ATLAS/ICESat-2 L2A Normalized Relative Backscatter Profiles, Version 3

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. 2020. *ATLAS/ICESat-2 L2A Normalized Relative Backscatter Profiles, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/ATLAS/ATL04.003. [Date Accessed].

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

Normalized Relative Backscatter (NRB) profiles of the atmosphere.

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 ATL04 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 | V03).

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 ATL04 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. ATL04 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. Onboard software aims the laser beams so that the RGT is always 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 between 14 October 2018 and 30 March 2019 the spacecraft pointing control was not yet optimized. As such, ICESat-2 data acquired during that time do not lie along the nominal RGTs, but are offset at some distance from the RGTs. Although not along the RGT, the geolocation information for these data is not degraded.

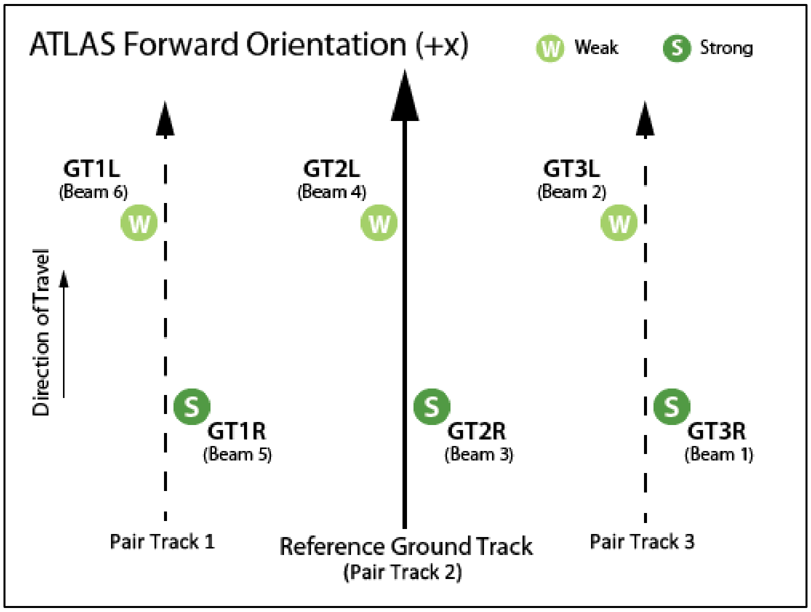


Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

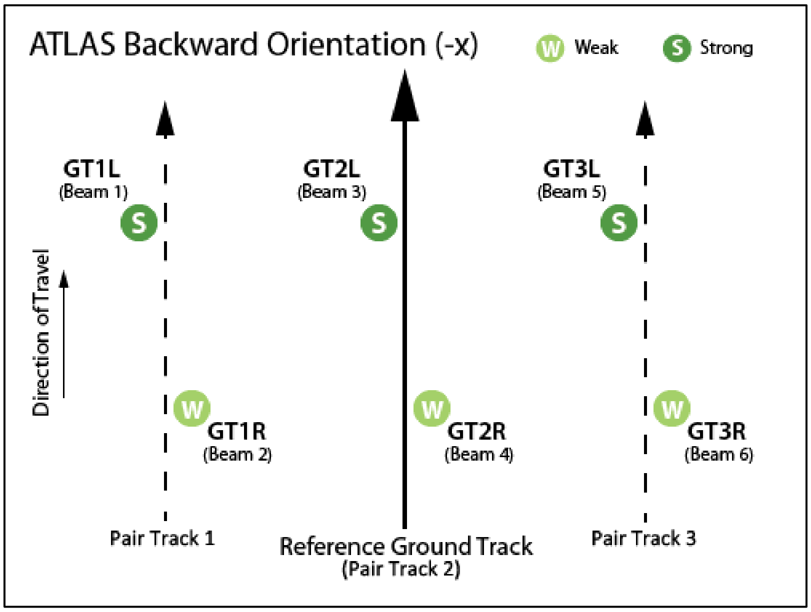


Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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 ATL04 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 Naming Convention

ATL04 data are provided as granules (files) that span one orbit (i.e. one RGT). Data files utilize the following naming convention:

Example:

- ATL04_20181221123517_04890101_001_01.h5
- ATL04_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL04	ATLAS/ICESat-2 L2A Normalized Relative Backscatter Profiles
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Hour, minute, and second of data acquisition (UTC)
tttt	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:

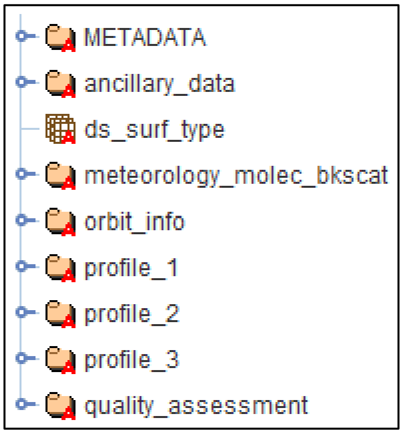
[1] Some ATLAS/ICESat-2 products (e.g. ATL03) are provided as files that span 1/14th of an orbit. As such, these products' file names specify a segment number that ranges from 01 to 14. Because ATL04 and ATL09 data files span one full orbit, the segment number is set to 01.

[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. ATL04 data files contain the top-level groups shown in the following figure:



METADATA
ancillary_data
ds_surf_type
meteorology_molec_bkscat
orbit_info
profile_1
profile_2
profile_3
quality_assessment

Figure 3. Top level data groups as shown in HDFView.

The following sections summarize the contents of the data groups in shown Figure 3. Additional details are available in "Section 3.2 | L2A Outputs" of the ATBD for ATL04. For a complete list of all ATL04 parameters, see the ATL04 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 meteorology_molec_bkscat

Sampled GEOS-5 FP-IT meteorological model data and molecular backscatter. Data are created from time/locations of the center profile (profile 2) and stored at a 1 Hz rate.

1.2.4.4 orbit_info

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

1.2.4.5 profile_[x]

The profile_1, profile_2, and profile_3 groups contain the NRB profiles (profile_[x]/nrb_profile) of the leftmost, center, and rightmost groundtracks (with respect to the satellite direction of motion). The profile_[x] data groups also contain a number of other key parameters, including the following:

- Latitudes and longitudes (WGS 84, top of the atmosphere histogram) of the profiles
- The ellipsoidal height at the top of the atmospheric range window (atm_tw_top) and its bin number within the 21 km vertically aligned frame (nrb_top_bin)
- Surface type (surf_type)
- Backgrounds (photons per bin) computed by three different methods (backg_method1, backg_method2, backg_method1)
- Counts of low-, medium-, and high-confidence signal photons for each NRB (sig_count_low, sig_count_med, sig_count_hi)
- Descriptive statistics (mean and standard deviation) for the low, medium, and high-confidence signal photon heights

1.2.4.6 quality assessment

QA data for the granule, plus summary QA data. These include statistical metrics for each profile related to: background computations, the calibration constant computation, and surface detection.

1.2.4.7 ds_surf_type

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

1.2.5 Browse Files

Browse files are available in HDF5 format that contain jpeg images designed to quickly assess the location and quality of each granule's data. HDF5 browse files contain images listed in Table 2.

Table 2. Images available in the HDF5 files

Parameter	Description
Background1	Plot of computed background using method 1
Background2	Plot of computed background using method 2
Background3	Plot of computed background using method 3
Cal_c	Plot of calculated calibration constants
groundtrack	Plot of satellite ground track on a global map
Nrb_profile	Image of Normalized Relative Backscatter (see Fig. 3)
Solar_elevation	Plot of solar elevation
Surface_sig	Plot of the magnitude of the surface return (photons)

