Multi-temporal laser scanning for forest structural monitoring – are we there yet?

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Swiss LiDAR Day

Introduction

Close-range remote sensing, and handheld mobile laser scanning (MLS) in particular, shows great potential for operational use in forest inventories. However, its robustness across challenging environments and the phenological cycle remains to be evaluated. Here, we assess the multi-temporal robustness of handheld MLS over three phenological cycles (2023–2025) and its capacity to detect forest structural changes for monitoring purposes.

Study Site

- Temperate mixed forest
- four 50 x 50 m² research plots to test out novel proximal remote sensing technologies.



Plot #1 (FP05)
#Trees: 90
Tree dens.: 360 T/ha
DBH [cm]: 7 – 69
DBH avg. [cm]: 31.2
Single layered



Plot #2 (FP07)
#Trees: 107
Tree dens.: 428 T/ha
DBH [cm]: 7 – 90
DBH avg. [cm]: 23.3
Multi layered



Plot #3 (FP08)
#Trees: 190
Tree dens.: 760 T/ha
DBH [cm]: 7 – 82
DBH avg. [cm]: 18.4
Multi layered



Plot #4 (FP10)
#Trees: 175
Tree dens.: 712 T/ha
DBH [cm]: 7 – 69
DBH avg. [cm]: 22.1
Multi layered

Data acquisition

- **Grid pattern**: 50 x 50 m²
- **Frequency:** weekly (March – June, September – November)

Evaluation

- Occlusion mapping
- Plant Area Index (PAI) estimation using AMAPVox (Vincent et al. 2017)
- Tree detection**
- DBH estimation**

** not shown here: ask presenter for more details.

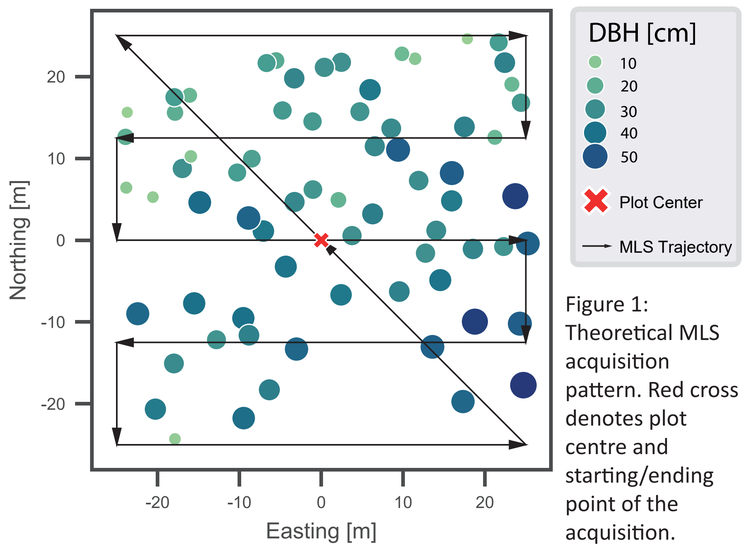


Figure 1: Theoretical MLS acquisition pattern. Red cross denotes plot centre and starting/ending point of the acquisition.

Occlusion analysis

Occlusion has been identified as a major source of uncertainty in laser scanning acquisitions of forests, introducing potential bias in retrieved forest structural parameters.

Occlusion mapping traces each laser pulse in a 3D voxel grid to detect and evaluate obstructed forest volume. This allows us to assess the representativeness of a laser scanning acquisition.

