ATLAS/ICESat-2 L3B Gridded Antarctic and Arctic Land Ice Height Change, Version 4

USER GUIDE

How to Cite These Data

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

Smith, B., T. Sutterley, S. Dickinson, B. P. Jelley, D. Felikson, T. A. Neumann, H. Fricker, A. Gardner, L. Padman, T. Markus, N. Kurtz, S. Bhardwaj, D. Hancock, and J. Lee. 2024. *ATLAS/ICESat-2 L3B Gridded Antarctic and Arctic Land Ice Height Change, Version 4*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL15.004. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL15

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

This user guide refers to the Ice, Cloud, and land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Land-ice DEM (ATL14) and Land-ice height change (ATL15) (ATBD for ATL14/15, V4 | https://doi.org/10.5067/R7PT3U8WSJFZ).

1.1 Parameters

This data set contains land ice height changes and change rates for the Antarctic ice sheet and regions around the Arctic gridded at four spatial resolutions (1 km, 10 km, 20 km, and 40 km). The data are derived from the ATLAS/ICESat-2 L3B Slope-Corrected Land Ice Height Time Series product (ATL11).

1.2 File Information

1.2.1 Format

Data are provided in netCDF formatted files.

1.2.2 File Contents

Data files are available for each of the four spatial resolutions (1 km, 10 km, 20 km, and 40 km). The data group structure is the same for each spatial resolution. To keep file sizes manageable, the Antarctica data are also split into four quadrants (A1, A2, A3, and A4) along 90º longitudes (Figure 1). Each quadrant is provided as a separate file (see Section 1.2.3 Naming Convention).

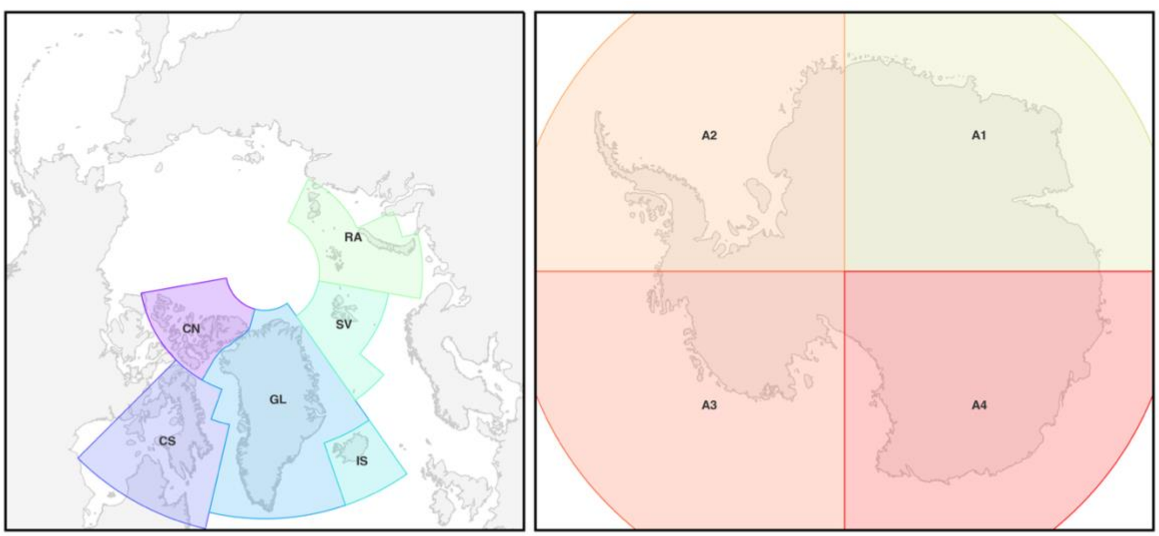

Figure 1. Regions for ATL15.

