IceBridge BedMachine Greenland, Version 5

USER GUIDE

How to Cite These Data

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

Morlighem, M., Williams, C., Rignot, E., An, L., Arndt, J. E., Bamber, J., Catania, G., Chauché, N., Dowdeswell, J. A., Dorschel, B., Fenty, I., Hogan, K., Howat, I., Hubbard, A., Jakobsson, M., Jordan, T. M., Kjeldsen, K. K., Millan, R., Mayer, L., Mouginot, J., Noël, B., O'Cofaigh, C., Palmer, S. J., Rysgaard, S., Seroussi, H., Siegert, M. J., Slabon, P., Straneo, F., van den Broeke, M. R., Weinrebe, W., Wood, M., & Zinglersen, K. (2022). *IceBridge BedMachine Greenland, Version 5*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/GMEVBWFLWA7X [Date Accessed].

Literature Citation

As a condition of using these data, we request that you acknowledge the authors of this data set by referencing the following peer-reviewed publication.

Morlighem, M., Williams, C., Rignot, E., An, L., Arndt, J. E., Bamber, J., Catania, G., Chauché, N., Dowdeswell, J. A., Dorschel, B., Fenty, I., Hogan, K., Howat, I., Hubbard, A., Jakobsson, M., Jordan, T. M., Kjeldsen, K. K., Millan, R., Mayer, L., Mouginot, J., Noël, B., O'Cofaigh, C., Palmer, S. J., Rysgaard, S., Seroussi, H., Siegert, M. J., Slabon, P., Straneo, F., van den Broeke, M. R., Weinrebe, W., Wood, M., & Zinglersen, K. (2017). BedMachine v3: Complete bed topography and ocean bathymetry mapping of Greenland from multi-beam echo sounding combined with mass conservation. *Geophysical Research Letters*, *44*. https://doi.org/10.1002/2017GL074954

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IDBMG4

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

This data set contains a bed topography and bathymetry map of Greenland based on mass conservation and ocean bathymetry data from multiple sources.

1.2 File Information

1.2.1 Format

The data are provided as a single netCDF (`.nc`) file. The bed elevation parameter (see section 1.2.2) is also provided as a geoTIFF file (`.tif`).

NetCDF comprises a set of machine-independent data formats and software libraries that can be used to create, share, and access scientific data sets. NetCDF is developed and maintained by Unidata, a University Corporation for Atmospheric Research (UCAR)'s Community Program. For more information, visit the Unidata Network Common Data Form (NetCDF) website.

GeoTIFF is an image format that contains embedded georeferencing information for use in GIS applications. For more information, visit the Open Geospatial Consortium website.

1.2.2 File Contents

All parameters of the data set are detailed in Table 1.

Table 1. File Parameter and Units

Parameter Name	Description	Units
bed	Bed elevation (bed topography) relative to the geoid	meters
dataid	Data ID number showing what type of data were available to constrain the map for each pixel: (0 = no data available, 1= gimpdem, 2 = radar, 7 = seismic bathymetry, 10 = multibeam bathymetry)	flag values
errbed	Bed topography/ice thickness error	meters
geoid	Height difference between the EIGEN-6C4 Geoid and WGS84 Ellipsoid	meters
mask	Mask (0 = ocean; 1 = ice-free land; 2 = grounded ice; 3 = floating ice; 4 = non-Greenland land)	flag values (0–4)

source	Data source, mass conservation/kriging/bathymetry: (0 = none; 1 = gimpdem; 2 = mass conservation; 3 = synthetic; 4 = interpolation; 5 = hydrostatic equilibrium; 6 = kriging; 7 = RTOPO-2; 8 = gravity inversion; 10+ = bathymetry data)	flag values (0–46)
surface	Ice surface elevation relative to the geoid	meters
thickness	Ice thickness	meters
x	Projection x coordinate	meters
y	Projection y coordinate	meters

1.2.3 Naming Convention

The netCDF data file is named as follows:

```
BedMachineGreenland-v5.nc
```

where "v5" refers to the version of the data set. The geoTIFF file has the same name but with "_bed" appended:

```
BedMachineGreenland-v5_bed.tif
```

1.2.4 Final Map Images

Figure 1 illustrates Greenland bed topography (m) with respect to mean sea level (left) and ice thickness (m) (right).

