AUTOMATED DEM VALIDATION USING ICESAT GLAS DATA

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ABSTRACT

Digital Elevation Model (DEM) vertical accuracy evaluations have historically been difficult to validate especially in regions of the world where there are limited ground control points due to either harsh environmental conditions or dangerous political situations. As a result, elevations defined by DEMs in these geographic locations may have errors as large as tens to even hundreds of meters and these errors may significantly impact user applications. To address this potential issue, an automated method utilizing NASA's Ice, Cloud and land Elevation Satellite (ICESat) Geoscience Laser Altimetry System (GLAS) global land surface altimetry data product was developed to evaluate the accuracy of DEMs worldwide. The new automated method pre-processes the ICESat data by removing any saturated laser returns, identifying and removing outliers and interpolating the DEM data set to the ICESAT laser spot locations. The method has been used to evaluate commercial, SRTM and ASTER-based DEMs. Since the entire ICESat archive was employed, on average over 10,000 GLAS data points were utilized for each tile evaluated. This paper describes the new automated DEM validation method and showcases some results. The results presented are compared to current methods.

Key Words: DEM, vertical accuracy, ICESat, GLAS

INTRODUCTION

There are many places throughout the world where accurate validated Digital Elevation Models (DEMs) do not exist. This is particularly true in regions where there are limited ground control points due to either difficult weather conditions, such as extreme northern and southern latitudes, mountainous regions, or dangerous and politically unstable situations. These DEMs have yielded errors as large as tens to even hundreds of meters, which have the possibility of significantly affecting the results of applications that rely on them.

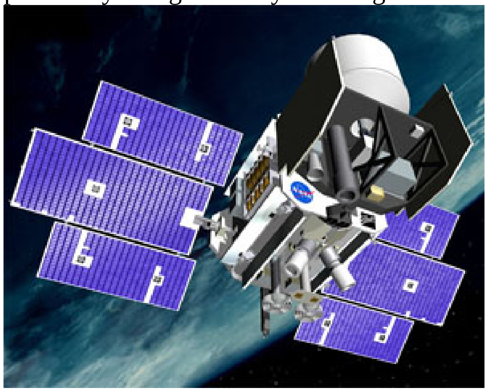

Figure 1. ICESat Mission.

To address this potential issue, Innovative Imaging and Research Corporation (I2R) developed an automated method that utilizes NASA's Ice, Cloud and land Elevation Satellite (ICESat) Geoscience Laser Altimetry System (GLAS) global land surface altimetry data product to evaluate the accuracy of commercially and government provided DEMs worldwide. ICESat is a satellite mission, shown in Figure 1, which was launched in 2003 to measure ice sheet mass balance, cloud and aerosol heights, as well as land topography and vegetation characteristics. GLAS is a space-based full waveform LIDAR and sole instrument onboard ICESat. The Nd:YAG laser operates in the near infrared at 1064 nm and transmits 40 5-nanosecond duration pulses per second. The laser beam spot sizes are approximately 65 meters in diameter and are separated by nearly 172 meters along the spacecraft's ground track. The instrument records a full waveform for each laser pulse to reach the Earth's surface and return back to the receiver. This waveform is combined with the instrument's position in space, established using a GPS receiver, star tracker and gyroscopes to estimate a height of the Earth's surface (UT Austin and NASA GSFC 2006). Published ICESat GLAS altimetry data product accuracy specifications are shown in Table 1 below (Carabajal and Harding 2005). The ICESat GLAS altimetry data product is geolocated using the Jason Topex Poseidon ellipsoid which is slightly different than WGS84 and EGM96.

Table 1. ICESat GLAS Land Surface Altimetry Data Product Accuracy Specifications

GLAS Elevation Product	Posting	RMSExy (meters)	RMSEz (meters)	CE90 Horizontal (meters)	LE90 Elevation (meters)	Ellipsoid
Nominal Terrain	172 meters linear	7.5	8.0	16.1	13.2	TOPEX Poseidon-Jason Ellipsoid
Rough Terrain	172 meters linear	-	15.0	16.1*	24.7*	TOPEX Poseidon-Jason Ellipsoid