Within data files, similar variables such as science data, instrument parameters, and metadata are grouped together. The following figure shows the top-level data groups for ATL15 data files:

Name	Long Name	Type
ATL15_CN_0321_01km_004_01.nc	SET_BY_META	Local File
delta_h	delta_h	—
dhdt_lag1	dhdt_lag1	—
dhdt_lag12	dhdt_lag12	—
dhdt_lag16	dhdt_lag16	—
dhdt_lag20	dhdt_lag20	—
dhdt_lag4	dhdt_lag4	—
dhdt_lag8	dhdt_lag8	—
METADATA	METADATA	—
orbit_info	orbit_info	—
quality_assessment	quality_assessment	—
tile_stats	tile_stats	—

Figure 2. ATL15 top-level data groups and variables.

The following sections describe the contents of the data groups stored at the top level in ATL15 data files.

1.2.2.1 delta_h

Variables describing height differences between the model surface and the 1 km DEM surface at any given time. Time values are expressed in days since the ICESat-2 epoch (midnight at the start of 1 January 2018). The 1 km files include three additional variables for root mean square (RMS) fitting: `data_count`, `misfit_rms`, and `misfit_scaled_rms`. Also included is an `ice_area` variable that indicates how much ice-covered area is within each grid cell for each time step. The `ice_area` variable is updated for each time step in Antarctica, where a time-varying mask is used to account for ice front calving and advance, and it is updated in other regions to remove cells where the inferred surface height falls below sea level (estimated based on the EGM2008 geoid).

1.2.2.2 dhdt_lag1/dhdt_lag4/dhdt_lag8/dhdt_lag12/dhdt_lag16/dhdt_lag20

Variables associated with the height-change rates corresponding to the time derivative of `delta_h`. Time values for the height-change rates are equal to the midpoints of underlying surface height change times. Height-change rates are provided at the temporal resolutions outlined in the following table:

Table 1. Temporal Resolutions and Corresponding Variables

Time	Variable Name
Quarterly	dhdt_lag1
Annually	dhdt_lag4
Biennially	dhdt_lag8
Triennially	dhdt_lag12
Quadrennially	dhdt_lag16
Pentennially	dhdt_lag20

As the mission duration increases, more `dhdt` groups will be added to span the full length of the ICESat-2 mission. For these groups, the `ice_area` variable indicates the area in each cell that is covered by ice in both the first and the last time steps over the differencing period.

1.2.2.3 METADATA

ISO19115 structured summary metadata.

1.2.2.4 orbit_info

Bounding polygons (in latitude and longitude) for each granule.

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. These variables will be marked as *valid(0)* in all released granules.

1.2.2.6 tile_stats

Information specific to the tiles (overlapping subdomains) on which the ATL14/15 solution was originally computed. These data sets are intended to help identify tiles on which there were significant problems.

- `N_bias`: number of bias values solved for
- `N_data`: number of data used in fit
- `Polar_Stereographic`: data projection
- `RMS_bias`: root mean of squared, scaled bias values
- `RMS_d2z0dx2`: root mean square of the constraint equation residuals for the second spatial derivative of z0
- `RMS_d2zdt2`: root mean square of the constraint equation residuals for the second temporal derivative of dz
- `RMS_d2zdx2dt`: root mean square of the constraint equation residuals for the second temporal derivative of dz/dt

- `RMS_data`: root mean of squared, scaled data misfits
- `sigma_tt`: weighting values for the constraint equations on the second temporal derivatives of the surface height
- `sigma_xx0`: weighting values for the constraint equations on the second spatial derivatives of the DEM
- `sigma_xxt`: weighting values for the constraint equations on the second spatial derivatives of the height-change rate
- `x`: tile-center x-coordinate in projected coordinates
- `y`: tile-center y-coordinate in projected coordinates

For additional information, see the following documentation on the ATL15 data set landing page:

- ATL15 Data Dictionary (complete list of variables stored)
- “Section 4.2: ATL15 product” in the “ATBD for Land-ice DEM (ATL14) and Land-ice height change (ATL15)”
- “Section 4.3: Parameters common among groups” in the “ATBD for Land-ice DEM (ATL14) and Land-ice height change (ATL15)”

1.2.3 Naming Convention

Data files utilize the following naming convention:

```
ATL15_[RR]_[CCCC]_[nn]km_[vvv_rr].nc
ATL15_CN_0321_01km_004_01.nc
```

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
ATL15	ATLAS/ICESat-2 L3B Gridded Antarctic and Arctic Land Ice Height Change product
RR	Region code. Antarctica = A1, A2, A3, or A4; Arctic Canada North = CN; Arctic Canada South = CS; Greenland and peripheral ice caps = GL; Iceland = IS; Svalbard = SV; Russian Arctic = RA.
CCCC	First and last complete cycles of repeat-track data included in the file (i.e., 0321 includes cycles 3 through 21, inclusive)
nn	Two-digit spatial resolution. Options are 01, 10, 20, and 40.
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 segment 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.

