IceBridge MCoRDS L3 Gridded Ice Thickness, Surface, and Bottom, Version 2

USER GUIDE

How to Cite These Data

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

Paden, J., J. Li, C. Leuschen, F. Rodriguez-Morales, and R. Hale. 2013. *IceBridge MCoRDS L3 Gridded Ice Thickness, Surface, and Bottom, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/YP1PVPR72IHG. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IRMCR3

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DETAILED DATA DESCRIPTION

This data set contains products from depth sounder measurements over Greenland and Antarctica including gridded ice thickness, surface and bottom. Additional products include flightlines, boundaries, preview images, and crossover analysis.

1.1 Format

The MCoRDS Level-3 data files are in Comma-Separated Value ASCII (CSV), Portable Network Graphics (PNG), Matrix Laboratory (MAT), ASCII text, and ESRI shapefile formats. Table 1 describes the data set directories and file contents.

Table 1. Directories and File Content

Directory	File Content
`/boundaries/`	ESRI shape files of study area extent.
`/errors/`	CSV and MAT files containing crossover analysis results for the data flightpaths. ASCII text files containing statistics from the crossover analysis results. PNG preview image of the crossovers plotted over the flight paths. Crossovers are corrected season by season, not across season. Errors present are across, not within season.
`/flightlines/`	ESRI shape files of the flight paths, all data points. Text file of the flight paths, all data points. A_SURF and A_BED are the variables used to interpolate. If NASA ATM data exists for a season, ATM Surface is used. ICESat data is used, if it exists, for IceFree Areas. Flightlines are clipped to a 10 km buffer of the boundary (Study Area).
`/grids/`	ESRI ASCII grids of Surface Thickness, Ice Thickness, and Ice Bottom. Note: Bottom is Ice Bottom; this includes floating ice where appliable. ASCII rasters for Surface, Thickness, and Bed Elevation are provided. An XYZ TXT File containing data from all grids is also provided.
`/preview_images/`	PNG preview images of the surface, ice thickness, ice bottom and flightlines.

1.2 File Naming Convention

The MCoRDS L3 Gridded Ice Thickness, Surface, and Bottom data files are named with a variety of variables as shown below and described in Table 2:

Example File Names:

```
Jakobshavn_2006_2012_Composite_StudyArea.shp
Petermann_2010_2012_Composite_Crossovers_Errors.txt
PineIsland_2009_2010_Composite_Flightlines.prj
Smith_2009_2010_Composite_XYZGrid.txt
Thwaites_2009_2010_Composite_Thickness_Preview.png
```

```
Location_Years_Description.xxx
```

Table 2. File Naming Convention

Variable	Description
`Location`	Gridded bed map location: 79N, Byrd, Helheim, Jakobshavn, Kangerdlugssuaq, KogeBugt, NWCoast, Petermann, PineIsland, RecoverySlessor, Smith, Thwaites.
`Composite Years`	Years of data capture. Example: 2010_2012_Composite.
`Description`	File content description. Examples: StudyArea, Crossovers, Errors, Preview, Flightlines, Bottom, Surface, Thickness, XYZGrid.
`.xxx`	File type. .csv = Comma Separated Values text file .png = Portable Network Graphics file .mat = MATLAB (Matrix Laboratory) file .shp = ESRI shapefile (includes associated files: dbf, prj, sbn, sbx, shp., shx) .txt = ASCII text file

1.3 Spatial Coverage

Spatial coverage for this data set includes Greenland and Antarctica. In effect, this represents the two coverages noted below.

Greenland:

Southernmost Latitude: 59° N

Northernmost Latitude: 83° N

Westernmost Longitude: 74° W

Easternmost Longitude: 12° E

Antarctica:

Southernmost Latitude: 90° S

Northernmost Latitude: 63° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

1.3.1 Spatial Resolution

Spatial resolution varies depending on the platform and year. See the Processing Steps section for details on grid size.

1.3.2 Geolocation

The following table provides details about the coordinate system for this data set.

