Operationalizing multi-temporal stem volume assessment based on ALS data

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1. Introduction

Large area stem volume information, one of the most important parameters in forestry, can be derived from various types of remote sensing data, such as microwave remote sensing, satellite-based optical data or airborne acquired optical data, including Airborne Laserscanning (ALS). Currently the highest accuracy combined with the highest spatial resolution of the derived stem volume maps are obtained from ALS data. Furthermore, ALS data have the advantage that they are not influenced by topographic shadows which is a limiting factor in complex topographic environments for the majority of the remote sensing methods. One limiting factor of ALS is the reduced temporal resolution of country-wide data sets, e.g. currently in Austria time steps of ≥6 years.

To estimate stem volume from ALS data for large areas (e.g. >1000 km²), area-based approaches are commonly applied. In the majority, these approaches are based on regression models using in-situ forest inventory (FI) data, i.e. on plot level, as ground reference for calibration purposes. Especially for large scale applications there is normally a time gap between the ALS data acquisitions and the in-situ FI measurements. This leads to deviations with respect to harvested trees and forest growth between the date of ALS and FI data acquisitions. On the other hand, multiple epochs of ALS data are in the meantime available for many forested regions.

The aim of this study is to investigate the potential of country-wide, multi-temporal stem volume estimations based on ALS and national forest inventory (NFI) data. The study is done for the federal state of Vorarlberg, Austria. Three ALS data sets, acquired in the framework of country-wide ALS campaigns and NFI data are used for this study.

2. Study area and data

The study area is located in the western part of Austria and covers the federal state of Vorarlberg with an area of 2601 km². The altitude varies between 396 m a.s.l. at the Lake Constance and 3312 m a.s.l. at the Piz Buin in the Silvretta mountains. In addition to the large Rhine Valley the area is characterized by several smaller valleys forming a complex mountainous landscape. Forests cover ~37% (970 km²) of the total area and consist of 82.8% coniferous and 17.8% deciduous tree species. The dominant coniferous tree species are spruce (*Picea abies*) with ~60.0% and fir (*Abies alba*) with 20.4% of the standing volume (BFW, 2021).

The ALS data were acquired within operational country-wide ALS campaigns in the years 2002-2006, 2011, and 2017. In the following, the ALS data sets are named ALS_2004, ALS_2011 and ALS_2017, respectively. The point densities vary in the range of 4-20 echoes per m² for ALS_2004, 7-40 echoes per m² for ALS_2011 and 15-80 echoes per m² for ALS_2017. From the ALS_2017 data a detailed digital terrain model (DTM) with a spatial resolution of 0.5x0.5 m² was derived. This DTM was used as reference for all three ALS data sets. Additionally, a high resolution (1x1 m²) forest mask generated by the BFW (www.bfw.ac.at) from aerial images and ALS data was used.

To calibrate the stem volume models, data from the Austrian NFI was used as reference. The NFI data are extracted from the operational NFI periods 2000-02, 2007-09 and 2016-21. For each sample plot, information about sample tree positions, diameters at breast height (DBH), tree species, tree heights and stem volumes are available. Further details about the NFI data can be found in Gschwantner et al. (2016).

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3. Methods

For each ALS data set a digital surface model (DSM) was calculated based on the land cover dependent approach described in Hollaus et al. (2010). This approach uses for rough surfaces the DSM calculated from the highest 3D point per raster cell and for smooth surfaces and for data gaps the DSM based on moving least squares interpolation of a local point cloud. Finally, the normalized digital surface model (nDSM) was calculated by subtracting the DTM from the DSM. The derived DSM and nDSM models have a spatial resolution of 1x1 m.

To use the NFI data as ground reference for ALS based regression models, the geolocation accuracy between ALS and NFI data has to be checked in a first step. This was done manually in a GIS environment by overlaying the nDSM with the NFI sample tree positions including the measured tree heights. As shown in Figure 1 the NFI sample tree positions were moved to the local maximas of the nDSM, which can be assumed as tree positions. Furthermore, Figure 1 shows that three sample trees were harvested in the time between ALS and NFI data acquisition. All harvested trees were excluded from the calibration procedure. To consider the mentioned time gap between ALS and NFI data acquisition a tree growth model (Ledermann, 2006; Ledermann et al., 2017; Monserud und Sterba, 1996) was used to model tree height and stem volume for the date of ALS data acquisition. The stem volume for each sample tree was calculated based on the volume functions described in Braun (1969), Pollanschütz (1974), and Schieler (1988).

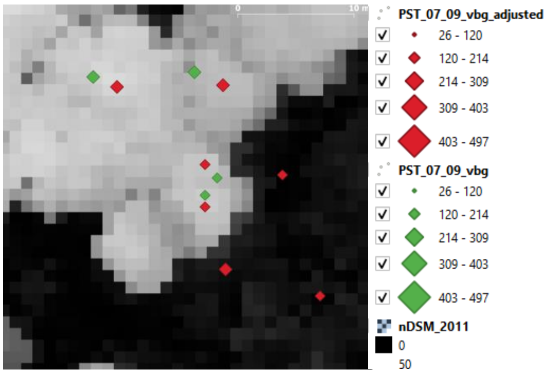

Figure 1: nDSM overlaid with NFI sample tree positions. The green diamonds represent the locations of the original positions and the red one the adjusted positions.

