Radiostratigraphy and Age Structure of the Greenland Ice Sheet, Version 1

USER GUIDE

How to Cite These Data

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

MacGregor, J. A., M. Fahnestock, G. Catania, J. Paden, P. Gogineni, S. K. Young, S. C. Rybarski, A. N. Mabrey, B. M. Wagman, and M. Morlighem. 2015. *Radiostratigraphy and Age Structure of the Greenland Ice Sheet, Version 1.* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/UGI2BGTC4QJA. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/RRRAG4

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

1.1 Format

The data files are HDF5-compliant MATLAB (.mat) and NetCDF (.nc) formats. The NetCDF file was generated using MATLAB R2015a and is v4.1.3 compliant.

1.2 File Naming Convention

Example file names:

RRRAG4_Greenland_1993_2013_01_age_grid.nc
RRRAG4_Greenland_1993_2013_01_radiostratigraphy.mat

The file naming convention is described below and in Table 1:

RRRAG4_LLLLL_YYYY_yyyy_XX_NNNN.xxx

Table 1. File Naming Convention

Variable	**Description**
RRRAG4	Data set ID
LLLLL	Location, e.g. Greenland
YYYY_yyyy	Span of years represented in data set, e.g. 1993 to 2013.
XX	Local version id
NNNN	Data file contents, e.g. grid, radiostratigraphy
XXX	Indicates file type, e.g. NetCDF (.nc), MATLAB (.mat)

1.3 Spatial Coverage

Spatial coverage for this data set includes Greenland.

Greenland:
Southernmost Latitude 58.91° N
Northernmost Latitude: 81.51° N
Westernmost Longitude: -88.33° W
Easternmost Longitude: 6.62° E

1.3.1 Spatial Resolution

Spatial resolutions are variable. The horizontal posting of the radar data is of the order of 10 m. Vertical range resolution of the ice-penetrating radar systems used are of the order of meters, but internal reflections were typically traced at no finer than 10 m. The horizontal resolution of the gridded age structure and isochrone depths is 1 km. The vertical resolution of the age structure is ice–thickness–dependent, for example for a 2 km ice column, the vertical resolution of the age volume is 1/25th of that, or 80 m.

The nominal vertical range resolution in ice of these data is 2.5 m to 4.4 m and their along-track horizontal resolution varies between 15 m and 150 m, depending on the system used and whether the data were focused using synthetic aperture radar (SAR) techniques.

1.3.2 Projection and Grid Description

The radar data are projected using the NSIDC Sea Ice Polar Stereographic North projection EPSG:3413. WGS84 ellipsoid, a standard parallel of 70°N, and a false central meridian of 45°W and sets both the northing and easting origin as the North Pole. Other Greenland data sets also used in this study are re-projected onto EPSG:3413.

1.4 Temporal Coverage

23 June 1993 to 26 April 2013

1.4.1 Temporal Resolution

Semi-annual from 1993 to 2013. Survey campaigns typically occurred over several weeks during the boreal spring/summer (March to July).

1.5 Parameter or Variable

1.5.1 Parameter Description

The gridded data file contains fields as described in Table 2.

Table 2. Gridded Data Parameter Description

Parameter	Description	Units
age_iso	Age of selected isochrones	Years
age_norm	Age at ice-thickness-normalized depths, evenly spaced vertically	Years

Parameter	Description	Units
age_norm_uncert	Age uncertainty at ice-thickness-normalized depths, evenly spaced vertically	Years
depth_iso	Depths of selected isochrones	Meters
depth_iso_uncert	Depth uncertainty of selected isochrones	Meters
depth_norm	Ice-thickness-normalized depth of vertical layers	Depth as fraction of ice thickness
num_age_iso	Number of isochrones	Count
num_depth_norm	Number of vertical layers	Count
thick	Ice thickness	Meters
x	x-dimension grid centered on Greenland	Kilometers
y	y-dimension grid centered on Greenland	Kilometers

The HDF5 traced radiostratigraphy data file contain fields as described in Table 3.

