Likely Basal Thermal State of the Greenland Ice Sheet, Version 1

USER GUIDE

How to Cite These Data

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

MacGregor, J. A., M. Fahnestock, G. Catania, J. Paden, P. Gogineni, M. Morlighem, W. Colgan, S. M. Nowicki, G. Clow, A. Aschwanden, S. F. Price, and H. Seroussi. 2017. *Likely Basal Thermal State of the Greenland Ice Sheet, Version 1.* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/R4MWDWWUWQF9. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/RDBTS4

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

The Likely Basal Thermal State of the Greenland Ice Sheet (GrIS) product contains key datasets that show how the likely basal thermal state was inferred from existing airborne and satellite datasets and recent methods, and provides a synthesis mask of the likely basal thermal state over the Greenland Ice Sheet (MacGregor et al., 2016).

1.1 Format

The data files are HDF5-compliant netCDF (.nc) format.

The data file is paired with an associated XML file. XML files contain point latitudes and longitudes, and file and campaign metadata.

1.2 File Naming Convention

File names:

RDBTS4_Greenland_1993_2013_01_basal_thermal_state.nc
RDBTS4_Greenland_1993_2013_01_basal_thermal_state.nc.xml

File naming convention:

RDBTS4_Location_YYYY_yyyy_0X_basal_thermal_state.nc

Table 1. File Naming Convention

Variable	Description
RDBTS4	Short name for Likely Basal Thermal State of the Greenland Ice Sheet data
Location	Location, e.g. Greenland
YYYY_yyyy	Temporal coverage of data collection from YYYY to yyyy, e.g. 1993_2013
0X	Data product version number, e.g. 01
basal_thermal_state	Basal thermal state of the Greenland Ice Sheet
xxx	Indicates file type, e.g. NetCDF (.nc), XML (.xml)

1.3 Spatial Coverage

Southernmost Latitude 58.91° N

Northernmost Latitude: 81.51° N

Westernmost Longitude: -88.33° W

Easternmost Longitude: 6.62° E

1.3.1 Spatial Resolution

5 km grid on EPSG:3413, centered on Greenland

1.3.2 Projection and Grid Description

Table 2 provides geolocation information for this data set.

Table 2. Geolocation Information

Projection	NSIDC Sea Ice Polar Stereographic North
Latitude of the origin	90°
Longitude of the origin (central meridian)	-45°
Standard parallel	70°
Scaling factor	1
False eastings	0
False northings	0
Ellipsoid	WGS84
Datum	WGS84
Units	Meters
EPSG code	3413

1.4 Temporal Coverage

23 June 1993 to 26 April 2013

1.4.1 Temporal Resolution

Varies

1.5 Parameter or Variable

1.5.1 Parameter Description

Table 3 provides descriptions of the individual parameters in this data set.

Table 3. NetCDF File Description

Parameter	Description	Units
agreement_basal_thermal_state	4-method agreement mask; total balance of methods indicating a specific basal thermal state	negative: frozen, positive: thawed
agreement_searise	SeaRISE agreement mask	threshold: -0.05C (standard / 0C (cold-bias) / -0.5C (warm-bias)
basal_melt_rate	basal melt rate inferred from Nye+melt 1-D model (std/lo/hi)	m/yr
d1_mask	D < 1 mask for constraining suitability of 1-D ice-flow models for radiostratigraphy interpretation	D < 1: 1 ; D > 1: 0
likely_basal_thermal_state	likely basal thermal state	-1: likely frozen; 0: uncertain; +1: likely thawed
mog_undulations	mask that outlines onset of MOG-observed surface undulations	dimensionless
number of contour points - conservative	a NetCDF dimension but not a NetCDF variable.	n/a
number of contour points - standard	a NetCDF dimension but not a NetCDF variable.	n/a
number of distinct fields: 2	a NetCDF dimension but not a NetCDF variable.	n/a
number of distinct fields: 3	a NetCDF dimension but not a NetCDF variable.	n/a
number of grid points in x-direction	a NetCDF dimension but not a NetCDF variable.	n/a
number of grid points in y-direction	a NetCDF dimension but not a NetCDF variable.	n/a
shape_factor	shape factor for ice column (std/lo/hi)	dimensionless
shear_layer_thickness	basal shear layer thickness	m

Parameter	Description	Units
speed_ratio	ratio of observed surface speed to modeled deformation of temperate ice column (std/lo/hi)	dimensionless
x	projected x-dimension grid centered on Greenland	km
x-y	a NetCDF dimension but not a NetCDF variable.	n/a
xy_mog_undulations_conservative	x/y that outlines onset of MOG-observed surface undulations (conservative)	km
xy_mog_undulations_standard	x/y that outlines onset of MOG-observed surface undulations (standard)	km
y	projected y-dimension grid centered on Greenland	km

1.5.2 Sample Data Record

Figure 1 shows the likely basal thermal state of the GrIS. The findings are that 43% of the bed is likely thawed, 24% is likely frozen, and the thermal state of the remainder (34%) is uncertain (MacGregor et al., 2016).

