Mobile Laser Scanning for Estimating Tree Structural Attributes in a Temperate Hardwood Forest

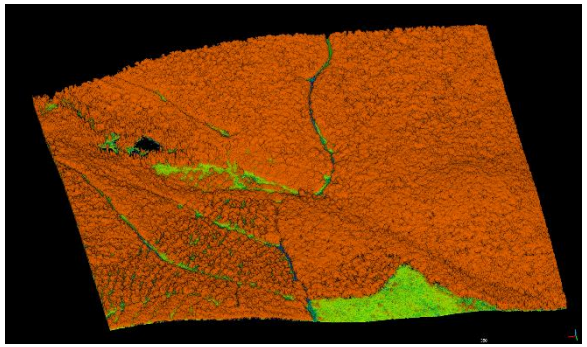
Olivier Martin-Ducup - Freelance
Richard Fournier - Université de Sherbrooke
Gaetan Pelletier - Northern Hardwood Research Institute Inc. (NHRI)
Philippe Lejeune - Université de Liège - Gembloux Agro-Bio Tech

Colloque TRIDIFOR – Méthodes innovantes d'analyses de données 3D en forêt – 2022-09-22

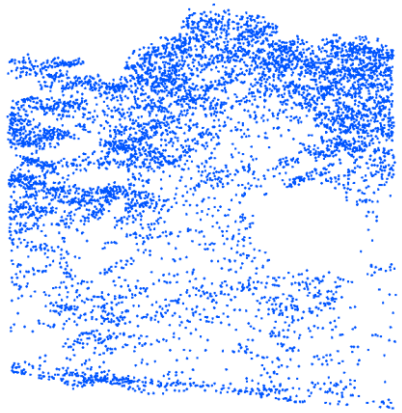
Bastien Vandendaele - U. Sherbrooke - U. Liège

Context

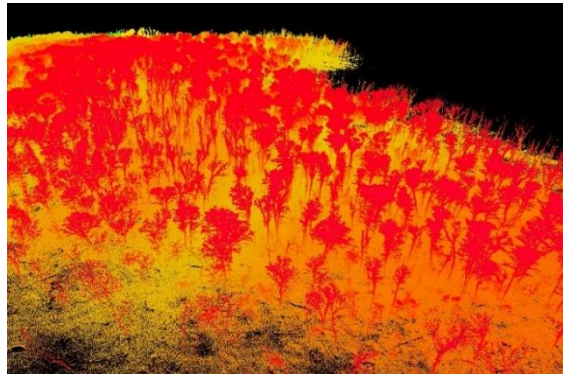
Airborne lidar



© GeoNB



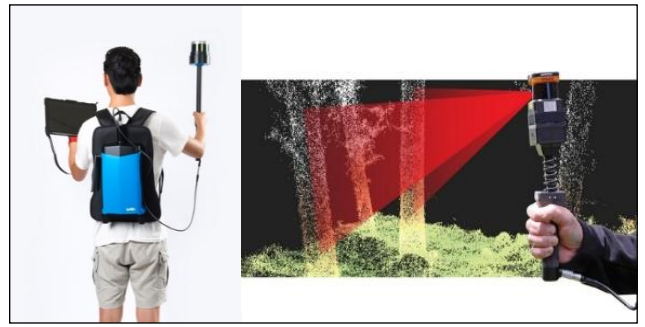
UAV lidar

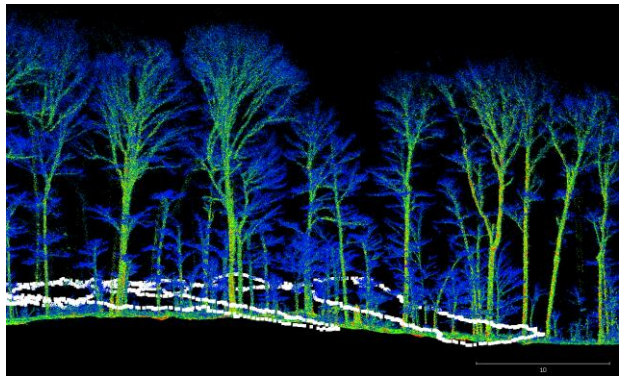


© NHRI https://doi.org/10.3390/rs13142796

Terrestrial lidar

Mobile lidar



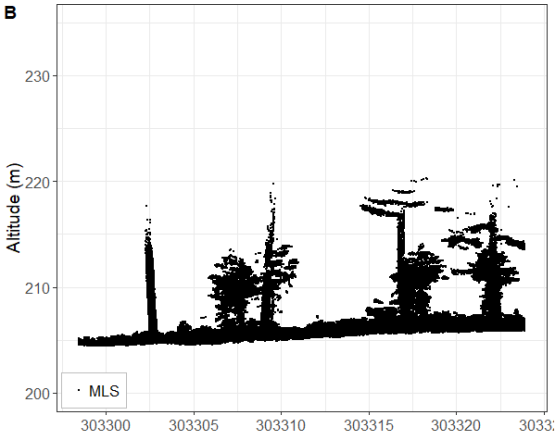


© NHRI

Investigation

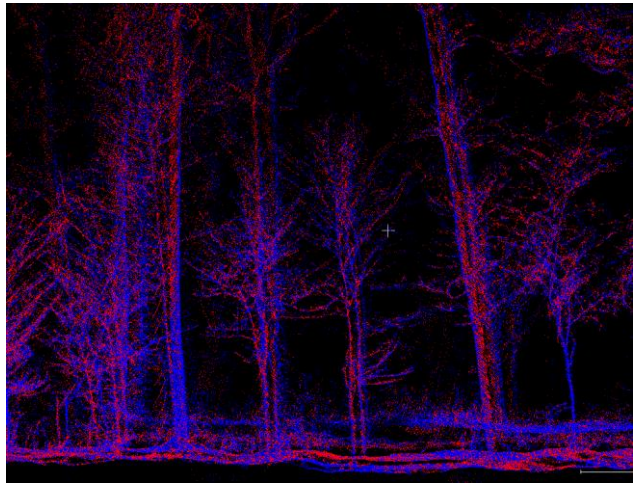
GeoSLAM Zeb-REVO

Limited range



LiBackPack DG50

SLAM issue



GeoSLAM Horizon & Hovermap (Emesent)

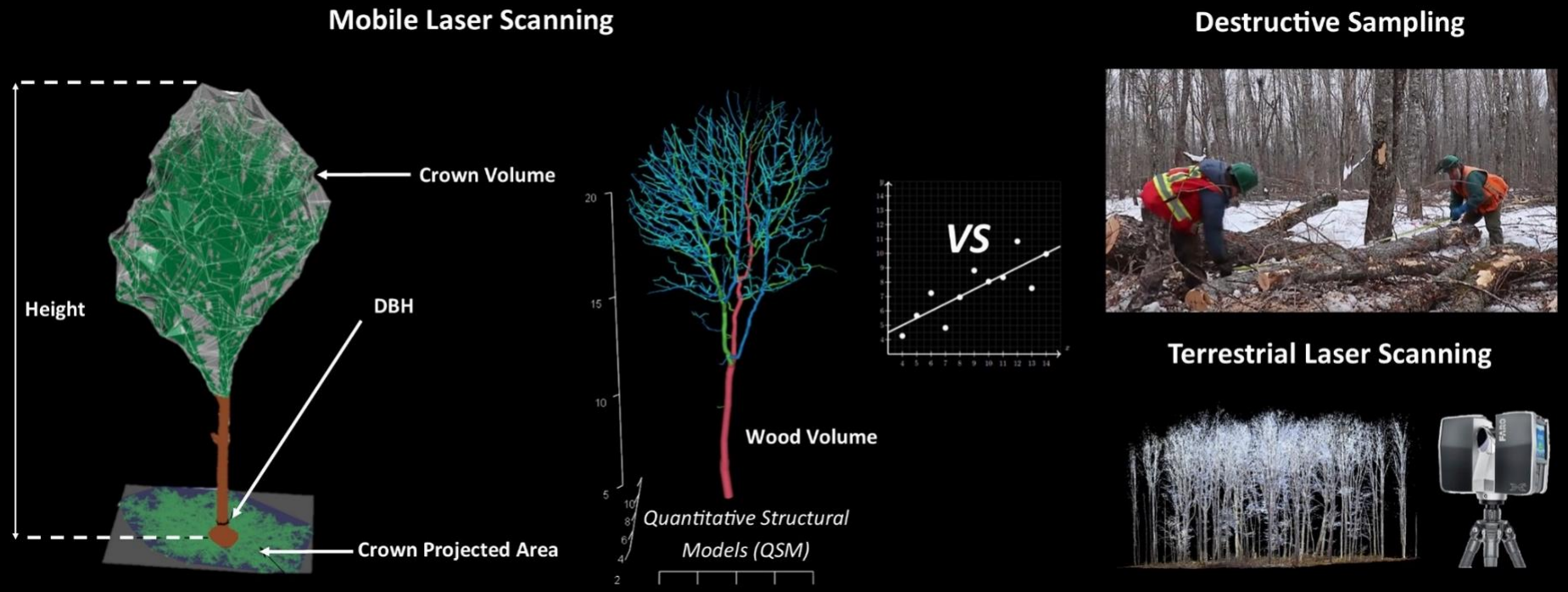
GeoSLAM Horizon

Hovermap (Emesent)

