ATLAS/ICESat-2 L3A Land Ice Height, Version 7

USER GUIDE

How to Cite These Data

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

Smith, B., Adusumilli, S., Csathó, B. M., Felikson, D., Fricker, H. A., Gardner, A., Holschuh, N., Lee, J., Paolo, F. S., Siegfried, M. R., Sutterley, T. & the ICESat-2 Science Team (2025). *ATLAS/ICESat-2 L3A Land Ice Height* (ATL06, Version 7). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL06.007. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL06

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1 DATA DESCRIPTION

The ATL06 data product is described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document for Land Ice Along-Track Height Product (ATL06 ATBD | V7, https://doi.org/10.5067/6QFWBG914OCK).

1.1 Summary

ATL06 contains geolocated land-ice surface heights above the WGS84 ellipsoid, plus ancillary parameters that can be used to interpret and assess the quality of the height estimates. The data were acquired by the Advanced Topographic Laser Altimeter System (ATLAS) instrument on board the ICESat-2 observatory.

1.2 File Information

1.2.1 Format

Data are provided as HDF5-formatted files.

1.2.2 Granule Regions

ATL06 data are provided as 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 1:

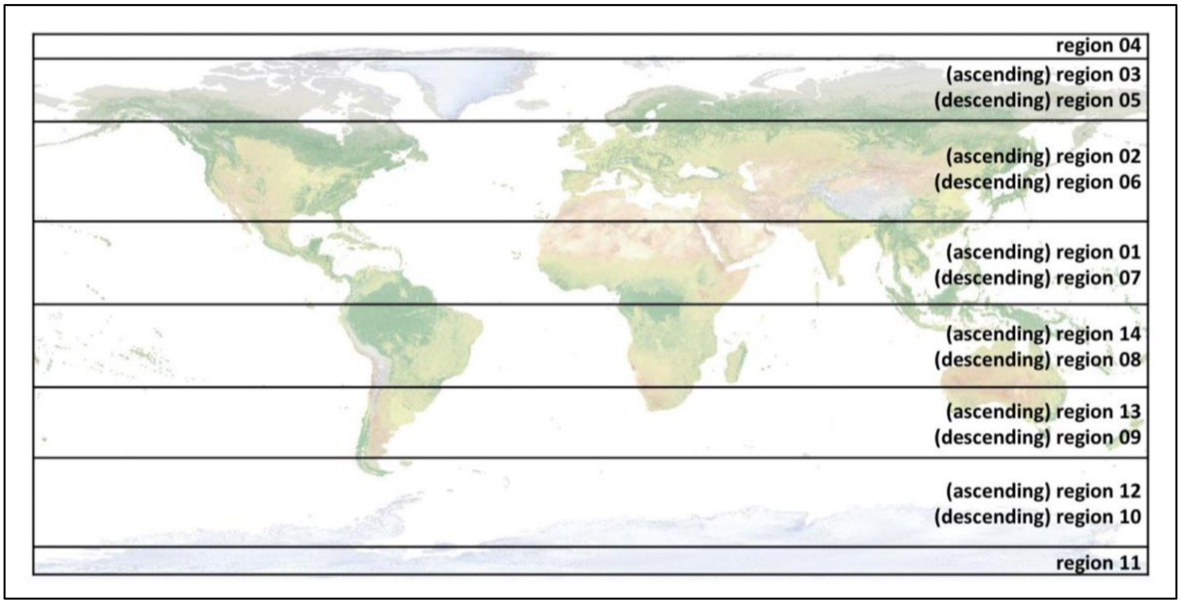

Figure 1. ATL06 region/granule boundaries.

The following table lists 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 ATL06 parameters is available in the ATL06 Data Dictionary.

