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# LOREY'S HEIGHT REGRESSION FOR ICESAT-GLAS WAVEFORMS IN HYRCANIAN DECIDUOUS FORESTS OF IRAN

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## ABSTRACT

Since Lidar technology provides the most direct measurements of 3D of phenomena, it plays a critical role in a variety of applications. Forest canopy height as a main factor in forest biomass estimation is costly and time consuming to be measured on the ground. This study aims to estimate Lorey's height " $H_{\text{lorey}}$ " using GLAS data based on regression models. Different metrics like waveform extent " $W_{\text{ext}}$ ", trail-edge extent " $H_{\text{trail}}$ " and lead-edge extent " $H_{\text{lead}}$ " were extracted from waveforms and a terrain index " $TI$ " was also calculated using a digital elevation model.  $H_{\text{lorey}}$  estimated using multiple regression models were compared to field measurements data. A 5-fold cross validation method was used to validate the results. Best model with lowest AIC (297.440) was resulted using combination of  $W_{\text{ext}}$  and  $TI$  ( $R_a^2=0.72$ ;  $RMSE=5.04\text{m}$ ). The results show capability of ICESat-GLAS to estimate Lorey's height in sloped area with a simple regression model. It is prospected to reach better result using other statistical methods and also improvement of processing techniques for LiDAR waveforms in the case of sloped terrain.

**Index Terms**— ICESat-GLAS, Lorey's height, Waveform extent, Terrain index, Regression model.

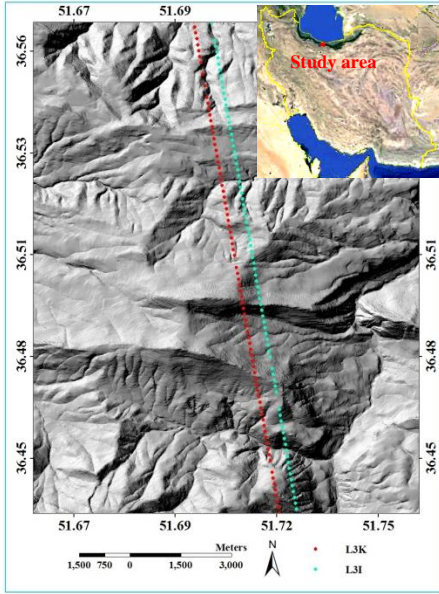
## 1. INTRODUCTION

Forest height is one of fundamental quantitative parameters in forest biometry. The information about vertical structure of forest is essential for ecosystem health assessment and biodiversity conservation [1]. On the other hand, carbon cycle modeling and

monitoring need to forest biophysical information like height [5]. Improvement in altimetry technology, airborne and consequently spaceborne Lidar, led to collect direct measurements of 3D information over whole countries. Geoscience Laser Altimeter System (GLAS) on board ICESat provides (used because it is down now) vertical profile of laser-illuminated surfaces, so-called waveform [3]. Based on references, vertical difference between the waveform signal start, which assumes to be the canopy top, and the ground peak is defined as canopy height over flat area. But vertical extent of each waveform increases as a function of terrain slope [6, 11]. Researchers have used GLAS data for estimating different biophysical parameters of forest such as forest height [6, 10, 13], forest volume [12] and biomass [2, 11] in various ecological and structural conditions, mostly over flat or low sloped area. This research aims to investigate how accurate would be GLAS estimation of Lorey's height over sloped area using regression models.

## 2. STUDY AREA AND DATASET

Nowshahr forests in north of Iran between 36.15 to 36.40 degrees North latitudes and 51.18 to 51.56 degrees East longitudes was selected as study area. This area containing broadleaved deciduous species is located mostly over sloped terrain (Figure 1). NASA Distributed Active Archive Center (NSIDC) distributes 15 Level-1 and Level-2 data products from GLAS. Two GLAS products (GLA01 and GLA14) related to October 2007 and 2008 were analyzed to estimate forest Lorey's height.



**Figure 1-** Location of study area in Iran (up right image), and L3K and L3I footprints over a hillshade.

### 3. FIELD MEASUREMENT

60 GLAS footprints were located on the ground using GPS. Diameter at breast height of all trees greater than 7.5 cm and height of 10 trees were measured within each 70 m diameter circle plot. DBH-height relationships were developed for 6 groups of species to compute height for all trees. Lorey's height, the basal area weighted height, was calculated in each plot:

$$H_L = \frac{\sum_{i=1}^n BA_i \times H_i}{\sum_{i=1}^n BA_i} = \frac{\sum_{i=1}^n DBH_i^2 \times H_i}{\sum_{i=1}^n DBH_i^2} \quad (1)$$

Where,  $H_L$ ,  $BA_i$ ,  $DBH_i$  and  $H_i$  are Lorey's height (m), basal area ( $cm^2$ ), diameter at breast height (cm) and height (m) of each tree (i), respectively, and n is total number of trees in each plot.

### 4. METHODOLOGY

#### 4.1. GLAS data processing

Different filters were performed to remove undesirable waveforms include cloud contaminated, saturated and noisy waveforms [2,6,7,9]. Required information and metrics were extracted from remained waveforms based on metadata of GLA01 and GLA14 products. Waveform extent ( $W_{ext}$ ) defined as vertical distance between ground return peak and signal start [10], trail-edge extent height ( $H_{trail}$ ) and lead-edge extent height ( $H_{lead}$ ) were derived from waveforms according

to [2,9]. To take into account ground topography effects on height estimation, Terrain Index (TI) was derived from a digital elevation model (DEM) of 10 meter resolution [6,10,12].

