ATLAS/ICESat-2 L3B Monthly 3-Month Gridded Dynamic Ocean Topography, Version 1

USER GUIDE

How to Cite These Data

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

Morison, J., D. Hancock, S. Dickinson, J. Robbins, and L. Roberts. 2023. *ATLAS/ICESat-2 L3B Monthly 3-Month Gridded Dynamic Ocean Topography, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL23.001. [Date Accessed].

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

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

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

This data set 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

The following sections refer to the Ice, Cloud, and Land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for ATL19/23 Gridded Dynamic Ocean Topography (ATBD for ATL19/23 | V3, https://doi.org/10.5067/5Z6E23H2TRNQ). The ATBD provides a detailed description on the gridding of the dynamic ocean topography and related variables from ATL12 SSH.

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 File Contents

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 :

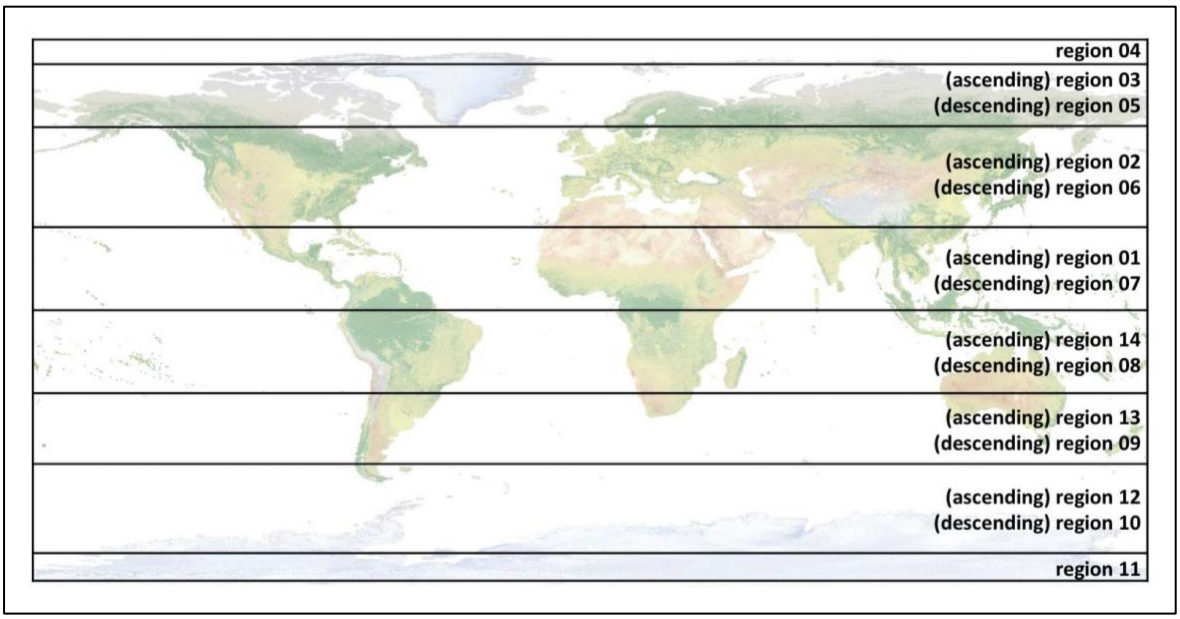

Figure 1. Region/granule boundaries.

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)

1.2.1 Naming Convention

Data files utilize the following naming convention:

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

Example:

```
ATL23_20221201000000_06301706_001_01.h5
```

Table 2. File Naming Convention

Variable	Description
ATL23	ATLAS/ICESat-2 L3B Monthly 3-Month Gridded Dynamic Ocean Topography product
yyyymmdd	4-digit year, 2-digit month, and 2-digit day of month corresponding to the first day of the middle month of the 3-month averaging period
hhmmss	2-digit hour, 2-digit minute, and 2-digit second of data acquisition start time in UTC; set to "000000" for all ATL23 file names
tttt	4-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.
cc	2-digit 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	2-digit segment number of the first ATL12 input file in each 3-month average. Segment numbers range 01–14 (approximately 1/14th of an orbit).
vvv_rr	3-digit version and 2-digit revision number*

The 3-month averaging period is centered on the month and year in the file name. In the example above, the 2-digit month of "12" and 4-digit year of "2022" indicate that the file contains the average of November 2022, December 2022, and January 2023.

*NOTE: 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. 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.

1.2.2 Data Groups

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.

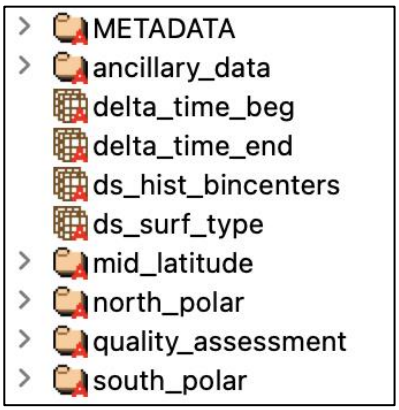

Figure 2. ATL23 Top-Level Data Groups and Variables

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

For additional information, see the following Technical References on the ATL23 data set landing page under Documentation:

- ATL23 Data Dictionary (complete list of variables)
- ATBD for Gridded Dynamic Ocean Topography (ATL19/23)

1.2.2.1 METADATA

ISO19115 structured summary metadata.

