# TLS, MLS & ULS in National Forest Inventory: a link in the chain of remote sensing forest monitoring?

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Terrestrial laser scanning in forest ecology
Expanding the Horizon
May 6 & 7, 2019 - Gent, Belgium

LIÈGE université
Gembloux
Agro-Bio Tech

# Outlines

- National Forest Inventory
- Allometric equations
- LiDAR systems

# National Forest Inventory: NFI

Key features related to remote sensing:

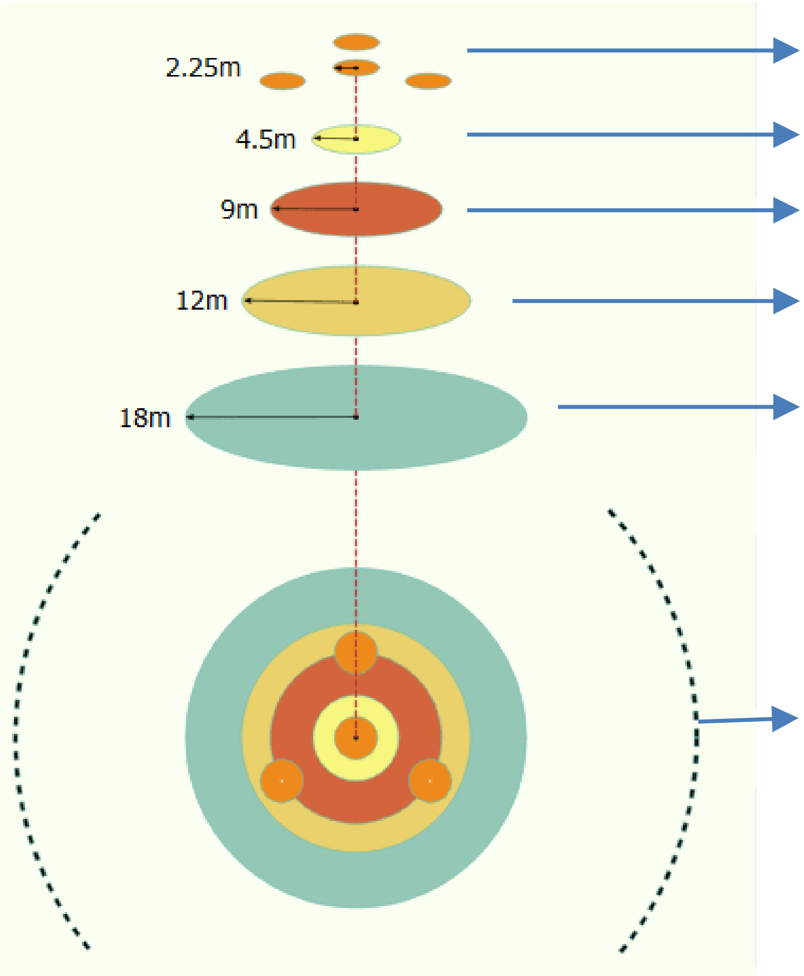
- Sampling of field plots
- Providing qualitative and **quantitative** information on the forest resources **at the national scale**

→ Potential basis for calibration of remote sensing models

# NFI: plot design

Mainly **concentric circular plots** in boreal and temperate countries

- Eg: plot design in Wallonia (Belgium)



4 microplots: regenertion details

**Subplot 3:** 6 cm ≤ DBH < 22 cm + coppice

**Subplot 2**: 22 cm ≤ DBH < 40 cm

Subplot 1: Vegetation assesment

**Main plot :** DBH ≥ 40 cm + topography, pedology, forest edges, …

Observation zone (radius 36 m)
History, main forest,functions, silviculture type, health conditions, game, …

# NFI: plot design

Example of Concentric circular plots:

- Russia

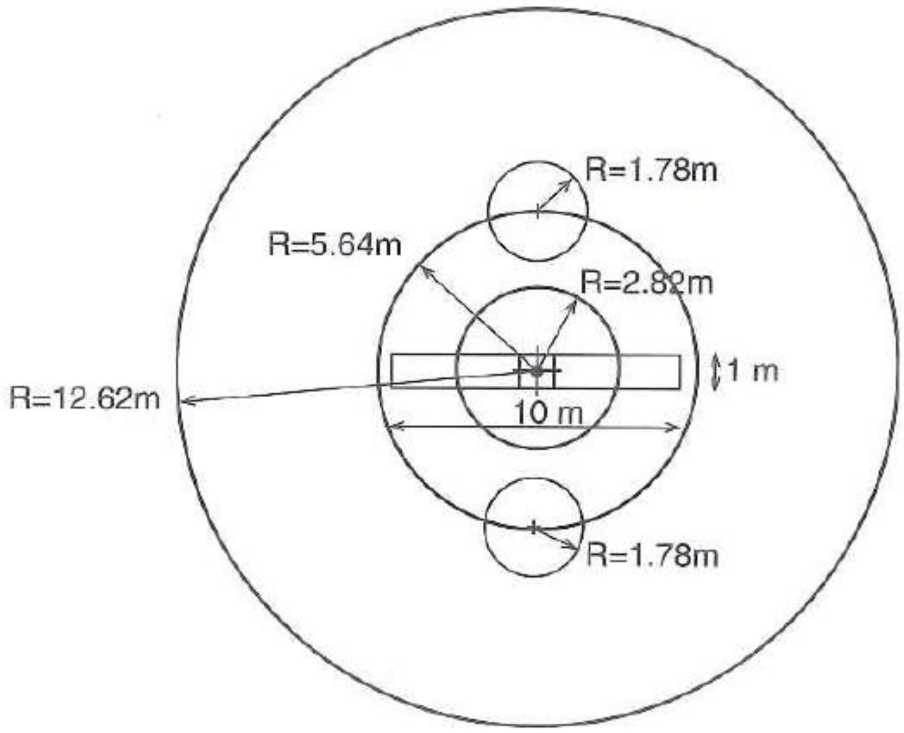


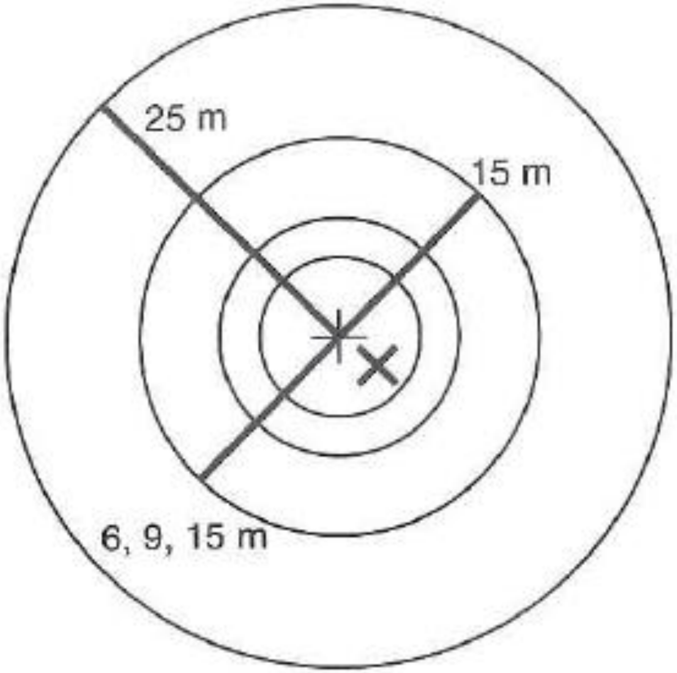
Fig. 31.1 Design of NFI Russia sample plot

Tomppo et al. 2010

# NFI: plot design

Example of Concentric circular plots:

- France



Tomppo et al. 2010

# NFI: plot design

Example of Concentric circular plots:

- USA

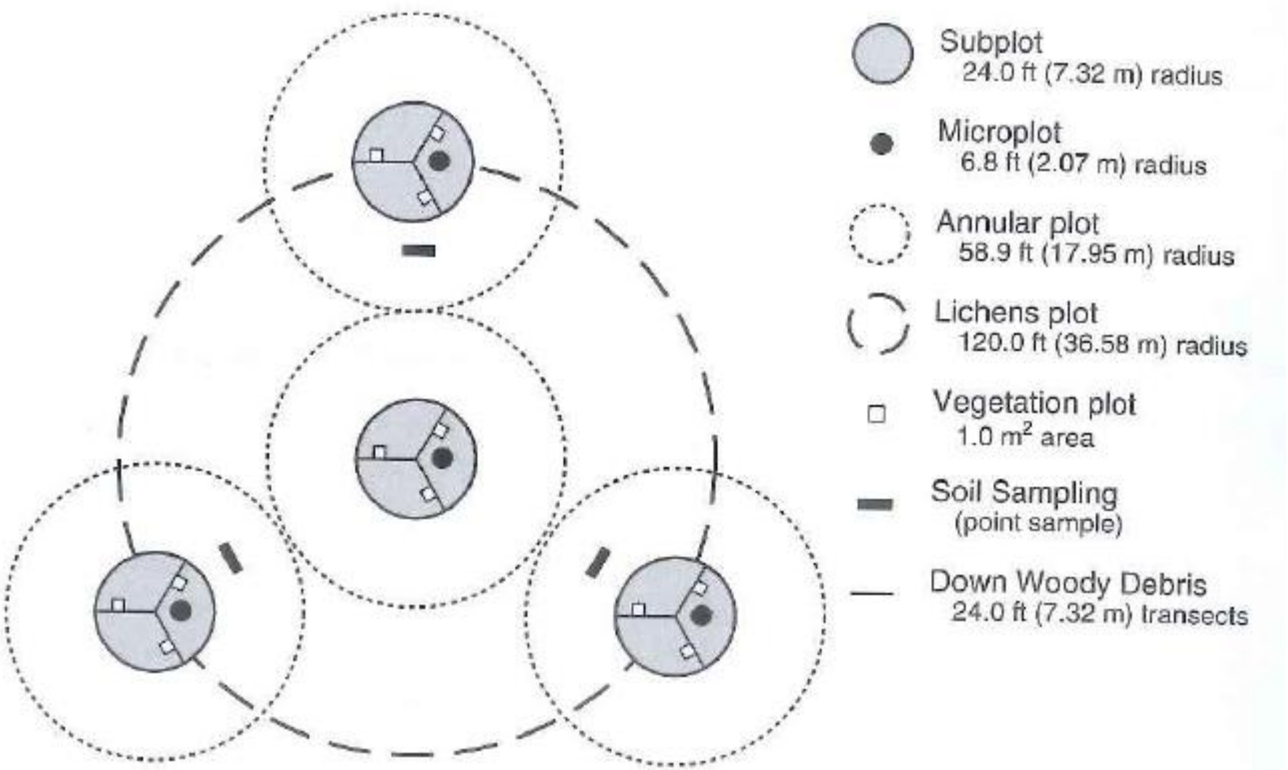


**Fig. 37.3** Phase 2 and 3 plot configurations

Tomppo et al. 2010

# NFI: plot design

Angle counting plots

- Example of Finland

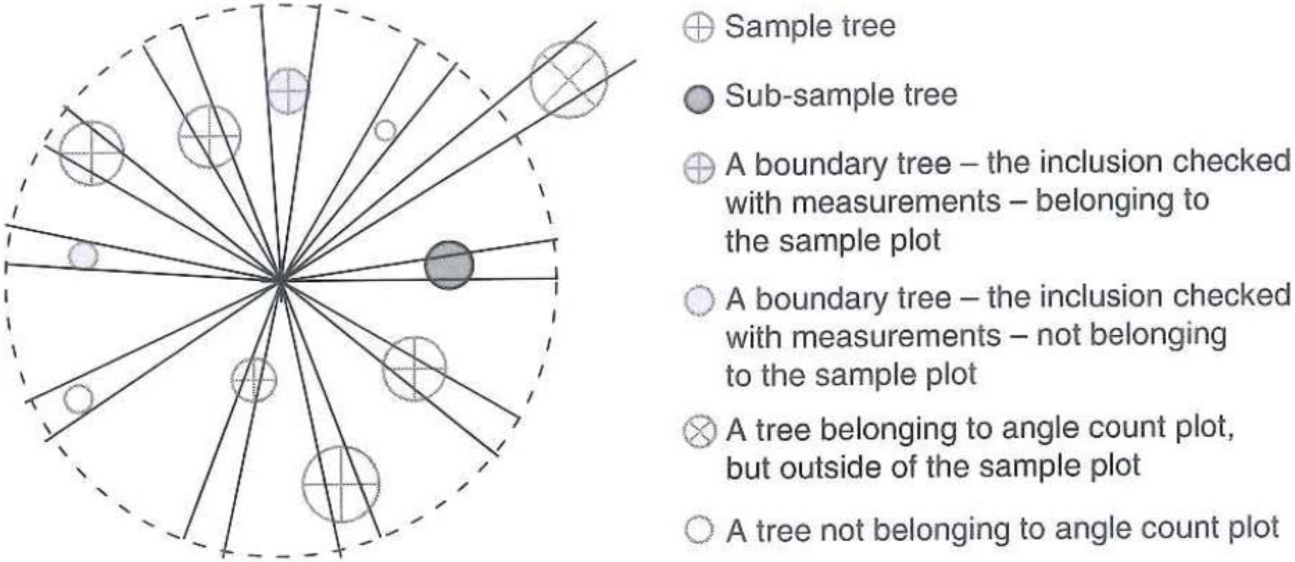


**Fig. 11.3** A sample plot as used in NFI10. The maximum radius for trees to be counted was 12.52 m in Southern Finland (q = 2) (regions 1–3) and 12.45 m in Northern Finland (q = 1.5) (regions 4–6). Every seventh tree is measured as a sub-sample tree. The trees are counted by crews, starting at the beginning of the field season

Tomppo et al. 2010

# NFI: plot design

Usually Rectangles/square plots in tropical forest

- Example of Brazil

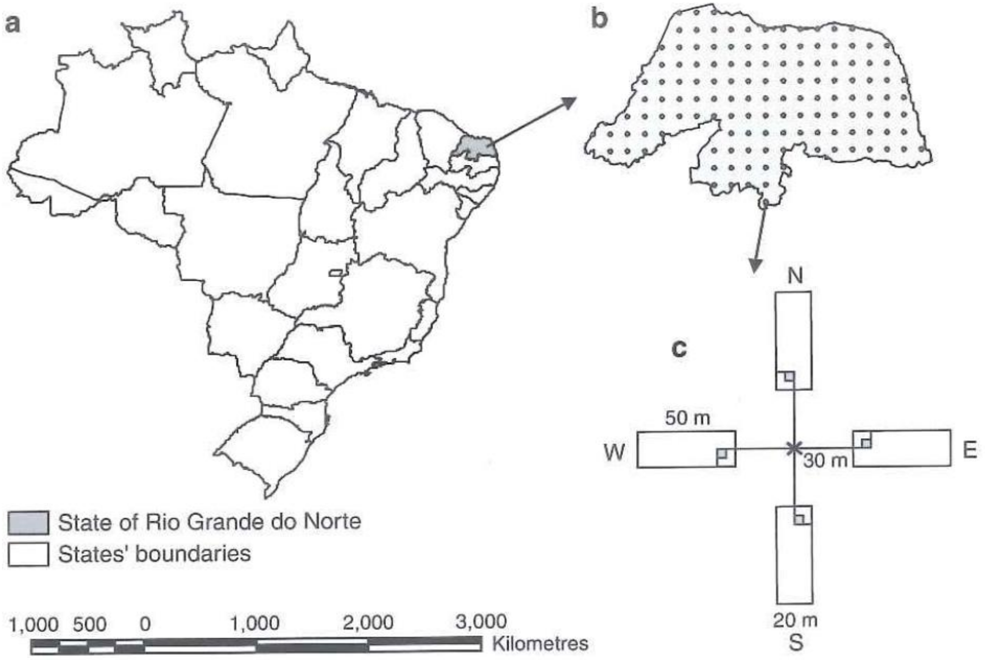


**Fig. 3.1** Brazil map (**a**) showing the State of Rio Grande do Norte, and details of the sampling design: 20 × 20-km base grid (**b**) laid out over the state and the basic cluster sample plot design (**c**) with plots (20 × 50-m), and the nested sub-plots for saplings (10 × 10-m) and seedlings (5 × 5-m)

Tomppo et al. 2010

# NFI: perspectives

NFI perspectives with remote sensing:

- Greater local precision of forest statistics:
  - Increasing sampling intensity with « remote sensing » plots
- Maps (wall to wall) of quantitative information:
  - Biomass
  - Basal area
  - Volume

# NFI: Remote sensing challenges linked to LiDAR systems

Reducing the uncertainty of the remote sensing models by (not exhaustive):