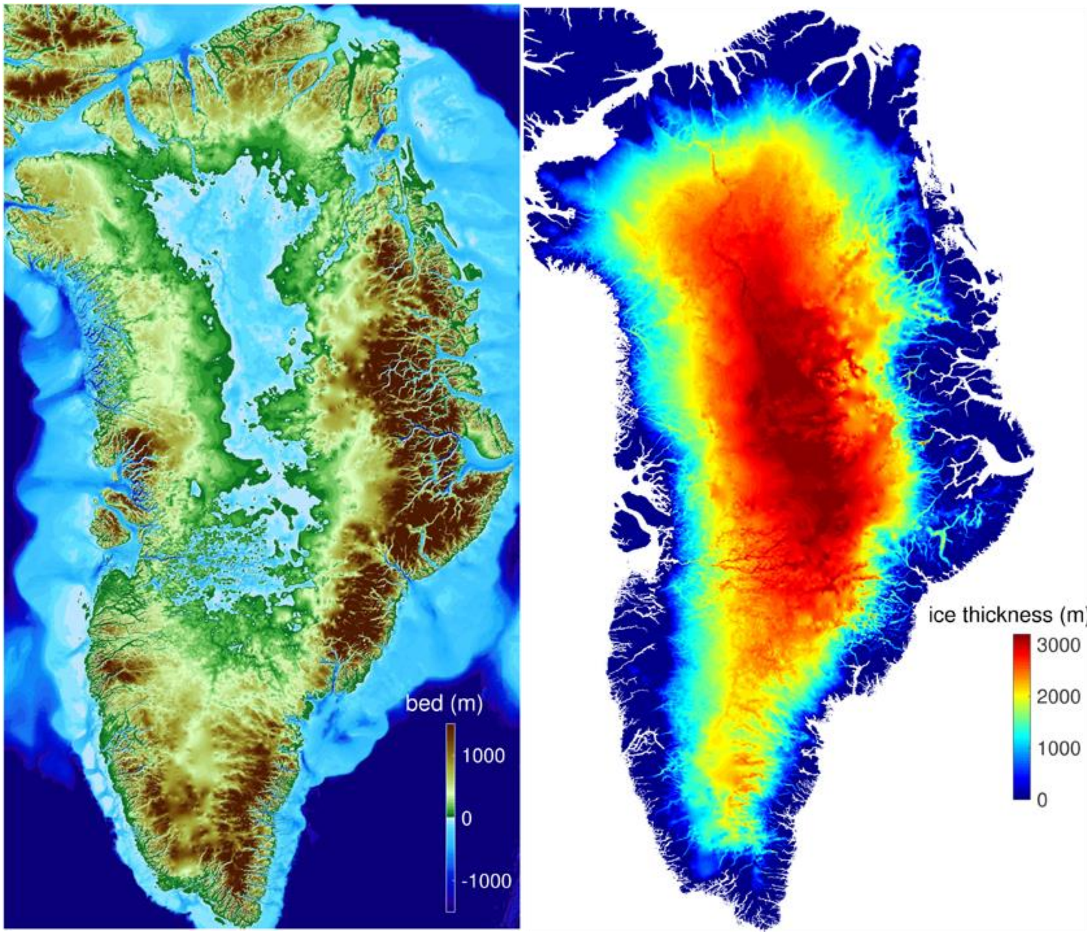

Figure 1. Greenland Bed Topography and Ice Thickness

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage for this data set includes Greenland and the Arctic.

Southernmost Latitude: 60° N
Northernmost Latitude: 90° N
Westernmost Longitude: 80° W
Easternmost Longitude: 10° E

1.3.2 Resolution

The output product is generated at a 150 m resolution. The true resolution varies between 150 m and 5 km.

1.3.3 Geolocation

The following table provides information for geolocating this data set.

