ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics, Version 5

USER GUIDE

How to Cite These Data

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

Palm, S. P., Y. Yang, U. C. Herzfeld, D. Hancock, K. A. Barbieri, J. Wimert, and the ICESat-2 Science Team. 2021. *ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics, Version 5*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL09.005. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL09

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION 2
1.1 Parameters 2
1.2 File Information 2
1.2.1 Format 2
1.2.2 ATLAS/ICESat-2 Description 2
1.2.3 File Naming Convention 5
1.2.4 Data Groups 6
1.2.5 Browse File 7
1.2.6 File Size 8
1.3 Spatial Information 8
1.3.1 Coverage 8
1.3.2 Resolution 8
1.3.3 Geolocation 9
1.4 Temporal Information 9
1.4.1 Coverage 9
1.4.2 Resolution 9
2 DATA ACQUISITION AND PROCESSING 9
2.1 Background 9
2.2 Acquisition 10
2.2.1 Inputs 11
2.2.2 Outputs 11
2.3 Processing 12
2.3.1 Calibrated Attenuated Backscatter (CAB) 12
2.3.2 Apparent Surface Reflectance 13
2.3.3 Cloud Detection 13
2.4 Quality, Errors, and Limitations 13
3 VERSION HISTORY 14
4 CONTACTS AND ACKNOWLEDGMENTS 15
4.1 Investigators 15
5 REFERENCES 15
6 DOCUMENT INFORMATION 16
6.1 Publication Date 16
6.2 Date Last Updated 16

1 DATA DESCRIPTION

1.1 Parameters

Calibrated, Attenuated Backscatter (CAB) profiles, layer integrated attenuated backscatter, plus other parameters including cloud layer height and other atmospheric characteristics obtained from the data.

1.2 File Information

1.2.1 Format

Data are provided as HDF5 formatted files. HDF is a data model, library, and file format designed specifically for storing and managing data. For more information about HDF, visit the HDF Support Portal.

The HDF Group provides tools for working with HDF5 formatted data. HDFView is free software that allows users to view and edit HDF formatted data files. In addition, the HDF - EOS | Tools and Information Center web page contains code examples in Python (pyhdf/h5py), NCL, MATLAB, and IDL for accessing and visualizing ICESat-2 files.

1.2.2 ATLAS/ICESat-2 Description

NOTE: The following brief description of the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) observatory and Advanced Topographic Laser Altimeter System (ATLAS) instrument is provided to help users better understand the file naming conventions, internal structure of data files, and other details referenced by this user guide. The ATL09 data product is described in detail in the ICESat-2 Algorithm Theoretical Basis Document for the Atmosphere, Part I: Level 2 and 3 Data Products (ATBD for ATL04/ATL09 | V05, DOI: 10.5067/JEB9UVKJUSXV) and Part II: Level 2 and 3 Data Products (ATBD for ATL09 | V05, DOI: 10.5067/48PJ5OUJOP4C).

The ATLAS instrument and ICESat-2 observatory utilize a photon-counting lidar and ancillary systems (GPS and star cameras) to measure the time a photon takes to travel from ATLAS to Earth and back again and to determine the photon's geodetic latitude and longitude. Laser pulses from ATLAS illuminate three left/right pairs of spots on the surface that as ICESat-2 orbits Earth trace out six ground tracks that are typically about 14 m wide. Each ground track is numbered according to the laser spot number that generates it, with ground track 1L (GT1L) on the far left and ground track 3R (GT3R) on the far right. Left/right spots within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction. The ATL09 data product is organized by ground track, with ground tracks 1L and 1R forming pair one, ground tracks 2L and 2R forming pair two, and ground tracks 3L and 3R forming pair three. Each pair also has a Pair

Track—an imaginary line halfway between the actual location of the left and right beams (see figures 1 and 2). Pair tracks are approximately 3 km apart in the across-track direction.

The beams within each pair have different transmit energies—so-called weak and strong beams—with an energy ratio between them of approximately 1:4. The mapping between the strong and weak beams of ATLAS, and their relative position on the ground, depends on the orientation (yaw) of the ICESat-2 observatory, which is changed approximately twice per year to maximize solar illumination of the solar panels. The forward orientation corresponds to ATLAS traveling along the +x coordinate in the ATLAS instrument reference frame (see Figure 1). In this orientation, the weak beams lead the strong beams and a weak beam is on the left edge of the beam pattern. In the backward orientation, ATLAS travels along the -x coordinate, in the instrument reference frame, with the strong beams leading the weak beams and a strong beam on the left edge of the beam pattern (see Figure 2). The first yaw flip was performed on December 28, 2018, placing the spacecraft into the backward orientation. ATL09 reports the spacecraft orientation in the sc_orient parameter stored in the /orbit_info/ data group (see Section 1.2.4 Data Groups). In addition, the current spacecraft orientation, as well as a history of previous yaw flips, is available in the ICESat-2 Major Activities tracking document (.xlsx).

