ATLAS/ICESat-2 L2A Global Geolocated Photon Data, Version 7

USER GUIDE

How to Cite These Data

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

Neumann, T. A., Hancock III, D. W., Robbins, J., Gibbons, A., Lee, J., Brenner, A., Felikson, D., Harbeck, K., Saba, J., Luthcke, S., Rebold, T., Reese, A., & Sutterley, T. (2025). *ATLAS/ICESat-2 L2A Global Geolocated Photon Data* (ATL03, Version 7). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL03.007 [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL03

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1 DATA DESCRIPTION

The ATL03 data product is described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document for Global Geolocated Photon Data (ATBD for ATL03 V7 | https://doi.org/10.5067/ENBSEIJENE3U).

1.1 Summary

ATL03 contains height above the WGS 84 ellipsoid, latitude, longitude, and time for each photon downlinked by the Advanced Topographic Laser Altimeter System (ATLAS) instrument on board ICESat-2. This product was designed to be a single source for all photon data and ancillary information needed by higher-level ATLAS/ICESat-2 products.

1.2 File Information

1.2.1 Format

Data are provided as HDF5-formatted files.

1.2.2 Granule Regions

ATL03 data are segmented into granules 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 1:

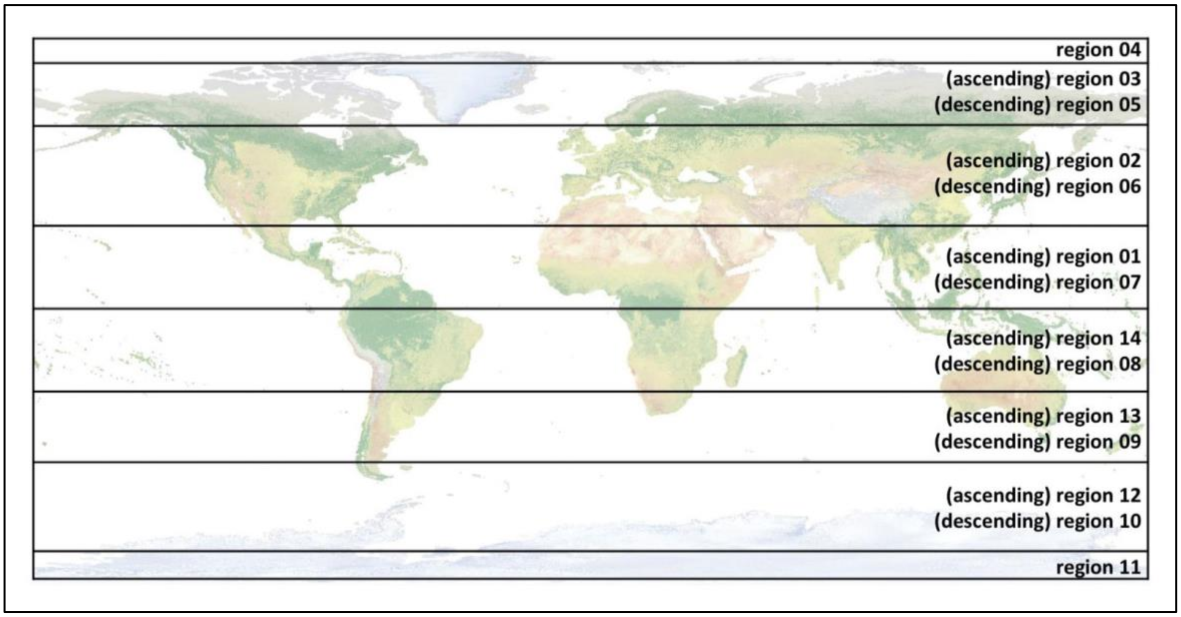

Figure 1. ATL03 region/granule boundaries.

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)

1.2.3 File Contents

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

Within data files, similar variables such as science data, instrument parameters, altimetry data, and metadata are organized into groups (directories) in the HDF model. ATL03 data files contain the top-level groups and variables shown in Figure . Heights, times, latitudes, and longitudes for individual photons are stored in the `/heights` group within each ground track group (`gt1l`–`gt3r`) (see Section 1.3.3.4).

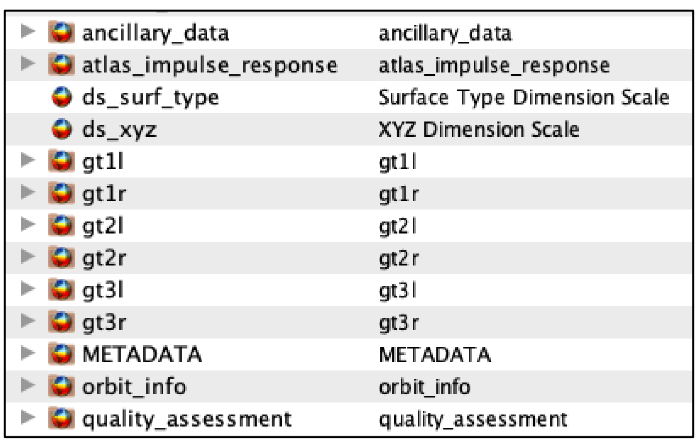

Figure 2. ATL03 top-level data groups and variables.

