ATLAS/ICESat-2 L3A Sea Ice Freeboard Quick Look, Version 7

USER GUIDE

How to Cite These Data

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

Kwok, R., Petty, A., Cunningham, G., Markus, T., Hancock III, D. W., Ivanoff, A., Wimert, J., Bagnardi, M., Kurtz, N. & the ICESat-2 Science Team (2025). *ATLAS/ICESat-2 L3A Sea Ice Freeboard Quick Look* (ATL10QL, Version 7). [Data set]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. https://doi.org/10.5067/ATLAS/ATL10QL.007. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL10QL

National Snow and Ice Data Center

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1 DATA DESCRIPTION

The ATL10 data product is described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document (ATBD) for Sea Ice Products (ATBD for ATL07/10/20/21 | V7, https://doi.org/10.5067/KPMXUOH7TNIY).

1.1 Summary

ATL10QL is the quick look version of ATL10 and is based on the same algorithms that generate the ATL10 final data products. Once final ATL10 files are available, the corresponding ATL10QL files are removed. ATL10 contains along-track sea ice freeboard calculated for 10 km swath segments. 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.

The ATL10QL product consists of up to 32 files (granules) per day: 16 for the Northern Hemisphere and 16 for the Southern Hemisphere. Each granule contains sea ice freeboard from data acquired over half an orbit. Six ground tracks within each granule span the width of the orbital swath with an across-track distance of 6 km.

1.2.2 File Contents

A complete list of all ATL10QL parameters is available in the ATL10 Data Dictionary.

Within data files, similar variables such as science data, instrument parameters, and metadata are grouped together according to the HDF model. ATL10QL data files contain the top-level groups shown in the following figure.

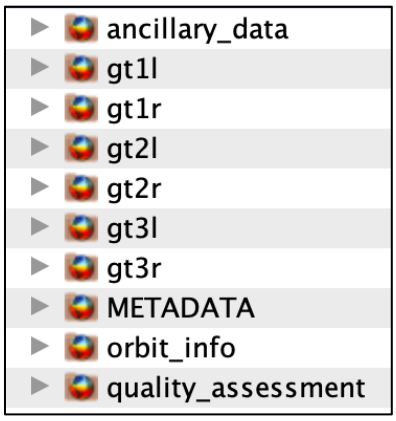

Figure 1. ATL10QL top-level data groups.

The following sections summarize the structure and primary variables of interest in ATL10QL data files. Additional details are available in "Section 5.2 | Output of Freeboard Estimation Algorithm" and Appendix A of the ATBD for ATL07/10/20/21.

1.2.2.1 ancillary_data

Information ancillary to the data product such as product and instrument characteristics and processing constants.

1.2.2.2 gt1l–gt3r

Six ground track groups (gt1l–gt3r), each with the following subgroups:

- `freeboard_segment`: freeboard estimate and associated parameters, including freeboard height for the beam (`beam_fb_height`), acquisition time, latitude and longitude, distance from the equator to the segment center (`seg_dist_x`), and quality indicators for the freeboard estimate.
- `leads`: parameters relating to the determination of open water leads and the reference surface heights.
- `reference_surface_section`: reference sea surface and mean freeboard parameters by beam.

1.2.2.3 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.

1.2.2.4 orbit_info

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

1.2.2.5 quality_assessment

Quality assessment data for the granule as a whole, including a pass/fail flag and a failure reason indicator.

1.2.3 Naming Convention

Data files utilize the following naming convention:

```
ATL10QL-[HH]_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5
```

Examples:

```
ATL10QL-01_20230606040409_11731901_007_02.h5
ATL10QL-02_20230606040409_11731901_007_02.h5
```

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL10QL	ATLAS/ICESat-2 L3A Sea Ice Freeboard Quick Look product
HH	Hemisphere code. Northern Hemisphere = 01, Southern Hemisphere = 02
yyyymmdd	Year, month, and day of data acquisition for the given RGT
hhmmss	ICESat-2 data acquisition start time, hour, minute, and second (UTC) for the given Reference Ground Track (RGT) (not the start of ATL07 data production)
tttt	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. This number corresponds to the first of the ICESat-2 along-track regions considered for input into ATL10QL processing. This region number will always be "01" except when a granule is split along a spacecraft orientation change, in which case, the region number is the last region before the switch and the first region after the switch, in consecutive granules.
vvv_rr	Version and revision number*

*Occasionally, NSIDC receives duplicate, reprocessed granules from our data provider. These granules have the same file name as the original (i.e., date, time, ground track, cycle, and region number), but the revision number has been incremented. Although NSIDC deletes the superseded granule, the process can take several days. As such, if you encounter multiple granules with the same file name, please use the granule with the highest revision number.

