ATLAS/ICESat-2 L2A Global Geolocated Photon Data, Version 6

USER GUIDE

How to Cite These Data

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

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National Snow and Ice Data Center

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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.

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 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 V6 | https://doi.org/10.5067/GA5KCLJT7LOT).

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) and ancillary systems (GPS, star cameras, and ground processing) to measure the time a photon takes to travel from ATLAS to Earth and back again and determine the reflected 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. Higher level ATLAS/ICESat-2 data products (ATL03 and above) are 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 Figure 1). 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, left). 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 1, right). The first yaw flip was performed on 28 December 2018, placing the spacecraft into the backward orientation. 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 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 ATL02 file names, by appending the two-digit cycle number (cc) to the RGT number, e.g., 0001cc to 1387cc.

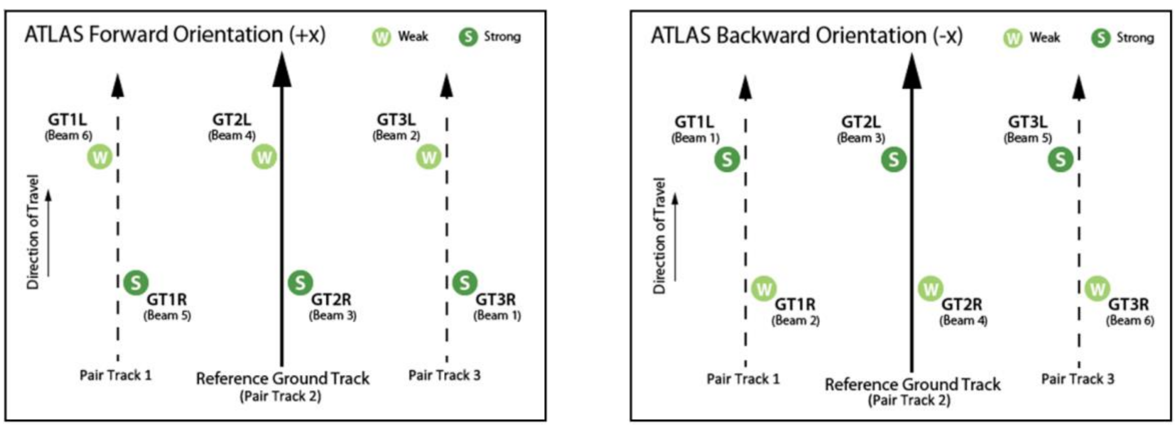

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction and backward (instrument coordinate -x) direction.

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.

Under normal operating conditions, data are not 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 PPD and POD solutions had been adequately resolved and the instrument had pointed directly at the reference ground track for at least a full 91 days (1,387 orbits).

Users should note that sometimes, for various reasons, the spacecraft pointing may lead to ICESat-2 data collected offset at some distance from the RGTs instead of along the nominal RGT. Although not along the nominal RGT, the geolocation information and data quality for these data are 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.

Various reference systems and dynamic processes, or geophysical corrections, occur during an ATLAS/ICESat-2 measurement (Figure 2). Table 1 lists the corrections needed for each surface type and ICESat-2 product. For example, to determine an estimate of the mean sea surface, several well-modeled, time-varying effects must be accounted for.

