GLAS/ICESat 500 m Laser Altimetry Digital Elevation Model of Antarctica and 1 km Laser Altimetry Digital Elevation Model of Greenland, Version 1

USER GUIDE

How to Cite These Data

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

John P. DiMarzio 2007. *GLAS/ICESat 500 m Laser Altimetry Digital Elevation Model of Antarctica, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/K2IMI0L24BRJ. [Date Accessed].

John P. DiMarzio 2007. *John P. DiMarzio 2007. GLAS/ICESat 1 km Laser Altimetry Digital Elevation Model of Greenland, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/FYMKT3GJE0TM. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/NSIDC-0304 or https://nsidc.org/data/NSIDC-0305

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

The Geoscience Laser Altimeter System (GLAS) instrument on the Ice, Cloud, and land Elevation Satellite (ICESat) provides global measurements of elevation, and repeats measurements along nearly-identical tracks; its primary mission is to measure changes in ice volume (mass balance) over time. These digital elevation models (DEMs) of Antarctica and Greenland are derived from GLAS/ICESat laser altimetry profile data and provide new surface elevation grids of the ice sheets and coastal areas, with greater latitudinal extent and fewer slope-related effects than radar altimetry.

These DEMs are generated from the first seven operational periods (from February 2003 through June 2005) of the GLAS instrument. They are provided on polar stereographic grids at 500 m grid spacing for Antarctica and 1 km grid spacing for Greenland. The grids cover all of Antarctica north of 86° S and all of Greenland south of 83° N. Elevations for both ice sheets are reported as centimeters above the datums, relative to both the WGS 84 Ellipsoid and the EGM96 Geoid, in two separate elevation data files. A data quality map of the interpolation distance is distributed for each ice sheet. ENVI header files are also provided.

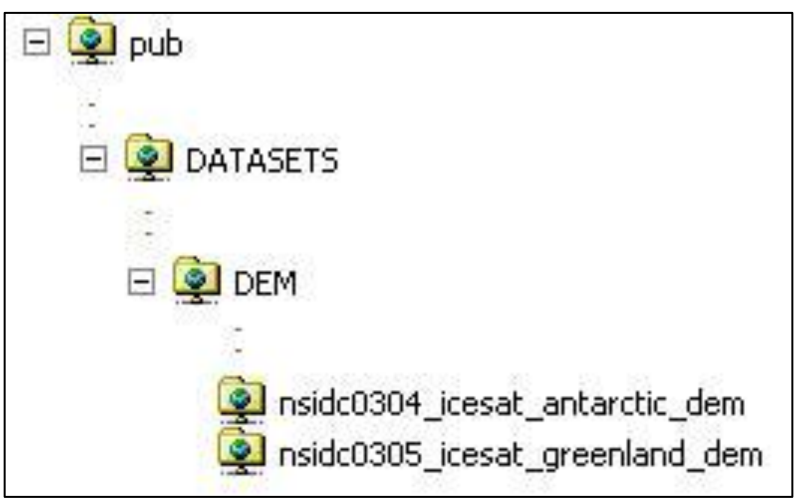
1.1 Format

The data are in 4-byte (long) signed integer binary files (big endian byte order).

1.2 File and Directory Structure

The DEM files are located on the HTTPS server in the directory:
https://daacdata.apps.nsidc.org/pub/DATASETS/DEM/.

Within the DEM directory, there is a separate subdirectory for each data set, as illustrated below.



1.3 File Naming Convention

Data files are named according to the following convention.

`NSIDC_Rrrssss_ddddd_vvvvv_uu.dat`

where NSIDC indicates the grid was created at NSIDC (derived from data provided by the authors) and

`Rrr`	=	Region of coverage for the DEM data set (`Ant` = Antarctica; `Grn` = Greenland)
`ssss`	=	Grid spacing (`1km` or `500m`)
`ddddd`	=	Datum (`wgs84` = WGS 84 Ellipsoid datum; `egm96` = EGM96 Geoid datum)
`vvvv`	=	Type of values in grid (`elev` = elevation; `dist` = mean distance)
`uu`	=	Unit of measurement (`cm` = elevation values reported as integer values in centimeters; `mm` = distance values reported as integer values in millimeters)

The data files are described in the following table.

