INTERMAP

Technical Review

NEXTMap® World 30™ Digital Surface Model

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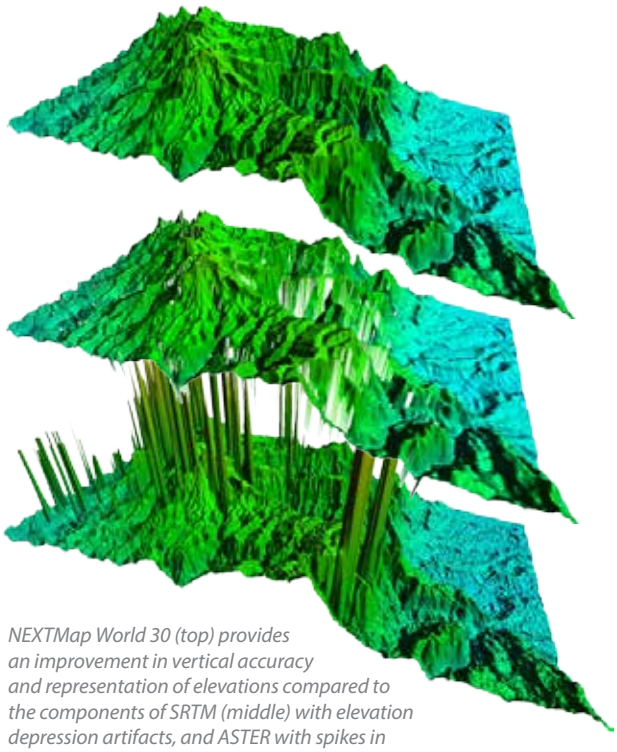


NEXTMap World 30 (top) provides an improvement in vertical accuracy and representation of elevations compared to the components of SRTM (middle) with elevation depression artifacts, and ASTER with spikes in elevation artifacts (bottom).

Summary

The NEXTMap® World 30™ Digital Surface Model (DSM) by Intermap Technologies® is a fused data model using corrected public data as the input source. This model provides seamless, best available surface elevation data with a 30-meter ground sampling distance (GSD) covering all land mass over the entire planet.

NEXTMap World 30 DSM is a combination of 90-meter Shuttle Radar Topographic Mission (SRTM) v2.1 data, 30-meter ASTER Global DEM v2, and 1-kilometer GTOPO30 data, all of which have been ground controlled using LiDAR data from NASA's Ice, Cloud and Land Elevation Satellite (ICESat) collection. Based on internal testing with airborne LiDAR datasets, Intermap believes ICESat data, when restricted to flat un-obstructed terrain, has an accuracy of 25 centimeters.

Intermap applies a proprietary algorithm when merging datasets into our World 30 DSM. Our approach involves a sequence of steps designed to optimize the vertical and spatial integrity of the final product. We pre-condition data with the application of a sophisticated varying vertical correction. Data fusion is then done with a complex weighting schema designed to retain higher value data. A non-linear blending is then passed over the boundary between datasets to ensure a smooth and continuous result. The result is a product that is specifically designed to generate, in Intermap's view, the best World digital elevation model (DEM) available today.

World 30 Inputs

The input DEM datasets used for producing the World 30 DEM along with their specifications (as downloaded) are described in Table 1.

SRTM90 v2.1

Ninety-meter posted DSM, IFSAR collection conducted in February of 2000. Data extends from 60 degrees north to 56 degrees south and has a claimed vertical accuracy of 14 meters LE95. Known issues include varying levels of vertical accuracy and significant numbers of data voids.

ASTER 30 v2.0

Thirty-meter posted DSM, optical satellite collection spanning from 1999 to 2007. Data extends from 83 degrees north to 83 degrees south and has a claimed vertical accuracy of 20 meters LE95. Known issues include poor vertical accuracy, data voids, and extensive spike blunders.

ICESat

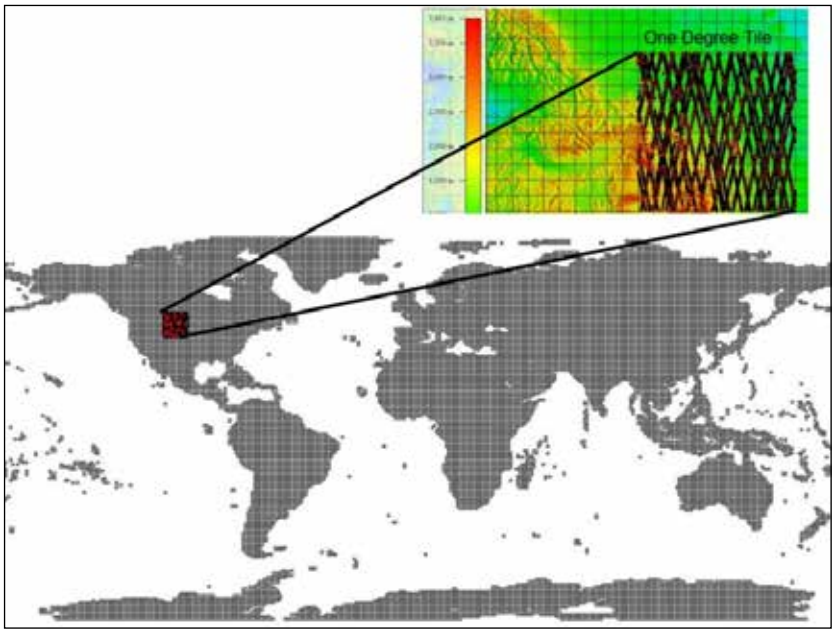
LiDAR points from a Geoscience Laser Altimeter System (GLAS) Satellite. Collection spanned from 2003 to 2010 and was conducted as a direct nadir pulse collected in a polar orbital path. Known issues include unreliable vertical elevations due to cloud returns and anomalies.

