International Journal of Applied Earth Observation and Geoinformation 38 (2015) 65–71

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

# Estimates of forest structure parameters from GLAS data and multi-angle imaging spectrometer data

Ying Yu*, Xiguang Yang, Wenyi Fan

*Northeast Forestry University, Harbin 150040, China*

ARTICLE INFO

*Article history:*
Received 30 July 2014
Received in revised form
19 December 2014
Accepted 22 December 2014

*Keywords:*
Lidar
GLAS
Tree height
Biomass
MISR

ABSTRACT

Quantitative estimates of forest vertical and spatial distribution using remote sensing technology play an important role in better understanding forest ecosystem function, forest carbon storage and the global carbon cycle. Although most remote sensing systems can provide horizontal distribution of canopies, information concerning the vertical distribution of canopies cannot be detected. Fortunately, laser radars have become available, such as GLAS (Geoscience laser altimeter system). Because laser radar can penetrate foliage, it is superior to other remote sensing technologies for detecting vertical forest structure and has higher accuracy. GLAS waveform data were used in this study to retrieve average tree height and biomass in a GLAS footprint area in Heilongjiang Province. However, GLAS data are not spatially continuous. To fill the gaps, MISR (multi- angle imaging spectrometer) spectral radiance was chosen to predict the regional continuous tree height by developing a multivariate linear regression model. We compared tree height estimated by the regression model and GLAS data. The results confirmed that estimates of tree height and biomass based on GLAS data are considerably more accurate than estimates based on traditional methods. The accuracy is approximately 90%. MISR can be used to estimate tree height in continuous areas with a robust regression model. The $R^2$, precision and root mean square error of the regression model were 0.8, 83% and 1 m, respectively. This study provides an important reference for mapping forest vertical parameters.



## Introduction

Quantitative measurements of forest vertical structure parameters, such as tree height and biomass, are important for research on forest ecosystem function and fluxes of energy and matter across the forest, especially forest carbon storage and the global carbon cycle (Dixon et al., 1994; Perry, 1994). Although, traditional remote sensing technology has been widely applied in the forest, most remote sensing systems only provide horizontal distributions of canopies and cannot provide information on the vertical distribution of canopies. For example, Landsat MODIS can provide typical forest parameters, such as forest type, cover, leaf area index and net primary production (Justice and Townshend, 2002; Lefsky et al., 2005a), but not vertical parameters. Additionally, it is difficult to retrieve forest biomass in high-density forest regions, such as tropical areas, using traditional remote sensing technology (Dubayah et al., 1997).

With the development of lidar (Blair et al., 1994; Blair et al., 1999; Lefsky et al., 1999), radar (Dobson et al., 1996; Imhoff, 1995; Kasischke et al., 1997; Ranson et al., 1994; Smith and Ulander, 2000; Treuhaft et al., 2002; Waring et al., 1995), multi-angle imaging spectrometry, and hyperspectral imaging spectrometry, good solutions to these issues have been obtained. Lidar uses multiple returns to obtain forest three-dimensional information and estimate forest vertical parameters. Researchers have successfully utilized this technology to estimate forest vertical structure information. The scanning lidar imager of canopies by Echo recovery (SLICER), which is a large-footprint airborne lidar instrument, and the laser vegetation imaging sensor (LVIS) have been used to successfully estimate tree heights, stand volume and aboveground forest biomass (Dubayah and Drake, 2000; Harding et al., 2001; Means et al., 1999; Weishampel et al., 2000). Using VCL (vegetation canopy lidar) and LVIS data, Jason B retrieved forest stand quadratic mean stem diameter, basal area, and aboveground biomass in tropical area and found that the precision was very high (Drake et al., 2002). Next, researchers began to use GLAS data for forest studies (Carabajal and Harding, 2005; Ranson et al., 2004a,b). The study by Lefsky estimated maximum forest height, which combined GLAS data and a shuttle radar topography mission (SRTM) DEM (Lefsky

* Corresponding author. Tel.: +86 18204618971.
*E-mail address:* yuying4458@163.com (Y. Yu).

http://dx.doi.org/10.1016/j.jag.2014.12.013
0303-2434/

et al., 2005b). The start peak, 44 percent of the energy and the highest energy parameters from the GLAS waveform metrics were used in Duncanson's work to estimate canopy height (Duncanson et al., 2010). However, the constant in the model was not statistically significant. Hayashi (Hayashi et al., 2013) found that the accuracy of forest canopy height retrieval by GLAS data was poorest in steeply sloped areas and developed a new model to estimate canopy height dependent on surface slope. Furthermore, GLAS data are also superior in highly inaccessible and high-density forest areas. Ballhorn (Ballhorn et al., 2011) used GLAS data to measure the topography of the peat soil and forest aboveground biomass. GLAS height metrics were chosen as predictors in a stepwise regression model for estimating aboveground biomass. The corrected coefficient of determination was 0.54, and the standard error of the estimate was 9.76 ton 0.13 $ha^{-1}$. However, these results can only be provided for spatially discontinuous height or biomass data. Continuous maps of forest vertical structure are needed to study the carbon cycle, water, and climate models (Cuevas, 2003; Dai et al., 2003; Engel et al., 2002; Hudak et al., 2002; Landsberg and Waring, 1997); therefore, Kimes examined the potential of using a multi-angle spectral sensor to determine forest vertical structure (Kimes et al., 2006). MISR data have been used to indicate the usefulness of off-nadir data for surface heterogeneity and vegetation structure studies (Gobron et al., 2002; Pinty et al., 2002). In the study by Sun (Sun et al., 2008), tree height from GLAS and the average tree height from LVIS within the GLAS footprint were highly correlated. The study also demonstrated the ability of multi-angle imaging spectrometer data to predict tree height information (Diner et al., 1998).

