IceBridge 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. 2013, updated 2020. *IceBridge ATM L1B Elevation and Return Strength, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/19SIM5TXKPGT. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ILATM1B

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

1.1 Format

The data are provided in HDF5 format (`.h5`). 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 root group in the HDF5 file contains individual parameters for the latitude, longitude, and elevation of the laser footprint. The root group also contains the two subgroups described in Table 2. Each data file is paired with an associated XML file (`.xml`), which contains additional metadata.

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

1.2 File Naming Convention

Example file names:

```
ILATM1B_20130320_141441.ATM4BT4.h5
ILATM1B_YYYYMMDD_141441.ATM4BT4.h5.xml
```

Files are named according to the following convention, which is described in Table 1:

```
ILATM1B_YYYYMMDD_hhmmss.ATMNXTn.xxx
```

Table 1. File Naming Convention

Variable	Description
ILATM1B	Data set ID
YYYYMMDD	Year, month, and day of survey
HHMMSS	Hours, minutes, and seconds (beginning of file time)
ATMNX	Airborne Topographic Mapper instrument identification; e.g., atm4c, ATM4B, or ATM5A
Tn	Identifier of transceiver used, affecting off-nadir scan angle: T2 = 15-degree T3 = 23-degree T4 = 30-degree
.xxx	Indicates file type: .h5 = HDF5 data file .h5.xml = XML metadata file

Note: The ATM data are organized in chronological order. Data from a single aircraft flight is broken into a sequence of files, each of which contains roughly one million laser measurements (about 5.5 minutes duration at 3 kHz laser pulse rate). The name of each file in the sequence contains the starting date and time for that file.

1.3 Spatial Coverage

Spatial coverage for the IceBridge ATM campaigns includes the Arctic, Greenland, Antarctica, and surrounding ocean areas. In effect, this represents the coverage 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

1.3.1 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. Resolution varies with the altitude flown and the scanner configuration for the lidar. At a typical altitude of 500 m above ground level, a laser pulse rate of 5 kHz, and a scan width of 22.5° off-nadir, the average point density is one laser shot per 10 m^2 within the swath.

1.3.2 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. For more on the reference frame, see the ITRF specification website.

1.4 Temporal Coverage

20 March 2013 to 20 November 2019

1.4.1 Temporal Resolution

IceBridge campaigns are conducted on an annually repeating basis. Arctic and Greenland campaigns are typically conducted during March, April, and May. Antarctic campaigns are typically conducted during October and November. Flights for the Alaska campaign were conducted from 13 to 21 July 2016.

1.5 Parameter or Variable

This data set includes glacier, ice sheet, and sea ice elevation measurements plus relative transmitted and return reflectance.

The ATM times are rounded to 0.001 seconds. The ATM instrument operates at a sampling rate of 3 or 5 kHz. When rounding to 0.001 seconds, three or five points will appear with the same time stamp.

1.5.1 Parameter Description

Laser spot elevations above the ellipsoid are stored at the root of the HDF5 file in "`elevation`." Laser spot latitudes and longitudes are stored in the "`latitude`" and "`longitude`" arrays. The root of the data file also contains the subgroups /`instrument_parameters`/ and /`ancillary_data`/. The contents of these subgroups are described in Table 2.

Table 2. HDF Group and Contents Description

Group	Parameter	Description	Units
/(root)	latitude	Laser spot latitude	Degrees
	longitude	Laser spot longitude	Degrees
	elevation	Laser spot elevation above ellipsoid	Meters
/instrument_parameters/	azimuth	Scanner azimuth angle	Degrees
	gps_pdop	GPS dilution of precision (PDOP)	Dimensionless
	pitch	Pitch angle	Degrees
	roll	Roll angle	Degrees

Group	Parameter	Description	Units
	rcv_sigstr	Received (reflected) signal strength	dimensionless relative values (or data numbers, DN)
	xmt_sigstr	Transmitted (start pulse) signal strength	dimensionless relative values (or data numbers, DN)
	pulse_width	Laser received pulse width at half height, number of digitizer samples at 0.5 nanosecond per sample	Count
	rel_time	Relative time measured from start of file	Seconds
	time_hhmmss	GPS time packed, example: 153320.100 = 15 hours 33 minutes 20 seconds 100 milliseconds.	Seconds
/ancillary_data/	reference_frame	ITRF designation of reference frame	Text name
	Min_latitude	Minimum value of latitude for this file	Degrees
	Min_longitude	Minimum value of longitude for this file	Degrees
	Max_latitude	Maximum value of latitude for this file	Degrees
	Max_longitude	Maximum value of longitude for this file	Degrees
	Header_text	Raw data (in human readable form) containing comments or processing history of the parameter data.	None
	Header_binary	Raw data (in binary form) containing comments or processing history of the parameter data.	None

1.5.2 Sample Data Record

Figure 1 shows the data file `ILATM1B_20130320_141441.ATM4BT4.h5` as seen in HDFView.

