IceBridge Narrow Swath ATM L1B Elevation and Return Strength, Version 2

USER GUIDE

How to Cite These Data

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

Studinger, M. (2014, updated 2020). *IceBridge Narrow Swath ATM L1B Elevation and Return Strength* (ILNSA1B, Version 2). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/CXEQS8KVIXEI [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ILNSA1B

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Summary

This data set contains spot elevation measurements of Greenland, Arctic, and Antarctic sea ice acquired using the NASA Airborne Topographic Mapper (ATM) 4CT3 narrow scan instrumentation. The data were collected as part of Operation IceBridge funded aircraft survey campaigns.

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.

1.2 File Information

1.2.1 Format

The fundamental form of the ATM topography data is a sequence of laser footprint locations acquired in a swath along the aircraft flight track. The narrow swath ATM data are sea ice elevation measurements only, and do not include land ice. The data are stored as HDF5-formatted files.

Note: For sub-sampled ATM data, see the IceBridge ATM L2 Icessn Elevation, Slope, and Roughness data set.

1.2.2 Naming Convention

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

```
ILNSA1B_YYYYMMDD_HHMMSS.ATM4CT3.h5
ILNSA1B_20130320_135710.ATM4CT3.h5
```

Table 1. File Naming Convention

Variable	Description
ILNSA1B	Short name for IceBridge Narrow Swath ATM L1B Qfit Elevation and Return Strength
YYYY	Four-digit year of survey
MM	Two-digit month of survey
DD	Two-digit day of survey
HH	Two-digit hours, beginning of file time
MM	Two-digit minutes, beginning of file time

SS	Two-digit seconds, beginning of file time
ATM4C	Airborne Topographic Mapper instrument identification
T3	ATM transceiver designation

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage for the narrow swath ATM campaign includes Arctic, Greenland, and Antarctic sea ice.

Arctic and Greenland Sea Ice:
Southernmost Latitude 59° N
Northernmost Latitude: 90° N
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

Antarctic:
Southernmost Latitude: 90° S
Northernmost Latitude: 63° S
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

1.3.2 Spatial Resolution

The ATM surface elevation measurements have been acquired from a conically scanning LIDAR system. Coupled with the motion of the aircraft in flight, the resulting array of laser spot measurements is a tight spiral of elevation points. The surface elevation measurements generally consist of a pattern of overlapping roughly elliptical patterns on the surveyed surface, forming a swath of measurements along the path of the aircraft.

The angular swath width of the ATM narrow scan instrument is approximately 2.7 degrees off-nadir (5.4 degrees full angle). At a nominal altitude above ground of 450 m, that scan angle will yield a swath on the ground roughly 45 m wide.

Resolution varies with altitude flown, aircraft groundspeed, and scanner configuration for the LIDAR. For the narrow swath data, at a typical altitude of 450 m above ground level, an aircraft groundspeed of 250 knots, a laser pulse rate of 3 kHz, and a scan width of 2.7 degrees off-nadir, the average point density is one laser shot per 2 m2 within the swath. However, the sampling of laser shots in the laser swath is not evenly distributed.

1.3.3 Projection and Grid Description

Data are given in geographic latitude and longitude coordinates. Data coordinates are referenced to the WGS84 ellipsoid. Reference frame is prescribed by the International Terrestrial Reference Frame (ITRF) convention in use at the time of the surveys.

1.4 Temporal Coverage

These data were collected as part of Operation IceBridge funded campaigns beginning 16 March 2011 to 8 November 2012.

1.4.1 Temporal Resolution

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

1.5 Parameter or Variable

This data set includes sea ice elevation measurements and relative transmitted and return reflectance.

The ATM times are rounded to 0.001 seconds. The ATM instrument operates at a sampling rate of 3 kHz. When rounding to 0.001 seconds, three points will appear with the same time stamp.

1.5.1 HDF5 File Parameter Description

Parameters contained in the ATM data files are described in Table 2.

