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Part 3: Accuracy of EAARL Lidar Ground Elevations using a Bare-Earth Algorithm in Marsh and Beach Grasses on the Chandeleur Islands, Louisiana

by Kara Doran, Asbury Sallenger, B.J., Reynolds, and C. Wayne Wright

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
Length		
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
kilometer (km)	0.5400	mile, nautical (nmi)
meter (m)	1.094	yard (yd)

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83)
Elevation, as used in this report, refers to distance above the vertical datum.

Accuracy of EAARL Lidar Ground Elevations Using a Bare-Earth Algorithm in Marsh and Beach Grasses on the Chandeleur Islands, Louisiana

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Introduction

The NASA Experimental Advanced Airborne Lidar (EAARL) is an airborne lidar instrument designed to map coastal topography and bathymetry. The EAARL system has the capability to capture each laser pulse return over a large signal range and can digitize the full waveform of the backscattered energy. Because of this ability to capture the full waveform, the EAARL system can map coral reefs, beaches, coastal vegetation, and trees where extreme variations in the laser backscatter are caused by different physical and optical characteristics present in the coastal zone. Post-processing of the EAARL data is accomplished using the Airborne Lidar Processing System (ALPS) (Nayegandhi et. al, in press). In ALPS, the waveform of the lidar is analyzed and split into first and last returns. The first returns are often indicative of vegetation canopy height, while last returns can be filtered to give bare-Earth elevations under vegetation.

In order to test the accuracy of the bare-Earth and first return EAARL data, topographic and vegetation surveys were conducted in the Chandeleur Islands concurrent with an EAARL lidar survey and an aerial oblique photo survey from September 20 to 27, 2006. The Chandeleur Islands, shown in Figure 1, are a north-south oriented chain of low-lying islands located approximately 100 kilometers east of the city of New Orleans, Louisiana. The islands are narrow North-South strips with marsh on the landward or west sides and sandy beaches on their Gulfward or east sides. Prior to Hurricane Katrina prominent sand dunes were present in the Northern Chandeleurs, but the storm removed them and post-storm elevations are generally less than 2 m above 0.0 NAVD88.

This report is part of a study of the impact of Hurricane Katrina on the Chandeleur Islands using pre-storm and post-storm lidar surveys to detect morphological changes. The islands lost over 80% of their land area during Hurricane Katrina and in the first two years following Katrina many of the islands experienced continued shoreline retreat. In addition to land area losses, the loss of the dunes made the islands increasingly vulnerable to future storm impacts. The USGS, along with our partners in the Louisiana Department of Natural Resources and the Army Corps of Engineers, continues to monitor changes in shoreline position, land area and elevation to detect magnitudes of recovery of the Chandeleur Islands.

Methods

An EAARL survey over the Chandeleur Islands was conducted on September 20 and 21, 2006 as part of the continued monitoring of the area. Typical EAARL flights survey a swath width of 240 m and provide one laser pulse every 2 to 4 m^2 (Nayegandhi et al, 2006). The area was covered by multiple overlapping passes to ensure complete coverage of the islands. The lidar survey acquired full waveforms which were then processed in ALPS for both first return and bare-Earth data. The lidar first and last returns are the first and last backscatter to return to the sensor from the laser pulse. First returns can be used to estimate canopy height in vegetated areas or rooftop height in developed areas while last returns can be used to estimate the elevation of the bare-Earth elevation under vegetation.

In order to retain only last returns that indicate the ground elevation under vegetation, the data are filtered in ALPS. For bare-Earth processing, the last return data are filtered using an Iterative Random Consensus Filter (IRCF) in ALPS (Nayegandhi et al, in press). A grid of non-overlapping square cells is overlaid on the original point cloud. An iterative process finds the largest number of points within a user-defined vertical tolerance to form an estimate of the ground elevation in each cell. The points within the vertical tolerance are selected as ground points. The ground points are then triangulated using Delaunay's Triangulation (Shewchuck, 1996) to create a triangulated irregular network (TIN) model. Points that were rejected by the IRCF can now be examined again to see if they may be included in the bare-Earth data. Each triangulated facet in the TIN model is defined as a three-dimensional plane, which allows for consideration of steeply sloping ground. Any points that fall within the user-defined vertical range of the TIN are added as ground points. After a prescribed number of iterations, the points that are incorporated into the TIN are output as the bare-Earth data.