Table 3. Geolocation Details for the Arctic/Greenland and Antarctica Data

	Arctic/Greenland	**Antarctica**
Geographic coordinate system	WGS 84	WGS 84
Projected coordinate system	WGS 84 / NSIDC Sea Ice Polar Stereographic North	WGS 84 / Antarctic Polar Stereographic
Longitude of true origin	-45° E	0°
Latitude of true origin	70° N	71° S
Scale factor at longitude of true origin	1	1
Datum	WGS 84	WGS 84
Ellipsoid/spheroid	WGS 84	WGS 84
Units	meters	meters
False easting	0	0
False northing	0	0
EPSG code	3413	3031
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	+proj=stere +lat_0=-90 +lat_ts=-71 +lon_0=0 +k=1 +x_0=0 +y_0=0 +datum=WGS84 +units=m +no_defs
Reference	EPSG: 3413	EPSG: 3031

1.4 Temporal Coverage

These data were collected as part of Operation IceBridge funded campaigns from 2010 to 2012. Multi-year data collected prior to Operation IceBridge from 2006 to 2009 are from CReSIS.

1.4.1 Temporal Resolution

IceBridge campaigns are conducted on an annual repeating basis. Arctic and Greenland campaigns are conducted during March, April, and May, and Antarctic campaigns are conducted during October and November.

1.5 Parameter or Variable

The MCoRDS L3 data set includes grids of MCoRDS L2 data for time, latitude, longitude, elevation, surface, bottom, and thickness. This data set is a merging of several data sources: radar depth sounder over multiple seasons, airborne lidar data for the ice surface, optical data for ice boundaries, and various ice surface digital elevation models for the ice surface to fill in where no lidar is available.

1.5.1 Parameter Description

The `XYZgrid.txt` files contain fields described in Table 4.

