FluxLetter

The Newsletter of FLUXNET

Vol. 2 No. 2, *June*, 2009

Highlight FLUXNET sites
The Arctic Observatory Network

Highlighting Sites in Northern Alaska & North East Russia

by Eugénie S. Euskirchen and M. Syndonia Bret-Harte

Flux stations were recently established in two locations in the Arctic during the International Polar Year (2007 -2009). These flux stations are located in northern Alaska, near the Toolik Field Station, which is owned and operated by the Institute of Arctic Biology, University of Alaska, Fairbanks, and which is the site of the Arctic Long-Term Ecological Research (LTER) program, and at the North East Science Station near Cherskii, Russia. These two observatories help to establish a network of observatories across the Arctic, which is funded through the NSF Arctic Observatory Network (AON) program. The other flux stations that participate in this network are located near Abisko, Sweden and Zackenberg, Greenland, as well as a series of sites across Arctic Canada. The goal of making flux measurements made at these sites is to: 1) quantify and understand the controls of carbon, water, and energy exchange at each site, 2) permit cross-site synthesis of the carbon, water, and energy fluxes across the representative terrestrial ecosystems in the Arctic, and 3) parameterize and validate ecosystem and land-surface models.

In northern Alaska during the summer of 2007, we established two flux stations on either side of a flux station that had been previously established in 2005. This forms a transect of three stations in three representative undisturbed ecosystem types of the arctic foothills of the Brooks Range: heath tundra, tussock tundra, and wet sedge tundra (fen). Furthermore, the largest-ever tundra fire in northern Alaska occurred ~39 km northwest of our sites in the summer of 2007, burning ~90,000 ha. This provided the opportunity to establish three more flux stations during the summer of 2008 in tussock tundra ecosystems of varying burn severity: severely burned, moderately burned, and an unburned control site. The objective of establishing sites in these disturbed ecosystems is to obtain information about the integrated impacts of tundra fires on terrestrial ecosystems in the tundra foothills, and to begin documenting the recovery process. In addition to measuring the carbon, water, and energy fluxes at these sites, a full suite of meteorological data is also collected. We also use chambers to measure NEE during summer field campaigns.

Figure 1: Map of sites in the Arctic Observatory Network

FLUXNET SITE cont. on page 2

In This Issue:

Sites in Northern Alaska & North East Russia

FLUXNET SITE cont. from page 1

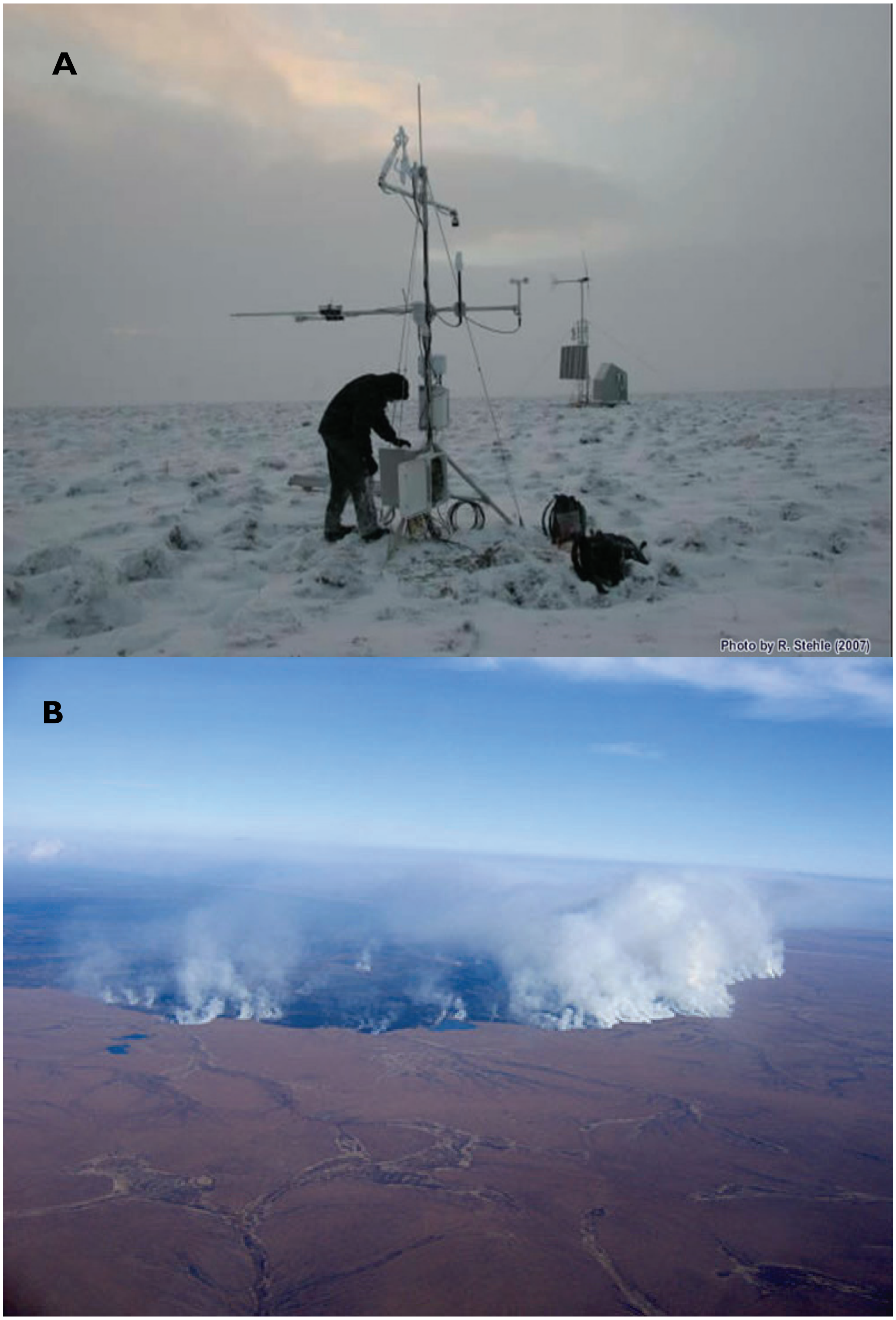

Figure 2: In (a), maintaining the eddy covariance equipment in northern Alaska is a challenge in winter. In (b), the tundra fire in northern Alaska burned for approximately 3 months, and was the largest tundra fire ever recorded in Alaska. Three flux towers have subsequently been located within the burned area. Photo Credits: Roy Stehle (a); Bureau of Land Management Fire Service (b);

At the end of August, 2008, a micrometeorological station was installed on a tall tower (40 m) near the North East Science Station. The greater height of this tower is necessary to account for the heterogeneity of the landscape and vegetation. The ecosystems of the North East Science Station are representative of the coastal plain of Northeast Siberia, a one million km^2 area of carbon-rich loess soils that accumulated carbon during the Pleistocene and have been gradually been releasing this carbon to the atmosphere and ocean through thawing of previously frozen soils during the Holocene. The carbon content of these soils is much greater than that of the permafrost soils in North America. This system at the North East Science Station includes: 1) an eddy covariance system to measure the fluxes of water, carbon, and energy, 2) A methane analyzer to measure the concentration of methane at a height of 30m which will subsequently be used by NOAA in the development of a regional methane flux model, 3) a closed-path eddy-covariance system to be used in conjunction with the methane analyzer to measure a local methane flux, and 4) a full suite of meteorological data. Three existing 10 m tall eddy covariance towers are also located near this tower, and have been collecting data for 8 years.