Table 1. Data File Descriptions

Antarctica DEM Data Set	
File Name	Description
`NSIDC_Ant500m_wgs84_elev_cm.dat`	Elevation (centimeters) relative to WGS 84 ellipsoid datum
`NSIDC_Ant500m_egm96_elev_cm.dat`	Elevation (centimeters) relative to EGM96 Geoid datum
`NSIDC_Ant500m_dist_mm.dat`	Mean distance (millimeters) from contributing GLAS data for each grid cell
Greenland DEM Data Set	
File Name	Description
`NSIDC_Grn1km_wgs84_elev_cm.dat`	Elevation (centimeters) relative to WGS 84 Ellipsoid datum
`NSIDC_Grn1km_egm96_elev_cm.dat`	Elevation (centimeters) relative to EGM96 Geoid datum
`NDISC_Grn1km_dist_mm.dat`	Mean distance (millimeters) from contributing GLAS data for each grid cell

ENVI header files are also provided for each data file. These header files are named the same as the data files, but with an additional `.hdr` extension appended to the file name; for example, `NSIDC_Ant500m_wgs84_elev_cm.dat.hdr`.

The three data files for each DEM are distributed in compressed (zipped) form. Each compressed file has a `.gz` extension appended to the end of the file name; for example, `NSIDC_Ant500m_wgs84_elev_cm.dat.gz`.

1.4 File Size

File sizes for each DEM data set are shown in the following table. The three data files (two elevation and one mean distance) are all the same size for each DEM (they all contain the same number of grid cells). The sizes shown are uncompressed. The three data files for each DEM are distributed in compressed (zipped) form; the ENVI header files are not compressed.

Table 2. File Sizes

DEM Data Set	Size Per Data File	ENVI Header File Size
Antarctica	425,382,144 bytes	481 bytes
Greenland	29,055,208 bytes	504 bytes

1.5 Volume

The total distribution volume for each DEM data set is listed below. The three data files for each data set are distributed in compressed (zipped) form; the ENVI header files are not compressed for distribution.

Table 3. File Volumes

DEM Data Set	Total Volume Uncompressed	Total Volume with Compressed Data
Antarctica	1,276,147,875 bytes	433,997,915 bytes
Greenland	87,167,136 bytes	25,141,042 bytes

1.6 Spatial Coverage

The following table shows the spatial coverage and the grid resolution for each DEM data set.

Table 4. Spatial Coverages

<table>
<tr><th>DEM Data Set</th><th colspan="2">Spatial Coverage</th><th>Grid Resolution</th></tr>
<tr><td rowspan="4">Antarctica</td><td>Southernmost Latitude:</td><td>86.0° S</td><td rowspan="4">500 m</td></tr>
<tr><td>Northernmost Latitude:</td><td>63.0° S</td></tr>
<tr><td>Westernmost Longitude:</td><td>180.0° W</td></tr>
<tr><td>Easternmost Longitude:</td><td>180.0° E</td></tr>
</table>

DEM Data Set	Spatial Coverage		Grid Resolution
Greenland	Southernmost Latitude:	60.0° N	1000 m
	Northernmost Latitude:	83.0° N	
	Westernmost Longitude:	73.0° W	
	Easternmost Longitude:	11.0° W	

1.6.1 Projection and Grid Description

The data grid projections are polar stereographic, projected from the TOPEX/Poseidon Ellipsoid. However, the horizontal location differences between TOPEX/Poseidon and WGS 84 postings are so small (less than one meter) that the projection ellipsoid can be considered to be WGS 84. (See also: How does the GLAS ellipsoid compare with WGS 84?) The latitude of true scale is 70° S (Antarctica) or 70° N (Greenland). (Note that some other data sets covering Antarctica are projected to 71° S, not 70° S; the 70° S latitude of true scale is the choice of the data providers.) For the EGM96-referenced grids, the ellipsoid-projected data is modified by a geoid correction for each grid cell (the geoid is the approximate local sea level elevation relative to the ellipsoid). The central longitude of the projection (parallel to the image y-axis) is 0° extending up from the South Pole for Antarctica and 45° W extending down from the North Pole for Greenland. The center of the Antarctic grid is not the South Pole. The grid spacing is 500 m for Antarctica and 1 km for Greenland. The full projection information is provided in the ENVI header files associated with each of the data files.

