Antarctic 1 km Digital Elevation Model (DEM) from Combined ERS-1 Radar and ICESat Laser Satellite Altimetry, Version 1

USER GUIDE

How to Cite These Data

As a condition of using these data, you must include a citation:

Bamber, J., J. L. Gomez-Dans, and J. A. Griggs. 2009. *Antarctic 1 km Digital Elevation Model (DEM) from Combined ERS-1 Radar and ICESat Laser Satellite Altimetry, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/H0FQ1KL9NEKM. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0422

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

This data set is a new Digital Elevation Model (DEM) of Antarctica combining radar and laser data. The result is a DEM where the number of interpolated grid points have been minimized while improving the accuracy of the topography for areas of high relief and south of 81.5°S latitude. The accuracy of the final DEM was assessed using a suite of independent airborne altimeter data and used to produce an error map.

The DEM contains a wealth of information related to ice flow and indirectly to ice thickness. The surface expression of subglacial lakes and other basal features are also illustrated. The DEM may also be used to derive new estimates of balance velocities and ice divide locations. Additional uses of the DEM may include fieldwork planning, numerical modeling studies, validating ability of a model to reproduce present-day geometry of an ice sheet, combining with other data to estimate steady-state velocities and ice thickness, and estimating mass balance of Antarctica using a mass budget approach.

The following two published journal articles provide additional information regarding the data description for this data product.

Bamber, J. L., J. L. Gomez-Dans, and J. A. Griggs. 2009. A New 1 km Digital Elevation Model of the Antarctic Derived from Combined Satellite Radar and Laser Data – Part 1: Data and Methods. *The Cryosphere*, 3, 101-111.

Griggs, J. A. and J. L. Bamber. 2009. A New 1 km Digital Elevation Model of Antarctica Derived from Combined Radar and Laser Data – Part 2: Validation and Error Estimates. *The Cryosphere*, 3, 113–123.

1.1 Format

Each image file is in binary little endian byte order Band Sequential Format (BSQ) format with 5601 samples.

1.2 File and Directory Structure

Data are available on the HTTPS site in the following directory:

`https://daacdata.apps.nsidc.org/pub/DATASETS/DEM/nsidc0422_antarctic_1km_dem/`

1.3 File Naming Convention

Files are named according to the following convention and as described in Table 1:

`krigged_dem_nsidc.bin`

`krigged_dem_nsidc.bin.hdr`

`krigged_dem_errormap_nsidc.bin`

`krigged_dem_errormap_nsidc.bin.hdr`

Where:

Table 1. File Naming Convention

Variable	Description
`krigged`	indicates the data were interpolated onto a regular 1 km polar stereographic grid using ordinary kriging
`dem`	Digital Elevation Model
`dem_errormap`	error map for the Digital Elevation Model
`nsidc`	National Snow and Ice Data Center
`.bin`	binary file
`.hdr`	ENVI header files. These header files are named the same as the data files, but with an additional `.hdr` extension appended to the file name

1.4 File Size

The DEM image file and the error map image file (`.bin`) are each ~120 MB.

Each header file (`.hdr`) is 1 KB.

1.5 Volume

The total distribution volume for the DEM data set is listed in Table 2.

Table 2. DEM File Volume

DEM File Name	Volume
`krigged_dem_nsidc.bin`	119.67 MB
`krigged_dem_nsidc.bin.hdr`	1 KB
`krigged_dem_errormap_nsidc.bin`	119.67 MB

DEM File Name	Volume
krigged_dem_errormap_nsidc.bin.hdr	1 KB

1.6 Spatial Coverage

Spatial coverage for the DEM derives from the ERS-1 SRA and from the ICESat GLAS laser altimeter. SRA data extend to 81.5° S, and ICESat GLAS data reach 86° S, and to equivalent latitudes in the northern hemisphere. The northerly limit of data used in this DEM is approximately 60° S.

