensing data. Accurate models can be trained for extensive areas, being thus a strategic alternative for forest managers for detecting fire affected zones and effectively treat them, for a quick restoration of the damaged areas and to avoid further damage on surrounding stands.

4.(16:30) Small area estimation of forest attributes within fire perimeters | *G Moisen*, T Frescino, R Bush, K Megown, B Quayle, J Gregory, C Baker, C Toney*

Recent emphasis has been placed on estimating amount and characteristics of forests affected by wildfire to inform decisions about post-fire management activities within burned areas. Data collected by US Forest Service, Forest Inventory and Analysis (FIA) Program is intended for estimation over large geographic areas and is too sparse to construct sufficiently precise estimates within small geographic areas such as burn perimeters, or small temporal domains such as annual fire effects. In this paper, we illustrate how landsat-based maps can be coupled with the FIA plot data to construct estimates of forest attributes affected by wildfire. This process dovetails with the Rapid Assessment of Vegetation Condition after Wildfire (RAVG) process developed for National Forest Systems lands. We compare several estimators including direct, generalized regression, synthetic, and empirical best linear unbiased predictors at both the area and unit levels. In the latter, we are able to internally balance the potential bias of synthetic estimates (generated solely from adding up pixels on predictive maps) against the instability of direct estimates (generated from small numbers of FIA plots). Different levels of ecoregion designation are explored to identify the best surrounding areas from which to draw strength, constructing models for automated processing. Data extraction and estimation methods are available in the R package FIESTA which was designed to streamline new estimators and applications for FIA scientists, analysts, and, ultimately, users. Methods are described and illustrated through applications to the devastating 2017 fire season, and more recent activity, in the Interior Western US.

5.(16:50) Implications of Peat Burn Severity on C Emissions and Post-Fire Successional Trajectories in Boreal Northwest Territories Canada | *L Bourgeau-Chavez*, J Graham, M Battaglia, N French, E Kane, S*

Grelik

Boreal Peatlands, which store most of their carbon belowground, cover more than 75% of southern Northwest Territories Canada and the effects of wildfire in these systems is largely understudied. Under funding from NASA's Arctic and Boreal Vulnerability Experiment, research has been conducted over the past three years to understand the effects of widespread wildfire on peatlands and uplands that traverse the taiga shield and taiga plains ecozones and gradients of ecosystem types, severity of burn and seasons of fire. Field observations collected in 2015-2018 are being linked to remote sensing to scale our field based observations to the landscape scale. The depth of peat consumption in these wildfires has a direct effect on carbon emissions and post-fire successional trajectories. We are finding relationships in the field between peat burn severity and post-fire conifer tree recruitment and relationships to broadleaf recruitment are under study. Landsat-8 algorithms have been developed to scale the field data on belowground consumption or peat burn severity to the landscape scale, and thus map peat burn severity across the region. In addition, multi-temporal, multi-sensor pre-burn radar and optical imagery was used to map peatland types and distribution across the study area. The intersection of these maps is allowing us to understand the patterns and controls of burn severity in peatlands across the ecological zones and also to predict where we expect conifer vs. broadleaf succession based on the field-derived correlations between peat burn severity and post-fire succession. Recent changes in climate including earlier springs, longer summers and changes in moisture patterns across the landscape, are affecting wildfire regimes of the Arctic-boreal region including intensity, severity and frequency of wildfires. By studying a range of sites stratified across the gradients of biotic and abiotic factors we are increasing our understanding of the vulnerability of peatland ecosystems to wildfire, fire behavior, C consumption/emissions and the trajectories of succession that are likely to ensue.

12B

FOREST COVER MAPPING

Moderator: Erik Willén

1.(15:30) Boreal canopy surface estimates from spaceborne stereogrammetry | *P Montesano*, C Neigh, W Wagner, M Wooten*

Surface elevation estimates from high resolution spaceborne image (HRSI) stereogrammetry are used to examine fine-scaled forest structure. In particular, the structural characteristics captured with these data can depict the spatial patterns of vertical forest structure at remote high latitude sites across the circumpolar domain where these estimates would otherwise be unavailable. HRSI acquisition characteristics (sun-sensor-target geometry), surface conditions, and the forest structure itself affect the surfaces captured with stereogrammetric elevation estimates, and the resulting interpretation of structure. This work is motivated by the need to both understand where these estimates are most effective at describing vertical forest structure, and to understand which canopy surfaces they represent. We evaluate the variation in canopy surface estimates captured from four general types of HRSI digital surface models (DSMs) across the full range of boreal canopy cover. These DSMs, classified according to the acquisition's sun elevation angle and ground condition (snow presence/absence), are understood to vary with acquisition characteristics and the details of this variation continues to be studied. We explore some of this variation by comparing the distributions of differences in canopy heights derived from small footprint LiDAR with surface elevations (normalized with the LiDAR terrain surface) derived from these 4 types of HRSI acquisitions. We examine the relationship in the variability of canopy surface estimates from HRSI DSMs to acquisition characteristics, ground conditions, and canopy cover. This variability is based on the association of DSM canopy surfaces with canopy percentile height estimates from LiDAR at forest canopy cover intervals in Tanana Valley, AK.

2.(15:50) How to apply forest definitions into multispectral imagery in the mountainous temperate forests? | *E Grabska*, WS Keeton, B Price, P Tompalski, K Ostapowicz*

Mountain forests are one of the most fragile environments, being highly sensitive, for example, to climate change and disturbances. They are important for provisioning of ecosystem services, such as hydrologic regulation and erosion control, as well as providing habitats for endemic and rare species. Delimitation of forest areas is therefore important for sustainable forest management.

Remote sensing can provide accurate information on forest extent from local to global scales. However, the definitions of forest vary - they are often different in different countries, and are based on different forest stand attributes. The key parameters in forest definitions are usually height, area, and crown coverage. The multitude of definitions of what a forest is, can lead to discrepancies in remote sensing-based forest cover estimations.

This study translates various criteria of defining a forest (e.g. canopy cover, minimum tree height, area) into information possible to extract from two different optical sensors: Sentinel-2 and Landsat 8. We assess how selected definitions of a forest can be applied in different mountainous areas, in eight countries, on two continents. Selected study sites include different mountain ranges and forests of different species composition, structure and disturbance regime, and different forest management.

Specifically, the study areas were selected in three mountain ranges: the Carpathians and the Alps in Europe and the Rocky Mountains in North America. For each of the study area we selected test sites representing diverse mountain forests in terms of environmental conditions, forest management practices, species composition and types of disturbances. In total there were eleven study areas.

We used imagery from Sentinel-2 and Landsat 8 missions for the years 2017-2018. We also used additional data: high-resolution orthophotos and LiDAR point clouds as a reference data in assessing tree heights and crown coverage. We used texture metrics and common vegetation indices and classified forest and non-forest areas using the Random Forest algorithm.

Results showed that selected definitions, methods and data, have a huge impact on the output maps of forest. Thus, it is recommended to develop and use one standardized definition which will enable the comparison of forest areas across the world.

We gratefully acknowledge support by the National Science Centre, project RS4FOR [project no. 2015/19/B/ST10/02127].

3.(16:10) A new tree extent and canopy height map for Bangladesh | *N Thomas*, P Baltezar, D Lagomasino, S Lee, T Fatoyinbo, J Green, M Rahman*

Trees in Bangladesh are disproportionately important. As little as 11% of Bangladesh is forested and it has one of the lowest forested land per capita (0.009 ha person) estimates globally (FAO., 2015). An estimated 39% of the Bangladesh natural forest area has been lost since 1930 (Reddy et al., 2016) driven by demands for wood products and agricultural land expansion. Discrete trees and small groups of trees in non-forest settings, known collectively as trees outside forest (ToF), therefore provide important ecosystem services and are an essential socioeconomic and ecological asset, particularly when they are the primary forest resource. Large scale assessments of ToF have often been limited by the unavailability of sufficient high-enough resolution imagery and have primarily utilized optical data only. Our aim was to generate a new extent and canopy height map for all trees within Bangladesh. We used a combination of ESA Sentinel-1 and Sentinel-2 and DLR Tandem-X imagery within the Google Earth Engine environment. Thresholds on Sentinel-1 Synthetic Aperture Radar (SAR) HV and Sentinel-2 NDVI were used to derive tree extent, at 10 m resolution (mmu 0.125 ha). A 30 m canopy height map was generated using an InSar TandEM-X digital surface model (DSM) and associated interpolated TanDEM-X digital terrain model (DTM) (RMSE 1.26 m). We mapped 4,417,917 ha of trees, equivalent to 30% of Bangladesh. This is larger than existing estimates of tree cover extent, interpreted to be a consequence of the use of higher resolution multi-modal imagery. We derived a canopy height map for almost the entirety of Bangladesh, that yielded an average canopy height of 9.5 m for trees outside of continuous forests (i.e., forested hillsides, mangroves). Further work will be oriented towards improving CHM estimates over elevated terrain and deriving height and biomass estimations from field collected information to estimate the total biomass of trees within Bangladesh. We have successfully provided a new tree extent and canopy height map that will serve as baseline products for the monitoring of terrestrial carbon within a heavily fragmented yet important forest resource. This work contributes to the USAID-funded SilvaCarbon Bangladesh program, which aims to provide technical support to the Bangladesh Forest Department to measure, monitor and manage forest and terrestrial carbon.

4.(16:30) Multi-sensor data synthesis for forest classifications with the Bayesian Updating of Land Cover (BULC) algorithm | *J Cardille*, M Crowley, X Giroux-Bougard, J Lee*

The proliferation of remote-sensing platforms and data has created a pressing need for a general method to fuse large amounts of data to better assess a variety of types of LULC change through time. The need has grown gradually: with each satellite launch in the decades since Landsat 1, researchers have developed specialized portfolios of useful analysis techniques tailored to each sensor's strengths and weaknesses. There are now scores of creative, mostly sensor-specific solutions used with great success to track forest change across decades. Despite this progress, it remains challenging to create multiple-category LULC time series tailored to particular needs, in a region of choice over a specified time.

To create coherent time series built from arbitrary sets of sensors, we developed the Bayesian Updating of Land Cover (BULC) algorithm. BULC ingests already-classified images and computes, for each pixel, a constantly updating vector of probabilities of each potential class, modifying them in light of new evidence from a new provisional classification made from any sensor. Here we detail one BULC application: tracking forest loss for the establishment of agriculture over the entire satellite record in a 12,000-km2 area in Mato Grosso, Brazil. In Google Earth Engine, we accessed data from 142 images from 14 sensors–all Landsats, Sentinels, ASTER, CBERS, etc.– creating provisional CART classifications in Earth Engine's interactive interface. BULC fused the classifications into a coherent time series that showed the evolution of a formerly very isolated area, the Roosevelt River, as ~10% of its area was converted for Agriculture in the satellite era. The five-decade BULC time series was more reliable than the single-day classifications while filtering most inter-classification noise. Furthermore, BULC estimated the LULC across the entire area at all time steps while some individual classifications, like ASTER, covered only a small portion.

Beyond these results, we survey other BULC projects to illustrate how BULC may be used for other, similar purposes. These include: sharpening a GlobCover classification to Landsat scale using unsupervised classifications; flood mapping; and tracing fire growth across British Columbia. In an era of almost unlimited free satellite data, BULC can be a useful, general approach to merging LULC from multiple platforms that leverages each platform's strengths to produce time series with user-specified categories.

5.(16:50) Urban Tree Canopy Assessments | *J O'Neil-Dunne*, M Grove, M Galvin, D Locke*

Urbanized areas around the world are facing numerous environmental pressures, from rising temperatures to stormwater runoff to poor air quality. Traditionally, these challenges were addressed through gray solutions, such building new water treatment plants or expanding transportation networks into the suburbs. Mapping efforts have mirrored the solutions; data on structures, roads, and property boundaries are typically excellent in the developed world. With water treatment plants at maximum capacity, multi-hour commutes from the suburbs getting longer, and summer after summer of record temperatures it is clear that the limits of gray solutions are being reached. The world's cities also find themselves in an era of intense global competition - to host the most successful companies and attract the brightest minds. Cities are making investments in their green infrastructure to provide ecosystem services to their citizens and make the urban environment more livable in the push towards sustainability. Despite massive investments in geospatial data and technology, most cities know little about their green infrastructure – how much they have, who owns it, who cares for it, and how it changes over time. The USDA Forest Service's Urban Tree Canopy (UTC) Assessments are changing this, providing decision makers with the information they need to manage their urban forests. The UTC assessments make use of existing high-resolution imagery and LiDAR data holding to map tree canopy and track changes over time. In this presentation we discuss how the UTC assessment methodology has evolved over time, the challenges of mapping forests in complex, heterogeneous environments, and how this information is being used by cities.

12C

FORESTS AND THE CARBON CYCLE

Moderator: Laura Duncanson

1.(15:30) A Spatial Carbon Budget Bookkeeping Model for Forest Disturbances | *W Gong*, F Zhao, C Huang, R Houghton, A Nassikas, K Schleeweis*

Forests contain more carbon than any other terrestrial ecosystems, storing over 80% of aboveground and 40% of belowground terrestrial carbon (Bradford et al., 2008; Gray & Whittier, 2014; Liu et al., 2008). Changes in forest carbon stock and/or flux can have substantial impact on atmospheric carbon dioxide concentrations. Thus, improving techniques to accurately assess forest carbon change over large areas has increasing global relevance (Bradford et al., 2008; Liu et al., 2008; Pflugmacher et al, 2014). This study adapts Houghton's bookkeeping model into a pixel-based spatial model, and integrates remotely sensed data to improve the estimation of forest carbon budget. The study chooses North Carolina as a test study area, and examines the impact of four forest disturbance types on carbon budget, including fire, harvest, conversion to cropland, and conversion to urban land. In this presentation, we highlight the major challenges and adopted solutions in converting the original non-spatial bookkeeping model to the new spatial model, and discuss the sensitivity of the model to various remote sensing based input datasets. The results demonstrate the need for annual map products of forest carbon density and disturbance intensity to improve model estimates of carbon fluxes driven by forest disturbance and recovery.

2.(15:50) Implications of errors in remote sensing-based maps on models of carbon emissions in the Colombian Amazon | *P Arevalo*, C Woodcock, P Olofsson*

The application of unbiased estimators to sample data for estimation of area of land cover and land change and associated uncertainty is becoming standard practice for users and producers of remote sensing-based maps. Classification errors are inevitable which entail that areas obtained directly from maps (pixel-counting) are erroneous. The use of an unbiased estimator accommodates the effects of map classification errors, and complies with the IPCC Good Practice Guidelines for reporting within the UNFCCC/REDD+ framework. However, higher level methodological approaches for UNFCCC/REDD+ reporting (Tier 3) stipulate modeling of carbon emissions at the pixel level and not at the population level. In a design-based inference framework, parameters of interest (e.g. area of deforestation) of a population (e.g. country), are estimated from sample data and pertain to the entire population and not to individual pixels. The result is a dichotomy between the estimation frameworks recommended by the remote sensing community and the approaches to Tier 3 reporting. What would help to close this gap are methods that would translate population-level estimates of bias and uncertainty down to the pixel-level, but such approaches are with a few exceptions nonexistent in the literature. We present the results of a methodology to generate a spatial representation of uncertainty in the map classification using reference data. The method is based on a generalized spatial model that predicts the probability of a pixel being correctly labeled. Covariates of the model include distance to class edges, class heterogeneity metrics and measures of time series instability based on the cumulative sum of regression residuals, among others. The maps were created using the results obtained from applying a break detection algorithm (Continuous Change Detection and Classification, CCDC) over Landsat time series, in conjunction with training and reference data. The approach provides more accurate results for spatializing the probability of a pixel being correctly classified compared to other methods like an inverse distance weighted interpolation. We discuss the implications of spatialization in a study of the carbon emissions and removals associated with land change at the pixel level across the Colombian Amazon. The study provides evidence of a decrease in primary forest as a result of conversion to pastures, as well an increase in secondary forest resulting from abandoned pastures.

3.(16:10) Using InSAR based Wall-to-Wall Forest Carbon Change Mapping for Estimating Forest Carbon Gain and Loss in all Protected Areas and buffer zones in Uganda : Implications to the Carbon Benefits of Conservation | *B Gizachew*, S Solberg, S Puliti*

Uganda designated 722 Protected Areas (PAs) (16% of its land area), being managed under five different categories. The predominant purpose of the PAs was habitat and biodiversity conservation, but PAs also offer great potential for carbon conservation in the context of climate change mitigation. Estimating and mapping the forest carbon change within and outside the territories of a large size and number of PAs, however, is challenging. We draw on a wall-to-wall map of net forest change for Uganda derived from two Digital Elevation Model (DEM) datasets, namely the SRTM acquired in 2000 and TanDEM-X acquired around 2012 based on Interferometric SAR (InSAR) and based on the height of the phase center. We (1) quantified forest carbon gain and loss within the entire territories of each of the 722 PAs, (2) quantified net carbon gain and losses in the buffer zones surrounding each PA at distances 0.5, 1, 5, and 10 km from the PA boundaries, and (3) evaluated the effectiveness of each PA and the prevalence of local leakage in terms of forest carbon loss. The approaches successfully quantified, with a reasonable accuracy, the forest carbon loss and gain, and its variation by management categories and the variation within PAs of the same management category. Accordingly about a Third of the PAs were effective, i.e., gained or at least maintained carbon during the period, while the rest were ineffective, i.e. lost carbon. Nevertheless, carbon losses in buffer zones of those effective PAs, significantly contrast with carbon gains inside the boundaries, providing evidence of leakage into landscapes outside PA boundaries. The InSAR based mapping approach was useful in revealing the combined losses in carbon inside the boundaries of a large number of PAs, together with leakage in buffer zones of the effective PAs, suggesting that PAs are threatened by deforestation and forest degradation. If Uganda will have to benefit from PAs through climate change mitigation mechanisms such as REDD+, there is an urgent need to look into the current PA management, and design strategies that account for the buffering landscapes and communities outside of the PAs. Countries with large size and number of PAs can benefit from InSAR based wall-to-wall forest mapping approaches demonstrated here, to estimate the carbon benefits of their conservation efforts.

4.(16:30) Sentinel-1 and -2 Data for optimized Forest Cover Detection in European Temperate Forests and South African Savanna: Investigation of sensor fusion and the impact of spatial autocorrelation | *K Heckel*, M Urban, P Schratz, M Mahecha, C Schmullius*

Reliable information about the extent of tree canopy cover (TCC) is essential for knowledge-based policy-makers and different research fields such as environmental modelling. Latter are interested in this topic, due to the crucial importance of forests as co-determinators for the regulation of the global carbon cycle. Hence, optimal forest cover detection requires input data that provides both high spatial and temporal resolution, allowing a more realistic spatial representation of forests cover, particularly in sparsely forested regions. These criteria are met by the Sentinel-1 and -2 satellites, which are operated by the European Space Agency (ESA). In order to derive accurate maps of forest cover in different latitudes and thus ecosystems, preprocessing and classification was firstly carried out using optical Sentinel-2 data only to derive TCC within this study. Following, a comparison with results from radar data (Sentinel-1) alone and from a synergistically classification approach (Sentinel-1 and -2) was accomplished, to evaluate the beneficial effect of data fusion for forest cover derivation in varying ecosystems. As study sites, Thuringia (Germany) and Kruger National Park (South Africa) were chosen, to assess the robustness of the machine-learning classification procedure. Therefore, the combination of spectral bands, vegetation parameters such as Fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and Leaf Area Index (LAI) from Sentinel-2 as well as multi-temporal metrics derived from Sentinel-1 were used in an non-parametric Random Forest (RF) approach, leading to considerably high classification accuracies between 80 and 95 %. In order to evaluate performance, cross-validation (CV) was carried out using an innovative approach applying the concept of spatial autocorrelation to account for model overfitting which is not part of traditional CV's and thus, causing the introduction of a BIAS into the classification. Results of spatial and non-spatial CV were then compared to each other to evaluate the impact of spatial dependence within the data. Analysis of the variable importance revealed that Sentinel-2 channels 11 & 12 (SWIR) as well as the minimum backscatter of the multi-temporal Sentinel-1 metrics where the most important parameters for the discrimination between forest and non-forest. The results indicate that Sentinel-1 and -2 fusion provides valuable information for forest cover derivation in varying latitudes and ecosystems.

5.(16:50) Unravelling the effects of inundation dynamics on methane cycling in forested wetlands using spaceborne optical and radar data | *B DeVries*, KL Hondula, C Huang, CN Jones, MW Lang, MA Palmer*

Wetlands play a critical role in the global methane budget, variably acting as sinks or sources depending on a range of environmental conditions. In particular, methane cycling in small ephemeral wetlands is driven by seasonal variability in the extent of inundated area and the associated moist margin. However, quantifying spatial and temporal variability of wetland inundation at the landscape scale presents significant challenges, with forested wetlands being particularly difficult to characterize. In this study, we combined a range of satellite and ground-based datasets to derive time series inundated area estimates and related methane emissions in two forested wetland catchments in the Delmarva Peninsula, USA. We first identified potential wetland depressions using inundation probabilities derived from historical Landsat data as well as a 1-m resolution lidar DEM. We then modelled trends in inundated extent for 2017 and early 2018 using sub-pixel water fraction from harmonized Landsat-Sentinel2 (HLS) data and backscatter time series from VV-VH polarized Sentinel-1 synthetic aperture radar (SAR) data. A comparison of these estimates with fine resolution optical, lidar, and in situ observations showed that under-canopy inundation could be detected using both optical and SAR under leaf-off conditions, while neither data source could reliably detect inundation in small wetlands under leaf-on conditions. Field measurements of methane fluxes showed high air-water fluxes from inundated areas, whereas non-inundated wetland sites had low or negative fluxes. Improved inundation predictions during leaf-on periods are needed to further determine the effects of seasonal inundation dynamics on methane emissions, and to scale inundation-emission models to other forested wetland catchments. For this reason, longer wavelength SAR sensors with greater capacity to penetrate the forest canopy, such as the upcoming L-band NASA-ISRO SAR (NISAR), will play an important role in characterizing seasonal inundation dynamics and related methane emissions in forested wetlands.

12D

TERRESTRIAL LASER SCANNING 2: 3D FOREST MEASUREMENTS STRUCTURE, FUNCTION, AND SATELLITE CAL/VAL

Moderator: Mathias Disney & Crystal Schaaf

1.(15:30) Is UAS-LiDAR the data acquisition method for future forest inventories? | *M Hollaus*, D Wang, M Wieser, N Pfeifer, G Bronner*

Forest inventories (FIs) deliver essential information for any forest monitoring and management activity. Traditionally, FIs are carried out mainly with simple field measurement tools (i.e. calliper, inclinometer) on plot levels to acquire tree attributes such as diameter at breast height (DBH) and tree height. Only for few FIs an additional stem diameter e.g. at 30% of the tree height is measured to derive local adapted allometric functions. Furthermore, the tree species is reported for each sample tree as well as further information about the forest structure (e.g. number of layers) or the health status of the forest. The individual tree parameters are commonly aggregated to plot-level.

The technical progress of remote sensing techniques i.e. terrestrial laser scanning (TLS) shows promising potential in supporting terrestrial forest inventories. TLS acquires millions of 3D points within few minutes, which enables fast determination of the forest structure in a highly automated manner. Several forest attributes that can't be directly measured in traditional FIs such as stem curve and volume or even ecologically related parameters such as leaf area index (LAI) can be estimated with high precision. The limitations of using TLS in operational FIs consist often in the limited terrain accessibility, area coverage and visibility in top canopy layer.

On the other hand, the development of lightweight, survey-grade LiDAR sensors mounted on unmanned autonomy systems (UAS) opens up new possibilities for forest inventories. The derived 3D points enable the modelling of individual trees with fine details up to branch level. The data can be acquired for plots or transects and achieve a high level of completeness with respect to the top canopy layer.

This contribution gives a comprehensive overview of different TLS as well as UAS-LiDAR systems for deriving forest attributes such as tree position, DBH, tree height, taper function, stem volume, main tree species groups and LAI

The achievable accuracies and completeness of the derived forest attributes for several coniferous as well as deciduous forest sites in Austria will be shown and discussed. Finally, possible integrations of UAV-LiDAR into operational forest inventories will be presented and its strengths and limitations will be discussed.

2.(15:50) Investigating the above-ground competition effects of liana load on tree structure and allometry using TLS | *SM Krishna Moorthy*, K Calders, E Kearsley, H Verbeeck*

Lianas compete intensely with trees for both aboveground and belowground resources thereby increasing tree mortality and reducing tree growth. Attempts to disentangle the aboveground and belowground competition between lianas and trees have shown that the aboveground competition affected the allocation of biomass in trees and resulted in poorly developed crowns. Recent study has shown that liana load on trees alter the allometry of trees by decreasing tree slenderness (height – diameter ratio) resulting in shorter and thicker stems. With liana abundance increasing in the tropics, quantifying the impact of lianas on the forest structure and biomass is very important. In this study, we use a Terrestrial Laser Scanner (TLS) to quantify the impact of liana load at individual tree level.

We collected TLS data between February 2016 and April 2016 from a tropical secondary forest in Gigante Peninsula, Panama. We selected three trees of same species with no liana load and trees across different levels of liana load (0 - 25%, 25 - 50%, 50 – 75% and 75 – 100%). We derive the following structural parameters for the trees: biomass, branching structure, trunk taper and crown structural parameters.

We compare the different structural parameters for these trees across different liana infestation gradients to quantify the liana impact on the tree structure. In addition, we compare the distribution of TLS-derived biomass across different parts of the trees to quantify the change in the biomass allocation of trees owing to increased liana load. Change in the biomass allocation of trees have important implications for ecosystem functioning.

3.(16:10) Application of a micro-TLS system to estimate woody shrub biomass | *J Batchelor*, LM Moskal, V Kane, A Kato*

In this case study we demonstrate the application of a micro terrestrial laser scanning (TLS) Sweep system from Scanse, built at a cost of less than a thousand USA $. The 700-gram scanner has a sampling rate of 1000 per second at an adjustable rotation frequency of 1-10 Hertz and a scanning range of 40 meters. The battery life of the unit is infinite as it can work off USB external battery packs or solar pack, the unit is operated through a website interface and wi-fi connection on a smart phone, tablet or laptop. We demonstrate the field setup of the system, including optimal micro TLS setup to reduce occlusion at multiple plot locations varying in woody shrub biomass. We further show target acquisition and multi-perspective stitching of the 3D point clouds to fill in occlusion. Our findings demonstrate that although the range of the scanner in optimal conditions is 40 m the functional range of the scanner is closer to 10 m in radius. Considering occlusion, a common issue in forest stands, this is an acceptable range and can provide information within an USDA Forest Service FIA subplot (~ 7.3-meter radius) or microplot (~2-meter radius). We demonstrate the scanner for inventory and leaf area index (LAI) acquisition, in comparison to more conventional methods such as field sampling for inventory and hemispherical camera photography for LAI estimation. We also compare the scanner to other, more expensive TLS scanners on the market. Although the 3D point cloud data acquired with the micro TLS system is much noisier then other models, the cost of the system, the ease of use and ability to collect data quickly shows a potential for these types of low-cost systems to have feasible applications in ecological and forestry applications.

4.(16:30) Detecting tree-related microhabitats in TLS point clouds using machine learning | *N Rehush*, M Abegg, L Waser, U Brändli*

Forests cover one third of Switzerland, providing important habits for plants and animals, as well as performing other functions. Tree-related microhabitats (TreMs), such as cavities, epithetic structures and others, are existential for a wide range of insect, bird and mammal species during their life cycles. TreMs thus play an important role in maintaining forest biodiversity and have recently received more attention in ecosystem conservation, forest management and research. However, TreMs have only been assessed by experts during field surveys, which are time consuming and difficult to reproduce.

Recent developments in close-range remote sensing techniques have made it possible to efficiently capture the information from surrounding objects with a very high level of detail. Moreover, object recognition has been dramatically improved when applying deep learning techniques for image and point cloud processing. In this study, we evaluate the potential of close-range terrestrial laser scanning (TLS) for semi-automated detection of different microhabitats on tree stems using machine learning (including deep learning) algorithms.

For this purpose, a Faro Focus 3D 120S terrestrial laser scanner was used to obtain very high-resolution 3D point clouds from multiple scans of representative beech habitat trees in temperate mixed forests across Switzerland. TreMs in the TLS point clouds were then detected using semi-automated point-wise classification by taking into account pointsï¸¢ local

3D neighborhood. To classify six groups of TreMs, two machine learning approaches were applied: 1) the Random Forest (RF) classifier, incorporating frequently used multidimensional local geometric features and two additional self-developed orientation features, and 2) a deep Convolutional Neural Network (CNN) utilizing rasterized local 3D neighborhoods. The performance of each model was assessed using object-wise leave-one-out cross-validation. The results confirmed that using multidimensional local geometric features is beneficial for detecting the six groups of TreMs in very high-resolution tree stem point clouds. The overall accuracy of the RF classification model was 66.9%, whereas that of the deep CNN was substantially higher (81.5%). The study also reveals that augmenting data when training CNN additionally increases the classification accuracy. Close-range TLS thus, when applying deep learning techniques, is promising for semi-automated TreM detection in forest monitoring.

5.(16:50) Benchmarking drone lidar using TLS for landscape-scale sampling of individual tree structure in support of space-mission calibration and validation. | *M Krůček*, K Cushman, J Trochta, K Král, J Kellner*

Quantifying aboveground forest biomass using spaceborne remote sensing is critically dependent on ground-based field inventories for calibration and validation (cal/val). Most of these field inventories are limited in their geographic representation and extent. Terrestrial laser scanning (TLS) is a proven technology for non-destructive aboveground biomass estimation. It also provides valuable three-dimensional data very useful in other ecological research besides pure biomass estimates. However, applicability of TLS for measuring large areas is clearly limited. High-density airborne laser scanning (ALS) data captured from low-altitude drones has promise to overcome this disadvantage and to achieve results comparable to TLS on much larger areas, while keeping the detail of individually identified and measured trees. Our aim is to develop a framework to automate complex measurement of individual trees by processing very high density drone lidar over an entire landscape. We hypothesize that high-density ALS data acquired by a low-altitude drone under specific conditions can, with appropriate processing, provide tree-level information comparable to TLS, though at scales appropriate for space mission cal/val. The high-density ALS data will be acquired using the Brown Platform for Autonomous Remote Sensing (BPAR), an Aeroscout GmbH helicopter drone equipped with a Riegl VUX-1 laser scanner, GPS-navigation equipment, and other sensors. We will collect measurements in April, 2018 (leaf-off conditions) and June 2018 (leaf-on conditions). The ALS data will be collected for an area of 1.1 × 1.1 km approximately centered on the 25 ha Žofín Forest Dynamics Plot (ZFDP), where the census of all living trees of DBH ≥ 1cm (following ForestGEO protocol) was performed in 2017. We will collect ALS data from 100 m altitude in 2 sets of orthogonal flights lines with scan angles up to 90 degrees. Each set of flight lines will produce a nominal point density of 2,500 points · m-2, for a total of 5,000 points · m-2. Additionally, TLS data will be collected concurrently with ALS flights on a 1 ha sub-sample. The LiDAR data processing framework will be based on the 3D Forest, software designed for processing stand-level pointclouds while keeping the detail of individual trees (http://www.3dforest.eu/). We will present results evaluating the performance of tree segmentation and measurement from the ALS data, using the 1 ha TLS plot and the ZFDP stem map (25 ha) as benchmarks.

12E

FOREST CARBON MRV AND ROLE IN FUTURE CLIMATE MITIGATION

Moderator: Ben Poulter, George Hurtt, Neil Pederson & Thomas Pugh

1.(15:30) Using NASA Carbon Monitoring System Data Products for Policy Applications in Maryland, USA | *E Campbell*, R Marks, G Hurtt*

The State of Maryland has committed to reducing greenhouse gas emissions in the state by 40% from 2006 levels, an expansion of the original Greenhouse Gas Reduction Act (GGRA) of 2009, requiring a 25% reduction by 2020. Forestry and sequestration programs comprise 13% of the planned reduction by 2020, 4.55 million metric tons of CO_2 equivalents. The Energy+Environmental Economics (E3) Pathways model will be used to simulate reductions in most emission sectors (e.g. transportation, electricity production, buildings), but this model does not include land based carbon sinks. The remote sensing of tree canopy, carbon storage, and carbon sequestration potential for Maryland produced by NASA CMS will greatly improve the estimates of carbon sinks from forests used for the prior GGRA. CMS data will be used to set feasible 2030 targets for carbon reductions from forest management, reforestation, and afforestation in Maryland. It will be utilized to assess the land available for establishing new or managing existing forest, and to estimate the resulting carbon benefit of those actions. Preliminary estimates for acreage totals and carbon sequestration goals from forestry activities from 2020-2030 will be presented here. In addition to GGRA applications, the state is using CMS data products for its ecosystem service mapping for the state, and is exploring using the high resolution canopy cover dataset to verify compliance with the Forest Preservation Act. This act mandates that forest lost to development be replaced in kind, and that the total percent forest of the state be maintained above 40%. These applications demonstrate how high resolution spatial data has broad potential to improve how government forms policies and regulations pertinent to forest resources.

2.(15:50) Climate change will alter montane forests, but how fast? Fusing Landsat time series and spatially dynamic vegetation models to inform montane forest management | *J Foster*, A D'Amato*

Predicting the abundance of montane forest species under climate change presents a challenge to public land-managers who must plan for the future while balancing multiple stakeholder objectives. The fate of subalpine forests in particular is uncertain; subalpine tree species are vulnerable to climate change, but the rate of change in forests is governed by demographic processes (e.g. mortality, dispersal, establishment) that span long-lived generations. These changes are difficult to monitor with traditional forest inventory methods, but emerging remote sensing data and ecosystem models provide new opportunities to quantify and predict forest change from the recent past to the end of the 21st century. We used Landsat time series, field data, and the spatially dynamic vegetation model LANDIS-II to predict changes in montane forests over the next 100 years and to compare alternative management scenarios that are being considered to maintain production of wood fiber, clean water, and wildlife habitat.

In the northeastern US, subalpine forests dominated by red spruce (Picea rubens) and balsam fir (Abies balsamea) are predicted to recede to higher elevations with climate change, causing concern for forest and wildlife managers. Landsat time series and field data have shown these forests expanding at the margins over 30 years of contemporary warming, increasing uncertainty. To understand these dynamics, we simulated future forest conditions under a combination of four global circulation model projections for two landscapes: the Green Mountains National Forest, VT, and the Adirondack National Park, NY. We used Landsat time series to map trends in forest composition and to quantify spatial and temporal patterns of forest management and disturbance. These analyses fed into model simulations that include climate change and disturbance dynamics, from wind, harvests and insect outbreaks, and spatially dynamic dispersal. We use spatial predictions of forest composition and aboveground biomass to work with public and private land and wildlife managers in VT and NY to prioritize areas expected to serve as refugia for target species and to evaluate the effectiveness of alternative management scenarios.

3.(16:10) A bottom-up, stakeholder-driven carbon monitoring system in the Northwestern USA | *A Hudak*, P Fekety, S Filippelli, M Falkowski, V Kane, G Domke, N Crookston, A Smith*

Airborne lidar collections associated with field plot measurements allow aboveground biomass (AGB) predictions with high confidence for carbon inventory and monitoring, reporting, and verification (MRV). In this project, multiple project-level AGB maps serve as training areas for predicting forest AGB synoptically across the Northwestern USA. In the regional model, predicted AGB pixels are randomly drawn from the project-level forest AGB maps following post-stratification. Predictor variables in the regional model include annual tasseled cap indices derived from LandTrendr (a Landsat image time series algorithm), the global forest canopy height product, and 30-year (1960-1990) climate normals produced for North America. Regional pinyon-juniper AGB was modelled separately using similar predictors, but local estimates of AGB used in training were derived from a high resolution map of pinyon-juniper canopy cover (Falkowski et al. 2017) and cover-based AGB allometrics. At both the landscape and regional modeling scales, we use Random Forests (RF) as our predictive modeling tool; because it bootstraps the data, RF also provides a means to quantify and map uncertainty. The regional model produces annual AGB maps at 30m resolution from 2000 through 2016 for the study region, which includes the states of Washington, Oregon, Idaho (Figure 1), and Montana west of the continental divide. Our verification approach is to aggregate the regional, annual biomass predictions to the county level and compare them to annual county-level biomass summarized independently from systematic, field-based, annual inventories conducted by the US Forest Inventory and Analysis (FIA) Program nationally. National-scale forest cover maps generated independently from PALSAR data at 25-m resolution are used to define forested areas for the AGB aggregations, and annual, county-level biases are calculated for MRV. In Idaho, state-level total forest AGB was somewhat overpredicted relative to FIA inventories, with biases from 2006-2012 ranging from 16-7%, respectively, while county-level biases varied as a function of the number of FIA plots located in the county. Non-forest areas defined as pinyon-juniper by Landfire existing vegetation type are used for aggregating AGB predictions for this landcover type. To date, stakeholders have contributed 3,672 project-level field plots and ~3M ha of lidar collections that drive our carbon monitoring system (CMS) from the bottom up.

4.(16:30) Satellite estimates of young North American boreal forest site-index for DGVMs | *C Neigh*, P Montesano, J Sexton, M Feng, S Channan, N Carvalhais, M Forkel, L Calle*

We have studied the growth, disturbance and carbon (C) storage of North American boreal forests to improve understanding of Arctic/Boreal terrestrial ecosystems that may be approaching a potential tipping point of C release. At continental scales, climate change is altering vegetation productivity, dynamics and C sequestration. These shifts are reflected in vegetation canopy structure (cover and height) that vary across the landscape. Currently a need exists to understand environmental constraints on canopy structure and to predict impacts of environmental change on vegetation cover and C-stock/flux. Dynamic Global Vegetation Models (DGVMs) thus far have found large increases in productivity and C-flux. However, turnover rates in these models have a large source of divergence between them. Site Index (SI) is a parameter widely used in forestry to describe the potential height-growth of trees in a particular location or 'site.' SI knowledge will reduce uncertainty of live C turnover into soil C pools. We have successfully estimated boreal forest SI by pairing Landsat estimates of forest disturbance with space-borne LiDAR and space-borne commercial sub-meter resolution stereo canopy height models. In this talk, explicit patterns of SI will be presented along with estimated rates of carbon accumulation. Boreal forest management questions will also be discussed in light of these new approaches

POSTER SESSION #1

Please use the search function (ctrl F) to find a specific abstract.

1. Forest health - using a multi-sensor UAV and satellite observations to monitor the state of UK forests and woodlands | E Cornforth*, M Williams, M Perks, E Mitchard

Early detection of plant stress is the key to a healthy forest, enabling forest managers to enact procedures to slow the spread and dampen the impact the stressor can take. Current assessments of forest health with experts on the ground will always be restricted by factors such as a large forest to cover, difficult terrain and a canopy far above. UAVs are becoming increasingly cheap, reliable and able to carry more for longer making them a prime candidate for detection of forest health change and doing so in a repeatable and objective manner. This research aims to utilise multiple UAV borne sensors combined with radiative transfer modelling to derive forest properties, enabling the detection of early signs of deteriorating forest health and for identification of the best performing trees in an environment.The instrumentation set up for this research is as follows: DJI Matrice 600 hexacopter with flightime of 16 minutes at max payload of 6kg. A 3-axis stabilised gimble carried by the UAV, with three imaging cameras mounted. Sony Î±7R 46 MegaPixel high resolution RGB camera, allows calculation of crown statistics, structural change and feature detection. The MAIA S2 multispectral sensor with downwelling irradiant light sensor, with which stress metrics such as leaf chlorophyll content and leaf moisture index can be computed. This is a VIS + NIR, 1280x960 pixel camera which shares the first 9 bands of the Sentinel 2 satellite allowing for upscaling from UAV to the orbital scale. A thermal camera, the Optris PI 640 to detect changes in temperature for example increases associated with stomatal closure as a response to drought.

2. Constraints on the US forest carbon balance through the assimilation of above-ground biomass maps into CARDAMOM | AA Bloom*, S Saatchi, Y Yu, N Parazoo, M Williams, TL Smallman, J Exbrayat

The terrestrial carbon balance and its temporal evolution is one of the least constrained components of the global carbon cycle. A large component of the uncertainty is attributable to the absence of temporal constraints on the evolution of the terrestrial C dynamics. The Earth observation record provides a range of spatially explicit datasets on the state and evolution of the terrestrial biosphere; in particular, Landsat imagery - merged with in-situ and allometric knowledge of forest C density - provides a key spatial and temporal constraint of ecosystem live biomass. Here, we implement the CARbon DAta-MOdel fraMework (CARDAMOM) at a 0.5°x0.5° constrained by 2005 and 2010 spatially explicit estimates biomass - as well as ancillary data, including MODIS leaf area, GOME-2 solar-induced fluorescence and soil carbon - to produce data-consistent estimates of US forest terrestrial C dynamics. We further incorporate constraints on the effects of fire, insect, wind and land-use disturbances into CARDAMOM. We find that the assimilation of ≥2 time-resolved biomass estimates substantially reduces the uncertainty of inter-annual NEE trends across most US forest areas,: the uncertainty reduction is partially linked to the relative contribution of soil C dynamics on the temporal C dynamics. Furthermore, our results reveal substantial reductions in allocation and turnover rate uncertainties, in line with recent site-level assimilations of multi-year biomass estimates in CARDAMOM. Finally, our analysis over US forest areas provides a novel insight into the synergistic capabilities of the current global carbon observing system in relation to the US forest carbon budget, and a valuable framework for quantifying the anticipated satellite measurements of canopy height and biomass.