Table 4. `XYZgrid.txt` File Parameters, Description, and Units

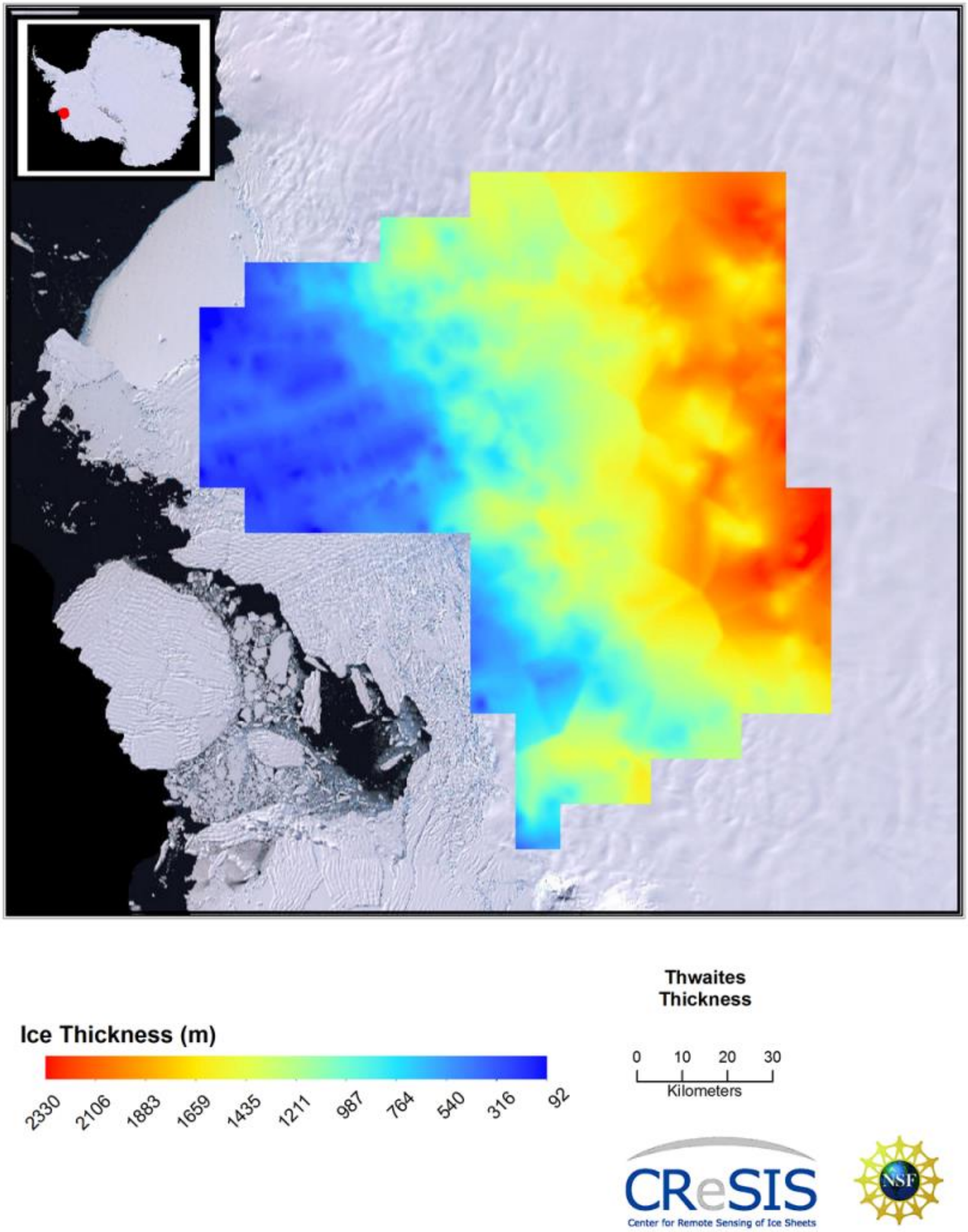
Parameter	Description	Units
`X`	Longitude	Meters
`Y`	Latitude	Meters
`Thickness`	Ice Thickness	Meters
`Surface`	Ice Surface Height	Meters
`Bottom`	Ice Bottom Height	Meters

1.5.2 Sample Data Record

Below is an excerpt from `Thwaites_2009_2010_Composite_XYZGrid.txt`.

```
X,Y,THICK,SURFACE,BOTTOM
-420250.000000,-1589750.000000,195.64,  2.34,-193.30
-420750.000000,-1589750.000000,191.05,  2.25,-188.81
-421250.000000,-1589750.000000,187.34,  2.15,-185.19
-421750.000000,-1589750.000000,184.70,  1.74,-182.96
-422250.000000,-1589750.000000,181.96, -0.68,-182.64
-422750.000000,-1589750.000000,178.07, -6.50,-184.57
-423250.000000,-1589750.000000,176.84,-11.90,-188.74
-423750.000000,-1589750.000000,179.83,-14.76,-194.59
-424250.000000,-1589750.000000,186.80,-14.28,-201.08
-424750.000000,-1589750.000000,192.96,-13.99,-206.95
-425250.000000,-1589750.000000,197.07,-14.32,-211.40
-425750.000000,-1589750.000000,200.07,-14.67,-214.74
-426250.000000,-1589750.000000,203.68,-14.94,-218.62
-426750.000000,-1589750.000000,210.32,-15.02,-225.33
-427250.000000,-1589750.000000,219.07,-14.87,-233.94
-427750.000000,-1589750.000000,229.04,-14.50,-243.54
-428250.000000,-1589750.000000,237.21,-14.00,-251.21
-428750.000000,-1589750.000000,243.68,-13.47,-257.15
```

The `Thwaites_2009_2010_Composite_Thickness_Preview.png` image is shown below.


