ATLAS/ICESat-2 L2A Global Geolocated Photon Data, Version 1

USER GUIDE

How to Cite These Data

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

Neumann, T. A., A. Brenner, D. Hancock, J. Robbins, S. B. Luthcke, K. Harbeck, J. Lee, A. Gibbons, J. Saba, and K. M. Brunt. 2019. *ATLAS/ICESat-2 L2A Global Geolocated Photon Data, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.5067/ATLAS/ATL03.001. [Date Accessed].

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

Height above the ellipsoid, time, and geodetic latitude and longitude for individual photons. Heights are provided in the ITRF2014 reference frame; geographic coordinates are referenced to the WGS84 ellipsoid.

1.2 File Information

1.2.1 Format

Data are provided as HDF5 formatted files.

HDF5 is a data model, library, and file format designed specifically for storing and managing data. For more information including tools and applications that can help you view, manipulate, and analyze HDF5-formatted data, visit the HDF Group's HDF5 Support Page.

1.2.2 ATLAS/ICESat-2 Description

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 ATL03 data product is described in detail in the Ice, Cloud, and land Elevation Satellite-2 Project Algorithm Theoretical Basis Document for Global Geolocated Photon Data (ATBD for ATL03). To obtain the most recent version of this ATBD, visit the NASA Goddard Space Flight Center's ICESat-2 Data Products web page.

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 trace out six approximately 14 m wide ground tracks as ICESat-2 orbits Earth. 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 ATL03 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. ATL03 reports the spacecraft orientation in the sc_orient parameter stored in the /orbit_info/ data group (see Data Groups).

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, for example in ATL03 file names, 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. Once the ATLAS/ICESat-2 Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions have been adequately resolved and the instrument has pointed directly at the reference ground track for a full 91 days (1387 orbits), the observatory will begin off-pointing data acquisition.

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.

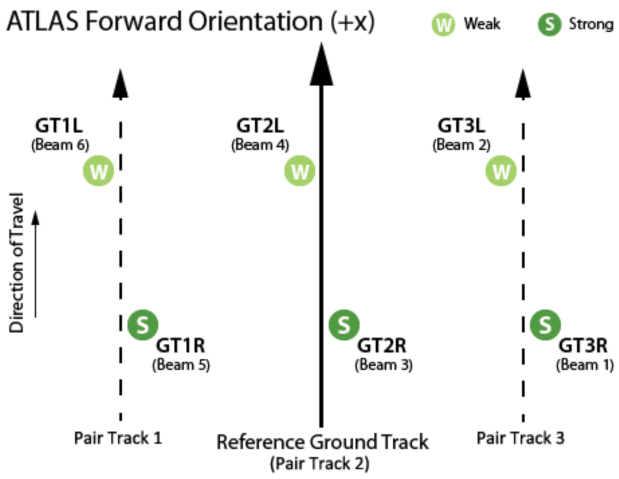

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

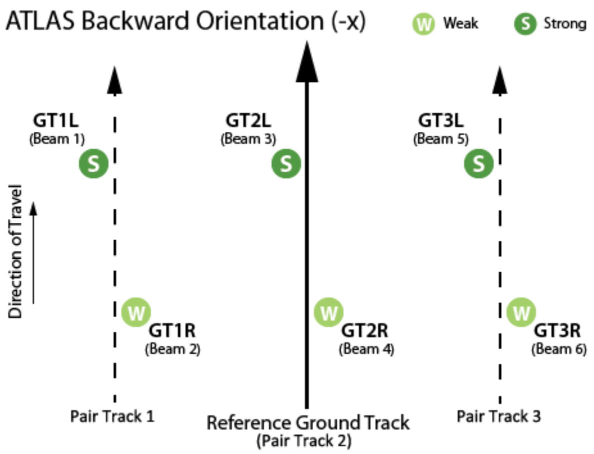

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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.

1.2.3 File Contents

ATL03 data are segmented into granules (files) that span about 1/14th of an orbit. Granule boundaries are delineated by lines of latitude that define 14 regions, numbered from 01-14 as shown in Figure 3:

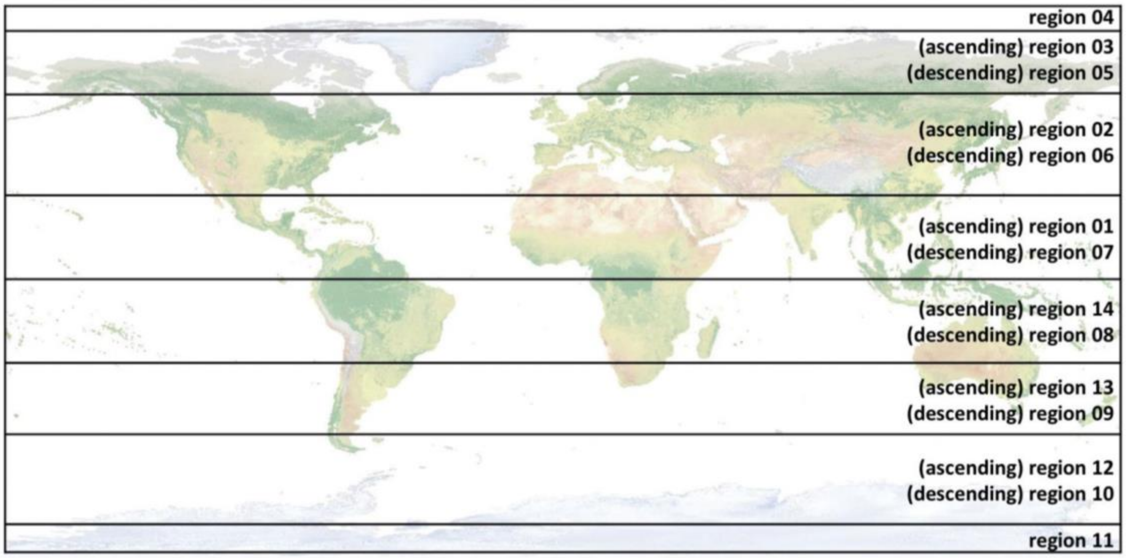

Figure 3. ATL03 region/granule boundaries.

The following table lists the latitude bounds and region numbers for all 14 granule regions:

Table 1. ATLAS/ICESat-2 Granule Boundaries and Region Numbers

Region #	Latitude Bounds	Region #	Latitude Bounds
01	Equator → 27° N (ascending)	08	Equator → 27° S (descending)
02	27° N → 59.5° N (ascending)	09	27° S → 50° S (descending)
03	59.5° N → 80° N (ascending)	10	50° S → 79° S (descending)
04	80° N (ascending) → 80° N (descending)	11	79° S (descending) → 79° S (ascending)
05	80° N → 59.5° N (descending)	12	79° S → 50° S (ascending)
06	59.5° N → 27° N (descending)	13	50° S → 27° S (ascending)
07	27° N (descending) → Equator	14	27° S → Equator (ascending)

1.2.4 Data Groups

Within data files, similar variables such as science data, instrument parameters, altimetry data, and metadata are grouped together according to the HDF model. ATL03 data files contain the top-level groups shown in Figure 4. Heights, times, latitudes, and longitudes for individual photons are stored in the /heights group within each ground track group:


METADATA
ancillary_data
atlas_impulse_response
ds_surf_type
ds_xyz
gt1l
gt1r
gt2l
gt2r
gt3l
gt3r
orbit_info
quality_assessment

Figure 4. Top-level data groups for an ATL03 granule shown in HDFView. Individual photon heights, times, latitudes, and longitudes for each ground track (1L – 3R) are stored in the corresponding gt1l – gt3r/heights data group, along with other ground track related parameters.

The following sections summarize the structure and primary variables of interest in ATL03 data files. Additional details are available in Section 2 and Appendix A of the ATBD for ATL03. The most recent version of the ATBD is available from the NASA Goddard Space Flight Center's ICESat-2 Data Products web page. A complete list of all ATL03 parameters is available in the ATL03 Data Dictionary (pdf).

1.2.5 METADATA

ISO19115 structured metadata with sufficient content to generate the required geospatial metadata (ATBD for ATL03 | Section 2.4.9).

1.2.6 ancillary_data

Parameters related to ATLAS that provide insight about the instrument transmit pulse, optics, receiver sensitivity, etc. These parameters are needed by higher level products and are in general passed to ATL03 from the ICESat-2 Science Unit Converted Telemetry product, ATL02. For more information, see Section 2.4.3 - Section 2.4.6 in the ATBD for ATL03 and the ATBD for ATL02.

1.2.7 atlas_impulse_response

Parameters needed by higher-level data products that require knowledge of the ATLAS system impulse-response function to account for how the ATLAS system impacts ground return statistics (ATBD for ATL03 | Section 2.4.2).