3. Fusing GEDI lidar, TanDEM-X InSAR and Landsat data for improved forest structure mapping | W Qi*, P Wang, J Armston, R Dubayah

The Global Ecosystem Dynamics Investigation (GEDI) mission is scheduled to be deployed on the international space station in Nov. 2018 and will provide unprecedented lidar observations of forest vertical structure. However, gaps are expected between GEDI's ground tracks, which requires ancillary spaceborne datasets and fusion-based methods to contiguously map forest structure at satisfactory resolution and accuracy.Owing to the global coverage and high spatial resolution, Interferometric Synthetic Aperture Radar (InSAR) data acquired by DLR TanDEM-X (TDX) mission is particularly suitable for fusion with GEDI data. Nevertheless, due to the limited penetration capability of X-band signal and polarization mode (only HH or HH/VV), large biases were found for forest heights estimated based on the widely used height-inversion model - Random Volume over Ground (RVoG) model using TDX data alone. These biases can be greatly reduced by exploring GEDI observations to constrain parameters of the RVoG model for TDX. However, when there are insufficient GEDI observations for a given study site, methods that simply interpolate parameters derived over limited GEDI footprints may fail to cover the whole spectrum of forest structure and may smooth through spatial discontinuities in forest structure.In this study, a new approach to parameterize the RVoG model is proposed. RVoG parameters, such as extinction coefficient and ground-to-volume amplitude ratio, are first estimated over GEDI footprints (simulated using airborne laser scanning data). RVoG parameterization over areas out of GEDI footprints are then achieved using a bottom-up knowledge propagation approach based on hierarchical segmentation of Landsat imagery. This method takes the actual ground conditions into consideration to produce spatially contiguous RVoG parameters and further enhances GEDI/TDX data fusion with optical observations.

4. The Regional Scale Forest Aboveground Biomass Estimation of South Central Plains with the Calibrated Global Forest Canopy Height Map | N Ku, S Popescu*

The estimation of the regional forest aboveground biomass is crucial to understand and manage the terrestrial carbon storage. United States Forest Service (USFS) and Woods Hole Research Center (WHRC) build national forest aboveground biomass map and dataset respectively. Nevertheless, both forest aboveground biomass maps are in need of updates for the latest forest aboveground biomass information. Thus, this research focuses on developing the regional forest aboveground biomass map with the spaceborne lidar product calibrated global forest canopy height map (cGCHM). The objectives of this research are to 1) generate a forest aboveground biomass map of South Central Plain ecoregion, and 2) validate and compare the forest aboveground biomass map with previous forest aboveground biomass maps. The regional forest aboveground biomass map integrates the cGCHM, remotely sensed data, and canopy coverage information. The result shows that the regional forest aboveground biomass map is more accurate (R2 = 0.34) than the USFS forest aboveground biomass map in the same region. In addition, the RMSE of the regional forest aboveground biomass is 27.85 Mg/ha. Consequently, the cGCHM aides to generate a more accurate regional forest aboveground biomass map than traditional USFS inventory efforts and our methodology paves the ground for future biomass maps with data from new lidar satellite missions

5. A Comparison of Regression Techniques for Estimation of forest above ground biomass using LiDAR and hyperspectral data | J Lv*, C Zhang

Forest biomass is an important parameter in forest carbon sink and global climate system. However, the accuracy of above ground biomass estimation using remote-sensing data needs to be improved to support operational forestry-monitoring tasks. This study aimed to combine airborne LiDAR and hyperspectral data in the Penobscot Experimental Forest(PEF) and Smithsonian Environmental Research Center (SERC) using machine learning approach. Canopy height models (CHMs) and hyperspectral were derived from Goddard's airborne LiDAR Hyper-spectral and Thermal Imager (G-LiHT). Vegetation indices (VIs) were caculated from hyperspectral data and combined with LiDAR height variables derived from CHM. Five approaches, including k-nearest neighbors (kNN) algorithm, artificial neural network regression (ANNR), support vector regression (SVR), random forest regression (RFR), deep learning (DL) were compared to generate accurate estimation of forest above ground biomass. The DL model achieves high validation accuracy for both sites, with the coefficient of determination (R2) = 0.73 for PEF and R2 = 0.78 for SERC. The study demonstrates the utility of airborne LiDAR and hyperspectral data with the selected machine-learning algorithms in developing above ground biomass estiamtion models in forests. The results indicate that the deep learning algorithm can help improve the accuracy of above ground biomass estimation in forest areas.

6. Linking lidar and forest modeling to assess biomass estimation across scales and disturbance states | N Knapp*, R Fischer, A Huth

Light detection and ranging (lidar) is currently the state-of-the-art remote sensing technology for measuring the 3D structures of forests. Studies have shown that various lidar-derived metrics can be used to predict forest attributes, such as aboveground biomass. However, finding out which metric works best at which scale and under which conditions requires extensive field inventories as ground-truth data.The goal of our study was to overcome the limitations of inventory data by complementing field-derived data with virtual forest stands from a forest model. The simulated stands were used to compare 29 different lidar metrics for their utility as predictors of tropical forest biomass at different spatial scales. We used the process-based forest model FORMIND and developed a lidar simulation model, based on the Beer-Lambert law of light extinction, and applied it to a tropical forest in Panama. Simulation scenarios comprised undisturbed primary forests and disturbed secondary forests, totaling 3.7 million trees on 4,200 ha.Several lidar metrics, in particular height metrics, showed good correlations with forest biomass. Estimation errors (nRMSE) increased with decreasing spatial scale from < 10% (200-m scale) to > 30% (20-m scale) for the best metrics. At the 1-ha scale, the mean top-of-canopy height obtained from canopy height models yielded the most accurate biomass predictions, with nRMSE < 6% for undisturbed and nRMSE < 9% for disturbed forests. This study represents the first time dynamic modeling of a tropical forest has been combined with lidar remote sensing to systematically investigate lidar-to-biomass relationships for varying lidar metrics, scales and disturbance states. In the future, this approach can be used to explore metrics from other remote sensing systems, e.g. radar data.

7. Estimating tree biomass using crown parameters derived from airborne lidar | A Zielonka*, D Pflugmacher, K Ostapowicz

Detailed tree and stand-level information on forest structure is a pre-requisite for forest managers and for understanding ecological processes related to the carbon cycle or biodiversity. Remote sensing plays a key role in precision forest management, in particular LiDAR is an efficient technique to measure individual trees. Methods for predicting forest biomass with lidar can be categorized into individual-tree based methods and area-based methods, each having their strengths and weaknesses. The aim of this study is to evaluate and compare individual-tree-based biomass estimation using lidar-derived tree crown and height measurements and area-based models at two temperate mountain forests in the Polish Carpathians. The study sites comprise conifer and deciduous stands of diverse structure and species composition. Lidar data were acquired in 2011 and 2012 within the national ISOK project (Informatyczny System Osłony Kraju) at a minimum density of 4 points/m2 using the LMS-Q680i scanner. The field data come from the Polish National Forest Inventory, which include measurements of individual trees like species, tree height, diameter, age, and position.Based on created Canopy Height Model tree height is recognized as surface uplift with calculated terrain correction for steep slopes (pit-free CHM model) in the Polish Carpathians. Vectors for contour trees were formed on CHM with minimum tree heights for the deciduous and coniferous forest. The localized contour tree method was applied. The derived delineated tree crowns structures were calculated to compactness index which is defined by the perimeter and area of the tree crown. In the final step, the derived tree crown structures were compared with the biomass estimated results based on DBH and tree height. The proposed method can achieve relatively high accuracy for the deciduous and coniferous forest. The higher accuracy is expected for homogenous forest structures which depend mostly on tree height and species composition. We gratefully acknowledge support by the National Science Centre, project RS4FOR [project no. 2015/19/B/ST10/02127].

8. Stand volume estimation using tree-level UAV based approach in mature boreal forest | A Kuzmin*, L Korhonen, M Maltamo

The presented study was conducted in order to evaluate the accuracy of stand volume estimation in mature boreal forests based on UAV photogrammetry. Individual tree detection (ITD) is applied to image-based 3D point cloud acquired in Eastern Finland, and its effectiveness is tested at 27 field plots. Freely available digital elevation model retrieved from airborne laser scanning by the National Land Survey of Finland was used as reference ground level in order to achieve an accurate 3D model of the forest structure. The watershed segmentation method was applied to find the edges of each crown in the UAV-derived Canopy Height Models, and the tops of individual trees were extracted within each crown boundary. The tree diameters were predicted from tree heights and crown diameters using existing nationwide models. The resulting root-mean-square error for stand volume with ITD approach was 24.4%. The results obtained in this study demonstrate the ability of low - cost UAV based photogrammetry to perform the stand volume calculation in boreal forests with relatively high accuracy.

9. Moratoria on land acquisitions reduce tropical deforestation: Evidence from Indonesia | B Chen*, C Kennedy, Y Jin, B Xu

The tropics have suffered substantial forest loss, and elevated deforestation rates have been closely linked to large scale land acquisitions (LSLA). Here, we investigate global LSLA networks and find that land acquisitions are predominately characterized by flows from the developing world to the developed world. Policy-driven moratoria on existing LSLA are a key mechanism used to minimize global forest loss and recently applied in Indonesia. Based on a spatially-explicit temporal analysis of forest loss, we find that relative to the average forest loss of 1.61 Mha/year in the 5-years before the moratorium (2008-2012), nationwide annual forest loss in Indonesia decreased on average by 1.57 Mha/year between 2012 and 2015. By comparing annual forest loss in logging, timber, and oil palm concessions within and outside the moratorium, we find that land concessions outside the moratorium experienced 33% to 409% higher rates of forest loss than in comparable land concessions within the moratorium. Decreased forest loss from full implementation of moratoria on all land concessions could mitigate a maximum aboveground biomass carbon (ABC) emission of 117,894±26,158 Mg C/year, which is a nearly 41.52% reduction relative to the counterfactual scenario of no moratorium. These findings lend support for international cooperation and collective action to put into practice land moratoria to reverse decade-long trajectories of tropical forest loss.

10. Ongoing primary forest loss in Brazil, Democratic Republic of the Congo, and Indonesia | S Turubanova*, P Potapov, A Tyukavina, M Hansen

Humid tropical forests provide numerous global ecosystem services, but are under continuing threatof clearing from economic drivers. Here, we report primary humid tropical forest extent for the year2001, and primary forest loss and distance to loss from 2002–2014 for the largest rainforest countriesof Brazil, Democratic Republic of the Congo (DRC), and Indonesia. Brazil's total area of primaryforest loss is more than twice that of Indonesia and five times that of DRC. Despite unprecedentedsuccess in slowing deforestation along its forest frontier, Brazil's most remote forests are increasinglynearer to loss, as extractive activities such as logging and mining intrude upon previously intactforests. In absolute terms, DRC has the lowest area of primary forest loss; however, its forests areincreasingly encroached upon as smallholder agriculturalists move into remaining forests, often toescape conflict and insecurity. The decrease in DRC forests' distance to loss as a function of area offorest loss was five times that of Brazil or Indonesia. In 2014, Indonesia had the least area of remainingprimary forest.

Despite an announced moratorium on concession licenses in 2011, Indonesiaexhibited a rate of primary forest loss twice that of DRC and triple that of Brazil by the end of thestudy period. Forest loss dynamics in Indonesia range from industrial-scale clearing of coastalpeatlands to logging of interior montane rainforests.While results illustrate considerable variation inforest loss dynamics between the three countries, the dominant narrative is of ongoing exploitation ofprimary humid tropical forests.

11. The use of Weibull coefficients as LiDAR metrics to identify selective logging impacted areas in the Amazon | C Reis, T Abib, E Görgens, A Melo, LC Rodriguez*

For several years, different types of pressures have been threatening the Amazon forest (agriculture, pasture, roads construction, extractives and conventional logging). Selective logging is a set of techniques that aim to reduce the impacts caused by wood exploitation. Despite being considered a relatively minor cause of damage, selective logging usually disturbs the surrounding vegetation, sometimes leading to land use change. Due to its broader spread across the landscape, areas that have been impacted by selective logging are difficult to identify and quantify. Remote sensing techniques can be used to avoid the extensive and expensive fieldwork to locate impacted areas. The majority of forest impacts caused by selective logging are associated with transport infrastructures (roads, wood storage yard, and skid trails). However, it is difficult to identify these features through optical remote sensors given their narrow extension and the dense canopy environment found in the Amazon forest. Thus, analyzing the understory alteration data provided by Airborne Laser Scanning (ALS) can be an alternative to locate damaged areas. Our study utilized an airborne lidar dataset obtained across a dense ombrophilous forest environment in eastern Amazon. The objectives of this study were to a) assess the canopy height profile (CHP) to identify areas impacted by selective logging, and b) quantify the effects of selective logging on the canopy and understory layers estimating the parameters of Weibull distribution functions. We used adjusted Weibull distribution functions for the canopy (> 10 meters high) and understory (≤ 10 meters high) layer datasets to generate maps containing pixels classified according to each parameters shape (γ) and scale (β) values. Both Weibull parameters obtained from the CHP for the understory layer displayed lower values and were strongly associated with transport infrastructure impacted areas. Higher values for the scale coefficient coincided adequately with areas of higher canopies (taller crowns). This work confirms that combining ALS and the Weibull distribution function is a valuable tool to support forest managers on monitoring spatially impacted forest areas.

12. Monitoring Black Wattle using GIS and Remote sensing techniques in Makhado Local Municipality, South Africa | N Nethengwe*, F Dondofema, K Mavhungu

Vegetation is the most important renewable natural resources playing role in the preservation of the environment and biodiversity. Various land use activity such as anthropogenic activity, climate change has been the major distributor of invasive plants, which change native vegetation cover and play a role in biodiversity loss. This study used remote sensing and Geographic Information Sciences as tools to monitor Black wattle in Makhado Local Municipality. In this study multi-temporal satellite image data is analyzed to identify a dynamic pattern of vegetation changes due to black wattle and the negative impacts it has on the environment. The overall accuracy for all classes was 90.5%, user accuracy was 91.2% and the producer accuracy was 91.2% with a kappa coefficient of 88.6% The result shows an increase in Black wattle coverage within the study area from 2.20% in 2008 to 19.51% in 2017. And a decrease in the bare land which was found to be the dominant factor in 2008 at 70.19% coverage to 31.11% in 2017. A p value of 0.0043 was obtained, the p value obtained was less than the p value within alfa (0.05). This means that the null hypothesis is rejected. Resulting in the data been significant. This data had f value of 10.104. The study shows that having more vegetation or vegetated covered area saves more water for an increase from 1.15% in 2008 to 2.51% in 2017.

13. Leaf- and stand-scale effects of age on canopy spectral signature dynamics in Chinese fir evergreen forests | Q Wu*, J Song, C Song, J Wang, S Chen, B Yu

With the accumulation of long-term optical remote sensing (RS) data, time series RS data has been applied to detect forest growth and canopy biophysical parameter variations, which have profound impacts on terrain biophysical processes and thus the global water and carbon cycles. Despite its wide application, significant gaps exist in our knowledge of factors underlying canopy signal variability, which limits our understanding of vegetation status based on remotely sensed data. To understand the effects of leaf aging at the leaf and canopy scales, a combination of field, remote sensing and physical modeling techniques was adopted to assess the canopy spectral signals of evergreen Cunninghamia forests. We observed an approximately 10% increase in Near-Infrared (NIR) reflectance for new leaves and a 35% increase in NIR transmittance for mature leaves from May to October. When variations in leaf optical properties (LOPs) of only mature leaves, or both new and mature leaves were considered, the Geometric Optical and Radiative Transfer (GORT) model-simulated canopy reflectance trajectory was more consistent with Landsat observations (R2 increased from 0.37 to 0.82~0.89 for NIR reflectance, and from 0.35 to 0.67~0.88 for EVI2, with a small RMSE (0.01 to 0.02)). Long time series canopy signatures were extracted from the Landsat and the MODIS sensors, and then used to study the variations in canopy reflectance signals at different growing stages: from young forest (stand age = 1 a) to mature forest (33 a). The variations in canopy structure parameters with stand development are the dominant controls on the inter-annual differences in canopy signals. Canopy reflectance at red and NIR band both decreased significantly from 1 a to 10 a, but they are controlled by different structure parameters. However, canopy greenness increased with stand development. This study highlights the importance of leaf- and stand- age related controls on canopy signatures, and provides evidence of age-dependent LOPs that have important impacts on canopy reflectance in the NIR band and EVI2, which are used to monitor canopy dynamics and productivity, with important implications for RS and forest ecosystem ecology.

14. Woody cover through the trees: How much woody cover are we overlooking in African savannas? | R Nagelkirk*, K Dahlin

Savannas cover a fifth of the Earth's land surface and their net primary productivity (NPP) disproportionately affects interannual variability of the global carbon cycle. Yet, our understanding of the factors controlling savanna NPP is limited, particularly in the case of woody cover. In African savannas, woody cover is suppressed by disturbances like elephant damage and fire. However, detecting the impacts of these disturbances on the landscape is a challenge due to current data limitations. Critically, current global datasets only classify woody cover in taller height classes ('tree cover'), leaving out saplings and shrubs that are particularly sensitive to disturbances. Here, as part of a larger analysis of savanna disturbances, we address this data limitation by mapping estimates of fine-scale, total woody cover within protected areas across eastern Africa, from Kenya to South Africa. To classify woody cover, we extract ground reference data from Google Maps using R, process and download Landsat imagery using Google Earth Engine, then classify woody cover using multiple endmember spectral mixture analysis. Results show total woody cover up to 70% higher than estimates of tree cover alone. This disconnect between tree cover and total woody cover has implications for estimates of savanna biomass and woody encroachment, studies of the determinants of woody cover, future climate scenarios, and the people and other organisms that rely on Africa's savannas.

15. Quantifying Forest Cover Loss based on Multi-Temporal L-Band SAR Intensity Value Representation | IEW Rachmawan*, T Tadono, Y Kiyoki

Rapid changes in today's global tropical forest could remotely tracked by earth observation satellites. Forest cover loss occurs continuously and it is particularly important to assess the loss frequently for providing reliable national forest inventory. The L-band SAR aboard JAXA's ALOS-2 provides outstanding means for the monitoring of tropical forests due its cloud and canopy penetration capability. Particularly, the use of horizontally-transmit dual-polarization low frequency L-Band images (HH and HV) has great merit for forest monitoring. While the use of bi-temporal clustering model is relatively simple to apply to identify the forest change, the use of multi-temporal data has proven to make analysis for quantifying forest cover loss more robust. The family of centroid and density clustering methods has been widely used for determining the temporal changes in forest regions. However, many of these clustering algorithms reported in the literature do not take into account the full complexity of the physical properties of radar backscatter from forests. In this study, we use temporal variation of the dual-polarized SAR backscattering intensity is used to develop a new analysis/synthesis technique for quantifying forest cover loss. To deal with the several weaknesses of it, such as the random initial sampling point and determining the changed area, we formulate and demonstrate methods for extracting the representation of intensity value from multi-temporal dual-polarization L-Band SAR. We design a density peak-picking formula for determining initial sampling points prior to clustering algorithm from HV and HH gamma naught and its texture. Since multi-temporal L-Band SAR data tend to have arbitrary shape, the determination of density peaks of an area of forest loss, the selection of cluster centers to automatically find the area and the cutoff distance between two significant different gamma naught value is proposed. Moreover, a new non-center point's allocation strategy and cluster merging and splitting processes are developed to adapt to the density peaks and adjust the clusters dynamically, which can improve the clustering accuracy and scalability. The intensity value representation method is evaluated with ScanSAR scenes acquired over one year in Sulawesi, Indonesia. The results demonstrate the effectiveness of the proposed method to accurately quantify forest cover loss area. Finally, the analysis/synthesis system forms the basis for new approaches

16. Estimation of Defoliation of Pine Trees by Using Single-scan Terrestrial Laser Scanning Data | L Huo*, X Zhang, N Zhang, Y Wu

Forest disruption caused by pest insects is a common disaster occurring in plantations, and it is a threatening factor to forestry ecology. Therefore, a precise method for monitoring individual tree health and estimating disturbance severity is urgently needed. Theoretically, terrestrial laser scanning (TLS) is a promising tool in high resolution remote sensing, which can provide information regarding the structural change of the affected trees with millimeter precision. However, few studies have explored the potential of TLS application in this field, especially when using only mono-temporal data. In this study, a single-scan, TLS data-based method was developed and validated for both individual-tree scale and plot scale defoliation classification. Sixty features were respectively extracted from TLS data on 48 plots and 1,098 individual trees and optimized to six (individual-tree scale) and five (plot scale) classifiers by using a Random Forest method to accomplish the classification. By this approach, individual trees can be classified into two defoliation levels with 87% overall accuracy (kappa value 0.75), or three defoliation levels with 77% overall accuracy (kappa value 0.65). Similarly, plot-scale classification had 98% overall accuracy (kappa value 0.96) for two levels or 92% overall accuracy (kappa value 0.88) for three levels. Evidently, the methods presented in this study are capable of providing satisfactory estimates of defoliation severity, and supporting a precise inventory and monitoring of forest health.

17. Monitoring gap structure of plantation forests with high resolution remote sensing data | S Li*, Q Liu

Gap distributions reflect the spatial pattern of plantation forests being caused by tree harvesting, windthrow, inter-tree competition, disease or senescence, and site condition. Delineating canopy gaps and quantifying gap characteristics (e.g., size, shape, and dynamics) are essential for understanding regeneration dynamics and understory species diversity in plantation forests. Traditional ground investigation of forest gaps are labor-intensive and takes a large amount of time, and very small gaps cannot easily be recorded with satellite images. The advancements of remote sensing technologies provide the potnetial to characterize the details about canopy gap of plantation forests. In this study, the three dimensional characteristics of typical plantations forests will be extracted from the airborne images with the object-based image analysis method and it would be helpful for deep understanding the vegetation dynamics in plantation forests.

18. Detecting of forest phenology and change trends for assessment of nature reserve in Tibetan Plateau during 2000-2016 | L Qian*, S Jinling

Forest plays a crucial role in terrestrial ecosystem carbon cycle. Establishing nature reserve is the most common technique for government to reducing forest destruction. However, does constructing nature reserve meet the expectation of protection the forest? In this study, we examined the forest growth trend change and analyzed effects of the trend in the start of the vegetation growing season (SOS) in the Three-Rivers Headwater Region of the Tibetan Plateau. The Landsat surface reflectance data and MODIS NDVI products were used to produce high spatial-temporal resolution time-series NDVI (Normalized Difference Vegetation Index, 30 meters, 8 day) between 2000 and 2016 through NDVI-BSFM model which has been validated that it can produced relatively high precision NDVIs,1,'. According to 30 m land cover map in 2000 and 2016, the forest-specific NDVI seasonal dynamics and the change pixels of forest-specific were extracted. The SOS date was defined as the rate of NDVI reaching a max value when in spring day. With the exception of accumulated temperature, elevation is considered as an influence factor of SOS. The SOS showed an advancing trend during 2000-2016, with the later SOS contributes at higher altitudes, which proved that the spatial pattern of the SOS is evidently influenced by elevation. For another, time series of 782 images were analyzed using BFAST model by pixel and forest area change was calculated by comparing land cover maps in 2000 and 2016. An abrupt change was detected in 2002 when the nature reserve established after 2 years later. Temporal analysis proved that there were the greening trends increased during 2000-2016 in most regions. The forest showed an earlier occurrence of green-up date before and after 2002, which indicate that nature reserve plays an important role for change the phenology of forest. Especially, the forest in most areas showed a positive trend in the timeline. Although the large perfection of forest greening across the most areas revealed great potential of nature reserve for protecting forest, browning trends in the narrow region revealed nature reserve was not a perfect way for protecting forest. Accurate protection for forest will be a future way.,1,'Liao L, Song J, Wang J, et al. Bayesian Method for Building Frequent Landsat-Like NDVI Datasets by Integrating MODIS and Landsat NDVI[J]. Remote Sensing, 2016, 8(6):452.

19. Individual tree size and stand volume estimation of Teak plantation using UAV | N Furuya*, W Himmapan, I Noda, G Hitsuma

Background.Teak (Tectona grandis) is one of the premier hardwood timbers in the world. Teak is also one of the important tree species that is selected for planting in the tropical to sub-tropical region all over the world. In Thailand, harvesting from natural forests was banned in 1989, and thereafter supplies from plantation-grown teak have become more and more important. In the shortage of human resources and budgets for field data collection, an efficient monitoring scheme using remote sensing is highly expected. A low-cost UAV observation can be a suitable tool for monitoring teak plantation at stand and operational level. Therefore, the objective of this study is to develop a methodology to estimate stand volume and individual tree size using UAV.Materials and Method. The study area was located in the north and northeast of Thailand. Small-scale teak plantations managed by farmers were the target of this study. Narrow spacing such as 2m x2m, 2m x3m, and 2m x4m was mainly selected as the initial plant spacing. UAV observation was conducted by X5 camera mounted on DJI Inspire1. Three dimensional modelling of teak plantation and terrain was done with PhotoScan. Tree census was conducted simultaneously at the field plot. Individual tree location map was also created for referring to the field measurement at individual tree level.Summary of results.In individual teak tree size estimation, a regression function between tree crown size and diameter at the breast height (dbh) was retrieved. Individual tree volume could also be estimated based on the measurement of tree height and tree canopy size by the UAV observation.Teak stand volume could be estimated simply and efficiently by the mean canopy height measured by UAV. High correlation was observed between the canopy size and dbh, but there was a bias between the field-measured canopy size and remote-sensed canopy size. It was also able to estimate stand volume by summing up individual tree volume, however the result of individual tree identification influenced largely on the accuracy of stand volume estimation.

20. Explorative Study of Allometric Relationships of Forest Above-Ground Biomass to Small Footprint LiDAR Data | Q Wang*, Y Pang, Z Li, W Ni, E Chen, G Sun

The accurate estimation of forest biomass is the basis for evaluating the contribution of forest carbon cycle, and is an important parameter of forest ecological function evaluation. However, the structure of forest is complex, and spatial structure heterogeneity exists in both vertical and horizontal directions. LiDAR can acquire high precision three dimensions data, and has the advantages of describing the spatial structure of individual tree, especially the three dimensions structure information of the canopy can be got through LiDAR. In this paper, the biomass of typical coniferous forest larch in northeast of China was extracted using the small footprint LiDAR point cloud data. Firstly, the LiDAR point cloud data was pre-processed, which includes the removal of the noise point, ground point filtering, point cloud normalization and individual tree segmentation, and the canopy structure parameters was extracted. And then based on the allometric growth model and the LiDAR echo equation, a new biomass inversion model was derived according to a certain physical mechanism, which considers the influence of tree canopy structure. The individual tree biomass was retrieved using the new biomass model, and the ground measured data of coniferous forest of China northeast was used to verify the accuracy of the biomass model. Part of the experimental results show that three-dimensional structure information of canopy can be extracted through the small footprint LiDAR data, and also found that the canopy can directly affect the assimilation of trees and is essential basis for forecast growth of tree. To combine the allometric growth model with the LiDAR echo equation and consider the influence parameter of canopy to biomass, the forecast accuracy of biomass model was improved. Moreover, the new biomass model in the paper has a certain physical mechanism and can be used universality.

21. Deep Learning uNet Method for Forest Types Classification Based on high resolution optical Remote Sensing Data | Y Guo*

Many researches has successfully applied the high resolution remote sensing satellite to forest resource survey. In recent years, much of the remote sensing image analysis work based on the CNN method has appeared in succession. FCN is a convolutionalized version of standard CNN has achieved state-of-the-art performance for high resolution remote sensing imagery classification. Compared to CNN method, the most important improvement to FCN model is it retains the size of output image as input image by replacing the fully connected layers in the standard network with convolution layers, establishing semantic image segmentation for the first time.However, since the information may be lost in the pooling process, the FCN model could only generate a coarse segmentation image. Therefore, determining how to provide a pixel segmentation result with high resolution has been a research hotspot. At present, there are two kinds of work have solved this problem.The first one was based on atrous convolution, which was also called the atrous convolution research.The other type was devoted to establishing the correlation between the pooling layer and non-pooling layer. uNet model is a kind of such structure, which constitutes a U structure through a contraction network and expansion network, establishing the feature extraction to the image.In this paper, the research attempted to applied the uNet model to get the type of forest with GF1 satellite remote-sensing image and compare the classified accuracy of classic multi-scale object-oriented method, typical CNN based on patch method and the two other typical FCN methods. The classification accuracy of the object-oriented multi-resolution segmentation and model based on patch was 50% and 68%, respectively. Compared with the former two methods, FCN-8s and FCN-Atrous-VGG16-CRF had a better effect, which were 81.33% and 81.29%. With CNN based on patch classified method, a large amount of farmland is wrongly divided into shrubs, and the classification results are rather fragmentized. Compared to uNet, FCN-8s and FCN-Atrous-VGG16-CRF misclassified more farmland and evergreen forest type. The total classification accuracy of uNet method was 83% with a Kappa coefficient 0.79. By comparing with the classic object-oriented method, the classification accuracy of CNN and FCN obviously increased.

22. Mapping tree species spatial distribution using discrete aerial laser scanning data | B Wu*, G Zheng

Accurately mapping the tree species distribution using remotely sensed data is a key and fundamental step for studying the biodiversity, carbon cycle, and wildfire monitoring at large spatial scale. The ability to capture the 3-D structural information using ALS data allows characterizing the tree structure and species information at the individual tree level in a forested mountain area. Since the factor of slope on complex terrain normalization and single crown segmentation in dense growing zones is difficult, we developed a point cluster-based treetop detection algorithm based on raster block statistics and point cloud indexing mechanism to map the tree crown locations at landscape level in this study, and further to discriminate the five different tree species including 3 broadleaved(California live oak (Quercus agrifolia), Blue oak (Quercus douglasii) and Madrona (Arbutus menziesii)) and 2 coniferous(Douglas fir (Pseudotsuga menziesii) and Redwood (Sequoia sempervirens)) species in Sonoma County, the United States. The single trees 3-D structural information combined with the laser return intensity and laser return frequency was used to feature extracting. Then we used an unsupervised clustering algorithm to identify tree species in corresponding feature spaces. The identification accuracy of mixed forest types (coniferous and broadleaved forest) and coniferous species were more than 89%. At the same time, we could statistic the number of each species and some tree 3-D structural factors, which was superior to mapping using optical images. But the identification accuracy of broadleaved species was lower than coniferous and less than 70%. Considering that the annual similar phenological features, high growth density and similar structure among broadleaved species in the research zone, the evergreen tree species in particular, the mapping methods of tree species spatial distribution in the Mediterranean climate zone need to be further studied.

23. VUX1-LR LiDAR specifications for forest inventory in virtual reality environment | B Del Perugia, D Travaglini*, G Chirici, S Gonzalez Aracil

Abstract: LiDAR (Light Detection and Ranging) data is now commonly used for forest inventory. Foresters are using LiDAR data to assess forest attributes including mean top height, basal area, stocking and total recoverable volume. Current LiDAR technology is capable of collecting point clouds with point density higher than in the past, and at a more reasonable price than older sensors. These datasets need to be explored.The present study has tested the Riegl VUX1-LR sensor over a forestry area, collecting LiDAR data at 30m, 60m and 90m altitudes with a 15m swath. The flight path was flown in NS, EW, NWSE and SWNE directions. The study will find the best flight path specifications for assessing the point cloud in a virtual reality environment. The study was conducted in Carabost State Forest, a Pinus radiata plantation managed by Forestry Corporation of New South Wales in Tumut, NSW, Australia. Four areas (200x200m) were selected targeting a diverse range of plantation canopy structures. Nine traditional inventory plots (13.82m of radius) were collected to validate the VUX1-LR dataset.The industry is looking to use this technology in forest inventory where LiDAR datasets can be used for assessing tree attributes in a virtual reality environment. A research group led by the Human Interface Technology (HIT) Lab from the University of Tasmania is developing a software for this purpose.

24. Inventorying forests in transformation to Continuous Cover Forestry using of-the-shelf UAVs | MG Bennett*, DA Hardy, DP Bunting

There is renewed interest in Britain in transformation of even-aged conifer plantations to Continuous Cover Forestry (CCF). This is a form of forest management which promotes irregular structure and avoids clear-cuts. CCF has been promoted as a key strategy for future sustainable management of woodlands in the UK. Shifting towards irregular forestry aligns the UK nearer to silvicultural practises and thinking's of many areas of Europe, where it is seen as a key characteristic of sustainable forestry. Transformation to irregular structures is a novel approach to managing upland conifer plantations in the UK. Therefore, there is a need for high temporal monitoring of forests in transformation to understand changes in forest dynamics in relation to management interventions, and to use remotely sensed data to inform future management strategies. Enhancements of off-the-shelf UAVs and improvements in image matching techniques has facilitated monitoring & inventorying of forests in transformation at high spatial and temporal resolutions. This research investigates methods to inventory forests in transformation at low cost using single tree segmentation methods. Data derived from segmented trees includes volume, basal area, crown diameter and height. To quantify spatial heterogeneity and compare stands in differing stages of transformation spatial distribution and size of gaps is analysed and quantified. This project will demonstrate the use of off-the-shelf UAVs to produce low cost methods of inventorying and monitoring upland conifer forests in Britain which are under a novel management.

25. The development of an automated tree detection tool using UAV-based datasets | AM Klein Hentz*, AP Dalla Corte, S Péllico Netto, M Strager, ER Schoeninger

Unmanned Aerial Vehicles (UAV) have been proven to provide an affordable high-resolution data source that can be applied to many forest management activities including individual tree modeling. The UAV can capture ultra-high resolution imagery which is also a challenge for processing, since most traditional remote sensing techniques have been developed for satellite imagery and LiDAR datasets; both with lower resolution compared to UAV. Therefore, there is a need to develop tools which account for the UAV particularities for forestry applications. In this study we present the development of an automatic detection tool for trees using high resolution data obtained from UAV. The tool is called TreeDetect, and it was built in ArcGIS using ArcPy language. The tool requires three parameters to be executed: 1) a raster file (single band, band index, digital models), 2) a conversion factor, and 3) an output folder. Three optional parameters can also be adjusted to improve the detection. To test the tool, it was applied in three study sites with different configurations: a) a young Eucalyptus sp. stand, in which the neighborhood trees are completely separated from each other; b) two adult stands composed homogenously by Eucalyptus sp. and Pinus sp., in where the neighborhood trees crowns are connected; and c) a Mixed Hardwood natural forest. In these study sites we also tested different raster inputs, as distinct spectral bands combinations, a vegetation index, and a digital surface model (DSM). The tool was shown to be efficient in detecting the individual trees in all the study sites, with some noted variability. In both plantation stands (young and adult), we observed the better results, with errors ranging from 1.3-10.3% in the young stand, and 0.1-30.4% in the adult stand. In the adult stands we observed larger errors (30% of error) when we applied the DSM as a raster source, while when using spectral band combinations, the maximum error was 3.6%. The detection accuracy in the natural stand was lower, with average error of 27.3%, but this was expected considering the characteristics of this forest type, and the presence of many trees under the canopy. Based on these results, the TreeDetect tool was considered efficient to detect individual trees in forest plantations and natural stands. Therefore, we suggest further investigation into the parameters selection process for distinct forest types and data input.

26. LiDAR360 individual tree detection performance in forest plantations from UAV-derived point clouds | AP Dalla Corte*, N Bonamichi Silva, M Klein Hentz, B Nascimento de Vasconcellos, MS Ruza

Unmanned Aerial Vehicles (UAV) have gain popularity in the last years, presenting many applications for forest management, and one of the most promising areas for UAV application is in the forest inventory. In the recent years studies have been focusing in automatic detection of tree individuals from UAV imagery with the objective to obtain more accurate forest production predictions. The objective of this study was to evaluate the performance of the LiDAR360 detection algorithm to automatically recognize the total number of trees individuals in point clouds produced from UAV images. A study site located in Paraná state (Brazil) was selected, and it is composed by stands of Eucalyptus grandis and Eucalyptus urophylla with 18 months of age (young stand), and Eucalyptus spp. with approximately 7 years of age (adult stand). The initial plant spacing was 3.75 x 2.4 m. A total of 20 images were taken with an eBee-Ag UAV equipped with a RGB camera (Canon S110) on September of 2015. Experiments were conducted to optimize the processing of the images using the Agisoft PhotoScan Professional software, in order to generate an orthomosaic and a 3D point cloud. The LIDAR360 software was applied in a subsequent step to detect the tree individuals. The LiDAR360 detection result was called as treatment 1 (T1), with two variables: (T1a) applied in the young stands, and (T1b) applied in the adult stands, both with two samples each. The control (T0) was obtained from the manual count of tree individuals in the orthomosaic. Parameter selection tests were performed during the processing using LiDAR360 to obtain the optimal values for the individual tree detection. Our previous results presented the underestimation of the total number of trees by the LiDAR360. In the adult stands (T1b), the detection success rate was 79.5% and 53.9% for samples 1 and 2, respectively. The height range (maximum and minimum) was the parameter that most influenced the detection results, and in this case the optimal values were 3 m for minimum and 40 m for maximum tree height. In the young stands (T1a) the detection presented larger errors compared to the T1b. Based in the results, we can conclude that the software is capable to detect individual trees, but there is a low success rate in the detection; this may suggest the need for customized algorithms to automatic detect trees from UAV imagery.

27. Estimation of pine cone counts using small unmanned aerial system (UAS) imagery | L Malambo*, S Popescu, B Bartlett, F Raley, T Byram, S Srinivasan

Loblolly pine (Pinus taeda L.) is the dominant commercial forest species in the southeastern United States. Approximately, 75% of all seedlings planted each year in the US are loblolly pine. Tree improvement programs over the past half-century have helped double the productivity (per acre mean annual increment) of southern pine plantations through the deployment of genetically superior genotypes. Additional genetic gains can be realized through full-sib breeding, which relies on controlled mass pollination (CMP) for large-scale production. CMP is becoming more prevalent, yet remains extremely labor intensive and relies on heavy equipment. Increased traffic in seed orchards has been demonstrated to negatively impact tree health and cone yields, due to soil compaction. Orchard managers require an accurate inventory for cone harvests in order to schedule and allocate resources, especially from CMP operations. To ameliorate soil compaction and labor costs, small UASs can quickly and accurately provide this service through the collection of high resolution images. This study develops and evaluates methods for estimating pine cone counts from high resolution UAS images. Images of individual pine trees were collected over a pine orchard in Livingston, Texas using a DJI Inspire-2 drone equipped with a 20 MP RGB camera by flying around individual trees. Oblique images (inclined at 60˚) were also collected by flying in a cross-stitch flight pattern over a section of the orchard at an altitude of 25m with an 85% image overlap. The cone detection approach developed in this study is based on a Random Forest classifier and relies on various features including spectral image bands, principal components and spatial textures. It also includes a post-detection step to split touching cones. We compare the derived cone counts with manually digitized cone counts for a selected number of trees and highlight the strengths and limitations of our approach and UAS-based data collection in general.

28. A Multi-Sensor Fusion Approach to Landsat Time Series Fitting | S Ghannam*, AL Abbott, ME Hussein, RH Wynne, VA Thomas

The growing Landsat archive provides a rich record of the Earth's surface, representing more than 4 decades of uninterrupted data acquisition. However, the relatively low temporal resolution of Landsat limits the utility of Landsat data for tracking rapid changes or investigating intra-seasonal variations. Previous attempts to estimate the Landsat values at time instances with no Landsat coverage by fitting Landsat per-pixel time series have been proposed. The previously proposed fitting-based techniques for predicting Landsat values did not perform any multi-sensor fusion at the time series level.This paper presents a novel model for estimating new Landsat-quality observations through fusion of existing Landsat time series with data time series from other sensors with higher temporal resolution but coarser spatial resolution than Landsat. The new approach, called MATSFM (Multi-sensor Adaptive Time Series Fitting Model), applies a multi-year statistical approach to guide the fitting of Landsat intensity values on a pixel-by-pixel basis. In our experimental work, MODIS has been chosen as the second sensor to fuse with Landsat. To our knowledge, no Landsat-MODIS fusion models based on processing a multi-year per-pixel time series have been previously proposed. MODIS time series are first preprocessed because they contain noisy measurements. MATSFM applies an approximation to map the preprocessed MODIS values into their corresponding Landsat values for the purpose of filling the large gaps in each Landsat per-pixel time series. Local regression using smoothing splines is then applied to the new filled Landsat time series.Our proposed MATSFM model has been tested on the available Landsat and MODIS images of two study areas in North Carolina: a challenging heterogeneous study area near Greensboro and a more homogeneous area at the east of Pittsboro over a three-year interval. The MATSFM model has been tested by predicting images that correspond to existing Landsat images. This approach has been used for 22 Landsat images for the first study area, and 37 images for the second study area. The prediction accuracy has been assessed using two different metrics: coefficient of determination (R^2) and structural similarity metric (SSIM). MATSFM produced average R^2 and SSIM results with medians of 0.98 and 0.88 respectively for both study areas. These results demonstrate a significant improvement over two baseline approaches.