The Reference Ground Track (RGT) refers to the imaginary track on Earth at which a specified unit vector within the observatory is pointed. During nominal operating conditions onboard software aims the laser beams so that the RGT is between ground tracks 2L and 2R (i.e. coincident with Pair Track 2). The ICESat-2 mission acquires data along 1,387 different RGTs. Each RGT is targeted in the polar regions once every 91 days (i.e. the satellite has a 91-day repeat cycle) to allow elevation changes to be detected. Cycle numbers track the number of 91-day periods that have elapsed since the ICESat-2 observatory entered the science orbit. RGTs are uniquely identified by appending the two-digit cycle number (cc) to the RGT number, e.g. 0001cc to 1387cc.

Under normal operating conditions, no data are collected along the RGT; however, during spacecraft slews, or off-pointing, some ground tracks may intersect the RGT. Off-pointing refers to a series of plans over the mid-latitudes that have been designed to facilitate a global ground and canopy height data product with approximately 2 km track spacing. Off-pointing began on 1 August 2019 with RGT 518, after the ATLAS/ICESat-2 Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions had been adequately resolved and the instrument had pointed directly at the reference ground track for at least a full 91 days (1387 orbits).

Users should note that sometimes, for various reasons, the spacecraft pointing may lead to ICESat-2 data collected not along the nominal RGT, but offset at some distance from the RGTs. Although not along the nominal RGT, the geolocation information and data quality for these data is not degraded. As an example, from 14 October 2018 and 30 March 2019 the spacecraft pointing control was not yet optimized. To identify such time periods, refer to the ICESat-2 Major Activities file.

