ATLAS/ICESat-2 L3B Monthly 3-Month Gridded Dynamic Ocean Topography, Version 2

USER GUIDE

How to Cite These Data

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

Morison, J., Hancock, D., Dickinson, S., Robbins, J., & Roberts, L. (2025). *ATLAS/ICESat-2 L3B Monthly 3-Month Gridded Dynamic Ocean Topography* (ATL23, Version 2). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL23.002

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL23

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

The ATL23 data product is described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document (ATBD) for ATL19/23 Gridded Dynamic Ocean Topography (Morison et al., 2024).

1.1 Summary

ATL23 contains monthly 3-month gridded averages of dynamic ocean topography (DOT) over midlatitude, north-polar, and south-polar grids derived from the along-track ATLAS/ICESat-2 L3A Ocean Surface Height product (ATL12). Monthly gridded sea surface height (SSH) can be calculated by adding the mean DOT and the corresponding weighted average geoid height. Both single beam and all-beam gridded averages are available: single beam averages are useful for identifying potential biases among the beams, and the all-beam averages are useful in physical oceanography. Simple averages, degree-of-freedom averages, and averages interpolated to the center of grid cells are included, as well as uncertainty estimates. Sea surface statistics histograms and wave statistics within grid are also provided.

1.2 File Information

1.2.1 Format

Data are provided as HDF5-formatted files.

WARNING: The data may appear “flipped” across the horizontal axis when plotting in some programs. Specifically, the upper-left coordinates in the file-level metadata appear as the lower-left coordinates of the grid (the y-direction starts in the southern latitudes).

1.2.2 Granule Regions

ATL23 data are segmented into granules (files) that span about 1/14th of an orbit. Granule boundaries are delineated by lines of latitude that define 14 regions, numbered 01–14, as shown in Figure :

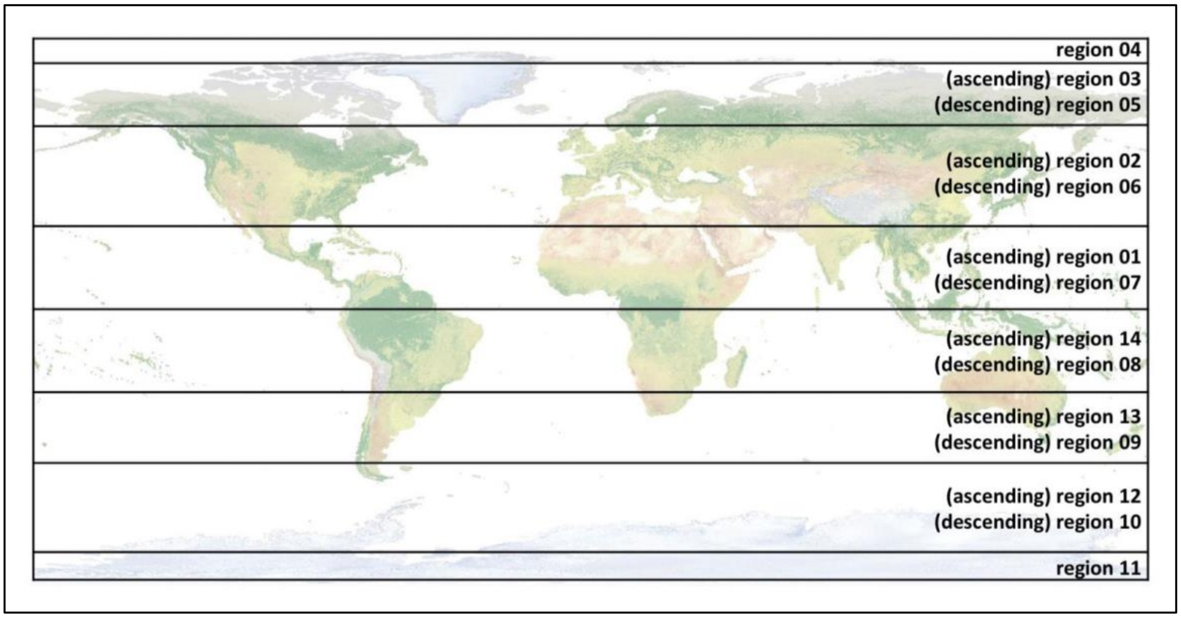

Figure 1. Region/granule boundaries.

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 ATL23 parameters is available in the ATL23 Data Dictionary.