GTOPO30

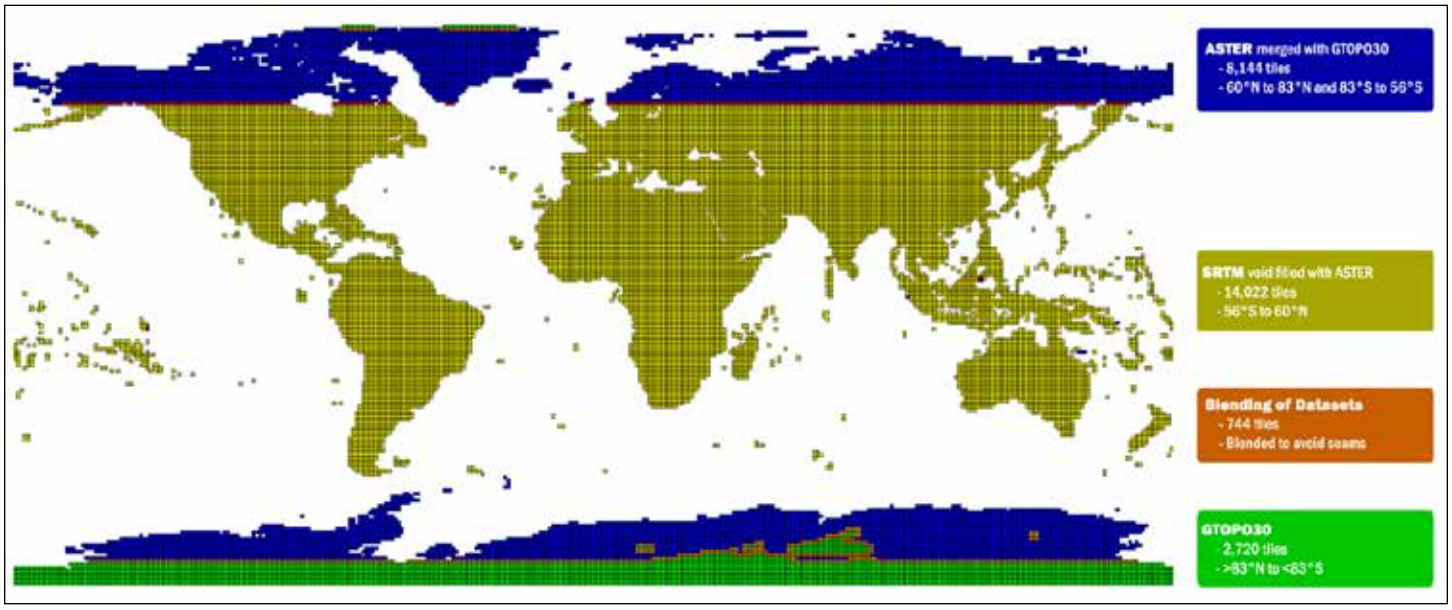
One thousand-meter posted DSM, derived from eight raster and vector sources by the USGS in 1996. The DSM is known to exclude ridgelines and valleys due to course resolution.

	SRTM3 v2.1	ASTER v2.0	GTOPO30
DEM Type	DSM	DSM	DSM
File Format	Signed 16-bit HGT	Signed 16-bit GeoTIFF	Signed 16-bit DEM/ HDR
Projection	Geographic	Geographic	Geographic
Horizontal Datum	WGS84	WGS84	WGS84
Vertical Datum	WGS84	WGS84	WGS84
Geoid	EGM96	EGM96	EGM96
Tile Size	1°x1°	1°x1°	50°x40° 30°x60° for Antarctica
Post Spacing	3″	1″	30″
Coverage	<=60°N & >=56°S	<=83°N & >=83°S	Worldwide
Void Value	-32768	-9999	-9999
Vertical Accuracy LE95	14m	20m	Variable
Horizontal Accuracy CE95	10m	30m	Variable

Table 1. Input dataset specifications.



Coverage of ICESat LiDAR satellite tracks (red diagonal lines) across a 1 degree tile.

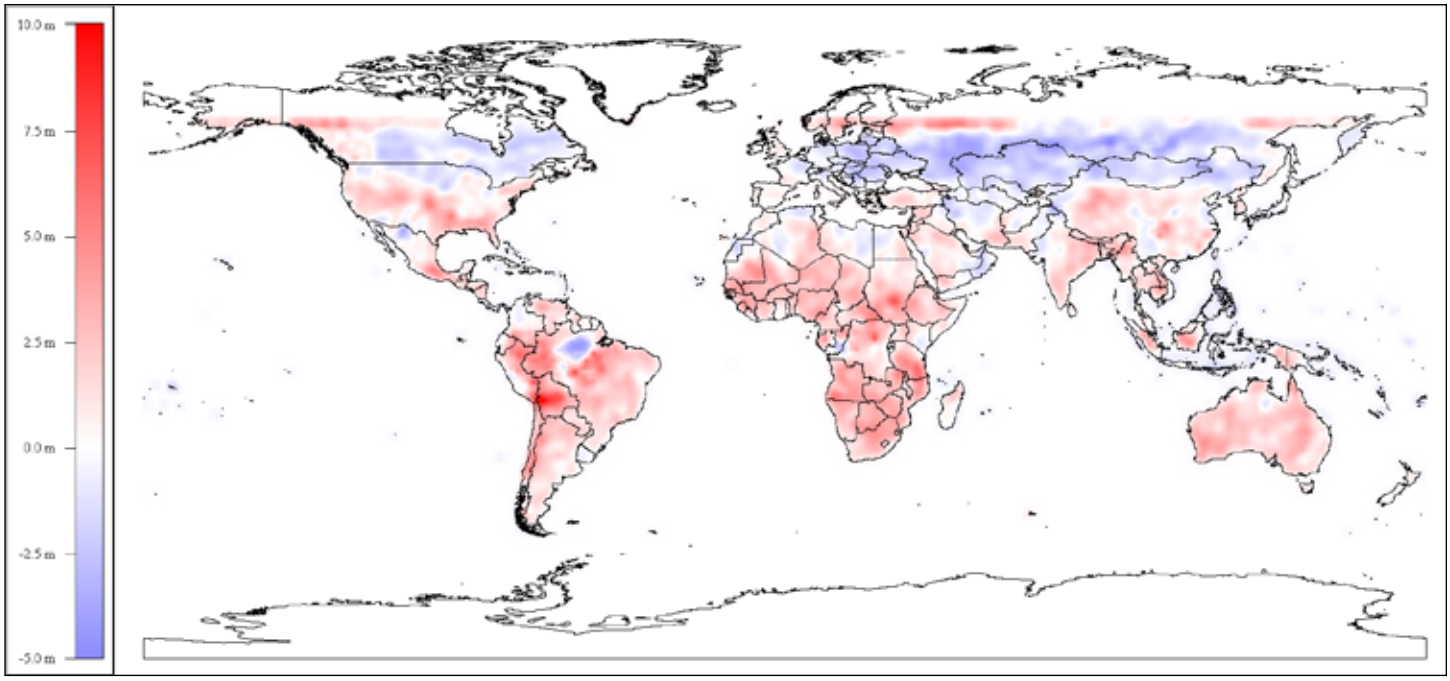


Process

The NEXTMap World 30 DSM is primarily composed of SRTM v2.1. To improve upon the SRTM data, Intermap improved its vertical accuracy, infilled all the voids, and up-sampled the resolution. To improve the vertical accuracy, Intermap first ran a proprietary filter process on the ICESat LiDAR points to remove all non-ground anomalies. The resulting ICESat data had dense global coverage and a 25 centimeter RMSE, well suited for use as a ground control dataset. With the ICESat as a control set, Intermap built a correction model for the SRTM surface and applied the correction to the z values of the DSM. For detailed regional comparisons of SRTM to World 30 control points, please see page 11.

The resulting corrected DSM model had vertical adjustments from -5 to +10 meters and the overall mean error was improved by 4 meters. These adjustments to the surface model were all made without compromising the SRTM hydro edits. The final output was then upsampled to a 30-meter post using a bicubic interpolation.

