IceBridge Ku-Band Radar L1B Geolocated Radar Echo Strength Profiles, 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. 2014, updated 2017. *IceBridge Ku-Band Radar L1B Geolocated Radar Echo Strength Profiles, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/D7DX7J7J5JN9. [Date Accessed].

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1 DETAILED DATA DESCRIPTION

Operation IceBridge products may include test flight data that are not useful for research and scientific analysis. Test flights usually occur at the beginning of campaigns. Users should read flight reports for the flights that collected any of the data they intend to use. Check IceBridge campaign Flight Reports for dates and information about test flights.

1.1 Format

The data files are in netCDF format. The `XXX_Echogram.jpg` files show depth echograms and the `XXX_Map.jpg` files show campaign flight locations and flight lines. The y-axis in the echogram JPEG files shows depth relative to a range around the surface. The surface is in the center of the y-axis and the y-axis is set to a fixed range, usually from 0 m to 60 m or from 0 m to 80 m for land ice, and from 0 m to 4 m for sea ice.

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

1.2 Deconvolution Files and Supplement Files

Deconvolution and supplement files are included in the data files from 19 March 2015 to 27 October 2016 for data captured over sea ice.

Deconvolution Files

Fast-time deconvolution filtering has been applied which affects the `amplitude` field in the data file. The deconvolution filter for each range line is constructed from nearby sea ice lead responses. The purpose of the deconvolution filter is to reduce sidelobes.

Supplement Files

Supplement files contain metadata information for the data segment (SS = segment and FFF = frame in the segment. There is one supplement file per data granule, containing a quality mask for each data frame. Supplement files contain the following seven classification masks:

1. coh_noise_removal_artifact: Coherent noise removal artifacts in radar echogram. uint8 type, set to 0 for no substantial coherent noise removal artifacts and 1 if artifacts exist.
2. deconvolution_artifact: Deconvolution artifacts (e.g. sidelobes) in radar echogram. uint8 type, set to 0 for no substantial deconvolution artifacts and 1 if artifacts exist.
3. vertical_stripes_artifact: Vertical stripes or raised noise floor artifacts in radar echogram. uint8 type, set to 0 for no substantial vertical striping artifacts and 1 if artifacts exist.
4. missing_data: Radar echogram is missing data because radar range gate clips echogram, truncating the radar return. uint8 type, set to 0 for no missing data and 1 if there is missing data.

5. low_SNR: Low signal to noise ratio. uint8 type, set to 0 for sufficient SNR and 1 if the SNR is low.
6. unclassified_artifact: Unclassified artifacts exist in radar echogram. uint8 type, set to 0 for no unclassified artifacts and 1 if artifacts exist.
7. land_ice: Land ice, ice shelf, or ice berg contained in echogram. uint8 type, set to 0 for sea ice and 1 for land ice.

NOTE: uint8 = Unsigned (no negative sign) Integers only 8 bits of information – min value 0, max value 255.

1.3 File Naming Convention

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

Examples:

`IRKUB1B_20121012_01_001.nc`

`IRKUB1B_20121012_01_001.xml`

`IRKUB1B_YYYYMMDD_xx_xxx.NNN`

`IRKUB1B_20150319_01_001_deconv.nc`

`IRKUB1B_20150319_01_001_supplement.nc`

`IRSNO1B_YYYYMMDD_xx_xxx.zzzzzz.NNN`

`IRSNO1B_20121012_01_001_Echogram.jpg`

`IRSNO1B_YYYYMMDD_xx_xxx_aaa.jpg`

Table 1. File Naming Convention

Variable	Description
`IRKUB1B`	Short name for IceBridge Ku-Band Radar L1B Geolocated Radar Echo Strength Profiles
`YYYY`	Four-digit year of survey
`MM`	Two-digit month of survey
`DD`	Two-digit day of survey
`xx`	Segment number
`xxx`	Frame number
`zzzzzz`	Ancillary file: deconv or supplement. Pertains only to data files captured over sea ice.
`aaa`	Image type. Examples: Echogram, Map
`NNN`	Indicates file type. For example: netCDF (`.nc`), XML (`.xml`), JPEG (`.jpg`)

1.4 File Size

NetCDF files range from approximately 400 KB to 5.2 MB. The total NetCDF file volume is approximately 1.5 TB.