Promising New Generation

Objectives

Evaluate the **potential of high-density mobile laser scanning (MLS) data** to estimate several forest inventory attributes in a mature hardwood stand, such as (i) tree **height**, **crown dimensions** and **diameter**, and (ii) **merchantable wood volume** using quantitative structural modeling (QSM) algorithms



https://doi.org/10.3390/rs14184522

Material

Study Site

- New Brunswick
- 1 ha hardwood
- Leaf-off (Oct.2021)
- 75-160 years
- 500 trees/ha
- 26 sample trees (destructive measures)

Mobile Laser Scanning (MLS)

SLAM-based MLS: Simultaneous Localisation and Mapping
Characteristics: 1,8 kg; 1H autonomy (x number of batteries)
Acquisition time: **45 min (1 ha)** – Automatic preprocessing: 3H

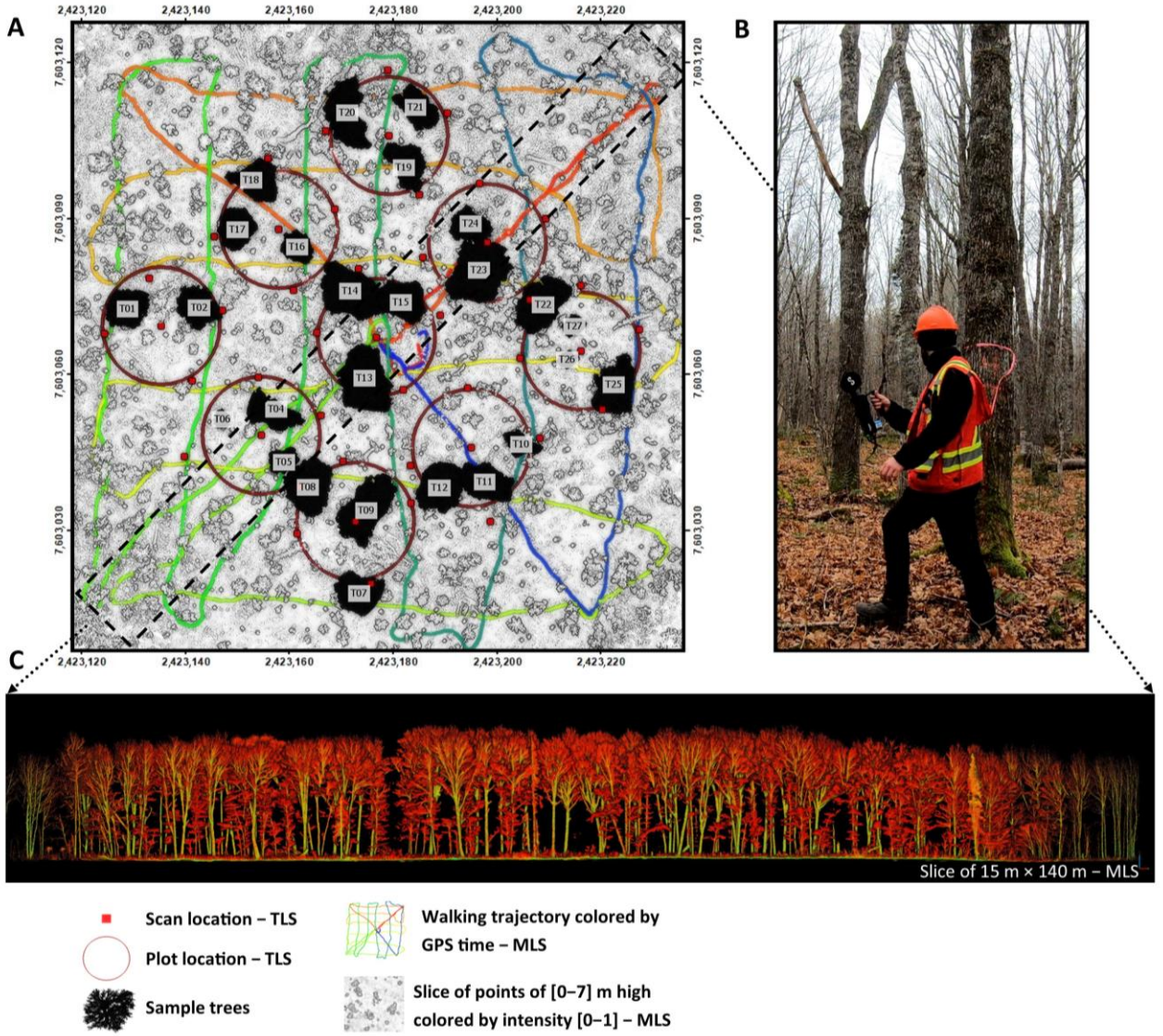
© Hovermap

Terrestrial Laser Scanning (TLS)

TLS: multi-scan acquisition (5 scans)
Characteristics: 5 kg; 4H autonomy (x number of batteries)
Acquisition time: **12 Hours (9 sample plots)** – Preprocessing: 4.5H