*Indicates derived accuracy

Prior to developing the automated DEM evaluation method, the accuracy of the GLAS ICESat altimetry product was validated by comparing it to the National Elevation Dataset (NED), which represents the highest resolution, best quality dataset available across the US (USGS NED). The NED data product was developed by merging the highest-resolution, best quality elevation data available across the US into a seamless raster to provide 1:24,000 scale, or approximately 30 meter resolution DEM data for the conterminous US and 1:63,360 scale or approximately 60 meter resolution DEM data for Alaska. The NED has a consistent projection (geographic), resolution (1 arc-second over the continental US) and elevation units (meters). The NED horizontal datum is the North American Datum 1983 (NAD83) while the NED vertical datum is the North American Vertical Datum of 1988 (NAVD88).

In the 2006 timeframe, NED accuracy over the continental US was determined through bilinear interpolation of the NED to an array of over 13,000 high precision surveyed geodetic control points that the National Geodetic Survey (NGS) uses for gravity and geoid modeling. The overall absolute vertical accuracy of the circa 2003 NED expressed as an average RMSE was found to be 2.4 meters. In that same assessment, the absolute vertical accuracy as measured by a linear error with a 90% confidence interval (LE90) was estimated to be 4.0 meters (Maune 2006). Nine US NED tiles were selected to validate the GLAS ICESat elevation product and are shown graphically, with the exception of an additional point in Hawaii, in Figure 2 below.

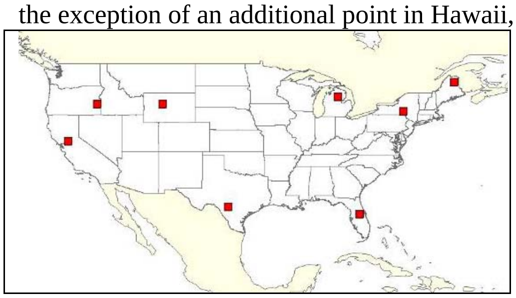

Figure 2. NED tile locations.

Sixty-nine GLA14 land centroid elevation product granules, each containing 14 orbital passes, totaling over 20,000 laser shots were selected to validate the vertical accuracy of the ICESat GLAS land surface altimetry data product. These granules were acquired by the instrument between Feb 17 and June 20, 2004 and were obtained through the National Snow and Ice Data Center Search 'N Order Web Interface (SNOWI) Website http://nsidc.org/data/snowi/index.html.

The results of the ICESat GLAS accuracy assessment are shown in Table 2 for a variety of locations and ground covers. Each of the NED tiles used in this evaluation is identified by the latitude and longitude of its lower left corner. Between approximately 900 and 3700 ICESat GLAS ICESat laser shots, identified as points, were compared to geographically corresponding NED product elevation values for each of the nine NED tile used in the assessment. The following equations were used to calculate the values identified within the table. LE90 was calculated empirically by determining the elevation difference at which 90% of the data point pairs evaluated fell within.

Elevation Difference = $\Delta Z_i = Z_{REF-i} - Z_{GLAS-i}$

Average Delta Z = $\overline{\Delta Z} = \sum_{i=1}^{n} \frac{\Delta Z_i}{n}$

STD Delta = Standard Deviation of the Average Delta

STD Delta Z = $\sigma_{\Delta Z} = \sqrt{\frac{\sum_{i=1}^{n} (\Delta Z_i - \overline{\Delta Z})^2}{(n-1)}}$

$$RMSE_{\Delta Z} = \sqrt{\sum_{i=1}^{n} \frac{(\Delta Z_i)^2}{n}}$$

Where: n is the total number of points evaluated within a tile

Z_{GLAS-i} is the elevation value of point I within the ICESat GLAS elevation data

Z_{REF-i} is the elevation value of point i within the reference tile

Table 2. Comparison of GLAS Elevation Data to the NED

NED File	No. of ICESat Points	Average ΔZ (meter)	STD ΔZ (meter)	RMSE ΔZ (meter)	Empirical LE90 (meter)
NED_n19w156	891	-3.4	7.7	8.4	13.5
NED_n28w082	1577	-1.4	2.9	3.2	5.1
NED_n29w100	1783	-0.2	4.4	4.4	7.5
NED_n38w122	3982	0.8	2.3	2.4	3.4
NED_n42w076	1324	-4.2	7.6	8.7	14.9
NED_n43w109	2742	1.0	5.6	5.6	9.8
NED_n43w118	2579	1.2	4.5	4.7	6.9
NED_n44w085	1673	-0.8	2.3	2.4	4.1
NED_n46w069	3544	-2.3	3.5	4.2	6.8
Mean Values		**-1.0**		**4.9**	**8.0**
Standard Deviation		**2.0**		**2.3**	**4.0**

