ALPINE FOREST BIOMASS LOCALIZATION BASED ON LIDAR DATA RESULTS OF THE NEWFOR PROJECT

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ABSTRACT: In the project NEWFOR, financed by the European Territorial Cooperation "Alpine Space", new remote sensing technologies (LiDAR & UAV) for a better mountain forest timber mobilization were investigated. In this contribution possibilities and limitations for detecting forest area and forest biomass as well as the accessibility of forest are shown and discussed. The method for forest area delineation is fully automatically, can be applied to large areas and fulfils the requirements of an operational application. Different forest definitions can be considered by this method. Therefore, an application to different countries with different forest definitions is enabled. For the biomass estimation a semi-empirical regression model was used. The derived biomass maps have a very high spatial resolution and allow comprehensive forest management for large areas and serve as input data for various forest planning activities. It could also be shown that multi-temporal LiDAR data is an excellent data source for change detection of forest parameters (i.e. forest area, biomass).Finally an approach for deriving the forest road network including the road properties width, radius and inclination is presented. The investigations are done within several study areas distributed over the entire Alpine region. Several LiDAR data sets with different properties are analysed and demonstrate their practical relevance in forestry.
Keywords: Harvesting, land use, renewable energies, timber, demonstration

1 Introduction

The role which mountain forests play is extremely varied. Their contribution to the stability and overall development of life and economic factors in mountainous regions is highly significant. The production of renewable resources like timber has positive effects on climate change consequences attenuation, employment and makes for a strong regional value chain, which in turn has an enormous impact on rural development. The objective of preserving and improving the efficiency of mountain forests is a point of public interest and can only be guaranteed if the planning and implementation of all respective measures are integrated into an adequate and well known socio-economic context. Managing forests in mountain territories is significantly more cost intensive than in plain ones. This is due to the topographic conditions, climatic adversity and limited access which drive partly the economic context. A good knowledge of the forest biomass location, its characteristics and mobilization conditions (exploitability, service roads, and mobilization costs) is a prerequisite for an effective wood harvesting and transport and for a sustainable wood industry. This knowledge is currently insufficient to provide at reasonable costs, the required guarantees on the wood supply and on its sustainability. Improving an efficient and robust evaluation of the forest growing stocks (volume and quality) and its accessibility are the efficient measures to mobilise more wood from mountain forests in a sustainable way. As building forest roads and other infrastructures are often complex and expensive, the availability of financial resources is a key challenge. This could be achieved by providing technology and financial support. With such knowledge and tools it will be then possible to develop an active and sustainable cultivation of mountain forests and an efficient European mountain forest management policy.

Recent developments in LiDAR technology – also called airborne laser scanning (ALS), combined to other available data sources (aerial photographs, aerial photo series by UAVs,…), are now allowing a precise and fine mountain forest resource quantification, qualification and mapping. Integrating this technology will provide an innovative response to the challenges of a precise and robust knowledge on the available growing stocks.

Thus, the objective of this paper is to present ALS data based methods to derive objective and comprehensible forest maps, to estimate biomass maps and to extract the forest road network.

