IceBridge MCoRDS L2 Ice Thickness, Version 1

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. 2010, updated 2019. *IceBridge MCoRDS L2 Ice Thickness, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/GDQ0CUCVTE2Q. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/IRMCR2

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

The data set includes measurements for elevation, surface, bottom, and thickness.

1.1 Format

The data files are in Comma-Separated Values (CSV) format.

Each data file is paired with an associated XML (.xml) file, which contains additional metadata.

The radar data are divided into segments. A segment is a contiguous data set in which the radar settings do not change. A day is divided into segments if the radar settings were changed, hard drives were switched, or other operational constraints required that the radar recording be turned off and on. The segment ID is YYYYMMDD_SS where YYYY is the four-digit year, MM is the two-digit month from 1 to 12, DD is the two-digit day of the month from 1 to 31, and SS is the segment number from 0 to 99. Segments are always sorted in the order in which the data were collected. Generally SS starts with 1 and increments by 1 for each new segment, but this is not always the case; only the ordering is guaranteed to match the order of data collection.

1.2 File Naming Convention

Example file name:

`IRMCR2_20131127_01.csv`

The files are named according to the following convention, which is described in more detail in Table 1:

`IRMCR2_YYMMDD_SS.xxx`

Table 1. File Naming Convention

Variable	Description
`IRMCR2`	Data set ID
`YYYY`	4-digit year
`MM`	2-digit month
`DD`	2-digit day
`SS`	flight segment number
`.xxx`	Indicates file type. For example: CSV (.csv), or XML (.xml)

1.3 Spatial Coverage

Spatial coverage for the IceBridge MCoRDS campaigns includes Antarctica and Greenland.

Antarctica:

Southernmost Latitude: 90° S

Northernmost Latitude: 63° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

Greenland:

Southernmost Latitude: 59° N

Northernmost Latitude: 83° N

Westernmost Longitude: 74° W

Easternmost Longitude: 12° W

1.3.1 Spatial Resolution

Spatial Resolution varies by surface characteristics and aircraft flown, as shown in Table 2.

Table 2. Spatial Resolution

Surface Characteristics	DC-8 Antarctica	P-3 Greenland
Smooth surface, across-track	641 m resolution where aircraft height = 500 m and ice thickness = 2000 m. 1518 m resolution where aircraft height = 8000 m and ice thickness = 2000 m.	323 m where height above the air/ice interface = 500 m and ice thickness = 2000 m.
Rough surface, across-track	965 m resolution where aircraft height = 500 m and ice thickness = 2000 m. 5416 m resolution where aircraft height = 8000 m and ice thickness = 2000 m.	651 m where height above the air/ice interface = 500 m, and ice thickness = 2000 m.

Surface Characteristics	DC-8 Antarctica	P-3 Greenland
Along-track	The final product has an along-track resolution of about 25 m and a sample spacing of about 14 m.	The final product has an along-track resolution of about 25 m and a sample spacing of about 14 m.
Depth	17.8 m resolution.	4.5 m resolution. Actual target location is ambiguous for a rough surface since the off-nadir returns in the antenna footprint can hide the nadir return. The ice thickness is still close to correct, but may not be for the nadir return.

1.3.2 Projection and Grid Description

These data are provided in WGS-84 geodetic coordinates and WGS-84 ellipsoid elevation reference. Image files are in Operation IceBridge polar stereographic projections for Greenland Standard Parallel 70° N and Longitude of the Origin 45° W, and Antarctica Standard Parallel 71° S and Longitude of the Origin 0° E.

1.4 Temporal Coverage

16 October 2009 to 16 November 2018

1.4.1 Temporal Resolution

IceBridge campaigns are conducted on an annually repeating basis. Arctic and Greenland campaigns are typically conducted in March, April, and May; Antarctic campaigns are typically conducted in October and November.

1.5 Parameter or Variable

This data set contains elevation, surface, bottom, and thickness measurements.

1.5.1 Parameter Description

The CSV files contain fields as described in Table 3.