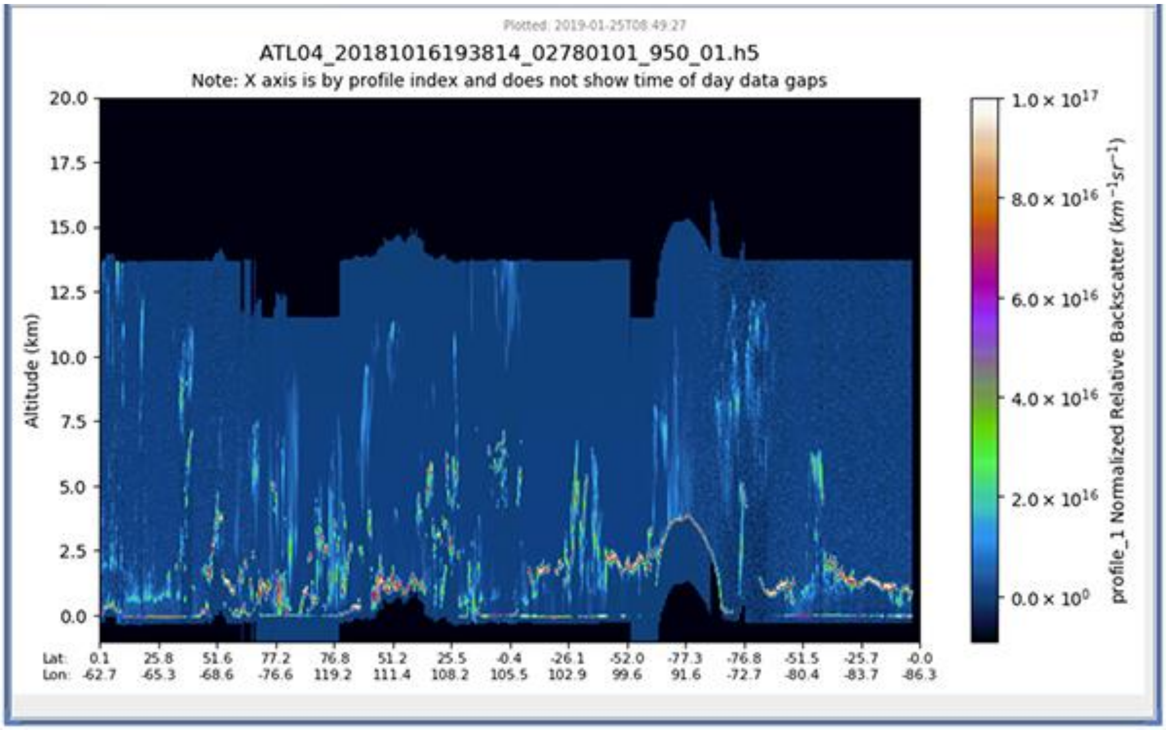


Figure 4. Sample browse image (nrb_profile) showing Normalized Relative Backscatter

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

- ATL04_20181221123517_04890101_001_01.h5
- ATL04_20181221123517_04890101_001_01_BRW.h5

1.2.6 File Size

Data files range in size from approximately 700 MB to 1 GB. Browse files are between 1 MB and 10 MB.

1.3 Spatial Information

1.3.1 Coverage

The ICESat-2 mission acquires data along 1,387 different reference ground tracks.

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 tables provide information for geolocating this data set.

Table 3. 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 11 November 2020

Note that satellite manuevers, 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, the ICESat-2 Science Computing Facility maintains an ongoing list of ATL03 data gaps (.xlsx) that users can download and consult.

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).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATL04 consists of Normalized Relative Backscatter (NRB) profiles, calculated 532 nm calibration coefficients, plus other ancillary parameters. The NRB profiles are created by subtracting background photon events from raw photon counts (passed from ATL02), multiplying by the square of the range from the satellite to the return height, and normalizing by the laser energy. These profiles are passed to and used by higher level products to characterize the atmosphere. Figure 5 illustrates the family of ICESat-2 data products and the connections between them:

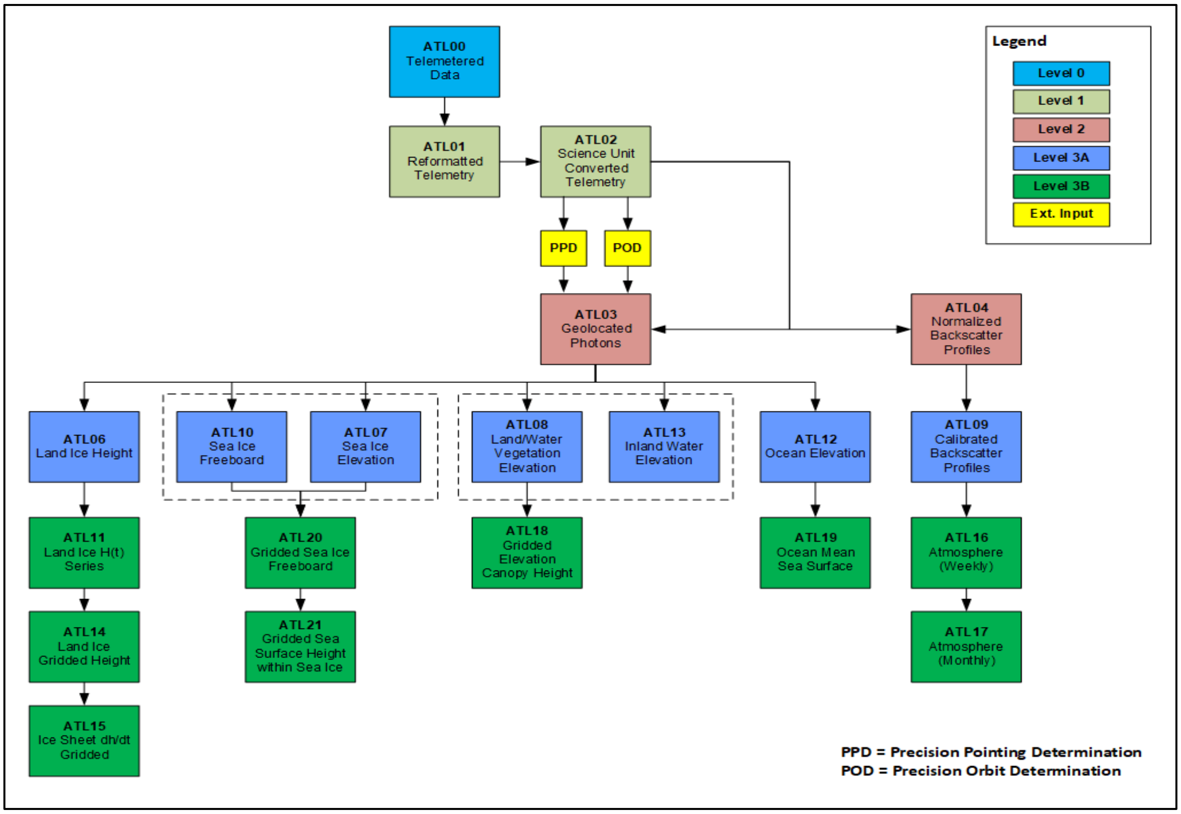


Figure 5. ICESat-2 data processing flow. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory.

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. For ATL04, 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. The actual height of the top of each profile is stored in profile_[x]/atm_tw_top. Its bin number within the 21 km vertically aligned frame is stored in profile_[x]/nrb_top_bin.

2.3 Processing

ATL04 consists of what are termed Normalized Relative Backscatter (NRB) profiles, calculated 532 nm calibration coefficients, plus additional supporting parameters. NRB profiles are created by subtracting background photon events from raw photon counts, multiplying by the square of the range from the satellite to the return height, and normalizing by the laser energy.

2.3.1 Inputs

The following inputs are required by the ATL04 algorithm:

- Ground signal photon magnitude and width (ATL03)
- Raw strong beam atmosphere profiles (ATL02)
- Laboratory data relating signal magnitude and width to detector efficiency
- Meteorological data from the Global Modeling and Assimilation Office (GMAO)
- Ozone concentration (mixing ratio) from GMAO
- Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) 1 km x 1 km digital elevation model
- Surface type (International Geosphere–Biosphere Programme)
- Solar azimuth and zenith angle
- Range from Spacecraft to start of atmosphere profile (ATL02)
- Spacecraft altitude above WGS84 ellipsoid
- Pointing angles for each beam
- Laser energy for each of the 3 strong beams, time, and lat/lon
- Onboard 50 shot background (ATL02)
- 200 shot sum shift amount (ATL02)

A number of corrections are applied to the raw atmospheric profiles before being processed into the Level 2 product. They include removing the transmit echo pulse (TEP), applying a dead time correction, and compensating for shifting between major frames. These corrections are detailed in the Section 2 of the ATBD for ATL04.