2 METHODS

2.1 Forest area

A fundamental task in forest management is locating and analysing forested areas. The delineation of forested areas has a long tradition in forestry and therefore, worldwide different forest definitions exist to define, whether an area can be classified as forest or non-forest. The delineation task is critical, as a broad field of applications (i.e. obligatory reporting) and users (i.e. governmental authorities, forest community) rely on this information. The results determined from these applications are highly dependent on the fundamental input parameters size and position of the delineated forest areas. In the past mainly aerial images were used for a manual or semi-automated delineation. Shadow effects limit this task, particularly for detecting small forest clearings and the exact delineation of forest borders on a parcel level. Additionally, the quality of the results of a manual delineation is subjective and variable between interpreters and may lead to inhomogeneous, maybe even incorrect datasets. An automatic delineation of forested areas based on ALS data can overcome these limitations in most cases. Within the project NEWFOR the method of Eysn et al. [1] was applied to several NEWFOR pilot areas characterized with different forest structure and growing conditions to detect forested areas. The method relies on four clearly defined geometrical criterions (minimum area, minimum height, minimum width and minimum crown coverage) which are subsequently checked against ALS data. The criterion land use is not considered as this information can hardly be obtained from remote sensing data. Other data sources, such as the cadastre, are needed to gather this information. From a hierarchical point of view, the four geometrical criteria have equal rights. To apply these criteria to remote sensed data, a hierarchy has to be defined with respect to a processing chain. For instance, it would make no sense to check the minimum forested area if there is no potential area detected yet. In this approach, the hierarchy is defined as follows: (1) min. height, (2) min. crown coverage, (3) min. area and (4) min. width, whereas (3) and (4) are checked in an iterative process. The minimum height criterion is applied by height thresholding the canopy height model within the vegetation mask. For the crown coverage calculation the 'tree triples' approach as described in Eysn et al. [1] was used. This approach provides a clearly defined reference size for calculating the crown coverage and overcomes limitations such as smoothing effects or dependency of the kernel size and shape of the moving window approach, especially in loosely stocked forests. The crown coverage value is calculated for each tree triple independently and therefore, an interaction with neighbouring triples is not considered. The minimum area criterion is applied by using standard GIS-queries. The areas of all valid polygons are calculated for the potential forest mask fulfilling the height- and crown coverage-criterion. The minimum width criterion is applied by using morphologic operations (open, close) based on the intermediate result fulfilling the criteria height, crown coverage and area. For this operation, a circular kernel with a radius of 5 pixels (pixel size 1×1 m) is used to eliminate narrow forested areas that do not fulfil the criterion. This operation is also related to the area criterion, because the removal of narrow areas leads to changes of the forested areas. Therefore, an iterative process of checking minimum area and width is applied.

2.2 Growing stock / Biomass

A common way to acquire information about forest resources is to perform terrestrial forest inventories. The obtained information is spatially limited and therefore, area wide forest management in terms of harvesting planning is limited. Remote sensing technology i.e. ALS allows an area wide mapping of the forest resource (i.e. growing stock) and provides the forest community with information suitable for area wide planning. Integrating this technology into the wood supply chain can provide an innovative response to the challenges of a precise and robust knowledge on the available growing stocks. A limitation of many ALS based growing stock models is the lacking sensitivity to local forest conditions. This means that growing stock models are often calibrated for large areas, local changes of the forest structure are not considered and the resulting models are smoothing the local situation. Within the project NEWFOR the model of Hollaus et al. [2] was applied to several pilot areas located in different Alpine Space countries in two different ways: (a) A general growing stock model was calibrated and applied for entire pilot areas and (b) growing stock models were calibrated for different strata. For the stratification different information obtained from remote sensing data was used. This information can for example be a tree species classification as presented for example in Waser [3] or Hollaus et al. [4] or a crown coverage map as presented in Eysn et al. [5]. The calibrated models were applied and tested for NEWFOR pilot areas.

For estimating the growing stock / biomass the method described in Hollaus et al. [2] is applied. This method assumes a linear relationship (Eq. 1) between the growing stock / biomass stock and the ALS derived canopy volume, stratified according to four canopy height classes to account for height dependent differences in canopy structure.

$$v_{FI} = 10^4 \cdot \sum_{i=1}^{m} \beta_i \cdot v_{\mathrm{can},i} \qquad \text{(Eq.1)}$$

where v_{FI} represents the growing stock (m³/ha), calculated from the forest inventory data, m is the number of canopy volumes and is set to four and β_i are the unknown model coefficients. Instead of the growing stock the above ground biomass in (t/ha) can be used. The canopy volumes ($v_{\mathrm{can},i}$) are calculated based on Eq. 2.

$$v_{\mathrm{can},i} = p_{\mathrm{fe},i} \cdot ch_{\mathrm{mean},i} \qquad \text{(Eq.2)}$$

where $p_{\mathrm{fe},i}$ represents the relative proportion of nDSM pixels within the corresponding canopy height class to the total number of nDSM pixels within a circular sample plot area with a radius of 12 m and $ch_{\mathrm{mean},i}$ is the mean height of the nDSM pixels within the corresponding canopy height class. The four canopy height classes are defined with the following height limits: ch_1 - 5 m to 15 m, ch_2 - 15 m to 25 m, ch_3 25 m to 35 m, ch_4 - 35 to 50 m.

2.3 Change detection

The high potential of ALS data for forestry applications has been confirmed in many studies during the last decade. The open question is still the application of ALS data for monitoring applications. Due to the ALS data acquisitions costs re-acquisition are rare until now. Consequently there is on the one hand a lack of data and on the other hand a lack of knowledge of using multi-temporal ALS data for forest monitoring tasks.