Thwaites
Thickness
Ice Thickness (m)
2330
2106
1883
1659
1435
1211
987
764
540
316
92
0
10
20
30
Kilometers
CReSIS
Center for Remote Sensing of Ice Sheets
NSF

2 SOFTWARE AND TOOLS

CSV files may be opened by any text viewing program.
MAT files may be opened using MATLAB, or using an open source tool such as Octave.
PNG files may be opened using any program capable of reading Portable Network Graphics files.
ASCII text files may be opened using any ASCII text reader.
Shapefiles may be opened using ESRI ArcGIS or other similar GIS software.

3 DATA ACQUISITION AND PROCESSING

The MCoRDS Level-3 data set is a merging of several data sources: radar depth sounder over multiple seasons, airborne lidar data for the ice surface, optical data for ice boundaries, and various ice surface digital elevation models for the ice surface when coincident lidar data are not available. This data set includes grids of MCoRDS Level-2 data for time, latitude, longitude, elevation, surface, bottom, and thickness.

External data used:

- NASA ATM LIDAR: IceBridge ATM L2 Icessn Elevation, Slope, and Roughness (http://nsidc.org/data/ilatm2.html).
- ICESAT 1 KM DEM: GLAS/ICESat 1 km Laser Altimetry Digital Elevation Model of Greenland (http://nsidc.org/data/nsidc-0305.html).
- IceFree Mask: Howat I.M and A. Negrete, in prep, A High-resolution Ice Mask for the Greenland Ice Sheet and Peripheral Glaciers and Icecaps, (http://www.bpcrc.osu.edu/gdg/data/icemask).
- ICESat 500 m DEM: GLAS/ICESat 500 m Laser Altimetry Digital Elevation Model of Antarctica (http://nsidc.org/data/nsidc-0304.html).
- IceFree Mask The Antarctic Digital Database, Scientific Committtee on Antarctic Research 1993 - 2006. E00 Rock Outcrop, Lines and Polygons, (http://www.add.scar.org/home/add7).

3.1 Data Acquisition Methods

3.1.1 P-3 Low Altitude

A waveform with a 1-μs duration and lower receiver gain settings is used to measure the round-trip signal time for the surface echo, while a waveform with a 10-μs duration and higher receiver gain settings is used to measure the round-trip signal time for the bed echo. The two different waveforms are used because of the large dynamic range of signal powers that are observed. The 10-μs duration and higher receiver gain settings are more sensitive to the bed echo, but the signal is generally saturated from the ice surface and upper internal layers.

3.1.2 DC-8 Low Altitude

The DC-8 low altitude method is the same as the low altitude P-3. However, during the first two field seasons (2009 Antarctica DC-8 and 2010 Greenland DC-8), extra antennas inside the cabin were used to detect the ice surface delay time because the Transmit Receive (TR) switches did not meet their switching time specification. The TR switches have not been fixed in subsequent field seasons, but the TR switch control signals have been set so that the surface echo is generally still detectable, although with diminished power even for very low altitudes down to 600 feet Above Ground Level (AGL).

3.1.3 P-3 High Altitude and DC-8 High Altitude

The dynamic range between the ice surface and ice bottom echoes is much smaller and a single high-gain and long pulse duration waveform is used to capture both echoes.

3.2 Derivation Techniques and Algorithms

3.2.1 Flightlines

Each flightline is provided in ESRI shapefile format as well as in an ASCII text file containing flight path data points. Flightlines are clipped to the study extent. The fields, A_SURF and A_BOTT, are used to interpolate the surface and bed respectively.

For flightline information for the 2010 Thwaites Glacier data sets and the 2011 Greenland data sets, lines were segmented between catchment and channel to allow for optimal grid resolution for each region.

3.2.2 Boundaries

The boundaries were derived to define the scientific study areas for the regions based on available data. Study area boundaries are provided as ESRI shapefiles. The boundaries were used to clip flightlines and mask the final gridded products.

3.2.3 Preview Images

Preview maps of flightlines, thickness, surface, and bed topography are provided in PNG format for preview and initial analysis only. The images show the grids without the -9999 'NoData' mask.

3.2.4 Crossover Analysis

Crossover analysis files are used for error estimation and data quality check. This includes a CSV file containing the data, and a PNG image.

