



# IceBridge ATM L1B Elevation and Return Strength with Waveforms, Version 1

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## USER GUIDE

### How to Cite These Data

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

Studinger, M. 2018, updated 2020. *IceBridge ATM L1B Elevation and Return Strength with Waveforms, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. <https://doi.org/10.5067/EZQ5U3R3XWBS>. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT [NSIDC@NSIDC.ORG](mailto:NSIDC@NSIDC.ORG)

FOR CURRENT INFORMATION, VISIT <https://nsidc.org/data/ILATMW1B>



National Snow and Ice Data Center

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# 1 DATA DESCRIPTION

## 1.1 Parameters

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This data set contains Level-1B geolocated and filtered spot elevation measurements and the waveforms associated with these elevation measurements. The elevations correspond to those in the *IceBridge ATM L1B Elevation and Return Strength* data set, which includes sea ice elevation measurements, and relative transmitted and return reflectance. These two data sets are closely related to the narrow-swath data sets, *IceBridge Narrow Swath ATM L1B Elevation and Return Strength* and *IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms*.

## 1.2 File Information

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### 1.2.1 Format

The data are in HDF5 format and were implemented using the HDF5 standard as defined by the [HDFGroup](#). Each data file is paired with an associated XML file, which contains additional metadata.

### 1.2.2 File Contents

Following the HDF5 convention, the data are organized into groups and subgroups within each file. Figure 1 shows an overview of the HDF5 group structure.

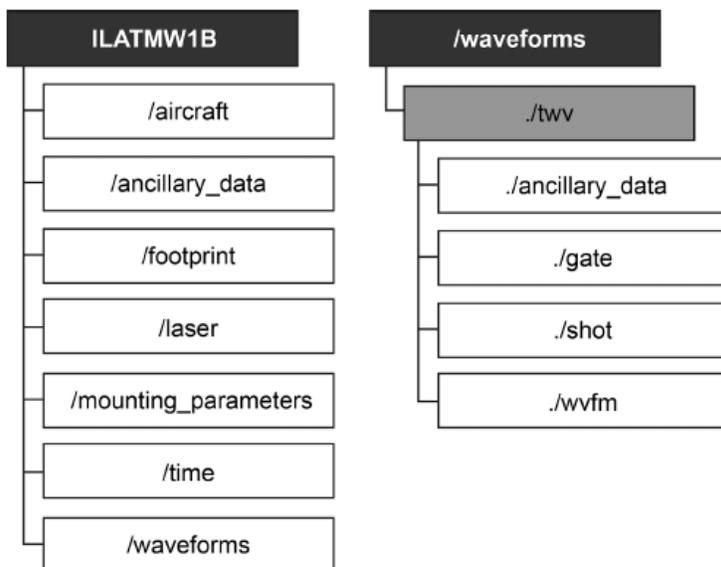


Figure 1. ATM HDF5 Group Structure

The individual groups contain the following information:

- /aircraft contains aircraft location and attitude, interpolated to the times of the laser shots.
- /ancillary\_data contains spatial and temporal limits along with documentation and metadata for the files.
- /footprint contains the geolocated and filtered spot elevation measurements as well as the geographical coordinates of the laser spots on the ground.
- /laser contains pointing and range information for the laser.
- /mounting\_parameters contains information used for computing the footprint location from the laser and aircraft information.
- /time contains the starting time of each laser pulse as UTC seconds of day.
- /waveforms/twv contains the waveform data and is described in more detail under the Methods section.

### 1.2.3 Naming Convention

Example file names:

ILATMW1B\_20170717\_144930.atm6AT5.h5

ILATMW1B\_20170717\_144930.atm6AT5.h5.xml

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

ILATMW1B\_YYYYMMDD\_hhmmss.atmNXTn.xxx

Table 1. File Naming Convention

| Variable | Description  |
|----------|--|
| ILATMW1B | 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., atm6A                 |
| Tn       | Identifier of transceiver used, affecting off-nadir scan angle:<br>T5 = 2.5-degree |
| .xxx     | Indicates file type:<br>.h5 = HDF5 data file<br>.h5.xml = XML metadata file        |

## 1.3 Spatial Information

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### 1.3.1 Coverage

Spatial coverage for this data set includes the Arctic, Greenland, Antarctica, and surrounding ocean areas. The following are the approximate latitude/longitude bounding coordinates:

#### **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

### 1.3.2 Resolution

The ATM surface elevation measurements were 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<sup>2</sup> within the swath.