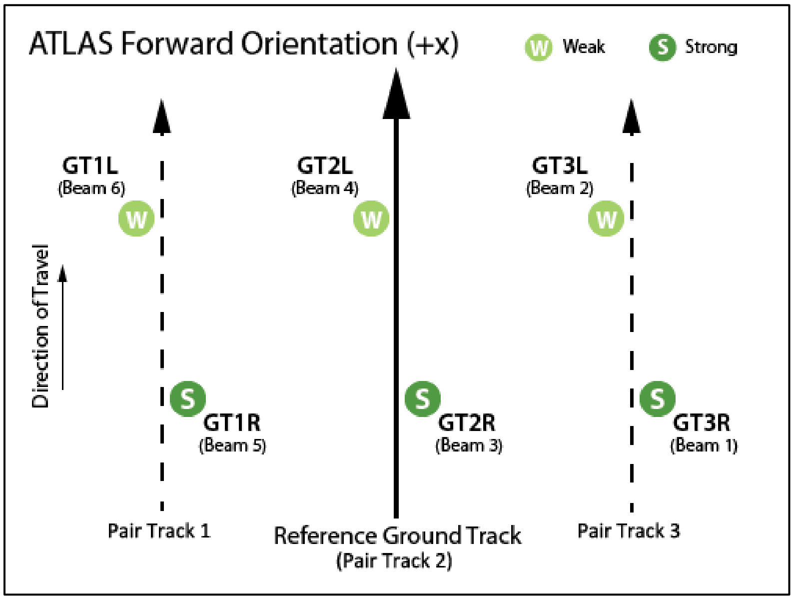

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

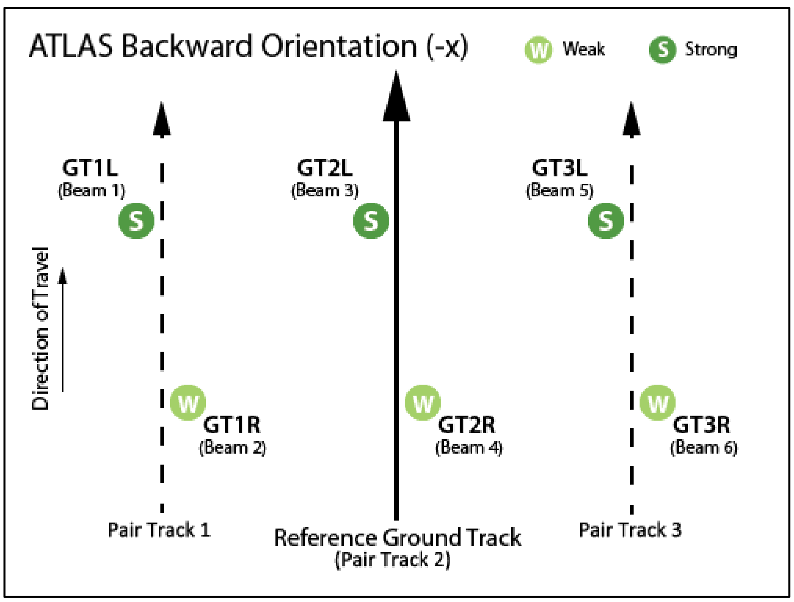

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

NOTE: ICESat-2 reference ground tracks with dates and times can be downloaded as KMZ files from NASA's ICESat-2 | Technical Specs page, below the Orbit and Coverage table.

Unlike ATLAS-derived altimetry, which utilizes both weak and strong beams, atmospheric profiles are generated from strong beams only: beams 1, 3, and 5. The ATL09 product contains three corresponding atmospheric profiles numbered 1, 2, and 3 from left to right, relative to the direction of spacecraft travel. Note, however, that the instrument orientation determines which beam corresponds to which profile. With ATLAS in the forward spacecraft orientation (+x), beam 1 lies to the left of the nadir ground track (profile 1), beam 3 lies along the nadir track (profile 2), and beam 5 is to the right (profile 3). The backward orientation reverses the locations on the ground of beams 1 and 5 (beam 3 remains in the center regardless of orientation), with beam 5 to the left of nadir (profile 1) and beam 1 (profile 3) to the right.

1.2.3 File Naming Convention

ATL09 data are provided as granules (files) that span one orbit (i.e. one RGT). Data files utilize the following naming convention:

Example:

- ATL09_20181221123517_04890103_005_01.h5
- ATL09_[yyyymmdd][hhmmss]_[RGTccss]_[vvv_rr].h5

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL09	ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics data product
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Hour, minute, and second of data acquisition (UTC)
RGT	Reference Ground Track. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle Number. Each of the 1387 RGTs is targeted in the polar regions once every 91 days. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.
ss	Segment number, always "01" for ATL04/ATL09.[1]
vvv_rr	Version and revision number.[2]

NOTE:

[1] Some ATLAS/ICESat-2 products (e.g. ATL03) are provided as files that span 1/14th of an orbit. As such, these products' file names specify a segment number that ranges from 01 to 14. Because ATL04 and ATL09 data files span one full orbit, the segment number is always set to 01.

[2] From time to time, NSIDC receives duplicate, reprocessed granules from our data provider. These granules have the same file name as the original (i.e. date, time, ground track, cycle, and segment number), but the revision number has been incremented. Although NSIDC deletes the superseded

granule, the process can take several days. As such, if you encounter multiple granules with the same file name, please use the granule with the highest revision number.

Each data file has a corresponding XML file that contains additional science metadata. XML metadata files have the same name as their corresponding .h5 file, but with .xml appended.

1.2.4 Data Groups

Within data files, similar variables such as science data, instrument parameters, orbit information, and metadata are grouped together according to the HDF model. ATL09 data files contain the top-level groups shown in the following figure:

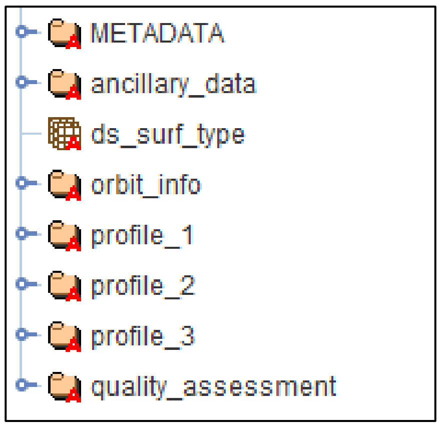

Figure 3. Top level data groups displayed in HDFView.

The following sections summarize the structure and primary variables of interest in ATL09 data files. Additional details are available in "Section 4.2 | L3 Outputs" of the ATBD for ATL09. For a complete list of all ATL09 parameters, see the ATL09 Data Dictionary.

1.2.4.1 METADATA

ISO19115 structured summary metadata.

1.2.4.2 ancillary_data

Ancillary information such as product and instrument characteristics and processing constants.