ESR-1 SRA

Southernmost Latitude: 81.5° S

Northernmost Latitude: 60° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

ICESat GLAS

Southernmost Latitude: 86° S

Northernmost Latitude: 60° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

1.5.1 Spatial Resolution

The DEM is a 1 km grid. In March 1994 ERS-1 was placed in two successive long repeat cycles of 168 days. The two phases were offset from each other so that they were equivalent to a single 336 day cycle, providing 8.3 km across-track spacing at the equator. This reduces to about 4 km at 60° S latitude and 2 km at 70° S. The along-track spacing of each altimeter height measurement is 335 m and the footprint size is about 4 km. This is the same data set that was used to produce an earlier 5 km posting DEM of Antarctica (Bamber and Bindschadler 1997). Due to interactions of the broad SRA beam with an undulating ice surface, the typical spatial resolution of SRA-based DEMs is 5 to 10 km. We have combined the ERS-1 data with all the available quality-checked ICESat data. ICESat has an along track spacing of 170 m and an across-track spacing of about 20 km at 70° S. In contrast to the radar altimeter, the footprint size of ICESat is about 70 m (Bamber et al. 2009).

Data were first re-sampled onto a quasi-regular 1 km grid by calculating the mean x, y and z values for each cluster of satellite data falling within a grid cell. The mean z estimates were weighted values of the combined ERS-1 and ICESat data. The weights for ICESat data were 1.0 and for the

ERS-1 data were inversely proportional to the variance of the difference between ERS-1 and ICESat as a function of surface slope (Bamber et al. 2009).

The grid scale of the DEM is 1 km. Actual spatial resolution varies from about 5 km in regions of radar altimetry data only (between ICESat tracks) to about 1 km in regions of high ICESat laser altimetry track density south of 81.5 degrees.

The final DEM as processed and merged has a precision on the order of 10 cm. That is, the grid postings are a precise measure of the mean elevation of a region centered on the grid scale and extending a few kilometers in all directions. In some regions there are surface undulations of several meters within this averaging area.

1.5.2 Projection

World Geodetic System 1984 (WGS 84) is the reference ellipsoid and datum. The projection is polar stereographic with a standard parallel of 71° S and origin of the South Pole.

1.5.3 Grid Description

The grid is a 1 km grid of 5601 by 5601 grid boxes centered symmetrically about the pole. Grid size of 1 km is an optimization of resolution and interpolated cells, resulting in less than 32 percent of grid cells having interpolated values.

1.6 Temporal Coverage

Data used to produce the DEM were collected at different times.

The ERS-1 SRA data are from the geodetic phase comprised of two long repeat cycles of 168 days initiated in March 1994 and have a dH/dt correction applied to move their time stamp to 2004.

The ICESat GLAS data used to create this DEM are from fourteen operational periods of the Antarctic and Greenland Ice Sheet altimetry Data product GLA12 release version 428 dating from 20 February 2003 through 21 March 2008. Refer to Table 3 (Bamber et al. 2009).

Table 3. Operation Periods of ICESat Data

Laser	Start Date	End Date
1a	02/20/2003	03/21/2003
2a	09/25/2003	11/18/2003
2b	02/17/2004	03/21/2004
2c	05/18/2004	06/21/2004

Laser	Start Date	End Date
3a	10/03/2004	11/08/2004
3b	02/17/2005	03/24/2005
3c	05/20/2005	06/23/2005
3d	10/21/2005	11/24/2005
3e	02/22/2006	03/28/2006
3f	05/24/2006	06/26/2006
3g	10/25/2006	11/27/2006
3h	03/12/2007	04/14/2007
3i	10/02/2007	05/11/2007
3j	02/17/2008	03/21/2008

1.6.1 Temporal Resolution

The DEM data is derived from two satellites and several data acquisition periods.

ICESat operational cycles for the data used in this DEM varied from year to year. Refer to Table 3. ICESat captures Antarctic data during approximately 14.8 orbits per day. For more, refer to the NSIDC Web page on Laser Operational Periods. ICESat GLAS laser pulses occur 40 times per second.

ERS-1 was placed in two successive long repeat cycles of 168 days in 1994. The two phases were offset from each other so that they were equivalent to a single 336 day cycle. ESR-1 SRA operates at 13.8GHz frequency, with ice mode bandwidth of 82.5 MHz.

The DEM has a time stamp of January 2004.