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 File

Each granule contains JPG browse images called `default1` and `default2`. `default1` visualizes the average quarterly rate of height change (`dhdt_lag1/dhdt`) at a 1 km resolution from cycles 03 to 21. `default2` visualizes the standard deviation (m) of the quarterly rate of height change (`dhdt_lag1/dhdt`) at a 1 km resolution from cycles 03 to 21. Example browse images are shown in Figure 3.

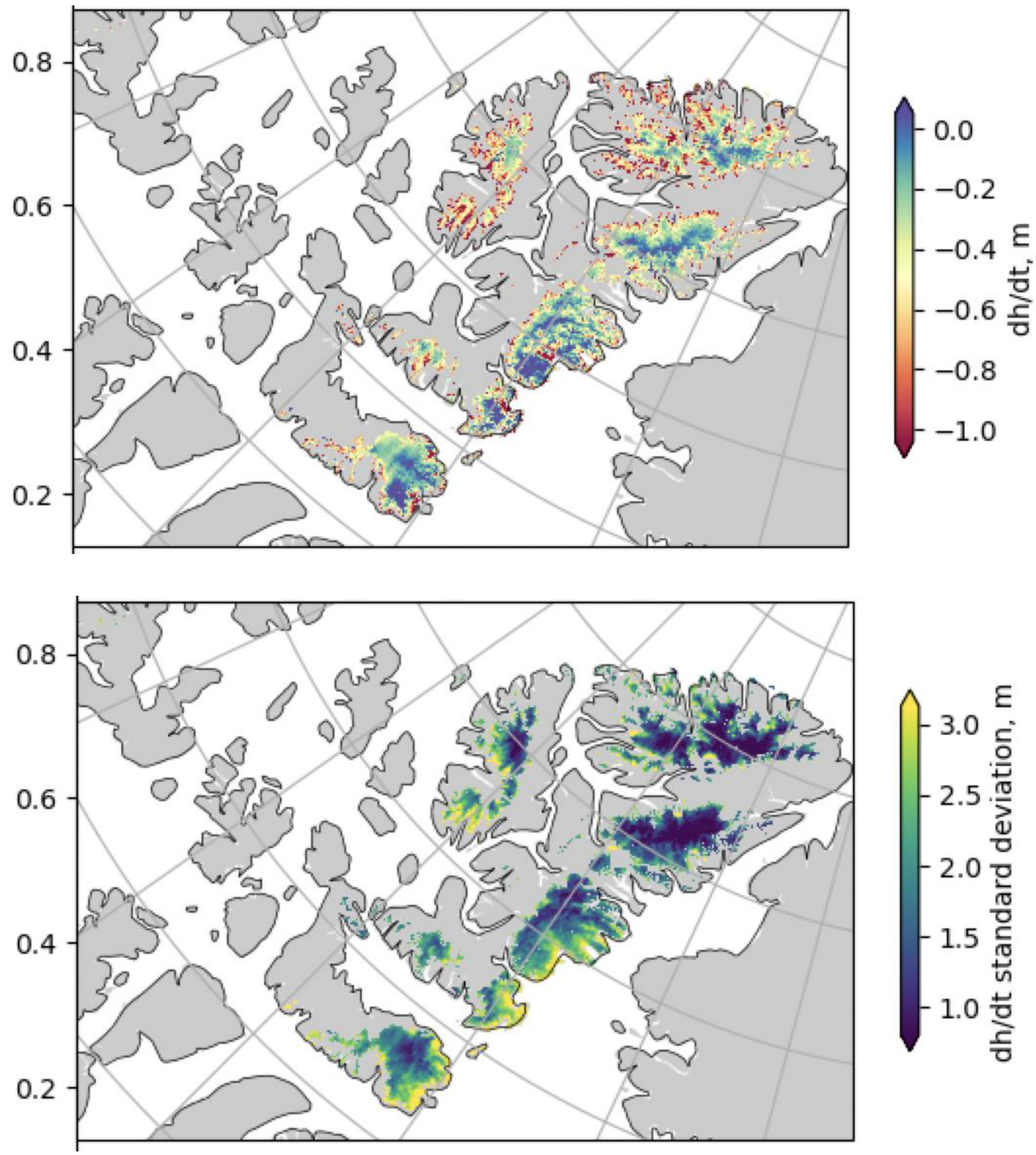

Figure 3. `Default1` (top) and `Default2` (bottom) browse images for `ATL15_CN_0321_01km_004_01_BRW`.

1.3 Spatial Information

1.3.1 Coverage

North and south polar regions:

- North of 59.0° N
- South of 60.0° S

1.3.2 Resolution

Full resolution of 1 km, as well as reduced resolutions of 10 km, 20 km, and 40 km

1.3.3 Geolocation

Northern Hemisphere: NSIDC Sea Ice Polar Stereographic North (EPSG 3413)

Southern Hemisphere: Antarctic Polar Stereographic (EPSG 3031)

The product is defined on grids that are square in the projected coordinates, thus the area of each grid cell is different from the square of the grid spacing.

1.4 Temporal Information

Time values are expressed in days since the ATLAS epoch (midnight at the start of 1 January 2018).

1.4.1 Coverage

1 January 2019 through the most current processing

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

Height difference surfaces: quarterly

Height change rates: quarterly, annually, biennially, triennially, quadrennially, and pentennially

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATL15 is a gridded version of the time-varying height estimates provided in ATLAS/ICESat-2 L3B Slope-Corrected Land Ice Height Time Series (ATL11). ATL15 provides coarse-resolution height-change maps at 3-month intervals, allowing for visualization of height-change patterns and the calculation of integrated regional volume change.

2.2 Acquisition

ATL15 is derived from ATL11, which contains spatially organized time series of land-ice surface heights derived from the ATLAS/ICESat-2 L3A Land Ice Height product (ATL06). The algorithm that produces a set of gridded height-change maps for ATL15 is summarized in the following sections.