1.2.4.3 orbit_info

Parameters that are constant for a granule, such as the RGT number, cycle number, and spacecraft orientation (sc_orient).

1.2.4.4 profile_[x]

The profile_1, profile_2, and profile_3 data groups each contain three subgroups:

/bckgrd_atlas/

- ATLAS 50-shot background data and derivations from ATL03 used to determine the background for method 3 (see Section 7.3, ATBD for ATL03 and Section 3.3.4,, ATBD for ATL09);

/high_rate/

- Parameters related to Calibrated Attenuated Backscatter (CAB) at 25 Hz, including: CAB profiles (cab_prof) from -1 to 20 km for the leftmost, center, and rightmost groundtracks with respect to the satellite direction of motion; latitudes and longitudes; parameters related to the background calculation; blowing snow layer characteristics; cloud characteristics; atmospheric payer characteristics; and high-, medium-, and low-confidence signal photon counts and statistics.

/low_rate/

- Parameters related to atmospheric characteristics at 1 Hz, including blowing snow layer characteristics; atmospheric layer characteristics (pressure; specific humidity; temperature; total column liquid water and cloud ice; and component winds).

1.2.4.5 quality assessment

Quality assessment data for the granule as a whole, plus summary QA data. QA parameters include statistical metrics for each profile related to: CAB and Apparent Surface Reflectance; cloud detection results; cloud optical depth (COD); surface detection; and ocean surface reflectance.

1.2.4.6 ds_surf_type

This parameter, stored at the top level along side the data groups, is a dimension scale variable indexing the surface type array (/profile_[x]/surf_type).

1.2.5 Browse File

Browse files are provided in HDF5 format that contain images designed to quickly assess the location and quality of each granule's data.

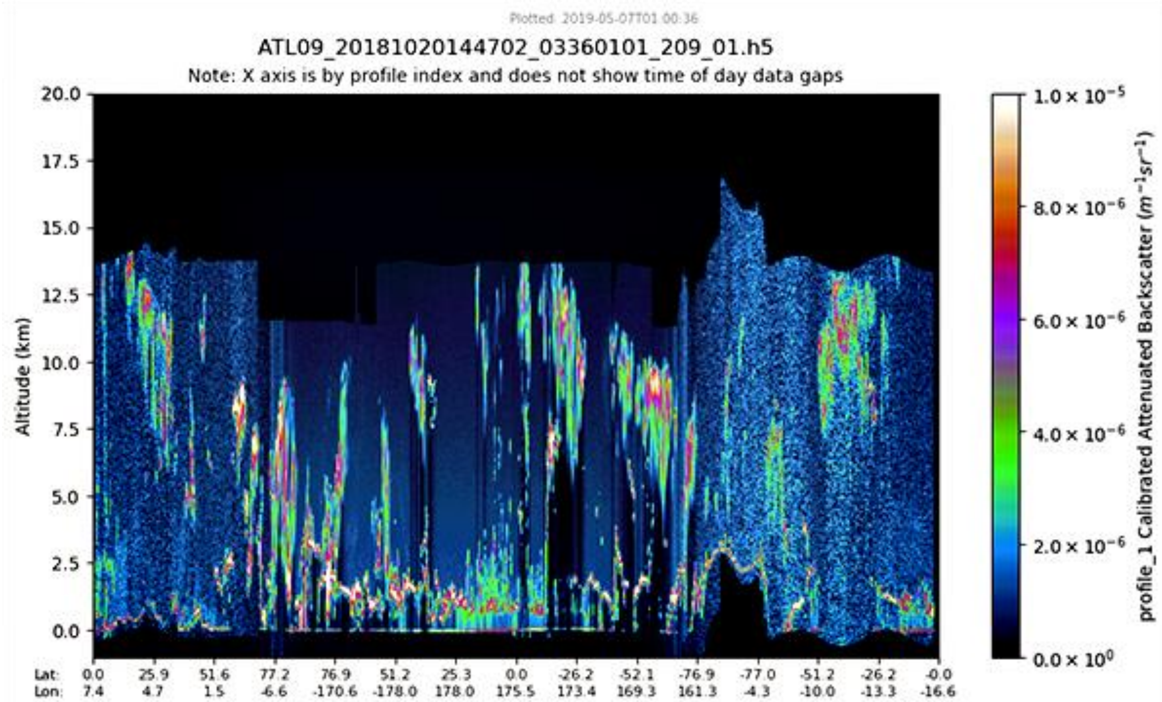

Figure 4. Sample browse image (cab_profile) showing calibrated attenuated backscatter.