The following sections summarize the structure and primary variables of interest in ATL03 data files. Additional details are available in Appendix A of the ATL03 ATBD.

1.2.3.1 ancillary_data

Contains information ancillary to the data product. This may include product characteristics, instrument characteristics, and/or processing constants. These parameters are needed by higher level products and are generally passed to ATL03 from ATLAS/ICESat-2 L1B Converted Telemetry Data (ATL02).

1.2.3.2 atlas_impulse_response

Contains parameters to characterize the ATLAS impulse response energy and pulse shape from Transmitter Echo Path (TEP) data.

1.2.3.3 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`), where 1 = land, 2 = ocean, 3 = sea ice, 4 = land ice, and 5 = inland water
- `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`), where 1 = X, 2 = Y, and 3 = Z

1.2.3.4 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, posted at the 50-shot rate.
- `geolocation`: parameters posted at ~20 m, the along-track interval for photon geolocation, which apply to all photons in a given geosegment (also known as geolocation segments or geosegs). For example, the number of photons in the given along-track segment, the fraction of saturated pulses, and the composite flag indicating the quality of input geolocation products for each ATL03 segment.
- `geophys_corr`: parameters used to correct photon heights for selected geophysical effects. Some of these additional geophysical parameters may be applied to photon heights, but some are provided for informational purposes only. See Section 2.3.4 and Table A-1 of this user guide for which geophysical corrections are applied. All parameters are posted at the same interval as the along-track segment interval (nominally 20 m). When no photons are within the segment, most parameters are filled with invalid or best-estimate values.
- `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.
- `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. These parameters are provided as subgroups for each surface type.

1.2.3.5 METADATA

ISO19115 structured summary metadata for the granule, including content that describes the required geospatial information. The version(s) of the input files are included in the file name attribute under the `Lineage` group.

1.2.3.6 orbit_info

Parameters that are constant for a granule, such as the Reference Ground Track (RGT) number and cycle, the spacecraft orientation, and various ATLAS parameters needed by higher level data products.

1.2.3.7 quality_assessment

Quality assessment data, including QA counters, ground-track-specific QA, and summary QA.

1.2.4 Naming Convention

Data files utilize the following naming convention:

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

Example:

`ATL03_20230606005535_11711901_007_01.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 RGT 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	Region number. ATL03 data files are segmented into approximately 1/14th of an orbit. Region numbers range 01–14. Note that some regions may not be available.
vvv_rr	Version and revision number*

*Occasionally, 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 region 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.

1.2.5 Browse Files

Browse files are provided as JPGs designed to quickly assess the usability of each granule's data. Browse files include, but are not limited to:

- Maps of low-, 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 and the digital elevation model (DEM) height, 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` on ATL03) 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, as well as the DEM height, plotted in three dimensions. The classifications used for this plot are independent of surface type, 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.

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 nearly global (approximately 88° N 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 that the number of signal photons that return to the telescope depends on surface reflectivity and cloud cover obscuring ATLAS's view of Earth. Therefore, the vertical resolution for three-dimensional structures varies.

1.3.3 Geolocation

Photon events are presented in geodetic latitude, longitude, and ellipsoidal height.

World Geodetic System 1984 (EPSG: 4326)
ITRF2020 (EPSG: 9988)

1.4 Temporal Information

1.4.1 Coverage

Temporal coverage is 13 October 2018 through the most current processing.

Satellite maneuvers, data downlink issues, and other events can introduce data gaps into the ICESat-2 products. Users can download and consult a regularly updated list of data gaps (`.xlsx`) on the data set landing page.

Note: Temporal updates to the product are made available to users a few times per year; these new files are not reflected in the Version History section of the user guide.

1.4.2 Resolution

ICESat-2 flies along each of its 1,387 RGTs once every 91 days (i.e., the orbit has a 91-day repeat cycle). During many repeat cycles, the beam pattern is shifted from the previous cycle's pointing pattern a variable amount in the cross-track direction during parts of each orbit to increase the density of spatial coverage.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATL03 acts as the bridge between the lower level, instrumentation-specific products and the higher-level, geophysical products. 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. Additionally, there are geophysical corrections that are supplied with ATL03 but not applied to the photon heights. Although this information is not explicitly required to generate ATL03, it is included to facilitate subsequent data products.

2.2 Acquisition

Each transmitted laser pulse is split by a diffractive optical element in ATLAS to generate six individual beams, arranged in three pairs (Figure 3).

Approximately 10^{14} photons leave the ATLAS sensor with each pulse and travel through the atmosphere to Earth. Of those that reflect off the surface, approximately 10 photons 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 if they are of a similar wavelength to those emitted by the ATLAS instrument (532 nm). 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 photon data 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 1,532 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. There can be up to two telemetry bands per spot, which is decided by the onboard electronics before downlinking.