Table 2. Parameter Description, Units with Scale Factor, and Range

Parameter	Description	Units with Scale Factor	Range
`rel_time`	Relative time measured from start of file	Seconds 10^{-3}	Greater than 0
`latitude`	Laser spot latitude	Degrees 10^{-6}	-90.0 to 90.0
`longitude`	Laser spot east longitude	Degrees 10^{-6}	0.0 to 360.0
`elevation`	Elevation of the laser spot above ellipsoid	Meters 10^{-3}	any real value

Parameter	Description	Units with Scale Factor	Range
xmt_sigstr	Start pulse signal strength (relative)	Dimensionless relative values (or data numbers, DN)	positive integer value
rcv_sigstr	Received laser signal strength (relative)	Dimensionless relative values (or data numbers, DN)	positive integer value
azimuth	Scan azimuth	Degrees 10^{-3}	0.0 to 360.0
pitch	Pitch	Degrees 10^{-3}	-90.0 to +90.0
roll	Roll	Degrees 10^{-3}	-90.0 to +90.0
gps_pdop	GPS Dilution of Precision (PDOP) times 10	Dimensionless	Greater than 0
pulse_width	Laser received pulse width at half height, number of digitizer samples at 0.5 nanosecond per sample.	Count	Greater than 0
time_hhmmss	GPS time packed; example: 153320100 = 15 hours 33 minutes 20 seconds 100 milliseconds.	Seconds of the day in GPS time. As of 01 January 2009 GPS time = UTC + 15 seconds.	000000000 to 235959999

2 DATA ACQUISITION AND PROCESSING

2.1 Background

A laser altimeter measures range from the instrument to a target by measuring the elapsed time between emission of a laser pulse and detection of laser energy reflected by the target surface. Range to the target is calculated as half the elapsed emission/return time multiplied by the speed of light. Target range is converted to geographic position by integration with platform GPS and attitude or Inertial Measurement Unit (IMU) information.

2.2 Data Acquisition Methods

The ATM instrument package includes suites of LIDAR, GPS and attitude measurement subsystems. The instrument package is installed onboard the aircraft platform and calibrated during ground testing procedures. Installation mounting offsets, the distances between GPS and attitude sensors and the ATM LIDARs, are measured using surveying equipment. One or more ground survey targets, usually aircraft parking ramps, are selected and surveyed on the ground using differential GPS techniques. Prior to missions, one or more GPS ground stations are established by acquiring low rate GPS data over long time spans. Approximately one hour prior to missions both the GPS ground station and aircraft systems begin data acquisition. During the aircraft flight, the ATM instrument suite acquires LIDAR, GPS and attitude sensor data over selected targets, including several passes at differing altitudes over the selected ground survey calibration sites. The aircraft and ground systems continue to acquire data one hour post-mission. Instrument parameters estimated from the surveys of calibration sites are used for post-flight calculation of laser footprint locations. These parameters are later refined using inter-comparison and analysis of ATM data where flight lines cross or overlap.

2.3 Derivation Techniques and Algorithms

Each ATM surface elevation measurement corresponds to one laser pulse. The measurements have not been re-sampled. The transmitted laser pulse and the received backscatter pulse from the ground surface are photodetected and captured by a waveform digitizer. Post-flight processing of the waveforms yields the time of flight between transmitted and received signals. This time of flight value is converted to a distance compensated for speed of light through atmosphere. GPS data is processed post-flight to yield the position of the aircraft at 0.5 second intervals. The scan azimuth of the LIDAR scanner mirror together with the aircraft attitude determine the pointing angle of the LIDAR. Aircraft position, pointing angle of the LIDAR, and range measured by the LIDAR are used to compute position of laser footprint on the ground.

Note: The 23 October 2012 data (20121023) were collected at a higher aircraft altitude than the other survey dates, so it has a slightly different accuracy. The accuracy of the elevation measurements is on decimeter-level, instead of the centimeter-level.

