Perspectives on long-term TLS time-series to detect changes in tree crowns

M. B. Campos[1], S. Junttila[2], A. Shcherbacheva[1], Y. Wang[1], X. Liang[1], J. Hyypä[1], E. Puttonen[1]

[1]Department of Remote Sensing and Photogrammetry, Finnish Geospatial Research Institute (FGI), National Land Survey of Finland, Masala, Finland
Email: {mariana.campos; anna.shcherbacheva; yunsheng.wang; xinlian.liang; juha.hyypa; eetu.puttonen }@nls.fi

[2] School of Forest Sciences, University of Eastern Finland, Joensuu, Finland.
Email:samuli.junttila@uef.fi

1. Introduction

The 3D Terrestrial laser scanner (TLS) information play a key role in monitoring and understanding forest dynamics. The monitoring of structural changes in tree crowns can be used as a basis to understand their growth dynamics and overall canopy interactions in forests. Canopy structure and spatial distribution of leaves are major factors that affect the efficiency of energy and mass exchange processes of water vapor, photosynthetic activity and carbon assimilation between forest and the atmosphere (Hatfield and Dold 2019). Precise canopy change detection is a difficult task due to the non-static behavior and non-symmetric shape. At present, many questions about tree canopy dynamics remain unanswered, such as when and how tree canopy grows. Previous work has shown that TLS can overcome several of the methodological problems inherent to conventional canopy analysis with passive optical methods (Seidel et al. 2012), such as varying lighting conditions and occlusion. However, traditional TLS data acquisition surveys are laborious, which limits the number of works focusing in long term and high temporal resolution monitoring of tree canopy dynamics with TLS. To address this challenge, a permanent TLS measurement station with high spatial and temporal resolution was built in Hyytiälä forest research station, in southern Finland (Campos et al. 2021). The permanent TLS measurement station has been fully operational since April 2020 and it provides a TLS time-series with high spatial (0.006° angular resolution) and temporal resolution (1 scan per hour). Here, we present a data assessment of the measurement station point clouds with an aim to demonstrate the potential of long-term TLS time-series to provide new insights about structural changes in tree crowns over time. Our results show that long-term TLS time-series enable the accurate detection of the sprouting and growing of new leaves during the spring growth season of 2020 and in the beginning of 2021.

2. Long-term TLS time-series Dataset

The 13-month long TLS time-series data assessment was performed with the focus on detecting visual and quantitative crown changes (point cloud density and reflectance response) of a single deciduous Silver birch (*Betula pendula*). The Silver birch tree is located about 6 m away from the tower, with a19m height and DBH of 173mm. The point cloud time-series of the Silver birch was collected with the permanent TLS measurement station over the entire growing season of 2020 till beginning of 2021-spring. More details about the TLS measurement station setting and output data can be found in Campos et al. (2021). 72 point clouds were selected and pre-processed to assess the potential of the measurement station data to detect changes in tree crowns. All selected scans were acquired in windless conditions during the night varying from 8 P.M to 2 A.M. The time-series used in the change assessment covered a time period from April 2020 to May 2021 with a temporal resolution of 5 days (~1 week). The data processing framework to detect changes in the Silver birch canopy from the time-series consisted of three main steps. These were i) tree segmentation from the full point cloud, ii) point cloud filtering, and iii) point cloud georeferencing in to ETRS89-TM35FIN frame (EPSG: 3067).

3. Results

Figure 1 presents the median reflectance response and the upper canopy height variation (90th percentile) of the birch tree crown over the observation period with the zero date set to 1 January 2020 (e.g. 2021 starts in day of the year 366). The reflectance response along the time-series can detect the first signal of the spring. In 2020, the reflectance values start to significantly increase after May 23 and decrease around September 22, which can be associated to the spring sprout of new green leaves and their falling in autumn. The dashed red and blue vertical lines in Figure 1 represent the time of solstices and equinoxes. In 2021, the reflectance values start to increase again around May 1st, manifesting the

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beginning of a new growing season. The increase in the point cloud density can also confirm the leaf sprout and green biomass changes in the birch crown during this period. For instance, the point cloud density increased 13.4% in 2020, from 4.7 million points in April 16 to 5.3 million points in May 25 and 17% in 2021, from 5.2 million points in April 15 to 6.1 million points in May 25. Figure 1 illustrates a closely synchronized behaviour between changes in reflectance response and in the 90th height percentile variation. The 90th height percentile correspond to the height at which 90% of the points of the whole cloud are below it. This approach enables a reliable timing of change events in the crown. However, the height percentile information alone cannot quantify where in the crown growth happens. In this regard, changes in TLS reflectance response, point density and canopy area of the birch crown are further explored in Figure 2, Figure 3 and Table 1, respectively.