A local topographic ground-based survey was conducted on September 24 and 25, 2006 for a small section of one of the northern Chandeleur Islands. During the survey a local ground control point network was established using GPS. Topographic mapping was conducted using a Spectra Precision Geodimeter 640 Total Station surveying instrument. The data were surveyed into the North American (Horizontal) Datum of 1983 and the North American Vertical Datum of 1988 using the GEOID96 model reference frame, which was also used to process the lidar data. (There are more recent geoid models available but using the Geoid96 model for both data sets introduces no error when the data are directly compared for differences.) The main species of vegetation at the survey point were identified and vegetation heights were measured directly with a meter stick. At some survey points photos were taken of the vegetation to assist in comparison of lidar and ground survey points.

Results

As described in the above section, first return data can be used to estimate vegetation height while bare-Earth data can be used to estimate the ground elevation under vegetation. A comparison of EAARL first return and bare-Earth elevations from the surveyed area can be seen in Figure 2. Since first return and bare-Earth points do not have the same exact location, each bare-Earth data point in the survey area was paired with the nearest first return data point within a 1 meter radius. The data are highly correlated (ρ=0.65), but bare-Earth elevations are biased low when compared to first return (ME =-0.16 m) as expected. The points where there is the greatest difference between first return and bare-Earth are most likely returns from the top of tall vegetation.

To compare the ground survey and lidar elevations, we form an average of all lidar points falling within a 2-meter radius of the ground survey point. An average value is computed for both bare-Earth and first return data, respectively. The bare-Earth average elevations are then compared with the ground survey elevations, while the first-return average elevations are compared with the ground survey elevations plus the measured vegetation height. For the comparisons, we assume that the ground survey points and measured vegetation heights have no vertical errors, even though the method of measuring vegetation height with a meter stick certainly introduces human error.

For each comparison, correlation (ρ), mean error (ME), and root mean square error (RMSE) are computed. The mean error indicates any bias in the lidar elevations, while the RMS error indicates the size of a typical deviation from the ground-based elevations. The results of the comparison for bare-Earth can be seen in Figure 3. The bare-Earth average lidar and ground elevations have a correlation coefficient of 0.76, revealing a high degree of linearity. The points are scattered about the 1 to 1 line, and the mean error is -0.08 m, indicating that there is no detectable bias between the bare-Earth lidar elevations and the ground survey. The RMS error for the comparison is 14 cm, well within the expected instrumental random error of 10 to 20 cm (Nayegandhi et al, in press).

The results for the comparison of first-return lidar elevations and ground elevation plus vegetation height are shown in Figure 4. The degree of correlation is higher, but the lidar first returns are lower than the ground plus vegetation height. The mean error is -0.37 m, indicating a possible bias. The RMS error is 47 cm, much larger than the expected random error. These large errors are typical of lidar first returns in short, sparse vegetation. In forested areas the first return reflects off of the tree canopy, but in areas like the Chandeleur Islands where the vegetation is low and sparse, the first return is a mixture of returns from the top of the vegetation and the ground.

In order to test EAARL's ability to accurately estimate vegetation heights and elevation under various types of vegetation we divided the surveyed area into four main types of vegetation: short grasses (a mixture of *Spartina Alterniflora, Distichlus,* and *Salicornia*), black mangroves (*Aricennia Germinans*), patches of *Spartina Patens* grass, and *Phragmites Australis* reed, shown in Figure 5. Then the bare-Earth average elevations under each type of vegetation were compared to the ground survey points, and the average first return elevations were compared to the height of each vegetation type plus the ground survey elevation.

The results of this analysis are shown in Figures 6 and 7. In Figure 6, average bare-Earth elevations are plotted in green with the ground surveyed elevations in blue for each of the four main vegetation types. The mean and RMS errors for each comparison are listed in each panel. The small RMS and mean errors for bare-Earth indicate the capability of the EAARL sensor combined with the ALPS bare-Earth filtering to get an accurate measurement of the ground under various types of marsh and beach vegetation. The mean and RMS errors for the first return comparison (Figure 7) are larger than the typical instrumental error. As expected, the RMS and mean errors increase with vegetation height; since the lidar returns will are a mix of reflections from the canopy top, ground, and everything in between.