Maintaining flux stations over a full annual cycle in the Arctic is a challenge due to the long,

FLUXNET SITE cont. on page 3

Sites in Northern Alaska & North East Russia

FLUXNET SITE cont. from page 2

cold, dark winters that make the sites less accessible and cause ice to form on the sensitive equipment. Snow is on the ground for most of the year, with the snow season starting at the beginning of September and ending by the first week of June. Furthermore, line power is not available, and power outages are a problem. Routine site visits are essential during the snow season, and are often extended in order to diagnose and fix any problems.

We have held two workshops in 2008 for the AON participants in which we identified topics of synthesis based on data collected at the sites across network. We will hold another workshop in 2010. We have also established an AON website: http://aon.iab.uaf.edu/index.html where more information about the project and data are available.

Research team:

University of Alaska Fairbanks: Brian M. Barnes, M. Syndonia Bret-Harte, Eugénie S. Euskirchen, Anja N. Kade, Glenn J. Scott, Katey M. Walter

Ecosystems Center, Marine Biological Laboratory: John E. Hobbie, Bonnie L. Kwiatkowski, Edward B. Rastetter, Adrian V. Rocha, Gaius Shaver, Gabrielle Tomalsky-Holmes,

North East Science Station: Sergei Zimov, Nikita Zimov

Contact information:

Eugénie Euskirchen

ffese@uaf.edu

Figure 3: In (a), the tall (40 m) tower in Northeast Russia, and in (b) a smaller tower located within the footprint of the tall tower. Photo Credit: Sergei Zimov

Opinion Contribution:
Conservation of Surface Fluxes in a Numerical Model
by Jinkyu Hong

The Atmospheric numerical models solve the differential equations of conservation of momentum, mass and thermodynamic energy. As a result, the conservation of momentum, mass and thermodynamic energy is a strong constraint and thus has been carefully checked in modeling atmospheric flows. However, the concept of surface flux conservation with different grid sizes had not been clearly addressed before Sellers et al. (1992, 1995, 1997). These pioneering studies focused on artificial loss/gain of surface fluxes as increasing grid resolution in a biosphere model due to nonlinear responses of surface fluxes to spatial variations in surface properties, and a concept of scale-invariance of surface fluxes was proposed so that a biosphere model made consistent estimates of surface fluxes as grid resolution changed (Fig. 1). Ideally, the scale-invariance of surface fluxes produces similar surface fluxes in spite of different grid sizes following Jensen's inequality (e.g., $\langle F \rangle = \langle F \rangle_M$

However, due to nonlinear responses of surface fluxes to environmental conditions, surface fluxes are not conserved in different grid resolutions (i.e., $\langle F \rangle \neq \langle F \rangle_M$

Numerical models from LES (Large-eddy simulation) to mesoscale, regional climate and earth system models apply nesting procedure to examine the detail structures of small domain. In this nesting procedure, atmospheric and surface conditions from a mother domain (i.e. a domain having coarse grid size) are fed into a fine grid simulation for initial and boundary conditions. Accordingly, it is inevitable to have some bias in surface fluxes simulated from a coarse grid size due to Jensen's inequality.

It was concluded that the nonlinear effects were negligible and thus the scale-invariance of surface fluxes was satisfied (Sellers et al., 1992, 1995, 1997). However, we should note that there was no interaction between surface fluxes and atmospheric conditions due to an off-line simulation in their studies. That is, it was assumed that atmospheric conditions such as downward radiation, wind, temperature and humidity were homogeneous in a whole domain. Indeed, the test of this scaling issue in fully coupled models (e.g., LES, mesoscale model or earth system model) has remained unresolved so far. We recently checked the conservation of surface fluxes in an atmospheric mesoscale model and found that surface fluxes were not conserved as grid size in the model increased (Hong and Kim, 2008) (Fig. 2). In the early stage of numerical integration, radiative forcing and surface conditions are considerably homogeneous because relatively homogeneous fields were fed from a mother domain to a domain of finer grid size for boundary conditions. Therefore, the nonlinear effects are trivial in such homogeneous conditions and thus the

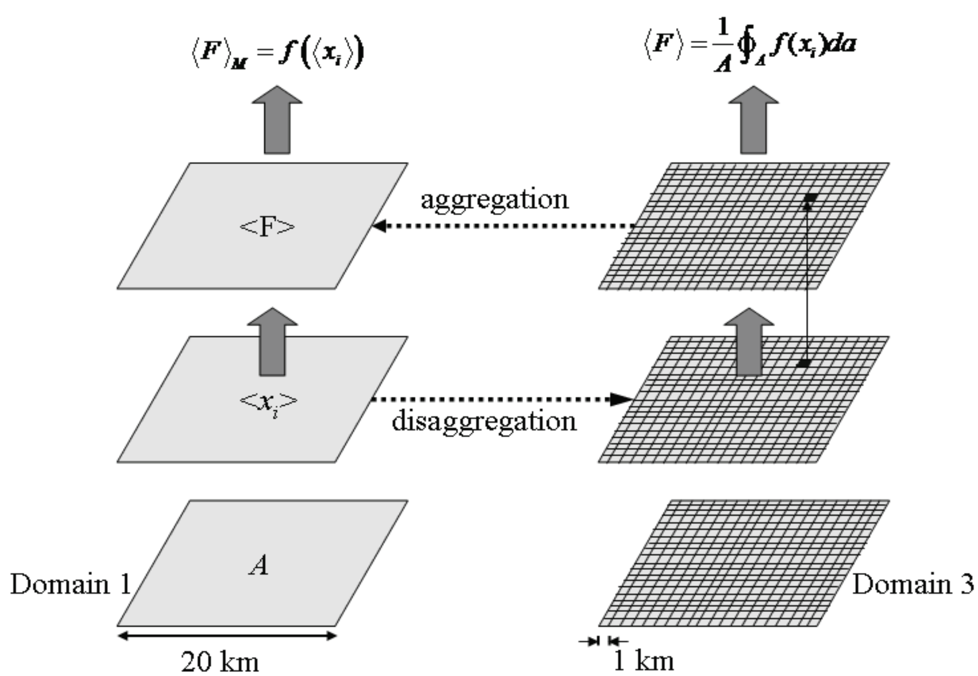

Figure 1. The concept of (dis)aggregation and scale-invariance of surface fluxes in the model adapted from Sellers et al. (1992). *F* is surface flux as a function of x_i (e.g. topography, surface conductance, soil moisture) and we can write $F = f(x_1, x_2, x_3, \ldots)$. Thus, complete values of *F* over an entire domain are calculated from $\langle F \rangle = \frac{1}{A}\iint_A f(x_i)da$ where *A* is the area of domain and the brackets denote area average over *A*. However, because of practical reason, *F* over an entire domain is calculated: $\langle F \rangle_M = f(\langle x_i \rangle)$ where $\langle F \rangle_M$ is an estimate of $\langle F \rangle$.