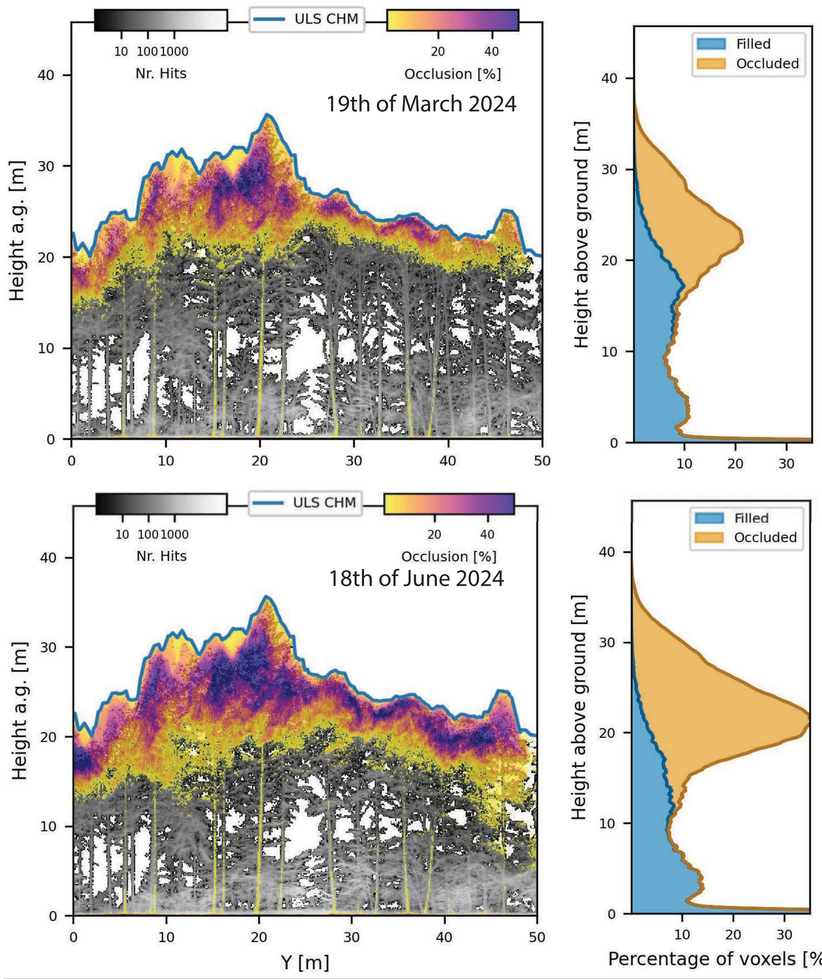


Figure 2: Example of a 3D occlusion map for a leaf-off (top) and leaf-on (bottom) acquisition. (left) Vertical transect through an occlusion mapping grid. Transect is 10 m deep. Grey pixels show accumulated number of laser returns over the 10 m deep transect. Red pixels show the accumulated number of occluded voxels in relation to transect depth: 100% = all voxels in the 10 m deep transect are occluded. Blue line: CHM derived from drone based laser scanning (ULS).

Check out our recent pre-print of our perspective paper on the potential of occlusion mapping for forest laser scanning. This was a collaborative effort within the framework of the 3DForEcoTech COST Action:
Kükenbrink et al. (under review).
Insights from the Unseen
– Occlusion in Forest Laser Scanning.

COST Action CA20118 3DForEcoTech Three-dimensional forest ecosystem monitoring & better understanding by terrestrial-based technologies

