ATLAS/ICESat-2 L3B Slope-Corrected Land Ice Height Time Series, Version 6

USER GUIDE

How to Cite These Data

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

Smith, B., S. Dickinson, B. Jelley, T. Neumann, D. Hancock, J. Lee, K. Harbeck. 2023. *ATLAS/ICESat-2 L3B Slope-Corrected Land Ice Height Time Series, Version 6.* [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL11.006. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL11

NSIDC National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

This user guide cites sections in the Algorithm Theoretical Basis Document (ATBD) for Land-Ice Along-Track Products Part 2: Slope-Corrected Land Ice Height Time Series (ATBD for ATL11 | V6 https://doi.org/10.5067/ZQB1BP2DSTGM). To download this and other relevant documents, see the Documentation section of the ATL11 V6 landing page.

1.1 Parameters

This data set contains spatially organized time series of land-ice surface heights derived from the ATLAS/ICESat-2 L3A Land Ice Height product (ATL06). Height changes are computed for repeat observations (91 days apart) along individual ICESat-2 ground tracks in polar regions.

ATL11 is intended primarily as an input for higher-level gridded products but can also be used on its own.

1.2 File Information

1.2.1 Format

Data are provided as HDF5 formatted files.

1.2.2 File Contents

The ICESat-2 satellite acquires data along 1,387 separate Reference Ground Tracks (RGTs), completing a “cycle” of all RGTs every 91 days. To keep file sizes manageable, some products (including ATL11) break up RGT data by region (see Figure 1 and Table 1). The ATLAS instrument is configured to make repeat measurements along RGTs in polar regions (poleward of 60° N and 60° S). This strategy allows ATL11 to construct time series of ice height changes from cycle to cycle (i.e., 91 days apart) for regions 3, 4, and 5 and 10, 11, and 12. See Section 1.2.6 for details.

Each ATL11 data file contains estimated land ice heights, plus other data, for one region of one RGT. Data are stored as (r,c) arrays, where r is the number of locations with data and c is the number of cycles.

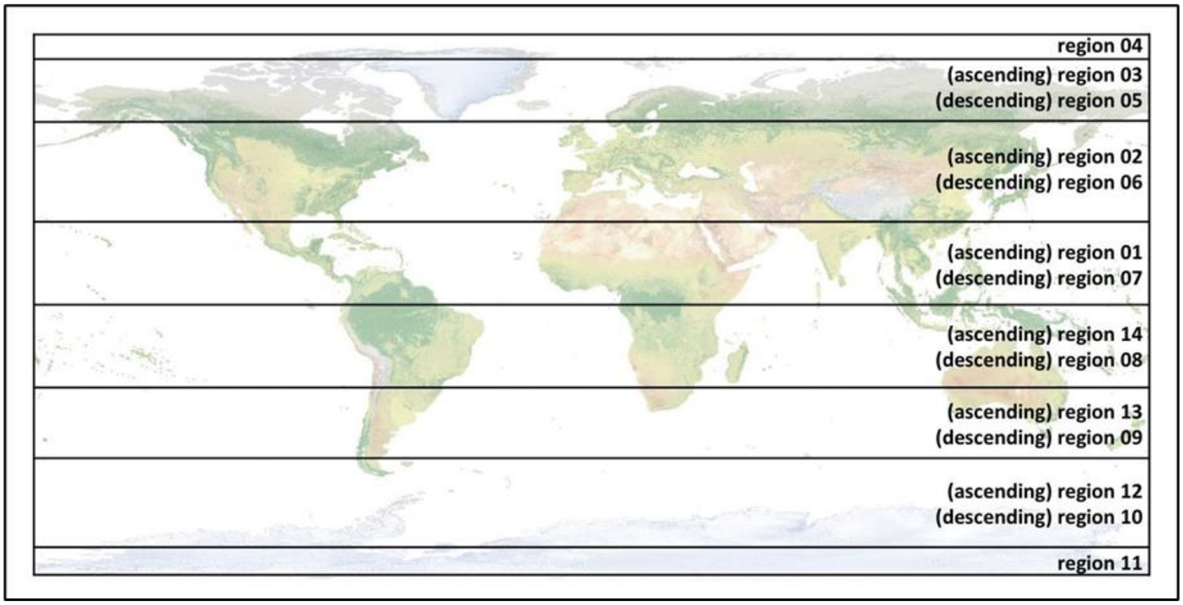

Figure 1. ATLAS/ICESat-2 region boundaries.

