IceBridge ATM L1B Near-Infrared Waveforms, Version 1

USER GUIDE

How to Cite These Data

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

Studinger, M. & Manizade, S. (2019, updated 2020). *IceBridge ATM L1B Near-Infrared Waveforms* (ILNIRW1B, Version 1). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/P8QCY55YPR8U [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ILNIRW1B

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Summary

This data set contains geolocated waveforms of Greenland, Arctic, and Antarctic sea ice measured by the Airborne Topographic Mapper (ATM) near-infrared (NIR) lidar. The data complement, and are intended to be used with, the IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms data, which are measured at green wavelength. The data were acquired as part of aircraft survey campaigns funded by Operation IceBridge.

1.2 File Information

1.2.1 Format

The data are in HDF5 (.h5) format. Each data file is paired with an associated XML file (.xml), 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 file structure, using the file ILNIRW1B_20181010_174600.atm6CT7.h5 as an example.

Figure 1. The ILNIRW1B variables follow the HDF5 ATM file 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.
- /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

The data files are organized in chronological order. Each file name contains the starting date and time for that file. Example file names:

ILNIRW1B_20181010_174600.atm6CT7.h5
ILNIRW1B_20181010_174600.atm6CT7.h5.xml

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

ILNIRW1B_YYYYMMDD_HHMMSS.atm6CT7.xxx

Table 1. File Naming Convention

Variable	Description
ILNIRW1B	Data set ID
YYYYMMDD	Year, month, and day of survey
HHMMSS	Hours, minutes, and seconds of survey (beginning of file time)
atm6C	Airborne Topographic Mapper instrument identification
T7	ATM transceiver designation
.xxx	Indicates file type: .h5 = HDF5 data file .h5.xml = XML metadata file

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage includes Greenland, the Arctic, and Antarctica, as noted by the spatial extents below.

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

Antarctica:
Southernmost Latitude: 90° S
Northernmost Latitude: 53° S
Westernmost Longitude: 180° W
Easternmost Longitude: 180° E

1.3.2 Resolution

The ATM measurements were acquired by a conically scanning lidar system. The resulting array of laser spots is coupled with the motion of the aircraft and forms a tight spiral. The laser footprints generally consist of overlapping, roughly elliptical patterns on the surveyed surface that form a swath of measurements along the aircraft flight path.

The ATM narrow swath instrument has a scan angle of approximately 2.7° off-nadir, or a full swath width of 5.4°. The resolution of the swath is a function of aircraft altitude, aircraft ground speed, and scanner configuration for the lidar. For example, an altitude of 450 m above ground level corresponds to a swath of roughly 45 m width on the ground. Assuming an aircraft ground speed of 250 knots, a laser pulse rate of 3 kHz, and a scan angle of 2.7° off-nadir, the average point density within the swath is one laser shot per 2 m^2. However, the sampling of laser shots within the swath is not evenly distributed.

1.3.3 Geolocation

Table 2 provides information for geolocating this data set. The reference frame is prescribed by the International Terrestrial Reference Frame (ITRF) convention, and is described in more detail on the ITRF specification website (see Related Websites section).

Table 2. Geolocation Details

Geographic coordinate system	WGS 84
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

1.4 Temporal Information

1.4.1 Coverage

10 October 2018 to 20 November 2019

1.4.2 Resolution

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

1.4.3 Instrumentation

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 NIR (1064 nm) and green (532 nm) wavelengths. The laser light is directed to a nutating scanner mirror and downward from the aircraft. Light that is backscattered upward is directed by the scanner 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 4 gigasample/second multi-trigger waveform digitizer. The captured waveforms from the NIR and green systems 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.

More information on the ATM transceivers used during IceBridge missions and the associated filename designations can be found in the List of ATM transceivers used during IceBridge missions.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

A laser altimeter determines the distance to a target by measuring the elapsed time between the emission of a laser pulse and the detection of laser energy reflected back by the target. The distance to the target is calculated as half of the elapsed emission/return time multiplied by the speed of light through the atmosphere. The target distance is then integrated with platform location and attitude information and converted to geographic position.

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. The distances between GPS, 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 Processing

2.3.1 Processing Steps

The following processing steps are performed by the data provider.