- Removing the concentric subplots effect
- Reducing uncertainty of the allometric models

# Outlines

- National Forest Inventory

- **Allometric equations**

- LiDAR systems

# Allometric equations

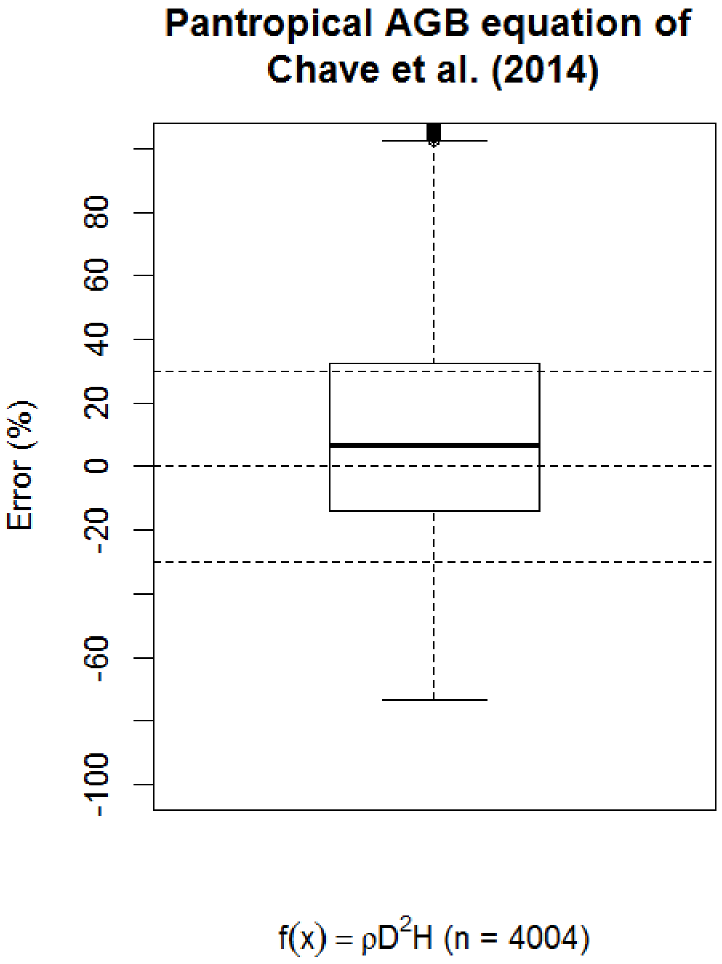
- 2 key attributes:
  - Above ground biomass (AGB)
    - Ecological process
    - Carbon cycle/Carbon budget
  - Stem volume (Vstem)
    - Commercial
- Estimated through easy measurable variables from NFI plots:
  - Diameter at Breast Height (D or DBH)
  - Total Height (TH)

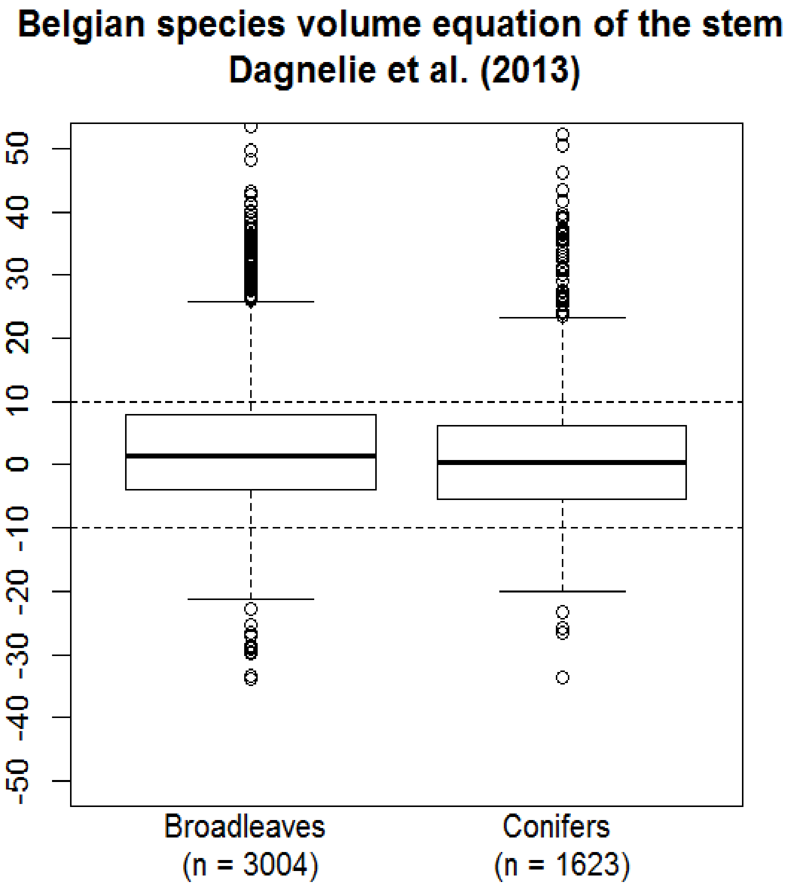
# Allometric equations

- Above ground Biomass (AGB)
  - Usually power models, as:
    - $AGB = a \cdot \mathbf{D}^{b}$ (Zianis et al., 2005; in Europe)
    - $AGB = \mathrm{a} \cdot (\boldsymbol{\rho}\, \mathbf{D}^{2}\, \mathbf{H})^{b}$ (Chave et al. 2005, 2014; Pantropical)
- Stem volume
  - Usually polynomial models, as:
    - $V_{\mathrm{stem}} = (\mathrm{a}) + \mathrm{b} \cdot \boldsymbol{D} + c \cdot \boldsymbol{D}^{2} + e \cdot \boldsymbol{D}^{3}$ *(Dagnelie et al., 2013; Belgium)*
    - $V_{\mathrm{stem}} = (\mathrm{a}) + \mathrm{b} \cdot \boldsymbol{D} + c \cdot \boldsymbol{D}^{2} + e \cdot \boldsymbol{D}^{3} + f \cdot \boldsymbol{H} + g \cdot \boldsymbol{D}^{2}\boldsymbol{H}$ *(Dagnelie et al., 2013; Belgium)*

# Allometric equations

# Uncertainty on individual trees

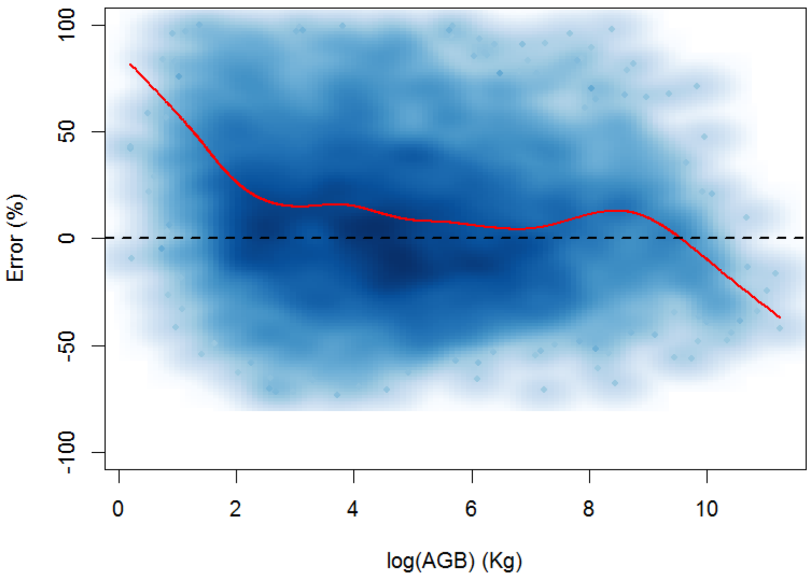


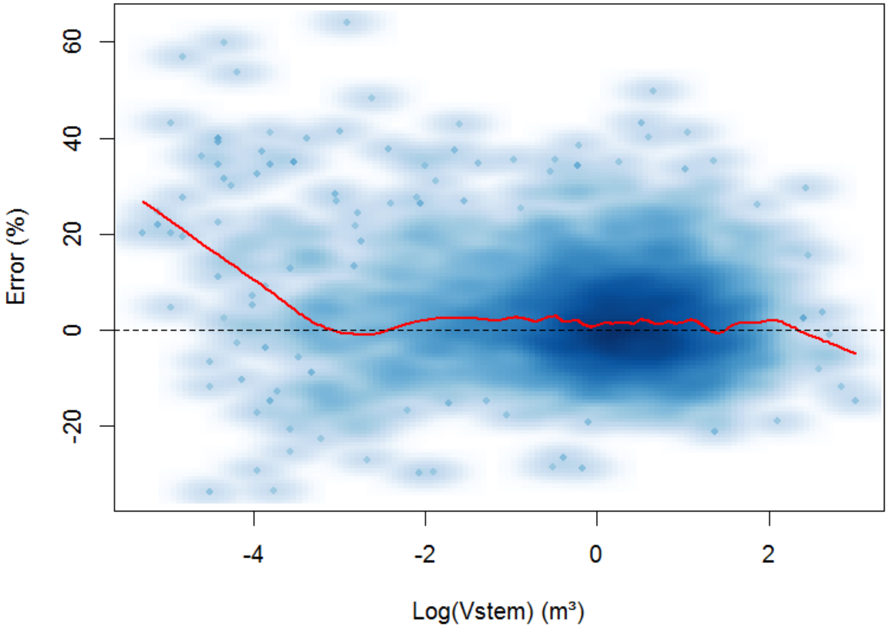


$\sigma = 44\%$

$\sigma = 10\ \%$ $\sigma = 13\ \%$

# Allometric equations
# Uncertainty on individual trees


Pantropical AGB equation of Chave et al. (2014)


Stem volume of broadleaves in Belgium

# Allometric equations: Perspectives

Reducing local error/bias

- Direct measurements of volumes
- New variables for allometric models

# Outlines

- National Forest Inventory

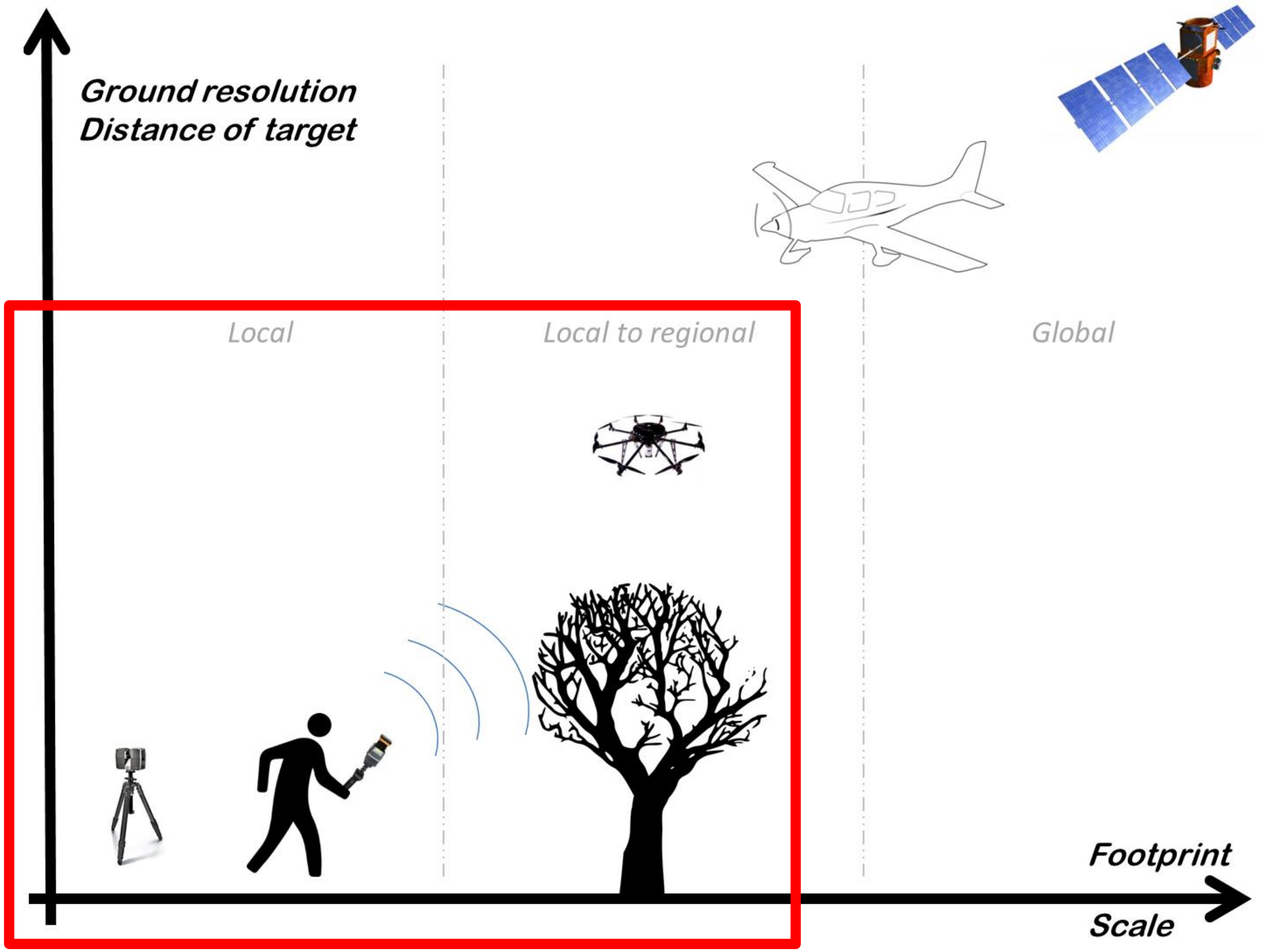
- Allometric equations

- **LiDAR systems**

# LiDAR systems

- Terrestrial Laser Scanning (TLS)
- Mobile Laser Scanning (MLS)
- Unmaned aerial Laser Scanning (ULS)
- Airborne Laser Scanning  (ALS)
- Spaceborne Laser Scanning (SLS)

# LiDAR systems



**Traditional data acquisition scale In NFI**

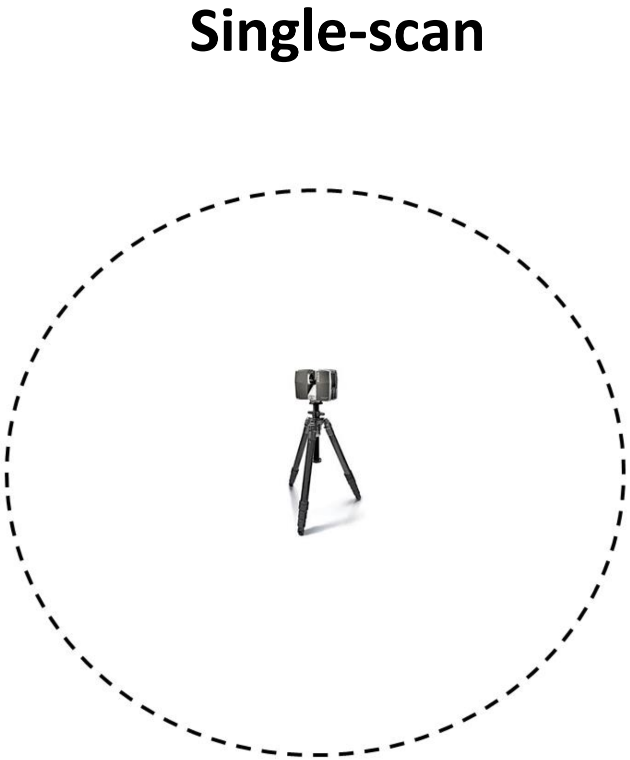
Michez et al., 2016

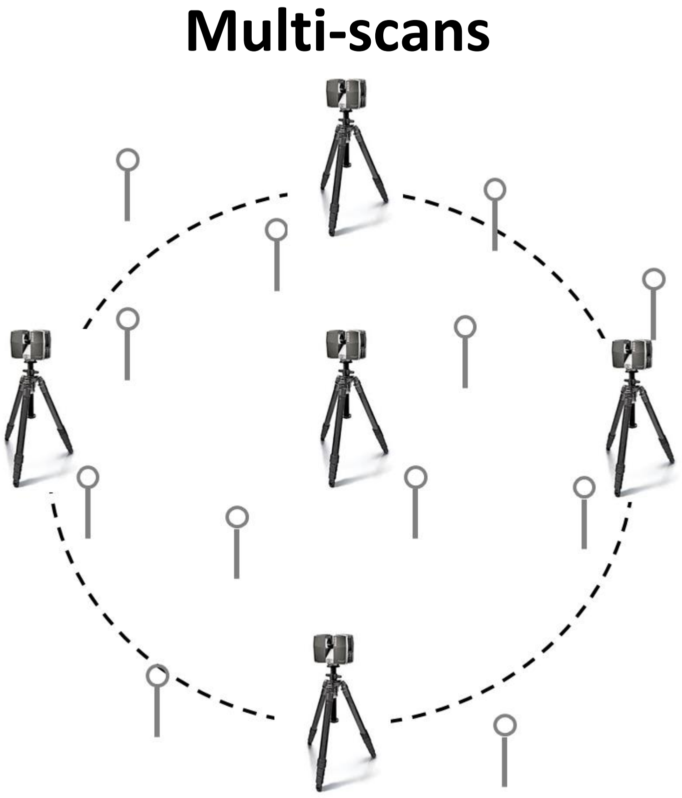
# LiDAR systems

- Terrestrial Laser Scanning (TLS)
- Mobile Laser Scanning (MLS)
- Unmaned aerial Laser Scanning (ULS)
- Airborne Laser Scanning (ALS)
- Spaceborne Laser Scanning (SLS)