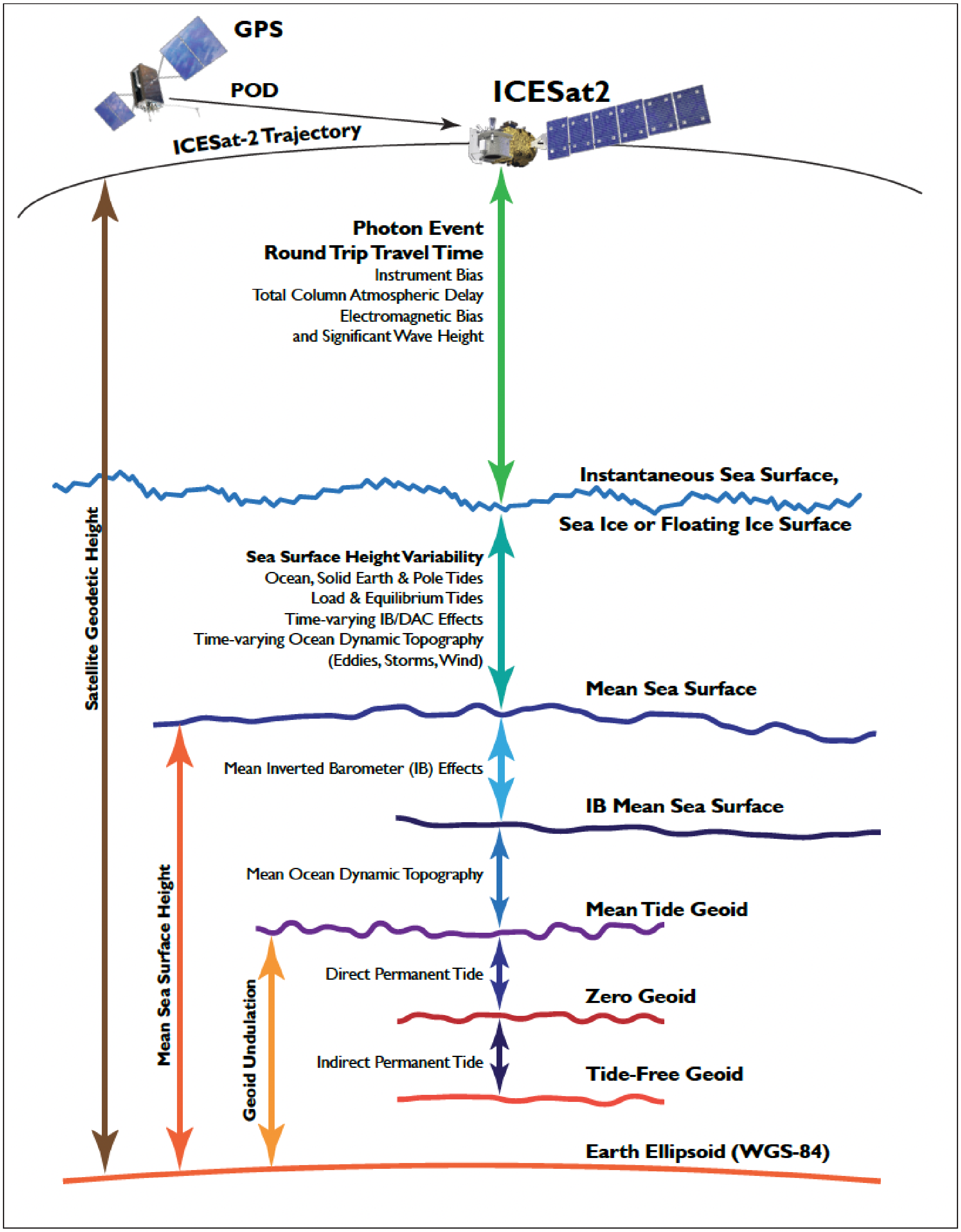

Figure 2. Geophysical corrections used in satellite altimetry. Taken from *ICESat-2 Data Comparison User's Guide for Rel006* available on the ATL03 data set landing page.

Table 1. Geophysical Corrections Applied to ICESat-2 Products

ICESat-2 Products by Surface Type	Geophysical Corrections[1]
Photon-level product (ATL03) (i.e., corrections applicable across all surface types)	Ocean loading Solid Earth tide Solid Earth pole tide Ocean pole tide Total column atmospheric range-delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Inverted barometer (IB)
Ocean (ATL12)	Ocean tide Long period equilibrium ocean tide

[1]For details, see Section 5 of the *ICESat-2 Data Comparison User's Guide for Rel006* available on the ATL03 data set landing page.

