Radiostratigraphy and Age Structure of the Greenland Ice Sheet, Version 2

USER GUIDE

How to Cite These Data

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

MacGregor, J. A., Fahnestock, M. A., Paden, J. D., Li, J., Harbeck, J. P., & Aschwanden, A. (2025). *Radiostratigraphy and Age Structure of the Greenland Ice Sheet* (RRRAG4, Version 2) [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/SZSVA3CWV3U4 [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 DATA DESCRIPTION

1.1 Summary

This data set presents the gridded radiostratigraphy of the Greenland Ice Sheet using very high frequency (VHF) radar sounding data collected by The Center for Remote Sensing and Integrated Systems (CReSIS) at The University of Kansas.

1.2 File Information

1.2.1 Format

The data are provided as a single NetCDF-4 (.nc) file.

1.2.2 File Contents

The data file contains the parameters listed in Table 1.

Table 1. Data Parameters

Parameter	Description	Units
age_norm	Age at thickness-normalized depth	ka
age_iso	Isochrone age	ka
age_std	Total uncertainty in age at thickness-normalized depth	ka
depth_iso	Isochrone depth below ice surface	m
depth_norm	Thickness-normalized depth	%
depth_std	Total uncertainty in isochrone depth below ice surface	m
mapping	Grid mapping details	N/A
x	Projected Cartesian x-coordinate	m
y	Projected Cartesian y-coordinate	m

1.2.3 File Naming Convention

The file naming convention is described below and in Table 2:

```
RRRAG4_LLLLL_YYYY_yyyy_XX_NNNN.nc
```

File name:

```
RRRAG4_Greenland_1993_2019_02_age_grid.nc
```

Table 2. File Naming Convention

Variable	Description
RRRAG4	Radiostratigraphy and Age Structure of the Greenland Ice Sheet data product
LLLLL	Location, e.g., Greenland
YYYY_yyyy	Span of years represented in the data set, e.g., 1993 to 2019
XX	Version number
NNNN	Data file contents, e.g., grid

1.3 Spatial Information

1.3.1 Spatial Coverage

Spatial coverage for this data set is Greenland:

Southernmost Latitude 58.9° N

Northernmost Latitude: 83.9° N

Westernmost Longitude: 73.5° W

Easternmost Longitude: 10.7° W

1.3.2 Spatial Resolution

The horizontal resolution is 5 km. The nominal vertical resolution is 2.5 to 4.4 m.

1.3.3 Geolocation

The data are projected using NSIDC Sea Ice Polar Stereographic North (EPSG: 3413).

1.4 Temporal Information

1.4.1 Temporal Coverage

24 June 1993 to 16 May 2019

1.4.2 Temporal Resolution

Not applicable. The single model result incorporates all of the input data over the temporal coverage.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Ice sheet models are essential for projecting ice mass loss and resulting sea level changes. The isochronal radiostratigraphy of the Greenland Ice Sheet is valuable for modeling studies, providing a history of the ice sheet's response to climate change as well as present-day subsurface dynamics. The RRRAG4 data set can be used to validate ice sheet models in terms of their overall climate sensitivity and parameterizations.

2.2 Acquisition

Between 1993 and 2019, 26 airborne campaigns surveyed the thickness and radiostratigraphy of the Greenland Ice Sheet using successive generations of coherent VHF radar sounders developed and operated by The University of Kansas (Table 3). Most of the ice sheet's internal VHF radiostratigraphy is composed of isochronal reflections. Version 1 of this data product was based on the first 20 campaigns, while Version 2 is based on all 26 campaigns and includes improvements in quality and survey coverage (MacGregor et al., 2025).

Table 3. Radar Sounding Surveys of the Greenland Ice Sheet. Adapted from MacGregor et al. (2025).

Year(s)	Aircraft	Radar Sounder
1993, 1995, 1996, 1997	P-3B	ICORDS
1998, 1999, 2001, 2002	P-3B	ICORDS v2
2003	P-3B	ACORDS
2005	DHC-6	ACORDS
2006	DHC-6	MCRDS
2007	P-3B	MCRDS
2008, 2009	DHC-6	MCRDS
2010	DC-8	MCoRDS
2010	P-3B	MCoRDS
2011	P-3B	MCoRDS v2
2011	DHC-6	MCRDS
2012	P-3B	MCoRDS v2
2013, 2014	P-3B	MCoRDS v3
2015	C-130H	MCoRDS v5
2016	WP-3D	MCoRDS v5
2017, 2018, 2019	P-3B	MCoRDS v3

2.3 Processing

Individual survey flights are composed of one or more flight segments, and each segment was further divided into a sequence of ~50-km-long data frames. The two-way travel times of both the air–ice and ice–bed reflections were traced and recorded by semi-automated algorithms and quality-controlled at CReSIS.