JPEG files range from approximately 775 Bytes to 380 KB. The total JPEG file volume is approximately 0.05 TB.

XML files range from approximately 4 KB to 6 KB. The total XML file volume is approximately 0.4 GB.

1.5 Volume

The entire data set is approximately 1.7 TB.

1.6 Spatial Coverage

Spatial coverage for the IceBridge Ku-Band Radar campaigns includes the Arctic, Greenland, Antarctica, and surrounding ocean areas. This represents the two coverages noted below.

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

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

1.6.1 Spatial Resolution

Spatial resolution varies dependent on along-track direction, cross-track direction, and aircraft height characteristics. See the Derivation Techniques and Algorithms section for further detail on resolution and bandwidth.

1.6.2 Projection and Grid Description

Referenced to WGS-84 Ellipsoid.

1.7 Temporal Coverage

12 October 2012 to 18 November 2016

1.7.1 Temporal Resolution

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

1.8 Parameter or Variable

This data set contains elevation and surface measurements.

1.8.1 Parameter Description

The netCDF files contain fields as described in Table 2.

Table 2. File Naming Convention

Parameter	**Description**	**Units**
`altitude`	WGS-84 geodetic elevation coordinate of the measurement's phase center. Dimension is `time`.	Meters
`amplitude`	Power detected radar echogram data matrix. The first dimension is `fasttime` and the second dimension is `time`. Power is relative to the current range line only. Each range line may contain a different bias and thus power comparisons between range lines may not be possible.	Relative power (log scale)
`Elevation_Correction`	Represents the number of zeros that were inserted during elevation compensation for each range line to simulate near-level flight. These zeros are not included in the truncation noise statistics. Only available when `amplitude` is truncated. Dimension is `time`.	Range bins

Parameter	Description	Units
`fasttime`	Fast-time. Zero time is the time at which the transmit waveform begins to radiate from the transmit antenna.	Microseconds
`heading`	Platform heading attitude (zero is north, positive to east). Dimension is `time`.	Degrees
`lat`	WGS-84 geodetic latitude coordinate of the measurement phase center. Always referenced to North. Dimension is `time`.	Degrees
`lon`	WGS-84 geodetic longitude coordinate of the measurement phase center. Always referenced to East. Dimension is `time`.	Degrees
`pitch`	Platform pitch attitude (zero is level flight, positive is up). Dimension is `time`.	Degrees
`roll`	Platform roll attitude (zero is level flight, positive is right wing tip down). Dimension is `time`.	Degrees
`Surface`	Estimated two-way propagation time to the surface from the collection platform. This uses the same frame of reference as the `fasttime` parameter. This information is sometimes used during truncation to determine the range bins that can be truncated. Dimension is `time`.	Seconds
`time`	UTC time of day. This is also known as the slow-time dimension. The parameter's units attribute contains a string of the form "seconds since YYYY-MM-DD 00:00:00", which indicates the day relative to `time`. This pertains to data sets that wrap over a UTC day boundary which will cause `time` to be outside the range [0,86400].	Seconds
`Truncate_Bins`	Indices into the original (before truncation) fast-time vector for which the amplitude values are available. Only available when `amplitude` is truncated. Dimension is `time`.	n/a
`Truncate_Mean`	Represents a mean of the noise power for the truncated range bins before the surface return. When no range bins were truncated before the surface return, the value is NaN. Only available when `amplitude` is truncated. Dimension is `time`.	n/a

Parameter	Description	Units
`Truncate_Median`	Represents a median of the noise power for the truncated range bins before the surface return. When no range bins were truncated before the surface return, the value is NaN. Only available when `amplitude` is truncated. Dimension is `time`.	n/a
`Truncate_Std_Dev`	Represents a standard deviation of the noise power for the truncated range bins before the surface return. When no range bins were truncated before the surface return, the value is NaN. Only available when `amplitude` is truncated. Dimension is `time`.	n/a
`*param*`	Multiple variables with a name containing the string "param." Contains radar and processing settings, and processing software version and time stamp information. Fields of structures are not static and may change from one version to the next.	

2 SOFTWARE AND TOOLS

See the NetCDF Resources at NSIDC page for tools to work with netCDF files.