Table 1. ATLAS/ICESat-2 Region Latitude Bounds (A = Ascending, D = Descending). ATL11 Data Are Available for Regions 03, 04, 05, 10, 11, and 12 (in bold).

Reg.	Latitude Bounds	Reg.	Latitude Bounds
01	Equator → 27° N (A)	08	Equator → 27° S (D)
02	27° N → 59.5° N (A)	09	27° S → 50° S (D)
03	**59.5° N → 80° N (A)**	**10**	**50° S → 79° S (D)**
04	**80° N (A) → 80° N (D)**	**11**	**79° S (D) → 79° S (A)**
05	**80° N → 59.5° N (D)**	**12**	**79° S → 50° S (A)**
06	59.5° N → 27° N (D)	13	50° S → 27° S (A)
07	27° N (D) → Equator	14	27° S → Equator (A)

1.2.3 Naming Convention

Data files are named according to the following convention:

```
ATL11_[tttt][ss]_[cccc]_[vvv_rr].h5
ATL11_000103_0319_006_02.h5
```

The following table describes the file naming convention variables:

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
`ATL11`	ATLAS/ICESat-2 L3B Slope-Corrected Land Ice Height Time Series product
`tttt`	RGT. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.

ss	Region (orbital segment) number. Region numbers for the ICESat-2 mission range 01–14, however, data files for this product are only produced for regions that lie poleward of 60° N and 60° S. This corresponds to regions 3, 4, 5, 10, 11, and 12.
cccc	First and last cycles of data included in the file. E.g., “0319” would indicate the file contains data from cycles 3–19, inclusive*.
vvv_rr	Version and revision number*

*When new ATL06 data are available, NSIDC receives reprocessed ATL11 granules from our data provider. These granules have the same file name as the original granule but the cycle number and/or 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 but different cycle and/or revision numbers, please use the granule with both the highest cycle *and* revision numbers.

1.2.4 Data Groups

Within data granules, similar variables such as science data, instrument parameters, and metadata are grouped together according to the HDF model. ATL11 data are organized within the following top-level groups:

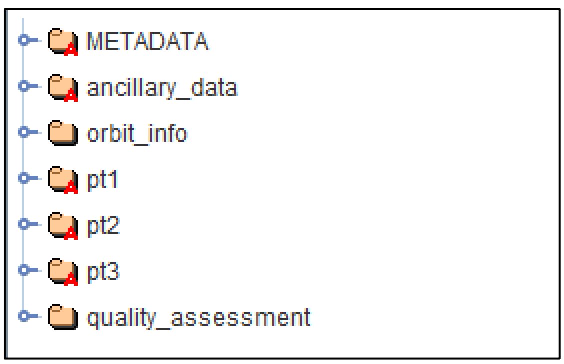

Figure 2. ATL11 data groups shown in HDFView.

The following sections summarize the contents of the above data groups and identify some parameters of interest. For a list and description of all output parameters on the ATL11 product, see “Section 4.0 | Land Ice Products: Land Ice H(t)” in the ATBD for ATL11.

1.2.4.1 METADATA

- ISO19115 structured metadata with sufficient content to generate the required geospatial metadata

1.2.4.2 ancillary_data

- Parameters that pertain to the granule in its entirety, such as product and instrument characteristics and/or processing constants

1.2.4.3 orbit_info

- Parameters that are constant for a granule such as the RGT number and cycle, the spacecraft orientation, and parameters passed through to higher-level products

1.2.4.4 pt[x]

These three data groups, one for each pair track, contain the primary science parameters for this data set, stored at the top level and in subgroups. Parameters at the top level include:

- Mean corrected height (`h_corr`) and corrected height error (`h_corr_sigma`)
- Latitude (`latitude`) and longitude (`longitude`) for each ATL11 data point
- QA flag (`quality_summary`)

The `pt[x]/cycle_stats/` subgroup contains summary information about segments for each reference point, including the uncorrected mean heights for reference surfaces, blowing snow and cloud indicators, and geolocation and height misfit statistics.

