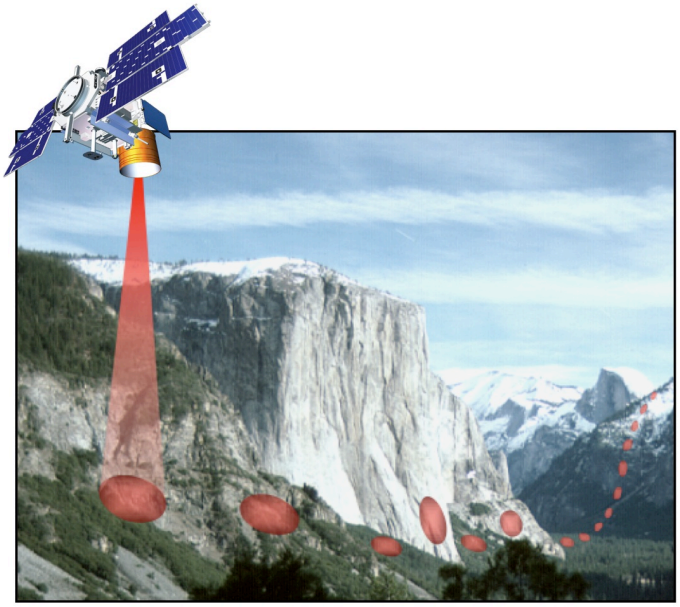
ASTER GLOBAL DEM VERSION 2.0 EVALUATION USING ICESat GEODETIC GROUND CONTROL



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INTRODUCTION

We have used ICEsat data to evaluate the accuracy of the 30 m resolution, near-global ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) V2 Global Digital Elevation Model (GDEM) produced by NASA/METI. The ICESat mission acquired single-beam, globally distributed laser altimeter profiles between ± 86° using the Geoscience Laser Altimeter Sensor (GLAS)[1, 2]. Data was collected from February, 2003 to October, 2009 during approximately month long observation periods, three times per year through 2006 and twice per year thereafter. These altimetry profiles provide a highly accurate and consistently referenced elevation data set with quantified errors. We select laser altimetry elevation measurements from ICESat to generate Ground Control Points (GCPs) with sub-decimeter vertical accuracy and better than 10 m horizontal accuracy. ICESat waveforms represent the vertical distribution of energy reflected within the laser footprint from vegetation where present, and the ground where illuminated through gaps in any vegetation cover [3]. Three lasers were used sequentially during the mission. Data acquired Laser 3 are used in this study, since the spatial distribution of the footprint energy was Gaussian with a diameter of about 50 m at the $1/e^2$ energy level, more suitable to evaluate a 30 m resolution elevation model. We are using ICESat footprint size estimates of centroid, ground where non-vegetated, highest and lowest elevations derived from ICESat waveforms. ICESat footprints are spaced ever 170 m along the profiles. Using attributes of the waveforms, we assess the accuracy of Digital Elevation Models (DEM) with respect to the highest elevations [ICESat (H)], the centroid (average elevation) [ICESat (C)], and lowest elevations [ICESat (L)] observed by ICESat for every laser footprint, and in some cases with respect to the ground [ICESat (G)] identified beneath vegetation cover, where a distinct, low peak is present in the waveform, or in bare areas [4, 5, 6, 7]. We estimate differences between ICESat elevations and the nearest-neighbor elevations from ASTER at the location of the ICESat footprint geolocation. SRTM elevations are from the SRTM v2 finished products, which are provided along with the ICESat GLA14 products used here [10]. Table 1 shows the various ICESat observation periods during Laser 3 operations, their collection dates and estimates of their pointing, horizontal and vertical accuracies. These estimates are based on the results of instrument calibration and validation using ocean scan maneuvers and cross-over analysis, and correspond to data processed as Release 31, which was used in this evaluation. The means and standard deviations are based on long orbit arc (~ 1,700 km) solutions [8].

We apply stringent editing criteria to yield a high quality GCP database (see References [6] and [7]. We exclude ICESat data identified as returns from water based on the ENVISAT MERIS Globcover land cover classification [9]. In addition to the Globcover land cover classification, we have used the MODIS Vegetation Continuous Fields (VCF) product to assess elevation differences with respect to percent cover. This product is an annual representation of percent tree cover, available in MODIS tile format from the EDC DAAC [11, 12]. The data used was ‘original, Collection 3, edition.'

ICESat data from clouds is excluded by editing elevations that are above SRTM elevations by more than 50 m where available. North of 60 degrees we use SRTM30 elevations, also provided in the ICESat products. Editing procedures for ICESat

altimetry in the ice regions are still in development. ICESat tracks followed reference tracks in the polar regions. When sufficient data along profiles were available on the ice sheets for all the periods, we have applied a cloud-clearing procedure that identifies the outliers from overlapping profiles using a threshold of 50 m for Greenland.

For all regions, we exclude data where the width of the waveform implies there is a significant height range detected within the laser footprint due to relief (slope and/or roughness of the ground) and/or vegetation cover. The impulse response for GLAS, that is the width of the received waveform from a flat, smooth target, is approximately 7 nsec (1 m) (the full width at half the peak amplitude) and approximately 17 nsec (2.5 m) at its base (the width from the start to the end of the waveform signal at a low threshold above the background noise). To obtain highly accurate GCPs we select waveforms with widths from signal start to end less than 5 m, indicating the within-footprint relief is very low and vegetation, if present, is of low stature [6, 7]. We also apply editing based on laser beam off-pointing and instrumental parameters, working with almost nadir looking data, and discarding significant saturation. Rigorous analysis has shown that for low relief locations the ICESat data meet the accuracy requirements of 6 m horizontal and 10 cm vertical (Table 1)[8]. This accuracy was somewhat degraded during the laser operating periods where the spacecraft was flying in airplane mode, indicated in Table 1 with an asterisk. However, we expect that our GCPs are of equivalent accuracy for all the observation periods used based on the stringent editing criteria applied to the data. All ICESat elevations were converted to WGS84/EGM96 for comparison.

ICESat Observation Period (91-day) Release 31	Start Date	End Date	Laser Energy Corrected for FOV Shadowing Effects (mJ)	Pointing accuracy (arcsec)	Long arc (~1700 km) Estimate Horizontal Accuracy (m)	Long arc (~1700 km) Estimate Vertical Accuracy 0.4° Slope (cm)
3A	10/3/2004	11/8/2004	63.7	0.19 ± 1.13	0.56 ± 3.29	0.4 ± 2.3
3B	2/17/2005	3/24/2005	59.1	0.02 ± 1.44	0.07 ± 4.20	0.1 ± 2.93
3C*	5/20/2005	6/23/2005	45.5	0.10 ± 1.00	0.29 ± 2.92	0.2 ± 2.04
3D	10/21/2005	11/24/2005	39.4	0.02 ± 0.98	0.07 ± 2.86	0.1 ± 2.0
3E	2/22/2006	3/28/2006	34.1	0.00 ± 1.17	0.00 ± 3.41	0.0 ± 2.38
3F*	5/24/2006	6/26/2006	30.8	0.47 ± 1.52	1.35 ± 4.42	1.0 ± 3.08
3G	10/25/2006	11/27/3006	27.1	0.02 ± 1.16	0.07 ± 3.37	0.1 ± 2.35
3H	3/12/2007	4/14/2007	22.6	0.00 ± 1.48	0.00 ± 4.29	0.0 ± 3.0
3I	10/2/2007	11/5/2007	20.5	0.22 ± 0.76	0.65 ± 2.22	0.5 ± 1.55
3J	2/17/2008	3/21/2008	17.7	0.21 ± 1.60	0.62 ± 4.66	0.4 ± 3.25
3K*	10/4/2008	10/19/2008	15.6	0.05 ± 1.29	0.15 ± 3.74	0.1 ± 2.61
***Airplane Mode**						

Table 1. ICESat Laser 3 observation periods, their timelines, transmit energy and long arc accuracy estimates from scan maneuvers and cross-overs [Pointing bias estimates from Luthcke, 2010 personal communication].

LC Value	Globcover Label
11	Post-flooding or irrigated croplands (or aquatic)
12	Post-flooding or irrigated shrub or tree crops
13	Post-flooding or irrigated herbaceous crops
14	Rainfed croplands
15	Rainfed herbaceous crops
16	Rainfed shrub or tree crops (cash crops, vineyards, olive tree, orchards…)
20	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)
21	Mosaic cropland (50-70%) / grassland or shrubland (20-50%)
22	Mosaic cropland (50-70%) / forest (20-50%)
30	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)
31	Mosaic grassland or shrubland (50-70%) / cropland (20-50%)
32	Mosaic forest (50-70%) / cropland (20-50%)
40	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
41	Closed (>40%) broadleaved evergreen and/or semideciduous forest (>5m)
42	Open (15-40%) broadleaved semi-deciduous and/or evergreen forest with emergents (>5m)
60	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
70	Closed (>40%) needleleaved evergreen forest (>5m)
90	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
91	Open (15-40%) needleleaved deciduous forest (>5m)
92	Open (15-40%) needleleaved evergreen forest (>5m)
100	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
101	Closed (>40%) mixed broadleaved and needleleaved forest (>5m)
102	Open (15-40%) mixed broadleaved and needleleaved forest (>5m)
110	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
130	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)
131	Closed to open (>15%) broadleaved or needleleaved evergreen shrubland (<5m)
132	Closed to open (>15%) broadleaved evergreen shrubland (<5m)
133	Closed to open (>15%) needleleaved evergreen shrubland (<5m)
134	Closed to open (>15%) broadleaved deciduous shrubland (<5m)
135	Closed (>40%) broadleaved deciduous shrubland (<5m)
136	Open (15-40%) broadleaved deciduous shrubland (<5m)
140	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
141	Closed (>40%) grassland
142	Closed (>40%) grassland with sparse (<15%) trees or shrubs
143	Open (15-40%) grassland
144	Open (15-40%) grassland with sparse (<15%) trees or shrubs
145	Lichens or mosses
150	Sparse (<15%) vegetation
151	Sparse (<15%) grassland
152	Sparse (<15%) shrubland
153	Sparse (<15%) trees

Table 2. Definition of the Globcover classes (LC) used in this analysis.

LC Value	Globcover Label
160	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
161	Closed to open broadleaved forest on (semi-) permanently flooded land – Fresh water
162	Closed to open broadleaved forest on temporarily flooded land - Fresh water
170	Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water
180	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
181	Closed to open (>15%) woody vegetation on regularly flooded or waterlogged soil - Fresh or brackish water
182	Closed to open (>15%) woody vegetation on temporarily flooded land
183	Closed to open (>15%) woody vegetation on permanently flooded land
184	Closed to open (>15%) woody vegetation on waterlogged soil
185	Closed to open (>15%) grassland on regularly flooded or waterlogged soil -Fresh or brackish water
186	Closed to open (>15%) grassland on temporarily flooded land
187	Closed to open (>15%) grassland on permanently flooded land
188	Closed to open (>15%) grassland on waterlogged soil
190	Artificial surfaces and associated areas (Urban areas > 50%)
200	Bare areas
201	Consolidated bare areas (hardpans, gravels, bare rock, stones, boulders)
202	Non-consolidated bare areas (sandy desert)
203	Salt hardpans
210	Water bodies
220	Permanent snow and ice
230	No Data

Table 2. (Cont.) Definition of the Globcover classes (LC) used in this analysis.

ANALYSIS:

Area	N	Mean (m)	Median (m)	STD (m)	RMSE (m)	Min. (m)	Max. (m)
Africa	14661568	-1.6	-0.325	11.61	11.72	-1802.16	267.80
South America	2283947	-2.17	-1.84	8.51	8.78	-1242.94	376.38
North America	5410981	2.11	1.96	11.73	11.92	-2761.32	514.40
Australia	4349145	2.83	2.97	7.08	7.62	-168.23	122.49
New Zealand	16836	-0.08	0.28	8.89	8.89	-132.79	52.05
Western Europe	1714027	2.77	2.77	10.71	11.06	-2436.01	339.45
Eurasia	15264903	1.60	1.65	11.76	11.87	-2347.37	496.431
Greenland*	4190411	-235.70	-109.04	535.00	584.62	-4152.07	3606.67

Table 3. Statistics for ICESat waveforms centroid elevations minus ASTER differences. [*Anomalously high/low elevations in ice-covered areas contaminate the statistics. See Tables G_1, G_2a, G_2b, G_3a, G_3b, G_4 and G_5, and figures for details.]

Statistics were computed with respect to number of scenes and/or fill source, land cover, relief, and ASTER elevation.

For all regions, the statistics have been reported in a similar manner, as follows:

TABLE [REGION]_1 – GLOBAL STATISTICS from all ICESat returns, for ICESat Centroid (C) – ASTER, Ground (C) – ASTER, Lowest (L) – ASTER, and Highest (H) – ASTER elevations, and differences with SRTM v2 finished product at the ICESat footprint location for comparison.

TABLE [REGION]_2a - DIFFERENCES WITH RESPECT TO NUMBER of SCENES AND/OR FILL (n)

Ranges for n show the statistics for groupings of number of scenes
Negative values indicate fill source (-11 = Alaska; -6 = CDED; -5 = NED; -2 = SRTMv2; -1 = SRTMv3

TABLE [REGION]_2b - DIFFERENCES WITH RESPECT TO NUMBER of SCENES AND/OR FILL PER CATEGORY

This table shows statistics per NUM value. Negative values same as above.

TABLE [REGION]_3a - DIFFERENCES WITH RESPECT TO ENVISAT MERIS LAND-COVER (Globcover, 300 m RESOLUTION)

TABLE [REGION]_3b - DIFFERENCES WITH RESPECT TO MODIS VCF LANDCOVER (500 m Resolution), showing statistics with respect to % BARE COVER, % HERBACEOUS COVER, % TREE COVER (where available), in 10% increments.

TABLE [REGION]_4 - DIFFERENCES WITH RESPECT TO RELIEF (SRTM V2.0 FINISHED 90 M, 3X3 CELLS SURROUNDING ICESat FOOTPRINT GEOLOCATION)

TABLE [REGION]_5 - DIFFERENCES WITH RESPECT TO ELEVATION (250 m INCREMENTS), also showing a range for negative elevations.

Region names have been abbreviated as follows:
AF = Africa
SA = South America
NA = North America
AU = Australia
NZ = New Zealand
WEU = Western Europe
EUA = Eurasia
G = Greenland

AFRICA:

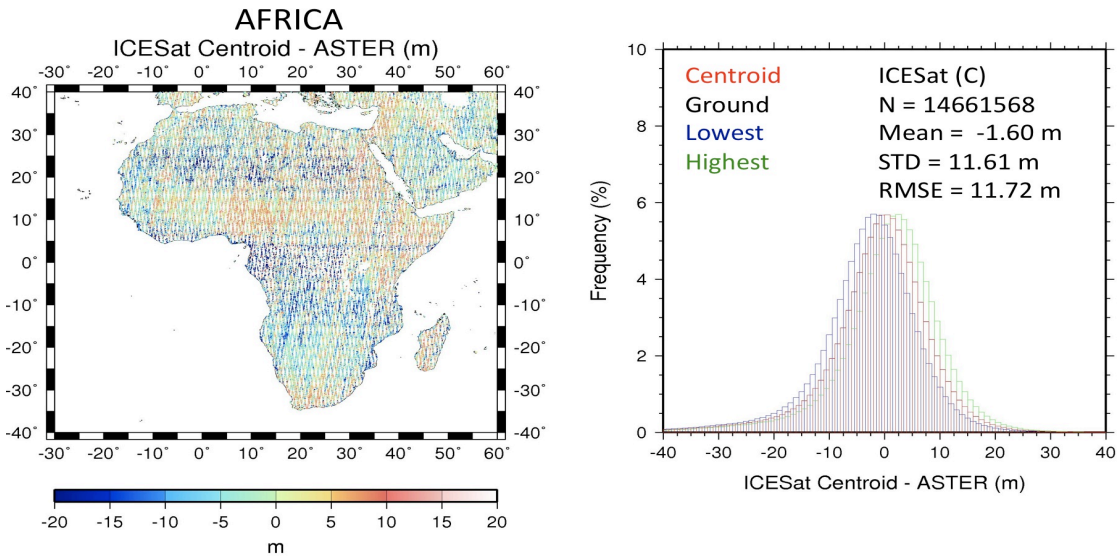


Figure 1_AF – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table AF_1 for Global Statistics.

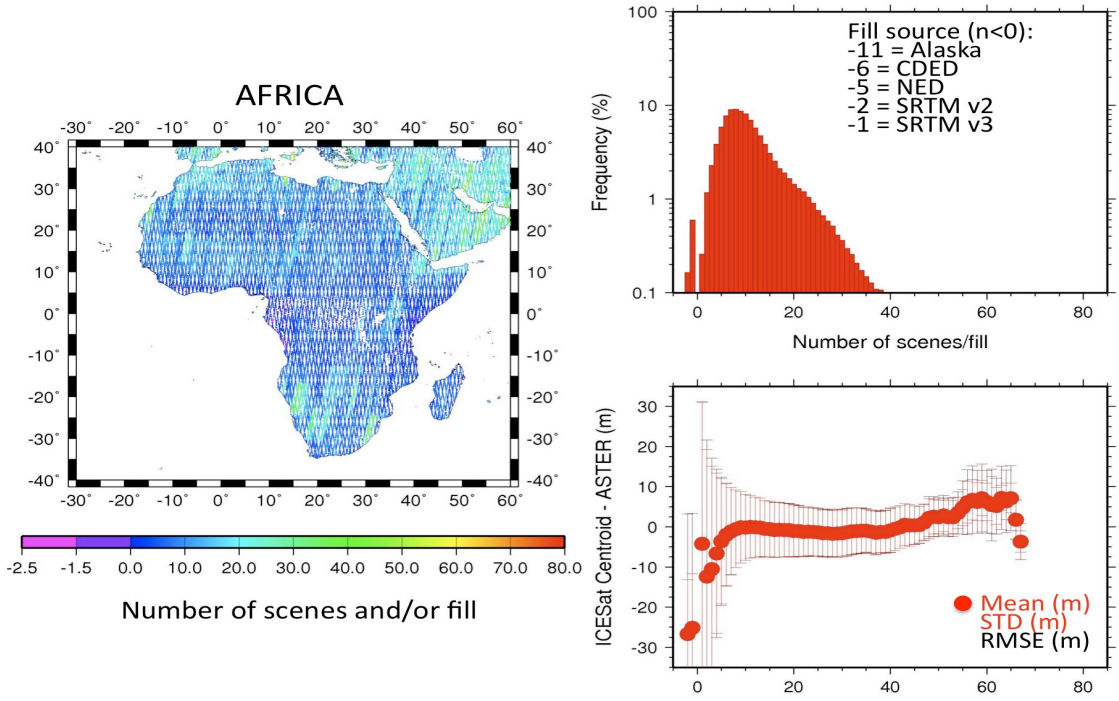


Figure 2_AF – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table AF_2a. Those for each category of NUM (plotted here) are in Table AF_2b.

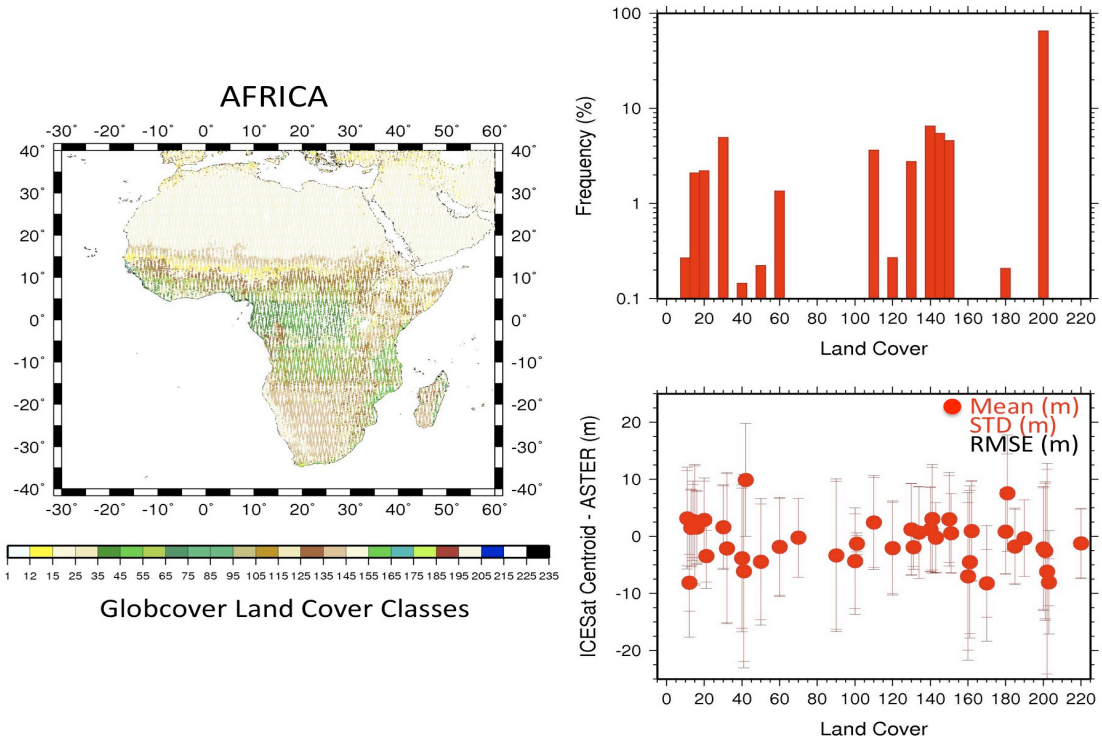


Figure 3_AF – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table AF_3a.

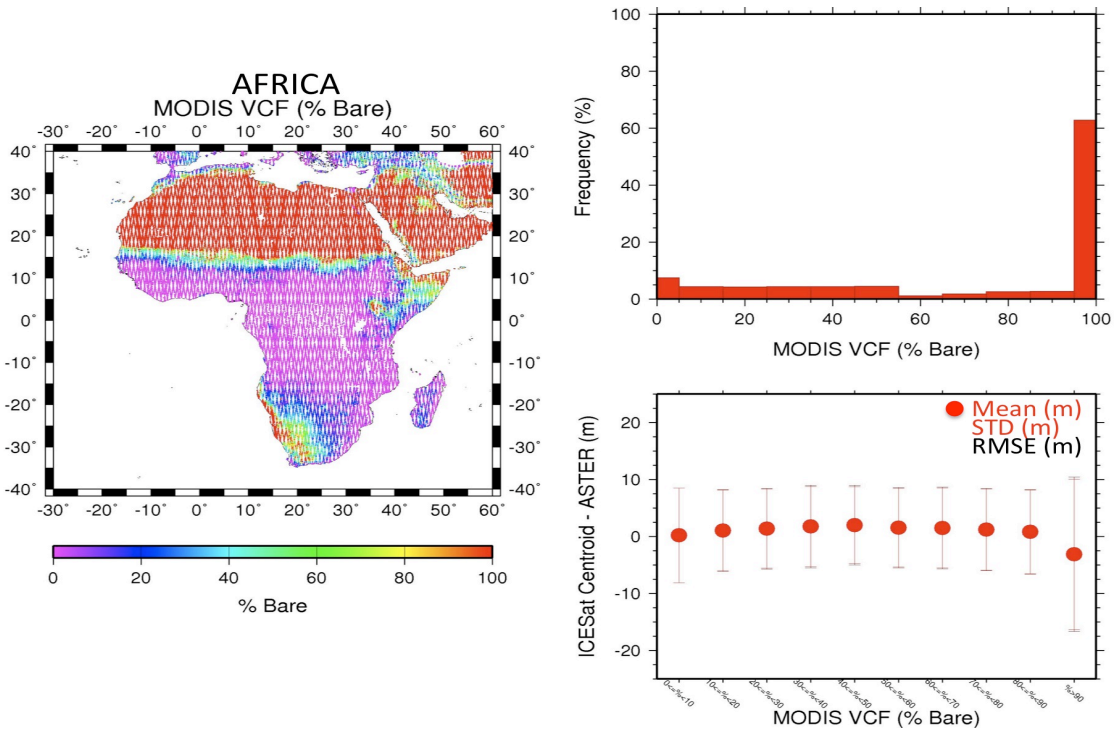


Figure 4_AF – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table AF_3b.