The results show that the ICESat GLAS overall mean vertical accuracy expressed in terms of LE90 is 8.0 meters ± 4.0 meters (1σ) when compared to the NED. Taking into account the NED absolute vertical accuracy expressed as LE90 of 4.0 meters (Gesch 2006), I2R estimated the GLAS absolute vertical LE90 accuracy to be 6.9 meters ± 3.8 meters (1σ). This value exceeds the 13.2 meter LE90 GLAS data specification derived from published values. Assuming a normal distribution, the ICESat GLAS data product absolute vertical linear error with a 95% confidence interval (LE95) accuracy is approximately 8.1 meters. The ICESat GLAS elevation data product therefore is an ideal product to use to evaluate DEMs in areas of the world where absolute control is limited or nonexistent.

ALGORITHM

An algorithm was developed to determine the vertical accuracy of a given DEM using the ICESat GLAS data product as a reference. The software was written using MATLAB software. MATLAB is a high-level programming language and interactive environment that enables computationally intensive code to be developed faster than with traditional programming languages. The algorithm reads the ICESat GLAS data files a record at a time to extract the latitude, longitude, elevation, SRTM DEM elevation (if available), geoid, and peak amplitude voltage. Scaling factors are applied to convert the data to appropriate units. The SRTM DEM elevation is used to perform a validity check on the ICESat GLAS surface altimetry data. If the absolute value of the difference between the SRTM DEM elevation and the ICESat GLAS elevation is greater than 100 meters, the current data point is considered an outlier (possible cloud) and the data is removed (Carabajal and Harding 2005). The algorithm also checks the peak amplitude voltage value for each data point. If the peak amplitude voltage is greater than or equal to 1.4 (saturated) (Maune 2006), the current data point is considered invalid and is not used. Each data record also contains the height of the geoid above the ellipsoid for the first and last shot in the record. The average of the geoid values is calculated and subtracted from the ICESat GLAS elevation. Once the data points have been processed, the latitude, longitude, elevation, SRTM DEM elevation, elevation difference (SRTM DEM – ICESat GLAS elevation), and peak amplitude voltage data are saved.

The algorithm reads a given DEM and performs an elevation assessment using the ICESat GLAS data as a reference data product. Bi-linear interpolations are performed to locate the ICESat GLAS laser shot on to the given DEM. The same analysis used to validate the ICESat GLAS product described above is used to determine the accuracy of a given DEM. In addition, the software automatically generates histograms of elevation differences found by comparing the ICESat GLAS laser shot to interpolated DEM elevation values and plots a trace of the ICESat GLAS data points used in the assessment over an image of the DEM. The software is written to read in and evaluate multiple DEMs within a single software execution step.

SAMPLE RESULTS

This software has been used to evaluate both commercial and government provided DEMS. Most recently this algorithm was applied in support of the Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) Global DEM (GDEM) product validation (ASTER GDEM Validation Team 2009). The GDEM was created by stereo-correlating the 1.3 million scene ASTER VNIR archive, covering the Earth's land surface between 83N and 83S latitudes. The GDEM is produced with 30 meter postings, and is formatted in 1 x 1 degree tiles as GeoTIFF files. The product was released for public download on June 29, 2009. Since the ASTER GDEM and ICESat GLAS land surface altimetry data products are both optical-based data sets with comparable spatial resolution, it is reasonable to assume that the ICESat GLAS data would be a valuable product to use to validate the ASTER GDEM. I2R evaluated three different ASTER GDEM tiles using the methods described above. These tiles were selected because they were in geographical regions known to contain poorly validated AST14DEM ASTER DEMS and are shown in Table 3.