The `pt[x]/ref_surf/` subgroup contains parameters that describe the reference surface fit at each reference point, including slope information from ATL06, the polynomial coefficients used for the fit, and misfit statistics.

The `pt[x]/crossing_track_data/` subgroup contains the corrected heights, latitude/longitude locations, and associated data at crossover locations (i.e., where ICESat-2 pair tracks cross). See “Section 2.3.3 | Crossing-Track Data” of this user guide for more information.

1.2.4.5 quality_assessment

Quality assessment flags that indicate whether or not the granule passed automatic QA (`qa_granule_pass_fail`) and why (`qa_granule_fail_reason`).

1.2.5 Browse Files

Each ATL11 data file has the following JPG browse files:

- Three-panel figure showing height data from most recent cycle, number of cycles with valid height data, and change in height over time (`default1`)
- Number of valid height measurements from each beam pair (`default2`)
- Change in height over time (`dHdt`)
- Histograms of change in height over time (`dHdt_hist`)
- Histograms of heights minus DEM heights (`h_corr-DEM_hist_cycles`)
- Heights from crossing track data and heights minus crossing track heights (`h_corr_CrossOver`)
- Heights for each beam pair and heights minus DEM (`h_corr_h_corr-DEM`)

- Histogram of number of cycles with valid height measurements (`validRepeats_hist`)

For more information about browse files, see the ATBD for ATL11 | Section 7.0. Browse Products.

Spatial Information

1.2.6 Coverage

Coverage spans the regions poleward of 60° N and 60° S. Thus, data files are only generated for regions in which the satellite makes repeat-track measurements (see note) and crosses a land surface (i.e., does not lie entirely over open ocean). This corresponds to regions 3, 4, 5 and 10, 11, 12 (see Figure 1 and Table 1).

> The ICESat-2 orbit does not cross directly over the North and South poles. This produces a gap in coverage, or "pole hole," between 88° and 90° in both the Northern and Southern Hemisphere.

1.2.7 Resolution

ATL11 data are posted every 60 m at locations that correspond to the center of every third ATL06 segment (ATL06 segment ID). The ATL11 algorithm uses all available ATL06 segments whose centers lie within 60 m of the central segment such that ATL11 data are derived from measurements spanning 120 m in the along-track direction.

1.2.8 Geolocation

The following table provides information for geolocating this data set.

Table 3. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	N/A
Longitude of true origin	Prime Meridian, Greenwich
Latitude of true origin	N/A
Scale factor at longitude of true origin	N/A
Datum	World Geodetic System 1984
Ellipsoid/spheroid	WGS 84
Units	degree
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

1.3 Temporal Information

1.3.1 Coverage

Data span 29 March 2019 (beginning of cycle 3) to present. Note, however, that data are only available at times when the satellite is poleward of 60° N and 60° S (regions 3, 4, 5 and 10, 11, 12) and crossing land. A new batch of ATL06 data becomes available approximately every 1.5–2 months.

1.3.2 Resolution

Temporal resolution is 91 days.

The ICESat-2 satellite traverses each of its 1,387 RGTs once every 91 days, i.e., the satellite has a 91-day repeat cycle. The ATLAS instrument is configured to make repeat measurements along RGTs in polar regions (poleward of 60° N and 60° S).

2 DATA ACQUISITION AND PROCESSING

The following sections summarize how ATL11 data are processed. Users seeking additional details should consult the referenced sections in the ATBD for ATL11.

2.1 Background

A number of successful techniques have been used to determine elevation changes from repeat-track data from ICESat/GLAS, the predecessor to ATLAS/ICESat-2. For example, where surface slopes are small relative to background geophysical processes, height changes have been isolated by subtracting the mean height from a collection of measurements along the same repeat track. In regions where off-track surface slopes are not negligible, height changes have been recovered by subtracting the mean height plus an estimate of the surface slope.

ATL11 extends this approach by fitting low-degree polynomial surfaces to ATL06 surface heights and surface-slope information and using these small (< 1 km) patches to correct for sub-kilometer surface topography.

