International Journal of Applied Earth Observation and Geoinformation 31 (2014) 37–44

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

journal homepage: www.elsevier.com/locate/jag

Accuracy of vegetation height and terrain elevation derived from ICESat/GLAS in forested areas

F. Enßle*, J. Heinzel[1], B. Koch

Remote Sensing and Landscape Information Systems, University of Freiburg, Tennenbacherstraße, 4, D-79106 Freiburg, Germany

ARTICLE INFO

Article history:
Received 22 October 2013
Accepted 21 February 2014
Available online 27 March 2014

Keywords:
ICESat
GLAS
LiDAR
ALS
Canopy height
Elevation

ABSTRACT

This paper focuses on accuracy assessment of canopy top elevation, ground elevation and vegetation height (VH) derived from space borne full-waveform LiDAR (Light Detection And Ranging) data across forested areas. Computed height metrics from LiDAR data which were acquired by the GLAS sensor aboard the ICESat (Ice Cloud and land Elevation Satellite) are compared against airborne laser scanning (ALS) based digital elevation models. Due to the dynamic topography of the sites under investigation, a wide range of slope angles could be investigated. ICESat's raw waveform data (GLA01) and the land surface altimetry data (GLA14) products are used to determine height metrics with different methods. GLA14 based elevation and vegetation heights are computed from range offset information. Values are provided for signal begin, signal end, land range and up to six Gaussian peaks for each received waveform. GLA01 based terrain heights are computed by locally weighted polynomial regression and peak detection on the received waveform itself. A range of different smoothing spans and noise threshold values on the original waveform, which is represented by 544 single values (bins), were tested. A new method based on the unsmoothed waveform was developed for the detection of the signal begin. By detecting the location above the noise threshold, where the signal rises at least for 5 bins (75 cm), achieved more precise results, than the given signal begin in the GLA14 product. For ground peak detection by smoothing of the waveform it was found that noise thresholds of 4 and 4.5 times the standard deviation plus the mean noise level give the best performance. For VH computation in areas of up to 10° terrain slope, a smoothing span of 10 bins achieved $r^2 = 0.58$, whereas the GLA14 based method achieved r^2 of 0.75 in flat terrain (0–5°). For these flat areas, best results in VH computation ($r^2 = 0.91$) were achieved by using the new method for canopy top detection and the GLA14 based ground elevations. Determination of terrain elevations was observed to be best by computation with GLA14 based parameters. The stronger of second last two peaks was found to be closest to the ground level elevation.

1. Introduction

Forest ecosystems are considered as important component in modelling global carbon pools. They conserve and sequester evidential quantities of carbon (Dixon et al., 1994). Forest carbon pools cannot be directly determined by remotely sensed data (Gibbs et al., 2007), but are of high interest within the United Nations' programme 'Reducing Emissions from Deforestation and Forest Degradation in Developing Countries' (REDD). However, forest carbon stocks can be estimated by conversion of above ground biomass (AGB) values to carbon. AGB can be estimated if vegetation height, such as mean canopy height, basal area weighted height metrics or maximum canopy height is available (Lefsky et al., 2005; Boudreau et al., 2008). More precise results can be achieved using forest height metrics together with density and vegetation type (Koch, 2010).

The Geoscience Laser Altimeter Systems (GLAS) aboard the Ice Cloud and Land Elevation Satellite (ICESat) was launched in January 2003. Besides the primary science objective to measure the seasonal changes in ice sheets, the measurement of canopy heights was also included in the list of objectives (Zwally et al., 2002). The GLAS consists of three lasers operating at 1064 nm wavelength for surface and cloud top measurements. Another laser system which operates at 532 nm was designed to measure height distributions of optically thin clouds and aerosol layers (Abshire et al., 2000).

* Corresponding author. Tel.: +49 76120367397; fax: +49 7612033701.
E-mail addresses: fabian.enssle@felis.uni-freiburg.de (F. Enßle), johannes.heinzel@jrc.ec.europa.eu (J. Heinzel), barbara.koch@felis.uni-freiburg.de (B. Koch).
[1] Current address: European Commission – Joint Research Centre, Institute for the Protection and Security of the Citizen, Global Security and Crisis Management, Ispra, Italy.

http://dx.doi.org/10.1016/j.jag.2014.02.009
0303-2434/

The GLAS system measures the distance to earth's surface with one of the three 1064 nm lasers at a time. Laser spot diameter on surface varied in size and shape for each laser campaign. The area on the earth's surface illuminated by the laser spot is elliptical in shape and single footprints are spaced 172 m apart along profiles with an average diameter of approximately 65 m (Schutz et al., 2005). The identifier of a specific laser campaign is composed of the laser number (L1–L3) and a chronologically ordered character (A–K). Laser campaign L1A and L2A had a total land height range of 81.5 m by sampling the waveform in 544 bins with 15 cm of vertical resolution (Harding and Carabajal, 2005). This equals a time interval of one nano second between consecutive bins. To avoid signal truncation for subsequent laser campaigns, the vertical resolution of upper 152 bins was shifted to 60 cm with a total height range of 150 m (Harding and Carabajal, 2005). Failed mechanism in a diode pump array led to the early loss of laser 1 (NASA, 2003). To extend the overall system lifetime the operation was shifted to non-continuous operation (Abshire et al., 2005; Schutz et al., 2005). With 33–56-day campaigns, roughly each four months the GLAS collected full-waveform records with near global coverage.