3.2.5 Processing Steps

The gridding process varies because of differing methods and data sources.

3.2.5.1 Grids

Grid files contain values for Surface, Bed, and Thickness. Cell size was defined so 50 percent of cells must contain at least one sample point. Ordinary Kriging interpolation was used to interpolate the data from the flightlines.

GRID processing:

- Surface is interpolated using Inverse Distance Weighting (IDW) interpolation in ArcGIS.
- Bottom is interpolated using TopoToRaster interpolation in ArcGIS. Note: any bottom past the grounding line represents ice bottom not ocean bottom.
- Thickness is calculated using Surface minus Bottom in ArcGIS.

GridNoDataValue: -9999 indicates 'NoData'.

GridCellSize: 500 m x 500 m.

XYZGrid files contain the values for Surface, Bed, and Thickness.

3.2.6 Version History

On August 14, 2013, the MCoRDS L3 Gridded Ice Thickness, Surface, and Bottom data were replaced by Version 2:

- V02 grid size is 500 m x 500 m. V01 coarse (3 x 3 km) and dense (1.5 x 1.5 km) grids are not included in V02.
- V02 contains separate grid .txt files for Surface, Thickness, and Bottom.
- V01 1995_2011_Petermann_Composite data are removed.
- V01 TIF files are removed; MAT files added in V02.
- ASCII text grid file is changed from CSV in V01 to .txt in V02.
- V01 crossover_analysis directory is removed; errors directory is added with .mat and errors.txt files.

3.2.7 Error Sources

The primary error sources for ice penetrating radar data are system electronic noise, multiple reflectors also known as multiples, and off-nadir reflections. Each of these error sources can create spurious reflections in the trace data leading to false echo layers in profile data. Multiple reflectors arise when the radar energy reflects off three surfaces, back-and-forth in the vertical dimension, and then returns to the receive antenna. Reflections occur in situations when multiple surfaces are present with high impedance, such as the upper surface (air/ground), the base of the ice or an ice-water interface, and the aircraft body which is also a strong reflector. The radar receiver only records time since the radar pulse was emitted, so the radar energy that traveled the additional path length appears later in time, apparently deeper in the ice or even below the ice-bedrock interface. Note that multiples of a strong continuous reflector have a similar shape but all slopes appear magnified, that is, doubled in the simplest geometric cases, relative to the main reflection.

Off-nadir reflections can result from crevasse surfaces, water, rock outcrops, or metal structures. Beam structure and processing of the MCoRDS system are designed to reduce these off-nadir reflected energy sources.

3.3 Sensor or Instrument Description

As described on the CReSIS Sensors Development Radar Page, the Multichannel Coherent Radar Depth Sounder operates over a 180 to 210 MHz frequency range with multiple receivers developed for airborne sounding and imaging of ice sheets. Measurements are made over two frequency ranges: 189.15 to 198.65 MHz, and 180 to 210 MHz. The radar bandwidth is adjustable from 0 to 30 MHz. Multiple receivers permit digital beamsteering for suppressing cross-track surface clutter that can mask weak ice-bed echoes and strip-map SAR images of the ice-bed interface. These radars are flown on twin engine and long-range aircraft including NASA P-3, DeHavilland Twin Otter (TO), and DC-8. GPS time corrections and frames where no good sync information was available are given in the vector worksheet in the IceBridge MCoRDS L2 Ice Thickness Parameter Spreadsheet.

4 REFERENCES AND RELATED PUBLICATIONS

Akins, Torry Lee. 1999. *Design and development of an improved data acquisition system for the coherent radar depth sounder*, Department of Electrical Engineering and Computer Science: Master's Thesis, University of Kansas.

Allen, Christopher, Lei Shi, Richard Hale, Carl Leuschen, John Paden, Benjamin Panzer, Emily Arnold, William Blake, Fernando Rodriguez-Morales, John Ledford, Sarah Seguin. 2011. Antarctic

Ice Depth Sounding Radar Instrumentation for the NASA DC-8, submitted for publication to *IEEE Transactions on Aerospace and Electronic Systems*, August 2011.

