IceBridge Sea Ice Freeboard, Snow Depth, and Thickness

This data set contains derived geophysical data products including sea ice freeboard, snow depth, and sea ice thickness measurements in Greenland and the Arctic retrieved from IceBridge Snow Radar, Digital Mapping System (DMS), Continuous Airborne Mapping By Optical Translator (CAMBOT), and Airborne Topographic Mapper (ATM) sensors. The data were collected as part of Operation IceBridge funded campaigns, and are stored in ASCII text files.

Overview

Platform	NASA DC-8 NASA P-3B
Sensor	ATM, Snow Radar, DMS, CAMBOT
Spatial Coverage	Greenland and the Arctic
Spatial Resolution	Freeboard: 40 m length scale Snow Depth: based on synthetic aperture dictated footprint size and averaged to a 40 m length scale in the along-track direction Thickness: 40 m length scale
Temporal Coverage	31 March 2009 to present
Temporal Resolution	Seasonal
Parameters	Freeboard Ice Depth/Thickness Snow Depth
Data Format	ASCII text
Metadata Access	View Metadata Record
Data Access	FTP

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Citing These Data

The following example shows how to cite the use of this data set in a publication. For more information, see our Use and Copyright Web page.

Kurtz, Nathan, Michael Studinger, Jeremy Harbeck, Vincent-De-Paul Onana, and Sinead Farrell. 2012. *IceBridge Sea Ice Freeboard, Snow Depth, and Thickness.*, [indicate subset used]. Boulder, Colorado USA: National Snow and Ice Data Center. http://nsidc.org/data/idcsi2.html

1. Contacts and Acknowledgments

Investigator(s) Name and Title

Nathan Kurtz, Michael Studinger, Jeremy Harbeck, Vincent-De-Paul Onana
Cryospheric Sciences Laboratory
NASA Goddard Space Flight Center
Greenbelt, Maryland USA

Sinead Farrell
Earth System Science Interdisciplinary Center (ESSIC)
University of Maryland
College Park, Maryland USA

Technical Contact

NSIDC User Services
National Snow and Ice Data Center
CIRES, 449 UCB
University of Colorado
Boulder, CO 80309-0449 USA
phone: +1 303.492.6199
fax: +1 303.492.2468
form: Contact NSIDC User Services
e-mail: nsidc@nsidc.org

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The production of a sea ice and snow thickness product would not have been possible without the help of many people. We would like to thank the IceBridge Sea Ice Science team and members of the community for support and guidance. We would also like to thank the instrument teams and air crews for long hours in the field and at home collecting and processing the data and the National Snow and Ice Data Center for archiving and publishing the data. This work is funded by NASA's Airborne Science and Cryospheric Sciences Programs.

2. Detailed Data Description

File and Directory Structure

Data files are organized on the FTP site, ftp://n4ftl01u.ecs.nasa.gov/SAN2/ICEBRIDGE_FTP/, as described in Figure 1.

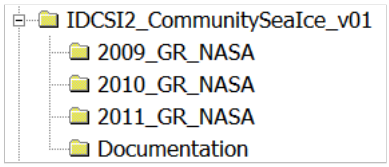

Figure 1. Directory Structure

File Naming Convention

Data files are named according to the following convention and as described in Table 1:

```
OIB_20110316_IDCSI2.txt
```

```
OIB_YYYYMMDD_IDCSI2.txt
```

Where:

Table 1. File Naming Convention

Variable	Description
`OIB`	Operation IceBridge
`YYYY`	Four-digit year of data collection
`MM`	Two-digit month of data collection
`DD`	Two-digit day of data collection
`IDCSI2`	Short name for IceBridge Sea Ice Freeboard, Snow Depth, and Thickness
`.txt`	Indicates ASCII text file

File Size

Data files range from approximately 8 MB to 60 MB.

Volume

The entire data set is approximately 644 MB.

Spatial Coverage

Spatial coverage for the IceBridge Sea Ice Freeboard, Snow Depth, and Thickness parameters currently includes Greenland and the Arctic.

Greenland / Arctic:
Southernmost Latitude: 60° N
Northernmost Latitude: 90° N
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

Spatial Resolution

Freeboard: adjusted 40 m length scale.