# Terrestrial Laser Scanning

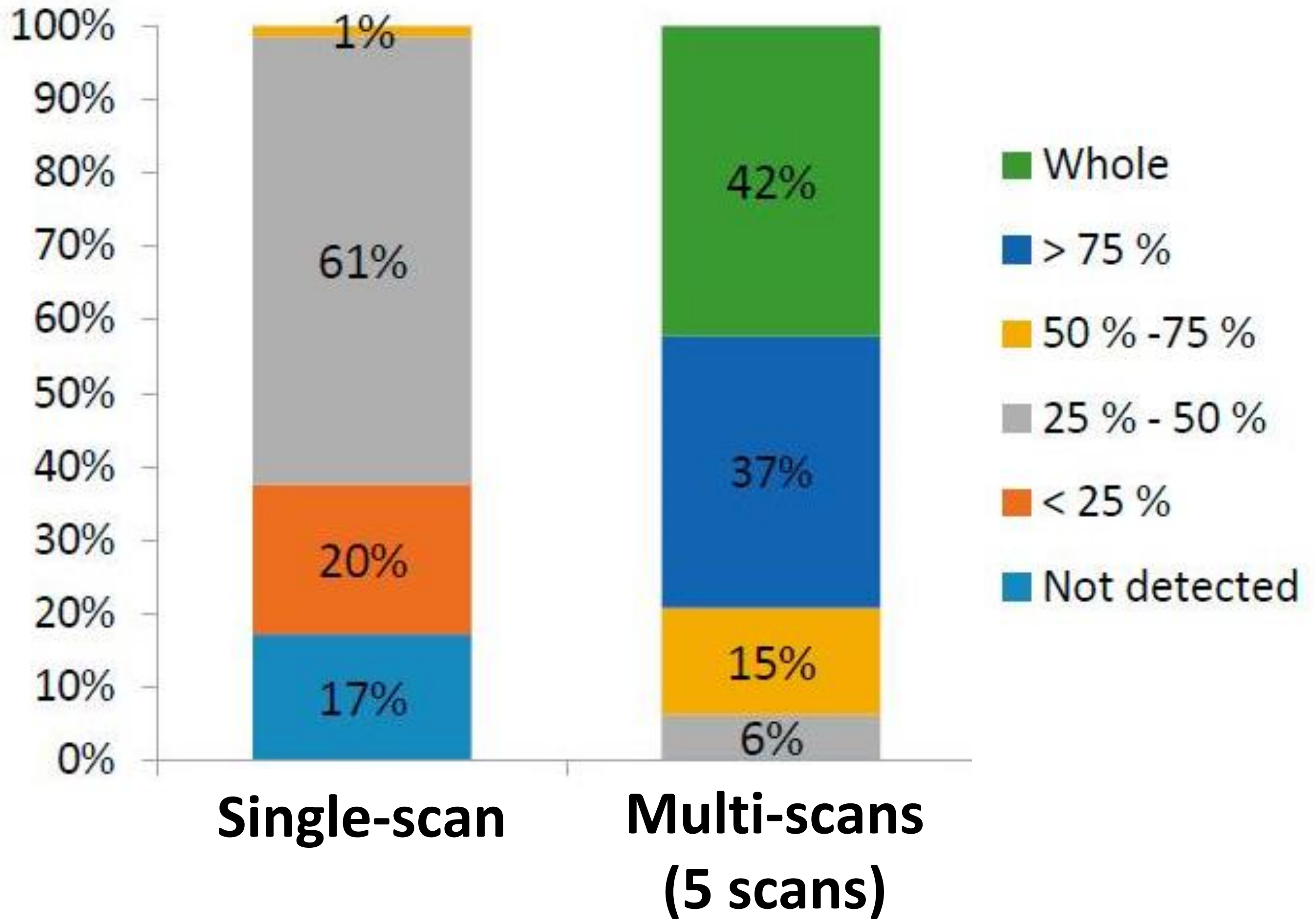
- Two scanning methods
  - – E.g. in circular plot

