IceBridge ATM L2 Icessn Elevation, Slope, and Roughness, Version 1

USER GUIDE

How to Cite These Data

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

Krabill, W. B. 2010, updated 2014. *IceBridge ATM L2 Icessn Elevation, Slope, and Roughness, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/FCCZIIFRPZ3O. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ILATM2

National Snow and Ice Data Center

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1 DETAILED DATA DESCRIPTION

1.1 Format

The ATM L2 Icessn Elevation, Slope, and Roughness data files are in fixed-width, space-delimited ASCII text format.

Note: Currently V01 ILATM2 data for 2009 through 2012 are in fixed-width, space-delimited ASCII format. Beginning with the 2013 Arctic campaign, all data will be provided in CSV format. In the near future, data from all campaigns prior to Spring 2013 will be replaced with CSV data and added to V02. For details on the V02 data, see the V02 documentation.

1.2 File Naming Convention

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

```
ILATM2_20121108_000047_50pt_smooth_nadir3seg
```

```
ILATM2_YYYYMMDD_HHMMSS_50pt_smooth_nadir3seg
```

Where:

Table 1. File Naming Convention

Variable	Description
ILATM2	File name prefix indicating ATM L2 data
YYYY	four-digit year
MM	two-digit month
DD	two-digit day
HH	start time: two-digit hours
MM	start time: two-digit minutes
SS	start time: two-digit seconds
50pt	50% overlap between successively smoothed blocks
smooth	alongtrack values smoothed in icessn process
nadir3seg	nadir block plus 3 off-nadir blocks per time stamp

A summary file is included for each data file. Summary files contain information for start time, stop time, swath width, segments, output interval, smoothing interval, minimum data points, comments and icessn and qfit processing header information.

Summary files are named according to the following convention and as described in Table 2:

```
ILATM2_20121108_000047_50pt_icessn_summary
```

```
ILATM2_YYYYMMDD_HHMMSS_50pt_icessn_summary
```

Where:

Table 2. Summary File Naming Convention

Variable	Description
ILATM2	File name prefix indicating ATM L2 data
YYYY	four-digit year
MM	two-digit month
DD	two-digit day
HH	start time: two-digit hours
MM	start time: two-digit minutes
SS	start time: two-digit seconds
50pt	50% overlap between successively smoothed blocks
icessn	format of smoothed data and reduced data volume
summary	summary file for corresponding icessn file

1.3 File Size

Elevation measurement files are approximately 26 KB to 350 KB.
Summary files are approximately 7 KB each.

1.4 Volume

The entire data set is approximately 5.5 GB.

1.5 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

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

1.5.1 Spatial Resolution

The ATM surface elevation measurements have been re-sampled at a variable along-track time interval, typically 0.5 seconds, which at aircraft survey speed is a distance along the flight track of approximately 50 meters. The distance can vary with aircraft speed. Each set of along-track records contains a fixed 80 m across-track nadir platelet as well as three or five additional platelets that together span the entire swath of the ATM scan. This data set contains data from one of two different ATM sensors depending on the year the data were collected. The ATM 15-degree off-nadir scanner (T2) has an off-nadir scan angle of 15 degrees and these data were smoothed into three across-track platelets. The ATM 23-degree off-nadir scanner (T3) has an off-nadir scan angle of 23 degrees and is smoothed into five across-track platelets. The across-track widths of these three to five additional platelets can vary with aircraft altitude.

1.5.2 Projection and Grid Description

No projection. Data are georeferenced to WGS-84.

1.6 Temporal Coverage

These data were collected as part of Operation IceBridge funded campaigns from 31 March 2009 to 08 November 2012.

1.6.1 Temporal Resolution

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

1.7 Parameter or Variable

The ATM L2 Icessn Elevation, Slope, and Roughness data set includes glacier, ice sheet, and sea ice elevation measurements, slope measurements, and roughness measurements.

1.7.1 Parameter Description

Icessn data files contain parameters as defined in Table 3.