Table 3. ASTER GDEMs Evaluated

Location	Lower Left Coordinate	Elevation Variation	No. of ICESat Points
Central Alaska	North 65 deg, West 151 deg	Approx. 0-1800 meters	12,416
Eastern Russia	North 63 deg, East 134 deg	Approx. 0-1800 meters	18,735
Southern India	North 10 deg, East 76 deg	Approx. 0-1800 meters	13,627

I2R utilized 522 ICESat GLAS granules, each containing 14 orbital passes that were acquired between February 2003 and March 2008 for this analysis. These granules contain over 365 million laser shots. At the time the assessment was performed, these granules comprised the entire GLA14 archive. GLAS data acquired before October 2007 was processed using Release 28 software, while GLAS data acquired after that time was processed using Release 29 software (Zwally et al. 2006-2008).

Figures 3-5 below show the ASTER GDEM tiles along with the ICESat GLAS laser shot traces used for to perform the DEM accuracy assessment.

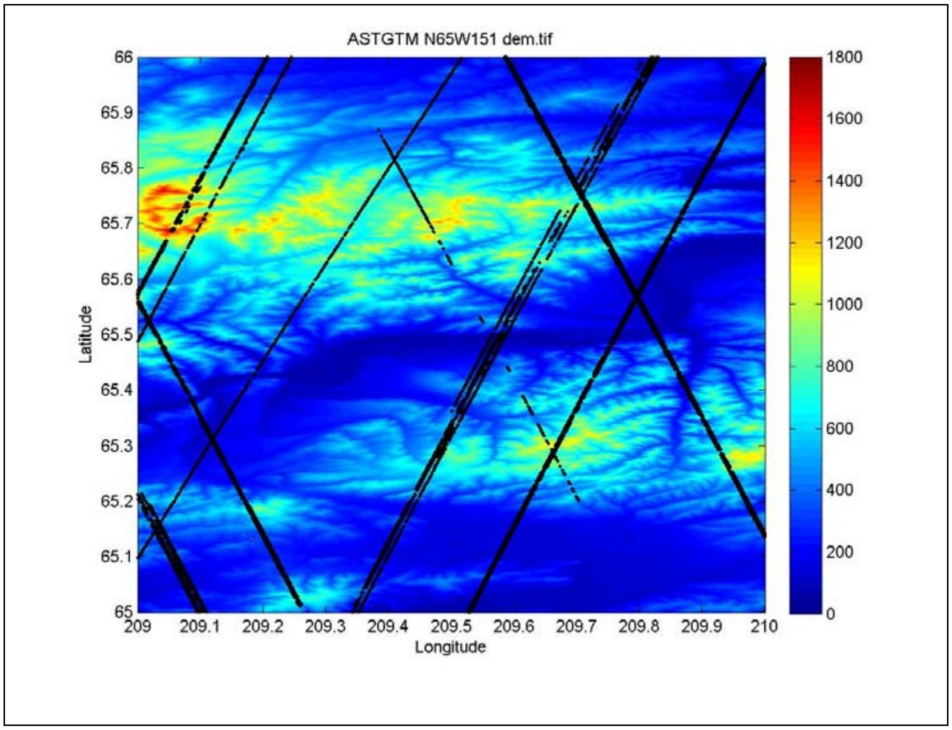

Figure 3. Central Alaska ASTER GDEM tile with ICESat GLAS data point location overlaid on top.