Blake, W., J. Ledford, C. Allen, C. Leuschen, S. Gogineni, F. Rodriguez-Morales, Lei Shi. 2008. A VHF Radar for Deployment on a UAV for Basal Imaging of Polar Ice. *Geoscience and Remote Sensing Symposium*. IGARSS 2008. IEEE International, 4: IV-498-IV-501, doi: 10.1109/IGARSS.2008.4779767.

Byers, K. J. 2011. *Integration of a 15-Element, VHF Bow-Tie Antenna Array into an Aerodynamic Fairing on a NASA P-3 Aircraft*, Department of Electrical Engineering and Computer Science: Master's Thesis, University of Kansas.

Byers, Kyle J., A. R. Harish, Sarah A. Seguin, Carlton Leuschen, Fernando Rodriguez-Morales, John Paden, Emily Arnold and Richard Hale. 2011. A Modified Wideband Dipole Antenna for an Airborne VHF Ice Penetrating Radar, submitted to *IEEE Transactions on Instrumentation and Measurement*, June 2011.

Chuah, T. S. 1997. "Design and Development of a Coherent Radar Depth Sounder for Measurement of Greenland Ice Sheet Thickness", *CReSIS Technical Report*, 151: 175.

Fujita, Shuji, Takeshi Matsuoka, Toshihiro Ishida, Kenichi Matsuoka, and Shinji Mae. 2000. A Summary of the Complex Dielectric Permittivity of Ice in the Megahertz Range and its Application for Radar Sounding of Polar Ice Sheets. *Physics of Ice Core Records*, (185-212). T. Hondoh, Editor. Hokkaido University Press, 2000, Sapporo.

Gogineni, S., T. Chuah, C. Allen, K. Jezek, and R. K. Moore. 1998. An Improved Coherent Radar Depth Sounder, *Journal of Glaciology* 44(148): 659-669.

Gogineni, S., D. Tammana, D. Braaten, C. Leuschen, T. Akins, J. Legarsky, P. Kanagaratnam, J. Stiles, C. Allen, and K. Jezek. 2001. Coherent Radar Ice Thickness Measurements Over the Greenland Ice Sheet, *Journal of Geophysical Research-Atmospheres* 106(D24): 33761-33772.

Lei Shi; C. T. Allen, J.R. Ledford, F. Rodriguez-Morales, W. A. Blake, B. G. Panzer, S. C. Prokopiack, C. J. Leuschen, and S. Gogineni. 2010. Multichannel Coherent Radar Depth Sounder for NASA Operation Ice Bridge, *Geoscience and Remote Sensing Symposium* (IGARSS), IEEE International, (1729-1732), doi: 10.1109/IGARSS.2010.5649518.

Leuschen, Carl, Chris Allen, Prasad Gogineni, Fernando Rodriguez, John Paden, and Jilu Li. 2011, updated current year. *IceBridge Snow Radar L1B Geolocated Radar Echo Strength Profiles*, [list dates of data used]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Leuschen, Carl, and Chris Allen. 2010, updated current year. *IceBridge MCoRDS L1B Geolocated Radar Echo Strength Profiles*, [list dates of data used]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Leuschen, Carl, and Chris Allen. 2011, updated current year. *IceBridge MCoRDS L2 Ice Thickness*, [list dates of data used]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media.

Li, Jilu, John Paden, Carl Leuschen, Fernando Rodriguez-Morales, Richard Hale, Emily Arnold, Reid Crowe, Daniel Gomez-Garcia and Prasad Gogineni. 2011. High-Altitude Radar Measurements of Ice Thickness over the Antarctic and Greenland Ice Sheets as a part of Operation Ice Bridge, submitted to *IEEE Transactions on Geoscience and Remote Sensing*, September 2011.