Table 3. Parameters, Units, and Range

Column	Description	Units	Range
1	Time at which the aircraft passed the mid-point of the block.	Seconds of the day in GPS time. As of 01 January 2009 GPS time = UTC + 15 seconds.	0 to 86400
2	Latitude of the center of the block.	Degrees	-90.0 to +90.0
3	East longitude of the center of the block.	Degrees	0.0 to 360.0
4	Height above WGS84 ellipsoid of the center of the block.	Meters	-100.0 to 10000.0
5	South to North slope of the block.	Dimensionless	any real value
6	West to East slope of the block.	Dimensionless	any real value
7	RMS fit of the ATM data to the plane.	Centimeters	Greater than 0.0
8	Number of points used in estimating the plane parameters.	Count	Greater than 0
9	Number of points removed in estimating the plane parameters.	Count	Greater than or equal to 0
10	Distance of the center of the block from the centerline of the aircraft trajectory (starboard = positive, port = negative).	Meters	real valued
11	Track identifier (numbered 1...n, starboard to port, and 0 = nadir).	Number	0, 1, 2, …

1.7.2 Sample Data Record

Figure 1 shows an excerpt from data file `090427_163654_smooth_nadir3seg_50pt`. The 11 columns in each record correspond to the columns described in Table 3.

59793.056	68.739359	310.257147	844.1786	-0.0226757	-0.0142736	22.42	921	3	73.	1
59793.056	68.739358	310.254909	845.3539	-0.0291822	-0.0149611	22.6	566	0	-1.7	2
59793.056	68.739356	310.252671	846.0009	-0.0218291	-0.0025508	14.13	1092	7	-107.	3
59793.056	68.739358	310.255325	845.1127	-0.0296985	-0.0162622	22.53	502	0	0.	0
59793.306	68.739678	310.25713	843.5832	-0.0142713	-0.0152234	29.5	920	2	73.	1
59793.306	68.739678	310.254871	844.5059	-0.0197343	-0.0117538	29.28	560	0	-18.	2
59793.306	68.739677	310.252612	845.3043	-0.016689	-0.0042611	18.42	1067	1	-109.	3

Figure 1. Sample Data Record

2 SOFTWARE AND TOOLS

2.1 Software and Tools

NSIDC provides a MATLAB reader that reads ATM icessn data files from the Operation IceBridge Airborne Topographic Mapper instrument. The elevation measurement files and the summary files also may be opened by any text editor or word processing program that reads ASCII text files.

3 DATA ACQUISITION AND PROCESSING

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.

3.1 Data Acquisition Methods

The ATM instrument package includes suites of LIDAR, GPS and attitude measurement subsystems. The instrument package is installed onboard the aircraft platform and calibrated during ground testing procedures. Installation mounting offsets, the distances between GPS and attitude sensors and the ATM LIDARs, are measured using surveying equipment. One or more ground survey targets, usually aircraft parking ramps, are selected and surveyed on the ground using differential GPS techniques. Prior to missions, one or more GPS ground stations are established by acquiring low rate GPS data over long time spans. Approximately one hour prior to missions both the GPS ground station and aircraft systems begin data acquisition. During the aircraft flight, the ATM instrument suite acquires LIDAR, GPS and attitude sensor data over selected targets, including several passes at differing altitudes over the selected ground survey

calibration sites. The aircraft and ground systems continue to acquire data one hour post-mission. Instrument parameters estimated from the surveys of calibration sites are used for post-flight calculation of laser footprint locations. These parameters are later refined using inter-comparison and analysis of ATM data where flight lines cross or overlap.

3.2 Derivation Techniques and Algorithms

The ATM surface elevation measurements have been re-sampled into an icessn format which smoothes the data and reduces the data volume. Users desiring unsampled data should use the ATM Level-1B Qfit format data.

The fundamental form of ATM topography data is a sequence of laser footprint locations acquired in a swath along the aircraft flight track. The icessn program condenses the ATM surface elevation measurements by fitting a plane to blocks of points selected at regular intervals along track and several across track. The block size and spacing can be specified, but a few typical values are used. The along-track distance smoothed is the distance which the aircraft moves in a fixed interval, 0.5 seconds for P-3 and DC8 aircraft, and 1.0 seconds for DHC-6 Twin-Otter. The data output interval is half of the smoothing interval so that there is 50 percent overlap between successively smoothed blocks. For each along-track position/time, there are multiple blocks spaced evenly across-track to span the swath width. Typically the number of blocks is five for the T3 scanner and three for the T2 scanner. There is an additional block located at aircraft nadir with a width typically set to 80 m. If a single profile is desired, the nadir profile can be selected from the full data set.