1.2.8 gt1l – gt3r

Six gt[x] groups, each of which contains the parameters for one of the six ATLAS ground tracks including height above the WGS 84 ellipsoid, time, latitude, and longitude for individual photons (ATBD for ATL03 | Section 2.4.1). Data are organized into the following subgroups:

- **/heights**: all parameters provided at the individual photon rate, i.e. one value per photon for the given ground track. For example, heights above the WGS 84 ellipsoid, latitude, and longitude. Each photon is also classified, based on surface type, as a likely background or signal photon with low, medium, or high confidence (ATBD for ATL03 | Section 2.4.1.1).
- **/geolocation**: parameters posted at ~20 m, the along-track interval for photon geolocation (also known as geolocation segments or geosegs). For example, the number of photons in the given along-track segment; the time interval boundaries along-track used to identify signal photons; and the mean and standard deviation of the background count rate used to determine thresholds for signal photon identification (see ATBD for ATL03 | Section 2.4.1.2 and the Photon Event Geolocation section of this user guide).
- **/geophys_corr**: best-available corrections, at geolocation rate (20 m), for known geophysical phenomena that may impact ICESat-2 photon ellipsoid heights. Values in this group are provided so that users can apply, remove, and/or replace any model, as needed. Applied corrections include: solid earth tides; ocean and solid earth pole tides; ocean tidal loading; and range corrections for tropospheric delays. Values provided for reference (i.e. not applied) include: geoid height (EGM-2008); ocean tides (GOT4.8 model, including long period equilibrium tides); and Dynamic Atmospheric Correction (Aviso MOG2D model). Details are available in the ATBD for ATL03 | Section 2.4.1.3 and the Geophysical Corrections section of this user guide.
- **/bckgrd_atlas**: parameters that can be used to calculate the background photon rate recorded by ATLAS (see ATBD for ATL03 | Section 2.4.1.4).
- **/signal_find_output**: parameters output for each time interval for which signal photons were selected, including parameters for the histogram used to identify signal photons and set the confidence parameter for a given time increment. (see ATBD for ATL03 | Section 5.0).

1.2.9 orbit_info

Parameters that are constant for a granule, such as the RGT number and cycle, the spacecraft orientation, and various ATLAS parameters needed by higher-level data products (ATBD for ATL03 | Section 2.4.7).

1.2.10 quality assessment

Quality assessment data, including QA counters, ground track-specific QA, and summary QA (ATBD for ATL03 | Section 2.4.8).

1.2.11 Dimension Scales

Two HDF5 dimension scales are stored at the top level alongside the data groups:

> ds_surf_type: dimension scale indexing the surface type array (gt[x]/geolocation/surf_type)
>
> ds_xyz: dimension scale indexing the X-Y-Z components of the spacecraft velocity (east component, north component, up component) an observer on the ground would measure (gt[x]/geolocation/velocity_sc)

1.2.12 Naming Convention

Data files utilize the following naming convention:

Example:

```
ATL03_20181014092931_02410101_001_01.h5

ATL03_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5
```

The following table describes the file naming convention variables:

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
ATL03	ATLAS/ICESat-2 L2A Global Geolocated Photon Data
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Data acquisition start time, hour, minute, and second (UTC)
tttt	Four digit Reference Ground Track number. 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. ATL03 data files are segmented into approximately 1/14th of an orbit. Segment numbers range from 01-14. Note that some segments may not be available.
vvv_rr	Version and 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.

1.2.13 Browse File

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

1. Maps of medium- and high-confidence reference photon locations for each of the three strong beams. These three maps indicate where the signal-to-noise ratio in a given granule is good. Photon classifications in these maps are surface-type dependent; they plot the highest confidence for a given photon. For example, if a photon is classified as high-confidence signal for surface type A and medium confidence for surface type B, surface type A is plotted.

2. Plots of the low-, medium-, and high-confidence signal photon ellipsoidal elevations versus geolocation segment id number for each surface type, for each of the three strong beams. As many as 15 of these images can exist per granule; 3 for each of the 5 surface types. They offer users a depiction of the low-, medium-, and high-confidence photon clouds for each of the three strong beams. Low-confidence photons are plotted first, followed by the medium- and high-confidence photons. As such, low confidence photons are in general only prominently visible if relatively few high- or medium- confidence photons exist in a particular segment.

3. A plot which shows the background rate (stored in /gt[x]/bckgrd_atlas/bckgrd_rate) for the entire granule versus time since the start of the granule for the three strong beams. This image provides a sense of the variation in the background photon rate.

4. Elevations for the low-, medium-, and high-confidence signal photons plotted in three dimensions. The classifications used for this plot are surface-type dependent, i.e. the highest-level classifications across all surface types. This image offers users a qualitative assessment of data quality and topography for the given granule.