2.3 Processing

The ATL14/15 algorithm works through several steps to fit height and height-change maps to the ATL11 repeat-track-corrected height estimates.

Define subdomains: The ice sheet is divided into 61x61 km tiles (44x44 km near the poles) to reduce computational costs. Independent calculations are performed on tiles centered on a 40 km grid to minimize edge effects.

Select high-quality data: Reliable along-track and crossover ATL11 data are selected based on a combination of geographic and parameter-based factors.

Compute two-component solution: The solution is a combination of (1) the model comprising the interpolating functions (between the model parameters and ATL11 height measurements) and a set of estimated height biases and (2) a regularized least-squares solution that identifies the simplest model that fits the height data and rejects statistically outlying measurements. This solution is iterated to remove outlying data points.

Calculate model errors: A dominant error source in ATL11 data is the effect of geolocation errors over sloping surfaces. Data biases are included as parameters in the solution to produce a smooth model.

Combine solutions: Error estimates are calculated, each tile solution is recomputed by applying linear constraint at the edges, and the solutions are combined using a weighting scheme to form the final ATL14/15 product. Each data point is assigned an error estimate based on the ATL11 data and bias-parameter constraints.

Details on the processing steps can be found in the ATL14/15 ATBD under "Section 3.0 | Algorithm Theory" and subsections therein.

2.4 Quality, Errors, and Limitations

The feature resolution of ATL15 is limited by the spatial resolution of the ICESat-2 tracks, the temporal sampling of the tracks, and the resolution of the grids chosen for these data products. More detailed information on all three limitations can be found in "Section 2.1 | Limitations of the ATL14/15 product" of the ATL14/15 ATBD. Users should consult the `data_count` and `delta_h_sigma` fields to help understand how spatial coverage by ICESat-2 might affect the accuracy of surface-height estimates.