Table 3. Radiostratigraphy Data File Parameter Description

Parameter	Description	Units
age	reflection age	Year
age_uncert	reflection age uncertainty	Year
distance	distance along segment	Kilometers
echo_intensity	ice depth to reflection	Decibels
elevation	layer elevation referenced to GIMP	Meters
elevation_bed	bed elevation referenced to GIMP	Meters
elevation_surface	surface elevation referenced to GIMP	Meters
latitude	latitude	Degrees
longitude	longitude	Degrees
time_gps	measurement time since 1 January 0000	Seconds
thickness	ice thickness	Meters
traveltime	traveltime to traced reflection	Seconds
traveltime_surface	traveltime to surface	Seconds
x	x value in EPSG:3413	Kilometers
y	y value in EPSG:3413	Kilometers

1.5.2 Sample Data Record

See NASA's Scientific Visualization Studio for a visualization of the Greenland Ice Sheet stratigraphy.

2 SOFTWARE AND TOOLS

The following external links provide access to software for reading and viewing HDF5 and netCDF data files. Please be sure to review instructions on installing and running the programs.

HDF Explorer: Data visualization program that reads Hierarchical Data Format files (HDF, HDF-EOS and HDF5) and also netCDF data files.

Panoply netCDF, HDF and GRIB Data Viewer: Cross-platform application. Plots geo-gridded arrays from netCDF, HDF and GRIB data sets.

For additional tools, see the HDF-EOS Tools and Information Center.

MATLAB files may be opened using MATLAB or the Octave high-level language.

See also: MATLAB scripts/functions for tracing reflectors in ice-penetrating radar data.

3 QUALITY ASSESSMENT

Data were quality controlled using multiple analysts, network graphs, and various other checks, especially to detect and resolve vertical overturning in the radar–inferred depth–age relationship.

The radiostratigraphy recorded within these radar data varies in quality depending on the system used and the area of the ice sheet surveyed. The overall quality of these radar data has improved over time as newer radar systems were developed and deployed. See MacGregor et al. (2015) for additional details on quality control methods.

4 DATA ACQUISITION AND PROCESSING

4.1 Theory of Measurements

See Gogineni et al. (1998) for a review of the theory and methodology underlying the collection of coherent ice-penetrating radar data.

4.2 Data Acquisition Methods

The two-way travel times of the air–ice and ice–bed reflections were measured by University of Kansas personnel throughout the acquisition period, for example Gogineni et al. (1998), and these travel times were used without further modification. The reflections were traced manually using a MATLAB-based interface.

These data include 512 transects of varying lengths (6–3965 km; median 530 km).

4.3 Derivation Techniques and Algorithms

The investigators examined the 479,595 km of 150 MHz and 195 MHz ice-penetrating radar data collected over the Greenland Ice Sheet by the University of Kansas between 1993 and 2013.

As described in MacGregor et al. (2015), core-intersecting reflections were dated using synchronized depth–age relationships for six deep ice cores. Additional reflections were dated by matching reflections between transects and by extending reflection–inferred depth–age relationships using the local effective vertical strain rate. Dated reflections are used to generate a gridded age volume for most of the ice sheet and also to determine the depths of key climate transitions that were not observed directly.

Figure 1 outlines the system designs, acquisition parameters, and processing techniques applied to the data. Please refer to MacGregor et al. (2015) for full details on each processing step. Section numbers (§) noted in Figure 1 refer to sections in MacGregor et al. (2015).