Within data granules, similar variables such as science data, instrument parameters, altimetry data, and metadata are grouped together according to the HDF model and organized within the following top-level groups:

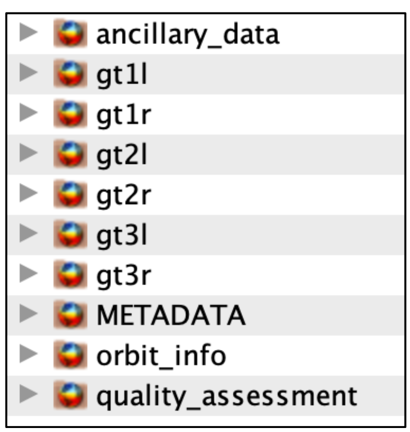

Figure 2. ATL06 top-level data groups.

The following sections summarize the contents of the data groups and certain parameters of interest. Data groups are described in detail in "Section 4 | ATL06 Data Product Description" in the ATBD for ATL06.

1.2.3.1 ancillary_data

Ancillary information such as product and instrument characteristics and/or processing constants. Data in this group pertain to the granule in its entirety.

1.2.3.2 gt1l–gt3r

Each ground track group (six in all) contains three subgroups:

- **land_ice_segments:** contains primary ATL06 derived parameters, e.g., land-ice height (`h_li`), latitude, longitude, standard error, and quality measures. Heights represent the mean surface height, averaged along 40 m segments of ground track spaced 20 m apart, for each of ATLAS's six beams. Data are only provided for segment pairs for which at least one beam has a valid land-ice height measurement. Each reported height has a corresponding segment ID (stored in `segment_ID`), which indicates the second of the two 20 m ATL03 segments used to generate the 40 m ATL06 height segment.
- **residual_histogram:** contains histograms of the residuals between photon event heights and the least-squares fit segment heights. Histograms are provided at a 200 m along-track rate.
- **segment_quality:** contains a record of the success/failure of the surface-finding strategies for every possible segment in the granule, plus locations of the reference points on the reference pair tracks. For segments with adequate data quality, this subgroup contains offsets into the data structures for the other groups that allow each segment to be efficiently located within the file. Data are spaced 20 m apart along-track.

1.2.3.3 METADATA

ISO19115 structured metadata with sufficient content to generate the required geospatial metadata. The version(s) of the input files are included in the file name attribute under the `Lineage` group.

1.2.3.4 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.

1.2.3.5 quality_assessment

Contains quality assessment data, including QA counters and QA along-track and/or summary data, organized in `gt[x]` subgroups. For more information, see "Section 4.0 | ATL06 Data Product Description" in the ATL06 ATBD.

1.2.4 Naming Convention

Data files utilize the following naming convention:

`ATL06_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5`

Example:

`ATL06_20181015093524_02560106_07_01.h5`

The following table describes the file naming convention variables:

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
`ATL06`	ATLAS/ICESat-2 L3A Land Ice Height product
`yyyymmdd`	Year, month, and day of data acquisition
`hhmmss`	Hour, minute, and second of data acquisition (UTC)
`tttt`	Reference Ground Track (RGT). 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 (see Figure 1). ATL06 data files cover approximately 1/14th of an orbit. Region numbers range 01–14.
vvv_vv	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.

1.2.4.1 Browse File

Browse files are provided as JPGs designed as data quality maps and profile plots. Browse files utilize the same naming convention as their corresponding data file but with "`_BRW`" and descriptive keywords appended.

A list of available images is shown in Table 3, and an example is shown in Figure 3.

Table 3. Images Available as Browse

Image	Description
`atl06_quality_summary`	Background image based on the MODIS mosaics, with color-coded points showing the best quality and potential problem segments
`h_li`	Surface height as a function of along-track distance
`h_li_sigma`	Height error estimate
`n_fit_photons`	Number of photon events per segment
`signal_selection_source`	Background image based on the MODIS mosaics, with color-coded points showing the signal selection source