2.3.2 Outputs

ATL04 outputs include the following parameters:

- Normalized Relative Backscatter (NRB) profiles for each of the 3 strong beams at 25 Hz.
- Background at 25 Hz
- Molecular backscatter profile from 20 km to 0 km, at 0.1 Hz, 30 m vertical resolution.
- Calibration coefficients with time and location tags
- Molecular Backscatter Average used to compute the calibration coefficient
- NRB average used to compute the calibration coefficient
- Pressure, temperature from 30 km to 0 km, at 0.1 Hz, 30 m vertical resolution.
- Range from spacecraft to start of atmospheric profile
- Pointing angles for each beam
- Laser energy, time, lat/lon
- Solar zenith and azimuth angle
- Surface type
- Surface 2 m wind velocity and temperature
- Wind velocity and temperature at 10 m height
- Onboard 50 shot background
- Meteorological data

For a list of ATL04 product parameters including variable names, see Table 3.1 in the ATBD for ATL04.

2.3.3 NRB Computation

The following section briefly describes the approach used to compute NRB from ATLAS/ICESat-2 lidar data. For a complete description, see Section 3 of the ATBD for ATL04.

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 then generated for each of the strong beams using:

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

$$= C\beta(z)T^2(z)$$

For ICESat-2, determining the solar background (p_b) represents the biggest challenge in the equation above (both E and r are well known). In practice, p_b and p_d are lumped together and their sum called simply ‘background’. At night, with no moon (and no effect from city lights), the background is simply p_d, the dark count rate. During the day the background is the sum of p_b and p_d.

The background computation would normally be performed using data below the ground; however, both molecular and cloud scattering may exist within this region due to range aliasing (i.e., the 10 KHz laser rep rate). Given that the background cannot be computed accurately without removing all atmospheric scattering from the profile—which is essentially impossible—alternate approaches are needed.

For the ATLAS/ICESat-2 atmospheric profiles, the ATL04 algorithm utilizes three different methods to compute the background and stores each result in a separate variable. Briefly, methods 1 and 2 locate and remove any cloud layers in the data and then look for a minimum in the cloud-cleared profile. Although this minimum may be associated with a particulate-free area of the profile, it will still contain some molecular scattering. However, this scattering can be modeled and removed leaving only background. Methods 1 and 2 differ only in how clouds are removed. Method 3 applies a different approach, by utilizing the onboard, 50-shot background rate parameter from ATL03, converted to units of per 30 m atmospheric bin and averaged over the profile.

The results of all three methods are stored within each profile_[x] data group in the backg_method1, backg_method2, and backg_method3 variables. The background method that was used (1, 2, or 3) is stored in both ATL04 and ATL09 in the ancillary variable backg_select (/ancillary_data/atmosphere/backg_select).

All three methods are detailed in "Section 3.3.4 | Background Computation" in the ATBD for ATL04.

"Section 3.3 | NRB Computation" in the ATBD for ATL04 provides complete descriptions about the theory and calculations used to determine NRB, including: the molecular backscatter coefficient (Section 3.3.1); the molecular scattering folding correction (Section 3.3.2); ozone transmission (Section 3.3.3); plus how the algorithm identifies the background (Section 3.3.4) and surface

(Section 3.3.5) signals. "Section 3.3.6 | Vertical Height Adjustment" details the procedure used to put the raw atmospheric profiles into a constant height frame of reference

2.3.4 Lidar Calibration

The theory behind the lidar calibration coefficient relates the power received by the detector to a physical quantity—the volume backscatter cross section—which is primarily a function of the transmission of the system optics (transmitting and receiving), detector efficiency, geometric considerations, and the degree of alignment between the receiver field of view and the laser spot (boresite alignment). Because these factors can and do change with time in the typical lidar system, and cannot easily be monitored, the lidar signal is calibrated continuously by comparing the measured signal to a reference target.