CReSIS netCDF files are compatible with HDF5 libraries, and can be read by HDF readers such as HDFView. If the netCDF file reader you are using does not read the data, see http://www.unidata.ucar.edu/software/netcdf/ and https://nsidc.org/support/faq/what-netcdf for information on updating the reader.

CReSIS MATLAB readers are available for loading, plotting, and elevation compensation for CReSIS Level-1B radar products. These tools are provided by the Principal Investigator as-is as a service to the user community in the hopes that they will be useful. Please note that support for these tools is limited. Bug reports, comments, and suggestions for improvement are welcome; please send to nsidc@nsidc.org.

JPEG files may be opened using any image viewing program that recognizes the JPEG file format.

XML files can be read with browsers such as Firefox and Internet Explorer.

3 DATA ACQUISITION AND PROCESSING

3.1 Data Acquisition Methods

The CReSIS Ku-Band Radar uses a Frequency Modulated Continuous Wave (FMCW) architecture (Carrara 1995). This is done to reduce the required sampling frequency of the Analog to Digital Converter (ADC) and is possible when the range gate is limited. Currently, the range gate is limited to low altitude flights to achieve the full bandwidth. In the FMCW radars, a long chirp signal of approximately 250 μs is generated which sweeps linearly from the start frequency to the stop frequency. This signal is transmitted and also fed to a mixer in the receiver to be used to demodulate the received signal. Signals outside the range gate are suppressed by the Intermediate Frequency (IF) filter and aliased by the system.

The dominant scattered signal is the specular or coherent reflection from the air-snow surface and shallow layers beneath this surface. A bistatic antenna configuration is used to provide isolation between the transmit and receive paths which is important because the FMCW system receives while transmitting and too little isolation means that the direct path from the transmitter to the receiver will be too strong and saturate the receiver. The antennas are mounted so that the main beam is pointed in the nadir direction to capture the specular surface and layer reflections.

The Pulse Repetition Frequency (PRF), or along-track sampling rate, does not necessarily capture the full Doppler bandwidth for point scatterers without aliasing. However, as the target energy is mostly coherent, it occupies only a small portion of the Doppler spectrum so the undersampling in along-track is not generally a problem. Since the coherent portion of the surface and layer scattering is the primary signal of interest, presumming is used to lower the data rate, which effectively low-pass-filters and decimates the Doppler spectrum.

The narrow beam width of the antennas have a fixed pointing direction, which means that when the aircraft rolls beyond approximately 10 degrees, the specular reflection falls outside the main lobe of the antennas and therefore the signal strength is reduced.

3.2 Derivation Techniques and Algorithms

The Echogram JPEG files include an altitude correction, but the netCDF files do not. In the case of the netCDF files, correction can be applied by shifting a record from bottom to top by the altitude correction value. To this end, altitude variations within a data file are removed by subtracting the minimum altitude from all values. The result is variation in meters from the minimum. These values are then converted to whole pixel values given the following radar parameters: sampling frequency, pulse duration, FFT length, and bandwidth. Sampling frequency before the 2009 Greenland campaign is 58.32 MHz, whereas after the Greenland campaign it was set to 62.5 MHz.

3.2.1 Flat Surface Range Resolution

For a flat surface the range resolution *r* is expressed by Equation 1:

$$r = \frac{k_t \cdot c}{2 \cdot B \cdot n}$$ **(Equation 1)**

Table 3. Flat Surface Range Resolution

Variable	Description
k_t	k_t = 1.5 due to the application of a Hanning time-domain window to reduce the range sidelobes of the chirped transmit waveform.
c	Speed of light in a vacuum
B	Bandwidth, nominally 3500 MHz (13 to 16.5 GHz range)
n	Index of refraction for the medium

Examples of range resolutions for several indices of refraction are shown in Table 4.

Table 4. Range Resolutions for Indices of Refraction

Index of Refraction	Range Resolution (cm)	Medium
1	6.4	Air
sqrt(1.53)	5.2	Snow
sqrt(3.15)	3.6	Solid Ice

3.2.2 Index of Refraction

The index of refraction *n* can be approximated by the calculation in Equation 2:

$$n = (1 + 0.51 \cdot \rho_{snow})^3$$ **(Equation 2)**

ρ_{snow} is the density of the snow in grams per cm3. In the data, a dielectric constant of 1.53 is used, which corresponds to a snow density of 0.3 g/cm3 (Warren 1999).