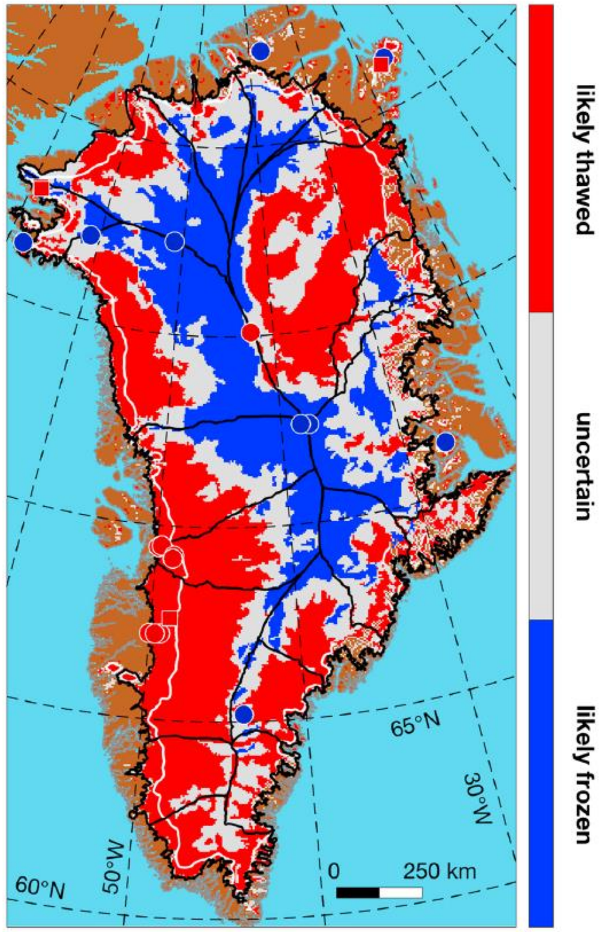

Figure 1. Likely basal thermal state of the Greenland Ice Sheet, based on where the standard, cold- and warm-bias estimates of this state agree (MacGregor et al., 2016).

2 SOFTWARE AND TOOLS

The following external links provide access to software for reading and viewing HDF5 and netCDF data files. Please be sure to review instructions on installing and running the programs.

HDF Explorer: Data visualization program that reads Hierarchical Data Format files (HDF, HDF-EOS and HDF5) and also netCDF data files.

Panoply NetCDF, HDF and GRIB Data Viewer: Cross-platform application. Plots geo-gridded arrays from netCDF, HDF and GRIB data sets.

For additional tools, see the HDF-EOS Tools and Information Center.

3 QUALITY ASSESSMENT

To qualitatively evaluate the four methods' inferences of the basal thermal state of the GrIS and our synthesis, we use the temperature–depth profiles measured in the six deep boreholes that have associated ice cores (Camp Century, DYE-3, GISP2, GRIP, NEEM, and NorthGRIP). Additional full-thickness borehole temperature profiles exist for the GrIS from its southwestern margin and elsewhere along the margin, and these are also included in our analysis (MacGregor et al., 2016).

4 DATA ACQUISITION AND PROCESSING

4.1 Theory of Measurements

The basal thermal state of an ice sheet (frozen or thawed) is an important control upon its evolution, dynamics, and response to external forcing. However, this state can only be observed directly at sparse boreholes or inferred conclusively from the presence of subglacial lakes. Here we synthesize spatially extensive inferences of the basal thermal state of the Greenland Ice Sheet to better constrain this state. Existing inferences include outputs from the eight thermomechanical ice-flow models included in the Sea Level Response to Ice Sheet Evolution (SeaRISE) effort. New remote-sensing inferences of the basal thermal state are derived from Holocene radiostratigraphy, modern surface velocity, and Moderate Resolution Imaging Spectroradiometer (MODIS) imagery. Both thermomechanical modeling and remote inferences generally agree that the Northeast Greenland Ice Stream and large portions of the southwestern ice-drainage systems are thawed at the bed, whereas the bed beneath the central ice divides, particularly their west facing slopes, is frozen. Elsewhere, there is poorer agreement regarding the basal thermal state. Both models and remote inferences rarely represent the borehole-observed basal thermal state accurately near NorthGRIP and DYE-3. This synthesis identifies a large portion of the Greenland Ice Sheet (about one third by area), where additional observations would most improve knowledge of its overall basal thermal state (MacGregor et al., 2016).

4.2 Data Acquisition Methods

Multiple airborne and satellite-borne sensors were used to acquire the data that were analyzed directly to generate this dataset or were used directly as boundary conditions for the ice-flow models. These sensors and their data acquisition methods and described in the references cited in MacGregor et al. (2016).

4.3 Derivation Techniques and Algorithms

The present basal thermal state of the GrIS was evaluated using four independent methods: 3-D thermomechanical modeling and basal motion inferred from radiostratigraphy, surface velocity, and surface texture, respectively.