Browse files utilize the same naming convention as their corresponding data file, but with _BRW appended. For example:

- ATL09_20181221123517_04890103_005_01.h5
- ATL09_20181221123517_04890103_005_01_BRW.h5

1.2.6 File Size

Data files range in size from 2 to 3 GB.

1.3 Spatial Information

1.3.1 Coverage

The ICESat-2 mission acquires data along 1,387 different reference ground tracks. The atmospheric profiles consist of 30 m vertical bins in a 14 km long (upward) column.

1.3.2 Resolution

Approximately 280m along-track resolution (400 shots). The atmospheric profiles consist of 467, 30 meter bins, vertically aligned within a larger data frame of 700 bins that spans -1 km to 20 km with respect to the ellipsoid.

1.3.3 Geolocation

The following table provides information this data set's coordinate system.

Table 2. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	WGS 84
Longitude of true origin	Prime Meridian, Greenwich
Latitude of true origin	N/A
Scale factor at longitude of true origin	N/A
Datum	World Geodetic System 1984
Ellipsoid/spheroid	WGS 84
Units	degree
False easting	N/A
False northing	N/A
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

1.4 Temporal Information

1.4.1 Coverage

14 October 2018 to 12 October 2022

1.4.2 Resolution

Each of ICESat-2's 1387 RGTs is targeted in the polar regions once every 91 days (i.e. the satellite has a 91-day repeat cycle).

Note that satellite maneuvers, data downlink issues, and other events can introduce data gaps into the ICESat-2 suite of products. As ATL03 acts as the bridge between the lower level, instrumentation-specific data and the higher-level products. On the data set landing page under technical references users can download and consult a regularly updated list of ATL03 data gaps (.xlsx).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATL09 consists of Calibrated, Attenuated Backscatter (CAB) profiles, plus other parameters including layer integrated attenuated backscatter, cloud layer height, and numerous atmospheric characteristics obtained from the data. CAB is generated from the Normalized Relative Backscatter (NRB) profiles and calibration constant computed in the ATL04 product. The following figure shows the ATLAS/ICESat-2 data processing flow.