Therefore, the capabilities of ALS data for operational forest monitoring of growing stock / biomass were analysed in the pilot area Montafon, Austria. In addition to two ALS data sets forest inventory data for both ALS acquisition times are available for this study.

In the first processing step topographic models are calculated and differences between the models originating from inaccuracies in the georeferencing are minimized. As shown in Hollaus et al. [6] errors in the assessed growing stock / biomass change map originating from digital terrain model (DTM) errors due to different terrain point densities can be avoided if one reference DTM is used for both dates. It is assumed that the DTM within the forests don't change during the two ALS acquisitions. Thus the DTM is determined from the ALS data set with the higher point density to derive a DTM with higher accuracy. For the calculation of the DTM the hierarchic robust filtering approach described in Kraus and Pfeifer [7] is applied, which is implemented into the software Scop++ [8].

For the derivation of the digital surface model (DSM) a land cover dependent approach described in Hollaus et al. [9] is applied. This approach uses the strengths of different algorithms for generating the final DSM by using surface roughness information to combine two DSMs, which are calculated based (i) on the highest echo within a raster cell and (ii) on moving least squares interpolation with a plane as functional model (i.e. a tilted regression plane is fitted through the k-nearest neighbours). Finally the two nDSMs (DSM_{2004}, DSM_{2011}.) are calculated by subtracting the DTM from the DSMs. The spatial resolution of all topographic models is 1x1 m².

The differences of the DSMs have shown that especially height differences of stable objects between the two surface models originating from strip differences or errors in the georeferencing have to be minimized using e.g. a least square matching (LSM) in a first step.

For differentiating between exploitation and forest growth the area is classified into areas with an (a) increased (=forest growth) and (b) decreased (=exploitation) surface height. As for each ALS data set small differences in the tree crown representation within the DSMs can occur morphologic operations (i.e. open / close) and a minimum mapping area of 10 m² are applied to the DSM difference map. For each classified area (exploitation, forest growth) the changes for the assessed growing stock is analysed separately. Finally the derived growing stock maps are validated with the corresponding field based forest inventory data.

2.4 Forest road network

An optimal planning of forest harvesting and logging relies on an up to date forest roads network. Ideally this network allows automatic routing for optimizing the transportation routes. Additionally the combination of growing stock / biomass maps and a routable forest roads graph enables efficient planning and optimizing of cable cranes. In contrast to public roads, which are of high interest for the society, forest roads are often not mapped or were mapped with insufficient information for routing. Therefore, the task of updating the forest roads network is fundamental for heading into the direction of an efficient forest management and wood supply chain.

Within the project NEWFOR a semi-automatically method for extracting forest roads from ALS derived terrain models and orthophotos was optimized and applied to different study areas.

ALS data can deliver terrain information below dense canopies, which enables an extraction of forest roads even in dense forested areas. This is an advantage to methods which purely rely on orthophotos. The developed algorithm relies on a weighted graph, automatically extracted from ALS data using watershed methods and slope information of the terrain. Additionally information from orthophotos is used. Based on this graph the forest roads are extracted as follows: A human interpreter defines starting and ending points of road sections. Between these points the shortest, best voted path within the weighted graph is automatically found. Using this method the forest roads network is sequentially extracted by the interpreter in a very efficient way. Based on the extracted geometry additional attributes about the road geometry (e.g. width, gradient, curve radii) are automatically derived and assigned to road sections. The method was applied and tested for NEWFOR pilot areas.

3 RESULTS AND DISCUSSIONS

3.1 Forest area

Within the project NEWFOR the forest area delineation approach was applied to several study areas characterized with different forest structure and growing conditions. The usage of these clearly defined geometrical criterions as defined in the method of Eysn et al. [1] delivers robust, repeatable and comprehensible delineation results. This is significant when the results are used for obligatory reporting or change detection based on multi-temporal data. Especially at loose stocked forests where the forest / non-forest decision is demanding the most the proposed technique for checking crown coverage works reliable (Fig. 1).

The method is fully automatically, can be applied to large areas and fulfils the requirements of an operational application. Different forest definitions can be considered by the method. Therefore, an application to different areas / countries with different restrictions is enabled. Furthermore, the method was easily applied to the local forest definition requirements of the different pilot areas within the NEWFOR project. For the pilot area Immenstadt in Germany the automatically derived forest mask was compared to a manually delineated reference mask. The resulting confusion matrix shows a Kappa of 0.83 and an overall accuracy of 93%.