With an improved vertical accuracy of the DSM complete, Intermap then focused on infilling the voids left in the terrain model from the SRTM. Using ASTER 30 as the infill data source, Intermap used their proprietary fusion process to adjust the vertical values and perform a planar tilt of

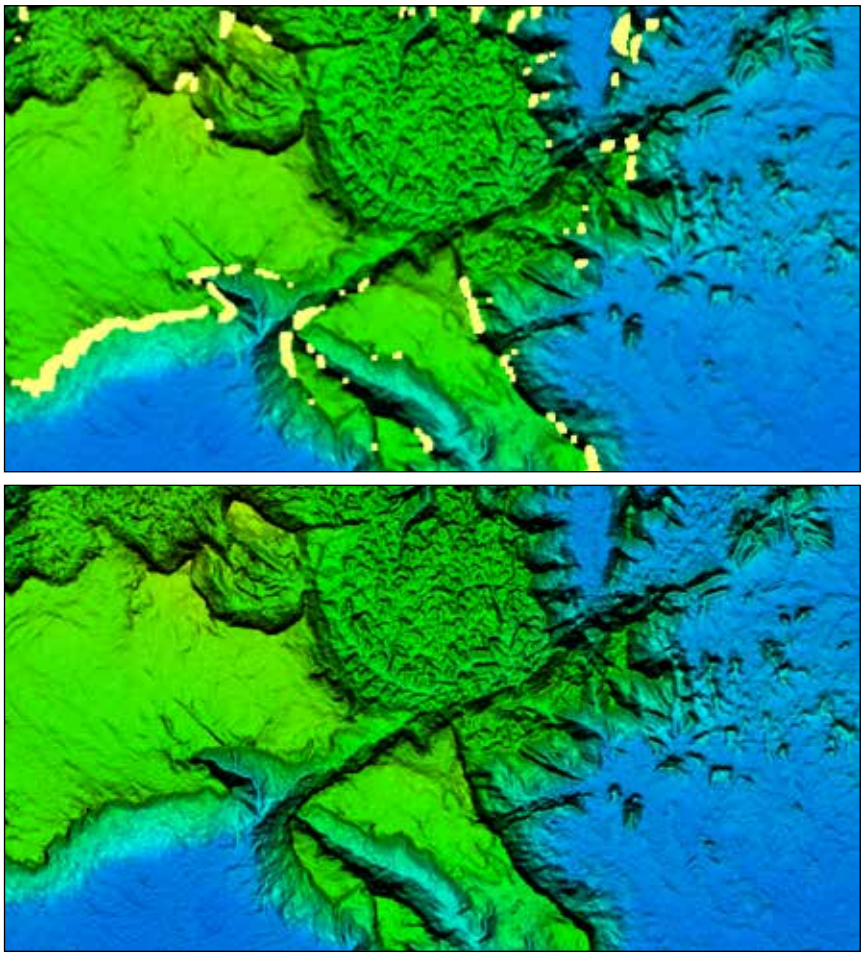


SRTM - ICESat adjustment (derived from over 87 million global GCPs)

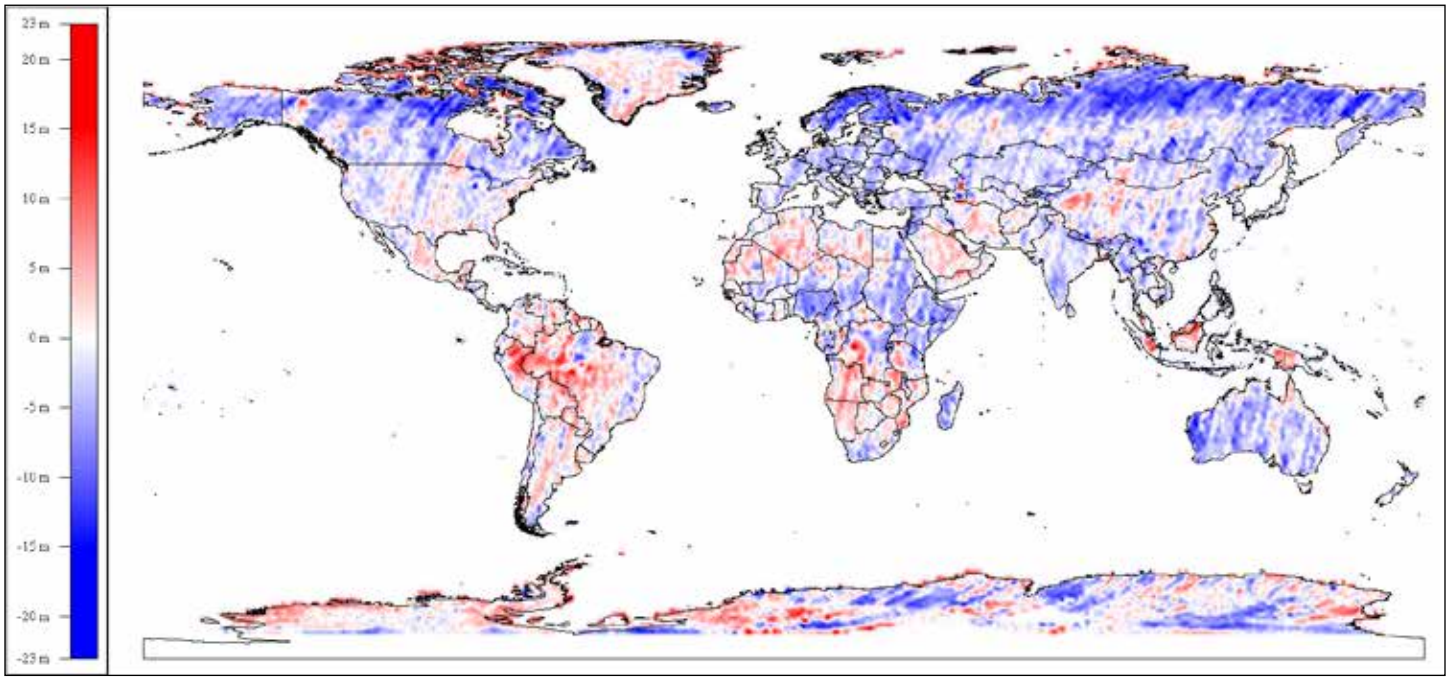
the data for each infill piece of ASTER data. The result was a seamless void filled dataset where the infilled ASTER matched all the surrounding edges of the master surface model. If any anomalies were detected in the input ASTER they were removed before being added to the World 30 DSM. In instances where both SRTM and ASTER had voids over the same geography GTOPO30 was used as the infill data.

The final component of the World 30 build was the addition of ASTER and GTOPO30 DSM models to the northern and southern latitudes allowing for full global coverage. Just as the SRTM surface had been corrected using the filled ICESat control points, so too was the ASTER surface model.

The ASTER surface model correction was significantly more extensive than the SRTM correction and resulted in adjustments to the z value that ranged from -23 meters to +23 meters. With the ASTER data vertically corrected it could be merged to the World 30 model at 60 degrees north latitude covering up to 89 degrees north latitude. The remaining last one degree of polar data was covered using the GTOPO30 data upsampled to a 30-meter post. The intersecting datasets had very similar vertical values at their lines of intersection since both were corrected using the same ground control set. But due to the texture detail differences of the varying DSM native posts, it was important to blend the data using a proprietary smoothing technique that extended 200 kilometers into the extent of both datasets.