cont. on page 5

Conservation of Surface Fluxes in a Numerical Model

cont. from page 4

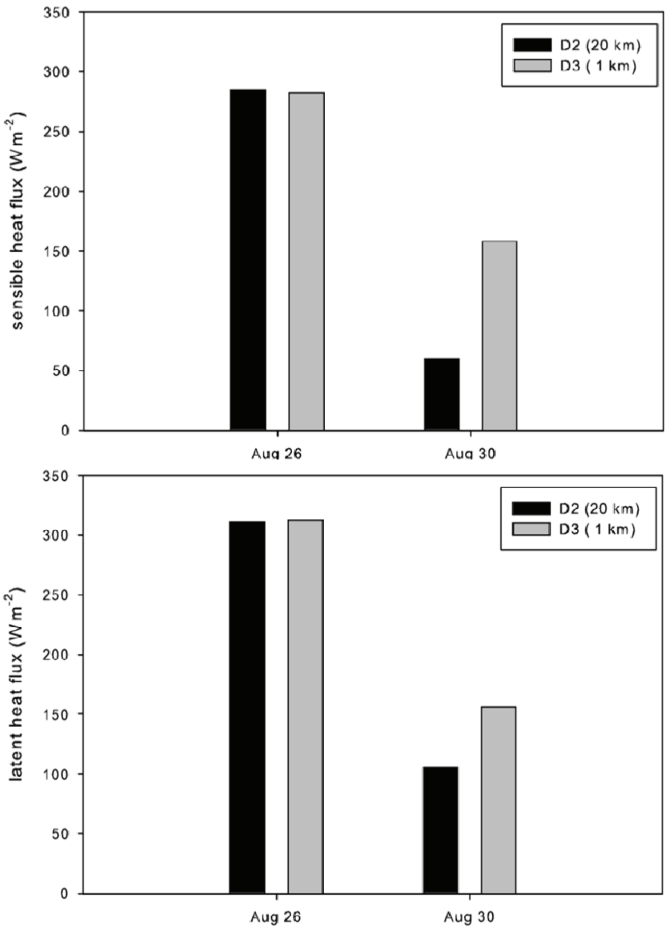

Figure 2. Comparison of sensible (*H*) and latent heat fluxes (*LE*) in domain 2 (D2: 20 km grid size) and domain 1 (D3: 1 km grid size) after aggregating to 20 km spatial scale around a flux tower at 05:00 UTC on August 26 and 30 respectively.

scale-invariance of surface fluxes is satisfied. As numerical integration progresses, spatial heterogeneities are, however, generated in the model, which produces the substantial nonlinearity.

Scientific implications are: 1) One should carefully apply the nesting procedures because the modeled surface fluxes can have artificial gain/loss due to the failure of the scale-invariance as the spatial heterogeneity grows up in the model; and 2) model bias will not necessarily result from intrinsic model inaccuracy when spatial variability in atmospheric conditions prevails. One possible remedy for scale-dependency of surface fluxes in a model will be to rectify surface fluxes and corresponding scalar concentration and wind in a coarse grid domain by assimilating surface fluxes aggregated in a fine grid domain into a mother domain.

contact:
Jinkyu Hong
Global Environment Lab/Dept. of Atmospheric Sciences, Yonsei University, Korea
jkhong@yonsei.kr

References

Hong, J., Kim, J. 2008. Scale-dependency of surface fluxes in an atmospheric mesoscale model: effect of spatial heterogeneity in atmospheric conditions. Nonlin. Processes in Geophys. 15, 965-975.

Sellers, P.J, Heiser, M.D., Hall, F.G. 1992. Relationships between surface conductance and spectral vegetation indices at intermediate (100 m^2 – 15 km^2) length scales. J. Geophys. Resear. 97, 19033-19060.

Sellers, P.J., Heiser, M.D., Hall, F.G., Goetz, S.J., Strebel, D.E., Verma, S.B., Desjardins, R.L., Schuepp, P.M, MacPherson, J.I. 1995. Effects of spatial variability in topography, vegetation cover and soil moisture on area-averaged surface fluxes: A case study using the FIFE 1989 data. J. Geophys. Resear. 100, 25607-25629.

Sellers, P.J., Heiser, M.D., Hall, F.G., Verma, S.B., Desjardins, R.L., Schuepp, P.M., MacPherson, J.I. 1997. The impact of using area-averaged land surface properties - Topography, vegetation condition, soil wetness - In calculations of intermediate scale (approximately 10 km^2) surface-atmosphere heat and moisture fluxes. J. Hydrol. 190, 269-301.

Highlight Graduate Student *Donatella Zona*

My name is Donatella Zona, I am a Ph.D student at the University of California Davis. I will graduate in 2 weeks, and I am currently dealing with formatting and printing of my dissertation… My Ph.D research is in Barrow, Alaska, under the direction of Prof. Walter Oechel and Prof. Susan Ustin. The focus of my research is the study of CO_2 and CH_4 fluxes from the arctic tundra. Tundra soils accumulation of large amounts of organic materials due to their generally cold and anaerobic soil conditions. The large amount of carbon stored in the Arctic tundra soil could be significant current and future global sources of CH_4 and CO_2 release. Soil drying in areas of continuous permafrost has been reported and appears to be due to an increasing gap between potential summer evapotranspiration and summer precipitation (Oechel et al., 1993; Oechel et al., 2000). On the other hand, some Arctic areas on continuous permafrost are showing increased lake numbers and/or extent (Smith et al., 2005). This could result in extensive new areas of anaerobic soils. Therefore, even under scenarios of warming and drying of the Arctic, many regions underlain by continuous permafrost are likely to show increased water availability and anoxic condition in the soil in coming decades. Because trace gas fluxes are so tightly linked to soil moisture and water table in the Arctic, my professor (Walter Oechel) initiated a large-scale manipulation in the Alaskan Arctic at the Barrow Environmental Observatory (BEO) in 2005 as part of the NSF Biocomplexity in the Environment- Coupled Biogeochemical Cycles. I was lucky to be involved in this project for my Ph.D research.

The target of this manipulation experiment includes increasing and decreasing the water table over large areas of tundra and observing the effects over the diverse microtopography of the region. The experiment was designed to investigate the link between CH_4 and CO_2 fluxes (measured with eddy covariance towers, see Fig. 2) as affected by changes in soil water, over complex terrain. During the first year of the manipulation (2007) dikes were established that slowed or prevented the water from moving from the north site to the south towards the natural outlet of the basin and the associated drainage channel. This resulted in a difference in water table heights between the three treatment areas, with the north and the central sites having the highest water table (respectively on average over the entire season of -5 cm and -4 cm) and the south the lowest (on average -10 cm). In summer 2008, water was pumped from the central area and a nearby lake to the north section (from the beginning of June to the end of August), while the south area was kept as control (Fig. 2). This resulted in the north site having a water table above the surface for the entire summer (Fig. 2), on average +6 cm, while the central and south sites had an average water table of -3 and -2 cm, respectively.