The atmosphere itself can act as a reference target so long as it is devoid of particulate scatterers (or the magnitude of particulate loading is known) and the density of the atmosphere is sufficiently well–known. For instance, in the absence of large volcanic eruptions the air in the lower and middle stratosphere is typically very clean. In these layers, the scattering consists only of molecular or Rayleigh scattering, which depends on only the pressure and temperature of the atmosphere. As such, the molecular backscatter cross section (i.e. the target) can be very accurately calculated in near real-time from NCEP (National Center for Environmental Prediction) or GMAO (Goddard Modeling and Assimilation Office) meteorological analyses or from short-range forecasts of temperature, pressure and moisture fields.

The calibration coefficient can in theory also be calculated from the surface return if certain conditions are met. The Science Team plans to evaluate this approach after launch.

"Section 3.3.7.1 | Theory" provides a introduction to the meaning and application of the lidar calibration coefficient. Users seeking details about how the calibration coefficient is computed by the ATLAS software can consult sections "3.3.7.2 | Calibration Algorithm using the Atmosphere" and "3.3.7.3 Calibration Algorithm using Surface Reflectance" in the ATBD for ATL04.

2.4 Quality, Errors, and Limitations

The browse file corresponding to each data granule contains a number of plots and images that can be used to assess the quality of ATL04 data. See Section 6.0 | Quality Assessment in the ATBD for ATL04 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: the background computations for all three methods; the calibration constant computation; surface detection.

Potential sources of error and their magnitudes in the NRB computation are discussed in Section 3 of the ATBD for ATL04 and in particular sections 3.3.2.1 | Error Analysis of Molecular Contribution and 3.3.7.4 | Calibration Error and Confidence. Furthermore, errors and uncertainties in input sources such as 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 3 (May 2020)

Changes for this version include:

- Implemented Calibration Method 3[1] to compute the calibration factor. Calibration Method 3 computes the calibration constant continuously over the whole orbit, both day and night, using the average NRB between 13 and 11 km (see "Calibration Method 3," "Section 3.3.7.2 | Calibration Algorithm using the Atmosphere" in the ATBD for ATL04). Previous versions utilized three calibration values: 1 for day, 1 for night and 1 for twilight. While this approach worked reasonably well for nighttime data, the calibration was often in error during daytime and twilight. Calibration Method 3 was developed to improve the calibration regardless of the solar background conditions.
- Implemented the scaling factor (alpha) for the molecular scattering folding correction to be a function of solar angle and PCE (photon counting electronics). The alpha scaling factor is used to control the amount of molecular folding computed from Equation 3.15 in the ATBD for ATL04. The slope of the average signal in clear air is sensitive to the amount of molecular folding that is subtracted from the profile. If too much is subtracted, the slope of the average signal in clear air is greater than molecular (it should be the same as molecular). If too little is subtracted, the slope is less than molecular. In release 002, alpha was set to zero, meaning no molecular folding was subtracted from the signal. By analyzing many cases, the ATL04 Product Team determined that setting alpha=0 produced an average signal in clear air with a slope less than molecular folding. The analyses also showed that the value of alpha was a function of the background level and PCE. As such, Version 03 utilizes non-zero values of alpha for day, night and twilight, for each of the 3 PCEs. As a result, the average signal in clear air has a slope very near if not equal to molecular regardless of background level.
- Changed the values for constants "cal_solar_elev_min" and "cal_solar_elev_max" to cal_solar_elev_min = -7 and cal_solar_elev_max = -1. These changes were implemented to re-define the twilight portion of the orbit for Calibration Method 3 (described above).
- The new parameters listed below were added to ancillary_data/atmosphere/. Each parameter is described in the file metadata and where applicable in the ATBD for ATL04:
    - default_nrb_twilight, min_nrb_twilight, max_nrb_twilight, min_calib_twilight, max_calib_twilight, alpha_day_pce1, alpha_day_pce2, alpha_day_pce3, alpha_night_pce1, alpha_night_pce2, alpha_night_pce3, alpha_twilight_pce1, alpha_twilight_pce2, alpha_twilight_pce3

[1] Although Calibration Method 3 was described in the ATBD for Version 2 of ATL04, it was not implemented until V03.

4 CONTACTS AND ACKNOWLEDGMENTS

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

23 May 2019

6.2 Date Last Updated

25 January 2022