ATLAS/ICESat-2 L3B Daily and Monthly Gridded Polar Sea Surface Height Anomaly, Version 4

USER GUIDE

How to Cite These Data

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

Petty, A. A., Kwok, R., Bagnardi, M., Kurtz, N., Wimert, J., Lee, J., & Hancock, D. (2025). *ATLAS/ICESat-2 L3B Daily and Monthly Gridded Polar Sea Surface Height Anomaly* (ATL21, Version 4). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL21.004 [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL21

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

The ATL21 data product is described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document (ATBD) for Sea Ice Products (Kwok et al., 2025).

1.1 Summary

ATL21 contains daily and monthly gridded polar sea surface height anomalies, derived from ATLAS/ICESat-2 L3A Sea Ice Freeboard (ATL10) along-track freeboard estimates.

1.2 File Information

1.2.1 Format

Data are provided as HDF5-formatted files.

1.2.2 File Contents

A complete list of all ATL21 parameters is available in the ATL21 Data Dictionary.

The data product comprises two files for each month: one for the Northern Hemisphere and one for the Southern Hemisphere. Each file contains a gridded monthly composite and the gridded daily composites.

Within data files, similar variables such as science data, instrument parameters, and metadata are grouped together according to the HDF model. The following figure shows data groups and variables stored at the top level in ATL21 data files:

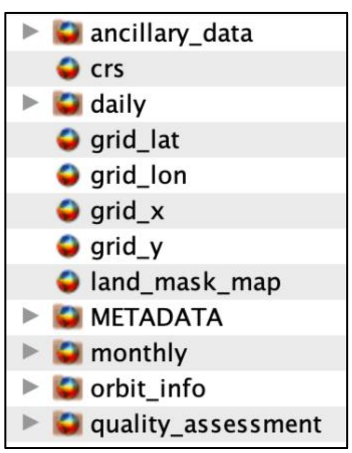

Figure 1. ATL21 top-level data groups and variables.

The following sections describe the data groups and their contents plus the variables stored at the top level in ATL21 data files.

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 daily

One subgroup for each day of the month containing:

- **`mean_ssha`**: Daily mean sea surface height anomalies (SSHA) for each daily grid cell.
- **`mean_weighted_earth_free2mean`**: Mean of the solid earth permanent tide correction sampled at each reference surface height location used in the daily grid cell. Subtract from `mean_ssha` to remove the solid earth permanent tide.
- **`mean_weighted_geoid`**: Mean of the geoid values sampled at each reference surface height location used in the daily grid cell. Geoid is expressed relative to the WGS84 reference ellipsoid from EGM2008 and is in a mean-tide system.
- **`mean_weighted_geoid_free2mean`**: Mean of the geoid free-to-mean correction sampled at each reference surface height location used in the daily grid cell. Subtract from `mean_weighted_mss` or `mean_weighted_geoid` to convert to a tide-free system.
- **`mean_weighted_mss`**: Grid cell mean of the mean sea surface (MSS) values sampled at each reference surface height location used in the daily grid cell. MSS is converted to mean tide when sampled by ATL21 using the `geoid_free2mean` correction.
- **`n_refsurfs`**: Number of reference surface sections used in each daily grid cell.
- **`sigma`**: Standard deviation of the daily gridded mean SSHA, computed as described in Section 6.3 of the ATBD.

1.2.2.3 monthly

- **`mean_ssha`**: Monthly mean SSHA for each monthly grid cell.
- **`mean_weighted_earth_free2mean`**: Mean monthly solid earth permanent tide correction calculated from all available daily `mean_weighted_earth_free2mean` values. Subtract from `mean_ssha` to remove the solid earth permanent tide.
- **`mean_weighted_geoid`**: Mean monthly geoid calculated from all available daily `mean_weighted_geoid` values. Geoid is expressed relative to the WGS84 reference ellipsoid from EGM2008 and is in a mean-tide system.
- **`mean_weighted_geoid_free2mean`**: Mean monthly geoid free-to-mean correction calculated from all available daily `mean_weighted_geoid` values. Subtract from `mean_weighted_mss` or `mean_weighted_geoid` to convert to a tide-free system.
- **`mean_weighted_mss`**: Mean monthly MSS calculated from all available daily `mean_weighted_mss` values.
- **`n_refsurfs`**: Number of reference surface sections used in each monthly grid cell.