Within data files, similar variables such as science data, instrument parameters, and metadata are grouped together according to the HDF model. Figure 2 shows data groups and variables stored at the top level in ATL23 data files.

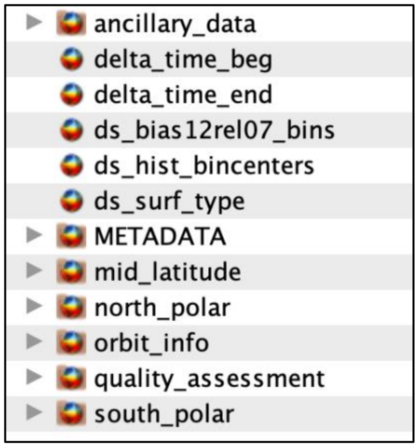

Figure 2. ATL23 top-level data groups and variables.

The following sections describe the data groups and their contents plus the variables stored at the top level in ATL23 data files.

1.2.3.1 ancillary_data

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

1.2.3.2 Top-Level Variables

The following variables are stored at the top level of ATL23 data files alongside the data groups:

- `delta_time_beg`: beginning elapsed GPS seconds for the data granule
- `delta_time_end`: ending elapsed GPS seconds for the data granule
- `ds_bias12rel07_bins`: bin centers for `h_bias12rel07` (`h_ice_free` minus `h_atl07_ice_free`) histograms, from 0% to 100% in 5% bins
- `ds_hist_bincenters`: DOT histogram bin centers
- `ds_surf_type`: dimension scale indexing the surface type array (1 = land, 2 = ocean, 3 = sea ice, 4 = land Ice, 5 = inland water)

1.2.3.3 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.

1.2.3.4 mid_latitude

Midlatitude DOT and related parameters averaged across all beams and for individual beams in separate subfolders.

1.2.3.5 north_polar

North polar DOT and related parameters averaged across all beams and for individual beams in separate subfolders.

1.2.3.6 orbit_info

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

1.2.3.7 quality_assessment

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

1.2.3.8 south_polar

South polar DOT and related parameters averaged across all beams and for individual beams in separate subfolders.

1.2.1 Naming Convention

Data files utilize the following naming convention:

`ATL23_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5`

Example:

`ATL23_20200701041604_00890801_002_01.h5`

Table 2. File Naming Convention

Variable	Description
ATL23	ATLAS/ICESat-2 L3B Monthly 3-Month Gridded Dynamic Ocean Topography product
yyyymmdd	Year, month, and day corresponding to the first day of the middle month of the 3-month averaging period. In the example above, the 2-digit month of "07" and 4-digit year of "2020" indicate that the file contains the average of June 2020, July 2020, and August 2020.
hhmmss	Data acquisition start time in UTC. Set to "000000".
tttt	Four-digit Reference Ground Track (RGT) number of the first ATL12 input file in each 3-month average. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.

Variable	Description
cc	Cycle number of the first ATL12 input file in each 3-month average. 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 of the first ATL12 input file in each 3-month average. Region numbers range 01–14 (approximately 1/14th of an orbit).
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.

1.2.2 Browse Files

Browse files are provided as JPGs that contain images designed to quickly assess the location and quality of each granule's data. A list of available DOT and significant wave height (SWH) images is shown in Table 3, and an example is shown in Figure 3.

Table 3. Images Available as Browse

Image	Description
mid_latitude.dot_avg_albm	3-month average DOT for all beams in the midlatitude region
mid_latitude.swh_avg_albm	3-month average SWH for all beams in the midlatitude region
north_polar.dot_avg_albm	3-month average DOT for all beams in the north polar region
north_polar.swh_avg_albm	3-month average SWH for all beams in the north polar region
south_polar.dot_avg_albm	3-month average DOT for all beams in the south polar region
south_polar.swh_avg_albm	3-month average SWH for all beams in the south polar region