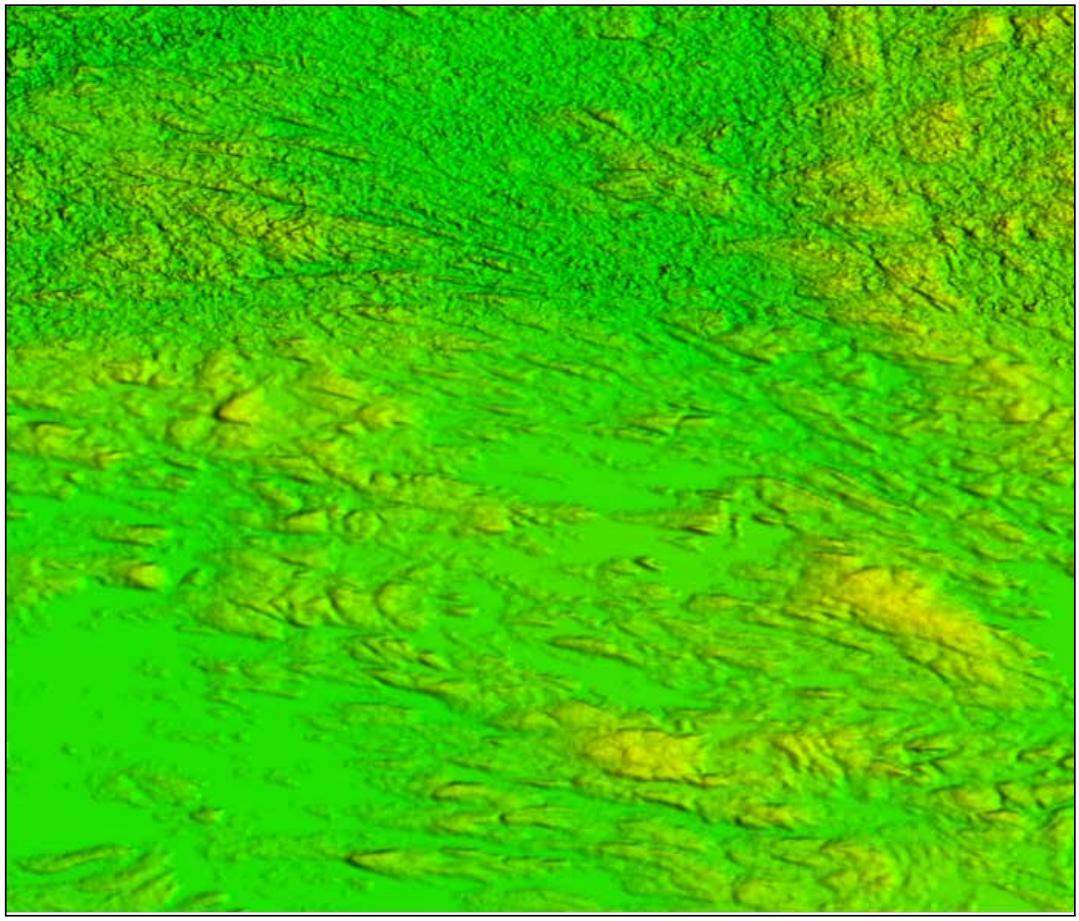


Coarse resolution and voids can be seen in this SRTM 90-meter DSM depicted in the top image. NEXTMap World 30 with a 30-meter GSD and filled voids is shown in the bottom image.



ASTER - ICESat adjustment (derived from over 117 million global GCPs)

For the southern latitudes the same process of correction and blending was used involving ASTER and GTOPO30. Thus the resulting dataset extended from pole to pole.



SRTM-ASTER blend: Blending was done over 200 posts (approximately 6km) in order to minimize the transition as much as possible.

Validation and Edits

The World 30 data was validated using automated elevation comparisons to verify that no outstanding differences were detected. The data was also subjected to a slope identification process that flagged all areas containing slopes over 80 degrees. Areas identified to have high slopes were manually edited to make sure the identified slope was an anomaly, and, if so, edited using infill data.

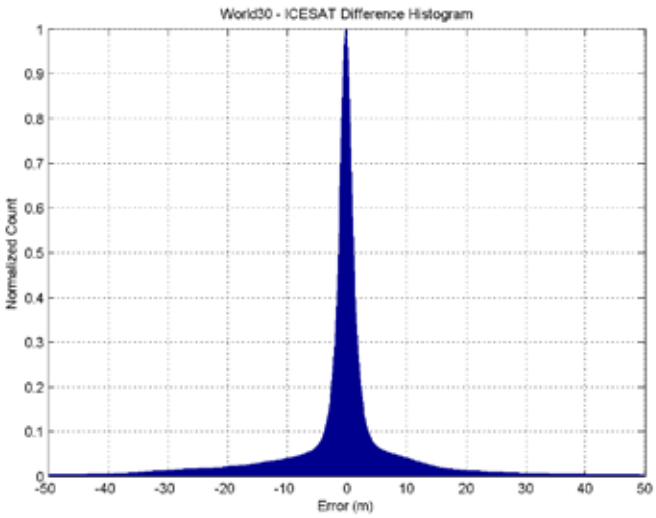
Accuracy Assessment

Intermap conducted three accuracy assessments on the World 30 DSM.

1. First, World 30 elevations were compared to the filtered ICESat LiDAR ground control points that have a vertical accuracy of 25 centimeter RMSE
    a. Methods: Sample selection criteria, data reformatting prior to analysis, statistics calculated
    b. Combined Samples: Statistics on all points, statistics on points between ±60°, statistics on points +60° N, and statistics on points -60° S
    c. ICESat Interpolation
        - Bilinear interpolation
    d. Statistics Calculated:
        - Maximum, Minimum, Mean, Standard Deviation, RMSE, LE68, LE90, LE95
        - Histogram, Cumulative Distribution Function
    e. The statistics calculated from all samples are summarized below (statistics do not include points with differences greater than 500 meters and points located over Greenland):

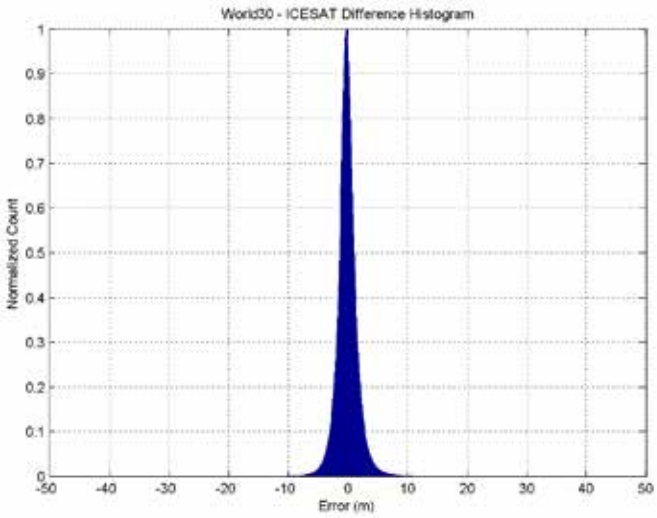
	Number of Points	Mean (m)	Standard Deviation (m)	RMSE (m)	LE68 (m)	LE90 (m)	LE95 (m)
All ICESat Points	181367248	0.70	83.88	83.88	10.6	83.8	196.9
± 60°	86979684	-0.08	2.61	2.61	1.4	2.8	3.7
± 60° North	20528706	0.86	13.67	13.70	8.9	15.8	20.5
> 60° South	73858858	1.57	131.21	131.22	52.9	235.9	352.3