1. Process ATM lidar data to apply calibration factors to convert time of flight to range, compute scan pointing angles, and interpolate attitude to each lidar measurement.
2. Process GPS data into aircraft trajectory files using double-differenced dual-frequency carrier phase-tracking.
3. Determine all biases and offsets: heading, pitch, roll, ATM-GPS [x,y,z] offset, scanner angles, range bias.
4. Process the lidar and GPS data with all biases and offsets through the QFIT program. The output files in this data set contain waveform and ancillary parameters. The output files in the IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms data set contain waveforms, ancillary parameters, and surface elevations (ellipsoid height). Both data sets contain geographic location information in latitude/longitude coordinates.

2.4 Trajectory and Attitude Data

Aircraft position is determined by Global Navigation Satellite System (GNSS) systems that incorporate NAVSTAR 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), or IMU.

2.5 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 pulse generates a laser waveform record, or shot, which can contain multiple range gates, each of which contains multiple waveform amplitude 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 2 shows a laser waveform reconstructed from a laser record containing six range gates: one for the transmitted pulse (TX; left panel), and four return gates (RX, right panel) from a complex target (tree). 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. To separate the recorded transmit pulse from the window reflection, the transmit pulse is routed through an optical delay fiber that is several meters in length; thus, it appears several tens of nanoseconds after the window reflection. The fiber length 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. The example in Figure 2 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, as described below.

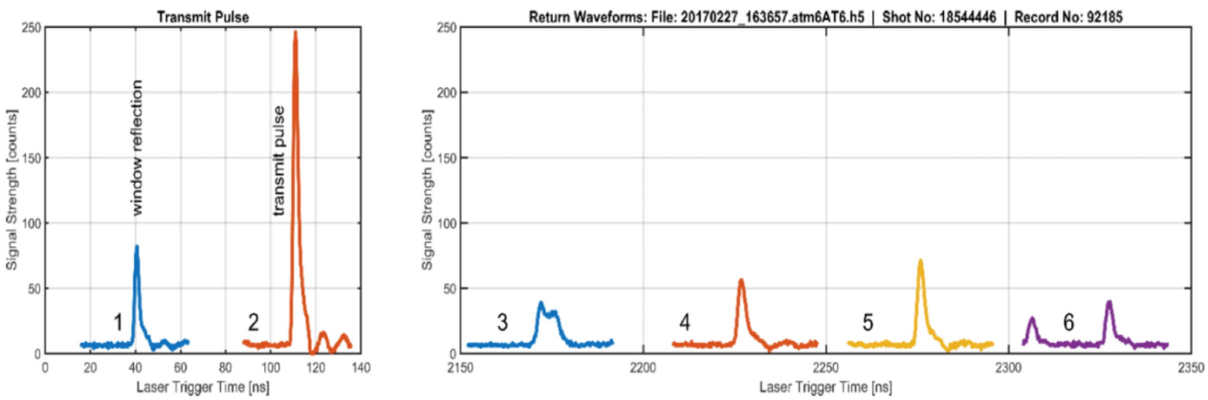

Figure 2. Example of how ATM waveform data are organized into range gates. Left panel: the transmit pulse is recorded through a delay fiber (Range Gate 2) and is sometimes preceded by a window reflection (Range Gate 1). Right panel: a laser shot over a complex target (tree) triggered four return range gates, Range Gates 3 to 6. Range Gate 6 contains multiple return pulses.

2.6 Methods

2.6.1 Waveform Data

The waveform data 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., `./shot/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 `./wvfm/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 3 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`), then the second range gate will begin at index 193 (`./gate/wvfm_start(2) = 193`).