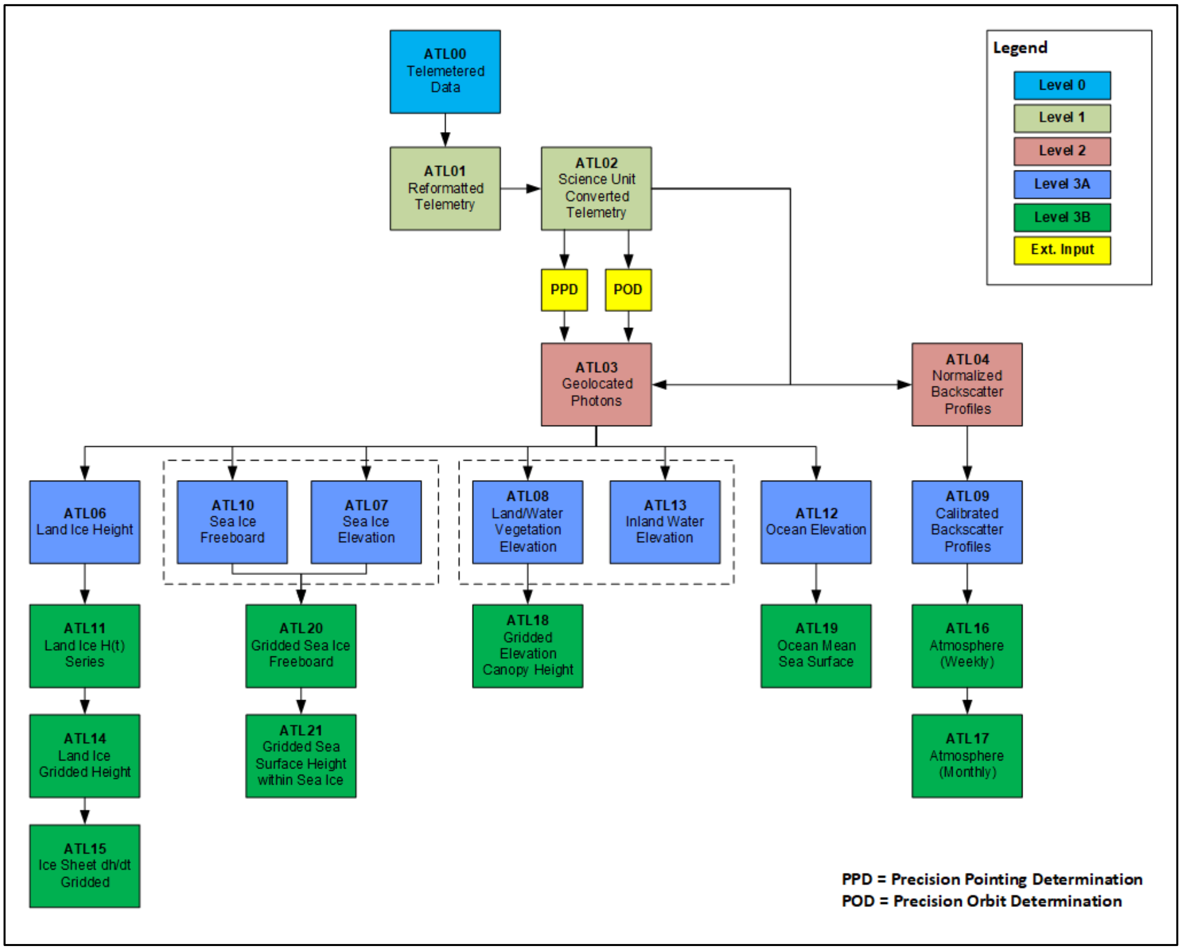

Figure 5. Schematic of the ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level-0 data and converts it into engineering units. ATL02 processing converts ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time.

2.2 Acquisition

The ATLAS instrument transmits green (532 nm) laser pulses at 10 kHz. At the nominal ICESat-2 orbit altitude of 500 km, this yields approximately one transmitted laser pulse every 0.7 meters along ground tracks. The three strong beams are downlinked after summing 400 pulses (280 m along-track resolution). The vertical data frame comprises 700, 30 meter bins that span -1 km to 20 km above the ellipsoid.

Within the larger data frame, the atmospheric profiles consist of 467, 30 meter vertically aligned bins extending upward in a column from -0.250 km to, nominally, 13.75 km above the local value of the onboard Digital Elevation Model DEM. However, various altimetry and calibration related activities will at times cause the top of the atmospheric profile to be lower than the nominal 13.75 km value.

2.2.1 Inputs

The following inputs are used to generate the ATL09 product:

- The current ATL04 granule, plus the preceding and subsequent granules;
- NOAA Global Multi-sensor Snow/Ice Cover Map;
- Surface albedo (produced by the ICESat-2 Science Team. See Section 4.6.2, ATBD for ATL09)

Algorithm adjustable parameters that are read in and used by the ATL09 algorithm are listed in Table 4.2 of the ATBD for ATL09.

2.2.2 Outputs

ATL09 contains numerous parameters related to CAB, blowing snow, and atmospheric characteristics. Output parameters are listed in Table 4.1 of the ATBD for ATL09. The following list contains the location of some of the key ATL09 output parameters. References to ATL04 denote values that are input from the ATL04 product. All other values are computed within ATL09:

- **profile_[x]/high_rate/ (25 Hz)**
  - back_c — background (ATL04)
  - backg_theoret — theoretical background
  - bsnow_h — height, blowing snow layer top (also provided at 1 Hz)
  - bsnow_od — optical depth, blowing snow layer (also provided at 1 Hz)
  - cab_prof — calibrated attenuated backscatter profile
  - cloud_conf_flag_asr — cloud probability from apparent surface reflectance
  - cloud_flag_atm — number of cloud/aerosol layers detected computed
  - column_od_asr — optical depth of atmosphere column from apparent surface reflectance
  - layer_attr — layer type flag (cloud, aerosol, or unknown)
  - layer_bot — height, bottom of detected layers
  - layer_con — layer confidence flag
  - layer_ib — layer integrated backscatter
  - layer_top — height, top of detected layers
  - ocean_surf_reflec — ocean surface reflectance

- **profile_[x]/low_rate/ (1 Hz)**
  - bsnow_h — height, blowing snow layer top (also provided at 25 Hz)
  - bsnow_od — optical depth, blowing snow layer (also provided at 25 Hz)
  - mol_backscatter — molecular backscatter profile (ATL04)
  - cal_c — calibration coefficient for each beam
- **ancillary_data/atmosphere/ (1 per granule)**
  - backg_select — method used to calculate background (ATL04)
  - cal_select — the calibration method used in the NRB calculation (ATL04)

2.3 Processing

2.3.1 Calibrated Attenuated Backscatter (CAB)

The following section briefly describes the approach used to compute CAB from Normalized Relative Backscatter (NRB). For a complete description, see Section 3.3 of the ATBD for ATL09.