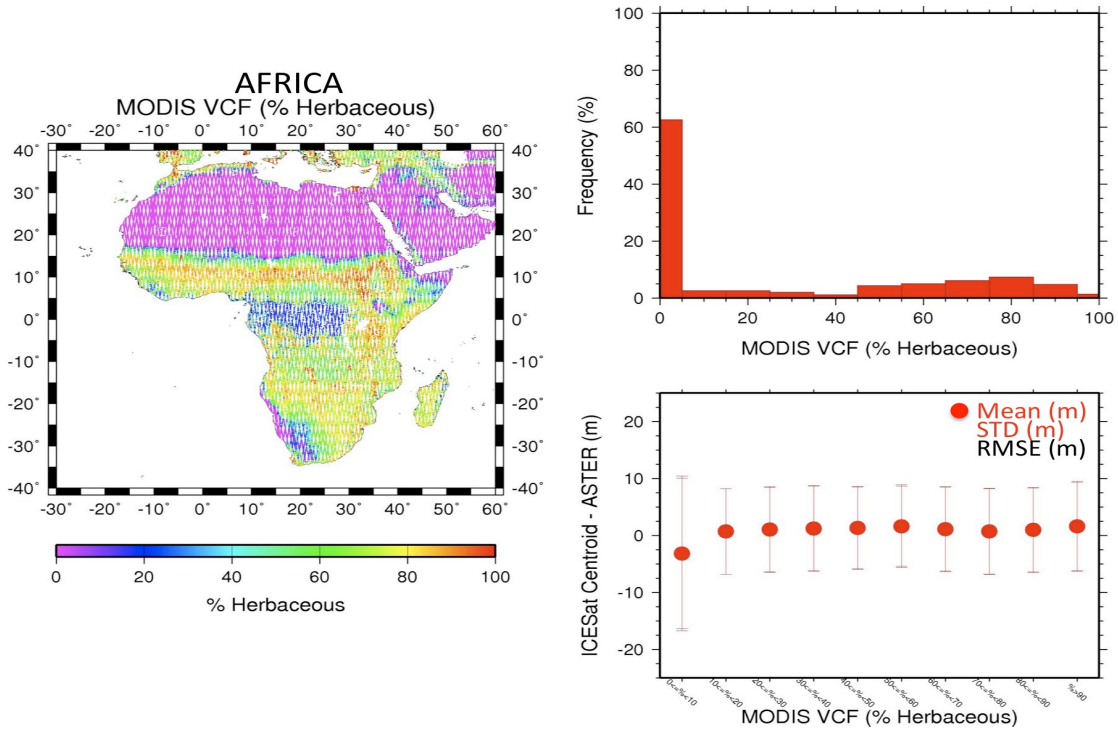


Figure 5_AF – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table AF_3b.

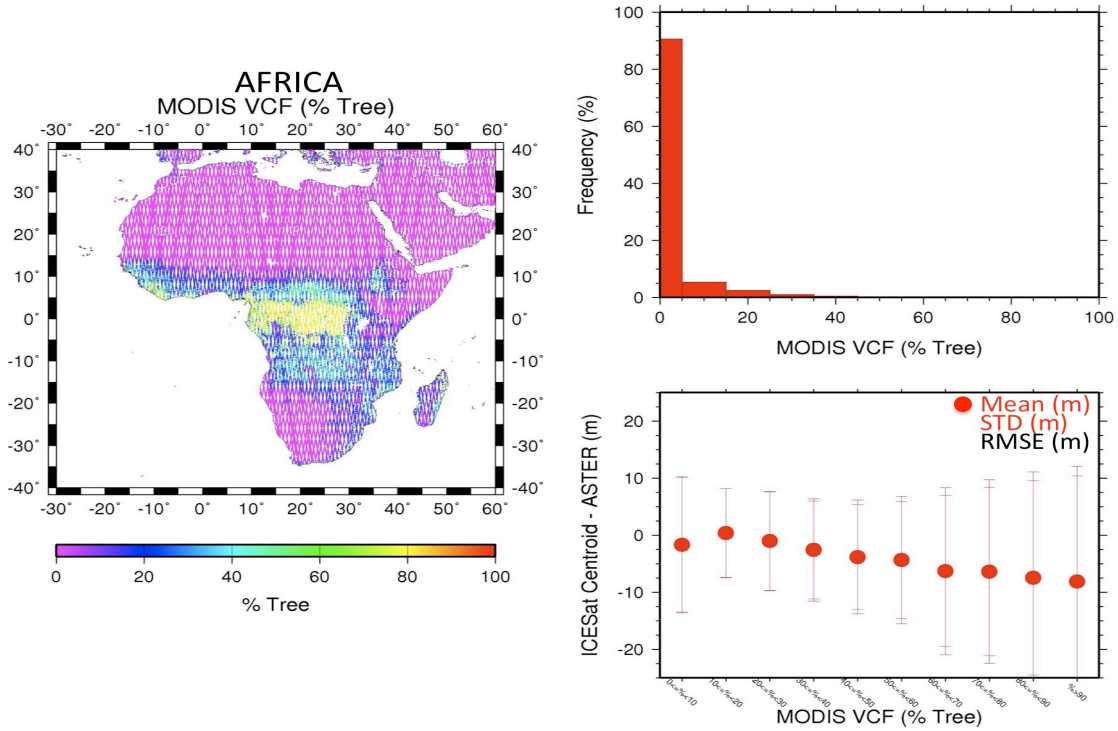


Figure 6_AF – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table AF_3b.

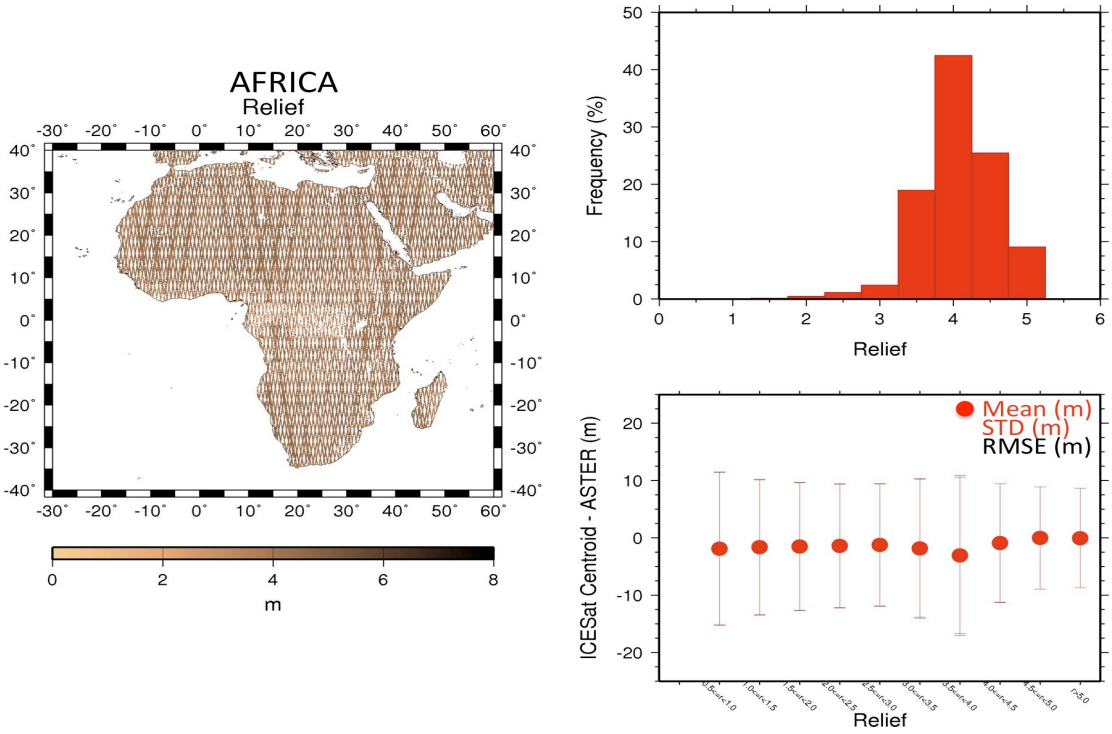


Figure 7_AF – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table AF_4 for complete statistics.

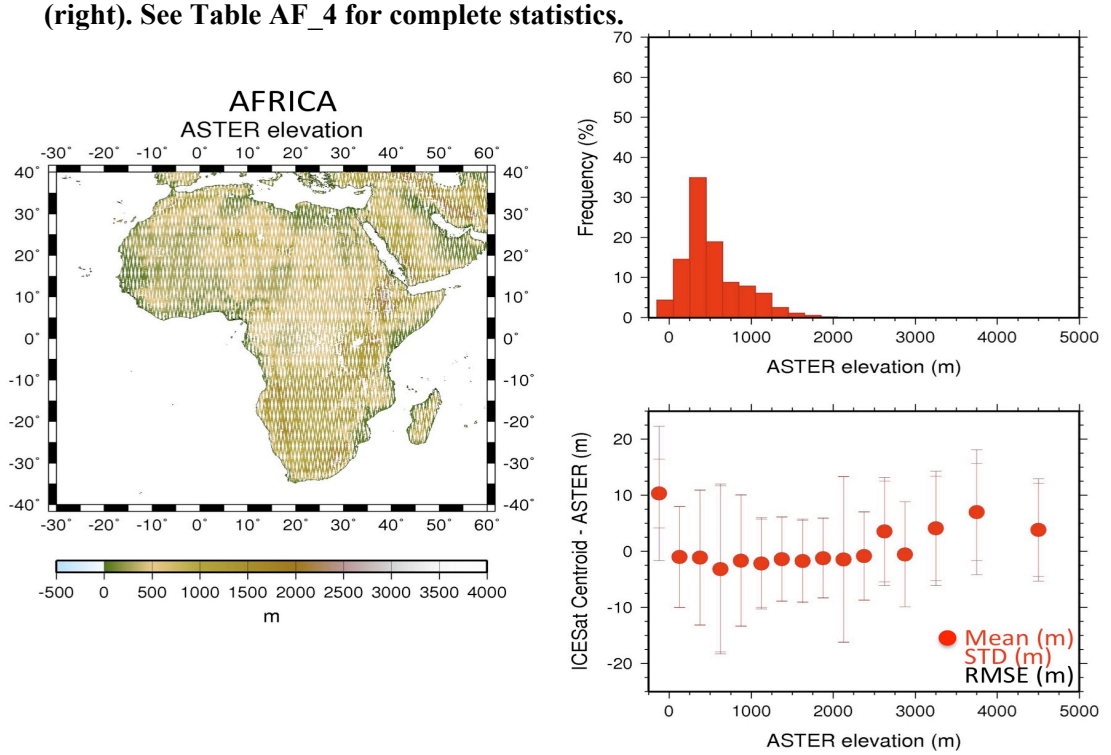


Figure 8_AF – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table AF_5 for complete statistics.

Observations for Africa:

Figure 1_AF shows elevation differences between ICESat and ASTER that exhibit relatively normal distributions, slightly skewed towards negative values (ASTER above ICESat by 1.60 m±11.61 m, with a median of -0.33 m). SRTM v2 (finished product) and ASTER seem to be in pretty good agreement as represented in the Global Statistics for the region. See Table AF_1.

Largest mean differences are observed where other data sources were used for fill, and when less than 5 scenes were used, while the smallest negative mean differences are seen when 9 to 15 scenes are used, with smaller standard deviations and RMSE values. Mean differences become positive and increase with number of scenes for NUM > 43. See Tables AF_2a and and AF_2b, and Figure 2_AF for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, the largest mean differences and standard deviations are observed for the least represented categories. For bare regions ASTER is above ICESat by 2.11 m±10.66 m. There seems to be no particular correlation of differences with a particular land cover. See Table AF_3a and Figure 3_AF.

When looking at the differences with respect to % bare cover from the VCF products, there is a negative bias when there is > 90% bare cover, and slightly positive biases for lower bare cover. As the % tree cover increases, the mean differences and standard deviations become increasingly more negative, with RMSEs that reach close to 20 m. See Tables AF_3b and Figures 4_AF, 5_AF and 6_AF.

The ICESat returns mostly represent areas with relief between 3 and 5 m. Maximum differences occur when relief is between 3.5 m and 4 m, where ASTER is above ICESat by ~3.0 m. RMSEs are up to 14 m. Mean differences may be influenced by a few spurious anomalously negative values. See Table AF_4 and Figure 7_AF.

Mean differences with respect to ASTER elevations show no particular correlation. See Table AF_5 and Figure 8_AF.

SOUTH AMERICA:

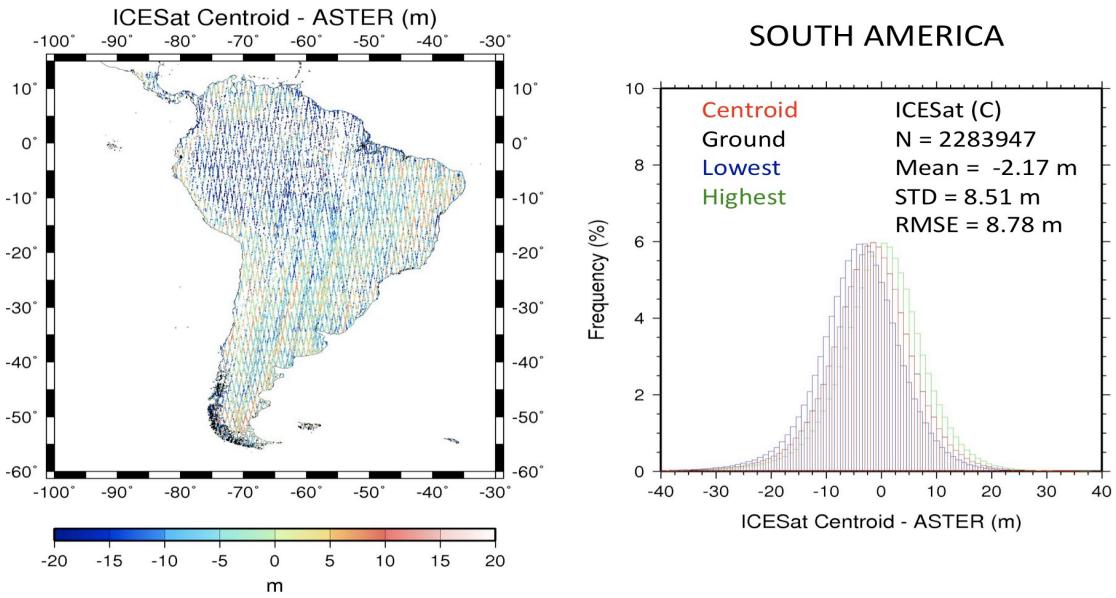


Figure 1_SA – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), round (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table SA_1 for Global Statistics.

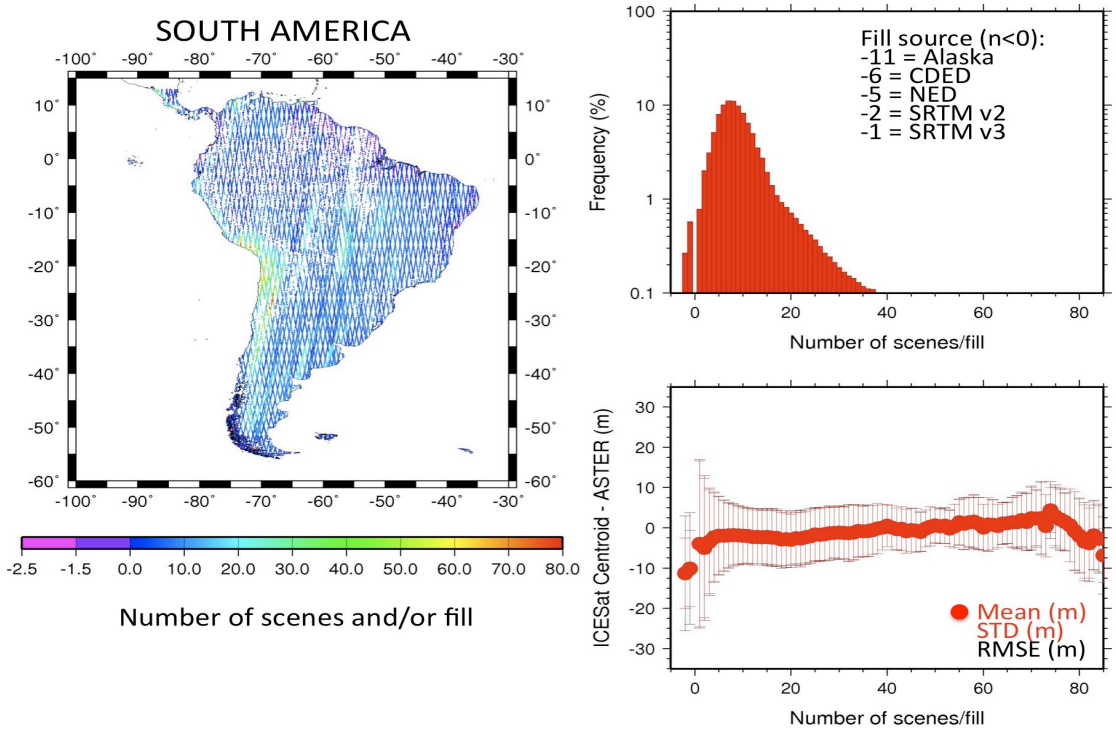


Figure 2_SA – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table SA_2a. Those for each category of NUM (plotted here) are in Table SA_2b.

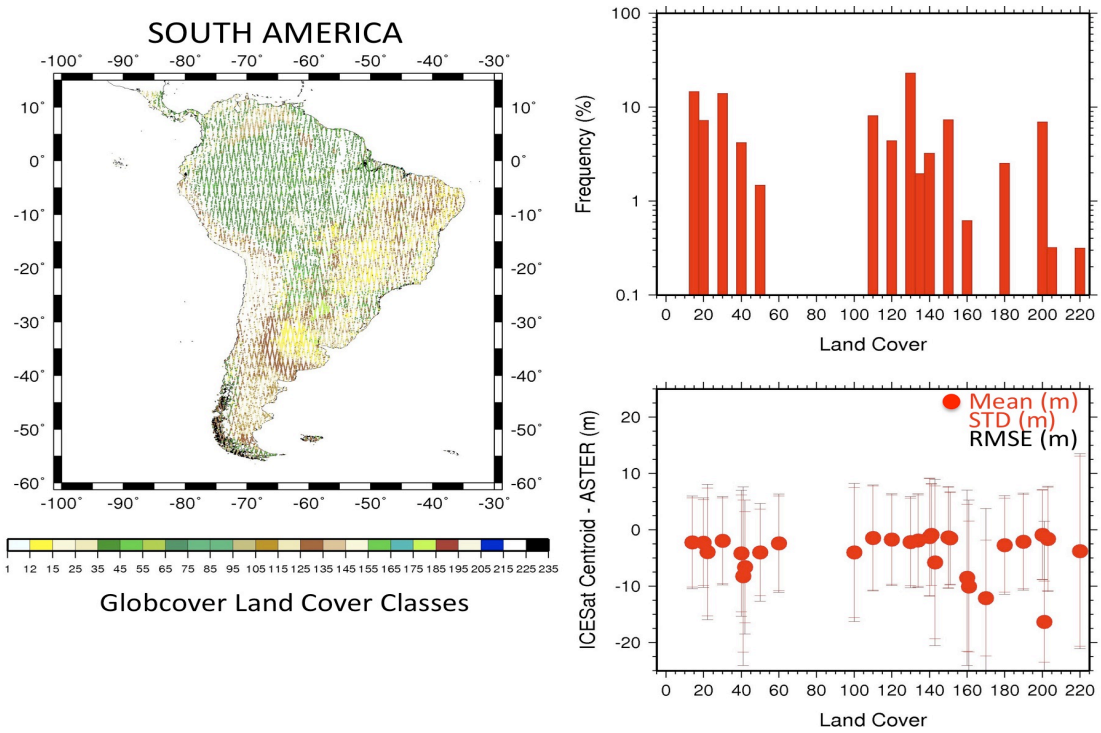


Figure 3_SA – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table SA_3a.

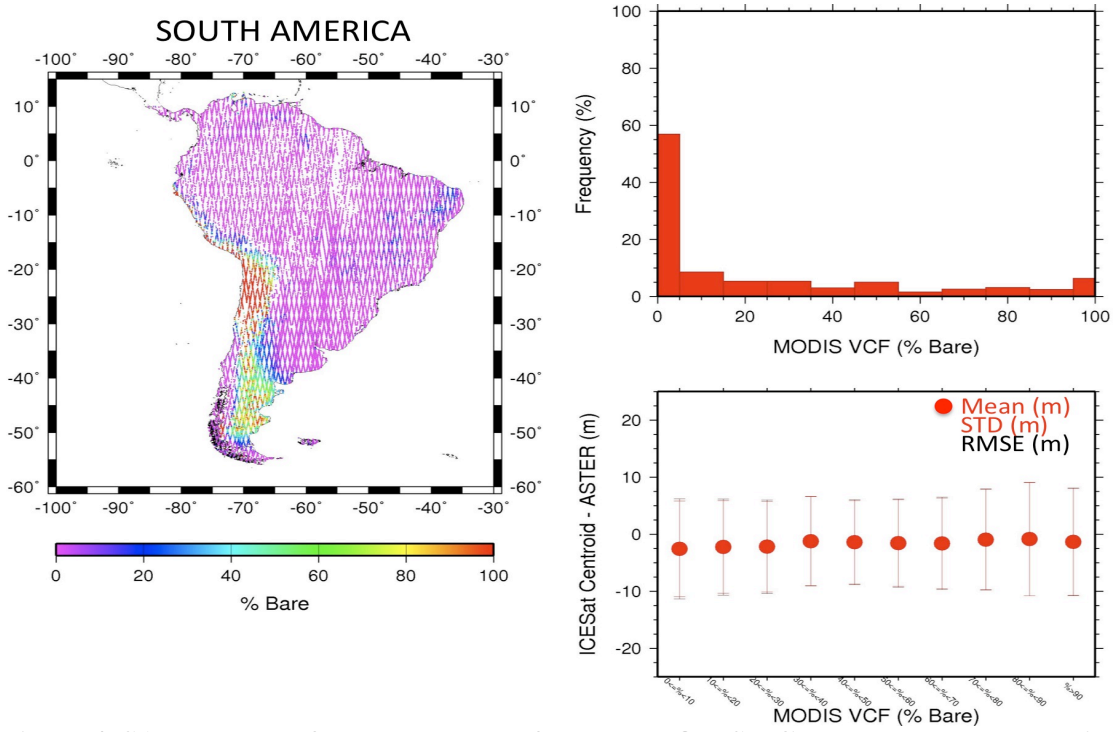


Figure 4_SA – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table SA_3b.