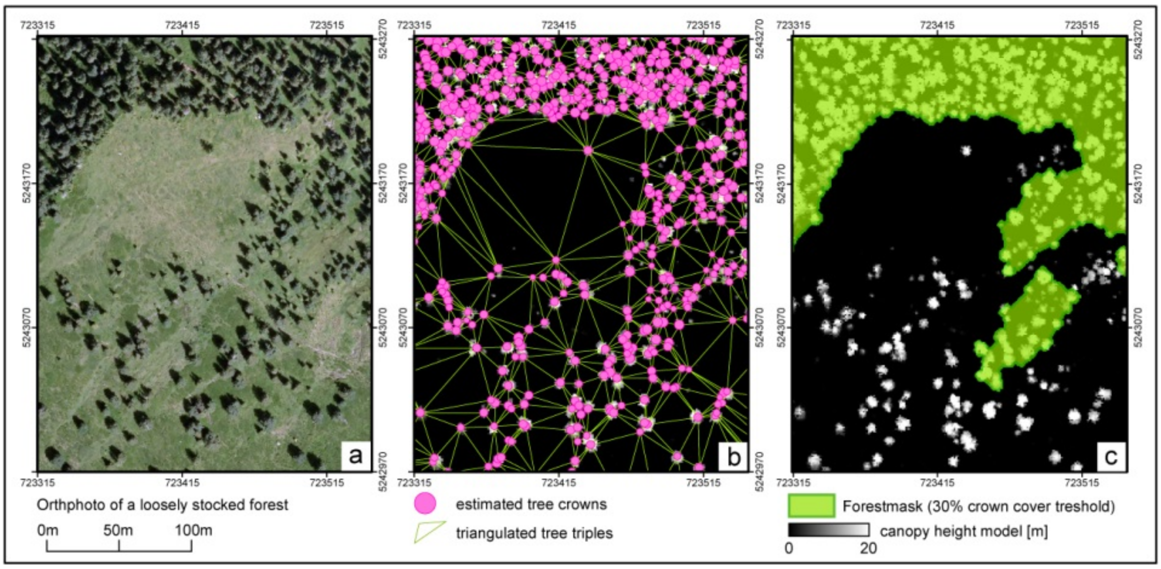

Figure 1: Delineation of forested areas based on ALS data. A) orthophoto of a loosely stocked forest B) Estimated tree crowns and detected tree tripels. C) Delineated forest areas (in the background is a z-coded canopy height model).

3.2 Growing stock / Biomass estimation

For each study area stratification was done. The criterion “species” classified the forest into areas of deciduous, mixed and coniferous forest, whereas the primary species classification can be derived from classification of aerial images as for example described in Waser [3] or from full-waveform ALS data classification [4]. The criterion “crown cover” classified the forest into areas with dense or sparse coverage. In total six different models were calibrated and applied using these criterions. In contrast to a general model without stratification the stratified models increased the accuracy (Fig. 2). This was expected as the general model does not account for local changes in the forests appearance and different strata might be incorrectly represented.