CAB profiles are computed by simply dividing NRB profiles by a calibration coefficient which is computed in ATL04 and passed to ATL09. To compute NRB, three corrections are applied to the raw level 0 data: laser energy normalization, range square correction, and background subtraction. The lidar equation is:

$$S(z) = \frac{CE\beta(z)T^2(z)}{r^2} + p_b + p_d$$

In the equation above, S(z) is the measured raw signal (photons) at height z; r is the range from the spacecraft to the height z; C is the lidar system calibration coefficient; E is the laser energy; β(z) is the 180° backscatter coefficient at height z; T(z) is the one way atmospheric transmission from the spacecraft to height z; p_b the solar background; and p_d the detector dark count rate.

NRB is generated for each of the strong beams using:

$$NRB(z) = \frac{(S(z) - p_b - p_d)r^2}{E}$$

CAB is then computed by dividing the NRB by the calibration coefficient C:

$$\beta(z)T(z)^2 = \frac{NRB(z)}{C}$$

The calibration coefficient is computed only over the polar regions, typically 3 - 4 values per orbit. To ensure the calibration values used in ATL09 have a smooth transition from granule to granule, the algorithm uses the last calibration point from the prior ATL04 granule, all calibration points from the current ATL04 granule, and the first calibration point from the next granule.

Calibration values at any time t within a granule are computed using a linear, piece-wise interpolation between calibration points. "Section 4.3 | Calibrated, Attenuated Backscatter Profiles" in the ATBD for ATL09 describes alternate interpolation strategies used if calibration values are not available for the prior or subsequent ATL04 granules.

2.3.2 Apparent Surface Reflectance

The Apparent Surface Reflectance (ASR) is, essentially, the received laser pulse energy from the surface divided by the transmitted laser pulse energy, multiplied by the two-way atmospheric transmission (T^2). For example, in the case of a planetary body with no atmosphere, like the moon, the ASR would equal the actual surface reflectance at the laser wavelength. On Earth however, the ASR is modified by the atmospheric transmission, which in general is not known. For a clear atmosphere, T^2 is about 0.81 at sea level (at 532 nm). Clouds and aerosols introduce further transmission loss ranging from a few tenths to a few orders of magnitude. This of course means that the ASR will always be less than the actual surface reflectance. For example, if snow has a reflectance of 0.9 at 532 nm, then the ASR measured through a clear atmosphere at sea level will be 0.73 (0.81 x 0.9). If the surface reflectance is known well enough, the ratio of the apparent surface reflectance to the actual surface reflectance can be used as a relative measure of T^2 and thus as an indicator of the likely presence of clouds. The ASR calculation for ATLAS/ICESat-2 is detailed in "Section 4.7 | Apparent Surface Reflectance (ASR)" of the ATBD for ATL09.

2.3.3 Cloud Detection

Clouds lower the returning energy that is reflected by the surface and thus lowers the ASR. When clouds are present, the ASR is a function of cloud optical depth (COD), but also to a lesser degree, cloud height and cloud microphysical properties. For example, based on model simulations, a cloud with a COD = 0.1 decreases the surface return by about 8% to 17%; a cloud with a COD = 1.0 decreases the surface return by 57% to 85%. As such, the cloud signal in ASR is strong enough to be used for cloud detection. Given that clouds can significantly reduce the ASR measured by ATLAS detectors, it is possible to set a threshold to differentiate cloudy from clear conditions. The ASR cloud detection method and implementation are described in detail in "Section 4.7.1 | Cloud Detection using ASR" and "Section 4.7.2 | ASR Cloud Detection Algorithm Implementation" of the ATBD for ATL09.

2.4 Quality, Errors, and Limitations

Because of the various limitations of the ICESat-2 atmospheric data, and the likelihood that only a few calibration points will be obtained per orbit, the calibration error and confidence are difficult to establish. The Science Team is evaluating methods to mitigate and more rigorously quantify calibration error on an ongoing basis.

The browse file corresponding to each data granule contains a number of plots and images that can be used to assess the quality of ATL09 data. See Section 6.0 | Quality Assessment in the ATBD for ATL09 for brief descriptions. In addition, QA parameters for each profile are stored in the top-level quality_assesment/ data group, including statistical metrics that describe: CAB and ASR; cloud detection results; cloud optical depth (COD); surface detection; and ocean surface reflectance.