2.3.1 Processing Steps

The following processing steps are performed by the data provider.

1. Preliminary processing of ATM LIDAR data through the cvalid program, applying calibration factors to convert time of flight to range, scan pointing angles, and interpolate attitude to each LIDAR measurement.
2. Processing of GPS data into aircraft trajectory files using double-differenced dual-frequency carrier phase-tracking.
3. Determination of all biases and offsets: heading, pitch, roll, ATM-GPS [x,y,z] offset, scanner angles, range bias.
4. Processing of the LIDAR and GPS data with all biases and offsets through the qfit program, resulting in output files containing a surface elevation (ellipsoid height) and a geographic location in latitude and east longitude, with ancillary parameters noted in Table 2.

2.3.2 Quality, Errors, and Limitations

Fall 2018 Campaign (updated May 2021)

The first release of the Operation IceBridge 2018 Antarctic ATM lidar data was delivered to NSIDC in Aug 2019. Subsequently a problem was identified related to the application of the solid Earth tide correction in the data-processing stage. The resulting errors in elevations varied in both space and time over wavelengths of hundreds of kilometers. The error was corrected, the data reprocessed, and the resulting change in position was computed. Over the entire campaign, the vertical change (reprocessing minus initial processing) varied between -10.3 cm and +14.4 cm. The mean change for each survey flight varied between -6.0 cm and +5.1 cm, with a root sum of squares (RSS) deviation from the mean of between 0.6 cm and 4.4 cm. The vertical change summary is presented in Figure 1. The mean is the large dot, the thick bar shows mean +/- the standard deviation, and the thin bar shows the full range from minimum to maximum. The horizontal change was less than 15 cm throughout the campaign.

