PREDICTING TREE HEIGHT AND BIOMASS FROM GLAS DATA

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ABSTRACT:

Our previous studies using airborne lidar data have shown that the tree height indices derived from the GLAS and LVIS waveforms were highly correlated. The quartile waveform energy heights derived from GLAS and LVIS data showed significant correlations too. Because of these correlations and the fact that airborne lidar data has been shown to be an accurate index of forest biomass, we believe that the GLAS data will be useful for biomass sampling in regional to global scales. In this study, field measurements at GLAS footprints were used to further understand the physical meaning of the height indices derived from GLAS data, and to investigate the prediction capability of GLAS data. The near-repeat-pass GLAS data acquired in Fall and early Summer were compared to investigate the data stability, seasonal effects, potential for change monitoring, and provide insight in sampling strategy of the heterogeneous forest structures.

1. INTRODUCTION

The Geoscience Laser Altimeter System (GLAS) instrument aboard the Ice, Cloud, and land Elevation (ICESat) satellite, launched on 12 January 2003. GLAS is the first lidar instrument designed for continuous global observation of the Earth (Zwally et al., 2002). Researchers have started using GLAS data for forest studies (Ranson et al., 2004a, b; Carabajal and Harding, 2005; Lefsky et al., 2005). Measurements derived from lidar waveforms were used to characterize the canopy vertical structure. These measurements include the lowest and highest detectable returns (above a threshold noise level), and the heights within the canopy where 25, 50, 75 and 100% waveform energy were received (Blair et al., 1999). The vertical distribution of plant materials, along with the gap distribution, determines the proportion of energy scattered at a given height. The use of GLAS data for deriving accurate forest parameters for regional studies requires full understanding of their characteristics. The tree height and biomass within GLAS footprints measured in the field were used to test the prediction capability of the GLAS data. The results show some of the potentials and problems of the GLAS data for vegetation structure studies.

2. STUDY AREA AND DATA

2.1. Study site

The study sites include forests around Tahe (52.5^o N, 125^o E) and Changbai Mountain (42.5^o N, 128^o E) areas in Northern China.

More than 80 GLAS footprints were measured in Northern China. After the center of GLAS footprint was located using GPS, four sampling plots with a radius of 7.5 meters (center, 22.5m to north, south-east, and south-west from center, see Fig. 1) were located within the footprint. Diameter at breast height (DBH) and tree height of all trees with DBH > 5cm were measured. Dominant trees within a ~100m circle but not inside these sampling plots were also measured. These measurements were later used to estimate the height of dominant trees and above-ground biomass in the GLAS footprints.

2.2. GLAS data

GLAS carries three lasers. Laser 1 started firing on February 20, 2003 and failed only 37 days later. Anomaly studies revealed systematic problems that reduced the lifetime of the laser system. Consequently, the GLAS mission started to operate with a 91-day repeat orbit (with a 33 day sub-cycle) over selected times of the year to maximize coverage of ice-covered areas. From early October to November 19, 2003, GLAS completed the first 33-day sub-cycle using laser 2 (L2A). Since then, more 33-day sub-cycle data sets have

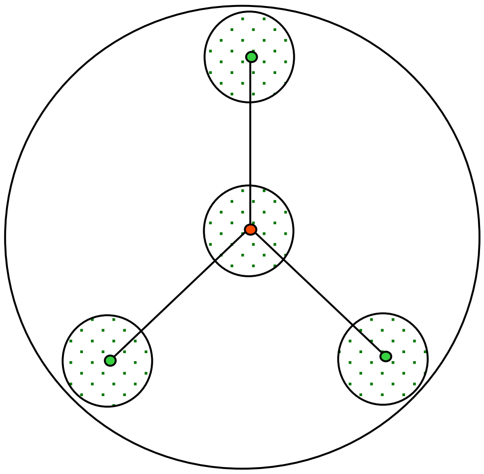

Fig. 1. Sampling plots within a GLAS footprint: Radius of sampling plots (small circle) is 7.5m. The distance between sampling plots is 22.5m.

been acquired in Feb-March, May-June and October-November periods each year. The use of laser 3 was initiated in October, 2004 (L3A), and continued in February-March (L3B), May-June (L3C), October-November (L3D) in 2005, and Feb-March (L3E), May-June (L3F) in 2006. These 33-day sub-cycles are nearly repeat-passes of the October-November 2003 data (L2A), providing a capability for seasonal and inter-annual change monitoring. GLAS data from L2A, L3A, L3C, L3D and L3F were used in this study.