5. A global map which shows the general location of the granule (it is not possible to distinguish the six ground tracks or assess data quality on this map).

For more information about browse files, see the ATBD for ATL03 | Section 8.0.

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

ATL03_20181014092931_02410101_001_01.h5

ATL03_20181014092931_02410101_001_01_BRW.h5

1.2.14 File Size

Data files vary in size from approximately 40 MB to as large as 10 GB. A typical file is approximately 3–4 GB. Browse files are approximately 1.3 MB.

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage spans approximately 88° N latitude to 88° S.

1.3.2 Resolution

The ATLAS instrument transmits 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. Note, however, that the number of photons that return to the telescope depends on surface reflectivity and cloud cover (which obscures ATLAS's view of Earth). As such, the spatial resolution varies.

1.3.3 Geolocation

Photon events are presented in geodetic latitude, longitude, and ellipsoidal height (above the WGS 84 ellipsoid, ITRF2014). For a summary of the geolocation algorithm, see the Photon Event Geolocation section of this user guide. Table 3 contains details about WGS 84. For information about ITRF2014, see the International Terrestrial Reference Frame | ITRF2014 webpage.

Table 3. Geolocation Details

Geographic coordinate system	**WGS 84**
Projected coordinate system	N/A
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

13 October 2018 to 19 February 2019

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

The simplest way to describe ATL03 is that it provides height, time, latitude, and longitude for all photon events that ICESat-2 downlinks. It acts as the bridge between the lower level, instrumentation-specific products and the higher-level, surface-specific products (ATL06 and above). By design, ATL03 is a single source for all photon data and ancillary information that the higher-level products need, including spacecraft and instrument parameters. For example, stored within ATL03 is the ATLAS impulse-response function utilized by the sea ice height and ocean height algorithms, as well as land ice, sea ice, ocean, land, and inland water surface masks. Although this information is not explicitly required to generate ATL03, it is included to facilitate subsequent data products.

The following figure illustrates the family of ICESat-2 data products and the connections between them:

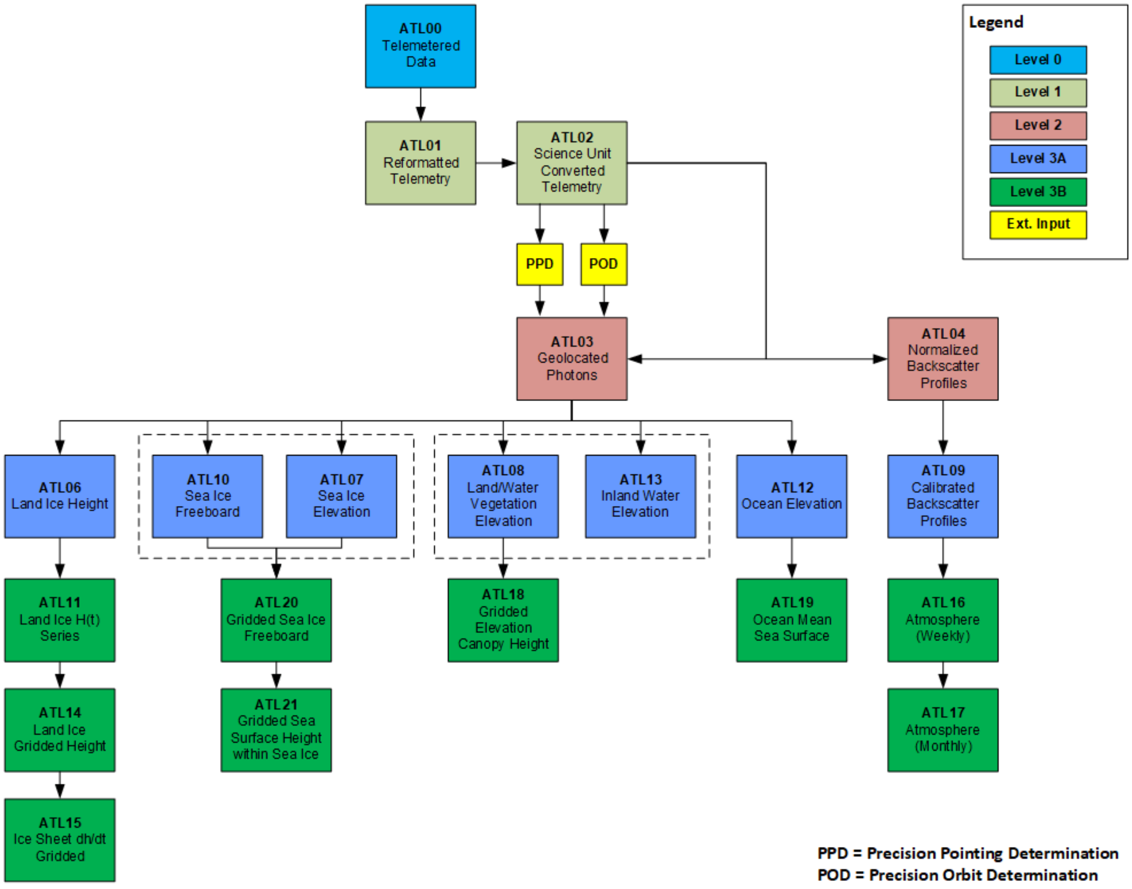

Figure 5. ICESat-2 data processing flow. ATL02 processing converts ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory.

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. Each transmitted laser pulse is split by a diffractive optical element in ATLAS to generate six individual beams, arranged in three pairs. Within each pair, the beams have different transmit energies—so-called weak and strong beams with an energy ratio of approximately 1:4—and are separated by 90 m in the across-track direction and approximately 2.5 km in the along-track direction. The distance between beam pairs is approximately 3 km in the across-track direction (see Figure 6).

Approximately 1014 photons leave the ATLAS sensor with each pulse and travel through the atmosphere to Earth. Of those which reflect off the surface, approximately 10 travel back through the atmosphere and into the ATLAS telescope, where their arrival is time-tagged by the instrument's electronics. If the sun is illuminating Earth's surface at the same time, background photons from sunlight also enter the telescope and are recorded. Any photon that is time-tagged by ATLAS, regardless of source, is referred to as a photon event. ICESat-2 downlinks time tags for all photon events that fall within the telemetry bands, both signal and background photon events.

> The subset of photons selected by the onboard science algorithm to be relayed to the ground is called the telemetry band (or downlink band). The telemetry band is relatively narrow (30 to roughly 2000 meters) and is a function of the signal to noise ratio of the data, the location on the earth (e.g. ocean, land, sea ice), the roughness of the terrain, and other parameters.

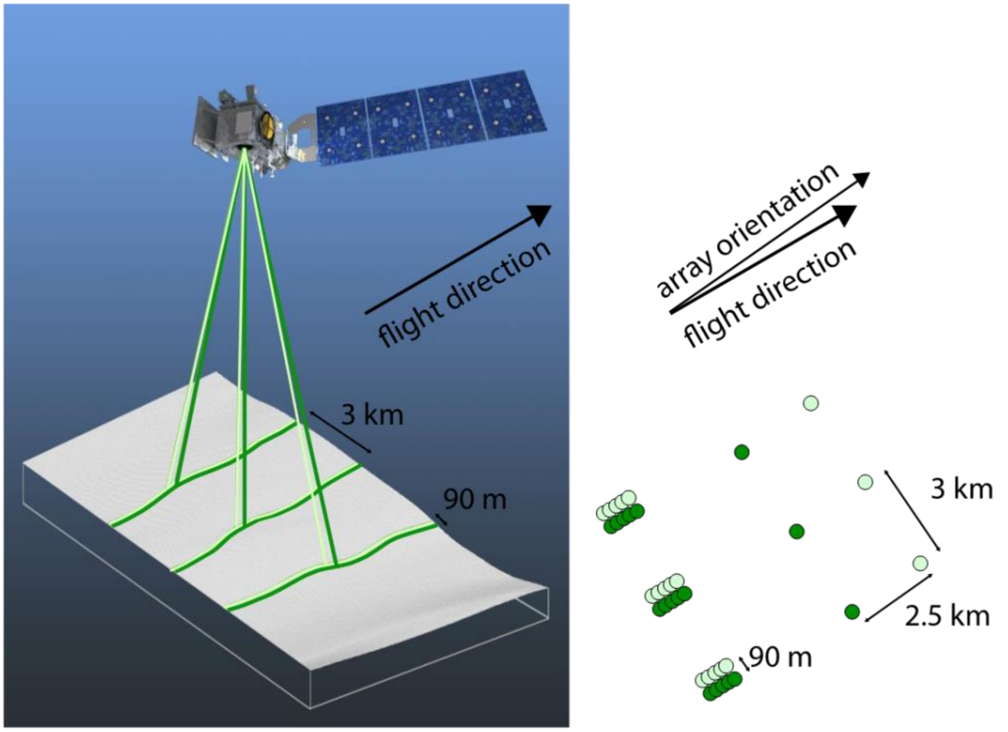

Figure 6. ATLAS idealized beam and footprint pattern. Adapted from the ATBD for ATL03.