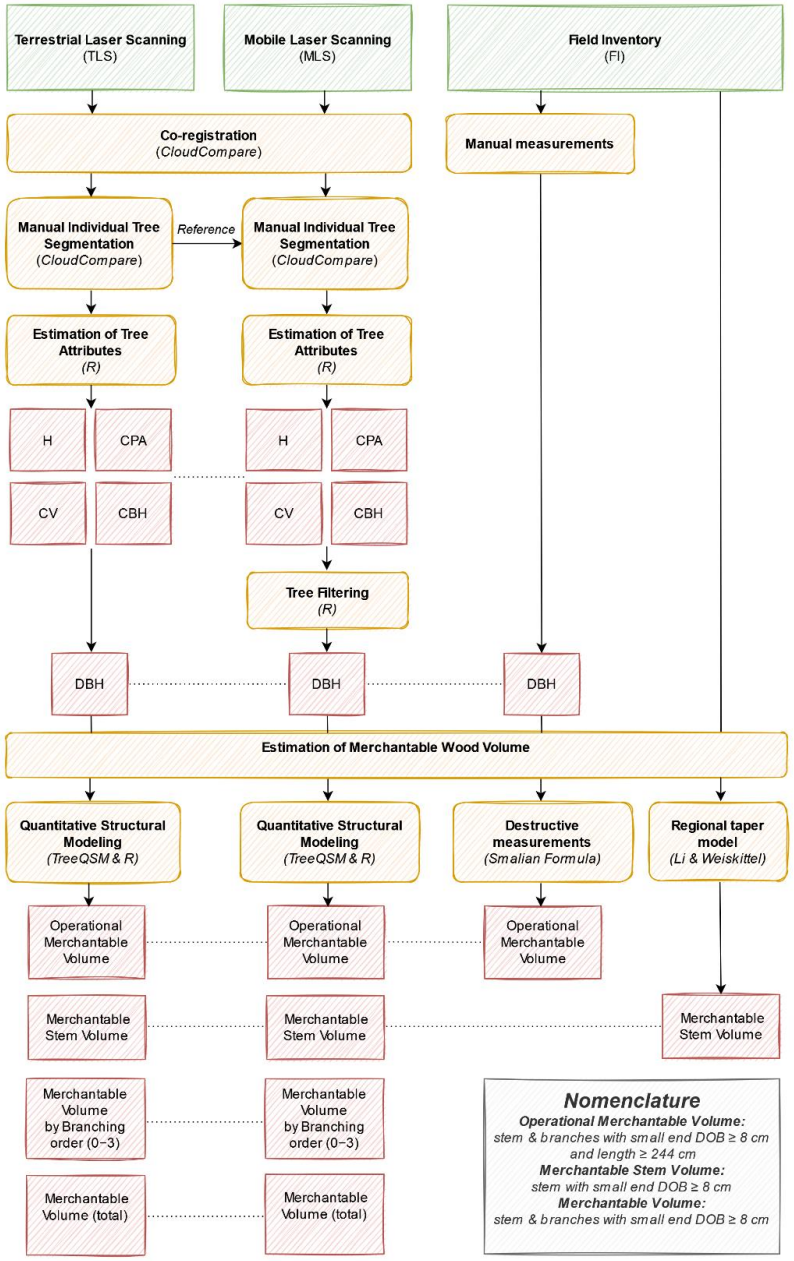
© Faro3DS120

Data Collection



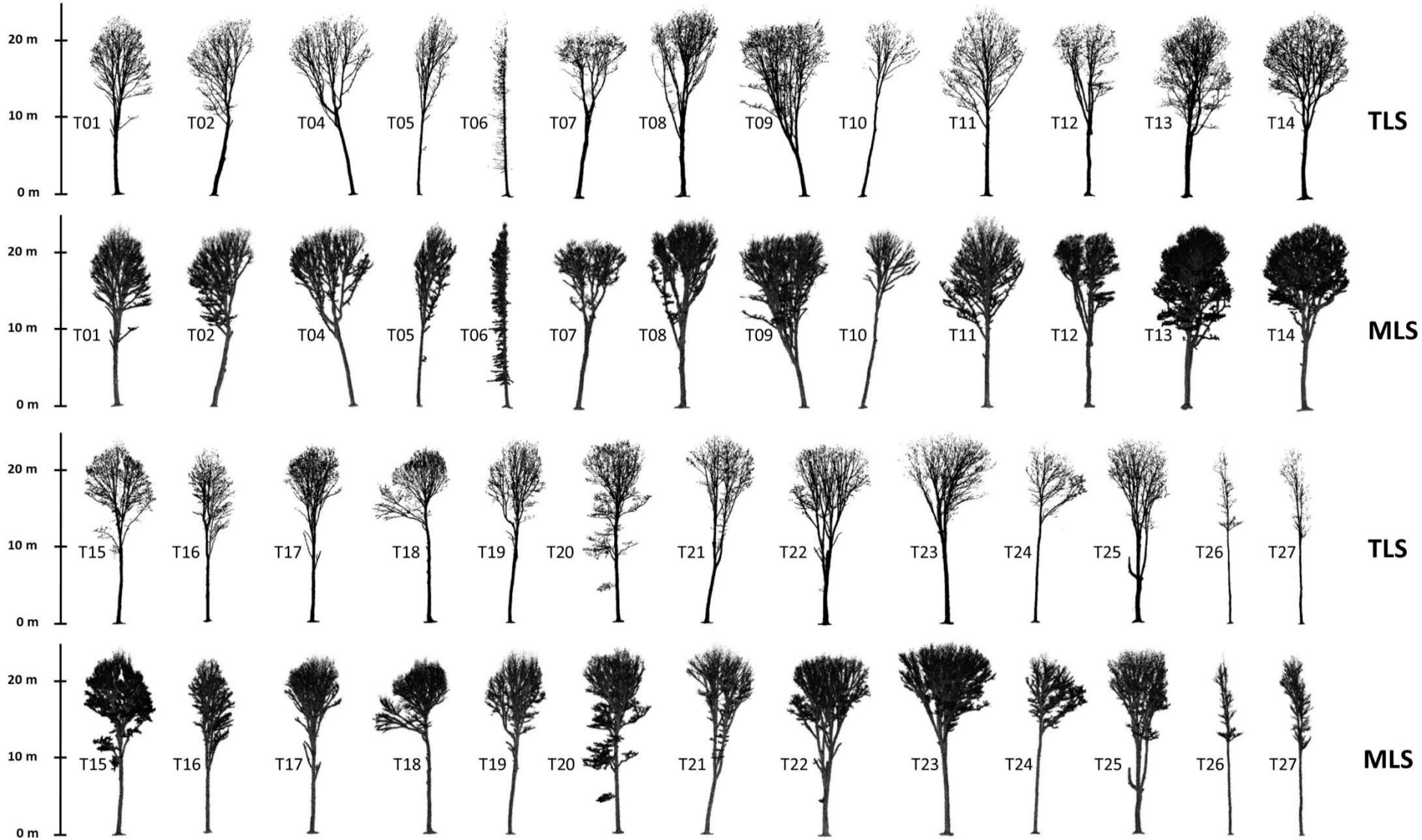
Methods

Overall Data Processing Workflow

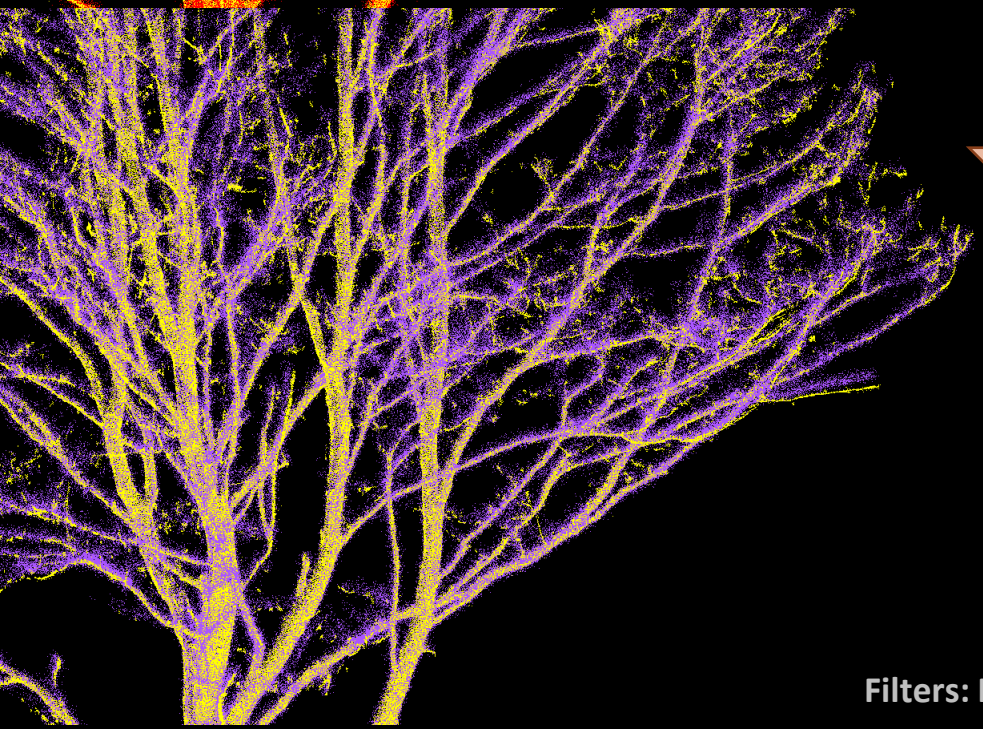


Methods

Manual Individual Tree Segmentation

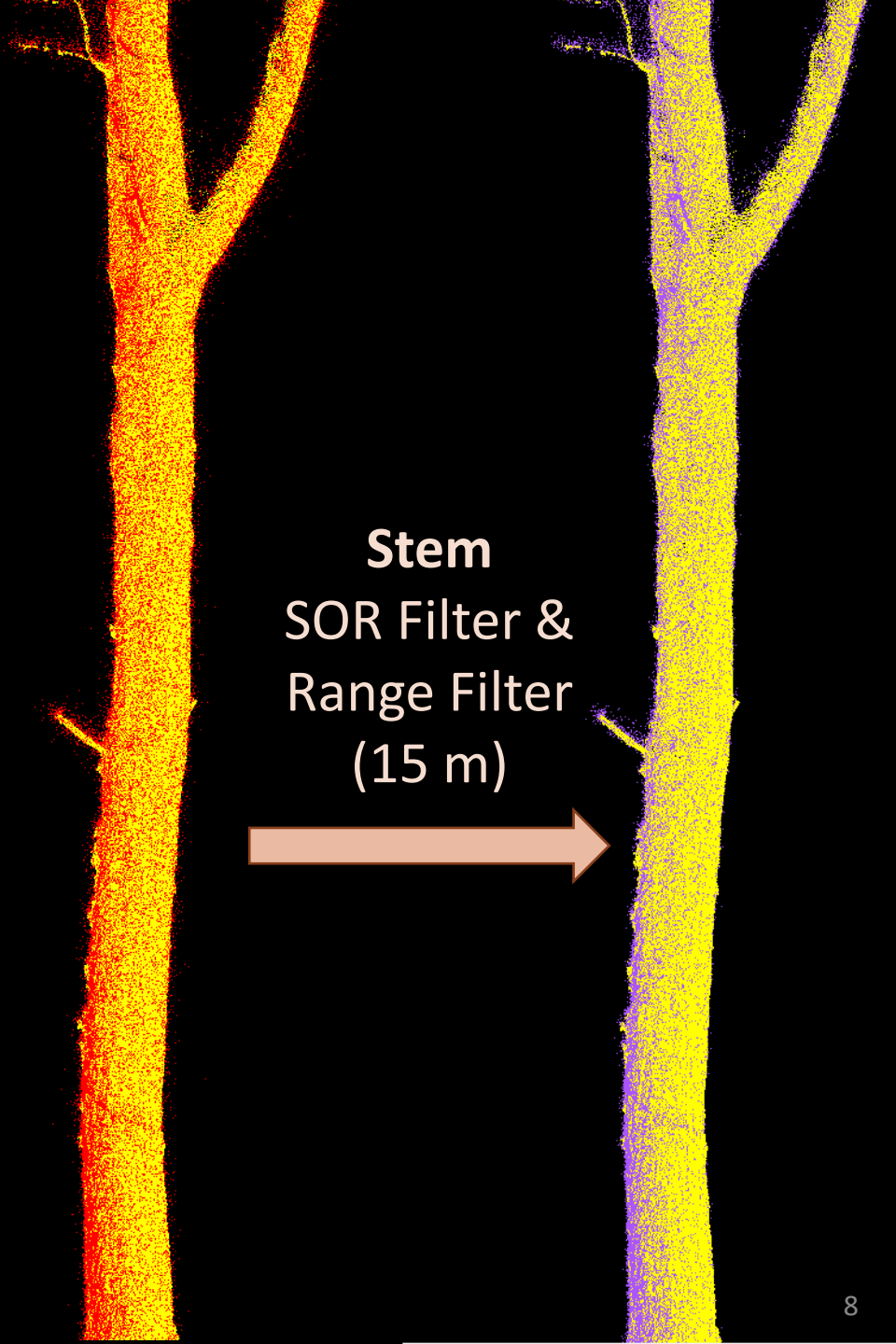


Filtering Process



Crown
Range Filter
(30 m)