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 01–14 as shown in Figure :

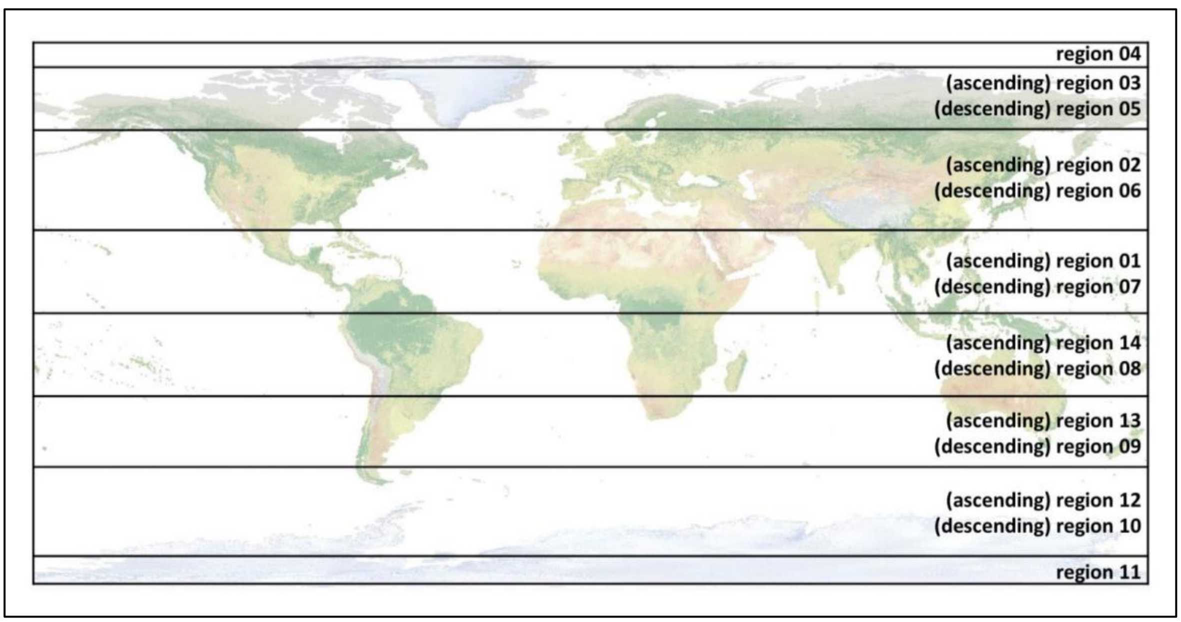

Figure 3. ATL03 region/granule boundaries.

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

Table 2. 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 . Heights, times, latitudes, and longitudes for individual photons are stored in the `/heights` group within each ground track group.

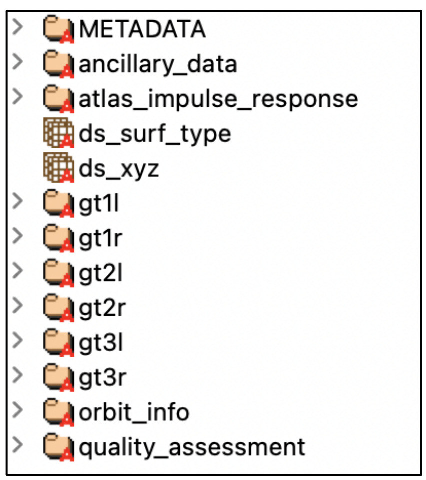

Figure 4. Top-level data groups for an ATL03 granule as displayed in HDFView. Individual photon heights, times, latitudes, and longitudes for each ground track (1L–3R) are stored in the corresponding `gt1l–gt3r/heights` data group, along with other ground-track related parameters.

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 ATL03 ATBD. A complete list of all ATL03 parameters is available in the ATL03 Data Dictionary.

1.2.4.1 METADATA

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

1.2.4.2 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 generally passed to ATL03 from the ICESat-2 Science Unit Converted Telemetry product, ATL02 (ATL02 and ATL03 ATBDs Sections 2.4.3–2.4.6).

1.2.4.3 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 (ATL03 ATBD | Section 2.4.2).

1.2.4.4 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`)

1.2.4.5 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 (ATL03 ATBD | Section 2.4.1). Data are organized into the following subgroups:

- `/bckgrd_atlas`: parameters that can be used to calculate the background photon rate recorded by ATLAS (ATL03 ATBD | Section 2.4.1.4).
- `/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 (ATL03 ATBD | Section 2.4.1.2 and Section 2.3.4 Photon Event Geolocation 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 ATL03 ATBD | Section 2.4.1.3 and Section 2.3.2 Geophysical Corrections of this user guide.