All Points



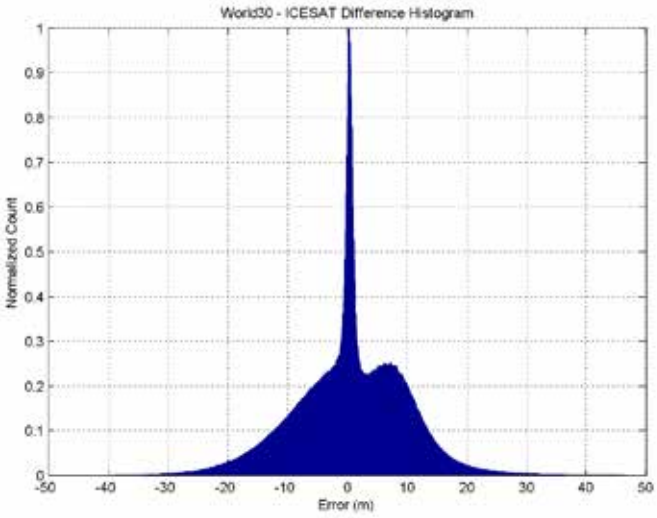
NumPoints = 181367248, Max (m) = 500.00, Min (m) = -500.00, Mean (m) = 0.70,
StdDev (m) = 83.88 RMSE (m) = 83.88 LE90 (m) = 83.80 LE95 (m) = 196.90

± 60°



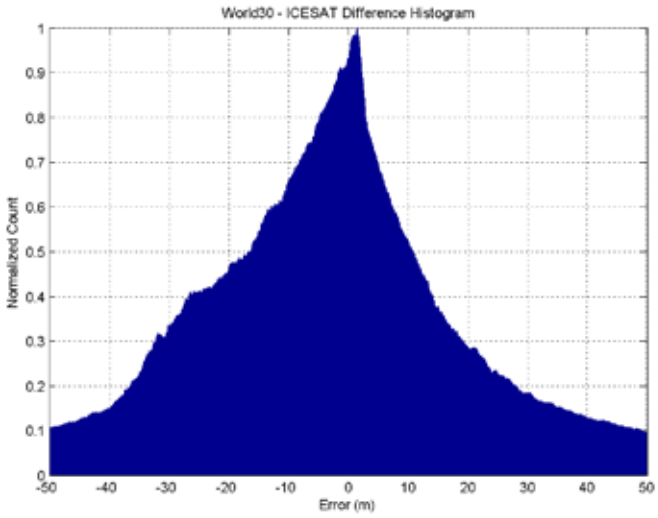
NumPoints = 86979684, Max (m) = 496.07, Min (m) = -495.48, Mean (m) = -0.08,
StdDev (m) = 2.61 RMSE (m) = 2.61 LE90 (m) = 2.80 LE95 (m) = 3.70

>60° N



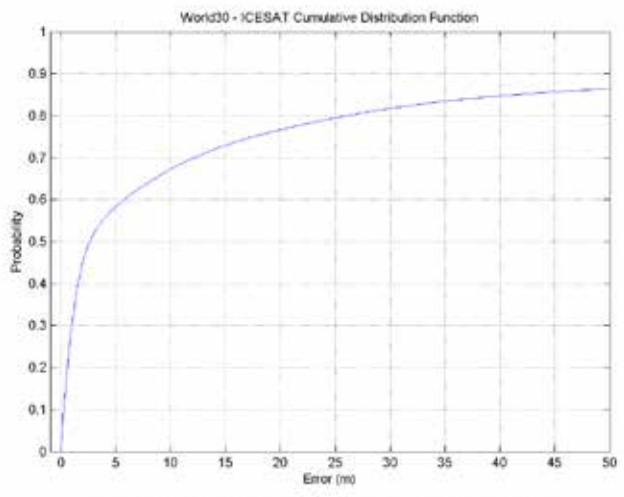
NumPoints = 20528706, Max (m) = 499.44, Min (m) = -499.74, Mean (m) = 0.66,
StdDev (m) = 13.67 RMSE (m) = 13.70 LE90 (m) = 15.80 LE95 (m) = 20.50

<60° S



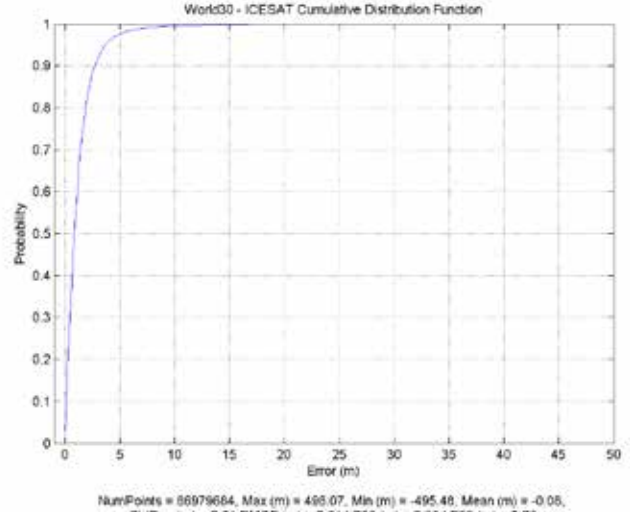
NumPoints = 73858858, Max (m) = 500.00, Min (m) = -500.00, Mean (m) = 1.57,
StdDev (m) = 131.21 RMSE (m) = 131.22 LE90 (m) = 235.90 LE95 (m) = 352.30

All Points



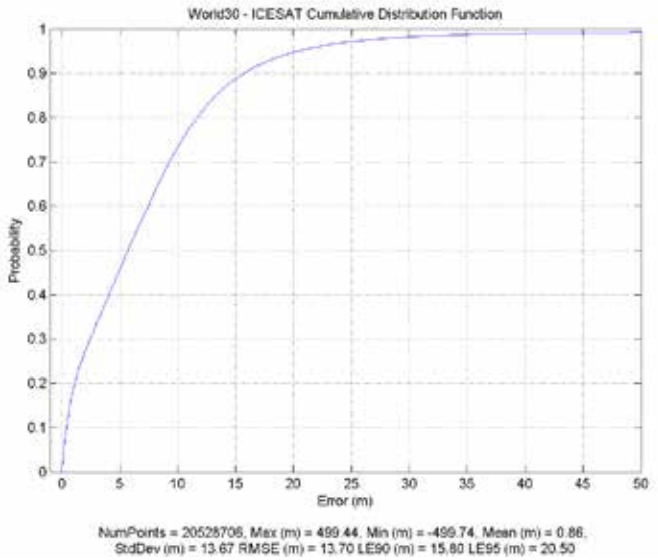
NumPoints = 181367248, Max (m) = 500.00, Min (m) = -500.00, Mean (m) = 0.70,
StdDev (m) = 83.88 RMSE (m) = 83.88 LE90 (m) = 83.80 LE95 (m) = 196.90