The two slopes estimated are used to estimate surface elevations at points other than the center point through the use of the following algorithm shown in the equation below and as described in Table 4:

ht(phi,lambda) = ht(phi0,lambda0) + SNslope * (phi - phi0) * 6378137 * pi/180
+ WEslope * (lambda - lambda0) * cos(phi0) * 6378137 * pi/180

Table 4. Surface Elevations Estimate Algorithm Variables

Variables	Description
ht	height in meters at coordinates (phi, lambda)
phi	latitude at location of interest (radians)
lambda	longitude at location of interest (radians)
phi0	latitude at center of tile (radians)
6378137	WGS84 ellipsoid semi-major axis (meters)
lambda0	longitude at center of tile (radians)

Variables	Description
SNslope	south/north slope of the tile
WEslope	west/east slope of the tile

Note: The multiple across-track planes at a given along-track position will have the same time tag.

3.2.1 Processing Steps

The following processing steps are performed by the data provider.

1. Preliminary processing of ATM LIDAR data through the cvalid program, applying calibration factors to convert time of flight to range, scan pointing angles and interpolated attitude to each LIDAR measurement.
2. Processing of GPS data into aircraft trajectory files using double-differenced dual-frequency carrier phase-tracking.
3. Processing of the cvalid program output combined with the GPS trajectory data through the qfit program, resulting in an output file containing a surface elevation (ellipsoid height) and a geographic location in latitude and east longitude with other ancillary parameters.
4. Processing of the qfit output through the icessn program which averages the qfit surface elevation data into a small number of blocks or surface planes.

3.2.2 Errors and Limitations

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 April 28, 2012 flight traversed the notoriously turbulent regions of 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. Following this event, the flight followed the Ikerssuaq flow line, then traversed straight 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 Level-1B T4 data were supplemented by the these Level-1B 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 ATM L1B Qfit Elevation and Return Strength data in the /2012.04.28/ folder. For details on the ATM 4BT3 and 4BT4 instruments, see the Sensor Or Instrument Description section below, and the IceBridge Narrow Swath ATM L1B Qfit Elevation and Return Strength data set documentation.

3.3 Sensor or Instrument Description

The ATM is an airborne LIDAR instrument used by NASA for observing the Earth's topography for several scientific applications, foremost of which is the measurement of changing Arctic and Antarctic icecaps and glaciers. The ATM instrument is a scanning airborne laser that measures surface elevation of the ice by timing laser pulses transmitted from the aircraft, reflected from the ground and returning to the aircraft. This laser pulse time-of-flight information is used to derive surface elevation measurements by combining measurement of the scan pointing angle, precise GPS trajectories and aircraft attitude information. The ATM instrument measures topography as a sequence of points scanned in a swath along the aircraft flight track. The sampling frequency for the ATM is 5 kHz.

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 Dryden Air Force Base in Palmdale, California. During previous campaigns, the ATM has flown aboard other P-3 aircraft, several de

Havilland Twin Otters (DHC-6), and a C-130. The ATM has been used for surveys flown in Greenland nearly every year since 1993. Other uses have included measurement of sea ice, verification of satellite radar and laser altimeters, and measurement of sea-surface elevation and ocean wave characteristics. The ATM often flies in conjunction with a variety of other instruments and has been participating in NASA's Operation IceBridge since 2009.

4 REFERENCES AND RELATED PUBLICATIONS

Brunt, K. M., Hawley, R. L., Lutz, E. R., Studinger, M., Sonntag, J. G., Hofton, M. A., Andrews, L. C., and Neumann, T. A. 2017. Assessment of NASA airborne laser altimetry data using ground-based GPS data near Summit Station, Greenland, *The Cryosphere*, 11:681-692. doi:10.5194/tc-11-681-2017.

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.

4.1 Related Data Collections

- 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
- IceBridge ATM L1B Elevation and Return Strength
- Pre-IceBridge ATM L1B Qfit Elevation and Return Strength
- Pre-IceBridge ATM L2 Icessn Elevation, Slope, and Roughness
- Trajectory Maps - ATM
- 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 Web site at NASA Wallops Flight Facility
- Description of DEM Generation, Dry Valleys, Antarctica
- IceBridge Data Web site at NSIDC
- IceBridge Web site at NASA
- ICESat/GLAS Web site at NASA Wallops Flight Facility
- ICESat/GLAS Web site at NSIDC

5 CONTACTS AND ACKNOWLEDGMENTS

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5.1 Acknowledgments

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

6 DOCUMENT INFORMATION

6.1 Publication Date

10 January 2011

6.2 Date Last Updated

29 January 2014