1.2.4 Browse Files

Browse files are provided as JPGs that contain images designed to quickly assess the location and quality of each granule's data. The following browse images are available for each beam:

- `beam_lead_n`: Number of leads used for the beam reference surface section
- `beam_fb_ht_hist`: Histogram of mean freeboard heights
- `beam_fb_height`: Freeboard height relative to `beam_refsurf_height`
- `groundtrack`: Reference surface number of leads

Browse files utilize the same naming convention as their corresponding data file but with "`_BRW`" and descriptive keywords appended. An example browse image is shown below.

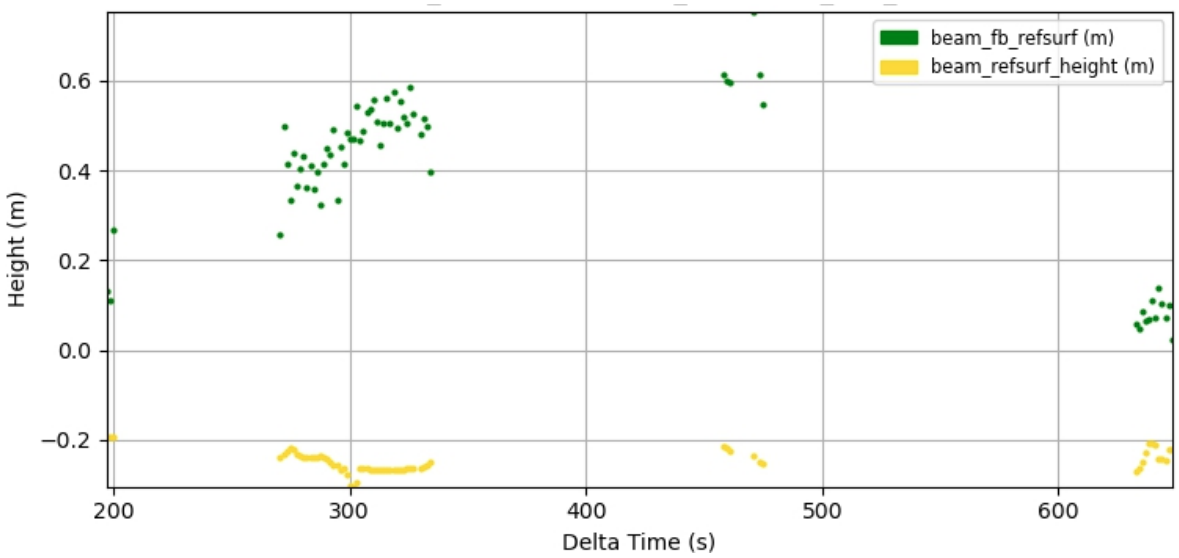

Figure 2. Example browse image of freeboard height (`beam_fb_height`).

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage spans the ice-covered oceans of the Northern and Southern Hemispheres where the sea ice concentration (SIC) is greater than 50% and at least 25 km from the coast. SIC is determined by near-real-time SSMI data (G10016).

1.3.2 Resolution

Freeboard is estimated from ATL07QL sea ice height segments that vary in length depending on the distance over which approximately 150 signal photons are accumulated and the availability of a reference sea surface. The along-track length of these input height segments is stored in `gt[x]/freeboard_segment/heights/height_segment_length_seg`.

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

The temporal coverage is a sliding window. Quick look data are published ~72 hours after satellite observation and removed when the final ATL10 files arrive or after three months if the final file does not get released due to quality issues.

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`) in the lower-level ATL03 product.

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

ICESat-2 provides multiple profiles of sea ice and sea surface heights for improved freeboard and thickness retrievals. Total freeboard is defined as the height of the air–snow interface above the local sea surface. For the Arctic Ocean, the total freeboard is typically assumed to consist of a snow layer superimposed on the freeboard of floating sea ice, i.e., a two-layered system. For Antarctic sea ice, wintertime layering and snow-ice formation (i.e., “flooded ice” from freezing of water-soaked snow) complicate freeboard characterization.