The data are provided in image-formatted grids of binary numbers. Data image arrays have upper-left, row-by-row organization. Image grid size is shown in the following table.

Table 5. Image Grid Sizes

DEM Data Set	Columns	Rows
Antarctica	11352	9368
Greenland	2611	2782

Projection plane corner points are shown in the following table.

Table 6. Projection Plane Corner Points

Antarctica DEM Data Set						
Center Point of Corner Grid Cell						
	Column	**Row**	**x**	**y**	**Latitude**	**Longitude**
Upper Left	0.0	0.0	-2812000.0	2299500.0	-57.3452815	-50.7255753
Upper Right	11351.0	0.0	2863500.0	2299500.0	-57.0043684	51.2342036
Lower Left	0.0	9367.0	-2812000.0	-2384000.0	-56.8847122	-130.2911169
Lower Right	11351.0	9367.0	2863500.0	-2384000.0	-56.5495152	129.7789915
Outer Corner of Corner Grid Cell						
	Column	**Row**	**x**	**y**	**Latitude**	**Longitude**
Upper Left	-0.5	-0.5	-2812250.0	2299750.0	-57.3422816	-50.7250190
Upper Right	11351.5	-0.5	2863750.0	2299750.0	-57.0013764	51.2336047
Lower Left	-0.5	9367.5	-2812250.0	-2384250.0	-56.8817144	-130.2915680
Lower Right	11351.5	9367.5	2863750.0	-2384250.0	-56.5465248	129.7794862
Greenland DEM Data Set						
Center Point of Corner Grid Cell						
	Column	**Row**	**x**	**y**	**Latitude**	**Longitude**
Upper Left	0.0	0.0	-890000.0	-629000.0	79.9641229	-99.7495626
Upper Right	2610.0	0.0	1720000.0	-629000.0	73.2101234	24.9126514
Lower Left	0.0	2781.0	-890000.0	-3410000.0	58.2706251	-59.6277136
Lower Right	2610.0	2781.0	1720000.0	-3410000.0	55.7592932	-18.2336764
Outer Corner of Corner Grid Cell						
	Column	**Row**	**x**	**y**	**Latitude**	**Longitude**
Upper Left	-0.5	-0.5	-890500.0	-628500.0	79.9630236	-99.7861964
Upper Right	2610.5	-0.5	1720500.0	-628500.0	73.2074291	24.9327117
Lower Left	-0.5	2781.5	-890500.0	-3410500.0	58.2653993	-59.6335252
Lower Right	2610.5	2781.5	1720500.0	-3410500.0	55.7536121	-18.2303578

1.7 Temporal Coverage

Data used to produce the DEMs were collected from the GLAS instrument from February, 2003 to June, 2005.

The DEM data providers (DiMarzio et al.) used data from the following GLAS/ICESat lasers and data acquisition periods to generate these DEMs. The DEM data are an average of those data.

- Five cycles of 8-day repeat data from Laser 1 (February-April, 2003)
- One 8-day cycle from Laser 2A (September, 2003)

- 41 days of data from the 91-day repeat pattern from the Laser 2A data acquisition period: the 33-day sub-cycle and an additional 8 days beyond that
- Five cycles of 33-day sub-cycles from the Laser 2B, 2C, 3A, 3B, and 3C acquisition periods, the last of which (3C) ended in June, 2005

1.8 Parameter or Variable

The parameter is elevation above the datum (WGS 84 Ellipsoid or EGM96 Geoid), measured in centimeters. The supporting distance files contain the mean distance, in millimeters, to the contributing data for each grid cell.