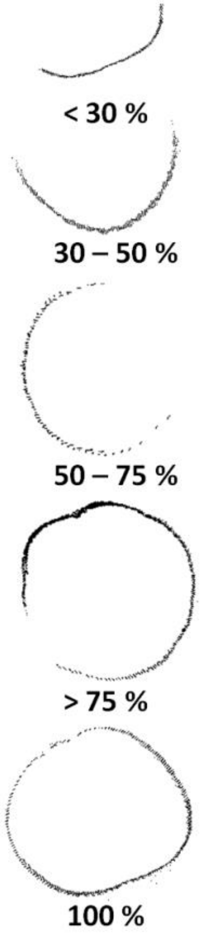




# Terrestrial Laser Scanning

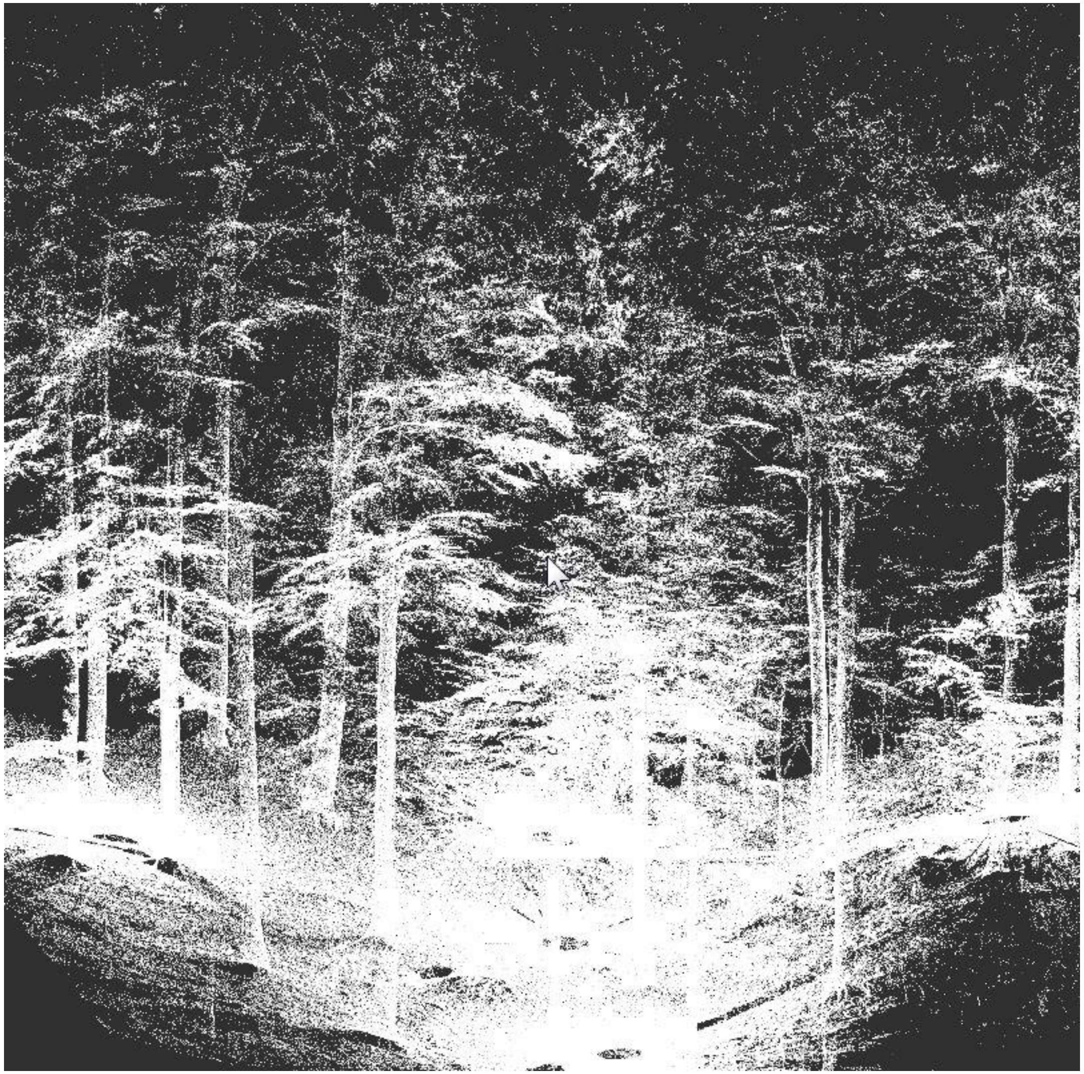
- Cross-section at 1.3 m on 8 plots





**Bauwens et al., 2016**

# Terrestrial Laser Scanning

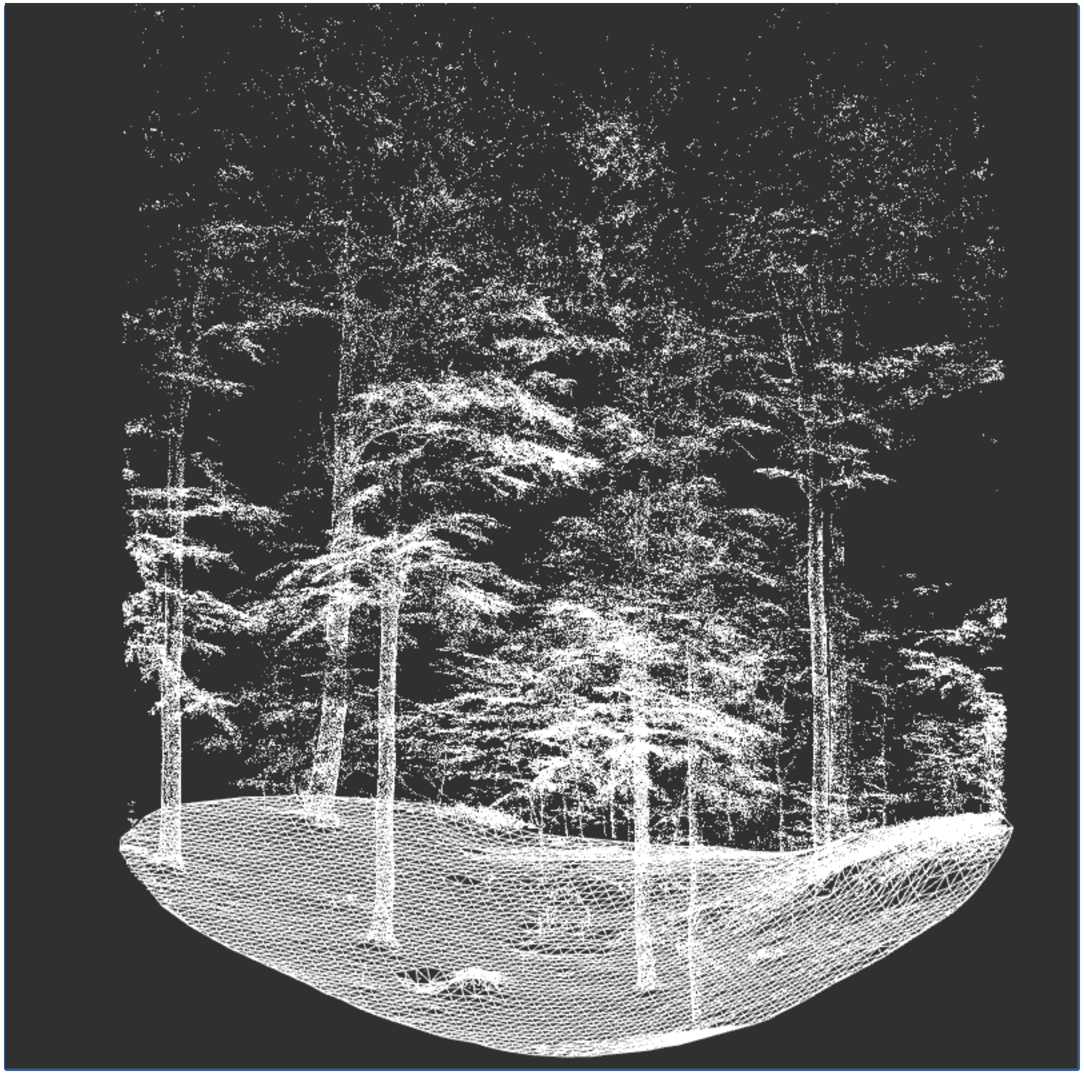


Michez et al., 2016

# Terrestrial Laser Scanning

Michez et al., 2016

# Terrestrial Laser Scanning



Michez et al., 2016

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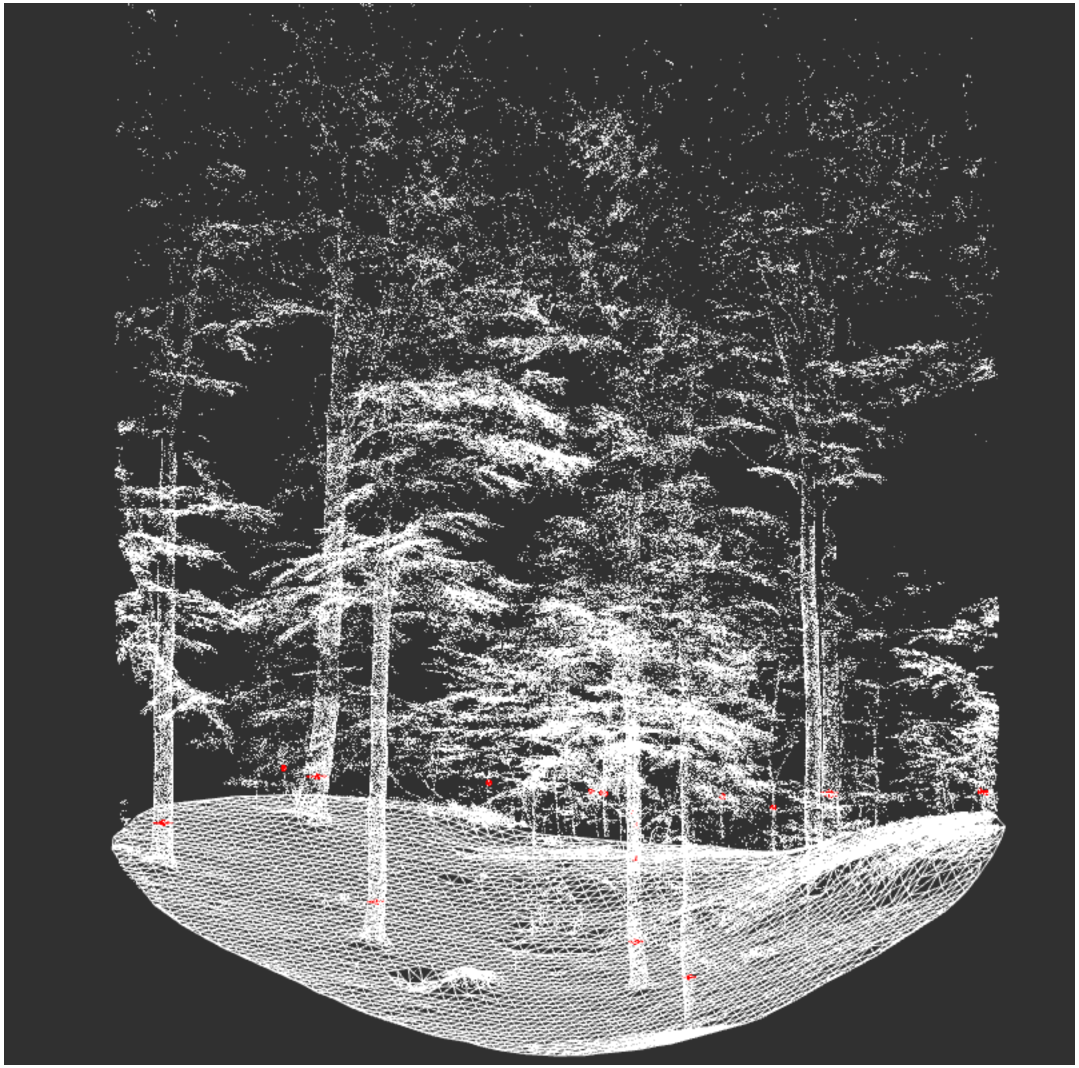
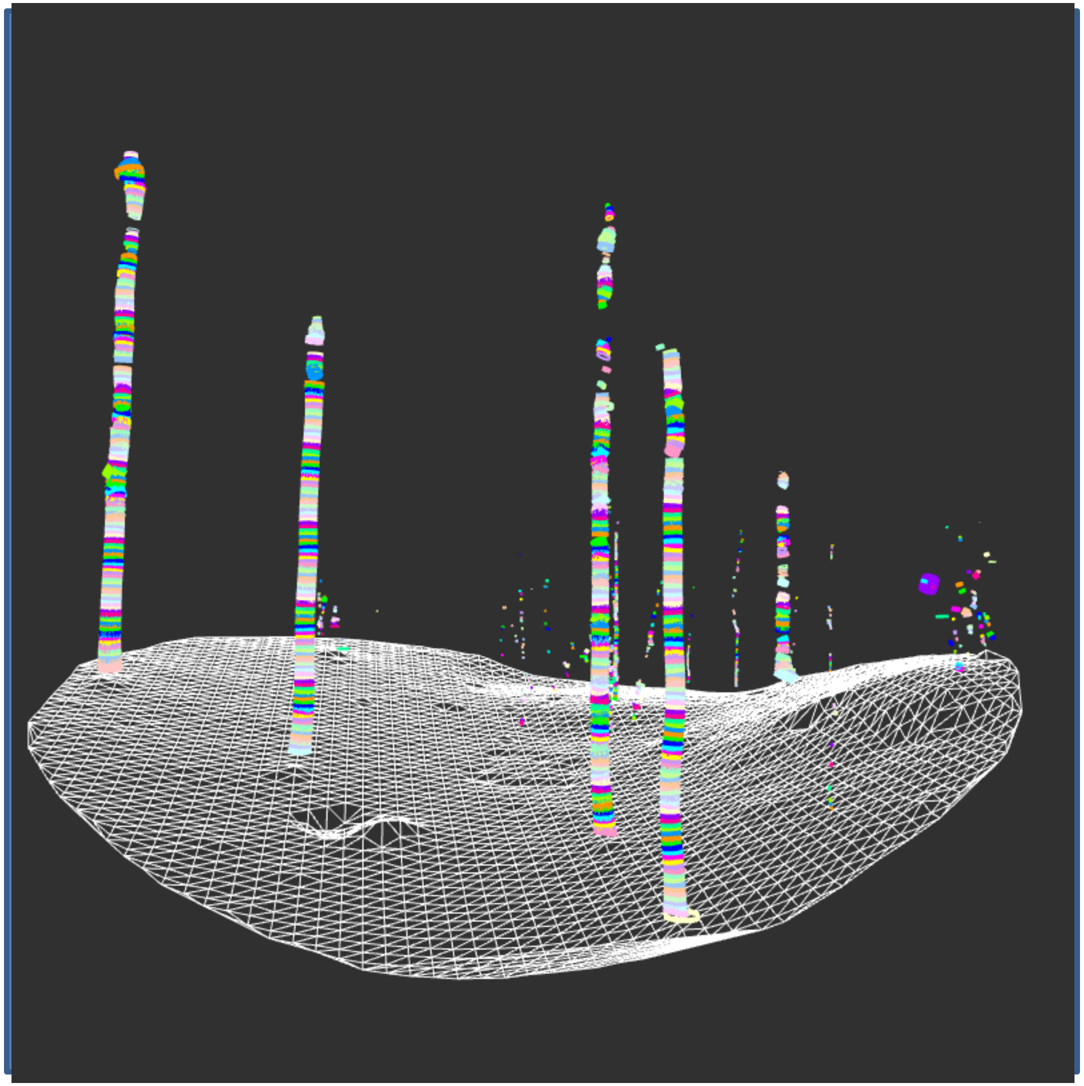


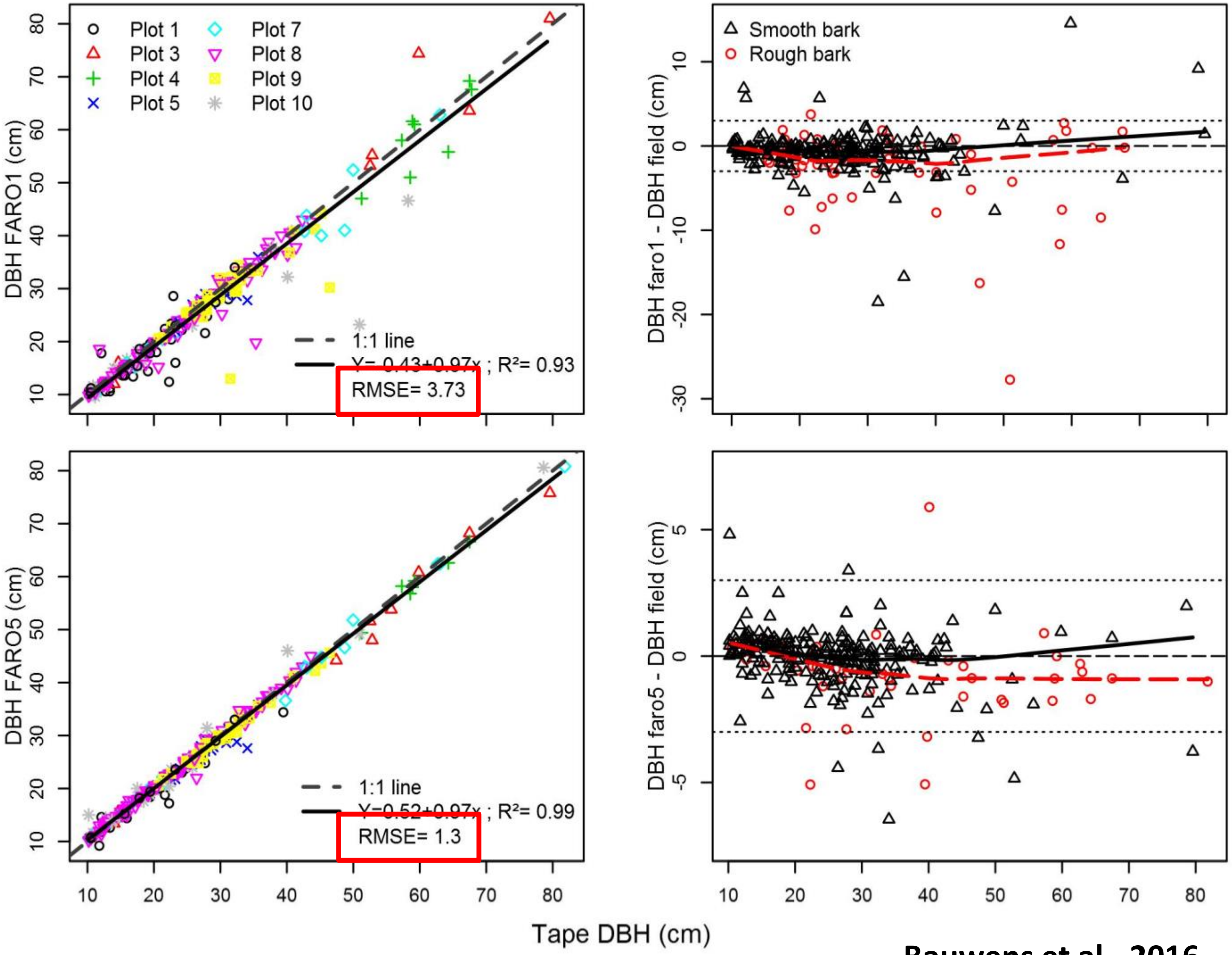
Michez et al., 2016

# Terrestrial Laser Scanning



Michez et al., 2016

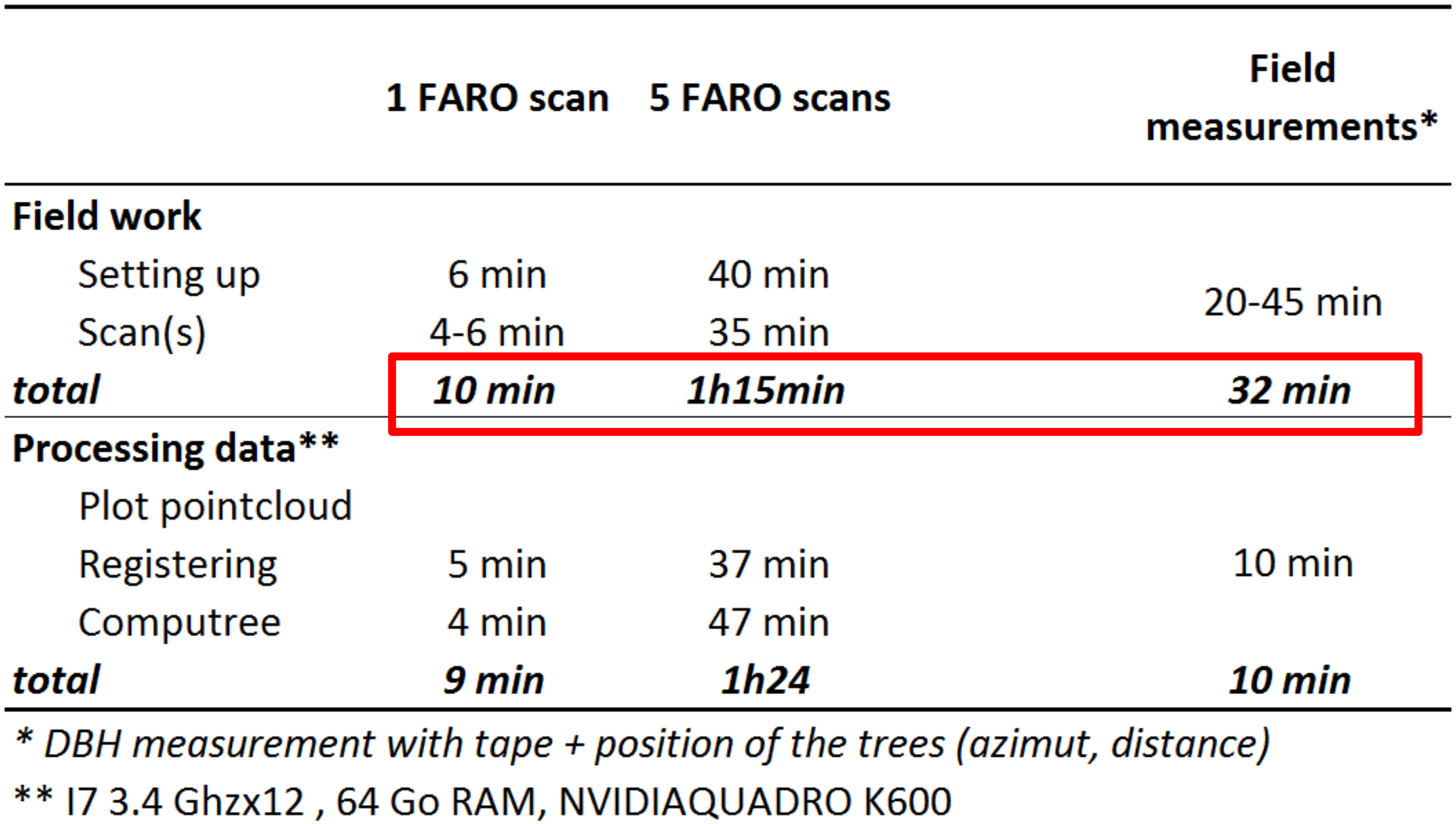
# Terrestrial Laser Scanning



**Bauwens et al., 2016**

# Terrestrial Laser Scanning

- Time cost



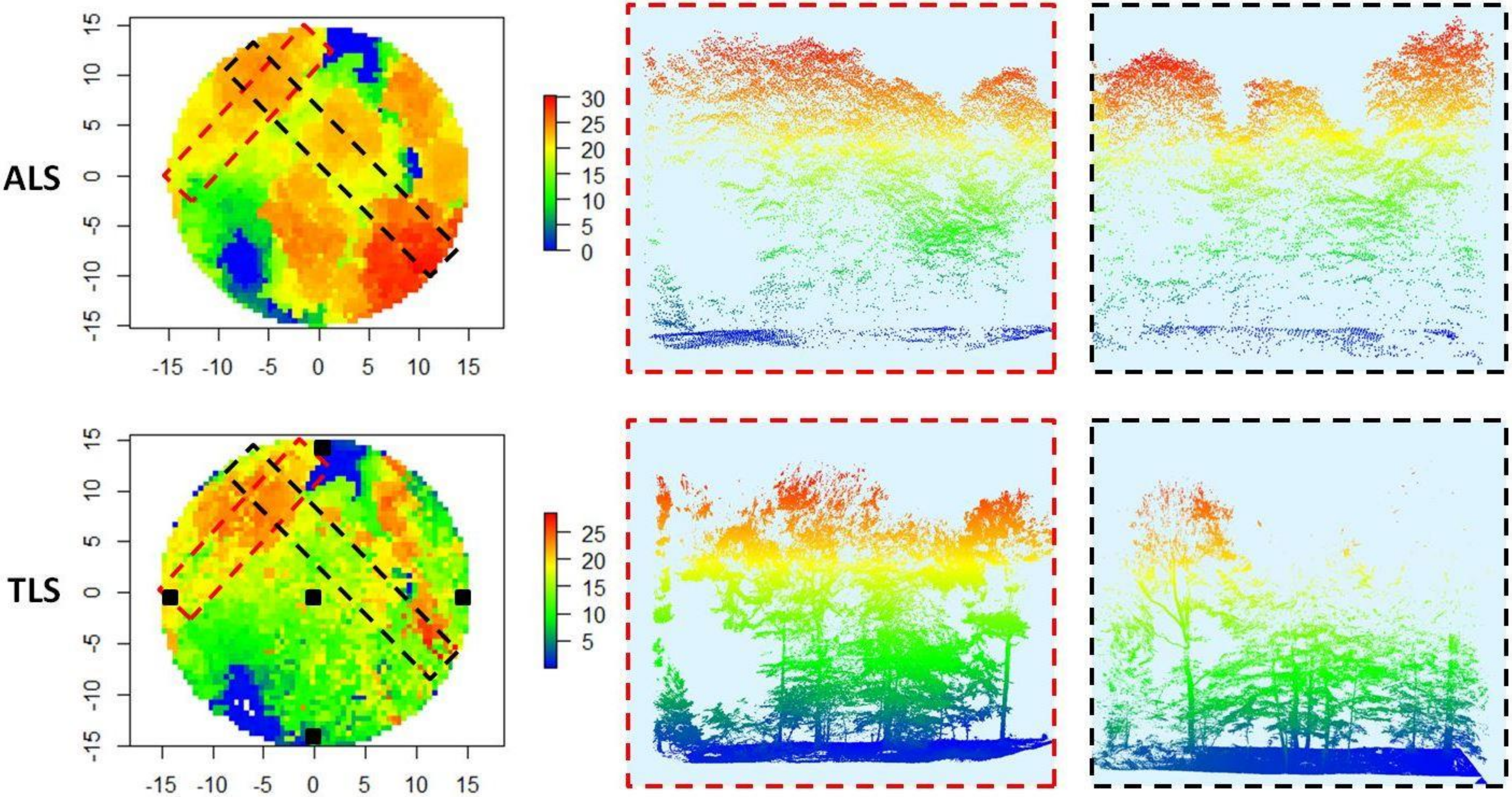
| | **1 FARO scan** | **5 FARO scans** | **Field measurements*** |
|---|---|---|---|
| **Field work** | | | |
| Setting up | 6 min | 40 min | 20-45 min |
| Scan(s) | 4-6 min | 35 min | |
| ***total*** | ***10 min*** | ***1h15min*** | ***32 min*** |
| **Processing data**** | | | |
| Plot pointcloud | | | |
| Registering | 5 min | 37 min | 10 min |
| Computree | 4 min | 47 min | |
| ***total*** | ***9 min*** | ***1h24*** | ***10 min*** |