29. Assessing the relationships between stand characteristics and Landsat-based aboveground forest biomass mapping uncertainty. | D Bell*, M Gregory, R Kennedy, D Saah, J Battles, B Collins, J Sanders

Maps of forest ecosystem status and change are increasingly needed to support natural resource planning, monitoring, and research efforts at the level of projects and landscapes. Multispectral, Landsat time series (LTS) data are often used in forest mapping and monitoring. Users require not only characterization of sources of remote sensing errors, but also the abiotic (e.g., topography) and biotic (e.g., vegetation height) correlates of model performance to guide when and where they can best leverage LTS-based vegetation maps. The aim of this research was to assess error in aboveground live forest biomass (AGB) stock mapping in several landscapes in California, USA, at the scale of individual stands as a function of vegetation and topographic patterns. An integrated disturbance and vegetation mapping approach that incorporates the LandTrendr change detection algorithm and the gradient nearest neighbor (GNN) imputation method was used to develop LTS-based AGB maps. We used lidar-based AGB maps as reference datasets for these comparisons across stands. To understand topographic and vegetation characteristics contributing to deviations between AGB maps, we modeled map deviations between mean stand-level LTS- and lidar-based AGB as a function of topography, lidar-based vegetation characteristics, and composition as represented by ecoregion. To assess the capacity to correct for these deviations (i.e., calibration), we modeled lidar-based AGB as a function of topography, ecoregion, and LTS-based AGB.As compared with pixel-level comparisons, root mean square deviations between mean LTS- and lidar-based AGB predictions declined at the level of forest stands. Still, stand-level LTS-based AGB tended to over-estimate lidar-based AGB at lesser AGB and over-estimate at greater AGB. Between 10%-60% of stand-level map deviations between lidar and LTS-based AGB were explained by topography, vegetation height, and ecoregion, with vegetation height accounting for most of the explanatory power. Calibrating LTS-based AGB maps to reflect lidar-based AGB led to 5%-45% increases in the coefficient of determination (R2), most often by correcting over-estimates of AGB at lesser values. Therefore, under-prediction at greater AGB levels implies spectral saturation as a continued major source of error in in LTS-based AGB mapping, even after calibration. These results highlight (1) the need for improved understanding of the relationships between remote sensing-based map performance and the topographic, structural, and compositional characteristics of forest landscapes and (2) the capacity to utilize lidar-based mapping as the basis for locally calibrating annual LTS-based maps used for forest monitoring and planning.

30. Inter-annual variation in springtime phenology of North American temperate and boreal forests | M Moon*, E Melaas, J Gray, M Friedl

Springtime phenology in boreal and temperate forests exerts important controls on land-atmosphere exchanges of carbon, water, and energy, affecting regional weather and climate. Numerous studies have reported trends in springtime forest phenology caused by warming temperatures. Recently, however, a number of studies have questioned whether other ecophysiological controls, such as reduced chilling or photoperiod, will buffer the long-term impact of warmer temperatures. In this study we present a continental-scale analysis of long-term changes and interannual variation in springtime phenology across North American temperate and boreal forests. Our study region encompasses seven EPA Level-II Ecoregions, and uses the newly available Collection 6 MODIS Land Cover Dynamics product (MCD12Q2). Our results show substantial geographical variability of changes in leaf emergence dates, but that overall, springtime phenology in most forested regions consistently trended earlier by an average of 4 days between 2001 and 2015, with the largest changes found in the Appalachian highlands. In contrast, some sub-regions of Canada's boreal forest showed overall trends towards later springtime onset dates. Interannual variability in springtime phenology was substantial and was highly correlated with preseason accumulated growing degree days across all ecoregions (e.g., minimum $R2 = 0.721$, $P < 0.01$). Similar to the observed trends in springtime phenology, Northern Forests showed higher sensitivity to interannual variation in accumulated growing degree days than Eastern Temperate Forests. These results suggest that in the coming decades, Northern Forests are likely to experience greater changes in springtime phenology (and inter-annual variation thereof) than Eastern Temperature Forests.

31. Landsat-based Upper Great Lakes Forest Phenoclimatology, 1984-2013 | M Garcia*, P Townsend

Past studies have connected mean forest phenology from remote sensing analyses to regional climatological patterns, usually relying on long-term average temperatures and derived growing degree day accumulations. This long-term mean phenology is then used to inform land surface model vegetation dynamics in meteorological and climate modeling systems. We present a detailed, spatially-explicit examination of remotely sensed forest phenology in the region of western Lake Superior, USA, based on a comprehensive 1984-2013 climatological assessment [Garcia and Townsend, 2016] and Landsat imagery over the same period. The previous work showed that regional warming on land areas of 0.56°C during the 30-year study period contrasted with ~2.5°C warming in Lake Superior, one of the fastest-warming large lakes in the world, indicating possible long-term changes in land-lake interactions and hence vegetation phenology. As well, summer warming is accompanied by a regional precipitation decline of 0.34 cm/y across the study area, potentially leading to vegetation moisture stress that can reduce carbon uptake rates and render the forest more vulnerable to disturbance agents. Changes appear most prominent in areas exhibiting strong influences of Lake Superior. We use our climatological analysis to explain the mean annual land surface phenological cycle and its interannual variability in temperate mixed forests. Differences in phenological indicators across our study area, especially the durations of (spring) green-up and (summer) maturity, are strongly correlated with spring and summer hydroclimatology. We then depart from traditional examinations of the fitted mean phenology, using partial-least-squares regression methods to associate Landsat vegetation index residuals (departures from the mean phenological curve) with short-term departures from location-specific climatology based on our analysis. The mean phenological curve typically explains ~50-70% of observed interannual variability from long-term Landsat records; our novel, spatially-explicit and climate-sensitive mixed modeling approach may explain as much as 90% of seasonal and interannual phenological variability. These methods may improve the information provided to land surface models in operational weather and long-term climate models that depend on accurate representations of vegetation state in the land-atmosphere system.

32. Large-Scale trailcam networks enhance interpretation of satellite phenology for ecological studies | N Liu*, J Clare, C Anhalt-Depies, B Zuckerberg, P Townsend

Snapshot Wisconsin is a broad-scale citizen science/crowdsourcing effort to deploy up to 5,000 camera traps in forests across Wisconsin. The objective of Snapshot Wisconsin is to link wildlife observations from the trailcams with satellite imagery representing vegetation phenology, productivity, composition and fragmentation to predict wildlife distributions, community composition and behavior in space and time. However, Snapshot Wisconsin also provides a unique daily record of vegetation characteristics that can be used to better understand and validate interpretations from satellite imagery. Here, we compare interpretations of phenology and snow cover from MODIS with those derived from daily 11am (local time) trailcam photos. After screening trailcams that were unrepresentative of vegetation in the larger 500-m MODIS pixel, we found significant offsets between understory and overstory phenology as derived from trailcam photos. MODIS phenology related strongly to temporal patterns of overall trailcam photo greenness (including both overstory and understory) with greatest sensitivity to overstory phenological timing. Differences in forest composition derived from Landsat explained residuals in regressions between MODIS and trailcam phenology. Using the trailcams, we also evaluated offsets between overstory and understory phenology. While MODIS phenology is most strongly related to overstory phenology, there were significant variations among forest types across Wisconsin in the relative timing of green-up and senescence between the overstory and understory. Ultimately, the combined phenology data from remote sensing and trailcam observations is being used to model spatial and temporal patterns in wildlife distributions and behavior.

33. Seasonal dynamics of forest albedo in European boreal region | A Hovi*, E Lindberg, M Lang, T Arumäe, J Peuhkurinen, S Sirparanta, S Pyankov, M Rautiainen

Albedo-related radiative forcing is among the main uncertainties when evaluating climate effects of forests and forest management. Numerous local studies demonstrate the effects of forest structure on albedo in the boreal zone. The boreal zone is however vast and relations between forest structure and albedo need preferably be established for geographically extensive areas. In addition, seasonal courses of albedo need to be studied in order to understand the effects of albedo on mean annual energy balance. Remote sensing (RS) is a viable option for accomplishing these goals, but there are many challenges related to e.g. the tradeoff between temporal and spatial resolutions, as well as long periods of cloud cover and low solar elevations in high latitudes which reduce the quality and availability of satellite observations. To address these questions, we analyzed the new MODIS Collection 6 (MCD43A3) albedo product that provides daily albedos, and analyzed MODIS albedo dependence on airborne LiDAR-based forest structure in 22 study sites in Estonia, Finland, Sweden, and Russia (57°-69° N, 12°-57° E). Because of their wall-to-wall coverage, LiDAR data allowed to show that taking into account the effective resolution of MODIS, which is larger than the nominal resolution of 463 m, notably improved correlations between albedo and forest structure. Because high quality albedo retrievals are often limited in high latitudes, we also quantified the effects of using the data from the backup algorithm (magnitude inversion) in our analysis. We demonstrated that snow dominated the seasonal course of albedo, and the contribution of snow to mean annual albedo increased towards high latitudes. In snow-free periods, there were only small differences in mean albedos between sites: those sites that had a large fraction of broadleaved trees differed from the rest by showing the highest albedos. Also the relations of albedo to forest structure within each site were stronger in snow-covered compared to snow-free periods. This means that the effect of forest structure on albedo increases towards north where the snow-covered period is long. However, the relative contribution of forest structure compared to snow was the highest in the south. Our results therefore indicate that future changes in albedo are mainly determined by forest management and disturbances in the southern part of boreal zone, whereas in the northern parts potential changes in snow cover are also important.

34. Customized web-based services to access the Daymet product: Analysis of user-based downloads provide insights into how scientists access large, complex data for their research needs | M Thornton*, Y Wei, A Boyer, P Thornton, S Vannan

The ORNL DAAC (a NASA EOSDIS data center) archives and distributes a dataset that consists of gridded surface weather variables available on a daily time-step for 1980 - 2017 at a 1-km spatial resolution over North America. Known as Daymet, this entire data product is freely available for download as CF-compliant netCDF files, however, many researchers find these file sizes and formats unfamiliar and challenging. NASA DAAC's provide reliable, robust services to users whose needs may cross the traditional boundaries of a science discipline. As a commitment to different scientific user communities and to maximize the usability of data, the ORNL DAAC has developed specialized tools and services that allow this multi-variable data product to be downloaded in user-specified subsets (both spatial and temporal) and formats. Services based on OPeNDAP architecture, THREDDS Data Service, and REST APIs provide interactive Web-based UIs that support data visualization and allow download through URLs with defined spatial and temporal parameters. These REST API's also enable download automation and compatible client software customization.Results/ConclusionsThe tools and web-based services provided by the ORNL DAAC greatly enable the use and usability of several datasets such as Daymet. As evidenced by the number and volume of data downloads, there is a documented need for daily, high resolution, gridded surfaces of meteorological data in standardized, interoperable formats that are both readily available and ingestible into common analysis packages. Since 2012, over 200 published journal articles cite the use of the Daymet data product in research products covering fields such as wildlife biology, terrestrial vegetation growth, hydrology, insect/pest management, and climate characteristics. Several governmental organizations have downloaded Daymet data resulting in a total number of orders exceeding well over 200,000 requests since 2012; a data volume of more than 261 GB. These include DOE, DOI, EPA, NASA, NOAA, USDA and state agencies. On a weekly basis, a service that provides automation of asci file downloads of single point locations often exceeds over 10,000 queries. A netCDF Subset Service has been utilized with over 200,000 downloads since 2016. These results demonstrate the need for data centers to continue to develop specialized data access services for data that have high value to the scientific community.

35. Estimating clearcut area in Mediterranean forests on the basis of Landsat time series analysis | G Chirici*, R Pegna, F Giannetti, RE McRoberts, E Mazza, D Travaglini

In the last decade the open access availability of the Landsat archive has stimulated the development of methods for the automatic mapping of forest disturbances. Landsat images are preferably used because their availability potentially goes backs to the seventies of the past century. To map clearcut areas methods are generally based on the multitemporal analysis of Landsat images since the forest loggings determine an abrupt decrease of photosynthetic activity as most or all trees are lodged, followed by an increasing trend due to regeneration.Most of the applications available in literature are developed in temperate or boreal forests where forest clearcut are carried out over large areas and the regeneration is from seeds or replanting.In Italy, the vast majority of clearcut is carried out in coppice forests where the vegetative natural regeneration is extremely fast in recovering harvested areas. It is therefore interesting to understand if it is possible to automatically detected clearcut areas in such Mediterranean forest ecosystems. We also noted that in literature most of the contributions present the results without providing a formal statistical calculation of the standard error in the clearcut area estimation.This study is carried out in Central Italy on the basis of one Landsat scene acquired for a time series of 16 years (between 1999 and 2015). We first analysed the spectral behavior of coppice forests to highlight specific spectral temporal trends. We then applied a method based on multiple multi-temporal changes in the Landsat Normalized Burn Ratio to automatically map forest clearcut area. On the basis of some test areas where the clearcut area was manually acquired without errors, we finally present the achieved results together with an innovative proposal for a formal error estimation of clearcut area.

36. Potential of Sentinel-1 time series for deforestation and forest degradation mapping in temperate and tropical forests | M Urbazaev*, F Cremer, C Schr[illegible]us, C Thiel

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In this study we investigated the po[illegible] dense synthetic aperture radar (SAR) time series collected by the ESA's Sentinel-1 satellites to detect deforesta[illegible] forest degradation areas. Since SAR data are affected by speckle, it is crucial to filter speckle before the time s[illegible] analysis. Accordingly, we explored the potential of empirical mode decomposition (EMD), a data-driven approach to decompose the temporal signal into components of different frequencies. Based on the assumption that the high frequency components are corresponding to speckle, these effects can be isolated and removed. Since the EMD approach operates in the time domain only, it fully preserves the geometric resolution, which is required to detect small scale changes (e.g., forest degradation). We assessed the speckle filtering performance of the EMD approach. The results over forested areas showed similar statistics compared to the multi-temporal Quegan speckle filter in terms of speckle suppression (based on Equivalent Number of Looks) and an improved edge preservation. In the next step, we analyzed EMD filtered Sentinel-1 data for detection of deforestation and forest degradation areas. For this, we first selected forested, deforested and degraded areas based on visual interpretation of multi-temporal very high resolution (1 m) optical imagery over temperate and tropical forests of Mexico. Further, we plotted EMD filtered Sentinel-1 time series for the three reference classes and were able to determine the time frame of deforestation and forest degradation. The initial analyses showed promising results regarding the separation of forest and forest-change classes with EMD-filtered Sentinel-1 data in contrast to original SAR backscatter images. In the further steps, we develop a method to determine breakpoints in the SAR time series to derive deforestation and forest degradation maps.

37. Validation and preliminary assessment of the Ecosystem Disturbance and Recovery Tracker (eDaRT) performance in forests of the Sierra Nevada, California. | E Haunreiter*, A Koltunov, C Ramirez, M Slaton, K Evans, T Kohler, L Young, S Ustin

Accuracy assessment is critical to the informed and sustained use of automated forest disturbance monitoring algorithms in forest management and scientific research. One of the challenges in evaluation is development of meaningful and accurate reference datasets, given practical constraints on availability, both temporally and spatially, and quality of truth data sources. We present our initial experiments to evaluate performance of the Ecosystem Disturbance and Recovery Tracker (eDaRT) algorithm currently operating in California to detect landscape disturbance events in dense Landsat image time series. These experiments focused on general classes of disturbance that are meaningful from an ecological and forest management perspective and also observable without reliance on Landsat imagery: No disturbance, Fire, Harvest, and Mortality. Reference datasets at the Landsat pixel scale were developed in two test scenes in the Sierra Nevada, California, based on high-resolution imagery and bi-temporal airborne LiDAR. High-resolution image sources included Google Earth, WorldView and National Agriculture Imagery Program (NAIP). With these data we assessed how the probabilities of detection and commission errors depended on disturbance magnitude, frequency of processed Landsat images, and land cover type. In particular, we observed that eDaRT was capable of detecting as little as 1% change in canopy cover (with probability of ~0.2) in these data, while a 20% loss of canopy cover has a probability of detection of ~0.8., with false positive rates of 10-20%. Based on a model of detection probabilities derived from these initial data and ongoing extended sampling, eDaRT performance can be predicted for the regions/samples with different distributions of disturbance events with respect to the above factors. How detection accuracy varies depending on disturbance intensity, especially for more subtle and lower intensity impacts, has been the most requested information by management agencies and other eDaRT users.

38. Time series data analysis for forest change-type attribution and applications for UK forest management and improving Hylobius abietis risk identification | I Bye, J Suárez, M Payne, J Rosette*, Z Yang, W Cohen, D Plugmacher

The GB Forestry Commission requires consistent, economical and objective means to maintain the currency of the public forest estate subcompartment database and National Forest Inventory data. This project has applied time series analysis using Landsat (and additionally Sentinel-2 data) to inform and facilitate the update of these national datasets.The principle of the research is based on expected phenological (and therefore spectral) stability during the summer growth season. Deviations from a stable trajectory are taken to indicate forest change. Indices relating to vegetation properties such as structure, productivity and condition are investigated as to their ability to detect different agents of forest change (harvest, regrowth, forest condition decline) as well as periods of stability. The classification was compared against available validation datasets such as felling licences, statutory plant health notices (felling orders as a result of quarantine pests or disease) indicating expected proceeding forest decline, forest management information, aerial imagery, etc.This first forest change type classification, produced promising results of 0.88 accuracy for identifying the above classes. This was achieved for a combined dataset comprising three geographically-dispersed sites across Britain, containing varied dominant forest types, and having different forest change histories (severe windthrow, catastrophic health impacts, and traditional silviculture practices). This commonality supports the potential for a nationwide classification of agent of forest change and for forestry-related applications.An example is for risk assessment from Hylobius abietis (large pine weevil) using the Hylobius Management Support System (HMSS), developed by Forest Research. Resulting losses cost the British forest industry between £5-40 million per annum. Although the weevil only breeds in conifer stumps, it will attack all tree species present on a restocked site.The location of newly clearfelled conifer stands (breeding site availability) is paramount for operational use of the HMSS model. However felling data are frequently unavailable (particularly from private land owners), or felling dates are not accurately recorded.The satellite-based detection of felled conifer stands offered substantial improvement in comparison to traditional reliance on field records of logging operations, furthermore providing a spatial context that would otherwise not be possible.

39. Structural Signatures of Forest Disturbance | J Atkins*, R Fahey, B Hardiman, E Stuart-Haëntjens, B McNeil, D Orwig, L Turner, A Stovall, C Gough

Forests are subject to disturbances from multiple sources, including but not limited to fire, pathogens, insect damage, drought, ice and wind. Classic disturbance ecology focuses on disturbance severity, intensity, and frequency, often with little regard for how disturbanceseven at similar levels of severitymay have vastly different structural, and consequently, functional outcomes. Understanding what the structural changes from various types of disturbance looks like, is vital to examining structure-function effects. Traditional means of describing disturbance (e.g. low, moderate, etc.) often fails to adequately quantify meaningful functional shifts. Though structural changes could differ significantly at given levels of severity, it follows that functional responses to disturbance may be expected to differ as a result of disturbance type. Here we use terrestrial LiDAR coupled with machine learning to test the hypothesis that different types of non-stand replacing, moderate severity disturbance will have unique structural signaturesdistinct quantifiable physical changes to the forest that occur in response to specific disturbance types. Using a survey approach, we examine the structural signatures of multiple disturbance types across multiple different forests using terrestrial LiDAR (Leica BLK360, Faro FOCUS, and portable canopy LiDAR systems). We examine response to moderate severity fire in the Great Smoky Mountains of Tennessee; insect defoliation at Colonial Point, Michigan; response to Hemlock Woolly Adelgid at Harvard Forest in Massachusetts; loss of overstory species as a function of forest succession at the FASET experiment in Michigan; ice storm damage at Hubbard Brook Experimental Forest in New Hampshire; and response to long-term nitrogen addition at the Fernow Experimental Forest in West Virginia.

40. Integration of Landsat and simulated spaceborne LiDAR data to estimate time since disturbance at the forest stand level | N Sanchez-Lopez*, L Boschetti, AT Hudak

Maps of stand-replacing disturbances are valued by forest managers and scientists to complement thematic maps of forest stand attributes and to monitor biomass and carbon stocks. Recent research on object-oriented analysis of airborne LiDAR data has been used to obtain stand-replacing disturbance history maps of time since disturbance (TSD) at decadal time steps over a period of more than one hundred years, greatly expanding the temporal range of the disturbance history, beyond that of traditional change detection techniques with optical satellite data constrained to the beginning of the Landsat data record in 1972. However, the use of airborne LiDAR to this end is limited by data availability and its high cost compared to satellite data. These limitations could largely be solved thanks to NASA's forthcoming Global Ecosystem Dynamics Investigations (GEDI) mission. GEDI will be a spaceborne LiDAR mission that will sample the structure of tropical and temperate forests with latitude up to 51.6°. The sampling configuration of GEDI data will impose certain constraints for continuous spatial analysis compared to the common discrete-return airborne LiDAR. Therefore, new data integration strategies are required between GEDI and other sources of information, such as Landsat and Sentinel. In this study, object-oriented techniques applied to Landsat data are used to delineate forest stand boundaries, and simulated GEDI-derived metrics are implemented to estimate TSD at the forest stand level. The study area was located in the Clear Creek and Selway River watersheds (~ 54,000 ha) in Idaho, where airborne LiDAR and reference maps on TSD were available for independent validation. Simulated GEDI footprints and waveforms were obtained from airborne LiDAR data. The methodology is divided into three main steps: (1) forest stand delineation using object-based techniques of image segmentation on Landsat derived data; (2) estimation of TSD at the GEDI footprint level using random forest analysis; and (3) estimation of TSD at the stand level based on the GEDI footprint estimates and the forest stand map obtained from Landsat image segmentation. The temporal requirements to obtain an adequate number of GEDI footprints per forest stand considering the mission sampling configuration and the probability of cloud cover also is assessed. These results provide insights on whether it is possible to obtain a suitable stand-replacing history map based on satellite-derived data alone.

41. Rapid Assessment of Post-Storm Windblow in Scotland using Sentinel-1 | S Fleming*, I Woodhouse, A Moyer, J Morel

The aim of this project was to build upon previous work using radar derived DEMs to develop a methodology which enables decision makers to react accordingly following catastrophic windblow events in Scotland. Using the European Space Agency satellite, Sentinel-1, the methodology was developed to assess the locations of where catastrophic windblow has occurred and, using a bespoke algorithm for assessing confidence in the identification and for generating a prioritisation ranking coefficient, enable decision makers to act accordingly.The primary dataset used for developing this methodology was Sentinel-1, taking advantage of the UK's existing investment this technology which offers a unique, high coverage solution for mapping forest change. Auxiliary data sources provided further information about the topography, land use, and other landscape features, which fed into the confidence and prioritisation analysis. Analysis Ready Data was prepared using a combination of standard radar data processing software packages to extract the information of particular interest, undertaking further processing using a purpose built script with final analysis undertaken within an open-source GIS environment.Our methodology works by comparing Sentinel-1 dataset pairs of different characteristics, before and after a windblow event. By layering the different data streams, manipulated through the use of filtering, thresholding and morphological manipulation, finessed using training data, the methodology will identify areas of likely windblow. From here auxiliary datasets are fed into the system to automatically assess confidence in the flagged windblow areas, and to provide an appropriate prioritisation ranking to help inform decision makers on the most efficient and effective form of action.The key findings were that Sentinel-1 can be an effective tool for rapidly assessing catastrophic windblow following storm events. No solution that solely uses Sentinel data is going provide all the information that is required for a rigorous windblow assessment. In order to have a complete operational system the Sentinel-1 data would have to be complemented by helicopter or UAV data. However, Sentinel-1 does provide a significant opportunity for cost reductions by directing these existing efforts to the locations where more information is required, rather than undertaking blanket surveys post-storm event, in short these very high resolution data acquisitions can be targeted.

42. National Maps Attributing Forest Canopy Loss Activities 1986-2010 | K Schleeweis*, G Moisen, C Toney, E Freeman, T Schroeder, C Huang, J Dungan

Approaches to estimating area and rates of forest change activities such as harvests, fires, conversions, wind storms, and insects and disease vary widely. A consistent national approach to mapping these activities in forest land may yield better information to for land managers and ecosystem services applications. We use a two step-modeling process to map disturbance causal agent through time with the help of the NASA Earth Exchange (NEX) Pleiades cluster. Each disturbance algorithm has its own strengths and weaknesses so we include the outputs from multiple disturbance algorithms as predictors into a Random Forest model. Validation with a probabilistic reference data set suggests that User's and Producer's accuracy for the Stable, no loss class, are 81.3 % (± 0.01 s.e.) and 94.4% (± 0.01 s.e.), respectively. The harvest class has 82.3 % (± 0.01 s.e.) User's and 72.2% (± 0.02 s.e.) Producer's accuracy. Qualitative measures of uncertainty from are also produced. Results explore the spatial and temporal patterns of each activity at different scales. We also link these activity results to Forest inventory plot data to explore relationships between tree-based variables that are difficult to capture with optical imagery. These are the first wall to wall maps of harvest activity in the US.

43. Mapping a changing fire frequency and carbon consumption in Alaskan black spruce forests | E Hoy*, K Barret, T Loboda, M Turetsky, E Kasischke

Changes to the fire regime in the boreal forests of Alaska have included increases in burned area and fire frequency over recent decades. These fire regime changes alter carbon storage and emissions, especially in the thick organic soils of black spruce (Picea mariana) forests, but there is uncertainty in the overall vulnerability of these landscapes to burning, especially in stands that burn while they are still immature (~<60 years old). A better understanding of both the vulnerability of immature stands, and of the carbon emissions impact of immature stands burning, is needed. In the research presented here we first assessed geospatial and remote sensing datasets from interior Alaskan fire events to analyze the relationship of fractional burned area (representative of the total burned area within a fire perimeter) with fire-free interval (a measure of fire frequency), vegetation, topography and the seasonal timing of burning. We then analyzed how fire frequency impacts carbon consumption in Alaskan boreal forests using a modeling framework. Interestingly, it was found that the fraction of burned area differed between mature forested areas and immature non-forested areas within the analysis. Results showed that considerable burning in interior boreal regions occurs in stands not yet fully recovered from earlier fire events (~20% of burned areas are in immature stands). These newly determined results were then incorporated into the modeling framework through adding an immature black spruce fuel type and associated ground-layer carbon consumption values. This alteration to the model lead to higher ground-layer carbon consumption (and thus total carbon consumed) for areas that burned in two years with high total burned area in Alaska (2004 and 2005). These new results provide insight into the fire-climate-vegetation dynamics within interior Alaskan boreal forests and can be used to both inform and validate modeling efforts to better estimate soil carbon pools and emissions in interior Alaskan boreal forests.

44. Advances of the identification and satellite monitoring system for forest fire danger zones (SIMPIF) originating

from agricultural burning in southern Chile. | P Acevedo*, M Castro, C Soto, C Carrasco

In Chile at least 60% of fires originate from anthropic causes, which correspond in their majority to intentionality, transit of people and the burning of agricultural and forest waste. The 'La Araucanía' region has the second largest number of forest fires resulting from agricultural and livestock operations, with 797 fires from 2003-2016. That is to say, at the national level, approximately 21% of all fires caused by agricultural burning that get out of control (fires) occur in La Araucanía.In this project the 'La Araucanía' region was chosen for the test area since it is one of the regions with the largest number of acres affected by forest fires caused by agricultural and livestock operations, with approximately 12,800 acres affected between 2003-2016, in other words 25% of the land surface affected nationwide.Given the extensive surface studied, remote sensing is the only source of information that can be utilized to monitor these activities in larger areas and in shorter time intervals. This includes designing, establishing and implementing a satellite system for spatial-temporal identification and monitoring of the degree of danger of forest fires derived from agricultural burning in southern Chile.This system can be described in four modules, the first being fixed data input (protected forests, the database of agricultural properties, power lines, road networks, urban areas, combustion index of different agricultural crops and the effect of accelerating or retarding components, characteristics of each crop), a second module for the input and processing of dynamic data (annual classification of ground cover and agricultural crops, surface temperature (ST), fuel moisture content (FMC), the Normalized Difference Vegetation Index (NDVI), precipitation, and wind), the third module which corresponds to creation of a fire danger map and the fourth module, a web mapping visual.The first results obtained, and a perspective of the expected final result of this project will be presented. The first results refer to the classification of land cover (overall accuracy 95%), classification of agricultural crops (overall accuracy 80%), and the ranking of combustion for the different crops and some forest species. In the classification of land cover and agricultural crops, Sentinel 2 data was used.

45. Variation in forest functional traits in tropical deciduous forests of India | T Zheng*, A Singh, N Krishnayya, P Townsend

The use of imaging spectroscopy to map foliar traits such as canopy nitrogen, leaf mass per area and pigments has greatest promise for locations and ecosystem types that are poorly studied and/or are logistically difficult to measure on the ground. We applied foliar trait models to AVIRIS-Next Generation data collected over tropical deciduous forest in the Western Ghats, India in 2016 as part of a NASA-ISRO joint campaign. Existing models performed adequately, but were much improved with the addition of in situ data from India. Indian forests showed strong variation in foliar traits, driven largely by rainfall gradients, and across the Western Ghats forest functional diversity was high. Most importantly, the work provided information about functional trait variation in the Western Ghats that was not previously known. Because the AVIRIS-NG data were collected during the dry season, the analyses were limited to evergreen forests or those that had not yet senesced, pointing to the need for additional measurement campaigns to characterize a wider range of species in the biome.

46. Combining multi-temporal Sentinel-2 data and forest inventory plots to estimate the percent cover of tree species in a mixed European forest | C Straub*, LT Waser

Precise information about the distribution of tree species is essential for the forestry sector regarding management, protection function, renewable resources and biodiversity.Currently, remote sensing technologies are integrated into operational forest management inventories in the Bavarian state forests to enable the production of wall-to-wall maps of inventory attributes such as timber volume per hectare. However, so far it is not possible to provide species-specific data. For this reason, the potential of multi-temporal Sentinel-2 images is examined in this study with the aim to estimate the percent cover of tree species and species groups. The presented approach is highly relevant for practical applications as operationally acquired inventory plots are used as training data to develop the models.In total, 980 circular field plots (size: 500 m^2) are available from a forest management inventory conduced in 2016 for a mixed forest with a size of 40 km^2 in northern Bavaria, Germany. Based on the basal area of the trees, the percent cover of species was derived for each plot. The main species in the test site are oak (Quercus spp.) 32%, beech (Fagus sylvatica) 18%, spruce (Picea abies) 23%, pine (Pinus sylvestris) 11%, other conifers 6% and other broadleaves 10%. Nine different cloud-free Sentinel-2 datasets from different phenological stages (from March to October) were downloaded. The Sentinel-2 images have a maximum time difference of one year to the field measurements of the inventory. For all datasets atmospheric corrections and topographic normalizations were carried out.The presented approach is largely automated. First, explanatory variables were derived from the nine different Sentinel-2 datasets for all inventory plots. For this purpose, all Sentinel-2 bands with 10 m and 20 m spatial resolution were considered and additional indices were calculated. Second, feature selection was applied to reduce the large number of explanatory variables from the nine different Sentinel-2 datasets. Third, different machine learning methods such as random forest and k-Nearest Neighbor were tested for model development at the plot level. Cross-validation was used for hyperparameter tuning and for model validation. First results are promising. The presented approach is currently being optimized by calculating additional remote sensing indices and by testing other machine learning techniques.

47. Estimating the last disturbance year of forest stands in Coastal Georgia using all the available Landsat imagery with Google Earth Engine | S Obata*, C Cieszewski, P Bettinger, R C. Lowe III, S Bernardes

The forested and agricultural area in Coastal Georgia, United States includes a complex interspersion of croplands, pasture, conifer plantations, deciduous bottomlands, cypress (Taxodium) forests, and mixed species stands. In addition, landscape of this area is changed dynamically due to the relatively short rotation age of the plantation forests that occupy majority of the land area. In this research project, we are utilizing all the available Landsat imagery to provide information on forest disturbance, and to estimate an age of the current forest landscape at a stand-level basis in our area of interest. Landsat imagery is processed using Google Earth Engine. We used all the available Landsat 5 TM, 7 ETM and 8 OLI Surface Reflectance imagery from Tier 1 products as of July 17, 2018. After filtering out imagery with more than 50 % of cloud cover, we acquired 434 scene. For each scene, Tasseled Cap brightness, greenness, wetness and Integrated Forest Z-score (IFZ) were calculated and stacked on Google Earth Engine. Moving average, standard deviation and median of the 5 subsequent elements were computed for every elements of the IFZ stack. For the 3 components of Tasseled Cap, harmonic regression was performed. The last disturbance was detected using three metrics to create a disturbance map. To evaluate the quality of the output, accuracy assessment for the disturbance year was conducted. In this process, User's accuracy and Producer's accuracy for each year is calculated as well as Overall accuracy. Support Vector Machine was applied to the disturbance map to classify 4 types of disturbance for each pixel using slope, amplitude and RMSE acquired in the harmonic regression for the 3 components of Tasseled Cap. Our method has advantage in terms of applicability to other area as the user of this model using Google Earth Engine does not have to locally manage the massive number of imagery. Comparing to the previous researches which use one imagery per year, our method can grab the seasonality of the reflectance values. Information of Seasonality makes it possible to distinguish coniferous forest and deciduous forest. Combined with the regeneration map that will be created after this project, age structure of forests in Coastal Georgia will be estimated with 30 meter by 30 meter resolution.

48. Identification of pine plantations with moderate management intensity using EWMA-CD on Landsat and harmonized Landsat-Sentinel (HLS) time series stacks | MN House*, VA Thomas, EB Brooks, RH Wynne

This study examines whether moderate intensity management of pine plantations can be mapped using, in part, control chart disturbance severity levels derived from exponentially-weighted moving average change detection (EWMA-CD) on both Landsat and Harmonized Landsat-Sentinel (HLS) time series stacks. Moderate-intensity management is defined, for this study, by whether a stand has been thinned at some point during its life cycle. Training data were derived from shape files outlining over 43,000 harvests obtained from the Virginia Department of Forestry (including both clear felling and any degree of thinning that required a harvest inspection). Flagged disturbances on previously identified plantations are separated into either thins or harvests based on disturbance severity.

49. Global forest mapping through the integration of microwave and optical remote sensing | X Xiao*, Y Qin, J Dong, J Wang, B Chen

The area, spatial distribution, and temporal changes of forest are critical for global carbon cycle and biodiversity. The previous forest maps are mainly generated by optical remote sensing imagery, which still has relatively large uncertainty, especially for tropical forest covered by frequent clouds. Microwave remote sensing is not affected by weather and is sensitive to forest structure and biomass. We have developed novel approaches for mapping the spatial patterns and temporal changes of forest worldwide using the integration of microwave (ALOS PALSAR, Sentinel-1) and optical (MODIS, Landsat) remote sensing imagery. We generated high accuracy PALSAR/MODIS/Landsat forest maps at the spatial resolution of 30-50 meters and analyzed their spatio-temporal changes in monsoon Asia, South America, and Oklahoma, USA from 2007 to 2010. We generated 30-m PALSAR/Landsat rubber forest in southeast Asia and analyzed their stand age. We tracked the spatio-temporal changes of juniper forest at the spatial resolution of 30 meters in Oklahoma, USA from the late 1980s to 2010. We generated high accuracy Sentinel-1/Landsat mangrove forest at the spatial resolution of 30 meters in East Asia in 2015. We used extensive field data from the Global Field Photo Library (http://www.eomf.ou.edu/photos/) to validate the robust of our proposed approaches and the high accuracy of our forest maps. These novel approaches are helpful for the advancement of global forest mapping and the various forest products are valuable for forest management, carbon emission reduction, and biodiversity conservation.

50. An Operational Remote Sensing Program for Conducting National Forest Health Surveys in the United States | W Monahan, F Krist, F Sapio*

The mission of Forest Health Protection (FHP), under the USDA Forest Service, is to protect, maintain, and enhance the health of America's forests. One of four major FHP program areas is Survey and Monitoring, which has primarily relied on trained observers collecting data in planes using sketch mapping software (Aerial Detection Survey, ADS). A new Operational

Remote Sensing (ORS) program led by FHP now uses a combination of imagery and auxiliary data to model, map, and attribute the causes of forest damage throughout most of the US. As a complement to ADS, this new form of survey is termed Satellite Detection Survey (SDS). SDS models include both supervised (mortality and conifer defoliation) and unsupervised (deciduous defoliation) classification techniques, using predictor variables from MODIS, Landsat, and Sentinel. Mapping of damage from the models entails additional steps to filter predictions by size, shape, and disturbance history, which eliminates most of the commission errors that arise from other non-target disturbances that share similar spectral signatures to damage caused by insects and disease. The final step of attribution uses over 20 years of historical ADS data to probabilistically identify the agent and host impacted. We first present our SDS methods, as well as how SDS builds on other aspects of the ORS program, and how SDS informs ADS in annual reporting. We then show and discuss results from SDS, based on a series of case studies. FHP successfully used SDS in 2017 to survey and map all mortality occurring from southern pine beetle throughout its range, as well as emerald ash borer mortality in the Midwestern US, Douglas-fir tussock moth defoliation and mortality in New Mexico, gypsy moth defoliation in the Northeastern US, bark beetle mortality in the Sierra Nevada of California, and spruce beetle in Alaska.

51. Three-dimensional Mapping of Forest Canopy Water Content using Dual-wavelength Terrestrial Laser Scanning | A Elsherif*, R Gaulton, J Mills

Satellite multispectral and hyperspectral remote sensing data are widely utilized in two-dimensional mapping of forest water content, quantified as the leaf equivalent water thickness (EWT). EWT can serve as a stress indicator and an early detector of wildfire risk and infection by pests and diseases. However, the estimation of EWT is affected by numerous factors. The satellite received signal is dominated by the reflectance from the canopy top, while most of the wildfires and many of the disease infections are believed to start in the bottom layers of the forest. The soil and understory vegetation also affect the satellite signal, especially in open canopy. In addition, the heterogeneity of the canopy structure and water content affect the light penetration and scattering within the canopy, and is usually ignored. On the other hand, Terrestrial Laser Scanning (TLS) instruments can overcome such limitations, as they record 3D intensity data of each scan. The intensity data can be linked to the scanned target's reflectance with proper calibration, opening the door to producing 3D estimates of EWT at leaf and canopy level. This study introduces a novel approach that combines the intensity data from two TLS wavelengths in a Normalized Difference Index (NDI) to generate 3D estimates of EWT at leaf and canopy level in a real forest environment. The wavelengths are 1550 nm shortwave infrared and 808 nm near infrared, employed in the commercially available Leica P40 and P20 TLS instruments respectively. NDI was found to be able to minimize the incidence angle and leaf internal structure effects without further calibration. A strong relationship was found between NDI and EWT at leaf level ($R2 = 0.94$). At canopy level, the average error in the EWT estimation in a broadleaf deciduous forest (Wytham Woods, UK) was found to be less than 7%. The approach has the potential to provide midday and predawn EWT estimates, to study the drying patterns of vegetation in high spatial and temporal resolution, to better understand the heterogeneity in biochemistry within forest canopies and to study and exclude the woody material influence on the EWT estimates.

52. Diurnal and seasonal cycles in leaf optical properties affect satellite-measured estimates of forest photosynthesis | M Mõttus*, R Hernández-Clemente, V Markiet

The spectral characteristics of plant leaves in the photosynthetically active region of the spectrum (between 400 and 700 nm) reflect their photosynthetic potential and the status of their photosynthetic apparatus. Changes in photosynthetic potential and status take place on very different time scales, from seconds (reversible changes in the xanthophyll cycle pigments) to months (composition of leaf pigment pools). These changes affect leaf spectral absorption and are frequently quantified using the Photochemical Reflectance Index (PRI) which is commonly used as one of the key tools enabling satellite-based tracking of photosynthetic activity. Most Earth observation satellites, including future instruments which will have the spectral capability to measure photosynthesis, are placed in near-polar orbits measuring the same geographical location at the same local solar time. We demonstrate that the seasonal cycles in the solar angle at measurement time created by this sampling scheme creates apparent variations in PRI which follow the photosynthetic activity of vegetation. To correct for this spurious correlation and account for changes in view geometry, we propose to use the fraction of sunlit foliage in the field of view of the sensor. The sunlit fraction can be easily calculated from the reflectance spectrum in the red edge, allows to untangle the spectral contributions of sunlit and shaded leaves and quantify the direct influence of solar irradiance on leaf reflectance spectrum around 530 nm. We further demonstrate that the explicit threedimensional structure of forest canopies uncouples the needle-level and canopy-level PRI daily courses. Using measurement data from two evergreen biomes, Amazon basin and European boreal forest that have different diurnal leaf PRI cycles, we demonstrate the necessity of understanding the relationship between incident photosynthetically active radiation and photosynthetic downregulation, and the daily PRI curve, for a correct interpretation of the instantaneous satellite-measured PRI value.

53. Mapping health status of chestnut forest stands using Sentinel-2 images | V. Chéret*, Y. Hamrouni, M. Goulard, J.P.

Denux, H. Poilvé, M. Chartier

In many parts of France, health status of chestnut forest stands is a crucial concern for forest managers. These stands are made vulnerable by numerous diseases and sometimes unadapted forestry practices. Moreover, since last years, they were submitted to several droughts. In Dordogne province, the economic stakes are important. About 2/3 of the chestnut forest area are below the optimal production level. The actual extent of chestnut forest decline remains still unknown. Sentinel-2 time series show an interesting potential to map declining stands over a wide area and to monitor their evolutions. This study aim to propose a method to discriminate healthy chestnut forest stands from the declining ones with several levels of withering intensity over the whole Dordogne province. The proposed method is the development of a statistical model integrating in a parsimonious manner several vegetation indices and biophysical parameters. The statistical approach is based on an ordered polytomous regression to which are applied various technics of models' selection. We aim to map 3 classes of predictive health status. In this study, Sentinel-2 images (10 bands at 10 and 20 m spatial resolution) acquired during the growing season of 2016 have been processed. Due to insufficient data quality related to atmospheric conditions, only 2 cloud-free images could be analyzed (one in July and one in September). About 36 vegetation indices were calculated from THEIA-MAJA L2A products and 5 biophysical parameters (Cover fraction of brown vegetation, Cover fraction of green vegetation, Fraction of Absorbed Photosynthetically Active Radiation, Green Leaf Area Index, Leaf water content) were processed from ESA level 1C product. These last parameters have been obtained with the Overland software (developed by Airbus DS Geo-Intelligence) by inverting a canopy reflectance model. This software couples the PROSPECT leaf model and the scattering by arbitrary inclined leaves (SAIL) canopy model. Calibration and validation of the predictive model are based on the health status of chestnut forest stands data survey. About 50 plots have been surveyed by foresters describing the chestnut trees health status by using two protocols (ARCHI and expert knowledge). Model stability over time and space will be further analyzed with Sentinel-2 time series during 2017 and 2018 on other different chestnut forest stands.