This paper has the following objectives: (1) establish a model to retrieve tree height in the Heilongjiang Province, China by processing and analyzing GLAS waveform data; (2) establish the relationship between GLAS waveforms and half energy height (HOME) to determine aboveground biomass; (3) develop a multivariate linear regression model to predict tree height by 36 MISR (multi-angle imaging spectrometer) multi-angle spectral radiance values; (4) compare the tree height derived from MISR and GLAS data.

## Data and methods

### Study area

The study area is Heilongjiang Province, 43°26'N to 53°33'N latitude and 121°11'E to 135°05'E longitude, in northeast China (Fig. 1, left). Its topographic form is high in the northwest and southeast. The total forestry management area of the entire province is 31,260,000 ha and occupies 68.9% of the land area in the entire province. Forest area, forest total volume and timber yield in this area are the highest in China. Heilongjiang Province is one of the nation's largest forestry provinces, and the status of its forest ecology is extremely important. Natural forests are the main forest resources of Heilongjiang Province and are mainly distributed in the Daxing'an mountain range, Xiaoxing'an mountain range and on Changbai mountain. Several typical forest farms in the Daxing'an mountain range, Xiaoxing'an mountain range and on Changbai mountain were chosen for this study.

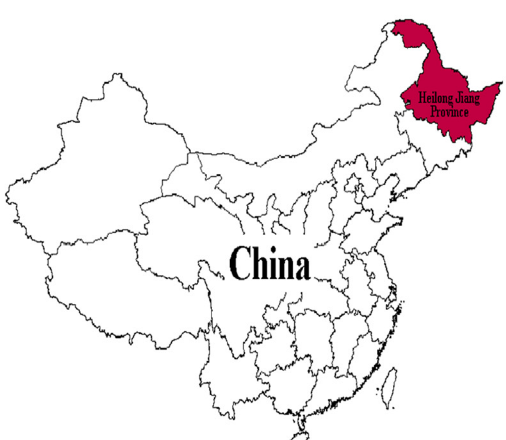
### Field measurements

Forest resources investigation data were collected from forestry bureaus, forest survey and design institutes of Heilongjiang Province, and from plotted data for this region. In August 2007, representative plots were established, and data were tallied in typical forest regions according to forest type and age. Furthermore, based on the ICEsat GLAS footprints, 18 plots with radii of 30 m and crown densities of approximately 0.8 were measured; measurements included breast diameter, tree height and aboveground biomass. The main tree species on the plots are *Pinus koraiensis, Pinus sylvestris, Larix gmelinii, Quercus mongolica, Tilia amurensis, Betula platyphyll*a and *Populus davidiana.*

### GLAS data

GLAS (geoscience laser altimeter system) was the first lidar instrument aboard the ICEsat (ice cloud and land elevation) USA science experimental satellite, which was launched on 12 January, 2003 (Harding and Carabajal, 2005) for the purpose of observing changes of the global atmosphere, ocean, land and biosphere. The satellite's orbital height is 590 km, the obliquity is 94 degrees and the period is 183 days. GLAS records returned laser energy from an ellipsoidal footprint. The footprint diameter is approximately 70 m with a 170 m interval, but its size has varied through the course of the mission (Abshire et al., 2005; Schutz et al., 2005).

The GLAS data products in order of high to low quality are the satellite data records (1A), including GLA01-GLA04, primary data production (1B), including GLA05-GLA07, and data production for applications (2), including GLA08-GLA15. For this study, GLA01 waveform data, GLA05 elevation data based on waveforms, GLA06 elevation data and GLA14 land/vegetation elevation data were used because of the application to land areas. Laser 3I GLAS data for Heilongjiang Province, China from October 2007 were used for this study (Fig. 1, right).



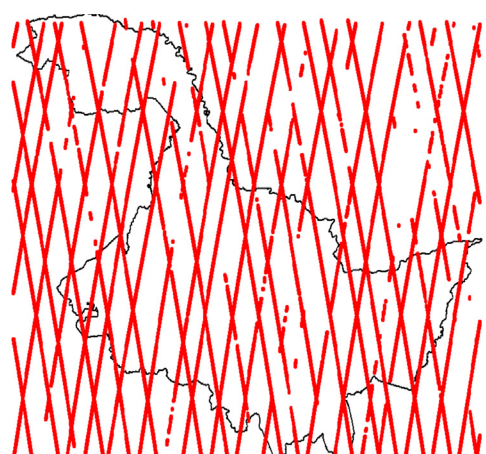



**Fig. 1.** Administrative boundaries of China (left); GLAS data distribution in Heilongjiang Province (right).