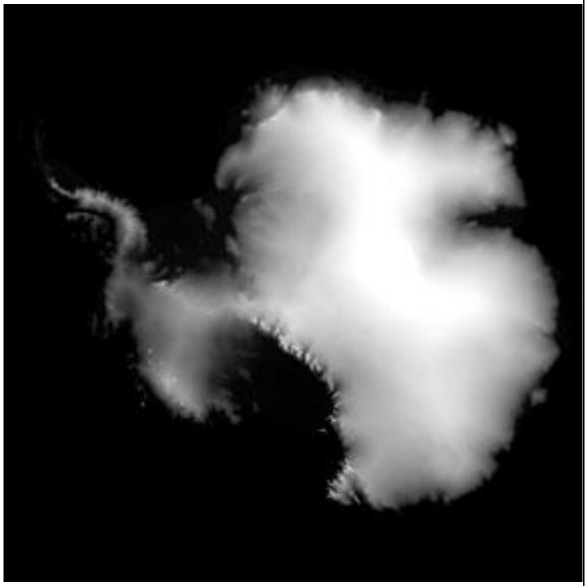
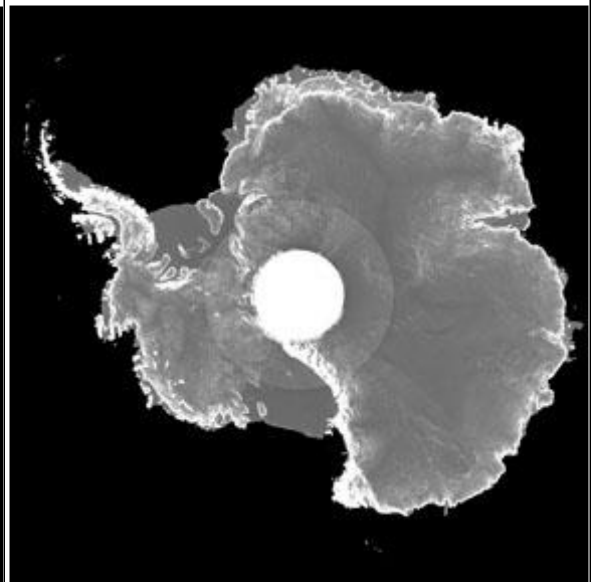
1.7 Parameter or Variable

The parameter for the 1 km Antarctic DEM is elevation in meters relative to WGS 84.

1.7.1 Parameter Range

Elevation values in the DEM range from -999 to 4185.72 meters. Values of -999 indicate grid cells with no measured or interpolated value, and typically occur in areas beyond the geographic extent of Antarctica.

Values in the Error Map range from -999 to 77.08. Values of 77.08 represent areas above 86° S latitude.

1 km Antarctic DEM	Error Map 1 km Antarctic DEM
	

2 SOFTWARE AND TOOLS

View the data files using ENVI, ArcGIS, or other similar commercial off-the-shelf software for image processing. ENVI header files are distributed with the data files.

2.1 Quality Assessment

The following two published journal articles provide information regarding the quality assessment of this data product.

Bamber, J. L., J. L. Gomez-Dans, and J. A. Griggs. 2009. A New 1 km Digital Elevation Model of the Antarctic Derived from Combined Satellite Radar and Laser Data – Part 1: Data and Methods. *The Cryosphere*, 3, 101-111.

Griggs, J. A. and J. L. Bamber. 2009. A New 1 km Digital Elevation Model of Antarctica Derived from Combined Radar and Laser Data – Part 2: Validation and Error Estimates. *The Cryosphere*, 3, 113–123.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

Laser altimeter measurements from GLAS onboard ICESat were combined with SRA data from the geodetic phase of the ERS-1 satellite mission. The former provide decimeter vertical accuracy but with poor spatial coverage. The latter have excellent spatial coverage but a poorer vertical accuracy. By combining the radar and laser data using an optimal approach, the vertical accuracy and spatial resolution of the DEM were maximized and the number of grid cells with an interpolated elevation estimate were minimized. The optimum resolution for producing a DEM based on a trade-off between resolution and interpolated cells was found to be 1 km (Bamber et al. 2009).