54. Investigation of spectral and structural changes in Pinus contorta plantations following red band needle blight infection | M Smigaj*, R Gaulton, S Barr, J Suarez

Climate change is having a significant effect on forest dynamics by altering the frequency and intensity of forest disturbances. In the case of forest insects and pathogens, impacts include damage to trees, growth loss and tree death. Monoculture plantations are particularly vulnerable to disturbance events as species uniformity makes such stands highly susceptible to pests and diseases. Red band needle blight is a disease that affects over 80 pine species worldwide in both natural and exotic forest locations. Historically, outbreaks have been sporadic, however, in recent years there has been an upsurge in its severity. Infection usually starts in the lower parts of the crown on older foliage and spreads upward. As red band needle blight infection is often only visible from aircraft in the advanced stages of the epidemic, the traditional infection detection method through aerial surveillance is ineffective. Remote sensing could serve as a more robust method to map the extent and severity of the disease.Current trends in research for detection of infections in forests almost exclusively involve the use of a single imaging technology. However, combining information from a range of sensors could potentially enhance the ability to diagnose and quantify the infection. The aim of this study was to investigate the potential of combining hyperspectral and LiDAR data for red band needle blight detection. The study location was the Loch Lomond and the Trossachs National Park, UK; two research plots were established in diseased Lodgepole pine stands with contrasting health statuses in terms of defoliation and the observed disease level. A comparative study was performed on the spectral signatures retrieved for each plot and on a range of LiDAR metrics retrieved at individual tree-level. A good separation was found between the more diseased and consequently more defoliated plot, and the healthier pine stand using a number of spectral indices. Similarly a distinction was found when intra-canopy distribution of LiDAR returns were analysed. Discriminant function analysis using leave-one-out cross-validation identified EVI, NGRDI, the number of ground returns within canopy extents, and median height to be the best predictors for detection of changes in the canopy resulting from defoliation induced by red band needle blight.

55. Method analysis for early detection of spruce vitality loss with remote sensing data | K Einzman, C Glas, C Atzberger, R Seitz, N Pinnel, M Immitzer*

Vitality loss of trees caused by extreme weather conditions, drought stress or insect infestations are expected to increase with ongoing climate change. For forestry it is important to detect vitality losses at an early stage to minimize ecological and economic damage. Remote sensing sensors have the potential to detect these changes over large areas down to the level of individual trees. The scope of our study is to detect such spectral changes at an early stage with hyperspectral and multispectral sensors. Two Norway spruce forest stands of different age and different maintenance were monitored over two vegetation periods in the field and using airborne/satellite sensors. Per test site 70 trees were artificially stressed (ring barking) and 70 trees were used as control trees. Data was collected multiple times and at different scales: (1) crown conditions were visually assessed using field observations, (2) needle reflectance spectra were acquired in the laboratory using a FieldSpec spectrometer, (3) hyperspectral airborne data (HySpex) were flown at 0.5 m spatial resolution, and (4) multispectral very high-resolution satellite data (WorldView-2) were acquired at 0.5 m spatial resolution. We aimed for a simultaneous data acquisition at the four levels.Using this unique data set, we investigate following research questions: 1) At which stage is it possible to differentiate weakened and healthy trees? 2) Do remote sensing sensors detect vitality changes before they are visible in the field?3) Which features are especially useful to detect vitality losses? 4) Is it possible to substitute experimental hyperspectral sensors (HySpex) with operational multispectral sensors (WorldView-2) – given the same spatial resolution?Several spectral transformations were applied to the needle and tree crown spectra, such as derivations, vegetation indices, angle indices, distance and similarity measures. All features were examined for their separability with Random Forest classification algorithm. The study revealed several key findings:1) the younger, well-maintained forest stand did only show minor changes over time2) for the older forest stand changes were observable both in the needle and in the hyperspectral tree crown spectra before changes were visible in the field3) the airborne hyperspectral sensor could detect minor reflectance changes of the trees4) the multispectral WorldView-2 data was not able to differentiate between stressed and control trees

56. Fagus sylvatica L. presence and recent dynamics in its Spanish southernmost limit characterized with spectro-phenological traits captured by Landsat intra-annual time series | C Gómez*, I Aulló-Maestro, P Alejandro, L Hernández, R Sánchez de Dios, H Sainz, F Montes

The Spanish Central Range hosts some of the southernmost populations of Fagus sylvatica L. (European beech) and there is no recent cartography of the species local distribution. Change in the use of land, biotic interactions, and short term climate oscillations are the drivers of these European beech populations' recent dynamics. The current distribution of beech in the Spanish Central Range was mapped based on its spectro-phenological distinctive traits shown by intra-annual series (June 2013-December 2017) of Landsat OLI/ETM+ images, and field verification over 208000 ha. The unique early opening of beech leaves in this area was captured by an 11th May 2015 image, and its high water content shown by stronger SWIR summer reflectance. Observations acquired DOY 12/132/172/268 of 2015 and complemented with a per-pixel compositing approach by 2013-2014 observations were classified with Support Vector Machine (SVM). Surface reflectance, Tasseled Cap Wetness (TCW) and Tasseled Cap Angle (TCA) were the input variables for classification. One-pixel samples (178) unevenly distributed among six vegetation types were identified on ancillary cartography and aerial photography. The SVM with Radial Basis Function kernel (ɣ 0.031, penalty 100) yielded best classification results, improved post-classification with DEM-derived information. During field campaign for verification in 2017 we established 116 plots measuring structural variables with ForeStereo, age, and ecological cohorts. The recent distribution dynamics (1984-2017) of beech in the area were explored with a dual approach: analysis of time-series of spectral values and classifications, and spatiotemporal geostatistics. We employed >500 images from the USGS and ESA archives, geometrically aligned with AROP and atmospherically corrected with LEDAPS. Temporal classifications were trained with samples which retrospective true character was confirmed by the age and basal area of current field measures. Geostatistical models ingested variables from our field data and data from 3 rotations of the National Forest Inventory, as well as TCW and TCA values. Compared with previous cartography (1978) our results show considerable densification of European beech dominant stands and some expansion gaining land to shrub formations and dominance over Quercus pyrenaica L. Landsat current data and its historical archive have made an important contribution to obtain insights of Fagus sylvatica L. dynamics in a Mediterranean area

57. Fusion of ALS and photogrammetric point cloud data in remote sensing of forest | A Kaasinen*, T Luostari, P Packalen, A Seppänen

The accuracy of point heights in the airborne image point cloud (IPC) is usually lower than the accuracy in airborne laser scanning (ALS) data, although IPC provide dense point clouds representing canopy surfaces. ALS data, on the other hand, is often less dense, due to high costs of acquiring dense ALS data. In this paper, we investigate the problem of fusing IPC data with ALS data. More specifically, the objective is to determine whether the inclusion of IPC data into low point density ALS data could allow improved detection of individual trees.We also introduce a new, computationally inexpensive method for estimating tree locations based on point cloud data without any kind of rasterization. First, we apply Gaussian kernel smoothing to the point cloud data, and approximate the topmost canopy/ground layer by a smooth function. Next, local maxima of the smooth function are sought, to localize the majority of the trees in the plot. Typically, the challenge in individual tree detection is to distinguish trees that are close to each other: in such cases, the shorter trees near taller trees may not yield local maxima in the canopy surface model, and consequently, they are often left undetected. In this paper, this problem is addressed utilizing prior information on the tree allometries - this complementary information enables recovering at least part of the trees that are undetected based on local maxima of the canopy surface only.The feasibility of the data fusion and the proposed tree detection approach is tested with ALS and IPC measurements from boreal forest and validated with field measurements. The analysis of the data shows that in a raw form, ALS and IPC data sets are not compatible due to differences, e.g., in the penetration depth of ALS and IPC points through the canopy. Furthermore, IPC data corresponding to shadowed areas in the photographs are shown to be unreliable. In this study, both of these aspects are accounted for when fusing ALS and IPC data. The results indicate that the proposed approach enables individual tree detection based on fused

ALSIPC data, and demonstrate the potential of the data fusion. Especially in cases where the density of the ALS data is low, the photogrammetric IPC data can offer complementary information, and improve the tree detection significantly.

58. Lidar collection methods compared through assessment and quantification of error in below-canopy forest structure characteristics in a fire-prone landscape. | J Donager*, T Sankey

In the southwestern United States, millions of hectares (ha) of ponderosa pine (Pinus ponderosa) forests are threatened by devastating wildfires and increased susceptibility to drought and insects. Land-use legacies created ideal conditions for seedling establishment, resulting in current tree densities beyond the carrying capacity of the system. A regional-scale restoration effort currently underway in northern Arizona, the Four Forest Restoration Initiative (4FRI), aims to treat up to 2.4 million acres over the next several decades by restoring forest structure (mechanical thinning) and ecological processes (controlled low-intensity surface fire). Post-management assessment and monitoring is rare and typically does not include below-canopy structural information, which can be directly used to estimate potential fire behavior.The goal of this study was to assess the accuracy and errors of estimated below-canopy forest structure derived from a 1) survey-grade terrestrial laser scanner (TLS) merged from multiple scan locations and a 2) mobile laser scanner (MLS) relative to a QL3 airborne lidar dataset (ALS). We compared these datasets to an existing field-collected data set among 32 0.1 ha plots, which collected tree locations, diameter at breast height (DBH) and height to crown (HTC) measurements among four forest treatment types (control, burn-only, thin-only, thin-and-burn). We used a within-cloud individual tree segmentation method and estimated tree characteristics from individually classified trees. We compared mis-segmentation of individual trees and errors in below-canopy structure estimates as a function of scanner type, overall tree density, and treatment type. We found tree density was equally well estimated among all three datasets in areas of thinned, low-density trees. However, in areas of high tree density, including non-thinned stands and dense patches, mobile lidar proved to provide the most accurate tree counts. Both DBH and HTC were poorly estimated from ALS and reasonably estimated from TLS. MLS provided the best estimates. Among all scanners, rates of error increased as tree density increased, but MLS had the smallest errors overall. These results show that a relatively simple MLS system and automated processing workflow can provide the most accurate estimates of below-canopy metrics. These findings are important for ongoing post-management monitoring efforts to assess the efficacy of forest treatments in reducing wildfire risk.

59. Classification of Tree Species and Oak Condition in a Mixed Broadleaf Forest Using Time Series of Hyperspatial Multispectral Unmanned Aerial System Imagery | J Iglhaut*, J Rosette

With changing climate and increasing globalization accelerating the spread and progression of pests and diseases the timely identification of declining forest condition is becoming increasingly important. Acute Oak Decline (AOD), a recently emerged disease in the UK, can cause tree mortality within a few years. Utilizing unmanned aerial systems (UAS) for the detection and monitoring the progression of such disease is highly attractive considering their potential for frequent and cost-effective deployment. Further UAS allow for acquisition of spatially continuous high-resolution imagery making it relevant for fine-scale analyses and increasing the usefulness in targeting forest management strategies.To explore the possibility of sensing AOD induced stress with UAS acquired remote sensing data a woodland where symptoms of the disease were newly identified was chosen as experimental site. The dense deciduous woodland is a natural reserve and features a rich species composition and high structural diversity. To investigate signals specific to oak species classification is hence undertaken. For this purpose hyperspatial imagery (<10cm) of the woodland's canopy was collected with a 5 band multispectral sensor as well as a RGB sensor on a PPK enabled fixed wing UAV. Structure-from-Motion photogrammetry is used as method to attain mapped coherent spectral and structural information. A reference dataset contains 348 position/class samples (24 oak with AOD symptoms obtained with a dGPS (Leica Zeno 20). For this ongoing work time series data from multi-temporal imagery acquired during the vegetative period serves as input for species classification. It is known that time-series allow for enhancing the phenological differences between species. Hence the best time frame and combination of acquisition dates to attain high accuracy classification results will be determined. Classification performance of common classification methods will be assessed at various scales. Variables derived from the spectral and structural information will be tested for their relevance. An initial classification trial based on summer and autumn 2017 imagery yielded an overall accuracy of 70% across 15 classes and 74% user accuracy for oak. For this early result the reference data was split in half for training and validation (stratified random sampling). Finalized results will be presented including spring imagery (to be collected early May 2018).

60. Processing PlanetScope time series images to detect post-fire regrowth | N Leach*, N Obrknezev

In recent years, the proliferation of small satellites for remote sensing has made it possible to monitor daily change with high resolution imagery. Planet is a San Francisco-based company operating a constellation of approximately 200 cubesats capable of acquiring sub-5 meter resolution imagery. This constellation, called PlanetScope, produces georeferenced 4-band multispectral imagery with daily global coverage. While the satellites in the constellation are radiometrically calibrated to one another, the deliberately inexpensive sensors have some radiometric variability and georeferencing errors. We have developed a method for processing big data sets of temporally-dense PlanetScope images, and for detecting both abrupt and gradual change in the time series. During processing each input image is compared to a reference image with well-established radiometry and spatial referencing. The spatial extent and resolution of this reference image may be different than the input images. Each image automatically processed individually, proceeding in three steps. First, tie points between the images are automatically generated, and the input image is rectified. Second, using multivariate alteration detection, no-change pixels are found between the input and reference images. Third, a regression model generates a linear transformation from the input image's radiometry to that of the reference image. This transformation creates an image with radiometry matching the reference image. Applying these steps to the full time series, we generate a set of rectified and radiometrically consistent images at high spatial resolution and with accurate georeferencing. This set of images is then input into change detection software. The temporal density of the images allows non-target change and noise to be filtered out. Sudden changes, such as forest fires, as well as gradual change, including post-burn regrowth, are then detected and recorded. Our study area was a region of the Alex Fraser Research Forest in British Columbia that was burned by wildfires in July 2017. Of the approximately 400 images intersecting the area of interest in the months before and after the fires, 50 scenes were chosen with low cloud cover and sufficient area coverage. Gradual change due to regrowth in burned areas was detected. This method could be a cost-effective tool for important change detection applications in forest monitoring, including burn scar mapping and understanding post-fire regrowth.

61. Establishing permanent large-scale forest dynamic plots of 100 ha at northeast China using UAV stereo imagery | W Ni*, Q Wang, D Zhang, Z Zhang, G Sun

1. ObjectivesStudies on large-scale forest dynamic plots have attracted much attention of forest ecologists over the last three decades. All trees within these plots are repeatedly surveyed to investigate forest compositions, structures and spatial and temporal dynamics. These plots could provide long term data on growth and change of trees, which is crucial for understanding of forest ecosystems and for conservation and management of forests. Large permanent sample plots are the only way to identify the causes of spatial and temporal variation of species diversity, density and distribution to monitor impacts of global climate change.Currently, the establishment of large-scale forest dynamic plots is based on the manual measurement of each tree in field. It is difficult to establish sufficient number of such kind of plots due to its labor and cost-intensive features. Besides, what could be accurately measured are the diameter at breast height (DBH) and tree species. Tree heights and crown size is difficult to be accurately measured on the ground. The unmanned aerial vehicle(UAV) is booming in recent years. The price of UAV such as the six or eight rotors drone is affordable. The stereo imagery acquired by off-the-shelf cameras onboard UAV could be used to make three-dimensional measurement of trees. There is a great chance to establish permanent large-scale forest dynamic plots from stereo imagery instead of manual measurements in field. This study will report our recent works on this topic. 2.Materials and methodsOur research was carried out at the Daxinganling forested area located at northeast China, which is one of the important Chinese timber bases over the past half century. Commercial logging has been forbidden by Chinese government since April 01,2014. Therefore, it is an ideal place to establish permanent large-scale forest dynamic plots. We have make experiments over more than 10 sites to build such kind of plots. According to our plan, about 150 - 200 plots will be established this year, which will be evenly scattered over the whole area of about 400 km * 700 km. The spatial coverage of each plot would be at least larger than 1.0 km * 1.0 km. 3. Summary of key findingsThe results of the established plots showed that the height, position, crown size, and species of each tree with sufficient size within each plot could be directly extracted from UAV stereo imagery. We would share details of our work on the conference.

62. A new approach to interpreting ICESat GLAS data for estimating canopy height in temperate woodlands in southwestern Australia | P Lee*, J Jeong

For measuring vegetation height using a satellite-borne laser sensor, Geoscience Laser Altimeter System (GLAS) is essential for conducting broad-scaled environmental and/or ecological research projects. Whereas various approaches to estimating vegetation height from GLAS data have been developed, most of them are not providing a simple and effective data processing procedure. Lack of generalised guidelines for GLAS metrics derived from the incomplete understanding of their characteristics may also cause more reliance on the use of other types of data. Therefore, this research aims to (i) validate vegetation height estimates from GLAS data through field measurements, and (ii) develop a methodology for consistently modelling canopy height directly from GLAS metrics. Vegetation height estimates were generated using a 'Centroid-Height model' which was designed for coping with the difference between the centre of the explicit ground pulse inferred ground surface height and the centre of the strongest pulse of vegetation areas considered as a canopy height. The modelled vegetation height estimates were examined using field measurements to rectify the errors derived from the difference between the estimates and the field measurements. Based on the result from the examination, modelled vegetation height was revised by the following major principles: (1) selecting modelled GLAS data which showed strong correlations with field measurements; and (2) deleting outliers verified by field measurements, and correcting errors of original GLAS data. A suite of processes were conducted comparing the GLAS data with field measurements. The accuracy of the model was compared with fresh field data. The most efficient rules for generating a GLAS data-based vegetation height model were empirically formulated. While some of the errors found in the GLAS data were rectified and some threshold values were defined, individual procedure was established as one of the refining rules. By applying the combination of the refining rules, a final model demonstrated a significant accuracy ($r2 = 0.7$). Such rules were defined as GLAS data refining rules for the best regression model of vegetation height. The comparison of field measurements with GLAS data was the most powerful and effective validating method. The Centroid-Height model with post hoc error correction was able to become a useful means of refining original GLAS data and providing a more accurate vegetation height. Acknowledgement This research was supported by a grant (18SIUE-B148326-01) from Satellite Information Utilization Center Establishment (SIUE) Program funded by Ministry of Land, Infrastructure and Transport of Korean government.

63. Estimation of growing stock volume of Scots pine stands using Sentinel-2 satellite imagery and airborne image-derived point clouds | P Hawryło*, P Wężyk

Estimation of forest stand parameters using remotely sensed data has considerable significance for sustainable forest management. Wide and free access to the collection of high resolution optical multispectral Sentinel-2 satellite imageries is very important in context of practical application of remote sensing technology in forestry. This study analysis the accuracy of Sentinel-2-based growing stock volume predictive models of single canopy layer Scots pine (Pinus sylvestris L.) stands and investigates whether Sentinel-2 data can improve the accuracy of models based on airborne image-derived point cloud data (IPC). A multiple linear regression (LM) and random forest (RF) methods were tested for generating predictive models. In general, the LM method provided more accurate models than RF. Model created only from Sentinel-2A image had low prediction accuracy characterized by high root mean square error (RMSE%) and low coefficient of determination (R2): RMSE%S2.LM = 35.14%, R2S2.LM = 0.24. Fusion of IPC data with Sentinel-2 reflectance values gave the most accurate model: RMSE%IPC.S2.LM = 16.95%; R2IPC.S2.LM = 0.82 but comparable accuracy was obtained in case of using the IPC-based model: RMSE%IPC.LM = 17.26%; R2IPC.LM = 0.81. The results show that for single canopy layer Scots pine dominated stands the incorporation of Sentinel-2 satellite imageries into IPC-based growing stock volume predictive models can slightly improve the model accuracy. However from operational point of view the relatively low increase in accuracy may be insufficient to justify additional utilization of Sentinel-2 data in this context.

64. Characterizing Stem Volume in Mangrove Forests Using Terrestrial Lidar Scanning | A Rouzbeh Kargar*, A Fafard, R MacKenzie, J Van Aardt

Terrestrial laser scanning (TLS) provides us with accurate 3D measurements of its surrounding area, allowing derivation of significant forest inventory traits. However, based on the density and forest properties, acquiring these attributes can be challenging. The goal of this work is to detect tree stems and estimate their mean volume in mangrove forest in Micronesia, after which the mean stem volume can be used as an input for modeling forest structure and biomass. Eight scans were collected for each of twenty plots using a TLS system (compact biomass lidar, or CBL). The first step was co-registering the plot-level scans with the pairwise registration and ICP (Iterative Closest Point) algorithm. ICP requires a good initial registration of the scans, making the pairwise registration a necessity. The mangrove forest has a dense and complicated structure, making the automatic estimation of the forest characteristics more difficult. The scenes used in this study contain roots aboveground, which can incorrectly be classified as stems in the lidar scans. We therefore used a Support Vector Machine (SVM) classifier to detect stems, by training a supporting SVM classifier on the roots derived from the scene. The initial stems and roots for the training set were detected by extracting the facets of the lidar point cloud in one plot and filtering based on the shape and angles of the stems and roots. Manual refinement was needed to increase the accuracy of the detection, given the intricate structure of this forest, e.g., removing noise/outlier points after filtering. Accuracy assessment shows that this classifier works well in forested areas with a high complexity. The accuracy for the stem detection was found to be 83%, while the precision was 74%. The accuracy and precision values for root classification were 76% and 69% respectively, i.e., lower than for the stem classification. This was attributed to the high diversity in root shapes. Another factor that decreased accuracy was the residual noise points after classification, which is unavoidable due to the dense structure of the mangrove forest. Finally, the stem components that were occluded from the laser scans were simulated using convex hulls. The mean volume of the stems then was obtained as 1.16m3, which needs to be verified via field reference data. A biomass model of this area will be presented at the conference. This approach can be used to calibrate synoptic air- and space-borne sensing biomass models.

65. Product generation for Calibration/Validation of the future NISAR mission biomass products | V Meyer*, S Saatchi, B Chapman

The NASA-ISRO Synthetic Aperture Radar (SAR), or NISAR, Mission is scheduled to launch in late 2021 and will make global measurements of land surface changes. One of its applications will be to capture forest volume and biomass over time. The NISAR project shall measure aboveground woody vegetation biomass annually at the hectare scale (1 ha) to an RMS accuracy of 20 Mg/ha for 80% of areas of biomass less than 100 Mg/ha. To achieve this science requirement, a calibration/

validation plan including pre-launch and post-launch activities is necessary. Cal/Val of the biomass algorithms is relying on biomass maps derived from field data and small-footprint Lidar data, which can be used as ground truth, as long as the uncertainty in biomass estimation is included in the propagation of errors (Xu et al, 2017). We present how to ensure that this uncertainty stays low by selecting sites where there are enough field plots (>20, depending on the plot size and site heterogeneity), where plots are large enough (>0.25ha, or less in homogeneous sites) and where the time difference between field data collection and Lidar data acquisition is small.Biomass algorithms are developed for 14 biomes, defined from a modified version of the WWF terrestrial ecoregions of the World (Olson et al., 2001). These biomes were chosen based on a preliminary analysis showing that the relationship between aboveground biomass and backscatter from ALOS was significantly different in each of them. A minimum of two sites per biome were selected for the pre-launch activities. A minimum of one site per biome will be used for post-launch activities.In each site, aboveground biomass (AGB) is estimated using allometric equations. Lidar data spanning a larger area covering the field plots is then being used to create Lidar-derived biomass models based on various Lidar height metrics such as Mean top Canopy Height (MCH) or other relative height metrics (rh25, rh50¦). In each site, the model with the smallest RMSE is used to produce a biomass map. The uncertainty relative to each of these maps is reported and used for error propagation. As the first step of the cal/val process, generating high quality Lidar-derived biomass maps is primordial to ensure that the remainder of the NISAR cal/val activities will be successful.

66. Accuracy of Plot-Level Forest Metrics from Terrestrial Photogrammetric Point Clouds | L Piermattei*, W Karel, D Wang, M Wieser, P Surový, J Tomaštík, M Mokroš, M Hollaus, N Pfeifer

Comprehensive and detailed information at the plot level about the state and dynamics of forests is essential for forest monitoring and management planning. Traditionally, plot-level information is collected by in-situ forest inventory methods. However, over the past fifteen years, Terrestrial Laser Scanning (TLS) has proven to be an increasingly practical option for providing detailed and accurate estimates of forest metrics from point clouds. Recently, terrestrial photogrammetric point clouds are rapidly gaining popularity in forestry as a low-cost, high quality alternative to TLS at the plot level. This study evaluates the applicability of terrestrial photogrammetry based on Structure from Motion (SfM) to model forests by means of consumer grade cameras. This investigation was conducted at six circular plots located in Austria, the Czech Republic and Slovakia, two in each country, in order to cover different conditions in terms of slope, forest density and age, undergrowth, and tree species. For each plot, we measured the diameters at breast height (DBH) with a calliper and the tree positions with the total station. The total station was also used to measure the photogrammetric and TLS targets. The photogrammetric targets were used as check points to estimate the accuracy of the photogrammetric reconstruction, or as ground control points for georeferencing the 3D model. Parallel to the photogrammetric acquisition, TLS data were collected for comparison purposes. We automatically derived tree positions, tree counts, DBHs and stem curves from both TLS and SfM for each plot using a software developed at TU Wien (FAIT, Forest Analysis and Inventory Tool), and we compared the results. For each plot, the images were oriented with errors of a few millimetres only, according to check point residuals. For all six plots, more than 90% of the trees where reconstructed from SfM data. All missing trees have diameters of less than 5 cm. Over all plots, the median difference of SfM and TLS DBH is 0.4 cm. The resulting stem curves show that the median difference of SfM and TLS stem diameters is 0.7 cm up to 3 m above ground and increases to 4 cm for higher elevations. This work shows clearly that terrestrial photogrammetry provides a cost-effective and high quality method to support forest management and monitoring at the plot level with accuracies comparable with those from TLS.

67. Forest Biomass Retrieval Studies from Coupled Models and Data Fusion | G Sun*, B Osmanoglu, AH Armstrong, KJ Ranson

Global remote sensing of forests is evolving rapidly from two-dimensional spatial analysis to three-dimensional analysis with the development of air- and space-borne LiDAR, radar, multi-angle and stereographic sensors. Lack of information on canopy vertical structure limits the capabilities of existing optical reflectance and radar systems for forest above-ground biomass mapping and leads to the saturation or large uncertainty when the biomass levels are high. The potential to improve forest biomass estimation from remote sensing data rests on the multi-sensor data fusion and model-based inversion. In this study, various forest stands, including mature forests disturbed by strip and shelterwood cuts, regeneration and plantation after clear cuts, which exist in our test site at Howland, Maine, were simulated by the spatially explicit version of SIBBORK individual-based gap model. These simulated stands were used as inputs to our 3D data backscatter model to simulate the polarimetric backscattering imagery for calculation of the backscatter intensity and the height of scattering phase center of L-band at HH, HV (VH) and VV polarizations. The same 3D structures of these simulated forest stands were also used as inputs to lidar wave form model and photon-counting lidar point cloud model to simulate GEDI- and ATLAS-like data for calculation of various waveform and point-cloud indices. The comparisons of simulated data with real SAR and lidar data will be presented. The preliminary results on biomass estimation from LUT inversion, and the potential of SAR/lidar data fusion for biomass mapping at high spatial resolution will be discussed.

68. Estimating Effective Leaf Area Index (eLAI) in Heterogeneous Riparian Forest-Buffers: ALS vs. SfM | LM Moskal*, T Axe

This study demonstrates and compares the estimation of effective leaf area index (eLAI) using two remote-sensing techniques: discrete-return Airborne Laser Scanning (ALS) and airborne Structure-from-Motion (SfM). The study examines riparian forest-buffers in the Mashel River watershed in Washington State which was chosen for both its hydrologically complex landscape and its range of riparian forest types. This study utilizes data from 113 forest-plots. Photos were taken at each plot with a hemispherical camera and were the source of eLAI reference-values. Other forest mensuration captured tree characteristics and size. These reference data were first compared to the output of ALS analysis, which replicated several models used in similar studies. These results showed that the penetration rate of Lidar first returns was strongly related to eLAI even when keeping the elevation threshold of penetration consistent with the actual height of the field camera. Models that tested light attenuation variations in accordance with of the Beer-Lambert law saw similar results. However, these were more limited due to the complexity of leaf angle distribution, canopy structure, and terrain. The reference data was then compared to SfM output, which utilized the point cloud of a digital surface model (DSM), rendered from airborne photography. A multivariate linear regression showed promise in estimating eLAI, by utilizing the distribution elevation values of upper-canopy point returns and the elevation values representing mid and max stand-level totals for each observation's respective point cloud. A spectral analysis yielded a second-order statistics grey-level co-occurrence matrix (GLCM) entropy: adding this variable further improved the regression results. SfM performed less well in the Beer-Lambert approach because of the relative lack of appropriate ground points, even when altering the elevation of the penetration threshold.

69. Assessment of sustainable forest management of a mixed conifer-broadleaf forest by combinations of airborne Lidar and UAV observation | N Furuya*, Y Hirata, T Owari, D Sakaue, S Inukai, Y Nakagawa, M Tokuni

Background.To achieve a sustainable wood production from natural forests, assessment of forest resources and conditions is more important than in tree plantation. It is important to monitor forest resources to set an allowable amount of harvesting and to preserve young trees of next generations. Various sizes and kinds of trees exist in a mixed conifer-broadleaf forest. In the shortage of human resources and budgets for field data collection, an efficient monitoring scheme using remote sensing is highly expected. A Lidar observation is expected to extract complex forest structure and a flexible and close-up observation by unmanned aerial vehicle (UAV) is expected to monitor seasonality and healthiness of trees in a mixed conifer-broadleaf forest. The objective of this study is 1. to develop a methodology to estimate forest resources of a mixed conifer-broadleaf forest at large area by airborne lidar and 2. to develop a methodology to evaluate forest diversity and healthiness at stand level by UAV observation.Materials and Method.The study area was a managed mixed conifer-broadleaf forest, a part of the University of Tokyo Hokkaido Forest, where sustainable forest management activities are continuously practiced. It is located in the central part of Hokkaido in northern Japan.Lidar observation was conducted in September 2017 with an Optec Orion M300. Mean point density was 16.1 points/m2. Multiple UAV observations were conducted with a normal X5 camera and a RedEdge multispectral camera. Ground measurement at Permanent sampling plot was utilized as field reference data.Summary of results.Canopy height measurement and separation of conifer-broadleaf tree by Lidar with combination of aerial photograph could be utilized for forest resource estimation. Based on simulation of DTM and DSM observation by lidar, a precision estimation of DTM by digital surface model from UAV or aerial photograph observation at leaf-on season could be expected at the managed natural forest stand. Multiple UAV observation enabled individual tree identification and main tree species discrimination. Multispectral observation could identify the healthiness of individual tree such as defoliation at tree top position.

70. Mapping forest structure of Afromontane forest remnants by airborne laser scanning | H Adhikari, J Heiskanen, R Valbuena, P Pellikka

The tropical montane forests are important reservoirs of carbon and biodiversity threatened and fragmented by land use change. The montane forests capture moisture and store precipitation on the hilltops, and hence have central role in the hydrological cycle. However, depending on the topographic position and degree of degradation, the extant montane forests remnants can have considerable differences in forest structure. This work aimed: (1) to analyze how well forest structural heterogeneity, described by Gini-coefficient of tree size inequality, can be predicted by two airborne laser scanning (ALS) data sets acquired from different altitudes and by two different sensors; (2) to study if prediction models are improved by including tree species sensitive seasonal metrics based on Landsat time series; (3) to generate Gini-coefficient maps showing differences between the three forest remnants and different forest types. The study area was located in the Taita Hills, in the northernmost part of the Eastern Arc Mountains of Kenya and Tanzania. The highest hilltops reach over 2,200 m in elevation. Most of the forest area has been cleared for croplands and agroforestry, and remnant forest are the patches of indigenous and plantation forest. The field measurements were carried out in a total of 85 circular 0.1 ha sample plots in 2013–2015, and ALS flights were conducted in 2013 (9.6 pulses m^{-2}) and 2014–2015 (3.1 pulses m^{-2}). We observed that Gini-coefficient was predicted more accurately by using ALS data set with higher point density. Furthermore, the models were improved when including additional Landsat seasonal metrics. Gini coefficient maps at 30 m x 30 m resolution were predicted using beta regression (cross-validated pseudo R2 0.587 and RMSE 0.065). The mean Gini-coefficients for indigenous forests in Ngangao, Yale and Vuria, 0.55, 0.48 and 0.46 respectively, show that tropical montane forest remnants have high degrees of structural heterogeneity. The single species plantation forests (Cypress, Pine, Eucalyptus and Acacia) of the same forest remnants showed less variation in Gini-coefficient (0.44, 0.46, and 0.46, respectively). The results demonstrate feasibility of ALS data for mapping forest structure of different forest within Afromontane forest remnants.

71. Comparing Sentinel-2 and Landsat 8 for detecting the invasive shrub species Ulex europaeus in South-Central Chile by using VHR UAV orthoimages | T Schmidt*, M Förster, A Clasen, F Fassnacht, B Kleinschmit

Central Chile has been declared a global biodiversity hotspot with a high proportion of endemic species. However, due to dramatic changes in land use, this region is also one of the most threatened ecosystems in the world. A further threat that goes hand in hand with the land use changes are the invasion of exotic species, which are considered a major factor for the global decline in biodiversity (CBD). One of the most prominent invaders in South-Central Chile is Ulex europaeus L. for which up-to-date maps are urgently needed to control mitigation measures and for an improved understanding of the invasion dynamics. In this study we analyze the potential of two new and promising satellite missions (Sentinel-2 & Landsat 8) to monitor the Ulex cover fraction on the Isla Chiloe in South-Central Chile.Four atmospherically and geometrically corrected image pairs (one per season) of Sentinel-2 (20m) and Landsat 8 (30m) from the years 2015 and 2016 were used. In addition, we utilized ten UAV (unmanned aerial vehicle) RGB-orthoimages from November 2016 as reference data. Based on the UAV images, the Ulex cover fractions were visually determined for 180 randomly selected sensor pixels. A spatial optimization approach was used to take into account the spatial offset between the UAV orthoimages and the two satellite data sets. During this optimization, the UAV orthoimages were systematically shifted in relation to the fixed satellite images to find the optimal reference data set (Ulex cover fraction). A random forest model was used to find the lowest RMSE value per UAV image. Once the optimal reference data sets were determined, they were used in a final random forest model to predict the Ulex cover fraction for the entire study area. In addition, we have used a semi-exhaustive search algorithm to determine the optimal acquisition dates for the satellite data and the most valuable spectral bands.Overall, Sentinel-2 (RMSE: 14.68; R^2: 0.7) outperformed Landsat 8 (RMSE: 18.8; R^2: 0.5) for estimating Ulex cover fractions. Due to the higher spectral (9 bands vs. 7 bands) and spatial resolution (20m vs. 30m) of Sentinel-2, different stages of Ulex cover fraction can be observed more accurately than with Landsat 8. For both sensors, the spring scene was the most important one to distinguish Ulex from the surrounding vegetation. The most valuable spectral bands were Red, Vegetation Red-Edge-2 & 3 and SWIR2 for Sentinel-2 and Green and Red for Landsat 8.

72. Individual Tree Mapping from LiDAR point clouds based on topological tools | X Xu*, F Luricich, L De Floriani

Light Detection and Ranging (Lidar) can generate precise three-dimensional (3D) point clouds of forests and has demonstrated possibilities for forest inventory at the individual-tree level. In this work we consider the problem of characterize the 3D structure of individual trees directly extracting it from the point cloud. Most state-of-the-art approaches for individual tree segmentation either require bundles of parameters or they are designed and tuned for specific typeS of forests. The aim of this study is the definition of a new method, based on topological tools, which is general and parameter-free.Firstly, we infer a structure to the points cloud by computing the Alpha shape on the entire dataset to outline the shape of forest points which is controlled by one parameter alpha A. In our method the A is automatically learned based on the density of points and the Alpha shape is generated using efficient data structures.Then a method rooted in computational topology, namely discrete Morse theory, is used for identifying individual trees within the Alpha shape. Discrete Morse theory defines a way to study a shape based on its critical points (CPs). Like by assigning to each vertex of a dataset its height function F. We obtain a set of CPs of F highlighting distinctive structures in the forest. Minima show points at the base of the forest (bases of each trunk), and saddles correspond to points where two crowns are overlapping and merging. Such information are computed efficiently by defining a discrete vector field, a combinatorial representation showing the connections among CPs. These connected CPs are called persistence features (PFs), which are further divided into two groups.Low PFs are minima connected to saddles at close distance according to F. These identify the uninteresting features like small branches merging into the main trunk.High PFs are pairs of minima and saddles posed at larger distance. These describe relevant features like two trees that partially overlap.Based on the persistence features we define an efficient algorithm for splitting Alpha Shapes into clusters of points. For each obtained cluster we delineate the crown and the trunk of each tree for computing additional measurements of trees like height, etc. The performances of our approach are demonstrated on datasets of different types (tropical rainforest, temperate deciduous/coniferous forest) and compared to state-of-the-art approaches set for certain forest type.

73. Non-supervised individual trees segmentation of LiDAR data in Amazonian forests with variable population densities | DDA Papa*, PHK Millikan, TH Abib, SDP Chaves e Carvalho, LCE Rodriguez

Legal logging in the Brazilian Amazon imposes low impact harvest operations extraction and is usually capped by a maximum extraction rate of 30 m3 per hectare. A very expensive census of all trees above 50 cm of DBH is required in the process. The use of airborne LiDAR and individual tree detection (ITD) algorithms to locate the most profitable trees can reduce the fieldwork. The work explores the use non-supervised ITD algorithms based on canopy height model(CHM) segmentation techniques, to (i) automatically detect dominant trees and (ii) to map yield variations over a gradient of different densities of trees per hectare. The study was developed on a large stand of natural Amazonian forest in Brazil, characterized by the endemism of palms, lianas, bamboos and large trees with variable crown heights. Field data include a tally of all trees with diameter at breast height (DBH;1.30 m) ≥ 50 cm; one airborne laser scanning (ALS) assessment flown close to the dates of the inventory measurements that involved a total of 723 sample plots distributed along a regular grid of 100 x 100 meters. The sample plots were grouped according to population density classes: 0 to 15 (g1), 16 to 20 (g2), 21 to 25 (g3) and > 25 trees per hectare (g4). Two different automatic tree detection methods (watershed and Dalponte) were tested using cell sizes of one m2 to generate canopy height models. The watershed method simulates an immersion of the standing forest in water to create a surface model. As a result, dams are formed corresponding to tree crowns. Dalponte's method uses local maxima for search windows sized 3x3 m to smooth the CHM and to apply a 2D convex hull algorithm. The number of commercial trees identified by the conventional fieldwork and the number estimated by the algorithms were statistically compared to each population class. The number of trees segmented by each method differed significantly between the classes. On average, 60% of the mapped trees could be identified by the detection algorithm in the four groups. As expected, tree crowns were easier to identify in plots with open canopy and low population densities, reaching 75% of accuracy. Plots with higher densities and closed canopies resulted in lower precision levels. More adjustments in the thresholds used for the specific parameters of each algorithm are still needed to get more definitive results. Some interesting trends, though, are presented which indicate how these adjustments should be made.

74. Detection of dead standing Eucalyptus camaldulensis without tree delineation for managing biodiversity in native Australian forest | M Miltiadou*, ND Campbell, S Gonzalez Aracil, T Brown, M Grant

In Australia, many birds and arboreal animals use hollows for shelters, but studies predict shortage of hollows in near future. Aged dead trees are more likely to contain hollows and therefore automated detection of them plays a substantial role in preserving biodiversity and consequently maintaining a resilient ecosystem. For this purpose full-waveform LiDAR data were acquired from a native Eucalypt forest in Southern Australia. The structure of the forest significantly varies in terms of trunk density, age and height. Additionally, Eucalyptus camaldulensis have multiple trunk splits making tree delineation very challenging. For that reason, this study investigates automated detection of dead standing Eucalyptus camaldulensis without tree delineation.The open source software DASOS, developed by the authors of this abstract, is also presented. DASOS was developed to ease the usage of full-waveform LiDAR data. It creates a discrete volumetric representation of the data for deriving information about the scanned area. This representation is resistant to noise related to the uneven footprint density of the emitted pulses. DASOS has three features; 3D polygonal meshes generation, 2D metrics aligned with hyperspectral imagery and 3D features extraction for object-level classifications. This study uses the 3rd feature of DASOS to extract 3D features characterizing dead trees. Afterwards, a random forest classifier, a weighted-distance KNN algorithm and a seed growth algorithm are used to create a 2D probabilistic field and to predict potential positions of dead trees. It is shown that tree health assessment is possible without tree delineation but since it is a new research direction there are many improvements to be made.

75. Reuse of historical data in forest inventory | AM de Lera Garrido*, HO Ørka, T Gobakken

Airborne laser scanning (ALS) assisted forest inventories have become common practice in the past decade in many countries. One of the major cost components in these inventories are the field measurements of sample plot data used for calibrating the biophysical forest characteristics. In order to cut the costs of the inventories, previously collected data can be reused and thus reducing the collection costs of new data. The aim of the study is to assess the potential information still inherent in the historical data and find an optimal use of it in the estimation of the current state of biophysical forest characteristics. This study is based on ground reference and ALS datasets from two points in time (2001 and 2016) from the Krødsherad municipality, southeastern Norway. The considered biophysical forest characteristics were mean tree height, dominant height, stem number, basal area, stem volume, and aboveground biomass. The area was divided in three different strata according to age class and dominant species. Two methods were evaluated (1) Create new regression models for each stratum based on field sample plot data from 2001 and apply and validate them for the 2016 data. (2) Create a total new ALS assisted inventory relying on entirely new data from 2016. For all the biophysical forest characteristics, the differences between predicted and ground reference data from the validation plots were assessed.The results show that the predictions in both methods, are considerably accurate with similar results for heights. However, the differences are more pronounced on the young forest compared to the other two mature strata.

