Likely Basal Thermal State of the Greenland Ice Sheet, Version 2

USER GUIDE

How to Cite These Data

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

MacGregor, J. A., W. Chu, W. T. Colgan, M. A. Fahnestock, D. Felikson, N. B. Karlsson, S. M. J. Nowicki, and M. Studinger. 2022. *Likely Basal Thermal State of the Greenland Ice Sheet, Version 2.* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/RQO5Q6F6E6LY [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 DATA DESCRIPTION

1.1 Parameters

This data set provides a revised synthesis mask of the likely basal thermal state of the Greenland Ice Sheet (GrIS) based on borehole data, thermomechanical ice-flow models, bed topography, a multi-year surface velocity mosaic, and airborne radar sounding (MacGregor et al., 2022).

Table 1 provides descriptions of the individual parameters in this data set.

Table 1. NetCDF File Description

Parameter	Description	Units
agreement_basal_thermal_state	4-method agreement mask; total balance of methods indicating a specific basal thermal state	dimensionless integer; more negative indicates likely frozen and more positive indicates likely thawed
agreement_basal_thermal_state_cold	cold-bias 4-method agreement mask; total balance of methods indicating a specific basal thermal state	dimensionless integer; more negative indicates likely frozen and more positive indicates likely thawed
agreement_basal_thermal_state_warm	warm-bias 4-method agreement mask; total balance of methods indicating a specific basal thermal state	dimensionless integer; more negative indicates likely frozen and more positive indicates likely thawed
agreement_ismip6	ISMIP6 standard agreement mask; sum of 10 ISMIP6 model instances for which a basal thermal state is determined using a temperature threshold of –1°C	dimensionless integer; negative values indicate a frozen bed and positive values indicate a thawed bed
agreement_ismip6_cold	ISMIP6 cold-bias agreement mask; sum of 10 ISMIP6 model instances for which a basal thermal state is determined using a temperature threshold of –1°C	dimensionless integer; negative values indicate a frozen bed and positive values indicate a thawed bed

Parameter	Description	Units
agreement_ismip6_warm	ISMIP6 warm-bias agreement mask; sum of 10 ISMIP6 model instances for which a basal thermal state is determined using a temperature threshold of –1.5°C	dimensionless integer; negative values indicate a frozen bed and positive values indicate a thawed bed
basal_melt	basal melt rate inferred from Nye+melt 1-D model	m/yr
basal_melt_max	maximum basal melt rate inferred from Nye+melt 1-D model	m/yr
basal_melt_min	minimum basal melt rate inferred from Nye+melt 1-D model	m/yr
basal_water	basal water mask inferred from radar sounding	dimensionless integer; count of basal water identifications
likely_basal_thermal_state	likely basal thermal state	dimensionless integer; –1: likely frozen; 0: uncertain; +1: likely thawed
speed_ratio	standard ratio of observed surface speed to modeled deformation of temperate ice column	dimensionless ratio
speed_ratio_max	maximum ratio of observed surface speed to modeled deformation of temperate ice column	dimensionless ratio
speed_ratio_min	minimum ratio of observed surface speed to modeled deformation of temperate ice column	dimensionless ratio
x	projected x-dimension grid centered on Greenland (EPSG:3413)	m
y	projected y-dimension grid centered on Greenland (EPSG:3413)	m

1.2 File Information

1.2.1 Format

The data file is HDF5-compliant netCDF (.nc) format. 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.

1.2.2 File Contents

Figure 1 shows the likely basal thermal state of the GrIS. The findings indicate that 33% of the bed is likely thawed, 40% is likely frozen, and the remaining 28% is in an uncertain state (MacGregor et al., 2022). The spatial pattern of the revised synthesis is broadly similar to that of Version 1 (MacGregor et al., 2016), including a scalloped frozen core and thawed outlet-glacier systems. Although the likely basal thermal state of nearly half (46%) of the ice sheet changed designation between Versions 1 and 2, the assigned state changed from likely frozen to likely thawed (or vice versa) for less than 6% of the ice sheet. This revised synthesis suggests that more of northern Greenland is likely thawed at its bed, and conversely, more of southern Greenland is likely frozen.