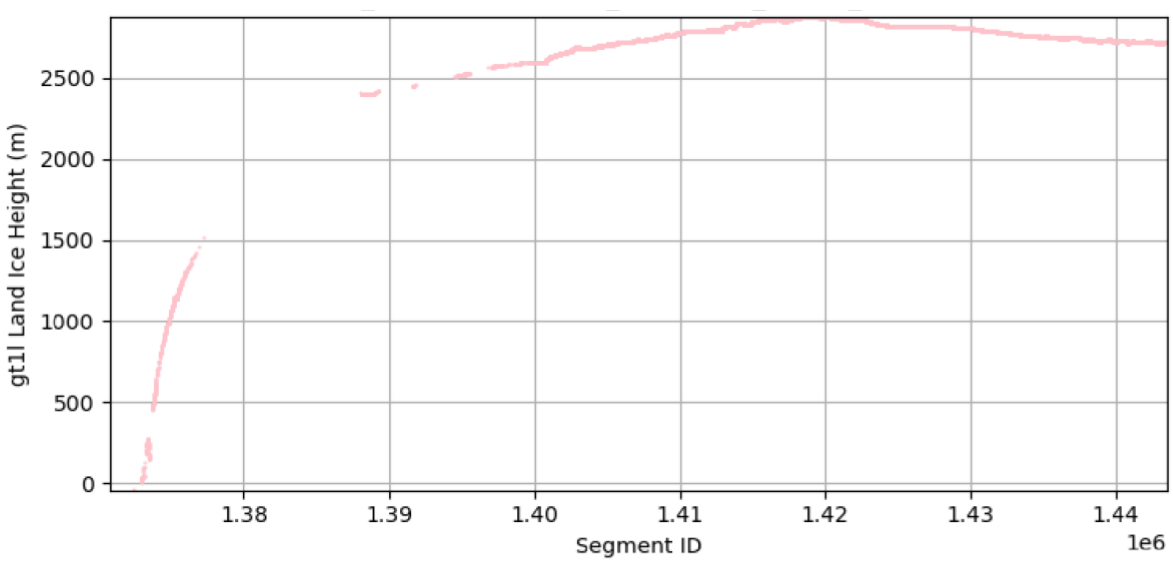

Figure 3. Example browse image (`h_li`).

1.3 Spatial Information

1.3.1 Coverage

The ICESat-2 mission acquires data along 1,387 different RGTs. However, this product does not produce data granules for orbital segments that span open ocean only (i.e., do not cross a land surface). As such, some granules/orbital segments will not be available.

Static surface masks (land ice, sea ice, land, and ocean) are applied to ATL03 to reduce the volume of data that a surface-specific along-track data product is required to process. The land ice surface mask directs the ATL06 land ice algorithm to consider data from only those areas of interest.

NOTE: Starting with Version 6, ATL06 data are being processed for all global land regions and not restricted to land ice only. However, data outside of polar regions have not been thoroughly evaluated and may contain errors. Refer to the ATL06 Known Issues document for more information on using this experimental data.

1.3.2 Resolution

Heights represent the mean surface height averaged along 40 m segments of ground track that overlap by 50%, resulting in a 20 m along-track resolution.

1.3.3 Geolocation

Points 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 14 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

The ATL06 product provides the most basic derived values from the ATLAS instrument: the surface height at a given point on Earth’s surface relative to the WGS84 ellipsoid at a given time.

2.2 Acquisition

ATL06 height estimates are derived from geolocated, time-tagged photon heights plus other parameters passed to ATL06 by the ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03) product.

2.3 Processing

ATL06 heights are based on fits of a linear model to ATL03 height data from short (40 m), overlapping segments of the ground track, centered on reference points spaced at 20 m intervals along-track. The same along-track sampling is used for both beams in each beam pair, and the same reference point for each segment height calculation is used for each cycle.

The processing steps are described in the sections below.

2.3.1 PE Selection

ATL03 provides photon event (PE) locations and timings for each beam. The first step in ATL06 processing is to select groups of PEs that determine the segment height at each along-track point. Processing is only carried out if the ATL03 podppd_flag indicates that the PE geolocation is of high quality for all pulses in the segment, otherwise the segment is skipped ("Section 3.3 | PE Selection" in the ATL06 ATBD).