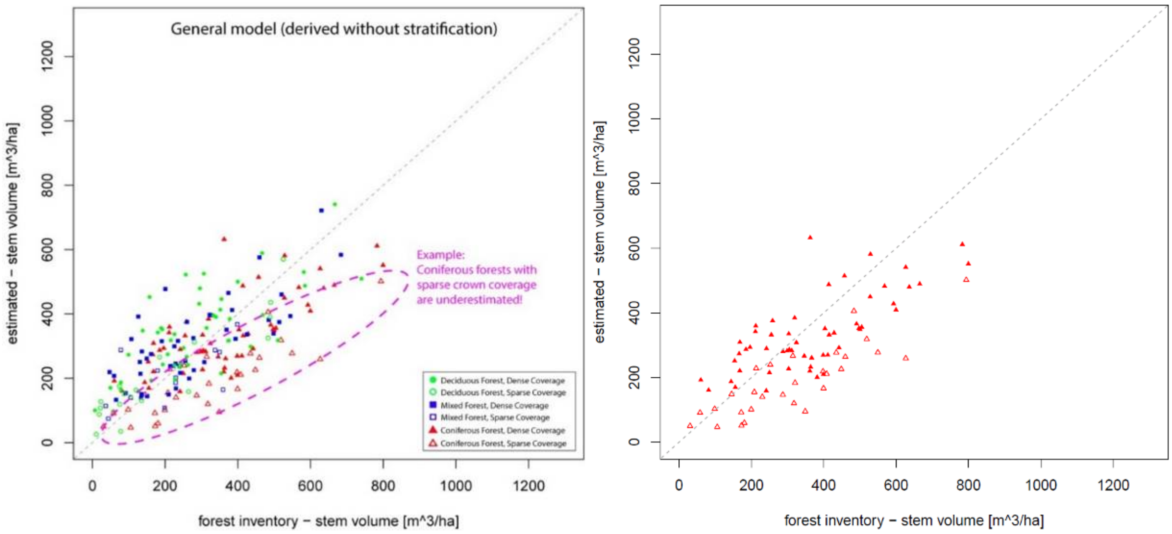

Figure 2: left image: Calibration Scatterplot of a general growing stock model. The data is classified and coloured to six different strata to visualize over- or underestimations for the different strata; Right image: Subplot of the two classes coniferous dense and coniferous loose stocked. The class coniferous loose stocked is clearly underestimated in the non stratified model.

Due to the stratification the relative standard deviation of the residuals between estimates and reference could be enhanced by 4% in average. The results of the tests within the project prove that growing stock maps with very high spatial resolution can be derived from remotely sensed data. These maps allow comprehensive forest management for large areas and serve as input data for various forest planning activities. The level of detail of growing stock maps in operational use is still under discussion. However, the discussions within the project consortium show a first trend for aggregating the resulting growing stock map, because it is too detailed for most applications. The aggregation could be performed by resampling the data to cell sizes of several meters (see Fig. 3) or by aggregating the data to stand levels or to forest management units.

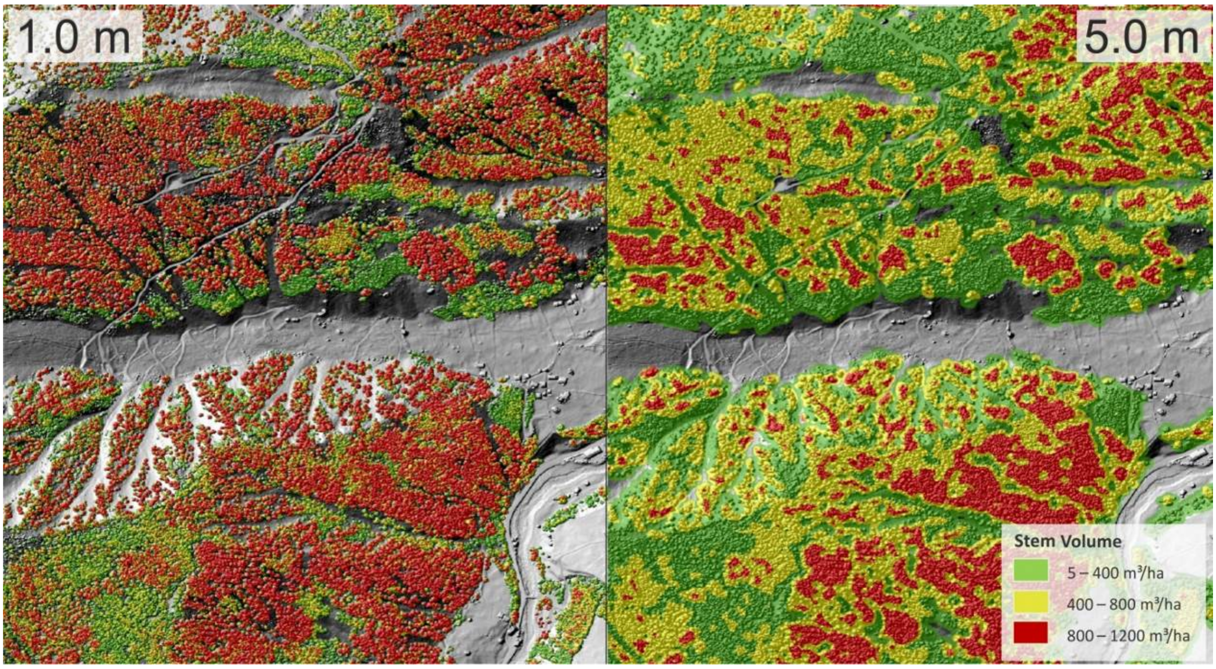

Figure 3: Derived growing stock map for a subset of the pilot area Montafon, (left) 1.0 m and (right) 5.0 m spatial resolution.