76. Potential of modern photogrammetry versus airborne laser scanning for estimating forest variables in a mountain environment | S Ullah*, M Dees, P Datta, P Adler, B Koch

Airborne laser scanning (ALS) data is known as to be the most accurate and primary source for estimating forest variables. However, in many countries, ALS data is not regularly updated as needed for continuous forest management due to its high cost. In contrast to ALS, digital stereo aerial photographs are periodically updated in many countries and offer a viable option for the regular update of information about forest variables. In this study, we compared the potential of image-based point clouds derived from three different sets of aerial photographs i.e. high overlapping pan-sharpened (80/60%), the high overlapping panchromatic band (80/60%), and standard overlapping pan-sharpened stereo aerial photographs (60/30%) versus ALS 3D point clouds for estimating plot-level forest attribute in a mountain environment. We used plot level height and density metrics derived from image-based and ALS point clouds as explanatory variables and Lorey's mean height, timber volume and mean basal area as response variables. We obtained RMSE = 8.83%, 29.24% and 35.12% for Lorey's mean height, volume and basal area using ALS data. Similarly, we obtained RMSE = 9.96%, 31.13%, 35.99% and RMSE = 11.28%, 31.01%, 35.66% for Lorey's mean height, volume and basal area using image-based point clouds derived from pan-sharpened stereo aerial photographs with 80/60%, and 60/20% overlapping respectively. For image-based point clouds derived from a panchromatic band of stereo aerial photographs (80%/60%), we obtained an RMSE = 10.04%, 31.19% and 35.86% for Lorey's mean height, volume and basal area. The overall findings indicated that image-based point clouds in the presence of pre-existing ALS-derived digital surface model (DTM) has significant potential and offer a viable option for operational forest management in all those countries where stereo aerial photographs are updated on a routine basis.

77. Forest Field Inventories Through Terrestrial Point Cloud: Status And Outlook | X Liang*, J Hyyppä, X Yu, Y Wang

Forest inventories are mostly based and depended on field samples. Conventional forest plot inventories are through tree-by-tree manual measurements which are labor-intensive and time-consuming. Lately, terrestrial point clouds (PC), i.e., from laser scanning, structure light, and structure from motion from terrestrial, mobile, and UAV platforms, have shown the potential to improve the accuracy and efficiency of field inventories. The major advantage of using terrestrial PC in forest inventories lies in its capability to document the forest automatically, which enriches both professional and non-professional users' capacity of understanding the forests and standing trees and, thus, leading to more sustainable development in silviculture and savings for forest owners and industry.Tremendous efforts have been put into research in the last two decades to develop methods in estimating tree attributes utilizing terrestrial PC for forest inventories. It was expected that the terrestrial PC can improve the knowledge of the field samples with high-quality tree attributes that are important but are not directly measureable in conventional forest inventories, such as the 3D profile of the stems. The actual performance of the terrestrial PC-based plot-level inventory is, however, hampered by the completeness of the 3D forest digitization and the capability of the automated feature extraction methodologies. This work presents a thorough evaluation on the status quo of terrestrial PC-based plot-level forest inventories. The study includes PC collected from stationary, mobile, and UAV platforms utilizing laser scanning (LS) systems and digital cameras. Through benchmarking of different datasets and different algorithms, the strengths and weaknesses of different platforms and sensors are analyzed, the performance of typical algorithms for estimating crucial tree attributes, e.g., tree location, tree height, DBH, stem curve, are evaluated, thus, the capability and the incapability of recent data sources and algorithms are clarified. Consider the gaps between the expectations and the reality of terrestrial PC based forest field inventory, outlooks are given from both the perspectives of system improvement and algorithm development.

78. The accuracy of direct lidar-based estimation of forest canopy cover | L Korhonen*, P Packalen, I Korpela

Forest canopy cover (CC) is commonly estimated from the fraction of laser pulses intercepted by the canopy. This variable is called first-echo cover index (FCI) and can be calculated as the fraction of laser pulses that have echoes ≥1.3 m above ground level. Earlier research in Finland showed that in a direct comparison with field-measured CC, FCI had only a small (3.1-4.6 percent points) systematic overestimation, as long as the scan angle was ≤15°. We report results from five new comparisons made in Finland using lidar data sets collected 2010-2016 with scanners operating at 1064 nm wavelength. Three of the new comparisons showed that the CC was overestimated similar to the earlier experiments (3.1-5.0%), but in two scans the overestimation was considerably larger (17.2-18.4%). The outlier scans were obtained from the same area using a Leica ALS 70 high-altitude scanner from altitudes of 2000 m and 3000 m with receiver gain set to maximum. Looking at pulses with canopy echoes at the sample plots, these acquisitions showed a considerably smaller fraction of single canopy echoes (8.6-11.1%) than the other three acquisitions (29.4-62.5%) or the old acquisitions reported earlier (46.3-56.1%). This observation indicates that the scanner used in the outlier acquisitions was considerably more sensitive to register multiple echoes per pulse than any of the others. Thus, the ratio of single vs. first-of-many canopy echoes could be used to identify data sets where direct estimation of CC from FCI might be unreliable.

79. Calibration of nationwide airborne laser scanning based stem volume models | E Kotivuori*, M Maltamo, L

Korhonen, P Packalen

In-situ field measurements of sample plots are a major cost component in airborne laser scanning (ALS) based forest inventories. Field measurements on new inventory areas can be reduced by utilizing existing stand attribute models from former inventory areas. However, large mean differences (MD) could occur at the inventory area level. The main objective of this study was to examine and minimize the regional and environmental effects on a nationwide stem volume prediction. We constructed a nationwide model for stem volume, and examined seven different calibration scenarios using sample plots from 22 inventory areas distributed evenly throughout Finland. Calibration scenarios were divided into three main categories: 1) calibration with additional predictor variables, 2) calibration with 200 geographically nearest sample plots, and 3) calibration with MS-NFI (Multi-source National Forest Inventory of Finland) volume at the target inventory area. Information of geographical location, site properties, climate, spectral and tree species composition were utilized as additional variables. Nearest sample plots were choose based on pure distance based approach, and considering influence of the forest vegetation sub-zones. MS-NFI based calibration was conducted using medians of MS-NFI predictions, eliminating also the loggings and other possible error sources. Calibration with degree days, precipitation, and proportion of birch resulted in the greatest decrease in error rate of stem volume predictions. The mean of the root mean square errors (RMSE) among the 22 inventory areas decreased from 28.6% to 25.9%, and the standard deviation of RMSEs from 4.3% to 3.9% using three additional predictor variables. Correspondingly, the mean and standard deviation of absolute values of mean differences (|MD|) decreased from 8.3% to 5.6% and from 5.6% to 4.4%, respectively. MS-NFI based calibration was also a reasonable option, especially if loggings and other inconsistencies between datasets could be detected and accounted for. Calibration with sample plots from geographically nearest inventory areas was useful when there were sample plots that offered a good representation of the target area, e.g. when sample plots were from the same vegetation sub-zone. All calibration scenarios decreased the error rate, especially the high |MDs| observed in the northern part of Finland.The study was recently published in Remote Sensing of Environment.DOI: 10.1016/j.rse.2018.02.069.

80. Predicting species-specific diameter distributions using a nearest neighbor imputation with various configurations - The effect of different ALS data | J Räty*, P Packalen, M Maltamo

This study considers the predictions of species-specific diameter distributions by means of airborne laser scanning (ALS) data and aerial images. This study is a sequel to the study of Räty et al. (2018) in which the main objective was to investigate different configurations in nearest neighbor (NN) imputation and to determine how changes in configurations affect to error rates of timber assortment (TA) volumes. According to the results, a couple of configurations was recommended to be used in the prediction of species-specific diameter distributions. Here we investigate the usability of the recommended configurations when the ALS data varies. In the original study, leaf-off data were employed as predictor variables. Here, we employ metrics derived from multispectral and unispectral leaf-on ALS data.The forest structure of the study area (43 000 ha) can be regarded as a typical managed Finnish forest that principally comprises of three main tree species: Scotch pine, Norway spruce and silver birch. Altogether 424 circular plots with fixed radius were distributed over the inventory area by means of a systematic sampling design. From leaf-on ALS, the height related metrics and echo intensity metrics were computed for the field plots. Moreover, spectral information from aerial images were computed for the field plots. The NN imputation was used as a modelling method and was applied in two different ways; (1) diameter distributions were predicted at the same time for all tree species by simultaneous NN imputation, and (2) diameter distributions were predicted for one tree species at a time by separate NN imputation. The performance assessments of the diameter distributions were implemented by means of the RMSE and the mean difference of species-specific TA volumes.Comparing our results to the original study implemented with leaf-off ALS and identical response configurations (Räty et al. 2018), the improvements attained in the prediction error rates of TA volumes were not as unambiguous as with leaf-off ALS. The results showed that the configuration tested with simultaneous NN imputation may not improve the error rates of TA volumes when leaf-on data is applied. However, the most successful results were achieved by separate NN imputation by tree species. According to the study, it can be stated that the leaf conditions of the ALS data seem to have an effect on the selection of response configurations, especially when simultaneous NN imputation is applied.

81. Large Area Vegetation Mapping Using NASA's LVIS Facility | M Hofton*, JB Blair, D Rabine

NASA's Land Vegetation and Ice Sensor (LVIS) has a proven heritage of providing wide-swath, precise and accurate waveform-based laser altimetry (lidar) measurements of vegetation heights and structure from medium-high altitude airborne platforms. In 2017, the system began operating as a NASA Facility with the goal of providing low cost, large area topography and 3-D surface structure measurements to NASA investigators and programs. Various data collection modes are possible, typically matched to the science goals of the investigation. In the nominal mode, lidar data are collected within a 2km-wide swath using 7m-wide footprints that are contiguous along and across track. LVIS is a waveform-based laser system, recording the shape of the transmitted and reflected waveforms. Information in the waveforms are used to precisely-geolocate multiple reflecting surfaces in each laser footprint. Standard LVIS data products available for every footprint are the

Level 1B geolocated waveform vector product and the Level 2 surface elevation, height (e.g., canopy top) and relative height product. Data products are distributed from NASA's National Snow and Ice Data Center (NSIDC) and the LVIS website. Most recently, 70,000 km^2 of data were collected for NASA's ABoVE and Operation IceBridge campaigns in 2017. Example data products will be shown as well as information on how investigators can request flights and data. LVIS is the airborne simulator for NASA's GEDI mission, scheduled for in November 2018 to the International Space Station.

82. Assessing the effects of multispectral aerial lidar viewing geometry on 3D and intensity features used for tree species identification | BC Budei*, B St-Onge

Tree species identification is important in forest management. The multispectral lidar Titan of Teledyne Optech Inc., with three integrated lasers scanning with different wavelengths (532, 1064 and 1500 nm) and different scan angles (7, 0 and 3.5 degrees), can improve tree species separation by providing classification features computed from the three-channel intensities, ratios and normalized differences. However, the value of features used in classification algorithms (e.g., random forest, RF) may vary with scan angle, which affects both incidence angle and range. The focus of the present study is to test if there is any significant influence of scan angle on the 3D and intensity features and if this relationship may affect the species classification accuracy. In a study region located in Ontario, Canada, six needleleaf species were sampled to train classifiers. Classification features included 3D features (e.g., slope of the crown), absolute intensity features (e.g., crownwise median of the range-normalized intensities in the 532, 1064 and 1500 nm channels), and three normalized difference index features. Returns with scan angles of ± 14 degrees were considered in feature calculation. For each tree, several versions of the same feature were computed from all different point clouds extracted from a single flight line - single channel dataset. These point clouds had different characteristics, as they were scanned with different scan angles and saw different parts of the same tree. We assessed the variation of the feature values with scan angle. Tests were reproduced for entire tree dataset, and also by species, for 3 tree height class and for combinations of species and tree height. Generally, increasing the angle generates an increase in feature value variability. 3D features were affected by changing return distribution in the crown, shifted to the upper crown. The features most affected by scan angles were those that characterize tree crown shape or those that are based on ratios of return numbers (e.g. #single returns / #1st returns). Normalization of return intensity according to range manages to reduce feature variability with scan angle. Features as channel ratios or normalized indexes were less influenced by scan angle and normalization produced only minor changes to their values. A slight increase in intensity with scan angle was seen, probably explained by the return distribution in the crown.

83. Feature standardization across areas of interest to optimize field sampling for individual tree species classification | P Rana, B St-Onge*, J Prieur, BC Budei

Species classification is a cornerstone in decision-making for environmental conservation as well as for many scientific, and management activities for forest managers. The goal of this research was to explore standardization approaches for airborne laser scanning (ALS) feature values (classification metrics). Standardization approaches could help to reduce the field sampling required for such classification across different areas of interest (AOI). Earlier studies revealed that tree species were classified with moderate to high accuracy using AOI specific random forest models and ALS data. Classification accuracy varies AOI to AOI, and model to model. However, field sampling and model development for each AOI still represent significant costs and time. This raises questions about ways to improve on this situation. First, do feature values for the same species deviate between AOIs within a same ecological region, and is this variation different for 3D and intensity features? Second, can we train a classifier using samples of a given AOI and apply it to another? Third, can we train a classifier from a sample composed of trees from different AOIs (defined as a global sample)? To answer above questions, we extracted both 3D and intensity features from multispectral and monospectral ALS data to identify trees. We standardized the feature values across three AOIs to minimize sampling needs and resolve classification issues. Three feature standardization approaches were employed: histogram matching, median based standardization, and linear regression based standardization. The improvements brought about by these methods were assessed through the Bhattacharyya distance (before vs. after standardization). The effects of standardization were also evaluated by analyzing the changes in the classification errors of random forest models (i.e. out-of-bag (OOB) error) for 11 tree species. The Bhattacharyya distance was reduced by between 17% to 27% for 3D features, and between 21% to 91% for intensity features. Training a random forest classifier using a sample from one AOI allowed OOB decrease of 14-21% when applied to other AOI after standardization. An OOB decrease after standardization of 4-20% was obtained when using a global sample. Our study reveals the prospect and challenges of different feature standardization methods for multispectral/monospectral ALS sensor to reduce field sampling at new AOIs while maintaining a good accuracy.

84. Evaluation of a method for yield forecasting produced using LiDAR derived forest data and harvester data | J Söderberg*, JJ Möller, E Willén

Yield forecasts are used to predict volumes of wood products, mainly timber and pulpwood, that will be produced in planned harvesting operations. This is important information for forest companies when planning logging activities, since inaccurate forecasts make it difficult to fill the forest industry's requirements for timber and pulpwood. There is a strong relation between forest parameters and product outcomes, so a detailed description of the forest is necessary for accurate yield forecasts. Airborne laser scanning (ALS) has proven to be an effective way to map large forest areas in detail. The project aims to increase the precision in yield forecasts by utilizing harvest planning information, ALS derived forest parameters and harvester data from regional Cut-To-Length (CTL) harvester operations.The detailed measurements of each processed log recorded by the harvester was used to reconstruct harvested trees. By segmenting harvester data into smaller areas of roughly 0.8 hectares based on tree heights and positions, homogenous reference units (RU) were created. Forest parameters were calculated for each RU from the reconstructed trees. Harvester data covering 400 km2 was collected from several large forest companies, resulting in over 50,000 RU's. To get a local reference dataset, the 1,000 RU's closest to the prediction site was pre-selected. Imputation with kMSN was used to predict yield outcomes with basal area, Lorey's mean height, basal area weighted mean diameter and species distribution as predictor variables. The yield forecasts were calculated from the mean yield volumes of the five most similar RU's. The method was evaluated through a validation study (VS) predicting yield outcome for 2,000 stratified and randomly selected RU's and an operational study (OS) predicting yield volumes using ALS forest data for 13 planned logging sites in southeastern Sweden.The results show that the total yield volume was estimated with a root mean square error (RMSE) of 12.3 (6%) and 21.2 m3sub/ha (7%) for VS and OS respectively. Bias was 0% for VS and -4% for OS, mainly due to dated ALS forest data. The method shows good results compared to traditional yield forecasts. This is probably due to accurate description of the local stem shapes, stem defect volumes and the impact of local bucking patterns, which are generally lacking in other methods. Imputation of local CTL-harvester data should reduce bias and variation in product yield forecasts.

85. The Integration of UAV and Backpack Lidar Systems for Forest Inventory | Y Su*, T Hu, H Guan, J Liu, Q Guo

Light detection and ranging (Lidar) has been demonstrated with strong capability in capturing three-dimensional (3D) forest structures. The reducing cost and weight of lidar sensors and the development of positioning systems make light-weighted near-surface lidar platforms, such as unmanned aerial vehicle (UAV) and backpack, become possible. These light-weighted lidar platforms have great potentials to be used as complimentary tools to improve both the accuracy and efficiency of forest inventory. In this study, we presented our self-developed low-cost UAV lidar system and backpack lidar system. A kinetic calibration algorithm and an improved 3D simultaneous localization and mapping algorithm were used to improve the positioning accuracy of the UAV lidar system and backpack lidar system, respectively. We then explored the possibility to automatically register backpack lidar data with UAV lidar data in a conifer forest using a two-step method based on segmented individual tree locations and the iterative closest point algorithm. The collected backpack and UAV lidar data were successfully used to estimate tree diameter at breast height and tree height with a high accuracy. Moreover, a new crown base height for automatically estimating crown base height from lidar point cloud was developed, which can reach a R2 over 0.85. The results of this study can provide guidance for a systematic lidar solution in forest inventory.

(At Ecometrica Booth). Forests 2020: Protecting and Restoring the World's Tropical Forests | N Moffat*, D Michelakis, P McGregor, S Middlemiss

Forests 2020 is an international project funded by the UK Space Agency to help protect and restore up to 300 million hectares of tropical forests using satellite data across six partner countries - Indonesia, Colombia, Mexico, Brazil, Kenya and Ghana. The project is addressing technical challenges in earth observation monitoring by developing methods to advance forest change/degradation detection, identify forests at risk and areas for restoration whilst providing a digital infrastructure which improves access and processing of satellite data.

POSTER SESSION #2

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1. A Semi-Automated Burned Area Mapping Methodology Using Sentinel-2 Imagery | N Georgopoulos, D Stavrakoudis, IZ Gitas*

Timely and accurate burned area mapping is essential for quantifying the environmental impact of wildfires and for designing short- to mid-term pre-emptive measures that can mitigate the possible impacts of the fire/heavy rainfall combination. This paper presents a semi-automated methodology for burned area mapping, exploiting Sentinel-2 imagery. Sentinel-2 provides high-resolution optical data, a short revisit cycle of five days and a wealth of spectral information that is crucial for burned area mapping. However, its high spatial resolution also aggravates the problem of developing a fully automated mapping methodology.The proposed methodology follows an object-based approach, thereby avoiding the salt-and-paper effect of pixel-based classifications and reducing the computational complexity of subsequent steps. Specifically, the image is segmented into small adjacent and non-overlapping objects using the well-known Mean Shift algorithm and a number of object-level features are calculated for each object. The subset with the most informative features is subsequently maintained, by means of an unsupervised feature selection algorithm based on evolutionary optimization. A small number of training objects is selected automatically, though an empirical procedure that employs a fuzzy C-means (FCM) clustering of the data. A pre-fire and a post-fire image are used for calculating a number of well-known burned area indices and their difference is employed for labeling a portion of the selected training patterns (the most unambiguous ones), through a set of empirical rules. The user can subsequently classify any remaining training patterns or accept the automated classification, which is performed through the Support Vector Machine (SVM) classifier.The proposed method has been preliminarily tested on a set of four wildfire incidents during the 2016 fire season in Greece, considering representative examples of burned landscapes with different complexity and topography. The results highlight the method's effectiveness in providing accurate mappings with reduced user effort, paving the way for the development of a fully automated burned area mapping method. More specifically, an average accuracy of 94.7% was achieved using only the automatically labeled samples, which rose to 96.2% if the user labeled the remaining training patterns, compared to manually delineated fire perimeters.

2. Regional burned area mapping based on Google Earth Engine | JA Anaya*, AM Rodríguez-Montellano, MI Cruz López, LDL Manzo Delgado, WF Sione, N Mari, G López-Saldaña, F Morelli, W Schroeder, JC Beltrán, A Bastarrika

Regionally-tuned burned area mapping in order to improve monitoring of fire-affected vegetation over global products which are known to show variable performance across distinct fire regimes and observation conditions (e.g., cloud coverage) The Latin American Network of Remote Sensing and Forest Fires (RedLaTIF) has been evaluating new means to detect burned area using 30-m resolution Landsat 8 Operational Land Imager (OILI) data with a focus on regional ecosystems over which global products are known to underperform. In Latin America, those areas are normally associated with sparse vegetation (e.g. low Normalized Difference Vegetation Index [NDVI] in pre- and post-fire images) or where burned areas are too small to be detected by daily Visible Infrared Imaging Radiometer Suite (VIIRS) or Moderate Resolution Imaging Spectroradiometer (MODIS) data. Several pre-defined fixed threshold algorithms were tested for select ecosystems although this approach proved problematic given the number of factors affecting pre- and post-fire reflectance. As an alternative, a supervised method was successfully demonstrated using time series analysis to generate maximum and minimum vegetation index annual composites to which thresholds are defined interactively by the user. The data analyses implementation uses the powerful features of Google Earth Engine and has been applied fire-prone areas in Mexico, Brazil, Argentina and Colombia with promising results.

3. Fusion of multiple and temporally dense remotely sensed data sources for refined near-real-time burned-area mapping | M Crowley*, J Cardille, M Wulder, J White

As freely available remotely sensed data sources proliferate, the capacity to combine imagery with high spatial and temporal resolution is enabling applications aimed at near-term disturbance detection. We created rapid and scalable methods for synthesizing information on burned area from multiple sources to map wildfires as they grow, slow, and are finally extinguished. We used the Bayesian Updating of Land Cover (BULC) algorithm to merge sensor-specific burned-area classifications from a range of remote-sensing sources such as Landsat-7 and -8, ASTER, Sentinel-2, Sentinel-3, and MODIS (MCD64A1 burned-area dataset). For each raw image, we compared the post-fire Normalized Burn Ratio against its expected value, based on a pre-fire best-available-pixel image composite for the previous year. This approach enabled the provisional classification of each pixel as burn or no-burn. BULC was then used to fuse these classified images in Google Earth Engine, producing a cohesive time-series stack with updated weekly burned areas for the historically large summer 2017 fire season across all of British Columbia. To focus data selection and processing activity, we used the provisional fire boundaries provided by the Province of British Columbia made available shortly after the end of the fire season. The method used permitted detection of burned areas within fire perimeters at each time step. We are able to retrospectively synthesize and analyze the dynamics and growth of individual fire events by using freely available imagery from different sources and with differing spatial resolutions with relative ease. These methods can be useful for reconstructing the progression of fires over their active lifespan, in order to better understand fire growth and underlying drivers. The ultimate target of this research is to inform and possibly augment single-date remote sensing and jurisdictionally produced burned-area datasets through the creation of a temporally dense fire-classification stack.

4. Leveraging VIIRS active fire data from the Suomi NPP and NOAA-20 satellites for improved global fire monitoring | I Csiszar*, M Tsidulko

The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor provides radiometric measurements at 375m and 750m resolutions that enable high quality fire detection and characterization. The first VIIRS has flown on the Suomi National Polar-orbiting Partnership (NPP) satellite since October 2011 on the 1:30 am/pm orbit. The second VIIRS is now flown on the NOAA-20 satellite, launched in November 2017. NOAA-20 is also on a 1:30 am/pm orbit, separated from Suomi NPP by 50 minutes. Statistical intercomparison of global VIIRS fire data from the two satellites has shown good agreement for both fire detections and fire radiative power (FRP) retrievals. This satellite configuration now offers an opportunity for leveraging compatible VIIRS fire observations to monitor spatial and temporal fire dynamics at local to global scales. Observations from the two satellites reduce the effect of cloud obscuration and thus offer more complete spatial coverage. Additionally, the half-swath angular separation of observations of the same location further reduces the residual angular dependence of the observations after VIIRS's pixel aggregation scheme along scanlines. Analysis of individual fire observations from consecutive VIIRS measurements enables short-term monitoring of fire progression. Further compatible missions of NOAA's Joint Polar Satellite System (JPSS) are expected to contribute to similar observing configurations. This presentation will provide an evaluation of the added value of such two-satellite polar observations as part of a global constellation of polar and geostationary fire monitoring systems.

5. A Hybrid Hyrcanian Forest Fire Detection Algorithm | M Rahim Zadegan, M Taefi Feijani*, M Zohary, A Tavakoli

Forest fire detection has been successfully reported based on temperature anomaly of MODIS infrared images. Here, by combining the three dominant algorithms, fire detection of Hyrcanian forests of Iran is performed. These algorithms are modified enhanced contextual fire detection algorithm for MODIS, improved algorithm for small and cool fire detection using MODIS data and evaluation of graph-based analysis for forest fire detections. Thus, the possibility of detection of all types of fire is increased.In order to locally calibrate these methods for the Hyrcanian forests, a sample of fifty previously occurred fires were selected to modify the thresholds of the models. Consequently, a separate 49 forest fire of Golestan National Park between 2013 and 2016 that are reported by Forest Region and Watershed Organization of Iran (FRWO) was analyzed. A 49 percent overall accuracy is observed. In addition, three not reported small fire were detected that later proved to have taken place. Thus the accuracy was elevated to 52 percent.From 23 false alarms, 12 of them were on the edge of cloud masks. This suggest an improved masking may reduce the chance of false alarms as well.

6. Detection of forest fires in Southeast Asia and western United Sates with optical and radar satellite observations | M Humber*, K Lasko

Forest and vegetation fires are prominent throughout much of Southeast Asia and the western United States. Ignition of these fires come from a variety of sources, with fires having impacts on land cover conversion, ecosystem productivity, and human health. Unfortunately, burned area detection from earth observations in the region suffers from high uncertainty as a result of persistent cloud cover. These issues remain even in the era of frequent observations from moderate resolution sensors such as the Landsat and Sentinel-2 constellations. On the other hand, synthetic aperture radar (SAR) systems, such as the C-Band instrument onboard the Sentinel-1 spacecraft, are able to penetrate cloud cover, thus continuing the observations of surface conditions.In recognition of these common issues and new opportunities, we propose a multi-sensor approach to moderate resolution burned area mapping relying on a combination of optical Landsat-8, Sentinel-2 imagery and C-band acquisitions from Sentinel-1. To test whether SAR data is capable of improving burned area classifications in this often cloud-covered region, we compare the results of multiple classifications of a large, persistent fire event durings the 2015 and 2016 fire season in Cambodia and in the western United States, implementing 1) only optical data (i.e. Landsat-8 OLI and Sentinel-2 MSI), and 2) a combined three sensor approach (i.e. Landsat 8 OLI, Sentinel-2 MSI, and Sentinel-1 C-band). Through our study, we test the potential for improvements to the detection rate of burned areas as well as the shape of the burn scar. Accordingly, we present an object-based framework for burn shape comparison which provides quality indicators reflecting the ability of the classification to preserve the boundaries of the fire. These metrics are particularly important when considering the growth of fire affected area through time. The results from our study will highlight the potential for SAR to improve burned area detection and burn delineation within a cloud-covered region in conjunction with multiple moderate resolution, multi-spectral earth observing satellite systems.

7. Combination of Sentinel-2 and Landsat 8 Data for Monitoring Wildfire Progression Using Google Earth Engine: The Case of the Massive Thomas Fire | X Hu*, A Nascetti, Y Ban, M Wulder

Multispectral imagery has been widely used to address post-fire ecosystem management, but rarely employed to monitor fire progression. The overall objective of study is to evaluate a Normalized Burn Ratio (NBR)-based method for optical images from multiple satellites to spatially trace the progress of wildfires. Specifically, we aim to answer following questions: (1) Can restrictedly available optical data from different satellites be stacked to augment the number of cloud-free imagery? (2) Which kind of spectral indices has the best fit to field measurements of fire progression? (3) Is there a spectral index with a high accuracy to indicate burn severity?The Thomas Fire was selected as study area. Ignited in Southern California on 2017.12.04, the Thomas Fire burned approximately 440 square miles and was fully contained on 2018.01.12. As a large-scale wildfire with long duration, monitoring its progression is highly crucial for the protection of people and property. Fusion of various satellite imageries, using Google Earth Engine (GEE), provides an alternative way for monitoring wildfire progression. Four Sentinel-2 and two Landsat 8 imageries available through GEE were stacked to assess biomass change before and during the Thomas Fire. Then, we analysed performance of vegetation spectral indices commonly used for burn severity assessment (NBR, NDVI, etc.) and derived the Instantaneous form of NBR (INBR), which denotes the temporary NBR during the fire, and the difference of INBR (dINBR) was calculated between adjacent imagery obtained on two neighbouring dates rather than traditional dNBR only based on pre-and-post fire NBR. Burn severity was last assessed in each progression stage with a flexible threshold.The preliminary results show that, using GEE, satellite imagery can be easily combined and used to detect changes, map trends, and quantify differences on wildfires. With benefits of shortwave-infrared band, INBR could be used to identify burned areas through penetrating fire smoke. Therefore, dINBR showed a better fit to indicate the moderate and high burn severity, demonstrating broad transferability than other indices. Using limited cloud-free imagery, three key stages of the Thomas Fire are established: initially snowballing stage from 2017.12.04 to 12.08, middle small expansion from 2017.12.08 to 12.09, and final period of explosive growth between 2017.12.09 and 12.13. The Thomas Fire only saw a small extension to edge areas after 2017.12.13.

8. Monitoring Long-term Variation in Mediterranean Burnt Forests Using Sentinel 1-SAR Time Series. The case of Doñana National Park. | J Ruiz-Ramos*, A Marino, CP Boardman, R Diaz-Delgado, J Suarez

Optical satellite imagery is generally chosen because it is very good at detecting and mapping landscapes transformation. However, its use is significantly affected by some technical and environmental conditions (eg.revisit frequency, sunlight or cloud coverage), which can compromise its performance.In response to this challenge, this research aims to highlight the capabilities of Synthetic Aperture Radar - SAR satellite sensors to investigate the environmental changes of forest areas affected by Mediterranean fire events. The use of a multitemporal analysis based on SAR and optical satellite images time-series allowed us to monitor the post-fire natural processes in the Doñana national park after the forest fire occurred in June-July 2017.The radar time-series was composed of 19 images acquired by ESA-Sentinel 1, co & cross polarized channel as level-1 Ground Range Detect (GRD), covering a total time window of 11 months. Optical dataset was formed by 11 images, one per month, acquired by Landsat-7 and ESA-Sentinel 2 missions, thus covering the same time window as the radar dataset. All the information about the areas affected by the fire was extracted from the fire severity study developed by ESA-Copernicus emergency management. Lastly, a meteorological dataset of the study area was obtained from the Spanish meteorological agency (© AEMET). Work focused on three different tasks: 1. The capability of optical and radar sensors to detect environmental changes in the study area; 2. Monitoring image intensity changes in dense time series of radar data; 3. Investigation of soil moisture changes after the fire that can be detected in intensities of radar images. The comparison between the optical and radar revealed that optical data are better to highlight and map the fire scars. However, SAR technology showed a greater performance when monitoring long-term environmental variations in the study area. The investigation of the radar backscatter signal for both polarised channels showed a consistent trend characterised by the progressive reduction of the signal intensity, which was only slowed down in certain periods due to rain events. We hypothesise that this signal behaviour responds to the appearance of the first symptoms of land erosion and desertification caused by the progressive drying of the superficial ground layers.In conclusion, the highest sensitivity of SAR to soil moisture enhances the capacity of this sensors to investigate natural disasters.

9. Examining Fire Background Temperature - Methods for Estimation of Obscured Pixel Values | B Hally*, L Wallace, C Engel, C Wickramasinghe, K Reinke, S Jones

The basic premise of most remotely--sensed fire detection products in common use is an accurate estimate of pixel background temperature. Whilst the absolute contrast of a pixel's brightness temperature from its surrounds helps with identification of fire activity, providing quantitative information about fire characteristics is reliant on knowing what a pixel should look like without the presence of fire. Most fire--detection products choose to derive their estimate of background temperature from the pixels surrounding a fire event, to take advantage of the spatial autocorrelation of components of upwelling radiation, such as solar reflection. In some cases, factors such as cloud, smoke, surface water and heterogeneity of land cover can complicate the calculation of background temperature from pixel context, with resulting values that can diminish or exaggerate the calculation of fire metrics. This study examines the relationship between the recorded state of a pixel and temperatures estimated from the pixel surrounds. The paper focuses in particular on the method of expanding the window of examined pixels in a contextual analysis, and the effect that distance from the target pixel has on temperature estimation. The paper also examines ways to utilise methods other than spatial context to derive background temperature. Initial findings show that the ideal candidate pixels for deriving background temperature may not be those positioned immediately adjacent, and that improving background estimation may be achieved using a mixture of temporal and contextual methods, rather than just focusing on methods using a single image.

10. Burned area detection using Sentinel-1 data and locally adaptive algorithms | MA Belenguer-Plomer*, MA Tanase, A Fernandez-Carrillo, E Chuvieco

About 2.1 PgC are released every year due to biomass burning. Due to its importance, several products were developed to map burned areas (BA). Most of these products are based on medium resolution optical sensors which are rather insensitive to small size fires. Moreover, frequent cloud cover may hinder BA detection. To mitigate such shortcomings BA may be derived from high resolution radar backscatter time-series captured by the ESA's C-band synthetic aperture radar (SAR) Sentinel-1. This study presents an algorithm. The algorithm uses temporal backscattering ratios of VV and VH polarizations. Changes between consecutive images (t-1 and t+1) are detected with the Reed-Xiaoli detector (RXD). A specific RXD is applied to each broad land cover type. Burned and unburned regions of interest (ROIs) are extracted automatically using hot spots from VIIRS and MODIS C6. The ROIs are used to train specific random forest models (by land cover type) to detect the burned areas. Preliminary results show an overall accuracy of 95%, an omission error of 44% and a commission error of 43% over 18 worldwide located tiles. This contribution further analyses the estimation errors as a function of biome, land cover type, and topography. Such an analysis is essential to improve the algorithm. The results are also compared with available global products based on MODIS images. Such a comparison allow estimating the influence of spatial resolution and sensor type on BA detection and demonstrates the utility of products derived from active microwaves sensors.

11. Predicting tree diversity with full-waveform lidar data in Gabon | S Marselis*, H Tang, J Armston, R Dubayah

Global biodiversity loss has become an important topic on the international agenda over the last decades as a result of increasing human and environmental pressures on the landscape. Deforestation, for example, has become a widespread phenomenon, leading to large-scale decline in biomass and biodiversity. Tropical forests are particularly vulnerable as they facilitate high biodiversity. However, exact measures of biodiversity losses are difficult to obtain, given the complexity behind measuring and mapping biodiversity. This study focusses on mapping tree diversity in the tropical forests of Gabon, Africa, using information of the vegetation structure derived from full-waveform airborne lidar data. Full-waveform lidar data was collected with the Land Vegetation and Ice Sensor (LVIS) in four regions in Gabon during the AfriSAR campaign in 2016. Lidar waveforms were processed to provide information on the vertical vegetation structure through Relative Height (RH) metrics and Plant Area Volume Density (PAVD) profiles. Field information in the form of (stem-mapped) forest plots are available in all four regions, providing the tree species of each individual tree with a diameter at breast height larger than 10 cm. The Shannon diversity index and the Total number of species per area were calculated to represent tree diversity in each field plot. For each plot the average vertical vegetation structure was calculated from all lidar waveforms within the plot boundary. Linear and random forest models were utilized to evaluate the predictability of tree diversity using the lidar metrics, while evaluating the effect of plot size on this relationship. The results showed that full-waveform airborne lidar data can be used to predict tropical tree diversity at different scales. These results are encouraging in the context of the upcoming Global Ecosystem Dynamics Investigation (GEDI) mission that will employ a full-waveform lidar instrument on the International Space Station in November 2018 and collect billions of lidar waveforms across the world, potentially enabling global mapping of local tree diversity.

12. An ensemble classifier approach for urban tree species classification from ground-based spectral references | J Aval*, S Fabre, E Zenou, D Sheeren, M Fauvel, B Xavier

This study aims at identifying the best object-based classification strategy that takes advantage of the richness of hyperspectral data, for classifying 8 tree species in an urban area (Toulouse, France). Field spectral measurements at the leaf and canopy level were carried out in a reference site, while airborne hyperspectral Visible Near-Infrared (160 spectral bands, spatial resolution of 0.4 m) and Short-Wavelength Infrared (256 spectral bands, 1.6 m) were acquired over Toulouse. We propose an ensemble classifier approach (at least one classifier per species) such as each classifier uses three vegetation indices, followed by Support Vector Machine (SVM) supervised classification. Then, a decision rule based on the classifiers votes is applied to predict the species. The vegetation indices triplet corresponding to each classifier is chosen in such way that it optimizes the F-score of a certain species, ensuring the complementarity of the classifiers. In this framework, the field data are intended to be used for learning whereas the airborne data are used for testing, in order to assess the potential of field measurements for such classification task. Two baseline approaches are used for comparison. A standard classification procedure using directly the spectral reflectance is chosen in order to evaluate the interest of using vegetation indices. A method which stacks all the selected indices in one feature vector is considered in order to assess the potential of the ensemble classifier. These methods are first compared on the reference site. This allows the best strategy to be selected with a view to introducing the method in an automatic process (tree crown delineation and species classification) on a test site. Concerning the reference site, the proposed method outperforms the baseline approaches in case of leaf level learning with an Overall Accuracy (OA) of 55%, instead of 21% and 32% respectively. Aesculus hippocastanum trees are well classified because of their senescence, caused by the horse-chestnut leaf miner, and highlighted thanks to the vegetation indices. For the test site, the Tilia tomentosa trees of the main alignment are identified with an OA of 81% in case of leaf level learning. In conclusion, the proposed ensemble classifier approach improves the performance. Also, it is shown that leaf level learning gives similar performance in comparison to the use of references from the images.

13. Identifying cerulean warbler habitat from forest structure using airborne laser scanning | R Wasson*, P Treitz

Cerulean Warblers (Setophaga cerulea) are canopy-dwelling migratory songbirds that breed in large continuous tracts of deciduous forest in central and eastern North America (Jones & Robertson, 2001, Auk). At the territory-level, this habitat specialist selects complex multi-age stands with multiple canopy layers and large dominant trees (Barg et al., 2006, Auk). Forest structure is a critical element of Cerulean Warbler habitat and can be examined using airborne laser scanning (ALS). ALS produces a spatially-explicit three-dimensional point cloud from which metrics describing horizontal and vertical forest components can be extracted (Guo et al., 2017, Ecol Inform). The goal of this project is to identify ALS-derived structural metrics that can be used to identify Cerulean Warbler habitat at the Queen's University Biological Station (QUBS). To this end, this project uses ALS, forest inventory and passive acoustic monitoring data, as well as existing ecological knowledge of Cerulean Warbler preferences, to generate predictive models of the occurrence of its habitat across the landscape. Cerulean Warbler populations have been declining at an annual rate of 3-4%, with 70-80% of the population lost since the 1960s, a trend largely attributed to habitat loss (Buehler et al., 2008, J Wildlife Manage). In Canada, this songbird is recognized as a species of special concern in the Federal Species at Risk Act, and as endangered by the Committee on the Status of Endangered Wildlife. There is an estimated 500 breeding pairs in Canada, with approximately half selecting habitat in the Frontenac Forests Important Bird and Biodiversity Area, which encompasses QUBS. This high Cerulean Warbler concentration suggests the presence of preferred forest types that it is able to select. While conventional surveying methods have been used to study habitat structure (Hamel et al., 2004, Auk), it poses several challenges and ALS offers an alternative method (Farrell et al., 2013, Ecosphere). Surveys are time and effort intensive, cover a limited spatial extent and are often restricted to accessible areas; this can lead to tradeoffs between resolution and extent and introduce biases (Bradbury et al., 2005, Ibis). ALS offers continuous fine resolution three-dimensional coverage across a wider spatial extent (Vierling et al., 2008, Front Ecol Environ). Thus ALS allows for accurate forest structure characterization from which the availability of Cerulean Warbler habitat can be assessed.

14. Forest biodiversity estimated from the space: testing the Spectral Variation Hypothesis comparing Landsat 8 and Sentinel 2 using a multi-temporal Rao Q. | M Torresani*, D Rocchini, R Sonnenschein, M Zebisch, G Tonon

Forests cover about 30 percent of the earth surface, they are the most biodiverse terrestrial ecosystems and they are at the base of many ecological processes and services. The loss of forest biodiversity makes in risk the benefits that the humans derived from theme. The assessment of biodiversity is therefore an important and essential goal to achieve, that however can result difficult, time consuming and expensive if estimated through field data. Through the remote sensing it is possible to estimate in a more objectively way the species diversity, using limited resources, covering broad surfaces with high quality and standardized data. One of the method to estimate biodiversity from remote sensing data is through the Spectral Variation Hypothesis (SVH) , which states that the higher the spectral variation of an image, the higher the environmental heterogeneity and the species diversity of that area. The SVH has been tested using different indexes and measures; recently in literature, the Rao's Q index, applied to remote sensing data has been theoretically tested as a new and innovative spectral variation measure. In this paper for the first time, the SVH through the Rao's Q index has been tested with an NDVI time series derived from the Sentinel 2 (with a spatial resolution of 10m) and Landsat 8 satellites (spatial resolution of 30m) and correlated with data of species diversity (through Shannon's H) collected in forest. The results showed that the Rao's Q is a grateful spectral variation index. For both the sensors, the correlation with the field data had the same tendency as the NDVI trend, reaching the highest value of correlation (through the coefficient of determination R2) in June, when the NDVI was at its peak. In this case the correlation reached a value of R2=0.61 for the Sentinel 2 and of R2=0.45 for the Landsat 8, showing that the SVH is scale and sensor dependent. The SVH tested with optical images through the Rao's Q index showed grateful and promising results in alpine forests and could lead to as much good results with other remote sensing data or in other ecosystems.

