MEaSUREs Greenland Ice Mapping Project (GIMP) Digital Elevation Model, Version 1

USER GUIDE

How to Cite These Data

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

Howat, I., A. Negrete, and B. Smith. 2015. *MEaSUREs Greenland Ice Mapping Project (GIMP) Digital Elevation Model, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/NV34YUIXLP9W. [Date Accessed].

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National Snow and Ice Data Center

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1 DATA DESCRIPTION

The following digital elevation models and data sources were used to construct the GIMP DEM: the ASTER Global Digital Elevation Model, Version 2 (GDEM2) and SPOT 5 SPIRIT[1] DEMs for the ice sheet periphery and margin south of approximately 82.5° N—effectively below the equilibrium line elevation; AVHRR photoclinometry for the ice sheet interior and far north.

All land elevation data are horizontally and vertically calibrated to average elevations from 2003-2009 acquired by the Geoscience Laser Altimeter System (GLAS) on board the Ice, Cloud, and land Elevation Satellite (ICESat). Ocean surfaces have been masked out using the GIMP Land Classification mask and replaced with mean sea surface heights from the Centre National d'Études Spatiales (CNES) CLS11 model.

1.1 Parameters

Glacier Elevation/Ice Sheet Elevation

1.1.1 Parameter Description

Elevations are reported in meters above the WGS84 Ellipsoid

NOTE: Users of GIMP DEM or GIMP 2000 Image Mosaic images may find it helpful to mask out areas outside of the Greenland coastline using the corresponding 15 m, 30 m, or 90 m ocean mask image from the MEaSUREs Greenland Ice Mapping Project (GIMP) Land Ice and Ocean Classification Mask, Version 1 data set. To apply the ocean mask, set the target mosaic image to the fill value (-9999) wherever the mask equals 1 (NSIDC has tested this approach).

1.2 File Information

1.2.1 Format

The DEM is posted at 30 m and divided into 36 tiles with 8310 columns x 15,000 rows of pixels. Two versions of each tile are available:

- A 16-bit (integer) GeoTIFF that reports meters above the WGS84 Ellipsoid for each pixel;
- An 8-bit (byte) GeoTIFF that displays the DEM in shaded relief (hillshade).

Downsampled 90 m versions of the DEM and hillshade are also available as single files.

1.2.2 Directory Structure

Data are available via HTTPS. Subfolders labeled "30" and "90" contain the files corresponding to the 30 m and 90 m versions of the DEM.

1.2.3 Naming Convention

This section explains the file naming convention used for this data set with an example.

Example File Name (30 m):

gimpdem0_0_v1.1.tif
gimpdem0_0_hillshade_v1.1.tif

Naming Convention (30 m):

gimpdemX_Y_v1.1.tif
gimpdemX_Y_hillshade_v1.1.tif

The X_Y variable in file names corresponds to the tile's column and row in the master tile grid (see Figure 1).

Naming Convention (90 m):

The 90 m DEM and hillshade files are named:

gimpdem_90m_v1.1.tif
gimpdem_90m_hillshade_v1.1.tif

1.2.4 File Size

Individual 30 m DEM and hillshade tiles range from approximately 2.5 MB to 74 MB. The down-sampled 90 m DEM and hillshade files are approximately 147 MB and 123 MB, respectively. All GeoTIFFs are LZW compressed, which is a lossless format supported by most Geographical Information System (GIS) programs.

1.2.5 Volume

The complete 30 m DEM and hillshade (72 tiles) is approximately 1.86 GB. The entire data volume (30 m plus 90 m resolutions) is 2.1 GB.

1.3 Spatial Information

1.3.1 Coverage

Northernmost Latitude: 83° N
Southernmost Latitude: 60° N
Easternmost Longitude: 14° W
Westernmost Longitude: 75° W

1.3.2 Resolution

This DEM is posted at 30 m. A 90 m downsampled version is also available. Note that the true resolution varies from 40 m in areas of SPOT 5 coverage to 500 m for the photoclinometry.

1.3.3 Projection and Grid Description

The DEM is provided in a polar stereographic projection with a standard latitude of 70° N and rotation angle of -45° (sometimes specified as a longitude of 45° E). With this convention, the x-axis extends south from the North Pole along the 45° E meridian. Elevations refer to the WGS84 ellipsoid.