3.3 Change detection

The results have shown that that the growing stock changes derived from the estimated growing stock maps are similar to those derived from the forest inventory data. For both models a similar accuracy could be achieved. The relative standard deviation derived from cross validation is rather high for both acquisition times and can mainly be explained by the angle gauge measurement using only one fixed basal area factor of four, which leads to discontinuities in the statistically calculated forest inventory growing stocks on a plot level. A further explanation is the fact that for the first ALS data set the ALS flights took place between 2002 and 2005, whereas the forest inventory data was collected in 2002. This means that changes in the DSM (i.e. forest growth, exploitation), which are available in ALS data acquired in the years 2003 to 2005 are not considered in the forest inventory data. Further details about the derived results can be found in Hollaus et al. [6].

In fig. 4 the difference map of the estimated growing stock stocks (2011-2004) overlaid with the detected exploitation areas is shown. The visual validation shows that the applied work flow for detecting harvested areas work well even on the level of single trees. Using GIS tools the total amount of harvested growing stock can be calculated for example for each exploitation polygon. For the estimation of the forest growth an averaging within homogenous areas (e.g. forest stands) is required to avoid errors originating from different tree crown representations (i.e. due to varying ALS point density, ALS sensors, ALS acquisition properties, wind effects, etc.) on a single tree level. Based on the forest inventory data the growing stock increased from 2002 to 2011 of 43.0 m³/ha in average for the used 184 sample plots. Using the estimated growing stocks derived from the ALS data an average difference of 42.5 m³/ha is observed.

Based on the findings of this study it can be stated that ALS data is an excellent data source for change detection of forest parameters (i.e. forest area and growing stock), which opens up interesting possibilities for operational forest inventories.

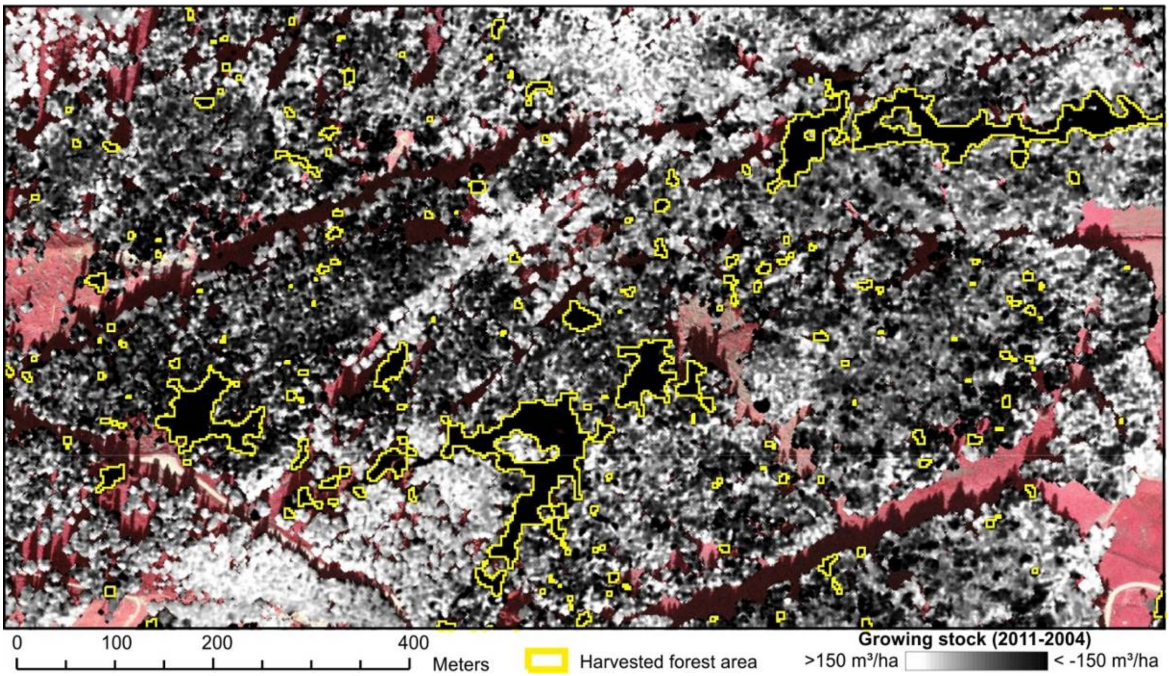

Figure 4: Difference map of estimated growing stocks (2011-2004) overlaid with the detected outlines of the harvested forest areas. In the background a CIR orthophoto is shown.