3.2.3 Bandwidth

The bandwidth B for a particular segment can be determined by reading the param_get_heights.radar.wfs structure in the netCDF files or by looking at the parameter spreadsheet values f0, f1, and fmult and doing the calculation in Equation 3:

$$B = (param\_radar.f1 - param\_radar.f0) \cdot param\_radar.fmult$$

(Equation 3)

Table 5. Segment Bandwidth Variable Definitions

Variable	**Name in netCDF file**	**Description**
`param_radar.f1`	`param_get_heights(1).radar(1).wfs(1).f1`	Stop frequency of chirp out of Direct Digital Synthesis (DDS) and into Phase-Locked Loop (PLL)
`param_radar.f0`	`param_get_heights(1).radar(1).wfs(1).f0`	Start frequency of chirp out of DDS and into PLL
`param_radar.fmult`	`param_get_heights(1).radar(1).wfs(1).fmult`	PLL frequency multiplication factor

3.2.4 Along-Track Resolution

Before any hardware or software coherent averages have been applied, the resolution of the raw data in the along-track direction is derived in the same manner as in the cross-track direction. However, a basic form of focusing is applied called Unfocused Synthetic Aperture Radar (SAR) Processing, also known as stacking or coherent averaging. If all effects are accounted for, the data may be coherently averaged to the SAR aperture length L, defined by Equation 4:

$$L = \sqrt{\frac{H \cdot \lambda_c}{2}}$$ **(Equation 4)**

Table 6. SAR Aperture Length Variable Definitions

Variable	**Description**
H	Height above ground level
λ_c	Wavelength at the center frequency

For H = 500 m and a center frequency of 14.75 GHz, the data are averaged to an aperture length L of 2.25 m. The resolution turns out to be approximately equal to this with the exact definition given below. However, these data are only coherently averaged 16 times which includes both hardware and software averaging, and decimated by this same amount. At a platform speed of 140 m/s this is an aperture length, L, of 1.12 m. The sample spacing is likewise 1.12 m. The approximation for the actual resolution, which is substantially less fine, is given in Equation 5:

$$\sigma_{x,SAR-qlook} = H \cdot \tan\left(\sin^{-1}\left(\frac{\lambda_c}{2 \cdot L}\right)\right)$$ **(Equation 5)**

Table 7. Actual Resolution Variable Definitions

Variable	**Description**
H	Height above ground level
λ_c	Wavelength at the center frequency
L	Aperture length

For H = 500 m, the along-track resolution is 4.54 m. A 1 range-bin by 5 along-track-range-line boxcar filter is applied to the power detected data and then decimated in the along-track by 5 so the data product has an along-track sample spacing of 5.6 m.

3.2.5 Fresnel Zone and Cross-Track Resolution

For a smooth or quasi-specular target, for example internal layers, the primary response is from the first Fresnel zone. Therefore, the directivity of specular targets effectively creates the appearance of a cross-track resolution equal to this first Fresnel zone. The first Fresnel zone is a circle with diameter given by Equation 6.

$$\sigma_{y,Fresnel-limited} = \sqrt{2 \cdot \lambda_c \cdot \left(H + \frac{T}{\sqrt{3.15}}\right)}$$ **(Equation 6)**

Table 8. First Fresnel Zone Diameter

Variable	Description
H	Height above the air/ice interface
T	Depth in ice
λc	Wavelength at the center frequency

Table 9 gives the cross-track resolution for this case.

Table 9. Cross-track Resolution Example

Center Frequency (MHz)	Cross-track Resolution H = 500 m T = 0 m
14750	4.5

For a rough surface with no discernible layover, the cross-track resolution will be constrained by the pulse-limited footprint, approximated in Equation 7.

$$\sigma_{y,pulse-limited} = 2 \cdot \sqrt{\frac{c \cdot k_t}{B} \cdot \left(H + \frac{T}{\sqrt{3.15}}\right)}$$

(Equation 7)

Table 10. Pulse-Limited Footprint

Variable	Description
H	Height above the air/ice interface
T	Depth in ice
c	Speed of light in a vacuum
k_t	k_t = 1.5 due to the application of a hanning time-domain window to reduce the range sidelobes of the chirped transmit waveform
B	Bandwidth in radians

Table 11 gives the cross-track resolution with windowing.