#### 4.2. Estimation of Lorey's height using regression models

The objective was to find the accuracy of ICESat-GLAS estimated Lorey's height with regression models over sloped area. The waveform extent increases as a function of slope and the footprint size, and returns from both canopy and ground surfaces can be mixed [8,10]. Hence it is necessary to decrease slope impact on waveform. Researchers tried to reduce the impact of terrain slope through adding complimentary information from a DEM [6,10] or based on information extracted directly from waveforms [11]. In this study multiple regression models were developed using variables including  $W_{ext}$ , TI,  $H_{trail}$  and  $H_{lead}$ . Different statistics including mean difference (MD.cv), adjusted R-square ( $R_a^2$ .cv), root mean square error (RMSE.cv), and Akaike information criterion (AIC.cv) were computed between the Lorey's height predicted from GLAS data and in-situ measured heights after 5-fold cross validation.

### 5. RESULT

The Performance of regression functions have been presented in table 1. To find best model, the difference between each model's AIC and minimum value of AICs ( $\Delta = AIC_{cv} - AIC_{cv_{min}}$ ) was calculated. The model with  $\Delta=0$  is the best model, and models with  $\Delta \leq 2$  have substantial support, those with  $4 \leq \Delta \leq 7$  have considerably less support and models with  $\Delta > 10$  have essentially no support to be the best model [4]. Model 4, as the best model ( $\Delta=0$ ) produced highest  $R_a^2$  and lowest RMSE equal to 0.72 and 5.04m, respectively. Figure 2 represents the comparison between estimated height and in situ lorey's height. As it is seen in the table 2, models with TI produced better result among all models.

Table 1- Performance of regression models

#	Model	RMSE.cv	R <sup>2</sup> <sub>a,cv</sub>	MD.cv	AIC.cv	Δ
1	$H_E = 0.8002W_{ext} - 0.3579TI + 1.539$	5.39	0.68	0.044	299.256	4.458
2	$H_E = 0.759W_{ext} - 0.368TI + 0.119H_{lead} + 2.096$	5.64	0.65	-0.024	300.852	6.054
3	$H_E = 0.830W_{ext} - 0.349TI$	5.27	0.70	-0.183	297.440	2.642
4	$H_E = 29.119\ln(W_{ext}) - 0.365TI - 72.620$	5.04	0.72	0.013	294.798	0.000
5	$H_E = 0.7767W_{ext} - 0.2577(H_{lead} + H_{trail})$	6.74	0.50	0.158	324.455	29.657
6	$H_E = 0.923W_{ext} - 0.256H_{lead} - 0.252H_{trail} - 6.562$	6.89	0.47	0.056	326.213	31.415
7	$H_E = 0.8538W_{ext} - 0.338TI - 0.1325H_{trail}$	5.41	0.68	-0.140	298.026	3.228
8	$H_E = 0.7037W_{ext} - 0.251H_{trail}$	7.00	0.46	0.174	325.164	30.366
9	$H_E = 0.8334W_{ext} - 0.2285H_{trail} - 5.9536$	7.03	0.46	0.075	325.370	30.572
10	$H_E = 0.792W_{ext} - 0.356TI + 0.078H_{lead} - 0.126H_{trail} + 2.133$	5.69	0.63	0.015	301.601	6.803
11	$H_E = 0.8397W_{ext} - 0.342TI + 0.052H_{lead} - 0.126H_{trail}$	5.59	0.65	-0.138	299.945	5.147
12	$H_E = 0.687W_{ext} - 0.139H_{lead}$	6.92	0.48	0.281	327.653	32.855

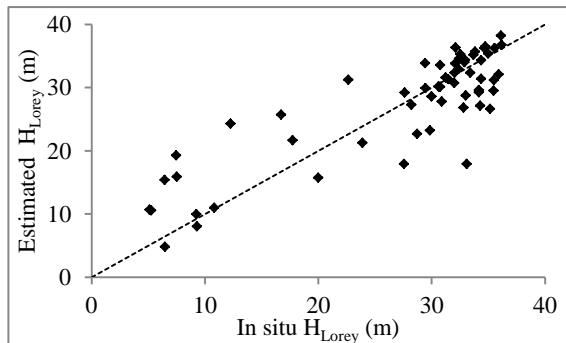


Figure 2- Estimated Lorey's height versus In situ Lorey's height using model 4

## 6. CONCLUSIONS

This study has proven the usage of regression models to estimate forest Lorey's height using ICESat-GLAS data. It became possible to predict the Lorey's height using a logarithmic regression of  $W_{ext}$  and TI variables with an accuracy of 5 m. This result is desirable especially in estimation of forest height in regional and national scales. Better performance of models including TI emphasizes the importance of terrain index in height estimation over steep area. It could be reasonable because the TI has been extracted from fine resolution DEM produced using 1:25000 topographic maps which provides good information about terrain variability. The result of [6] in sites with average slope of 20%, confirms this idea too. As trail and lead-edge extents rely on accurate recognition of ground and canopy top peaks, and this would be more challenging over sloped area [11], regression models based on these metrics have not produced good results.

The time interval of 5 years between GLAS data and field measurements, and also the possible error of

locating footprints on the ground could be two sources of error in height estimation. Better results are expected by overcoming these errors. Furthermore, more investigation is needed to find out representative metrics of slope which are more reliable to extract from waveform or other ancillary data.

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