There are four data sources:

- Basal temperature fields from SeaRISE control runs of 8 ice-sheet models from Nowicki et al. (2013)
- Gridded basal melt rate, shear layer thickness and shape factor inferred from 1-D modeling of the radiostratigraphy presented by MacGregor et al. (2015)
- Modeled ratio of surface speed (Joughin et al., 2010) to modeled maximum deformation speed
- Traced onset of surface undulations in the MODIS Mosaic of Greenland (Haran et al., 2013)

Data Collection Methods:

- 3-D thermomechanical numerical modeling
- 1-D steady-state modeling of dated Holocene radiostratigraphy
- Modeling of the maximum deformation speed of a temperate ice column and comparison with observed surface speed
- Visual analysis of MOG surface texture

Each method is included without weighting so as to generate an unbiased assessment of the agreement between these methods and the likely basal thermal state. See MacGregor et al. (2016) for additional details regarding the algorithm applied.

We synthesize these multiple methods of constraining the basal thermal state across Greenland described above by simply assessing where each of the above independent methods produces a clear signal regarding this state. We initialize a 5-km gridded ice-sheet “agreement” mask to zero. For each method at each grid point, if a signal exists for a frozen (thawed) bed, then –1 (+1) is added to this mask.

If a given method does not yield an unambiguous signal regarding the basal thermal state, then this agreement is not adjusted there based on that method. We do not weight any of the methods with respect to each other. Prior to but following the same procedure as for the main mask, a separate mask is generated using the 3-D thermomechanical model outputs, each weighted equally. In this manner, each independent method contributes to an unbiased synthesis of the basal thermal state.

Based on confidence bounds or uncertainty estimates for each of the four methods described above and their discriminating characteristics, two additional instances of the agreement mask are generated: a cold-bias instance and a warm-bias instance. We then generate a new likely basal thermal state mask that synthesizes the agreement between the different methods and represents the likely thermal state of the bed. This new mask is also initialized to zero and then assigned –1 (+1), representing a frozen (thawed) bed where at least two of the three instances of the agreement mask agree on the basal thermal state (sign, regardless of their degree of agreement in this state (magnitude). If only two instances agree, then the assignment is made only if the other instance does not suggest the opposite basal thermal state.

We assume that regions of the bed where the likely basal thermal state is uncertain that are surrounded by likely thawed or frozen bed are more likely than not to possess the same basal thermal state as their surroundings. Following this reasoning, we reassign uncertain “holes” less than 10 grid cells in size (≤250 km2) with their surrounding basal thermal state. Similarly, in regions where this mask is uncertain, we reassign likely frozen or thawed “holes” of the same limited size to the surrounding basal thermal state.

4.3.1 Processing Steps

See Section 4.3 Derivation Techniques and Algorithms.

4.3.2 Errors Sources

Potential error sources are numerous and are considered explicitly in this dataset. Confidence intervals or existing uncertainties for the datasets used are incorporated into the cold-bias and warm-bias agreement masks, which ultimately inform the likely basal thermal state mask.

4.4 Sensor or Instrument Description

See Section 4.2 Data Acquisition Methods.

5 REFERENCES AND RELATED PUBLICATIONS

Haran, T., J. Bohlander, T. Scambos, T. Painter, and M. Fahnestock. 2013. MEaSUREs MODIS Mosaic of Greenland 2005 (MOG2005) Image Map, Version 1. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: http://dx.doi.org/10.5067/IAGYM8Q26QRE.

Joughin, I., B. E. Smith, I. M. Howat, T. Scambos, and T. Moon. 2010, Greenland flow variability from ice-sheet-wide velocity mapping, *Journal of Glaciology*, 56(197):415–430.

MacGregor, J.A., M.A. Fahnestock, G.A. Catania, A. Aschwanden, G.D. Clow, W.T. Colgan, S.P. Gogineni, M. Morlighem, S.M.J. Nowicki, J.D. Paden, S.F. Price and H. Seroussi. 2016. A synthesis of the basal thermal state of the Greenland Ice Sheet, *Journal of Geophysical Research Earth Surface*, 121:1328–1350, doi:10.1002/2015JF003808.

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Nowicki, S., et al. 2013. Insights into spatial sensitivities of ice mass response to environmental change from the SeaRISE ice sheet modeling project II: Greenland, *Journal of Geophysical Research: Earth Surface*, 118:1025–1044, doi:10.1002/jgrf.20076.

5.1 Related Data Collections

Radiostratigraphy and Age Structure of the Greenland Ice Sheet
Level 4 9 ka Greenland Ice Sheet Balance Velocity
MEaSUREs MODIS Mosaic of Greenland 2005 (MOG2005) Image Map, Version 1
MEaSUREs Greenland Ice Sheet Velocity Map from InSAR Data

5.2 Related Websites

IceBridge web page at NSIDC
IceBridge web page at NASA
NASA Greenland Ice Sheet stratigraphy video
NASA Cryosphere Science Research Portal

6 CONTACTS AND ACKNOWLEDGMENTS

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7 DOCUMENT INFORMATION

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18 January 2017

7.2 Date Last Updated

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