2.3.2 First-Photon Bias

The first-photon bias is caused by an inherent limitation with ATLAS's photon-counting detectors. After an individual pixel of each detector detects a photon, it cannot detect another for a short amount of time (approximately 3.2 ns). Thus, photons early in a ground return are more likely to be detected than those later on.

A correction is generated for the first-photon bias based on a model of the detector for PEs aggregated over a 40 m ground track segment. The algorithm generates a histogram representing the distribution of heights around the ground return for the segment, as represented by the histogram of PE residuals to the best-fitting sloping segment model. The effective gain of the detector is estimated (the probability that a photon would have been detected if it reached the detector). This function corrects the received histogram to an estimate of the histogram of all the photons, detected and undetected. Statistics of this histogram are used to improve estimates of the surface height ("Section 3.4 | First-Photon Bias" in the ATL06 ATBD).

2.3.3 Transmit-Pulse Shape Correction

The transmitted pulse is not symmetric in time around its centroid; therefore, its median is different from its mean, and the centroid of any truncated subset of the photons from this pulse has a non-zero bias relative to those from the full waveform. This introduces a potential bias in ATL06 height estimates, depending on the shape of the "tail" of the transmitted waveform, the width of the surface window, and the effective surface roughness. ATL06 corrects this bias by modeling expected return-pulse shapes and calculating the biases for these shapes, then subtracting the bias from the measured height estimates ("Section 3.5 | Transmit-pulse shape correction" in the ATL06 ATBD).

2.3.4 Signal, Noise, and Error Estimates

The relative contributions of signal and noise PEs to the observed PE count are important to estimate before calculating error. ATL06 considers the background PE rate, signal PE count, per-photon errors, propagated height errors, and uncorrected reflectance. See "Section 3.6 | Signal, Noise, and Error Estimates" in the ATL06 ATBD for descriptions of how each of these errors is calculated.

2.3.5 Across-Track Slope Calculation

The across-track slope is computed for a beam pair based on the first-photon-bias-corrected median heights for the two segments. If only one beam returned a height, then the slope is set to "invalid" for both beams ("Section 3.7 | Across-track slope calculation" in the ATL06 ATBD).

2.3.6 Scattering Bias

Sub-surface scattering bias is caused by photons that experience multiple scattering within snow or ice before returning to the sensor. Currently, a correction is not offered due to the varied and unknown properties of snow/ice during processing. Similarly, the downward laser pulse can experience atmospheric scattering, and any potential correction relies on external data sets ("Section 3.8 | Subsurface-Scattering Bias" and "Section 3.9 | Atmospheric-Scattering Bias" in the ATL06 ATBD).

2.3.7 Segment Geolocation

The segment location is defined as the reference-point location plus the across-track distance provided by ATL03 for the selected PE. See "Section 3.10 | Segment geolocation" in the ATL06 ATBD for details of the calculations and the related parameters.

2.3.8 Robust Dispersion Estimate

To estimate the spread of a distribution of PE heights, the algorithm uses the Robust Dispersion Estimate (RDE). For low-noise distributions, the standard deviation is equal to half the difference between the 16^{th} and the 84^{th} percentiles of a distribution. For high-noise distributions, the standard deviation is considered the difference between the 25^{th} and 50^{th} percentiles of the distribution, divided by a correction factor of 1.349.

The noise-corrected RDE and median improve upon the performance of their uncorrected counterparts, but their performance is limited by the accuracy of the signal-level estimate ("Section 3.11 | Noise-corrected robust estimators of spread" in the ATL06 ATBD).