The data were gridded via bilinear interpolation to a master grid with an origin at 59.1996° N, 55.7983° W (Figure 1) and posted at 30 m. The master grid is partitioned into 36 tiles of 6 rows by 6 columns, each with dimensions of 15,000 by 8,310 pixels (see Figure 1).

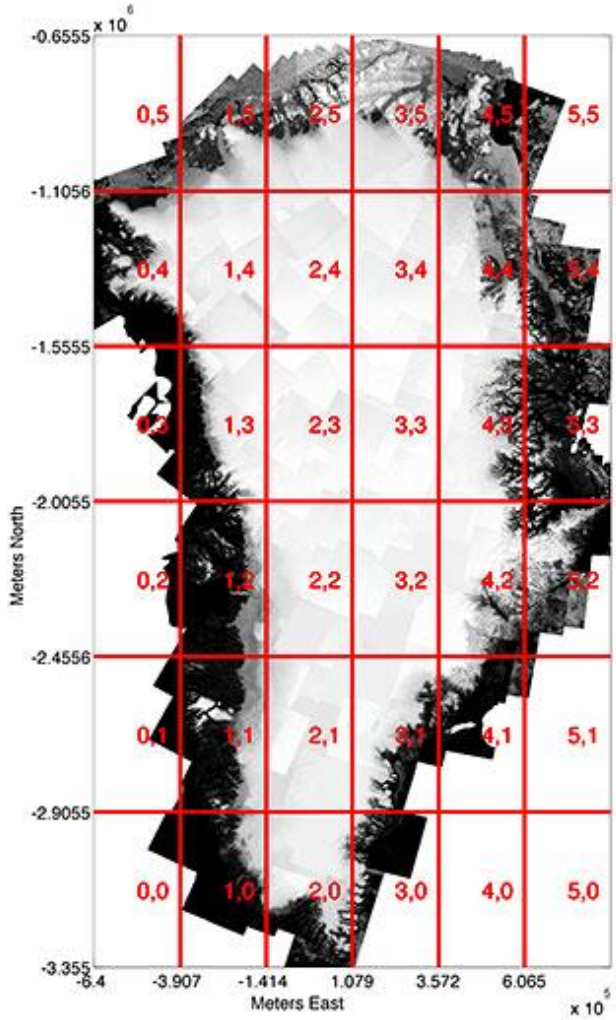

Figure 1. Tile Locations for the 30 m DEM grid.

1.4 Temporal Information

1.4.1 Coverage

All land elevation data were horizontally and vertically calibrated to average elevations acquired by ICESat/GLAS between 2003-2009, and thus the DEM has a nominal date of 2007. However, users should exercise caution in areas of rapid change such as major outlet glaciers south of 70° N. See section 2.3 of this documentation for additional information about temporal coverage.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Current global elevation data sets over the Greenland Ice Sheet are too low quality for robust glaciological applications. The most widely used DEM for glaciological studies was generated by Bamber et al. (2001) from mid 1990s satellite radar altimetery and aerial photogrammetry. A subsequent study (see Scambos and Haran, 2002) used AVHRR photoclinometry to enhance the Bamber DEM, hereafter referred to as the Photo-Enhanced Bamber (PEB) DEM; however, while this approach improved the effective spatial resolution and accuracy over the relatively flat interior of the ice sheet, errors over regions with higher relief such as the margins and periphery remained equivalent to the Bamber DEM.

The GIMP DEM achieves enhanced resolution and accuracy by merging the PEB DEM with high-quality photogrammetric topography for the margins and periphery and registering all land elevations to ICESat/GLAS laser altimetry data. Registration in this context refers to the process of correcting elevations in the merged DEM based on the average of multiple nearby ICESat/GLAS elevations acquired between 2003-2009. This approach ignores temporal changes in ice elevation, which can exceed 100 meters near the fronts of some rapidly retreating glaciers, to focus on generating a continuous surface that approximates the mean elevation over the ICESat operational window.

2.2 Acquisition

The DEM was generated using the following data:

- Photo-enhanced Bamber DEM (PEB)[1]
- Global Digital Elevation Model, Version 2 (GDEM2)
- SPOT 5 stereoscopic survey of Polar Ice: Reference Images and Topographies (SPIRIT)
- GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data (GLA12), Version 33
- Centre National d'Etudes Spatiales (CNES) CLS11 Mean Sea Surface Height

[1]Obtained via personal communication from T. Scambos, the National Snow and Ice Data Center.