Table 3. File Parameters, Description, and Units

Parameter	Description	Units
Latitude	Latitude	Degrees North
Longitude	Longitude	Degrees East
Time	UTC Time	Seconds of day
Thickness	Ice Thickness: Bottom minus Surface. Constant dielectric of 3.15 (no firn) is assumed for converting propagation delay into range. -9999 indicates no thickness available.	Meters
Elevation	Elevation referenced to WGS-84 Ellipsoid.	Meters
Frame (YYYYMMDDSSFFF)	Fixed length numeric field. YYYY = year, MM = month, DD = day, SS = segment FFF = frame.	N/A
Surface	Range to Ice Surface. Actual surface height is Elevation minus this number.	Meters
Bottom	Range to Ice Bottom. Actual ice bottom height is Elevation minus this number. Constant dielectric of 3.15 (no firn) is assumed for converting propagation delay into range. -9999 indicates no thickness available.	Meters
Quality	1: High confidence pick 2: Medium confidence pick 3: Low confidence pick	NA

Note: When aligning with GPS time tagged data, account for leap seconds.

1.5.2 Sample Data Record

Below is an excerpt from data file `IRMCR2_Data_20101026_01.csv`. The fields in each record correspond to the columns described in Table 3.

LAT	LON	TIME	THICK	ELEVATION	FRAME	SURFACE	BOTTOM	QUALITY
-64.0653	-54.8825	50446	0	2388.0533	2E+12	2353.63	2353.63	1
-64.0654	-54.8823	50446	0	2387.18	2E+12	2352.86	2352.86	1
-64.0655	-54.8821	50446.1	0	2386.3066	2E+12	2352.08	2352.08	1
-64.0656	-54.8818	50446.2	0	2385.4333	2E+12	2351.31	2351.31	1
-64.0656	-54.8816	50446.3	0	2384.5601	2E+12	2350.53	2350.53	1
-64.0657	-54.8814	50446.4	0	2383.6868	2E+12	2349.76	2349.76	1
-64.0658	-54.8812	50446.4	0	2382.8136	2E+12	2348.98	2348.98	1
-64.0659	-54.881	50446.5	0	2381.9405	2E+12	2348.21	2348.21	1
-64.066	-54.8807	50446.6	0	2381.0674	2E+12	2347.43	2347.43	1

2 SOFTWARE AND TOOLS

CSV files may be opened by any text viewing program.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

Ice thickness is typically determined using data collected from waveforms with different pulse durations. Generally, all receive channels are used to produce the best result. The two reflections that are of most interest are the ice surface and ice bottom. The difference in the propagation time between the ice surface and ice bottom reflections is then converted into ice thickness using an estimated ice index of refraction of ice (square root of 3.15). The media is assumed to be uniform, i.e. no firn correction is applied.

Data collection modes used for typical operation are described below in the Data Acquisition Methods section.

3.2 Data Acquisition Methods

3.2.1 P-3 Low Altitude

A waveform with a 1-Âµs 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-Âµs 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-Âµs 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.

3.2.2 DC-8 Low Altitude

The same concept is used as for the 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).

3.2.3 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.

2009 Antarctica DC-8 Radar Settings

Bandwidth: 180-210 MHz (DC-8 platform restricted to 189.15-198.65 MHz)

Tx power: 550 W

Waveform: eight channel chirp generation, 14 bit ADC at 111 MHz bandpass sampling

Acquisition: eight channels

Dynamic Range: waveform playlist

Rx Aperture: 1.5 wavelength aperture

Tx Aperture: 1.5 wavelength aperture; fully programmable

Monostatic Rx/Tx

Data rate: 12 MB/sec per channel

2009 Antarctica Twin Otter Radar Settings

Bandwidth: 140-160 MHz

Tx power: 500 W

Waveform: eight channel chirp generation

Acquisition: eight channels

Rx Aperture: 3 wavelength aperture

Tx Aperture: 3 wavelength aperture; fully programmable

Bistatic Rx/Tx

Data rate: 12 MB/sec per channel

2010 Antarctica DC-8 Radar Settings

Dynamic Range: waveform playlist coupled with low gain and high gain channels

2010 Greenland P-3 Radar Settings

Bandwidth: 180-210 MHz (EMI restricted to 10 MHz within 180-210 MHz most segments)