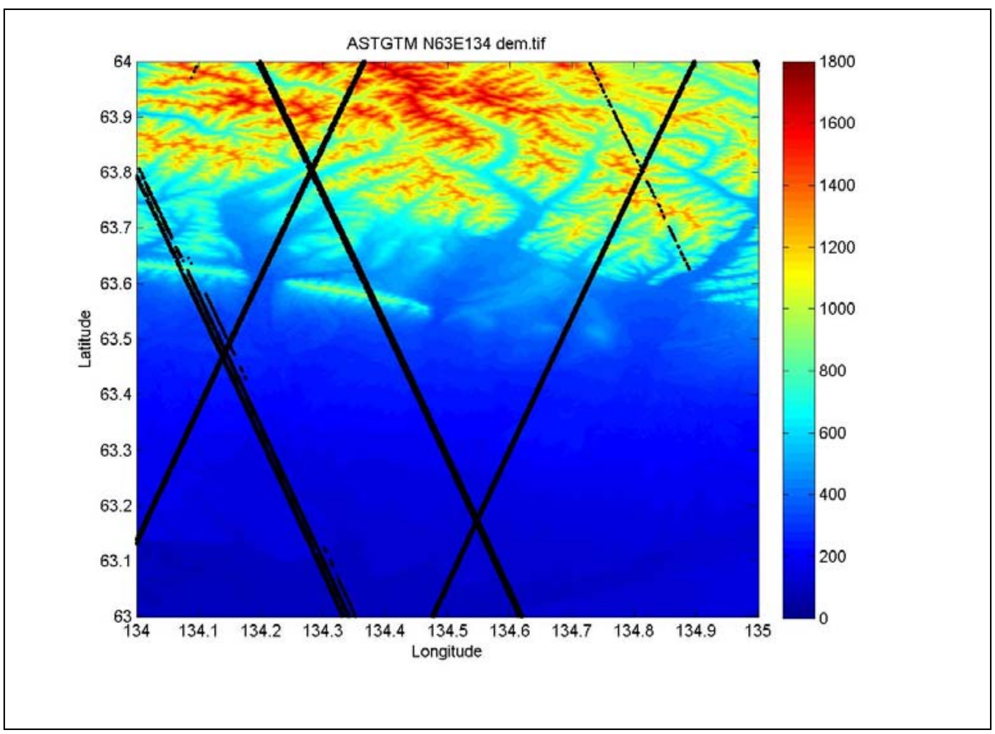

Figure 4. Eastern Russia ASTER GDEM tile with ICESat GLAS data point location overlaid on top.

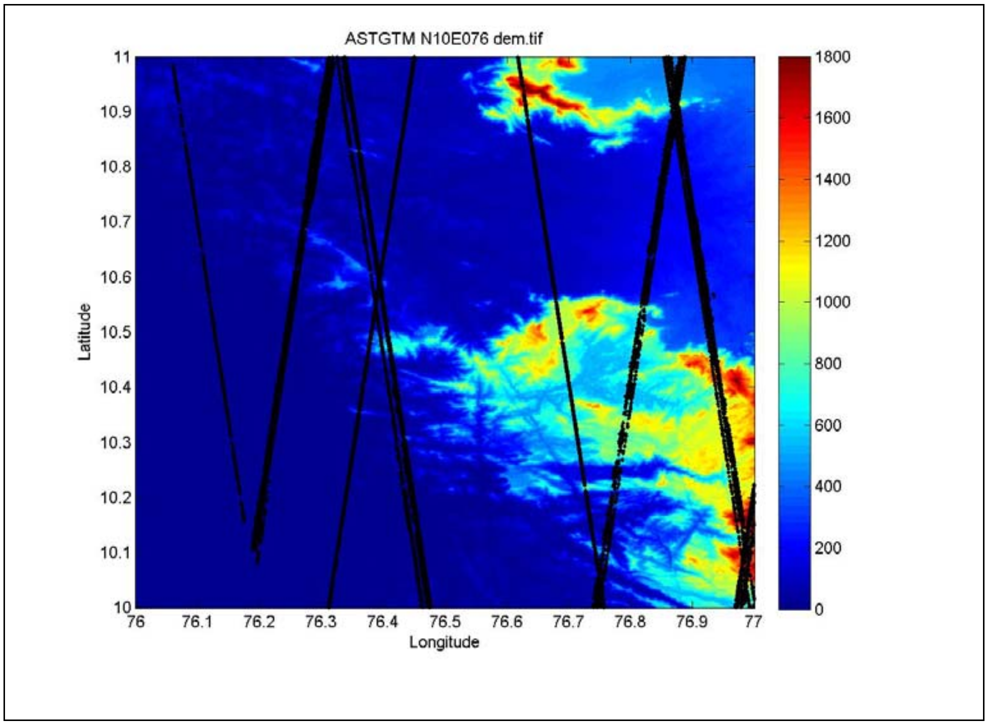

Figure 5. Southern India ASTER GDEM tile with ICESat GLAS data point location overlaid on top.

The following table summarizes the accuracy results of the three ASTER GDEM tiles evaluated. Elevation differences were obtained by subtracting the ICESat GLAS elevation value from the ASTER GDEM elevation value ($Z_{DEM} – Z_{REF}$). The ASTER GDEM Validation Team requested that accuracy be provided in terms of LE95. LE95 was calculated empirically by determining the elevation difference at which 95% of the data point pairs evaluated fell within.