15. Non-Native Spathodea campanulata in Puerto Rico, Pre and Post 2017 Hurricane Season | I Paynter*, B Cook, D Morton, S Martinuzzi, S Serbin

Spathodea campanulata (the African tuliptree) is a specialist colonizer of open ground and cleared land. The native forests of Puerto Rico were largely clear-cut in the 1930's, providing the initial conditions for Spathodea, a non-native species, to achieve widespread and dominant colonization. This succession has occurred as an integral part of the process of forest regrowth, making it of particular ecological interest, with several native insect species even adapting to feed on Spathodea. During Phase 1 of the Department of Energy's Next Generation Ecosystem Experiment (NGEE-Tropics, March 2017) multi-sensor data were acquired in Puerto Rico using NASA Goddard's Lidar Hyperspectral and Thermal (G-LiHT) airborne imaging system. The fine resolution image data afforded the opportunity to identify the distinctive, red-orange flowers of Spathodea, and therefore to document the occurrence of Spathodea prior to the historic 2017 hurricane season. For many of the previously observed regions of Puerto Rico, G-LiHT observations are to be reacquired in April 2018, providing an opportunity to observe the role Spathodea is playing in the regrowth and recovery of forests damaged in the 2017 hurricane season. Observations from the G-LiHT airborne imaging system included fine spatial resolution aerial imagery (4 cm GSD, Phase One iXU-R 1000), with coincident lidar data (nominally 10 cm diameter footprint at 12 pulses per m2, Riegl VQ-480). Structural observations from stereo photogrammetric processing of the Phase One imagery, in conjunction with the airborne lidar data, enable both the retrieval of tree heights and crown structure for Spathodea, and the characterization of change in forest structure between the 2017 and 2018 observations. Through analysis of tree heights and morphology we will seek to separate recovery of damaged individuals from growth of new Spathodea individuals, as well as characterizing the structural and energy availability conditions that may control Spathodea distribution.

16. The use of Cloud-Computing Approaches for Land Cover/Use Mapping to Support Ecosystem Accounting in West Africa using High Resolution Optical Data | C Sousa*, T Fatoyinbo, C Neigh, M Honzák, T Wright, T Larsen

In recent years, the environmental research has focused on understanding the importance of ecosystems and services that they provide to humans. Quantifying changes in the ecosystem extent, services ecosystem service stocks and flows are key components of ecosystem accounting framework that aims to support sustainable development by avoiding ecosystem depletion and/or degradation. The initial step in the ecosystem accounting framework is quantification and monitoring of the spatial and temporal dynamics of the ecosystem extent. Recent advances in cloud-based geospatial computing approaches and multi-date, multi-sensor satellite image sources, offer an opportunities for mapping land cover/use over large areas that is the prerequisite for mapping the ecosystem extent. In this study, we take an advantage of the GEE cloud platform to produce a 30-m resolution land cover/use map for Liberia that will be combined with a generalized dissimilarity modelling (GDM) approach to produce the extent of ecosystems. We will present the methodology and initial results and discuss potential implication in a broader context of the ecosystem accounting.

17. Remote sensing of forest structural attributes in restoration plantings | N Camarretta*, A Lucieer, PA Harrison, B Potts, N Davidson, M Hunt

With large investments in forest restoration worldwide, mapping and monitoring is increasingly required for restoration implementation and effective monitoring. Forest structural attributes are well-recognised indicators of forest ecosystem health, but can be time consuming and expensive to quantify on a large-scale in field inventories. Accordingly, there is increasing interest by the forest restoration industry, in the use of remote sensing technologies such as LiDAR (Light Detection and Ranging).We tested the use of LiDAR sensors mounted on an Unmanned Aerial Vehicle (UAV) for the assessment of key structural attributes measured in an 8-year old mixed species restoration planting. The restoration planting included replicated experiments where pedigreed trees were grown in grids and readily located. The key structural attributes we focussed on were diameter at breast height (dbh); stand basal area; tree height; canopy volume; canopy layering; canopy cover; biomass. UAV-borne LiDAR data was collected over four plots (15 ha in total) in January 2018, with a point density of > 1000 points/m2. Ground control field inventory measurements of comparable traits were collected for validation.We here report (i) the success of quantifying comparable forest structural attributes using LiDAR, at tree level and (ii) the opportunities for quantifying additional structural attributes that are too time-consuming to assess in large-scale field inventory.

18. Integration of ForeStereo-LiDAR data using Universal Kriging models: a geostatistical approach for forest inventories | I Aulló-Maestro*, C Gómez, E Marino, M Cabrera, A Vázquez, F Montes

Forest characterization is essential for effective management and conservation policies. Forest inventories have played an essential role as a cost-efficient way to assess forest structure and monitoring forest dynamics. ForeStereo provide field-based estimates of individual tree level and stand level variables based on the analysis of stereoscopic hemispherical images collected at sampling locations. Yet Modelling is needed to evaluate measured values of the variables over the entire area of interest. Remote sensing provides spatially explicit and comprehensive variables to support modelling of forest variables, as airborne LiDAR- derived statistics which are widely used in forest inventory. In this work we propose the application of geostatistics for the estimation of forest resources over Valsaín Scots pine pinewood, in the Central Mountain Range of Spain, applying ForeStereo survey supported by airborne LiDAR data. A 400 m grid was set for the ForeStereo survey with 112 sampling points throughout the study area. We developed a region-growing segmentation and automated matching of the ForeStereo stereoscopic hemispherical images from which is determined the individual tree position, diameter and volume. A method to correct the instrument bias and the occlusions was developed to derive the following stand level variables: number of trees per hectare (N), Quadratic Mean Diameter (QMD), Basal Area (BA) and volume (V). Universal Kriging was used to predict the ForeStereo variables at a 15 x 15 m grid covering the study area. As auxiliary variables we include the Percentile 01, 20 and 95 of elevations (P01, P20 and P95 respectively), the Total Return Count and the Return 1 count above 2.00 LiDAR metrics. All these auxiliary variables showed significant (p-value <0.05) coefficients in their respective trend surface function. Validation of predictions at 15x15 m pixels was carried out on independent plots. The kriging predictions were unbiased presenting a bias minor to 15%. The proposed approach exploit the complementarity of ForeStereo and the LiDAR spatial coverage to obtain precise maps and estimations of diameter distributions, basal area and volume.

19. Essential Biodiversity Variables obtained from airborne and spaceborne LIDAR | R Valbuena*, B O'Connor, F Zellweger, F Morsdorf, P Vihervaara, W Simonson, F Danks, G Chirici, N Coops, D Coomes

Harmonisation of observations for biodiversity assessment necessitate a set of Essential Biodiversity Variables (EBVs) that aims to capture the multidimensionality of biodiversity. Regular monitoring of these EBVs can help identifying where conservation efforts are needed and evaluate their efficacy. The Group on Earth Observations within the Biodiversity Observation Network (GEO BON) has been refining this list of EBVs according to those that can be reliably observed using remote sensing. Light detection and ranging (LIDAR), an active form of remote sensing, provides accurate measurements of vegetation structure at very high spatial resolution. In this contribution we review the potential and limitations of LIDAR for monitoring EBVs in terms of feasibility, global validity and sensitivity to change. We identify two pathways through which LIDAR technology can inform EBVs: (i) derivation of morphological traits of species, communities and ecosystems, directly from LIDAR and (ii) prediction of variables using LIDAR plus ancillary data for calibration. Over the past decade there has been convergence on which morphological traits can be directly evaluated from LIDAR, including: (1) vegetation height, (2) vegetation density, and (3) vertical vegetation structure, all of which can be derived from both airborne and spaceborne sensors. Spatio-temporal changes in these morphological traits can be linked to local changes in species community composition (i.e alpha diversity), as well as changes between communities or ecosystems (i.e. beta diversity). Airborne LIDAR (a.k.a. ALS) provides spatially continuous coverages of these traits, giving opportunities to derive landscape scale assessments of habitat extent, horizontal structure, connectivity and fragmentation. Spaceborne LIDAR will provide the added advantage of consistent global assessments. But gaps in spatial coverage between laser pulses from space means that deriving continuous maps will require sampling-based approaches, coupling satellite LIDAR with other remote sensing sources, among which ALS will play an important role. We challenge the widespread notion that ALS is unfeasible at continental scales due to high cost, given the availability of public whole-country surveys, useful both for monitoring EBVs and as a key source of ground-truth for calibrating spaceborne data. Additionally, coupling LIDAR with ancillary data can provide EBV estimates with higher accuracy than other feasible alternatives.

20. Quantifying Multi-Source Carbon Cycle Model Uncertainties: Sensitivity Analysis, Perturbed Parameter Ensemble, and Uncertainty Attribution | Y Zhou*, C Williams, H Gu

Results from terrestrial carbon cycle models have multiple sources of uncertainty, each with its behavior and range. Their relative importance and how they combine has received little attention. This study investigates how various sources of uncertainty propagate, temporally and spatially, in CASA-Disturbance (CASA-D). CASA-D simulates the impact of climatic forcing and disturbance legacies on forest carbon dynamics with the following steps. Firstly, we infer annual growth and mortality rates from measured biomass stocks (FIA) over time and disturbance (e.g., fire, harvest, bark beetle) to represent annual post-disturbance carbon fluxes trajectories across forest types and site productivity settings. Then, annual carbon fluxes are estimated from these trajectories by using time since disturbance which is inferred from biomass (NBCD 2000) and disturbance maps (NAFD, MTBS and ADS). Finally, we apply monthly climatic scalars derived from default CASA to temporally distribute annual carbon fluxes to each month. This study assesses carbon flux uncertainty from two sources: driving data including climatic and forest biomass inputs, and three most sensitive parameters in CASA-D including maximum light use efficiency, temperature sensitivity of soil respiration (Q10) and optimum temperature identified by using EFAST (Extended Fourier Amplitude Sensitivity Testing). We quantify model uncertainties from each, and report their relative importance in estimating forest carbon sink/source in Pacific Northwest, United States.

21. Analysis of vegetative resilience and water use efficiency for the continental part of Ecuador using remote sensing and modelling. | JI Gamez-Badouin*, JM Madrigal-Gomez, GA Juarez Cansdales

The identification and monitoring of ecosystems with greater resilience to climatic variables (Seddon et al., 2016) are today an issue of global importance, the application of a quantitative model that uses remote sensing data in Ecuador will provide important tools to improve decision-making around the country's environmental policies.Objectives are to identify by remote sensing and mathematical models the areas of greatest sensitivity to climatic and hydrological key variables, identifying trends of spatio-temporal vegetation change and water use efficiency in the continental zone of the country of Ecuador, in addition to their respective watershed basins.The TERRA and AQUA satellite products of the MODIS sensor (MOD13C2 and MOD16A2) are used to obtain improved vegetation index data (EVI, Huete et al., 2006), real evapotranspiration (ETA), potential evapotranspiration (ETP) and cloud data. In order to create an insolation index, data were also incorporated from the MERRA-GEO5 analysis to obtain the spatial distribution of the climatic variables as: air temperature and precipitation (mm / month). Finally data from the IMO sensor were used to get radiant fraction of cloudiness, these products served as a basis to identify the most resistant vegetation to the climatic and hydrological variables present in the continental zone of the country of Ecuador. Finally, these results were compared with the primary Productivity and Monthly Primary Productivity (NPP, GPP) MOD17A2/A3 products (Heinsch et al., 2003) ratio to ET known was water use efficiency (Stanhill, 1986) identifying the influence of the areas of greater resilience to the Primary Productivity and ecosystem functionality.Preliminary results indicate that the areas of greatest resilience are located specifically to the east of the Andes mountain range, in what corresponds to the Amazon basin, where the areas of higher productivity and water availability are also located.The present investigation is useful to know the behavior of the dynamics and the response of the vegetation space-temporarily for a better management of the hydrographic basins and natural resources in the country of Ecuador.

22. Assessing post-hurricane damage in mangrove forests of south Florida using repeat LiDAR, Landsat imagery and U.S. Forest Service, Forest Inventory and Analysis (FIA) data | T Schroeder*, M Brown, J Nowak, K Cummins, B Cook, C Giri

With hurricane frequency, intensity and duration on the rise, the economic and ecological benefits of mangrove forests are becoming more valued across the globe. Given their protective qualities, focus has been placed on improving conservation efforts, however land managers often lack the information needed to make sound decisions. To facilitate better management and protection there is an urgent need for more accurate information regarding the distribution, abundance and health of mangrove forests. To date, high resolution airborne laser scanning data (ALS) has been widely used to map changes in mangrove canopy height, however most previous studies have focused on limited geographic areas. In this study a large collection of ALS strip samples collected before (March 2017) and after (December 2017) hurricane Irma are used to analyze mangrove damage over a north/south transect spanning roughly 150 miles of Florida's southwest coastline. To facilitate assessment of regional impacts, the ALS strips are grouped into 5 geographic subsets (Key West, Everglades, Marco Island, Sanibel Island, and Port Charlotte) with similar locations and orientations from the eye wall of the storm. Canopy height models (CHM) for the March and December ALS acquisitions are differenced to estimate canopy height change. Tree heights measured on U.S. Forest Service FIA subplots are used to validate the 1 m resolution CHMs. Although FIA and Lidar maximum heights displayed a strong linear relationship ($R2 = .95$) there was some negative bias above 15 m (98 ft), which was likely the result of FIA measuring the total length of leaning crowns versus Lidar which mostly measures vertical height perpendicular to the sensor. Comparisons across the 5 groups revealed interesting differences in the magnitude and spatial structure (i.e. gaps) of disturbance after the hurricane. In addition, distributions from the ALS strips and FIA plots are used to determine how well FIA's sample captures the broader landscape pattern of mangrove canopy structure. To evaluate other remote sensing products more suitable for larger-scale, operational monitoring, the CHM differences are also used to validate photo-interpreted changes in canopy cover derived from 1 m NAIP imagery and disturbance derived from 30 m Landsat change maps. In conclusion, the results will be used to discuss FIA's future plans for using remote sensing to improve inventory estimates of mangrove forest.

23. Variations in mangrove canopy chlorophyll content with respect to species, submerged conditions and seasonality | C Shi*, L Wang, X Cao

Chlorophyll content is an important biophysical parameter that reflects the physiological state of vegetation and environmental stresses. It is affected by seasonality, species, submerged conditions. The seasonal variations in mangrove chlorophyll content have been studied by remote sensing, but they do not take into account the impact of submerged conditions. Therefore, the present study aimed to explore the variations in mangrove canopy chlorophyll content (CCC) of different submerged conditions, species and seasons by remote sensing. First, the submerged conditions were obtained by combining Landsat8 images with tidal data, in which the mangroves were successfully divided into two submerged conditions: often flooded area (OFA) and rarely flooded area (RFA). Then, the green chlorophyll index (GCI) was considered as the optimal index ($R2 = 0.7635$) representing mangrove CCC. Finally, the changes of mangrove GCI were analyzed. We found that the distribution difference of mangrove GCI was significant between OFA and RFA for all test species and seasons, with mangroves growing better in RFA. The distribution of mangrove GCI between Avicennia marina and Kandelia candel had the largest difference in autumn especially in OFA. Furthermore, the distribution difference of GCI between summer and the other three seasons were significant as compared to the insignificant distribution difference observed between winter and spring for any of the submerged conditions and species, such that mangroves grew better in summer.

24. Automated Quantification of Mangrove Change from Earth Observation Data, Matang Forest Mangrove Reserve, Malaysia | R Lucas*, V Otero, R Van De Kerchove, B Satyanarayana, F Dahdouh-Guebas

The expansion of timber harvesting in mangroves is set to increase given the increased recognition of retaining a mangrove cover to assist coastal protection and other ecosystem services (e.g., fisheries). Using the Matang Mangrove Forest Reserve (MMFR) in Perak Province, Malaysia, this research demonstrates the use of the Earth Observation Data for EcoSystem Monitoring (EODESM) for historical and near real time monitoring mangroves and advocates its use for ongoing monitoring of mangroves to support sustainable utilisation. Initially, land covers within and surrounding the MMFR were classified according to the Food and Agriculture Organisation's (FAO) Land Cover Classification System (LCCS) for 2000 and 2016 and from thematic and continuous environmental layers generated from optical and radar (polarimetric and interferometric) spaceborne data. Using a comprehensive forest age class map generated through time-series comparison of annual Landsat and sub-annual Japanese L-band Synthetic Aperture Radar (SAR), relationships were established with both mangrove canopy height and above ground biomass and used to approximate the height of forest as a function of age following regeneration in all years between 1987 and 2016. Additional information obtained from the SAR imagery related to the extent and characteristics of water, bare ground (including woody debris within logged coupes) and the forests themselves. For each year, FAO LCCS classifications were generated and comparisons of the classes (including component codes describing individual elements of the forest; e.g., height) and associated environmental variables (e.g., biomass) allowed evidence to be accumulated that could be used to detect and describe change according to pre-defined categories (e.g., forest clearance, regeneration, flooding). Capacity was also introduced to allow changes in all land cover categories to be highlighted as new imagery were introduced. The EODESM system is accompanied by a mobile application developed to support the EODESM classifications of land cover and change. The approach can be applied to mangroves worldwide and can be adapted to encompass a wide range of change categories.

25. Mangrove forests of Ecuador: Extent, biomass and forty years of change | N Thomas*, M Simard, S Howard, V Rivera-Monroy, E Castañeda-Moya, S Lee, T Fatoyinbo

Mangroves are coastal forested wetlands that straddle the terrestrial and marine interface. They provide a plethora of ecosystem services and one of the most carbon rich ecosystems in the tropics (Lee et al., 2014; Donato et al., 2011). Despite their importance, mangrove forests are increasingly under threat and have lost in excess of 35% of their global area (Valiela et al., 2001). The mangrove wetlands of the Guayas River Estuary Ecosystem (GREE) on the pacific coast of southern Ecuador have been used to highlight the impact of anthropogenic activity on mangrove extent, although the key drivers causing net losses since the 1980s remain relatively unidentified and unquantified. Our aim was to definitively assess the impact of anthropogenic activity on mangrove loss from the onset of aquaculture. We used recent (2014) and archival (ca. 1980) Landsat imagery to assess the change in mangrove forest extent over a 40-year period. Landsat 2 MSS data was registered to contemporary imagery and a hybrid object-oriented supervised-unsupervised method was used to map extent. In addition, we used DLR Tandem-X InSar data to create a mangrove canopy height map (CHM) for the region and estimates of mangrove biomass were derived from global relationships between mangrove height and biomass. We mapped a total of 136,428 ha of mangroves in 2014 (accuracy > 95%) reduced from an ca.1980 estimate of 170,219 ha. Since the advent of aquaculture in the region a total of 136,428 ha of shrimp ponds and rice paddies now exist, driving the loss of 38,987 ha of mangroves. We interpret that the loss of mangrove attributed to aquaculture has been historically overestimated, with early aquaculture replacing 44,628 ha of mudflat. Mangrove losses over the past 40 years have not been offset by observed gains in extent of 5,726 ha. Estimated average aboveground biomass within the GREE is estimated at 127 Mg ha equivalent to 57.3 Mg C ha, totaling 368.4 Mg C ha when combined with below ground biomass equivalent carbon (including soil data to a depth of 1 m). Regional and globally significant canopy heights of 40 m yielded large estimates of AGB that enabled them to be resistant to conversion to aquaculture. Due to the availability of archival imagery we were able to define the impact of aquaculture in the region and provide a robust baseline to continue advancing natural resource management programs in this highly productive coastal region.

26. Mapping deforestation and forest structure deterioration: the potential of dense Sentinel-1 time series | K Urban*, F von Poncet, L Fehrmann, M Freudenberg

Within the international processes on climate, biodiversity and desertification, the role of forests, their status and changes are high on the policy and research agenda. Reliable information on forests is needed and remote sensing support becomes ever more relevant. With the launch of the C-band radar satellites Sentinel-1A and B, as part of the Copernicus program by ESA, monitoring of forest become feasible at a high spatial and temporal resolution, free of cost and independent of cloud cover. To monitor deforestation and forest structure deterioration due to fire, we investigate the potential of Sentinel-1, solely and in combination with different sources of additional information like optical and radar imageries. In this context, we define deforestation as the complete loss of forest cover and forest structure deterioration as an indicator for an incipient deforestation, both strictly based on land cover features. The study is conducted in two test sites in Jambi Province, Sumatra, Indonesia, which were affected by the El Niño driven fires in Southeast Asia in 2015. Both, Harapan Rainforest and Berbak National Park represent unique and valuable ecosystems. Using the Ground Range Detected (GRD) product for the time covering the fire period from beginning 2015 until mid of 2016 and deep learning algorithms, structural changes of different degrees can be classified. The deep learning algorithm was trained with preprocessed backscatter information and different statistical and structural variables derived from these. Combining C-band information with L-band SAR as well as canopy surface roughness calculated from UAV derived point clouds and on-site data, we expect to produce more detailed and meaningful information on changes of forest structure, from which inference on forest change may be drawn. First results show that emphasis should be laid on the preprocessing of the radar data. The adaption of calibration and filtering according to environmental characteristics improves the distinction between complete deforestation, highly structural changed and intact forests. Moreover, we expect that with a more detailed assessment of vertical and horizontal structures and identification of cleared areas within the forest, an improved classification of destroyed and degraded forests will enhance the overall performance of forest status mapping.

27. Validation of JICA-JAXA's deforestation monitoring system: JJ-FAST | M Hayashi*, I Nagatani, T Watanabe, T Tadono, M Watanabe, C Koyama, M Shimada, T Ogawa, K Ishii, T Higashiuwatoko, M Miura, H Okonogi, T Morita

Japan International Cooperation Agency (JICA) and Japan Aerospace Exploration Agency (JAXA) cooperate to develop a new deforestation monitoring system: JICA-JAXA Forest Early Warning System in the Tropics (JJ-FAST) for 77 tropical countries, and it was released in November 2016. The system uses ALOS-2/PALSAR-2 image, so, it is effective even in cloud-covered areas during rainy season. In this study, we conducted field survey and image interpretation to clarify the detection accuracy of JJ-FAST.The field survey was conducted in four countries: Peru (November-December 2016 and October 2017), Botswana (April 2017), Gabon (July 2017), and Brazil (October 2017 and February 2018). We went to the deforestation areas detected by JJ-FAST, and investigated the actual condition. And, we also conducted the image interpretation for the entire region of Peru. For that, we established 1,300 validation points by random sampling at each of inside and outside of JJ-FAST's deforestation polygons, then, interpreted Sentinel-2 and Google Earth image at those points.As a result of the field survey, the user's accuracy was 76.0% for all of the four countries, 100.0% for the two African countries, and 60.0% for the two South American countries. Main factors of the degradation in accuracy in South American countries were misdetection of seasonal changes in agricultural land and grassland. As a result of the image interpretation in Peru, the user's accuracy was 62.3% and the producer's accuracy was 69.0%. Main factors of misdetection (degrading the user's accuracy) were seasonal changes in agricultural land and wetland. And, main factor of detection omission (degrading the producer's accuracy) was small-area deforestation, because speckle noise in PALSAR-2 image prevents to detect small changed-area. Based on these validation results, we are currently improving the JJ-FAST's algorithm to detect deforestation accurately. Along with the accuracy improvement in the future, we hope that JJ-FAST will be used more and more for illegal activity monitoring and forest management in the tropics.

28. Using Sentinel-2 satellite images for automated detection of forest changes | T Pitkänen, A Kangas*, L Sirro, T Häme, L Häme

Finland has 23 million hectares of forest, which is annually a source for over 60 million cubic meters of timber products. Utilization of forests is primarily regulated by the Forest Act, which also obliges forest owners to announce the Finnish Forest Center if major management activities are planned. These announcements, called as notifications of forest use, are contemporarily used as the main source to gain updates on forest management and to monitor the compliance of the Forest Act. Notifications of forest use, however, are only indicating plans which can be committed within three years from approval, and their actual results are verified mainly by manual fieldwork. Further, reliance on the notifications does not indicate unannounced loggings or changes originating from other reasons, such as storm damages. To respond to these needs and be able to assess recently occurred forest changes without extensive fieldwork, a tool based on automated change detection using Sentinel-2 satellite images has been developed.Core functionality of the change detection applied in this study is based on a method called AutoChange, developed by the VTT Technical Research Centre of Finland. AutoChange relies on spectral clustering of two satellite images from different dates, which are applied to evaluate the type and the magnitude of changes at a pixel level. These results are used to find moderately (thinning activities or partial disturbances) and significantly (clear-cuts or major damages) changed boreal forests. Change detection is tested with a single pair of Sentinel-2 images as well as by applying the AutoChange method to several images through pairwise processing. Gained results are evaluated with assistance of high-resolution images from Pléiades and WorldView-2 satellites. Eventually, the study aims at creating an operational tool for automated change detection and related error assessment to be used by the Finnish Forest Center and other end users.According to initial results, clear-cuts can be distinguished reliably as long as they are large enough to exceed a certain filtering threshold. Successful detection of less intensive changes, however, depends more on external factors like atmospheric effects, image quality and homogeneity of the changed areas. Development of the processing is still under way, but preliminary experiences indicate the usability of Sentinel-2 images for automated change detection, and support their operational use in this context.

29. Improving near real time tropical forest change monitoring with multiple data sources | S Martin del Campo*, J Reiche, D Tuia, J Verbesselt, M Herold

Forest cover loss in the tropics is mainly driven by agriculture and other activities such as mining and timber logging. Tropical countries need reliable and timely measurements of the extent of forest disturbances to prevent and reduce unsustainable and illegal activities. Time series-based forest monitoring at near real time (NRT) has the capacity of detect forest changes once a new satellite image is available. NRT forest multi-sensor monitoring approaches have proven to increase accuracy in tropical forest change detection; although, current methods are still not capable of detecting changes with high spatial accuracy after a few observations. The inclusion of ancillary datasets, e.g. road networks, in combination with satellite time series via machine learning approaches has the potential to provide information about the drivers of forest change and therefore to increase the change detection accuracy. The main objective of this study is to develop such a multi-source approach. A NRT scenario will be simulated in the province of Madre de Dios, Peru. Sentinel 1, Sentinel 2 and Peru's road network datasets will be combined through the approach developed by Reiche et al. (2018) to detect forest changes. This approach calculates the conditional probability of forest cover change once a new image of the input time series is available. The conditional probability of forest change is computed using Bayesian updating, and forest change events are detected. New satellite observations are used to update the conditional probability of forest change along the time axis, and to confirm or reject forest change events detected previously. Very high resolution images, available through Planet Archive, will be used as guided reference data to collect training and validation data. The TimeSync tool will be used to estimate the temporal accuracy of the proposed method. Both spatial and temporal accuracy will be evaluated for the forest cover loss maps; therefore enabling us to discuss the utility of the data combination pipeline, as well as the importance of the single sources.This project was funded by the National Council for Science and Technology of Mexico (CONACYT).Reiche, Johannes et al. 2018. Improving near-Real Time Deforestation Monitoring in Tropical Dry Forests by Combining Dense Sentinel-1 Time Series with Landsat and ALOS-2 PALSAR-2. Remote Sensing of Environment 204(April 2017): 147-61. https://doi.org/10.1016/j.rse.2017.10.034.

30. The Ecosystem Disturbance and Recovery Tracker system (eDaRT) for large-area multi-satellite monitoring of forest dynamics | A Koltunov*, C Ramirez, S Ustin, M Slaton, E Haunreiter, M. L. Whiting

The Ecosystem Disturbance and Recovery Tracker (eDaRT) is a highly automated prototype system in continuous development, which has been operated since 2012 by the USDA Forest Service in diverse California forests to generate most current disturbance maps at Landsat scale. In this presentation we discuss the algorithm, its large-scale application approach, and the targeted performance assessment experiments.As a system designed to process all usable Landsat-class images, eDaRT can be used for long-term retrospective studies, year-around continuous monitoring, and near-real-time applications. To map large areas, the analysis is applied in parallel to individual scenes defined based on available computational resources. Disturbances are detected by an ensemble of empirical anomaly tests across all three dimensions of dense Landsat image time series: spectral, temporal, and spatial. In contrast to classic time series algorithms, pixels from the same land cover type are processed jointly as a group, rather than independently. In this way, the disturbance targeted by eDaRT are pixel changes that cannot be explained by a typical evolution of the land cover type. Among such changes are harvest/treatment, tree mortality, fire burns, and other ecologically meaningful disturbance types. In the first stage of the algorithm, in every available Landsat image, eDaRT estimates normalized metrics and maps classes of disturbance status (cumulative effect) relative to the same baseline period. In the second stage, a pixel-wise time series analysis is applied to find events of persistent change in the status. These events are the primary output of eDaRT. Currently, the scope is limited to natural ecosystems and does not include disturbance attribution or characterization of time intervals (e.g. long-term trends) as single units of analysis. The eDaRT core methods for anomaly detection are built for generic, cross-sensor comparisons along mixed-source image sequences, which we believe will simplify the future incorporation of non-Landsat image sources. Work is underway also to enhance the system's functionality, evaluate its performance beyond California ecosystems, and explore the algorithm's potential to take advantage of supercomputers and complement other forest monitoring efforts.

31. Development of a fuel loading database for calculating and mapping fire emissions from wildland fires within the United States | N French*, R Ottmar, S Prichard, M Billmire, M Kennedy, D McKenzie, E Kasischke, A Andreu, P Eagle, D Tanzer

Wildland fire is a primary force for land change in many biomes, with vegetation type and biomass key variables driving fire occurrence and serving as the fuel for fire. Fuel loading, the amount of combustible material, including vegetation, ground litter, and other live and dead surface materials at a site, helps define wildland fire behavior and smoke emissions. Patterns in fuel loading vary across space and time, but current geospatial fuel datasets do not account for this variability, making inventories of smoke and emissions challenging, hard to replicate, and difficult to defend both scientifically and for their diverse applications to wildland fire management and policy. This presentation will provide an overview of a current project funded by the Joint Fire Science Program (JFSP) to develop a database of fuels for the Contiguous United States (CONUS) and Alaska (AK) that quantifies the known variability in fuel loadings and reveals current gaps in fuel loading knowledge for the US. These data are derived from high-quality field-based datasets available from extensive field sampling over the past 20+ years. The project deliverables include a geospatial database of fuel loading distributions; software to manipulate and display its contents; sample outputs and guidance on how to use the database; and reports on results of a sensitivity analysis and validation methods, successes, and challenges. The compiled dataset will enable quantitative accounting of fire emissions with a realistic assessment of uncertainty. The long-term goal of developing this dataset is to develop fuels mapping products for use in geospatial modeling of fire emissions and smoke that can be used in national- and regional-scale smoke assessment by assigning each component of a fuel type (fuelbed strata) a characteristic range of variation that accounts for variability of fuel loadings in space and time. The presentation will address the importance of fuels in emissions and smoke modeling, the development of the fuel loading database, and the value of using data on fuel loading that includes an understanding of variability as well as what data is lacking related to fuel loading. A demonstration of the geospatial database information system developed under the JFSP project will be included, as well as an overview of what was learned regarding data gaps that can guide future data collections.

32. EPIC-simulated and MODIS-derived Leaf Area Index (LAI) comparisons across multiple spatial scales | J Iiames*, E Cooter, A Pilant, Y Shao

Aims and ObjectivesLeaf Area Index (LAI) is an important parameter in assessing vegetation structure for characterizing forest canopies over large areas at broad spatial scales using satellite remote sensing data. This variable is critical to models that simulate human and ecosystem exposure to atmospheric pollutants. Satellite-derived LAI, however, can be limited by obstructed atmospheric conditions yielding sub-optimal values, or complete non-returns. The United States Environmental Protection Agency is investigating the viability of supplemental modelled LAI inputs into satellite-derived data streams to support various regional and local scale air quality models for retrospective and future meteorological assessments. Our objective for this study is to calculate LAI estimates generated from the USDA Environmental Policy Impact Climate (EPIC) model (a widely used, field-scale, biogeochemical model) on four forest complexes spanning three physiographic provinces in Virginia and North Carolina at a 12-km spatial resolution. EPIC may work in combination with the satellite feed by constraining or inflating LAI values to reasonable figures based on biases observed in these validation studies. Thus, the modeled LAI could provide bias corrections where the satellite-derived LAI could provide the timing of green-up and senescence and relative seasonal changes in LAI. We compare EPIC LAI estimates with upscaled 12-km MODIS LAI. Included also is a comparison of in situ LAI to MODIS 1 km LAI. Methods and ResultsIn situ LAI data was regressed against Landsat ETM+ NDVI at all four sites to produce predictive equations for all forested area within a 1 x 1 km MODIS pixel. All non-forested LAI was estimated through values found in the literature. This in situ upscaled LAI was then compared to MODIS LAI at the same location. Comparing in situ scaled LAI (1 x 1 km) with the corresponding 1 km2 MODIS LAI for all four sites across all dates showed mean MODIS LAI values 1.5 to 3.0 times that of the in situ scaled LAI values. Large discrepancies occurred primarily after leaf-out and prior to leaf senescence where better correspondence was seen during the spring leaf-out and fall senescence periods. EPIC/MODIS LAI estimates at the 12 x 12 km spatial resolution showed a positive bias with MODIS LAI, where mean differences ranged from 0.84 - 1.21 over nine 12 km x 12 km grid cells centered in an upland hardwood site. Results from the other three sites will be presented at ForestSat.

33. Mapping forest management | D Schepaschenko*, F Kraxner, S Fuss, G Kindermann, M Dürauer, F Di Fulvio, A Krasovskii, M Lesiv

FAO FRA (Food and Agriculture Organization's Forest Resource Assessment) provides national statistics on different categories of forest: Primary forest, Production forest, Multiple use, Planted forest etc. Forest certification statistics again at national level is provided by certification schemes FSC (Forest Stewardship Council) and PEFC (Programme for the Endorsement of Forest Certification). There are currently no spatially explicit, openly accessible and reliable data on forest management below national level. This information is crucial for land use and economic models (e.g. GLOBIOM), estimation of sustainable biomass use potential, climate change adaptation and mitigation. More than 50% of global forest is used for wood production and about 10% of forest area has been certified globally. However, the speed of certification has slowed down and the vast majority of certified forests are located in the northern hemisphere. Understanding the drivers of these developments, examining the scope for further certification and using this information for development of future sustainable forest management strategies are challenging. We present a methodology for the development of a spatially explicit global map of managed and certified forest areas as well as an online tool (http://forest.geo-wiki.org) for visualization and interactive improvement of the map, which is aimed at a range of stakeholders including certification bodies, third-party certifiers, green NGOs, forestry organizations, decision-makers, scientists and local experts. A new methodology for downscaling national forest certification statistics has resulted in the first spatially explicit global forest certification map at a 1km resolution. Regional validation (Russia) suggests an overall accuracy of 89%. By building such a community-based online tool, more accurate information on forest certification will become available, promoting the sharing of data and encouraging more transparent and sustainable forest management. Such an approach is intended to encourage transparency in the forest certification arena but will also provide benefits to multiple users, e.g. in monitoring, marketing and in the development of targeted policy strategies.

34. The value of fusing MODIS and Landsat data for analyzing phenology and mapping forest tree species | K Turlej*, V Radeloff, F Gao, M Ozdogan

Forests provide numerous services to natural systems and humankind, but which services a forest provides depends greatly on its tree species composition. Therefore, it is important to track not only changes in forest extent, something that remote sensing excels in, but also to map tree species. The main goal of our work was to map tree species using data from MODIS and Landsat imagery fused via STARFM algorithm, and to maximize the applicability of the STARFM to very large areas.We developed an approach making it possible to generate the an[illegible] time series of cloud free Landsat surface reflectance using STARFM, even for years when fully cloud-free Landsat a[illegible]tions are not available. We tested the outcomes of our approach for year 2016 by mapping the extent and trackin[illegible] phenology of 27 temperate and boreal tree species present in the forests covering single Landsat footprint ([illegible]) located in Northern Wisconsin, USA. We selected this area because we had access to a high quality reference data set for local forests containing polygon-scale information on both pure and mixed stands. We used gradient boosting decision trees in order to generate a map of dominant tree species at the pixel- and stand-level.We obtained three important results. First, we achieved producer's accuracies in the range of 70-80% and user's accuracies in range 80-90% for the most abundant tree species in our study area. Second, we mapped tree species with the data from single year, even when the original fully cloud-free Landsat acquisitions were not available. Finally, we tracked annual phenology by generating synthetic time series of Landsat surface reflectance despite low data availability, which excluded either the standard application of STARFM and pixel based gap filling algorithms. Our approach excelled, since it does not rely neither on individual Landsat acquisitions fully covering the area of interest nor on numerous observations per pixel.We conclude that our approach to fusion of MODIS and Landsat data via STARFM algorithm can be seen as a solution for mapping temperate and boreal tree species over large areas. Especially, in scenario of low Landsat data availability where pixel based methods of gap filling fail. Moreover, we see our method useful for applications outside forestry such as mapping general land cover classes or monitoring agriculture and wildlife habitat productivity that would benefit from high quality data on phenology at a 30-meter resolution.

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35. Sentinel-2 image time series analysis for forest classification: On the way to a Germany-wide tree species map | S Preidl*, M Lange, D Doktor

With the ongoing technical evolution of satellite systems, the interest in new, highly detailed thematic forest maps has increased among forest managers, scientists and policy makers. Identifying conservation priorities and changes in land use with remote sensing requires up-to- date, high-resolution and area-wide mapping of forest parameters such as tree species and stand age. Our objective was therefore to develop a supervised image classi cation using Sentinel-2 imagery for tree species identi cation at pixel level. Our approach integrates spatially differentiated reference data (forest inventory) that is used as input for calibrating a variety of machine learning models. A method for creating as many cloud-free image composites from a pool of satellite imagery has been developed. The cloud-free time series were generated on a high-performance computer to map a maximum of phenological stages.The distinction of tree species is nally based on the spectral differences over time. Furthermore, this approach allows us to attribute classi cation uncertainties at pixel level. The developed process is highly automated and will be scaled up to the national level in further phases of the project. Stand age was additionally derived for our study site from high resolution LiDAR airborne data. The overall accuracy for the classi cation of eight individual tree species and one mixed deciduous forest class was 71.3%. For birch, spruce, Douglas r and pine, a producer's accuracy of over 80% has been achieved; the highest user's accuracy is 90.5% (oak). Homogeneous forest areas are clearly re ected in the result map. We found a logarithmic relationship ($R2 = 0.67$) between tree height estimation (based on LiDAR) and tree age (inventory data). A machine learning approach was subsequently used to estimate stand age for the entire study site. Our results on species composition and stand age are the basis for a better characterization of the conservation status of forests, which could also be relevant for future environmental assessments, for example in the framework of the planned power grid expansion in Germany.

36. Large spatial variation of leaf angle distribution quantified by terrestrial LiDAR in natural European Beech forests | J Liu*, A Skidmore, T Wang, S Jones, M Heurich

Leaf inclination angle and leaf angle distribution (LAD) are important plant structure traits, influencing the flux of radiation, carbon and water. LAD has been used as important parameters in radiative transfer, canopy photosynthesis, and rainfall interception modelling. Although LAD may vary spatially and temporally, its variation is often neglected in ecological models, due to difficulty in quantification.In this research, we aim to explore and quantify the variation of LAD in natural European Beech forests. Terrestrial LiDAR was used to scan 36 European beech plots of various forest structures. After extracting leaf points and reconstructing leaf surface, leaf inclination angle was calculated automatically. Then the mean (Î¸mean), mode (Î¸mode), and skewness of LAD were calculated to quantify LAD variation.Moderate variation of LAD was found in different successional status stands (Î¸mean ˆˆ [37°, 41°], Î¸mode ˆˆ [17°, 43°], skewness ˆˆ [0.07, 0.48]). LAD in all stands are most similar to plagiophile rather than conventional assumption of spherical distribution. A strong negative correlation was also found between plot Î¸mean and plot median canopy height, making it possible to estimate plot specific LAD from canopy height data. Larger variation of LAD was found on different canopy layers (Î¸mean ˆˆ [34°, 53°], Î¸mode ˆˆ [14°, 64°], skewness ˆˆ [-0.30, 0.71]). Beech leaves grow more vertically in the top layer, while more obliquely or horizontally in the middle and bottom layer.LAD variation quantified by TLS in this research, can be used to improve leaf area index mapping, and canopy photosynthesis modelling.

37. Retrieving forest canopy leaf area index using terrestrial laser scanning data | L Ma*, G Zheng, W Ju

Objective: Accurately quantify forest canopy leaf area index (LAI) is important to understand carbon and water cycles. Terrestrial laser scanning (TLS) provides an accurate way for LAI estimation since it can acquire three dimensional (3D) data with high density. Our goal in this research is to retrieve LAI using TLS data. Material and methods: Two study sites used different TLS data collecting modes were selected for this research. The first study site is the Washington Park Arboretum (WAP) in Seattle, WA. Thirty forest plots with different densities were selected, and TLS data were acquired using one center station hemispherical mode with sampling space as 0.1 m at 30 m. The second study site is the Baima Research and Experimental Forest (BM) in Nanjing, China. Three plots were chosen to represent high-density coniferous forest plot (plot-HC), medium-density broadleaf forest plot (plot-MB) and low-density broadleaf forest plot (plot-LB), respectively. TLS data were collected using multi-station mode with sampling spaces as 10 mm @ 10 m for plot-HC and -MB, 10 mm @ 15 m for plot-LB. Besides, digital hemispherical photos (DHP) and tracing radiation and architecture of canopy (TRAC) data were also collected to derive reference data.We developed algorithms to estimate LAI based on Beer's law from TLS data. Three key parameters were used in this theory, including gap fraction, extinction coefficient and clumping index, and we estimated them using TLS data firstly. Specifically, we developed a voxel-based gap size (VGS) algorithm to estimate gap fractions and clumping index with TLS data acquired with different modes. Meanwhile, we proposed a method to calculate extinction coefficient by considering leaf orientation distribution, including both inclination and azimuthal angles distribution. Lastly, TLS-based LAI results were compared with estimates from DHP and TRAC.Key findings: (1)TLS data can efficiently retrieve forest gap fraction, clumping index, extinction coefficient and LAI;(2)Sampling spacing is an excellent reference value to determine the voxel size of VGS algorithm;(3)TLS-based retrieval method can calculate LAI at different heights or different view directions if a relatively comprehensive forest TLS dataset was acquired.

