Physically-based Multi-temporal LiDAR Traits for Species Discrimination in a Temperate Mixed Forest

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Zusammenfassung: Basierend auf einem Datensatz von 873 Einzelbäumen untersuchen wir ob physikalisch-basierte ALS Merkmale einen zur Trennung von Arten geeigneten phänologischen Trend aufweisen. Hierzu berechnen wir die Differenz dieser Merkmale zwischen jeweils zwei belaubten und unbelaubten ALS Datensätzen innerhalb der einzelnen Baumkronen. Reine Höhenmerkmale wie die Baumhöhe bleiben in unserem Testgebiet zwischen verschiedenen Sensoren und Jahreszeiten stabil, und Merkmale, die die Dichte der Vegetation repräsentieren, lassen sich in gewissen Grenzen zur Trennung von Arten benutzen. Bei komplexeren Merkmalen zeigt sich jedoch schnell der Einfluss der Aufnahmegeometrie oder des verwendeten Sensors, so dass hier weitere Studien, möglichst auch mit Modellsimulationen, nötig sind.

1 Introduction

The spatial distribution of tree species is an important parameter when judging the quality of the forest habitats and its biodiversity, and is equally relevant for forest management purposes. Due to the limited large-scale applicability of exhaustive in-situ observations, passive remote sensing approaches have been used extensively for the mapping of tree species in different forest ecosystems. However, some species remain indistinguishable using image based features alone. Airborne laser scanning (ALS) is now an established method in remote sensing of forests, with having the unique advantage of providing a direct link to the structural characteristics of the forest canopy. Some early studies hinted at the potential of using structural features for species classification, but either were lacking in the number of species (e.g. Scandinavian studies often only differ between three tree species) or the number of datasets used. With the ever increasing availability of regional and nationwide ALS datasets, multi-temporal aspects and the comparability of datasets acquired with different sensors and survey settings gets more in the focus. In addition, knowledge about the interpretability of features is important when working towards site independent methods. Thus, we use a hypothesis based selection of a smaller feature set, rather than testing a long list of features in a black box approach typical of many empirical studies. The objectives of this study are to (i) test a set of physically-based, multi-temporal and full-waveform features for their tree species classification potential in a temperate mixed forest forest and to (ii) to differentiate changes in features resulting from objects from those resulting from sensor properties. To do this, we exploit data from four (two leaf-on, two leaf-off) different

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ALS campaigns and use crown outlines together with tree species information of more than 800 trees.

2 Study area and data

2.1 Study area

The Laegeren site is located at N 47º 28′, 49″ and E 8º 21′, 05″ at 682 m a.s.l. on the south slope of the Laegeren mountain, approximately 15 km northwest of Zürich, Switzerland. The south slope of the Laegeren marks the boundary of the Swiss Plateau, which is bordered by the Jura and the Alps. The mean annual temperature is 8ºC. The mean annual precipitation is 1200 mm and the vegetation period is 170-190 days. The natural vegetation cover around the tower is a mixed beech forest. The western part is dominated by broad-leaved trees, mainly beech (Fagus sylvatica L.) and ash (Fraxinus excelsior L.). In the eastern part beech and Norway spruce (Picea abies (L.) Karst.) are dominant. The forest stand has a relatively high diversity of species, ages, and diameters. The ground cover consists of bare soil, boulders, and litter while existing understory is characterized by a dense herb and shrub coverage. Average ALS based canopy height is 24.9 m, with a maximum of 49 m, and the field based stem density is 290 stems per ha.

2.2 Multi-temporal airborne laser scanning data

In 2010, two airborne laser scanning campaigns were carried out, using RIEGLs LMS-Q680i scanner (under leaf-on conditions) and using RIEGLs LMS-Q560 scanner under leaf-off conditions in a mainly semi-natural, deciduous dominated forest stand in Laegeren (Swiss Jura), yielding in two independent datasets. The used flight strips have an overlap of approximately 50%. Full-waveform features, namely echo width and intensity, were extracted from the full-waveform data using the software RiAnalyse and were assigned to each individual return contained in the multiple-echo point cloud. However, we found systematic differences in the intensity calibration between the two datasets and thus will not use the intensity, but only the echo width feature in this study. Another leaf-on and off dataset was acquired in 2014, this time with an LMS-Q680i in both acquisitions, albeit with slightly larger maximum scan angle (±22 deg) an lower average point density than the 2010 data. The specifications of all four datasets used in this study are displayed in Table 1. For the 2010 data, the DTM was interpolated using our own algorithm (for details see LEITERER et al. 2013), while for the 2014 data we used the DTM provided by the data supplier, which was created using the TerraScan software suite. For each echo, the height above ground was then calculated as a subtraction of the interpolated DTM value at the x,y coordinates of each respective echo.