Results from the initial year of the manipulation show a significant impact of the observed variation and progression in water table on CO_2 and CH_4 fluxes. Contrary to common expectation, we showed that the effect of a decrease in water table is not necessarily a decrease in CH_4 release. An increase in water table above the surface could increase the diffusive resistance to CH4 release. Additionally, a drop in water table below the surface may not

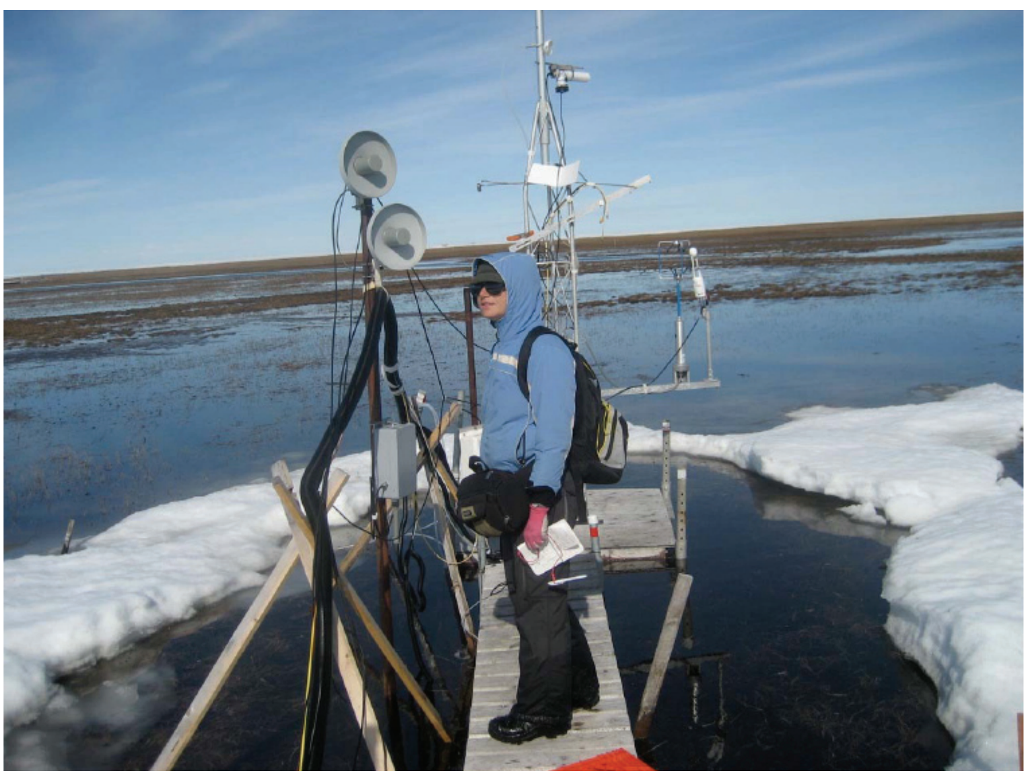

Figure 1 - Donatella Zona at one of the three CO2 and CH4 eddy covariance towers in the NSF Biocomplexity experiment, in Barrow, Alaska, in the beginning of summer 2008.

cont. on page 7

Highlight Graduate Student

cont. from page 6

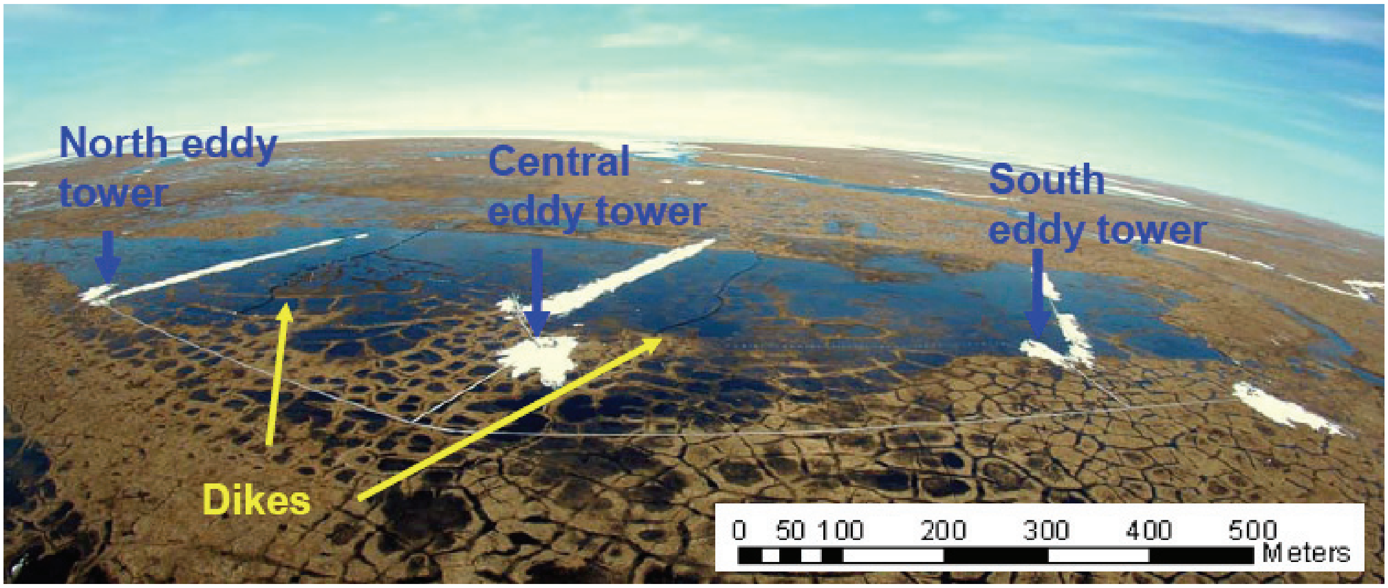

Figure 2 Site of the manipulation during June 2008. Blue arrows indicate the locations of the three eddy towers, while yellow arrows indicate the location of the dikes.

decrease CH_4 emissions, when there is a concurrent increase in thaw depth, and therefore soil volume available for methanogenesis (see Zona et al., 2009). The comprehensive results that describe the effect on CO_2 fluxes are in preparation.

contact: Donatella Zona
dzona@ucdavis.edu

website
http://gcrg.sdsu.edu

Note: Donatella finished her PhD on June 11th, 2009 under the direction of Prof. Walter Oechel and Prof. Susan Ustin.

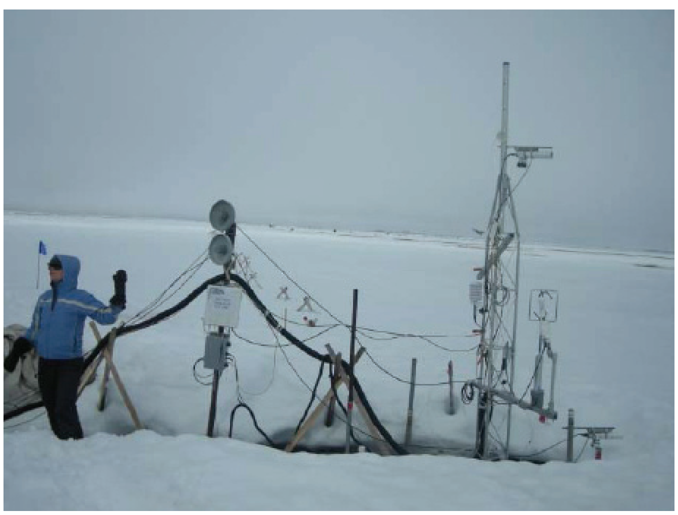

Figure 3 Donatella Zona at one of the three CO2 and CH4 eddy covariance towers

Further Reading

Oechel, W. C., G. L.Vourlitis, , S. J. Hastings, R.C. Zulueta, L. Hinzman, and D. Kane (2000), Acclimation of ecosystem CO2 exchange in the Alaskan Arctic in response to decadal climate warming, Nature 406, 978-981.