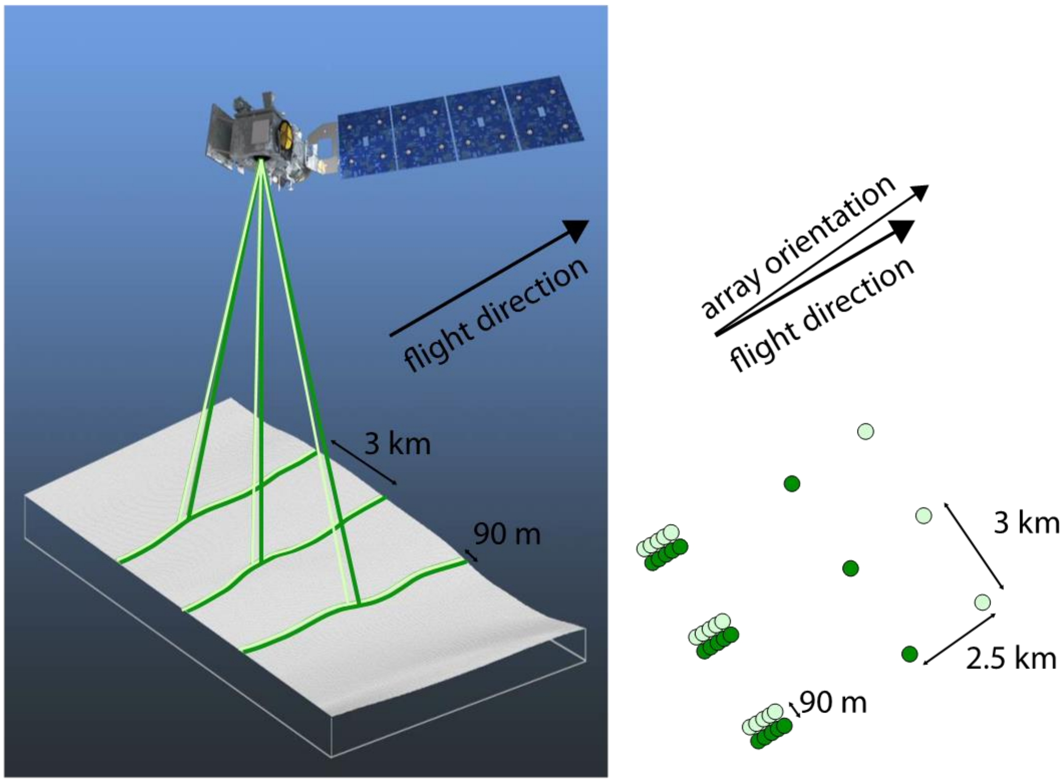

Figure 3. ATLAS Idealized Beam and Footprint Pattern (Source: ATL03 ATBD)

2.3 Processing

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) and ancillary systems (GPS, star tracker cameras, and ground processing) to measure the round-trip time a photon takes to travel from ATLAS to Earth and back again. The time-of-flight, absolute time, spacecraft location and pointing are used to determine the reflected photon's geodetic height, latitude, and longitude.

The ATLAS instrument uses a single laser and a beam splitter to illuminate six different “spots” that each trace out a ~11 m wide track (Magruder et al., 2020) as ICESat-2 orbits Earth (Figure 4). Three of the spots are considered “strong” (spots 1, 3, and 5) and the other three “weak” (spots 2, 4, and 6). Three independent Photon Counting Electronics (PCEs) record the photons returned to the telescope, each for a single pair of strong/weak spots. PCE1 records spots 1 and 2; PCE2 records spots 3 and 4; and PCE3 records spots 5 and 6.

Higher-level ATLAS/ICESat-2 data products are organized by ground track (GT), with GT1L and GT1R forming pair one, GT2L and GT2R forming pair two, and GT3L and GT3R forming pair three. Each GT is numbered according to the relative location of the laser spot that generates it, with GT1L on the far left and GT3R on the far right. Left/right beams within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction.

The mapping between the strong and weak spots of ATLAS, and their relative positions 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 (Figure 4, left), with the weak spots leading the strong spots. In the backward orientation, ATLAS travels along the -x coordinate in the instrument reference frame, with the strong spots leading the weak spots (Figure 4, right). Atmospheric profiles are generated from strong spots only, and the instrument orientation determines which GT label ("gtx") corresponds to which profile.