Namburi, S. P. V. 2003. *Design and Development of an Advanced Coherent Radar Depth Sounder*, Department of Electrical Engineering and Computer Science, Master's Thesis, University of Kansas.

Paden, John, Christopher Allen, Sivaprasad Gogineni, Kenneth Jezek, Dorthe Dahl-Jensen, and Lars Larsen. 2005. Wideband measurements of ice sheet attenuation and basal scattering, *IEEE Geoscience and Remote Sensing Letters*, (2)2.

Paden, J. 2006. *Synthetic Aperture Radar for Imaging the Basal Conditions of the Polar Ice Sheets*, Department of Electrical Engineering and Computer Science, PhD Dissertation, University of Kansas.

Paden, J., T. Akins, D. Dunson, C. Allen, and P. Gogineni. 2010. Ice-sheet bed 3-D tomography, *Journal of Glaciology* 56(195): 3-11.

Player, K., Lei Shi, Chris Allen, Carl Leuschen, John Ledford, Fernando Rodriguez-Morales, William Blake, Ben Panzer, and Sarah Seguin. 2010. A Multi-Channel Depth-Sounding Radar with an Improved Power Amplifier, *High-Frequency Electronics*, October 2010: 18-29.

Rodriguez-Morales, F., P. Gogineni, C. Leuschen, C. T. Allen, C. Lewis, A. Patel, L. Shi, W. Blake, B. Panzer, K. Byers, R. Crowe, L. Smith, and C. Gifford. 2010. Development of a Multi-Frequency Airborne Radar Instrumentation Package for Ice Sheet Mapping and Imaging, *Proc. 2010 IEEE Int. Microwave Symp.*, Anaheim, CA, 2010: 157–160.

Shi, Lei, C.T. Allen, J.R. Ledford, F. Rodriguez-Morales, W.A. Blake, B.G. Panzer, S.C. Prokopiack, C.J. Leuschen, and S. Gogineni. 2010. Multichannel Coherent Radar Depth Sounder for NASA Operation Ice Bridge, *Geoscience and Remote Sensing Symposium (IGARSS), 2010 IEEE International*, 25-30 July 2010: 1729-1732.

4.1 Related Data Collections

GLAS/ICESat 1 km Laser Altimetry Digital Elevation Model of Greenland
GLAS/ICESat 500 m Laser Altimetry Digital Elevation Model of Antarctica
Greenland 5 km DEM, Ice Thickness, and Bedrock Elevation Grids

IceBridge ATM L2 Icessn Elevation, Slope, and Roughness

IceBridge MCoRDS L1B Geolocated Radar Echo Strength Profiles

IceBridge MCoRDS L2 Ice Thickness

IceFree Mask The Antarctic Digital Database

IceFree Mask - Howat I.M and A. Negrete, in prep, A High-resolution Ice Mask for the Greenland Ice Sheet and Peripheral Glaciers and Icecaps.

4.2 Related Websites

CReSIS website

CReSIS Sensors Development Radar web page

IceBridge product website

IceBridge website at NASA

ICESat/GLAS website at NASA Wallops Flight Facility

ICESat/GLAS website at NSIDC

5 CONTACTS AND ACKNOWLEDGEMENTS

Center for Remote Sensing of Ice Sheets (CReSIS)

Nichols Hall, The University of Kansas

2335 Irving Hill Road

Lawrence, Kansas 66045

data@cresis.ku.edu

Acknowledgments:

The radar systems and software were developed with funding from a variety of sources including NASA (NNX16AH54G), NSF (ACI-1443054), and the State of Kansas. The Operation IceBridge data were collected as part of the NASA Operation IceBridge project. The processing requires GPS and attitude data that are made available by various groups including the Airborne Topographic Mapper team, the Digital Mapping System team, and the Sanders Geophysics company. We also acknowledge all the personnel involved in supporting the field operations.

6 DOCUMENT INFORMATION

6.1 Publication Date

August 2013

6.2 Date Last Updated

October 2020