- **sigma**: Standard deviation of the monthly gridded mean SSHA, computed as described in Section 6.3 of the ATBD.

1.2.2.4 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.

1.2.2.5 orbit_info

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

1.2.2.6 quality_assessment

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

1.2.2.7 Top-level variables

- **crs**: coordinate reference system identification for NSIDC Sea Ice Polar Stereographic
- **grid_lat**: latitude at the center of each grid cell
- **grid_lon**: longitude at the center of each grid cell
- **grid_x**: x value at the center of each grid cell
- **grid_y**: y value at the center of each grid cell
- **land_mask_map**: gridded map that denotes each grid cell as land (1) or ocean/sea ice (0)

1.2.3 Naming Convention

Data files utilize the following naming convention:

`ATL21-[HH]_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5`

Examples:

`ATL21-01_20230601012940_10951901_004_01.h5`

`ATL21-02_20230601012940_10951901_004_01.h5`

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL21	ATLAS/ICESat-2 L3B Daily and Monthly Polar Sea Surface Height Anomaly product
HH	Hemisphere code. Northern Hemisphere = 01, Southern Hemisphere = 02

Variable	Description
yyyymmdd	Year, month, and day of data acquisition of the first ATL10 granule used in the monthly gridded data set
hhmmss	Start time hour, minute, and second of data acquisition of the first ATL10 granule used in the monthly gridded data set
tttt	Four-digit RGT of the first ATL10 granule used in the monthly gridded data set. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle number of the first ATL10 granule used in the monthly gridded data set. Each of the 1387 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 ATL21 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 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 Browse Files

Browse files are provided as JPGs that contain composite images designed to quickly assess the location and quality of each granule's data. A list of available images is shown in Table 2, and an example is shown in Figure 2.

Table 2. Images Available as Browse

Image	Description
mean_ssha	Monthly mean sea surface height anomalies
mean_weighted_earth_free2mean	Monthly mean solid earth tide free-to-mean conversion
mean_weighted_geoid	Monthly mean geoid
mean_weighted_geoid_free2mean	Monthly mean geoid free-to-mean conversion
mean_weighted_mss	Monthly mean MSS
n_refsurfs	Monthly population count
sigma	Monthly standard deviation