2.2 Acquisition

ATL10QL is derived from ATLAS/ICESat-2 L3A Sea Ice Height Quick Look (ATL07QL).

2.3 Processing

A freeboard estimate is provided for all ‘good quality’ height segments (not filtered by surface type). Only nominal height segments are included in ATL10QL. The algorithm first finds the leads, which consist of collections of height segments that are designated as sea surface height segments in ATL07QL. Then, the leads are used to estimate the height of the reference surface for computing the local freeboard over a 10 km region. Reference surface heights are interpolated (if neighboring reference surfaces are available) to the freeboard height location before the freeboard height computation.

2.3.1 Freeboard Estimation

The sea surface reference (for calculating freeboard) is first estimated for each *L*-km segment for each beam. Freeboard height is computed for each ATL07QL sea ice height segment by subtracting the beam reference surface determined by using only the leads along the beam (i.e., each beam has its own reference surface).

ATL10QL maintains the ATL07QL segment heights used for the freeboard calculations. For more information, see "Section 5 | ALGORITHM DESCRIPTION: ATL10" of the ATBD.

2.4 Quality, Errors, and Limitations

A constraint imposed by the inherent capability of the instrument is the impact of clouds on the visibility of sea ice cover. In particular, a reduction in coverage is significant during the summer after the spring-to-summer seasonal transition. Further, the first photon bias is an inherent problem with the photon-counting detectors selected for ATLAS. Even though the biases are at centimeter to sub-centimeter levels for most sea ice surfaces, the effect is large for intense pulses and for pulses from flat surfaces where the return energy is concentrated over a short duration.

Errors in the determination of sea ice freeboard are described in Magruder et al. (2025). The error is a function of the instrument precision, the number of sea ice leads used in the sea ice reference surface, the surface roughness, and the number of signal photons used in the surface height retrieval.

Limitations are imposed by height retrievals and surface classification. Multiple scattering within the ice or snow volume is not quantified and may impact height retrievals. For sea ice, these effects are mitigated in the surface-finding process via windowing of the photon height distributions to avoid potential tails in the distributions. Because snow properties may be unknown at the time of ATLAS acquisitions, a height correction due to subsurface scattering must be determined independently using external data. The design of the surface type retrieval procedure focuses on

sea surface signatures, and there are uncertainties associated with the labeling of the other ice types.

There are also assumptions related to height retrievals: (1) sampled photon heights are random realizations from a Gaussian or lognormal distribution and (2) the first photon bias correction assumes that the photon statistics at a given height remain stationary over time. For more details, see "Section 10 | Constraints, Limitations, and Assumptions" in the ATBD.

The `/gt[x]/freeboard_segment/` subgroup contains key segment quality indicators, such as:

- `beam_fb_confidence`: confidence level in the freeboard estimate
- `beam_fb_quality_flag`: flag describing the quality of the results of the along-track fit
- `/heights/height_segment_confidence`: confidence level in the surface height estimate based on analysis of the error surface

2.4.1 Quick Look Data Quality

There are two primary differences between final and quick look products: (a) the geolocation uncertainty of the segment and (b) the uncertainty in the reported segment heights.

Analysis to date shows that between 1% and 2% of granules have substantially larger errors than reported below. The ICESat-2 Project Science Office is working to identify and withhold these from further distribution.

2.4.1.1 Geolocation Uncertainty

The final data (ATL10) are based on the best possible solutions for the position of the observatory in space through time. These data use the final orbits of the GPS constellation tracked by the GPS receiver aboard ICESat-2. These products have a geolocation uncertainty of < 5 m. That is, the latitude and longitude of the segments in the ATL10 product are accurately located with less than a 5 m uncertainty.

The ATL10QL data use less precise orbits of the GPS constellation tracked by the GPS receiver aboard ICESat-2. These quick look data have a geolocation uncertainty of ~100 m. That is, the latitude and longitude of the segments in the ATL10QL data are accurately located with approximately 100 m uncertainty.

2.4.1.2 Height Uncertainty

As a result of the larger uncertainty on the position of the ICESat-2 observatory in space, there is a corresponding impact on any ATL07QL absolute heights which are directly passed along to ATL10QL. For ATL10QL data, the reported absolute heights (e.g., heights relative to a reference

surface) are lower than the absolute heights on the final data products by 2.7 m and have a standard deviation of ~7 m. To get the most accurate heights, users can add 2.7 m to the absolute heights reported on ATL10QL data; the resulting heights will have a mean bias (measured over a month) of approximately zero and a standard deviation of approximately 7 meters.