Error estimation for ATL15 is detailed in the "Section 3.4.8 | Error estimates" of the ATBD.

Cycles 1 and 2, comprising all data before April 2020, were not collected along the ICESat-2 reference ground tracks. They were collected with larger off-nadir angles than is typical for other cycles. As a result, these data have larger errors than other cycles and are not included in the ATL11 repeat-track calculations. All cycle 1 and 2 data are derived from crossover points—where the ground tracks from these cycles cross the ICESat-2 reference pair tracks—which greatly reduces the number of data points available. Cycles 1 and 2, as represented in ATL15, have much larger errors than the other cycles and should be treated with caution. The first high-quality reference-track data come from cycle 3.

3 VERSION HISTORY

Table 3. Version History Summary

Version	Release Date	Description of Changes
V4	July 2024	• Extend temporal coverage through cycle 21 • Relax constraints for higher velocity ice sheets in Greenland • Smooth error estimates before interpolation to correct for zero error conditions reported • Correct longitude metadata extents for Antarctic regions • Remove data from cycle 1 (Quarter 4 of 2018) to avoid artifacts from previous geolocation challenges This version was derived from ATL11 V6
V3	October 2023	All regions: • Extend temporal coverage through cycle 18 Antarctica:

Version	Release Date	Description of Changes
		• Update and improve time-varying ocean mask based on data from the IceLines project • Data from the 400x400 km square surrounding the pole are calculated on 44 km tiles rather than 60 km tiles • Data are split into four quadrants (A1, A2, A3, and A4) along 90° longitudes Greenland: • New time-varying ice-front mask This version was derived from ATL11 V6
V2	November 2022	• Extend temporal coverage through cycle 14 • Include one independent bias parameter for each RGT, cycle, and beam pair in the bias model • In all regions except Antarctica, use minimum error estimate for every unique crossover • Apply a time-variable ice mask, as reflected in the ice_area variable • Achieve tile-to-tile matching using linear constraint at tile edges • Decrease computation tile size to 61x61 km, and compute tiles in two stages instead of three This version was derived from ATL11 V5
V1	December 2021	Initial release; this version was derived from ATL11 V4

4 RELATED DATA SETS

- ATLAS/ICESat-2 L3A Land Ice Height (ATL06)
- ATLAS/ICESat-2 L3B Slope-Corrected Land Ice Height Time Series (ATL11)
- ATLAS/ICESat-2 L3B Antarctic and Arctic Land Ice Height (ATL14)

5 DOCUMENT INFORMATION

5.1 Publication Date

July 2024

5.2 Date Last Updated

July 2024

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 travel time is 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 trace out a ~11 m wide track 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 modified 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).

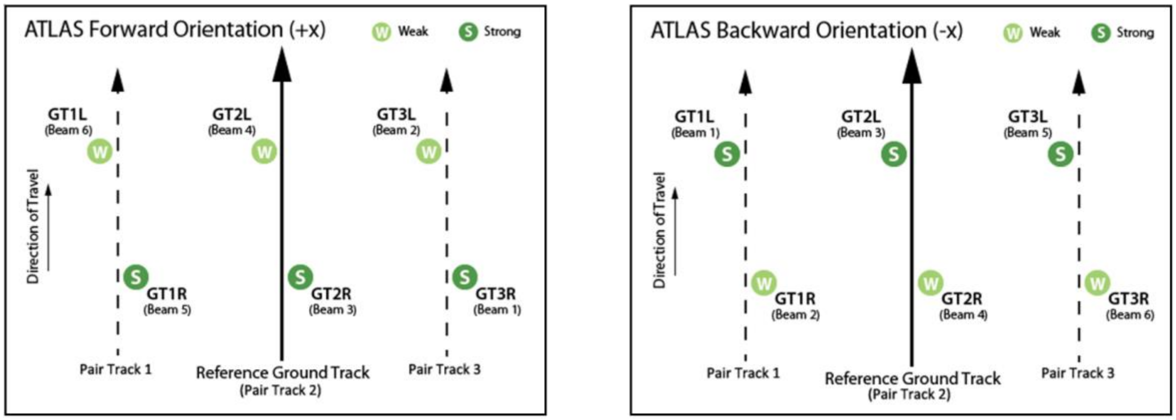

Figure A - 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction and backward (instrument coordinate -x) direction.