2.2 Acquisition

ATL11 is generated from ATL06 repeat track data. As described above in "Section 1.2.2 | File Contents", the ATL06 product is distributed as granules (files) that span about 1/14th of an orbit. ATL11 data are processed from ATL06 granules in regions 3, 4, 5 and 10, 11, 12.

2.3 Processing

2.3.1 Coordinate System

Although ATL11 heights are geolocated with lat/lon coordinates, computations are performed using the ATL06 along-track coordinate system. Briefly, this coordinate system is defined separately for each RGT, with an x-coordinate that starts (and ends) at the equator and increases in the ascending direction (north from the equator). The y-coordinate is perpendicular to the x-coordinate and positive to the left. Thus, the x-coordinate for each RGT runs from zero to about 4×10^7 m and the y-coordinate runs from about -3.3×10^3 m (the right beam pair) to approximately 3.3×10^3 m (the left beam pair).

2.3.2 Along-Track Ice Heights

ATL11 output data are centered on reference points which share the same along-track coordinate as the central ATL06 segment, but are displaced in the across-track direction to better match the aggregate location of the ATL06 measurements from all of the cycles present.

ATL06 land ice height estimates consist of 40 m overlapping surface segments whose centers are spaced 20 m apart along each of ICESat-2's three reference pair tracks (RPTs). These segments are displaced horizontally both relative to the RPT and to one another due to small imprecisions in measurement locations on the ground (a few tens of meters or less). ATL11 heights are corrected for these offsets between the reference tracks and the location of the ATLAS measurements by using ATL06 height and local surface slope information to construct a reference surface.

For a set of reference points spaced every 60 meters along each RPT (centered on every third segment center), the ATL11 algorithm considers all ATL06 segments whose centers lie within 60 m along-track and 65 m across-track of a reference point. As such, the fit for each ATL11 segment contains as many as seven distinct along-track ATL06 segments from each beam and cycle.

To calculate the reference surface using the most reliable subset of available data, the algorithm performs tests on these segments and selects a subset with self-consistent slopes and small errors, which it uses to define a time-variable surface height and a polynomial surface-shape model. The algorithm then applies the surface-shape model to calculate corrected heights for segments which were not chosen for the initial subset.

Figure 3 shows the data selection process as a flow chart. The ATBD for ATL11 describes these steps in "Section 3.0 | Algorithm Theory: Derivation of Land Ice H (t)." This section includes subsections that detail: input data editing (Section 3.1); reference surface shape corrections (Section 3.2.); corrected height calculations for repeats with no selected pairs (Section 3.4); parameter averaging (Section 3.7); and output data editing (Section 3.8).

