Pre-IceBridge ATM L1B Qfit Elevation and Return Strength, Version 1

USER GUIDE

How to Cite These Data

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

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1 DATA DESCRIPTION

1.1 Format

ATM data are generally distributed in the output format of the processing program, qfit, which combines airborne laser ranging data and aircraft attitude from the INS with positioning information from a processed kinematic differential GPS trajectory. Qfit output files, which usually have names ending in a `.qi` extension, are organized as 32-bit (4-byte) binary words scaled to retain the precision of the measurements. The beginning of each file contains a header of one or more records followed by a data segment in which there is one record per laser shot. For surveys prior to and including spring 2010, qfit processing was performed on an Apple PowerPC processor (and Sun/Motorola before that). Accordingly, data from spring 2010 and earlier were written in big-endian byte order.

The files are organized into fixed-length logical records. The beginning of the file contains a header of one or more records followed by a data segment, in which there is one record per laser shot. It is not necessary to interpret the header to use the laser data. The first word of the header (and the file) is a 32-bit binary integer giving the number of bytes in each logical record. Commonly, qfit files have 12 words per record; this integer will be the number 48. The remainder of the initial logical record is padded with blank bytes (in this case, 44 blank bytes). 10-word and 14-word formats have also been used, as described below in Section 1.6 Parameters.

The remainder of the header is generally a series of logical records containing the processing history of the file. In these logical records, the initial word contains a 32-bit binary integer with a value between -9000000 and -9000008. The remaining bytes in each header record is filled with a string of ASCII characters containing information on file processing history. In this case, the byte offset (as a longword integer) from the start of file to the start of laser data will be the second word of the second record of the header. A simple method for removing the header records is to eliminate records that begin with a negative value since the first word of records in the data segment is always a positive number.

In the data segment of the file, the information contained in words 2-9 of the output record pertains to the laser pulse, its footprint, and aircraft attitude. The last word of each record is always the GPS time of day when the laser measurement was acquired.

For more information, see ReadMe.qfit.txt.

1.2 File Naming Convention

Files are named according to various conventions from 1993 to 2008. File name examples are shown in Table 1.

Table 1. File Name Examples by Campaign Year and ATM Instrument

Year and ATM Instrument	Example File Names
1993	BLATM1B_930627aoltm_t2f2_c
1994	BLATM1B_940528aoljr_160236
1995_atm1	BLATM1B_950519atm1_125126
1996_atm1	BLATM1B_960523atm1_145648sr
1997_atm1	BLATM1B_970425atm1_185451sr
1998_atm1	BLATM1B_980627atm1_135623sr.gapF
1999_atm2	BLATM1B_990513atm2_131725jr.lutFx
2000_atm2	BLATM1B_000529atm2_153655jr.lutFx
2001_atm3	BLATM1B_010520atm3_110524jr.lutFx
2002_atm2	BLATM1B_20021122atm2_161135jr
2002_atm3	BLATM1B_20020528atm3_132805jr.lutFx
2003_atm3	BLATM1B_20030320atm3_203456jr.lutFx
2004_atm2	BLATM1B_20041118atm2_171917jr.lutF
2005_atm4	BLATM1B_20050505_183352
2006_atm4	BLATM1B_20060531_171650
2007_atm4b	BLATM1B_20070925_123435.atm4bT2.rangeExample
2008_atm4	BLATM1B_20081030_152251.ATM4BT2.rangeExample

Variables for the naming conventions listed in Table 1 are described in Table 2:

Examples:

```
BLATM1B_950519atm1_125126
BLATM1B_YYMMDDatminst_HHMMSS

BLATM1B_960523atm1_145648sr
BLATM1B_990513atm2_131725jr.lutFx
BLATM1B_YYMMDDatminst_HHMMSSaa.aaaaa

BLATM1B_20070925_123435.atm4bT2.rangeExample
BLATM1B_YYYYMMDD_HHMMSSatminst.rangeExample
```

Table 2. File Naming Convention

Variable	Description
BLATM1B	Short name for Pre-IceBridge ATM L1B Qfit Elevation and Return Strength
YY or YYYY	YY = Two-digit year, YYYY = Four-digit year
MM	Two-digit month
DD	Two-digit day
atminst	ATM instrument version identification, for example: aoltm, aoljr, atm1, atm1(sr), atm1, atm1, atm2(jr), atm2, atm3, atm4, atm4aT3, atm4bT2, atm4cT3, atm4bT2. (aol refers to the early ATM, the terrain mapping configuration of the Airborne Oceanographic Lidar, sometimes called the AOL-TM.)
HH	Two-digit hours, beginning of file time
MM	Two-digit minutes, beginning of file time
SS	Two-digit seconds, beginning of file time
aa	jr = junior, sr = senior
aaaaa	gapF: QA filtering step to clean up erroneous data due to an artifact of data acquisition. lutF: Method used with leading-edge range determination that included the application of a lookup table, derived from a ground calibration, to filter out very saturated signals and apply a range adjustment to the received laser pulse, based on its integrated energy. lutFx: Similar to lutF, except the adjustment was applied to the transmitted laser pulse, in addition to the received pulse.
rangeExample	Range determination module that utilized leading-edge tracking.

