ATLAS/ICESat-2 L3A Ocean Surface Height, Version 7

USER GUIDE

How to Cite These Data

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

Morison, J. H., Hancock III, D. W., Dickinson, S., Robbins, J., Roberts, L., Kwok, R., Palm, S. P., Smith, B., Jasinski, M. F., & the ICESat-2 Science Team. (2025). *ATLAS/ICESat-2 L3A Ocean Surface Height* (ATL12, Version 7). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL12.007 [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL12

National Snow and Ice Data Center

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1 DATA DESCRIPTION

The ATL12 data product is described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document (ATBD) for Ocean Surface Height (Morison et al., 2024).

1.1 Summary

ATL12 contains along-track sea surface height (SSH) of the global open ocean relative to the WGS84 ellipsoid. Height averages, distributions, and uncertainties are provided over ocean segments 400 to 7,000 m in length. Heights relative to the EGM2008 geoid and variables such as photon return rate are provided in 10 m along-track bins within each ocean segment. Additionally, 10 m bins corresponding to ATL07 bright leads are identified, and heights within the bins are averaged over ocean segments to yield accurate SSHs where ice concentrations are greater than 15%. The data were acquired by the Advanced Topographic Laser Altimeter System (ATLAS) instrument on board the ICESat-2 observatory.

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 ATL12 parameters is available in the ATL12 Data Dictionary.

ATL12 data are provided as granules (files) that span four full orbits. Within data files, similar variables such as science data, instrument parameters, altimetry data, and metadata are grouped together according to the HDF model. ATL12 data files contain the top-level groups shown in the following figure:

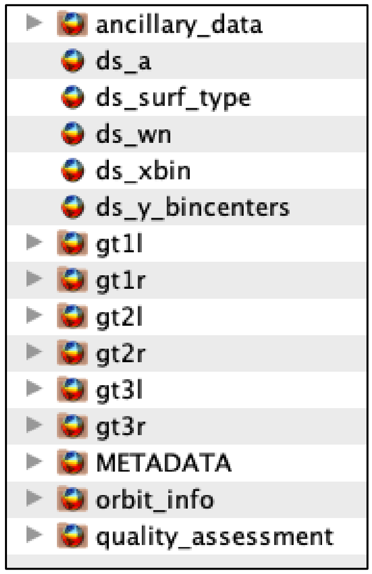

Figure 1. ATL12 Top-Level Data Groups and Variables

1.2.2.1 ancillary_data

Information that is ancillary to the data product. This may include product and instrument characteristics and/or processing constants.

1.2.2.2 Dimension Scales

Five HDF5 dimension scales are stored at the top level alongside the data groups:

- Harmonic coefficient dimension scale (`ds_a`)
- Surface type dimension scale (`ds_surf_type`)
- Wave number dimension scale (`ds_wn`)
- 10 m bin centers dimension scale (`ds_xbin`)
- Dimension scale for Y bins center (`ds_y_bincenters`)

1.2.2.3 gt1l–gt3r

Six ground track groups (gt1l–gt3r) that contain the per-beam data parameters (within the `/ssh_segments` subgroup) for the specified ATLAS ground track. Mean latitude and longitude, time, and duration of the segment, are stored at the top level of `/ssh_segments`. The `/heights` subgroup contains parameters relating to the calculated SSH. Quality and corrections to the SSHs are stored in `/stats`. Key parameters include:

- SSH (`/heights/h`); variance (`/heights/h_var`); skewness (`/heights/h_skewness`); kurtosis (`/heights/h_kurtosis`)
- EGM2008 geoid (mean tide system) average over the ocean segment (`/stats/geoid_seg`)

- ocean segment-average height relative to the geoid in bright lead 10-m bins (`/heights/h_ice_free`)
- significant wave height (`/heights/swh`)
- sea state bias (`/heights/bin_ssbias`); not valid for ice-covered water
- segment length (`/heights/length_seg`)
- total number of photons (`/stats/n_ttl_photon`) and number of surface photons (`/stats/n_photons`) in the segment
- percentage of non-open ocean included in the segment (`/stats/surf_type_prcnt`)
- ice concentration from AMSR (`/stats/ice_conc`)

NOTE: Over purely ocean regions, ATL12 includes data from strong beams only. However, over ocean regions that overlap ice cover and land marginal zones, weak beam data are also processed identically to strong beam data and output in addition to the strong beam results.