2.4 Quality, Errors, and Limitations

Errors in ATLAS land-ice products stem from a variety of sources:

1. Sampling error: ATLAS height estimates are based on a random sampling of the surface height distribution
2. Background noise: Random-noise PEs are mixed with the signal PEs, thus sampled PEs will include random outliers
3. Complex topography: The along-track linear fit and across-track polynomial fit do not always resolve complex surface topography
4. Misidentified PEs: The ATL03 product will not always identify the correct PEs as signal PEs
5. First-photon bias: This error is inherent to photon-counting detectors that results in a high bias in the mean detected PE height, depending on signal strength
6. Atmospheric forward scattering: Photons traveling downward through a cloudy atmosphere may be scattered through small angles but still be reflected by the surface within the ATLAS field of view; these will be delayed, producing an apparently lower surface
7. Subsurface scattering: Photons may be scattered many times within ice or snow before returning to the detector; these will be delayed, producing a surface estimate with a low bias

Each of these errors are treated differently during the ATL06 processing:

- 1 and 2 (above) are treated as random errors and their effects are quantified in the error estimates associated with the product.

- 3 and 4 produce relatively large errors that need to be addressed with consistency checks when higher-level products are generated.
- 5 is corrected routinely during ATL06 processing.
- 6 and 7 are not quantified in ATL06. They require information about cloud structure and ice-surface conditions that are not available when ATL06 is processed. Correcting for these errors remains an active avenue of research.

Potential error sources and mitigation strategies are detailed in "Section 2.3 | Potential Errors" and "Section 3.6 | Signal, Noise, and Error Estimates" in the ATL06 ATBD.

3 VERSION HISTORY

Table 4. Version History Summary

Version	Date	Description of Changes
7.0	26 Aug 2025	• Removed backup signal finder from ATL06 algorithm. • Added fpb_warning_flag variable to indicate ATL06 segments that could be impacted by signal saturation and for which the first-photon bias correction has failed.
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 14 Oct 2018 to 13 Oct 2022.
6.0	18 May 2023	• **Processed data for all global land regions**. These data are considered experimental, and no quality checks are being performed for the data outside of the polar regions. • **Dynamically computed the radial component of geolocation uncertainty** (sigma_geo_r). Previously, this value was fixed. The uncertainty is calculated for ATL03 (sigma_h) and the value is passed through to ATL06 (sigma_geo_r). Values for the horizontal geolocation uncertainties (sigma_geo_at and sigma_geo_xt) remain at fixed, pessimistic values of 5 m.
4.0 (retire)	13 Jun 2022	Removed data access for v4.0. Data coverage was 14 Oct 2018 to 15 Jul 2021.
3.0 (retire)	25 Jan 2022	Removed data access for v3.0. Data coverage was 14 Oct 2018 to 11 Nov 2020
5.0	29 Nov 2021	h_robust_sprd was removed from the ATL06_quality_summary flag.
2.0 (retire)	21 May 2021	Removed data access for v2.0. Data coverage was 14 Oct 2018 to 15 Nov 2019.
4.0	13 Apr 2021	Removed and added parameters, as well as changed values for several parameter descriptions. See the User Guide for a list.
1.0 (retire)	3 Jun 2020	Removed data access for v1.0. Data coverage was 14 Oct 2018 to 12 Jan 2019.
3.0	5 May 2020	• ATL09 pass-through data (cloud flag parameters) are now written to ATL06 to predict forward scattering (/layer_flag). If two flags intersect an ATL06 segment, the higher flag value is used.