The height biases and variation of the ATL10QL data in comparison to the final ATL10 data products appear to occur over long length scales and thus have only a small impact on the determination of relative height measurements such as sea ice freeboard. Figure 3 shows an example comparison of sea ice segment heights from final ATL07 and quick look ATL07QL data. (Note: the plotted ATL07 segment heights are passed along to ATL10). The absolute height bias in the quick look data is readily apparent.

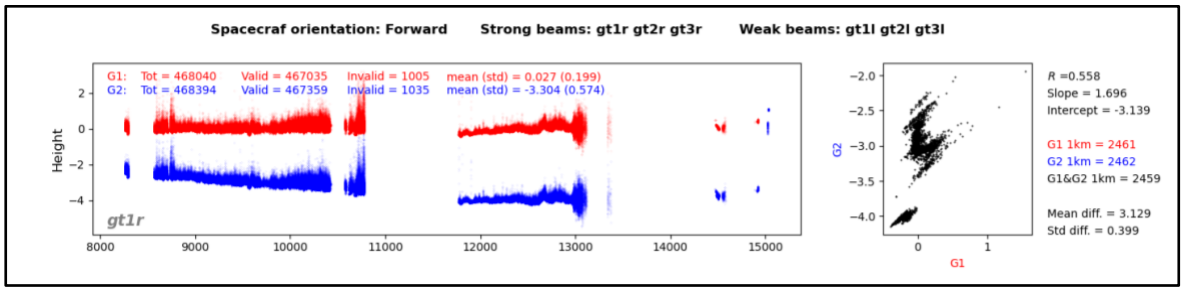

Figure 3. Comparison of sea ice segment heights from the final ATL07 (G1, red) data and the ATL07QL (G2, blue) data. Note: the plotted ATL07/ATL07QL segment heights are passed on directly to ATL10/ATL10QL.

2.4.1.3 Freeboard Uncertainty

As noted above, the additional uncertainties in the quick look data product tend to occur over large length scales and thus have much less impact on measurements of relative height such as sea ice freeboard. Comparisons of ATL10QL and final ATL10 sea ice freeboard results show a mean bias of approximately zero and have a standard deviation of differences of ~0.02 m. There does appear to be a small difference in the number of valid freeboard segments retrieved between the final and quick look products. An example comparison of two granules is shown in Figure 4. Overall, we expect the quick look sea ice freeboard results to be unbiased but with an additional uncertainty of ~0.02 m compared to the final data product.

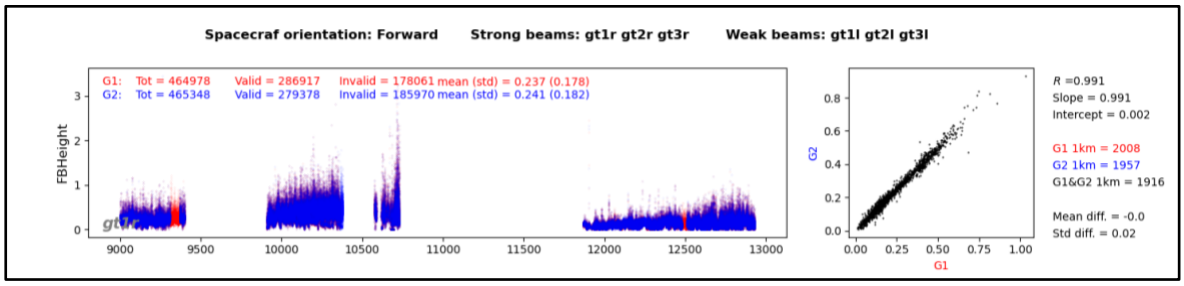

Figure 4. Comparison of sea ice freeboard from final ATL10 data (G1) and quick look ATL10QL (G2) data. A zero mean difference is seen along with a standard deviation of differences of 0.02 m.