Potential sources and magnitudes of error in the ATL04 NRB computation, which is passed to ATL08, are discussed in Section 3 of the ATBD for ATL09 and in particular sections 3.3.2.1 | Error Analysis of Molecular Contribution and 3.3.7.4 | Calibration Error and Confidence. Errors and uncertainties in input sources to ATL04, including ATL02 and ATL03, can propagate into downstream products. Users interested in these error sources should consult the ATBDs for ATL02 and ATL03.

3 VERSION HISTORY

Version 5 (November 2021)

Changes for this version include:

- Added new routine process_blow_snow_dens to compute blowing snow height and diamond dust heights based on methods defined in the Density Dimension Algorithm (DDA) ATBD. bsnow_h_dens now has valid values when the DDA detects blowing snow.
- Added constants bs_quartile, bs_gap, bs_bin_thresh, dd_min_top_bin, dd_bin_thresh, bs_thresh_sens, bs_thresh_bias, bs_downsample, bs_thresh_seg_len to ATL09
- Added parameters bsnow_dens_flag, ddust_htop_dens, ddust_hbot_dens to ATL09.
- Added parameter podppd_flag to ATL09. podppd_flag provides identification of ATLAS data in nominal geolocation quality status or a degraded quality. podppd_flag =0 means geolocation is in reference ground track pointing with normal quality. podppd_flag =4 means geolocation is in around-the-world scan or ocean scan with normal quality. Other values are degraded quality.
- Set Fill Value to 127 for snow_ice on ATL09.
- Density Dimension Algorithm (DDA) processing is now done on same solar elevation sub-chunks (day, night, twilight) rather than using the first solar elevation per processing chunk.
- Added check on invalid aclr_true and raised limit of aclr_clim to prevent errors.
- Changed dead time correction algorithm used to correct the surface signal magnitude. This should improve the accuracy of the parameter surface_sig. This improved Apparent Surface Reflectivity (ASR) accuracy.
- Replaced ANC32 surface reflectance map based on GOME with one generated from actual ICESat-2 ASR measurements in clear (no cloud or aerosol layers) conditions. This should increase the accuracy of ASR-based cloud detection and column optical depth measurements.

Version 5 was retired in January 2024

4 CONTACTS AND ACKNOWLEDGMENTS

4.1 Investigators

Steve Palm

Science Systems and Applications, Inc.

NASA Goddard Space Flight Center

Greenbelt, MD 20771

Yeukui Yang

NASA Goddard Space Flight Center

Mail Code: 613

Greenbelt, MD 20771

Ute Herzfeld

Department of Electrical, Computer, and Energy Engineering

University of Colorado Boulder

Boulder, CO 80309

5 REFERENCES

- Bodhaine B. A., N. B. Wood, E. G. Dutton, and J. R. Slusser. 1999. On Rayleigh optical depth calculations. *J. Atmos. Ocean Technol.* 16:1854-1861. DOI: https://doi.org/10.1175/1520-0426(1999)016<1854:ORODC>2.0.CO;2
- Essery, R., L. Long and J. Pomeroy. 1999. A distributed model of blowing snow over complex terrain. *Hydrol. Process.* 13:2423-2438. DOI: https://doi.org/10.1002/(SICI)1099-1085(199910)13:14/15<2423::AID-HYP853>3.0.CO;2-U
- Iqbal, M. *An Introduction to Solar Radiation.* Academic Press, New York, NY, 1983.
- Ismail, S. and E. Browell. 1989. Airborne and spaceborne lidar measurements of water vapor profiles: a sensitivity analysis. *Appl. Opt.* 28:3603-3615. DOI: https://doi.org/10.1364/AO.28.003603
- Lambert, A., P.L. Bailey, D.P. Edwards, J.C. Gille, C.M. Halvorson, B.R. Johnson, S.T. Massie and K.A. Stone. 1999. High Resolution Dynamics Limb Sounder Level-2 Algorithm Theoretical Basis Document. https://eospso.gsfc.nasa.gov/sites/default/files/atbd/ATBD-HIR-02.pdf
- She, C. 2001. Spectral structure of laser light scattering revisited: Bandwidths of nonresonant scattering lidars. *Appl. Opt.* 40:4875–4884. https://doi.org/10.1364/AO.40.004875
- Vigroux, E. 1953. Contribution a l'etude experimentale de l'absorption de l'ozone. *Ann. Phys.* 8:709-761. DOI: https://doi.org/10.1051/anphys/195312080709

6 DOCUMENT INFORMATION

6.1 Publication Date

November 2021

6.2 Date Last Updated

January 2024