2.3 Derivation Techniques and Algorithms

The following sections describe how the input data were prepared and merged into the final DEM. The following figure illustrates this process:

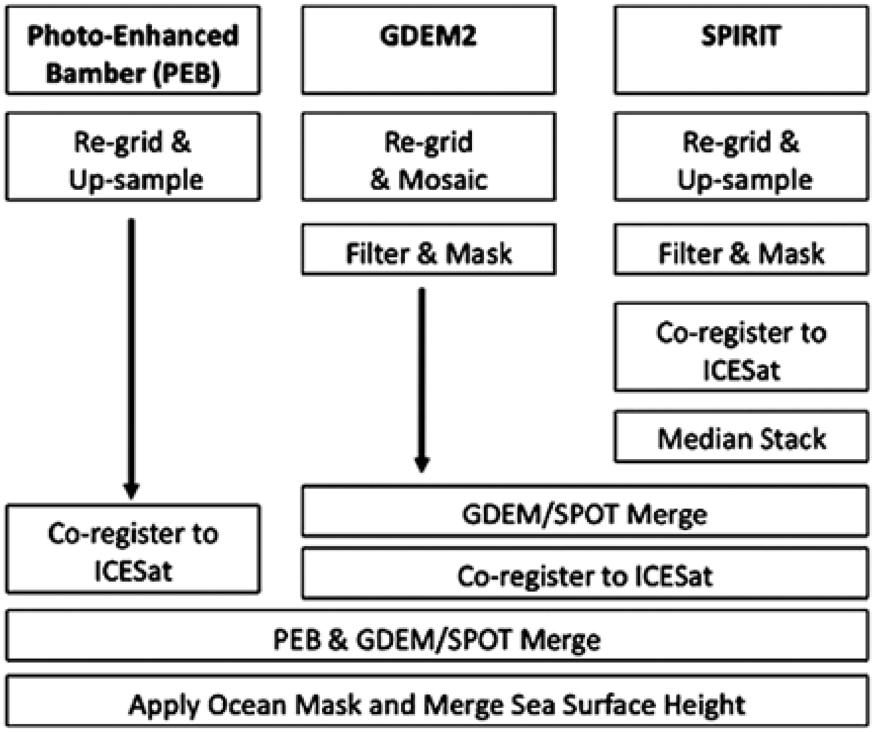

Figure 2. Illustration showing how the final GIMP DEM was constructed (Howat et al., 2014).

2.3.1 Data Preparation

Input data were registered to ICESat/GLAS elevations using the GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data, Version 33 data set (GLA12 V33[1]). The GLA12 data were corrected for detector saturation and time-varying elevation biases estimated from apparent variations of the mean sea surface height. The time-varying bias correction should also account for offsets associated with campaign-to-campaign variations in the shape of the transmitted pulse (see Borsa et al., 2014). Poor-quality returns were removed using techniques that identify the best-quality returns based on parameters which describe the shape and amplitude of the returned laser pulse (see Shepherd et al., 2012). Elevations calculated in this manner should be accurate to better than 0.1 m, or two orders of magnitude smaller than the expected uncertainty in the DEM.

[1]GLA12 V33 was subsequently replaced with GLA12 V34. See ICESat/GLAS | Description of Data Releases for details.

2.3.1.1 Photo-Enhanced Bamber (PEB) DEM

The PEB DEM was regridded from a spherical Lambert azimuthal projection posted at approximately 627 meters to the WGS84/NSIDC Sea Ice Polar Stereographic North projection (EPSG:3413)[1]. The regridded data were up-sampled to 30 meters using bilinear interpolation and then registered to ICESat/GLAS using an iterative, 3-D conformal transformation that yields residuals between the DEM surface and the ICESat point cloud with a normal distribution and a mean of 0 (see Noh and Howat, 2014). The registration was performed on 25 km x 25 km tiles with 5 km of overlap. The registered tiles were then mosaicked using linear distance-weighted edge feathering.

The registered tiles have a total root mean square (RMS) error of ±21.8 m, nearly three times the error reported by Bamber et al. in 2001 and Scambos and Haran in 2002. This likely reflects more extensive sampling by the laser altimeter system on board ICESat compared with the airborne altimetry used in the earlier studies, especially over ice-free terrain where errors are much higher. RMS errors over the ice sheet interior are more consistent with the original Bamber and PEB DEMs.