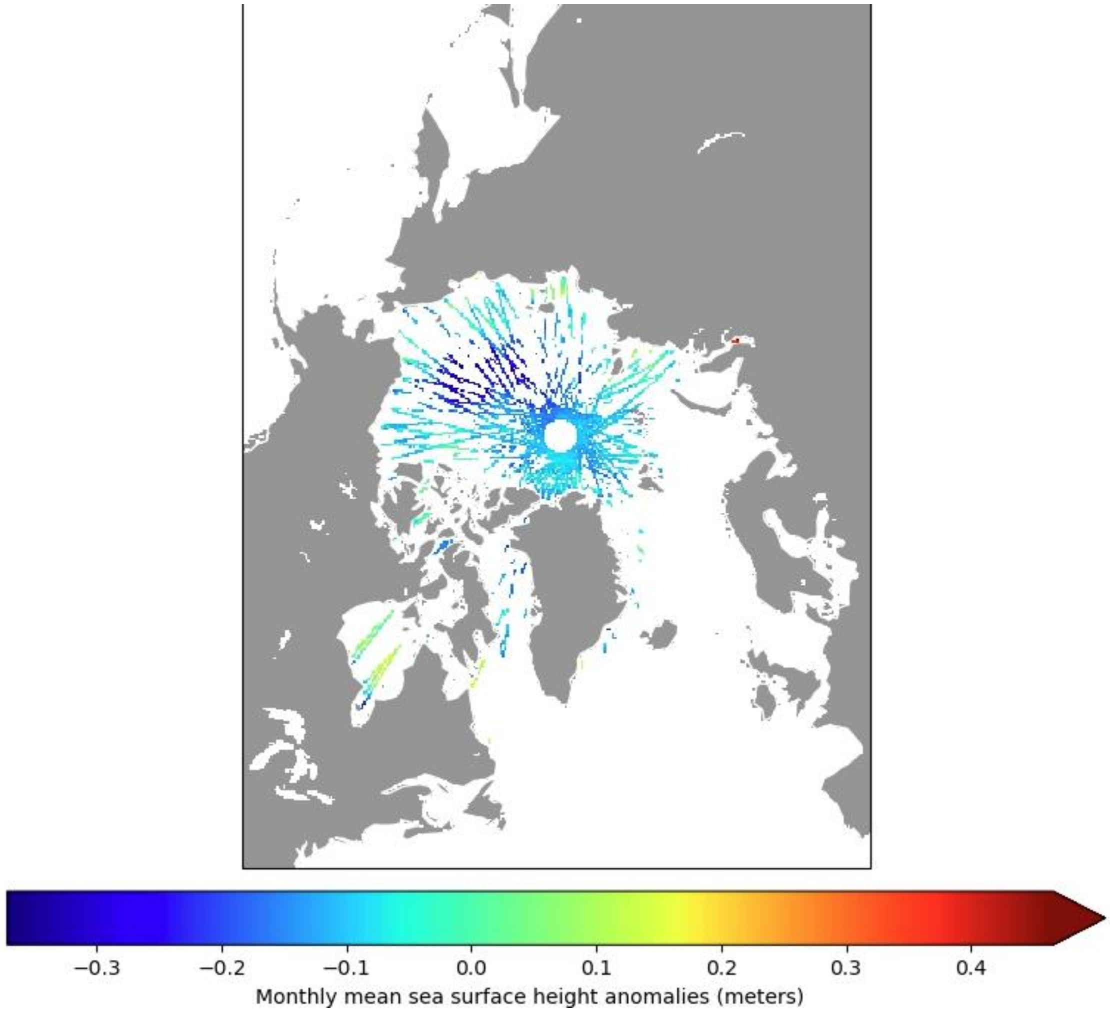

Figure 2. Example browse image for monthly mean sea surface height anomalies (`mean_ssha`).

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:

Northern Hemisphere: 37º N to 89º N, 180º E to 180º W
Southern Hemisphere: 53º S to 79º S, 180º E to 180º W

1.3.2 Resolution

25 km

1.3.3 Geolocation

Data are mapped using NSIDC's Polar Stereographic Projection:

NSIDC Sea Ice Polar Stereographic North (EPSG: 3411)
NSIDC Sea Ice Polar Stereographic South (EPSG: 3412)

Grid details for both projections are shown in the table below.

Table 3. Grid Details

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

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

Data are provided at daily and monthly resolutions. Months are defined as the first through the last day of each calendar month.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Accurately resolving spatio-temporal variations in sea surface height across the polar oceans is important for understanding changes in ocean circulation, fresh water storage, and energy balance. ICESat-2 measurements can be used to estimate regional and seasonal polar sea surface height variability, as described in the next sections.

2.2 Acquisition

ATL10 identifies leads in sea ice, i.e., narrow cracks in sea ice that form when separate patches of floating ice diverge or shear as they move parallel to each other, and establishes a reference sea surface used to estimate SSH in 10 km along-track segments. ATL21 aggregates the ATL10 along-track SSH estimates and computes daily and monthly gridded SSHA in NSIDC Polar Stereographic Northern and Southern Hemisphere 25 km grids.

2.3 Processing

To compute SSHAs, the algorithm collects all the ATL10 center strong beam SSH (10 km reference surface height) segments from the time span of interest and performs the following steps. This version of ATL21 uses only the center strong beam as beam alignment efforts are still ongoing. For more details, see the Known Issues document on the ATL21 data set landing page.

1. Read in the MSS and geoid from ATL10 that were sampled at the freeboard along-track segment length (*L*-km) reference surface scale.
2. Gather consecutive candidate lead height segments into groups to identify leads and calculate each lead height mean, error estimate, and length. Label the leads used to calculate the `refsurf` .
3. Calculate the *L*-km segment mean and error estimates of `refsurf` using the lead values.
4. Calculate the center of a given *L*-km segment using along-track distance. Time, latitude, and longitude are determined by interpolating sea ice segment values to this location.