Table 2. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	WGS 84 / NSIDC Sea Ice Polar Stereographic North
Longitude of true origin	-45° E
Latitude of true origin	70° N
Scale factor at longitude of true origin	1
Datum	WGS 84
Ellipsoid/spheroid	WGS 84
Units	meters
False easting	0
False northing	0
EPSG code	3413
PROJ4 string	+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs
Reference	https://epsg.io/3413

1.4 Temporal Information

1.4.1 Coverage

The data were collected between 01 January 1993 and 31 December 2021. The nominal year of this data set is 2007.

1.4.2 Resolution

Not specified

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Bed topography and seafloor bathymetry regulate ice dynamics and water flow around Greenland, which impact glacier undercutting, calving, and movement. High-resolution mapping of subglacial features can improve understanding of ice-ocean interactions and ice sheet changes.

Bed topography and ice thickness data are primarily collected by airborne radar sounders; however, the data quality is insufficient along coastal margins. Using multiple data sources and methods, along with the radar-derived ice thickness, optimizes mapping to provide a comprehensive bed topography and fjord bathymetry map of Greenland.

2.2 Acquisition

Source data used in deriving this product are listed below.

Ice thickness data

- Operation IceBridge radar-derived thickness data, posted at 30–60 m, with a vertical precision of 30 m, collected by the MCoRDS radar (IceBridge MCoRDS L2 Ice Thickness)
- Ice thickness data from the Doppler focused radar of the Technical University of Denmark (DTU) for the region of 79 North (Thomsen et al., 1997; Christensen et al., 2000) and Russell (Lindbäck et al., 2014)
- Ice thickness data from the High CApability Radar Sounder (HiCARS; Peters et al., 2005; Peters et al., 2007) operated by the University of Texas, Institute for Geophysics
- Ice thickness data from the Pathfinder Advanced Radar Ice Sounder (PARIS; Raney, 2010)
- Ice thickness data from the Alfred Wegener Institute (AWI; Nixdorf et al., 1999)
- Ice thickness data from Uppsala University (UU; Lindbäck et al., 2014), collected in the vicinity of Russell Gletscher
- Ice thickness for ice caps from Millan et al. (2022)

Sounding data

- Multibeam echo sounding data from Oceans Melting Greenland (OMG 2016, 2017, and 2020 Missions) along the coast of West and Southeast Greenland

Bathymetry data

- Bathymetry data from Oceans Melting Greenland (OMG 2021 Mission)
- Bathymetry data from Slabon et al. (2016) along the Northwest coast
- Bathymetry data from Weinrebe et al. (2009) in Torssukataq and Uummannaq Fjords
- Bathymetry data from O'Cofaigh et al. (2013) in Uummannaq Fjord
- Bathymetry data from Dowdeswell et al. (2014), Rignot et al. (2015), Fried et al. (2015), and Rignot et al. (2016) in Uummannaq Fjord

- Bathymetry data from Schumann et al. (2012), Holland et al. (2008) and Straneo et al. (2012) in Illulisat Icefjord
- Bathymetry data from Mix et al. (2015) in front of Petermann Fjord and the adjacent Hall Basin
- Bathymetry data from Sutherland et al. (2014) near Kangerdlussuaq
- Bathymetry data from Dowdeswell et al. (2016) in Nordvestfjord
- Bathymetry data from Chauché et al. (2014) near Lille Gletscher
- Bathymetry data from Straneo et al. (2016) in Sermilik fjord
- Bathymetry data from Motyka et al. (2017) in Godthåbsfjord
- Bathymetry data from Stevens et al. (2016) in Sarqardleq fjord
- Bathymetry data from Kjeldsen et al. (2017) in Timmiarmiut Fjord, Heimdal Glacier and Skjoldungen Fjord
- Bathymetry data from Rysgaard et al. (2003) in Young Sound fjord
- Bathymetry data from Bendtsen et al. (2017) near Flade Isblink Ice Cap
- Single beam bathymetry data from Sutherland and Pickart (2008) on the continental shelf along the Southeast coast
- Single beam data from Olex and crowd sourced data from fishing and recreational vessels (MaxSea)
- Bathymetry data from An et al. (2019) along the Northwest Greenland coast
- Bathymetry data from Millan et al. (2018) and An et al. (2019) in Southeast Greenland
- Bathymetry data from An et al. (2021) in Northeast Greenland
- Bathymetry data from the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, in front of the Northeast Ice Stream