Tx power: 600 W

Waveform: eight channel chirp generation

Acquisition: sixteen channels (multiplexed on to 8 channels), 14 bit ADC at 111 MHz bandpass sampling

Rx Aperture: 2 wavelength, 3.5 wavelength, and 2 wavelength apertures, baseline of 6.4 m between each aperture

Tx Aperture: 3.5 wavelength aperture; fully programmable

Mixed monostatic and bistatic tx/rx

Data rate: 6 MB/sec per channel

2011 Antarctica DC-8 Radar Settings

Dynamic Range: waveform playlist coupled with low gain and high gain channels

2011 Antarctica Twin Otter Radar Settings

Tx power: 1500 W

Rx Aperture: two 3 wavelength apertures with 13.8 m baseline

Tx Aperture: 3 wavelength aperture; fully programmable

2011 Greenland Twin Otter Radar Settings

Bandwidth: 180-210 MHz

Tx power: 500 W

Waveform: eight channel chirp generation

Acquisition: sixteen channels (multiplexed onto 8 channels), 14 bit ADC at 111 MHz bandpass sampling

Rx Aperture: two 3 wavelength apertures with 13.8 m baseline

Tx Aperture: 3 wavelength aperture; fully programmable

Mixed monostatic and bistatic tx/rx

Data rate: 6 MB/sec per channel

2011 Greenland P-3 Radar Settings

Bandwidth: 180-210 MHz

Tx power: 1050 W

Waveform: Eight channel chirp generation

Acquisition: sixteen channels, 14 bit ADC at 111 MHz bandpass sampling

Dynamic Range: waveform playlist

Rx Aperture: 2 wavelength, 3.5 wavelength, and 2 wavelength apertures, baseline of 6.4 m between each aperture

Tx Aperture: 3.5 wavelength aperture; fully programmable

Mixed monostatic and bistatic tx/rx

Data rate: 32 MB/sec per channel

3.3 Derivation Techniques and Algorithms

3.3.1 Processing Steps

The layer tracking of ice surface and ice bottom reflections are manually driven processes with basic tools for partial automation. The tools used are determined by the operator picking the data and include:

1. Manual picking and interpolation.
2. Snake tracker which follows the strongest return within a window centered on the last tracked location from range line to range line.
3. Leading edge detector searches for the crossing of a threshold beneath the peak return.
4. Peak detector.

Various processing outputs, for example Minimum Variance Distortionless Response (MVDR), standard, quick look, dynamic range of the image, averaging, and detrending methods are used to better highlight features in the echogram as needed.

For further detail on data processing, including algorithms, see the Data Processing section in the *IceBridge MCoRDS L1B Geolocated Radar Echo Strength Profiles* documentation.

3.3.2 Version History

On 12 April 2011, the 2009 Antarctica MCoRDS L2 data were replaced by Version 1.1. The original 2009 Antarctica data were processed through a temporary process with quicklook data products only. Version 1.1 data are produced from full Synthetic Aperture Radar (SAR) processing.

On 17 October 2011, the MCoRDS L2 data were replaced by Version 1.2. The csv_good and CSARP_layer data were removed from the previous version.

3.3.3 Error Sources

The data are not radiometrically calibrated. This means that they are not converted to an absolute standard for reflectivity or backscattering analysis. The MCoRDS science team is working on data processing and hardware modifications to do this.

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 two surfaces more than once (or resonates) in the vertical dimension, and then returns to the receive antenna. Reflections occur in situations when two or more large reflectors are present with large electromagnetic constitutive property changes, such as the ice surface (air/ground), the bottom of the ice, 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 because the propagation time is a multiple of the resonance cavity. The most common multiple is between the air-ice surface and the aircraft. This "surface" multiple shows up at twice the propagation time as the original surface return and all the slopes are doubled.

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

2009 Antarctica DC-8 Specific Issues

Transmit/Receive Switch: 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 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 ft. AGL.

Some of the data collected during this season are from high altitude. The high altitude data are generally lower quality than the low altitude data. This is because:

1. the cross-track antenna resolution is proportional to range creating severe layover problems in mountainous terrain, for example 05 November 2009 high altitude peninsula flight.
2. the sidelobes from the long pulse duration mask out some of the returns that otherwise would have had a high enough signal to noise ratio.
3. the range to target is greater so the spherical spreading power loss is greater leading to a lower signal to noise ratio.