- `/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 (ATL03 ATBD | Section 2.4.1.1).
- `/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 (ATL03 ATBD | Section 2.4.1.5).

1.2.4.6 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 (ATL03 ATBD | Section 2.4.7).

1.2.4.7 quality assessment

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

1.2.5 Naming Convention

Data files utilize the following naming convention:

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

For example:

```
ATL03_20181014030520_02360114_006_01.h5
```

The following table describes the file naming convention variables:

Table 3. 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 1,387 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 01–14. Note that some segments may not be available.
vvv_rr	Version and revision number*

*NOTE: From time to time, NSIDC receives 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. 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.

1.2.6 Browse Files

Browse files are provided as JPGs designed to quickly assess the usability of each granule's data. Browse files contain:

- 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, then surface type A is plotted.
- 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: three for each of the five 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. Thus, low confidence photons are generally only prominently visible if relatively few high- or medium- confidence photons exist in a particular segment.
- A plot that 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.
- 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.
- A global map that 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 ATL03 ATBD | Section 8.0.

Browse files utilize the same naming convention as their corresponding data file but with `_BRW` and descriptive keywords appended.

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage is global.

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 that the number of photons that return to the telescope depends on surface reflectivity and cloud cover (which obscures ATLAS's view of Earth). Therefore, 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 Section 2.3.4 Photon Event Geolocation. Table contains details about WGS 84. For information about ITRF2014, see the International Terrestrial Reference Frame | ITRF2014 webpage.

Table 4. 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	WGS 84
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

Temporal Information

1.3.4 Coverage

13 October 2018 to present

Note that satellite maneuvers, data downlink issues, and other events can introduce data gaps into the ATL03 product. An ongoing list of ATL03 data gaps (.xlsx) can be downloaded from the data set landing page under Documentation.

1.3.5 Resolution

Each of ICESat-2's 1,387 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 description of 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 suite of ICESat-2 data products and their connections:

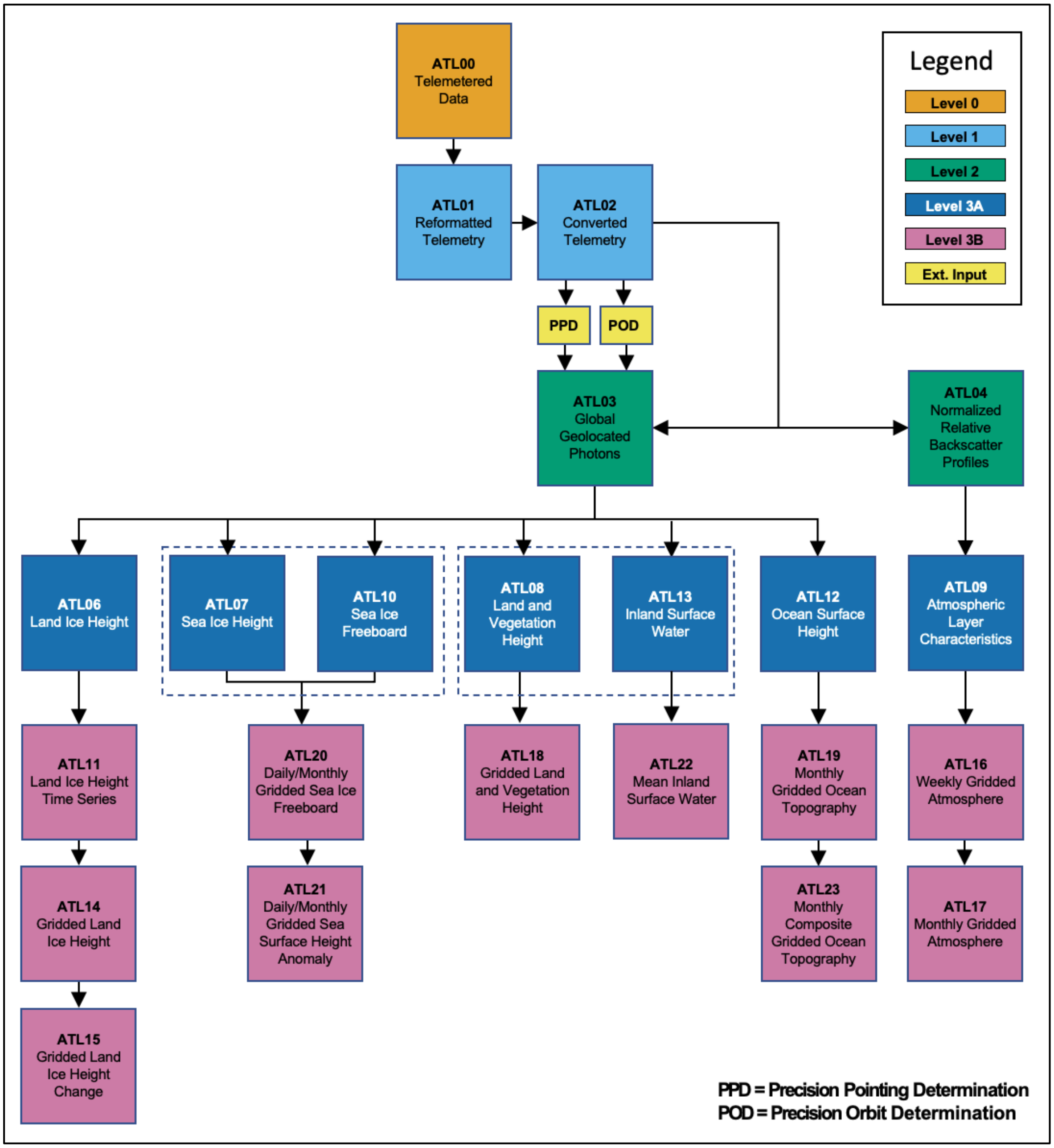

Figure 5. ICESat-2 data processing flow. ATL02 processing converts ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory.

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).

Approximately 10^{14} 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.

NOTE: 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 (approximately 30 to 2,000 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.

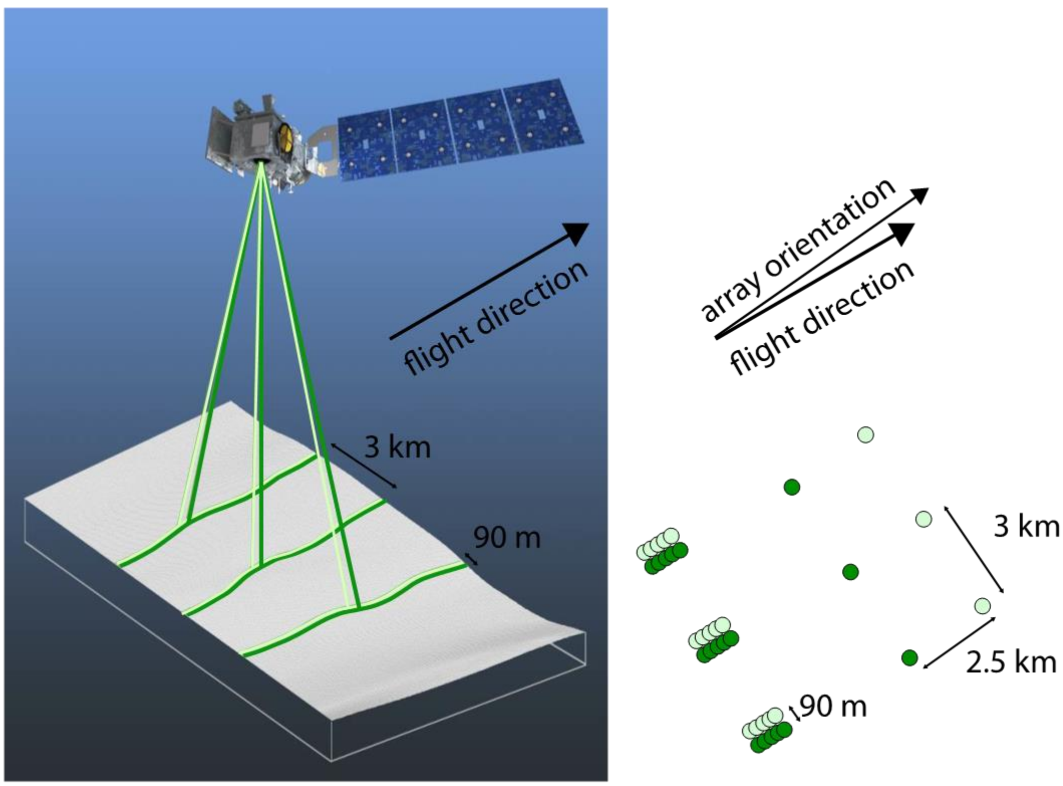

Figure 6. ATLAS idealized beam and footprint pattern. Adapted from the ATL03 ATBD.