Satellite radar altimeters measure the time it takes an electromagnetic signal to travel from the altimeter antenna to the ice sheet surface and back to the altimeter's receiver. This "range measurement" allows investigators to determine the satellite's height above the ice sheet. NSIDC's Radar Altimeter document describes the instrument and how it works.

ERS-1 SRA operates at 13.8GHz frequency, with ice mode bandwidth of 82.5 MHz. Echo waveform samples are 64 samples x 16 bits at 20 Hz, 3.03 or 12.12 ns / sample (ocean or ice mode). Equivalent window width is 30 m in ocean mode, and 120 m in ice mode.

3.2 Data Acquisition Methods

The GLAS data were extracted using the Interactive Data Language (IDL) reader software provided by the National Snow and Ice Data center (NSIDC) and transformed from the Topex/Poseidon ellipsoid to the WGS 84 ellipsoid for consistency with the ERS-1 data and the geoid model applied. Corrections were also applied to account for saturation of the laser over the ice sheet as recommended by the NSIDC (Bamber et al. 2009).

In March 1994 ERS-1 was placed in two long repeat cycles of 168 days. The two phases were offset from each other so that they were equivalent to a single 336 day cycle, providing 8.3 km across-track spacing at the equator. This reduces to about 4 km at 60° S latitude and 2 km at 70° S. The along-track spacing of each altimeter height measurement is 335 m and the footprint size is approximately 4 km. The total number of data points, after filtering, over the ice sheet was about 40 million (Bamber and Bindschadler, 1997). Data reduction methodology provided a 1 Hz mean waveform as well as 20 Hz retracked elevations and summary wave from shape data using threshold retracking methodology described in detail in Bamber (1994). (Bamber et al. 2009).

3.3 Derivation Techniques and Algorithms

3.3.1 Processing Steps

ICESat and ERS-1 Data Pre-processing

Geophysical quality assurance filters were applied to the ICESat GLAS data. Corrections were applied to account for saturation of the laser over the ice sheet. Geophysical quality assurance filters were used to remove any returns that contained residual cloud or other artifacts that affect the elevation estimate. These filters combined, removed 5.4 percent of the data (Bamber et al. 2009). Refer to Table 4. The geophysical filters used were:

1. Attitude control classified as good
2. Only one waveform detected
3. Reflectivity of surface greater than 10 percent
4. Gain less than 200
5. Variance of waveform from Gaussian less than 0.03 V

Table 4. Amount of ICESat Data Removed by Each Stage of QA Filtering (Bamber et al. 2009).

Filter	No. of data points	Percentage Remaining
Original Data	144632388	
After Geophysical Filters	122328755	84.6%
After 3 Sigma Filter	121728068	84.2%
After DEM Filter	115619957	79.9%

The data were gridded with 5 km spacing and a three standard deviation filter was applied to remove additional elevation outliers. Visual inspection indicated that a small number of anomalous ERS-1 and ICESat data remained and these were removed in a final filtering step. This was achieved by using a preliminary version of the 1 km DEM (Bamber and Gomez- Dans 2005) and removing points where the difference was great than (11.5×slope angle) for slopes between 0.1 and 1 degree. These values were chosen based on the standard deviation of differences between ICESat and ERS data as a function of surface slope derived in an earlier study (Bamber and Gomez-Dans 2005). Data were only filtered in this step if they originated from an area where the surface slope was less one degree. In areas of higher slope, individual returns may be expected to have large departures from the average surface height in the grid box, so such a filter is inappropriate. Also at these higher surface slopes, there are relatively few data points in the comparison between ICESat and ERS. Surface slopes were determined with a 2 km spatial resolution from the "first guess" DEM. This final quality assurance filter removed a further four percent of the original data (Bamber et al. 2009).

The ERS-1 data used are the same as those used to derive a 5 km Antarctic DEM in the 1990s (Bamber and Bindschadler 1997). The data have been retracked, slopecorrected and filtered, as described elsewhere (Bamber 1994, and Bamber and Bindschadler 1997). These data were shown to suffer a roughness-dependent surface bias, which was believed to be due to the fact that the SRA does not sample kilometer scale surface roughness uniformly (Bamber 1994, Bamber et al. 1998, and Bamber and Gomez-Dans, 2005). Instead the peaks of undulations are oversampled compared to the troughs, causing a positive bias in the observed elevations, which increases with the amplitude of the undulations (Bamber et al. 2009).