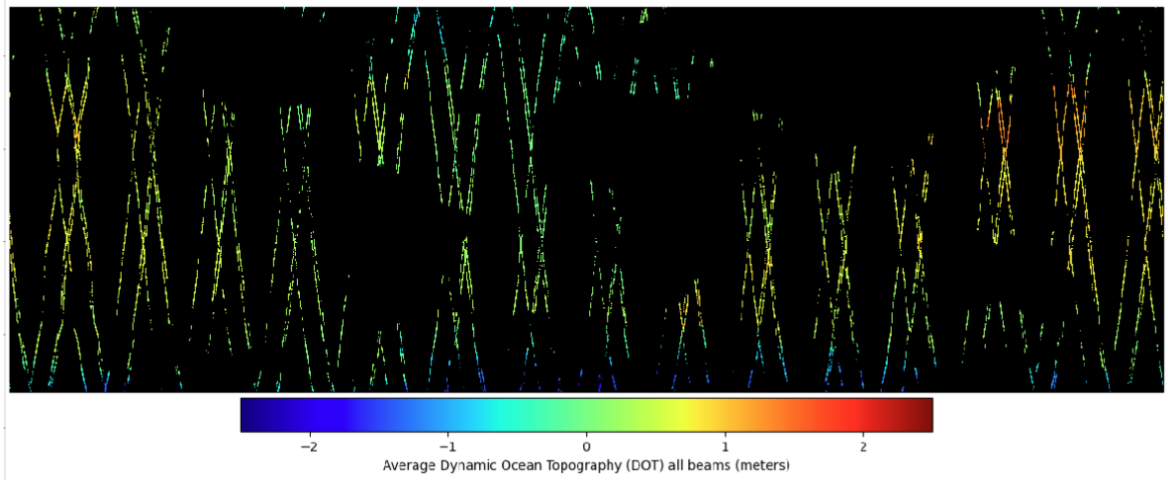

Figure 3. Example Browse Image for the Midlatitude Region (`dot_avg_albm`).

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 spans the global ocean surface from approximately 88° N to 88° S.

1.3.2 Resolution

- Midlatitudes (60° N to 60° S): 1/4° grid resolution
- Polar latitudes (north of 60° N and south 60° S): 25 km grid resolution

1.3.3 Geolocation

ATL23 uses three grids: north and south polar stereographic 25 km grids (EPSG 3411 and EPSG 3412), as well as an overlapping midlatitude curvilinear 1/4° latitude-longitude grid between 60° N and 60° S (EPSG 4326). The gridding is done individually for each beam on the ocean segments with average positions inside the grid cell. The following tables describe the different projection and grid details. See the grid details in the table below.

Table 4. Grid Details

	North Polar	South Polar	Midlatitude
Nominal gridded resolution	25 × 25 km	25 × 25 km	0.25° x 0.25°
Grid size (rows × columns)	448 × 304	332 × 316	480 x 1440
Geolocated lower left point in grid	(-3850 km, -5350 km)	(-3950 km, -3950 km)	(-60°, -180°)
Grid rotation	0	0	0
ulxmap: x-axis coord, center of upper left pixel (XLLCORNER)	-3,837.5 km	-3,937.5 km	-179.875°
ulymap: y-axis coord, center of upper left pixel (YLLCORNER)	5,837.5 km	4,337.5 km	59.875°

1.4 Temporal Information

1.4.1 Coverage

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

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

1.4.2 Resolution

3-month averages provided at a monthly resolution (also see Section 1.2.1 Naming Convention).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATL12 along-track ocean surface heights are derived from ATL03 photon heights, removing variations from tides and atmospheric forcing. To further reduce height variability of the photon heights, the EGM2008 geoid is subtracted in the mean tide system to express photon heights as DOT. Based on ATL12, ATL23 contains gridded DOT estimates spanning three months, from the beginning of the first month to the end of the third month. ATL23 therefore provides a more complete filling of grid cells and better interpolation of DOT to the center of grid cells compared to ATL19 1-month averages but with consequent temporal smoothing.

2.2 Acquisition

The ATL23 algorithm inputs ATL12 data and computes monthly 3-month gridded averages of DOT and related parameters as described in the following section.

2.3 Processing

For each grid cell in ATL23, all of the available along-track ATL12 data are temporally averaged as monthly, 3-month moving averages. As with the ATL19 1-month averages, data from all six beams are used, both individually and averaged together. Prior to the summer of 2021, only strong beam data were available over the ocean.

The gridding process follows the general steps of binning, averaging, and interpolation to the grid cell center. Beginning with ATL23 Version 2, major improvements to minimum uncertainty averages and DOT accuracy in ice-covered waters were implemented.