2.3 Processing

The following sections summarize the approach used to generate the ATL03 data product. For a more complete description, consult the ATL03 ATBD.

2.3.1 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.

Surface slopes present one of the main challenges to identifying signal photon events because they are not known *a priori*. The algorithm histograms photon event heights relative to the ellipsoid, stepping 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. After the algorithm identifies possible signal photon events, it selects additional bins to ensure inclusion of all signal photon events.

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; therefore, two additional steps are performed. 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 (slant histograms). If sufficiently large time gaps exist, the assumption that the surface slope is linear may not be appropriate, and the algorithm generates slant histograms using a variable surface slope at each Δtime 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 that 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 classified 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 transmitter echo path (TEP) returns are assigned a confidence level of -2.

2.3.2 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.

The following sections list the time-dependent geophysical corrections. Geophysical corrections are stored in the `gt[x]/geophys_corr/` group and described in detail in Section 6 of the ATL03 ATBD.

2.3.2.1 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. Magnitude = ±1.5 cm.
- Ocean pole tide. Magnitude = ±2 mm amplitude.
- Geocenter Motion (*not* applied to ATL03 but accounted for in POD). Magnitude = 3 to 5 mm amplitude in x, y, z.

2.3.2.2 Photon round-trip range correction

[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 ATL03 ATBD | Section 5.1.2.

- Total column atmospheric delay. Magnitude = -2.6 to -0.9 m

2.3.2.3 Corrections provided as reference values but NOT applied

- Geoid (static quantity). Magnitude = -105 m to +90 m (max)
- Ocean tides, including diurnal and semi-diurnal and longer period tides. Magnitude = ±5 m.
- Dynamic atmospheric correction, including inverted barometer effect. Magnitude = ±50 cm.
- Digital elevation model (DEM)

2.3.3 Height Computation

Given the geophysical corrections above, ATL03 photon heights (H_{gc}) are computed as follows:

$$H_{gc} = H_{P} - H_{OL} - H_{SEPT} - H_{OPT} - H_{SET} - H_{TCA}$$

where H_P is the photon event height; H_{OL} is the ocean loading deformations; H_{SEPT} is solid Earth pole tide; H_{OPT} is ocean pole tides; H_{SET} is solid Earth tides; and H_{TCA} is the total column atmospheric delay.

2.3.4 Photon Event Geolocation

NOTE: 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 ATL03 ATBD.

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 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 20 m for left and right ground track pairs, they could be greater or less than 20 m depending on the curvature of the ground tracks on the surface of the Earth.

2.3.5 Range Bias Correction

Details on range bias correction can be found in "Section 3.3 | ATLAS Range Bias Correction and Uncertainty" of the ATL03 ATBD. The primary measurement of the ICESat-2 mission is the height of the Earth's surface. Potential sources of measurement bias, as well as bias uncertainty, are evaluated.

The ATLAS zero-range distance was measured before launch to account for optical and electrical path lengths within the instrument for many permutations of ATLAS settings and configurations (documented in the ATLAS pre-launch calibration product CAL-08). The TEP provides an option to internally calibrate ATLAS in orbit.

Range bias uncertainty is due to (1) uncertainty in the TEP-based bias estimate, (2) uncertainty in the model of the TEP variation around the orbit, and (3) uncertainty in the atmospheric delay correction. The overall height uncertainty estimate is provided at the along-track geolocation segment rate and contributes to `sigma_h`.