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 KMZ 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.

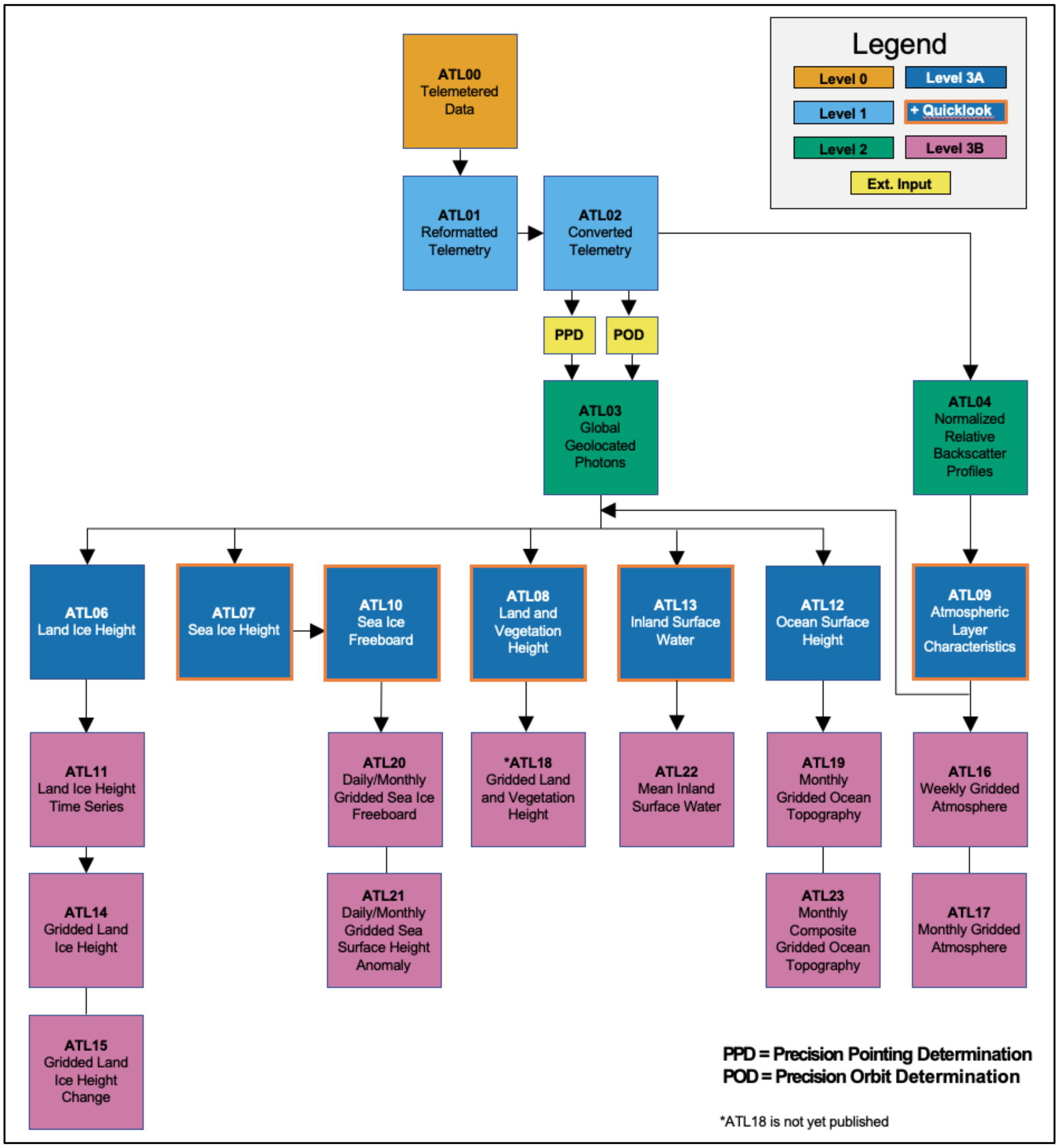

Figure A - 2. Schematic of ICESat-2 data processing and data products.