### 1.3.3 Projection and Grid Description

Data are given in geographic latitude and longitude coordinates. Data coordinates are referenced to the WGS84 ellipsoid. The 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 Information

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### 1.4.1 Coverage

17 July 2017 to 20 November 2019

### 1.4.2 Resolution

IceBridge campaigns are conducted on an annually repeating basis. Arctic and Greenland campaigns are typically conducted in March, April, and May; Antarctic campaigns are typically conducted in October and November.

## 1.5 Methods

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### 1.5.1 Level 1B QFIT Geolocated Spot Elevation Measurements

The primary science data products are the geolocated and filtered spot elevation measurements in the group `/footprint`. Data are organized in chronological order. For example, if number of laser shots in the file is  $N$ , the timestamps of the laser shots are stored in an array of length  $N$  contained in `/time/seconds_of_day`, and the corresponding measured elevations are stored in an array of length  $N$  contained in `/footprint/elevation`.

### 1.5.2 Waveform Data

Waveform data for surveys beginning with Antarctica 2014 are stored in the subgroup `/waveforms/twv`. Each laser shot can be associated with a varying number of range gates that can also vary in length (number of digitizer samples). Elements in the subgroup `/ancillary_data` are single values. The subgroup `./shot` contains arrays of  $N$  values (e.g., `./number`), corresponding to each laser shot. Arrays in the subgroup `./gate` correspond to each range gate. The largest subgroup (`./wvfm`) contains the 8-bit digitizer samples in the field `./amplitude` as a concatenation of all the waveform gates recorded in the file. The link between laser shots, range gates, and digitizer samples/range bins is implemented by a pointer/index scheme. The waveform data for a particular laser shot is found by locating the gates recorded for the laser shot, then locating the waveform samples associated with those gates. Consider a laser shot  $j$ , where  $1 \leq j \leq N$ . Using the conventions that  $a(j)$  is the  $j$ -th element of array  $a$  and  $a(i:j)$  is the sub-array taken from elements  $i$  through  $j$ , the time of the shot is given by `./shot/seconds_of_day(j)`. The number of gates associated with this laser shot is `./shot/gate_count(j)`. Data for the first gate associated with this shot is located in the gate arrays at index `./shot/gate_start`. The first waveform sample for the first gate of this laser shot is located at `./shot(gate_start(j))`.

The value of this first waveform sample

is `./wvfm/amplitude(./gate/wvfm_start(./shot/gate_start(j)))`. The number of samples in each gate is stored in the array `./gate/wvfm_length`. Therefore, the waveform recorded in the first gate of shot  $j$  can be read as:

```
./wvfm/amplitude(k2:k3)
```

Where:

$$k = ./shot/gate\_start(j)$$

$$k2 = ./gate/wvfm\_start(k)$$

$$k3 = ./gate/wvfm\_start(k) + ./gate/wvfm\_length(k) - 1$$

More generally, the digitized waveform for range gate  $i$  of the laser shot  $j$  would be:

```
./wvfm/amplitude(k2:k3)
```

Where:

$$k = ./shot/gate\_start(j)$$

$$k2 = ./gate/wvfm\_start(k+i-1)$$

$$k3 = ./gate/wvfm\_start(k+i-1) + ./gate/wvfm\_length(k+i-1) - 1$$

In order to reassemble all range gates into a time tagged series, the offset for the first range bin/sample needs to be known. This information is stored in the field `./gate/position` as the number of digitizer samples since the laser was triggered. Together with the length of each range bin/sample in nanoseconds (`./ancillary_data/sample_interval = 0.25 ns` for 4 Giga samples per second digitization rate), the time in nanoseconds can be calculated using `./gate/position*sample_interval`. In this way, the range gates for a laser shot can be reassembled in order to determine the time of flight between the transmit and receive pulses. Figure 2 illustrates the indexing scheme using values from an example data file. If the first range gate within a file starts at index 1 (`./gate/wvfm_start(1) = 1`) and is 192 range bins/samples long (`./gate/wvfm_length(1) = 192`), the second range gate will begin at index 193 (`./gate/wvfm_start(2) = 193`).