1.3 Spatial Coverage

The focus of the ATM surveys has been Greenland, but they also include Iceland, Svalbard, Canada, Alaska, Antarctica (West/Peninsula and McMurdo region), Patagonia, and several sea ice regions. In effect, this represents the coverage noted below.

<u>Arctic / Greenland:</u>

Southernmost Latitude 60° N

Northernmost Latitude: 90° N

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

Antarctica / Patagonia:

Southernmost Latitude: 90° S

Northernmost Latitude: 46° S

Westernmost Longitude: 180° W

Easternmost Longitude: 180° E

1.3.1 Spatial Resolution

The ATM qfit 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 degrees 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.

1.4 Temporal Information

These data were collected as part of Operation IceBridge funded campaigns beginning 23 June 1993 to 30 October 2008.

1.4.1 Temporal Resolution

Arctic and Greenland campaigns were conducted during March, April, and May, and Antarctic campaigns were conducted during October and November.

1.5 Parameters

The Pre-IceBridge ATM L1B Qfit Elevation and Return Strength data set includes glacier, ice sheet, and sea ice elevation measurements, and relative transmitted and return reflectance.

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

1.5.1 Parameter Description

The data formats and parameters are described in Tables 3, 4, and 5. The format is designated by the logical record length given in the first word of the data file.

Table 3. 12-word qfit Format (in use since 2006) Parameter Description

Column	Description	Units with Scale Factor
1	Relative Time measured from start of file	Seconds 10^{-3}
2	Laser Spot Latitude	Degrees x 1,000,000
3	Laser Spot Longitude	Degrees x 1,000,000
4	Elevation	Meters 10^{-3}
5	Start Pulse Signal Strength (relative)	Dimensionless relative values (or data numbers, DN)
6	Reflected Laser Signal Strength (relative)	Dimensionless relative values (or data numbers, DN)
7	Scan Azimuth	Degrees x 1000
8	Pitch	Degrees x 1000
9	Roll	Degrees x 1000
10	GPS Dilution of Precision (PDOP) times 10	Dimensionless
11	Laser received pulse width	Count, digitizer samples
12	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.

Table 4. 10-word qfit Format (in use prior to 2006) Parameter Description

Column	Description	Units with Scale Factor
1	Relative Time measured from start of file	Seconds 10^{-3}
2	Laser Spot Latitude	Degrees x 1,000,000
3	Laser Spot Longitude	Degrees x 1,000,000
4	Elevation	Meters 10^{-3}
5	Start Pulse Signal Strength (relative)	Dimensionless relative values (or data numbers, DN)
6	Reflected Laser Signal Strength (relative)	Dimensionless relative values (or data numbers, DN)

7	Scan Azimuth	Degrees x 1000
8	Pitch	Degrees x 1000
9	Roll	Degrees x 1000
10	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.

Between 1997 and 2004, some ATM surveys included a separate sensor to measure passive brightness. In the 14-word format, words 10–13 pertain to the passive brightness signal, which is essentially a relative measure of radiance reflected from the earth's surface within the vicinity of the laser pulse. Some records that have passive data without valid laser data will contain zeros in place of the laser latitude, longitude, and elevation. The horizontal position of the passive footprint is determined relative to the laser footprint by a delay formulated during ground testing. The elevation of the footprint is synthesized from surrounding laser elevation data. NOTE: The passive data is not calibrated and its use, if any, should be qualitative in nature. It may aid the interpretation of terrain features. The measurement capability was engineered into the ATM sensors to aid in the identification of the water/beach interface acquired with the instrument in coastal mapping applications.

Table 5. 14-word qfit Format (in use since between 1997 and 2004) Parameter Description

Column	Description	Units with Scale Factor
1	Relative Time measured from start of file	Seconds 10^{-3}
2	Laser Spot Latitude	Degrees x 1,000,000
3	Laser Spot Longitude	Degrees x 1,000,000
4	Elevation	Meters 10^{-3}
5	Start Pulse Signal Strength (relative)	Dimensionless relative values (or data numbers, DN)
6	Reflected Laser Signal Strength (relative)	Dimensionless relative values (or data numbers, DN)
7	Scan Azimuth	Degrees x 1000
8	Pitch	Degrees x 1000
9	Roll	Degrees x 1000
10	Passive Signal (relative)	Dimensionless relative values
11	Passive Footprint Latitude	Degrees x 1,000,000
12	Passive Footprint Longitude	Degrees x 1,000,000
13	Passive Footprint Synthesized Elevation	Millimeters
14	GPS Time packed	example: 153320100 = 15h 33m 20s 100ms