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 Rel006* available on the ATL03 data set landing page.

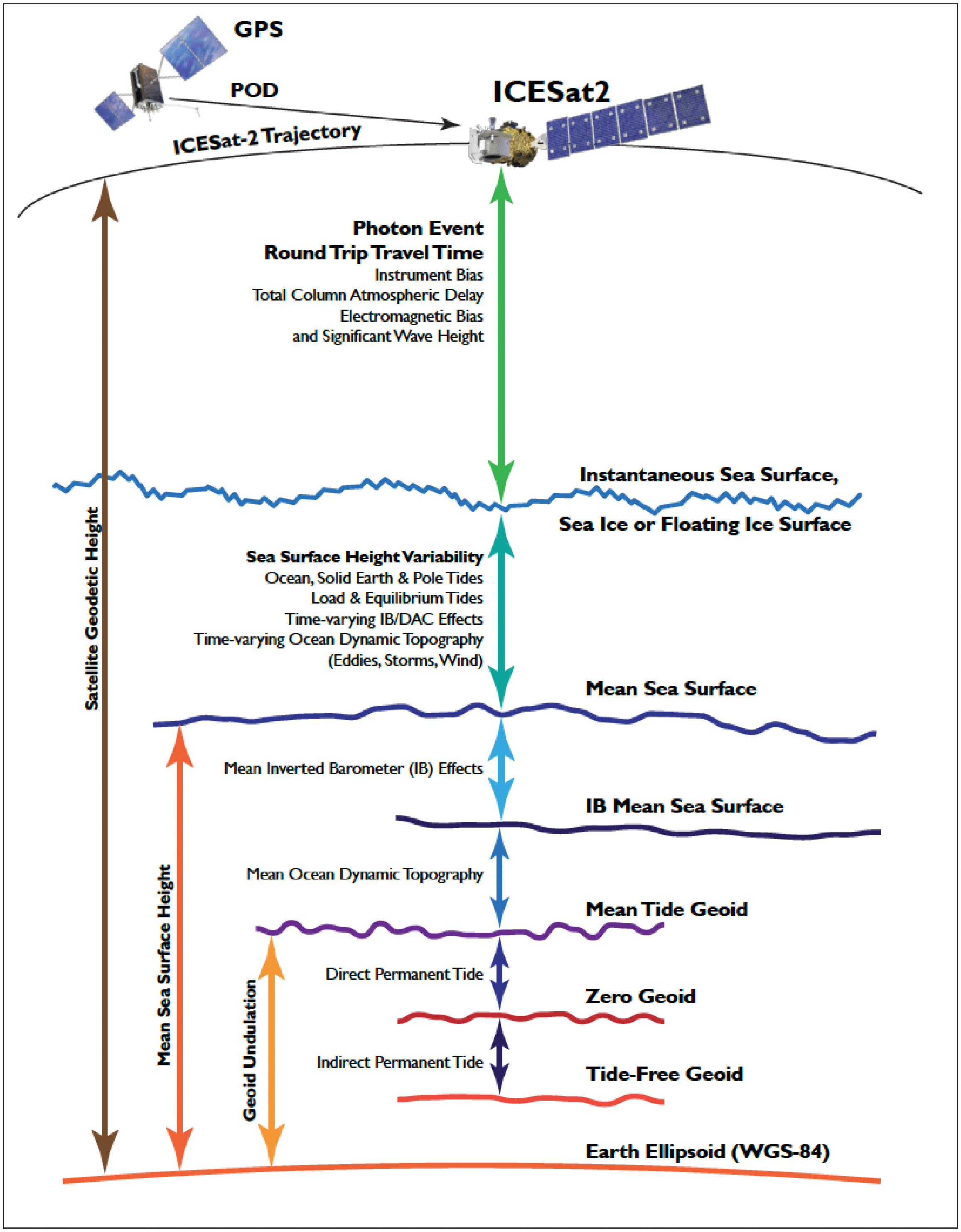

Figure A - 3. Geophysical corrections used in satellite altimetry.
Taken from *ICESat-2 Data Comparison User's Guide for Rel006*
available on the ATL03 data set landing page.