IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness, Version 1

USER GUIDE

How to Cite These Data

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

Kurtz, N., M. Studinger, J. Harbeck, V. Onana, and D. Yi. 2015. *IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/G519SHCKWQV6. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IDCSI4

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DETAILED DATA DESCRIPTION

The IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness (IDCSI4) product is informally regarded as Version 2 of the IceBridge Sea Ice Freeboard, Snow Depth, and Thickness (IDCSI2) Version 1 product. Adding L4 (Level-4) to the data set name for this version more accurately represents the data processing level. On 20 August 2015, the IDCSI2 data set was fully replaced by IDCSI4.

For details on changes made between Version 1 (IDCSI2) and Version 2 (IDCSI4), see the Operation IceBridge Sea Ice Freeboard, Snow Depth, and Thickness Data Products Manual, Version 2.

NOTE: This data set has an associated Quick Look counterpart: IceBridge Sea Ice Freeboard, Snow Depth, and Thickness Quick Look.

1.1 Format

The data files are in comma delimited ASCII text format. Each data file is paired with an associated XML file. The XML files contain latitude and longitude, along with instrument, sensor, and campaign metadata.

1.2 File Naming Convention

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

IDCSI4_20090402.txt
IDCSI4_20090402.xml
IDCSI4_YYYYMMDD.xxx

Table 1. File Naming Convention

Variable	Description
IDCSI4	Short name for IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness
YYYY	Four-digit year of data collection
MM	Two-digit month of data collection
DD	Two-digit day of data collection
.xxx	Indicates ASCII text file (.txt) or XML (.xml)

1.3 Spatial Coverage

Spatial coverage for the IceBridge L4 Sea Ice Freeboard, Snow Depth, and Thickness parameters currently includes Antarctica, Greenland and the Arctic.

Antarctica:
Southernmost Latitude: 90° S
Northernmost Latitude: 53° S
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

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

1.3.1 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.

1.3.2 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.

1.4 Temporal Information

1.4.1 Temporal Coverage

31 March 2009 to 25 April 2013.

1.4.2 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

1.5.1 Parameter Description

The data files contain parameters as described in Table 2.

Note: In the Level-4 Sea Ice Freeboard, Snow Depth, and Thickness data, the geoid correction (geoid_corr) in the previous IDCIS2 product has been replaced with the DTU10 Mean Sea Surface height (mss) (Andersen and Knudsen, 2009).

Table 2. File Parameter and Units

Parameter	Description	Units
lat	Latitude	Degrees
lon	Longitude	Degrees
thickness	Sea ice thickness	Meters
thickness_unc	Sea ice thickness uncertainty	Meters

Parameter	Description	Units
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 mean sea surface, 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
mss	Mean sea surface	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 surface elevation	Meters
load_tide_corr_part	Load tide for the surface elevation	Meters
earth_tide_corr_part	Solid earth tide for the surface elevation	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

Parameter	Description	Units
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
low_en_corr	Correction added to the ATM elevation data for low signal strength	Meters
sa_int_elev	Height of radar derived snow-air interface relative to the WGS-84 ellipsoid	Meters
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	n/a
empty0...empty9	Empty columns which may be used in future versions	n/a

1.5.2 Sample Data Record

The sample record shows the header and three records from data file: `IDCSI4_20090402.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,mss,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,sa_int_elev,si_int_elev,my_ice_flag,empty0,empty1,empty2,empty3,empty4,
empty5,empty6,empty7,empty8,empty9

   84.032906,  300.829926,-99999.0000,-99999.0000,    0.7177,    0.7177,    0.0896,-99999.0000,-99999.0000,
 247,    0.000000,    0.000000,    0.000000,    0.4979,   21.9489,20090402, 52698.898437500,   -0.1027,
22.3300,    0.7135,    0.0628,   -0.0542,   -0.0015,    0.1185,   -0.2225,  251,    0.0818,    0.0000,
54502.304687500, 205944.5938,    0.403039, 20090402_143809.ATM4BT2.qi,  1771.3,  139.0,-99999.00,-
99999.00,    0.0803,-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

   84.033274,  300.830077,-99999.0000,-99999.0000,    0.6302,    0.6302,    0.0896,-99999.0000,-99999.0000,
 248,    0.000000,    0.000000,    0.000000,    0.4066,   21.8562,20090402, 52699.148437500,   -0.1027,
22.3286,    0.7135,    0.0628,   -0.0542,   -0.0015,    0.1185,   -0.2225,  251,    0.0818,    0.0000,
54502.304687500, 205911.4063,    0.336200, 20090402_143809.ATM4BT2.qi,  1771.3,  139.0,-99999.00,-
99999.00,    0.0791,-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