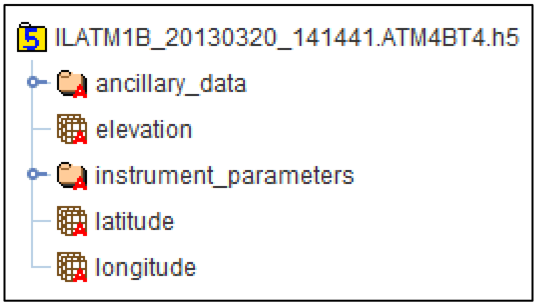

Figure 1. `Data File Contents (HDFView)`

2 SOFTWARE AND TOOLS

The data files can be opened by software that supports the HDF5 and/or netCDF format, such as HDFView and Panoply.

3 DATA ACQUISITION AND PROCESSING

3.1 Theory of Measurements

A laser altimeter measures the range from the instrument to a target by measuring the elapsed time between the emission of a laser pulse and the 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.

3.2 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 the 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 for 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.

3.3 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. The scan azimuth of the lidar scanner mirror together with the aircraft attitude determine the pointing angle of the lidar. GPS aircraft position, pointing angle of the lidar, and range measured by the lidar are used to compute position of laser footprint on the ground.

3.3.1 Trajectory and Attitude Data

Aircraft position is determined by Global Navigation Satellite System (GNSS) systems that incorporate NAVSTAR Global Positioning System (GPS) and, for later campaigns, the Globalnaya Navigatsionnaya Sputnikovaya Sistema (GLONASS). Carrier phase measurements are logged by an antenna and receiver on the aircraft. In post-flight processing, these measurements are combined with similar measurements from static ground stations to produce a kinematic differential solution of the aircraft trajecotry at 0.5 second intervals, and more recently at 0.1 second intervals.

Aircraft attitude is logged from a commercial Intertial Navigation System (INS), also known as an Inertial Measurement Unit (IMU).

3.3.2 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.

3.3.3 Version History

- **Version 1:** The data for 2009 through 2012 are stored in qfit format as ILATM1B Version 1.
- **Version 2:** Beginning with the 2013 Arctic campaign, all data are provided in HDF5 format.

3.3.4 Errors and Limitations

12 and 13 April 2010:

During collection of IceBridge ATM Greenland data on 12 and 13 April 2010, hydraulic oil progressively leaked from the forward landing gear on the DC8 aircraft. The oil was blown back along the bottom of the fuselage and across the nadir window through which the ATM was transmitting and receiving the laser signal. The ATM signal was attenuated, and data in part of the scan is missing as a result. The problem developed during the flight and worsened through time. The ATM still acquired more than half of the shots throughout the scan. The net effect of this problem is to decrease the number of shot returns logged, the same as if the laser power was reduced. To the user this will appear as a reduced point density on the ground. This issue will not affect the accuracy of the data. In the Antarctic 2010 campaign, fuel leakage degraded the signal in a similar fashion.

The flight on 28 April 2012 traversed the notoriously turbulent regions over Greenland's southeast glaciers. During the flight, two planned glaciers were skipped due to concern about expected severe turbulence. The survey data spans roughly 11:15 to 18:20 UTC. On the approach to Ikerssuaq glacier at 16:56:19.5 (GPST=60994.5 secs), both the ATM T3 and T4 instruments quit recording data within 0.1 second of each other. T3 resumed at 16:57:05.3, whereas T4 did not resume for the rest of that day's flight. After this event, the flight followed the Ikerssuaq flow line, then traversed directly west across the icesheet back to the Kangerlussuaq airport. The data gap spans 46 seconds, from the fjord up to about 500 m elevation on the Ikerssuaq glacier. The T4 data quit during the creation of the file `20120428_165532.ATM4BT4.F1.qi.` The T4 data are being supplemented by the these narrow swath files of T3 data from the latter part of the survey:

```
20120428_165449.atm4cT3.F1.qi
20120428_170030.atm4cT3.F1.qi
20120428_170524.atm4cT3.F1.qi
20120428_171019.atm4cT3.F1.qi
20120428_171514.atm4cT3.F1.qi
20120428_172008.atm4cT3.F1.qi
20120428_172503.atm4cT3.F1.qi
20120428_172957.atm4cT3.F1.qi
```

```
20120428_173452.atm4cT3.F1.qi
20120428_173947.atm4cT3.F1.qi
20120428_180815.atm4cT3.F1.qi
20120428_181219.atm4cT3.F1.qi
20120428_181619.atm4cT3.F1.qi
```