Radar data

- Ice velocity measurements derived from satellite radar data collected during 2008–2009, posted at 150 m, with errors of 10 m yr^{-1} in speed and 1.5° in flow direction (Mouginot et al., 2017):
    - Japanese Advanced Land Observing System (ALOS) PALSAR
    - Canadian RADARSAT-1 SAR
    - German TerraSAR-X
    - European Envisat Advanced SAR (ASAR)
- Radar data from Center for Remote Sensing of Ice Sheets (CReSIS) (2017)
- Radar data from Hiawatha thickness (Kjaer et al., 2018)
- Radar data from the Programme for Monitoring of the Greenland Ice Sheet (PROMICE) (Søren et al., 2019)
- Radar data from East Greenland Ice Core Project (EGRIP) thickness (Franke et al., 2020)
- Radar data from Northeast Greenland Ice Stream (NEGIS) thickness (Jansen et al., 2020)

Ancillary products used include:

- Surface Mass Balance (SMB) averaged for the years 1961 to 1990 downscaled to 1 km with a precision between 7 percent and 20 percent in the ablation zone (Noël et al., 2016; data set available from the authors upon request)

- Ice thickening rates from altimetry data differencing between the years 2003 and 2006 (Khan et al., 2014)
- Surface elevation from the Greenland Mapping Project (GIMP) Digital Elevation Model (Howat et al., 2014)
- Ice and Ocean mask from the Greenland Mapping Project (GIMP) Digital Elevation Model (Howat et al., 2014)
- RTopo-2 (Schaffer et al., 2016)

2.3 Processing

Sparse, airborne radar-sounding-derived ice thickness data are combined with comprehensive, high-resolution ice motion derived from satellite interferometric synthetic aperture radar to calculate ice thickness based on mass conservation. The mass conservation method solves the mass conservation equation to derive ice thickness while minimizing the departure from the original radar-derived ice thickness data. Ice surface motion provides a physical basis for extrapolating sparse ice thickness data to larger areas with few or no data. The method works best in areas of fast flow, where errors in the flow direction are small and glaciers slide on the bed. In the interior regions, where errors in the flow direction are larger, kriging is used to interpolate ice thickness for the 1993–2016 data (Morlighem et al., 2014). Beginning with the 2017 data, streamline diffusion was used in the interior regions instead of kriging.

Ocean bathymetry is mapped by combining sparse bathymetry measurements from single and multibeam measurements and casts and RTopo-2 (Schaffer et al., 2016).

The algorithm neglects ice motion by internal shear, which is an excellent approximation for fast-flowing glaciers (>100 m yr^{-1}) (Morlighem et al., 2014).

The bed topography is derived by subtracting the ice thickness from the Greenland Mapping Project (GIMP) Digital Elevation Model.

2.4 Quality, Errors, and Limitations

Sources of error include error in ice velocity direction and magnitude, error in surface mass balance, and ice thinning rates. In a trial setting with unusually dense radar sounding coverage, errors in the mass-conservation-inferred thickness were 36 m, only slightly higher than that of the original data. In areas less well constrained by radar-derived thickness data or constrained by only one track of data, for example, in south Greenland, errors may exceed 50 m (Morlighem et al., 2013).

No or very little data were available for some fjords, and uncertainty may be high (>500 m).

An error estimate of the bed elevation and ice thickness is provided in the data set, illustrated in Figure 2.