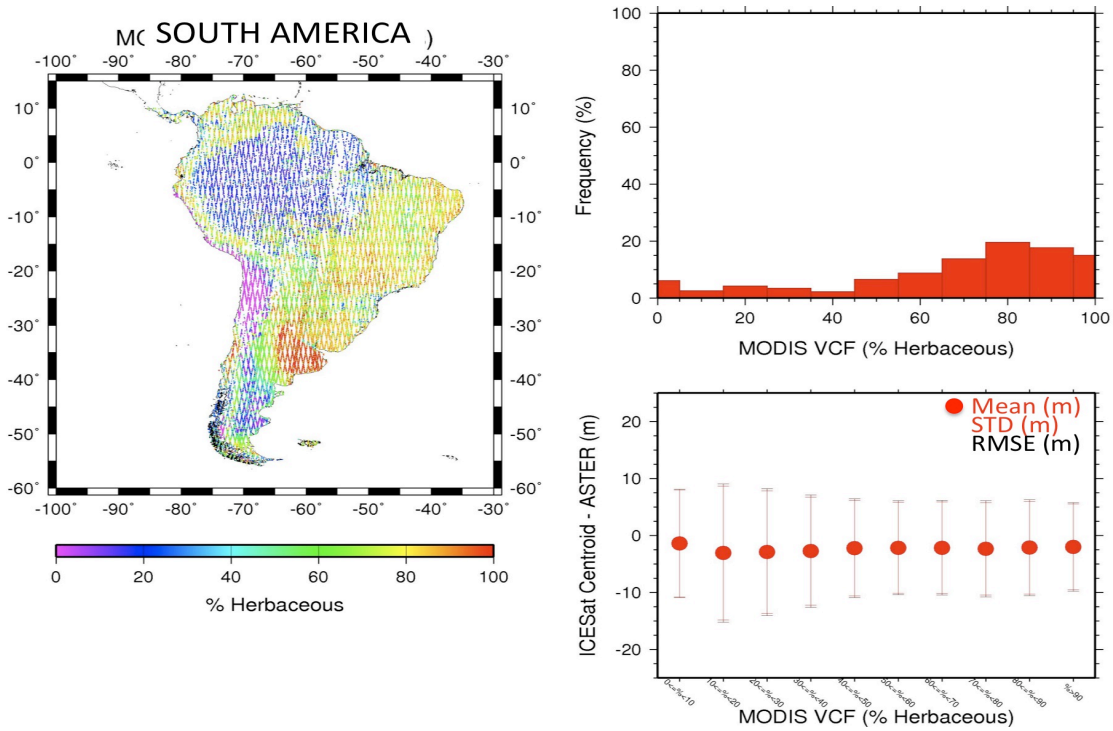


Figure 5_SA – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table SA_3b.

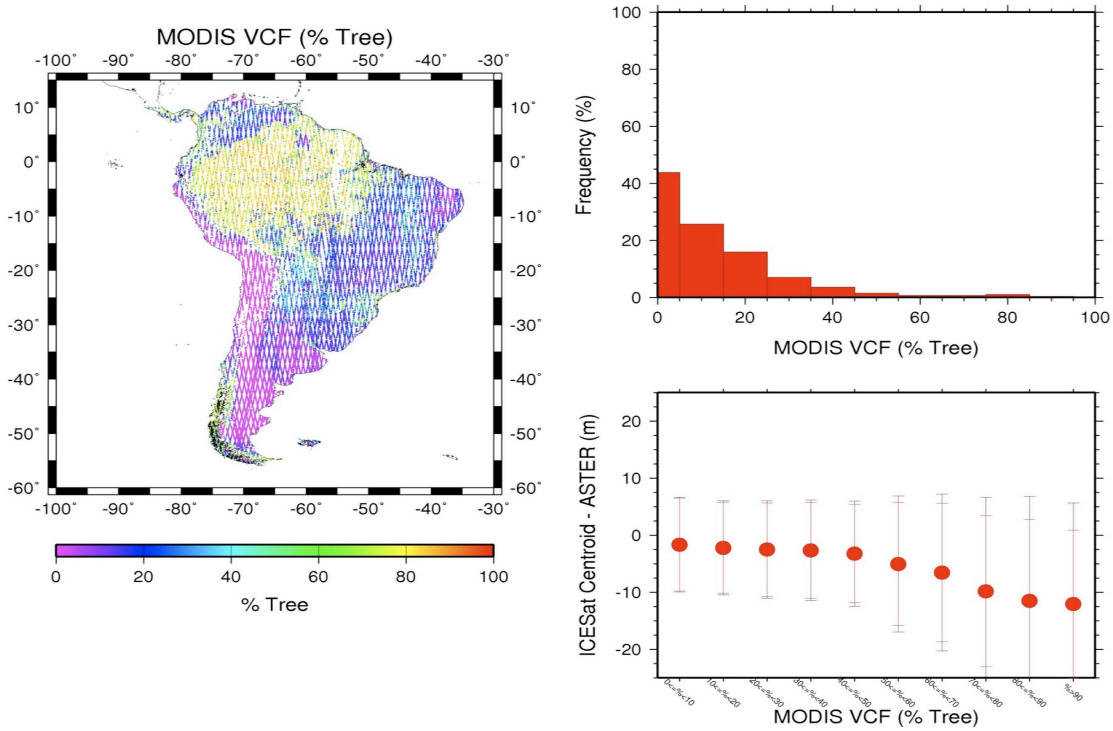


Figure 6_SA – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table SA_3b.

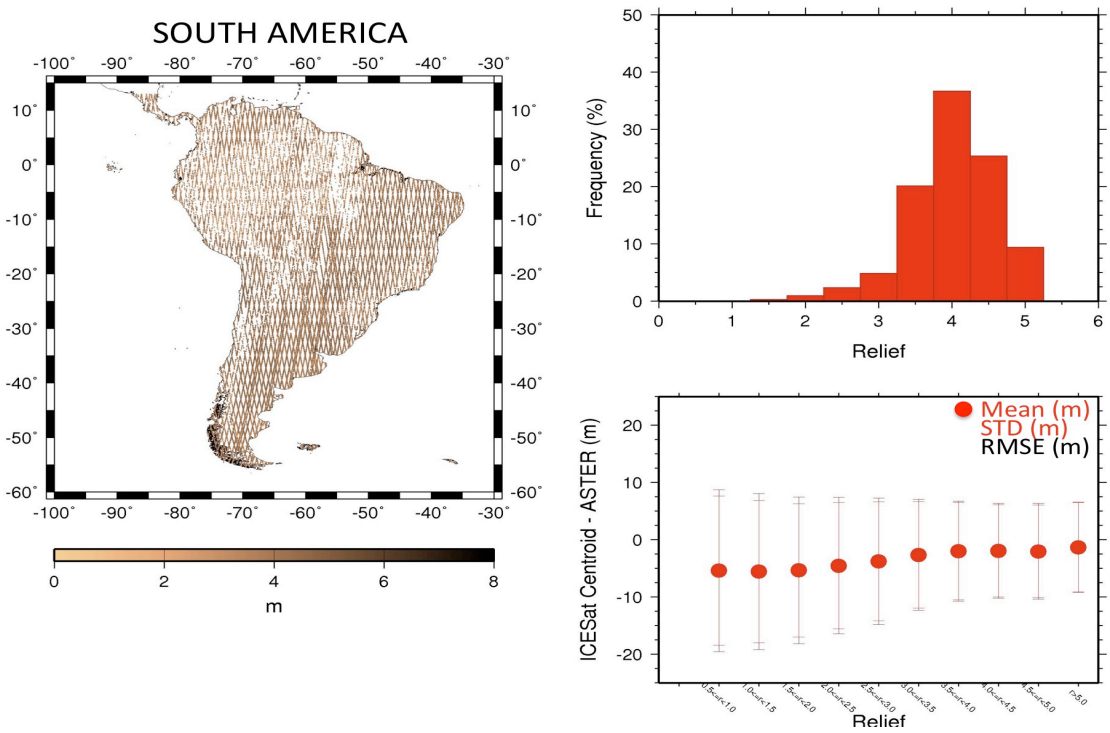


Figure 7_SA – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table SA_4 for complete statistics.

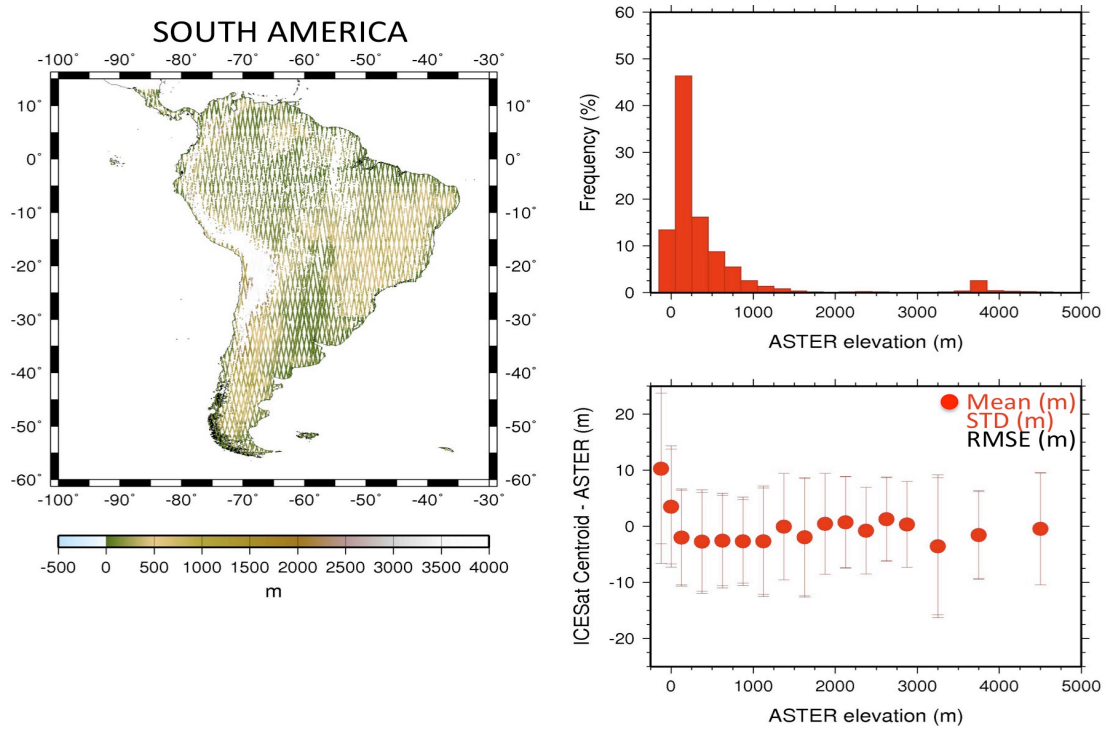


Figure 8_SA – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table SA_5 for complete statistics.

Observations for South America:

Figure 1_SA shows elevation differences between ICESat and ASTER that also exhibit relatively normal distributions, and distributions slightly skewed towards negative values (ASTER above ICESat by 2.17 m±8.51 m, with a median of -1.84 m). SRTM v2 (finished product) and ASTER seem to be in pretty good agreement as represented in the Global Statistics for the region. See Table SA_1.

Largest mean differences are observed where other data sources were used for fill, and when less than 4 scenes were used, while the smallest negative mean differences are seen when 9 to 15 scenes are used, with smaller standard deviations and RMSE values as more scenes are used. Mean differences become increasingly positive as the number of scenes increases. See Tables SA_2a and and SA_2b, and Figure 2_SA for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, mean differences and standard deviations are pretty consistent, except for the least represented categories. For bare regions ASTER is above ICESat by 0.1186 m±7.92 m. Largest mean differences are seen for LC = 41, 161 and 170, corresponding to Closed (>40%) broadleaved evergreen and/or semideciduous forest (>5m), Closed to open broadleaved forest on (semi-) permanently flooded land – Fresh water, and Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water, respectively. See Table SA_3a and Figure 3_SA.

When looking at the differences with respect to % bare cover from the VCF products, mean differences become less negative as % bare cover increases, and slightly positive biases for lower bare cover. RMSEs do not exceed 9.5 m. Statistics are pretty consistent for most Herbaceous categories. In contrast, mean differences become more negative as the % tree cover increases, and standard deviations increase, with RMSEs that reach close to 18.5 m. See Tables SA_3b and Figures 4_SA, 5_SA and 6_SA.

The ICESat returns mostly represent areas with relief between 3 and 5 m. Maximum differences occur when relief is between 3.5 m and 4 m, where ASTER is above ICESat by ~2.0 m. There seems to be a decrease of the absolute differences and standard deviations as relief increases up to 5 m. RMSEs are up to 14 m. See Table SA_4 and Figure 7_SA.

Mean differences with respect to ASTER elevations are pretty consistent for elevations between 250 m and 1250 m, with ASTER above ICESat by ~2.6 m. Smaller RMSE values are seen between 500 m and 750 m, and 2250 m and 3000 m. See Table SA_5 and Figure 8_SA.

NORTH AMERICA:

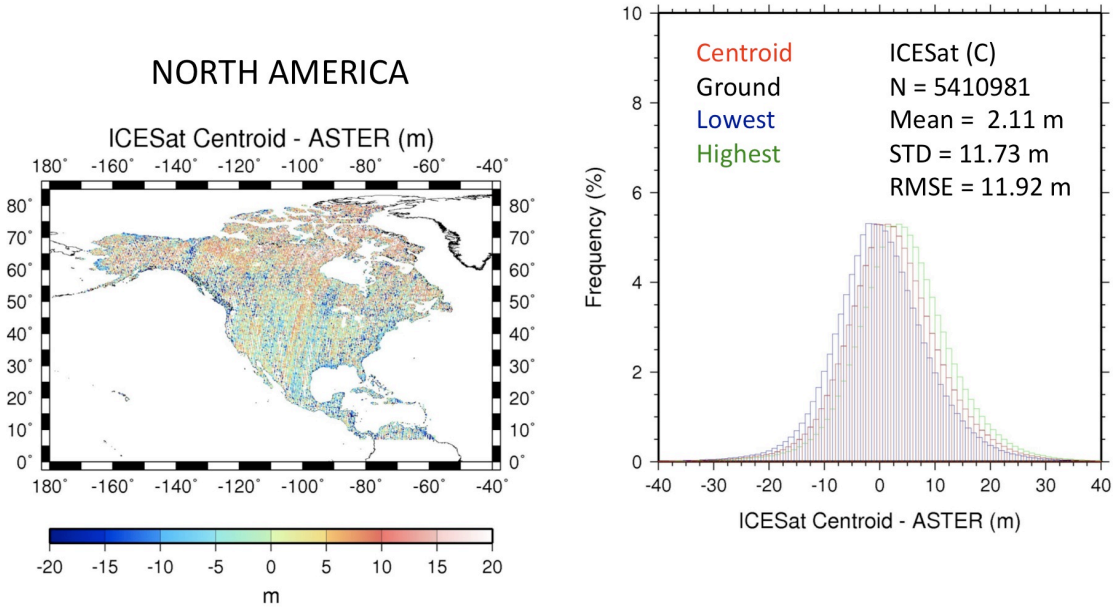


Figure 1_NA – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table NA_1 for Global Statistics.

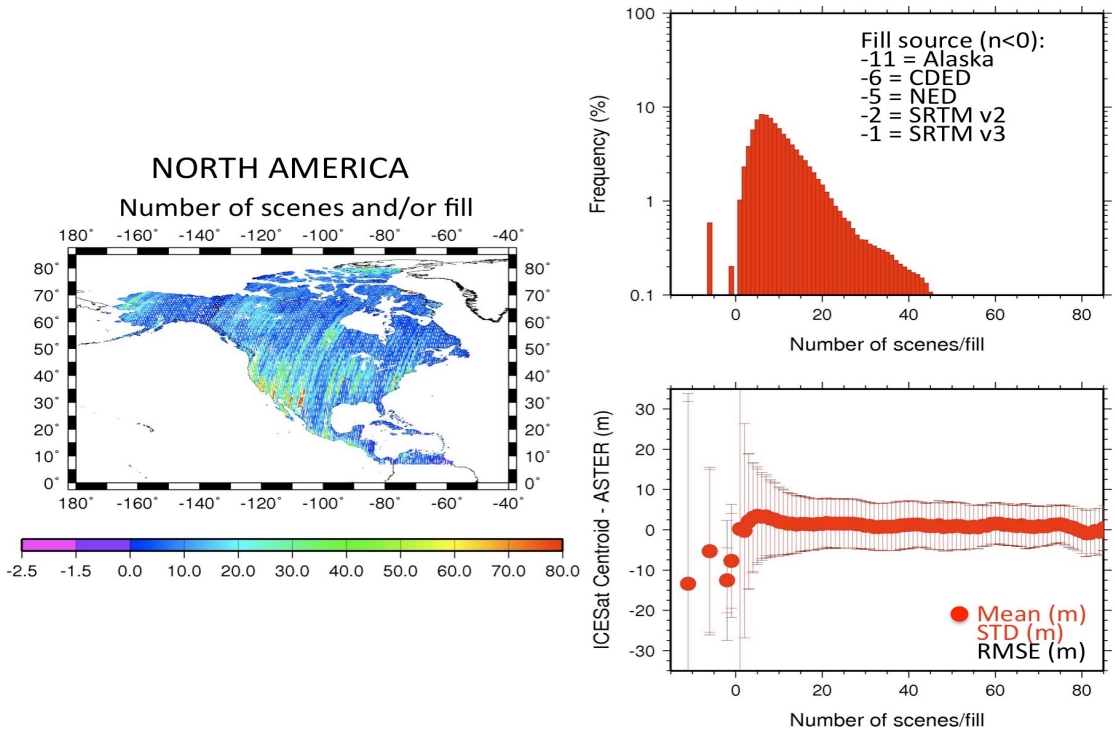


Figure 2_NA – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table NA_2a. Those for each category of NUM (plotted here) are in Table NA_2b.

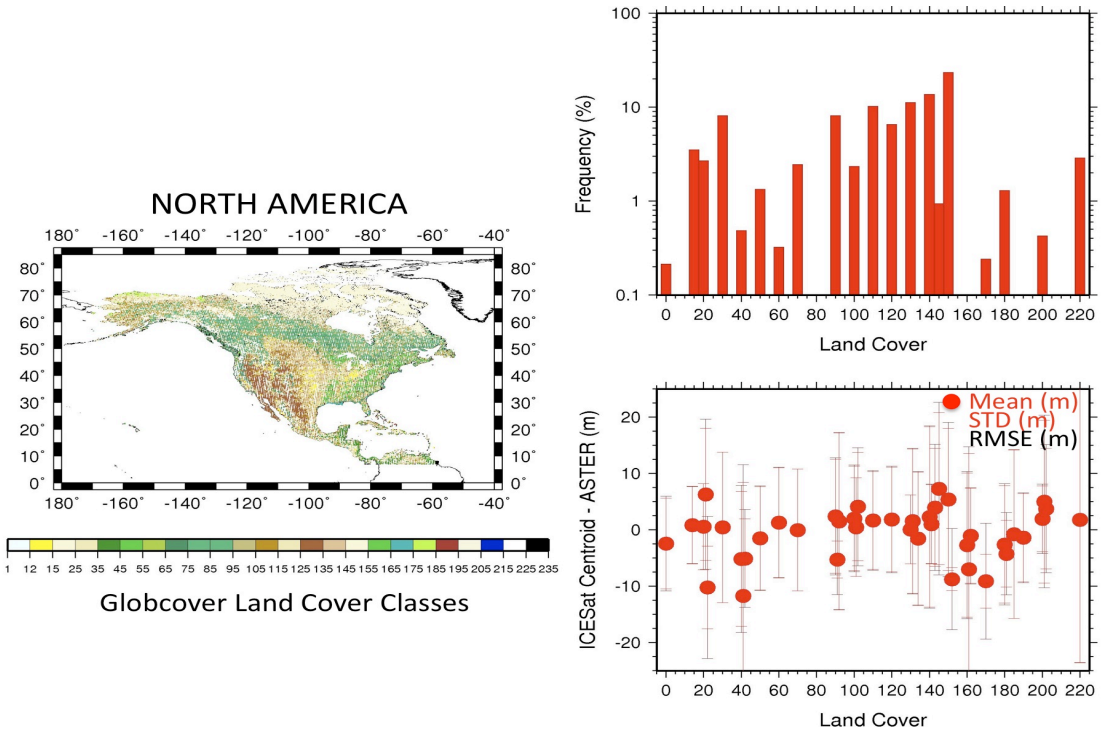


Figure 3_NA – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table NA_3a.

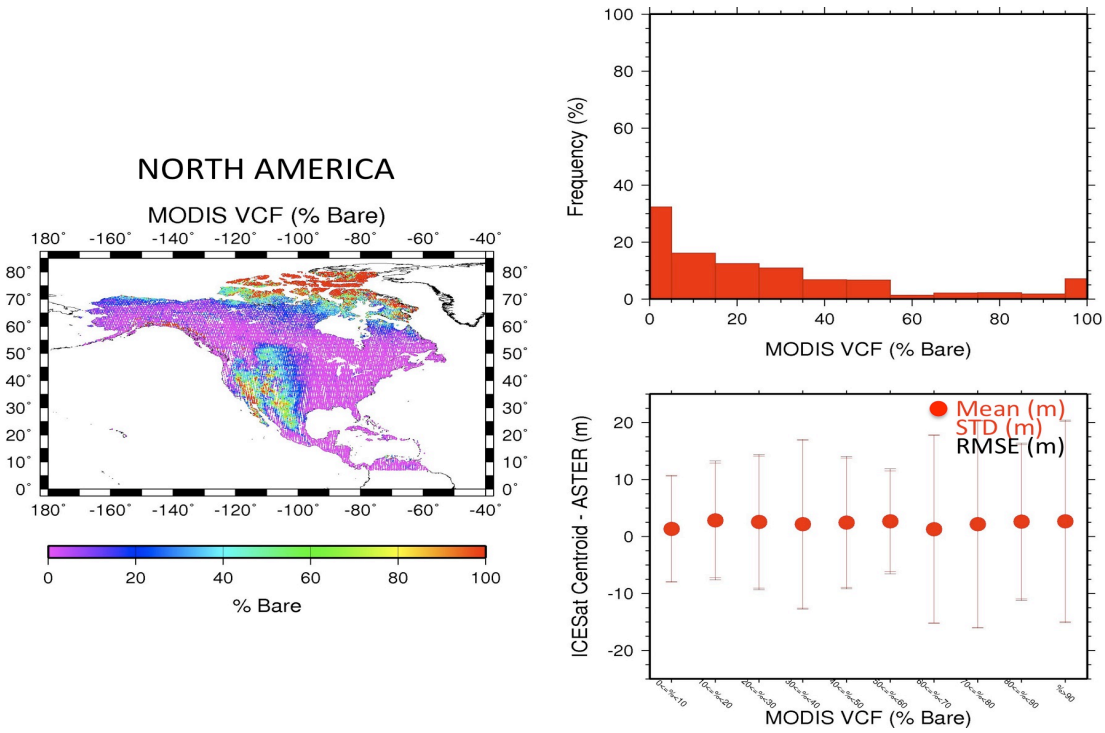


Figure 4_NA – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table NA_3b.

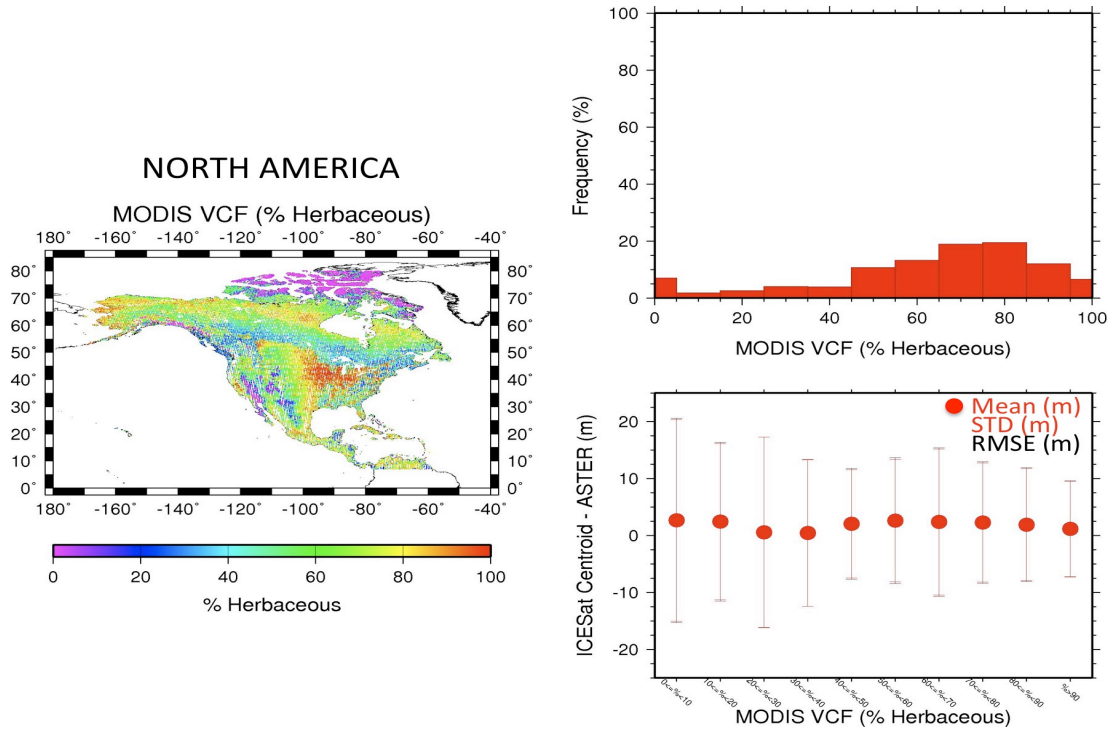


Figure 5_NA – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table NA_3b.