GLAS uses 1064-nm laser pulses and records the returned laser energy from an ellipsoidal footprint. The footprint diameter is about 65m, but its size and ellipticity have varied through the course of the mission (Schutz et al, 2005; Abshire et al., 2005). GLA01 products provide the waveforms for each laser shot, but only an estimated geolocation for all 40 shots acquired within 1 second. For the land surfaces, the waveform has 544 bins with a bin size of 1-nsec or 15cm. The bin size from bin 1 to 151 has been changed to 60cm starting from acquisition L3A, so the total waveform length increased from 81.6m to about 150m. The product GLA14 (Land/Canopy Elevation) doesn't contain the waveform, but various parameters derived from the waveform. The GLAS waveforms were smoothed using filters, and the signal beginning and end were identified by a noise threshold. The smoothed waveform was initially fitted using many Gaussian peaks at different heights, and then the peaks were reduced to six by an iterative process (Zwally et al., 2002; Harding and Carabajal. 2005). GLAS14 data provides the surface elevation and the laser range offsets for the signal beginning and end, the location, amplitude, and width of the six Gaussian peaks. Fig. 2 shows a GLAS waveform from our study area with the Gaussian peaks (Hofton et al., 2000) and other parameters extracted from GLA14 data products. Assuming that the last peak near the ground is from surface reflection, the distance from the signal beginning and this ground peak is the top canopy height (referred to as H14). This works only for flat area, and requires significant energy return from ground surface. For cases with dense canopies, rough surfaces with slopes, the elevation of the ground peak becomes questionable.

3. GLAS DATA PROCESSING

The GLA14 data were first retrieved along with the record index, the serial number of the shot within the index (from 1 to 40), acquisition time, latitude, longitude, elevation, range offsets of signal beginning, signal ending, waveform centroid, and fitted Gaussian peaks. In the GLA01 data file, the 40 shots received in one-second are assigned only one estimated latitude and longitude. Using the record index and shot number found in GLA14 data, the individual waveform was extracted from GLA01 data along with other parameters such as estimated noise level, noise standard deviation, and transmitted pulse waveform, which were used later in waveform processing.

A method for calculating the heights of quartile waveform energy from GLAS waveform was implemented. A Gaussian filter with a width similar to the transmitted laser pulse was used to smooth the waveform. For many cases, the noise level before the signal beginning was lower than the noise after the signal ending. Consequently, we estimated the noise levels before the signal beginning and after the signal ending from the original waveform separately using a method based on the histogram. Using three standard deviations as a threshold above the noise level, the signal beginning and ending were located. The total waveform energy was calculated by summing all the return energy from signal beginning to ending. Starting from the signal ending, the position of the 25%, 50%, and 75% of energy were located by comparing the accumulated energy with total energy. Since the heights of these quartiles refer to the ground surface, not the signal ending, the ground peak in the waveform needs to be located. Searching backward from the signal ending, the peaks can be found by comparing a bin's value with those of the two neighboring bins. If the first peak is too close to the signal ending, i.e. the distance from signal ending to the peak is less than the half width of the transmitted laser pulse, this peak was discarded. The first significant peak found is the ground peak. As terrain slope and surface roughness increase, the ground peak of the waveform becomes wider and the signal beginning moves upwards in a proportional manner. The distance between the signal ending and the assumed signal ending when the surface is flat was used as an adjustment to the signal beginning.

4. PREDICTION OF TREE HEIGHT AND BIOMASS FROM GLAS DATA

The field measurements and the processed GLAS data were used to train a neural network for prediction of tree height and stand biomass. Fig. 2 shows the correlation between field biomass measurements and the biomass predicted by a trained neural network model from GLAS indices. The model used six input variables derived from total length of waveform, top canopy height, 25% and 75% waveform quartiles, with 10 nodes in a hidden layer. Fig. 3. shows the correlation between field maximum tree height measurements and the height predicted by a trained neural network model from GLAS indices. The model used 5 input variables derived from total length of waveform, quadratic mean canopy height, 25% and 50% waveform quartiles, with 3 nodes in a hidden layer.

These neural models then were applied to all GLAS footprints acquired in Fall, 2003. The statistics of tree height and stand biomass within an area of 38° to 50° N, 120° to 130° E were calculated for major forest classes, and disturbed areas. Fig. 4 and 5 show the histograms f tree height and biomass in this region. Table 1 is a list of average tree height and biomass for various forest classes in the region.

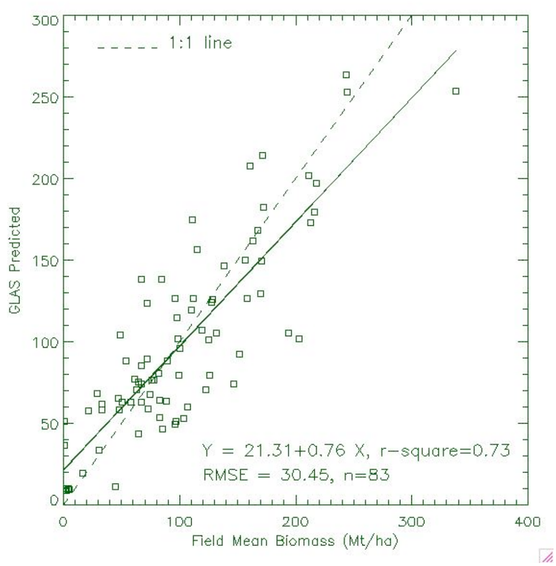

Fig. 2. Prediction of stand biomass from GLAS data.