1.2.2.2 ancillary_data

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

1.2.2.3 mid_latitude

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

1.2.2.4 north_polar

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

1.2.2.5 south_polar

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

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 Other Variables

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

- `delta_time_beg`: beginning elapsed GPS seconds for the data granule
- `delta_time_end`: ending elapsed GPS seconds for the data granule
- `ds_hist_bincenters`: DOT histogram bincenters
- `ds_surf_type`: dimension scale indexing the surface type array

1.2.3 Browse File

JPG browse files are provided for each granule:

- `default1` and `default2`: `default1` visualizes the average DOT for all beams and `default2` the average significant wave height (SWH) for all beams
- `mid_latitude.dot_avg_albm`: 3-month average DOT for all beams in the midlatitudes
- `mid_latitude.swh_avg_albm`: 3-month average SWH for all beams in the midlatitudes
- `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

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage spans the world ocean surface from approximately 88° N latitude 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, as well as an overlapping midlatitude curvilinear 1/4° latitude-longitude grid between 60° N and 60° S. 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.

Table 3. Midlatitude Projection 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	WGS 84
Ellipsoid/spheroid	WGS 84
Units	degree
False easting	N/A
False northing	N/A
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

Table 4. North and South Polar Projection Details

Projected coordinate system	**NSIDC Sea Ice Polar Stereographic North**	**NSIDC Sea Ice Polar Stereographic South**
Geographic coordinate system	Unspecified datum based upon the Hughes 1980 ellipsoid	Unspecified datum based upon the Hughes 1980 ellipsoid
Longitude of true origin	-45°	0°
Latitude of true origin	70°	-70°
Scale factor at longitude of true origin	1	1
Datum	Unspecified, based on Hughes 1980 ellipsoid	Unspecified, based on Hughes 1980 ellipsoid
Ellipsoid/spheroid	Hughes 1980	Hughes 1980

Projected coordinate system	NSIDC Sea Ice Polar Stereographic North	NSIDC Sea Ice Polar Stereographic South
Units	meter	meter
False easting	0	0
False northing	0	0
EPSG code	3411	3412
PROJ4 string	+proj=stere +lat_0=90 +lat_ts=70 +lon_0=-45 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs	+proj=stere +lat_0=-90 +lat_ts=-70 +lon_0=0 +k=1 +x_0=0 +y_0=0 +a=6378273 +b=6356889.449 +units=m +no_defs
Reference	https://epsg.io/3411	https://epsg.io/3412

Table 5. Grid Details

Hemisphere	North Polar	South Polar	Midlatitude
Grid cell size	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°)
Nominal gridded resolution	25 km	25 km	0.25°
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

13 October 2018 to present

1.4.2 Resolution

3-month averages provided at a monthly resolution. See Section 1.2.3 Naming Convention.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

ATL19, based on ATL12, contains gridded monthly estimates of DOT from all ICESat-2 tracks from the beginning to the end of each month. ATL23 contains gridded 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 is computed for the first four moments of sea surface height (mean (*h*), variance (*h_var*), skewness (*h_skewness*) and kurtosis (*h_kurtosis*)) for each segment from ATL12. Gridding involves three steps: binning, averaging, and interpolation to the grid cell center. Both simple averages and averages weighted by the degrees-of-freedom for each ocean segment are included.

For more details on the gridding process see “Section 3.2 | Gridding DOT for ATL19/23” in the ATL19/23 ATBD.

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

- First-photon bias (inherent with photon-counting detectors)

These errors in ATLAS/ICESat-2 upstream products can propagate into ATL23.

2.5 Instrumentation

See APPENDIX A: ATLAS/ICESAT-2 DESCRIPTION for a description of the instrument.

3 RELATED DATA SETS

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

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

4 DOCUMENT INFORMATION

4.1 Publication Date

September 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).