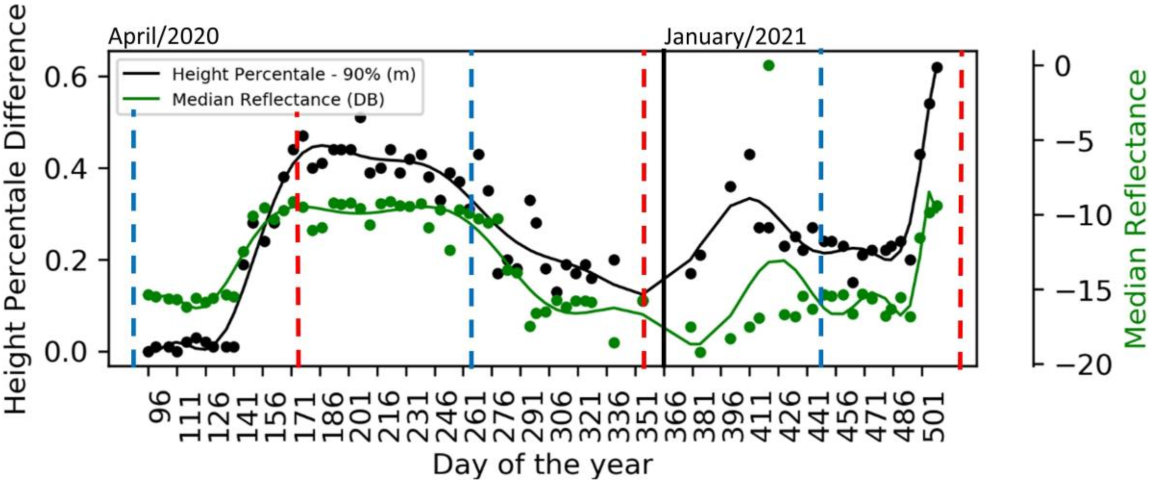

Figure 1: Polygonal fit of median reflectance response (green) and height percentile variation (black) of a Silver birch tree from April 2020 to May 2021. Red and blue dash lines are the solstices (summer, winter) and equinoxes (spring, autumn) days, respectively. Black line represents the begging of 2021.

To visualize the state and reflectance response of the Silver birch crown during the spring growing season, a top view of eight georeferenced point clouds from early-spring of 2020 (Day of the years - 107, 126, 137 and 146) and 2021 (Day of the years in Figure 1-470, 490, 500, 509) is presented in Figure 2. The point clouds coordinates (E, N) were converted to polar coordinates and presented according to the azimuth direction and distance from the tree stem centre position, ranging from 0 to 3m. The point clouds were colorized with respect to the reflectance parameter values, ranging from 0 to 2.