1.8.1 Parameter Range

The minimum and maximum data values for each data file are shown in the following table.

Table 7. Minimum and Maximum Data Values

Antarctica DEM Data Set		
File Name	Minimum	Maximum
`NSIDC_Ant500m_wgs84_elev_cm.dat`	1	422547
`NSIDC_Ant500m_egm96_elev_cm.dat`	1	426194
`NSIDC_Ant500m_dist_mm.dat`	4	996087
Greenland DEM Data Set		
File Name	Minimum	Maximum
`NSIDC_Grn1km_wgs84_elev_cm.dat`	-89838	400459
`NSIDC_Grn1km_egm96_elev_cm.dat`	1	395636
`NDISC_Grn1km_dist_mm.dat`	6	994056

Note: The very large negative values in the Greenland DEM data are artifacts of the re-projection and re-gridding process and are limited to the grid corner areas. Users should ignore values that are outside the coast of Greenland.

1.8.2 Sample Images

The following images were created using hill-shading in ENVI from the EGM96 Geoid elevation data.

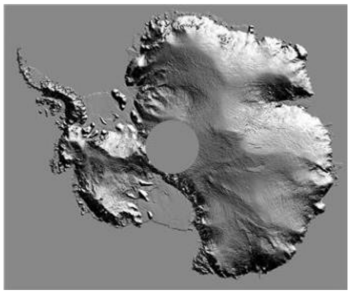


Figure 1. Antarctica DEM Data Set

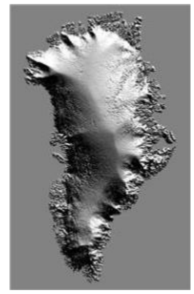


Figure 2. Greenland DEM Data Set

1.8.3 Sample Data Record

The following data sample was created from the `NSIDC_Grn1km_egm96_elev_cm.dat` file using the Unix command "`od -t d4`". This command interprets each 4-bytes as signed integers and displays the values. In this sample, only a few data values from the file are illustrated, and each row of four data values is preceded by its byte-offset in the file (such as 3221540). The asterisks indicate that all the data in that part of the file are zeroes.

```
0000000      0      0      0      0
*
3221540      0      0      0   8236
3221560      0      0      0      0
*
3221640      0      0      0   3562
3221660      0      0      0      0
*
3246040      0      0      0  55906
3246060  47321  34042  14507      0
3246100      0      0      0      0
*
3246160      0   1265   2615   2619
3246200   1896      0      0      0
3246220      0      0      0      0
*
3272340      0      0      0  46945
3272360  48231  53159  51417  48451
3272400  34656  16470   8105      0
3272420      0      0      0      0
*
3272460      0      0      0   2336
3272500   2026   3224   2043   1092
3272520      0      0      0      0
*
```

2 SOFTWARE AND TOOLS

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

2.1 Quality Assessment

Slope and elevation accuracy of the DEMs is best near the latitudinal limit of satellite coverage (±86°), and provides a good representation of the ice sheet and mountain areas (based on comparison with satellite images). DEM accuracy decreases as track spacing between ICESat profiles increases equatorward.

As a quality and accuracy indicator, the mean distance of all contributing GLAS surface spot data to the grid cell center was recorded in a separate identical grid for each ice sheet. These mean distance files are provided with the elevation data.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

Satellite laser altimetry is an active measurement technique using on-board laser light along with a detector telescope and timing system to measure range to a reflecting spot on the Earth's surface from the satellite. Precision orbit determination (POD) and precision attitude determination (PAD) are used to calculate a ground location of the laser spot.

Several additional corrections are required, including atmospheric refraction, return waveform analysis for complex or multi-level returns, and detector saturation correction. The measurement is susceptible to obscuration by thick clouds, and thin clouds can affect the reported surface elevation (in general making it appear too low). Clouds also reduce the amount of returned (reflected) energy, and an automatic gain adjustment is applied to the detectors after a few low-energy shots are received. Gain settings range from a minimum of 13 (maximum returned energy) to a maximum of 250 (weak energy return). Characteristics of the surface, such as slope or roughness, can also modify the return waveform.