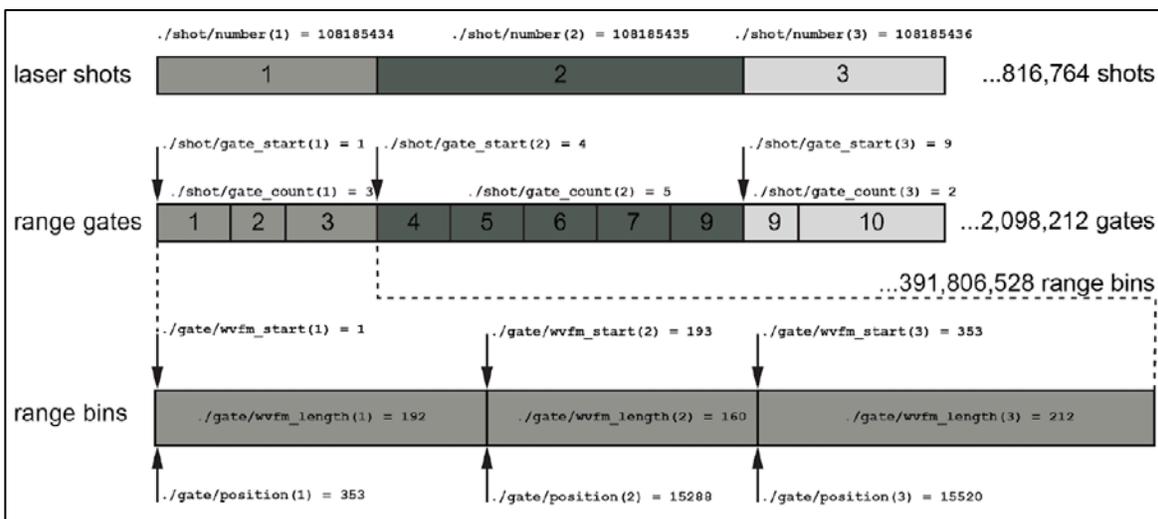


Figure 2. Pointer and indexing schema for access of the waveform data (range gates) for a particular laser shot. Range gate numbers are also referred to as record numbers.

The example file contains 816,764 individual laser shots whose unique shot identifiers are stored in the field `./shot/number`. The start index for the first range gate for each shot (`./shot/gate_start`) and the number of range gates for each shot (`./shot/gate_count`) are of the same size as `./shot/numbers`. Together, the 816,764 individual laser shots contain a total of 2,098,212 range gates that are comprised of 391,806,528 digitizer samples.

### 1.5.3 Waveform Signal Quality and Complex Return Pulses

Several parameters, provided in the subgroup `/waveforms/twv/gate/pulse`, allow users to assess the quality and complexity of waveforms (Table 2).

Table 2. Parameters Used to Assess Waveform Quality and Complexity

| Field                    | Description   |
|--------------------------|---|
| <code>./area</code>      | Area of waveform pulse above noise floor  |
| <code>./count</code>     | Number of pulses in gate (number of threshold crossings divided by 2)                   |
| <code>./sat_count</code> | Number of waveform amplitudes at saturation value                                       |
| <code>./width</code>     | Width of pulse (number of samples) based on a threshold of 35% of the maximum amplitude |

Some return signals contain complex waveforms. Complex returns showing multiple peaks or a broadened pulse indicate interaction of the laser pulse with complex surfaces such as sea-ice pressure ridges, crevasses, or melt ponds (Figure 3).

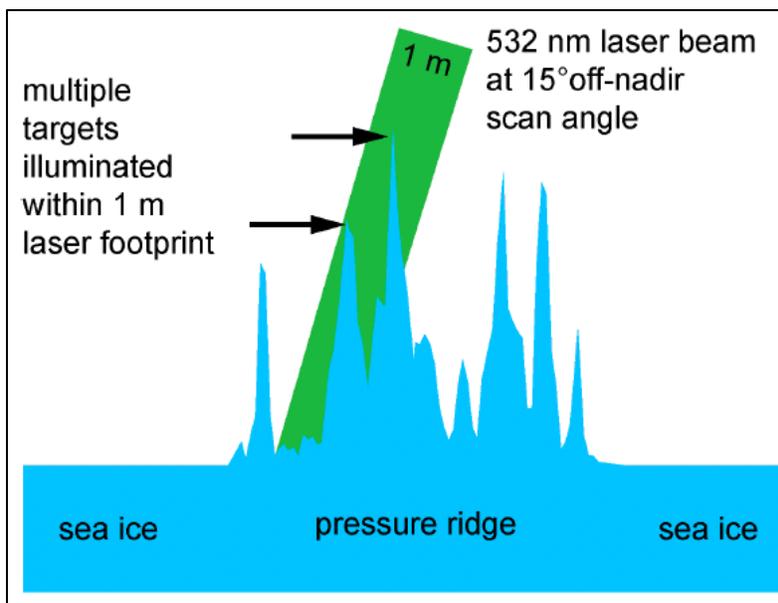


Figure 3. Example of surface characteristics that can cause complex return waveforms, when the laser pulse hits multiple targets within the size of the footprint.