Snow depth: at the 460 m nominal flight altitude the snow radar has a footprint size of 11 m across track dictated by the pulse-limited footprint size, and 14.5 m along-track dictated by the synthetic aperture formed. The data are averaged in the along-track direction to a 40 m length scale.

Thickness: estimates sea ice thickness over a 40 m length scale to provide the highest resolution available from the data.

Projection and Grid Description

ATM Data
Referenced to the ITRF-2005 reference frame and projected onto the WGS-84 ellipsoid.

Snow Radar Data
Referenced as a relative distance from the aircraft with latitude and longitude coordinates provided by the GPS system on the aircraft.

CAMBOT Images
Georeferenced as a series of camera locations: latitude, longitude, elevation and altitude above ground (WGS-84) and aircraft orientation roll, pitch, and heading.

DMS Images
Arctic. Polar Stereographic Standard Parallel 70° N, Longitude of the origin (central meridian): 45° W, WGS-84 ellipsoid.
Antarctic. Polar Stereographic Standard Parallel 71° S, Longitude of the origin (central meridian): 0°, WGS-84 ellipsoid.

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.

Parameter or Variable

Parameter Description

The Sea Ice Freeboard, Snow Depth, and Thickness data files contain parameters as described in Table 2.

Table 2. File Parameters and Units

Parameter	Description	Units
lat	Latitude	Degrees
lon	Longitude	Degrees
thickness	Sea ice thickness	Meters
thickness_unc	Sea ice thickness uncertainty	Meters
mean_fb	Mean freeboard from the combined ATM and DMS data set	Meters
ATM_fb	Mean freeboard from the ATM data set only (may be biased due to the loss of data over thin ice and water)	Meters
fb_unc	Freeboard uncertainty	Meters
snow_depth	Snow depth	Meters
snow_depth_unc	Snow depth uncertainty	Meters
n_atm	Number of ATM measurements used	n/a
pcnt_ow	Percentage of open water detected in the DMS imagery over the 40 m area	n/a
pcnt_thin_ice	Percentage of grease ice and/or nilas detected in the DMS imagery over the 40 m area	n/a
pcnt_grey_ice	Percentage of non-snow-covered grey ice detected in the DMS imagery over the 40 m area	n/a
corr_elev	Surface elevation after the removal of geoid, atmospheric pressure, and tidal corrections	Meters
elev	Mean ATM elevation	Meters
date	Date of measurement in YYYYMMDD format	n/a
elapsed	Elapsed time from the start of the day in UTC	Seconds
atmos_corr	Atmospheric pressure loading term	Meters
geoid_corr	Geoid value	Meters
ellip_corr	Conversion factor between the WGS-84 and Topex/Poseidon ellipsoids	Meters
tidal_corr	Sum of the ocean, load, and earth tides	Meters
ocean_tide_corr_part	Ocean tide for the sea surface height	Meters
load_tide_corr_part	Load tide for the sea surface height	Meters
earth_tide_corr_part	Solid earth tide for the sea surface height	Meters
ssh	Local interpolated sea surface height	Meters
n_ssh	Number of ATM measurements used to determine the nearest sea surface height estimate	n/a
ssh_sd	Standard deviation of ATM elevations used to determine the nearest sea surface height estimate	Meters
ssh_diff	Difference between the centroids of the final and initial Gaussian fits to the nearest sea surface height	Meters
ssh_elapsed	Elapsed time since the last sea surface height data point was encountered	Seconds
ssh_tp_dist	Distance to the nearest sea surface height tie point	Meters
surface_roughness	Standard deviation of the ATM elevation points in the 40 m grid	Meters
ATM_file_name	Name of the ATM file which the surface elevation measurements were from	n/a
Tx	Mean transmit signal strength (40 m resolution) of the ATM data	Relative
Rx	Mean received signal strength (40 m resolution) of the ATM data	Relative
KT19_surf	Surface temperature from the KT-19 instrument	Celsius
KT19_int	Internal temperature of the KT-19 instrument	Celsius

si_int_elev	Height of radar derived snow-ice interface relative to the WGS-84 ellipsoid	Meters
my_ice_flag	Flag for ice type, 0: first year ice, 1: multi-year ice, from 12.5 km resolution AMSR-E data	n/a
empty1...empty10	Empty columns which may be used in future versions	n/a