Several studies have examined the accuracy of GLAS derived height metrics, and have applied different methods to improve height estimates by ICESat data. In particular, the precise definition of the canopy top and the ground return is of major importance to determine accurate vegetation height (VH). Top of the canopy is defined by the signal begin, which is the position in the waveform, where the recorded energy is above a specific threshold. Besides, it is also critical to determine the position of the ground return, as it can be mixed with reflections from vegetation. The first method to derive a corrected maximum canopy height was introduced by Lefsky et al. (2005). They used the waveform extent, which is the difference of signal begin and signal end, together with a terrain index, the later derived from an additional data set. Rosette et al. (2010) found that this method produced a greater ground surface offset compared to standard GLAS data product derived heights. To avoid the use of an additional data set, this method was further improved with a leading and trailing edge method (Lefsky et al., 2007). This approach was also used by Helmer et al. (2009) to estimate biomass accumulation rates in the Amazon basin. Rosette et al. (2008) achieved $r^2 = 0.91$ between forest inventory heights and maximum GLAS derived ones by using the strongest of last two peaks as the ground return. The same observation was made by Chen (2010a). This method was furthermore applied in the studies of Ballhorn et al. (2011) and Hilbert and Schmullius (2012). Other approaches were presented as well, e.g. by Duong et al. (2008) who applied a 15% amplitude ratio of last and second last peak as selection criteria for ground returns. A quality control which is based on mode locations of the first derivative of the received waveform was presented by Neuenschwander et al. (2008) and adapted by Popescu et al. (2011). An approach to calculate separate thresholds for the waveform part before signal begin and after signal end was invented by Sun et al. (2008). Focusing on the improvement of canopy top estimations, an algorithm presented by Hancock et al. (2011) used a noise tracking method at the beginning of received waveform.

Determination of signal begin and signal end are dependent on the threshold level of the background noise within the waveform, and there is no commonly used methodology to determine this threshold. Among the above mentioned studies thresholds of 3.5, 4 and 4.5 times the standard deviation of the noise plus mean noise level have been used. Besides, the methods for data preparation are quite different and several quality flags, which are provided within the standard product by the NSIDC are used. Some of the studies additionally incorporated high resolution DEMs as a quality filter, which reduces the comparability in those study areas where this information is not available.

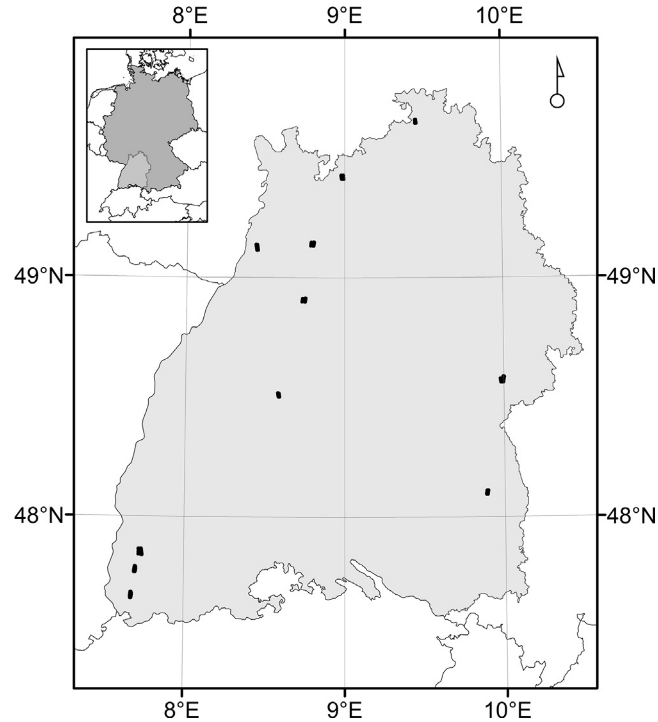

Fig. 1. Distribution of test sites across the federal state of Baden-Württemberg-Germany (black dots).

This study investigates the accuracies of calculated canopy top heights, ground surface heights and VH from GLAS data. The main objective is to test different methods for the calculation of above mentioned height metrics, and to assess their usability in different terrain conditions. The specific questions addressed in this study are: (1) is the assumption that ground elevation derived by the stronger of second last two peaks in GLA14 product is more precise than using last peak location true? (2) Does the choice of the noise threshold significantly affect the localization of the signal begin and can its identification be improved? (3) How accurate is a locally-weighted polynomial regression for smoothing the waveform and can the ground elevation be determined by a local peak detection? (4) Which is the most preferable method for canopy height estimations? (5) Does the data set used in this study support the recommendation of excluding the GLAS shots at steep terrain (slope >10°) for VH, as stated by other researchers?

2. Materials and methods

2.1. Study area

For the investigation of GLAS derived heights in forested areas a reference data set was collected for eleven spatially separated sites as illustrated in Fig. 1. The study sites are distributed across the federal state of Baden-Württemberg (BW), which is located in south-western Germany. In the West of the smooth Upper Rhine valley the slopes of the Black Forest mountain range arise. In the western part the south-western German cuesta forms a series of plains, which are separated by steep slopes. The elevation, which is referenced throughout this study to the GRS80 ellipsoid, ranges from 150 m to 1180 m. Main tree species in BW are Norway spruce (*Picea abies*) and European beech (*Fagus Sylvatica*). The sites contain pure and mixed forest stands with different species and age classes.