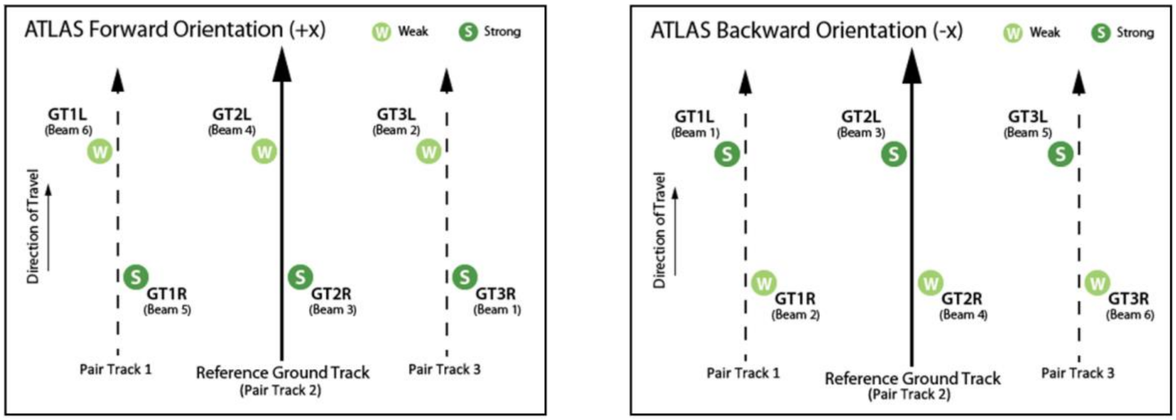

Figure 4. Spot and ground track (GT) naming convention.

The Reference Ground Track (RGT) is an imaginary track on Earth through the six-spot pattern that is used to point the observatory. 1,387 RGTs are sampled over the course of 91 days, allowing seasonal height changes to be detected. Onboard software aims the laser beams so that the RGT is between GT2L and GT2R (i.e., coincident with Pair Track 2). Nominal RGT pointing occurs over the oceans and polar regions and is periodically adjusted over vegetated land areas to broaden global coverage. 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.

Over lower latitudes, the satellite points slightly off the RGT during most cycles to measure canopy and ground heights. 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 were adequately resolved, and the instrument had pointed directly at the RGT for at least a full 91 days (1,387 orbits).

NOTE: ICESat-2 RGTs with dates and times can be downloaded as KML files from NASA's ICESat-2 | Technical Specs page, below the Orbit and Coverage table. Pointing plans summarized by cycle and off-pointing angle are posted in the ICESat-2 Major Activities document.

The ATLAS data and data collected from ancillary systems are telemetered to the ground and processed into several data products (Figure 5). The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts ATL01 data to science units, applies instrument corrections, and produces photon time-of-flight data. The PPD and POD solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time. ATL02, PPD, and POD are used to produce the global geolocated photon data of ATL03 and the normalized relative backscatter profiles of ATL04, which are the base products for all higher-level data sets.