Tab. 1: Specification of the four ALS data sets used in this study.

Campaign	**Laegern (2010)**		**Aargau (2014)**	
ALS Instrument (Riegl)	LMS-Q560	LMS-Q680i	LMS-Q680i	LMS-Q680i
ø Altitude (ABG) [m]	500		600	700
Scanning method	rotating multi-facet mirror			
Echo detection method	full-waveform processing			
Pulse length [ns]	~ 4			
Max. scan angle [deg]	±15		±22	
ø echo density	20	40	15	30
Acquisition date	10. April	1. August	March/April	June/July

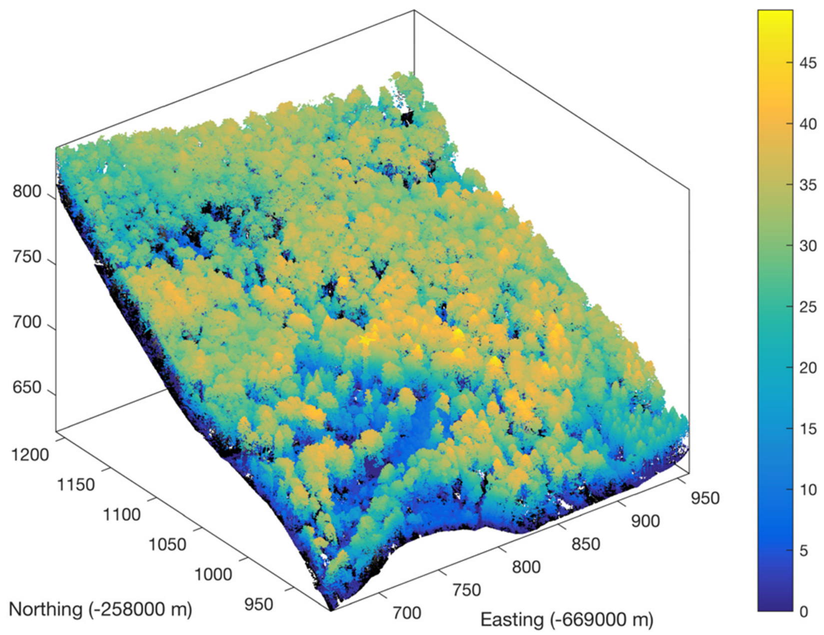

Fig. 1: Leaf-on and leaf-off point cloud of the study area from 2010. Leaf-on data is colored with height above ground, while leaf-off data is a using gray-scaled colormap to display height above ground. Note the flux-tower towards the center of the image.

2.3 Validation data

The area of exhaustive single-tree inventory is 330 m × 260 m in size and its elevation ranges from 620 to 810 m above sea level (a.s.l.). The high diversity in respect to species type, age (up to 185 years) and diameter distribution results in a very heterogeneous forest canopy, both horizontally and vertically. Despite the small size of the area, it contains all the tree species present in the larger Laegeren area and includes very dense deciduous-dominated canopy in the north, and less dense conifer-dominated stands in the south (Fig. 1). Therefore, this area can be considered as a good representative for the forested area around. Collecting tree species data at the single-tree level was part of a comprehensive in-situ forest inventory in April 2013. Each tree with a diameter at breast height (DBH) greater than 0.2 m was accurately located (<1m) using a total station, with a linkage to global coordinates through a set of DGPS points in forest gaps. In addition to tree species, other tree variables were measured as well (e.g. DBH, social status, horizontal crown displacement, number of canopy layers, vitality, approximated crown size, and crown projection area). To get accurate crown segments for the aggregation of features, we used an UAV to acquire images in fall, where leaf senescence aids the delineation of single tree crowns. The platform was an ultra-light drone, called eBee (SenseFly), which was flown on October 21, 2013, at 270 m above ground. Following the geometric rectification of 174 images, the resulting 0.08 m × 0.08 m spatial resolution ortho-mosaic was geometrically co-registered to the ALS dataset. Using a semi-automatic segmentation approach, possible ITCs were detected from combined UAV-derived ortho-mosaic and ALS-derived CHM. The extracted tree crown shapes were visually checked to avoid any conflict or mixed crowns. Crown polygons that appeared to contain more than a single, top-layer tree crown were consequently removed from the final datasets. The in-situ observed trees were linked to the UAV-delineated ITCs using geometrical (coordinates and crown size) and attributive (vertical layer) constraints. As a result, 873 well-matched trees were used as the reference data. Table 2 contains more details about the linked trees and their abundance.