38. What is the effect of varying wood density on lidar-derived above-ground biomass? | M Demol*, S Moorthy, K Calders, H Verbeeck, I Janssens, B Gielen

One of the most promising features of 3D terrestrial laser scanning (TLS) is the non-destructive acquisition of forest structural parameters in very high detail. This allows us to estimate the volume of trees and derive their above-ground woody biomass. Wood density is used to convert TLS derived tree volume into biomass. It is often undesirable, impractical or too time consuming to collect in situ samples for wood density for individual trees. Therefor, wood density values from repositories (e.g. DRYAD) or from a small sample of trees are used, neglecting the potentially large variability in wood density at forest stand scale.   In this study, we validate the TLS-derived biomass estimates against the destructive measurements of 60 trees (Pinus sylvestris, Fraxinus excelsior, Fagus sylvatica) in four different Belgian forest stands. Tree stems and crowns were weighted for above-ground biomass. Wood density was measured using i) wood disks along the main stem, and ii) increment borer samples at breast height. First results show that wood density varies among species and individuals, but also along the vertical and radial profile within the tree. Using the increment cores, beneficial because it is non-invasive, we generally overestimate wood density as compared to the full disk method. We will demonstrate the effects of these variations on our biomass estimations from TLS, using destructive measurements of 60 fully harvested trees as reference data. With this case-study we shed more light on the effect of wood density on biomass measurements at forest stand scale. These insights are important since the launch of several biomass mapping satellites in the near future will depend on accurate ground-based estimates of biomass.

39. Terrestrial laser scanning to derive non-destructive estimates of liana AGB | SM Krishna Moorthy*, K Calders, H Verbeeck

Tropical forests are currently experiencing large-scale structural changes, including an increase in liana abundance. Since lianas are disturbance-adapted plants, liana abundance is likely to increase with increased forest disturbance, thereby increasing tree mortality and reducing tree growth. Despite the increasing liana abundance, lianas are often ignored in the AGB estimation of the forest as they are assumed to contribute very little to the total AGB. Very few studies have established allometric equations for estimating liana AGB by destructive harvesting. Like trees, also for lianas one of the main limitations is the lack of data from larger lianas. Despite being few in numbers, large lianas represent a large fraction of the total liana biomass. Accurate quantification of liana AGB is necessary not only to better understand the role lianas play in the carbon cycle of the forest but also to estimate how much of the tree biomass displaced by lianas is replaced by them. Since terrestrial laser scanning (TLS) derived volume estimates do not assume any prior information about the structure of lianas, they can yield better estimates of AGB compared to the allometric equations.Our study was conducted in the Nouragues Ecological Research Station, French Guiana. We collected TLS data using RIEGL VZ1000 from lianas ranging in diameter from 4 to 28 cm in August 2017. We derived biomass for each liana from Quantitative Structure Modelling (QSM) derived volume estimates and an average wood density of 0.4 g/cm3 (from literature). We compared the TLS-derived biomass with six different allometric equations. Our results show that liana AGB estimates from the most commonly used pan-tropical allometric equation was as much as 90% higher than the TLS-derived liana AGB. On the other hand, the region-specific allometric equation for a secondary forest in Ghana significantly underestimated the liana AGB by 77%. TLS-derived liana AGB was comparable to the AGB from the allometric equation developed for French Guiana highlighting the necessity for region-specific allometries. This has important implications for global vegetation models attempting to include lianas as the choice of an allometric equation decides the way the plants allocate their carbon in the model. The method can be used to establish better allometric equations for deriving liana AGB without the need for destructive harvesting especially for large lianas, which are practically more difficult to harvest.

40. A New Method of Equiangular Sectorial Voxelization of Single-scan Terrestrial Laser Scanning Data and Its Applications on Forest Defoliation Estimation | L Huo*, X Zhang

Single-scan terrestrial laser scanning (TLS) is a technique generating 3D points of the objects which has been widely applied in forest inventory in recent years. To reduce the redundant from TLS data, voxelization is an efficient and frequently used process of TLS data reduction. In this study, an innovative method of equiangular sectorial voxelization was presented based on the distinctive point distribution characteristic of single-scan TLS. To verify the effectiveness of the new voxelization method and illustrate its application, 48 plots and 1098 individual trees with different needle loss degree were scanned using single-scan TLS. Their defoliation could be linear regressed using only point density derived from this new shape of voxels, and obtained 0.89 R2 value and 88.1% accuracy (for individual-tree-scale estimation), and 0.83 R2 value and 87.9% accuracy (for plot-scale estimation). Based on such results, point density became the only required indicator for defoliation estimation, and thus the estimation method was further refined to be practically applied, avoiding regression and massive field measurement. We concluded that the new voxelization method was effective, and the point density calculated based on that was an efficient feature revealing forest attributes.

41. Novel TLS Device with Excentric Automotiv Scanner to avoid occlusion in single stand-point scanning | G Bronner*

TLS in forestry has to deal with occlusion, unless the additional effort of scanning from multiple stand-points is accepted. (Meinrad Abegg, Daniel Kükenbrink, Jürgen Zell, Michael E. Schaepman and Felix Morsdorf 2017)A novel scanning device was constructed to avoid or reduce this handicap. There is a horizontal protruding arm of 80 cm which rotates round the vertical axis of a tripod in a very slow motion, 0.3 R/min. On the outer end of the horizontal arm, there is an automotive scanner mounted, where the scanner unit rotates round the horizontal axis of the arm with 5-30 R/sec. On the opposite end of the arm, the CPU and battery helps to balance the construction.   A prototype of this scanner is currently under construction. It uses Quanergy M8 as sensor, which produces > 400.000 pulses per sec. and records 3 echoes per pulse; theoretically the sensor can reach out 200 m. The costs of the components will most likely stay under $10.000, while we expect outstanding accuracy from 1,2 Mio echoes/sec.First simulation runs show, that the geometrical setup can avoid 80-95% of occlusion compared to conventional TLS, depending on stand density and sample area.Additionally, the simulations suggest 80cm as an optimal length of the excentric arm. By this way of scanning, the occlusion is minimized to a degree, where missing trees could easily be substituted by statistic means. We are working on a sophisticated combination of the Bitterlich approach on the one hand with a fixed circular sample plots on the other hand to maximize the efficiency of such measurements. A simulation software was programmed which allows virtual measurements with different scanning geometries, different rotation speeds and different sensor characteristics. As forest data-sets for the simulations we used TLS-test-beds measured with Faro-scanner at multiple stand points, where tree positions and DBH are known.Simulation runs on real and virtual forest data-sets of different forest types are continued during the next weeks. The results will be statistically evaluated. In the same time we are working on the optimization of processing methods.The construction of the prototype will be finished by July. We are aware of noisy data from automotive scanners and look forward to first in situ measurements.

42. Seasonal structure-function interactions: fusing solar induced fluorescence and terrestrial LiDAR for holistic ecosystem measurement | A Stovall*, R Maini, R Nardacci, H Shi, H Shugart, X Yang

Dynamic changes in forest structure drive trends in ecosystem-level photosynthesis globally, but gross primary production (GPP) and forest structure remain challenging to accurately quantify in detail across space and time. Most estimates of GPP are based on modeling and flux observations, but both approaches are indirect and coarse in spatial scale. A new remote sensing technique measuring solar induced fluorescence (SIF) is directly linked to biophysical processes at the leaf level, providing essential information for estimating GPP at ecosystem scales. SIF measurements are directly impacted by horizontal canopy structure - increasing leaf area increases GPP. However, the impact of vertical structure or complexity on SIF measurements is not well understood and may enhance GPP at the canopy-scale. A monitoring framework that disentangles the structural signal in both horizontal and vertical dimensions would ultimately provide essential information for maximizing the utility of ground-based SIF observations. We monitored spring phenology and quantified changes in canopy structure to investigate seasonal structure-function relationships at a mixed temperate forest site in Virginia. We deployed high frequency terrestrial LiDAR to quantify fine-scale seasonal changes in canopy structure and increasing LAI. Tower-based SIF measurements provided estimates of GPP over the study period for comparison to structural changes. Both acquisitions were augmented with ongoing flux tower observations, weekly drone flights, and hemispherical photography to capture major shifts in ecosystem function due to structural change. We present preliminary findings from the first year of seasonal observations and discuss potential future applications for fusing 3D structural measurements with ongoing monitoring of photosynthesis at ecosystem scales.

43. Instrument-based LiDAR point cloud modeling with DART | T Yin, J Qi, B Cook*, J Gastellu-Etchegorry, S Wei, D Morton

Light Detection And Ranging (LiDAR) has been successfully applied in spaceborne, airborne and ground-based platforms. The point clouds generated from Aerial and Terrestrial Laser scan (ALS and TLS) allow retrievals of geometrical and biophysical information of vegetation canopies at individual plant and landscape levels. However, most of the existing approaches (gap fraction computation, Leaf Area Index (LAI) and Leaf Area Density (LAD) retrieval, etc.) rely on other measurements or allometric equation fitting to account instrumental artifacts (e.g. partial hit, limited number of returns, and unknown definition of point intensity) different from theoretical estimation. Understanding the LiDAR points requires modeling approaches that can precisely account the instrumental configuration and the physical interaction between the emitted laser pulse and reflecting targets. Here, We present the latest development of the Discrete Anisotropic Radiative Transfer (DART) model in simulating discrete-return points, photon-counting points and waveforms with output in text format and industrial ASPRS LAS format. Both discrete return and photon counting data are generated from the physical principles of sensor acquisition and mathematical methods (e.g., Gaussian Decomposition) applying on time-dependent waveform modeling. We study the influencing parameters on existing point cloud inversion for the gap, the LAI and the LAD estimation, including the footprint size, the spatial and temporal power distribution, the leaf size and shape, the height of canopy, and the number of returns accepted by LiDAR receiver. These studies are carried out with specified aerial and terrestrial instruments, including Riegl VQ-480i ALS device and Leica ScanStation P40 TLS device. Results show that realistic point cloud can be simulated by DART. Several existing inversion approaches based on return number counting, and intensity for ALS are evaluated using DART point cloud simulation. DART provides this tool for scientific and educations purposes with free licenses. This development is currently used for improving the LiDAR inversion of Genhe ecological site in China. It will also be used to simulate LiDAR data onboard Goddard's LiDAR, Hyperspectral & Thermal Imager (G-Liht) shortly, and combining with the fluorescence measurement for investigation of heterogeneous biophysical configuration influences.

44. Quantifying Riparian Buffer Zones and Floodplain Vegetation Roughness using a Drone-based Lidar | J Resop*, WC Hession

Riverscapes are complex ecosystems linking channels, banks, riparian zones, and floodplains. Physical measures of riverscapes, such as channel geometry, spatial complexity, and vegetative cover, are important for a range of ecological and hydromorphological processes. Hydraulic roughness, as influenced by channel terrain and vegetation, can be a particularly difficult metric to quantify. Roughness directly effects hydraulic properties that influence aquatic habitat, flooding, sediment transport, water quality, and channel morphology. Roughness itself can be classified with respect to its components at different stream stages, such as surface bed material and floodplain vegetation. Traditional measures of stream roughness include manual surveys of grain size and vegetative cover, comparisons to images of streams with known roughness, and back calculations from onsite flow measurements. The goal of this study is to use high-resolution, drone-based lidar to estimate roughness at different stages in a more quantitative and direct manner. Drone-based lidar combines the high resolution surveying capabilities of lidar with the mobility of unmanned aerial vehicles. The result is a high-density point cloud with the resolution of terrestrial laser scanning and the coverage of aerial laser scanning. We will present pipelines for processing drone-based lidar data to produce high-resolution models of terrain and canopy height. The results of these pipelines will also include measures of surface roughness (based on the variability of the terrain) and vegetative roughness (based on the variability of the riparian and floodplain vegetation). Roughness measures will be quantified at different flow stages and across seasons (reflecting changes in vegetation) for a reach of Stroubles Creek in Blacksburg, VA.

45. The operational application of airborne Lidar technology for forest stand-level inventory in the South of China | Y Pang*, C Li, H Dai, Z Li

Forest stand map, which is generated by forest management inventory, is the most fundamental map in the forest management of China. In a stand forest map, the smallest unit is forest stand subcompartment which is also the smallest operational unit forest management planning in many countries such as China, Russia, and Finland. Forest stand map contains many attributes for each sub-compartment (the basic forest management unit). Traditional methods for forest stand map generation are based on high space resolution remote sensing image, topographic map and field inventory, and generally are very tedious and time-consuming. The airborne lidar technology brings new possibilities for forest stand map generation, especially in forest stand parameters estimation. This study showed the operational application of lidar-derived fine-resolution forest parameter information for forest stand maps. We used airborne lidar data and field data of concomitant plots in a forest of Guangxi, South of China to estimate several typical forest parameters, including dominate height, mean height, volume density, biomass, and canopy closure. The project area is about 20, 000 km2. The forest stand polygons were digitized based on aerial photos with 0.5 m spatial resolution. Forest type information was also interpreted by local foresters using these aerial photos. Five classes were used to stratify forest parameter estimation models, which include Chinese Fir, pine, eucalypt, broadleaf forest, and shrub forest. The overall accuracies are 92% for mean height and 90.7% for volume density.

46. Mapping smallholder forest plantations in Andhra Pradesh, India using Sentinel 2 | PT Williams*, S More, SA Cerv, RH Wynne

The Indian state of Andhra Pradesh has been an area in which overall forest cover has decreased (Forest Survey of India 2013), while there are apparent increases in forest plantation area, predominantly through conversion of degraded and existing agricultural land. Unfortunately, there are constraints to accurately mapping forest plantations using remotely-sensed data due to their small (2 ha median) size, short rotation ages (often 3-5 years), and spectral similarities to croplands. Our goal is to use remotely-sensed data to map (smallholder) forest plantations. Random forests classifications used all minimally cloud-impacted Sentinel 2 MSI data acquired since launch (tiles QNE and QPE in East and West Godavari), both multitemporal (a) VNIR (10 m) alone or (b) combined (downscaled) VNIR, red edge bands, and SWIR bands (20 m). In situ data on forest plantations provided by collaborators was supplemented with additional training data representing other land cover classes (water, natural forest, agriculture, sand, and urban) in the region. Initial three-category (nonforest, plantation forest, and natural forest) classifications show promise even using only the VNIR, with 85% out-of-bag accuracy, although there is room for improving the separation of forest plantations from agricultural land uses. Variable importances show the clear need for multitemporal imaging with the red and blue bands being the most used across seasons.

47. A review of field and laboratory spectral measurements of coniferous forest components | M Rautiainen*, P Lukeš, L Homolová, A Hovi, J Pisek, M Mõttus

Coniferous species are present in almost all major vegetation biomes on Earth. Monitoring coniferous forests with satellite and airborne remote sensing is active due to the forests' great ecological and economic importance. We review the current understanding of spectral behavior of different components forming coniferous forests. We look at the spatial, directional and seasonal variations in needle, shoot, woody element and understory spectra in coniferous forests based on measurements. To identify which coniferous species and geographical regions have been the most investigated, we went through all openly available datasets containing spectra of coniferous trees' elements, as well as publications in which needle, shoot, bark or understory spectra had been measured, even if the data are not openly accessible. Despite the fact that coniferous structures are often complex and difficult to measure, a large number of efforts have been made to collect empirical data on coniferous forests' spectra in Northern and Central Europe and North America. The number of scientific studies especially on the spectral properties of coniferous needles has notably increased during the past decade: based on our literature review, approximately 40% of the studies reporting e.g., needle spectral data have been published after 2010, and 75% of the studies have been published after 2000. Our literature review shows that, in general, the spectral properties of coniferous forests growing in the boreal biome are better documented than the spectral properties of coniferous forests elsewhere. For boreal coniferous forests, there are already a few open access data sets on needle and bark spectra for key species and one open access dataset on understory spectra. Typically, the spectral data reported in these databases and other scientific articles have been collected only during peak growing season. The general behavior of the spectral response of coniferous needles is now much better understood than fifteen years ago. There is a clear gap, however, in knowledge concerning the optical properties of needles and bark of coniferous species growing in the tropics, and also for many species growing in the temperate zone. Finally, we also provide a synthesis of gaps in the current knowledge on spectra of elements forming coniferous forests that could serve as a recommendation for planning scientific efforts in the future.

48. Upscaling dorsiventral leaf optical properties in forest radiative transfer model | P Lukeš*, E Neuwirthová, R Janoutová, Z Lhotáková, L Homolová, J Albrechtová

Radiative transfer models (RTM) are excellent tools to study interaction of photos in vegetation canopies. They allow us to study the complex effects of canopy structure and leaf optical properties on top-of-canopy reflectance. Importantly, inversion of the model simulations against observed forest reflectances may yield vegetation parameters without the need of in-situ data for model calibration. However, to achieve good retrieval accuracies, forest reflectance simulations must fit the observed ones. Leaf optical properties are the key input parameters in RTM. They hold an information on leaf biochemical (chlorophyll and carotenoid content, water content) and structural (leaf thickness, distribution of pigments within a leaf) properties. Whereas leaf biochemical effects on reflectance is well understood, leaf internal structure and its effect on dorsiventral leaf optical properties asymmetry has been neglected, assuming equal leaf optical properties on both leaf sides. This may lead to significant discrepancies between modeled and observed forest reflectance, and ultimately, in decreased performance of the inversion of forest parameters.In this study, we first test the performance of Dorsiventral Leaf Radiative Transfer Model (DLM) for the simulations of dorsiventral leaf optical properties. Model performance is tested on leaf samples of six tree species (Populus tremula, Salix caprea, Betula pendula, Alnus glutinosa, Alnus incana) of different inner leaf structures (fraction of air spaces, thickness palisade and spongy parenchyma) fort both upper and lower leaf reflectance. By coupling measured dorsiventral leaf optical properties with DLM model simulations of measured input parameters (internal structures and biochemistry), we were able to validate forward DLM model simulations. Next, wide range of dorsiventral leaf optical properties (DLM model simulations) were further up-scaled to canopy level using Discrete Anisotropic Radiative Transfer model (DART) to quantify the sensitivity of inner leaf structure parameterization in the model (i.e. assuming equal optical properties on both sides, or dorsiventral leaf optical properties asymmetry), both in nadir and off-nadir observation geometries. Finally, we discuss the influence of dorsiventral leaf optical properties parametrization on forest reflectance simulations for wide range of leaf inner structures and their impact on forest product retrievals.

49. A digital mapping method for linking high resolution remote sensing images to individual tree crowns | S Graves*, S Bohlman

Remote sensing data provides unique information about Earth's surface that can be used to address ecological questions. Linking high resolution remote sensing data to field-based ecological data requires methods to identify objects of interest directly on the digital images while in the field. Mapping individual trees with a GPS often has location error and is focused on position of the tree stem. This presents a mismatch between field data and the pixel information in the digital image. We present a mapping workflow that uses a consumer-grade GPS receiver and a tablet computer to spatially match individual trees measured in the field directly to a digital image of their crowns taken from above the canopy. This paper outlines the challenges associated with mapping individual trees, a field protocol for collecting these data, and supplementary code. As more sensing data with a resolution capable of resolving individual trees becomes more available, the opportunities to leverage these data for ecological studies grows. If ecologists can make use of the data, there is great potential for expanding the spatial scale and extent at which ecological studies are conducted.

50. Reforestation and Economic Security in a Developing World | D Oetter*

An important aim of the UN Sustainability Goals is the reduction of poverty across the planet, and an equally critical aim of the UN Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation is to help reforest cleared lands in order to sequester atmospheric carbon. The American South, in particular Central Georgia, has transitioned in the last 150 years from native mixed forest to intensive agriculture, and then after the collapse of the cotton economy to modern industrial agroforestry. These transitions were largely due to the economic and social drivers of globalization, similar to the forces that are currently in play throughout the developing world. This research links the spatial mapping of reforestation to the local and state economic condition, exposing a grave concern: reforestation does not necessarily drive economic success. Using Landsat 8 imagery to create a forest cover map of an 9,914 km2 region spanning ten counties, a geographic regression was used to relate forest cover to US Census data for economic indicators. It is apparent that there is a strong inverse relationship between the amount of forest cover and the county-level per-capita income ($R2 > 0.50$). It appears that counties that have accomplished reforestation, most often through intensive pine agroforestry, are associated with lower income levels. The implications of this relationship challenge global efforts to promote forest planting while simultaneously promoting economic growth and this relationship must be addressed in order to gain the support of local and state agencies.

51. Multidecadal rates of arctic and boreal land cover change in ABoVE inferred from dense Landsat time series | J Wang*, D Sulla-Menashe, C Woodcock, O Sonnentag, M Friedl

The rapid climate change in arctic and boreal ecosystems is resulting in drastic changes to land cover composition, including woody expansion in the arctic tundra, successional shifts following boreal fires, and permafrost thaw-induced wetland expansion. The impacts on physical climate and the carbon cycle of these land cover transformations are well-documented in field and modeling studies, but there have been few attempts to estimate overall rates of land cover on decadal and continental scales. Previous studies were either too coarse in spatial resolution or too limited in temporal range to analyze relevant rates of change. As part of NASA's Arctic Boreal Vulnerability Experiment (ABoVE), we employ dense time series of Landsat remote sensing data to map disturbances and classify land cover types across the ABoVE domain, spanning western Canada and Alaska, over the last three decades (1982-2014) at 30m resolution. We utilize regionally-complete and repeated acquisition high-resolution (<2 m) remote sensing imagery to build a database of training data that samples from geographically diverse regions and follows a nested, hierarchical classification scheme encompassing vegetation form, wetland status, vegetation cover density, and land use. We use the Continuous Change Detection and Classification (CCDC) algorithm to estimate change dates and stable temporal-spectral features to predict land cover types using a semi-supervised random forest algorithm augmented with tree-based clustering. Land cover change information provides substantial insights into the nature of satellite-observed 'greening' of the arctic and boreal ecosystems and the potential climate-carbon implications of regional shifts in forest types.

52. Identifying and correcting biases in global tree cover products: a case study in Costa Rica | D Cunningham*, M Fagan, P Cunningham

Global forest products are widely used in analyses of deforestation, fragmentation, and connectivity, but rarely critically assessed. Inaccuracies in these products could have consequences in future decision making, especially in data-poor regions like the tropics. In this study, we assess potential biases in global and local tree cover products across gradients in elevation, precipitation, and agricultural land cover in a diverse tropical country, Costa Rica. To evaluate product accuracy and bias, freely available high-resolution imagery was used to quantify tree and land cover at random locations across these gradients. Both global and local forest cover products showed biases with climate, elevation, and agricultural cover. Relative to the local national forest cover map (Fernández-Landa et al., 2016), global products (Hansen et al.,2013; Sexton et al., 2013) underestimate tree cover below 250 mm of precipitation and at elevations above 500 m, with a larger bias for precipitation. For agriculture, global and local products classify agricultural fields as forest; perennial erect crops (banana, oil palm, and coffee) were particularly misclassified by all products examined. To correct for the observed global and local biases, we attempted to generate a corrected local map of tree cover. First, a country-wide agricultural land cover map was classified using crop validation data from a national crop database. Then, the Random Forests algorithm was used to create an integrated prediction of tree cover for Costa Rica in 2015, with the agricultural land cover map, data on elevation and precipitation, and existing global and local land cover maps as inputs. The accuracy of tree cover prediction increased fourfold over the best global and local products. This research demonstrates a simple, transferable methodology to correct for observed biases in global and local forest cover products, especially in tropical regions with low precipitation, significant topography, and/or perennial agricultural production.

53. Mapping human settlements and population density in the Democratic Republic of Congo using Landsat data | P Lola Amani*, P Potapov, A Pickens, M Steininger, M Hansen

Population maps are dependent on the availability of up-to-date, spatially-explicit population census data, typically created by disaggregating population estimates from census units and attributing them to mapped human settlements footprints. Previous studies have demonstrated the ability to distribute population more precisely over land by using satellite-derived estimates of settlement locations. The Democratic Republic of Congo (DRC) represents a challenge to population estimation because of a large and mostly rural population and a lack of data on settlement locations. We report here a study that generated three products for the DRC: 1) a map of settlement distribution, 2) a new estimate of national population, and 3) a map of population distribution within settled areas. Our methods: we first mapped human settlements using a supervised, a decision-tree classification of Landsat imagery, assessed map accuracy and bias using stratified random sampling and report the adjusted areas of settlements with known uncertainty. For the total population, we conducted a stratified-random sample, with strata based on the settlements map. For each sample we manually counted observable dwelling units, using high-resolution satellite imagery available on Google Earth, and multiplied by the national mean number of people per dwelling, provided by the 2013-2014 Demographic Health Survey (DHS). For the map of population density, we again used a decision-tree regression, this time of the population values from the same sample points against Landsat imagery. We estimate the total settled area in DRC at 12,930.17 km2, or 0.55% of the national land area (2,345,000 km2). We estimate DRC's total population in 2013 at 101.4M inhabitants +/- 7.1M (standard error). Of these, 18.8% live within 300-m of all mapped settlements. DRC remains a very rural country, where over 51.1 percent of the population lives beyond 50 kms from a major city. This study provides the first model-based estimate of national population as well as the first fine-resolution estimation of settlement and population distribution. These data can allow improved land use planning at the national and sub-national scales.

54. Human-Guided v. Automated Classifications of Ponderosa Pine Plantations in the Willamette Valley, Oregon | A Riddell*, B Strimbu

Forest species classifications are becoming increasingly automated as advances are made in machine learning. These algorithms range from simple decision trees to intricate neural networks, and often excel in accurately distinguishing between species. However, complex algorithms can have high input costs, including the cost of high resolution data and time required to train both the researcher and the algorithm. Furthermore, publications demonstrating the skill of such algorithms frequently test a small focus area, and attempt to classify down to the individual tree level. Large-scale classifications may be impractical for such detailed techniques, and instead can benefit from simple, traditional methods of classification, such as maximum likelihood (ML). In this study, we compared the results of a human-guided ML classification with the results of a highly automated ML classification of ponderosa pine stands in the southern Willamette Valley. The area classified comprised about 8,166 km2. The goal of the classification was to identify contiguous stands of ponderosa pine against a mixed-forest and non-forest vegetation background. The human-guided classifications involved raster-specific training data that were refined through iterations of classifications. The automated classifications used a single training dataset collected from all rasters that was used to predict pine and non-pine locations in each raster. The classifications were performed using 1m resolution RGBI aerial imagery from the National Agriculture Imagery Program. Following classification, we applied a height mask from a 3m resolution lidar-derived canopy height model. The lidar data was acquired from the Oregon Lidar Consortium. The masks removed mature mixed-conifer forests and agricultural areas from the pine results, decreasing commission error. Human-guided classification accuracy correlated with availability of regional training data, but on average reached accuracies of 87% (producer) and 74% (user) without the lidar height mask. Masked classifications have the potential to reach overall accuracies of up to 90%. Initial tests of automated ML classifications without lidar height masks have not surpassed human-guided ML classifications, instead averaging about 75% overall accuracy.

55. Simulating Empirically Observed Forest Patterns Using a Hybrid Demand-Allocation Land Use Change Algorithm | E Brooks*, J Coulston, K Riitters, D Wear

Future projections of land use at fine spatial grains are essential for both research and policy. However, most projections are given at aggregate levels, requiring downscaling into spatially explicit projection maps for many ecosystem service analyses. Demand-allocation algorithms take given quotas and convert cells across the raster, typically based on a modeled probability surface. Such algorithms generally employ at least one of two allocation approaches: contagious or random. Contagious allocation guarantees conversion of cells with high transition probability, but it yields only one outcome for a given quota and tends to produce unrealistically contiguous regions of conversion (e.g., uniform development expansion along highways). Random allocation produces variable outcomes but may not effectively utilize the probability surface. We present a hybrid seeding approach that 1) randomly determines a patch center (seed) by taking the highest-probability cell of a limited sample of size n over the study area, then 2) converts neighboring cells through a joint function of transition probability and distance to the seed. We assessed seeding in terms of its ability to capture observed forest fragmentation (as well as comparisons to pure contagious and random approaches) based on a landscape pattern metric, using a modified version of the National Land Cover Database from 2001-2011 as reference data. We found that outputs based on relatively low values of n typically captured the selected fragmentation metric for multiple scales and fragmentation classes. For values of n greater than 200, we found little variation between realizations. The seeding outputs' accuracy was largely independent on the scale for which the fragmentation statistic was computed, as well as the fragmentation class. Thus, we recommend basing future land use projections on multiple seeding realizations deriving from a range of values for n between 20 and 200, to best capture the expected variability.

56. Sentinel-1 CSAR Forest Land Cover Mapping of Troms County, Norway. | J Haarpaintner*, HA Tømmervik

NorthState - TromsSAR was an extension of the EU FP7 project NorthState in order to apply the experience of forest land cover (FLC) monitoring with Sentinel-1 CSAR on Troms County.All Sentinel-1 data over Troms County from January 2015 to October 2017 have been acquired, processed and statistically analyzed in regard to 9 different land cover types: water, settlements, glaciers/snow, bare land/rocks, heathland, peatland, grassland/agricultural land, deciduous forest and conifer forest.Mean monthly backscatter signatures of co- and cross-polarization backscatter, VV and VH, respectively, have been established, using training polygons extracted from visual interpretation of aerial photography from the Norwegian Mapping Authority (norgeibilder.no), SAR mosaics and the official 50m-resolution land cover data set from the Norwegian Institute for Bio-Economy (NIBIO).The same training polygons have then been used for a maximum likelihood classification using the monthly dual-polarization mean backscatter mosaics from May to October as well as a winter average (December to March) as features. Other feature combinations as well as data from each single year have also been tried.The result of the classification is a 9-class land cover map over Troms County based only on Sentinel-1 CSAR data. The land cover map has then been assessed with the full AR50 data set over the whole region, showing an overall agreement of 65% comparing seven land cover classes by excluding water and settlements that have been masked. When only comparing the super-classes forest and non-forest, the overall accuracy of the Sentinel-1 land cover map according to the AR50 data is 87.8 %. The results here are encouraging, since Sentinel-1 CSAR data can be utilized independently of clouds, which is important in Fennoscandia and Arctic. A field campaign using a remote piloted aerial system (RPAS), a DJI Phantom 3 Pro quadcopter, was undertaken collecting very high resolution aerial image mosaics at 5 different locations on the test area Breivikeidet. These observations are also compared to the FLC map and to in-situ measurements of vegetation properties using hand held NDVI-instruments/NDVI-cameras as well as vegetation composition, forest stand properties and tree heights. These measurements could serve for further validation of the satellite image classifications using fused SAR-Optic imagery for further improvements of the FLC maps.

57. National wide CHM, deforestation areas and forest boundaries from airborne lidar data in Estonia | A Vain*, K Sepp, J Raet, M Villoslada Peciña, M Lang

Forest is one of the main national resourced of Estonia. Around 51% of the territory of Estonia is covered with forest and 40% of that is owned by the state. This means that 60% of the forest in Estonia is private owned. Main forest type is mixed forest with four main tree species: spruce, pine, birch and aspen. Recent years have raised a lot of questions and debates weather state is allowing to cut too much forest. Using Estonian Land Board airborne lidar data it is possible to monitor deforestation on a national level. Estonian Land Board has been making national wide airborne lidar measurements since 2008. From that period the territory of Estonia has been measured already three times which enables to detect changes between measurements. One of the changes that can be detected is deforestation. Comparing canopy height models (CHM) that are derived from airborne lidar data it is relatively easy to detect areas where deforestation has occurred. Areas where the canopy height between different CHM-s had reduced less than 5 meters and areas that were smaller than 2500 m2 where neglected. The end result is an automatically calculated national wide map of deforestation that contains information about the dates between what the deforestation occurred and the area. Next steps will be to calculate for each detected area the average tree volume per hectare and monitor areas where the trees are starting to grow again. From CHM-s it is also possible to extract forest boundaries. For forestry applications the height limit that the tree is considered as a part of forest is 1.3 meters. For mapping purposes that height limit is 4 meters. For this study 4 meters were used simply because the lidar data was not dense enough the produce reliable results in the CHM under 2 meters. Automatically calculated forest boundaries can be used to semi-automatically update national topographic maps.The wider use of products derived from airborne lidar data helps to monitor changes in forest and improve the existing monitoring methods. Repeated measurements are useful for change detection like deforestation and canopy growth.

58. Forest mapping with machine learning methods | R Boesch*

Forest mapping with machine learning methodsSince several years very deep convolutional networks (CNN) started to become mainstream, yielding substantial gains in various applications.Imagenet (Krizhevsky et al.) and Inception (Szegedy et al.) are prominent representations of computer vision based classification apporaches with deep convolutional neural networks among many others. But the required training of millions of images for a complete model is a major effort and often not feasible due to limited data. Transfer learning is therefore a kind of shortcut by combining large parts of an existing model and adding a new classification layer.Using aerial images acquired with an ADS80 sensor with ground resolution of 25cm from the Swiss national forest inventory, 8 different classes have been defined to evaluate, if an already trained convolutional neural network can be created also with aerial imagery content. Typically trained computer vision models like Inception or ImageNet consist of oblique scenes in human environments, mostly with artificial edges from buildings or other man-made structures. Aerial images contain much less linear information and specially forested areas are dominated by varying color patterns with limited structure. Therefore 3 channel images using NIR (833-920 nm), green and blue band from the ADS80 sensor has been used for retraining the CNN to achieve optimal color discrimination.The established computer vision model of inception has been selected because of its retraining capability. It has been demonstrated for many computer vision applications, that retraining is surprisingly effective and works with moderate amounts of training data.Preliminary results show reliable discrimination of broadleaf and conifer forest is feasible, but forest cover discrimination is strongly related to the training effort for forest classes.A. Krizhevsky, I. Sutskever, and G. E. Hinton. Imagenet classification with deep convolutional neural networks. In Advances in neural information processing systems, pages 1097-1105, 2012. C.Szegedy,V.Vanhoucke,S.Ioffe,J.Shlens,andZ. Wojna. Rethinking the inception architecture for computer vision. arXiv preprint arXiv:1512.00567, 2015.

59. Spatial prediction of old-growth forest fire refugia in the US Pacific Northwest | G Meigs*, M Krawchuk

Across western North America, increasing wildfire activity presents a challenge to land managers seeking to protect and restore late-successional and old-growth (LSOG) forests. Fire refugia – locations that remain unburned or burn less severely than surrounding areas – influence forest regeneration and wildlife recolonization, and their probability is higher under specific topoedaphic and weather conditions. Here, we develop spatial predictions of LSOG fire refugia based on topography, fuels, fire weather, and climate. We focus on recent fires in forests managed under the Northwest Forest Plan, which maintains a network of LSOG forest reserves to sustain and restore habitat for the northern spotted owl (Strix occidentalis caurina) and other vulnerable species. Specifically, within large forest fires that burned between 2004 and 2015 in the West Cascades of Washington and Oregon (n = 44), we use annualized imputation maps to identify locations that supported LSOG forest composition and structure prior to burning. We classify refugia as those LSOG locations exhibiting minimal change in the Landsat-based RdNBR severity index (30-m grain). This refugia class corresponds to estimated tree basal area mortality of 0-10% based on pre- and post-fire field observations across the region. We define the remaining burned LSOG locations as non-refugia (estimated basal area mortality: >10-100%). We then employ boosted regression tree modeling to quantify refugia predictability and to render maps of refugia probability under variable fire weather conditions. Topographic metrics at multiple scales explain the variability of refugia occurrence and conditional probability, but their relative importance depends on fire weather, pre-fire fuels, and interannual climate. We will integrate results from this study with ongoing conservation planning initiatives to determine locations most likely to persist as fire refugia, particularly in LSOG forest environments critical to the survival of threatened and endangered species. Landscape-scale maps based on these spatial models could enable forest managers to prioritize locations where it is appropriate to either suppress or allow wildfires to burn under specific fire weather conditions.

60. Utilizing high-performance and data-rich cloud platforms for nearest neighbor imputation models: Bringing NN to the cloud | M Gregory*, D Bell, N Gorelick, V Myroniuk

Nearest neighbor (NN) imputation is a non-parametric approach for predictive mapping of forest structure and composition attributes. In this multivariate approach, forest inventory plot attributes are predicted, or imputed, to unsampled forest land based on a suite of environmental and spectral predictor variables and, optionally, an ordination metric that relates forest attributes to environmental signatures. The wide use of NN methods has been facilitated by popular code libraries, such as yaImpute for the R programming environment. While variations of NN imputations have been used extensively at regional extents utilizing mid-scale imagery (e.g., 30-m Landsat data) and at national extents utilizing coarse-scale imagery (e.g., 250-m MODIS data), management of large geospatial datasets and the computational demands of data processing and analysis currently limit the application of NN for many users. In this study, we couple the functionality of the yaImpute library and the computing power and vast spatial library of Google Earth Engine (GEE) to bring NN functionality into the GEE platform. Working with the GEE development team, we have written a new server-side module for NN methods that will be available through the public facing GEE application-programmer interface (API). To make the use of these methods intuitive to existing users, we follow the same calling conventions of GEE's well-known classifier and clusterer APIs. Because NN imputation is a multivariate prediction of many forest attributes, we provide methods to create attribute maps of k >= 1 plots stored in associated Google Fusion Tables, as well as diagnostic and accuracy-assessment tools. Based on early testing, we estimate that using GEE as a platform for NN methods can reduce model run times by a factor of ten when compared to a single workstation. We illustrate this new functionality using national forest inventory plots from northeastern Ukraine measured in 2013 to predict forest type and aboveground biomass. We explore the capacity to generate NN-based maps, facilitating rapid and simple model selection for both research and natural resources management applications. The development of a NN module for GEE provides a flexible toolset for predictive and spatially-exhaustive mapping of forest attributes from existing forest inventory data and temporally deep and spatially extensive satellite remote sensing archives.

61. The ICESat-2 Mission: an Overview | A Neuenschwander*, S Popescu, T Neumann, L Magruder

NASA plans to launch the ICESat-2 (Ice, Cloud, and land Elevation Satellite-2) laser altimeter in September 2018. While the primary mission goal of ICESat-2 is to monitor elevation changes in the cryosphere, it will also collect data over much of the Earth's terrestrial surfaces. The Advanced Topographic Laser Altimeter System (ATLAS) instrument on-board ICESat-2 is a lidar system with detection sensitivities at the photon level and operates at the 532 nm wavelength. The laser repetition rate of ATLAS (10 kHz) combined with a laser footprint diameter of 13 m results in a 70 cm separation for each laser shot on the surface. A diffractive optical element in ATLAS will split the single outgoing laser beam into 3 pairs of beams approximately 3 km apart on the surface at a laser repetition rate of 10 kHz. Each pair of beams will have a designated strong beam and weak beam based on their relative energy levels which will help detect surfaces of both high and low reflectivity. Each pair is separated by ~3.3 km in the across track direction, which provides a capability to separate regional slope from elevation change detection on repeat passes. The ICESat-2 orbit (92 degree inclination, 91 day exact repeat cycle) was designed for providing repeat ground track coverage to facilitate ice sheet elevation change and sea ice characteristics (freeboard, extent) at monthly, seasonal and annual timescales. For the mid-latitudes (approximately 60S to 60N) the satellite beam configuration provides a benefit for terrestrial ecosystems studies because it enables a denser spatial sampling than what was achieved with ICESat, particularly in the along-track direction. To further improve the longitudinal spatial sampling in the mid-latitudes to better than 2 km between equatorial ground tracks, ICESat-2 will be off-nadir pointed a maximum of 1.8 degrees from the reference ground track rather than maintaining the repeat ground track coverage.

62. Mapping Forest Aboveground Biomass with Simulated ICESat-2 Data | L Narine*, S Popescu, A Neuenschwander, S Srinivasan

Accurate and spatially complete assessments of forest AGB can reduce uncertainties with the quantity and distribution of terrestrial carbon stocks. The Ice, Cloud and Land Elevation Satellite-2 (ICESat-2) will be launched in September, 2018 and will provide data which will offer prospects for mapping AGB and forest carbon at multiple spatial scales. The goal of this study was to develop an approach for utilizing vegetation data that will be delivered in ICESat-2's land-vegetation along track product (ATL08), to produce a map of AGB. ICESat-2 photon counting lidar (PCL) data were simulated from airborne lidar data over Sam Houston National Forest (SHNF) in south-east Texas and two regression models were developed. One was used for modeling the relationship between simulated ICESat-2 photon-counting lidar metrics and airborne lidar-derived AGB and another, for relating mapped predictor variables to simulated PCL estimated AGB. A multiple linear regression model was used to relate simulated PCL metrics for 100 m segments along ICESat-2 ground tracks to AGB estimated from airborne lidar data. The regression tree method Random Forest (RF) was then used to model AGB using Landsat reflectance data, landcover and canopy cover from the National Land Cover Database (NLCD), and estimate AGB for areas not overlaid by ICESat-2 tracks. The multiple linear regression AGB model explained 84% of the variance in airborne lidar-estimated AGB and gave a root mean square error (RMSE) of 17.62 Mg/ha. Using predicted AGB estimates and the mapped predictor variables, the RF regression tree model explained 49% of the variance in AGB with a RMSE of 19.01 Mg/ha. Findings highlight a synergistic approach for utilizing data that will be acquired by ICESat-2 to estimate forest structure and characterize the spatial distribution of AGB.