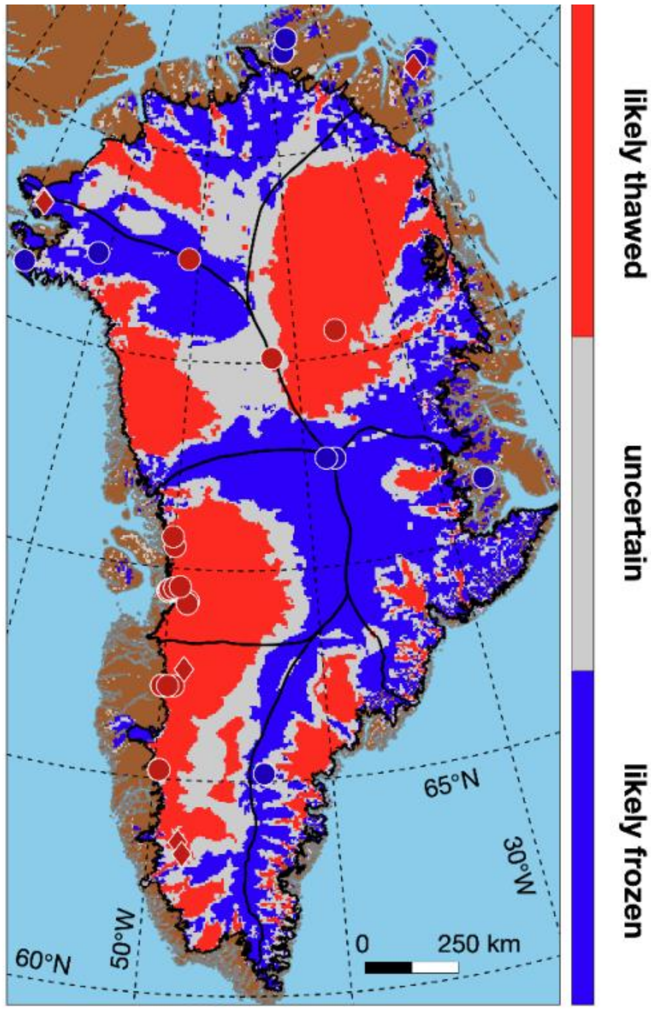

Figure 1. Likely basal thermal state of the Greenland Ice Sheet based on where the standard, cold- and warm-bias estimates of this state agree (MacGregor et al., 2022).

1.2.3 Naming Convention

The data file is named according to the following convention:

```
RDBTS4_Location_YYYY_yyyy_xx_basal_thermal_state.nc
```

Table 2. 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, inclusive (i.e., 1993_2017)
xx	Data product version number, e.g., 02
basal_thermal_state	Keywords of the data set title

The final file name is:

```
RDBTS4_Greenland_1993_2017_02_basal_thermal_state.nc
```

1.3 Spatial Information

1.3.1 Coverage

Southernmost Latitude 58.91° N

Northernmost Latitude: 83.56° N

Westernmost Longitude: 88.33° W

Easternmost Longitude: 6.62° E

1.3.2 Resolution

Nominal 5 km resolution valid at the standard parallel.

1.3.3 Geolocation

Table 3 provides geolocation information for this data set.

Table 3. Geolocation Details

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 Information

1.4.1 Coverage

23 June 1993 to 20 May 2017

1.4.2 Resolution

Varies

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The basal thermal state of the Greenland Ice Sheet has few direct measurements, yet knowledge of this state is becoming increasingly important for understanding ice flow dynamics. The first synthesis of this state relied on inferences from airborne and satellite observations and numerical models, for which most of the underlying datasets have since been updated. New and independent constraints on the basal thermal state have been developed from analyses of basal and englacial reflections observed by airborne radar sounding.

2.2 Acquisition

New and updated data underlying this product include boreholes, subglacial lakes, 3-D modeling output, GrIS thickness, long-term surface velocity, airborne radar sounding data, and basal texture (MacGregor et al., 2022). The four main data sources for the data set synthesis are as follows:

- Basal temperature fields from 10 Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6) control runs (Goelzer et al., 2020)
- Gridded basal melt rate inferred from 1-D steady-state modeling of radiostratigraphy (MacGregor et al., 2016)

- Modeled ratio of surface speed to maximum deformation speed (Joughin et al., 2016)
- Basal water from airborne radar sounding (Panton and Karlsson, 2015; Leysinger-Vieli et al., 2018; Jordan et al., 2018; Bowling et al., 2019)

2.3 Derivation Techniques and Algorithms

Methods used for constraining the likely basal thermal state of the GrIS are described below.