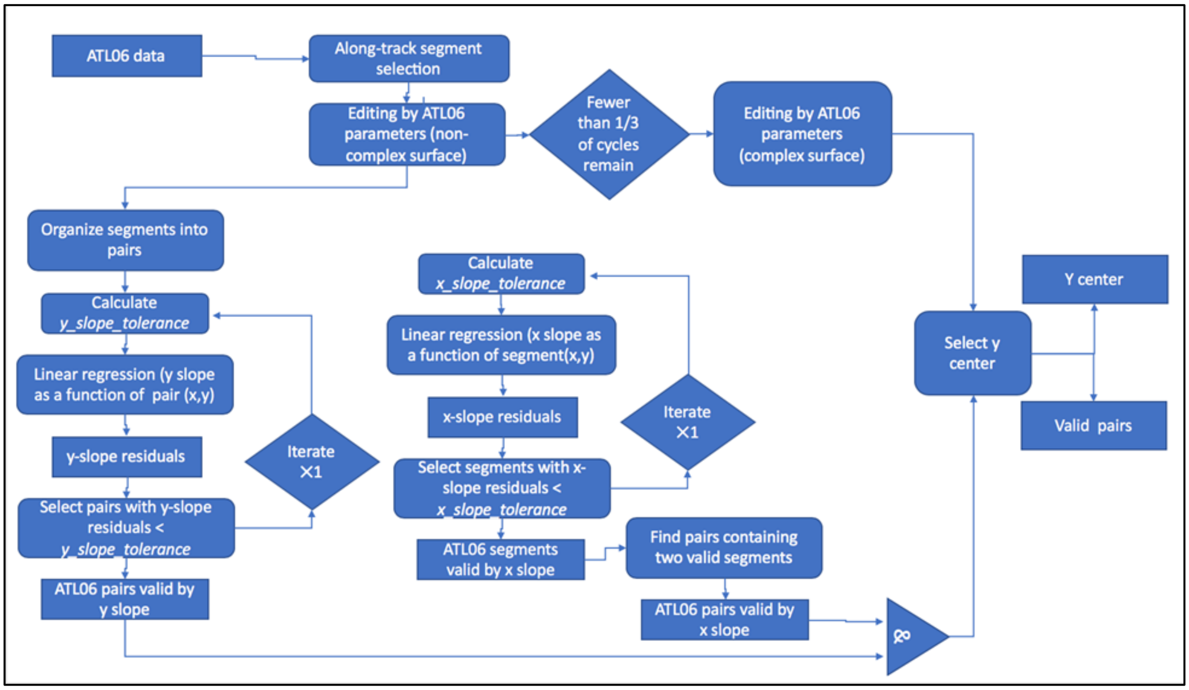

Figure 3. Flowchart showing the data selection process (source: ATBD for ATL11)

2.3.3 Crossing-Track Data

Locations where ground tracks cross provide opportunities to check the accuracy of measurements by comparing surface-height estimates between different ground tracks. In addition, these crossing data offer additional temporal detail than the 91-day repeat cycle.

At crossover points, the algorithm corrects elevations using the reference surface computed for the along-track segments at that location. This computation is detailed in "Section 3.6 | Calculating Shape-Corrected Heights For Crossing-Track Data" in the ATBD for ATL11.

2.4 Quality, Errors, and Limitations

The ATL11 algorithm propagates errors for each step and computes formal height error estimates that account for sampling error in ATL06 and systematic errors due to geolocation errors in the slope of the surface-shape model. Formal error estimates are described in the ATBD for ATL11 in “Section 3.3 | Reference-shape Correction Error Estimates“, “Section 3.5 | Calculating Systematic Error Estimates“, and "Section 3.9 | Antarctic Geolocation Biases".

ATL11 error estimates are stored in the following locations:

- pt[x]
  - `h_corr_sigma` (error in the corrected height)
  - `h_corr_sigma_systematic` (all errors correlated at scales larger than a single fit center)
- pt[x]/crossing_track_data/
  - `h_corr_sigma` (error in the crossing-track corrected height)
  - `h_corr_sigma_systematic` (all crossing-track errors correlated at scales larger than a single fit center)
- pt[x]/cycle_stats/
  - `sigma_geo_at` (along-track geolocation error)
  - `sigma_geo_h` (vertical geolocation error)
  - `sigma_geo_xt` (cross-track geolocation error)
- pt[x]/ref_surf/
  - `misfit_RMS` (surface polynomial RMS misfit)
  - `misfit_chi2r` (surface polynomial chi-square misfit)
  - `poly_coeffs_sigma` (errors in the polynomial coefficients)

3 VERSION HISTORY

A summary of the version history is provided in Table 4, followed by a detailed list of changes for the current version.

Table 4. Version History Summary

Version	Release Date
V1	December 2020
V2	January 2021
V3	April 2021
V4	December 2021
V5	March 2022
V6	August 2023

Changes for Version 6 are as follows:

- Corrected height bias from geolocation imperfections
- Adjusted *y* polynomial fit sensitivity for small distances
- Added `dh_geoloc` to `/ptx/crossing_track_data`
- Added `dh_geoloc` to `/ptx/cycle_stats`

- Removed `slope_change_t0`, `slope_change_rate_x`, `slope_change_rate_x_sigma`, `slope_change_rate_y`, and `slope_change_rate_y_sigma` from `/ptx/ref_surf`