Conclusions

After comparison of the EAARL first return and bare-Earth lidar elevations with a ground-based survey, we find that the EAARL sensor combined with the ALPS bare-Earth filtering successfully estimated the elevation of the ground under various types of marsh and beach vegetation. For beach and marsh vegetation such as in the Chandeleurs, the EAARL first-return elevations are not indicative of vegetation height, but rather a mixture of returns from vegetation and land. A study is planned to evaluate 2001 pre-Hurricane Katrina Airborne Topographic Mapper (ATM3) lidar data with ground surveys from the Louisiana Department of Natural Resources. We will repeat a similar analysis for the ATM3 lidar in expectation that the results will help us to better compare the pre-storm and post-storm island elevations.

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Nayegandhi, A., Brock, J.C., and Wright, C.W., in press, Small footprint, waveform-resolving lidar estimation of submerged and sub-canopy topography in coastal environments: submitted to the International Journal of Remote Sensing.

Shewchuck, J.R., 1996, Triangle: Engineering a 2D quality mesh generator and Delaunay triangulator *in* Lin, M.C. and Manocha, D. eds., Applied Computation Geometry: Towards Geometric Engineering, v. 1148 of Lecture Notes in Computer Science, Berlin, Springer-Verlag, p. 203-222.

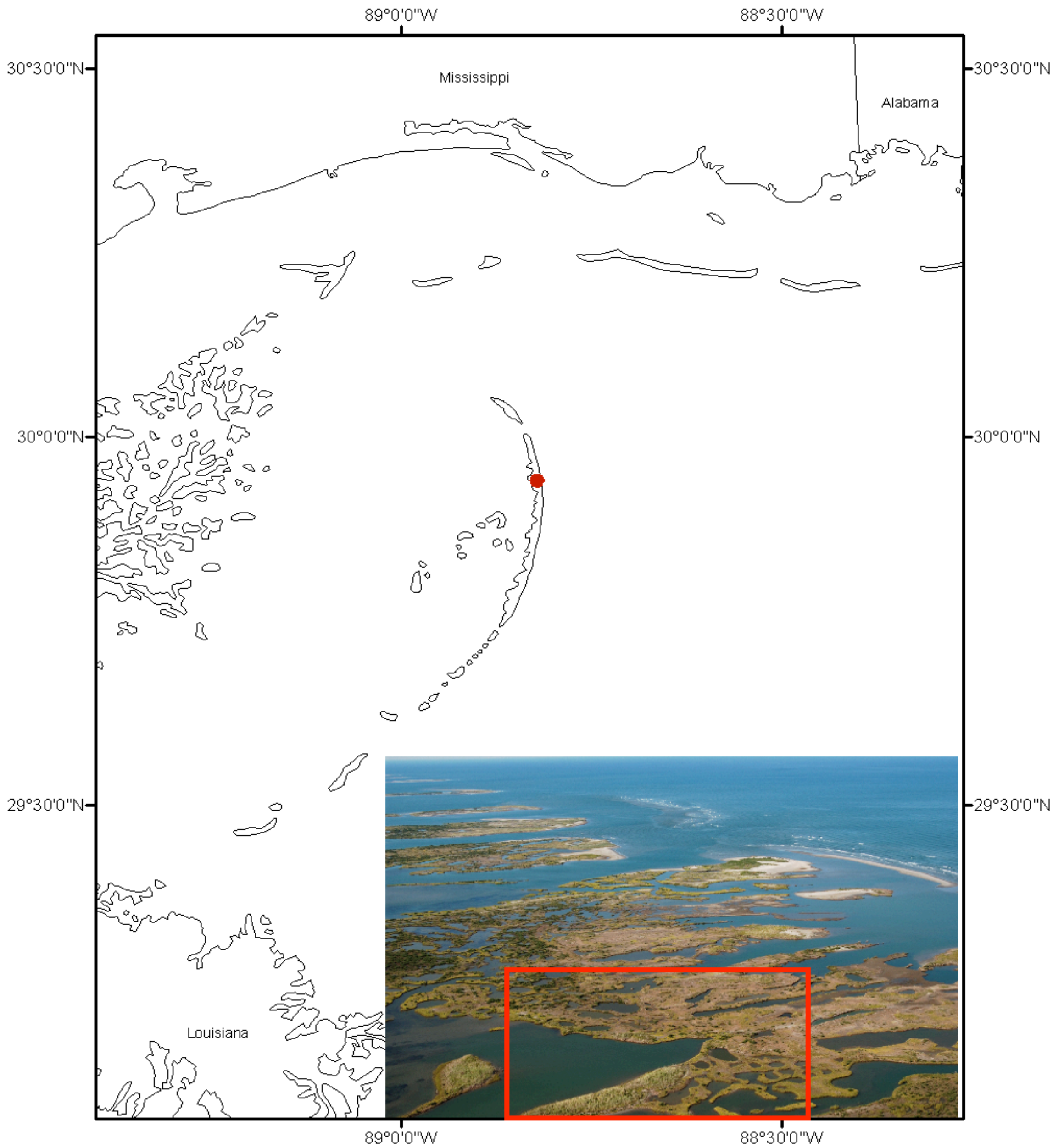

Figure 1. Map of the Chandeleur Islands showing the survey location (red dot). The photo in the bottom right corner is a blow up of the general location at the red dot taken on September 26, 2006 during an oblique aerial photography survey. The approximate extent of the local topographic survey is outlined by the red box on the photograph.

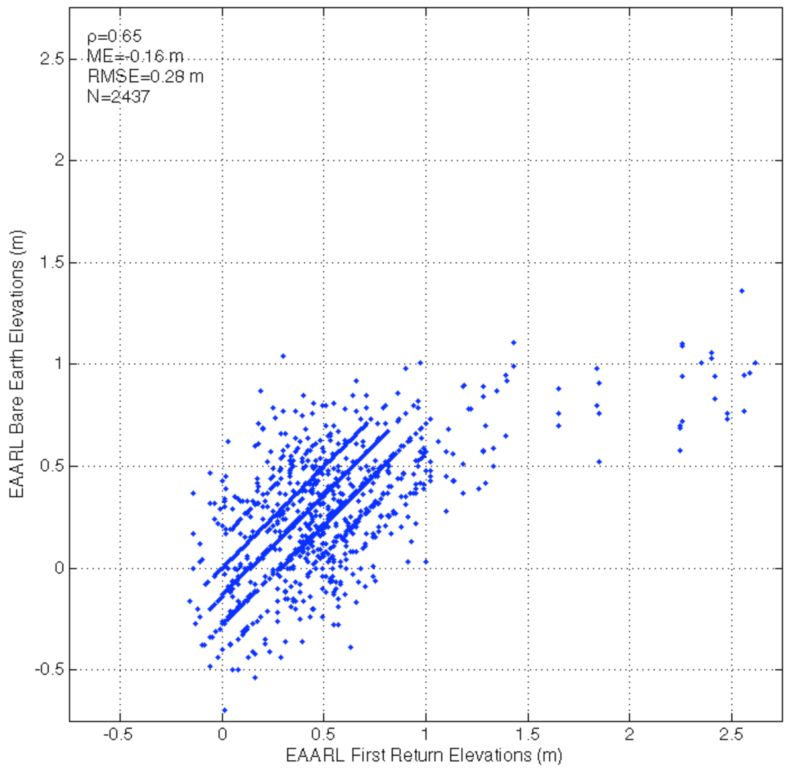

Figure 2. First return lidar elevations compared to the nearest bare-Earth elevations within the survey area.