- **TLS**
- **MLS no filter**
- **MLS filtered**



Stem
SOR Filter &
Range Filter
(15 m)

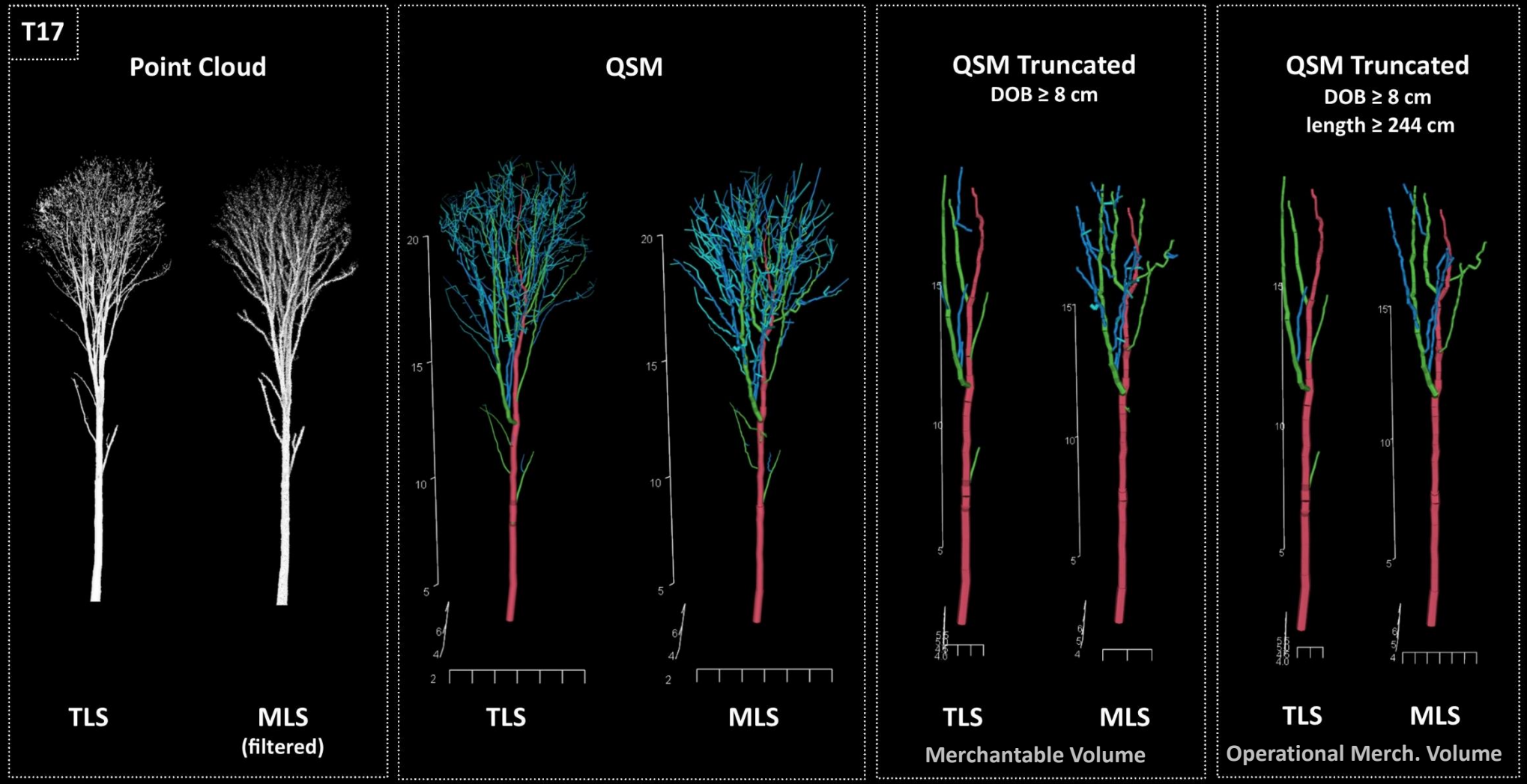
Filters: R package VoxR (Lecigne et al., 2018)

Quantitative Structural Modeling

Quantitative Structural Modeling (QSM) : *TreeQSM* (Raumonen et al., 2013)
QSM parameters optimization: Martin-Ducup et al. (2021)