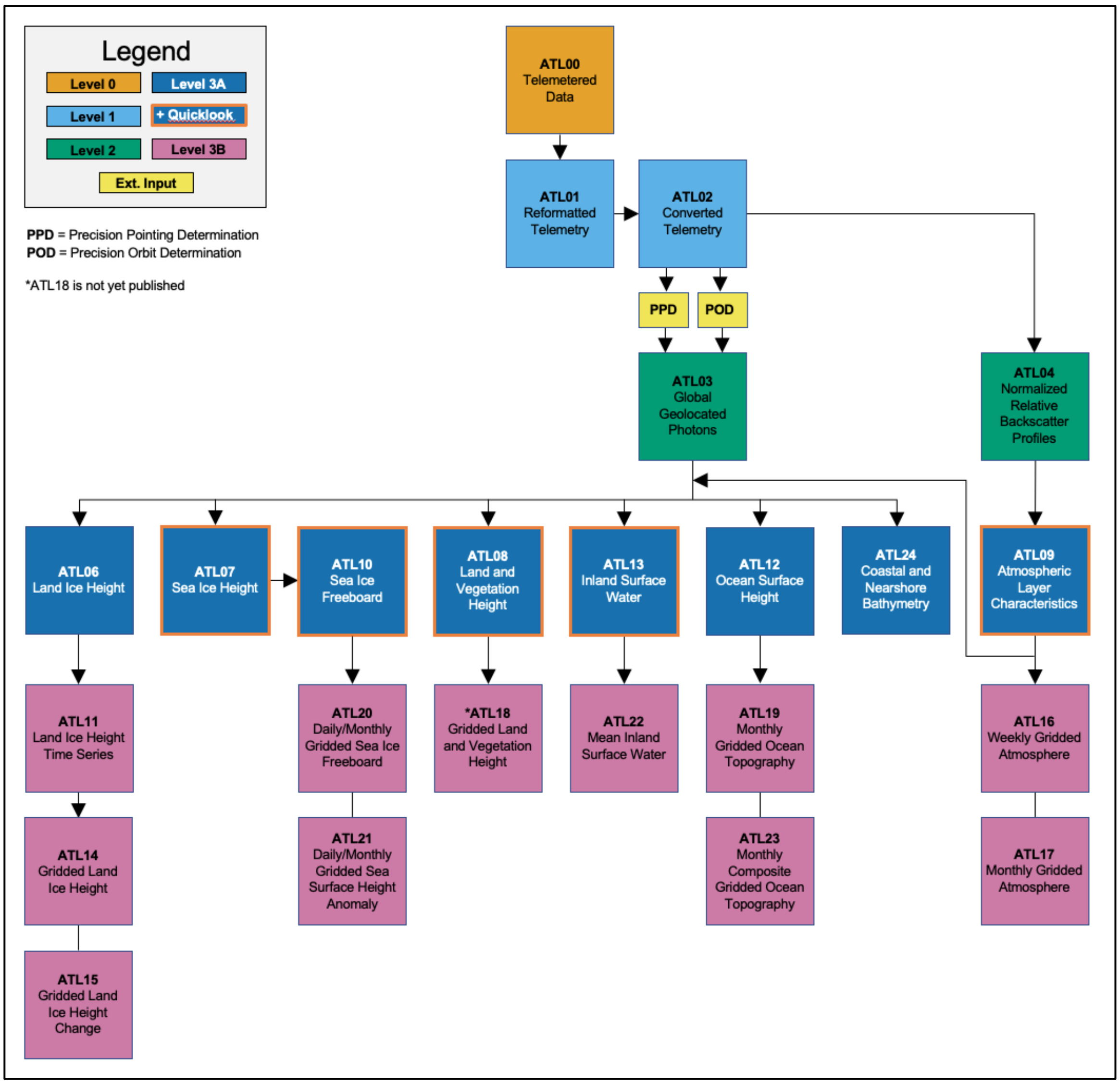

Figure 5. Schematic of ICESat-2 data processing and data products.

2.3.1 Geolocation

An accurate determination of the laser spot location on the Earth's surface is required for analyses of altimetry data. The geolocation of the laser spot with respect to the Earth's center of mass is determined by both the orbital location of ATLAS in an appropriate reference frame and the direction of the laser beams within the same reference frame.

Each individual photon event is initially geolocated without the correction for atmospheric path delay. These geolocated photons are passed to the signal finding algorithm, and the signal characterized photons are binned into ~20 m along-track segments that are fixed to the RGT in predetermined locations. A reference photon is selected from the likely signal photons. The atmospheric path delay and its derivatives with respect to ellipsoid height are computed for the reference photon. The geodetic spherical coordinates of all photons within the segment are then corrected for atmospheric path delay using the reference photon computed information. Placement of the geolocated photons into along-track geolocation segments includes identifying the RGT segment number for each photon and computing the segment-centric cartesian coordinates for each photon from the geodetic spherical coordinates. Note that the along-track segments could be greater than or less than 20 m depending on the curvature of the ground tracks on the surface of the Earth and the angle of pointing off the RGT.

The geolocation procedure is documented in detail in the ATL03g ICESat-2 Receive Photon Geolocation ATBD.

> 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, most parameters are set to invalid or best-estimate values. Specifically, because the segment identifiers are monotonically increasing, the segment level variables will still exist but may be invalid in the case where there are no associated photon events.

2.3.2 Surface Masks

ATL03 provides five surface masks (land ice, sea ice, land, ocean, and inland water) to reduce the volume of data that must be processed to generate the higher-level ICESat-2 data products that consider specific areas of interest. To protect against omission errors in these masks, a buffer has been added to the best estimate of the geographic bounds of regions of interest. Consequently, the grids overlap each other on the order of tens of kilometers in most regions. 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. See "Section 4.0 | SURFACE MASKS" of the ATL03 ATBD.

2.3.3 Photon Classification

Based on pre-launch testing of the ATLAS photon-counting system, the ATL03 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 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.

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. 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 to define the local surface slope. It then histograms the photon heights relative to the local surface slope to search for signal returns along a linear trend determined by the adjacent surface slopes.

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 whether it is a photon event that was added as a buffer. A confidence parameter—high, medium, or low confidence—is included for each likely signal photon event based on the signal-to-noise ratio of each histogram bin.

The `weight_ph` parameter provides the relative density of each photon based on the number of and distance to neighboring photons within an elliptic kernel. Weight values are relative to the weight of a signal photon when ATLAS returns are completely saturated. The higher the weight, the more likely a photon should be considered signal. Starting with Version 7, photon weights are completely independent of the 20-meter geosegments and may be aggregated at any rate. An example use-case for `weight_ph` is to identify signal photons based on a signal-to-noise ratio calculated by evaluating the distribution of `weight_ph` values within an aggregation. Note that a single photon within the elliptic kernel contains a non-zero value. Zero-value weights are assigned to photons intentionally ignored by selection criteria as described in the ATL03 ATBD. The `weight_ph` parameter is calculated independently of `signal_conf_ph` and may be used alone or in concert with `signal_conf_ph`.

The photon signal classification `signal_class_ph` (new with Version 7) is the result of an algorithm that uses `weight_ph` to classify photons as one of three possible surfaces using signal/noise thresholding and least-squares fitting techniques. This algorithm is considered experimental and subject to refinement in later versions. The `signal_class_ph` parameter is calculated independently of `signal_conf_ph` and may be used alone or in concert with `signal_conf_ph`.

See "Section 5.1 | Photon Signal Confidence", "Section 5.2 | Photon Weights", and "Section 5.3 | Signal_class_ph" in the ATL03 ATBD for details on the classification methods.

2.3.4 Geophysical Corrections

ATLAS-emitted photons pass through the atmosphere and experience delays that depend on the refractive index along the optical path (Figure 6). 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, 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. Table 3 lists the geophysical corrections applied to ICESat-2 products. Upper-level products may undergo additional height corrections, including corrections for pulse shape and instrument characteristics. For more information, refer to the data product's ATBD.