2.3.1 Daily

For each 25 km grid cell (x, y, D), where D is day-of-month, the algorithm calculates the mean SSH and standard deviation as follows:

$$\bar{h}(x, y, D) = \frac{\sum_N h_s^i}{N}$$

$$\sigma^2(x, y, D) = \frac{\sum_N \left(h_s^i\right)^2}{N} - \bar{h}^2(x, y, D)$$

In the equations above, *h* is the SSH for segment i and *N* is the number of segments in the given daily grid cell.

2.3.2 Monthly

Monthly gridded SSH is computed from the daily composites as follows:

$$\bar{h}_M(x, y) = \frac{\sum_D \bar{h}(x, y, D)}{N_D}$$

N_D is the number of days in the month. Additional information about how ATL21 is constructed is available in “Section 6.3 | Dataflow and procedural steps (ATL21)” in the ATBD (Kwok et al., 2025).

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.

Limitations are imposed by height retrievals and surface classification. Multiple scattering within a thin ice layer of sea ice leads 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 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 (Kwok et al., 2025).

3 VERSION HISTORY

Table 4. Version History Summary

Version	Date	Description of Changes
3.1 (retire)	11 May 2026	Data access was removed for v3.1. Data coverage was 14 Oct 2018 to 28 Feb 2025.
4.0	4 Nov 2025	Updated the attribute grid mapping and CRS variable to improve NetCDF compliance.
3.1	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.
2.0 (retire)	26 Feb 2024	Data access was removed for v2.0. Data coverage was 14 Oct 2018 to 30 Sep 2022.
3.0	24 Aug 2023	• Corrected reported longitude values to agree with NSIDC Polar Stereographic projections. • Added grid_mapping attribute to land_mask_map array. • Updated the MSS variable description. Added mentions of the source of the MSS (which uses CryoSat-2 data) and clarified the use of the tide-free system.
1.0 (retire)	13 Jun 2022	Data access was removed for v1.0. Data coverage was 1 Nov 2018 to 1 Jul 2021.
2.0	14 Dec 2021	No changes in the ATL21 algorithm
1.0	2 Aug 2021	Initial release

4 REFERENCES

Kwok, R. Petty, A., Bagnardi, M., Wimert, J. T., Cunningham, G. F., Hancock, D. W., Ivanoff, A., & Kurtz, N. (2025). *Ice, Cloud, and Land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Sea Ice Products*. NASA Goddard Space Flight Center. https://doi.org/10.5067/KPMXUOH7TNIY

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

November 2025

5.2 Date Last Updated

May 2026

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).

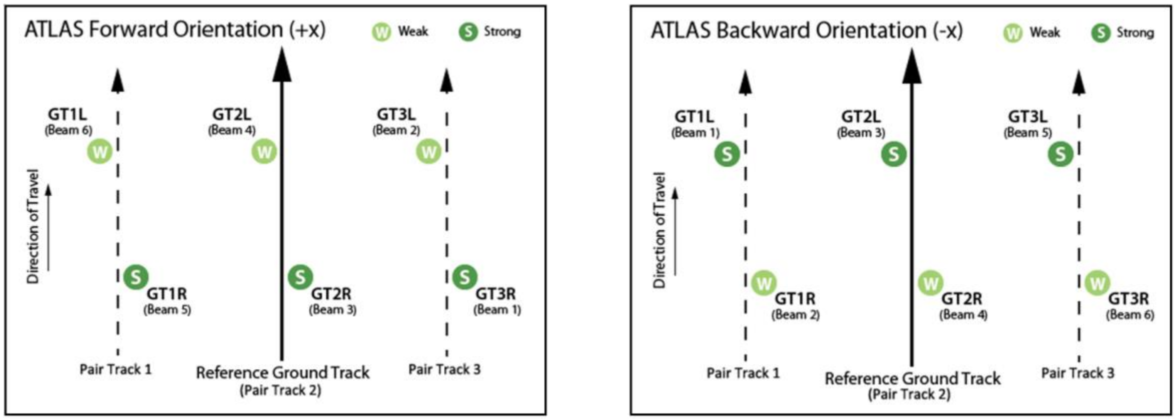

Figure A - 1. Spot and Ground Track (GT) naming convention.