Version	Date	Description of Changes
		• The large DEMs previously used by ATL06 are no longer required inputs. If they are provided in the processing control file, the values are queried as in previous releases; if the DEMs are not provided in the control file, DEM values from ATL03 are used. • Molecular transmission used to compute effective background is now being read from ATL09. • Added radial orbit error as sigma_geo_r (parameter sigma_h from ATL03). • ATL03 data flagged with non-zero values in podppd_flag are no longer processed for ATL06, ensuring that land ice data are created only from ATL03 data that are accurately geolocated and eliminates most ATL06 data that in prior versions contained substantial correlated errors. • Changed the residual histograms to range from -50 m to +50 m with varying bin sizes. Residual histogram bins that are not fully encompassed by at least one of the two possible telemetry band range windows are marked as invalid. These larger histograms encompass the full potential vertical range of forward-scattering returns below the surface and allow sampling of backscatter from blowing snow above the surface. • Residual histograms are centered on h_mean instead of h_li to yield a better representation of the segment-to-segment statistics for the residuals.
2.0	24 Oct 2019	• The Arctic and Antarctic DEMs were changed to utilize sources that have more recent and accurate data and better coverage. • The num_tx_pulses calculation was changed to estimate an expected number of pulses that is not an integer. As such, the input used to calculate num_tx_pulses was changed to a floating point value (the output of the unified pulse count estimation). • A single algorithm was implemented to estimate the number of pulses within a specified distance, and this single routine was integrated into the rest of the land ice height development code. • Equilibrium tide values from ATL03 were added to the geophysical group
1.0	28 May 2019	Initial release

3.1 References

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Yi, D. H., & Bentley, C. R. (1999). Geoscience Laser Altimeter System waveform simulation and its applications. *Annals of Glaciology, 29,* 279–285. https://doi.org/10.3189/172756499781821580

4 DOCUMENT INFORMATION

4.1 Publication Date

August 2025

4.2 Date Last Updated

August 2025

APPENDIX A – ICESAT-2/ATLAS DESCRIPTION

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 A - 1). 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 A - 1, 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 A - 1, right). Atmospheric profiles are generated from strong spots only, and the instrument orientation determines which GT label ("gtx") corresponds to which profile. The spacecraft orientation is tracked in the ICESat-2 Major Activities document (.xlsx).

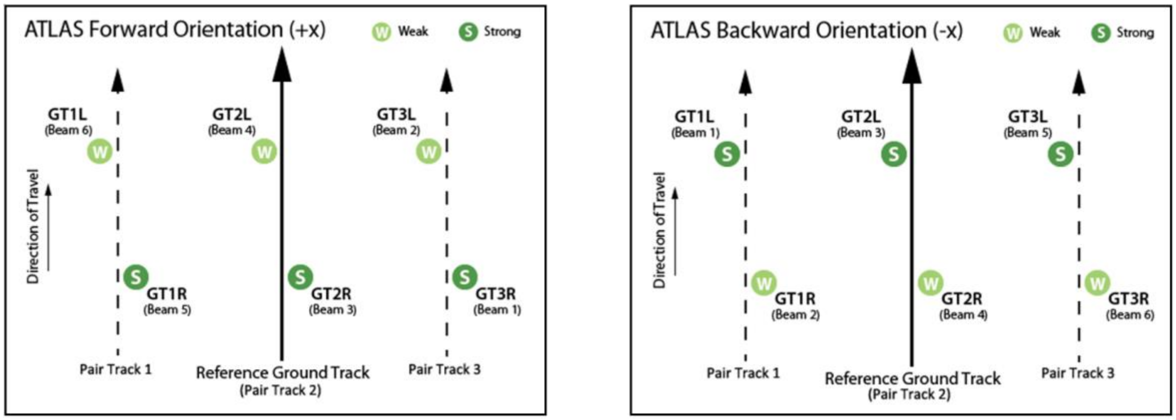

Figure A - 1. Spot and Ground Track (GT) Naming Convention

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 A - 2). 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.