3.4 Forest roads

The weighted graph methodology enabled fully automatically processing of the input data and was applicable do different datasets as they exist in the NEWFOR consortium. For both, steep as well as flat terrain, sufficient information could be extracted from ALS data and orthophotos. To enable comfortable digitizing of forest roads in a functional Open Source GIS environment, a Quantum GIS Plugin was implemented. Based on the weighted graph and knowledge from a human interpreter a topologically correct forest roads network could be extracted using this Plugin. The sequentially digitization process delivers user controlled results where errors can be corrected immediately during the process. This is a big advantage to fully automatically methods where only little user interaction is given. The semi automatically digitization process was found to be more efficient than a manually extraction as large road segments can be digitized easily. Additional attributes as for example road width, curve radii and gradient of segments were derived for the extracted roads (Fig. 5). This information is important for routing purposes. Attributes can also be extracted from existing datasets (i.e. axis of the road network) originating from other sources as for example Open Street Maps. For the Austrian pilot area a visual inspection of the extracted roads compared to a manually extracted reference layer was performed and showed a good agreement. Especially in dense forested areas the use of ALS data performed well compared to a digitization purely based on orthophotos. Related to a sufficient wood supply chain it could be shown that the updating process of the forest roads network can be performed in an efficient way by using remote sensing data.

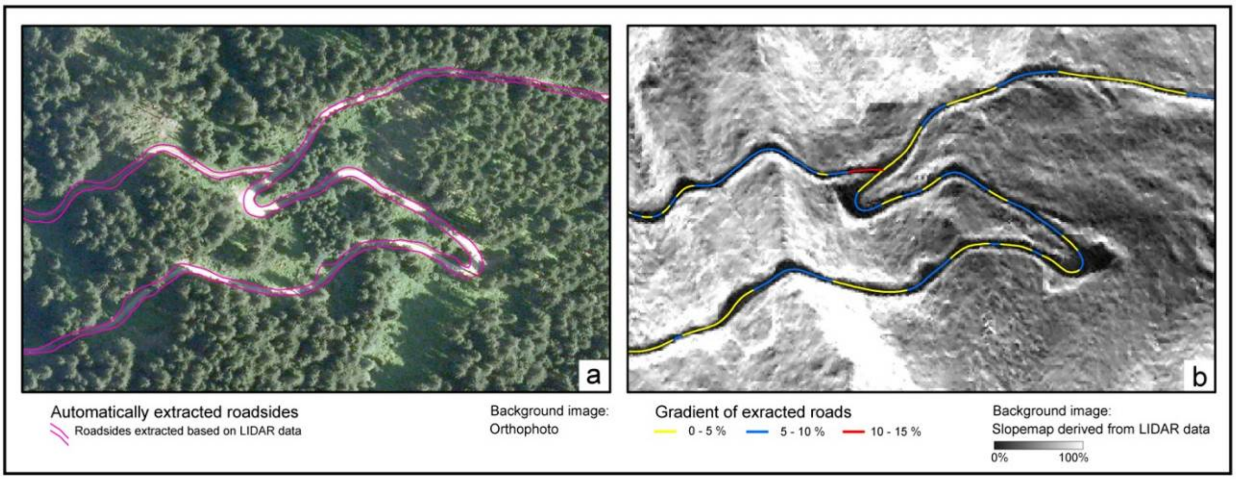

Figure 5: Example for extracted forest roads. A) Automatically delineated roadsides B) Extracted road network. The road segments are colour coded by gradient.

4 CONCLUSION

A fundamental task in forest management is locating and analysing forested areas. The presented approach for delineating forest area produce reliable and reproducible results and can consider different forest definitions. This is significant when the results are used for obligatory reporting or change detection based on multi-temporal data. The presented approaches have shown that remote sensing technology i.e. LiDAR allows an area wide mapping of the forest resource (i.e. growing stock / biomass) and provides the forest community with information suitable for area wide planning. In combination with the derived road network the integration of all these technologies into the wood supply chain can provide an innovative response to the challenges of a precise and robust knowledge on the available growing stocks and their mobilization.

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