2.3 Processing

The following sections summarize the approach used to generate the ATL03 data product. For a more complete description, consult the ATBD for ATL03 on the NASA Goddard Space Flight Center's ICESat-2 Data Products web page. ATBDs on this page are updated periodically to remain consistent with the latest product versions.

2.4 Signal Finding Algorithm

Ground processing/science software correctly discriminates between signal photon events and background photon events, based in part on a window of the likely surface location generated by onboard software. Based on pre-launch testing of the ATLAS photon-counting system, the algorithm assumes that background photon events recorded by ATLAS follow a Poisson distribution, and therefore outliers to this distribution represent possible signal photons. To make this discrimination, the algorithm constructs histograms with photon events aggregated into along-track and vertical bins. According to Poisson statistics, background photon events are thus randomly distributed among the bins while signal photons cluster into one or a few bins. The algorithm is driven by numerous input parameters, many of which are surface type dependent, to optimize signal detection while minimizing execution time.

Given the background rate, the algorithm calculates a signal threshold and then generates a histogram of photon ellipsoidal heights (above the WGS-84 ellipsoid). It then distinguishes signal photons from background photons as those that pass a series of tests dependent on the signal threshold. Data from each ground track is considered independently for the ellipsoidal histogramming procedure.

Surface slopes present one of the main challenges to identifying signal photon events. Ideally, one would histogram the photon event heights relative to the direction of the slope of the surface so all the signal photons would be combined into one bin. However, the surface slope over the integration span is not known a priori. As a first step, the algorithm histograms photon event heights relative to the ellipsoid. It then steps through the data granule in uniform time increments, Δtime. For each Δtime, the algorithm histograms the photon events over an integration time, δt, at a vertical resolution, δz. The algorithm automatically adjusts δt and δz until it either identifies vertical bins that contain more photon events than a threshold based on the background count distribution, or it reaches a pre-defined limit on δt and δz without identifying any bins that contain signal photon events for a given Δtime. This automatic adjustment allows the algorithm to maintain the highest resolution possible in terms of the histogram bin dimensions when identifying signal photon events. After the algorithm identifies possible signal photon events, it then selects additional bins to ensure all signal photon events are included.

Ellipsoidal-based histograms allow for signal photon events to be readily identified over low-slope regions. However, when this approach is applied over sloped surfaces it can spread the signal photon events across several bins, making it less likely that the algorithm will correctly identify bins that contain signal photon events. As such, two additional steps are performed over surface types where significant slopes may be present. First, the algorithm performs running linear fits to the surface height profile, as determined by ellipsoidal histogramming, to define the local surface slope, α. It then histograms the photon heights relative to α to search for signal returns along a linear trend determined by the adjacent surface slopes, or so-called slant histograms. Next, if sufficiently large time gaps exist, the assumption that the surface slope is linear may not be appropriate. In these cases, the algorithm generates slant histograms using a variable surface slope at each time increment within these gaps to try to identify any additional signal photons.

After all signal photons have been identified, the algorithm generates a flag for each photon event indicating whether it is likely signal or background, or a photon event which was added as a buffer[1] (as well as the parameters used to classify the photons). This flag, gt[x]/heights/signal_conf_ph, also includes a confidence parameter for each likely signal photon event—high, medium, or low confidence—based on the signal to noise ratio of each histogram bin. signal_conf_ph is a 5 x N array, where N is the number of photons in the ground track group and the 5 rows indicate signal finding for each surface type: in order, land, ocean, sea ice, land ice, and inland water. The surface-type-specific confidence levels associated with each photon event are: 0 (noise); 1 (added as buffer, but classifed by the algorithm as background); 2 (low confidence signal); 3 (medium confidence signal); and 4 (high confidence signal). Additionally, events not associated with a specific surface type are assigned a confidence level of -1, while events evaluated as TEP returns are assigned a confidence level of -2.

[1] To meet the requirements of higher-level products, additional surrounding background photons are added as a buffer if the identified signal photons for a Δtime do not meet a minimal height span requirement (at least 20 meters vertically). See ATBD for ATL03 | Section 5.4.4.

2.5 Geophysical Corrections

ATLAS emitted photons pass through the atmosphere and experience delays that depend on the refractive index along the optical path. The round-trip time of a photon is what constitutes its base input measurement for geolocation. Over oceans, sea ice and ice shelf surfaces, each photon event typically requires corrections to account for temporal variability in atmospheric-oceanic interactions (for example, inverted barometer and wind field effects) as well as tidal states and other factors. Over land surfaces, each photon event requires corrections to account for deformations induced by, for example, ocean loading and solid earth tides. These constitute what are referred to as geophysical corrections.