> NOTE: For ATL03 Versions 1–4, the range bias was calculated from pre-launch analysis and instrument calibration. This range bias correction was beam-specific and constant over time. Beginning with Version 5, the range bias correction is dynamically calculated to include time- and temperature-dependent corrections from on-orbit calibration data. The mean offset between the pre-launch (Version 4 and lower) and post-launch (Version 5 and higher) range bias correction is about 1.2 cm. An additional time-dependent range bias on the order of ± 2 mm is indicated by the analysis of on-orbit calibrations over the first two years of the mission. The temperature-dependent portion of the range bias correction is < 0.1 mm over two orbits.

2.3.6 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. 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 the same ATL03 granule as input.

Surface type is written 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 ATL03 ATBD contains a complete description of each surface mask and how it was generated.

2.3.7 Geolocation Segment Rate Parameters

The `gt[x]/geolocation/group` contains some 30 parameters that 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`); and estimated uncertainties, solar azimuth and elevation, and transmit pulse characteristics.

2.3.8 Quality, Errors, and Limitations

NOTE: 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. 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. 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. Test cases 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 (see ATL03 ATBD | Section 5.1).

3 SOFTWARE AND TOOLS

PhoREAL is a free library of geospatial analysis tools and source code written specifically for working with ATL03 (and ATL08) data.

4 VERSION HISTORY

A summary of the version history is provided in Table 5, followed by a detailed list of changes for the current version.

Table 5. Version History Summary

Version	Release Date	Description
V1	May 2019	Initial release
V2	October 2019	Refer to V2 User Guide
V3	May 2020	Refer to V3 User Guide
V4	April 2021	Refer to V4 User Guide
V5	November 2021	Refer to V5 User Guide
V6	May 2023	See below
V6.1	May 2024	Data from 13 November 2022 to 26 October 2023 were reprocessed using ITRF2014 (replacing ITRF2020) for consistency across the entire data set.

Changes for Version 6 include:

- Added parameters for photon weights including `weight_ph` at the photon rate, `knn` at the 20 m geolocation segment rate, and `win_h`, `win_x`, and `min_knn` in the `/ancillary_data/altimetry` group. The new `weight_ph` parameter is an indicator of photon density within a geosegment. The weight value is the relative weight of each photon within a 20 m geolocation segment based on the vertical distance between a given photon and its knn number of neighbors. Parameter values `win_h`, `win_x`, and `min_knn` are used to calculate photon weights.
- Updated `sigma_h` to be dynamically calculated as the sum of the `ph_uncorrelated_error`, the ATL03g-derived `sigma_h`, and 4 mm for geophysical correction uncertainties. This update represents the best estimates of height uncertainty for a reference photon in on-orbit data.
- Changed data type for `ph_id_count` to an unsigned 1-byte integer (bug fix). Prior releases of ATL03 stored the value as a signed datatype, limiting the reported value to 127.
- Changed the geographic extent metadata from a predicted orbit path to a geodetic polygon, providing better information on where ATL03 data exist for spatial queries.
- Updated the ANC42 TEP reference file to reflect changes in the ATL02 time-of-flight (TOF) calculations stemming from calibration file updates. The updated reference TEPs allow the appropriate TEPs passing QA to be written from ANC41 to ATL03 files.
- ATL03 V6 encompasses several updates affecting photon heights (h_ph), particularly changes in the TOF calibrations, zero-range point, and range bias correction. The time and temperature dependent range bias correction was first introduced in V5 but applied with an incorrect sign. This was fixed in V6. The mean offset between the pre-launch (V5) and post-launch (V6) zero range point is about -4 cm (V6 is ~4 cm lower than V5) and varies by spot and strength. Table 6 below shows spot-specific mean offsets and standard deviations.

Table 6. Mean Height Differences and Standard Deviations Between V6 and V5 (V6-V5) in cm*.

Height Differences	Spot 1	Spot 2	Spot 3	Spot 4	Spot 5	Spot 6
Mean	-3.92	-4.42	-3.81	-4.32	-3.91	-4.41
Standard Deviation	1.03	1.19	1.41	1.75	1.38	1.25

*Values calculated from one month of ATL03 photon-to-photon height differences (September 2019).

5 DOCUMENT INFORMATION

5.1 Publication Date

May 2023

5.2 Date Last Updated

May 2024