63. Leaf area density from airborne LiDAR: Comparing sensors and resolutions in a temperate broadleaf forest ecosystem | A Kamoske*, K Dahlin, S Stark, S Serbin

With terrestrial ecosystems storing around 11 gigatonnes of atmospheric carbon dioxide (CO2) per year, approximately one third of anthropogenic emissions, forests are a critical component of the Earth's carbon cycle. Forest processes that play an essential role in carbon sequestration, such as light use efficiency, photosynthetic capacity, and trace gas exchange, are closely related to the three-dimensional structure of forest canopies. However, these relationships are not static; leaves at varying vertical positions within the canopy are physiologically unique due to differing light environments, therefore the whole-canopy is able to store more carbon than if light conditions were constant throughout. Due to this within-canopy variation, inclusion of three-dimensional structural traits are critical to making improvements to carbon storage estimates by Earth System models and to better understanding the effects of disturbances on carbon sequestration in forested ecosystems.In this study, we describe a reproducible and open-source methodology using the R programming language for estimating leaf area density from airborne LiDAR based on well-established methods and theories. Using this approach, we compare leaf area density estimates at the Smithsonian Environmental Research Center (SERC) in Maryland, USA, from two publicly available airborne LiDAR systems, NEON AOP and NASA G-LiHT, which have different specifications, collection goals, and data densities. Further, this study describes the challenges and considerations for using these data and suggests potential solutions to overcoming important differences in LiDAR datasets with varying degrees of canopy penetration and pulse density. We also describe how these local scale studies may connect to future spaceborne missions such as NASA's GED and the ESA's BIOMASS.

64. Impact of PAD estimation method and of observation angles on the performance of forest structure classifications using lidar derived PAD profiles | F De Boissieu*, S Durrieu, A Piboule, A Munoz, J Bock, A Jolly, J Renaud

Knowing vegetation 3D distribution is crucial for forestry studies and forest management. Vegetation vertical structure can be characterized with Plant Area Density profiles (PADP) computed from airborne laser scanner (ALS) data. Parameters derived from such profiles have been successfully used as input variables in models developed to assess stand characteristics. Several methods can be used to estimate PADP, from simplified approaches based on the counting of lidar echoes above, within and bellow each vegetation layer to more complex voxelization approaches that take into account light trajectory and multiple interceptions. Moreover, point clouds are composed of several overlapping flight-lines leading to unequal distributions of observation angles over forest areas. The aim of this study is twofold: to evaluate the impact of the methods used to compute PADP and of observation angles (1) on profile shapes and (2) on the performances of basal area (G) estimation models and of stand structural type classifications.The study area is a deciduous forest over which an ALS dataset was acquired with 10 pulses/m², ±25° scan angle range, and a 50% overlap between flight lines. First, 4 PAD estimation methods were compared: a simple echo-based method, a method based on weighted echoes, and 2 voxelization approaches, one using cubic voxels further aggregated at plot level for each vegetation layer and another one processing each layer as a single parallelepipoid voxel. The influence of observation angles was also assessed by computing PADP for various angle ranges. Second, the several kinds of PADP were used within G estimation models and classification approaches developed to categorize stands into either two (regular vs irregular) or 8 structural types based on the distribution of tree basal areas among 3 size categories. Model and classification results were then compared.Considering the layer-based voxelization PADP as the reference, results show a global overestimation for aggregated cubic voxel PADP, and an over and underestimation for the echo-based and echo-weighted methods, respectively. An influence of incident angle on profile shapes was also found, especially at the bottom of the profiles. Such analyses can help optimizing the use of PADP to improve ALS-based models developed to characterize stand structure. For example, preliminary results show an improvement of G estimations when ALS data are filtered to limit scan angle range before computing PADP.

65. VIIRS active fire products in different resolution in NOAA operations | M Tsidulko*, I Csiszar, W Schroeder

The presentation describes Active Fire products from the Visible Infrared Imaging Spectroradiometer (VIIRS) on the Suomi National Polar-orbiting Partnership (NPP) satellite and the NOAA-20 satellite, as they are implemented in NOAA's near-real-time pre-operational environment and operational production system. The Suomi NPP was launched in October 2011, and launching of the NOAA-20 in November 2017 opened wide perspective of inter-comparison of VIIRS fire products from two satellites 50 minutes apart and with moderate 750m and imagery 375m resolution. Using products from different satellites and two different resolutions enables more accurate fire detection and characterization. The 750m moderate resolution Active Fire product was implemented in the NOAA's Suomi NPP Data Exploitation environment (NDE) in March 2016 and currently the operational fire information is used in key NOAA applications. The NOAA-20 750m resolution fire product is running in the NDE parallel testing system and is going to be implemented operationally shortly. NASA's 375m imagery resolution algorithm was incorporated into NOAA pre-operational environment, both for Suomi NPP and NOAA-20. Initial evaluation shows a good agreement in moderate and imagery resolution fire products for both satellites. After testing, tailoring for NOAA purposes and potential improvements in the algorithm, the 375m product is planned to be proposed for implementation in the NDE operational system. A quantitative assessment of improved detection performance and additional fire radiative power (FRP) retrievals from the 375m product compared to the 750m product is done to evaluate the expected impact of the improved VIIRS fire input on key downstream NOAA applications such as the NOAA Hazard Mapping System (HMS), eIDEA (enhanced Infusing satellite Data into Environmental Applications) and the High Resolution Rapid Refresh (HRRR) Smoke modeling system.

66. Using Window Regression to Repair Landsat ETM+ Data | E Brooks*, R Wynne, V Thomas

The continued development of algorithms that use multitemporal Landsat data also creates opportunities to develop and adapt imputation algorithms to improve the quality of that data as part of preprocessing. Here, we assessed the applicability of window regression (WR), an algorithm originally designed to impute low-quality MODIS data, to de-stripe Enhanced Thematic Mapper Plus (ETM+, onboard Landsat 7) images and impute gaps caused by other poor-quality or missing data (e.g., clouds and shadows). We obtained multiple data stacks for the 2003-2010 time period using Landsat Analysis Ready Data, extracted the missing/low-quality data markers from the ETM+ images, and overlaid these markers on the corresponding Thematic Mapper (TM, onboard Landsat 5) images. We used these modified TM images as inputs into WR, then compared the resulting imputations with the original TM data. We also explored the WR tuning parameter space, and we added a re-imputation parameter designed to enable WR to successively update its own predictions as new imputed data are made available. WR yielded the highest accuracy and lowest computation time when using a relatively wide spatial radius (here, a 19x19 pixel window) and a moderate temporal radius (here, 5 image dates), with most other tuning parameters having an insignificant effect on the quality and timing of the imputation. The re-imputation parameter tripled the WR processing time without significantly improving the imputation quality. Because it relies only on data in the stack, WR is a convenient tool for imputing missing data.

67. A Kalman Filter Approach to Estimate Leaf Index in Loblolly Pine Plantations in the Southeast United States using Ground Based Measurements and Satellite Data | S Kinane*, C Montes

IntroductionLeaf area index (LAI) is an important indicator of a stand's productivity as it measures the stand's ability to exchange material and energy with its environment and has been shown to maintain a positive relationship with biomass production (Grier and Running, 1977; Albaugh et al., 1998). Methods for estimating LAI include destructive sampling, hemispherical lenses, models for remotely sensed data, or use of plant canopy analyzers, such as the Li-Cor 2200.
Prior models that utilize satellite imagery to estimate LAI of a site have been put forth but were shown to be biased, underestimating leaf area index (Flores et al., 2006). The objective of this study is to develop an unbiased model that estimates LAI for loblolly pine plantations in the southeastern United States from Landsat 5 and 7 derived vegetation indices.

Materials and methodsThe Southeast Tree Research and Education Site (SETRES) data, where a combination of fertilization and irrigation treatments were applied to eight-year-old loblolly pine trees, was used in this study (Peduzzi et al., 2002). LAI of each treatment plot was estimated using a Li-Cor LAI-2000 Plant Canopy Analyser on a monthly interval from March 1992 until September 2004 (Sampson et al., 2003). Surface reflectance values were queried and extracted from Landsat 5 and 7 images. Several vegetation indices were calculated for testing. A model was fitted to the best fit vegetation index using a Kalman Filter approach to assimilate both measurements and projections. Data was further compared to the in-situ leaf area index measurements. To reduce bias artefacts from using errors on ground truthing values, simulation extrapolation was used to account for noise in our dependent variables. ResultsEarly results show good agreement between ground-based estimates and satellite data. Normalized difference vegetation index (NDVI) was found to be weaker as a LAI predictor as compared to the normalized difference moisture index (NDMI) (AIC =2587.4 vs. 1885.8). The two comparisons had large errors, and a very weak correlation between their first order differences. Nevertheless, an equation was fitted using the Kalman filter to account for the uncertainty in LAI prediction.ConclusionsOur models show good agreement with the accumulated LAI behavior in spite of the large errors shown at each regression. Practitioners can make use of these equations provided an understanding of the risks associated with the estimates.

68. Post-hurricane forest damege mapping in Bory Tucholskie (Poland) based on up-scaling approach of photogrammetry-point clouds and Sentinel-2 imagery | P Wezyk*, P Hawrylo, M Brach, K Zieba-Kulawik, M Ratajczak, P Szymanski

One of the consequences of global climate changes observed in recent decades is more frequent occurrence of a violent atmospheric phenomena. Natural disasters such a forest fires or hurricanes can affect very quickly both local and wide areas. Assessing the extent of wide post-hurricanes damages of forest areas is a challenging task. Traditional mapping methods using GNSS receivers are often very risky, time consuming and limited to relative small areas. In this context remote sensing technologies may be very useful for reliable and quick forest damage mapping on wide areas.The huge hurricane took place on the night of 11/12 August 2017 in Bory Tucholskie Forests (Poland), at the belt with a length of 300 km. The Polish State Forests National Holding assessed the losses in wood biomass to 9.8 million m3 of fallen and broken trees. The hurricane occurred at 79.700 ha, including 39.200 ha of total damage.The aim of the study was to determine the suitability of Sentinel-2 (ESA) imageries to up-scaling the stage of forest damages determined on highly precise Canopy Height Model (CHM) based on photogrammetry-point cloud (matching of aerial photographs). As a reference data about forest damage the difference CHM models (between pre- and post-hurricane; 1.0 m GSD) was used. Pre-hurricane CHM was generated from the 3D LiDAR ALS point cloud (4 pts/m2) and post-hurricane CHM from aerial photographs (0.15m GSD) using the image-matching approach (SfM; PhotoScan). Additionally the interpretation of VHR UAV (DJI INSPIRE-2; approx. 600 photos; 85% overlap; 3.0cm GSD) orthophotomap was performed. The UAV photogrammetric-point clouds were generated using DroneDeploy software. In the next step, a number of vegetation indexes (VIs) were calculated based on Sentinel-2 bands. The surface reflectance and VIs were then used as explanatory variables for creating a predictive models of forest damage. The classification and regression models of forest damage were evaluated for Sentinel-2 (ESA) data using the Random Forest (RF) method. The obtained results confirmed the huge information potential of the spectral bands of the SENTINEL-2 satellite, which thanks to its high temporal resolution and relatively good spectral resolution covers very large areas. Not without significance is the free use of SENTINEL-2 (COPERNICUS; ESA) and access to archive data from LiDAR ALS from the ISOK project in Poland (2011-2015) and photogrammetric works carried out regularly (every 3 years).

69. Variation in foliar functional traits from the NEON Airborne Observation Platform | Z Wang*, A Chlus, T Zheng, A Singh, E Kruger, P Townsend

The National Ecological Observatory Network (NEON) comprises 20 domains intended to cover the ecological and climatological variability in the U.S. The NEON Airborne Observation Platform (AOP) flies over multiple field sites within each domain annually. The AOP collects both imaging spectroscopy (hyperspectral) and lidar data for the characterization of foliar functional traits and vegetation structure. We are working on the development and evaluation of cross-site algorithms to map a broad suite of foliar traits from the hyperspectral data across all NEON domains. The foliar traits include pigments, leaf mass per area, structural and defensive compounds, physiological parameters, macro- and micronutrients. Using the data from forested biomes sampled in 2016-2017, we show the capacity to develop robust algorithms for trait mapping across sites and a wide range of forest types. We show: 1) Trait mapping algorithms using AOP data are structured similar to previous published algorithms; 2) Output from new models using AOP data and the application of earlier published models are highly correlated, with bias possibly resulting from differences in image preprocessing; 3) Pixel size (1 m with AOP imagery) results in variations in canopy illumination that needs to be addressed through consistent preprocessing and aggregation of final predictions.

70. Substituting spatial information for spectral resolution in multi-sensor time series | MJ Hughes*, J Braaten, S Hooper, R Kennedy

Tying together data from multiple sensors to create composite time series presents a host of challenges. A significant hurdle is harmonizing differences in spectral resolution and band definition, a challenge that has long kept MSS imagery from being fully integrated into the later Landsat record and also is a stumbling point for integrating data from the many smallsats. Both cases lack the shortwave infrared (SWIR) data that is essential for high-quality canopy, biomass, and forest change products. Traditional approaches to harmonization include reducing datasets to the subset of bands all sensors have in common and performing pixel-wise regressions to estimate target bands or indices, often with limited success.However, because the number of spectral signatures of extant landcovers is far fewer than the possible number of such signatures, information about shape, scale, and texture can provide clues that limit the search space when presented with reduced spectral information and improve upon traditional methods. Essentially, the spatial signal encodes the same information about land cover as some portion of the spectral signal.To demonstrate this approach across sensors, we first acquire data from both the MSS and TM sensors aboard Landsat 5 for twenty scenes stratified by global ecoregions. We then estimated values for the two TM SWIR bands from the concurrently acquired MSS data, which does not have SWIR bands, using two methods. In the first, we used a simple neural network to create a pixel-wise nonlinear regression; in the second we use a convolutional neural network (CNN) to additionally incorporate spatial information. The second approach explains more than twice the error as the simple approach. In addition to being able to leverage spatial shape and structure, the CNN approach also appears to alleviate complications due to sensor saturation.Finally, we produce a timeseries of a SWIR-based index, NBR, composed of MSS, TM, OLI, and Planet data with associated Bayesian-modeled errors to demonstrate the utility of space-for-spectral substitution.

71. Spectral libraries for boreal forests | A Hovi*, P Raitio, P Forsström, M Mõttus, M Rautiainen

Spectra of scattering elements (leaves, needles, branches) are needed in modeling reflectance and absorption of forest canopies, and in interpretation of remotely sensed data. To date, limited amounts of data on reflectance and transmittance characteristics of various scattering elements have been available for boreal forests. Research in our spectral laboratory at Aalto University has addressed this need by collecting new spectral libraries of vegetation and developing measurement methodologies that would enable faster measurements and hence collection of more extensive spectral libraries. The laboratory is equipped with an ASD FieldSpec 4 spectrometer as well as different integrating sphere systems. In summer 2016, we measured leaf-level spectra of 25 boreal tree species, including many ecologically and commercially important coniferous and broadleaved species in North America and Eurasia. These data form to-date the most extensive spectral library of boreal tree species. Within- and between species differences in spectra were analyzed, revealing important parts in shortwave infrared spectrum where species are separable. As part of method development, we have focused on application of a new double-integrating sphere (OceanOptics SpectroClip-TR) for faster spectral measurements. The method has been compared to conventional measurements made with a single-integrating sphere (ASD RTS-3ZC), and to a leaf clip (PP Systems Mini Leaf Clip, which is an instrument commonly used by e.g. plant physiologists). The comparison showed that reflectance measurements made with integrating spheres are in good agreement, whereas more research is needed in improving comparability of transmittance measurements as well as reflectance measurements performed with the leaf clip. In the future, we are going to extend the spectral library by acquiring in situ spectra of understory and bark, of which very limited data are currently available.

72. Deep learning to identify trees outside forests in Andhra Pradesh using Sentinel-2 and harmonized Landsat Sentinel data | S More*, PT Williams, RH Wynne

Studies have shown that there has been a decrease in total forest cover in the Indian state of Andhra Pradesh in recent years, while forest plantation area has significantly increased. These smallholder plantations, composed largely of Casuarina and Eucalyptus species, were primarily established through conversion of agricultural land. Our objective is to use deep learning methods to identify these small, rapidly cycling, forest plantations. The study area consists of two districts, East Godavari and West Godavari, in Andhra Pradesh, India. Images consist of Landsat, Sentinel, and harmonized Landsat Sentinel data. Plantation training data samples (location, tree species, ownership, etc.) were provided by forest products producers based on their interaction with local wood suppliers. This training dataset has been extended by adding samples in agriculture, water, urban, sand and natural forest. In addition to intra-annual multi-temporal approaches, Landsat-derived annual maximum greenness (NDVI) has also been extracted and analyzed. Work to date has utilized a sequential artificial neural network with a rectified linear unit as the activation for the input and hidden layers. Activation for the output layer is softmax. A portion of the of the neurons are randomly dropped in the input and hidden layers to avoid overfitting. Initial results show promise for the separation of plantations from other land uses, but substantial additional training data are required to maximize the utility of this analytical approach.

73. G-LiHT v2.0: NASA's Second-Generation, Multi-Sensor Airborne Remote Sensing System for Studying Ecosystem Form and Function | BD Cook*, L Corp, D Morton, H Anderson, H Margolis

Goddard's Lidar, Hyperspectral and Thermal (G-LiHT) airborne remote sensing system was conceptualized, designed and assembled by NASA scientists during 2011 for the purpose of collecting coincident, fine spatial resolution (1 m) image data that is needed for many ecological studies, and to demonstrate the benefits of multi-sensor data fusion. G-LiHT simultaneously maps the composition, structure, and function of terrestrial ecosystems using a scanning lidar, VNIR imaging spectrometer, and thermal camera. During 2017, G-LiHT was completely redesigned and rebuilt as part of a joint NASA-USFS partnership. The primary, commercial-off-the-shelf instruments were upgraded on the next-generation G-LiHT v2.0 to increase the spectral and spatial resolution of the data products; a second lidar was added to provide redundancy and increase the density of lidar point cloud data; and a fine-resolution (3 cm) stereo RGB camera has been integrated to identify very-fine structural elements of plant canopies (e.g., branches, flowers) and contextualize their contribution to coarser resolution data products. New technical specifications for G-LiHT v2.0 will be presented, as well as applications and new science that has been enabled by the system. During its first two years of operation, G-LiHT has been used to measure rates of second-growth tropical forest regeneration; assess post-hurricane damage in Florida and Puerto Rico; complement USFS Forest Health Protection surveys for insect and disease outbreaks; and augment a relatively sparse sampling of USFS Forest Inventory Analysis field plots in interior Alaska.

74. The 2017 ABoVE airborne campaign | E Hoy*, C Miller, P Griffith

The Arctic-Boreal Vulnerability Experiment (ABoVE), a field campaign sponsored and initiated by NASA's Terrestrial Ecology Program, is a large-scale study of changes to terrestrial and freshwater ecosystems in the Arctic and boreal regions of western North America and the implications of these changes for local, regional, and global social-ecological systems. Over 80 projects and 500 scientists are affiliated with ABoVE. As part of ABoVE, an airborne campaign (the ABoVE Airborne Campaign, or AAC) was conducted from April through November 2017. The AAC involved ten aircraft in more than 200 science flights and surveyed over 4 million km2 in Alaska and northwestern Canada. The airborne strategy involved collecting domain-wide measurements with L- and P- band synthetic aperture radar (SAR), imaging spectroscopy, full waveform LIDAR, and atmospheric carbon dioxide and methane with focused studies using Ka-band SAR and solar induced chlorophyll fluorescence. Additional measurements were coordinated with the NEON Airborne Observing Platform, the ASCENDS instrument suite, and the ATom investigation. Many of the flights during the AAC were coordinated with same-day ground-based measurements to link process-level studies with geospatial data products derived from satellite sensors. The AAC collected data spanning the critical intermediate space and time scales that are essential for a comprehensive understanding of scaling issues across the ABoVE Study Domain and extrapolation to the pan-Arctic. Airborne data from many of the instruments is currently available for download and use, while other projects continue to develop products based on their flights. The AAC provided unique opportunities to validate satellite and airborne remote sensing data for northern high latitude ecosystems.

75. Testing the tree diversity - productivity and tree diversity - stability hypotheses in Białowieża forest using remote sensing time series | B Rombouts*, L D'Haene, W De Keersmaecker, B Jaroszewicz, K Stereńczak, O Bouriaud, B Somers, B Muys

Forest ecosystems provide a wide variety of ecosystem services. However, climate change might have both positive and negative effects on the services provided by temperate forests. On the one side, increased temperatures might increase productivity. On the other side climate change will put additional pressure on ecosystems because it leads to an increased number of forest disturbances (e.g. storms, pests, and heat waves). To ensure the future sustainability of forests, it is key to understand what drives their stability and how their resistance and resilience can be maintained or even improved. It is hypothesized that increased biodiversity will not only lead to increased productivity, but will also increase stability. Here, these hypotheses are tested using plots along a tree diversity gradient in the polish part of the primeval Białowieża Forest. Productivity and stability are quantified using remote sensing derived time series of the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI). Satellite data from both Landsat and MODIS are used. To ensure the relevance of these remote sensing indices for prediction of forest productivity, their time series were successfully correlated with time series obtained from in situ extracted tree ring cores. Results show a productivity increase in the period 2000-2017. Although this relationship is found at all diversity levels, productivity is found to be higher with increasing tree diversity. For the diversity-stability relationship a diversity effect is present when looking at variance as a long-term stability indicator. For the event-based indices a inversed relationship is found for resistance, but not for resilience.

76. Assessment of forest recovery using time series of satellite data and in-situ observations of ecosystem element budgets | L Homolová*, M Švik, R Janoutová, O Brovkina, P Lukeš, F Oulehle

The Central Europe and in particular the Czech Republic belongs to a region that was strongly affected by the acid deposition during the 20th century, but it is also exhibit most pronounced decrease in regional sulphur and nitrogen emissions amongst European countries (Hruška et al. 2002). In order to study changes in precipitation, stream water chemistry and overall ecosystem response, a network of 15 semi-natural small catchments that are dominated by Norway spruce forest stands and represents variety of environmental conditions (e.g. altitude, bedrock and soil types) was established in the Czech Republic and regular monitoring is carried out there continuously since 1994 (GEOMON network, e.g., Oulehle 2017). Detailed in-situ data such as collected within the GEOMON network are indeed very unique, but typically available for limited areas, therefore our motivation was to explore satellite optical data that would enable spatio-temporal outreach. The main objective was to analyze time series of remote sensing vegetation indices (derived from Landsat and Modis) linked to forest health and relate them to field observations of key element budgets (e.g., S, N) within the period 1994 - 2016. Monthly field observations of input-output elements' concentrations were aggregated to annual characteristic. Remote sensing vegetation indices (e.g., NDVI, EVI, NDII, disturbance index) were computed using Google Earth Engine (GEE) such as they represented an annual characteristic derived from cloud-free scenes available during the vegetation growth period (Jun - Sep).Field data indicated strong decrease in bulk S deposition and long-term accumulation of N in the ecosystems across almost all the catchments. Analysis of satellite data revealed significant correlations between annual S deposition and individual Landsat bands, as well as indices such as NDVI, NDII, mainly on those catchments that were affected by acid depositions most. Disturbance index computed from Landsat tasseled cap indicated that the largest re-vegetation and forest recovery occurred on sites with the most pronounced decrease in acid depositions. Moderately strong linear relationship ($R2=0.55$) was found between the change (i.e. difference between values observed in 2016 and 1994) in mean disturbance index and S deposition, similar trend, but less significant was found with N deposition.

77. Mining dense Landsat time series for secondary forest succession on abandoned agricultural lands mapping in heterogeneous mountainous landscapes | K Ostapowicz*, E Grabska, A Zielonka

Remote sensing systems provide massive information about land cover and its change in different spatial and temporal scales, being a powerful instrument to monitor the state and changes of environment. One of the environmentally important types of land change is agriculture land abandonment and then slow secondary forest succession which influences, e.g. carbon sequestration, biodiversity or landscape change. This study aimed to develop an approach which allows to detect and assess rates and patterns of agriculture land abandonment and then secondary forest succession for large areas over last 40 years. We tested our approach in the northern part of the Carpathians Mountains for seven Landsat footprints. We downloaded all available Landsat-4 TM, Landsat-5 TM, Landsat-7, and Landsat-8 images for WRS-2 footprints 186-188/025-026 recorded in an average vegetation period from 15th May to 15th October between years 1984 and 2017, with cloud cover lower than 40%, as surface reflectance products with systematic terrain correction from the USGS Landsat Data Archive (Landsat Collection 2). Moreover, to extend the timeline for our analysis, we downloaded as well all available Landsat 1-3 and Landsat 4-5 MSS images, respectively for WRS-1 footprints 200-202/025-026 and WRS-2 footprints 186-188/025-026 recorded in the vegetation period defined above, with cloud cover lower than 40% (Landsat Collection 1). Then, we spatially and spectrally linked all MSS, TM, ETM+, and OLI images through time and produced annual cloud-free image composites for years 1976-2017. In next step, we mapped the abandoned agriculture lands and secondary forest succession trends using spatio-temporal segmentation and classification algorithms. We fit spectral trajectories to, e.g. Tasseled Cap (TC) or normalised burn ratio (NBR) time series and extract a set of temporal-spectral metrics. Based on this metrics, using random forest algorithm, we assessed and mapped among others tree stages of secondary forest succession. We found that our spatial and temporal segmentation approach captured the changes, both agriculture land abandonment and secondary forest succession well (overall mapping accuracy = 95 +/- 1%) even in such heterogeneous mountainous landscapes (mosaic of relatively small agricultural fields and forest patches) like the northern part of the Carpathian Mountains. We gratefully acknowledge support by the National Science Centre, project RS4FOR [project no. 2015/19/B/ST10/02127].

78. The effects of sample size on accuracy estimates of burned areas in the Amazon | A Fernandez-Carrillo*, MA Tanase, MA Belenguer-Plomer, E Chuvieco

Remote sensing-derived maps contain errors from different sources. To identify classification errors, accuracy assessment is usually carried out. The need for statistical robustness in sample design is especially important for mapping fires, as they rarely occur and in spatio-temporal clusters. Several strategies have been proposed to define an optimal sampling design leading to a precise and statistically robust accuracy assessment.In this work, a stratified random sampling approach as proposed by Padilla et al. (2017) was applied to validate a burned area (BA) product as part of the ESA's Fire-cci project. This sampling design considers sample allocation as a function of burned area proportion inside each present biome. In our study the sampling size was computed as suggested by Olofsson et al. (2014). The objective of this study was to assess to which extent a reduction in the sampling size influences the accuracy metrics. The validation was carried out for BA detected from Sentinel-1, and two MODIS based-products generated for the year 2017 in the Amazon region. The reference BA dataset was generated using optical images acquired by Landsat-7 ETM+ and Landsat-8 OLI sensors. Pairs of Sentinel-2 MSI images were used to fill the temporal gaps due to the presence of clouds in the Landsat series. The BA products were validated three times: i) over n = 46 sample units (as computed from Olofsson et al. 2014); ii) considering a sample size of to n/2, and iii) considering a sample size of n/4, to test the sensitivity of the accuracy assessment to changes in the sampling strategy over the tropics.The results showed how variations in sample size maintaining the mentioned stratified allocation method affected the accuracy assessment estimates. The results provide evidence for the optimal sampling size for BA products of different spatial resolution.

79. Bayesian Spatio-Temporal Models for Map Reconstruction and Forest Inventory Prediction | A Chakraborty, K Khan, G Petris*, T Wilson

The USDA Forest Service aims to use satellite imagery for monitoring and predicting changes in forest conditions over time across large geographic regions within the country. The auxiliary data collected from satellite are relatively dense in space and time and can be used to efficiently predict how the forest condition changes over time. However, the auxiliary data contain a huge proportion of missing values at every location. We develop a spatiotemporal model to reconstruct these missing values from posterior predictive distributions. The model consists of a temporal fixed effect based on periodic patterns, a spatiotemporal random effect based on a conditional autoregressive (CAR) prior and a temporal random effect based on a AR(1) prior. Once we reconstruct the full spatiotemporal map, we use it to model the presence/absence of forest and the amount of basal area across the region. These models are formulated using functional regression and horseshoe regularization is performed to identify important auxiliary variables. Restriction in sudden increase in the basal area is also incorporated in the later model.

80. Utilizing auxiliary information when designing field survey of National Forest Inventory | M Räty, A Kangas*, J Heikkinen

The Finnish National Forest Inventory (NFI) collects information on hundreds variables. An inventory round lasts for 5 years and comprises about 60,000 plots. Annually the field measurements are covering the entire country with a systematic sampling grid. The exceptions are the northernmost part and southwestern archipelago, which are surveyed during one summer.In a previous study a spatially balanced sampling method called local pivotal method (LPM) was found to be more efficient in parameter estimation than the traditional systematic sampling design. In the study, we aimed at enhancing the NFI of temporary clusters in design phase in the archipelago by utilizing remote sensing data, namely, multi-source forest inventory (MS-NFI) forest resources maps for land class and four growing stock volume maps: total, pine, spruce, birch and other broadleaves. LPM selects a sample whose multi-dimensional distribution of auxiliary variables matches to the population's distribution. Thus the second phase clusters are not any more in a systematic grid. Here we utilized above mentioned five maps and spatial location as auxiliary information in LPM.The cluster design for the region was determined with simulation. In the previous inventory round the temporary cluster was L-shaped with 9 sample plots at 200 m distances. In our simulation cluster size was allowed to vary from 4 up to 9 sample plots at 200 or 400 m distances. The number of clusters chosen for a sample in simulations was restricted with a cost constraint related to the time required to access the plots in the archipelago. The time consumption was estimated by an inventory expert separately for each plot. With the constraint we ensured that equal resources were allocated for different cluster designs.The most efficient design was a 5-plot cluster design with a 200 m plot-to-plot distances. Further, LPM was robust regarding the utilized auxiliary information. Differences between different sets of auxiliaries were small. Thus LPM with three auxiliary variables: the total and broadleaf growing stock volumes and information of the land use was performing at sufficient level.Finally, the 5 sample plot temporary clusters were chosen from the first stage grid with LPM for the coming field survey in summer 2018. We are looking forward to analyze the results of this experimental field survey during winter 2018/19!

81. Modeling Tree Canopy Cover based on Crowdsourced Interpretations: A multi-scale bagging approach | J Derwin*, V Thomas, R Wynne, SS Peery, J Coulston, K Luther

The 2011 NLCD Tree Canopy Cover product and the subsequent 2016 product (in production) utilize training data collected by experienced interpreters with a photo interpretation (PI) approach. Observations of TCC were collected using 1-meter NAIP imagery overlain with a 90x90m dot grid. At each of the 105 points in the dot grid, experts interpreted whether the point fell on canopy or not. The proportion of positive observations compared to the total number of dots in the grid yielded percent TCC. Using a multi-scale bootstrap-aggregation or 'bagging' approach, we are testing whether crowdsourced observations of TCC are capable of training comparable models of TCC compared to those trained by expert measurements. Our data collection includes repeated samples of TCC across parts of Georgia and South Carolina, with multiple observers interpreting each point. Our multi-scale bagging approach will randomly select sets of interpretations from randomly chosen interpreters to train consecutive models. We also hope to apply this bagging methodology to individual dot observations in the case that high variance in interpretations of a single 90x90m plot occurs. We will aggregate the coefficient of determination and root mean square error for the models obtained from these bagged samples, and compare them to a similar approach taken with expert-interpreted data to see if crowdsourcing could provide an adequate replacement for expert interpretations.

82. Using RGB camera-mounted unmanned aerial vehicles to quantify individual tree-based leaf phenology in a tropical moist forest | J Park*, H Muller-Landau, J Lichstein, S Rifai, J Dandois, S Bohlman

Plant phenology has long been recognized as a critical driver of ecosystem processes, and one heavily influenced by climate. Understanding the patterns, drivers, and consequences of leaf phenology in tropical forests is difficult because of their high plant diversity and large interspecific variation in leaf phenology strategies. Quantifying leaf phenology for individual plants of known species identity is crucial to understand species strategies and mechanistically explain stand-level leafing patterns and their consequences for ecosystem carbon and water fluxes. Camera-mounted unmanned aerial vehicles (UAVs, or 'drones') have the potential to monitor canopy phenology for thousands of canopy trees. Here, we piloted such an application, and developed associated methods, in a 50-ha plot on Barro Colorado Island (BCI), Panama. We obtained high-resolution (7-cm) orthomosaic images approximately every two weeks from October 2014 to September 2015 (34 dates total). We manually delineated 2,100 distinct tree crowns and linked them with tagged trees of known species identity through fieldwork using a tablet-based GIS tool. For each delineated crown on each date, we extracted multiple image features, including first-order statistics (mean and standard deviation) of color, endmembers, and texture information. To create a training and testing dataset, we visually quantified leaf cover (%) for 2,203 images of 86 trees. We applied a machine learning algorithm to this dataset and evaluated the performance of alternative models including different combinations of features. We then applied the best model to predict leaf cover for ~60,000 images of 2,100 trees. For 68 canopy species with mean individuals per species 28.1 [±SD 31.4], we averaged leaf cover time series for conspecifics to obtain mean species-level time series. The model including color, endmember and texture features had high precision and accuracy (R2=0.81) in 10-fold cross-validation. The 68 focal tree species varied continuously from evergreen to highly deciduous, and deciduous species varied widely in the timing of leaf drop and leaf flush. In addition, there was strong intraspecific variation in leaf phenology, as individuals within some species varied markedly in their timing of leaf drop and/or leaf flush. Our work provides new methods to quantify deciduousness from high-resolution RGB imagery and demonstrates the usefulness of UAVs for quantifying individual tree phenology for thousands of trees.

83. Overview and Status of the CEOS Land Product Validation Subgroup | J Nickeson, M Roman, F Camacho, L Duncanson*, J Armston

The Committee on Earth Observation Satellites (CEOS), the space arm of the Group on Earth Observations (GEO), plays a key role in ensuring long-term confidence in the accuracy and quality of Earth Observation data and products. The Land Product Validation (LPV) subgroup of the CEOS Working Group on Calibration and Validation (WGCV) arose out of the recognition that standardized approaches to global land product validation were essential for wide acceptance and use of science-quality products. A common approach to validation, based on internationally recognized best practices protocols, has helped encourage widespread use of fiducial reference datasets; helping science product developers move towards standardized approaches for intercomparison and validation across products from different satellite, algorithms, and CEOS agency sources.This presentation will provide the status and activities of eleven LPV subgroup focus areas, that now include nine Global Climate Observing System (GCOS) terrestrial Essential Climate Variables (ECVs) and two GEO Biodiversity Observation Network (BON) Essential Biodiversity Variables (EBVs): (1) Snow Cover, (2) Surface Albedo, (3) Land Cover, (4) Leaf Area Index, (5) Fraction of Absorbed Photosynthetically Active Radiation (FAPAR), (6) Active Fires, (7) Soil Moisture, (8) Land Surface Temperature and Emissivity, (9) Land Surface Phenology, (10) Biomass, and (11) Vegetation Indices.The LPV subgroup is also focusing on the implementation of a global validation framework for product intercomparison and validation. This framework is based on a citable protocol, fiducial reference data, and automated subsetting. Ideally, each of these parts will be integrated into an online platform where quantitative tests are run, and standardized intercomparison and validation results reported for all products used in the exercise. The establishment of consensus guidelines for in situ measurements as well as inter-comparison of trends derived from independently-obtained reference data and derived products will enhance coordination of the scientific needs of the Earth system communities.

84. Quality assessment of MODIS Vegetation Continuous Fields of Tree Cover over France | D Sheeren*, V Thierion, P Herrault

The MODIS VCF is the unique product that enable to map tree cover at globalscale and assess its dynamic for almost two decades. It is used for a wide rangeof environmental studies and provide essential knowledge on the distribution oftrees on earth. The product has already been validated in different areas ofthe world. However, information on its accuracy remains very patchy and theunderstanding of the spatial distribution of errors limited.In this study, we investigate the accuracy of the MODIS VCF percent treecover layer (collection 5, 250-m spatial resolution) over France using the mostdetailed topographical vector database available at the national scale (BDTopo,French mapping agency IGN; minimum mapping unit of 500 m2). We alsocompare the VCF data with a new national land cover map (the OSO product)based on a fully automatic processing chain using Sentinel-2 image time series.In a first time, we estimate for each VCF pixel (n = 5,909,620), the corresponding tree cover percentage of the two reference datasets, while ensuring consistency between the production years. Then, a set of multiple independentvariables are computed including some environmental factors (such as elevationand slope), the level of fragmentation of woody vegetation, and the land covercomposition in the VCF pixel. Finally, uncertainty is quantified from classicalstatistical indicators (Root-Mean-Squared Error, Mean Bias Error, Mean Abso-lute Error) and differences in tree cover are mapped, to understand the spatialpattern and possible sources of errors.Preliminary results show significant differences between the VCF tree coverand the reference products despite the high positive correlation (Spearman'srho correlation = 0.75 for VCF vs BDTopo, and rho = 0.74 for VCF vs OSO;p<0.001). Negative bias with high variability was measured relative to BDTopo(MBE = -12.04 ± 22.41%; RMSE = 25.44%) and OSO (MBE = -6.59 ± 22.34%;RMSE=23.29%). Understimation of VCF tree cover is mainly observed from25% to 75% of cover. Overestimation also appears, mainly in pixels dominatedby grasslands. These findings corroborate previous studies, except for sparselytree areas. No relationship is observed with the quality level of the VCF product.Differences are only slightly explained by slope and elevation.This study contributes to the effort of independant validation of the VCFproduct and may help to better understand the classification errors in variouslandscape contexts.

85. Sentinel-2 time series images analysis : a rapid and an accurate solution to map large-scale forest cover | V Thierion*, A Vincent, J Inglada

Nowadays, several large-scale forest cover products exist such as the MODISVegetation Continuous Fields (VCF) or the Global Land Cover Facility(GLCF) corresponding to global forest-cover dataset. At the Europeanscale, we can list the Copernicus products such as the forest types ofCorine Land Cover (CLC) database or tree cover density and dominantleaf type products of the Copernicus Pan-European High ResolutionLayers (HRL). All of these products have the distinction of beingbased on satellite image analysis.In the same way, in France, in the framework of Land Cover ScientificExpertise Centre (CES OSO) of French Theia Land Data Centre, a newlarge-scale land cover product has been produced, called CES OSO landcover map. This product benefits from the new availability ofSentinel-2 time series images in terms of its revisiting capabilityand fine spatial resolution. In order to obtain this up-to-date landcover product, we developed an operational supervised classificationmethodology (iota²) for the fully automatic production of acurate landcover maps at country scale using Sentinel-2 and Landsat-8images. This land cover map is composed of 17 land cover classesrepresenting main land cover types whose two main dominant leaftypes are broadleaved or coniferous forest.This presentation will describe the methodology to produce thislarge-scale land cover map, its characteristics and especially itsforest component. In a second part, this forest component will bestatistically and visually compared to two products at two differentscales: 1. to the French national database BD TOPO\tiny®\normalsize\thinspace(French mapping agency -IGN), potentially the most accurate product in France (minimum mapping unit of 500 m²)and 2. to the HRL layers dedicated to forestmapping at continental scale (minimum mapping unit of 5 000 m²). On one hand, we will show the highcontingency (over 90%) with the French national database while theproduction methods are very diffent (manual interpretationvs. automatic image analysis). In other hand, we will illustrate theomissions of the forest cover of the HRL product.

86. Using the new French Land Cover Map (OSO) as spatial inputs in forest ecological modeling | P Herrault*, V Thierion, D Sheeren

Since 2016, a new French Land Cover Map (the OSO product) is available at a country scale with 17 land cover classes representing main land cover types (urban, agricultural and semi-natural). It is based on a fully automatic processing chain using Sentinel-2 image time series and Landsat images. The classification accuracy is around 90\% and reasonably enables to use this map as spatial inputs in species-habitat model. However, information on potential spatial uncertainty effects in these ecological models remain limited yet.In this study, we explore the impact of spatial uncertainty on a Generalized Linear Model (GLM) that investigates area and connectivity effects of 48 woodlands on the species richness of forest specialist hoverflies. We compared three different models calibrated from the three OSO products available (10m raster, 20m raster and the 20m vectorized product).Firstly, AREA and CONNECTIVITY were derived for all detected sampled forest fragments in each forest product. Then, a statistical protocol was defined in order to evaluate performances and sensitivity of each model : (1) a Leave One Out Cross Validation (LOOCV) was applied. Then, we computed mean and standard deviation for indicators usually analyzed in ecological statistical models outputs : the deviance explained (D2), the significance of regression coefficients (p-value) and the predictive capability (Root Mean Squared Error - RMSE) ; (2) We used a boostrapping technique (1000 runs) to approximate the distribution and test the stability of regression coefficients estimates for each model. Therefore, for each k-1 cross validation run, we also analyzed the standard deviation of the RMSE.Preliminar results show that spatial inputs derived from OSO products had no impacts on the predictive capability of the models (Rho = 0.85, p < 0.001). Nevertheless, we observed strong impacts on the quantity of Deviance explained (Mean Absolute Error (D2) = -0.12 ± 0.08) and the significance of the coefficients. AREA effect on the response variable remains significant with the « raster 10 m » (p-value <0.05) product but disappears in the other model's configurations. The significance level of the connectivity variable also decreases with the increase of spatial resolution and/or simplification. It became strictly non-existent in the model based on variables from the « vectorized product ».

(At Ecometrica Booth). Forests 2020: Protecting and Restoring the World's Tropical Forests | N Moffat*, D Michelakis, P McGregor, S Middlemiss

Forests 2020 is an international project funded by the UK Space Agency to help protect and restore up to 300 million hectares of tropical forests using satellite data across six partner countries - Indonesia, Colombia, Mexico, Brazil, Kenya and Ghana. The project is addressing technical challenges in earth observation monitoring by developing methods to advance forest change/degradation detection, identify forests at risk and areas for restoration whilst providing a digital infrastructure which improves access and processing of satellite data.