3 VERSION HISTORY

Table 2. Version History Summary

Version	Date	Description of Changes
6.0 (retire)	14 Jul 2025	Removed data access for v6.0. Data coverage was mid-Jan 2023 to 17 Jun 2025.
7.0	17 Jun 2025	• Introduced interpolation of reference surface heights when computing freeboard heights. In previous releases, a static value of the 10 km reference surface was used to compute freeboard heights. In v7, reference surface heights are interpolated (if neighboring reference surfaces are available) to the freeboard height location before freeboard height computation. • Introduced option to include heights computed using a lognormal distribution when available. • Fixed oc_depth parameter. Previously, oc_depth only had values of 0.0.
5.0 (retire)	20 Apr 2023	Removed data access for v5.0. Data coverage was 10 Jan 2022 to 14 Jan 2023.
6.0	19 Jan 2023	• Added new uncorrected sea ice segment height parameter, which is directly computed using ATL03 photon heights. This provides additional coverage for areas where corrected sea ice segment heights cannot be processed. • Added AMSR2 sea ice concentration (SIC) data as follows: 1. Use AMSR2 by default (AU_SI12) 2. Where AMSR2 is unavailable, use SSMI (G02202) 3. Where G02202 data are unavailable, use near-real-time SSMI data (G10016) • Implemented land filtering. The introduction of uncorrected caused many returns over land, so `distance_to_land` and bathymetry ancillary files were introduced. The bathymetry file and `distance_to_land` filter remove and lower the mean sea ice height. • Added ANC10 ancillary file to read in sea level pressure, which was previously input from ATL09, to provide mean sea level pressure over the oceans for the dynamic inverted barometer (IB) correction. • Added Yet Another Photon Classifier (YAPC) parameters by aggregating YAPC metrics from ATL03 to ATL07 sea ice segment heights data. • Introduced interpolation and extrapolation routines for ocean tides and MSS. The ocean tide reported on ATL03 (GOT4.8 model) has spatial gaps and the MSS grid lacks coverage along coasts and in bays. If the missing parameters are interpolated, then the interpolated geophysical corrections are applied, and corrected heights are produced. Extrapolated parameters are not used to compute a corrected height, and only uncorrected heights are available. • Updated the `PODPPD_flag` filter so that a processing option is available for every flag value.

Version	Date	Description of Changes
		• Apply dynamic IB for processing and read/interpolate sea level pressure directly from ANC10. The updated dynamic IB improves model accuracy and is comparable to the IB corrections commonly provided by other altimetry missions. • The metadata has been updated so that lineage information for ANC10 and ANC48 is written to the ATL07 data product. • Updated the MSS variables description, added mentions of the source of the MSS, and clarified the use of the tide free system.
5.1	25 May 2023	SIC data switched from AMSR2 to SSMI (G10016) to address an issue that occurs based on the presence or absence of ANC49 inputs during processing.
5.0	22 Mar 2022	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

Magruder, L. A., Neumann, T., Kurtz, N., Sutterley, T. C., Hancock, D., Vornberger, P., Robbins, J., & Smith, B. (2025). Assessment of the Ice, Cloud, and Land Elevation Satellite-2 Performance Against Prime Mission Science Requirements. *Earth and Space Science*, *12*(4). https://doi.org/10.1029/2025EA004221

5 DOCUMENT INFORMATION

5.1 Publication Date

June 2025

5.2 Date Last Updated

July 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).

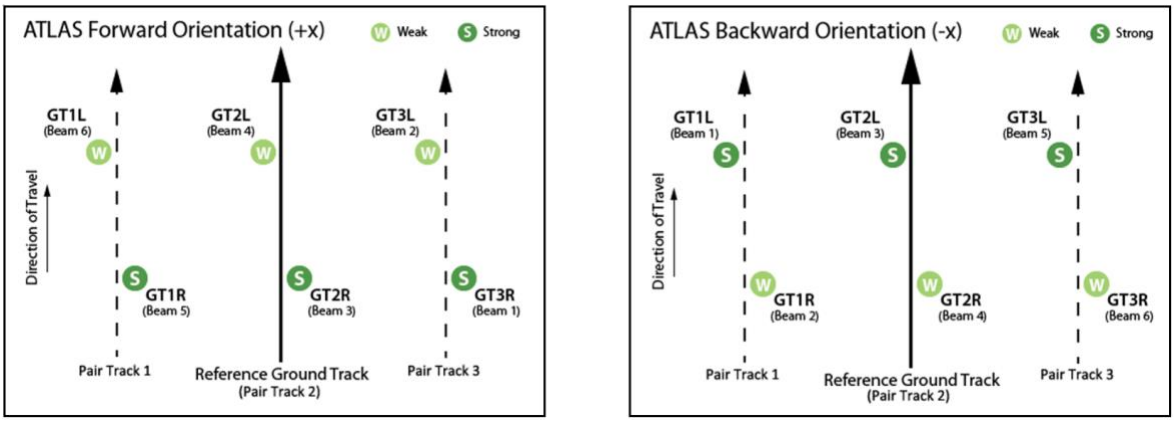

Figure A - 1. Spot and Ground Track (GT) naming convention.