The above files can be found with the *IceBridge Narrow Swath ATM L1B Qfit Elevation and Return Strength* 2012 Greenland data. For details on the ATM 4BT3 and 4BT4 instruments, see the Sensor Or Instrument Description section, and the ILNSA1B data set documentation.

No data for 14 April 2015:

On 14 April 2015, the ATM wide-scan instrument suffered a failure in the scanning mechanism and did not collect data for that mission.

Fall 2015 Campaign:

For the Fall 2015 ATM data, some ATM elevations are adjusted slightly (~10 cm) to compensate for a systematic anomaly related to the ATM scanner azimuth. The overall mean elevation is not changed, but some elevations around the scan are adjusted upward or downward as a function of scanner azimuth. For further details on the adjustment method, see Yi et al. (2015).

Fall 2016 Campaign:

On 07 November 2016, the ATM wide-scan lidar (ATM6aT6) suffered a laser system failure and did not collect any usable ILATM1B data for that flight. However, the ATM narrow-scan lidar (ATM5bT5) operated normally. Generally, data from the narrow-scan instrument are only provided for sea ice flights, where the smaller off-nadir angle is beneficial for lead detection. In this case however, ILNSA1B data were made available for the flight on 07 November 2016 as a substitute for the missing ILATM1B data.

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 and contained 11 of the 24 campaign surveys (November 3, 2018 – November 16, 2018). 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 2. 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.

In addition, the T6 transceiver experienced a malfunction related to wear of the scanner mechanism. Errors were introduced into the knowledge of the scanner rotational position and thereby into the calculated horizontal and vertical location of the laser footprint. After October 19, 2018, the scanner was adjusted in the field and the scan speed reduced from 26 Hz to 20-21 Hz, thereby improving somewhat the instrument operation for October 20, 2018 and later. The errors comprised a systematic, reproducible component and a more random, variable component. The vertical part of the systematic component was estimated from suitable ground surfaces or crossings of two ATM tracks and removed to the extent possible. The variable component introduced perturbations at spatial scales varying from a portion of a full scan to across multiple scans. The mean elevation error averaged across roughly 1 s tends to zero because the impact varies both positive and negative in different parts of the scan.

The ATM T6 scanner mechanism was rebuilt after conclusion of the 2018 Antarctic campaign and operated well during the subsequent 2019 Arctic spring campaign. An improved method of measuring the scanner position was implemented for the 2019 Arctic summer campaign, further reducing geolocation errors related to the scanner mechanism.

The data set now includes all 24 surveys with the errors in solid earth tide corrected.