3.2 Data Acquisition Methods

Please see the GLAS/ICESat L1B Global Elevation Data (GLA06) documentation for a description of the acquisition of individual elevation points from the ICESat/GLAS sensor.

3.2.1 Data Source

These DEMs were generated using data from the GLAS/ICESat L1B Global Elevation Data (GLA06) data set. This source data set includes the removal of the solid tides and the application of atmospheric corrections (Brenner et al., 2003).

3.3 Derivation Techniques and Algorithms

Several criteria and filters were applied to the total data set to minimize the number of low-quality elevation points in the data used for gridding. Off-nadir data acquired during "round the world scans" (a calibrating technique for testing pointing accuracy) were not used. Other non-surface return data (for example, cloud-impacted, fog-impacted, or blowing-snow-impacted elevations) were filtered out by only selecting data points with relatively low gain (that is, high surface return power; gain was limited to <50). No saturation correction was applied to the selected data because the saturation correction was still under development at the time of DEM generation. Saturation can cause errors (elevation underestimates) of up to 50 cm during high power laser operations periods, such as Laser 2A and 3A (Abshire et al., 2005).

Individual elevation point data were gridded onto a polar stereographic projection, combining many elevation points for each grid cell. Satellite altimetry data are unevenly spaced due to obscuration and variations in track spacing. For each grid node, a bi-quadratic surface was fitted to all elevations within a circular region surrounding the node (hereafter referred to as the "cap"). This was accomplished via a singular value decomposition (SVD) algorithm (Zwally et al., 1990). In the fitting routine, a weight (w) is assigned to each elevation within the cap according to

$$w = 1/(d^2\sigma_0)$$

Where:

d	=	the distance from the spot elevation to the grid node center
σ_0	=	the expected error of each elevation

The expected error value (σ_0) was set to 20 cm for all observations based on the standard deviation of crossover differences (DiMarzio et al., 2004; see also Shuman et al., 2006). When the fit quality estimate from the SVD algorithm indicates insufficient data within the cap for a valid bi-quadratic surface fit, the cap size was increased to include more data. Once a valid fit was found, an interactive procedure was used in which elevations differing by more than three standard deviations from the fitted surface are eliminated, and the SVD algorithm was re-applied.

Error estimates associated with each node (σ_g) are determined by the output of the SVD algorithm and the weighted root-mean-squared differences of the remaining elevations with the fitted surface. If σ_g was greater than 30 m, the estimate was declared invalid and the cap-fitting and error-estimation process was redone with a larger cap size. If no cap size (below 20 km) yields a valid elevation, then a bi-linear fit to the nearest data was applied. Cap sizes ranged from 2 km to 20 km for Antarctica and from 5.5 km to 20 km for Greenland.

The grid spacing is 500 m for Antarctica and 1 km for Greenland. The reduced grid spacing for Antarctica fully exploits the greater data density available in the areas just north of 86° S.

3.3.1 Validation and Accuracy

The DEM data providers (DiMarzio et al.) evaluated the GLAS/ICESat laser altimetry Greenland DEM data set by comparing it to airborne laser altimetry data. Airborne Topographic Mapper (ATM) data over Greenland have a reported accuracy of ±10 cm (Krabill et al., 2002). Using all ATM data within 600 m of the GLAS/ICESat 1 km gridded DEM nodes, a comparison of elevation data over northwestern Greenland (the region of densest ATM tracks) indicates ATM elevations are generally lower than the GLAS/ICESat Greenland DEM elevation data. The overall mean difference between the ATM and GLAS/ICESat DEM data is -41 cm (ATM elevations below GLAS/ICESat DEM elevations), with an error range of ±44 cm. The mean difference varies with slope: for regions with <0.1° slopes, the mean difference is -32 ±43 cm; for regions with 0.1° to 1.0° slopes, the mean difference is -66 ±61 cm.