Oechel, W. C., S. J. Hastings, G. L. Vourlitis, M. Jenkins, G. Riechers, and N. Grulke (1993), Recent Change of Arctic tundra ecosystems from a net carbon dioxide sink to a source, Nature, 361, 520-523.

Smith L. C., Y. Sheng, G. M. MacDonald, L. D. Hinzman (2005), Disappearing Arctic Lakes, Science, 308, 1429.

Zona, D., W. C. Oechel, J. Kochendorfer, K. T. Paw U, A. N. Salyuk, P. C. Olivas, S.F. Oberbauer, and D. A. Lipson (2009) Methane fluxes during the initiation of a large-scale water table manipulation experiment in the Alaskan Arctic tundra, Global Biogeocheical. Cycles, 23, GB2013, doi:10.1029/2009GB003487

Zona D., W. C. Oechel, K. M. Peterson, R. J. Clements, K. T. Paw U, and S. L. Ustin, Characterization of carbon fluxes of a drained lake basin chronosequence on the Alaskan Arctic Coastal Plain, *submitted to Global Change Biology*

Highlight Young Scientist

Adrian V. Rocha

I've always enjoyed the outdoors, but never thought that I would get to work in such beautiful places as the Northern Hardwood forests of Michigan, the boreal forests of Manitoba, Canada, the freshwater wetlands of California, and the Arctic tundra of Alaska's North Slope. I feel extremely privileged to have such a fulfilling career, and am indebted to those that have fostered my scientific interests.

My scientific interests began to take shape working as a research assistant for Lars Pierce and Fred Watson at the California State University of Monterey Bay (CSUMB). My job was to run around the bush in the early hours of the morning to measure the predawn water potential in chaparral plants. The data that I collected would eventually be used to parameterize an ecosystem model, but I was more interested in the excitement of being in the bush while everyone else was asleep. I actually couldn't believe that I was getting paid for having so much fun, and after a field season of collecting data I decided to pursue a career in ecology.

I pursued a Masters degree with Peter Curtis at the Ohio State University after graduating from CSUMB. My first field season was at the University of Michigan Biological Station (UMBS), where Peter managed an eddy covariance tower in a Northern Hardwood Forest. The instrumentation on the tower was impressive and unlike anything I had seen before. I found it exciting that these instruments were monitoring the "breathing" of the forest, and decided to use these data to understand how clouds and aerosols influenced canopy photosynthesis and water use efficiency for my thesis (Rocha et al. 2004).

After completing my thesis, I returned to California to pursue a Ph.D. with Mike Goulden at the University of California, Irvine. During the second year of my dissertation several lab members and I traveled to Thompson, Manitoba, Canada to core hundreds of trees in order to understand the relationship between tree growth and forest physiology. We were surprised to find a poor relationship between canopy photosynthesis and ring width and attributed this unusual pattern to carbohydrate reserves (Rocha et al. 2006), which can buffer plant growth from environmental variations and decouple photosynthesis from plant growth. It was during this project that I gained an appreciation for the biology and internal dynamics of the vegetation, and decided to focus on these processes for my dissertation. I found similar relationships between plant growth and photosynthesis in a Southern Californian freshwater marsh (Rocha and Goulden 2009), and determined that within plant carbon storage and allocation was important for linking the annual "breathing" of the forest to plant growth.

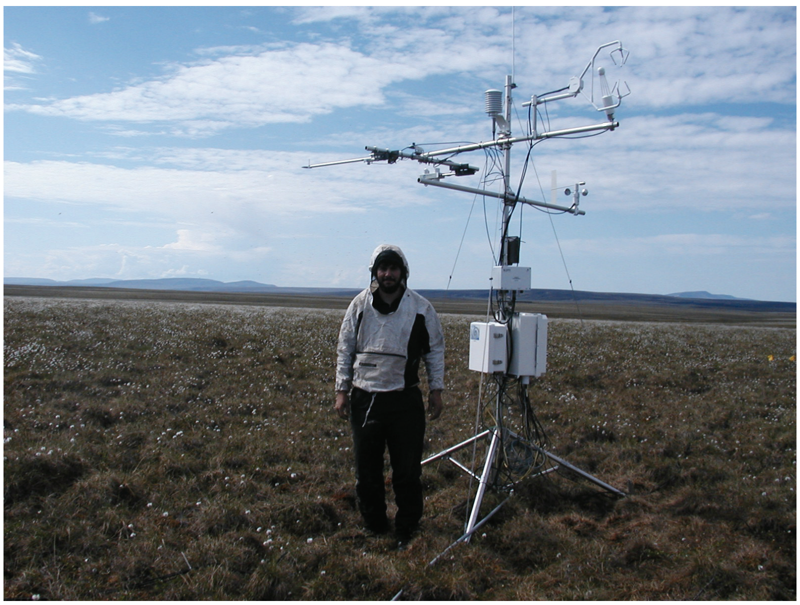

Figure 1: Adrian at an eddy covariance tower in Alaska

I am two weeks away from returning to the North Slope of Alaska for my second summer field season. I am working with my postdoctoral advisor's Gauis Shaver and Ed Rastetter from the Marine Biological Laboratory's Ecosystems Center in Woods Hole, MA to determine how burn severity influences post-fire energy and mass exchanges in arctic tundra. Fires often create a mosaic of patches that differ in burn severity, and we took advantage of one of the largest fires to occur on the North Slope (the Anaktuvuk River Fire) to determine how these patches influence vegetation recovery and post fire surface exchanges of mass and energy. We are running three eddy covariance towers along a burn severity gradient and combining these data with satellite information to determine the importance of fire induced landscape heterogeneity in scaling up the flux measurements to the region. We are very excited about this project, and encourage future collaboration with members of the Fluxnet community.

contact: Adrian Rocha
arocha@mbl.edu

Further Reading

Rocha, A.V. and M.L. Goulden (2009) Why is marsh productivity so high? New Insights from Eddy Covariance and Biomass Measurements in a *Typha* Marsh. Agricultural and Forest Meteorology. 149, 159-168.