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 and cycle and the spacecraft orientation (`sc_orient`).

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.

1.2.3 Naming Convention

Data files utilize the following naming convention:

```
ATL12_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5
```

Example:

```
ATL12_20200813220135_07570801_007_01.h5
```

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL12	ATLAS/ICESat-2 L3A Ocean Surface Height product
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Data acquisition start time, hour, minute, and second (UTC)
tttt	Four-digit Reference Ground Track (RGT) number of the first of four tracks in the granule. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle number. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.
ss	Region number. Not used for ATL12. Always 01.[1]
vvv_rr	Version and revision number.[2]

[1] Some ATLAS/ICESat-2 products (e.g., ATL03) are provided as files that span 1/14th of an orbit; therefore, these products' file names specify a region number that ranges from 01 to 14. Because ATL12 data files span four full orbits, the region number is always set to 01.

[2] 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 images designed to quickly assess the location and quality of each granule's data. A list of available images is shown in Table , and an example is shown in Figure 2.

Table 2. Images Available as Browse

Image	Description
along_track_DOT	Along-track dynamic ocean topography (DOT)
along_track_depth_ocn_seg	Along-track average depth_ocn of geo-segments used in the ocean segment
along_track_length_seg	Along-track length of segment
along_track_swh	Along-track significant wave height
groundtrack	Ground tracks of the four orbits included in the granule
heights	Calculated mean SSH
kurtosis	Kurtosis of SSH

Image	**Description**
`mean_height`	Mean SSH in meters, relative to the WGS84 ellipsoid
`mix_m1`	Fraction of component 1 in 2-component Gaussian mixture
`mix_m2`	Fraction of component 2 in 2-component Gaussian mixture
`mix_mu1`	Mean of component 1 in 2-component Gaussian mixture
`mix_mu2`	Mean of component 2 in 2-component Gaussian mixture
`mix_sig1`	Standard deviation of component 1 in 2-component Gaussian mixture
`mix_sig2`	Standard deviation of component 2 in 2-component Gaussian mixture
`sdev`	Standard deviation of SSH
`skewness`	Skewness of SSH
`swh`	Significant wave height

Browse files utilize the same naming convention as their corresponding data file but with "`_BRW`" and descriptive keywords appended.

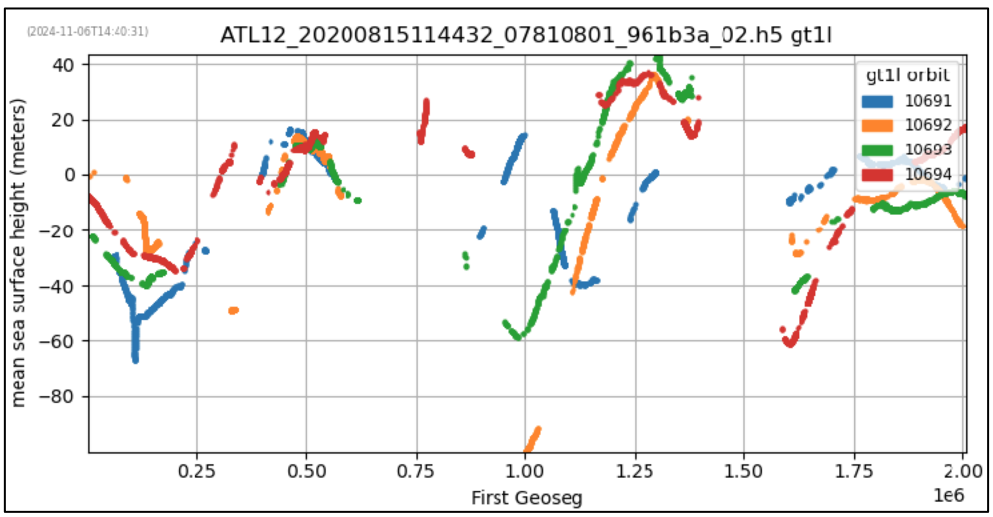

Figure 2. Example browse image for mean sea surface height (`heights`).