   84.033642,  300.830226,-99999.0000,-99999.0000,    0.7354,    0.7354,    0.0896,-99999.0000,-99999.0000,
 249,    0.000000,    0.000000,    0.000000,    0.5134,   21.9623,20090402, 52699.398437500,   -0.1027,
22.3279,    0.7135,    0.0628,   -0.0542,   -0.0015,    0.1185,   -0.2225,  251,    0.0818,    0.0000,
54502.304687500, 205882.5625,    0.376432, 20090402_143809.ATM4BT2.qi,  1771.3,  139.0,-99999.00,-
99999.00,    0.0774,-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
```

Figure 1. Sample data record from `IDCSI4_20090402.txt`.

2 SOFTWARE AND TOOLS

2.1 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.

2.2 Quality Assessment

For details on data quality, see *Sea Ice Thickness, Freeboard, and Snow Depth Products from Operation IceBridge Airborne Data* (Kurtz et al., 2013).

3 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.

For instrument details related to specific campaigns, see the Mission, Campaign, and Flight-Specific Notes.

3.1 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:

- IceBridge KT19 IR Surface Temperature for 2012
- IceBridge NSERC L1B Geolocated Meteorologic and Surface Temperature Data for 2010

Figure 2 describes the retrieval of sea ice thickness, snow depth, and freeboard (Kurtz et al., 2013). 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.

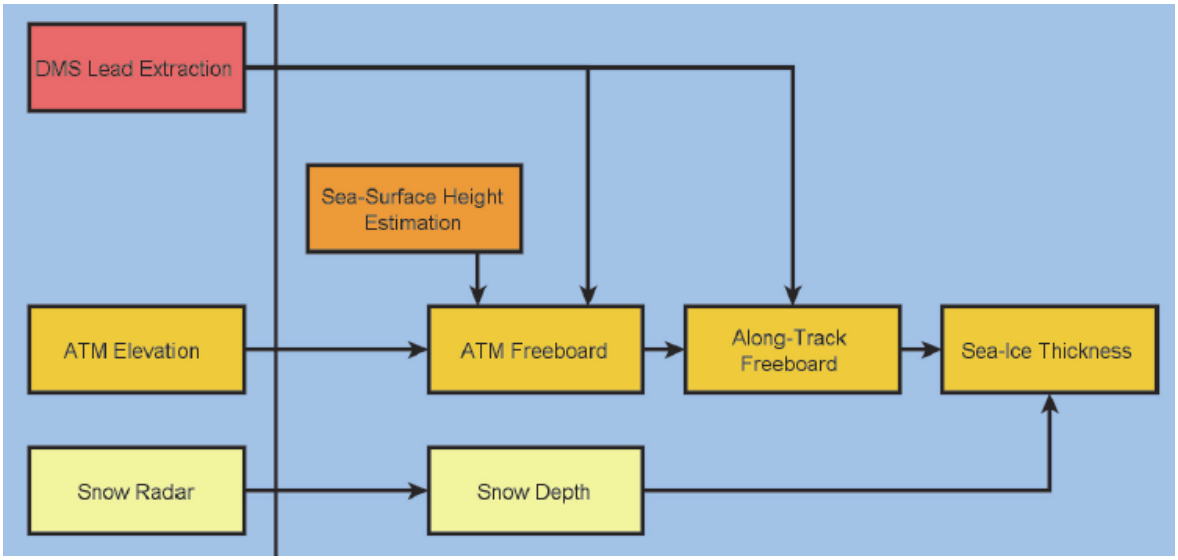

Figure 2. Product Retrieval from Instrument Data

3.2 Derivation Techniques and Algorithms

IceBridge L4 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 and algorithms, see (Kurtz et al. 2013).

3.2.1 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., 2013).

3.2.2 Sea Ice Snow Depth

Retrieval methods for the IceBridge snow radar have been described by Kurtz and Farrell (2011), and Kurtz et al. (2013). 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. (2013) 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., 2013).

3.2.3 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:

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

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).

3.2.4 Processing Steps

For details about processing of the Level-4 product, and details on specific seasonal campaigns, see the Operation IceBridge Sea Ice Freeboard, Snow Depth, and Thickness Data Products Manual, Version 2.

3.2.5 Version History

Version 1.2 Minor Version change: In Version 1 of the IDCSI4 data files, it was discovered that the Surface Temperature variable was blank. Version 1.2 data now include the Surface Temperature values. In addition, Greenland data for 2013.03.26, 2013.03.27, and 2013.04.25 are now included, and Antarctica data for 2009 and 2010 have been added to the data set. **Note:** there is no Minor Version 1.1. Minor Version 1.1 designation has been precluded in order to sync data set minor version 1.2 and the LocalVersionID = 002.

3.2.6 Errors and Limitations

Error Information for IDCIS4

Scan angle bias: a scan angle bias was discovered in the ATM elevation data and is described in detail in Yi et al. (2015). An empirical correction to this error is now implemented in the IDCSI4 products, and the recorded elevation correction is now in the product file.

Sea surface height interpolation: an error in the sea surface height interpolation processing code was discovered which caused the formation of singular covariance matrices and reverted the interpolation to a purely distance weighted approach. This may have caused discontinuities in the calculated sea-surface height in previous versions. The issue has been fixed.

Ocean and load tide errors: the TPXO6.2 tide model has been updated to a newer version, the TPXO8.0 tide model which is used to estimate the hocean and hload components. In previous uses of the TPXO6.2 model for the 2009-2012 Arctic campaigns, the sign for the tidal correction was incorrectly applied. This has been fixed in IDCSI4 products.

Product spacing: an error in the processing code was identified which led to irregular spacing of the 40 m averaged data product. The IDCSI4 product has fixed this error with all data now having a correct spacing of 40 m between the output products.

Snow radar averaging: an error in the previous product version was discovered which utilized only a single snow radar measurement within the 40 m averaged data product, rather than the mean of all measurements within the 40 m average segment. This issue has now been fixed.

For further details about error fixes for the Level-4 product, see Section 7.2 of the Operation IceBridge sea ice freeboard, snow depth, and thickness data products manual, version 2 processing document.