Rocha, A.V., M.L. Goulden, A.L. Dunn, and S.C. Wofsy. (2006) On linking interannual ring width variability with observations of whole-forest CO_2 flux. Global Change Biology. 12:1378-1389

Rocha, A.V., H.B. Su, C. Vogel, H.P. Schmid, and P.S. Curtis (2004) Photosynthetic and water use efficiency responses to diffuse radiation by an aspen-dominated northern hardwood forest. Forest Science. 50:793-801

Measuring air-ice CO_2 fluxes in the Arctic

Heinesch B, Yernaux M, Aubinet M, Geilfus N-X, Papakyriakou T, Carnat G, Eicken H, Tison J-L, B.Delille

Sea ice covers about 7% of Earth's surface at its maximum seasonal extent, representing one of the largest biomes on the planet. For decades, sea ice has been considered by the scientific community and biogeochemical modellers involved in assessing oceanic CO_2 uptake as an inert and impermeable barrier to air-sea exchange of gases. However, this assumption is not supported by studies of the permeability of ice to gases and liquids, which show that sea ice is permeable at temperatures above -10°C. Recently, uptake of atmospheric CO2 over sea-ice cover has been reported (Delille et al., 2007; Semiletov et al., 2004; Zemmelink et al., 2006) supporting the need to further investigate pCO_2 dynamics in the sea-ice realm and related CO_2 fluxes. The processes by which the CO_2 exchange between the ocean and the atmosphere can take place are the following. While CO_2-enriched brines are expelled from the ice, carbonate minerals could remain trapped in the brine tubes and channels until spring and summer, when they would dissolve within the sea ice or in the underlying water. Such dissolution consumes CO_2 and therefore acts as a sink for atmospheric CO_2. Other processes can potentially act as sinks of CO_2. First, sea ice hosts algae communities, which imply primary production. Second, during sea-ice growth, most of the impurities (solutes, gases,

Figure 1: Set up of the mast with sonic anemometer, air intake of the CO_2 analyser and radiometer over sea ice near Barrow (Alaska) in January 2009. The temperature was -35°C.

cont. on page 10

Measuring air-ice CO_2 fluxes in the Arctic

cont. from page 9

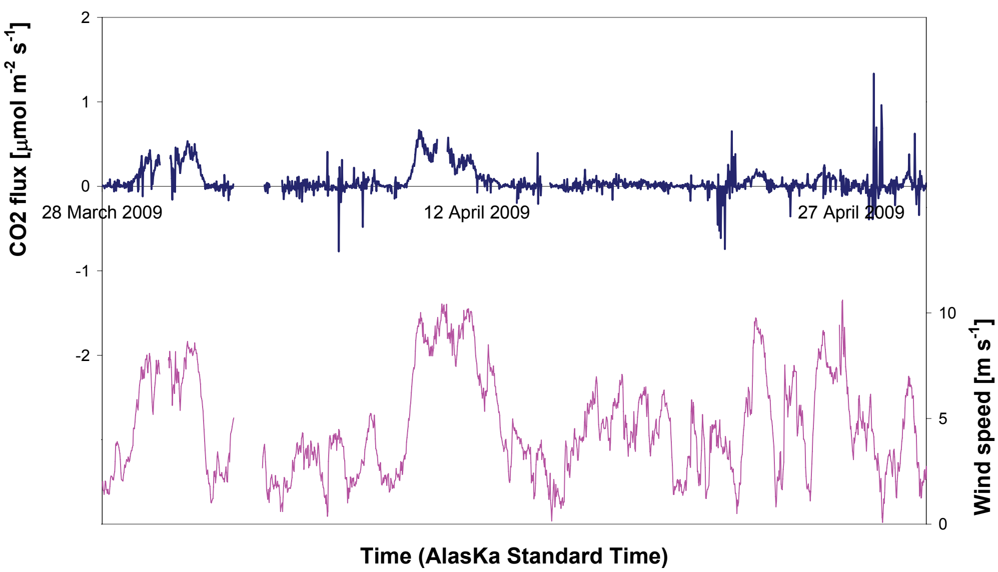

Figure 2 : CO_2 flux and wind speed in April 2009 over sea-ice in Barrow (Alaska).

particulate matter) are expelled from the pure ice crystals at the ice-water interface. The CO_2 rejected into the boundary layer will either diffuse or be convectively driven downward into the underlying water, removing CO_2 from the surface water. During spring, melting of CO_2-depleted sea ice would decrease pCO_2 of surface waters. Such a mechanism would act as a sink for atmospheric CO_2. On the whole, spring sea ice appears to act as a CO2 sink that may be significant in the budget of CO_2 fluxes in the Polar Oceans (Delille et al., 2007; Zemmelink et al., 2006). However, previous studies are sparse, and limited in term of spatial and temporal coverage.

In January 2009, we started a study that aims to robustly follow up CO_2 exchange between land fast sea-ice and the atmosphere during the winter and spring season. To this aim, a meteorological mast equipped for eddy-covariance measurements was installed on landfast sea-ice near Barrow (Alaska), 1 km off the coast, from end of January 2009 to beginning of June 2009, before ice break-up. There is some concerns about using open-path analyzer in cold environment (Burba et al., 2008) so the mast was equipped with a CO_2 closed-path analyser together with a C-SAT 3D sonic anemometer. These data were supported by continuous measure of solar radiation, snow depth, ice thickness and temperature profile in the ice. Biogeochemical data necessary for the understanding of the CO_2 dynamics in sea-ice were obtained through regular ice coring.

First results coming from this campaign show that the resolution of the eddy-covariance technique in these conditions is high enough to measure CO_2 fluxes that are typically below 1 mmol m^{-2} s^{-1}. Despite low temperature at the ice-snow interface (-14°C), we observe in April some effluxes from the ice to the atmosphere (see figure 2). This is consistent with the CO_2 oversaturation of sea-ice brines observed at the site. The fluxes are triggered by wind speed over 7 m s^{-1} suggesting that wind pumping trough the snow (snow thickness was about 20 cm) is one of the main process controlling the air-ice fluxes at that time.

As the sea ice is warming up, the partial pressure of sea ice brines is expected to decrease significantly and to pass the threshold of saturation. Sea ice would then shift from a source to a sink for atmospheric CO_2. In addition, increase of temperature will increase the permeability of sea ice, promoting the increase of the magnitude of fluxes. The system deployed in Barrow should allow us to follow these processes and to budget the net CO_2 transfer from the atmosphere to the ice over winter and spring.

This project is supported by the Fonds de la Recherche Scientifique, the National Science Foundation and the University of Alaska Fairbanks. We are indebted to the Barrow Arctic Science Consortium and the North Slope Borough for their logistical support.

contact:
Bernard Heinesch
Heinesch.b@fsagx.ac.be

References

Burba, G.G., McDermitt, D.K., Grelle, A., Anderson, D.J. and Xu, L.K., 2008. Addressing the influence of instrument surface heat exchange on the measurements of CO2 flux from open-path gas analyzers. Global Change Biology, 14(8): 1854-1876.

Delille, B., Jourdain, B., Borges, A.V., Tison, J.L. and Delille, D., 2007. Biogas (CO2, O-2, dimethylsulfide) dynamics in spring Antarctic fast ice. Limnology and Oceanography, 52(4): 1367-1379.

Semiletov, I., Makshtas, A., Akasofu, S.I. and Andreas, E.L., 2004. Atmospheric CO2 balance: The role of Arctic sea ice - art. no. L05121. Geophysical Research Letters, 31(5): 5121-5121.

Zemmelink, H.J. et al., 2006. CO2 deposition over the multi-year ice of the western Weddell Sea - art. no. L13606. Geophysical Research Letters, 33(13): 13606-13606.