** DBH measurement with tape + position of the trees (azimut, distance)*

** I7 3.4 Ghzx12 , 64 Go RAM, NVIDIAQUADRO K600

**Bauwens et al., 2016**

# Terrestrial Laser Scanning



Michez et al., 2016

# Terrestrial Laser Scanning

## Summary

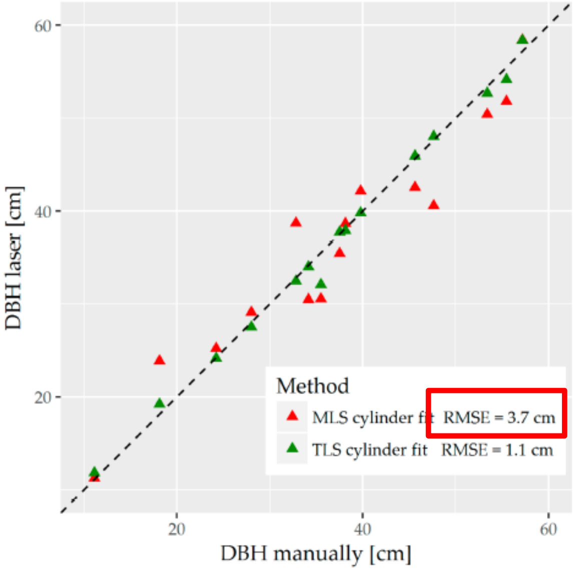
- TLS
  - Single-scan: limited potential
    - Angle counting for basal area estimates
    - Local Digital Terrain Model
  - Multi-scans:
    - ⊖ Time consuming
    - ⊖ Occlusion
      - increase the number of scans in one plot -> big data
    - ⊕ Stem volume « measurment » possible
    - ⊕ No more concentric plot and an accurate stem map

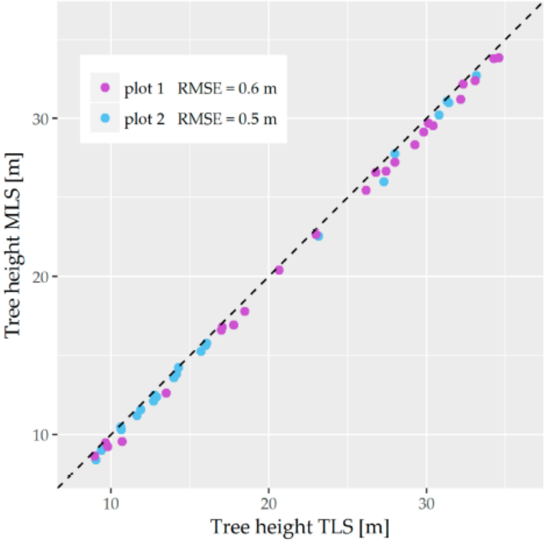
# LiDAR systems

- Terrestrial Laser Scanning (TLS)
- **Mobile Laser Scanning (MLS)**
- Unmaned aerial Laser Scanning (ULS)
- Airborne Laser Scanning (ALS)
- Spaceborne Laser Scanning (SLS)

# Mobile Laser Scanning

Bienert et al., 2018





## Mobile Laser Scanning

# Personal Laser Scanning

**Experimental systems**

Kukko et al., 2012

Liang et al., 2014

Holmgren et al., 2017

**Commercial systems**

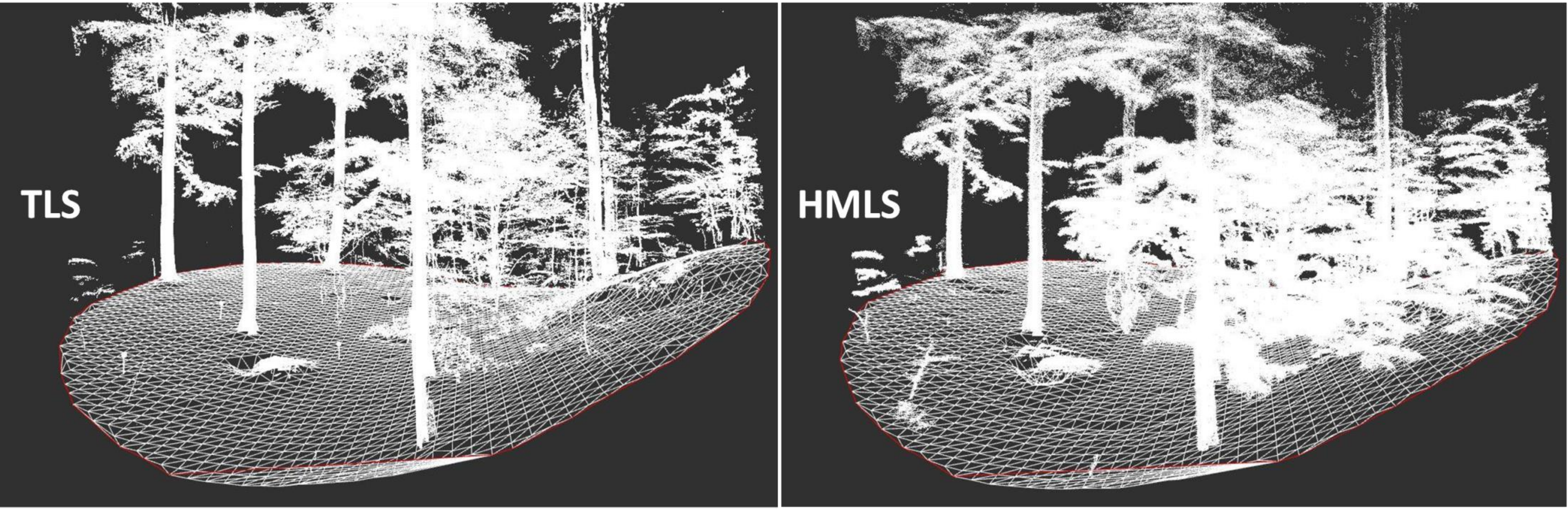
Bauwens et al., 2016

LiBackpack

## Mobile Laser Scanning

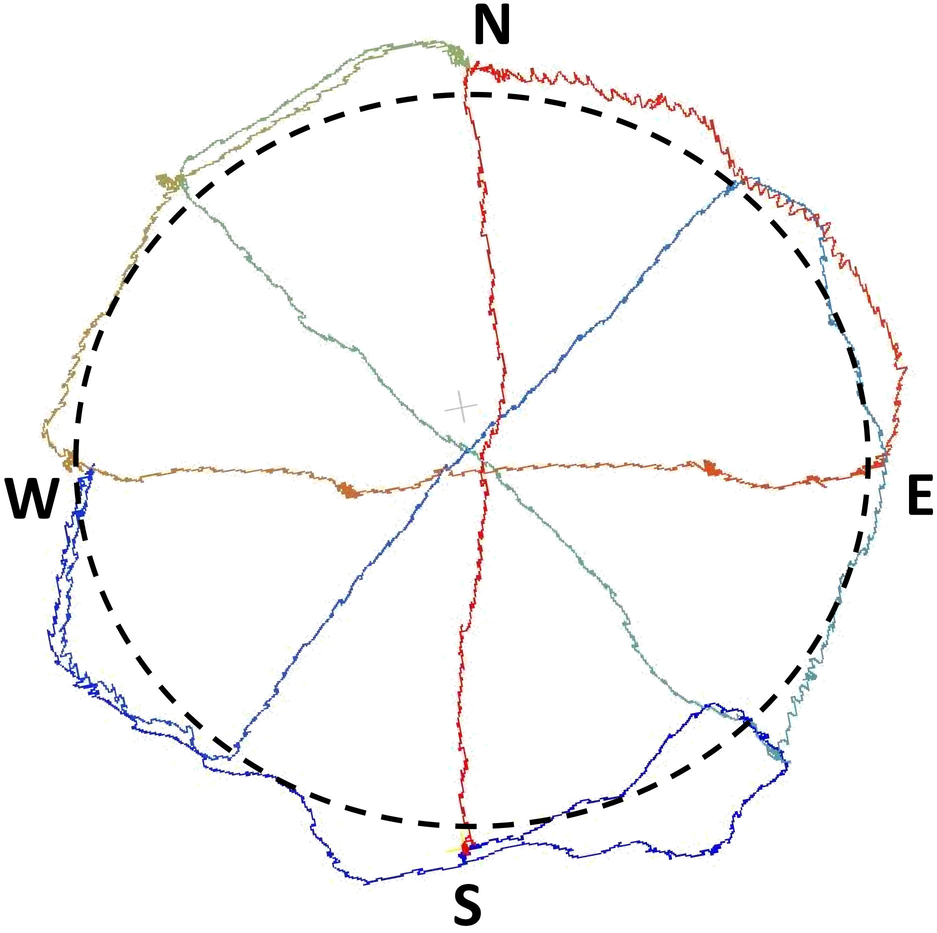
# Personal Laser Scanning

- Study case in Belgium with ZEB1



# Mobile Laser Scanning
# Personal Laser Scanning

- Study case in Belgium with ZEB1



# Mobile Laser Scanning
# Personal Laser Scanning

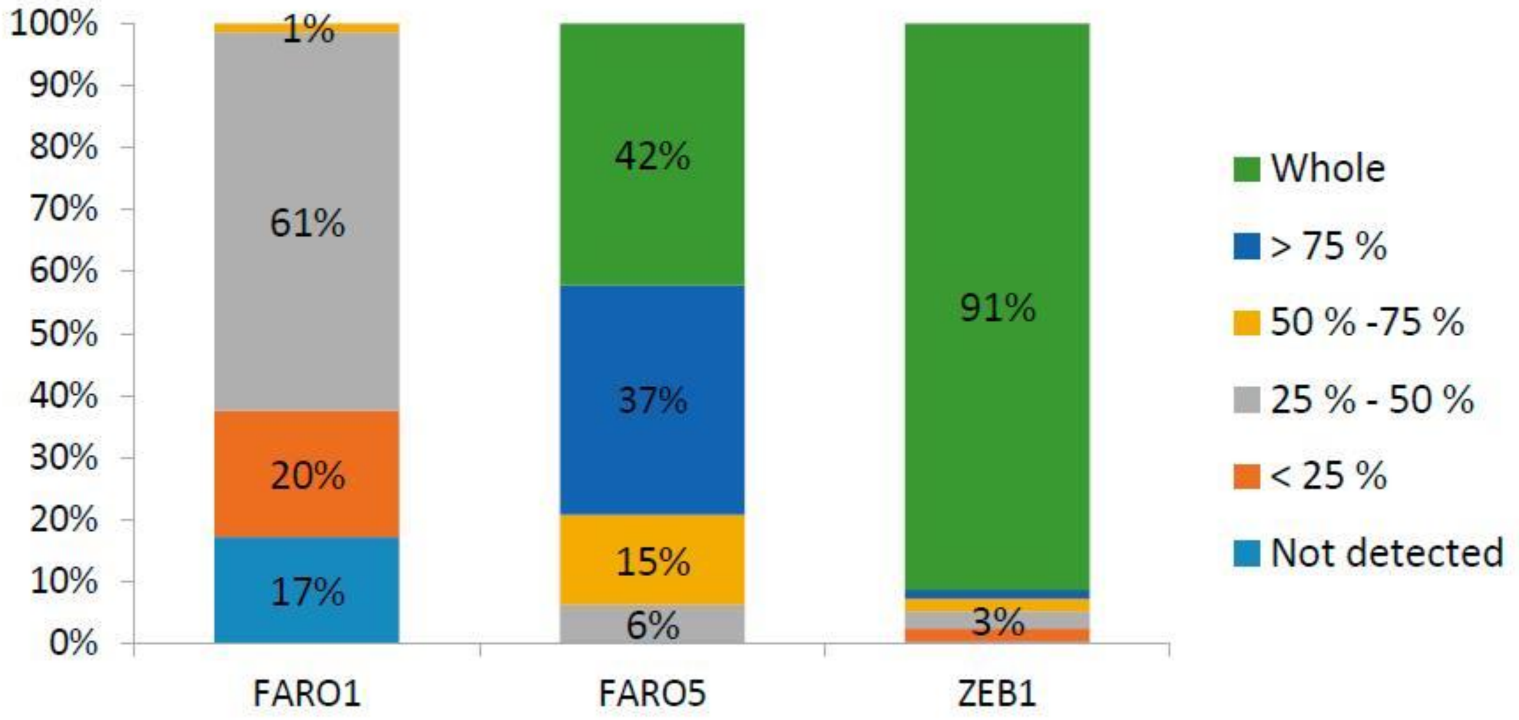
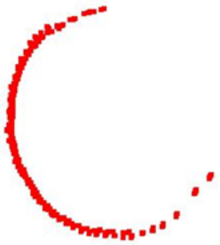


**Figure 4.** Percentage of the cross-section closure between the three different scanning methods according to the visual interpretation of the point cloud slices at 1.3 m height (thickness of 10 cm) of the eight plots.

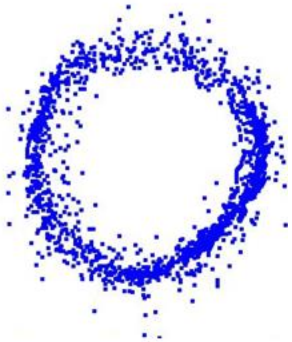
**Bauwens et al., 2016**

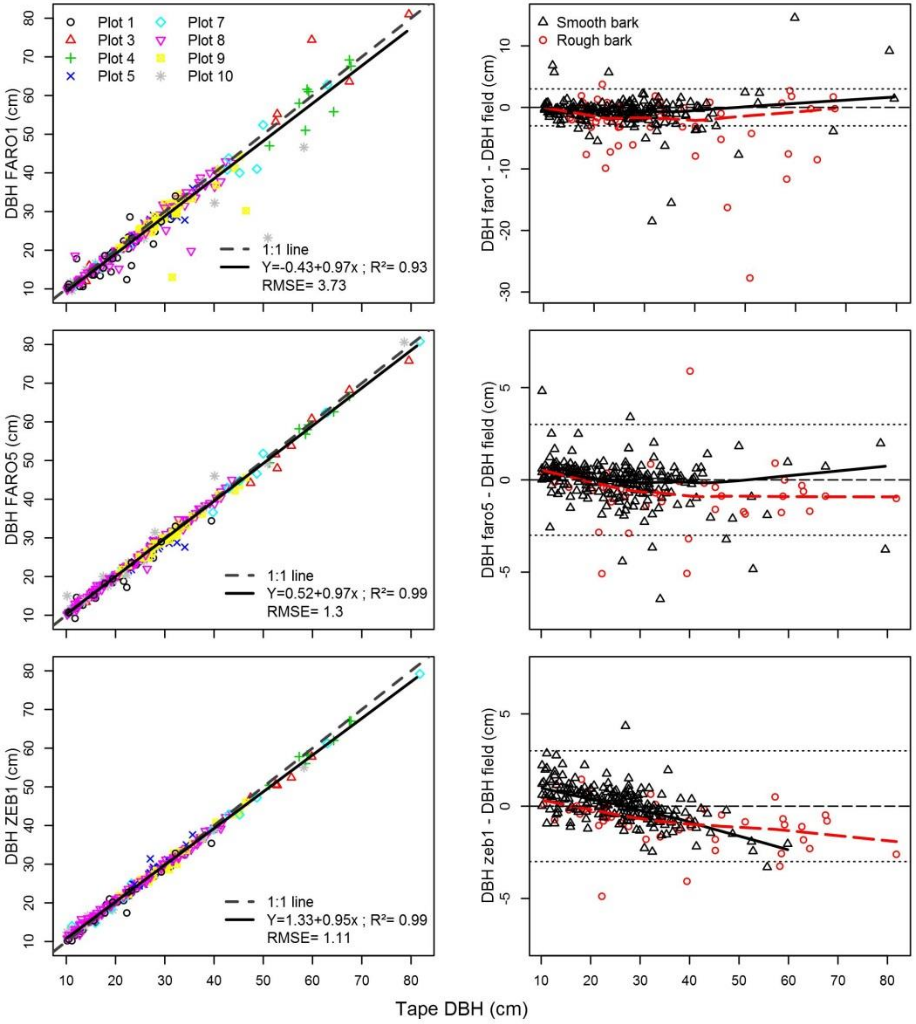
# Mobile Laser Scanning
# Personal Laser Scanning