Tab. 2: Abundance of tree species in the reference data set and species identifier used in the box plots.

Species Name	**Number of trees**	**Species identifier**
Silver fir (*abies alba***)**	79	11
Norway spruce (*picea abies***)**	40	14
Norway maple (*acer platanoides***)**	23	22
Sycamore maple (*acer pseudoplatanus***)**	118	23
European beech (*fagus sylvatica***)**	376	29
European ash (*fraxinus excelsior***)**	147	31
Large-leaved Lime (*tilia platyphyllos***)**	56	56
Which elm (*ulmus glabra***)**	24	59

3 Methods

We used the crown polygons derived from on the UAV data to subset the raw ALS data based on their x and y coordinates. Only echoes with their x,y-location inside the crown polygon were retained for the subsequent analysis. For the computation of the features, we used an additional height threshold of 3 m above ground to differentiate crown from non-crown returns. The total number of echoes within the polygon is only used when computing the fraction of crown returns in comparison to all returns. For each of the crown segments, we computed a set of ten traits or features, which are listed in Table 3, along with a description of how they were computed and what was the hypothesis behind choosing this particular feature. Please note that we only had the FW width feature in the 2010 data, while the intensity based features were only useable in the 2014 data. The latter had to do with a non-recoverable semi-empirical intensity correction done by the data provider, which skewed the distribution of intensity values and rendered a multi-temporal comparison of these features impossible. The crown segments used in this study are displayed in Figure 2. After subsetting the point cloud using the crown segments, we computed the features for each crown segment, subtracted the leaf-on feature from the leaf-off one for the same year and displayed these phenological differences as boxplots with mean and stand and deviation for each of the eight species in the results section.

Tab. 3: List of features that were computed from the point clouds contained by the crown segments.

Feature/Trait	**Computation**	**Hypothesis/Remarks**
max. height	maximum echo height above ground	should be stable for conifers, impacted by leaf state for deciduous trees
median height	median of all echo heights > 3 m above ground	should be influenced by leaf state in deciduous tree
std. height	standard deviation of all height values > 3m	should be influenced by crown shape
median int.	median of all intensity values within crown > 3 m	should indicate small scale structure and/or reflectance changes (2014 data only)
std. int.	standard deviation of all intensity values > 3 m	should indicate small scale structure and/or reflectance changes (2014 data only)
fraction of single echoes	number of single echoes divided by total of echoes within crown	should change with phenology and species
fraction of ground echoes	number of single echoes divided by total of echoes within crown	should change with phenology and species
median width	median width of echoes (FW feature)	possible linkage with fine-scale vertical structure and incidence angle (2010 data only)
std. width	standard deviation of echoes (FW feature)	possible linkage with fine-scale vertical structure and incidence angle (2010 data only)