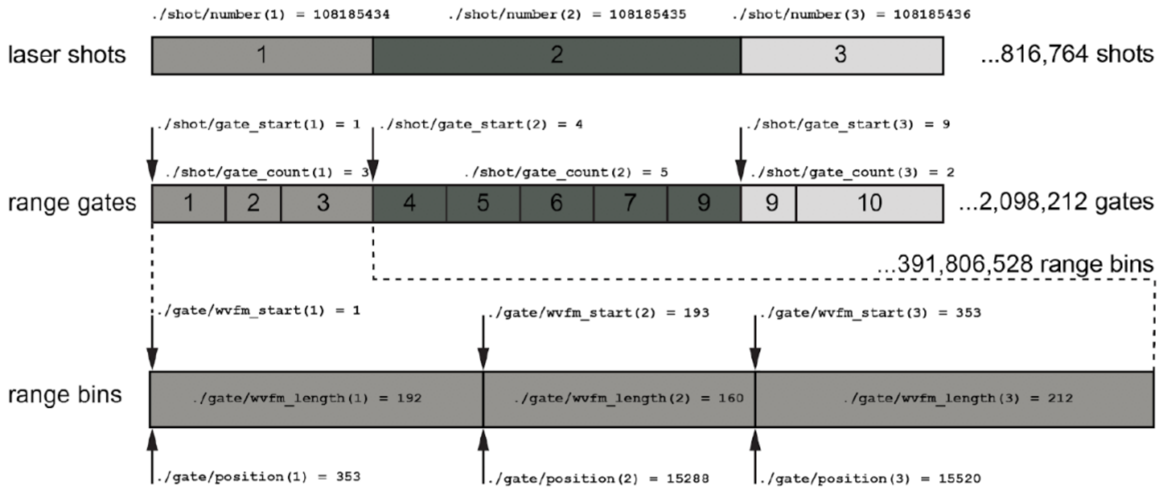

Figure 3. Pointer and indexing schema for access of the waveform data (range gates) for a particular laser shot. Range gate numbers are also referred to as record numbers.

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.

2.7 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 3).

Table 3. Parameters Used to Assess Waveform Quality and Complexity

Field	Description
./area	Area of waveform pulse above noise floor
./count	Number of pulses in gate (number of threshold crossings divided by 2)
./sat_count	Number of waveform amplitudes at saturation value
./width	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 4).

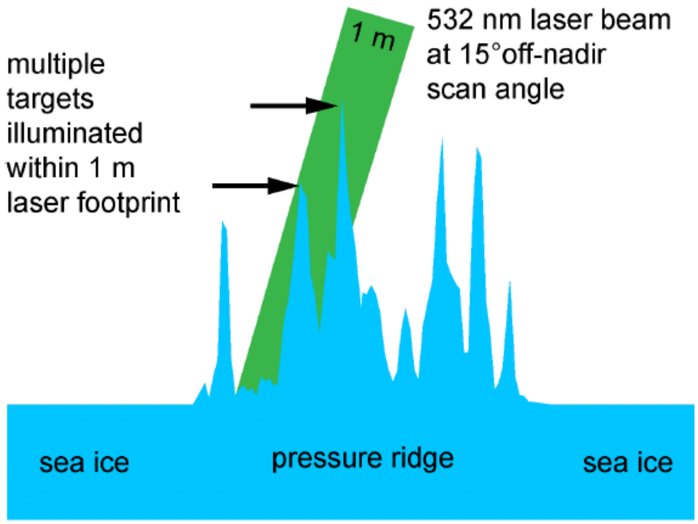

Figure 4. Example of surface characteristics that can cause complex return waveforms, when the laser pulse hits multiple targets within the size of the footprint.

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 5b). 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 5a).