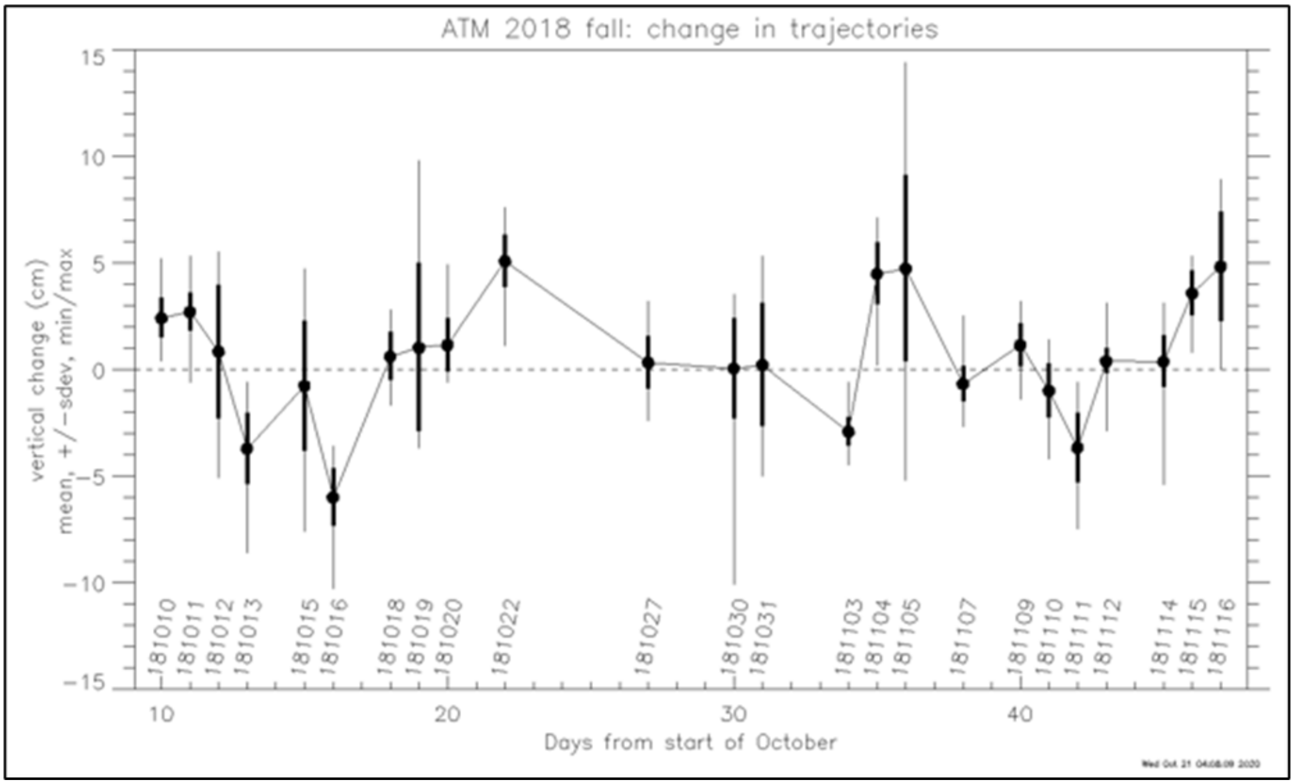

Figure 1. ATM 2018 Fall: Change in Trajectories After Solid Earth Tide Correction

Spring 2019 Campaign (updated May 2021)

The first release of the Operation IceBridge ATM lidar data was delivered to NSIDC in April 2020. At that time, a problem had been identified related to the application of the solid Earth tide correction in the data-processing stage. The resulting errors in elevations varied in both space and time over wavelengths of hundreds of kilometers. The error was subsequently corrected, the data reprocessed, and the resulting change in position was computed. Over the entire campaign, the vertical change (reprocessing minus initial processing) varied between -6.5 cm and +8.8 cm. The mean change for each survey flight varied between -1.8 cm and +2.8 cm, with a root sum of squares (RSS) deviation from the mean between 0.5 cm and 2.6 cm. The greatest magnitudes of vertical change tended to be at distances farthest from the staging airport (at Thule, April 3-23, 2019 or Kangerlussuaq, May 5-16, 2019). The results are presented in Figure 2. The horizontal change was less than 10 cm throughout the campaign.