**FARO5**



**ZEB1**



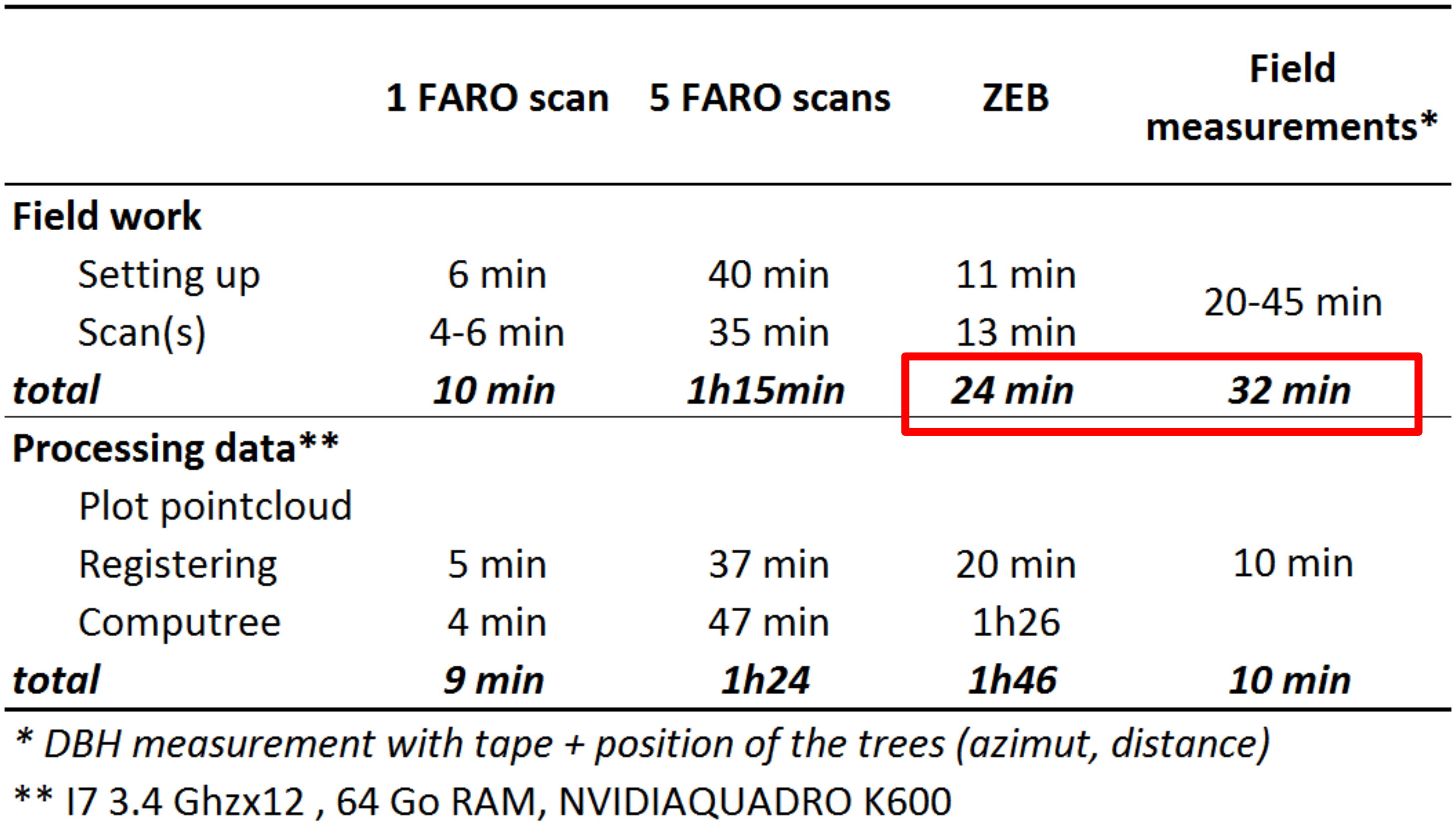


**Bauwens et al., 2016**

## Mobile Laser Scanning

# Personal Laser Scanning

- Time cost



| | 1 FARO scan | 5 FARO scans | ZEB | Field measurements* |
|---|---|---|---|---|
| **Field work** | | | | |
| Setting up | 6 min | 40 min | 11 min | 20-45 min |
| Scan(s) | 4-6 min | 35 min | 13 min | |
| ***total*** | ***10 min*** | ***1h15min*** | ***24 min*** | ***32 min*** |
| **Processing data**** | | | | |
| Plot pointcloud | | | | |
| Registering | 5 min | 37 min | 20 min | 10 min |
| Computree | 4 min | 47 min | 1h26 | |
| ***total*** | ***9 min*** | ***1h24*** | ***1h46*** | ***10 min*** |

** DBH measurement with tape + position of the trees (azimut, distance)*

** I7 3.4 Ghzx12 , 64 Go RAM, NVIDIAQUADRO K600

**Bauwens et al., 2016**

# Mobile Laser Scanning:
## Summary

- MLS with a car :
  - – limited potential
    - Restricted to a buffer zone alongside the road
- PLS :
  - ⊖ Precision of the point cloud
  - ⊕ Time effective
  - ⊕ Limited occlusion in the lower part of the stems
  - ⊕ Measurement of the stem base possible
  - ⊕ No more concentric plot and an accurate stem map

# LiDAR systems

- Terrestrial Laser Scanning (TLS)
- Mobile Laser Scanning (MLS)
- **Unmaned aerial Laser Scanning (ULS)**
- Airborne Laser Scanning (ALS)
- Spaceborne Laser Scanning (SLS)

# Unmaned aerial Laser Scanning

- 2 main brands

**Riegl**

**Velodyne**

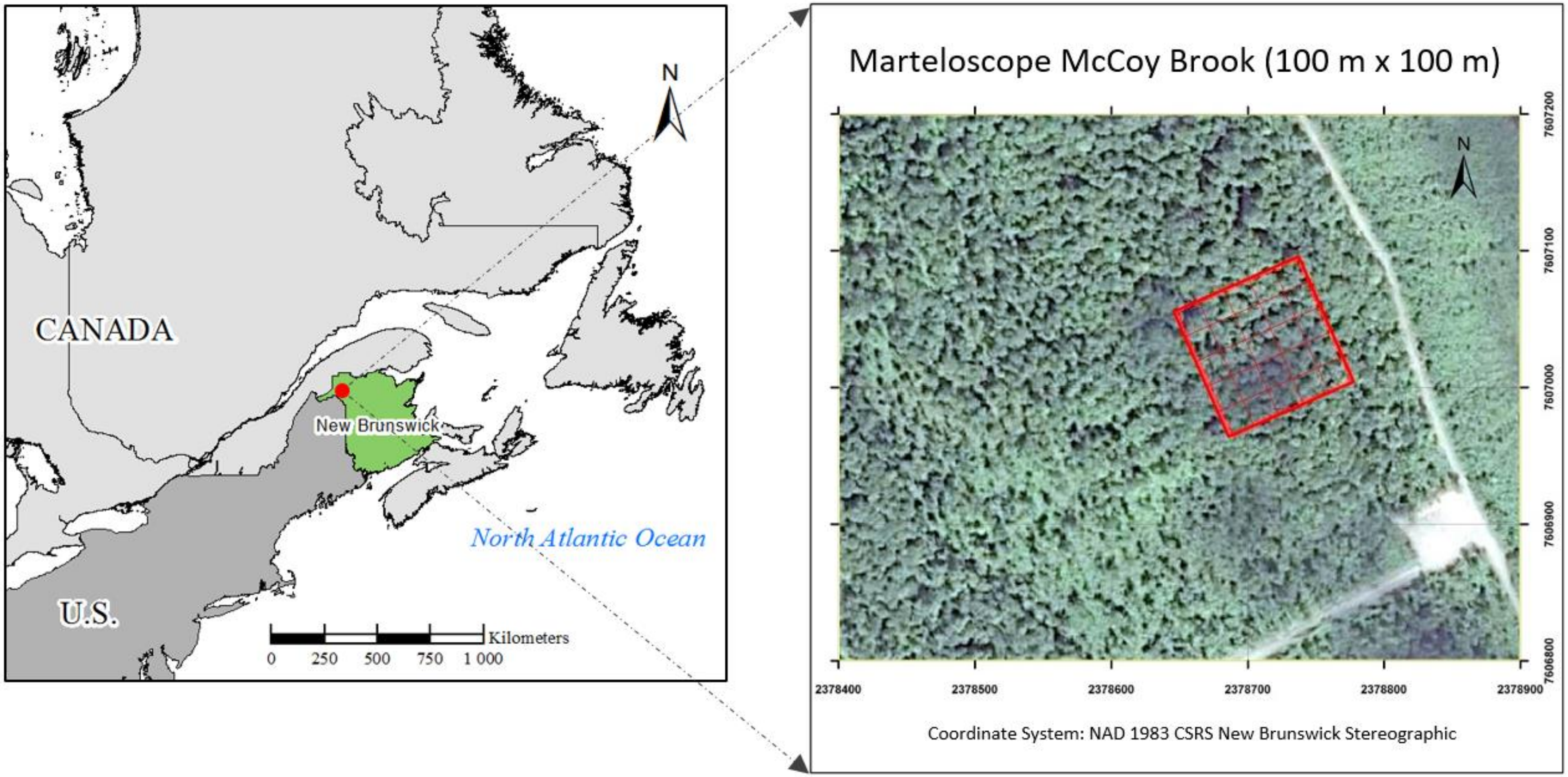
# ULS: Study case

Section based on the thesis of:

- Vandendaele Bastien (U. Sherbrooke - U. Liège)
  - Director : Richard Fournier - U. Sherbrooke
  - Co-director : Udayalakshmi Vepakomma - FPInnovations
  - Co-director : Philippe Lejeune - U. Liège