Table 11. Cross-track Resolution with Windowing

Bandwidth (MHz)	Cross-track Resolution H = 500 m T = 0 m
3500	16.0

For a rough surface where layover occurs, the cross-track resolution is set by the beamwidth, β, of the antenna array. The antenna beamwidth-limited resolution is expressed by Equation 8.

$$\sigma_{y,beamwidth-limited} = 2 \cdot \left(H + \frac{T}{\sqrt{3.15}}\right) \cdot \tan\left(\frac{\beta_y}{2}\right)$$ **(Equation 8)**

Table 12. Antenna Beamwidth-limited Resolution

Variable	Description
H	Height above ground level
T	Depth in ice
β_y	Beamwidth in radians

3.2.6 Footprint

The antenna installed in the bomb bay of the P-3 aircraft and in the wing roots of the DC-8 aircraft is an ETS Lindgren 3115. The E-plane of the antenna is aligned in the along-track direction for the P-3 aircraft and in the cross-track direction for the DC-8 aircraft. The approximate beamwidths are 45 degrees in the along-track direction and 45 degrees in the cross-track direction. The footprint is a function of range as shown in Equation 9.

$$\sigma = 2 \cdot H \cdot \tan\left(\frac{\beta}{2}\right)$$ **(Equation 9)**

Table 13. Footprint

Variable	Description
H	Height above ground level.
β	Beamwidth in radians

For H = 500 m, the footprint is 167 m in both the along-track and the cross-track directions.

3.2.7 Trajectory and Attitude Data

The trajectory data used for this data release was from a basic GPS receiver. Lever arm and attitude compensation has not been applied to the data.

3.2.8 Processing Steps

The following processing steps are performed by the data provider.

1. Set digital errors to zero. Error sequences are four samples in length and occur once every few thousand range lines.
2. Synchronization of GPS data with the radar data using the UTC time stored in the radar data files.

3. Conversion from quantization to voltage at the ADC input.
4. Removal of DC-bias by subtracting the mean.
5. For 2013 Greenland P3 and later, a tracking and truncation function has been implemented in the hardware which reduces the recorded data volume. Each range line is tracked and truncated separately and a step is added here to undo the tracking and truncation step so that the data can be placed in a matrix with constant time bins. This requires zero padding and time shifting of the data to get each range line to line up.
6. The quick look output is generated using presuming or unfocused SAR processing for a total of 16 coherent averages which includes hardware and software averages. If the PRF is 2000 Hz, the new effective PRF is 125 Hz.
7. A fast-time FFT is applied with a Hanning window to convert the raw data into the range domain, analogous to pulse compression. The data are flipped around based on the Nyquist zone.
8. A high pass filter is applied in the along-track to remove coherent noise.
9. A 1 range-bin by 5 along-track-range-line boxcar filter is applied to the power detected data and then decimated by 5 in the along-track direction.
10. The quick-look output is used to find the ice surface location, fully automated.
11. The output is elevation compensated to the nearest radar range bin and then truncated in fast time to reduce the data volume.

The purpose of the elevation compensation, when applied, is to remove the large platform elevation changes to make truncation more effective. The process is not designed to perform precision elevation compensation and is probably not sufficient for scientific analysis. The following steps are performed:

1. Let:
    a. Elevation_Orig be the 1 by N elevation vector before elevation compensation
    b. Data_Orig be the M_orig by N data matrix before elevation compensation
    c. Time_Orig be the M_orig by 1 fast-time time axis before elevation compensation
    d. Elevation be the 1 by N vector from the data product file
    e. Dat be the matrix from the data product file
    f. Time be the M by 1 fast-time time axis from the data product file
    g. maxElev = max(Elevation_Original)
2. dRange = maxElev - Elevation_Original
3. dt = Time_Orig(2) - Time_Orig (1)
    a. Sample spacing in fast-time (i.e. one range bin)
4. dBins = round(dRange / (c/2) / dt)
    a. This is a 1 by N vector of the number of range bins for each range line used to shift Data_Orig. In other words, this is the elevation compensation for each range line written in terms of range bins.
5. M = M_orig + max(dBins)
6. The original data matrix is zero padded to M and then each range line is shifted by the corresponding entry in dBins.
    a. Because of the round function for creating dBins, the elevation compensation is only done with range bin accuracy.
    b. The new Data matrix is similar to what would have been collected if the aircraft had flown at a constant elevation of maxElev.