Output includes simple arithmetic averages of DOT, degree-of-freedom-weighted averages, and multi-cell least-squares linear interpolations to grid cell centers. Version 2 also includes degree-of-freedom-uncertainty weighted averages in which ocean segment DOT averaged values are multiplied by weighting factors equal to the inverse of their uncertainties squared. This calculation produces cell averages with minimum uncertainties. Similarly, degree-of-freedom-uncertainty interpolations of DOT to grid cell centers in which ocean segment interpolated DOT values are multiplied by weighting factors equal to the inverse of their uncertainties squared. This calculation produces cell-centered interpolations with minimum uncertainties.

In Version 1, DOT values were biased by sea ice freeboard. Beginning with Version 2, for ATL12 Version 7 ocean segments with ice concentration greater than 15%, ATL23 uses the ocean segment average DOT in the 10 m bins corresponding to ATL07 bright leads as input. The associated uncertainties in these bright lead DOTs are used in all uncertainty-based averaging and interpolations in ice-covered waters in ATL23 (and ATL19).

The standard deviation, skewness, and kurtosis of the DOT are also included. The mean SSH is calculated as the mean DOT plus the weighted average geoid height. For more details on the gridding process see “Section 3.2 | Gridding DOT for ATL19/23” in the ATBD (Morison et al., 2024).

2.4 Quality, Errors, and Limitations

Errors in the ATLAS/ICESat-2 height retrievals can arise from a variety of sources, including sampling error (heights reflect random point sample of the height distribution), background noise from random non-signal photon returns, misidentified signal photons, atmospheric forward scattering delays, subsurface scattering within ice or snow, and first-photon bias (inherent with photon-counting detectors).

3 VERSION HISTORY

Table 5. Version History Summary

Version	Date	Description
2.0	30 Oct 2025	• Changed degree-of-freedom (dfw) averages to averaging weighted by degrees-of-freedom uncertainty by changing all the dfw averages from averages weighted by DOF = np_effect to averages weighted by Wi = $(1/h\_uncrtn)^2$. Because this weight is equal to np_effect/dot_sigma, it includes the effect of wave amplitude as well as degrees-of-freedom on uncertainty; the resulting averages weighted by Wi should have the minimum uncertainty. The dfw variable names were not changed but are referred to generically as degree-of-freedom-uncertainty weighted variables. • Made extensive modifications to incorporate h_ice_free to yield DOT in ice-covered waters. ATL07 provides a flag in ATL12 10 m bins indicating the presence of bright leads and h_ice_free is the average of the htybin in these bright lead 10 m bins. In V4 of ATL19, h_ice_free is substituted for h-geoid_seg whenever it appears and h-geoid_seg is taken to represent the top of the ice, h_icetop_geoid, when ice concentration is greater than 15%. A small number of variables are added to outputs, but the previous processing routines are left unchanged when making the substitution of h_ice_free where it exists for h-geoid_seg.
1.1	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.
1.0	14 Sep 2023	Initial release

4 RELATED DATA SETS

ATLAS/ICESat-2 L3A Ocean Surface Height (ATL12)

ATLAS/ICESat-2 L3B Monthly Gridded Dynamic Ocean Topography (ATL19)

5 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

Morison, J., Hancock, D., Dickinson, S., Robbins, J., & Roberts, L. (2024). *Ice, Cloud, and Land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Gridded Dynamic Ocean Topography.* NASA Goddard Space Flight Center. https://doi.org/10.5067/J3NTF6TM1SZ7

6 DOCUMENT INFORMATION

6.1 Publication Date

October 2025

6.2 Date Last Updated

October 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).