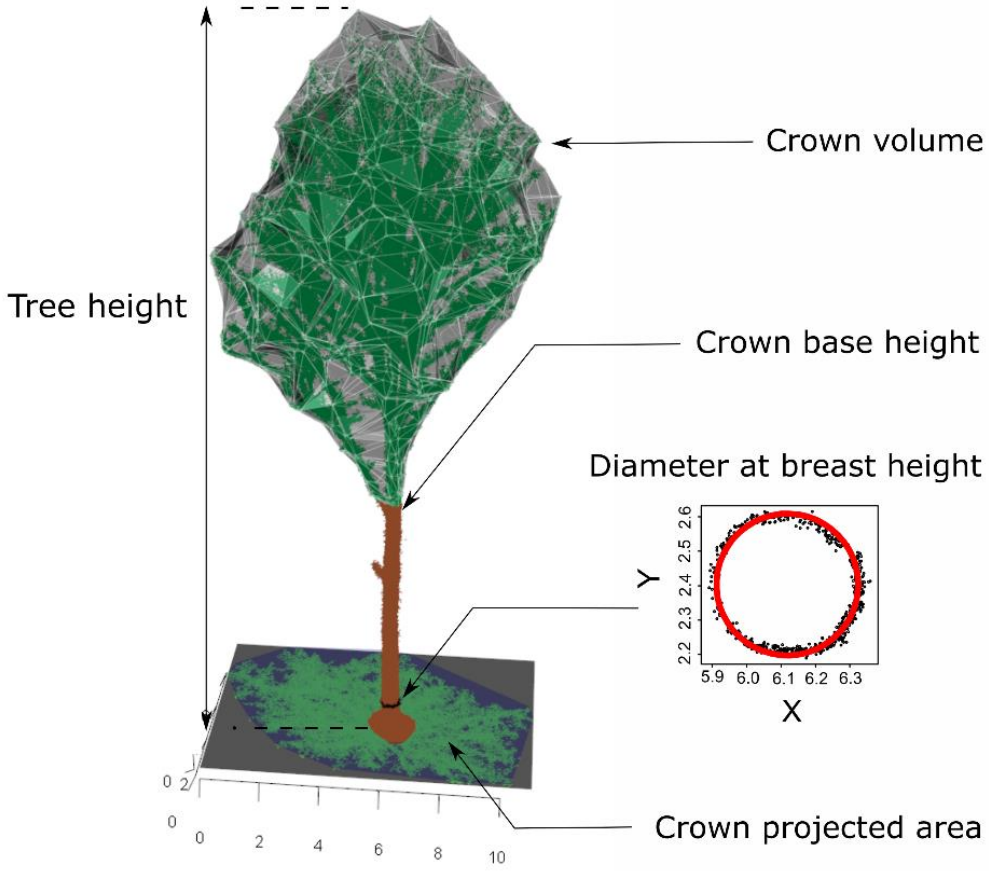
Truncated QSMs

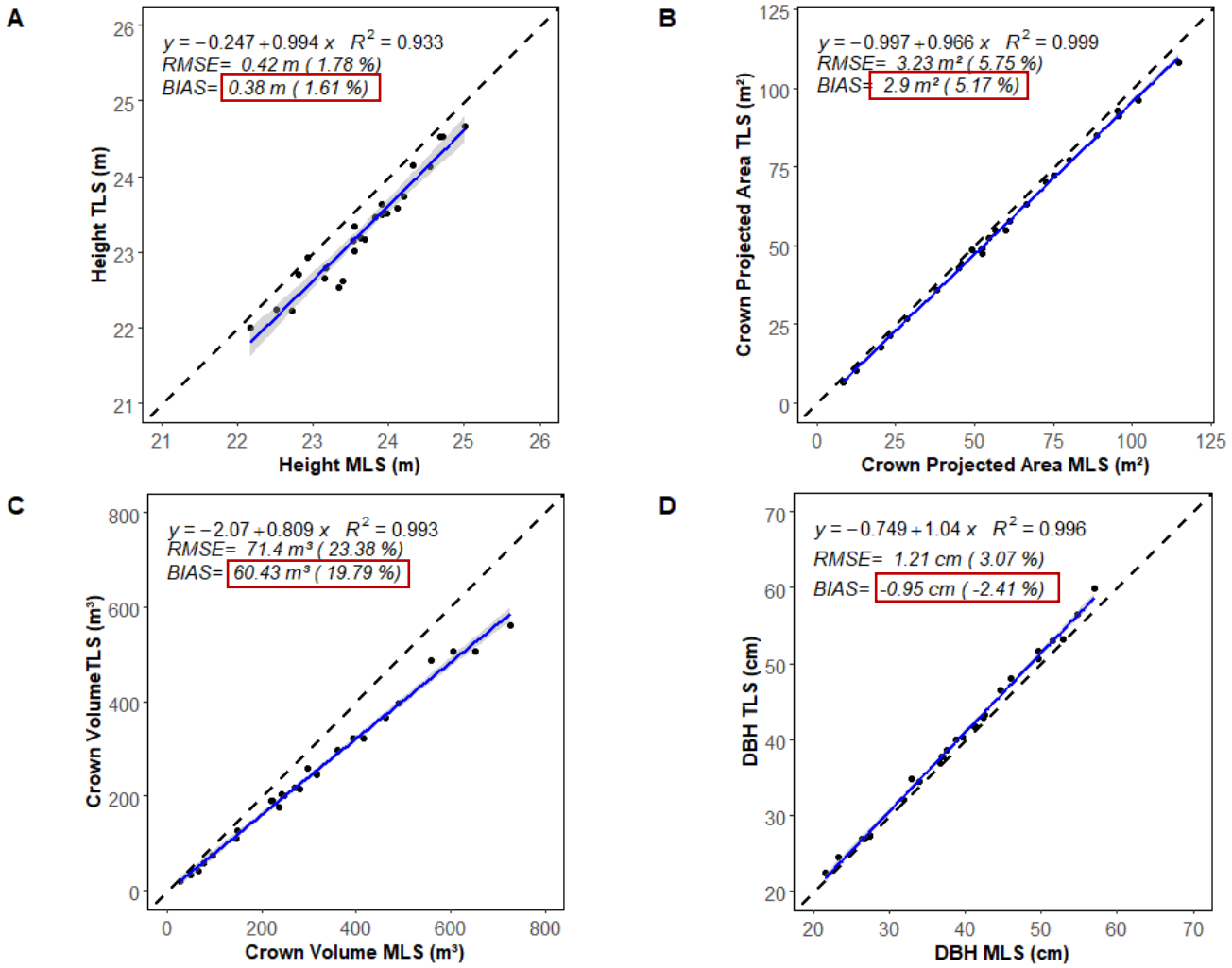
Truncated QSMs : Package R aRchi (Martin-Ducup & Lecigne, 2022)



Results

Tree Attributes (H, CPA, CV, DBH)





Comparison of (**A**) tree height (H); (**B**) crown projected area (CPA); (**C**) crown volume (CV) and (**D**) diameter at breast height (DBH) for the 26 TLS and MLS trees. The blue line represents the linear regression. The grey zone is the 95% confidence band for predictions. The dashed black line represents the 1:1 line.

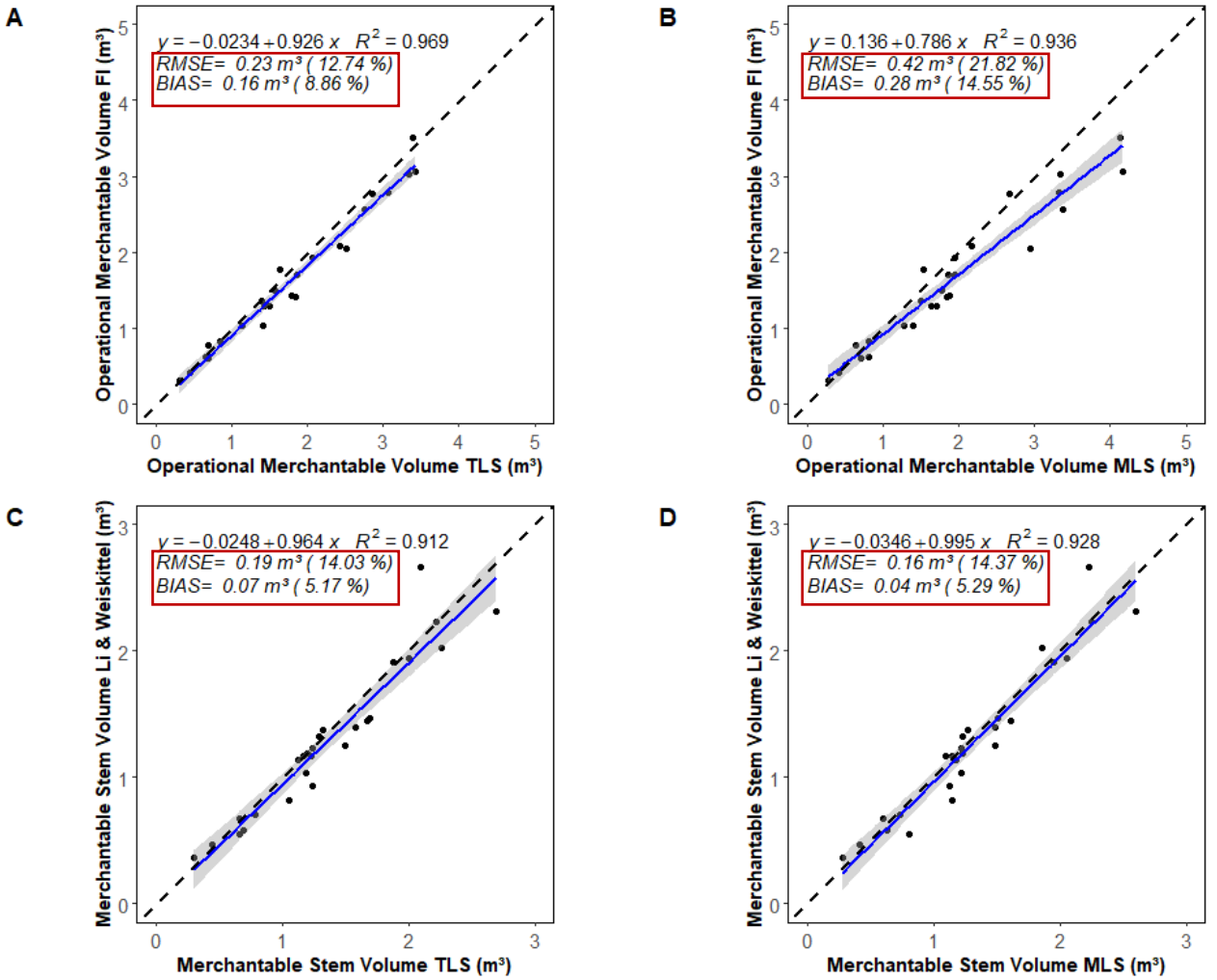
Results

Operational Merchantable Wood Volume

- **Destructive sampling** (main stem and branches)

- **Allometric model** (main stem; Li & Weiskittel)

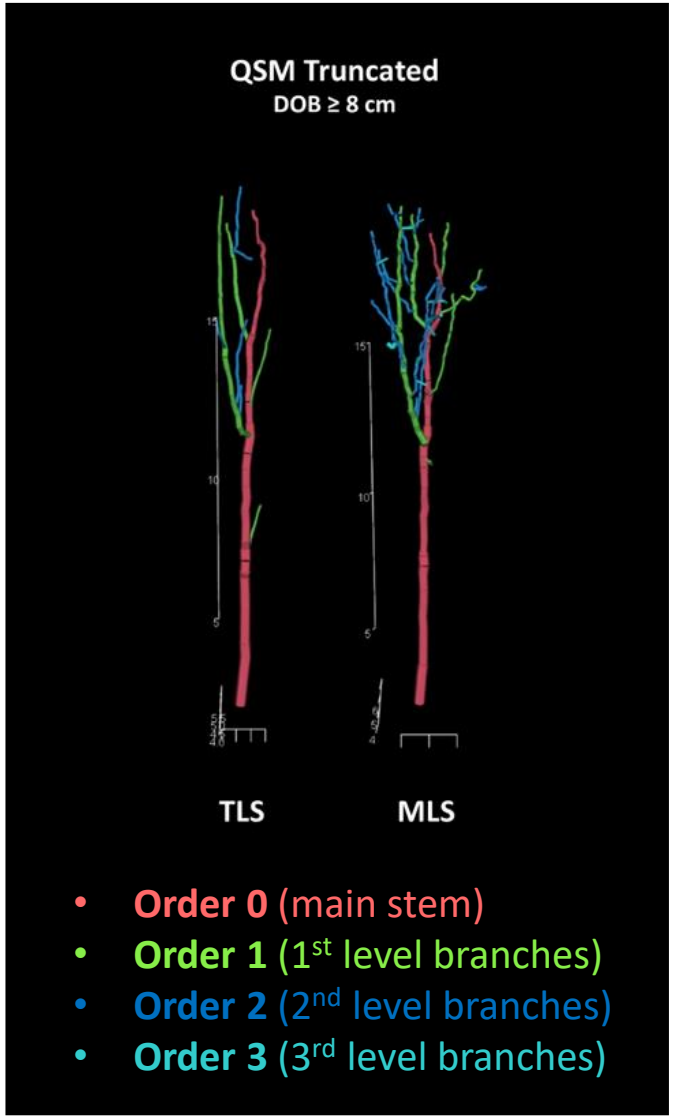
$$d = \alpha_0 D^{\alpha_1} H^{a_2} X^{\beta_1 z^4 + \beta_2 (1/e^{D/H}) + \beta_3 X^{0.1} + \beta_4 (1/D) + \beta_5 H^Q + \beta_6 X}$$