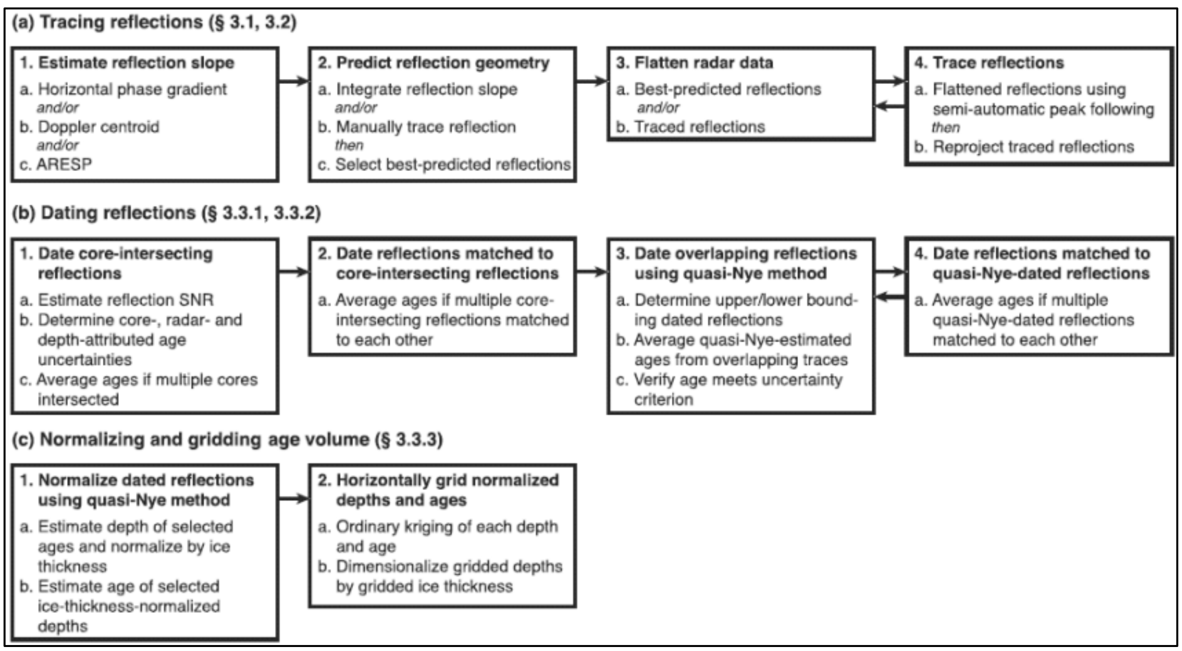

Figure 1. Key Steps and Order of Operations for (a) Tracing, (b) Dating, and (c) Normalizing the Radiostratigraphy (MacGregor et al., 2015).

4.3.1 Trajectory and Attitude Data

Transect locations are given in both geographic and projected coordinates, along with elevations as given. Corrected elevations are also provided, so the surface elevation inferred from the ice–air reflection and the aircraft is consistent with the *MEaSUREs Greenland Ice Mapping Project (GIMP) Digital Elevation Model* data set.

4.3.2 Processing Steps

The radar data were typically SAR focused. Data were traced at the highest available processing level.

4.3.3 Error Sources

The primary potential error sources include errors in tracing and dating the radiostratigraphy contained within these data sets. Errors in tracing, for example an incorrectly traced reflection or an incorrectly matched pair of discontinuous reflections, produce structural uncertainty in subsequent analyses including dating and gridding that cannot easily be quantified. Such errors will be resolved as they are identified and addressed in later revisions of these data products. Uncertainty in dating is quantified following MacGregor et al. (2015), both for individual reflections and the gridded products, and it represents the best estimate of the error in this aspect of the data set. It is a function of the age uncertainty reported for the ice–core depth–age scales and the degree of interpolation and extrapolation necessary to reach any given point in the ice sheet.

4.4 Sensor or Instrument Description

The radar systems used were designed to sound the entire ice thickness and to detect internal reflections close to the bed. See CReSIS rds_readme.pdf for further instrument details.

4.4.1 ICORDS: Improved Coherent Radar Depth Sounder, 1993 to 2002

ICORDS: Bandwidth: 141.5-158.5 MHz, Tx power: 200 W, Pulse duration: 1.6 us, Waveform: Analog chirp generation (SAW), Acquisition: Single channel 8 bit ADC, 18.75 MHZ IQ sampling (coherent averaging, but incoherent recording only), Dynamic Range: Sensitivity timing control, Rx aperture: 2 wavelengths (4 dipoles), Tx aperture: 2 wavelengths (4 dipoles), Bistatic Rx/Tx, Data rate: ~0.05 MB/sec.