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage spans the global ocean surface from approximately 88° N to 88° S. Each granule contains data obtained during four consecutive ATLAS orbit tracks.

1.3.2 Resolution

Average heights of the sea surface relative to the WGS84 ellipsoid are defined for ocean segments that vary in length from 400 m to 7,000 along the ground track. This strategy is used to ensure at least 8,000 photon counts and to obtain reasonable average height uncertainties over many ocean wavelengths. However, surface finding, sea state bias (SSB) determination, wave harmonics, heights relative to the geoid in ice-covered waters, first photon bias, and other variables are typically computed at a 10-m scale and output in 10-m along-track bins.

1.3.3 Geolocation

World Geodetic System 1984 (EPSG: 4326)
ITRF2020 (EPSG: 9988)

1.4 Temporal Information

1.4.1 Coverage

Temporal coverage is 13 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)` in the lower-level ATL03 product.

> 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

ICESat-2 flies along each of its 1,387 RGTs once every 91 days (i.e., the orbit has a 91-day repeat cycle). During many repeat cycles, the beam pattern is shifted from the previous cycle's pointing pattern a variable amount in the cross-track direction during parts of each orbit to increase the density of spatial coverage.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

Over distances of several kilometers, the sea surface appears nearly flat. However, variations in surface slopes and long-wavelength undulations are present, caused by the geoid, ocean currents, and variations in atmospheric pressure and seawater density. In contrast, over shorter distances, the sea surface is characterized by ocean waves and swell. ICESat-2 uniquely resolves features as small as the scale of its lidar footprint.

ATL12 provides SSHs and DOT over the global open ocean. Open ocean surfaces have low but variable reflectance (resulting in relatively low photon counts); thus, heights over the sea surface are defined for ocean segments that gain 8,000 surface returns. Notably, the correlation length scale over surface waves is 50–100 m such that averaging over a 7 km length is required to produce statistically meaningful average DOT.

The ocean mask overlaps with all the other surface types in buffer zones up to 20 km wide. To determine how much non-open ocean is included in any given ocean segment, users can check the `gt[x]/ssh_segments/stats/surf_type_prcnt` output variable.

2.2 Acquisition

For ATL12, the primary ATL03 inputs are photon heights in the telemetry or downlink band and associated time, geolocation, geoid, ocean tides, and dynamic atmospheric correction data; additional input is the ATL09 cloud flag every 400 laser pulses and ocean depth from gridded ocean bathymetry. ATL07 and ATL12 are synchronized, ATL12 10 m bins falling within ATL07 bright leads are identified, and ATL07 surface heights in the bright leads are input to ATL12. Over open ocean (or sea ice) regions not overlapping with terrestrial or ice sheet regions, the downlink band is ±15 m centered about the signal area identified by the ATLAS on-board flight software. In ocean regions overlapping with land and ice sheet regions, the downlink band expands to match the band for those regions.

2.3 Processing

There are two main steps in determining SSH from ATL03: (1) identifying photon heights that likely represent reflection from the sea surface ("surface finding") and (2) determining the correct statistics of the SSH distribution. Because the sea surface is in constant motion, the SSH is set as equal to the mean of the height distribution. See the ATL12 ATBD (Morison et al., 2024) for more information.

2.3.1 Surface Finding

For surface finding, all photons in the downlink band are considered as follows: 1) where ocean depth is greater than 10 m; 2) where heights are corrected for short and long-period tides and for the EGM2008 (mean tide geoid), as well as heights with ATL03 signal confidence > 1; and 3) where saturation is 0 (no saturation) or 1 (partial saturation).

Coarse histogram selection: Coarse surface finding is done solely to determine the length of record sufficient to include a minimum number of candidate surface photons. With few surface returns per pulse and significant wave heights in the height range (geoid ±15 m) of downlinked photons, the majority of the surface height bins contain only noise photons. Thus, coarse surface finding identifies those height bins in the distribution of photon heights with counts exceeding the median number of counts, i.e., 8,000 candidate surface-reflected photons.