The bias was removed by calculating the difference between the ERS-1 and ICESat data as a function of surface roughness over a length scale of 5 km. Surface roughness was determined from the standard deviation of the surface slope of a “first guess” DEM for a 5×5 grid centered on the cell in question (Bamber et al. 2009).

A correction for surface elevation changes between the acquisition period of the ERS-1 data (1994–1995) and the ICESat data (2003–2008) was applied to the ERS-1 data. Annual elevation change estimates derived from ERS-1 radar altimetry between 1992 and 2003 (Davis et al. 2005) were used. A correction was applied in regions where the height change over the entire period was more than 1m as this was assumed to be the likely cumulative error in the measurements based on an approximately 10 cm per yr detection limit. In addition, no correction was applied to the ice shelves (Bamber et al. 2009).

Ocean tide corrections were removed from both the ERS-1 and ICESat data and replaced with the global inverse tide model, TPXO6.2 (Egbert and Erofeeva 2002), that has been determined to be an optimum model for the entire circum-Antarctic seas (King and Padman 2005). All tidal components (8 major and 16 minor) were applied using the grounding line mask that came with the model. In some areas of floating ice the mask lies seaward of the true grounding line, which reduces the precision of the elevations in these small areas. The ocean loading and solid earth tides provided with the ERS-1 and ICESat products were used to correct for these effects (Bamber et al. 2009).

The following two published journal articles provide additional information regarding the processing steps for this data product.

Bamber, J. L., J. L. Gomez-Dans, and J. A. Griggs. 2009. A New 1 km Digital Elevation Model of the Antarctic Derived from Combined Satellite Radar and Laser Data – Part 1: Data and Methods. *The Cryosphere*, 3, 101-111.

Griggs, J. A. and J. L. Bamber. 2009. A New 1 km Digital Elevation Model of Antarctica Derived from Combined Radar and Laser Data – Part 2: Validation and Error Estimates. *The Cryosphere*, 3, 113–123.

3.3.2 Gridding

The metric used to determine the optimum resolution was the ratio between the number of grid cells containing observations against those that did not. The coverage of the two altimeters used in this study is latitude dependent, increasing toward the latitudinal limit of the satellite orbits of 81.5° and 86° S for ERS-1 and ICESat respectively. The interpolation ratio was examined for three latitudinal bands: 70–75, 75–80 and 80–85° S. The first band is largely populated, numerically, by ERS-1 data, the middle band is a mixture of the two while the last band is dominated by ICESat data (Bamber et al. 2009).

The interpolation ratios were calculated using the number of valid data points within each latitude band, which were binned into cells with spacings between 500 and 5000 m (Bamber et al. 2009).

Data were first re-sampled onto a quasi-regular 1 km grid by calculating the mean x, y and z values for each cluster of satellite data falling within a grid cell. The mean z estimates were weighted values of the combined ERS and ICESat data (Bamber et al. 2009).

A land/ocean mask was applied to the quasi-regular grid so that data over ocean/sea ice were not included in the interpolation and did not create biases at the ice edge. The mask defining the coastline was created using version 5 of the Antarctic Digital Database (ADD consortium, 2006) which has a variable resolution of between 5 m and greater than 5 km (Bamber et al. 2009).

The data were then interpolated onto a regular 1 km polar stereographic grid with a standard parallel of 71° S, using ordinary kriging using open source software from the Geostatistical Software Library (GSLIB) (Deutsch and Journel, 1997) (Bamber et al. 2009).

In data-sparse and mountainous regions (along the Antarctic Peninsula and Transantarctic Mountains) a handful of clearly erroneous interpolated values were identified from visual inspection of DEM surface slope values. These points were replaced using a nearest neighbour approach. South of 86° S, ADD cartographic data were merged with the DEM by weighting the two data sets using Hermite basis functions over a distance of 40 km at the southern limit of the satellite data set (Bamber et al. 2009).

3.3.3 Data Source

The ICESat data product used for this data set was the Level 2 Antarctic and Greenland Ice Sheet altimetry Data product (GLA12), Release Version 428.

