IceBridge ATM Waveform Derived Snow Effective Grain Radius, Version 1

USER GUIDE

How to Cite These Data

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

Smith, B., T. Sutterley, and M. Studinger. 2024. *IceBridge ATM Waveform Derived Snow Effective Grain Radius, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/1207YUVC7KOO [Date Accessed].

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

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

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

This data set reports surface grain size estimates of snow and ice using waveform measurements from NASA's Airborne Topographic Mapper (ATM) narrow-swath and wide-swath instrumentation over the Greenland ice sheet and surrounding sea ice. The data are generated based on a waveform-fitting algorithm that matches measured waveforms with simulated waveforms (Smith et al., 2023). The data set also includes geolocation parameters directly from the ATM files.

1.2 File Information

1.2.1 Format

The data are provided as NetCDF-4 formatted files (`.nc`).

1.2.2 File Contents

Each file contains a collection of point measurements of nominal grain sizes. The file parameters are described in the following table.

Table 1. File Parameters

Variable	Description	Units
`A`	Scaling applied to the model waveform to match the measured waveform	N/A
`delta_t`	Time shift required to align the best-fit model waveform with the measured waveform	nanoseconds
`elevation`	WGS84 footprint elevation, calculated in ATM processing	meters
`L_scat`	Effective distance in air traveled between isotropic scattering events for the best-fitting waveform	meters
`latitude`	Geodetic latitude of the footprint, calculated in ATM processing	degrees north
`longitude`	Geodetic longitude of the footprint, calculated by ATM processing	degrees east
`noise_RMS`	Estimated noise in the waveform as measured before the start of the signal	counts
`r_eff`	Effective grain radius for the best-fitting model waveform	meters
`RMS_misfit`	Root-mean-squared misfit between the measured waveform and the best-fitting model	counts

Variable	Description	Units
`shot_count`	Shot count from the start of the input ATM waveform file, starting from zero	counts
`sigma`	Gaussian broadening applied to the model waveform to match the measured waveform	nanoseconds
`t_origin`	Time of the first sample in the measured waveform relative to the transmit time of the shot	nanoseconds
`time`	Time since the start of the calendar day for each shot; the origin for this coordinate is defined in the 'units' attribute of the variable	seconds since 2017.07.17 00:00:00

1.2.3 Naming Convention

Files are named according to the following convention, which is described in Table 2:

`ILATMGR_CCCCCCCC_YYYYMMDD_hhmmss.atmNXTn.nc`

Table 2. File Naming Convention

Variable	Description
`ILATMGR`	IceBridge ATM Waveform Derived Snow Effective Grain Radius data product
`CCCCCCCC`	ATM waveform data set from which the individual file was derived; i.e., either `ILNSAW1B` for wide-swath data or `ILATMW1B` for narrow-swath data
`YYYYMMDD`	Year, month, and day of data acquisition
`hhmmss`	Hour, minute, and second of the start of data acquisition
`atmNX`	ATM instrument identification
`Tn`	ATM transceiver identification
`.nc`	netCDF file extension

Examples:

`ILATMGR_ILNSAW1B_20190423_154300.atm6DT7.nc`

`ILATMGR_ILATMW1B_20170717_144930.atm6AT5.nc`

1.3 Spatial Information

1.3.1 Coverage

The data span the Arctic, with the majority of data over the Greenland ice sheet:

Northernmost Latitude: 90° N

Southernmost Latitude: 60° N

Easternmost Longitude: 180° E

Westernmost Longitude: 180° W

Note that the spatial coverage of the data changes seasonally, as shown in Figure 1.

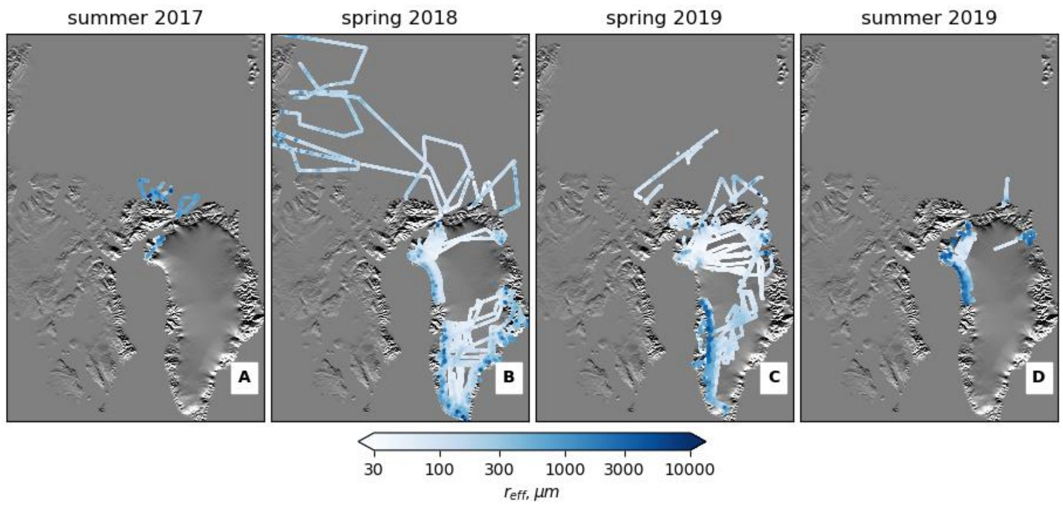

Figure 1. Season-by-season spatial coverage of the data.