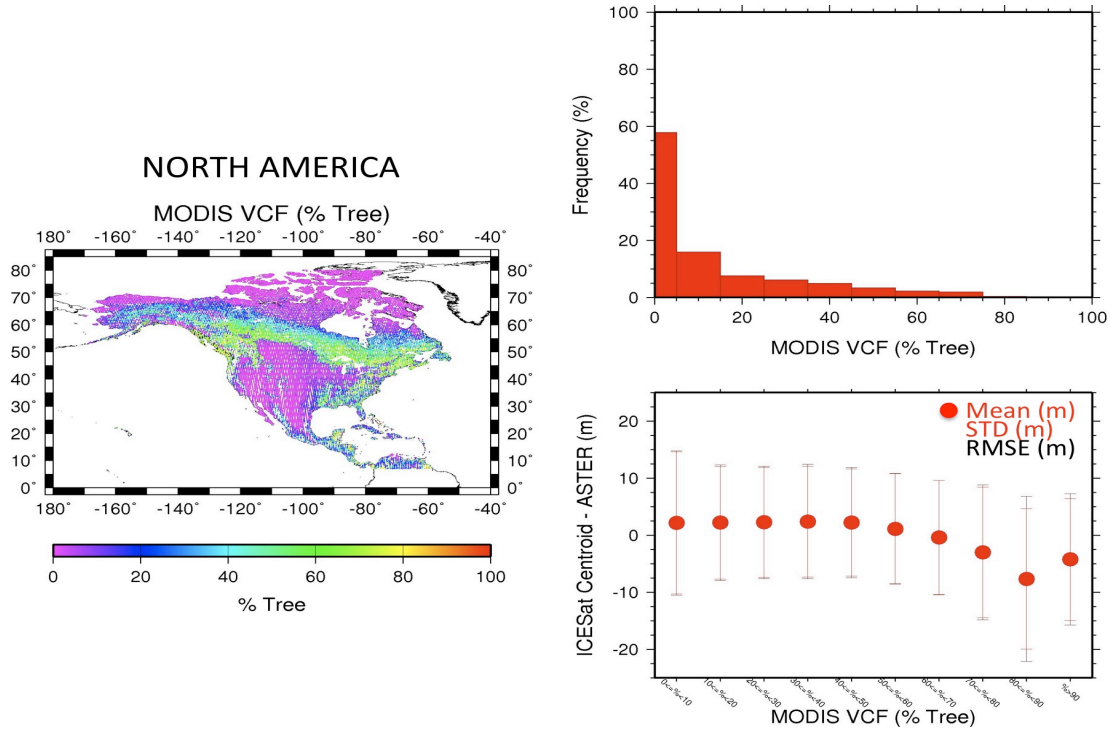


Figure 6_NA – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table NA_3b.

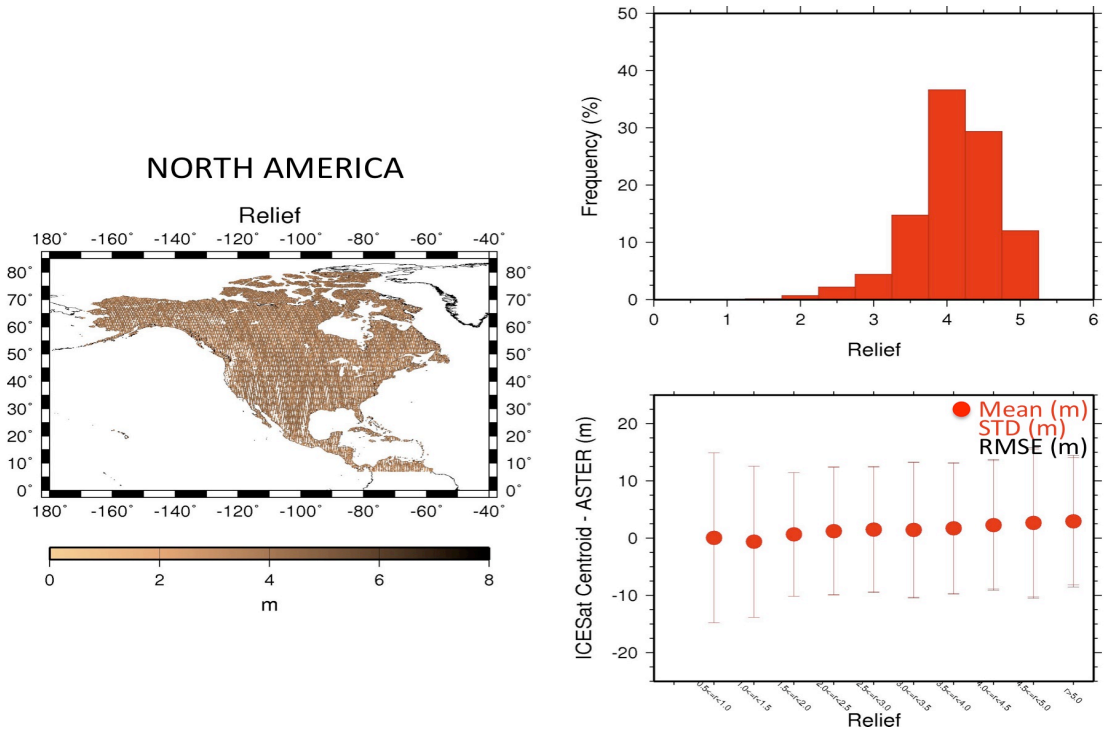


Figure 7_NA – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table SA_4 for complete statistics.

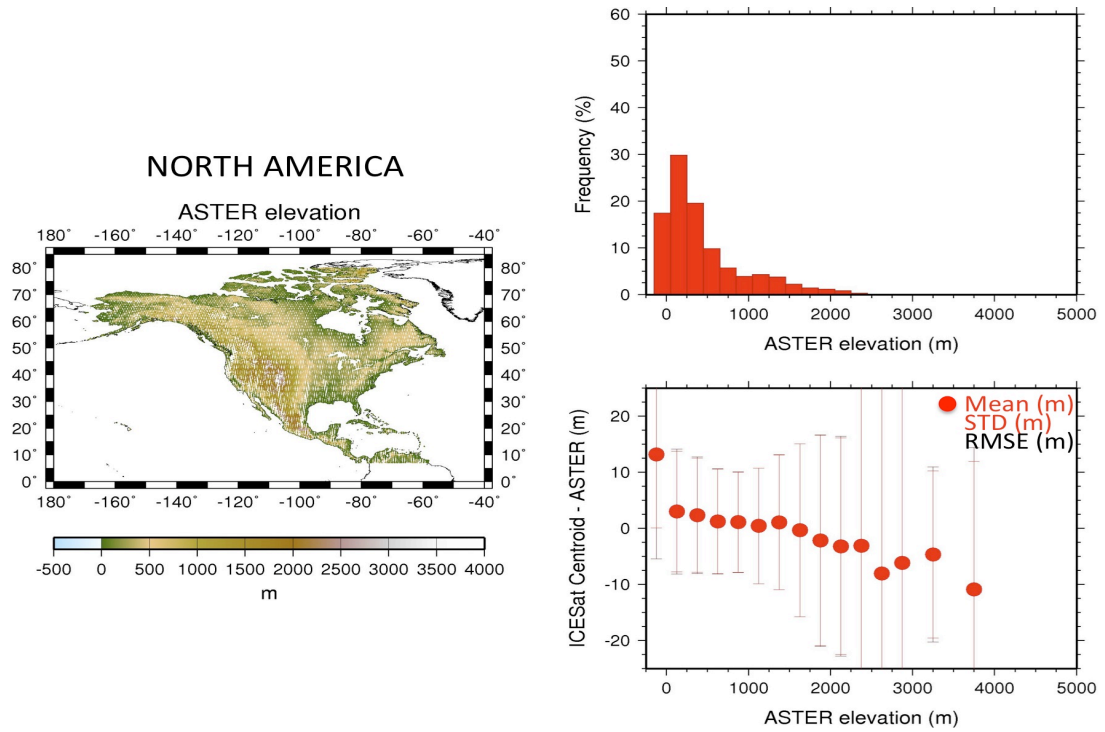


Figure 8_NA – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table NA_5 for complete statistics.

Observations for North America:

Figure 1_NA shows elevation differences between ICESat and ASTER that also exhibit relatively normal distributions. ASTER is below ICESat by 2.11 m±11.73 m, with a median of 1.96 m). SRTM v2 (finished product) is above ASTER by 0.81 m as represented in the Global Statistics for the region. RMSE values do not exceed 12.5 m. See Table NA_1.

Largest mean differences are observed where other data sources were used for fill. Mean differences decrease as the number of scenes increases, with smaller standard deviations and RMSE values as more scenes are used, and become stable when more than 15 scenes are used. See Tables NA_2a and NA_2b, and Figure 2_NA for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, mean differences and standard deviations are pretty consistent, except for the least represented categories. For bare regions ASTER is above ICESat by 1.96 m±5.86 m. Largest negative mean differences are seen for LC = 41, 161 and 170, corresponding to Closed (>40%) broadleaved evergreen and/or semideciduous forest (>5m), Closed to open broadleaved forest on (semi-) permanently flooded land – Fresh water, and Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water, respectively. For LC=145 (Lichens or mosses) there are large positive mean differences around 8 m, but the class is less represented. See Table NA_3a and Figure 3_NA.

When looking at the differences with respect to % bare cover from the VCF products, mean differences become slightly more positive as % bare cover increases, and slightly positive biases for lower bare cover. RMSEs do not exceed 18.3 m. Mean differences decrease from positive to negative values as the % tree cover increases, and standard deviations are pretty stable, with RMSEs that reach close to 14.5 m. See Tables NA_3b and Figures 4_NA, 5_NA and 6_NA.

The ICESat returns mostly represent areas with relief between 3 and 5 m. There is an increase in the mean differences with relief, where ASTER is below ICESat between 0 to 3.0 m. RMSEs are up to ~15 m. See Table NA_4 and Figure 7_NA.

Mean differences with respect to ASTER elevations show a marked decrease with increasing elevations, with ASTER becoming increasingly higher than ICESat for higher elevations. Smaller standard deviations and RMSE values are seen for elevations between 500 m and 1000 m. See Table NA_5 and Figure 8_NA.

AUSTRALIA:

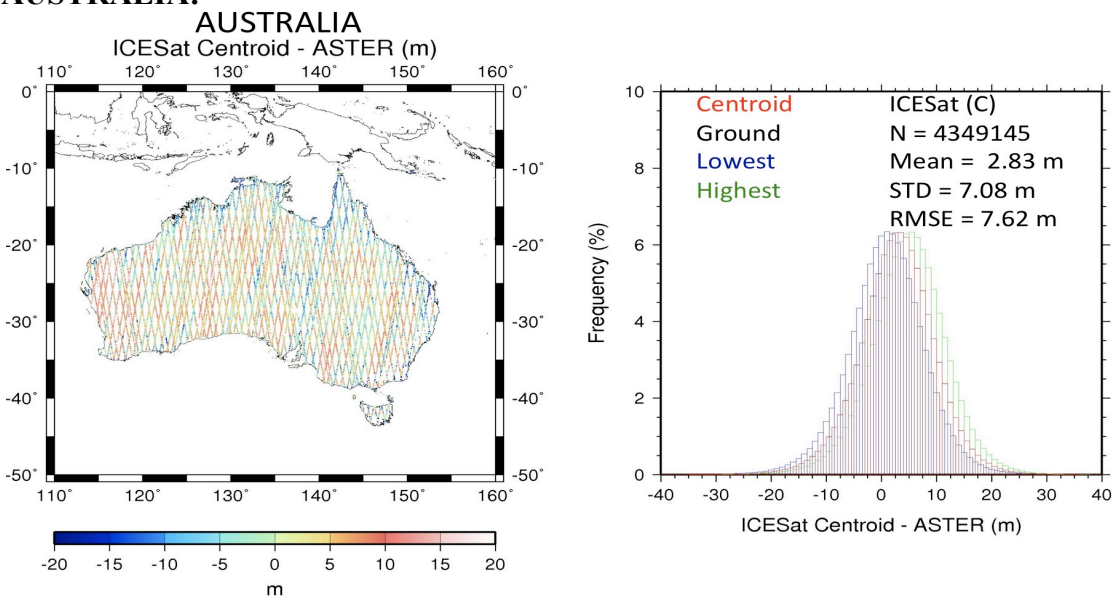


Figure 1_AU – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table AU_1 for Global Statistics.

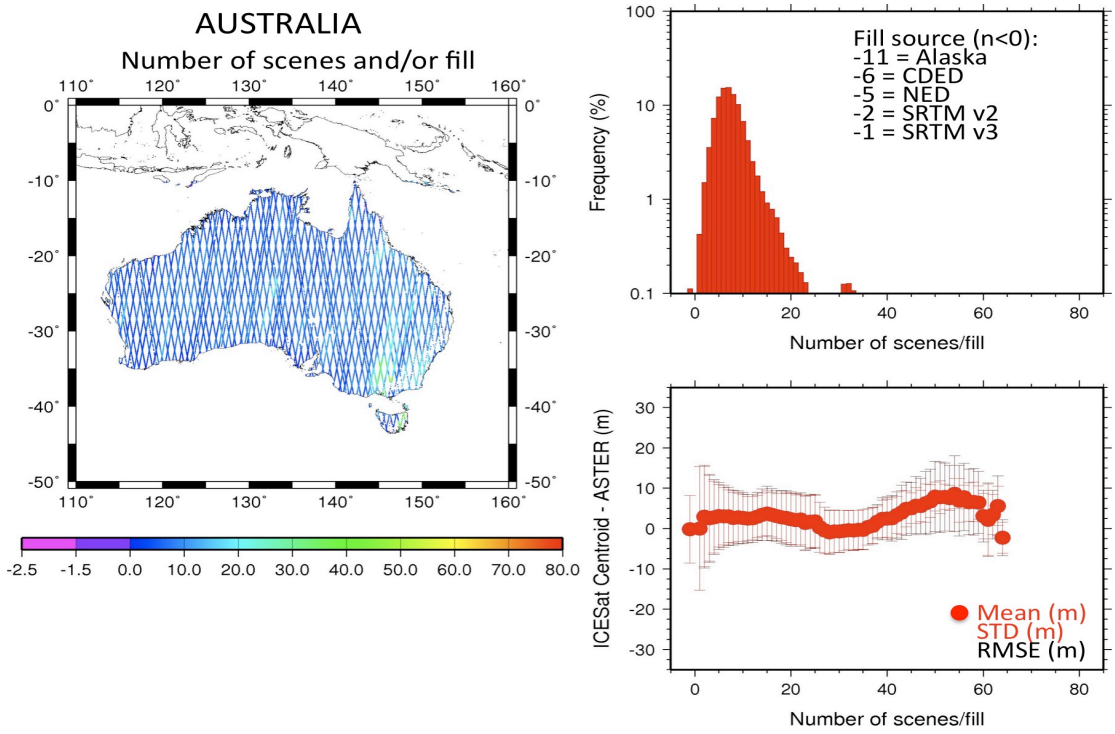


Figure 2_AU – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table AU_2a. Those for each category of NUM (plotted here) are in Table AU_2b.

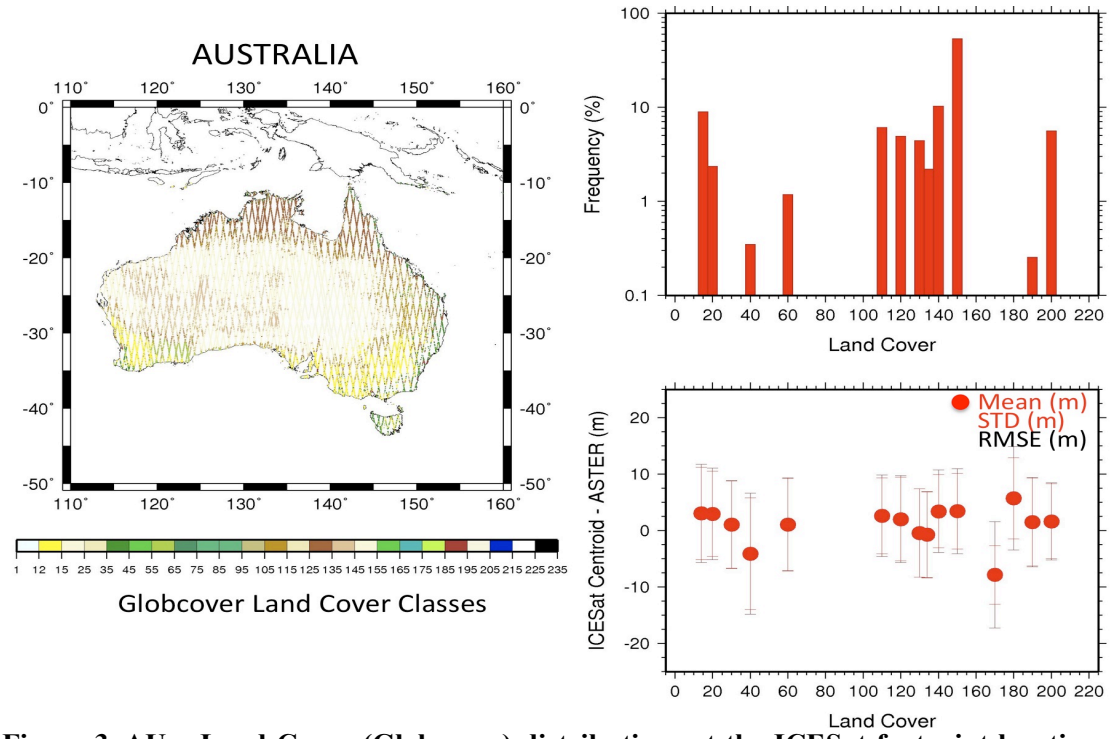


Figure 3_AU – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table AU_3a.

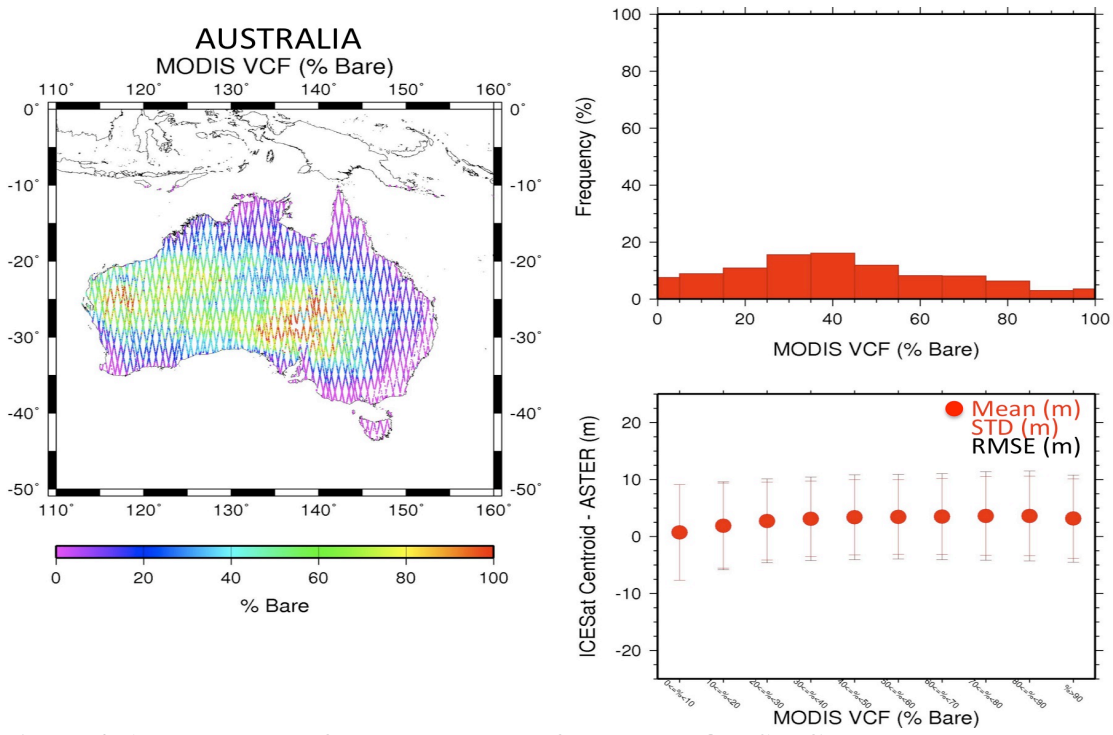


Figure 4_AU – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table AU_3b.

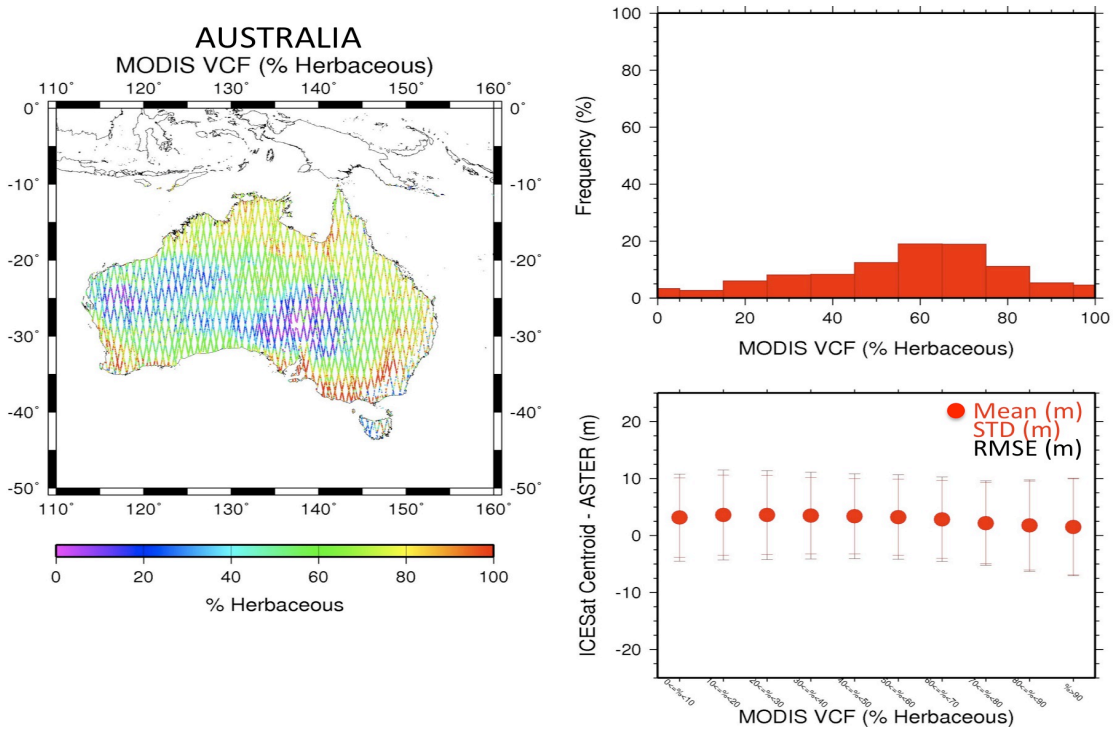


Figure 5_AU – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table AU_3b.