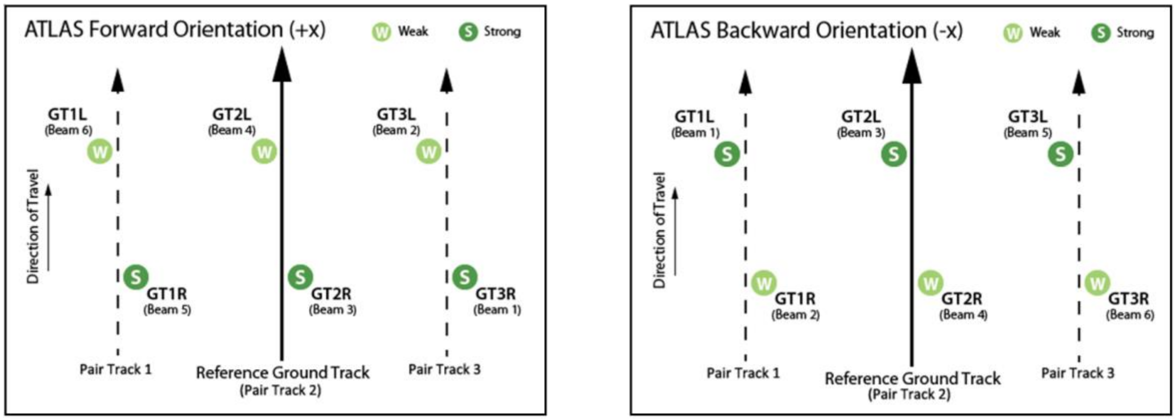

Figure A - 1. Spot and Ground Track (GT) naming convention.

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.

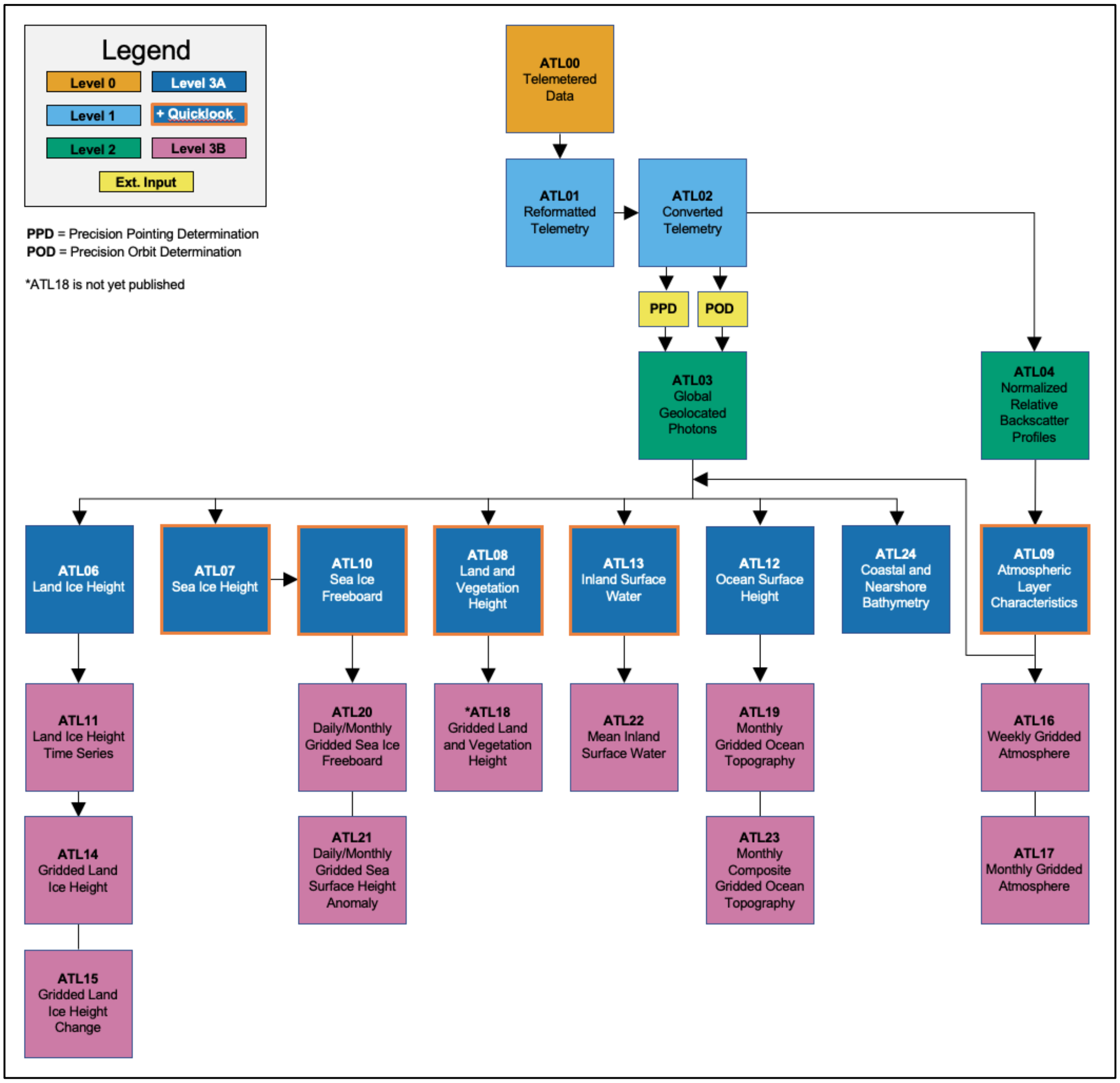

Figure A - 2. Schematic of ICESat-2 data processing and data products.