[1]For details about WGS84/NSIDC Sea Ice Polar Stereographic North (EPSG:3413), go to EPSG Geodetic Parameter Registry, select the "Retrieve by Code" tab, and search for code 3413.

2.3.1.2 ASTER GDEM

The Global Digital Elevation Model (GDEM) is produced by NASA and the Ministry of Economy, Trade, and Industry (METI) of Japan. The GDEM is created by average-stacking individual stereo-photogrammetric DEMs acquired by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) between 2000 and 2010. The GDEM is posted at 30 m and distributed in 1° x 1° tiles in geographic projection. The GDEM metadata specifies the number of individual granules that were stacked to obtain each posted elevation, but not which scenes were used. As such, the time period of elevation measurements cannot be determined directly.

GDEM data quality is poor over much of the ice sheet owing to low contrast between adjacent surfaces on snow and ice. Additionally, artifacts are abundant over all terrains due to shadows, clouds, and errors made by the automated matching algorithm. Following reprojection and gridding to EPSG:3413, the investigators applied a pyramiding standard deviation filter in which the DEM was progressively smoothed to finer resolutions and differenced from the native-resolution DEM. Pixels with differences exceeding 2.5σ of the mean were discarded. The filter was applied separately to ice-covered and ice-free terrain using land classification masks because ice-covered terrain is substantially smoother than ice-free. Following automated filtering, remaining artifacts were manually masked on a hillshade image of the DEM. These procedures removed nearly all data from above 1600 m elevation, which coincides approximately with the average mass balance equilibrium line altitude. The final filtered and masked GDEM covers 30% of Greenland's total area and 92% and 19% of its total ice-free and ice-covered terrain, respectively.

2.3.1.3 SPIRIT DEM

Photogrammetrically derived DEMs over Greenland were produced from images acquired in 2007 and 2008 as part of the Satellite Pour l'Observation de la Terre (SPOT 5) stereoscopic survey of Polar Ice: Reference Images and Topographies (SPIRIT) program. The SPIRIT DEM is distributed in UTM projection referenced to the EGM96 Geoid and posted at 40 m. Two versions are available, processed with different correlation parameters, along with data quality and interpolation masks. Based on validation experiments using ICESat, SPIRIT DEMs offer slightly better precision and accuracy (< ±5 m) than ASTER DEMs (see Korona et al., 2009).

As advised by Korona et al., all available Version 2 SPIRT DEM products covering Greenland were obtained and interpolated pixels were masked out. The DEMs were then reprojected to EPSG:3413, up-sampled to 30 m, and filtered and masked using the same procedure as the GDEM. Each individual SPIRIT DEM was then registered to overlapping regions of the filtered GDEM using the previously described 3-D conformal transformation (see Noh and Howat, 2014). This provided a consistent registration between the SPIRIT and GDEM data sets to facilitate merging. Each individual SPIRIT DEM was then stacked into a single mosaic by taking the median elevation at each pixel. The resulting filtered SPIRIT mosaic covers 10% of Greenland's total area and 24% and 8% of its total ice-free and ice-covered terrain, respectively. The most continuous coverage is along the southwestern and southern coasts: approximately 50% of the land and ice area is covered in each tile, which accounts for most of the land and ice area below 1500 m elevation.

2.3.2 Data Merging

Following registration and stacking, the SPIRIT DEM mosaic was differenced from the GDEM and the differences were extrapolated across the grid using an inverse-distance interpolation. The extrapolated difference map was then added to the SPIRIT DEM. The GDEM and corrected SPIRIT DEMs were then merged at each pixel using the following conditions:

1. If there was a GDEM value but no SPIRIT value, the pixel was assigned the GDEM value;
2. If there was a SPIRIT value but no GDEM value, the pixel was assigned the corrected SPIRIT value;
3. If there were both GDEM and SPIRIT values and the pixel was over ice-free terrain, the pixel was assigned GDEM value. This is due to the GDEM's higher spatial resolution;
4. If there were both GDEM and SPIRIT values and the pixel was over ice, the pixel was assigned a weighted average of the GDEM and SPIRIT values (see Howat et al. 2014).