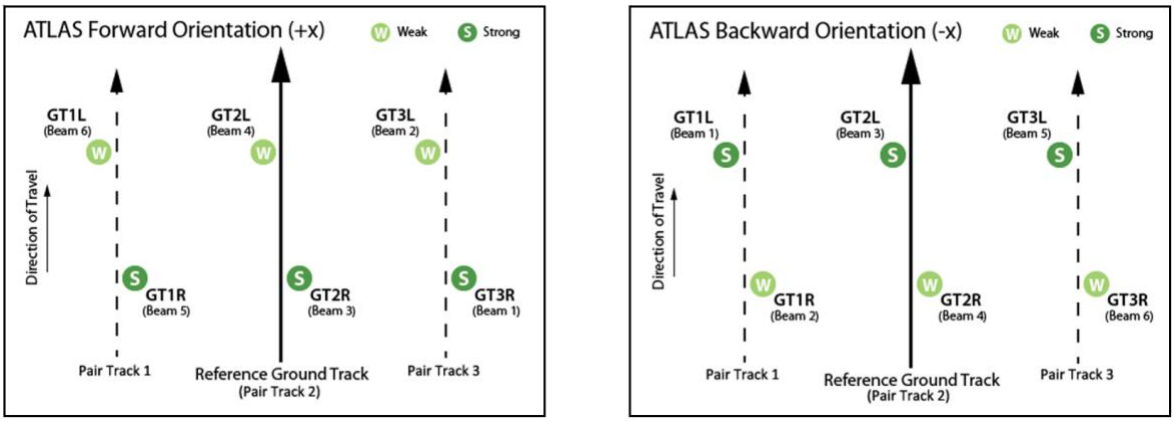

Figure A1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction and backward (instrument coordinate -x) direction.

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.

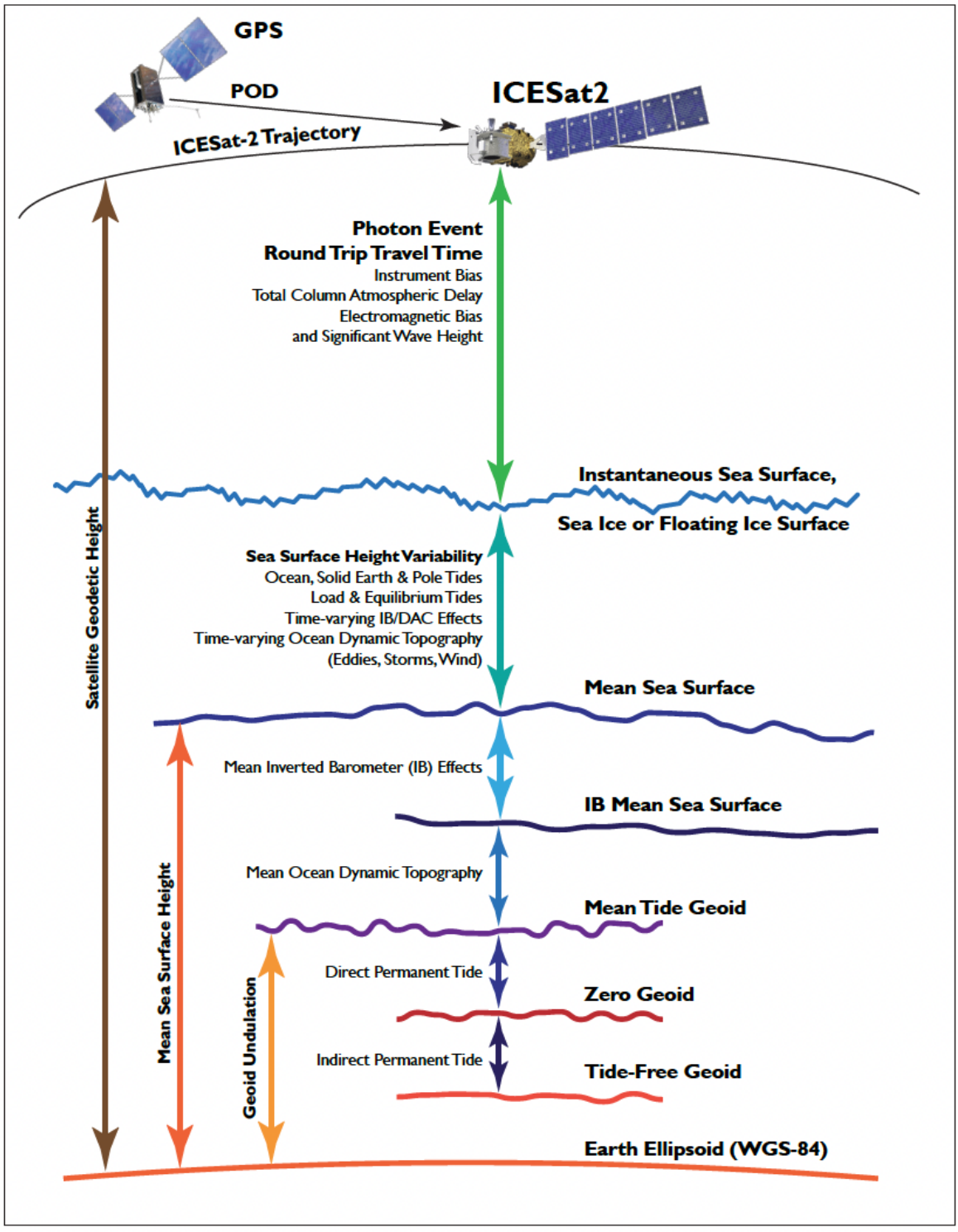

Figure A2. Geophysical corrections used in satellite altimetry.
Taken from *ICESat-2 Data Comparison User's Guide for Rel006*
available on the ATL03 data set landing page.

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.