# ULS: Study case

## Study Site



# ULS: Study case

UNIVERSITÉ DE SHERBROOKE

LIÈGE université
Gembloux
Agro-Bio Tech

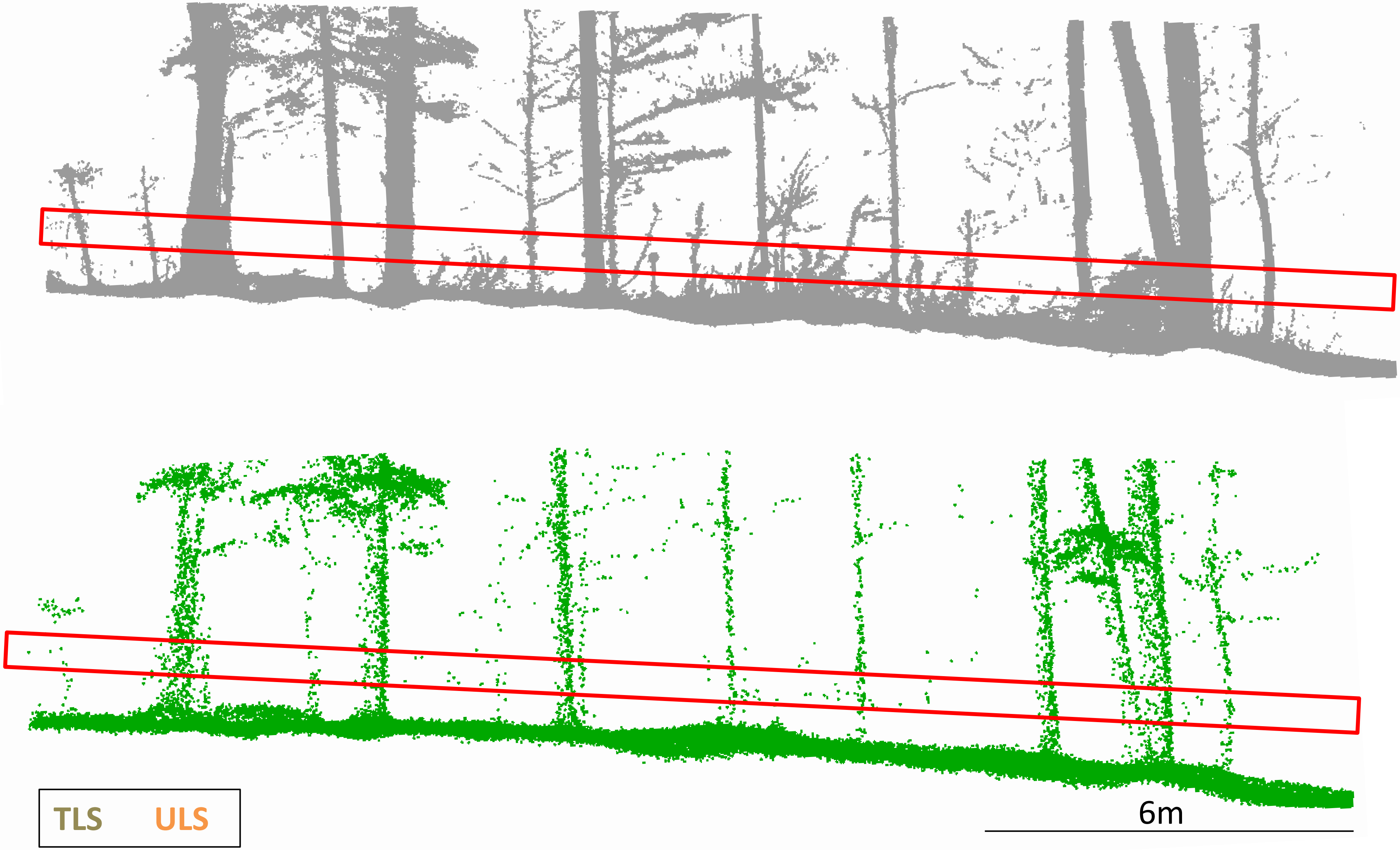
## Perspective view

**TLS**

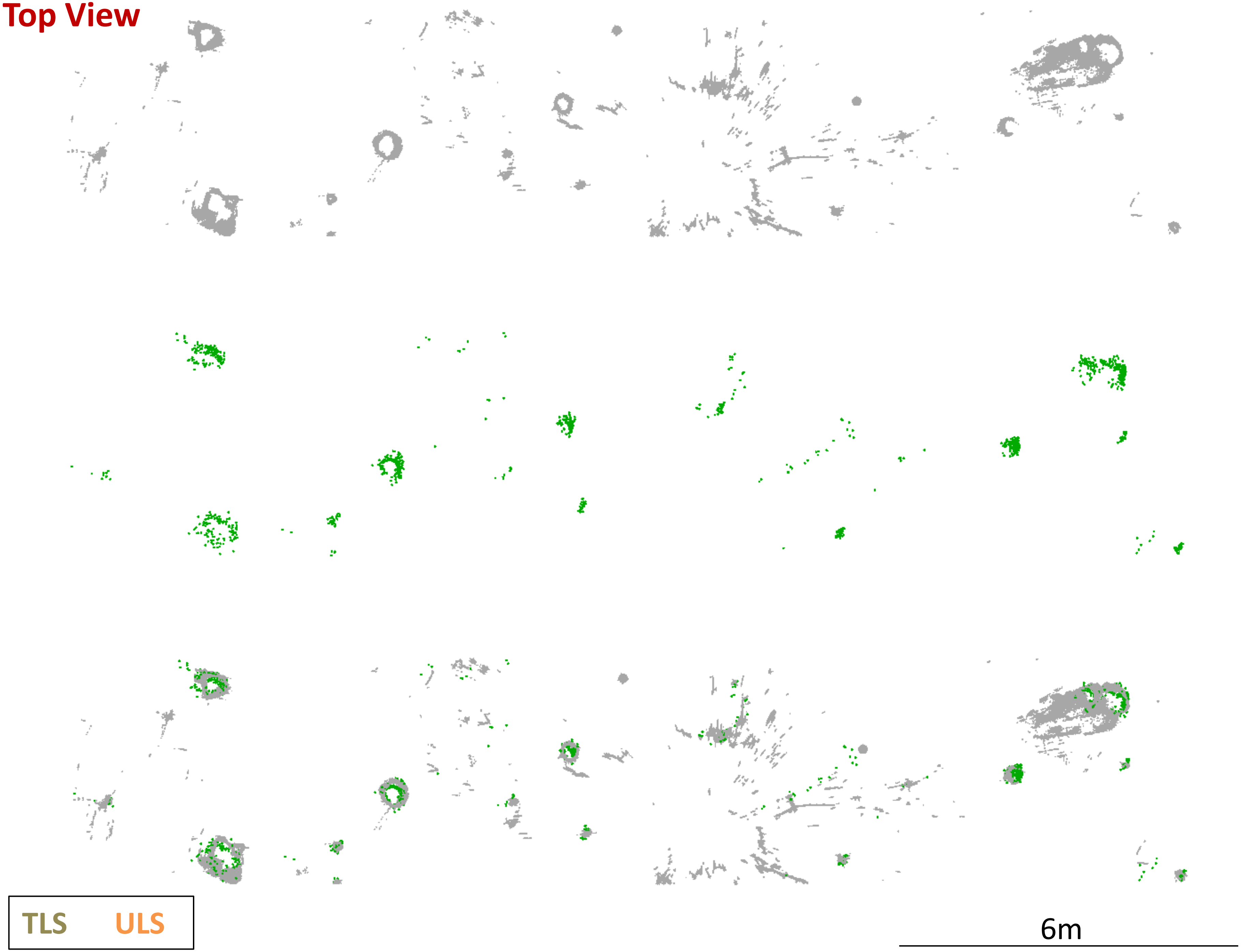
**ULS**

# ULS: Study case

**Perspective view**

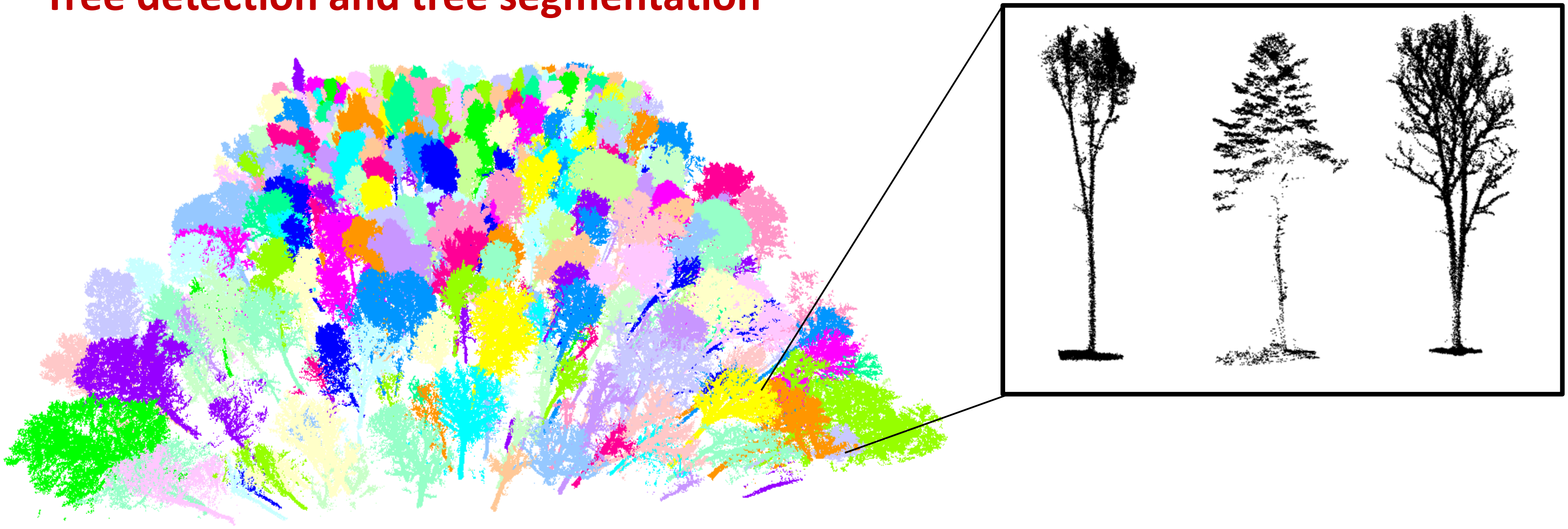


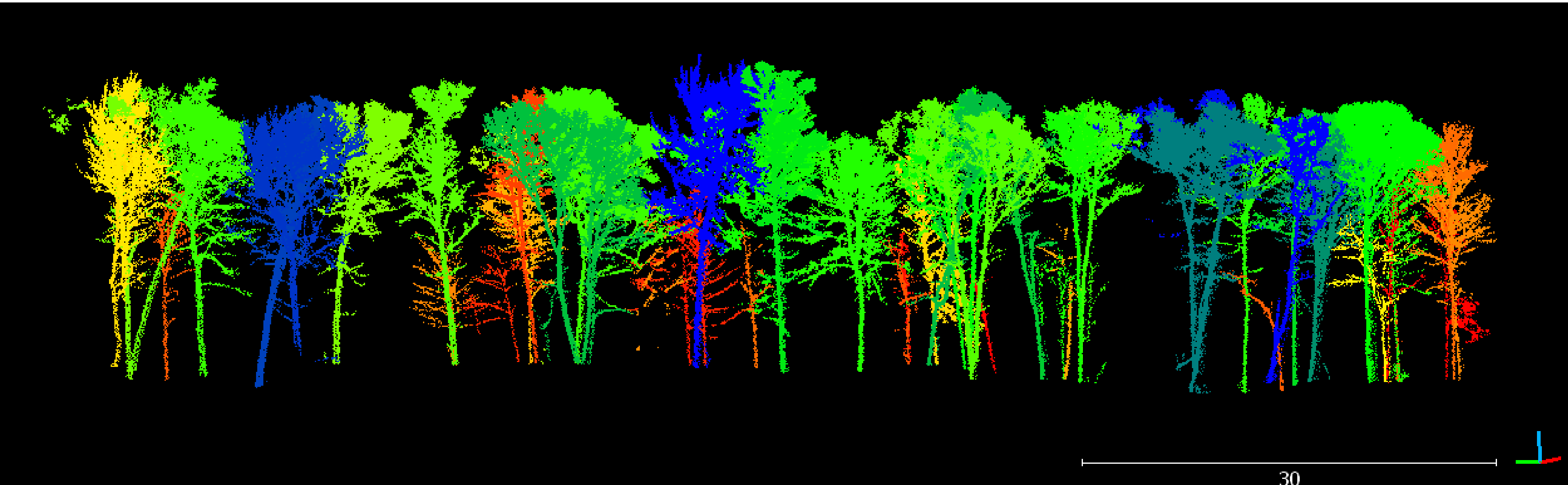
**Top View**



# ULS: Material

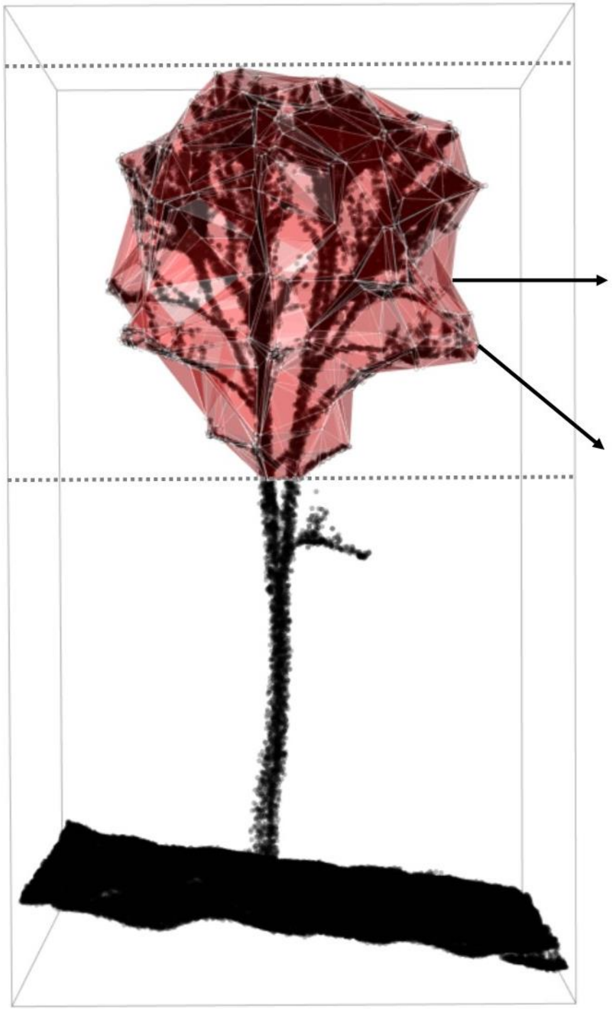
## Tree detection and tree segmentation





# ULS: Material

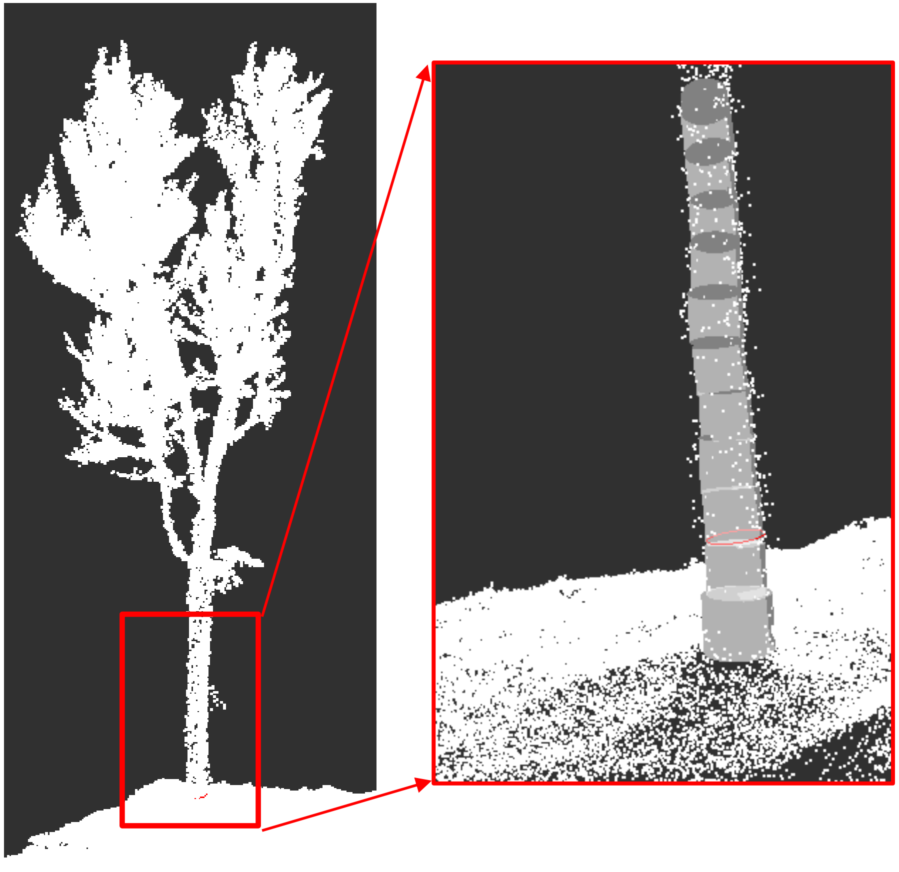
## Extraction of tree attributes – Crown and stem features



**Point cloud**
- Tree height (Ht)
- Crown based height (Crbased)
- Crown lenght (CrL)

**α-shape (3D)**
- Crown volume (CrV)
- Crown surface (CrS)

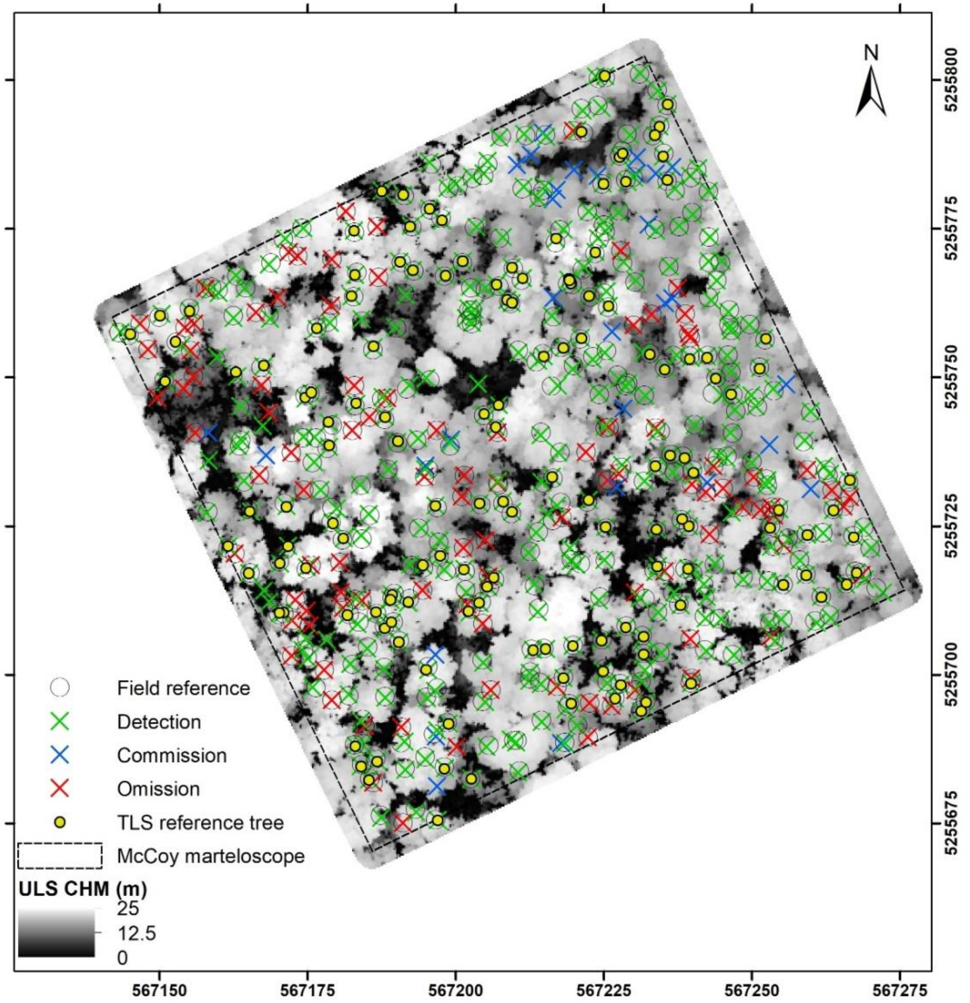
**α-convex hull (2D)**
- Crown diameter (CrD)
- Crown perimeter (CrP)
- Crown projected area (CrPj)



« Cylinder Fitting » technique (Othmani, 2011)