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.

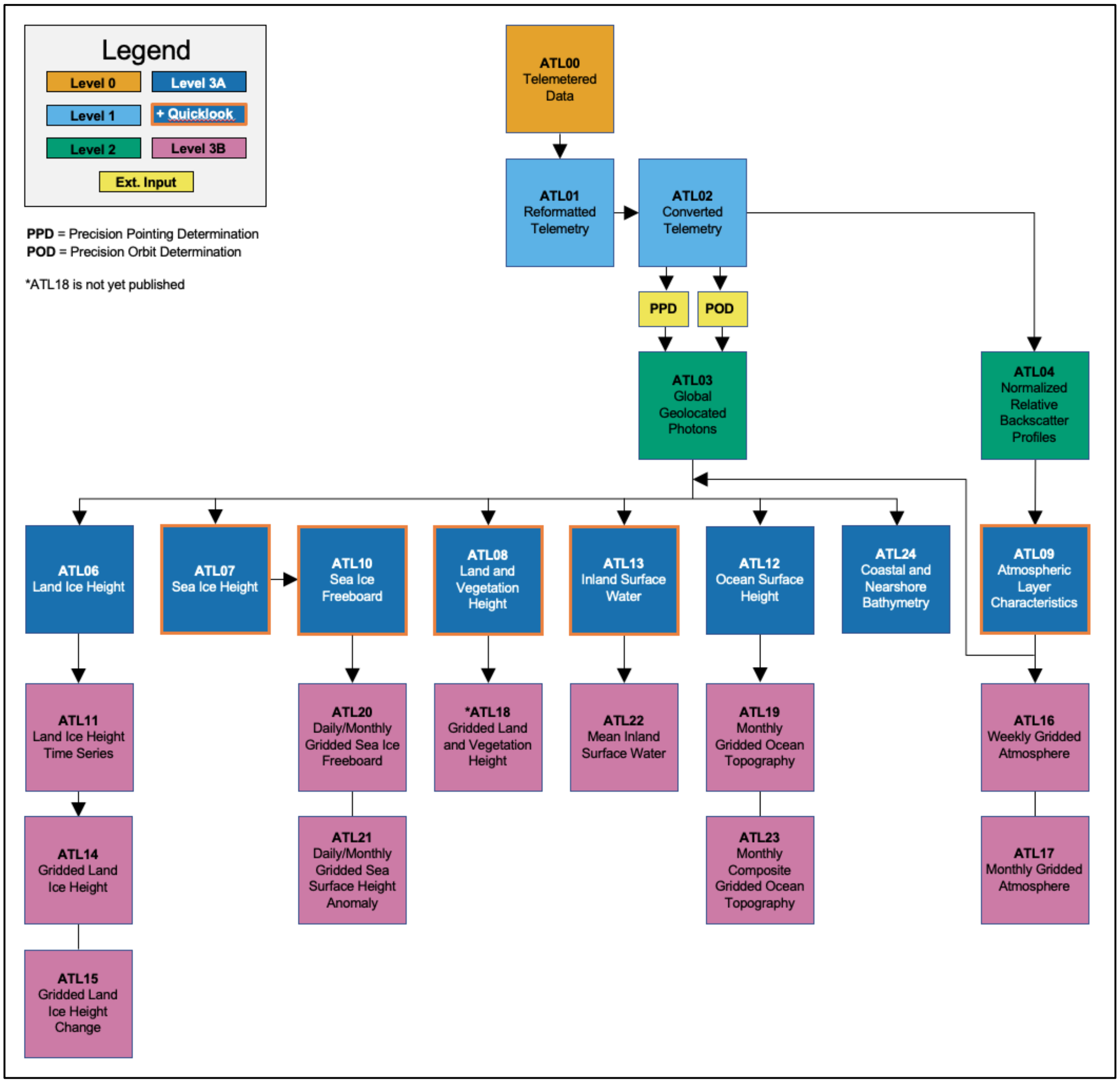

Figure A - 2. Schematic of ICESat-2 data processing and data products.