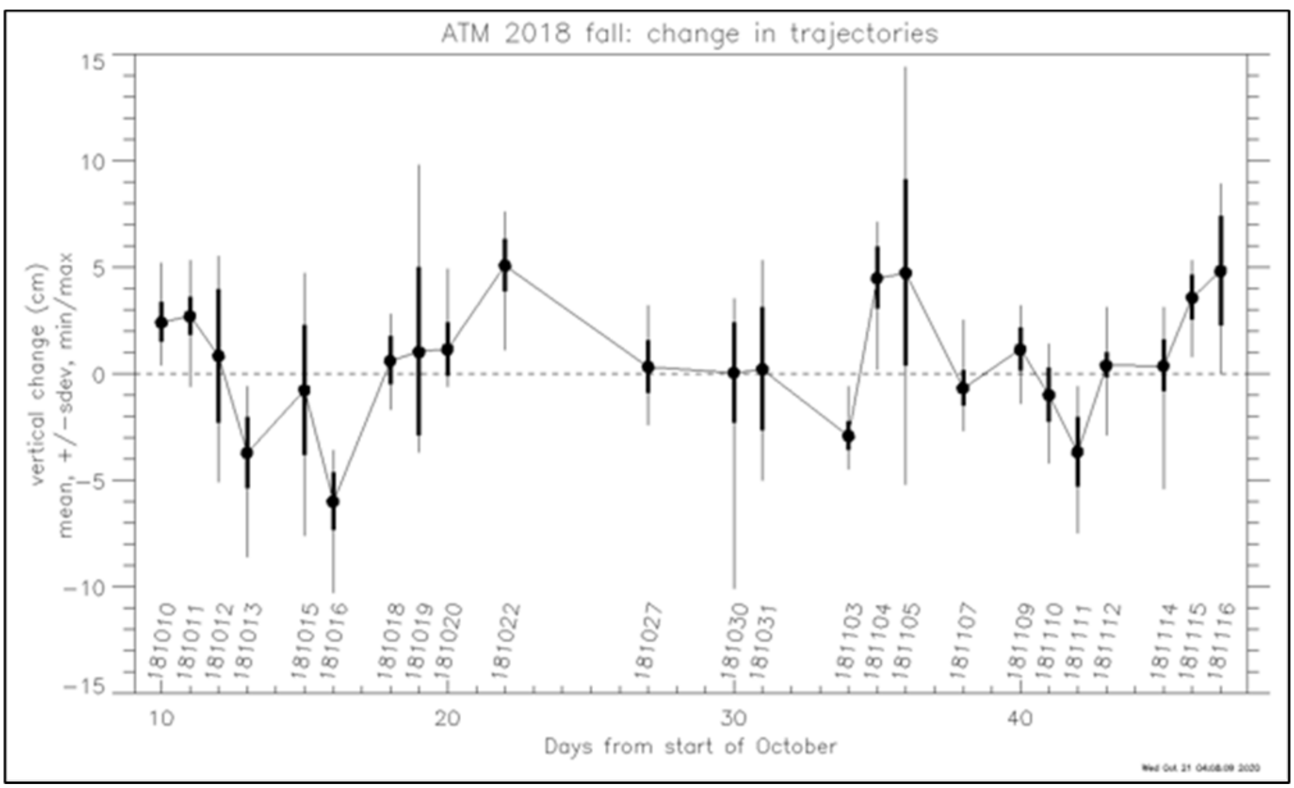

Figure 2. ATM 2018 Fall: Change in Trajectories After Error Corrections

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 3. The horizontal change was less than 10 cm throughout the campaign.