The following sections list the time-dependent geophysical corrections that: (1) have been applied to the photon ellipsoid heights; (2) have not been applied, but are provided as reference values; and (3) are static reference values, given along with their typical, respective, magnitudes. Geophysical corrections are stored in the gt[x]/geophys_corr/ group and described in detail in Section 6 of the ATBD for ATL03.

Corrections applied due to variations in surface bounce point:

- Solid Earth tides. Magnitude = ±40 cm (max).
- Ocean loading. Magnitude < 10 cm.
- Solid Earth pole tide deformation. Occurs due to centrifugal effect from small variations in polar motion. Magnitude = ±1.5 cm.
- Ocean pole tide. Global height correction caused by deformational load upon the Earth due to centrifugal effect from small variations in polar motion. Magnitude = ±2 mm amplitude.
- Geocenter Motion, broadly defined as the translational motion of the center of mass of the Earth system (solid earth, oceans, cryosphere and atmosphere) with respect to the center-of-figure (CF) of the solid earth surface. *Not* applied to ATL03, but accounted for in precision orbit determination. Magnitude = 3 mm to 5 mm in x, y, z amplitude.

Corrections provided as reference values but NOT applied

- Ocean tides, including diurnal and semi-diurnal (harmonic analysis) and longer period tides (dynamic and self-consistent equilibrium) tides. Magnitude = ±5 m.
- Dynamic Atmospheric Correction (DAC). Includes the inverted barometer (IB) effect. Magnitude = ±50 cm.

Photon round-trip range corrections:

- Total column atmospheric delay. Magnitude = -2.6 m to -0.9 m
- Geoid. Static Quantity. Magnitude = -105 m to +90 m (max)

2.6 Height Computation

Given the geophysical corrections above, ATL03 photon heights (Hgc) are computed as follows:

Hgc = HP - HOL - HSEPT - HOPT - HSET - HTCA

where, HP is the photon event height; HOL is the ocean loading deformations; HSEPT is solid Earth tides; HOPT is ocean pole tides; HSET is solid Earth tides; and HTCA is the total column atmospheric delay.

2.7 Photon Event Geolocation

The following section briefly summarizes the geolocation algorithm for ATL03. Received photon geolocation is described in detail in the Ice, Cloud, and land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for ATL03g: ICESat-2 Receive Photon Geolocation.

When no photons are present in a given along-track segment (i.e., gt[x]/geolocation/segment_ph_cnt = 0), no reference photon exists. In this case, all values that depend on the existence of the reference photon are set to invalid. Rough estimates are provided for other parameters such as the latitude, longitude, and delta_time values. For more information, see Section 3.2 of the ATBD for ATL03.

Each individual photon event is initially geolocated without correcting for atmospheric path delay. These geolocated photons are then provided to the signal finding algorithm. Photon events that are characterized as likely signal are then binned in approximately 20 m along-track segments that are fixed to the Reference Ground Track (RGT) in predetermined locations and a reference photon is selected. These segments are referred to as the along-track geolocation segments. The atmospheric path delay and its derivatives with respect to ellipsoid height are then computed for the reference photon and used to correct the geodetic coordinates of all photons within the segment.

Geolocated photons are placed into along-track geolocation segments by identifying the RGT segment number for each photon and computing its segment-centric Cartesian coordinates from the geodetic coordinates. The segment-centric Cartesian coordinates are: x–distance from the segment start boundary in the along-track vector direction; y-distance perpendicular to the segment along-track vector to the surface of the ellipsoid at the photon location; and the ellipsoid height of the photon return, which is the same as the ellipsoid height in the geodetic coordinates.

It is worth noting that the along-track geolocation segment is a rectangular coordinate system defined using the RGT as y = 0 for each 20-m along track segment and the beginning of the segment as x = 0. When the observatory is pointed to the RGT, this means that photon along-track x-values range from 0 m to approximately 20 m. The across-track y-values run from approximately -3.3 km to +3.3 km. The boundaries between consecutive along-track geolocation segments (where x resets to 0 from its maximum value of ~20 m) are not co-linear due to the curvature of the ground tracks on the surface of the earth. Consequently, while the length of the along-track segments along the RGT are nominally 20m for left and right ground track pairs, they could be greater or less than 20m depending on the curvature of the ground tracks on the surface of the earth.