Sample Data Record

The sample record shows the header and three records from the 2011 Greenland data file: `OIB_20110316_IDCSI2.txt`.

```
lat,lon,thickness,thickness_unc,mean_fb,ATM_fb,fb_unc,snow_depth,snow_depth_unc,n_atm,pcnt_ow,
pcnt_thin_ice,pcnt_grey_ice,corr_elev,elev,date,elapsed,atmos_corr,geoid_corr,ellip_corr,tidal
_corr,ocean_tide_corr_part,load_tide_corr_part,earth_tide_corr_part,ssh,n_ssh,ssh_sd,ssh_diff,
ssh_elapsed,ssh_tp_dist,surface_roughness,ATM_file_name,Tx,Rx,KT19_surf,KT19_int,low_en_corr,s
a_int_elev,si_int_elev,my_ice_flag,empty1,empty2,empty3,empty4,empty5,empty6,empty7,empty8,emp
ty9,empty10

    81.410301,   263.314270,     4.0937,     1.3230,     0.8235,     0.8235,     0.1169,
0.5640,     0.0570,  110,     0.000000,     0.000000,     0.000000,     0.8913,
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    0.0036,     0.1164,     0.0514,     79,     0.0229,     0.0030, 46627.531250000,
99507.8594,     0.418452, 20110316_124407.atm4cT3.qi,  1465.0,  1828.8,-99999.00,-99999.00,-
99999.0000,-99999.0000,-99999.0000,     1.00,-99999,-99999.00000,-99999.00000,-99999.00000,-
99999.00000,-99999.00000,-99999.00000,-99999.00000,-99999.00000,-99999.00000,

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99999.0000,-99999.0000,    93,     0.000000,     0.000000,     0.000000,     0.8280,
9.9773,20110316, 45924.222656250,    -0.1634,     9.7693,     0.7134,     0.0700,    -0.0500,
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99452.5938,     0.238488, 20110316_124407.atm4cT3.qi,  1465.0,  1828.8,-99999.00,-99999.00,-
99999.0000,-99999.0000,-99999.0000,     1.00,-99999,-99999.00000,-99999.00000,-99999.00000,-
99999.00000,-99999.00000,-99999.00000,-99999.00000,-99999.00000,-99999.00000,

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99999.00000,-99999.00000,-99999.00000,-99999.00000,-99999.00000,-99999.00000,
```

3. Data Access and Tools

Data Access

Data are available via FTP.

Software and Tools

The data files may be opened by any text editor or word processing program that reads ASCII text files.

A MATLAB program is available for reading the ASCII data files and displaying graphical representations of the data.

Quality Assessment

For details on data quality, see *Sea Ice Thickness, Freeboard, and Snow Depth Products from Operation IceBridge Airborne Data* (Kurtz et al. 2012).

4. Data Acquisition and Processing

This data set contains the geophysical data products sea ice thickness, freeboard, and snow depth retrieved from Operation IceBridge Level-1B ATM, Snow Radar, DMS, and CAMBOT data.

Data Acquisition Methods

IceBridge Sea Ice Freeboard, Snow Depth, and Thickness products are derived from four Operation IceBridge data sets:

- IceBridge ATM L1B Qfit Elevation and Return Strength
- IceBridge Snow Radar L1B Geolocated Radar Echo Strength Profiles
- IceBridge DMS L1B Geolocated and Orthorectified Images
- IceBridge CAMBOT L1B Geolocated Images

Surface temperature data are provided by the KT-19 infrared pyrometer:

Figure 2 describes the retrieval of sea ice thickness, snow depth, and freeboard (Kurtz et al. 2012). In addition to the ATM and Snow Radar instruments, Operation IceBridge DMS and CAMBOT were used to identify features and surface types on the sea ice.