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.

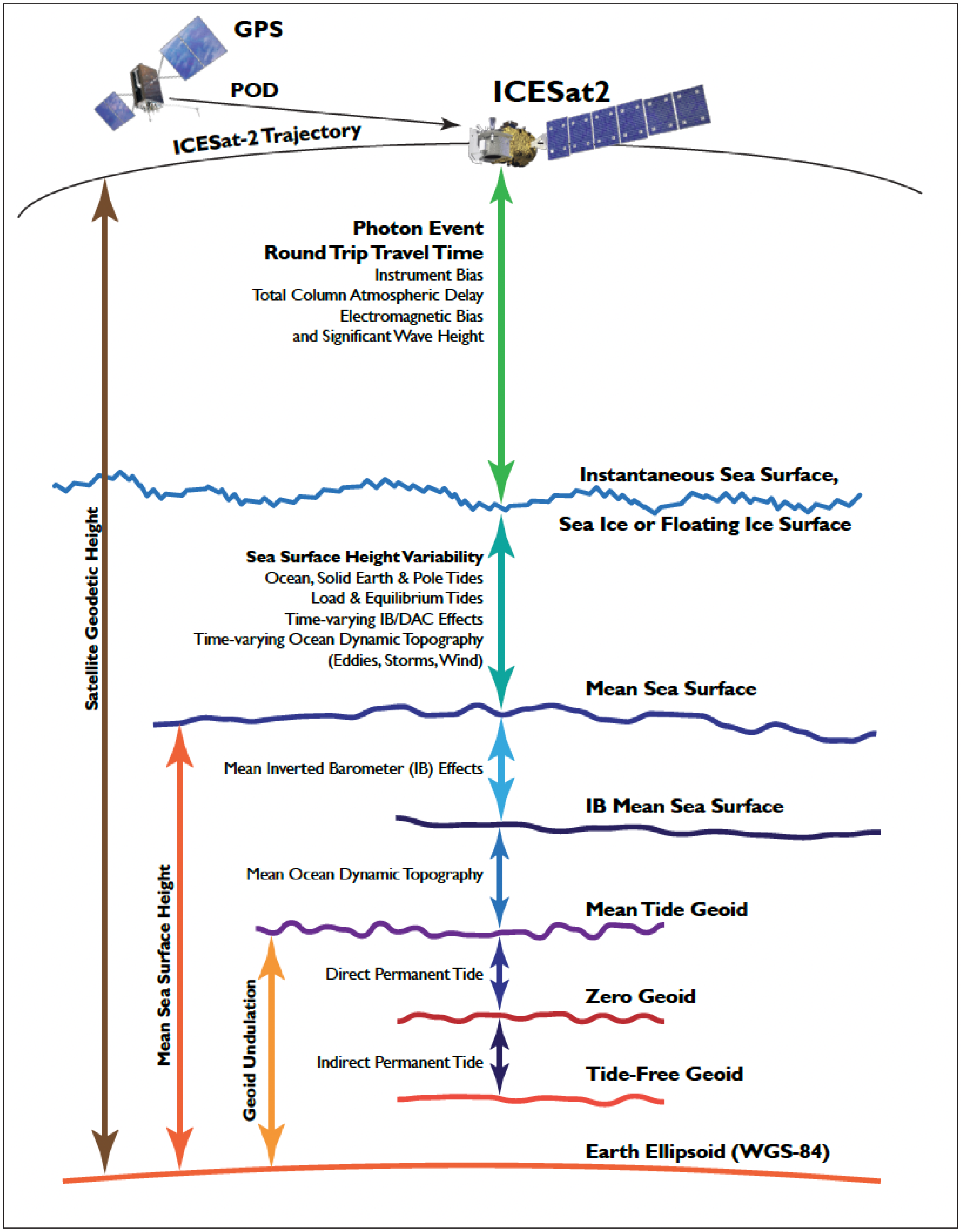

Figure A - 3. Geophysical corrections used in satellite altimetry (Source: *ICESat-2 Data Comparison User's Guide for Rel007,* available on the ATL03 data set landing page).