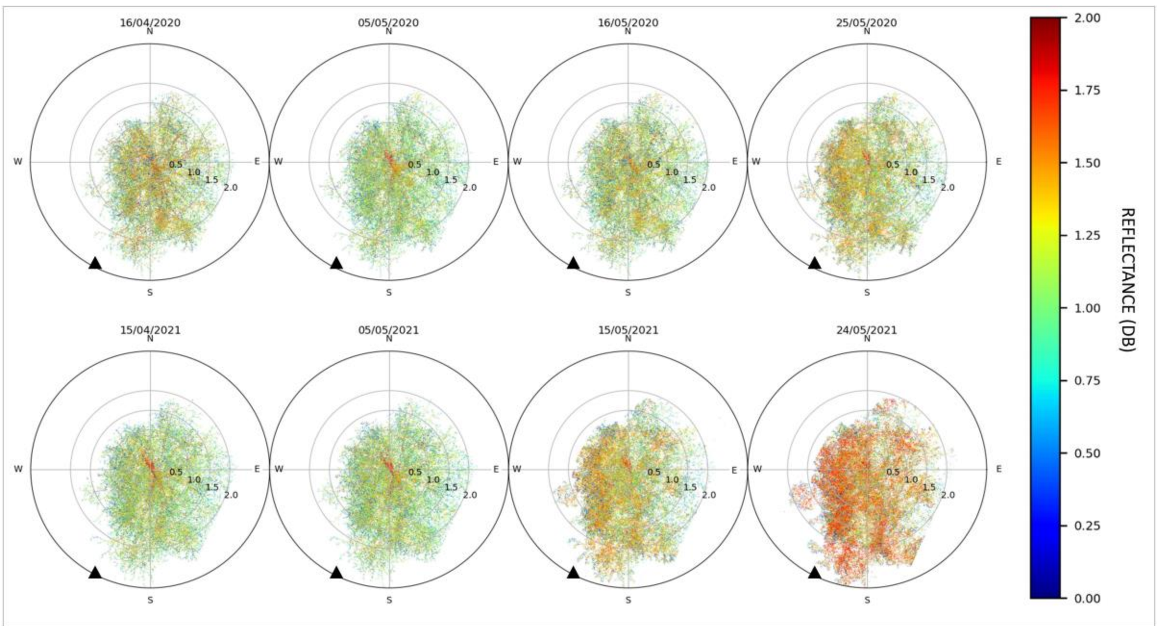

Figure 2: Seasonal variation in a Silver birch crown during the spring growth season of 2020 and 2021. The color scale presents individual laser point reflectance in logarithmic scale (0–2).The black triangle shows the direction to the permanent TLS measurement station.

For more accurate volumetric change assessment, point cloud density variation can be associated to volumetric dynamics on the tree crown using methods such as point cloud voxelization. A 2D point cloud voxelization is presented in Figure 3, in which a voxel size of 5×5 cm dimensions was used to detect the birch crown changes at 2021(DoY- 470, 490, 500, 509). The tree crown changes can be observed comparing the point density in each voxel element at different times of the 2021 growing season. From mid-April to late-May, the density of points increase in the voxel of the centre of the crown. The number of point also increase in minor magnitude at tree edges, which can be associated to tree crown area growth. Table 1 present quantitative results of the tree crown change from the estimation of canopy area via alpha shape algorithm (Edelsbrunner and Mücke 1994). As show in Figure 3, the birch tree canopy area increases especially after Early-May. The estimated area increased 5% in 2020 and 12% in 2021 from mid-April to late-May. The response of the birch tree to the spring have started earlier in 2021 than 2020 (Figure 1), which can justify the difference in the percentage of increased area.

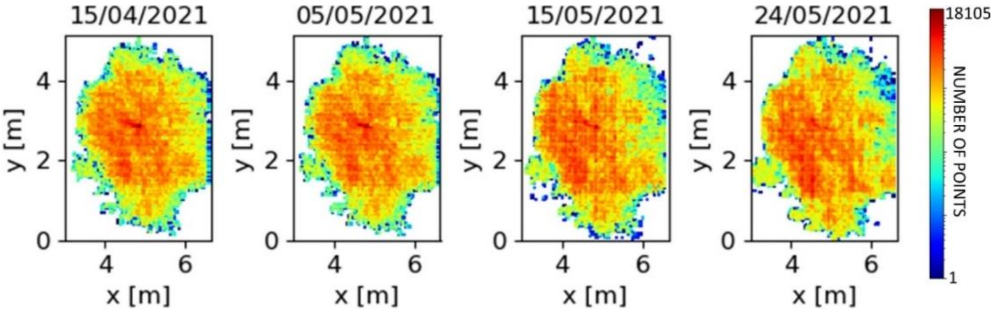

Figure 3: Seasonal variation in a Silver birch crown in the 2D voxel space between Mid-April and Late-May. The color scale presents the number of points per 2D voxel.

Table 1. Birch Tree canopy area in spring 2020 and 2021 computed with alpha shape.

Year	Mid/April	Early/May	Mid/May	Late/May
2020	10.01 m^2	9.93 m^2	10.01 m^2	10.44 m^2
2021	10.41 m^2	10.50 m^2	11.20 m^2	11.67 m^2

4. Conclusions

Our first results show that long-term TLS time-series can support the detection of structural changes in individual tree crowns. Reflectance detection enables the accurate timing of the sprouting and falling of leaves during the spring growth season of 2020 and in the beginning of season 2021. Correlation and regression analysis of reflectance, temperature, and other environmental factors relevant to tree life cycles will be performed in future to determine the exact sequence of events that drive tree sprouting and fall. High temporal resolution of the time-series allow canopy growth monitoring and quantification with several different methods, such as height percentile and voxel point densities. We demonstrate the potential of high-density TLS time-series as a plot scale measurement tool that captures accurate temporal snapshots of the actual state of the forest. These dense time-series information enable forest structure analyses on level that have not been achievable with earlier techniques. In future, our work will focus on expanding the present analysis to cover all high visibility trees in the monitoring area to quantify, time, and analyze their phenological events and the overall forest dynamics.

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