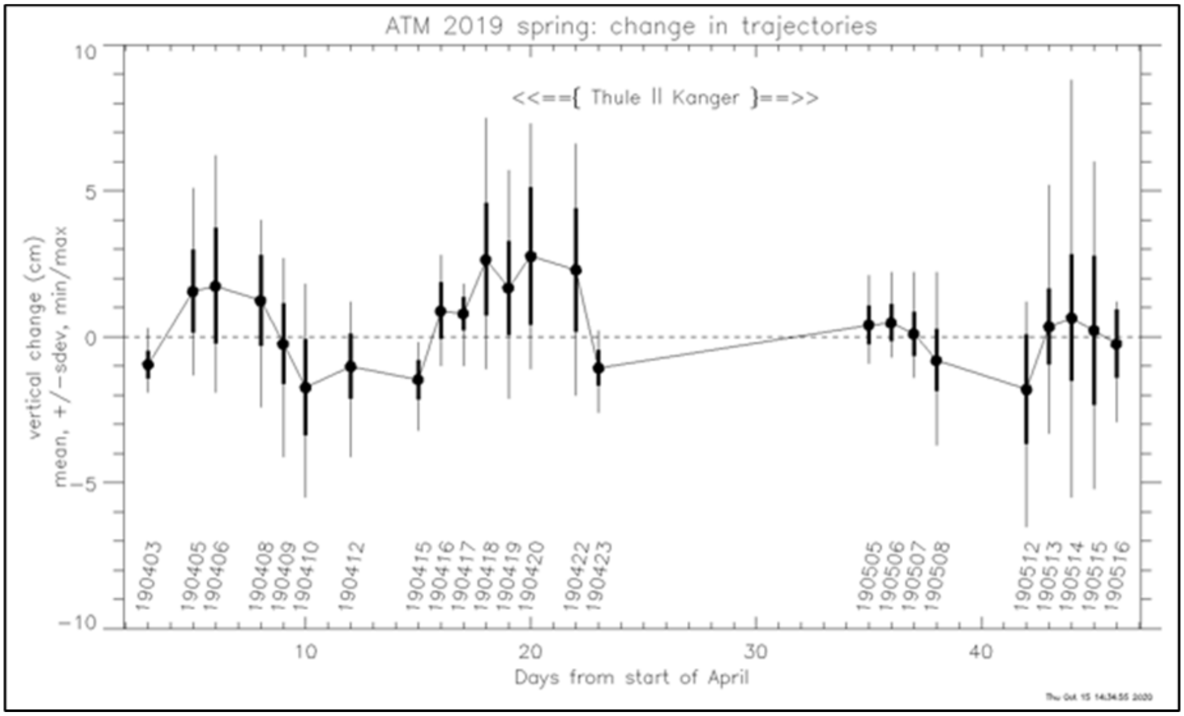

Figure 2. ATM 2019 Spring: Change in Trajectories After Solid Earth Tide Correction

Note: The information below has been retained for provenance. The issues have been addressed as described in the preceding sections.

Fall 2018 and Spring 2019 Campaigns (10/10/2018 to 05/16/2019):

As compared to most other Operation IceBridge ATM laser altimetry data sets, this particular data set has certain limitations in accuracy that result from a recently identified problem related to the application of the solid Earth tide correction in the data processing stage. This error can cause long-wavelength errors in elevations that are less than decimeter in magnitude and which vary in both space and time. The error wavelength is typically hundreds of kilometers, so it should not significantly affect most analyses of this data set, but it can be smaller because it depends on the number and position of base stations used for the trajectory solution and on other factors including moon phase. The error only affects the 2018 DC-8 Antarctic and 2019 P-3 Arctic Spring ATM data sets published at NSIDC DAAC. Resolution of this error is in progress, and a future version of this data set will eliminate it. The user should consider the elevation issue in any scientific interpretation or other use of the data set. Users are requested to report their findings about data quality to NSIDC User Services, to be forwarded to the ATM team, for information and comment before publication or reporting elsewhere.

2.4 Sensor or Instrument Description

The ATM is an airborne LIDAR instrument used by NASA for observing the Earth's topography for several scientific applications, foremost of which is the measurement of changing Arctic and Antarctic icecaps and glaciers. The ATM instrument is a scanning airborne laser that measures surface elevation of the ice by timing laser pulses transmitted from the aircraft, reflected from the ground and returning to the aircraft. This laser pulse time-of-flight information is used to derive surface elevation measurements by combining measurement of the scan pointing angle, precise GPS trajectories and aircraft attitude information. The ATM measures topography as a sequence of points conically scanned in a swath along the aircraft flight track at rates up to 5000 measurements per second. The sampling frequency for the data is 3 kHz.

The ATM instruments are developed and maintained at NASA's WFF in Virginia, USA. During Operation IceBridge, the ATM has been installed aboard the NASA P-3 aircraft based at WFF, or the NASA DC-8 aircraft based at Dryden Air Force Base in Palmdale, California. During previous campaigns, the ATM has flown aboard other P-3 aircraft, several de Havilland Twin Otters (DHC-6), and a C-130. The ATM has been used for surveys flown in Greenland nearly every year since 1993. Other uses have included measurement of sea ice, verification of satellite radar and laser altimeters, and measurement of sea-surface elevation and ocean wave characteristics. The ATM often flies in conjunction with a variety of other instruments and has been participating in NASA's Operation IceBridge since 2009.