ICORDS2: Bandwidth: 141.5-158.5 MHz, Tx power: 200 W, Pulse duration: 1.6 us, Waveform: Analog chirp generation (SAW), Acquisition: Single channel 12 bit ADC, 18.75 MHz IQ sampling, Dynamic Range: Sensitivity timing control, Rx aperture: 2 wavelengths (4 dipoles), Tx aperture: 2 wavelengths (4 dipoles), Bistatic Rx/Tx, Data rate: ~0.5 MB/sec.

4.4.2 ACORDS: Advanced Coherent Radar Depth Sounder, 2003 to 2005

Bandwidth: 140-160 MHz, Tx power: 200 W, Waveform: Single channel chirp generation, Acquisition: Single channel, Dynamic Range: low and high gain channels, Rx aperture: 2 wavelengths (4 dipoles), Tx aperture: 2 wavelengths (4 dipoles), Bistatic Rx/Tx, Data rate: 20 MB/sec.

4.4.3 MCRDS: Multi-Channel Radar Depth Sounder, 2006 to 2009

MCRDS: Bandwidth: 140-160 MHz, Tx power: 800 W, Waveform: Single channel chirp generation, Acquisition: Eight channels, 12 bit ADC at 125 MHz bandpass sampling, Dynamic Range: waveform playlist, Rx Aperture: 3 wavelength aperture (6 dipoles), Tx Aperture: 3 wavelength aperture; but configurable for ping-pong operation (6 dipoles), Bistatic Rx/Tx, Data rate: 30 MB/sec total.

MCRDS on P3: Bandwidth Selection: 140-160 MHz or 435-465 MHz, Rx Aperture: 2 wavelength aperture (4 dipoles), Tx Aperture: 2 wavelength aperture (4 dipoles).

4.4.4 Multichannel Coherent Radar Depth Sounder (MCoRDS), 2010 to 2013

Bandwidth: 180-210 MHz (DC-8 platform restricted to 189.15-198.65 MHz), Tx power: 550 W, Waveform: Eight channel chirp generation, Acquisition: Eight channels, 14 bit ADC at 111 MHz bandpass sampling, 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.

MCoRDS on DHC-6 Twin Otter (v1), Bandwidth: 140-160 MHz, Tx power: 500 W, Rx Aperture: 3 wavelength aperture, Tx Aperture: 3 wavelength aperture; fully programmable, Bistatic Rx/Tx.

MCoRDS on P3-B Orion: Bandwidth: 180-210 MHz (EMI restricted to 10 MHz within 180-210 MHz most segments), Tx power: 600 W, 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.

MCoRDS on Douglas DC-8: Dynamic Range: waveform playlist coupled with low gain and high gain channels.

MCoRDS on DHC-6 Twin Otter (v2): Tx power: 500 W, Acquisition: Sixteen channels (multiplexed on to 8 channels), 14 bit ADC at 111 MHz bandpass sampling, Rx Aperture: Two 3 wavelength apertures with 13.8 m baseline.

5 REFERENCES AND RELATED PUBLICATIONS

MacGregor, J. A., Fahnestock, M. A., Catania, G. A., Paden, J. D., Prasad Gogineni, S., Young, S. K., Rybarski, S. C., Mabrey, A. N., Wagman, B. M., & Morlighem, M. (2015). Radiostratigraphy and age structure of the Greenland Ice Sheet. Journal of Geophysical Research: Earth Surface, 120(2), 212–241. https://doi.org/10.1002/2014jf003215

Gogineni, S., Chuah, T., Allen, C., Jezek, K., & Moore, R. K. (1998). An improved coherent radar depth sounder. Journal of Glaciology, 44(148), 659–669. https://doi.org/10.3189/s0022143000002161

5.1 Related Data Collections

MEaSUREs Greenland Ice Mapping Project (GIMP) Digital Elevation Model
IceBridge BedMachine Greenland (Morlighem et al., 2015)

5.2 Related Websites

IceBridge product web page at NSIDC
IceBridge web page at NASA
NASA Greenland Ice Sheet stratigraphy video
University of Texas Institute for Geophysics website

6 CONTACTS AND ACKNOWLEDGMENTS

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7 DOCUMENT INFORMATION

7.1 Publication Date

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7.2 Date Last Updated

02 November 2020