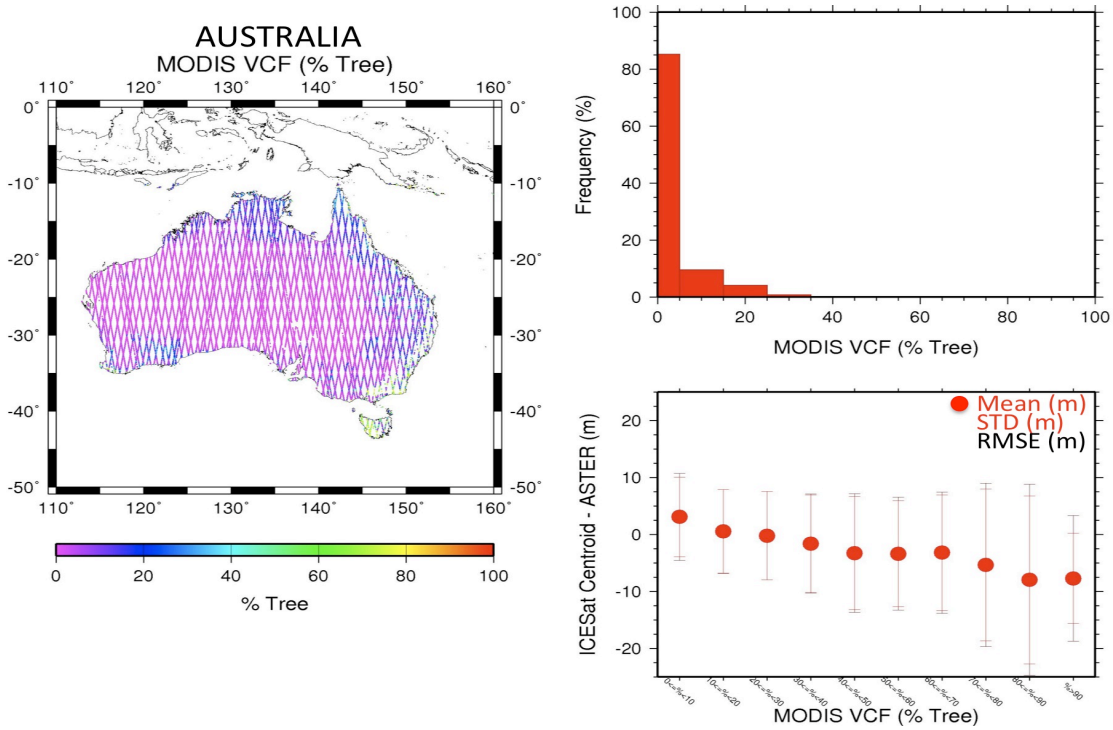


Figure 6_AU – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table AU_3b.

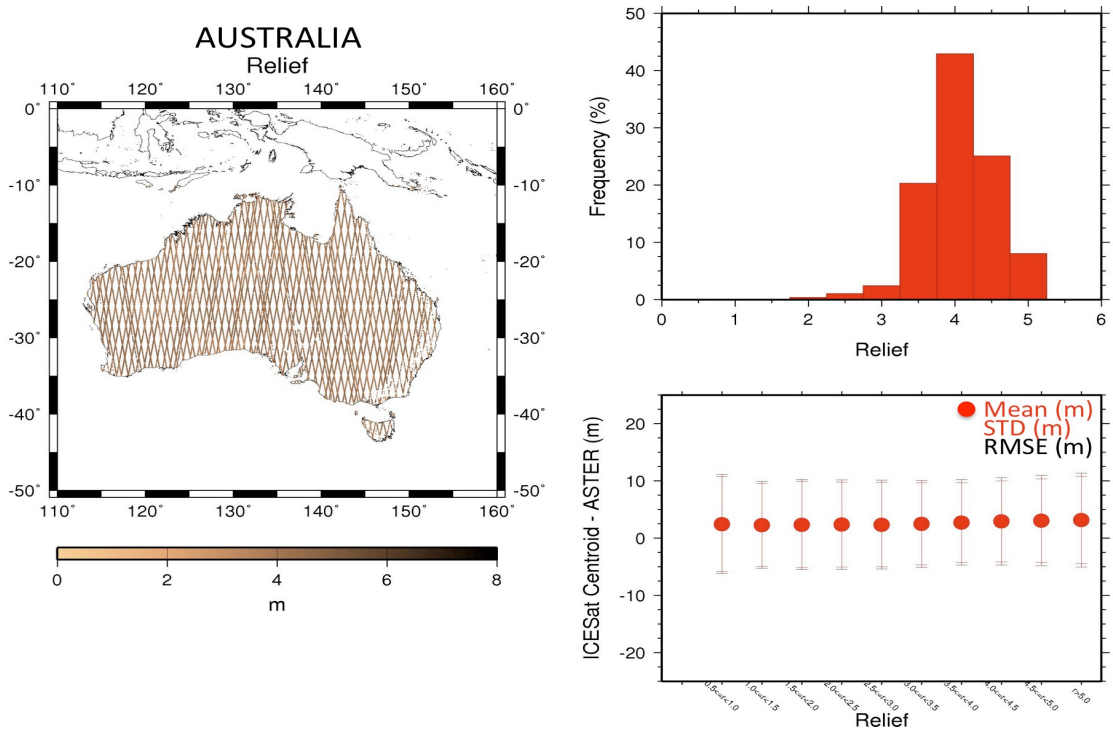


Figure 7_AU – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table AU_4 for complete statistics.

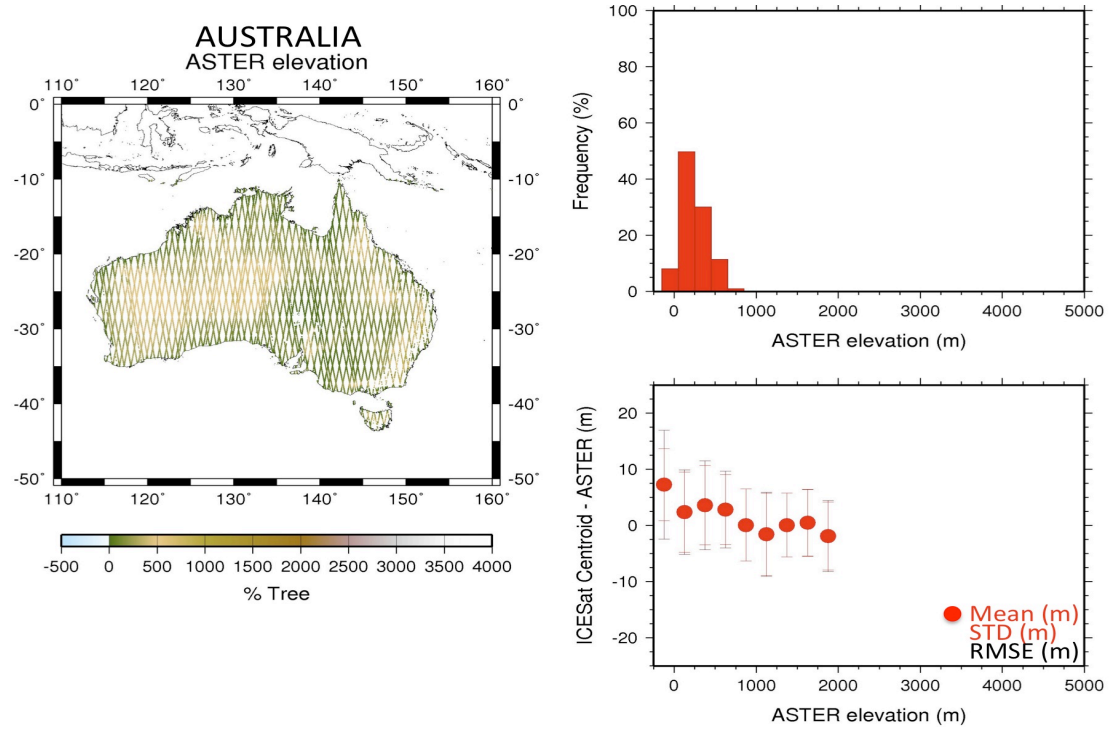


Figure 8_AU – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table AU_5 for complete statistics.

Observations for Australia:

Figure 1_AU shows elevation differences between ICESat and ASTER that exhibit relatively normal distributions. ASTER is below ICESat by 2.83 m±7.08 m, with a median of 2.97 m). SRTM v2 (finished product) is above ASTER by 4.90 m as represented in the Global Statistics for the region. RMSE values do not exceed 8.6 m. See Table AU_1.

Mean differences and standard deviations are pretty stable, with larger RMSE values when < 5 scenes are used. See Tables AU_2a and AU_2b, and Figure 2_AU for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, mean differences and standard deviations are pretty consistent. For bare regions ASTER is below ICESat by 1.64 m±6.64 m. Largest negative mean differences are seen for LC = 40, and 170, corresponding to Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m), and Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water, respectively. See Table AU_3a and Figure 3_AU.

When looking at the differences with respect to % bare cover from the VCF products, mean differences become consistent when % bare cover increases above 20%, with a positive trend between 0 and 20% bare cover. RMSEs do not exceed 8.5 m. Mean differences become more negative as as the % tree cover increases above 20%, as the number of point decreases significantly, and standard deviations are pretty stable. See Tables AU_3b and Figures 4_AU, 5_AU and 6_AU.

The ICESat returns mostly represent areas with relief between 3 and 5 m. There is an increase in the mean differences with increasing relief, where ASTER is below ICESat between 2 to 3.2 m. RMSEs are up to ~8.7 m. See Table AU_4 and Figure 7_AU.

Mean differences with respect to ASTER elevations show a decrease with increasing elevations, with ASTER becoming increasingly higher than ICESat for higher elevations. However, the observations at elevations above 1000 are significantly less. See Table AU_5 and Figure 8_AU.

NEW ZEALAND

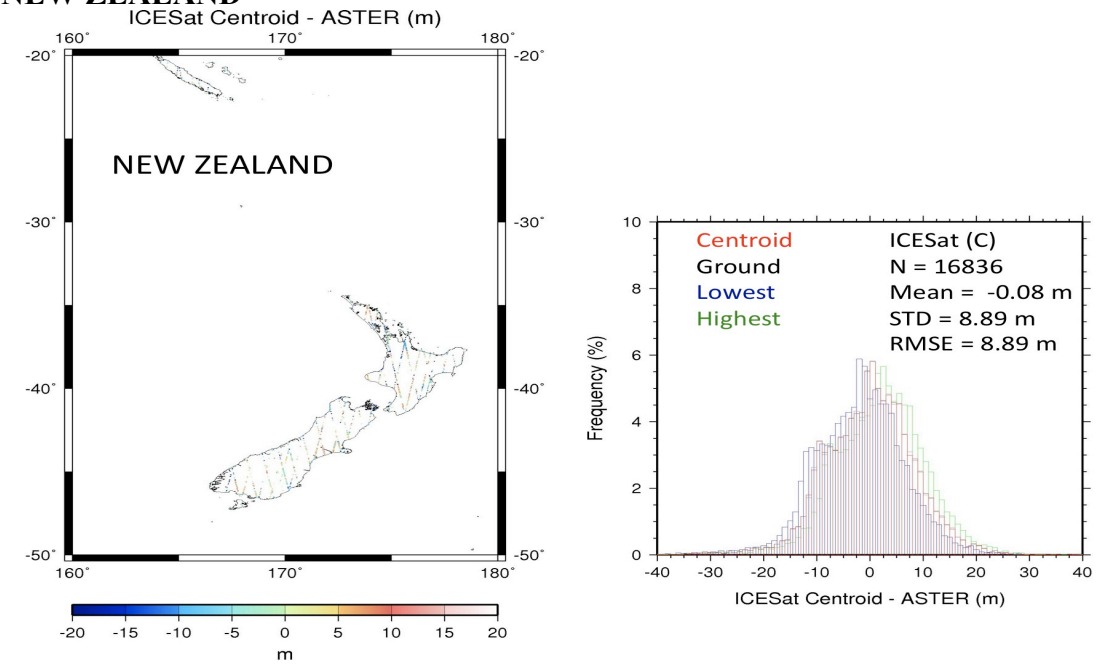


Figure 1_NZ – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table NZ_1 for Global Statistics.

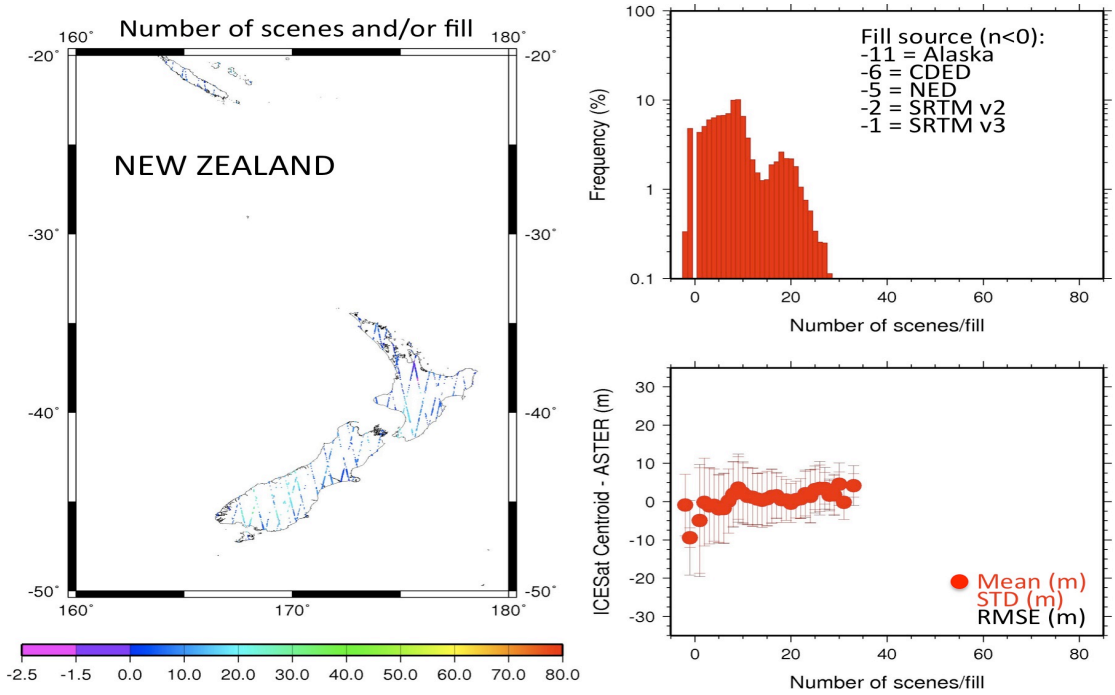


Figure 2_NZ – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table NZ_2a. Those for each category of NUM (plotted here) are in Table NZ_2b.

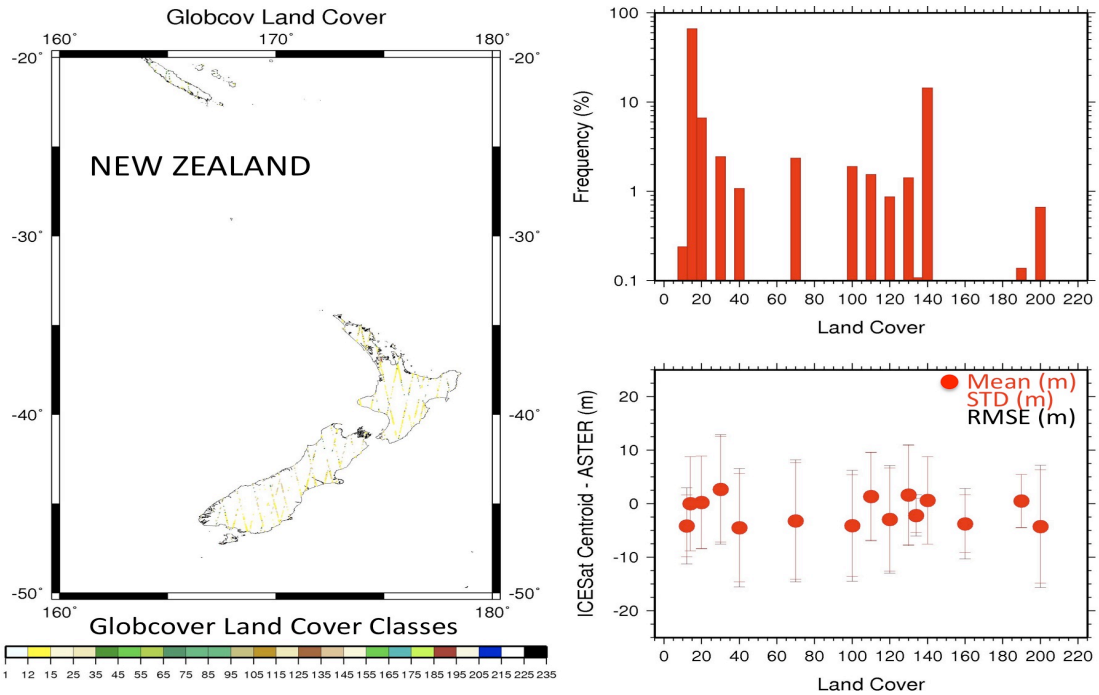


Figure 3_NZ – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table NZ_3a.

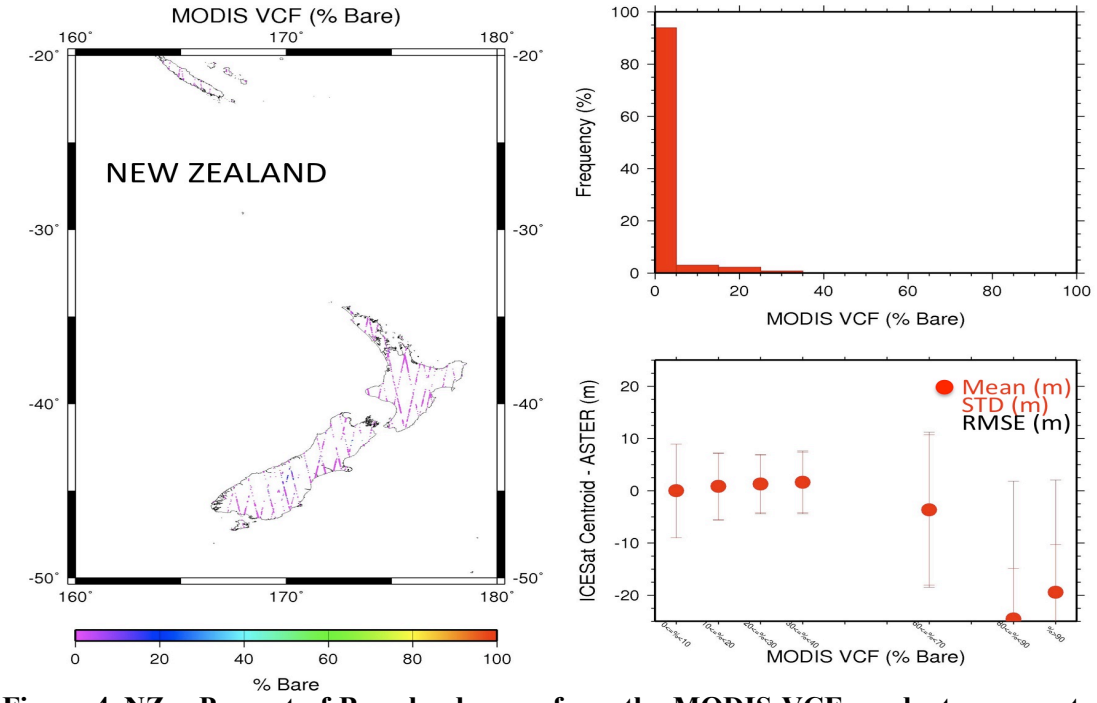


Figure 4_NZ – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table NZ_3b.

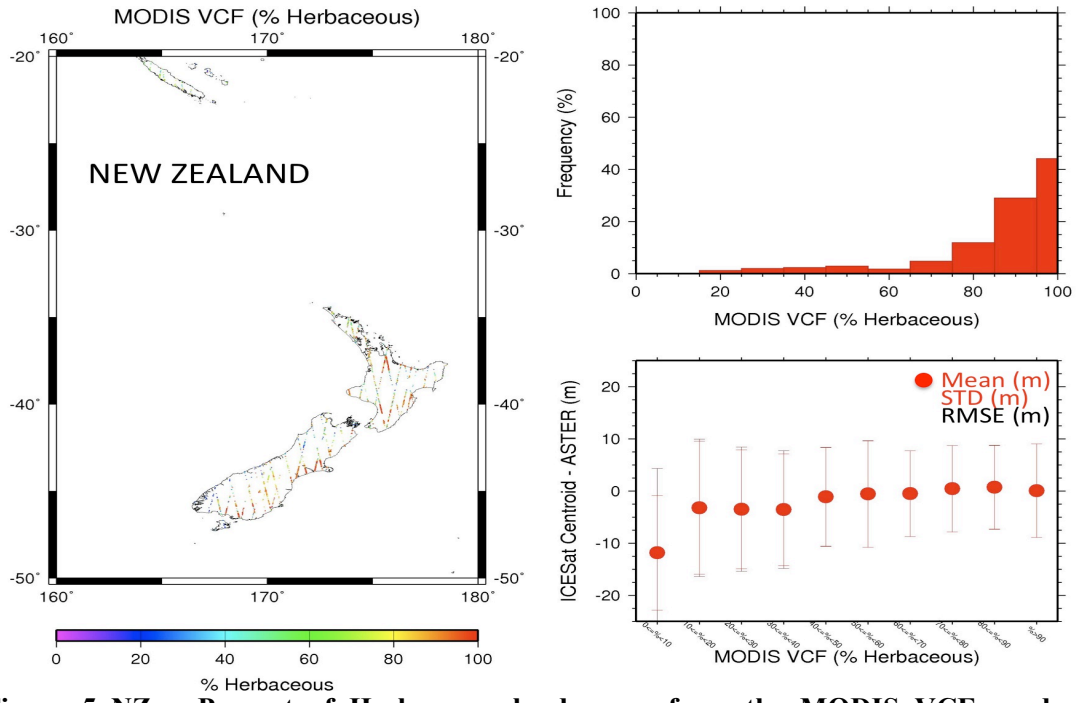


Figure 5_NZ – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table NZ_3b.

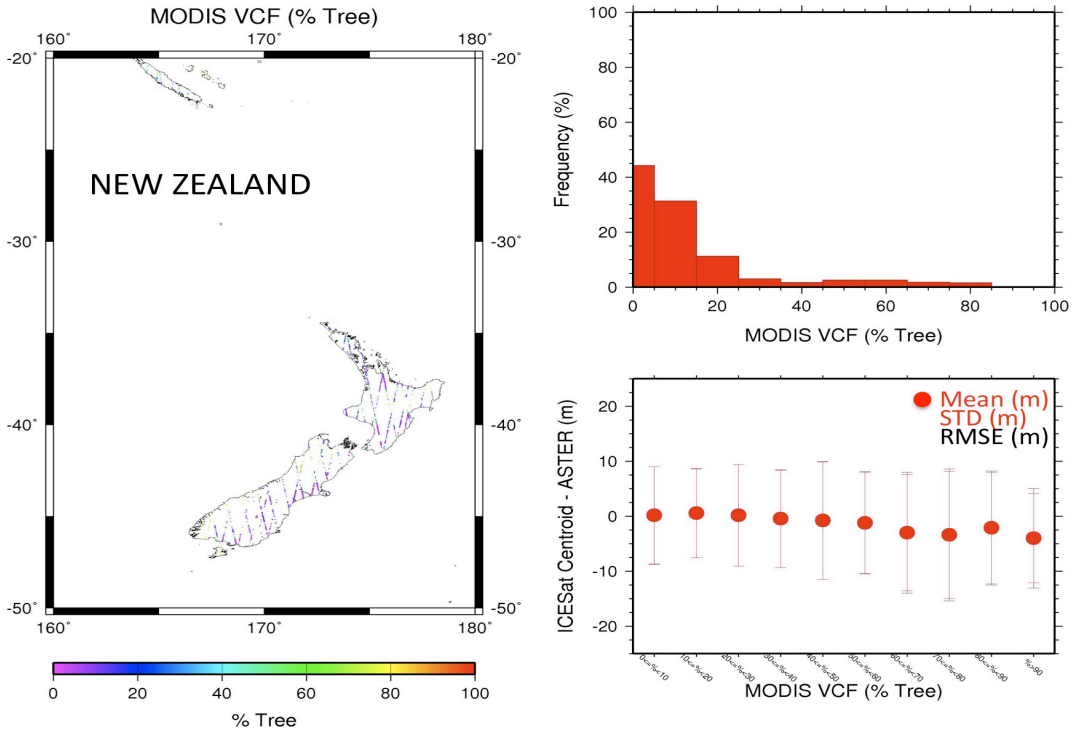


Figure 6_NZ – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table NZ_3b.