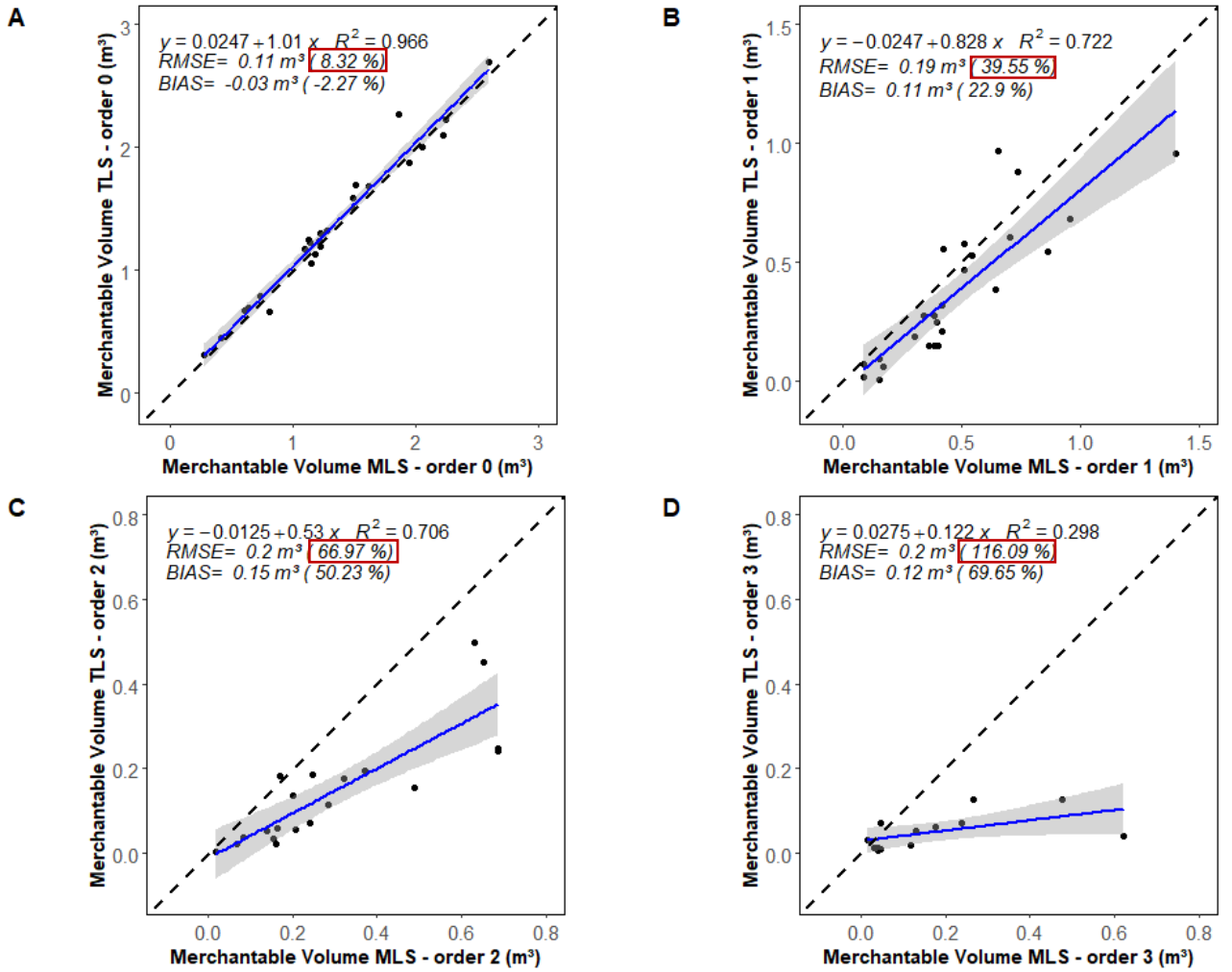


(**A**,**B**) Comparison of operational merchantable volume derived from the destructive field inventory (FI) (i.e., stem and branches with small end diameter outside bark (DOB) ≥ 8 cm and length ≥ 244 cm) with the QSM-derived value (i.e., branching order 0–3 with small end DOB ≥ 8 cm and length ≥ 244 cm) from (**A**) TLS and (**B**) MLS data. (**C**,**D**) Comparison of the merchantable stem volume derived from Li and Weiskittel's taper model (i.e., main stem with small end DOB ≥ 8 cm) with the QSM-derived value of the stem (i.e., branching order 0 with small end DOB ≥ 8 cm) from (**C**) TLS and (**D**) MLS data. n = 26 trees. The blue line represents the linear regression. The grey zone is the 95% confidence band for predictions. The dashed black line represents the 1:1 line.