Table 3. 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 delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No geophysical corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	ATL03 corrections Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Dynamic atmosphere correction
Ocean (ATL12)	ATL03 corrections Ocean tide Long period equilibrium ocean tide

[1]For details, see Section 5 of the *ICESat-2 Data Comparison User's Guide for Rel007* available on the ATL03 data set landing page.

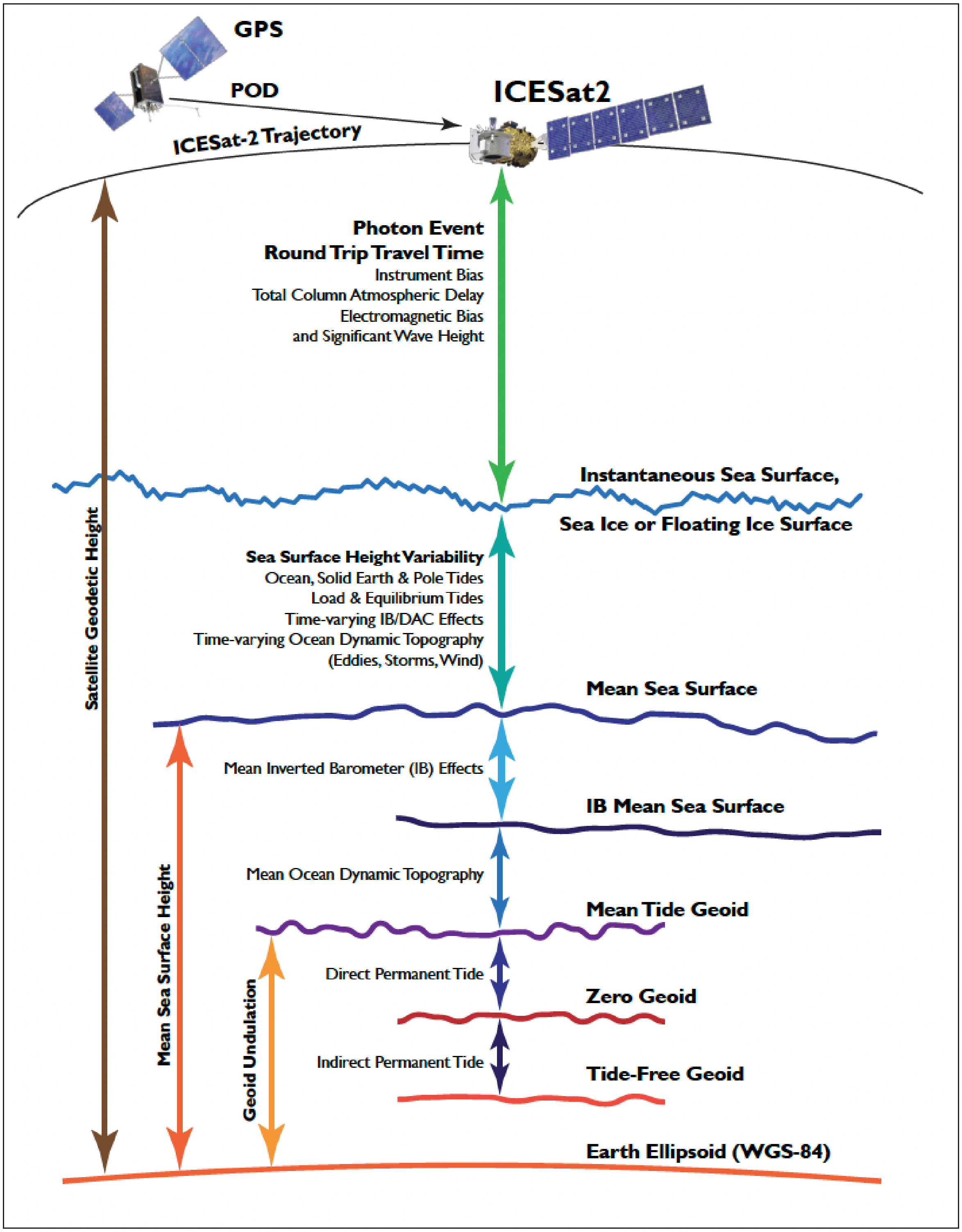

Figure 6. Geophysical corrections used in satellite altimetry
(Source: *ICESat-2 Data Comparison User's Guide for Rel007,*
Available on the ATL03 Data Set Landing Page).

Considering the geophysical corrections, 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.

2.3.5 Quality, Errors, and Limitations

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.

Generally, 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 Section 5.1 of the ATL03 ATBD).

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

`/gt[x]/geolocation/`

- `sigma_h`: estimated height uncertainty for the reference photon bounce point (note: see Known Issues document)
- `surf_type`: flag describing the surface types for each geolocation segment

`/gt[x]/geophys_corr/`

- `geoid`: geoid height with respect to the WGS 84 reference ellipsoid, derived from EGM2008 in a "tide-free" system. The parameter is used to convert to orthometric heights and is not applied to the photon cloud.