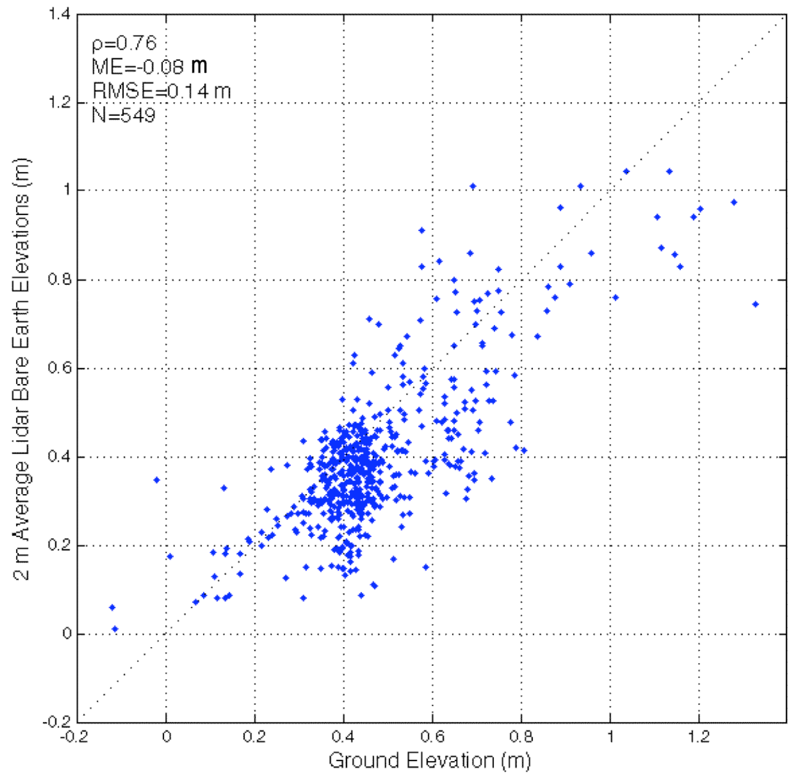

Figure 3. Bare-Earth average lidar elevations compared to ground survey elevations.

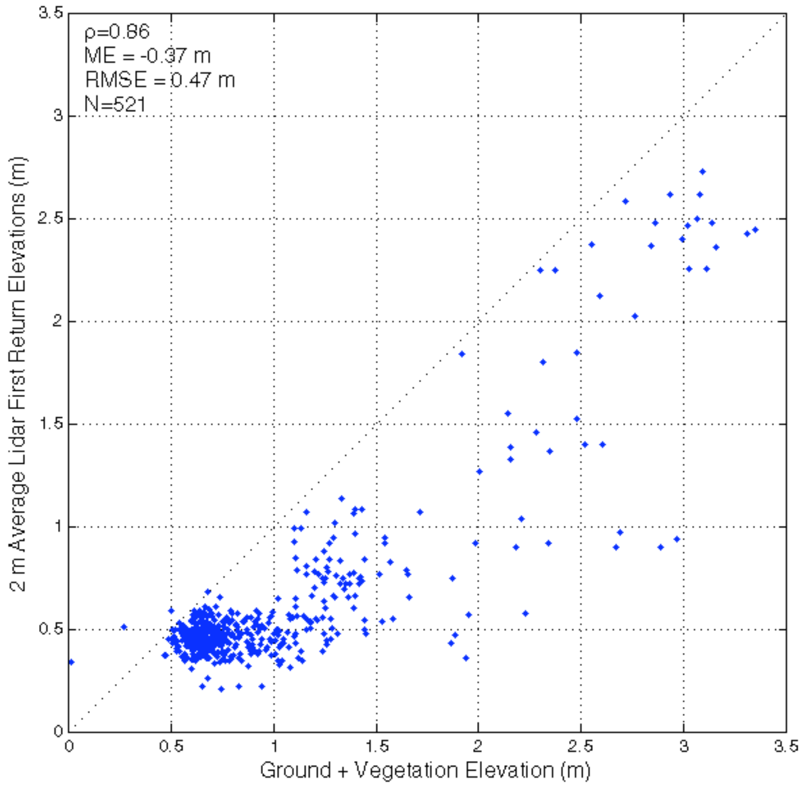

Figure 4. First Return average elevations compared to ground plus vegetation height survey elevations.