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.

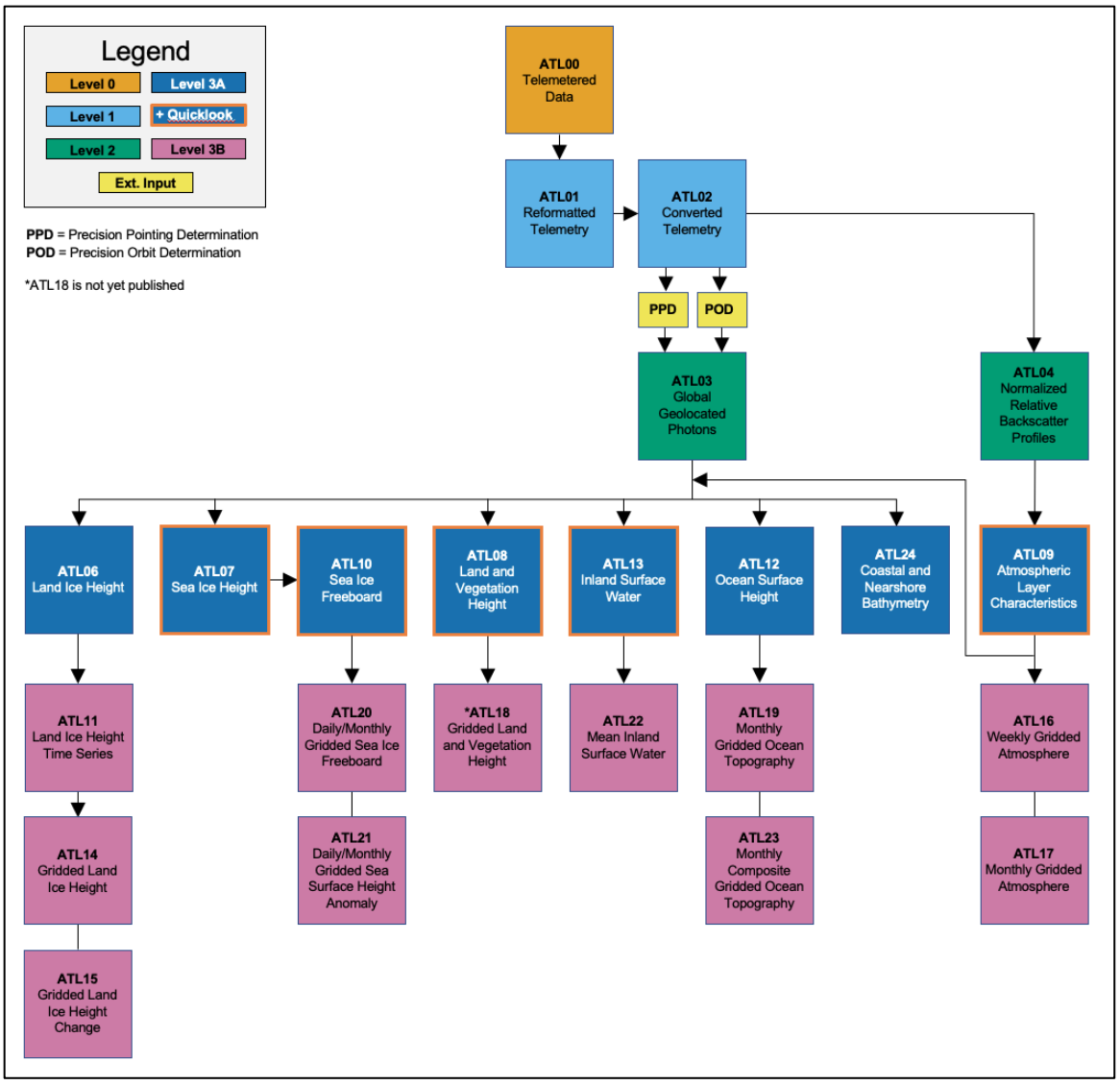

Figure A - 2. Schematic of ICESat-2 data processing and data products.