To identify these scientifically interesting waveforms, several parameters can be used that indicate a deviation from a single return on a relatively smooth ice surface. The `.width` field indicates pulse broadening from interacting with a complex target or a steep surface within the laser footprint (Figure 4b). Only data points above the threshold (35% of the maximum amplitude) are used. The `.area` parameter also indicates pulse broadening but takes into account all data points above the noise floor. This allows for the identification of changes in the waveform in the tail of a laser pulse. The `.count` parameter indicates multiple targets for a single transmit pulse (such as returns from the water surface and bottom of shallow melt ponds) or multiple targets over extremely rough surfaces (such as pressure ridges) (Figure 4a).

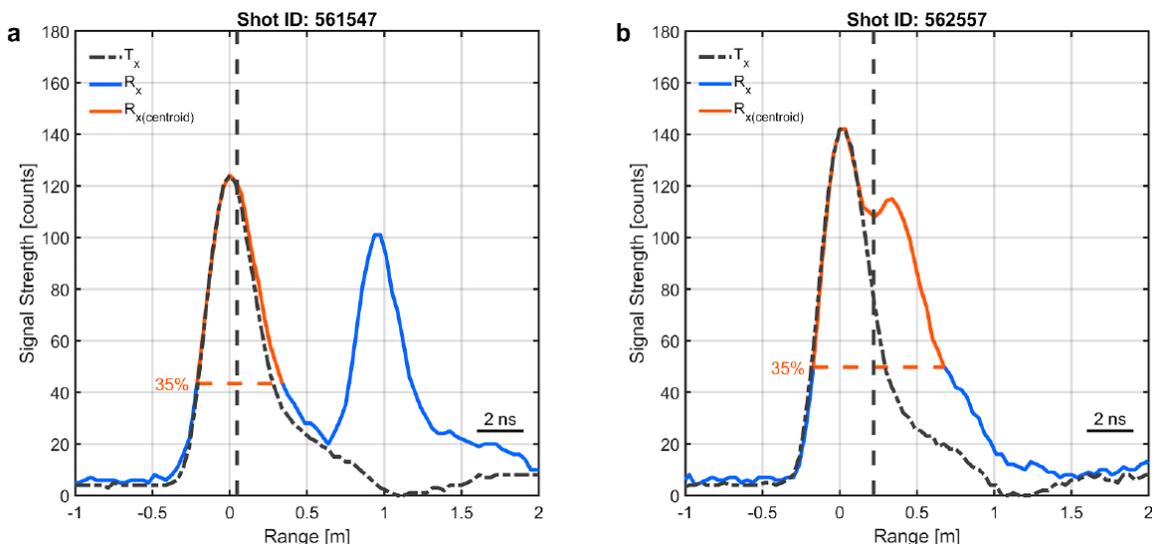


Figure 4. Example of complex return waveforms (blue) over a sea-ice pressure ridge. The transmit waveform is shown in dashed gray and scaled to the maximum amplitude of the return pulse to show the deviation of the return pulse. Multiple separate return pulses can be identified by the `./count` parameter (a), while return pulses much broader than the transmit pulse (b) will be revealed by larger values in the `./width` field. The vertical dashed line in both panels marks the location of the centroid, indicating that the centroid estimates from complex return pulses need to be interpreted properly.

## 2 DATA ACQUISITION AND PROCESSING

### 2.1 Theory of Measurements

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 Acquisition

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 the inter-comparison and analysis of ATM data where flight lines cross or overlap. A more detailed description can be found in Martin et al. (2012).

## 2.3 Derivation Techniques and Algorithms

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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.