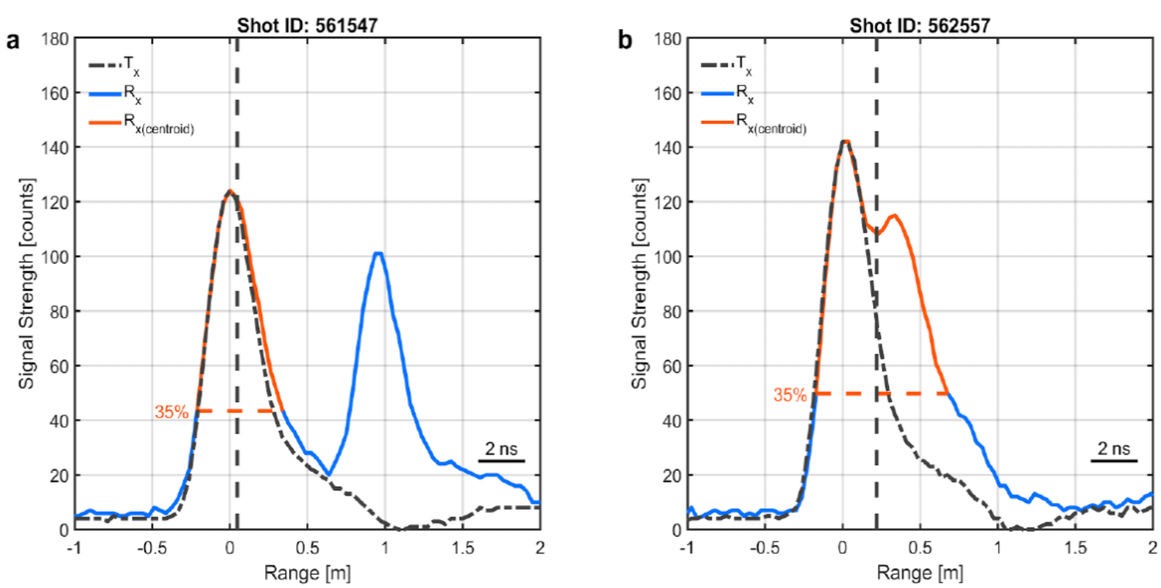

Figure 5. Example of complex return waveforms (blue) over a sea-ice pressure ridge. The transmit waveform is shown in dashed gray and scaled to the maximum amplitude of the return pulse to show the deviation of the return pulse. Multiple separate return pulses can be identified by the ./count parameter (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.

The NIR and green wavelength measurements provided in this data set and in the IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms data set, respectively, were acquired by separate data systems. The data records from the two data systems need to be matched, as occasionally one or the other system will miss recording a laser shot. This co-registration can be performed using a Python script for finding matching shots in both data products. Figure 6 shows the matching returns for the NIR and green wavelengths on the example file ILNIRW1B_20181010_200400.atm6CT7.h5.

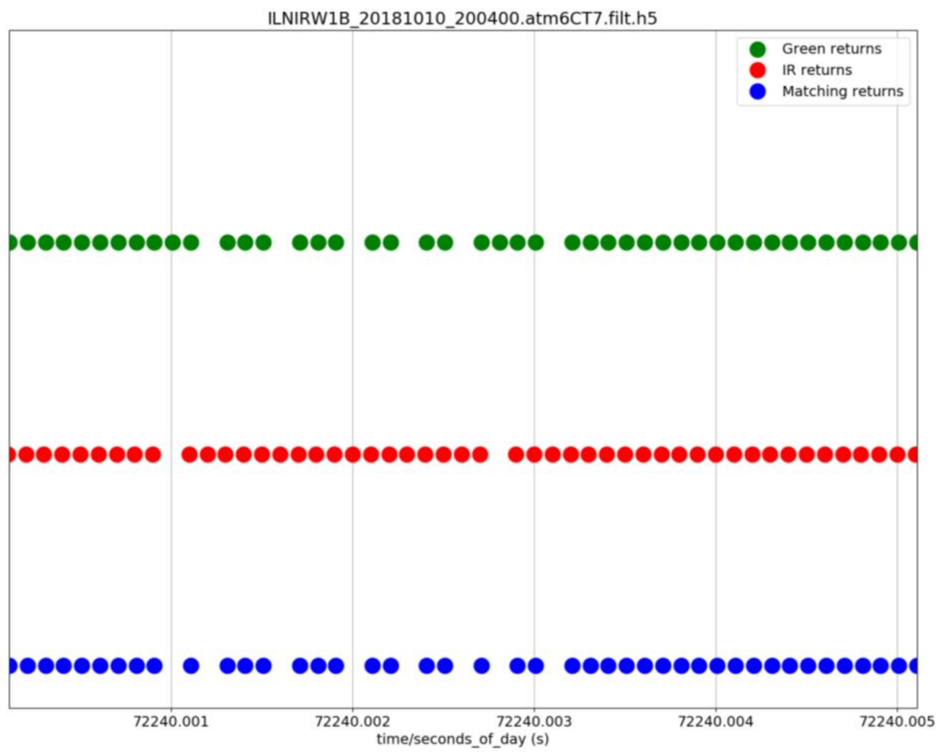

Figure 6. The blue line shows the matching returns of the NIR and green wavelengths, measured by two different systems.

3 RELATED DATA SETS

IceBridge Narrow Swath ATM L1B Elevation and Return Strength with Waveforms
IceBridge ATM L1B Elevation and Return Strength with Waveforms

4 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.

5 DOCUMENT INFORMATION

5.1 Publication Date

July 2018

5.2 Date Last Updated

April 2025