The ERS-1 radar altimetry data product used for this data set was the geodetic phase comprised of two long repeat cycles of 168 days initiated in March 1994.

3.3.4 Error Sources

The accuracy of the DEM was assessed using a range of extensive airborne altimeter data sets covering both East and West Antarctica, interior plateau regions, marginal areas and ice shelves. The results of this comparison were used to estimate an error map for the entire continent. Bilinear interpolation was used to calculate the DEM elevation at the exact location of the airborne measurement and differences are calculated by subtracting the interpolated DEM value from the airborne measurement (Griggs and Bamber 2009).

Four airborne data sets were compared to the DEM to assess its accuracy. These data sets were:

Centro de Estudios Cientifios / National Aeronautics and Space Administration (CECS/NASA) over the Antarctic Peninsula and Pine Island, Thwaites, Pope, Smith and Kohler glaciers

Airborne Geophysical Survey of the Amundsen Sea Embayment, Antarctica (AGASEA) over the Amundsen Sea sector

Support Office for Aerogeophysical Research – Corridor Aerogeophysics of the South East Ross Transect Zone (SOAR CASERTZ) over the south-eastern Ross Embayment

Ice-house Earth: Stability Or DYNamism?/WIlkes basin/transantarctic mountains System Exploration (ISODYN/WISE) in northern Victoria Land

The agreement between the DEM and CECS/NASA data in the Amundsen Sea sector has a histogram of differences showing a mean bias of -7.42 m and a modal bias of -2.05 m and a RMS difference of 17.92 m. For AGASEA, the mean bias observed across the whole data set is -4.55 m with a modal bias of -0.61 m and an RMS difference of 13.14 m. The mean bias between the SOAR airborne data and the DEM for the entire data set is 0.21 m with a modal difference of 1.97 m and an RMS difference of 4.75 m. A mean bias of 1.64 m, a modal bias of 2.38 m and RMS difference of 9.83 m was obtained when comparing the entire ISODYN/WISE data set and the DEM and a mean bias of 2.78 m with an RMS difference of 6.25 m when comparing just those data points with elevation over 2200 m (Griggs and Bamber 2009).

Table 5 shows the results of the comparison of the DEM with the independent airborne altimetry data sets. The results of these comparisons were used to derive an error map for the new DEM, with the following assumptions: errors in the airborne data are neglected; the effects of differences in spatial resolution are ignored; and the assumption is that there are sufficient airborne validation data to fully characterize the errors in the DEM. (Griggs and Bamber 2009).

Table 5. Statistics of the Comparisons Between the DEM and Each Airborne Data Set

	Number of Airborne Data Points	Number of DEM Grid Boxes	Mean Bias (m)	Modal Bias (m)	Standard Deviation (m)	RMS Difference (m)	FWHM (m)
CECS/NASA peninsula	98781	7964	1.08	0.29	33.77	33.78	2.2
CECS/NASA Amundsen	200974	8959	−7.42	−2.05	16.31	17.92	14.1
AGASEA	1672797	37674	−4.55	−0.61	12.33	13.14	11.7
AGASEA (central area)	138077	3024	0.09	1.35	4.68	4.68	3.9
SOAR CASERTZ	1615531	285894	0.21	1.97	4.74	4.75	4.5
ISYDYN/WISE	2176824	96487	1.64	2.38	9.69	9.83	3.3
ISODYN/WISE (elevations over 2200m)	912235	40815	2.78	2.76	5.60	6.25	3.3

A multiple regression model was used to express the mean of the required variable, Y, the RMS error in the DEM, as a linear combination of k dependent variables, Xl(l =1, 2,..., k) for all n points in the airborne study region. The form of the regression relationship found was:

$$Y = 1.672 + 3.952X_1 + 8.132X_2 -0.019X_3 + 0.033X_4 + 0.345X_5 + 1.051X_6$$

Where:

Table 6. Regression Equation Description

Variable	Description
X_1	surface slope
X_2	surface roughness
X_3	number of satellite data points in the DEM grid box
X_4	standard deviation of satellite data points in the DEM grid box
X_5	deviation of the interpolated value in the DEM grid box from the quasi-regular grid box
X_6	distance of the DEM grid box from a satellite data point

This model was tested using backwards elimination and all dependent parameters (X1-X6) where found to be significant at the 99 degree confidence level. The model could then be applied to the whole of Antarctica to create a map of RMS error. For further description and discussion of the regression model variables, see Griggs and Bamber (2009).