1.3.2 Resolution

Grain-size estimates are reported for every fourth waveform measured by the narrow-swath system and for every second waveform from the wide-swath system. This produces point-to-point measurement distances (measured along each scan) of approximately 1 m for the narrow-swath data and 2.8 m for the wide-swath data.

1.3.3 Geolocation

The geolocation for this data set, shown in the table below, is based on the underlying ATM data.

Table 3. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	N/A
Longitude of true origin	Prime Meridian, Greenwich
Latitude of true origin	N/A
Scale factor at longitude of true origin	N/A
Datum	WGS 84
Ellipsoid/spheroid	WGS 84
Units	degree
False easting	N/A
False northing	N/A
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

1.4 Temporal Information

1.4.1 Coverage

17 July 2017 to 11 September 2019

1.4.2 Resolution

1 ms

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Laser altimeters measure distance to a target based on the time-of-flight of a laser pulse from the transmitter to the surface and back again. The shape of the return pulse helps characterize how light is scattered within snow and ice. This data set provides direct measurements of snow grain size with meter-scale spatial resolution. This is one of the only data sets that directly measures the effect of light scattering within ice on altimetry waveforms, and it has the potential to be used in calculating corrections to ICESat-2 altimetry data.

2.2 Acquisition

The snow grain sizes of this data set are derived from two Level-1B data sets: *IceBridge ATM L1B Elevation and Return Strength with Waveforms* and *IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms*.

2.3 Processing

Each ATM waveform record provides the timing and digitizer counts for the reflection of a single laser pulse from the ice sheet surface. The waveform records are converted to grain-size estimates by searching a library of candidate model waveforms for the waveform most similar to each measured waveform (Smith et al., 2023).

The candidate model waveforms are based on (1) an estimate of the ATM impulse-response function and (2) a scattering model of returns expected from a flat snow surface for a range of grain sizes from 20 µm to 3000 µm. For each grain size, the model waveform is shifted in time and a Gaussian smoothing parameter is adjusted to find the best matching measured waveform. For each waveform, the data set reports the grain size, time offset, and smoothing parameter for the model waveform that matches the measured waveform according to least squares. The `L_scat` variable allows users with the surface density for specific sites to calculate their own estimates of grain size (see Equations 1 and 2 in Smith et al., 2023).

2.4 Quality, Errors, and Limitations

The broadening of lidar returns depends on both the grain size and the density of the scattering medium. Because the spatial variation of the ice sheet surface density was unknown, a constant surface density of 400 kg m^{-3} was assumed for the scattering model and used to calculate the density of snow grains as well as the time required for light to interact with each snow grain. This density is nominal — firn and ice in many parts of Greenland often have different grain sizes. The uncertainty in density is expected to contribute approximately a factor of two to uncertainties in grain size.

Over rough ice sheet surfaces, or when the incidence angle between the laser and the surface is large, the surface return is smoothed and some of the details for estimating scattering are lost. This situation contributes to uncertainty in the grain size, especially at small grain sizes (i.e., smaller than 30–40 µm for spreading parameters larger than ~1 ns).

When grain sizes are small, the fitting procedure may not be able to distinguish between a non-scattering waveform and a small-grain-size model. The fitting procedure may report a grain size of zero, especially in areas where the grain size is small. These waveforms should be treated as non-significantly different from a small grain size of 20–30 µm.

2.5 Instrumentation

2.5.1 Description

The data are derived from ATM narrow-swath and wide-swath scanners utilized onboard NASA aircraft for Operation IceBridge. The ATM instrument package includes suites of lidar, GPS, and attitude measurement subsystems. The ATM T7 transceiver contains a Northrop-Grumman Fiber Laser that generates laser pulses of roughly 1.3 ns duration at a 10 kHz pulse repetition frequency. The pulses contain co-aligned near-infrared (1064 nm) and green (532 nm) wavelengths. The laser light is directed to a scanner mirror and downward from the aircraft. Light that is backscattered upward is directed by the mirror to a telescope and then separated into two paths toward separate photodetectors. Each photodetector is connected to separate but similar data systems, each containing a waveform digitizer. The captured waveforms are tagged with a precise time, which can be used to pair the waveforms received from a specific laser pulse from the same ground location.

3 VERSION HISTORY

Table 4. Version History Summary

Version	Release Date	Description of Changes
1	April 2024	Initial release

4 RELATED DATA SETS

IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms (ILNSAW1B)
IceBridge ATM L1B Elevation and Return Strength with Waveforms (ILATMW1B)
IceBridge ATM L1B Near-Infrared Waveforms (ILNIRW1B)

5 RELATED WEBSITES

ATM instrumentation webpage at NASA Airborne Science Program

6 ACKNOWLEDGMENTS

The authors would like to thank the ICESat-2 project, and the brave scientists and aviators who collected the original ATM data.

7 REFERENCES

Smith, B., Studinger, M., Sutterley, T., Fair, Z., & Neumann, T. (2023). Understanding biases in ICESat-2 data due to subsurface scattering using Airborne Topographic Mapper waveform data. *Cryosphere Discussions*, 1–29, https://doi.org/10.5194/tc-2023-147

8 DOCUMENT INFORMATION

8.1 Publication Date

April 2024

8.2 Date Last Updated

April 2024