# ULS:
# Preliminary results

## Tree detection and tree segmentation



### Tree detection

**Reference**: Field inventory

**N°Tree**: 459

- Detection: 78 %
- Omission: 22 %
- Commission: 6 %

### Tree segmentation

**Reference**: Terrestrial Lidar

**N°Tree**: 145

- Correctly segmented: 79 %
- Over-segmented: 7 %
- Under-segmented: 14 %

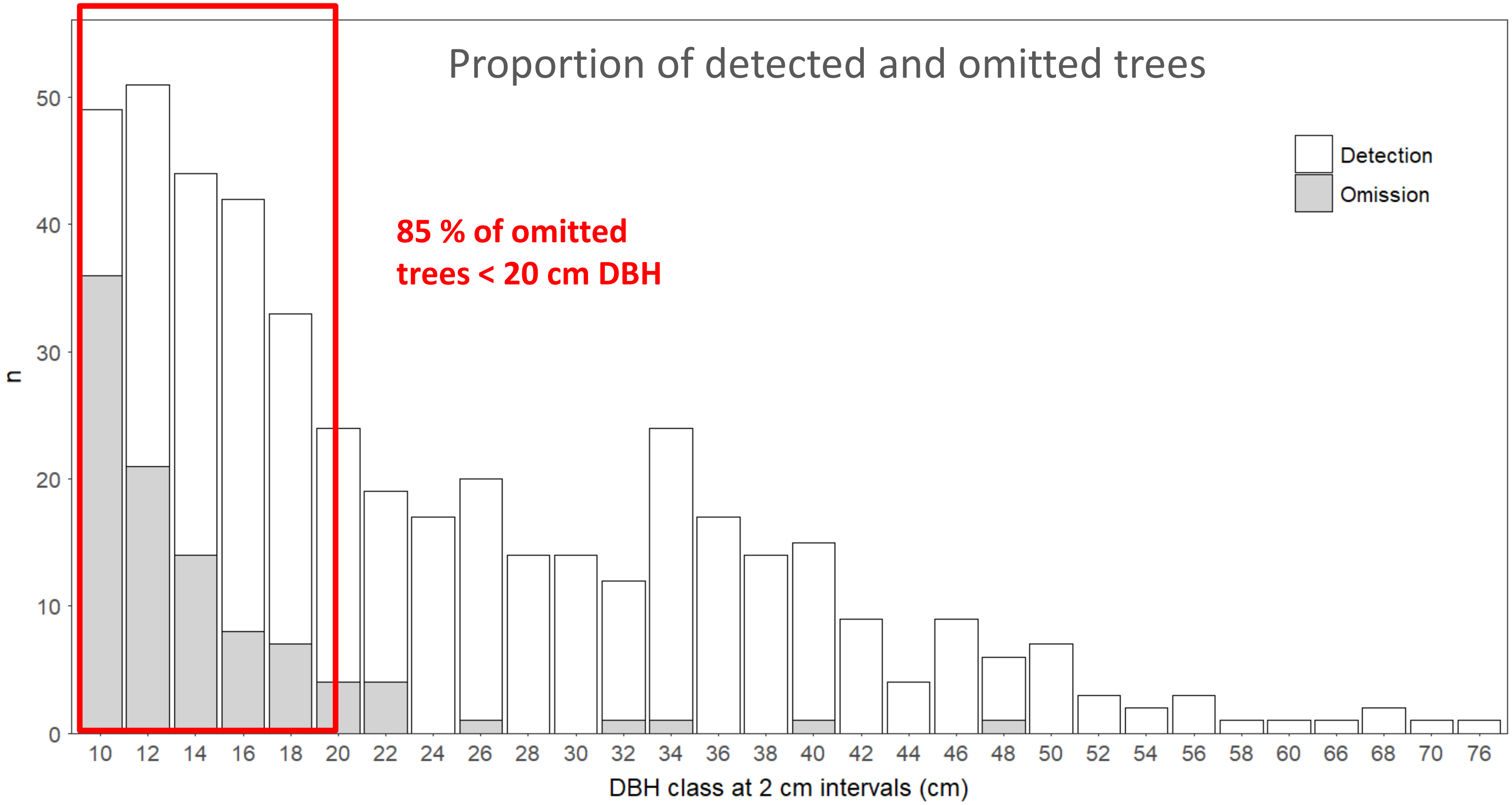
# ULS:
# Preliminary results

## Tree detection

**Reference**: Field inventory

**N°Tree**: 459

- Detection: 78 %
- Omission: 22 %
- Commission: 6 %

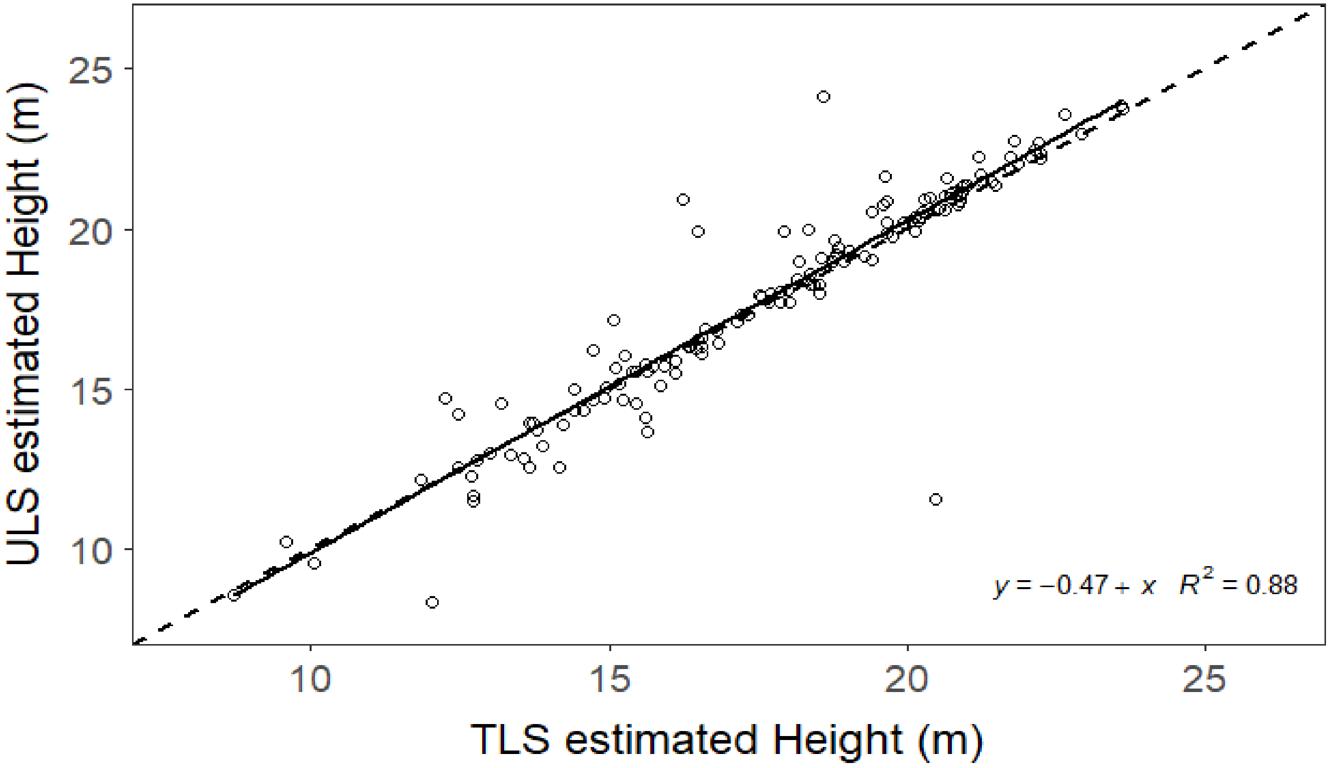


Proportion of detected and omitted trees

85 % of omitted trees < 20 cm DBH

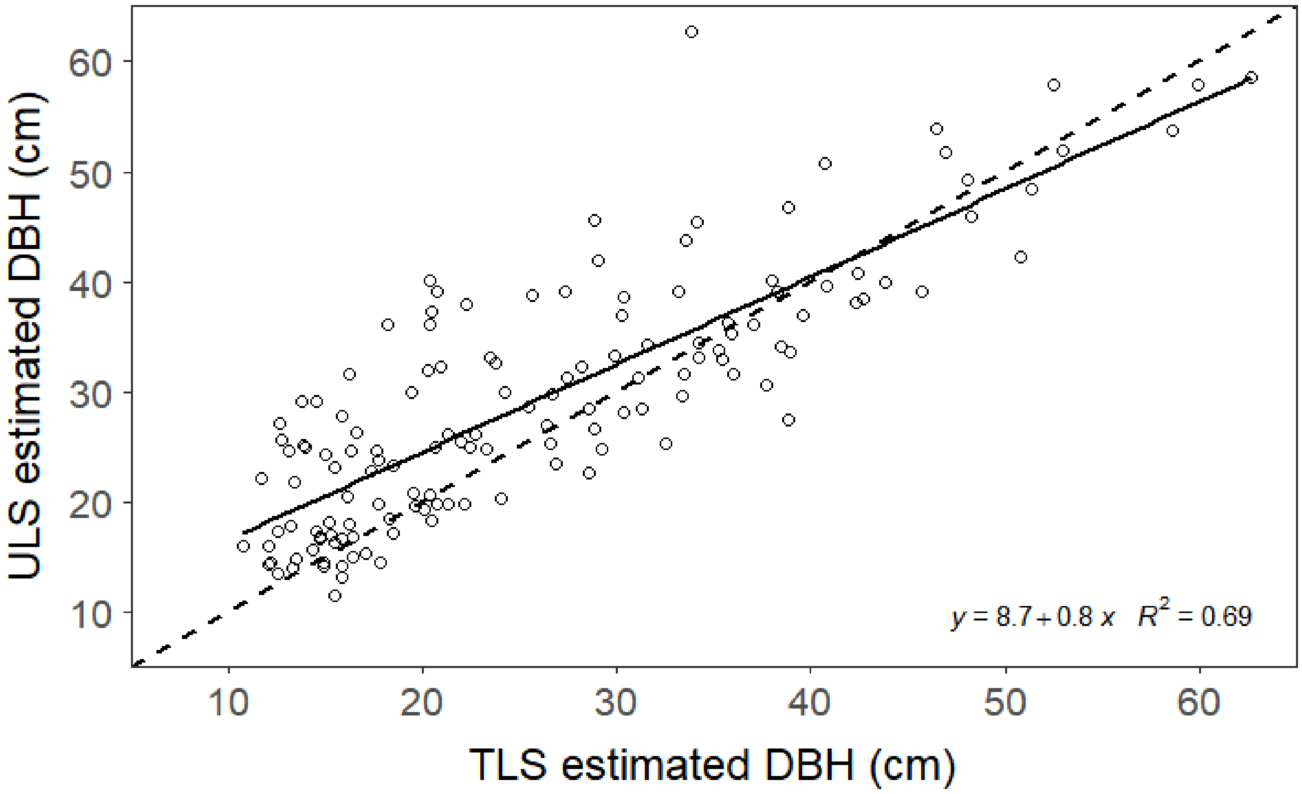
# ULS:
# Preliminary results

## Tree structural attributes – Tree Height



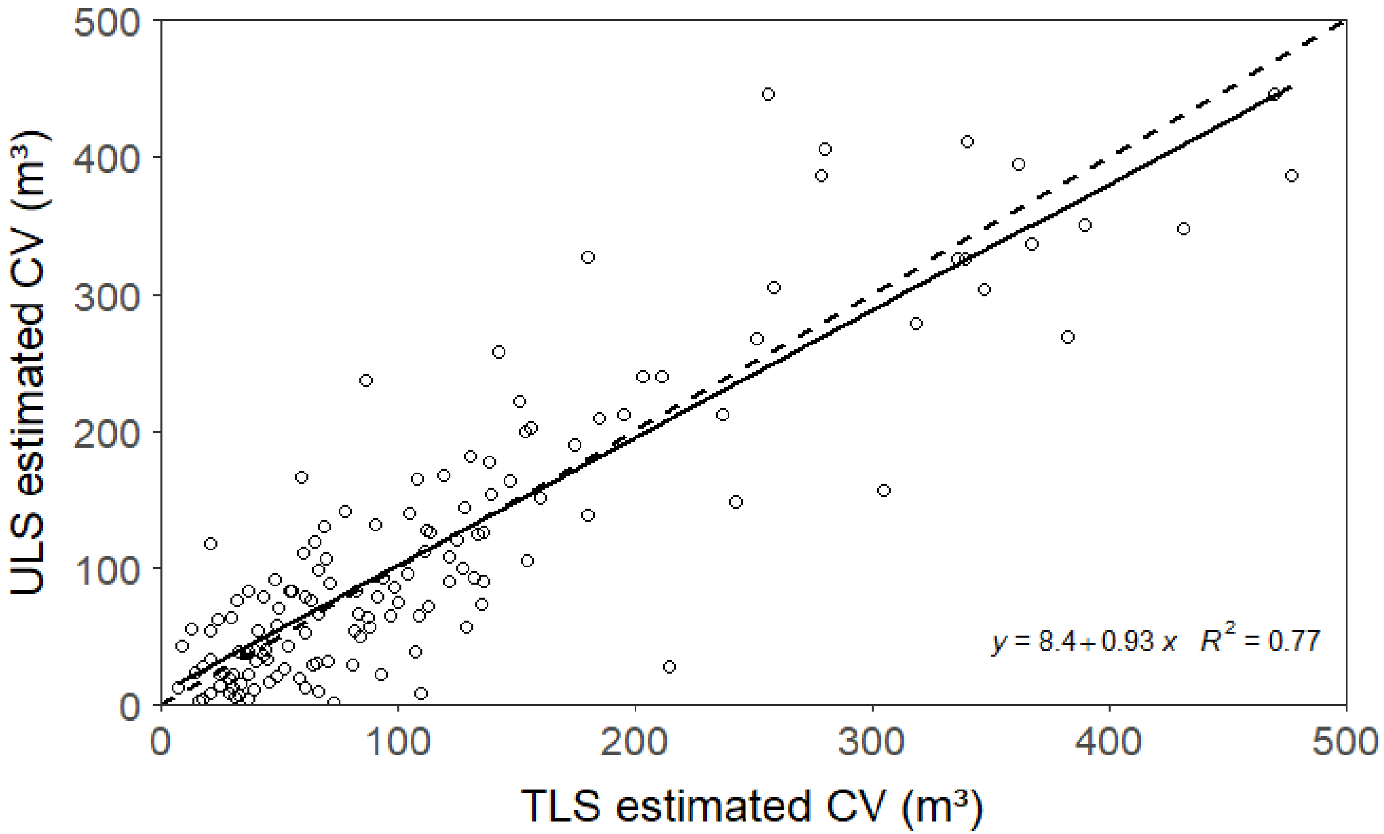
# ULS:
# Preliminary results

## Tree structural attributes – DBH



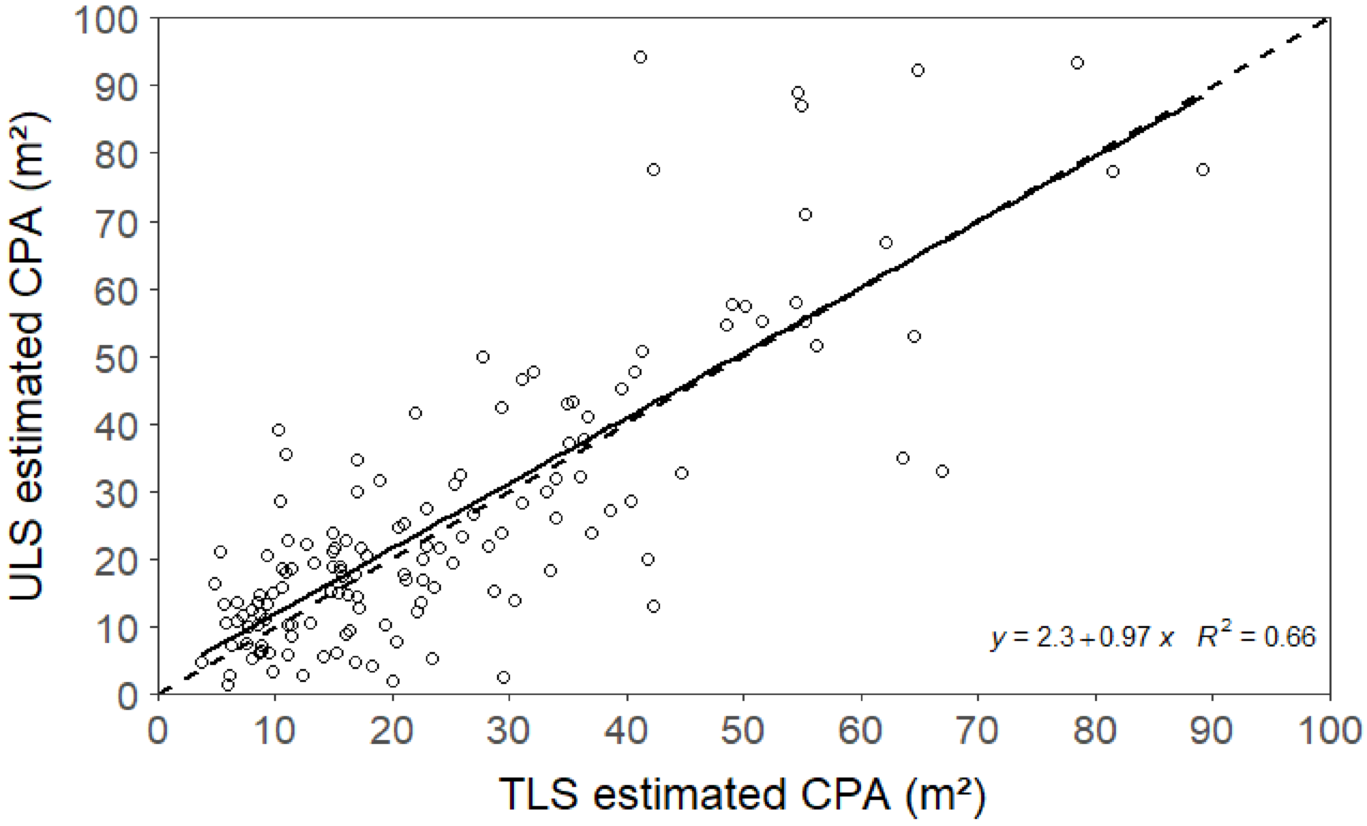
# ULS:
# Preliminary results

## Tree structural attributes – Crown Volume



# ULS:
# Preliminary results

## Tree structural attributes – Crown Projected Area



# ULS: Summary

In a deciduous stand, in leaf-off condition, ULS Velodyne has a **great potential for**:

- Tree detection (> 20 cm DBH);
- Bottom to top segmentation of individual trees;
- Direct estimation of crown attributes

In a deciduous stand, in leaf-off condition, ULS Velodyne reaches some **limits for**:

- Tree detection (< 20 cm DBH);
- Direct estimation of stem attributes: more accurate sensor than Velodyne & adapted flight pattern acquisition are required

With these first results, what are the **perspectives** of ULS for supporting forest inventory?

- The development of local relationships between ULS tree crown attributes and stem geometric models from TLS to predict tree volume;
- The high quality of segmented crown provide a great potential for the calibration of ALS ITC algorithms

# Take home message

In the context of NFI

- LiDAR systems might bring
  - – Tree compartment volume measurement
    - The stem or total volume: TLS, but …
    - Base of the stem : PLS
    - Crown α-shape volume (stem volume): ULS

⇨ New allometric models with these measurements
to reduce uncertainty of forest attributes at the plot scale

  - – Measurement and mapping of all the trees within a plot

# Thank you!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