1.5.2 Sample Data Record

Below is an ASCII format excerpt of the 20080627_134422.atm4cT3.rangeExample.qi data file converted from binary. The 12 fields in each record correspond to the columns described in Table 3.

```
#
REL_TIME,LATITUDE,LONGITUDE,ELEVATION,strt_pulse_sigstr,ref_sigstr,azi,p
itch,roll,GPS_dil_prec,pulse_width,TIME-HHMMSS
  0.000000 69.8458700 -46.1178110 2129.953    4063  1076   256
0.730       0.225     35.0        8.0 134438.000000
  0.000000 69.8458700 -46.1178110 2129.960    4136   927   256
0.730       0.224     35.0        7.0 134438.000000
  0.000000 69.8458700 -46.1178110 2129.960    4115  1131   256
0.729       0.224     35.0        7.0 134438.000000
  0.000000 69.8458700 -46.1178120 2129.898    4362  1216   256
0.729       0.223     35.0        7.0 134438.000000
  0.001000 69.8458700 -46.1178120 2129.901    4163   997   256
0.728       0.223     35.0        7.0 134438.001000
  0.001000 69.8458700 -46.1178130 2129.831    4034   950   256
0.728       0.223     35.0        6.0 134438.001000
  0.001000 69.8458700 -46.1178130 2129.879    4209  1179   256
0.728       0.222     35.0        7.0 134438.001000
  0.001000 69.8458700 -46.1178130 2129.927    3999  1129   256
0.727       0.222     35.0        7.0 134438.001000
  0.001000 69.8458700 -46.1178140 2129.887    4296  1231   256
0.727       0.222     35.0        6.0 134438.001000
  0.002000 69.8458700 -46.1178140 2129.876    3942  1047   256
0.727       0.221     35.0        6.0 134438.002000
```

Figure 1. ASCII format excerpt of the 20080627_134422.atm4cT3.rangeExample.qi data file converted from the binary.

2 SOFTWARE AND TOOLS

2.1 Software and Tools

The elevation measurement files contain qfit binary data. The qfit format was developed for use at Wallops Flight Facility (WFF). LAStools can read and write NASA ATM qfit format.

3 DATA ACQUISITION AND PROCESSING

3.1 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.

The fundamental form of the ATM topography data is a sequence of laser footprint locations acquired in a swath along the aircraft flight track.

Prior to 2008 surveys, the GPS trajectory was edited to restrict PDOP<9 in order to limit GPS errors to be less than roughly 5 cm. The output survey data would therefore have occasional gaps where the PDOP>9. Some applications of ATM data have less stringent accuracy requirements that would be better served by preserving the data in these gaps. Starting in 2008, the PDOP limit was changed to 20, which could allow occasional GPS errors up to about 15 cm. The PDOP value is carried in the qfit output and can be used to edit data for applications requiring greater precision. Any file in the 10-word format, or files in the 12-word format processed prior to January 2009, will have PDOP limited.

3.2 Data Acquisition Methods

The ATM deployments included two lidar systems whenever the aircraft platform would allow. The redundancy reduced the risk of hardware failures and provided a means of validating modifications to the lidar. The data were processed from both instruments up to a point, but then efforts concentrated on refining and delivering data from a single lidar. Each campaign therefore has a "primary" lidar, and sometimes a "secondary" lidar. This data set contains only data from the primary lidar.

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.

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. 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.

3.3.1 Processing

The processing program, qfit, combines airborne laser ranging data and aircraft attitude from the Inertial Navigation System (INS) with positioning information from a processed kinematic differential Global Positioning System (GPS) trajectory.

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 3.

3.3.2 Sensor or Instrument Description

ATM is an airborne lidar instrument developed at NASA's Wallops Flight Facility (WFF) for observing the Earth's topography for several scientific applications, foremost of which is the measurement of changing Arctic and Antarctic icecaps and glaciers. ATM measures surface elevation of ice by timing laser pulses transmitted from the aircraft, reflected from the ground, and returned 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 altitude information. 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.

4 REFERENCES AND RELATED PUBLICATIONS

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. doi: 10.1029/2011JC007654.

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. https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120008479_2012008321.pdf

Yi, Donghui, Jeremy P. Harbeck, Serdar Manizade, Nathan T. Kurtz, Michael Studinger, and Michelle A. Hofton. 2015. Arctic Sea Ice Freeboard Retrieval With Waveform Characteristics for NASA's Airborne Topographic Mapper (ATM) and Land, Vegetation, and Ice Sensor (LVIS). IEEE Trans. Geoscience and Remote Sensing 53(3): 1403-1410. doi: 10.1109/TGRS.2014.2339737.

4.1 Related Data Collections

- IceBridge ATM L1B Qfit Elevation and Return Strength
- IceBridge Narrow Swath ATM L1B Qfit Elevation and Return Strength
- IceBridge ATM L2 Icessn Elevation, Slope, and Roughness
- Pre-IceBridge ATM L2 Icessn Elevation, Slope, and Roughness
- USGS United States Antarctic Resource Center LIDAR High-resolution DEM Final DATA Downloads (DEMs created from ATM Data)

4.2 Related Websites

- Airborne Topographic Mapper at NASA
- Description of ATM QFIT Output Data (revised 13 February 2009)
- Description of DEM Generation, Dry Valleys, Antarctica
- IceBridge Data at NSIDC
- IceBridge at NASA
- ICESat/GLAS at NASA
- ICESat/GLAS at NSIDC

5 CONTACTS AND ACKNOWLEDGMENTS

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6 DOCUMENT INFORMATION

6.1 Publication Date

05 August 2016

6.2 Date Last Updated

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