Monostatic elements: All monostatic elements used for transmit and receive have an unknown fast-time gain profile because the transmit/receive switches take about 10 microseconds to fully switch positions. This fast-time gain profile has not been corrected so that using the surface or shallow layer returns for antenna equalization or for radiometric purposes is not recommended. All five of the antennas on the DC-8 are monostatic antennas.

2010 Antarctica DC-8 Specific Issues

Transmit/Receive Switch: This is a similar problem as with the 2009 Antarctica DC-8 season. However, we were able to set the TR switch control signals so that the surface is recoverable with the regular array down to an altitude of 600 ft. AGL but with very much reduced signal strength. The regular array is preferred over the EMI antenna setup because the radiation pattern characteristics are better. At an altitude of 1500 ft., no degradation in signal detectability is observed.

High altitude data: See 2009 Antarctica DC-8.

Monostatic elements: See 2009 Antarctica DC-8.

2010 Greenland DC-8 Specific Issues

One of the in-cabin Electromagnetic Interference (EMI) antennas is used to produce the quick look data product. The EMI antennas were not designed to receive the surface return. However, the transmit-receive switch for the primary array was set so that the surface returns for platform altitudes below 1500 feet were greatly attenuated. Because of this, the EMI antennas are used for picking the surface return at low altitude.

2010 Greenland P-3 Specific Issues

Monostatic elements: See 2009 Antarctica DC-8. Only the center seven elements are monostatic on the P-3.

EMI: Due to lack of shielding, a noisy switching power supply, and potentially other unidentified sources the radar was operated with 10 MHz bandwidth (190-200 MHz) for most of the field season. The signal quality is still lower than expected in this band due to broadband noise which is present at all times and periodic burst noise from other pulsed instruments on the P-3 and from random burst noise. The noise present at all times manifests itself as an increase in the noise floor and the burst noise manifests itself as smeared point targets.

2011 Greenland P-3 Specific Issues

The MCoRDS2 data acquisition system fielded for the first time this season has a known issue with radar data synchronization with GPS data. The synchronization time correction that must be added to the radar time stamp is either 0 or -1 second. When the radar system is initially turned on, the radar system acquires Universal Time Coordinated (UTC) time from the GPS National Marine Electronics Association (NMEA) string. If this is done too soon after the GPS receiver has been turned on, the NMEA string sometimes returns GPS time rather than UTC time. GPS time is 15 seconds ahead of UTC time during this field season. The corrections for the entire day must include the offset, either -15 or -16 seconds. GPS corrections have been applied to all of the data using a comparison between the accumulation radar and the MCoRDS radar. The accumulation radar from 2011 is known to have only the GPS/UTC problem. The GPS/UTC problem is easily detectable by comparing the data to raster imagery, so the only correction that could be in error is the 0 or -1 second offset and this generally happens when there are no good features in or above the ice to align the accumulation and MCoRDS2 radars. GPS time corrections and frames where no good sync information was available are given in the vector worksheet of the Parameter Spreadsheet.

Two of the missions, SE Glaciers on 11 April 2011 and Helheim/Kanger/Midguard on 19 April 2011, suffered from radar configuration failures and about 40 dB of sensitivity was lost on the high gain channel. Short portions of these data are still good so the datasets are published, but most of the data are not useful.

3.4 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, 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 Parameter Spreadsheet.

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4.1 Related Data Collections

IceBridge MCoRDS L1B Geolocated Radar Echo Strength Profiles

IceBridge PARIS L2 Ice Thickness

IceBridge HiCARS 1 L2 Geolocated Ice Thickness

Greenland 5 km DEM, Ice Thickness, and Bedrock Elevation Grids

4.2 Related Websites

CReSIS website
CReSIS Sensors Development Radar web page
IceBridge data website at NSIDC
IceBridge website at NASA
ICESat/GLAS website at NASA Wallops Flight Facility
ICESat/GLAS website at NSIDC

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6 DOCUMENT INFORMATION

6.1 Publication Date

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6.2 Date Last Updated

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