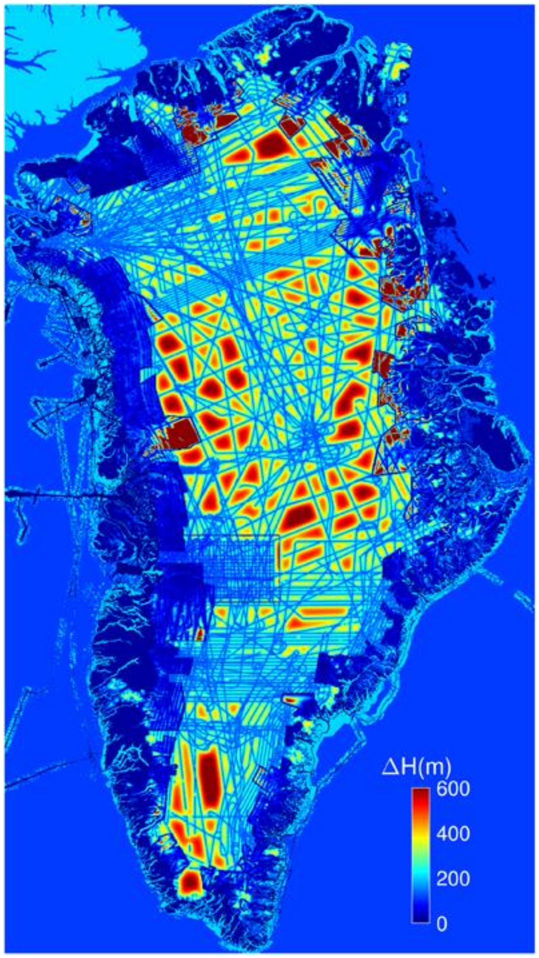

Figure 2. Error Estimate of Greenland Bed Elevation and Ice Thickness

2.5 Instrumentation

2.5.1 Description

The Center for Remote Sensing of Ice Sheets (CReSIS) Multichannel Coherent Radar Depth Sounder (MCoRDS) operates over a 180 to 210 MHz frequency range with multiple receivers developed for airborne sounding and imaging of ice sheets. See IceBridge MCoRDS L2 Ice Thickness, Version 1 for further information on the MCoRDS radar and the Level-2 data.

3 SOFTWARE AND TOOLS

The netCDF data file is compatible with HDF5 libraries and can be read by HDF readers such as HDFView, a visual interface for viewing the file hierarchy, modifying the contents of a data set, and creating new files. The file can also be opened and plotted with the Panoply data viewer.

GeoTIFF files can be viewed with a variety of GIS software packages, including QGIS and ArcGIS.

4 VERSION HISTORY

Table 3. Version History Summary

Version	Release Date	Description of Changes
V1	13 January 2015	Initial release
V2	19 May 2015	Version 2 improved processing of some basins and added Operation IceBridge 2014 data. Heights were provided with respect to mean sea level, instead of the WGS84 ellipsoid. The geoid was included in an additional field in the data.
V3	25 September 2017	Version 3 added ocean bathymetry all around Greenland based on data from NASA's Ocean Melting Greenland (OMG) and other campaigns of bathymetry measurements. The subglacial bed topography was also updated by including more ice thickness data and constraining the ice thickness at the ice/ocean interface based on bathymetry data when available.
V4	13 May 2021	Version 4 incorporated updated radar data to better constrain the ice thickness inland. Multibeam data for ocean bathymetry were updated to include data from 2017 and 2020 OMG campaigns. Bathymetry data were added from new gravity inversions. The format of surface, bed, and thickness was changed to "single". Streamline diffusion was implemented in the interior regions instead of kriging beginning January 2017.
V5	06 September 2022	Version 5 added bathymetry measurements from the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research, in front of the Northeast Ice Stream, ice thickness for ice caps from Millan et al. (2022), and bathymetry data from the 2021 OMG campaign. A geoTIFF file of bed elevation was also added.

5 RELATED DATA SETS

IceBridge MCoRDS L2 Ice Thickness, Version 1

6 RELATED WEBSITES

Ice Future Research Group, Department of Earth Sciences, Dartmouth College

7 CONTACTS AND ACKNOWLEDGMENTS

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7.2 Acknowledgments

Versions 1 to 4 of this data set were funded by the NASA Cryospheric Sciences Program (#NNX15AD55G) and the National Science Foundation’s ARCSS program (#1504230), in cooperation with the University of Bristol as part of the Basal Properties of Greenland project (NERC grant NE/M000869/1).

Version 5 was funded by the NASA Studies With ICESat-2 program (#NNH20ZDA001N-ICESAT2) and Heising Simons Foundation grants (2019-1161 and 2021-3059).

We would like to thank Greenland Ice Sheet Ocean Research Coordination Network (GRISO RCN) for their help in finding available bathymetry data.

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9 DOCUMENT INFORMATION

9.1 Publication Date

06 September 2022

9.2 Date Last Updated

06 September 2022