Users seeking data quality flags may find the following parameters useful:

/gt[x]/geolocation/

- `podppd_flag`: composite flag indicating periods of potentially degraded POD/PPD input data solutions

/gt[x]/heights/

- `quality_ph`: flag indicating photons that may not be suitable for certain analyses

3 VERSION HISTORY

Table 4. Version History Summary

Version	Date	Description of Changes
6.1	2 Feb 2026	Removed data access for v6.1. Data coverage was 13 Oct 2018 to 3 Mar 2025.
7.0	31 Jul 2025	• ATL02 improved TOF, range calibrations, and range bias correction (average change in range is about -0.7 mm). • ATL02 added a variable to the first photon bias and radiometric correction tables to reflect invalid correction values due to unreliable calibration values. New variable max_valid_stren_strong carried from ATL02 for rad_corr (CAL19) and ffb_corr (CAL34). • Moved from ITRF2014 to ITRF2020. Up to a 7 mm regional height change, maximum values at poles. • ANC03/04 products generated from POD solutions use updated global modeling. • Correction to the center-of-mass data set generation in ANC04, which should shift the z-component by ~1.0–1.2 cm during airplane mode periods (solar array, i.e., SADA). Airplane/sailboat changes are documented in the Major Activities Table, under the yaw flip changes. • ANC05 products were calibrated using results from recent full mission week calibration solutions. • Used GEOS5-IT for atmosphere delay calculation from NASA GMAO. No significant height change from v6 based on ~1 month of photon-to-photon comparisons • Updated tide model from GOT4.8 to an extrapolated FES2014b for ocean, load and long-period tides. FES2014b has a higher spatial resolution, improved predictions, and improved near-shore coverage. Land masks are not applied to the tide parameters on ATL03. No adverse systemic change in affected parameters between v6 and v7. Parameters affected in /gtx/geophys_corr include tide_ocean, tide_load, and tide_equilibrium. • Updated weight_ph to use DDA-03's Radial Basis Function Normalized for Instrument Characteristics. This allows weight_ph values to be consistent across all ICESat-2 data, as opposed to v6 where weight_ph values were normalized within a geosegment. • Added signal_class_ph as experimental DDA-03 parameter to classify photons using algorithms developed for evaluating weight_ph. • Updated quality_ph to include flag values to identify noise bursts and streaks, and all photons in a pulse that are considered nearly or fully saturated and whether the return occurs at the surface, after pulse, impulse response. v6 flag values of 1 and 2 are obsolete in v7. • Added beta_angle and orbit_angle at geoseg rate, carried forward from ATL03g. • Cloud optimization of H5 files for more efficient access/use in cloud environments. • Product metadata updates.

Version	Date	Description of Changes
6.1	1 May 2024	Data from 13 Nov 2022 to 26 Oct 2023 were reprocessed using ITRF2014 (replacing ITRF2020) for consistency across the entire data set.
5.0 (retire)	11 Jan 2024	Removed data access for v5.0. Data coverage was 13 Oct 2018 to 13 Oct 2022.
6.0	11 May 2023	• 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 /ancillary_data/altimetry. 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.
4.0 (retire)	13 Jun 2022	Removed data access for v4.0. Data coverage was 13 Oct 2018 to 15 Jul 2021.
3.0 (retire)	25 Jan 2022	Removed data access for v3.0. Data coverage was 13 Oct 2018 to 11 Nov 2020.
5.0	29 Nov 2021	• Updated ATL03 photon heights to include time-dependent range bias. This is calculated with on-orbit data and better represents changes to the zero-range point over the mission. • In v1–4, the range bias for each spot was calculated from pre-launch analysis and calibration. The range bias correction for these releases was beam-specific and constant over time. In v5 and later, the range bias is dynamically calculated to include mission time- and temperature-dependent corrections from on-orbit transmitter echo pulse (TEP) data. The mean offset between the pre-launch (v4) and post-launch (v5) range bias correction is about 1.2 cm (v5 photon heights are ~1.2 cm higher than v4 photon heights). Analyses of the on-orbit TEP data collected over the first 2 years of the mission indicate the time-dependent range bias adds +/- 2 mm to photon height observations. The temperature-dependent portion of the range bias correction is < 0.1 mm over two orbits. • Added XML metadata to indicate the percentage of each surface type within an ATL03 granule. New product-specific attributes (PSAs) are included in the ATL03 XML metadata file for each of the 5 surface types. The value for each of these PSAs is the percent (0–100) of the presence of each corresponding surface type data within a particular ATL03 granule. Since the ICESat-2 surface masks overlap, the sum of these percentages is not expected to equal 100. • Updated the podppd_flag parameter to include identification of ATLAS calibration scans that may indicate degraded geolocation accuracy and affect data quality. Values greater than 3 denote an ATLAS calibration period (around-the-world scan or ocean scan).