Presence and absence of permafrost – implications for atmospheric exchanges of CO_2 and CH_4

Torben R. Christensen, Mikhail Mastepanov and Margareta Johansson

Permafrost, soil that stays frozen for two or more years in a row, is a hot topic that has attracted a lot of attention in both the scientific and popular literature in recent years. Permafrost underlies 25% of the land areas in the northern hemisphere. With a warming climate that is particularly pronounced at high northern latitudes, where most permafrost is present, many questions have been raised regarding what may happen to ecosystems and their functioning in the areas when permafrost thaw. In areas with infrastructure such as towns in northern Siberia or oil and gas pipelines through areas underlain by permafrost, the thawing represents a serious and extremely expensive issue to deal with. Thawing permafrost may however even be an issue with global implications through changes in natural ecosystem greenhouse gas emissions.

Permafrost areas in the circumpolar North is estimated to hold more than 1600 Gt of organic C including almost 300 Gt in the form of peat (McGuire *et al.* in press; Tarnocai *et al.* in press). In terms of atmospheric exchange of C, in the form of CO_2 and CH_4, the potential for additional releases are, hence, probably greater from these areas than anywhere else in the world. While the potential release from the huge stocks of carbon is significant, the actual data and year-round monitoring of atmospheric exchanges are still rare and continuous flux measurements of CO_2 are limited to a handful of sites. Continuous monitoring of CH_4 fluxes is even rarer; the number of operational sites is less than five. Our empirically based understanding of what permafrost does to the dynamics and interannual variability in atmospheric (and dissolved run-off) fluxes of organic carbon is therefore still very poor.

Basic features of how these ecosystems are functioning with and without permafrost have recently been discovered. Schuur *et al.* (2009) showed from a central Alaskan site how old organic previously frozen carbon gets respired as the permafrost thaws and in Siberian thaw lakes methane was shown formed on recently thawed old organic deposits (Walter *et al.*, 2007).

The interannual and across-site variability of CO_2 exchange in continuous permafrost ecosystems are driven primarily by growing-season dynamics and moisture conditions. Growing-season rates of CO_2 uptake by these ecosystems have been shown in several studies to be closely related to the timing of snow melt, with earlier snowmelt resulting in greater uptake of atmospheric CO_2 (Aurela *et al.,* 2004; Groendahl *et al.,* 2006). The annual C budget is not only controlled by growing-season exchange, but to a large extent by the losses during the shoulder (snow melt/soil thaw and senescence/soil freeze) and winter seasons (Johansson *et al.,* 2006). These more complex impacts on the annual budgets become more important when moving

Figure 1. The Zackenberg valley in NE Greenland, an area underlain by continuous permafrost. The automatic chambers were used for the studies of methane emission dynamics during freeze in (Mastepanov et al., 2008). Local inhabitants, the muskoxen, are present in the background. Photo credit: Charlotte Sigsgaard.

cont. on page 12

Presence and absence of permafrost

cont. from page 11

out of permafrost regions and into climatically milder off season conditions.

In northern Sweden we have documented changes in permafrost dynamics and effects on ecosystems and their feedbacks on climate in terms of methane emissions (Christensen *et al.*, 2004; Johansson *et al.*, 2006) and in relation to catchment scale greenhouse gas exchanges (Christensen *et al.*, 2007). Here the thawing permafrost generally leads to wetter hydrological conditions and subsequently greater emissions at the landscape scale. The seasonal and interannual pattern is at the subarctic site rather predictable and the emissions rather stable from year to year (Jackowicz-Korczyński *et al.*, submitted). In contrast we observed some surprising and interesting autumn emission dynamics at our high arctic measurement site in NE Greenland (Figure 1). These findings (Mastepanov *et al.*, 2008) show a second seasonal peak of emissions during the freeze-in (Figure 2), a distinct feature not previously observed and not seen in the subarctic studies most likely since no earlier flux studies in continuous permafrost regions have extended into the frozen season. After further investigation together with atmospheric scientists we have preliminary concluded that it could well be a likely general feature of permafrost areas and in fact it helps to explain the observed seasonal dynamics in atmospheric methane concentrations during the autumn (Mastepanov *et al.*, 2008).

The mechanism behind the freeze-in emissions in continuous permafrost areas is hypothesized as a release of methane from the subsurface pool accumulated over the growing season (Figure 3). The methane is present mainly in gaseous form in entrapped gas bubbles below the water table level. The volume of the gas phase in the peat beneath the water table can be significant (from 0 to 19% - Tokida *et al.*, 2005), while the volumetric percentage of methane in this gas can be more than 50% (Tokida *et al.*, 2005). When the soil is starting to freeze from the surface down, a gas-proof layer is forming and it propagates downwards. The permafrost works as a gas-proof bottom preventing the gas to migrate deeper down. As the ice has lower density than water, the freezing process is causing increase of the volume of the freezing zone, raising the pressure in the unfrozen layer. This process preconditions the squeezing of the gas with high methane content to the atmosphere. An additional hypothesized necessary condition for the late-season methane burst to occur is the presence of some channels for the pressurized gas to get out to the atmosphere. We suggest it may be residuals of vascular plant tissues, or some cracks in the frozen upper soil layer.

Back in the geographical margins of the permafrost zone is the intensively studied region of northern Sweden, the Abisko area, where permafrost has been monitored for decades. The surface active layer that thaws every summer has become thicker during the last three decades. In nine mires along a 100 km long transect the trend has been similar and in some mires the permafrost has even disappeared completely (Åkerman & Johansson, 2008). This trend is reflected also in larger scale modeling of the whole of permafrost (palsa) mires in northern Scandinavia (Fronzek *et al.*, 2006) and from observations in North America (Vallee & Payette, 2007; Turetsky *et al.*, 2007). On the whole this uniform trend towards transformation of permafrost landscapes calls for an understanding of ecosystem fluxes both where the permafrost is still present and where it has disappeared. From the few data we have our understanding is as shown above that these ecosystems with and without permafrost differ significantly in their

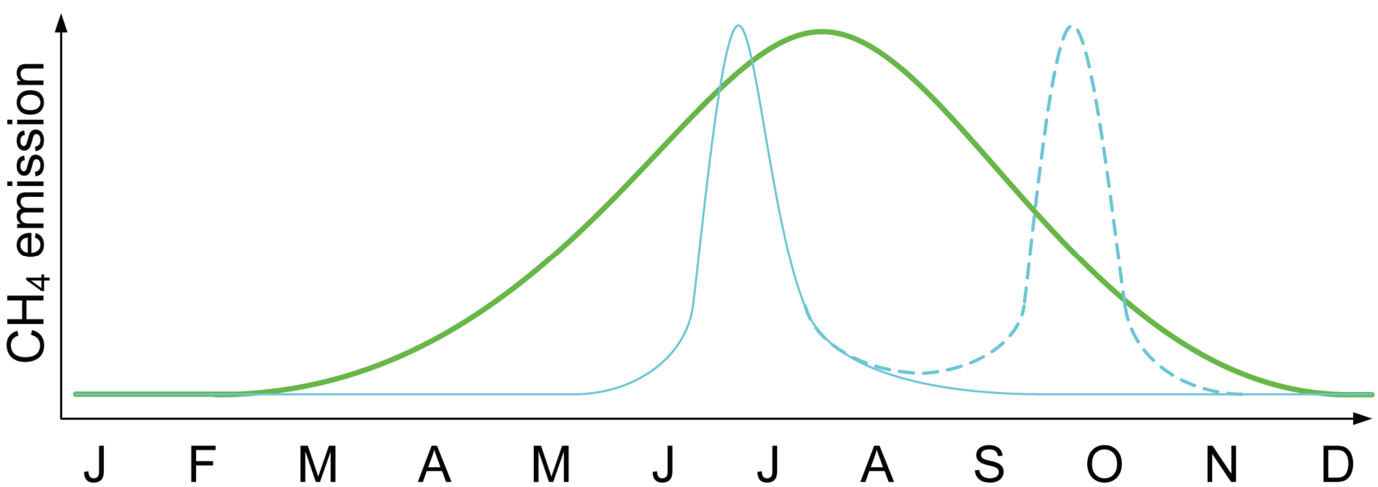

Figure 2. Schematic illustration of the seasonal dynamics of emissions as observed in Zackenberg (light blue) and subarctic Sweden (green) respectively. These very different seasonal patterns reflects differences depending on both the length of the growing season and the special emission patterns with the freeze-in burst observed in a continuous permafrost environment (based on