Results

Merchantable Wood Volume by Branching Order

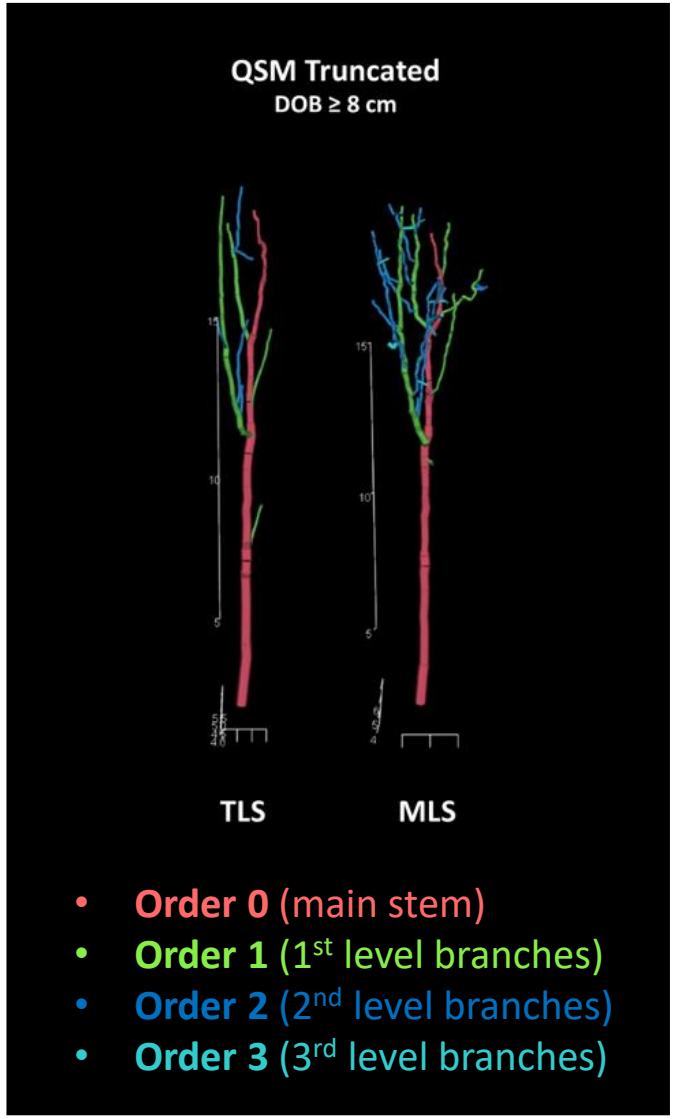


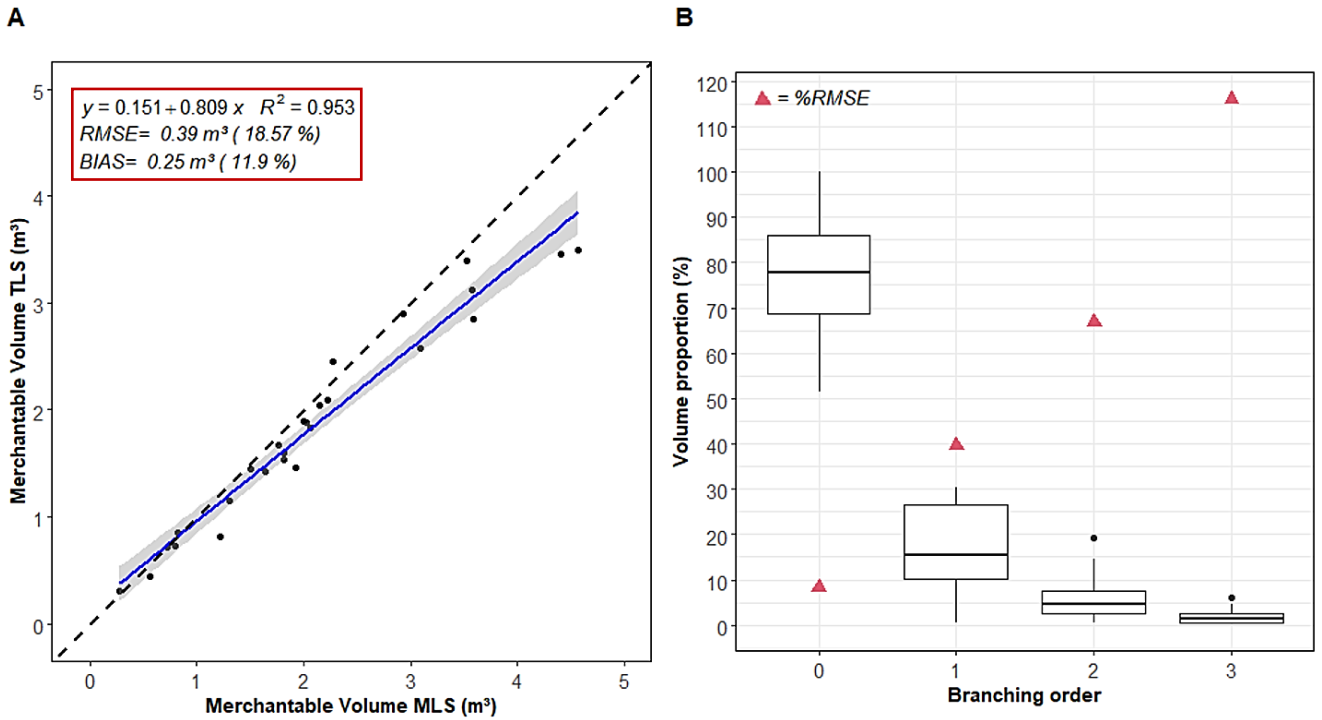


(**A**–**D**) Comparison of merchantable volume (i.e., stem and branches with small end diameter outside bark (DOB) ≥ 8 cm) derived from TLS and MLS QSMs presented by branching order (with small end DOB ≥ 8 cm): (**A**) order 0 = main stem; (**B**) order 1 = first-level branches; (**C**) order 2 = second-level branches; (**D**) order 3 = third-level branches. *n* = 26 trees. The blue line represents the linear regression. The grey zone is the 95% confidence band for predictions. The dashed black line represents the 1:1 line.

Results

Merchantable Wood Volume (Total: order 0-3)





(**A**) Comparison of total merchantable volume (i.e., stem and branches with small end diameter outside bark (DOB) ≥ 8 cm) derived from TLS and MLS QSMs (i.e., branching order 0–3 with small end DOB ≥ 8 cm). *n* = 26 trees. The blue line represents the linear regression. The grey zone is the 95% confidence band for predictions. The dashed black line represents the 1:1 line. (**B**) Boxplots of the proportion of merchantable volume by branching order (0 = main stem; 1 = first-level branches; 2 = second-level branches; 3 = third-level branches) from TLS QSMs. Red triangles represent the %RMSE by branching order.

Discussion

- **Key findings**
  - SLAM-based Mobile Laser Scanning (MLS) was efficient to scan a 1 ha stand
  - Key inventory attributes (e.g. tree Height, CPA, DBH) were estimated with high accuracy
  - Operational merchantable volume estimated from MLS data was close to the field measurements
  - Branching volume derived from MLS was overestimated when compared to TLS

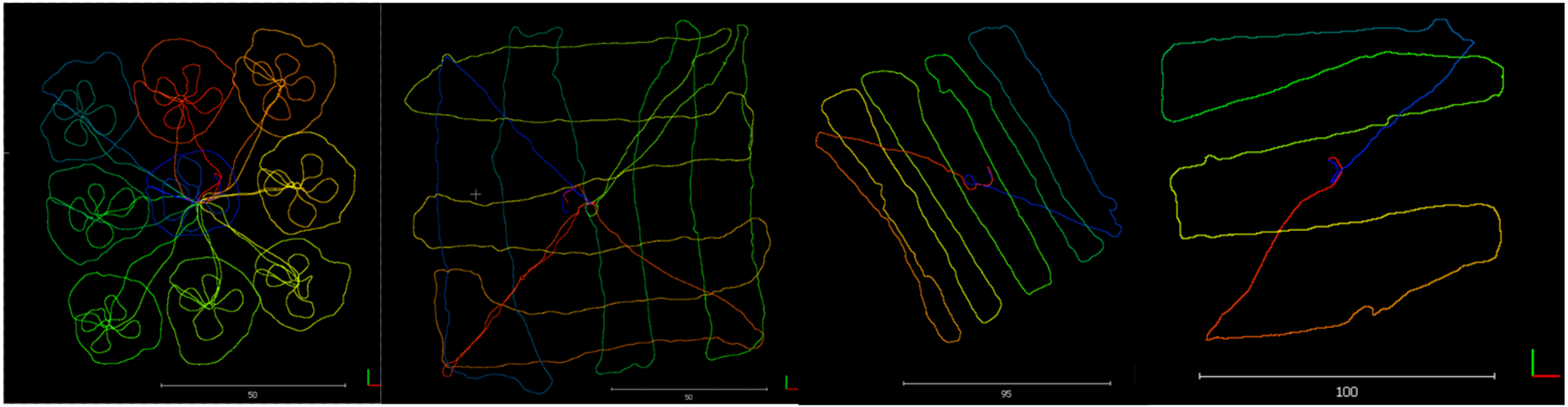
- **Applicability of SLAM-based MLS data**
  - Practical and simple to use in forest environment
  - Flexible data acquisition pattern – interesting to acquire various size of sample plots
  - Minimize signal occlusion
  - Short acquisition time makes it more flexible against wind
  - Automatic preprocessing

- **Limits**
  - Observations were done under favorable forest conditions (flat terrain, little low vegetation)
  - Further study is required to understand the impact of walking pattern acquisition on data quality and data completeness
  - Manual tree segmentation: not applicable on large scale
  - QSMs algorithms: complex to parametrize, work at the tree-level; require clean point clouds

Next Steps

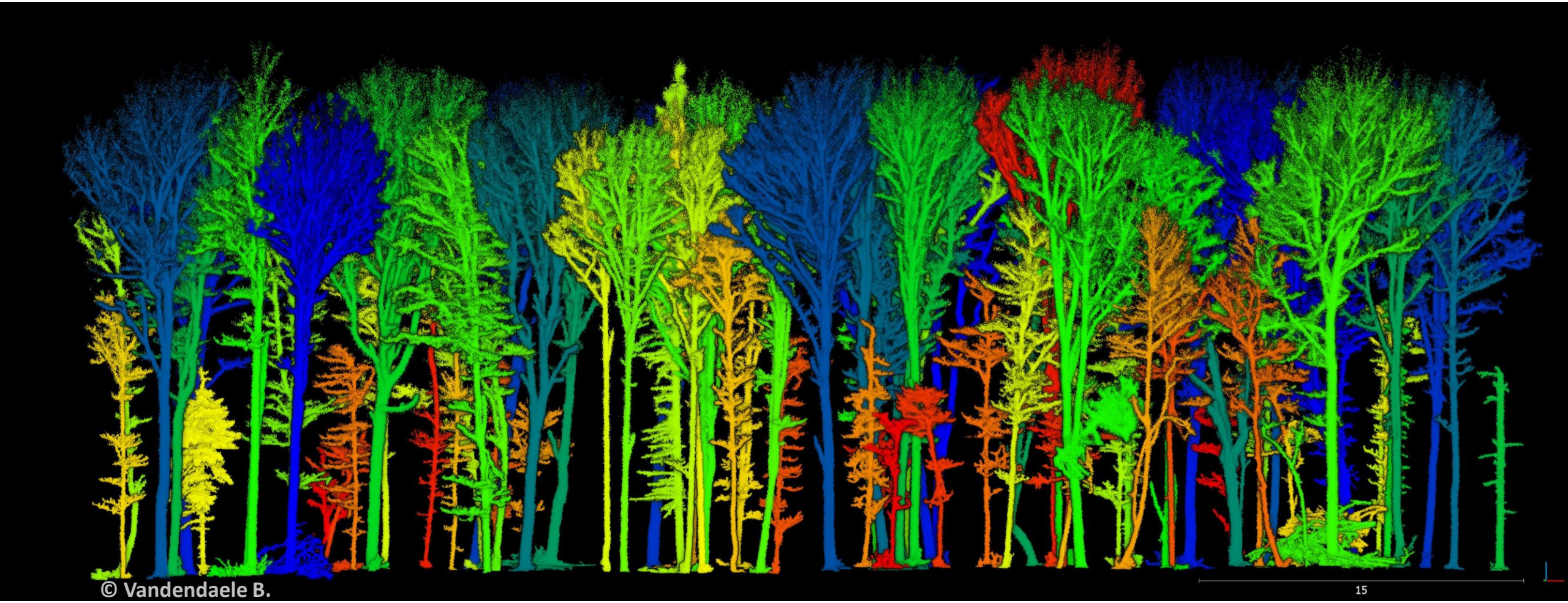
- Analyse the impact of walking pattern acquisition on tree structural attributes accuracy