Version	Date	Description of Changes
		• Updated the default uncertainties to represent the current best estimates using on-ortbit data: sigma_h = 0.17 m, sigma_along = 5 m, sigma_across = 5 m, sigma_lat = 0.000063 deg, and sigma_lon ~= 0.000063 deg. • Improved TEP flagging to better identify TEP photons, and fixed TEP detection to function only in ATLAS spots 1 and 3. The improved TEP flagging captures more TEP photons, particularly in low-signal cases. • Updated the reference photon selection algorithm to more accurately follow the logic described in the ATBD. • Fixed the calculation and application of the neutral atmosphere delay derivative to non-reference photons in a geolocation segment. • Improved the quality_ph flagging.
2.0 (retire)	21 May 2021	Removed data access for v2.0. Data coverage was 13 Oct 2018 to 15 Nov 2019.
4.0	13 Apr 2021	• Added a per-photon indicator of possible saturated conditions and/or instrument related effects (quality_ph) allowing users to easily identify photons that are not likely true surface due to saturation conditions and/or internal reflections within the ATLAS instrument. • Improved the saturation fraction computations for near_sat_frac and full_sat_frac to accommodate the quality_ph calculation. • Added roll, pitch and yaw from the ANC04 POD file and interpolated them to the geolocation segment rate. These parameters provide the users the components necessary to determine spacecraft orientation and altitude that may influence relative distance between the beams. • Replaced GMDED2010 with the 3 arc-second MERIT DEM as the global DEM. ATL03 uses reference DEMs to exclude photons outside of the primary telemetry band from signal classification to reduce the number of clouds inadvertently classified as signal. The 3 arc-second spatial resolution of the MERIT DEM is an improvement over the 7.5 arc-second resolution of GMTED2010 providing better terrain heights, particularly over forested regions and river basins. Usage of the MERIT DEM improves absolute bias, striping and speckling noise and also results in an improved three height bias. • Changed geoid from EGM2008 mean-tide system to EGM2008 tide-free system. This allows users more easily to re-reference photon heights above the geoid without additional corrections, bringing consistency to the tidal systems on ATL03. • Added conversion factors for geoid and solid earth tide that allow easy conversion from/to tide-free/mean-tide systems allowing users to flexibly convert between the tide systems.
1.0 (retire)	3 Jun 2020	Removed data access for v1.0. Data coverage was 13 Oct 2018 to 19 Feb 2019.
3.0	5 May 2020	• Added a QA parameter (confidence level) that indicates the percentage of reference photons at specified distances from the reference DEM (at the geolocation segment rate). The thresholds corresponding to photon confidence levels are 50 m for high confidence; 100 m for medium confidence; 200 m for low confidence; and 200 m for buffer/noise level reference photons. This parameter provides a means to quickly assess whether the photon being classified as signal lies within an appropriate distance of a known surface value. • Fixed a logic error that occurred when combining the POD and PPD degrade values. In addition, the podppd_flag parameter was simplified to indicate that the geolocation solution is degraded in the POD, PPD, or both. This change addresses concerns that the approach used in previous versions was too complex to accurately document. • Photons in telemetry bands that do not intersect the DEM height within a +/- 30 m buffer are no longer considered by the signal classification processing algorithm. Additionally, photons that are poorly geolocated (as indicated by the podppd_flag) are no longer classified as potential signal. This change helps mitigate high-cloud photon returns from being erroneously classified as signal. • Added two new parameters (/gtx/geolocation/near_sat_frac and /gtx/geolocation/full_sat_frac) to indicate nearly or fully saturated ATLAS shots. The

Version	Date	Description of Changes
		parameters report the percentage of observed shots that are nearly or fully saturated within a geolocation segment.
2.0	24 Oct 2019	• Added the equilibrium tide as a parameter (/gtx/geophys_corr/tide_eq). • Corrected the ph_id_channel description. • Added additional ATLAS housekeeping/status values from ATL02 to the /atlas_engineering group to fully describe the ATLAS configuration state. • Adopted an improved inland water mask. • Added DEM height and flag at the 20 m geolocation segment rate. DEM height (/gtx/geophys_corr/dem_h) is the best available height from one of several region-specific and global DEMs. The DEM flag (/gtx/geophys_corr/dem_flag) indicates the DEM from which the height was retrieved. • Added a composite flag for POD/PPD quality at the 20 m geolocation segment rate. A non-zero value indicates a possibly degraded geolocation solution. • Updated default uncertainties (sigma_h = 30 m; sigma_along = 20 m; sigma_across = 20 m; sigma_lat ~= 0.00018 deg; and sigma_lon = 0.00018 deg) to better represent actual uncertainties in the ATL03 photon data.
1.0	28 May 2019	Initial release

4 REFERENCES

Magruder, L. A., Brunt, K., Neumann, T., Klotz, B., & Alonzo, M. (2020). Passive ground-based optical techniques for monitoring the on-orbit ICESat-2 altimeter geolocation and footprint diameter. *ESS Open Archive*. https://doi.org/10.1002/essoar.10504571.1

5 DOCUMENT INFORMATION

5.1 Publication Date

July 2025

5.2 Date Last Updated

February 2026