± 60°

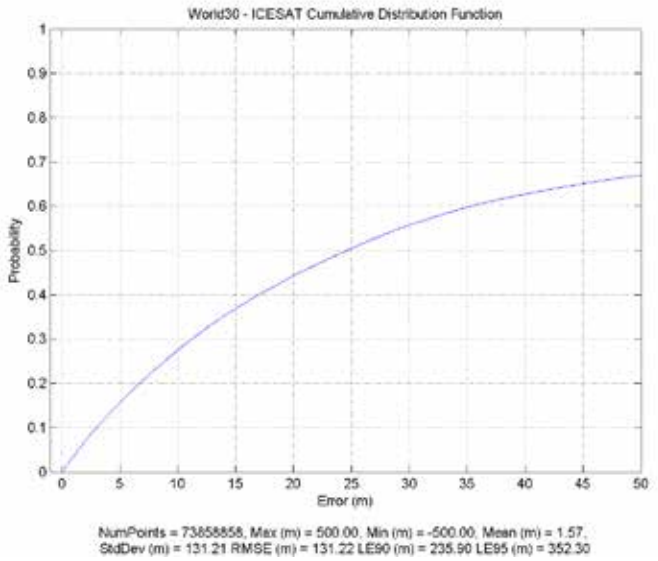


NumPoints = 86979684, Max (m) = 496.07, Min (m) = -495.48, Mean (m) = -0.08,
StdDev (m) = 2.61 RMSE (m) = 2.61 LE90 (m) = 2.80 LE95 (m) = 3.70

All Points

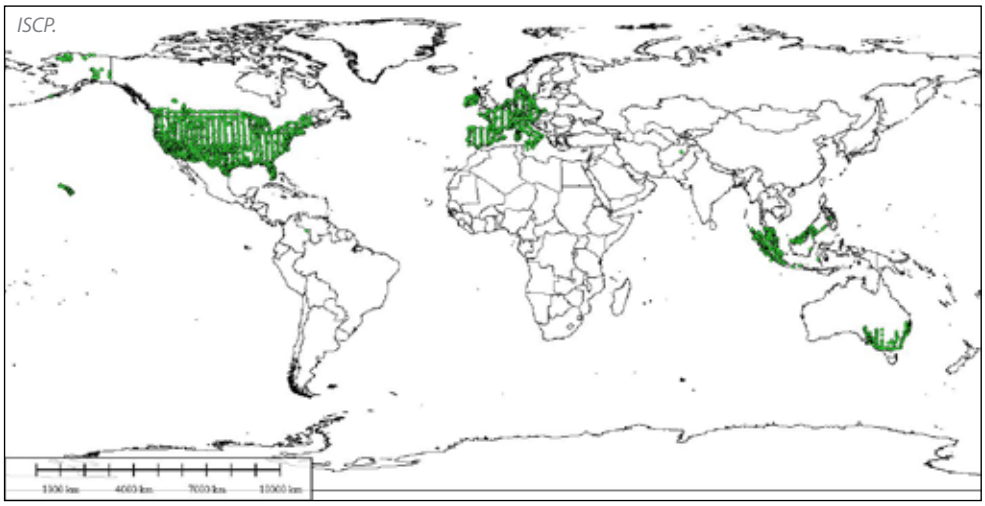


± 60°

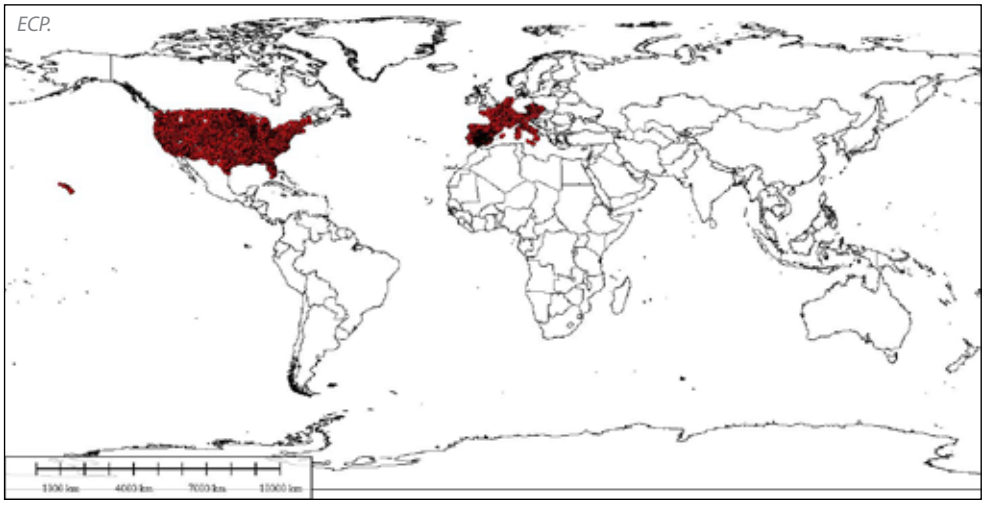


2. For the second assessment, the World 30 DSM was compared to surveyed and validated Intermap ground control points as well as external ground control points from government programs.

ISCP.



ECP.



a. The statistics calculated for the control points are summarized below:

	Number of Points	Maximum (m)	Minimum (m)	Mean (m)	Standard Deviation (m)	RMSE (m)	LE68 (m)	LE90 (m)	LE95 (m)
All ISCP	3895	66.05	-153.76	0.04	5.50	5.50	3.0	6.4	11.0
± 60° ISCP	3761	18.43	-153.76	-0.01	5.19	5.19	2.9	6.0	9.0
> 60° ISCP	134	66.05	-16.64	1.44	11.12	11.21	9.2	15.9	18.8
All ECP	23131	29.36	-27.3	-1.55	2.74	3.15	2.7	4.9	6.3

b. Intermap Survey Control Points (ISCP) and External Control Points (ECP)