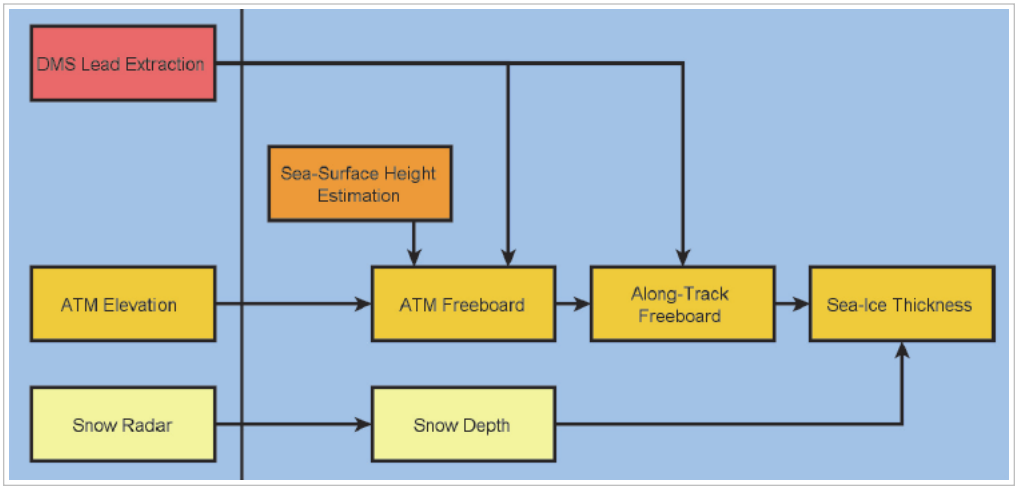

Figure 2. Product Retrieval from Instrument Data

Derivation Techniques and Algorithms

IceBridge Sea Ice Freeboard, Snow Depth, and Thickness is a retrieval of three products obtained from IceBridge data.

Technical summaries are provided below. For further details on derivation techniques, algorithms, processing steps, and error sources, see *Sea Ice Thickness, Freeboard, and Snow Depth Products from Operation IceBridge Airborne Data* (Kurtz et al. 2012).

Sea Ice Freeboard

Freeboard is retrieved using geolocated aerial photography and a lead discrimination algorithm to maximize the quality and number of laser altimeter data points used to determine the sea surface height. This method is used to deal with loss of data due to specular reflection of the laser pulse away from the receiver when insufficient surface roughness elements are present to cause diffuse scattering. The combination of photography and laser altimetry allows for more accurate retrieval of sea ice freeboard. The primary ATM laser altimeter product is surface elevation referenced to the WGS-84 ellipsoid. The conversion of ATM elevation data into sea ice freeboard is accomplished by subtracting out the instantaneous sea surface height from each elevation measurement (Kurtz et al. 2012).

Sea Ice Snow Depth

Retrieval methods for the IceBridge snow radar have been described by Kurtz and Farrell (2011), Kurtz et al. (2012), and Farrell et al. (2012). The Kurtz and Farrell (2011) method is used to retrieve snow depth for the 2009 IceBridge campaign for this product and the Kurtz et al. (2012) method is used for all subsequent campaigns. The retrieval algorithms for the snow radar system detect the snow-air and snow-ice interfaces within the radar waveform and determine the snow depth by multiplying the time separation between the interfaces by the speed of light within the snow pack (Kurtz et al. 2012).

Sea Ice Thickness

Sea ice thickness, h_i, is calculated using the corresponding 40 m scale freeboard and snow depth data as input for the hydrostatic balance equation:

$$h_i = \frac{\rho_w}{\rho_w - \rho_i} \mathrm{fb}_{adj} - \frac{\rho_w - \rho_s}{\rho_w - \rho_i} h_s \quad \textbf{(Equation 1)}$$

Where:

Table 3. Hydrostatic Balance Equation

Variable	Description
fb_{adj}	freeboard
h_s	snow depth
ρ_w	density of sea water
ρ_i	density of sea ice
ρ_s	density of snow

ρ_w and ρ_i are taken to be 1024 kg m^{-3} and 915 kg m^{-3} which are derived from the result of numerous field measurements summarized by Wadhams et al. (1992).

ρ_s is taken to be 320 kg m^{-3} following the climatological values compiled by Warren et al. (1999).