Adapted from the plot-based approach presented in Hollaus et al. (2009) it is assumed that the single tree stem volume can be correlated to the mean canopy surface height above the ground level derived from the ALS data. Crown area was estimated for each sample tree (NFI) using an empirical function depending on tree species (NFI), tree height (ALS), and altitude (ALS). The estimated crown area was used as spatial reference for extracting the average nDSM value, which corresponds to the average crown height. These derived crown heights were used as explanatory variable in a polynomial function.

Finally, the derived stem volume model was applied to each ALS data set for the entire forest area of Vorarlberg. The derived stem volume maps with a spatial resolution of 5x5 m² were used to assess the amount of harvested areas and their corresponding stem volume amount as well as the increase of stem volume due to tree growth. The processing of the ALS data was done with the OPALS software (Pfeifer et al., 2014).

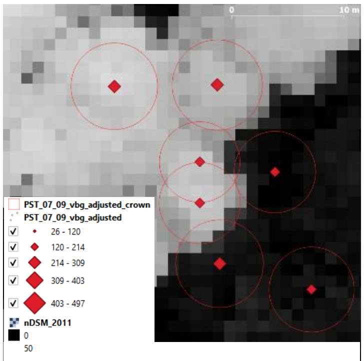

Figure 2: nDSM overlaid with adjusted NFI sample tree positions and the estimated crown areas.

4. Results and discussion

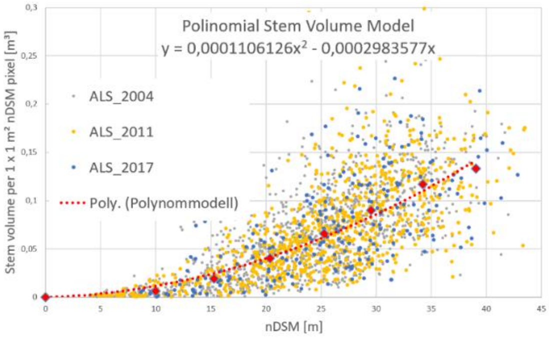

Figure 3: Scatterplots for stem volume and average crown height (nDSM). The three different colors represent the three ALS data sets. The red dashed line shows the fitted polynomial stem volume model.

Based on the described co-registration approach 1146, 857, and 222 sample trees respectively were useable for calibrating the polynomial model. The reason for the low number of sample trees for ALS_2017 is that this inventory is still ongoing and not all NFI plots are surveyed yet. Figure 3 shows the correlation between the NFI derived sample tree stem volumes and the ALS derived mean nDSM heights. As visible in Figure 3 there is no statistically significant difference of the correlations between the three ALS data sets. Therefore, only one polynomial model was calibrated for assessing the multi-temporal stem volume maps. The calibrated stem volume model was applied for all three ALS data sets. In Figure 4 the changes of the stem volumes between ALS_2004 and ALS_2011, and ALS_2011 and ALS_2017 are shown. In total 3,36 Mio m^3 stem volume was harvested between ALS_2004 and ALS_2011 and 2,50 Mio m^3 between ALS_2011 and ALS_2017. In the same time periods the stem volumes increased by 4,42 Mio m^3 and 5,56 Mio m^3 respectively. The quantified changes are in good agreement with the federal state wide NFI statistics. The benefit of the ALS derived stem volumes map is the high spatial resolution of 5x5 m^2 and thus demonstrate the high potential of ALS data for large- as well as small-scale operational stem volume estimation.

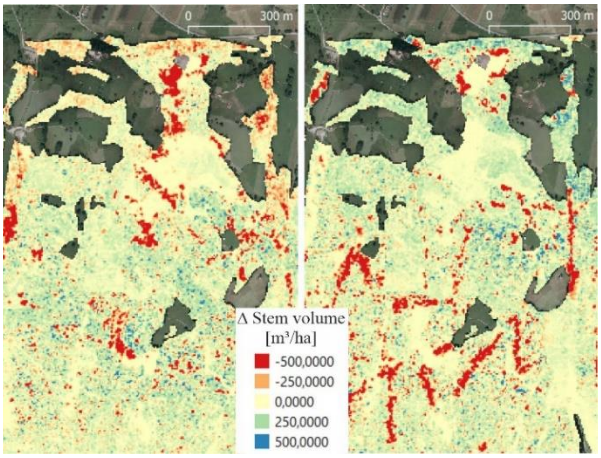

Figure 4: Derived stem volume maps. (Left) difference stem volume map ALS_2011 - ALS_2004 and (right) ALS_2017 – ALS_2011. The spatial resolution is 5x5 m^2.

5. Conclusion

This study shows the high potential of multi-temporal stem volume estimation based on country-wide ALS and NFI data. The derived stem volume maps allow detailed quantification of harvested forests as well as of stem volume increase with high spatial resolution. In further investigations the influence of different tree species and forest management practices (i.e. forest thinnings) will be investigated. Furthermore, the integration of image matching data to increase the temporal resolution will be studied.

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