The ATM project has been acquiring lidar data over ice and snow regions since 1993. There have been many instrument upgrades over the years to ensure that the NASA ATM systems collect the most accurate lidar elevations possible. The ATM project normally installs and operates two lidars on the aircraft platform (P-3 or DC-8). From 2009 to 2010, data were provided to NSIDC only from the ATM 4B2T that collects wide scan lidar data. In 2011, a new ATM transceiver scanner assembly designated as ATM 4BT4 replaced the ATM 4BT2. The ATM 4BT2 and 4BT4 qfit data are in the IceBridge ATM L1B Qfit Elevation and Return Strength data set.

The second lidar system on the aircraft, designated ATM 4CT3, was operated in the past as a backup to the ATM 4BT2 lidar instrument, or was modified to test alternate lidar system improvements. In 2011, the 4CT3 instrument was modified by replacing the original scanner motor assembly, which contained a 22-degree off-nadir mirror, with a newer scanner motor assembly containing a 2.7-degree off-nadir mirror. ATM 4CT3 laser power was reduced and data were collected using the narrow swath scanner. Analysis of the 2011 ATM 4CT3 low altitude data combined with the wider swath ATM 4BT4 data captured at the same time, shows great promise in helping sea ice scientists measure sea surface elevations over open leads. The current ATM 4CT3 narrow swath data are provided for sea ice missions only. The instrument is not used for land ice missions.

Note: CAMBOT images and .cam files containing aircraft position and attitude corresponding to the ATM qfit data can be found in the IceBridge CAMBOT L1B Geolocated Images data set.

Table 3 provides information on ATM transceivers used during IceBridge missions and the resultant filename designations.

Table 3. ATM System Designations by IceBridge Campaign

Year	Campaign	Wide ATM System* (xx) = Full Scan Angle (degrees)	Narrow ATM System* (x) = Full Scan Angle (degrees)
2009	Greenland	4BT2 (30)	n/a
2009	Antarctica	4CT3 (44)	n/a
2010	Greenland (DC-8)	4CT3 (44)	n/a
2010	Greenland (P-3)	4BT2 (30)	n/a
2010	Antarctica	4BT2 (30)	n/a
2011	Greenland	4BT4 (30)	4CT3 (5)**
2011	Antarctica	4BT2 (30)	4CT3 (5)**
2012	Greenland	4BT4 (30)	4CT3 (5)**
2012	Antarctica	4BT4 (30)	4CT3 (5)**
2013	Greenland	4BT4 (30)	4CT3 (5)**

* The ATM system designation is noted in the filename for each data file.

** Data are provided for sea ice missions only.

3 VERSION HISTORY

- **Version 1:** The data for 2011 and 2012 are stored in qfit format in IceBridge Narrow Swath ATM L1B Elevation and Return Strength, Version 1.
- **Version 2:** Beginning with the 2013 Arctic campaign, all data are provided in HDF5 format.

4 REFERENCES

Kwok, R., G. F. Cunningham, S. S. Manizade, and W. B. Krabill. 2012. Arctic sea ice freeboard from IceBridge acquisitions in 2009: Estimates and comparisons with ICESat. Journal of Geophysical Research 117: C02018. https://doi.org10.1029/2011JC007654

5 RELATED DATA COLLECTIONS

- IceBridge ATM L1B Qfit Elevation and Return Strength
- IceBridge ATM L2 Icessn Elevation, Slope, and Roughness
- Pre-IceBridge ATM L2 Icessn Elevation, Slope, and Roughness
- IceBridge CAMBOT L1B Geolocated Images
- Antarctic 5-km Digital Elevation Model from ERS-1 Altimetry
- GLAS/ICESat 500 m Laser Altimetry Digital Elevation Model of Antarctica

6 ACKNOWLEDGMENTS

The ATM project team would like to acknowledge the dedicated NASA P3 and DC8 flight crews, whose efforts allowed the safe and efficient collection of this data over some of the most isolated and extreme regions on this planet.

7 DOCUMENT INFORMATION

7.1 Publication Date

January 2012

7.2 Date Last Updated

April 2025