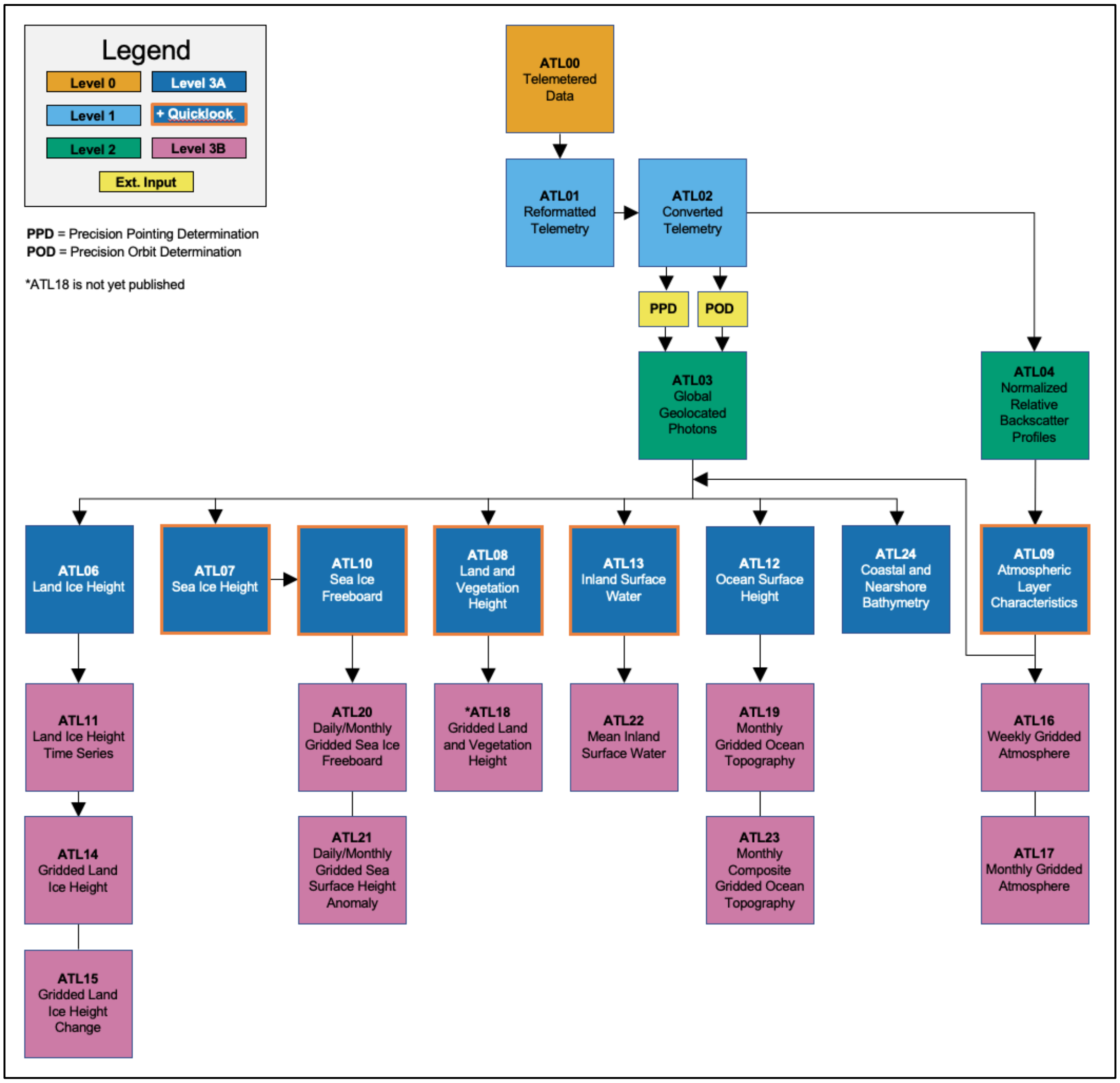

Figure A - 2. Schematic of ICESat-2 Data Processing and Data Products

In satellite altimetry, the reflection point of an emitted signal occurs on an instantaneous and often dynamic planetary surface (Figure A - 3). For ICESat-2, reflective surfaces include oceans, inland water bodies, solid ground, ice, vegetation, and manmade structures. Depending on the product and surface type, geophysical corrections are applied to measurements to account for various time-varying processes (Table A - 1). 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 A - 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 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.