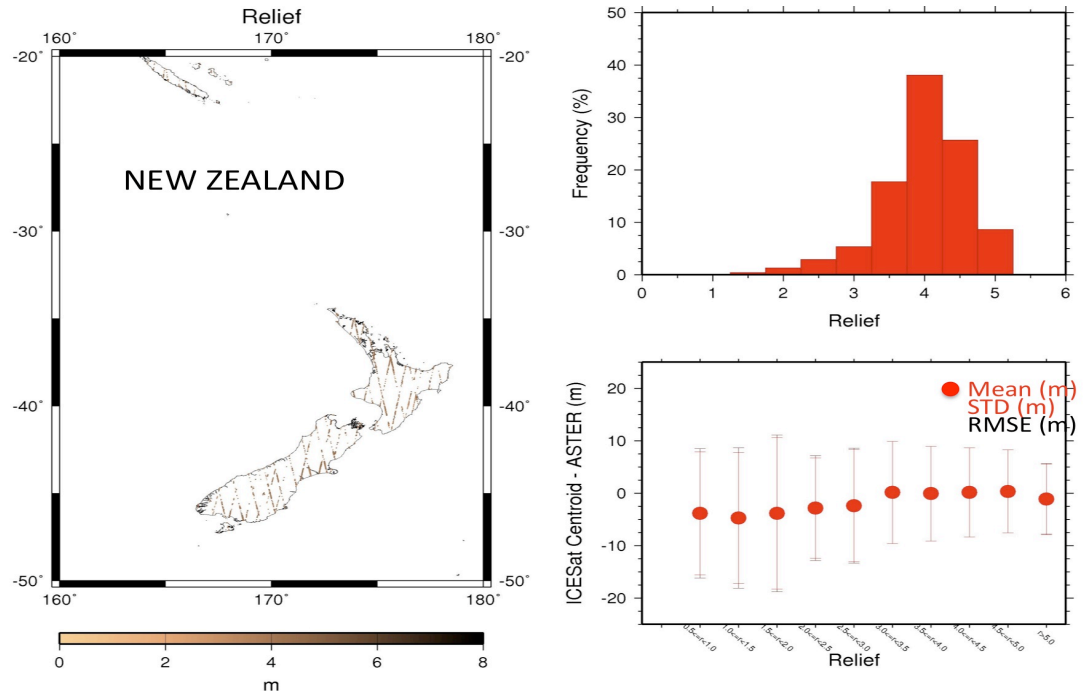


Figure 7_NZ – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table NZ_4 for complete statistics.

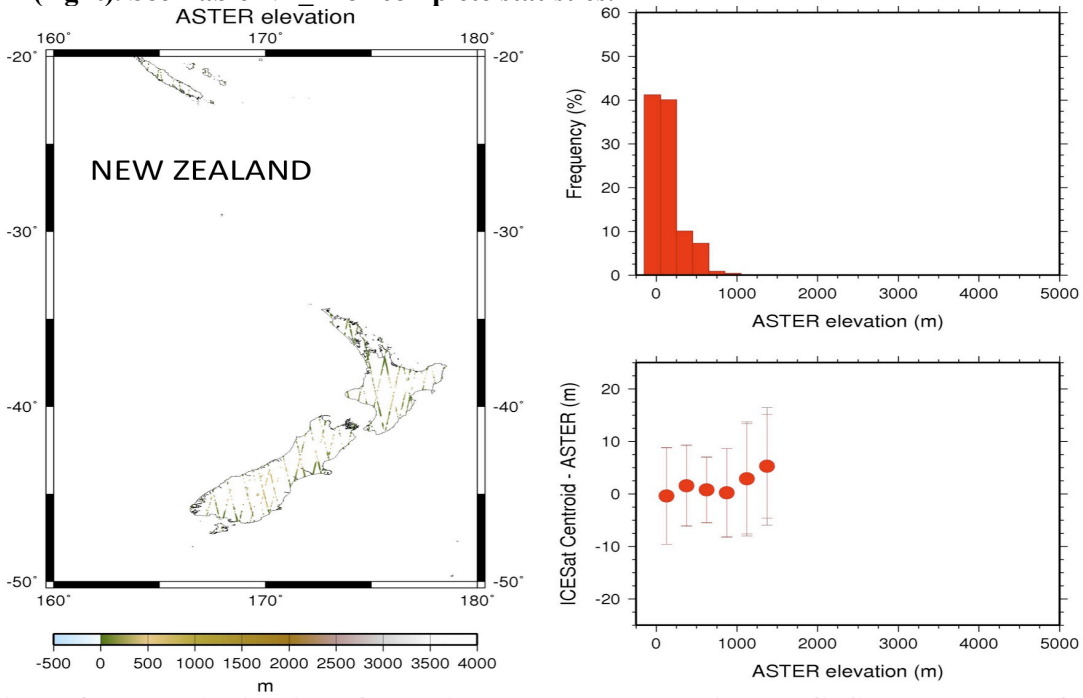


Figure 8_NZ – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table NZ_5 for complete statistics.

Observations for New Zealand:

Figure 1_NZ shows elevation differences between ICESat and ASTER that exhibit not normal distributions negatively skewed. ASTER is above ICESat by 0.08 m±8.89 m, with a median of 0.28 m). SRTM v2 (finished product) is above ASTER by 1.70 m as represented in the Global Statistics for the region. RMSE values do not exceed 9.2 m. See Table NZ_1.

Mean differences and standard deviations are pretty stable for all number of scenes, with larger RMSE values when < 5 scenes are used. See Tables NZ_2a and NZ_2b, and Figure 2_AU for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, the largest represented class (~70% of the returns) is in the Rainfed croplands (LC=14). Mean and standard deviations are -0.02±8.80 m. For bare regions ASTER is above ICESat by -4.25 m±10.59 m, but this class represents less than 1% of the data. See Table NZ_3a and Figure 3_NZ.

When looking at the differences with respect to % bare cover from the VCF products, most of the returns are at locations below 10% bare cover, below 10% for tree cover, and higher than 90% herbaceous. Mean differences for herbaceous > 90% are 0.06 m±8.97m. RMSEs do not exceed 12.02 m. No significant trends are observed. See Tables NZ_3b and Figures 4_NZ, 5_NZ and 6_NZ.

The ICESat returns mostly represent areas with relief between 3 and 5 m. Mean differences shift from negative to positive with increasing relief, where ASTER is above or below ICESat between 5 to 0.4 m, respectively. RMSEs are up to ~15.0 m. See Table NZ_4 and Figure 7_NZ.

Mean differences with respect to ASTER elevations show a positive trend with increasing elevations, with ASTER becoming increasingly lower than ICESat for higher elevations. However, most observations are at elevations below 750 m. See Table NZ_5 and Figure 8_NZ.

WESTERN EUROPE:

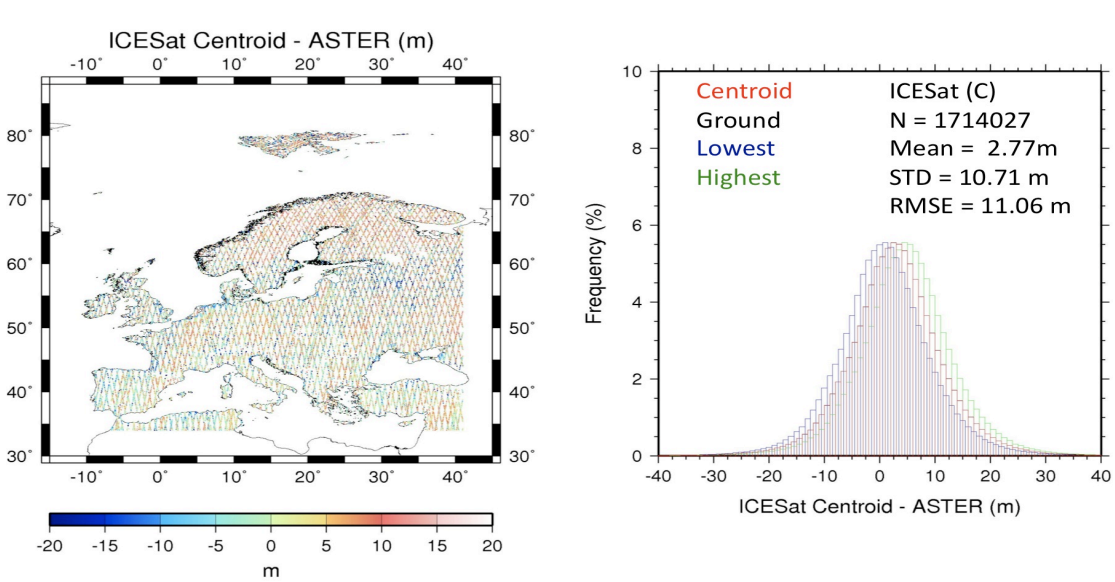


Figure 1_WEU – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table WEU_1 for Global Statistics.

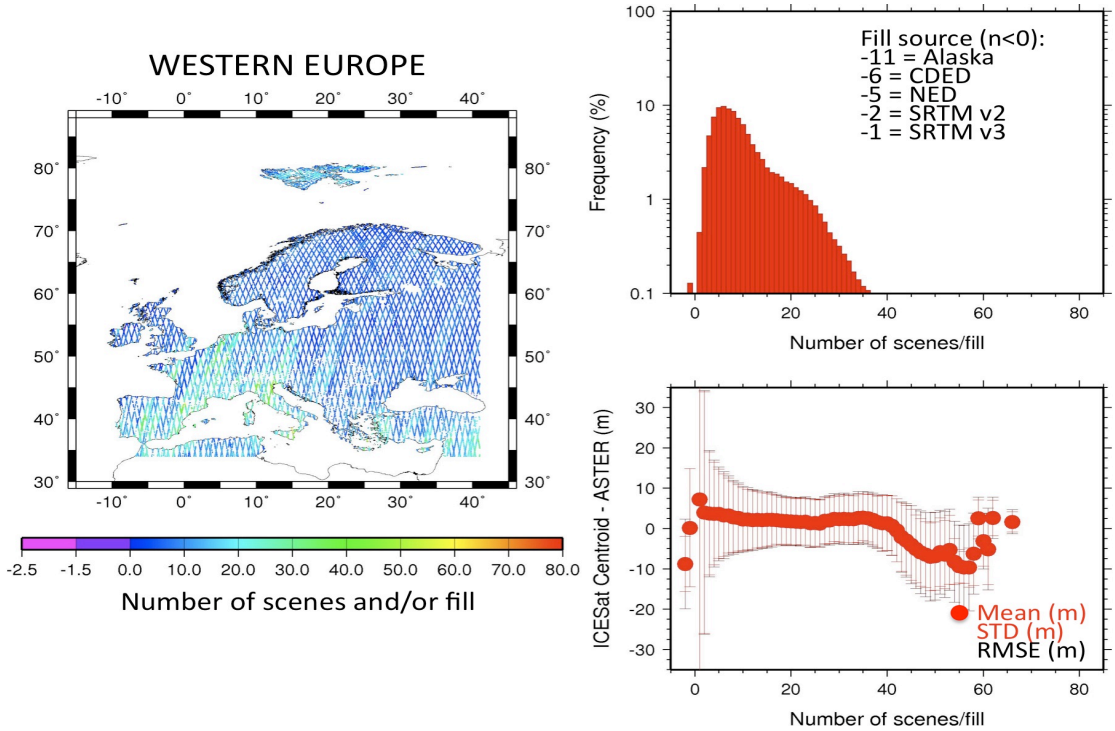


Figure 2_WEU – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table WEU_2a. Those for each category of NUM (plotted here) are in Table WEU_2b.

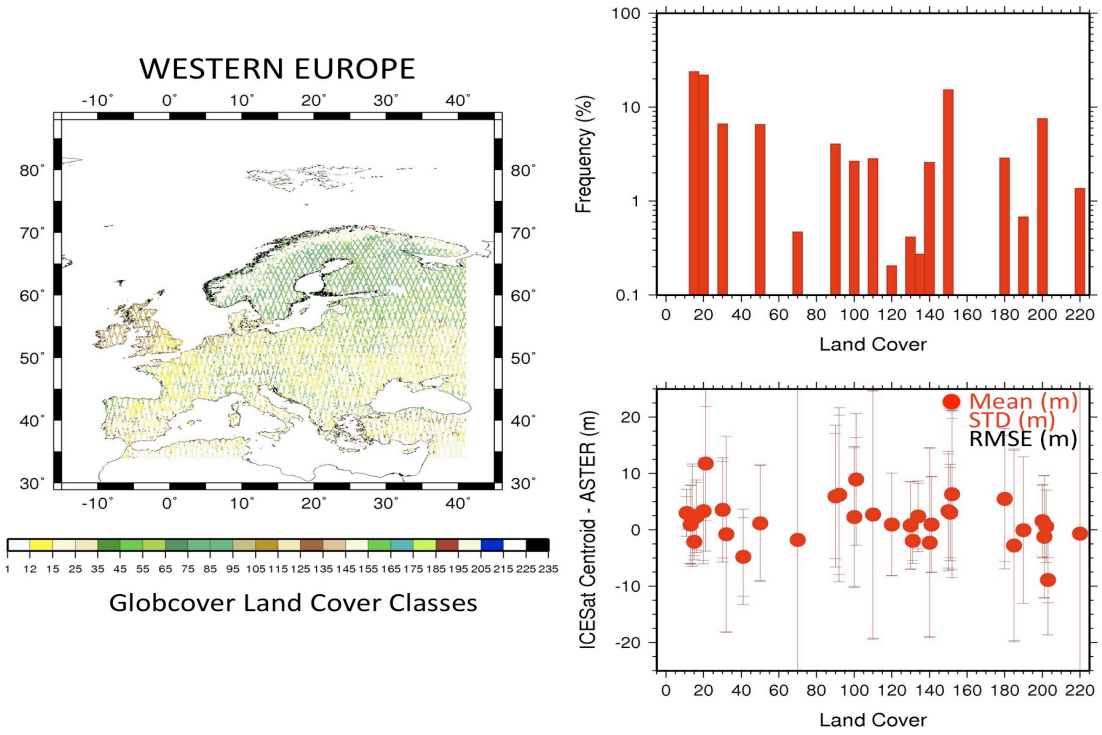


Figure 3_WEU – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table WEU_3a.

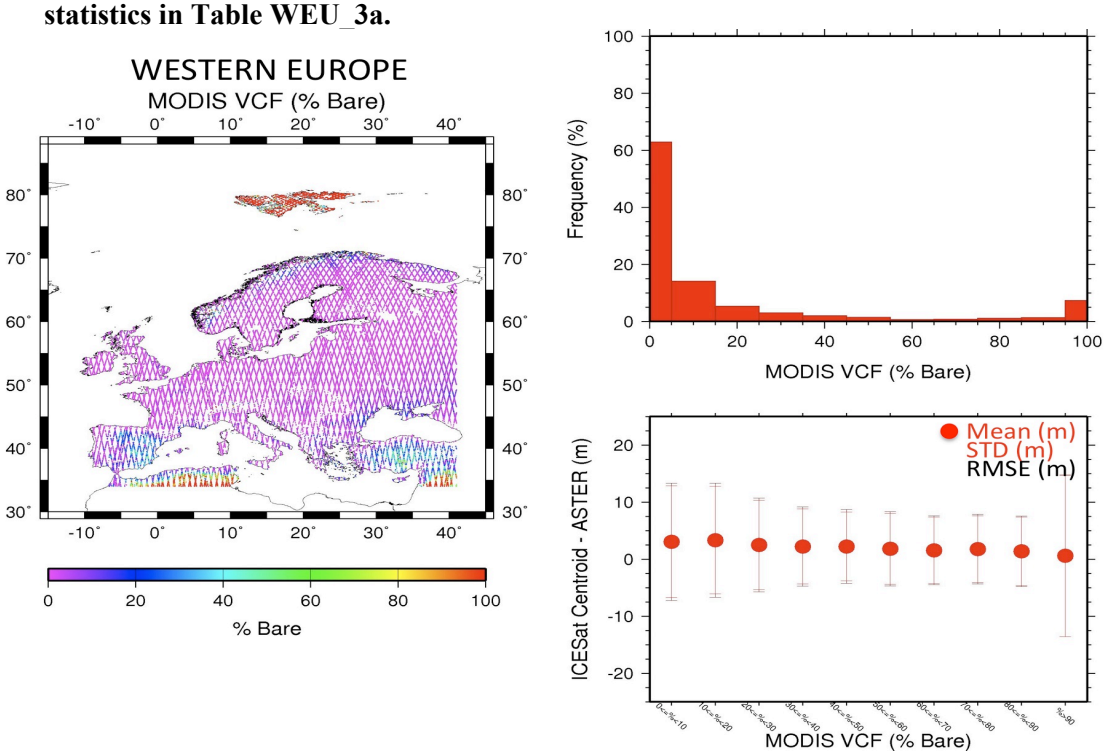


Figure 4_WEU – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table WEU_3b.

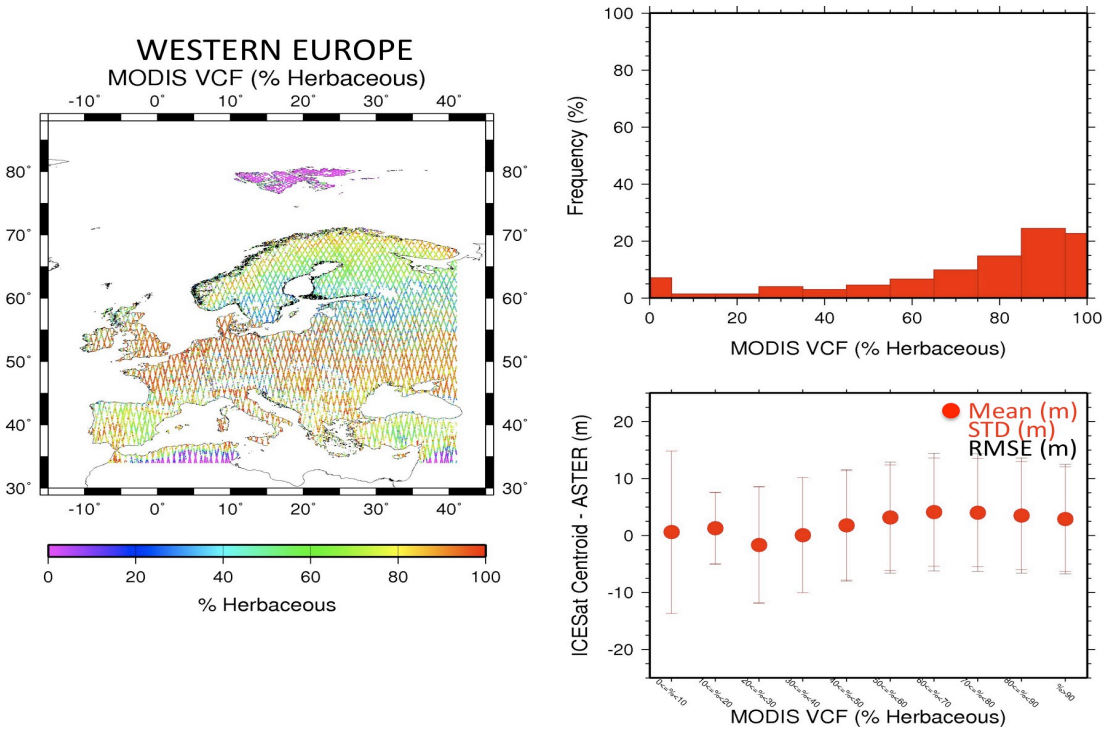


Figure 5_WEU – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table WEU_3b.

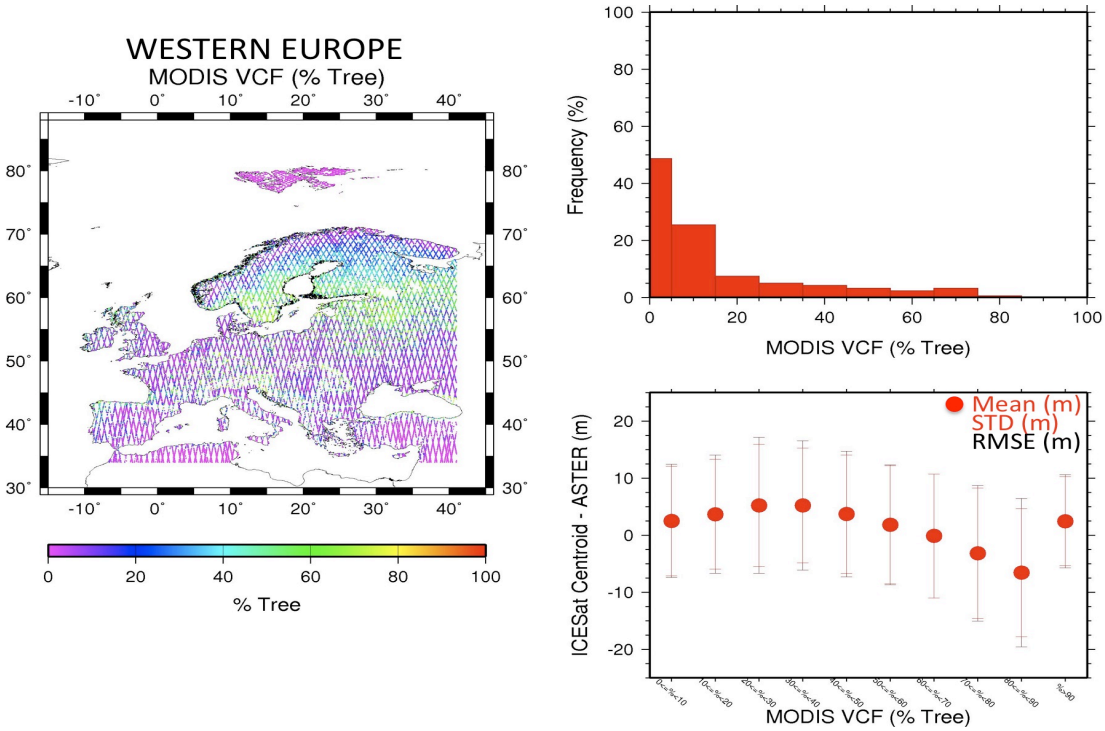


Figure 6_WEU – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table WEU_3b.