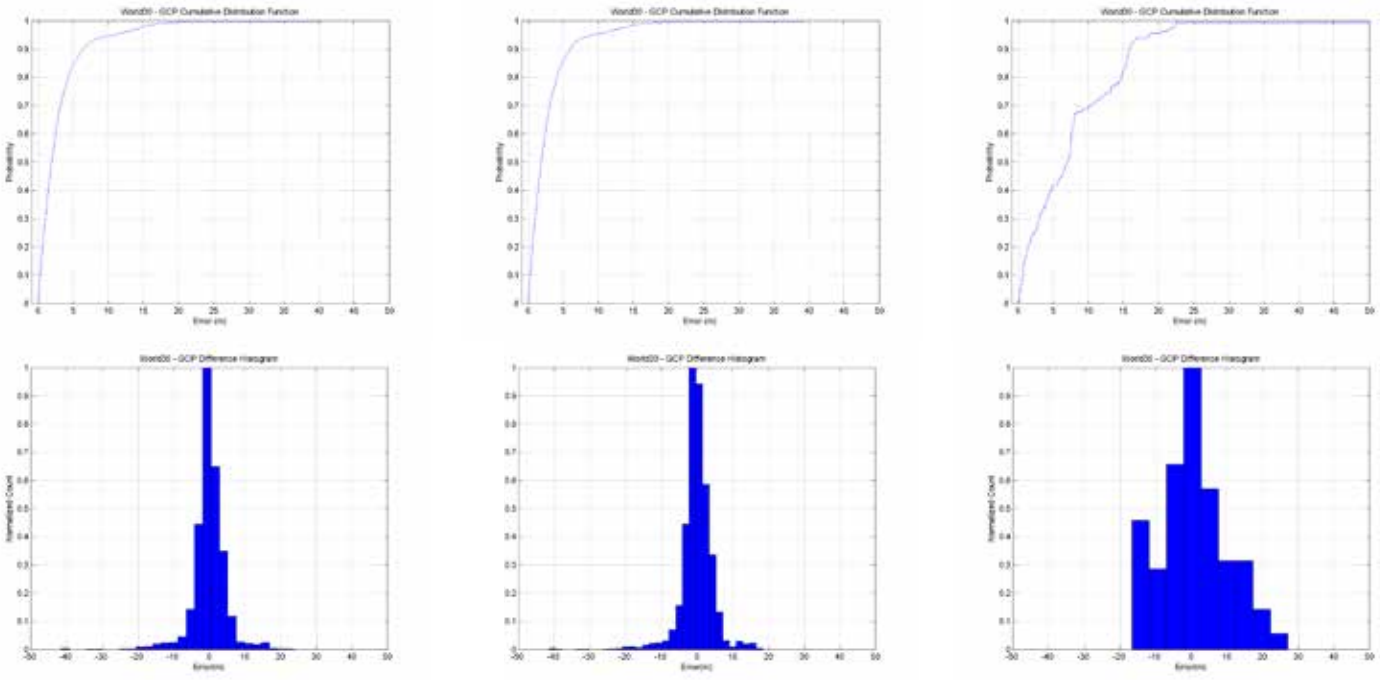
- Control points used to validate NEXTMap
- Bilinear interpolation used when differencing to World 30

c. Statistics Calculated:

- Maximum, Minimum, Mean, Standard Deviation, RMSE, LE68, LE90, LE95
- Histogram, Cumulative Distribution Function

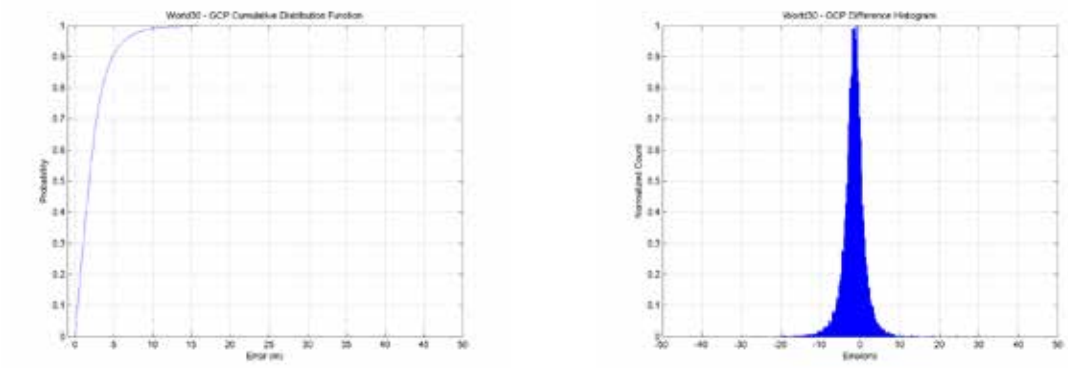
Statistics by Latitude: World 30 - ISCP

All Points *Between ±60°* *Greater than 60° N*



Statistics by Latitude: World 30 - ECP

All Points (Between ±60°)



d. ISCP by Continent

	Number of Points	Maximum (m)	Minimum (m)	Mean (m)	Standard Deviation (m)	RMSE (m)	LE68 (m)	LE90 (m)	LE95 (m)
North America	1647	66.05	-52.41	-1.53	4.91	5.14	3.1	7.0	10.6
Europe	709	6.20	-153.76	-1.67	7.31	7.49	2.0	4.5	11.6
Australia	170	5.56	-6.58	0.34	1.99	2.02	2.1	3.1	3.7
SE Asia	1366	18.43	-40.55	2.79	4.12	4.98	3.9	6.6	11.7

e. ECP by Continent

	Number of Points	Maximum (m)	Minimum (m)	Mean (m)	Standard Deviation (m)	RMSE (m)	LE68 (m)	LE90 (m)	LE95 (m)
North America	17515	29.36	-27.30	-1.15	2.60	2.85	2.5	4.3	5.5
Europe	5616	8.40	-25.68	-2.80	2.78	3.95	3.5	6.5	8.2

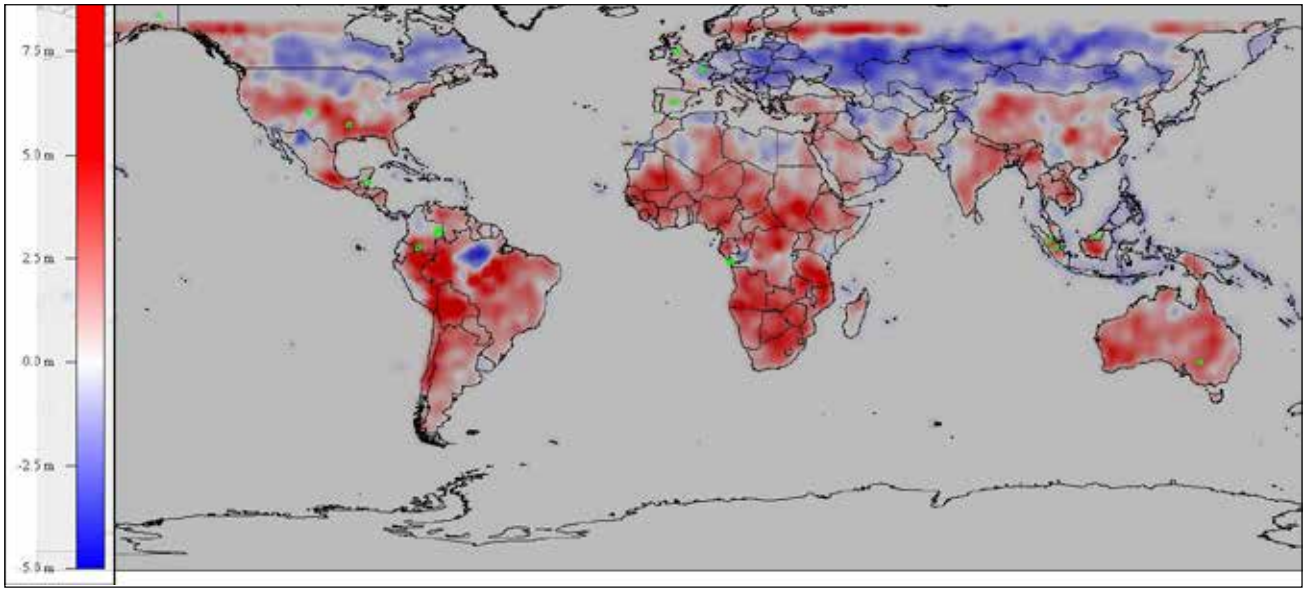
3. The final accuracy assessment was done using Intermap's 5-meter posted IFSAR DSM data.

a. The statistics calculated from the samples are summarized below:

	Maximum (m)	Minimum (m)	Mean (m)	Standard Deviation (m)	RMSE (m)	LE68 (m)	LE90 (m)	LE95 (m)
All Samples	541.74	-601.97	-0.81	6.97	7.01	4.0	8.8	11.8
± 60° (water pixels removed)	541.74	-601.97	-1.20	5.40	5.53	3.6	7.8	10.0
> 60°	324.01	-510.88	3.09	15.04	15.35	9.8	20.0	27.8

b. Sample sites were chosen based on:

- SRTM – ICESat adjustment model
- Location of NEXTMap DSM data
- Global distribution



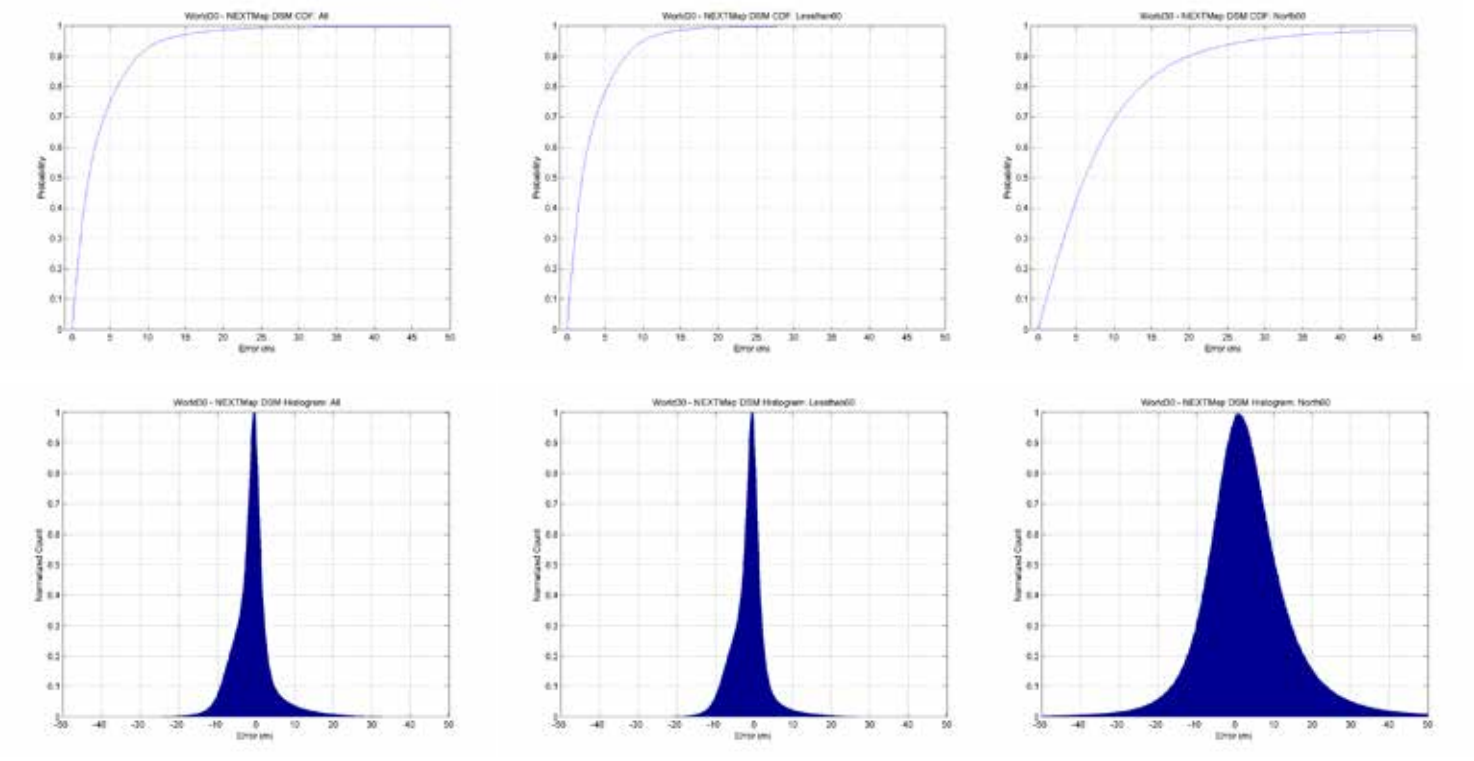
c. NEXTMap 5 meter DSM down-sampled to 30 meter
   - "Average" down-sampling method
   - Some samples reprojected from UTM to Geographic
   - Some samples datum transformation applied
   - Some samples geoid transformation applied

d. Final NEXTMap Format:
   - Projection: Geographic
   - Horizontal Datum: WGS84
   - Geoid: EGM96

e. Statistics Calculated:
   - Maximum, Minimum, Mean, Standard Deviation, RMSE, LE68 LE90, LE95
   - Histogram, Cumulative Distribution Function

Overall Statistics

All Samples *±60°* *>60° N*



Summary of NEXTMap World 30 Product Specifications

- World wide coverage digital surface model
- A fusion of SRTM, ASTER, GTOPO30, using ICESat for vertical control
- Format: bil, hdr, row major starting in upper left corner
- 1 arc second postings (~30 meter)
- 1°x1° cell (~50MB)
- File dimensions 3601 X 3601
- Pixel size IEEE 32 bit floating point
- Geographic Projection
- WGS84 Horizontal Datum
- WGS84 Vertical Datum
- EGM96 Geoid
- No data value -10000.0

f. Individual Sample Statistics: Note the SRTM Water MAsk was used to remove points over water for all samples in the below table, except Alaska.

Continent	Sample Locations	Maximum (m)	Minimum (m)	Mean (m)	Standard Deviation (m)	RMSE (m)	LE68 (m)	LE90 (m)	LE95 (m)
North America	New Mexico	33.12	-59.53	-1.38	2.19	2.59	2.5	4.0	5.0
	Arkansas	38.28	-31.29	-3.42	4.06	5.31	5.7	8.4	9.6
	Alaska	324.01	-510.88	3.09	15.04	15.35	9.8	20.0	27.8
Central America	Belize	107.77	-137.11	1.49	3.23	3.55	2.6	4.9	6.7
South America	Columbia and Peru	24.33	-23.19	-5.15	2.84	5.88	6.6	8.6	9.5
	Guaviara River	44.88	-30.07	-1.91	2.39	3.06	3.1	4.7	5.5
Europe	Spain	41.81	-20.60	0.00	1.38	1.38	1.2	2.1	2.7
	France	31.43	-26.28	-2.31	2.94	3.74	2.4	7.1	8.8
	UK	48.43	-59.73	-0.36	2.47	2.50	1.9	3.8	5.2
Africa	Congo	49.29	-49.70	0.29	4.92	4.93	4.0	7.8	10.3
SE Asia	Malaysia	541.74	-601.97	0.57	12.07	12.08	7.9	14.3	17.9
	Sumatra	220.25	-148.81	-1.58	7.49	7.66	6.9	11.8	15.0
Australia	Australia	18.56	-25.53	-0.05	1.42	1.43	1.3	2.3	2.8

Comparison of Vertical Differences

Vertical differences identified between SRTM and World 30 control points based on one-degree grid comparisons.