A second evaluation compared the GLAS/ICESat laser altimetry Greenland DEM to a 5 km gridded radar altimetry DEM data set (Zwally and Brenner, 2001). This comparison indicates a mean difference of -2 ±9 m. The mean difference varies with slope: for regions with <0.1°slopes, the mean difference is 1 ±5 m; for regions with 0.1° to 1.0° slopes, the mean difference is -24 ±20 m.

NSIDC conducted a separate evaluation of the GLAS/ICESat laser altimetry Antarctic and Greenland DEMs, using filtering, shaded-relief processing, and comparison to satellite image mosaics of the ice sheets. Horizontal spatial resolution of these DEMs is approximately 7.5 km, despite the finer gridding scale for the data. This is likely a result of the large "cap" region and the simple surface-fitting routine used to evaluate the grid elevations. In several areas, large spike and divot errors (features not present in the image mosaics) deviated from the likely surface elevation by several tens of meters. A somewhat smaller dimple pattern due to gridding algorithm limitations is also present throughout both data sets. NSIDC provides these DEMs as unfiltered; however, for many regional mapping applications, the user may find that a 7.5 km low-pass-filtered version of the DEMs will give a better representation of the true surface (smoothed to that same scale), with subdued dimple, spike, and divot features, relative to the distributed DEM data.

As a quality and accuracy indicator, the mean distance of all contributing GLAS surface spot data to the grid cell center was recorded in a separate identical grid for each ice sheet. This interpolation distance file is distributed with the elevation data.

3.3.2 Error Sources

Several localized elevation artifacts associated with cloud effects, track mislocations, and gridding algorithms are present in the grids. DEM accuracy decreases as track spacing between ICESat profiles increases equatorward.

3.4 Sensor or Instrument Description

Please visit the official NASA Goddard Space Flight Center (GSFC) ICESat/GLAS Web site for details about the ICESat platform and GLAS instrument.

Also see ICESat Reference Orbit Ground Tracks for a summary of the orbits for each laser operational period.

4 REFERENCES AND RELATED PUBLICATIONS

Abshire, J. et al. 2005. Geoscience Laser Altimeter System (GLAS) on the ICESat mission: on-orbit measurement performance. *Geophysical Research Letters* v. 32, L21S02, doi:10.1029/2005GL1024028.

Brenner, A. et al. 2003. Derivation of range and range distributions from laser pulse waveform analysis for surface elevations, roughness, slope, and vegetations heights, Algorithm Theoretical Basis Document (ATBD) v.4.1, available at http://www.csr.utexas.edu/glas/atbd.html.

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Zwally, H. J., A. C. Brenner, J. A. Major, T. V. Martin, and R. A. Bindschadler. 1990. Satellite radar altimetry over ice, Vol. 1. Processing and corrections of Seasat data over Greenland. *NASA Reference Publication 1233*.

Zwally, H. J. and A. C. Brenner. 2001. "Ice sheet dynamics and mass balance." In: *Satellite Altimetry and Earth Science*, L-L. Fu and A. Cazenave, Eds., Academic Press, Ch. 9, 351-369.

4.1 Related Data Collections

ICESat/GLAS Data at NSIDC

4.2 Related Websites

ICESat Reference Orbit Ground Tracks

GLAS/ICESat L1B Global Elevation Data (GLA06)

4.3 Citing These Data

As a condition of using these data, you must cite the use of this data set using the following citation. For more information, see our Use and Copyright Web page.

The following examples show how to cite the use of these data sets in a publication. The citation to use depends on which data set you use. List the principal investigators, year of data set release, data set title and version (if applicable), publisher information (NSIDC), and indicate digital media distribution.

DiMarzio, J., A. Brenner, R. Schutz, C. A. Shuman, and H. J. Zwally. 2007. *GLAS/ICESat 500 m laser altimetry digital elevation model of Antarctica*. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

DiMarzio, J., A. Brenner, R. Schutz, C. A. Shuman, and H. J. Zwally. 2007. *GLAS/ICESat 1 km laser altimetry digital elevation model of Greenland*. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

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6 DOCUMENT INFORMATION

6.1 Publication Date

June 2007

6.2 Date Last Updated

December 2020