2.8 Surface Masks

ATL03 includes gridded surface masks (land ice, sea ice, land, ocean, and inland water) to reduce the volume of data that must be processed to generate the surface-specific higher-level ICESat-2 data products. For example, the land ice surface mask directs the ATL06 land ice algorithm to consider data from only those areas of interest to the land ice community. In order to protect against errors of omission in these masks, a buffer has been added to the best estimate of the geographic bounds of regions of interest. Consequently, the grids do not perfectly tessellate the surface of the Earth and overlap each other on the order of tens of kilometers in most regions. This means that a given latitude and longitude point could appear in two or more surface masks and two or more higher-level data products. Differences among the algorithms used by higher-level data products for a multiple-classified granule of ATL03 are expected. For example, many permafrost areas are included in the land ice, land, and inland water masks and will be included in the associated ATL06, ATL08, and ATL13 data products, although they will all take as input the same ATL03 granule.

Surface type is writen to the surf_type parameter—one for each of the six ground tracks—stored in the geolocation group within each ground track's corresponding gt[x] group. The surf_type parameter, located in the gt[x]/geolocation/ group, is posted at the along-track, geolocation segment rate at reference photon locations and reports false (0) or true (1) for each of the five currently defined surface types.

Section 4 of the ATBD for ATL03 contains a complete description of each surface mask and how it was generated.

2.9 Geolocation Segment Rate Parameters

The gt[x]/geolocation/ group contains some 30 parameters which are reported at the geolocation segment rate (i.e. the reference photon). In addition to the surf_type parameter described in the preceding section, users can find parameters such as the spacecraft altitude above the WGS 84 ellipsoid (altitude_sc); transmit time of the reference photon (delta_time); the index of the reference photon within the set of photons grouped within in the geoseg (reference_photon_index); plus estimated uncertainties, solar azimuth and elevation, and transmit pulse characteristics.

Geophysical corrections (in the gt[x]/geophys_corr/ group) are also reported at the geolocation segment rate.

2.10 Quality, Errors, and Limitations

Users seeking estimates of uncertainty may find the following parameters useful:

/gt[x]/geolocation/

- sigma_across, sigma_along: estimated Cartesian across-, along-track uncertainty for the reference photon
- sigma_h: estimated height uncertainty for the reference photon bounce point
- sigma_lat, sigma_lon: estimated geodetic latitude/longitude uncertainty for the reference photon
- surf_type: flag describing the surface types for each geolocation segment /gt[x]/geophys_corr/
- geoid: geoid height above WGS 84 reference ellipsoid (not applied to the photon cloud)

The probability of identifying likely signal photons varies as a function of background rate. Pre-launch, the ICESat-2 Science Team simulated a surface and varied the background photon rate to determine the sensitivity of the photon classification algorithm to background photon rate (see ATBD for ATL03 | Section 5.2). In general, the surface is classified with high confidence up to a few MHz of background photon events. As the background photon rate increases, the fraction of medium and low-confidence photons increases. Above approximately 10 MHz, the algorithm identifies relatively few photons with a high degree of confidence and the surface becomes predominantly classified with low-confidence. Of note, as the background rate increases summing the high, medium, and low confidence signal photon events yields a similar total number of likely signal photons. It is the relative fraction of each classification that changes.

Authors of each of the higher-level surface-specific ICESat-2 ATBDs that draw on the ATL03 data product have provided guidance regarding the fidelity to which the ATL03 algorithm needs to discriminate signal and background photon events. In general, each higher-level data product requires ATL03 to identify likely signal photon events within +/- 10 meters of the surface. Because the signal finding algorithm uses histograms, the vertical resolution at which signal photons are selected is directly proportional to the histogram bin size. All photons in any one bin are either classified as signal or background events. One of the goals of the algorithm is to use the smallest bin size for which signal can be found, to classify photons at the finest resolution possible. Pre-launch tests indicate that this resolution meets or exceeds the needs of the higher-level data products in all but very weak signal conditions. This smallest bin size varies as a function of surface slope and background count rate.

3 VERSION HISTORY

Version 1

4 CONTACTS AND ACKNOWLEDGMENTS

Tom Neumann
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Anita Brenner
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

David Hancock
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

John Robbins
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Scott B. Luthcke
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Kaitlin Harbeck
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Jeff Lee
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 2077

Aimée Gibbons
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Jack Saba
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

Kelly Brunt
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

IceSAT-2 Science Team
NASA Goddard Space Flight Center
Mail Code: 615
Greenbelt, MD 20771

5 DOCUMENT INFORMATION

5.1 Publication Date

23 May 2019

5.2 Date Last Updated

25 November 2020