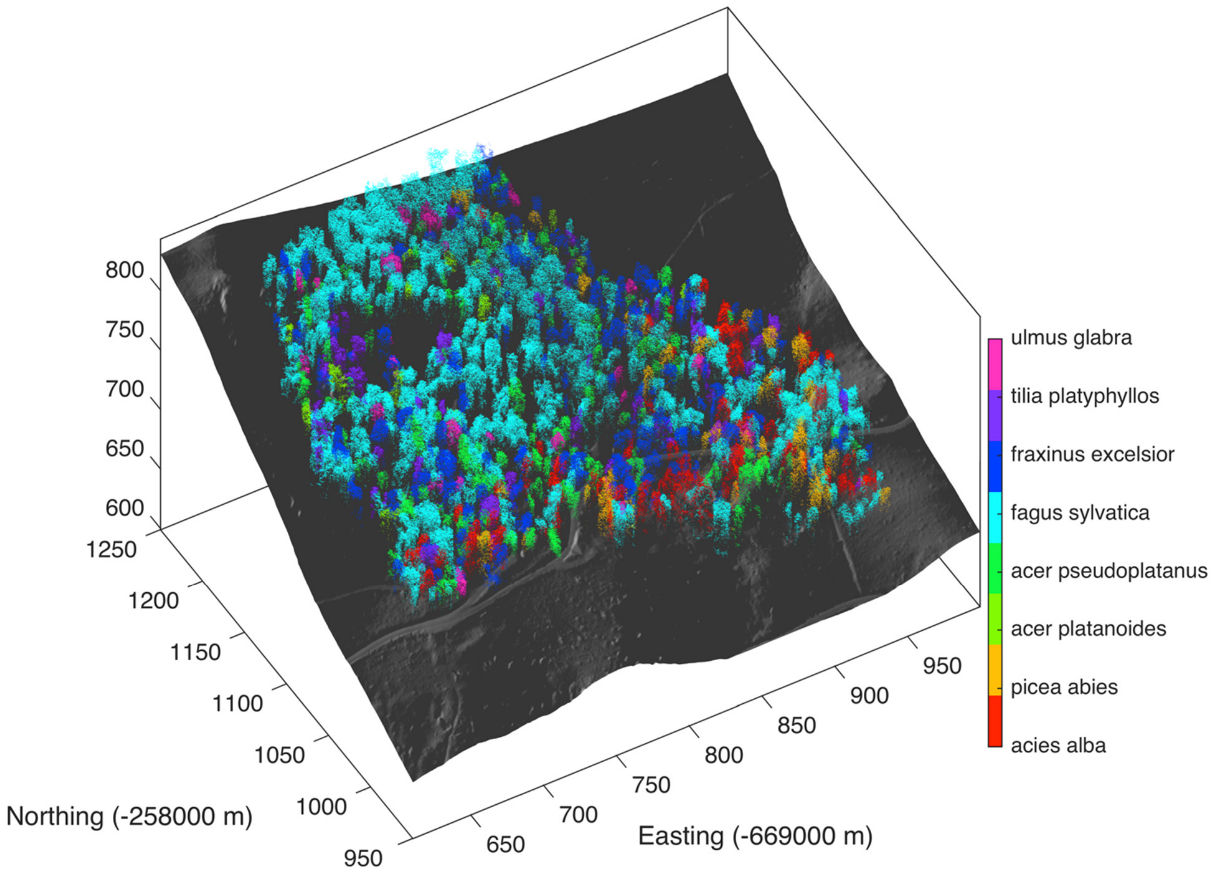

Fig. 2: Point cloud of studied crown segments colored according to their respective field measured species. The ALS data shown here is the 2014 leaf-on data.

4 Results and Discussion

Figure 3 presents the results of both 2010 and 2014 phenologic differences of the features in boxplots, indicating median, 75% and 25% and min/max values of the data. Studying the max and median height features, the conifer tree species (11 and 14) show less seasonal change than the deciduous ones (22-59), more (~ 2 m difference in median) so for median height (especially in 2010) than for maximum height (< 1 m difference in median). Standard deviation is much smaller for maximum height and with the rather small seasonal differences it appears as if leaf-on and leaf-off data would perform comparable when estimating tree height by using the maximum ALS return within a crown segment. There is a much larger difference in the change of median height in 2010 between conifers and deciduous trees (~ 0 m for conifers, ~ -2 m, for deciduous), whereas in 2014 all the median height differences for all trees are negative and in the same order of magnitude, irrespective of the species. A similar behavior can be seen in the fraction of single echoes, which should correspond to the density of canopy material, and is much higher for the conifers in 2010, but again more or less the same in 2014. This unexpected outcome might be partly explained by the two different sensors used in 2010. Echo detection methods and energy output might severely impact both the height distribution of echoes as well as the fraction of single echoes within a canopy. For the FW data from 2010, the median echo width shows a separation between conifers and deciduous trees, but this again could be an artefact of the two different sensors used. On the other hand, in the 2014 data the median intensity feature shows some differences between conifers and deciduous, potentially linking to the different geometric-optical properties of foliated and non-foliated branches, as the seasonal change for the conifers remains close to zero, while the deciduous trees show higher intensity values in summer, which is likely due to the increased amount of scattering material in summer. Interestingly, the penetration ratio linked feature (fraction of ground echoes) does not show any significant species related difference, neither for the 2010, nor for the 2014 data.