Fine histogram selection: Beginning with Version 4, surface finding is based on the distribution of the photon height anomalies relative to a moving 11-point moving average of high-confidence photon heights. As opposed to using raw heights, this approach filters out subsurface returns, particularly under the crests of surface waves. The central surface-photon portion of the histogram of the anomalies is initially defined as that above a preliminary lower limit bin and below a preliminary upper limit bin for which smoothed histogram photon counts are greater than 1.5 times the median number of counts. The average number of counts in histogram bins above (below) the upper (lower) limit bin is the upper (lower) photon noise level. The first-cut surface photon heights are those with anomalies between 1.5 times the lower noise limits and 1.5 times the upper noise limit. The mean height and trend of the first-cut surface photon heights is computed and removed from all the photon heights. The fine histogram selection process is then applied again to the de-meaned and de-trended photon heights to determine the surface-reflected photons.

The chosen surface reflected photons heights are processed in 10 m along-track bins and aggregated into an overall height histogram for the entire ocean segment. Each ocean segment, 400 to 7,000 m long, is divided into 10 m bins. The 10 m bin data provide a high-resolution height record, parameters for correcting the ocean segment average heights, and characterization of smaller scale features. The aggregate distribution provides the best statistical description of sea surface height including the mean, standard deviation, skewness, and kurtosis.

2.3.2 10-Meter Bin Data

2.3.2.1 Sea State Bias and Significant Wave Height

Significant wave height is four times the standard deviation of the bin-averaged heights. The electromagnetic sea state bias of the ocean segment average height is computed as the covariance of the 10 m bin photon rate and height divided by the average photon rate (Arnold et al., 1995; Morison et al., 2024).

2.3.2.2 First Photon Bias

First photon bias for partially saturated data (typically occurring in bright leads) is calculated using pre-launch experimental tables in ATL03 using the photon rate and height variance in each 10 m bin.

2.3.2.3 Uncertainty

The uncertainty in ocean segment average surface height is overwhelmingly due to the correlated noise of surface waves. We use the 10 m bin averages to estimate the correlation length scale, which calculates the effective number of degrees-of-freedom in the ocean segment average height. Using the standard deviation in the 10 m bin average heights, the uncertainty in ocean segment average height is obtained.

2.3.2.4 Wave Harmonics

Wave harmonics are calculated by the Vaníček least-squared-error technique, which is not dependent on evenly space data, i.e., Fourier analysis of the 10 m bin average heights.

2.3.2.5 DOT in Ice-Covered Waters

Beginning with Version 7, DOT is determined in ice-covered waters (ice concentration > 15%) without bias by sea ice freeboard. In ATL07 processing, the ATL07 sea ice product is included as an input to and synchronized with ATL12. This allows us to determine which ATL12 10 m bins are in the ATL07 open water patches mainly characterized by high photon return rates, called “bright leads", that represent the true sea surface height. Except at the highest ice concentrations, the ATL12 10 m bin DOT agrees with the corresponding ATL07 bright lead DOT within about 1 cm. For AMSR ice concentrations greater than 15%, ATL12 reports averages of DOT in ATL12 bright lead 10 m bins and ATL07 bright leads in the ocean segment. Further, for ice concentrations greater than 15%, ATL19 and ATL23 use the ATL12 bright lead 10 m bin averages of DOT as ocean segment DOT. At the highest ice concentrations (>75%), ATL07 DOT is used as the ocean segment DOT. This results in a smooth variation in DOT across the full range of ice concentrations.

2.3.3 Statistics of the SSH Distribution

The surface height of the ocean covered with waves is characterized as a Gram-Charlier distribution (Kinsman, 1965) with non-zero skewness and kurtosis. Consequently, the goal has been to compute the surface height distribution and its first four moments. However, the distribution of surface photon heights from the surface finding steps is actually the true distribution of surface heights convolved with the ATLAS instrument impulse response. The instrument impulse response is the total of all instrument surface height uncertainty, dominated by the uncertainty in the time that the individual photons are transmitted. Therefore, our approach includes correcting the heights for the instrument impulse response using Weiner Deconvolution in the Fourier Transform domain (ATL12 ATBD) and assuming that the impulse response is equal to the Transmit Echo Pulse (TEP) measured on-orbit by ATLAS.

From the resulting true surface distribution of heights, we use an expectation maximization approach to compute the 2-component Gaussian mixture corresponding to the surface height distribution. The 2-component Gaussian yields maximum likelihood estimates of the mean, standard deviation, skewness, and kurtosis of the surface distribution.