Table 4. ASTER GDEM Elevation Accuracy Summary

Location	Min Diff (meters)	Max Diff (meters)	Mean Diff (meters)	STD Diff (meters)	RMSE (meters)	LE95 (meters)
Alaska	-149.0	920.0	-8.6	12.8	15.4	23.6
Russia	-205.3	40.0	-10.4	8.0	13.1	22.7
India	-229.5	137.6	-2.5	11.4	11.7	21.9

Histograms was generated which show the elevation difference (ASTER GDEM – ICESat GLAS) distribution across the scenes and are shown in Figures 6-8 below. In all three cases the histograms show a fairly normal Gaussian distribution of elevation difference. No effort was made to remove ASTER GDEM outliers in this assessment, which can be clearly seen as shifts along the x-axis in the histogram plots.

I2R developed an algorithm to systematically and rapidly evaluate DEMs using ICESat GLAS global surface altimetry data as a reference. The ICESat GLAS data product has been shown to have an absolute vertical accuracy as measured by a linear error with a 95% confidence interval (LE95) of 8.1 meters using the NED. This technique has successfully been employed to validate the newly released ASTER GDEM product as well as other commercial DEMs.

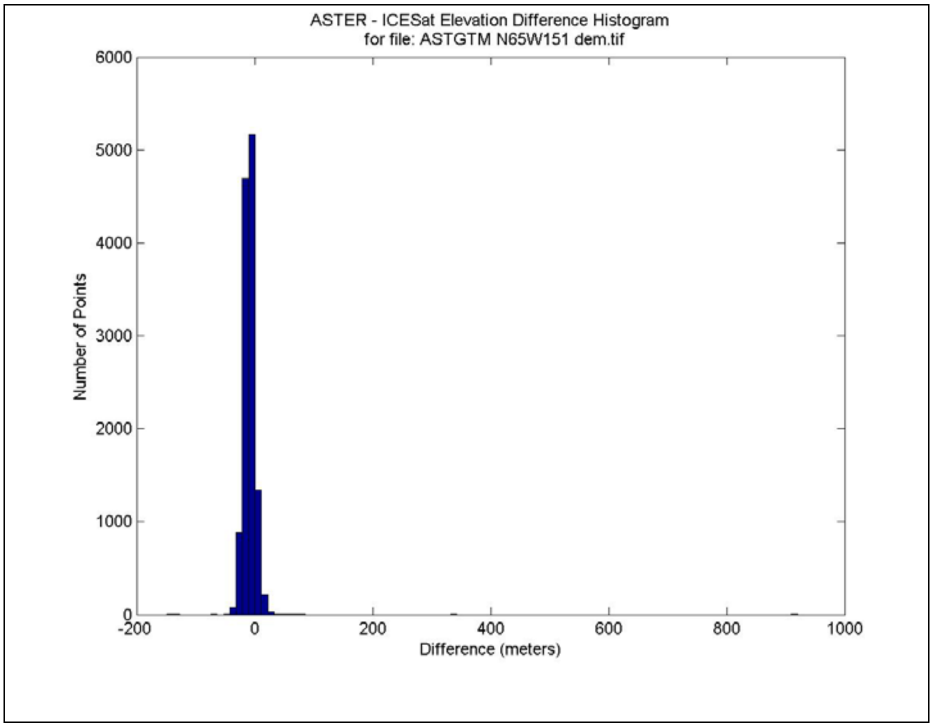

Figure 6. Histogram of Central Alaska ICESat GLAS ASTER GDEM elevation difference.