MLS9plots | MLSgrid20m | MLS15m | MLS35m



Next Steps

- Investigate automation processes at the plot level (ITD, tree metrics, QSMs) …



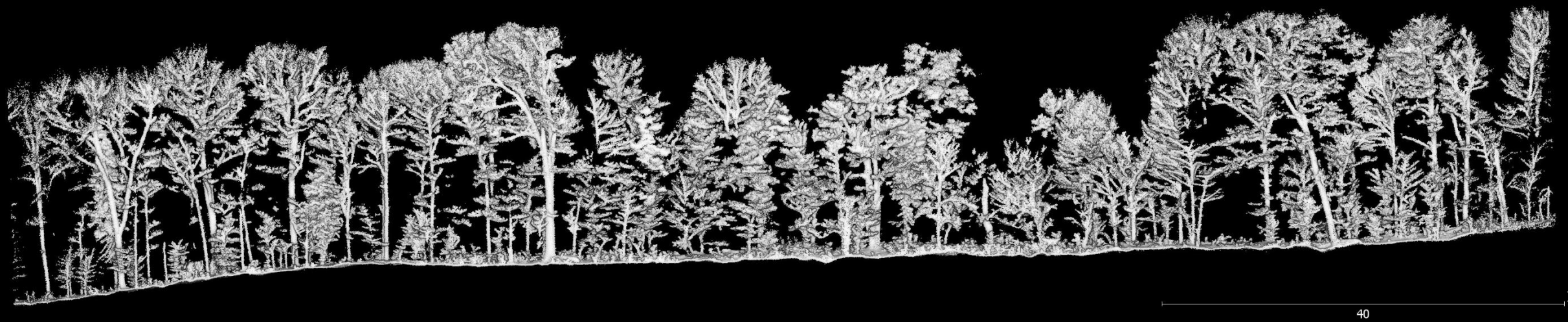
SLAM-based MLS data segmented from Computree (https://computree.onf.fr/?page_id=497)

Next Steps

- … from a variety of hardwood stands

McCoy Brook Forest
(New-Brunswick)

Raw MLS data from a 1 ha uneven-aged northern hardwood stand using a similar 20 m x 20 m walking pattern acquisition (Slice of 4 m x 140 m)



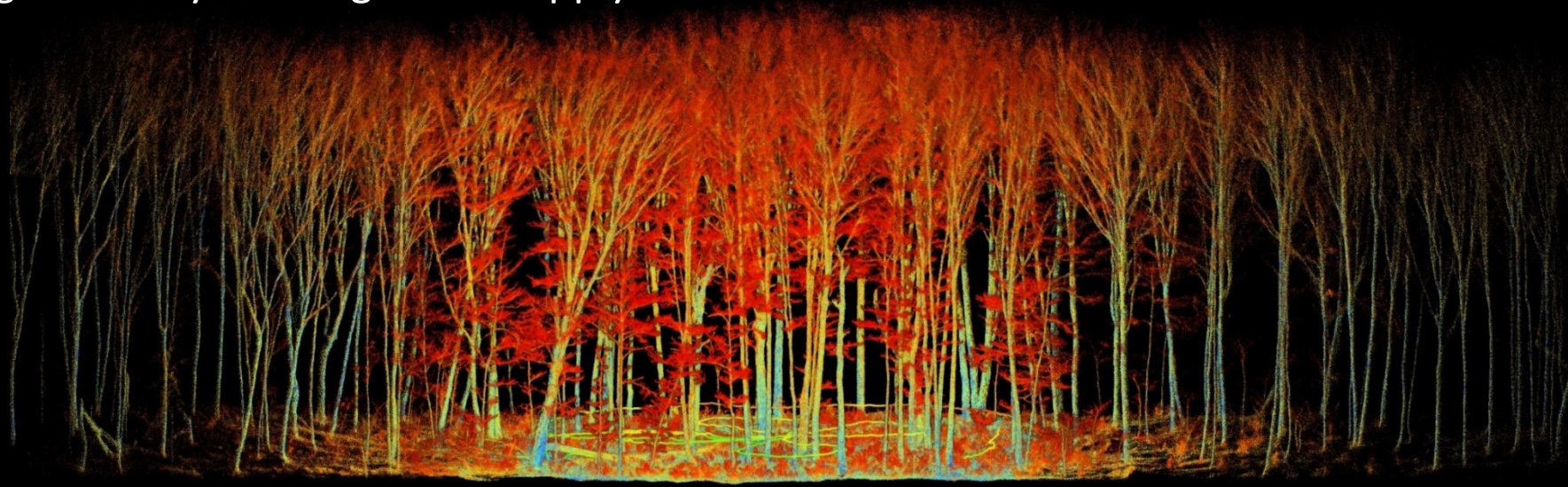
Perspectives of Mobile Laser Scanning

What for?

- Enhancing forest inventories
- Supporting operation planning
- Assisting harvesting activities
- Improving inventory tracking in the supply chain…

… a first step towards a better assessment of

- Volume, biomass
- Species
- LAI, competition, allometric models, growth, …



Institut de recherche sur les feuillus nordiques Inc.
Northern Hardwoods Research Institute Inc.

Thank you for your attention! Questions?

bastien.vandendaele@usherbrooke.ca

More info: https://doi.org/10.3390/rs14184522

Open to Collaborations

Special thanks to NHRI Inc. and RMUS Canada https://hardwoodsnb.ca/en

UNIVERSITÉ DE SHERBROOKE

Institut de recherche sur les feuillus nordiques Inc.
Northern Hardwoods Research Institute Inc.

MitAcs

FPInnovations

Gembloux Agro-Bio Tech
Université de Liège

Bibliography

- Lecigne, B.; Delagrange, S.; Messier, C. Exploring Trees in Three Dimensions: VoxR (https://CRAN.R-project.org/package=VoxR), a Novel Voxel-Based R Package Dedicated to Analysing the Complex Arrangement of Tree Crowns. Ann. Bot. 2018, 121, 589–601. https://doi.org/10.1093/aob/mcx095

- Martin-Ducup, O.; Lecigne, B. ARchi: Quantitative Structural Model ('QSM') Treatment for Tree Architecture. R Package Version 2.1.0. Available online: https://CRAN.R-Project.Org/Package=aRchi (accessed on 20 April 2022).

- Martin-Ducup, O.; Mofack, G.; Wang, D.; Raumonen, P.; Ploton, P.; Sonké, B.; Barbier, N.; Couteron, P.; Pélissier, R. Evaluation of Automated Pipelines for Tree and Plot Metric Estimation from TLS Data in Tropical Forest Areas. *Ann. Bot.* **2021**, *128*, 753–766. https://doi.org/10.1093/aob/mcab051

- Raumonen, P.; Kaasalainen, M.; Markku, Å.; Kaasalainen, S.; Kaartinen, H.; Vastaranta, M.; Holopainen, M.; Disney, M.; Lewis, P. Fast Automatic Precision Tree Models from Terrestrial Laser Scanner Data. Remote Sens. 2013, 5, 491–520. https://doi.org/10.3390/rs5020491

- Vandendaele, B.; Fournier, R.A.; Vepakomma, U.; Pelletier, G.; Lejeune, P.; Martin-ducup, O. Estimation of Northern Hardwood Forest Inventory Attributes Using Uav Laser Scanning (Uls): Transferability of Laser Scanning Methods and Comparison of Automated Approaches at the Tree- and Stand-level. Remote Sens. 2021, 13, 2796. https://doi.org/10.3390/rs13142796

- Vandendaele, B.; Martin-Ducup, O.; Fournier, R.A.; Pelletier, G.; Lejeune, P. Mobile Laser Scanning for Estimating Tree Structural Attributes in a Temperate Hardwood Forest. Remote Sens. 2022, 14, 4522. https://doi.org/10.3390/rs14184522

- Weiskittel, A.; Li, R. Development of Regional Taper and Volume Equations: Hardwood Species; DendroMetrics, LLC: Welches, OR, USA, 2012.