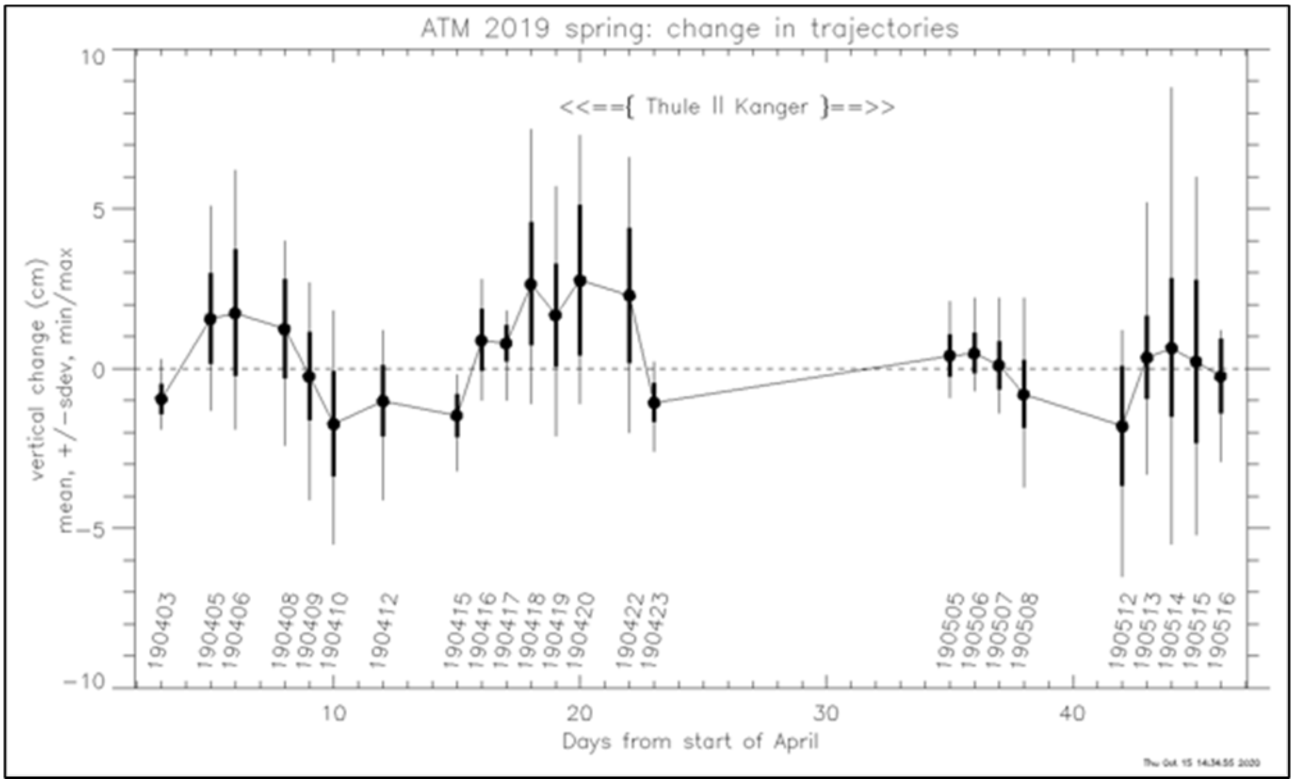

Figure 3. ATM 2019 Spring: Change in Trajectories After Solid Earth Tide Correction

> **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.

3.4 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, glaciers, and sea ice. The ATM instrument is a scanning airborne laser that measures surface elevation of the ground 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 ATM instruments are developed and maintained at NASA's Wallops Flight Facility (WFF) in Virginia, USA. During Operation IceBridge, the ATM has been installed aboard the NASA P3-B aircraft based at WFF, or the NASA DC8 aircraft based at NASA's Dryden Flight Research Center 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 verification of satellite radar and laser altimeters, and measurement of sea-surface elevation and ocean wave characteristics. See also the *Pre-IceBridge ATM L2 Icessn Elevation, Slope, and Roughness* data set. 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 normally installs and operates two lidars on the aircraft platform. From 2009 to 2010, data were provided to the NSIDC DAAC only from the ATM 4BT2 that collects wide scan lidar data. In 2011, a new ATM transceiver scanner assembly designated as ATM 4BT4 replaced the ATM 4BT2. The second lidar system on the aircraft, designated ATM 4CT3, was operated prior to 2011 as a backup to the ATM 4BT2 lidar instrument, or was modified to test alternate lidar system improvements. In 2011, ATM 4CT3 swath width was reduced. Data from the 4CT3, provided for sea ice missions only, are found in the *IceBridge Narrow Swath ATM L1B Qfit Elevation and Return Strength* data set. More information on the ATM transceivers used during IceBridge missions and the associated filename designations can be found under Technical References in the List of ATM Transceivers Used During IceBridge Missions.

4 REFERENCES AND RELATED PUBLICATIONS

Yi, D., Harbeck, J. P., Manizade, S. S., Kurtz, N. T., Studinger, M., & Hofton, M. (2015). Arctic Sea Ice Freeboard Retrieval With Waveform Characteristics for NASA's Airborne Topographic Mapper (ATM) and Land, Vegetation, and Ice Sensor (LVIS). IEEE Transactions on Geoscience and Remote Sensing, 53(3), 1403–1410. https://doi.org/10.1109/tgrs.2014.2339737

4.1 Related Data Collections

- IceBridge ATM L1B Elevation and Return Strength with Waveforms
- IceBridge Narrow Swath ATM L1B Elevation and Return Strength
- IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms
- IceBridge ATM L2 Icessn Elevation, Slope, and Roughness
- Pre-IceBridge ATM L1B Qfit Elevation and Return Strength
- 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
- GLAS/ICESat L1 and L2 Global Altimetry Data

4.2 Related Websites

- ATM Trajectory Maps
- Airborne Topographic Mapper website at NASA Wallops Flight Facility
- Description of ATM QFIT Output Data (revised 13 February 2009)
- Description of DEM Generation, Dry Valleys, Antarctica
- IceBridge data website at NSIDC
- IceBridge website at NASA
- ICESat/GLAS website at NASA Wallops Flight Facility
- ITRF 2008 Specification website

5 CONTACTS AND ACKNOWLEDGMENTS

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5.1 Acknowledgments

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6 DOCUMENT INFORMATION

6.1 Publication Date

February 2017

6.2 Date Last Updated

August 2020