Error information from the original IDCSI2 product:

Time tags in the 'elapsed' data field in some samples are identical yet have different latitude and longitude, and there are jumps in lat/lon at those points where the time stamps do not change. This timestamp issue appears to be present in each of the files for the 2011 Arctic campaign, apparently arising from the initial 2011 snow radar data set. This should only be an issue with the timestamp, not the location information, so the latitude and longitude fields should be correct. Reprocessed and corrected 2011 snow radar data have been received, and a fully corrected version will be released in the near future with Version 2 of the IDCSI2 data set. Version 2 will cover all data released to date and will include fixes for errors such as this as well as multiple upgrades.

During the processing of this data all averaging was based on the locations of the snow radar footprints. Each lat/lon ˜40 m spot was processed individually. During this process, if ATM data was available for this footprint, the timestamp was recorded from the ATM data within the footprint. If there were no ATM data available for the location, the timestamp from the snow radar was used. The code was initially designed for calculating ATM freeboard and the snow radar / thickness portion was added afterwards. This idiosyncrasy has since been removed and all timestamps are assigned at the beginning, similar to the lat/lon fields and are not dependent upon other data fields.

In the assignment of the timestamp from the snow radar data source, a coding error was made that failed to regularly update the timestamp being assigned to the correct one for the current location being processed. Due to this error, when the final script ran and rearranged every point to ensure that the elapsed time field was monotonically increasing, it also rearranged every other field, including the lat/lon fields. So even though the lat/lon fields appear to have "bad spots," they are actually just out of order in the file.

The lat/lon fields in the original ˜40 m footprint snow radar data set were ingested for the lat/lon positions. Other than being out of order, the values are identical. This means that the user has two options:

1. To use the data spatially, use the lat/lon fields to plot everything; keeping in mind that the file may spatially jump around a bit, but all the data, other than the small repeating areas only in the ELAPSED field should be good.
2. For the data to be monotonically increasing in time/along-track, filter the data by eliminating the entries that are missing ATM data, as the problem occurs only where the snow radar locations do not contain ATM data. For example, use a filter that treats all entries where the ELEV field is greater than -99999.0 as good. If fields filtered in this manner are plotted, the problem areas are erased.

3.3 Sensor or Instrument Description

3.3.1 ATM

The NASA ATM instrument is a scanning airborne laser that measures surface elevation of the ice by timing laser pulses transmitted from the aircraft, reflected from the ground and returning to the aircraft. This laser pulse time-of-flight information is used to derive surface elevation measurements by combining measurement of the scan pointing angle, precise GPS trajectories, and aircraft attitude information.

3.3.2 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.

3.3.3 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.

3.3.4 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.

4 REFERENCES AND RELATED PUBLICATIONS

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Yi, D., J. P. Harbeck, S. S. Manizade, N. T. Kurtz, M. Studinger, and M. Hofton. 2015. Arctic Sea Ice Freeboard Retrieval With Waveform Characteristics for NASA's Airborne Topographic Mapper (ATM) and Land, Vegetation, and Ice Sensor (LVIS), IEEE Transactions on Geoscience and Remote Sensing 53(3):1403-1410, doi: 10.1109/TGRS.2014.2339737.

4.1 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

4.2 Related Websites

- Airborne Topographic Mapper website at NASA Wallops Flight Facility
- CReSIS Sensors Development Radar website
- IceBridge mission page at NSIDC
- IceBridge website at NASA
- NASA Digital Mapping System web page

5 CONTACTS AND ACKNOWLEDGMENTS

5.1 Contacts

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6 DOCUMENT INFORMATION

6.1 Publication Date

29 June 2015

6.2 Date Last Updated

20 August 2015