4 DOCUMENT INFORMATION

4.1 Publication Date

August 2023

4.2 Date Last Updated

February 2024

APPENDIX A: ATLAS/ICESAT-2 DESCRIPTION

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) and ancillary systems (GPS, star cameras, and ground processing) to measure the time a photon takes to travel from ATLAS to Earth and back again and to determine the photon's geodetic latitude and longitude. Laser pulses from ATLAS illuminate three left/right pairs of spots on the surface that as ICESat-2 orbits Earth trace out six ground tracks that are typically about 14 m wide. Each ground track is numbered according to the laser spot number that generates it, with ground track 1L (GT1L) on the far left and ground track 3R (GT3R) on the far right. Left/right spots within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction. Each pair also has a Pair Track—an imaginary line halfway between the actual location of the left and right beams (see Figure A1). Pair tracks are approximately 3 km apart in the across-track direction.

The beams within each pair have different transmit energies—so-called weak and strong beams—with an energy ratio between them of approximately 1:4. The mapping between the strong and weak beams of ATLAS, and their relative position 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 (see Figure A1, left). In this orientation, the weak beams lead the strong beams and a weak beam is on the left edge of the beam pattern. In the backward orientation, ATLAS travels along the -x coordinate, in the instrument reference frame, with the strong beams leading the weak beams and a strong beam on the left edge of the beam pattern (see Figure A1, right). The first yaw flip was performed on 28 December 2018, placing the spacecraft into the backward orientation. The current spacecraft orientation, as well as a history of previous yaw flips, is available in the ICESat-2 Major Activities tracking document (`.xlsx`).

The RGT refers to the imaginary track on Earth at which a specified unit vector within the observatory is pointed. During nominal operating conditions onboard software aims the laser beams so that the RGT is between ground tracks 2L and 2R (i.e., coincident with Pair Track 2). The ICESat-2 mission acquires data along 1,387 different RGTs. Each RGT is targeted in the polar regions once every 91 days (i.e., the satellite has a 91-day repeat cycle) to allow elevation changes to be detected. 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 to the RGT number, e.g., 000103 (RGT 0001, cycle 03) or 138705 (RGT 1387, cycle 05).

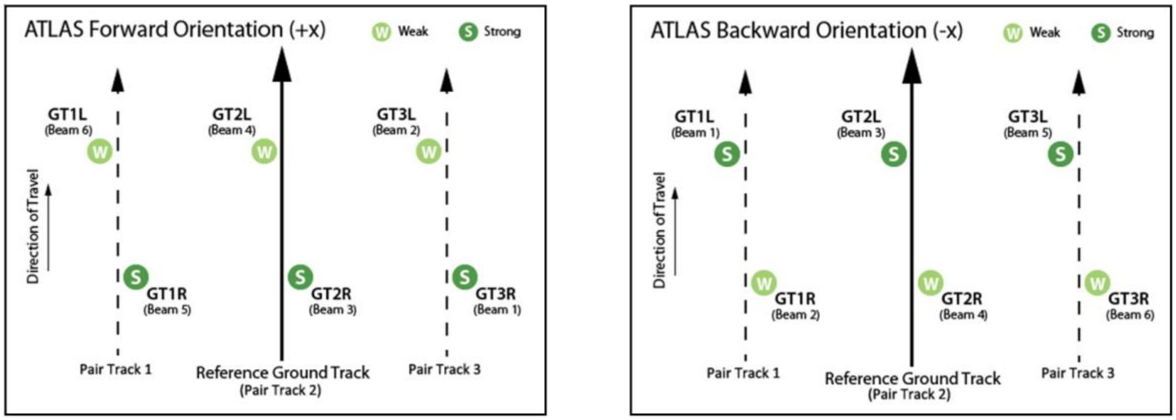

Figure A1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction and backward (instrument coordinate -x) direction.

Users should note that between 14 October 2018 and 30 March 2019, the spacecraft pointing control was not yet optimized. Thus, ICESat-2 data acquired during that time do not lie along the nominal RGTs but are offset at some distance from the RGTs. Although not along the RGT, the geolocation information for these data is not degraded.

Various reference systems and dynamic processes, or geophysical corrections, occur during an ATLAS/ICESat-2 measurement (Figure A2). Table A1 lists the corrections needed for each surface type and ICESat-2 product. For example, to determine an estimate of the mean sea surface, several well-modeled, time-varying effects must be accounted for.