Occlusion Timeseries

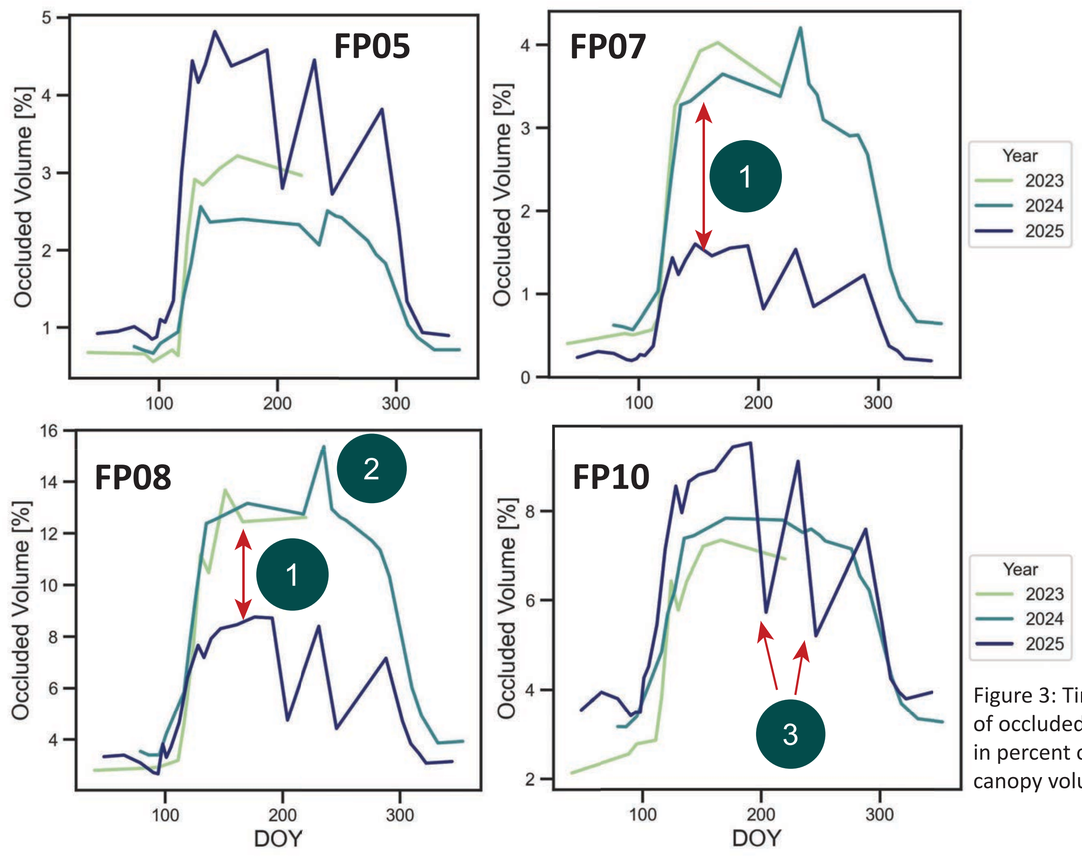


Figure 3: Time series of occluded volume in percent of entire canopy volume.