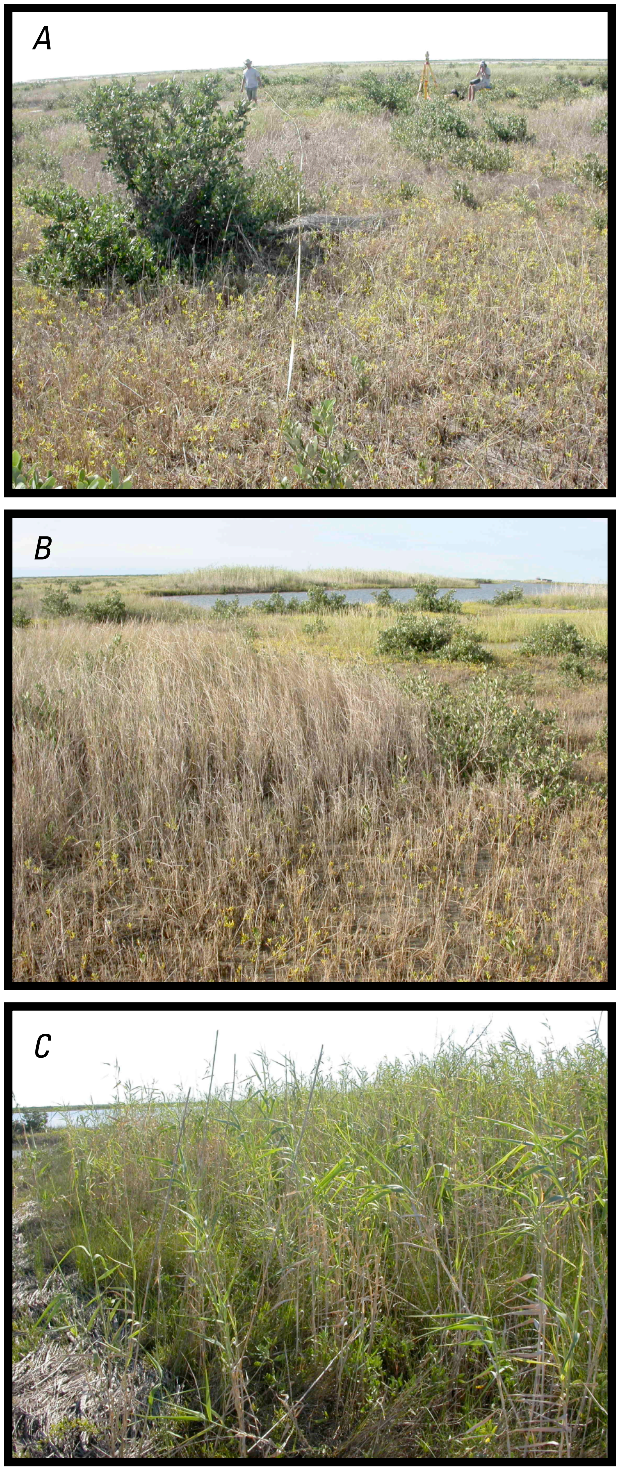

Figure 5. Photos taken of the survey area showing: *A*) Mangroves (0.4 m height) and short grasses (0.3 m) *B*) Spartina Patens (0.7 m) and *C)* Phragmites Australis (1.7 m).