7. The elevation matrix is modified according to the elevation compensation so that: Elevation_Orig = Elevation - dBins*dt*c/2. Once again, because of the round function, the Elevation vector will be nearly constant, but not quite: the quantization noise caused by the round function remains.
8. The Time_Orig vector is extended in length by the maximum bin shift to create the new Time vector.

3.2.9 Version History

Version 1 of the IRSNO1B data. All Version 1 contains data from 2009 to 2012, which were provided in binary format. For details on the Version 1 data, see the Version 1 documentation.

Version 2 of the IRKUB1B data: Version 2 data start in 2012 and are provided in netCDF format.

3.2.10 Error Sources

GPS Time Error:
The CReSIS accumulation, snow, MCoRDS, and kuband data acquisition systems have a known issue with radar data synchronization with GPS time. 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 whole day must include the offset -15 second correction. GPS corrections have been applied to all of the data using a comparison between the accumulation, snow, and kuband radars which have independent GPS receivers. A comparison to geographic features and between ocean surface radar return and GPS elevation is also made to ensure GPS synchronization. GPS time corrections are given in the vector worksheet of the parameter spreadsheet.

The error affects Version 2 of the Level 1B CReSIS data sets. Ku-band radar data are affected for the time period: October 2012 - 2013. In the near future, the NSIDC DAAC will publish updated data files with a correction to the 'Time' field.

For the data on 19 May 2016, the Ku-Band Altimeter frequency band was set to a value between 12 GHz to 18 GHz, instead of the usual 12 GHz to 15 GHz. As these data were processed with the same settings as the previous data, the two-way propagation times for the ice or snow surface and the internal layers were incorrectly calculated. This error affected the calculation of the elevations of the internal layers, as well as the layer thicknesses. The data for 19 May 2016 have been reprocessed and replaced with the corrected data.

3.3 Sensor or Instrument Description

As described on the CReSIS Sensors Development Radar Web site, the ku-band radar operates over the frequency range from 13 to 17 GHz. The primary purpose of this radar is high precision surface elevation measurements over polar ice sheets. The data collected with this radar can be analyzed in conjunction with laser-altimeter data to determine thickness of snow over sea ice. The radar has been flown on the NASA DC-8 and P-3 aircrafts, and the National Science Foundation-provided Twin Otter aircraft.

4 REFERENCES AND RELATED PUBLICATIONS

Carrara, W. G., R. S. Goodman, and R. M. Majewski. 1995. *Spotlight Synthetic Aperture Radar: Signal Processing Algorithms*, Artech House, Norwood, MA, pp. 26-31.

Patel, A. E., P. S. Gogineni, C. Leuschen, F. Rodriguez-Morales, and B. Panzer. 2010. An Ultra Wide-band Radar Altimeter for Ice Sheet Surface Elevation and Snow Cover Over Sea Ice Measurement, Abstract C41A-0518 presented at 2010 Fall Meeting, AGU, San Francisco, California, 13-17 December, 2010.

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, May 2010, 157-160.

Warren, S., I. Rigor, and N. Untersteiner. 1999. Snow Depth on Arctic Sea Ice, *Journal of Climate*, 12: 1814-1829.

4.1 Related Data Collections

IceBridge Accumulation Radar L1B Geolocated Radar Echo Strength Profiles
IceBridge MCoRDS L1B Geolocated Radar Echo Strength Profiles
IceBridge MCoRDS L2 Ice Thickness

4.2 Related Websites

CReSIS Sensors Development Radar website
CReSIS website
IceBridge product website
IceBridge website at NASA
ICESat/GLAS website at NASA Wallops Flight Facility
ICESat/GLAS website at NSIDC

5 CONTACTS AND ACKNOWLEDGEMENTS

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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

October 2014

6.2 Date Last Updated

February 2023