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.

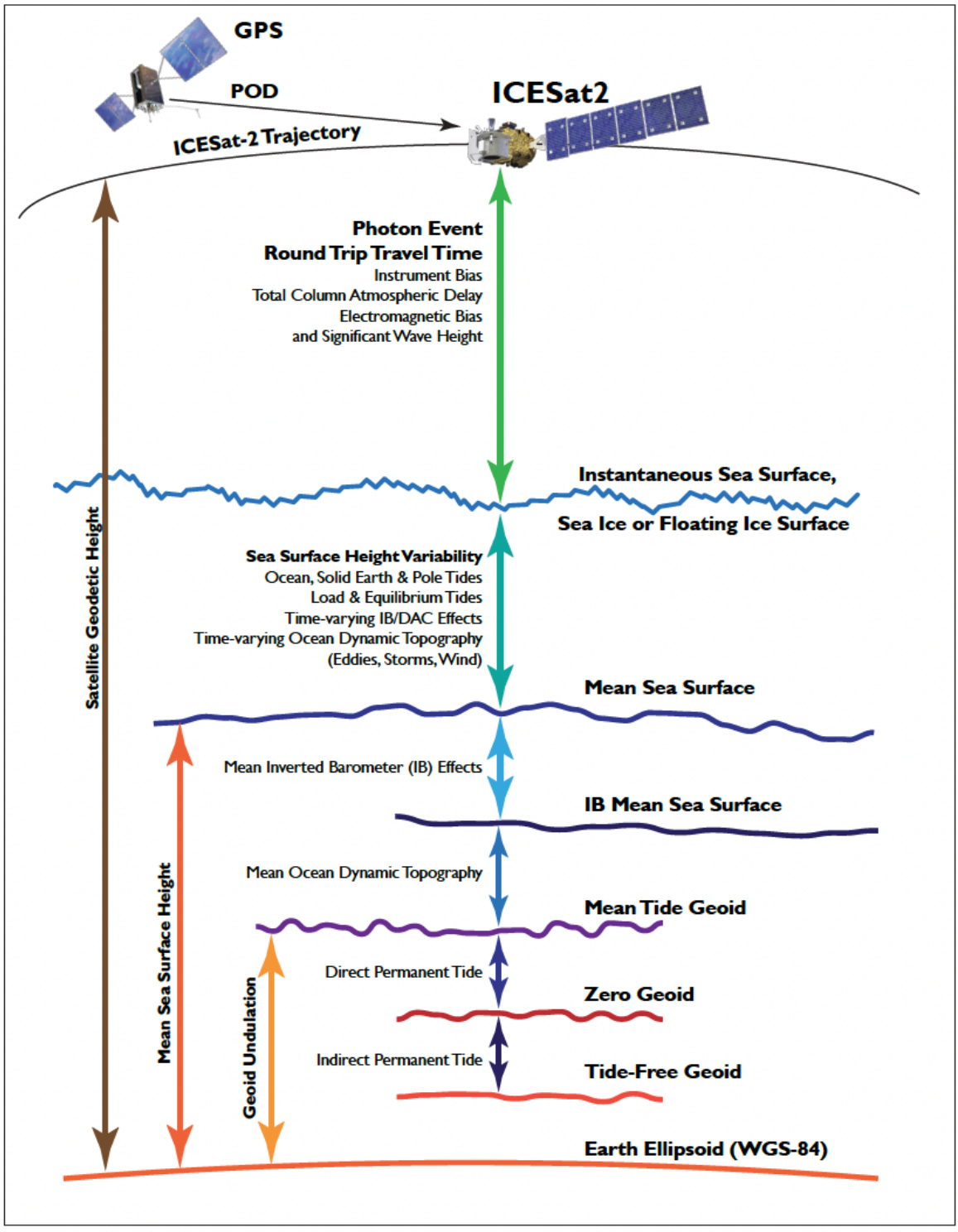

Figure A - 3. Geophysical corrections used in satellite altimetry
(Source: *ICESat-2 Data Comparison User's Guide for Rel007,* available on the ATL03 data set landing page).