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.

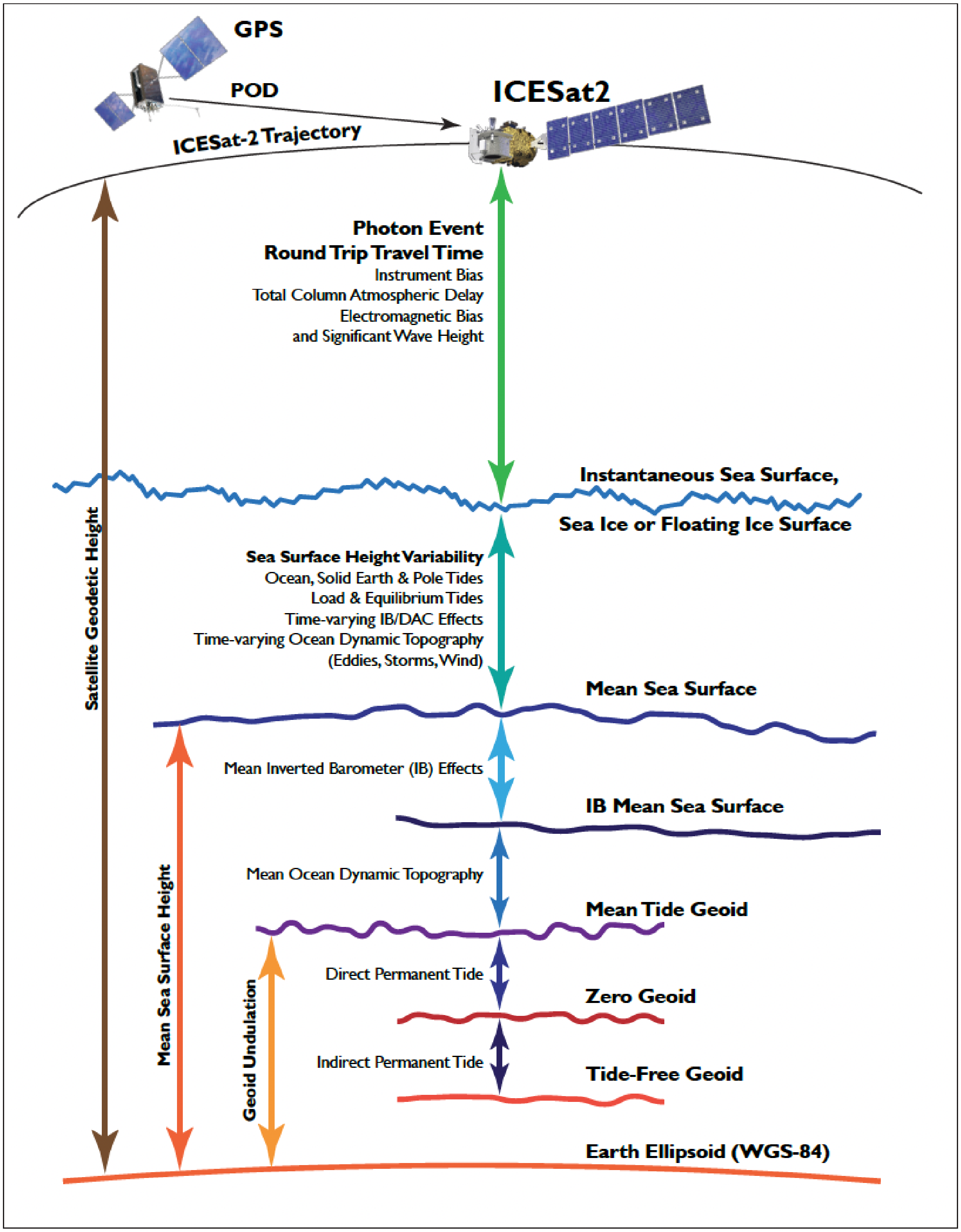

Figure A - 3. Geophysical corrections used in satellite altimetry (Source: *ICESat-2 Data Comparison User's Guide for Rel007,* available on the ATL03 data set landing page).