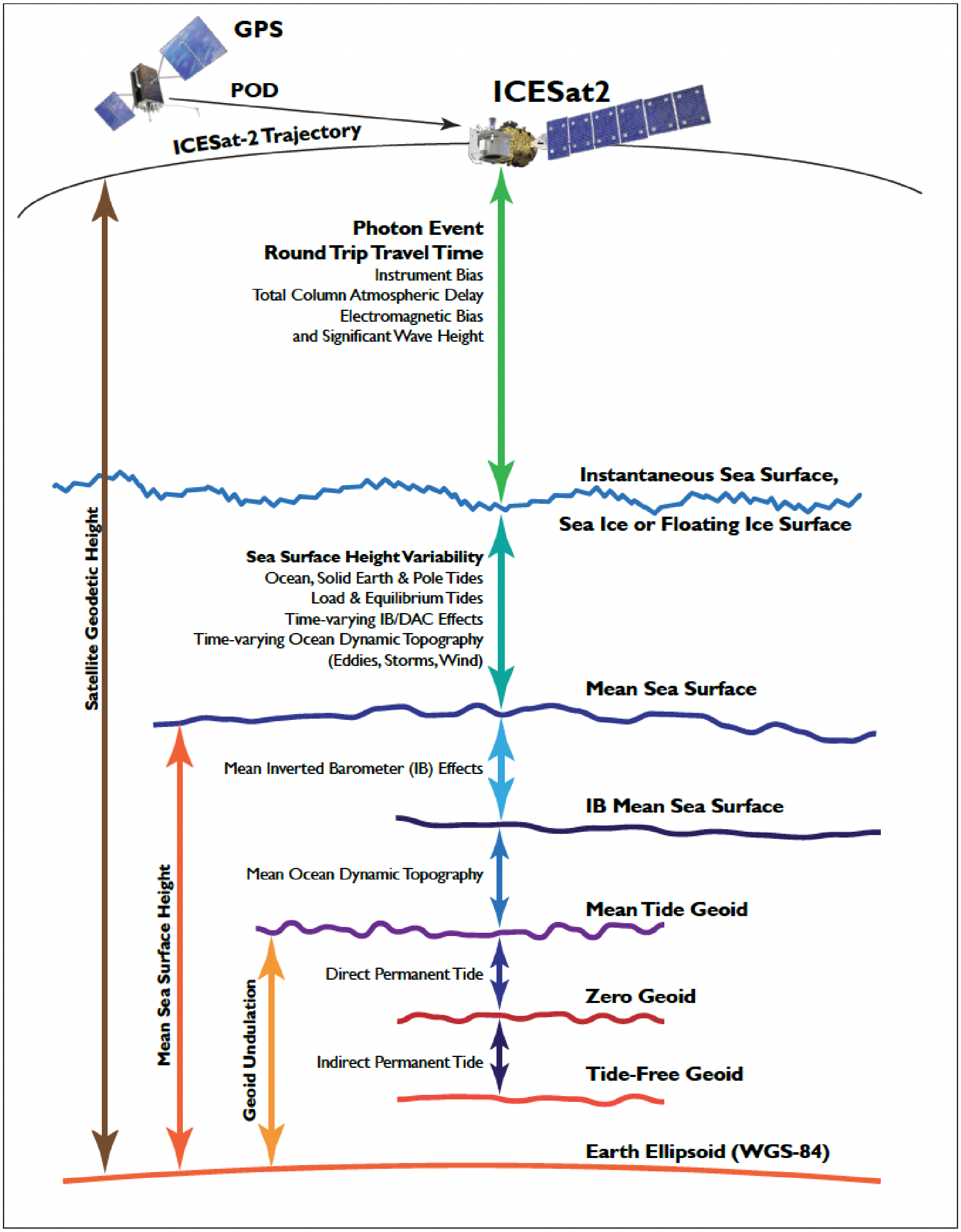

Figure A2. Geophysical corrections used in satellite altimetry.
Taken from *ICESat-2 Data Comparison User's Guide for Rel006*
available on the ATL03 data set landing page.

Table A1. 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 range-delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Inverted barometer (IB)
Ocean (ATL12)	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.