PAI Timeseries

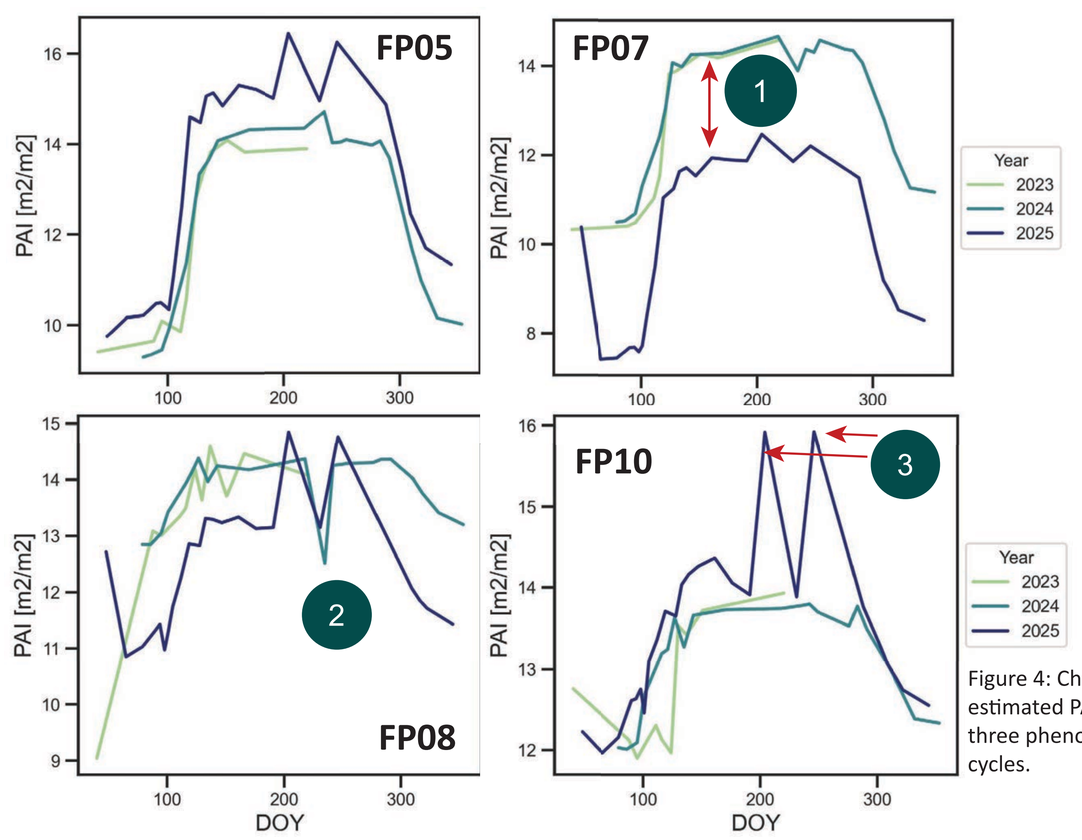


Figure 4: Changes in estimated PAI over three phenological cycles.

Generally we can see similar patterns between occlusion and PAI time series. Decreased occlusion in summer acquisition tend to translate into higher PAI estimates. Some timeseries features can be explained by various factors:

1. Larger management event, with multiple cut down trees
2. Change in operator, resulting in large differences in acquisition pattern
3. Testing a new MLS (FARO ORBIS Premium) with doubled pulse density

Especially more complex structural parameters (like PAI/PAD) are susceptible to changes in acquisition strategies or sensor cahracteristics. Other parameters like tree position, DBH, canopy height have shown to be less affected by these changes and are therefore estimated more robustly from this kind of data.

Conclusion

Handheld MLS shows great potential for monitoring forest structural dynamics. Its fast data acquisition enables high-frequency time series, supporting in-depth multi-temporal analyses. However, several factors — sensor, acquisition pattern, operator, and environmental conditions — can affect its ability to detect actual structural changes. Occlusion mapping may help identify areas with limited point cloud information. As multi-temporal proximal laser scanning data becomes more available, greater efforts in harmonizing data across sensors and time points are needed. Platforms to openly share forest point cloud data with associated meta data could largely facilitate method development for better data harmonization:

Forest3DTwin - an open platform for 3D forest scans

WSL has established, within the Open Research Data initiative by the ETH Zurich, a platform for storing and sharing plot-level forest laser scanning data acquired with proximal sensing technologies (MLS, TLS, ULS). The data is hosted on the established Envidat platform run by the WSL. Check out the platform and consider sharing your data. Just follow this QR Code:

References

Kükenbrink, D., Gassilloud, M., Brede, B., Bornand, A., Calders, K., Cherlet, W., Eichhorn, M.P., Frey, J., Gretler, C.M., Höfle, B., Kattenborn, T., Klinger, L., Mokros, M., Pitkänen, T., Saarinen, N., Terryn, L., Weiser, H., Göritz, A., 2025. **Insights from the Unseen - Occlusion in Forest Laser Scanning**. EarthArXiv.

Vincent, G., Antin, C., Laurans, M., Heurtebize, J., Durrieu, S., Lavalley, C., Dauzat, J., 2017. **Mapping plant area index of tropical evergreen forest by airborne laser scanning. A cross-validation study using LAI2200 optical sensor.** Remote Sensing of Environment 198, 254–266.

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