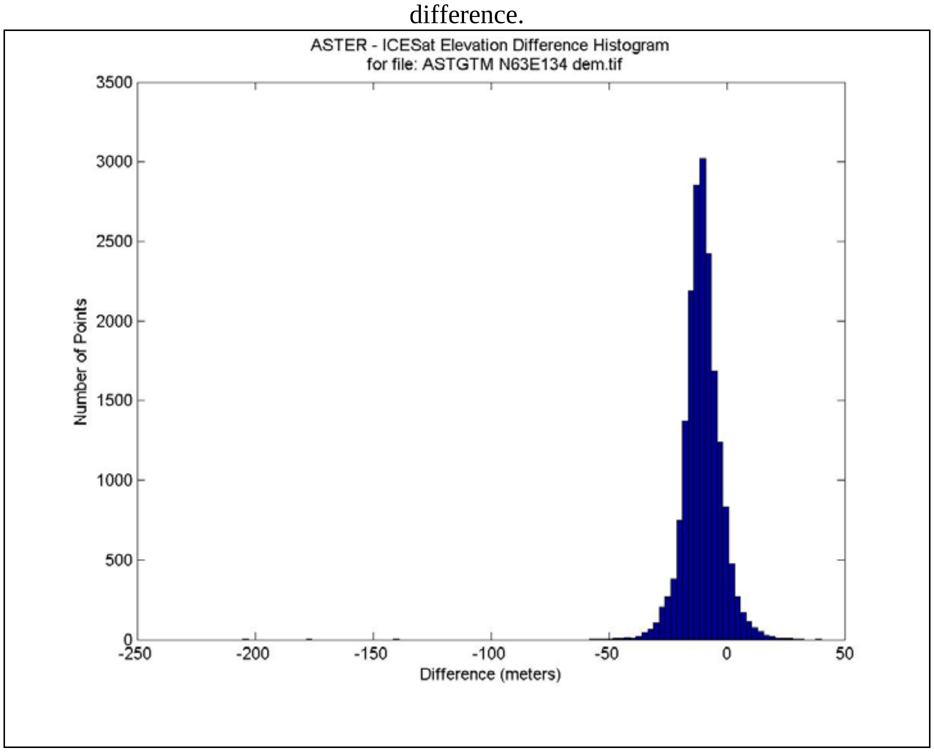

Figure 7. Histogram of Eastern Russia ICESat GLAS ASTER GDEM elevation difference.

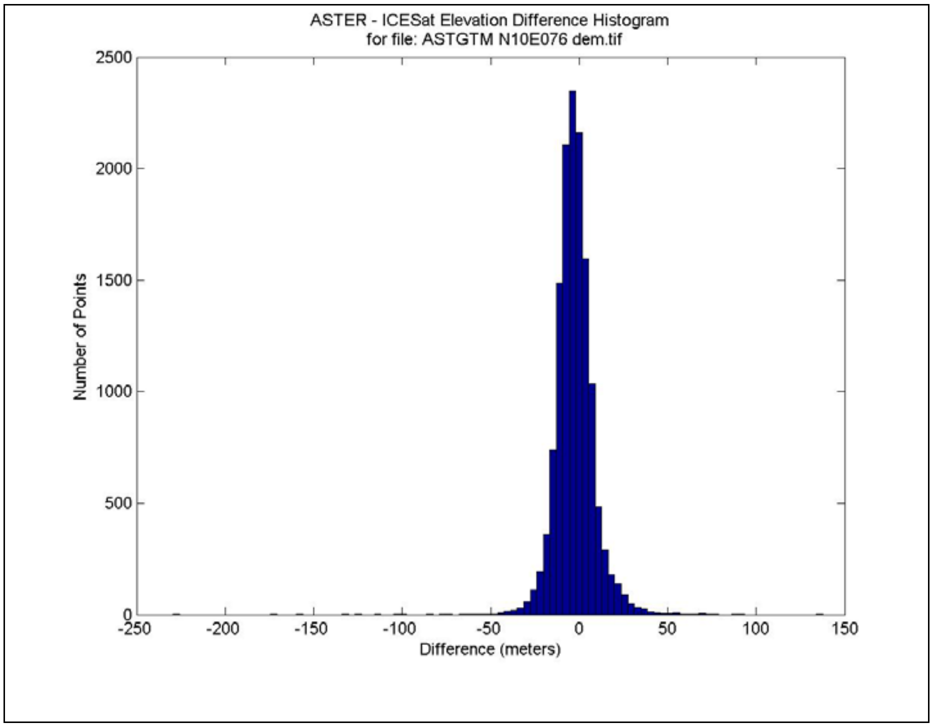

Figure 8. Histogram of Southern India ICESat GLAS ASTER GDEM elevation difference.

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