### 2.3.1 Overview of the TX and RX Range Gate Structure

The analog output from the optical detector is captured by an 8-bit waveform digitizer, sampling at a constant rate (2 or 4 gigasamples per second). A sequence of samples, or range bins, is recorded whenever the signal amplitude exceeds a programmable trigger threshold. Each sequence, or range gate, can contain a variable number of range bins depending on how long the signal exceeds the threshold. Each laser shot generates a laser waveform record, which can contain multiple range gates, each of which contains multiple waveform samples. The laser record contains the starting position of each range gate, from which the time of each range bin can be determined. For example, Figure 5 shows a laser waveform reconstructed from a laser record containing six range gates: one for the transmitted pulse (TX), and four return gates (RX) from a complex target (trees). Range Gate 6 contains two distinct return pulses. The transmitted laser pulse travels through an optical window in the nadir view port on the aircraft to the target. The reflection of the transmitted laser pulse on the optical window can exceed the amplitude trigger threshold and is then recorded in a range gate. In order to separate the recorded transmit pulse from the window reflection, the transmit pulse is routed through an optical delay fiber several meters in length so it appears several tens of nanoseconds after the window reflection. The length of the fiber can change with various system configurations and its delay is incorporated in the calibration for range determination. Since the window reflection does not occur on every laser shot, sometimes the recorded transmit pulse is in Range Gate 1 or Range Gate 2. Figure 5 shows an example that includes a window reflection. Therefore, the recorded transmit pulse that is used for

the ATM range determination is in Range Gate 2. The capability of recording multiple range gates of varying lengths for each laser shot requires a pointer and indexing scheme to access the waveform data within an HDF5 file that is described below.

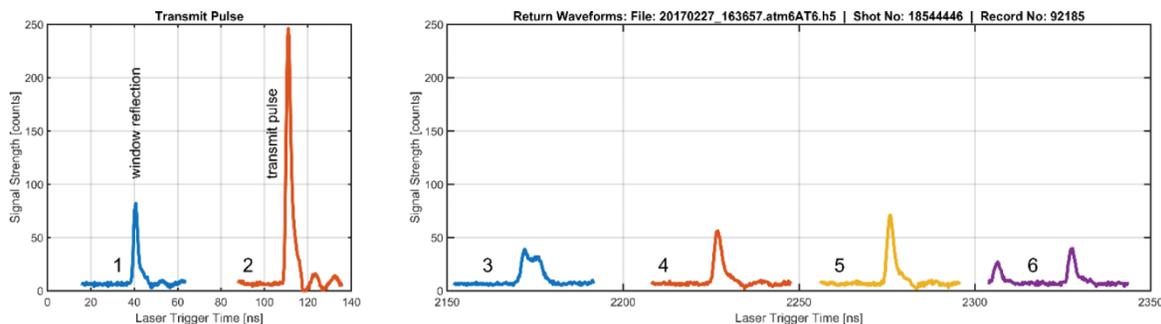


Figure 5. Example of how ATM waveform data are organized into range gates. The example shows a laser shot over a complex target (tree) that has triggered four return range gates, Range Gates 3 to 6, some of which contain multiple return pulses. The transmit pulse is recorded through a delay fiber (Range Gate 2) and is sometimes preceded by a window reflection (Range Gate 1).

### 2.3.2 Range Determination

The transmit and receive waveforms are captured in separate range gates. The time delay between transmitted and received waveforms includes the delay between the TX and RX range gates and the tracked location of the pulse within each gate. When the laser fires, an electronic trigger starts the digitizer counting the number of elapsed sampling intervals. The gate start position is the value of this counter at the first bin of the gate. The trigger time, i.e., the time relative to the trigger, of any range bin can be computed as the gate start position plus the bin position within the gate, multiplied by the digitizer sampling interval. The time between any range bins in the two gates can be accurately computed as the difference between the two trigger times. A more complex task is the assignment of a sample time to a waveform. Figure 6 shows the two windows and the current ATM method for calculating the range measurement between the two windows.