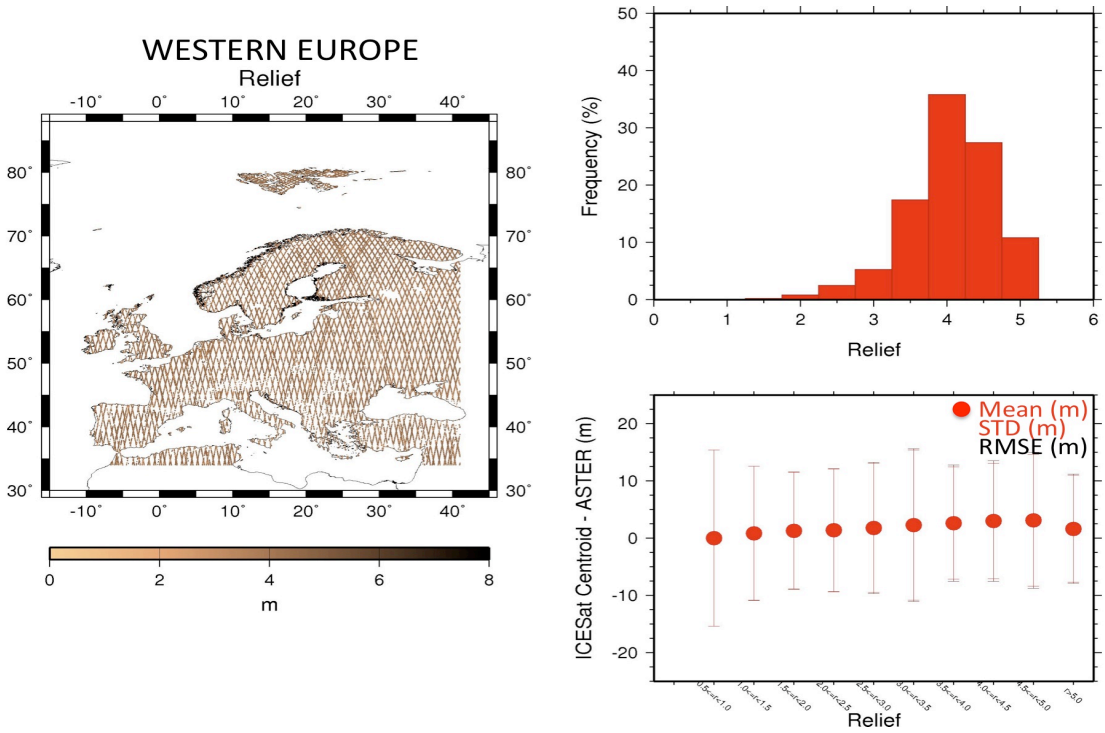


Figure 7_WEU – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table WEU_4 for complete statistics.

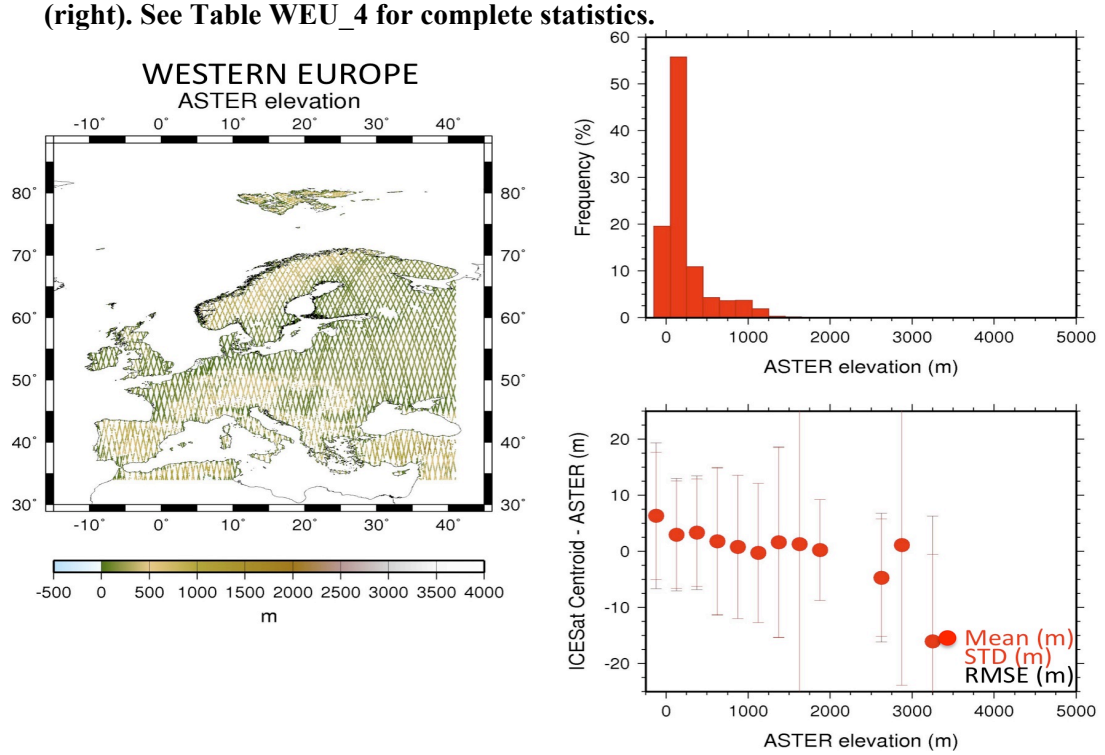


Figure 8_WEU – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table WEU_5 for complete statistics.

Observations for Western Europe:

Figure 1_WEU shows elevation differences between ICESat and ASTER that exhibit normal distributions slightly negatively skewed. ASTER is below ICESat by 2.77 m±10.71 m, with a median of 2.77 m. SRTM v2 (finished product) is above ASTER by 1.72 m as represented in the Global Statistics for the region. RMSE values do not exceed 11.75 m. See Table WEU_1.

Mean differences and standard deviations are pretty stable for all number of scenes below 7, and decrease with 8< NUM < 26. Larger RMSE values when < 5 scenes are used, at 19.5 m. See Tables WEU_2a and WEU_2b, and Figure 2_WEU for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, there is no particular trend with a particular land cover class. The largest represented classes are 14, 20 and 150, which correspond to Rainfed croplands, Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%), and Sparse (<15%) vegetation. Mean and standard deviations are 2.56±8.72 m, 3.34 m±8.72 m, and 3.34 m±10.10 m. For bare regions ASTER is above ICESat by 1.56 m±6.34 m. See Table WEU_3a and Figure 3_WEU.

When looking at the differences with respect to % bare cover from the VCF products, there is a decrease of the mean differences as bare cover increases, and ASTER is always below ICESat centroids, with decreasing standard deviations. RMSEs do not exceed 12.02 m. There is a trend towards more positive mean differences as % herbaceous and % tree increase. See Tables WEU_3b and Figures 4_WEU, 5_WEU and 6_WEU.

The ICESat returns mostly represent areas with relief between 3 and 5 m. Mean differences become more positive with increasing relief, where ASTER is below ICESat between 0 and 3 m. RMSEs are up to ~15.5 m. See Table WEU_4 and Figure 7_WEU.

Mean differences with respect to ASTER elevations show a negative trend with increasing elevations, with ASTER becoming increasingly higher than ICESat for higher elevations. However, most observations are at elevations below 1250 m. See Table WEU_5 and Figure 8_WEU.

EURASIA:

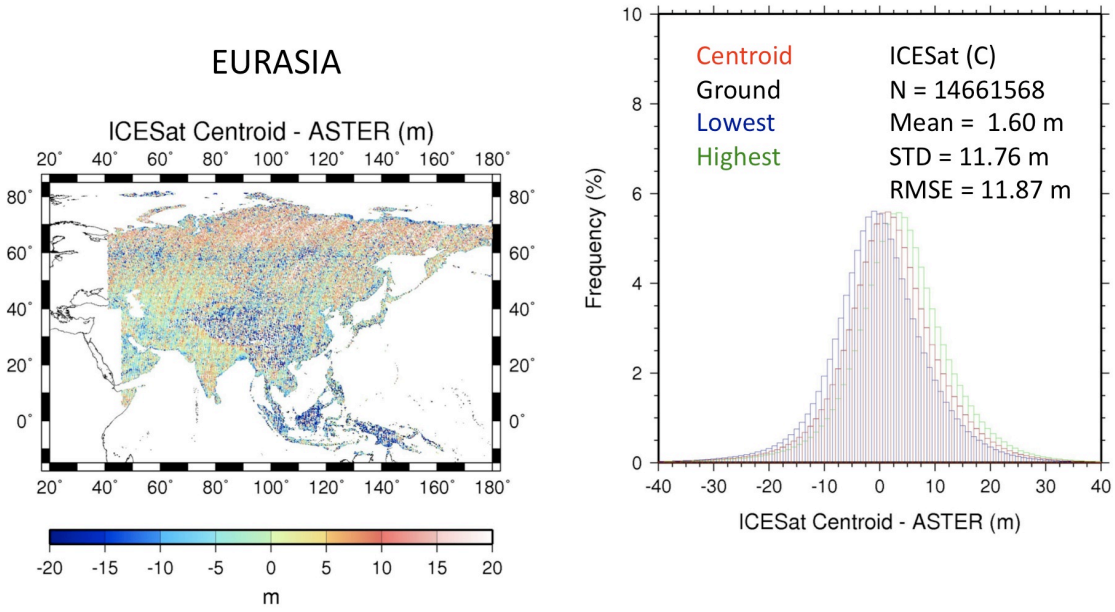


Figure 1_EUA – Differences between selected ICESat elevations and ASTER v2 (left), and histograms of elevation differences for ICESat Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location. The number of points and statistics computed for the distributions are also shown for the centroid. See Table EUA_1 for Global Statistics.

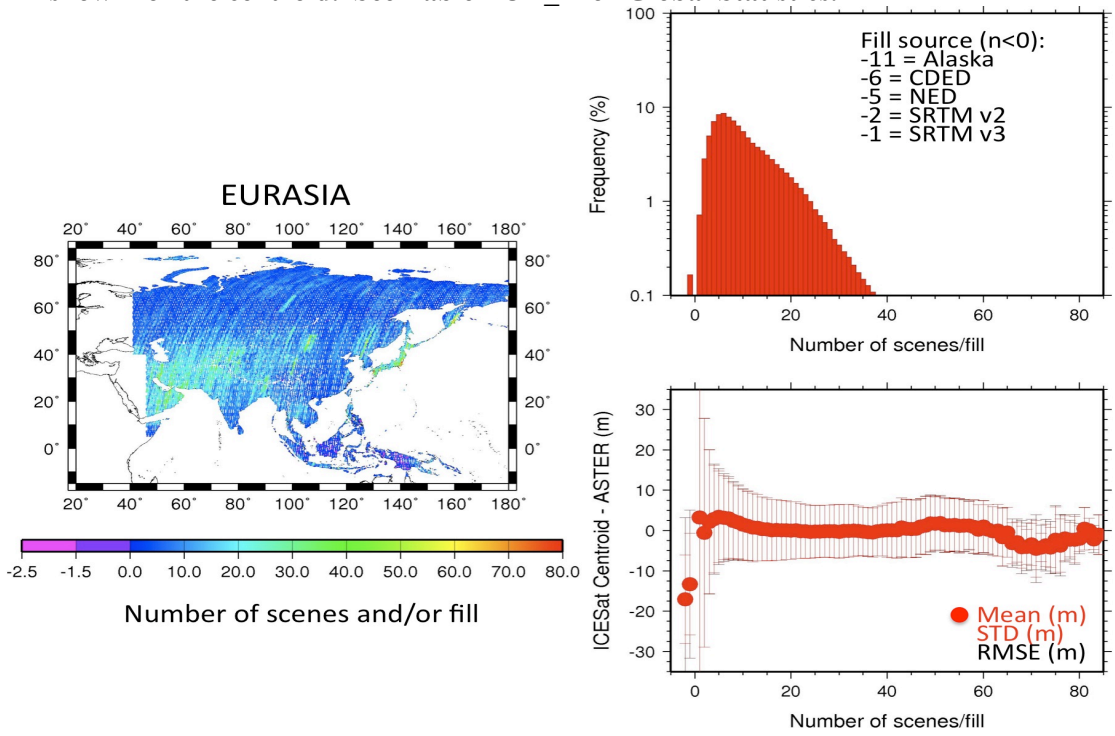


Figure 2_EUA – Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table EUA_2a. Those for each category of NUM (plotted here) are in Table EUA_2b.

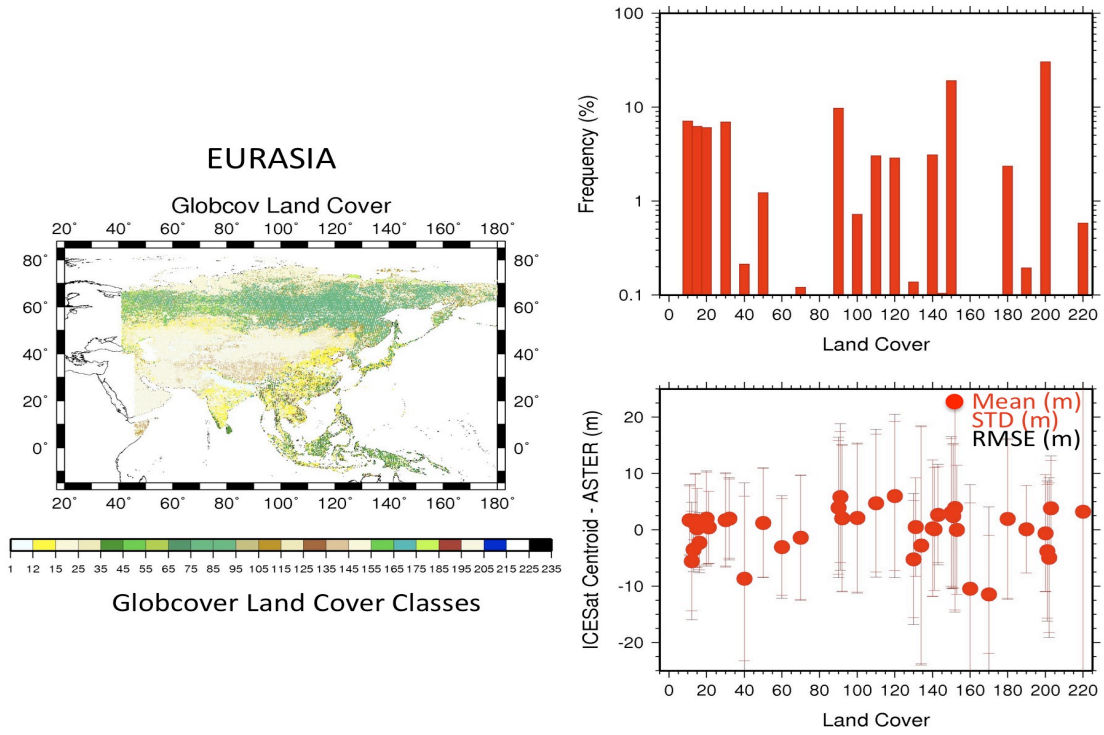


Figure 3_EUA – Land Cover (Globcover) distributions at the ICESat footprint locations (left) and Means, Standard Deviations and RMSE for ICESat centroid–ASTER elevation differences, in meters. See land cover classification in Table 2, statistics in Table EUA_3a.

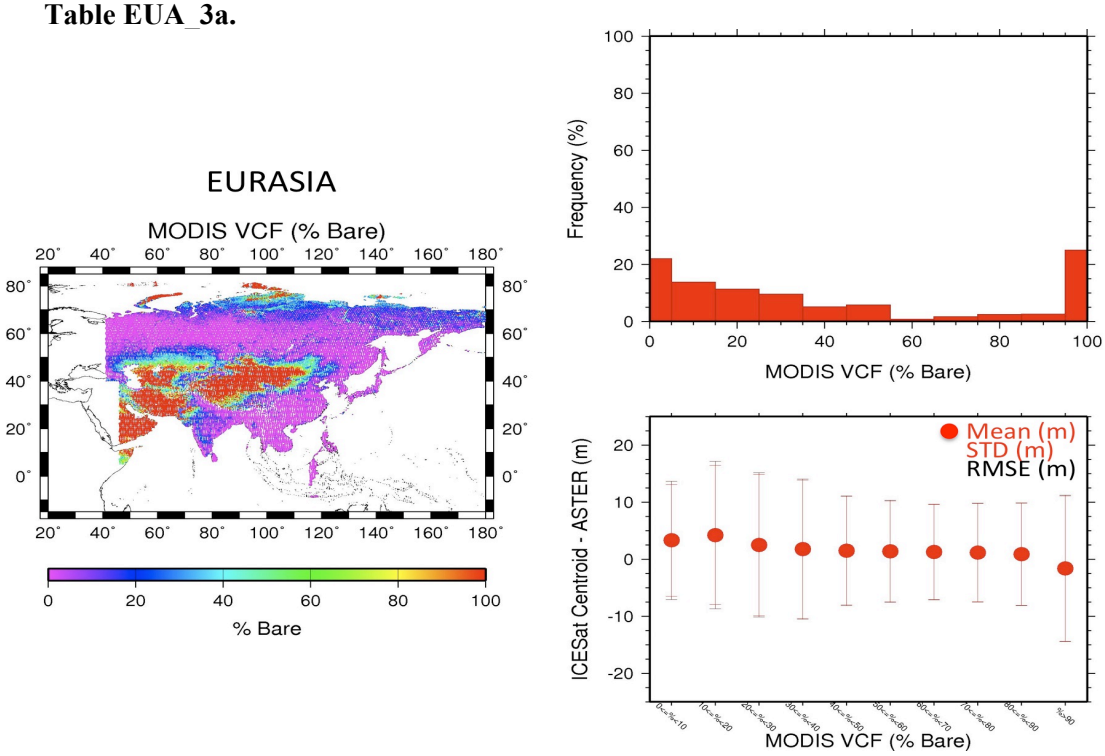


Figure 4_EUA – Percent of Bare land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table EUA_3b.

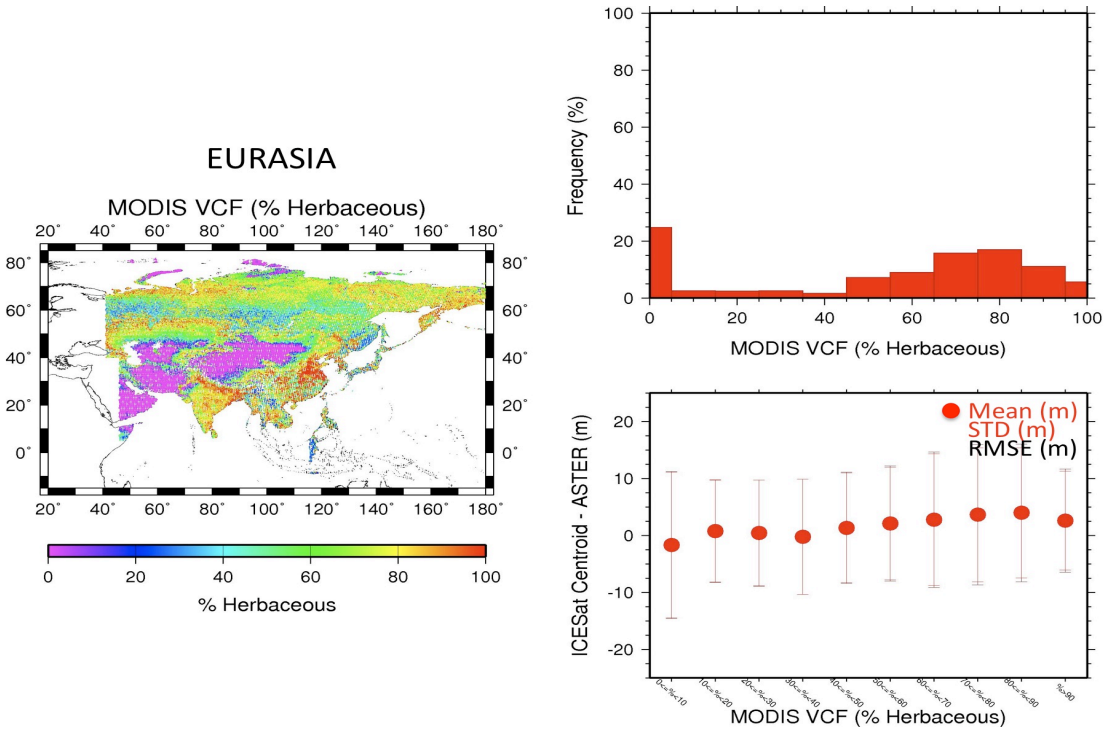


Figure 5_EUA – Percent of Herbaceous land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table EUA_3b.

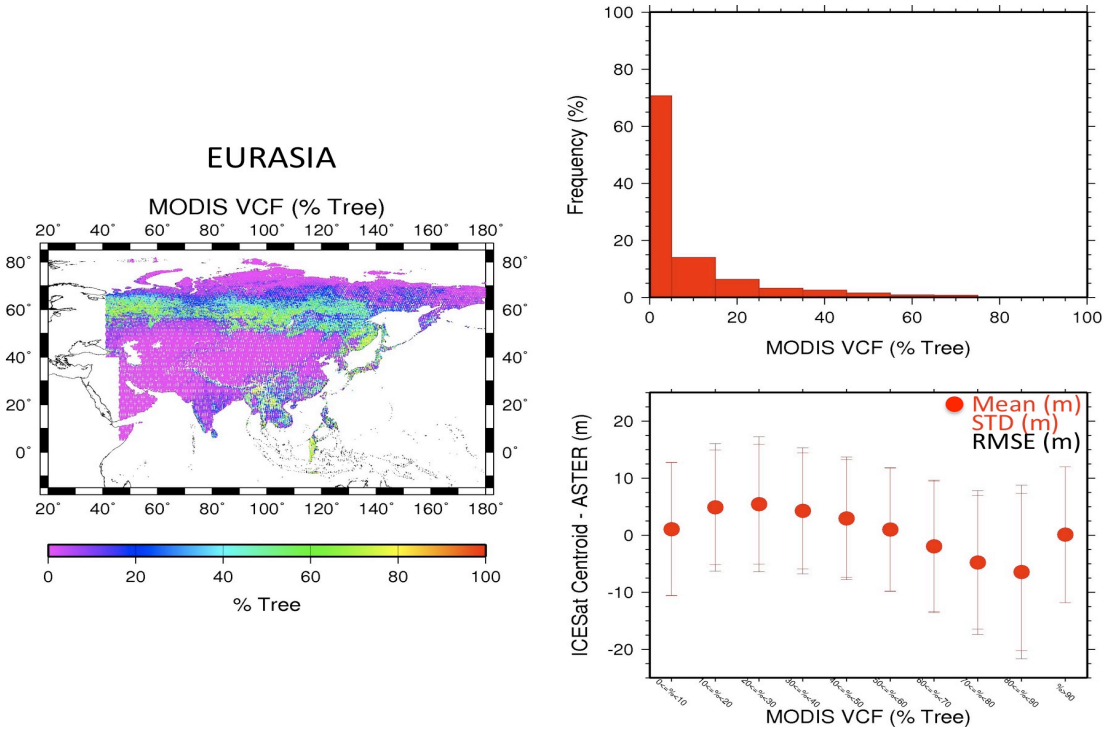


Figure 6_EUA – Percent of Tree land cover from the MODIS VCF product represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 10% increment category for the ICESat centroid–ASTER elevation differences are shown in meters. See Table EUA_3b.

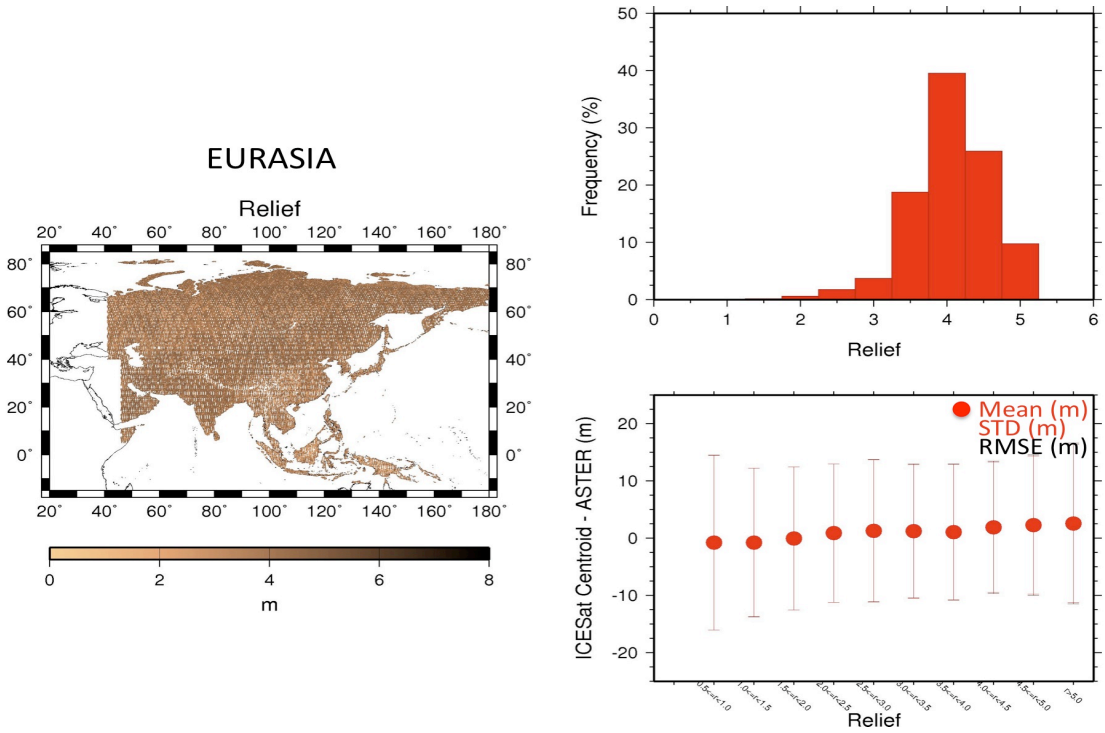


Figure 7_EUA – Distribution of relief (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 0.5 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table EUA_4 for complete statistics.