To avoid tracing repeat tracks, the method includes collating a “reduced set” using campaign priority ratings, manually inspecting a map of all flight tracks, and identifying all contiguous sets of frames required for a complete radiostratigraphy of the ice sheet. The next step was to concatenate contiguous sets of frames as needed for the reduced set, resulting in 536 sets of concatenated radar data frames that vary between 12 and 3774 km long.

The radar data were “flattened” with respect to predicted or previously traced reflections, and thickness-normalized reprojection was introduced to accelerate tracing. Thickness normalization of radargrams provides a quick assessment of whether internal reflections drape over or override subglacial topography. The two main steps were as follows:

- Smooth the surface and bed travel times using a 3-km-long locally weighted filter in the along-track direction
- Vertically interpolate the returned power onto a single monotonic normalized depth vector that has the same number of samples as the original radargram

This reprojection is relatively simple, parallelizable, and reduces the need to adjust the vertical axis when tracing. Here, traced reflections were primarily distinct, relatively isolated reflections in the upper ~80% of the ice column that were not diffuse or part of a disrupted basal unit. Importantly, for Version 2, a quality control check for stratigraphic conformability was added ensuring that the sign of the depth difference between any pair of reflections was the same and non-zero throughout the radargram.

After tracing, all reflections were vertically readjusted to match the local maximum in returned power. Intersections between traced segments were automatically identified, and a set of reflection matches was generated using iterations of quality control. Then, the reflections were dated using multiple dated and synchronized ice cores. Finally, the depths of the along-track isochrones were gridded using ordinary kriging. A 5 km grid was selected to focus on the large-scale age structure of the ice sheet. A 2D Gaussian filter was applied to reduce noise and fill in small gaps, and any portions of the grid that would result in unconformities relative to adjacent grids were removed. For further details, see MacGregor et al. (2025).

2.4 Quality, Errors, and Limitations

While it is relatively easy to trace many reflections in any one of the VHF radargrams that cross the northern Greenland Ice Sheet, it is much more difficult to trace discontinuous reflections within ∼300 km of the ice margin (and even more so within ∼100 km). The methods used here for mapping radiostratigraphy have some limitations. First, a series of static data sets were developed in sequence such that if a tracing error is identified, then any matches between that reflection and others must be manually re-verified and dating/gridding applied again. A second limitation is the challenge of using dynamic intersecting segments for 2D gridding. Third, although machine learning is useful when working with large data volumes, it also requires large training data sets and presents issues with discontinuous data. The addition of radar sounding data from other sources could help fill in coverage gaps, assuming that the various frequencies and bandwidths of the sensors could be accounted for.

Note that uncertainties for ice ages and isochrone depths are provided as data parameters.

3 VERSION HISTORY

Table 4. Version History Summary

Version	Date	Description of Changes
1.0 retire	8 Dec 2025	Removed data access for v1.0. Temporal coverage was 23 Jun 1993 to 26 Apr 2013.
2.0	6 Nov 2025	• Added data from six airborne campaigns (2014–2019) • Improved quality control and accelerated reflection tracing and matching by including an automatic test for stratigraphic conformability, a thickness-normalized reprojection for radargrams, and automatic inter-segment reflection matching • Reviewed and augmented the 1993–2013 radiostratigraphy and applied an existing independently developed method for predicting radiostratigraphy to the previously untraced campaigns (2014–2019) to accelerate their semi-automatic tracing
1.0	11 Aug 2015	Initial release

4 REFERENCES

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

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

MacGregor, J. A., Fahnestock, M. A., Paden, J. D., Li, J., Harbeck, J. P., & Aschwanden, A. (2025). A revised and expanded deep radiostratigraphy of the Greenland Ice Sheet from airborne radar sounding surveys between 1993 and 2019. *Earth System Science Data*, 17, 2911–2931. https://doi.org/10.5194/essd-17-2911-2025

5 DOCUMENT INFORMATION

5.1 Publication Date

November 2025

5.2 Date Last Updated

December 2025