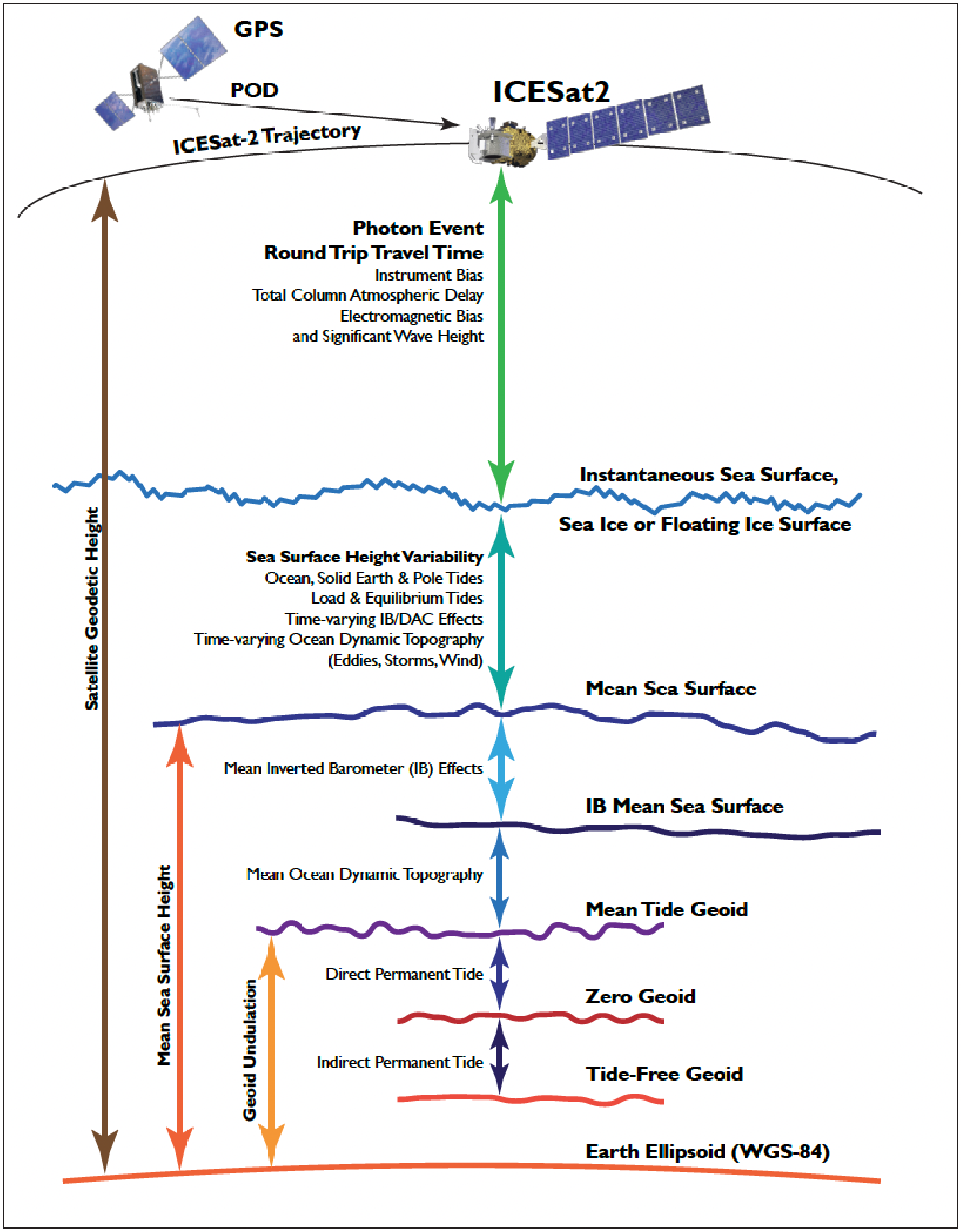

Figure A - 3. Geophysical Corrections Used in Satellite Altimetry
(Source: *ICESat-2 Data Comparison User's Guide for Rel007,*
Available on the ATL03 data set landing page)