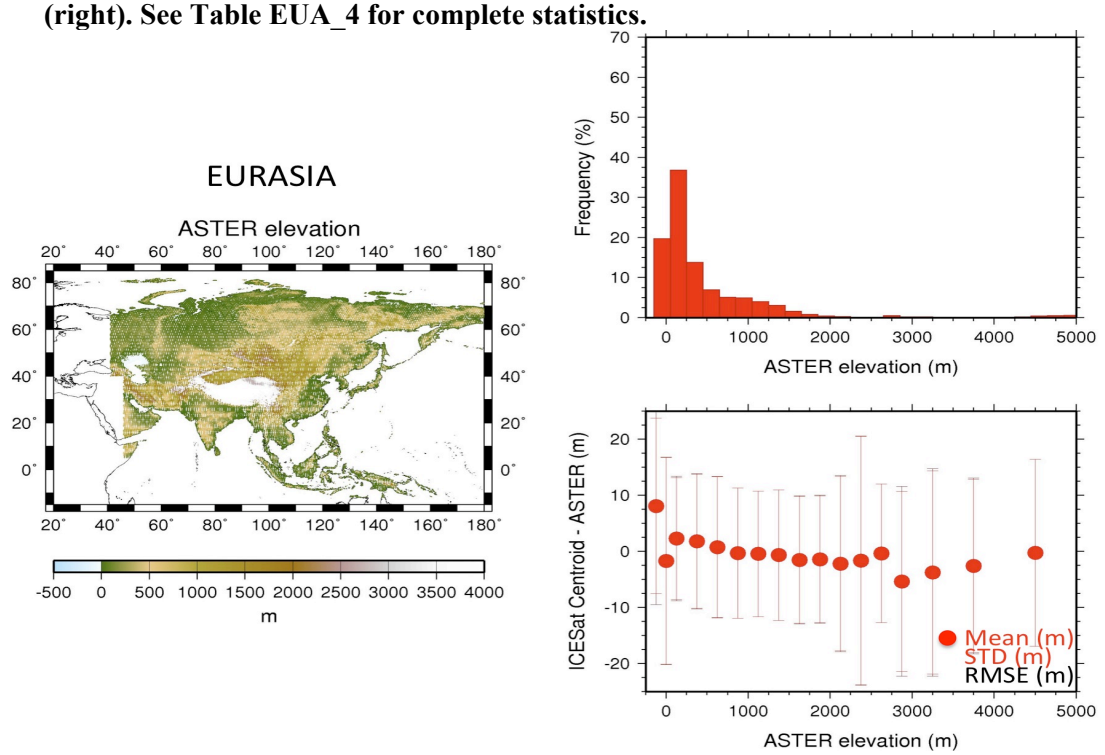


Figure 8_EUA – Distribution of elevations (m) represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every 250 m increment category for the ICESat centroid–ASTER elevation differences are shown (right). See Table EUA_5 for complete statistics.

Observations for Eurasia:

Figure 1_EUA shows elevation differences between ICESat and ASTER that exhibit normal distributions slightly negatively skewed. ASTER is below ICESat by 2.77 m±10.71 m, with a median of 2.77 m. SRTM v2 (finished product) is above ASTER by 1.72 m as represented in the Global Statistics for the region. RMSE values do not exceed 11.75 m. See Table EUA_1.

Mean differences and standard deviations are pretty stable for all number of scenes above ~10 and below ~60. Means vary between ± 1 m, with RMSE values between 6 m and 8 m. See Tables EUA_2a and EUA_2b, and Figure 2_EUA for geographic distribution of number of scenes, and frequency distributions, means and RMSEs.

With respect to Globcover land cover, the largest represented category is bare earth, with mean and standard deviations of -0.58±10.36 m. there is no particular trend with a particular land cover class. Large negative means are seen for categories LC = 40, 160 and 170, corresponding to Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m), Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water, and Closed (>40%) broadleaved forest or shrubland permanently flooded – Saline or brackish water, respectively, with mean and standard deviations are -8.65±14.60 m, -10.42 m±15.22 m, and -11.46 m±10.48 m. Largest mean differences are for LC = 91, Open (15-40%) needleleaved deciduous forest (>5m), with a mean and standard deviation of 4.84 m±11.61 m, and LC = 120, Mosaic grassland (50-70%) / forest or shrubland (20-50%), with a mean and standard deviation of 5.99 m±13.22 m. See Table EUA_3a and Figure 3_EUA.

When looking at the differences with respect to % bare cover from the VCF products, there is a decrease of the mean differences as bare cover increases from 4.0 m to -1.6 m. RMSEs do not exceed 13 m. Smallest mean differences are seen for < 10 % tree cover, and 50%-60% tree cover, and they go from 5.5 m to -6.5 m as the tree cover increases. RMSE values are pretty stable. See Tables EUA_3b and Figures 4_EUA, 5_EUA and 6_EUA.

The ICESat returns mostly represent areas with relief between 3 and 5 m. Mean differences increase from -0.8 m to 2.6 m from low to high relief. RMSEs are up to ~15.5 m. See Table EUA_4 and Figure 7_EUA.

Mean differences with respect to ASTER elevations show a negative trend with increasing elevations, at least up to about 4000 m, with ASTER becoming increasingly higher than ICESat for higher elevations. Most observations are at elevations below 1000 m. See Table EUA_5 and Figure 8_EUA.

GREENLAND:

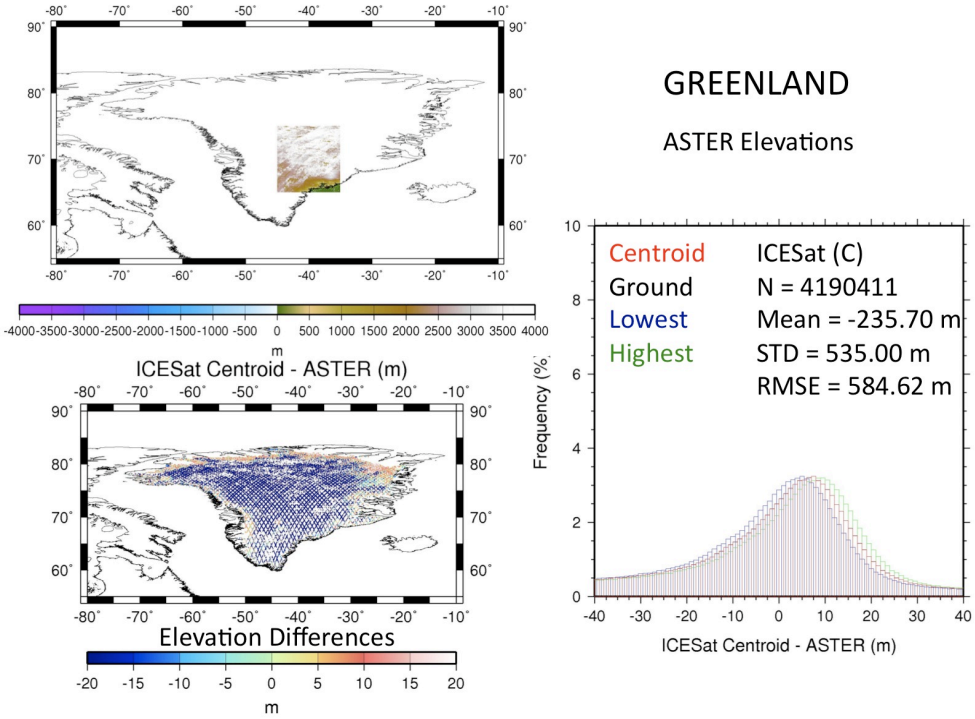


Figure 1_G – Differences between selected ICESat elevations and ASTER v2 (left, bottom), and histograms of elevation differences (right) for Centroid (red), Ground (black), Lowest (blue) and Highest (green) elevations observed at the ICESat footprint location and ASTER. The number of points and statistics computed for the distributions are also shown for the centroid. See Table G_1 for Global Statistics. Elevations for a 10 by 10 degrees region in Greenland are shown on the top left.

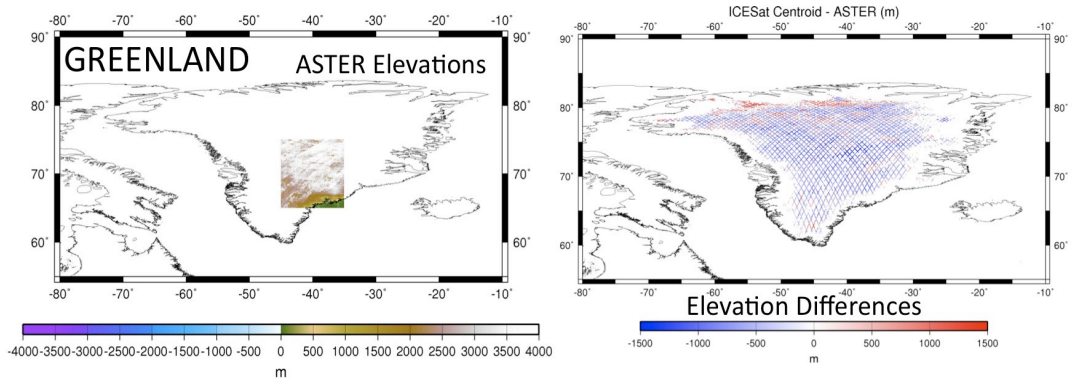
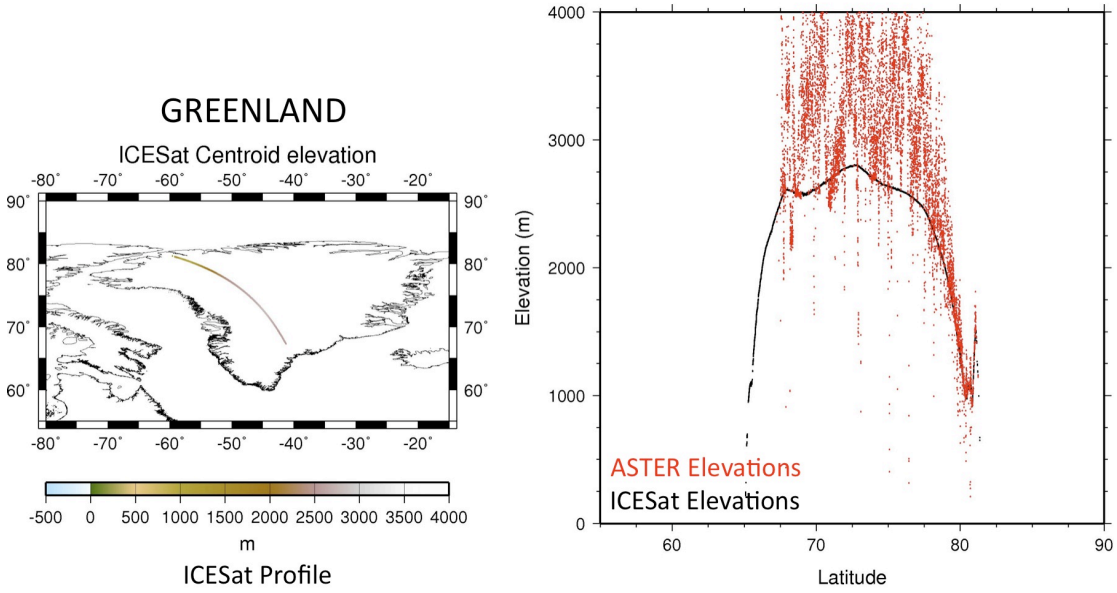
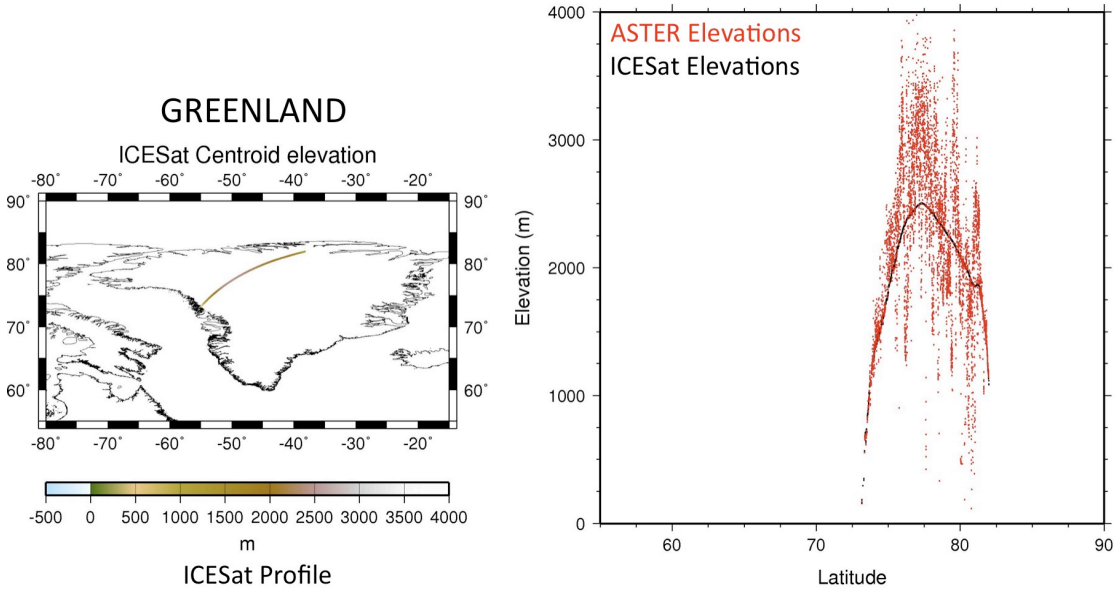


Figure 2_G –Elevations for a 10 by 10 degrees region in Greenland are shown on the top left (same as above) and differences between selected ICESat Centroid elevations and ASTER v2 between -1500 and 1500 m. See Table G_1 for Global Statistics reflecting issues with cloud cover and anomalously low elevations in ice cover areas.



(a)



(b)

Figure 3_G –Geographic location of an ICESat ascending and descending elevation profile for Greenland (a, left; b, left, respectively) and elevation profiles for ICESat (black) and ASTER v2 (red) at the location of the ICESat footprints (a and b, right).

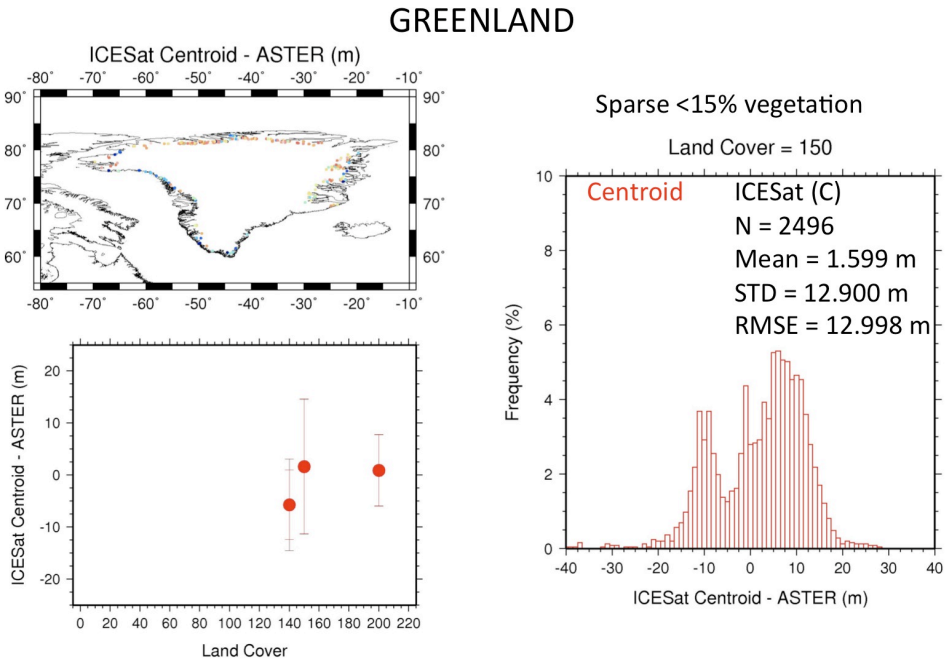


Figure 4_G – Land Cover (Globcover) distributions not corresponding to permanent snow and ice, showing geographic location (top, left) and means and standard deviations and RMSE for Closed to Open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses) [140], Sparse (<15%) vegetation [150], and Bare Areas [200], at the ICESat footprint locations (bottom, left) and Frequency distributions, Mean, Standard Deviation and RMSE for ICESat centroid–ASTER elevation differences for the most abundant class [150], in meters. See land cover classification in Table 2, and statistics in Table G_3a.

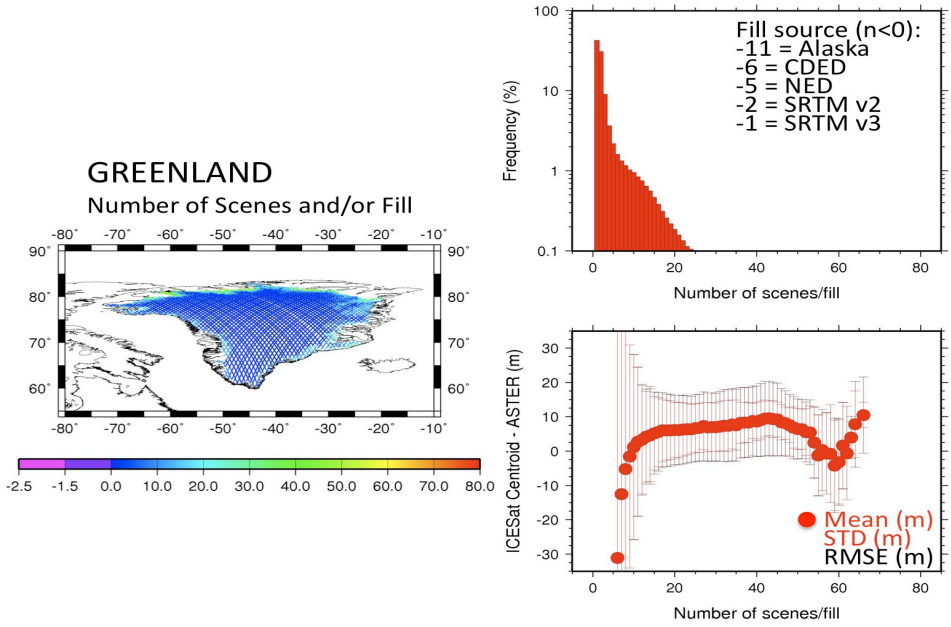


Figure 5_G – Geographic distribtion of Number of scenes (NUM) and/or fill represented in the ICESat data used (left). Frequency distributions, Means, Standard Deviations and RMSE for every NUM category for the ICESat centroid (C)–ASTER elevation differences, in meters. Statistics for grouped categories of NUM are shown in Table G_2a. Those for each category of NUM (plotted here) are in Table G_2b.

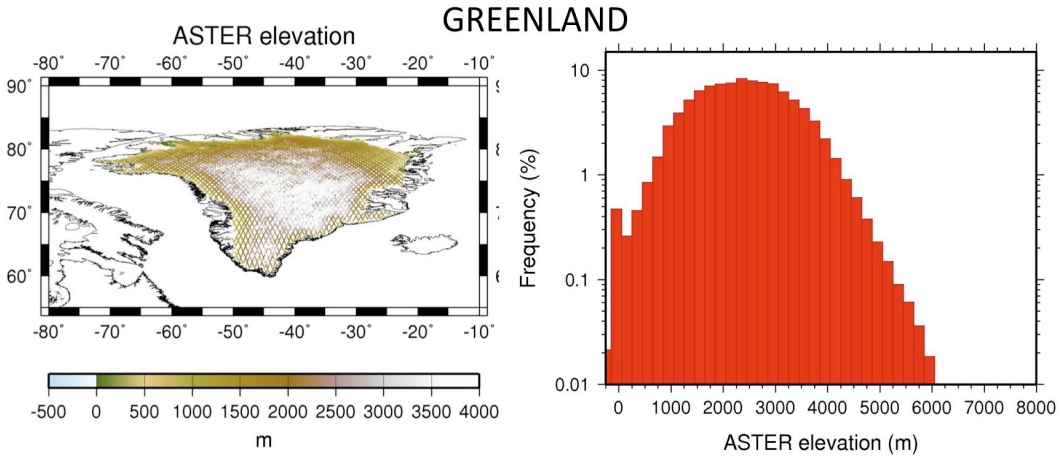


Figure 6_G – Geographic distribution of ASTER elevations (m) represented in the ICESat data used (left). Frequency distributions of ASTER elevations are plotted on a logarithmic scale. Statistics for every 250 m increment category for the ICESat centroid–ASTER elevation differences are detailed on Table G_5.

Observations for Greenland:

There seem to be anomalously high and low elevations for Greenland. Figure 1_G shows ASTER elevations over a 10 by 10 degree region including ice-covered areas, with large differences between ICESat and ASTER. Their geographic distribution using a saturated scale is shown on the bottom left of the figure. The differences distributions show large positive and negative tails, with differences in excess of 4000 m in absolute values. The statistics are clearly contaminated by the outliers. Figure 2_G shows those differences with a less saturated scale.

Figures 3_G, (a) and (b) show a couple of elevation profiles across Greenland, illustrating the nature of these differences between ICESat and ASTER. While the ICESat profiles (black) are within a few meters along a reference tracks with slightly different geographic location, the ASTER elevations (red) significantly depart from the ICESat elevation profiles, and are much noisier.

Figure 4_G shows the distribution of ICESat minus ASTER elevation differences for Sparse (<15%) vegetation cover as represented by the Globcover land cover category 150, and the geographic distribution is also shown. Frequency distributions are not normal for this class, with a mean and standard deviation of 1.60 m ±12.90 m for 2500 samples, and a 3.83 m median. The distribution is highly bimodal, with a significant peak around -10 m and 10 m.

There are a significant number of outliers when the number of scenes falls below 15. The most abundant number of scenes used is below 5 (almost 75 % of the sampled data). When more than 15 scenes are used, the RMSEs fall below 12 m. There is an increasing trend in the means with lower standard deviations. See Tables G_2a and G_2b, and Figure 5_G for geographic distribution of number of scenes, and frequency distributions, means and RMSEs. Figure 6_G shows the distribution of ASTER elevations and their histogram.

ACKNOWLEDGEMENTS
The development of the ICESat Geodetic Control Data Base is being supported by NASA's Earth Surface and Interior (ESI) Program, managed by Dr. John Labrecque, Contract NNH09CF42C: "Building an ICESat Geodetic Control Data Base for Global Topographic Mapping and Solid Earth Studies." Dr. David J. Harding is a Co-I in this proposal. Vijay Suchdeo helps with processing of the ICESat data. Processing of ASTER evaluation was done in collaboration with Dr. Jean-Paul Boy (University of Strasbourg) while visiting NASA/GSFC at the Planetary Geodynamics Laboratory.

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