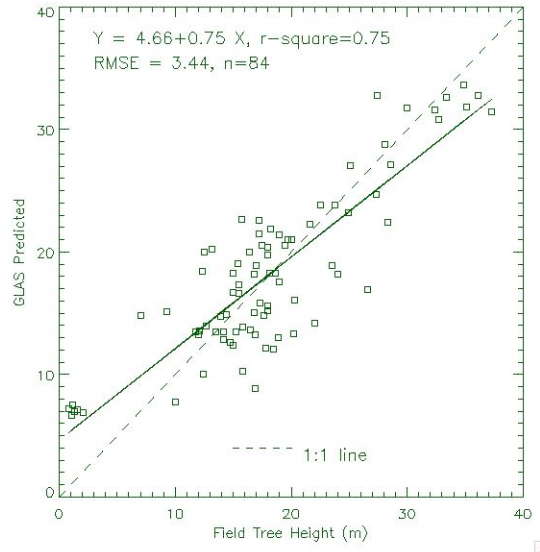

Fig. 3. Prediction of top tree height from GLAS data.

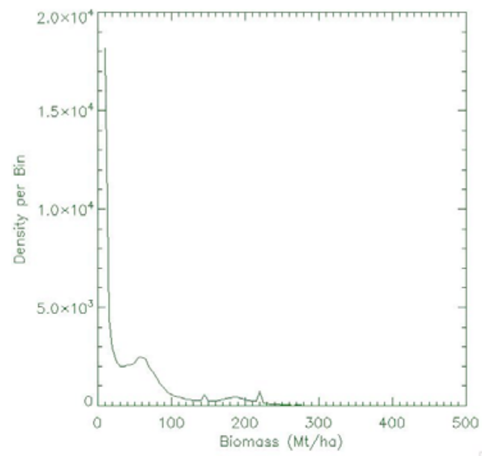

Fig. 4. Histogram of biomass in the region (min. = 6.42, max. = 427.41). Peak at < 20Mt/ha is non-forest area.

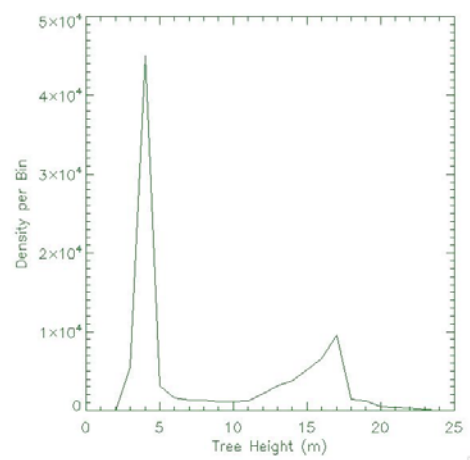

Fig. 5. Histogram of tree height in the region (min. = 2.5m, max. = 24.14m). The peak at ~4m is non-forest area.

Table 1. Average tree height and biomass for different forest types in a region of $38^o – 50^o$ N, $120^o – 130^o$ E, estimated from GLAS data. ENC – Evergreen Needle Conifer, DNC – Deciduous Needle Conifer, DB1-3 – Deciduous Broadleaf, Mix1-3 – Mixed Forests, Bn1-2 – disturbed (burned) forests.

	ENC	DNC	DB1	DB2	DB3	Mix1	Mix2	Mix3	Bn1	Bn2
Height (m)	13.33	13.96	14.12	13.79	12.02	14.53	14.45	14.27	8.85	8.98
Biomass (kg/m^2)	14.93	10.72	10.18	8.67	6.44	13.75	10.96	11.77	3.75	4.17

There were total 174,553 GLAS footprints in this 12^o by 10^o area. 63,906 samples were in forested area (36.6% forest cover). Both the tree height and biomass values are reasonable. In the disturbed area (mainly by fire), tree height is shorter, ad biomass is lower. These results will be compared with data from other resources in future studies.

5. CONCLUSIONS

The Geoscience Laser Altimeter System (GLAS) is the first lidar instrument for continuous global observation of the Earth. Field measurements were mainly conducted at flat areas or with small slopes. The study showed that for these cases GLAS waveform data provides reasonable prediction for the heights of dominant trees and above-ground biomass. The study also shows that GLAS samples provides a reasonable statistics on biomass level, forest coverage but further studies area needed to evaluate the terrain effects, seasonal variation of GLAS samples, etc.

6. ACKNOWLEDGEMENT

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