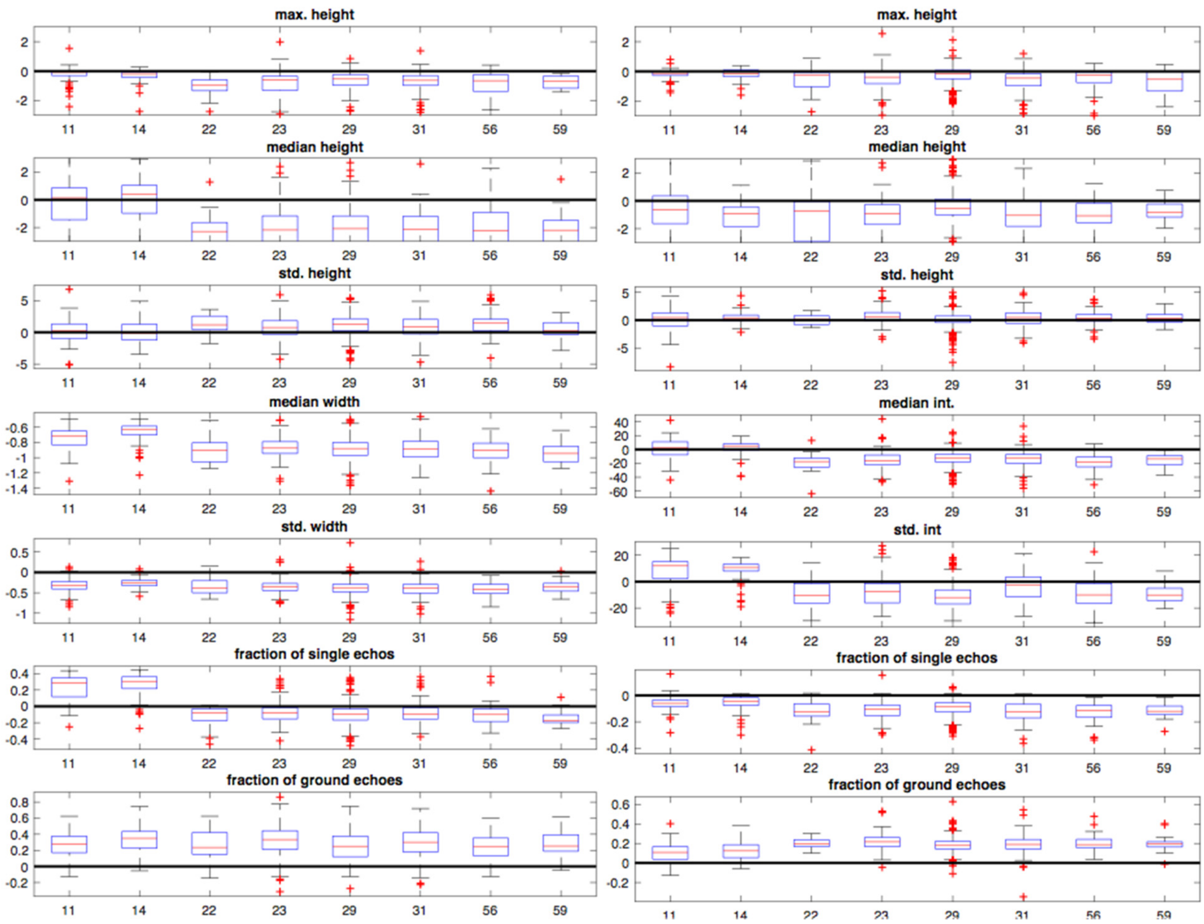

Fig. 3: Boxplots of the **difference** of the selected variables between leaf-off - leaf-on state for 2010 (right panel) and 2014 (left panel). Values are those of the respective leaf-off campaign subtracted by those from the leaf-on campaign. This corresponds well with the negative values for median height seen for the deciduous trees (id > 22). Tree identifiers are: 11 - silver fir, 14 - norway spruce, 22 - norway maple, 23 - sycamore maple, 29 - european beech, 31 - european ash, 56 - large-leaved lime, 59 - whych elm. The red line denotes the median, the top and bottom of the blue box the 75% and 25% percentiles, the black bars the min and max values and the red crosses outliers.

5 Conclusions and Outlook

Using a large dataset of 873 field-labelled crown polygons, we derived a set of physically-based features and investigated if their phenological differences could be linked to the eight different tree species present in our dataset. Maximum height was stable across acquisitions and seasons, showing how robust tree height measurements based on ALS data are. Intensity was very useful to show the difference in leaf state. Unfortunately, some of the more complex features showed different behavior and in some cases it was not clear if the changes were due to differences in instruments and survey configurations or actual changes within the vegetation canopy. To get the most species information out of the ALS data, more studies of this type and very likely accompanying model simulations using ray-tracing and virtual tree models are needed.

6 References

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