- 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
- Synthesis of basal water observations from radar sounding and altimetry
- Meta-analysis of the above methods

These methods are synthesized by assessing where each produces a clear signal regarding the basal thermal state. A 5 km gridded ice-sheet “agreement” mask is initialized 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. For the ISMIP6 ensemble, the result is considered significant only where at least 7/10 models agree. All methods and 3-D models are weighted equally. The mask generation is repeated using cold- and warm-bias thresholds based on each method’s confidence bounds or *ad hoc* uncertainty estimates.

Based on the standard (S), cold-bias (S_{cold}), and warm-bias (S_{warm}) masks, the likely basal thermal state mask is generated. The processing steps are as follows:

- Likely basal thermal state mask is initialized to 0 (uncertain state)
- If S and S_{warm} agree that the bed is thawed *and* S_{cold} does *not* indicate that the bed is frozen, then +1 is assigned for a *likely thawed* bed
- If S and S_{cold} agree that the bed is frozen *and* S_{warm} does *not* indicate that the bed is thawed, then –1 is assigned for a *likely frozen* bed

Uncertain “holes” ≤ 10 grid cells (≤ 250 km^2) in predominantly thawed regions are filled in as *likely thawed*. This process is repeated for holes in frozen regions assuming a *likely frozen* state. The basal thermal state for holes in uncertain regions remains unassigned.

2.4 Quality, Errors, and Limitations

A comparison between Versions 1 and 2 of this data set indicates that changes in bed topography influence thermomechanical model agreement. The change in modeled basal thermal state is attributed to the spin-up surface mass balance (SMB) fields of the two ensembles (SeaRISE for V1 and ISMIP6 for V2). Specifically, SMB is higher in southern Greenland and lower in northern Greenland using ISMIP6 compared to SeaRISE.

The suite of methods employed may be approaching a limit in resolving the basal thermal state. This product is reported on a 5 km grid, however, the basal thermal state and englacial thermal structure can vary at finer scales. Finer-resolution geophysical models and observations for the entire ice sheet are needed to determine Greenland's basal thermal state. Future improvements may include intensive borehole investigations and a more complete synthesis of basal water identifications.

3 SOFTWARE AND TOOLS

The netCDF data file is compatible with netCDF and HDF5 libraries and can be read by HDF readers (e.g., HDFView) and netCDF readers (e.g., Ncview). The file can also be opened and plotted with the Panoply data viewer.

4 VERSION HISTORY

Table 4. Version History Summary

Version	Release Date	Description of Changes
V1	09 February 2017	Initial release
V2	06 September 2022	The first synthesis relied on inferences from widespread airborne and satellite observations and numerical models, for which most of the underlying datasets have since been updated. Version 2 features a revised synthesis mask of the likely basal thermal state over the Greenland Ice Sheet based on four input sources: • Basal temperature fields from ISMIP6 control runs of 10 ice sheet models (Goelzer et al., 2020) • Gridded basal melt rate inferred from 1-D modeling of radiostratigraphy (MacGregor et al., 2016) • Modeled ratio of surface speed to maximum deformation speed (Joughin et al., 2016) • Basal water from radar sounding (Panton and Karlsson, 2015; Leysinger-Vieli et al., 2018; Jordan et al., 2018; Bowling et al., 2019)

5 RELATED DATA SETS

Radiostratigraphy and Age Structure of the Greenland Ice Sheet
Level-4 9ka Greenland Ice Sheet Balance Velocity
MEaSUREs MODIS Mosaic of Greenland (MOG) 2005, 2010, and 2015 Image Maps
MEaSUREs Greenland Ice Sheet Velocity Map from InSAR Data

6 RELATED WEBSITES

Operation IceBridge at NSIDC
Operation IceBridge at NASA
NASA Greenland Ice Sheet Stratigraphy video
NASA Cryosphere Science Research Portal

7 CONTACTS AND ACKNOWLEDGMENTS

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9 DOCUMENT INFORMATION

9.1 Publication Date

06 September 2022

9.2 Date Last Updated

06 September 2022