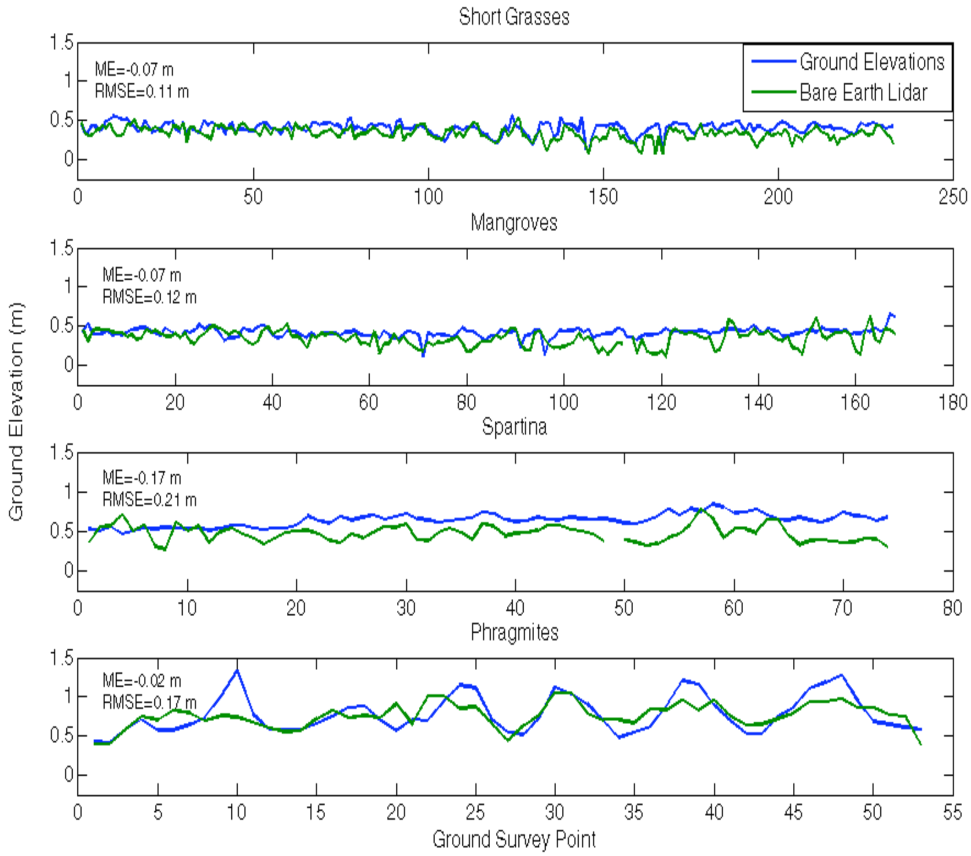

Figure 6. Average bare-Earth elevations are plotted in green, while the ground-survey elevations are plotted in blue. There is no significant difference in the mean (ME) and RMS (RMSE) errors for the four different types of vegetation.

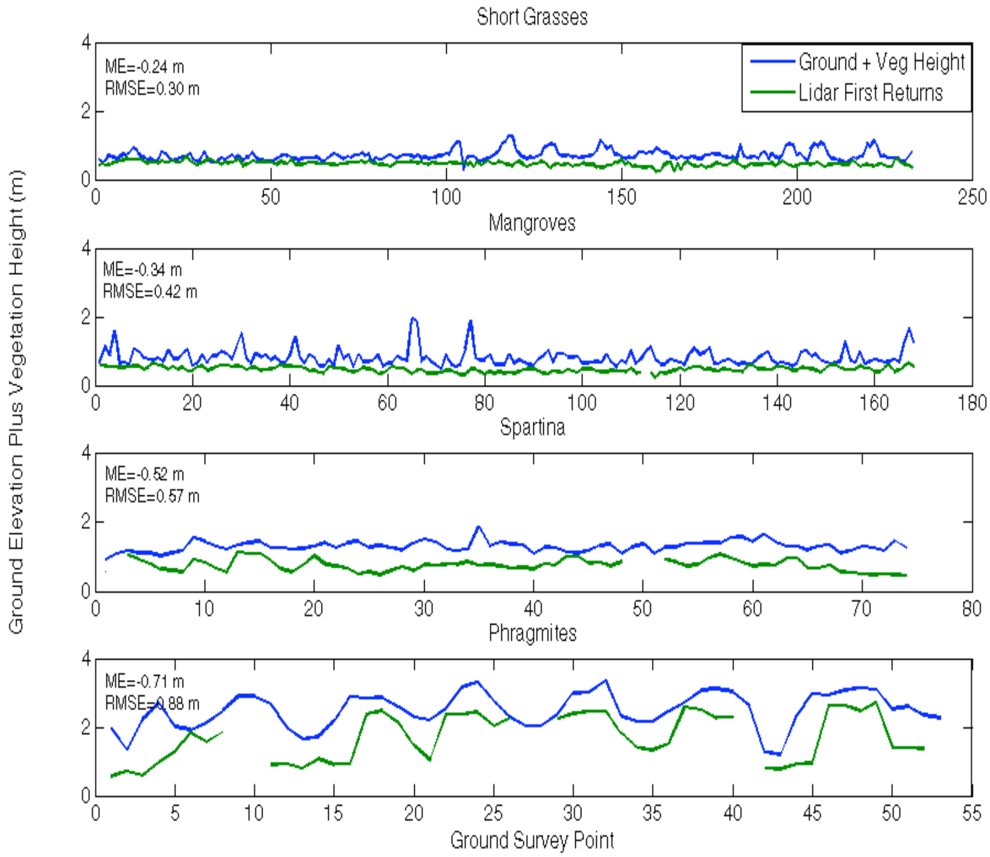

Figure 7. Average first-return elevations are plotted in green, while the ground-survey elevation plus vegetation height are plotted in blue. The mean (ME) and RMS (RMSE) errors are larger than the typical lidar random error and increase with vegetation height.