cont. on page 13

Presence and absence of permafrost

cont. from page 12

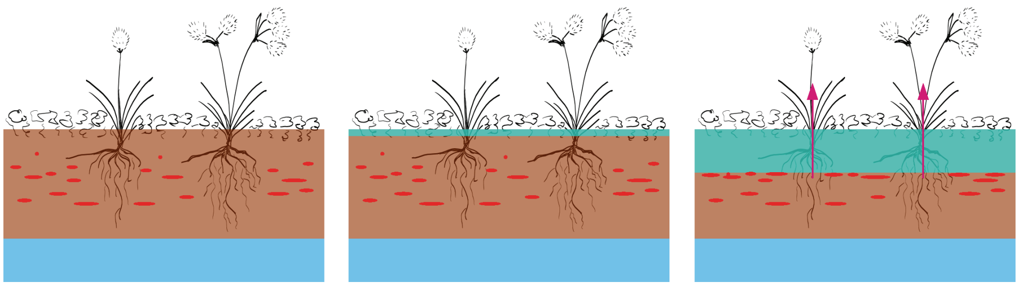

Figure 3. A hypothesis illustrated for how the freeze-in burst of methane emission in continuous permafrost environments emerges. As the ground freezes primarily from the surface down the pressure builds up in the unfrozen zone and the accumulated gas in the soil gets pressed out through physical cracks and pores remaining in place from senesced vascular plants.

functioning and this calls for more continuous measurements both to document ongoing changes and to gain a process understanding for the purpose of modeling large scale transitions in permafrost affected ecosystems and their interactions with climate.

contact:
Torben R. Christensen
GeoBiosphere Science Centre, Lund University, Sweden
torben.christensen@nateko.lu.se

References

Aurela, M., T. Laurila & J.P. Tuovinen (2004) The timing of snow melt controls the annual CO2 balance in a subarctic fen. *Geophysical Research Letters,* **31,** 4.

Christensen, T.R., T. Johansson, H.J. Akerman, M. Mastepanov, N. Malmer, T. Friborg, P. Crill & B.H. Svensson (2004) Thawing sub-arctic permafrost: Effects on vegetation and methane emissions. *Geophysical Research Letters,* **31,** L04501.

Christensen, T.R., T. Johansson, M. Olsrud, L. Ström, A. Lindroth, M. Mastepanov, N. Malmer, T. Friborg, P. Crill & T.V. Callaghan (2007) A catchment-scale carbon and greenhouse gas budget of a subarctic landscape. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences,* **365,** 1643-1656.

Fronzek, S., Luoto, M. & Carter, T.R., 2006. Potential effect of climate change on the distribution of palsa mires in subarctic Fennoscandia. *Climate Research* **32** (1): 1-12.

Groendahl, L., T. Friborg & H. Soegaard (2006) Temperature and snow-melt controls on interannual variability in carbon exchange in the high Arctic. *Theoretical and Applied Climatology,* **88,** 111-125.

Jackowicz-Korczyński, M., T.R. Christensen, K. Bäckstrand, P.M. Crill, T. Friborg, M. Mastepanov, & L. Ström (submitted revised version) Annual cycles of methane emission from a subarctic peatland. *J. Geophys. Res.*

Johansson, T., N. Malmer, P.M. Crill, T. Friborg, J.H. Akerman, M. Mastepanov & T.R. Christensen (2006) Decadal vegetation changes in a northern peatland, greenhouse gas fluxes and net radiative forcing. *Global Change Biology,* **12,** 2352-2369.

Mastepanov, M., C. Sigsgaard, E.J. Dlugokencky, S. Houweling, L. Strom, M.P. Tamstorf, & T.R. Christensen (2008) Large tundra methane burst during onset of freezing. *Nature,* **456,** 628-U58.

McGuire, A.D., Anderson, L.G., Christensen, T.R., Dallimore, S.,Guo, L., Hayes, D.J., Heimann, M., Lorenson, T.D. , Macdonald, R.W., and Roulet, N. Sensitivity of the carbon cycle in the Arctic to climate change. *Ecological Monographs*, in press.

Schuur, E.A.G., J.G. Vogel, K.G. Crummer, H. Lee, J.O. Sickman & T.E. Osterkamp (2009) The effect of permafrost thaw on old carbon release and net carbon exchange from tundra. *Nature,* **459,** 556-559.

Tarnocai, C., Canadell, J.G., Schuur, E.A.G., Kuhry, P., Mazhitova, G. & Zimov, S. *In press.* Soil organic carbon pools in the northern circumpolar permafrost region. *Global Biogeochemical Cycles.*

Tokida, T., T. Miyazaki, M. Mizoguchi & K. Seki (2005) In situ accumulation of methane bubbles in a natural wetland soil. *European Journal of Soil Science,* **56,** 389-396.

Turetsky MR, Wieder RK, Vitt DH, et al., 2007. The disappearance of relict permafrost in boreal north America: Effects on peatland carbon storage and fluxes. Global Change Biology **13**, 1922-1934.

Vallee S & Payette S., 2007. Collapse of permafrost mounds along a subarctic river over the last 100 years (northern Quebec). *Geomorphology* **90**, 162-170.

Walter, K.M., M.E. Edwards, G. Grosse, S.A. Zimov & F.S. Chapin (2007) Thermokarst lakes as a source of atmospheric CH_4 during the last deglaciation. *Science*, **318**, 633-636.

Åkerman, H.J. & M. Johansson (2008) Thawing permafrost and thicker active layers in sub-arctic Sweden. *Permafrost and Periglacial Processes,* **19,** 279-292.

FluxLetter
The Newsletter of
FLUXNET

Vol.2 No.2 June, 2009

FluxLetter is produced quarterly at the FLUXNET Office with support from the National Science Foundation.

This issue of FluxLetter was edited, designed and produced by:

Rodrigo Vargas
Dennis Baldocchi

FLUXNET Office, 137 Mulford Hall, University of California, Berkeley, CA 94720
ph: 1-(510)-642-2421
Fax: 1-(510)-643-5098

We plan to make the FLUXNET newsletter a powerful information, networking, and communication resource for the community. If you want to contribute to any section or propose a new one please contact the FLUXNET Office. THANKS!!