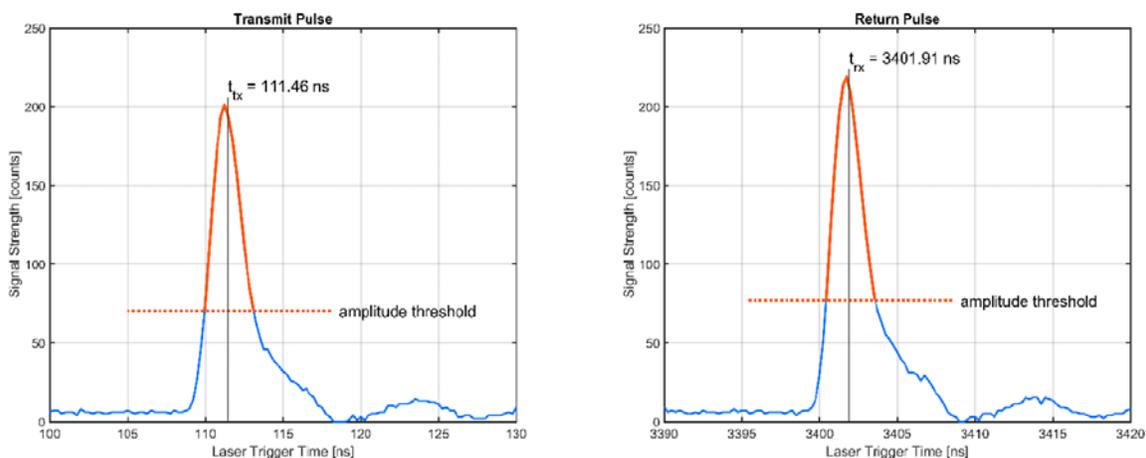


Figure 6. Example of range determination using a centroid estimate that cuts off data points below 35% of the maximum amplitude of the transmit and return pulse.

The ATM range determination uses a centroid estimate that cuts off all values below 35% of the maximum amplitude of the transmit or return pulse. The uncalibrated range between two positions in the TX and RX windows is given by the following equation:

$$range_{uncalibrated}[m] = \frac{1}{2} \cdot c \cdot (t_{rx} - t_{tx})$$

where *c* is the propagation speed of light through the atmosphere.

The example shown in Figure 7 yields an uncalibrated range of 493.22 m. As previously described, the optical delay fiber and other system components introduce a range bias that is determined in ground tests by shooting the laser at a target at a known distance.

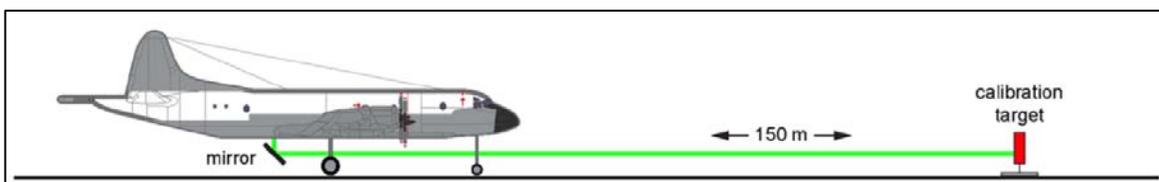


Figure 7. Range bias determination (a.k.a. ground test) using a calibration target with a known distance. The distance to the calibration target is measured with an electronic distance meter (a.k.a. total station) with an accuracy of a few millimeters.

The range bias is a function of the return signal strength. For the ATM centroid tracker, the bias is almost constant for typical signal strengths encountered in flight, but deviates for weak signals that barely exceed the amplitude trigger threshold and for strong signals that saturate the digitizer. The range bias calibration determined from ground tests depends on the waveform tracking method. Users who wish to determine ranges using a different tracking method will need to develop a suitable calibration from the ground test data.

## 2.4 Processing

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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.

## 2.5 Quality, Errors, and Limitations

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### **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.

## 2.6 Instrumentation

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### 2.6.1 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 *Pre-IceBridge ATM L2 Icessn Elevation, Slope, and Roughness*. 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 NSIDC 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 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](#).

## 2.6.2 Trajectory and Attitude

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 trajectory at 0.5 second intervals, and more recently at 0.1 second intervals.

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

## 3 SOFTWARE AND TOOLS

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

## 4 RELATED DATA SETS

- [IceBridge ATM L1B Elevation and Return Strength](#)
- [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 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](#)

## 5 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](#)

## 6 CONTACTS AND ACKNOWLEDGMENTS

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### 6.1 Acknowledgments

---

The ATM project team would like to acknowledge the dedicated 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 REFERENCES

Martin, C. F., W. B. Krabill, S. S. Manizade, R. L. Russell, J. G. Sonntag, R. N. Swift, and J. K. Yungel. 2012. Airborne Topographic Mapper Calibration Procedures and Accuracy Assessment. Greenbelt, Md.: National Aeronautics and Space Administration, Goddard Space Flight Center. *NASA Technical Memorandum 2012-215891*.  
[http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120008479\\_2012008321.pdf](http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120008479_2012008321.pdf)

## 8 DOCUMENT INFORMATION

### 8.1 Publication Date

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August 2017

### 8.2 Date Last Updated

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August 2020