Sensor or Instrument Description

ATM

Snow Radar

The University of Kansas CReSIS ultra-wideband snow radar operates over the frequency range from 2 to 8 GHz to map near-surface internal layers in polar firn with fine vertical resolution. The radar also has been used to measure thickness of snow over sea ice. Information about snow thickness is essential to estimate sea ice thickness from ice freeboard measurements performed with satellite radar and laser altimeters.

DMS

The NASA Digital Mapping System is an airborne digital camera that acquires high resolution natural color and panchromatic imagery from low and medium altitude research aircraft.

CAMBOT

The CAMBOT system is comprised of a Canon Rebel XTi (or alternatively the XSi model) camera and a Mac Mini running custom data acquisition software. The camera is powered with an AC power adapter and connected to the Mac mini via USB. The camera is outfitted with a Canon Zoom Lens EF-S 18-55 mm lens.

5. References and Related Publications

Farrell, S. L., N. T. Kurtz, L. Connor, B. Elder, C. Leuschen, T. Markus, D. C. McAdoo, B. Panzer, J. Richter-Menge, and J. Sonntag. 2012. A First Assessment of IceBridge Snow and Ice Thickness Data over Arctic Sea Ice. *IEEE Transactions on Geoscience and Remote Sensing,* 50(6):2098-2111, doi:10.1109/TGRS.2011.2170843.

Kurtz, N. T. and S. L. Farrell. 2011. Large-scale Surveys of Snow Depth on Arctic Sea Ice from Operation IceBridge. *Geophysical Research Letters,* 38:L20505, doi:10.1029/2011GL049216.

Kurtz, Nathan, S. L. Farrell, M. Studinger, N. Galin, J. P. Harbeck, R. Lindsay, V. D. Onana, B. Panzer, and J. G. Sonntag. 2012. Sea Ice Thickness, Freeboard, and Snow Depth Products from Operation IceBridge Airborne Data. *The Cryosphere Discussions,* 6:4771-4827. http://www.the-cryosphere-discuss.net/6/4771/2012/tcd-6-4771-2012.html.

Wadhams, P., W. B. Tucker III, W. B. Krabill, R. N. Swift, J. C. Comiso, and N. R. Davis. 1992. Relationship Between Sea Ice Freeboard and Draft in the Arctic Basin, and Implications for Ice Thickness Monitoring. *Journal of Geophysical Research,* 97(C12):20325-20334.

Warren, S. G., I. G. Rigor, N. Untersteiner, V. F. Radionov, N. N. Bryazgin, Y. I. Aleksandrov, and R. Colony. 1999. Snow Depth on Arctic Sea Ice. *Journal of Climate,* 12:1814-1829.

Related Data Collections

- IceBridge ATM L1B Qfit Elevation and Return Strength
- IceBridge Snow Radar L1B Geolocated Radar Echo Strength Profiles
- IceBridge DMS L1B Geolocated and Orthorectified Images
- IceBridge CAMBOT L1B Geolocated Images
- IceBridge KT19 IR Surface Temperature
- IceBridge NSERC L1B Geolocated Meteorologic and Surface Temperature Data

Related Web Sites

- Airborne Topographic Mapper Web site at NASA Wallops Flight Facility (http://atm.wff.nasa.gov/).
- CReSIS Sensors Development Radar Web site (https://cms.cresis.ku.edu/research/sensors-development/radar).
- IceBridge Data Web site at NSIDC (http://nsidc.org/data/icebridge/index.html).
- IceBridge Web site at NASA (http://www.nasa.gov/mission_pages/icebridge/index.html).
- NASA Digital Mapping System Web page (http://asapdata.arc.nasa.gov/dms/).

6. Document Information

Acronyms and Abbreviations

The acronyms used in this document are listed in Table 3.

Table 3. Acronyms and Abbreviations

Acronym	Description
ASCII	American Standard Code for Information Interchange
ATM	Airborne Topographic Mapper
CAMBOT	Continuous Airborne Mapping By Optical Translator
CIRES	Cooperative Institute for Research in Environmental Science
DMS	Digital Mapping System

NASA	National Aeronautics and Space Administration
NSIDC	National Snow and Ice Data Center
WGS-84	World Geodetic System 1984

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