The regression model was applied to all DEM grid boxes north of 86° S. South of this limit, there were no satellite data and the DEM was filled with cartographic data as described in Bamber et al. (2009). These data do not have the same properties as the satellite derived areas. In the areas of cartographic data, a value of the RMS error was calculated as the RMS difference between the DEM and cartographic data from the same source in a latitude band between 81.5° S and 86° S. The error in the area south of 86° S was found to be 77.09 m (Griggs and Bamber 2009).

Based on the error map, 81 percent of the DEM has an RMS error less than 5 m. Biases are shown to close to zero for all surface slopes surveyed with random errors being about half those from older DEMs based on ERS data only (Bamber and Gomez- Dans, 2005) and between 7 and 30 percent smaller than those for the DEM containing only GLAS data (Griggs and Bamber 2009).

The following two published journal articles provide additional error analysis information for this data product:

Bamber, J. L., J. L. Gomez-Dans, and J. A. Griggs. 2009. A New 1 km Digital Elevation Model of the Antarctic Derived from Combined Satellite Radar and Laser Data – Part 1: Data and Methods. *The Cryosphere*, 3, 101-111.

Griggs, J. A. and J. L. Bamber. 2009. A New 1 km Digital Elevation Model of Antarctica Derived from Combined Radar and Laser Data – Part 2: Validation and Error Estimates. *The Cryosphere*, 3, 113–123.

3.4 Sensor or Instrument Description

The ERS-1 radar altimeter is a Ku band (13.8 GHz) nadir-pointing active microwave sensor, designed to measure the echoes from ocean and ice surfaces. It has two measurement modes (tracking modes), optimized for measurements over ocean and ice, respectively. In ice mode the instrument measures surface height, surface wind speed modulus and surface elevation for extracting information on ice/land topography and other surface features. Please refer to the official European Space Agency Earthnet Online Web site for details of the radar altimeter.

ICESat GLAS is a laser-ranging (lidar) instrument for continuous global observations. The instrument measures ice-sheet topography and associated temporal changes, cloud and atmospheric properties. The laser transmits short pulses (4 nano seconds) of infrared light (1064 nanometers wavelength) and visible green light (532 nanometers). Photons reflected back to the spacecraft from the surface of the Earth and from the atmosphere, including the inside of clouds, are collected in a 1 meter diameter telescope. Laser pulses at 40 times per second illuminate spots (footprints) 70 meters in diameter, spaced at 170-meter intervals along Earth's surface. Please refer to the official ICESat/GLAS Web site at NASA Goddard Space Flight Center (GSFC) for details of the GLAS instrument.

4 REFERENCES AND RELATED PUBLICATIONS

Antarctic 5-km Digital Elevation Model from ERS-1 Altimetry (http://nsidc.org/data/nsidc-0076.html).

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Goddard Space Flight Center GLAS Instrument, GLAS instrument description (http://icesat.gsfc.nasa.gov/glasinstrument.php).

Griggs, J. A. and J. L. Bamber. 2009. A New 1 km Digital Elevation Model of Antarctica Derived from Combined Radar and Laser Data – Part 2: Validation and Error Estimates. The Cryosphere 3: 113–123.

ICESat/GLAS web site at NASA Wallops Flight Facility (http://glas.wff.nasa.gov/).

ICESat/GLAS Web site at NSIDC (http://nsidc.org/daac/projects/lidar/glas.html).

ICESat/GLAS Web site at University of Texas (http://www.csr.utexas.edu/glas/).

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4.1 Related Data Collections

Antarctic 5-km Digital Elevation Model from ERS-1 Altimetry
GLAS/ICESat 500 m Laser Altimetry Digital Elevation Model of Antarctica

Other ice sheet altimetry data sources include:

Radar Altimetry Polar Ice Sheet Data (Goddard Space Flight Center Ice Altimetry)

See also: GLAS/ICESat L1 and L2 Global Altimetry Data

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6 DOCUMENT INFORMATION

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