The merged GDEM and SPIRIT DEM (merged G-S) was then registered to the ICESat/GLAS point cloud using the 3-D conformal transformation described in the preceding sections (Noh and Howat, 2014).

To combine the merged G-S DEM and PEB DEM, the PEB DEM was first adjusted by differencing it from the merged G-S DEM and interpolating the differences across areas of no data in the merged G-S DEM. The difference was then added to the PEB DEM and the two DEMs were combined using the following rules at each pixel:

1. If there was a merged G-S DEM value, the pixel was assigned the merged G-S value;
2. If there was no merged G-S DEM value, the pixel was assigned the adjusted PEB DEM value.

Lastly, to ensure correct sea surface heights, ocean surfaces in the final DEM were masked out using the GIMP Ice & Ocean Mask and replaced with heights from the CLS11 Mean Sea Surface product from the Centre National d'Etudes Spatiales. The CNES CLS11 consists of mean sea surface heights computed from measurements acquired by several satellite radar altimeters during 1993-2009. For this project, the CLS11 was reprojected from its native 1/3° grid to EPSG:3413 and up-sampled to the 30 m GIMP grid using bilinear interpolation.

The final GIMP DEM thus provides an altimeter-registered, relief-enhanced version of the PEB DEM. The improvement is most pronounced over regions of high relief on the margin and periphery of the ice sheet. Notably, whereas outlet glaciers are not clearly defined in the PEB DEM, the GIMP DEM resolves outlet glacier termini and fjord walls in detail.

2.4 Quality, Errors, and Limitations

2.4.1 Error Sources

The overall root-mean-square (RMS) difference between GIMP DEM and ICESat elevations is ±9.1 m, which is less than half the RMS of the ICESat-registered PEB. The error on ice-free terrain (±18.3 m) is more than twice that of ice-covered terrain (±8.5 m), which is to be expected considering the higher relief at the ice-free margin. Note that an unknown fraction of this error can be attributed to differences between the geometries of the GLAS footprint (a typical diameter of 70 m) and pixels in the DEM, and that the impact of this difference increases with slope. Furthermore, some of the error over ice-covered terrain stems from temporal variations in surface elevation, ranging from 10ths of a meter over the ice sheet interior to 10s of meters over rapidly thinning outlet glaciers. In addition to ice thinning, crevasses and other surficial features advected by ice flow contribute unknown error. These errors should therefore be viewed as an upper bound for the true standard data error.

The largest errors lie in the most northern regions, where few high-resolution data exist and coverage is mostly from the PEB DEM. Errors exceeding ±20 m can also be found in areas of extreme relief such as the Geikie Peninsula (tiles 4,2 and 5,2), where gaps in high-resolution data exist over steep mountain glaciers and ice caps. RMS errors are smallest for the flattest surfaces, for example in the interior of the ice sheet, and increase with slope to a peak of ±24 m at 2° slope. This peak roughly corresponds to the equilibrium line of the ice sheet, and thus the boundary between the merged G-S and PEB DEMs. Errors in both DEMs result in spurious, step-like transitions when crossing boundaries between them. This effect yields a continuous zone of large errors running along the southeast margin, which is especially steep.

For additional information about errors in the final merged DEM, see Howat et al., 2014.

3 SOFTWARE AND TOOLS

GeoTIFF files are most easily accessed using GIS software such as QGIS and ArcGIS.

4 VERSION HISTORY

Version 1.1 was released April 2017. Refer to Table 1 for this data set's version history:

Table 1. Version History

Version	Description
V1.1	Corrects the location of the upper left pixel in each GeoTIFF file
V1	Initial version (November 2015)

5 RELATED DATA SETS

ASTER Global Digital Elevation Model (GDEM), Version 2
SPIRIT (SPOT 5 stereoscopic survey of Polar Ice: Reference Images and Topographies)
GLAS/ICESat L2 Antarctic and Greenland Ice Sheet Altimetry Data, Version 33
Centre National d'Etudes Spatiales (CNES) CLS11 Mean Sea Surface Height
Greenland Ice Sheet Mapping Project (GIMP)

6 RELATED WEBSITES

MEaSUREs Data at NSIDC
NASA MEaSUREs Projects
Greenland Ice Sheet Mapping Project (GIMP)

7 REFERENCES

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8 DOCUMENT INFORMATION

8.1 Publication Date

November 2015

8.2 Date Last Updated

29 December 2020