2.4 Quality, Errors, and Limitations

Data quality metrics provided with the ATL12 product are listed in "Section 7.0 | Data Quality" in the ATBD (Morison et al., 2024). In addition, users should consult "Section 9.0 | Constraints, Limitations, and Assumptions" in the ATBD. This section summarizes the important factors that impact ATL12 coverage and quality and determine how the data should be interpreted and compared with other open ocean topography data sets.

ATL12 aims to achieve standard errors in mean SSH of 1 cm or better under typical sea states. However, due its utilization of 532 nm (visible light range), the ATLAS sensor requires mostly clear skies to sample the ocean surface. Furthermore, the relatively low reflectance of the ocean surface requires greater along-track lengths to accumulate enough height measurements to meet the desired statistical significance.

Limitations in the current understanding of altimetric returns from the sea surface carry through to the ATL12 product. In particular, subsurface scattering from bubbles and particles has not yet been addressed. However, these scattering effects are reduced in the deep ocean and are offset by surface waves. Subsurface scattering is most important in coastal regions where sediment and biological productivity increase the density of scatterers. Sea state bias is not expected to impact ICESat-2 because traditional retracking and Gaussian surface distributions are not used. Beginning with Version 7, ATL07 bright leads are used to accurately determine SSHs in ice-covered waters, whereas prior versions were biased by sea ice freeboard.

Finally, a key assumption in ocean surface height retrievals is that the fine-scale surface finding cuts off the negative histogram tail due to subsurface return.

3 VERSION HISTORY

Table 3. Version History Summary

Version	Date	Description of Changes
6.1	7 Apr 2026	Removed data access for v6.1. Data coverage was 13 Oct 2018 to 2 Mar 2025.
7.0	7 Oct 2025	• Significantly improved ocean surface height in ice-covered water by using aligned ATL07 sea ice reference surface data (leads) if ATL12-estimated heights are considered contaminated by ice • Added ice-free height estimates based on aligned ATL07 sea ice product reference surface data (leads) at both the ocean segment rate and 10-meter rate

Version	Date	Description of Changes
		• Added 10-meter rate standard deviation of htybin (htybin_std_seg). • Added the along-track distance from the equator crossing to the first 10 m bin for each ocean segment (xbind_first_dist_x). This allows accurate alignment for ATL13 short segments with other ICESat-2 data products. • Added the first photon bias correction for each 10 m along-track bin in each ocean segment (fpb_10m) • Added the estimated error in first photon bias correction (fpb_corr_stdev) • Added computation of the sea slope bias estimated from the correlation of photon return rate with along-track 10-meter bin averaged surface height (bin_slopebias) • Added computation of the sea slope magnitude bias estimated from the covariance of the photon rate and the slope (bin_magslopebias) • Excluded photons without a valid tide_ocean from ocean segment processing • Added selective use of ocean scan calibration data to be included or excluded from being processed • Add usage of ATL03 photon quality into ocean photons selection to remove fully saturated pulses • Changed the source for bathymetry to the 2022 GEBCO bathymetry grid • Changed the source for ice concentration (ice_conc) to the high-resolution AMSR2 passive microwave SIC dataset.
6.1	19 May 2025	Revision 1 data were replaced with revision 2 because the revision 1 orbit count was exceeded. Science quality of the data was not impacted in either of the data revisions (31 Jul 2024 to 7 Nov 2024).
6.1	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.
5.0 (retire)	11 Jan 2024	Removed data access for v5.0. Data coverage was 13 Oct 2018 to 13 Oct 2022.
6.0	18 May 2023	• Fixed an error in the surface type percentage calculation. Surface type percentage is based on the overlapping ATL03 surface type mask. The ocean surface type percentage now indicates 100% for all ocean segments. Other surface types properly indicate if the ATL03 mask for that type is fully, partially, or not overlapping the ocean segment. If there is an overlap (non-zero percent), then that surface-type-specific data product may contain results processed by the other algorithm; it does not indicate the ocean segment is contaminated by that surface type. • Updated the ATL12 template. The min and max values for htybin were changed to ±20.0. • Added the earliest time for the granule (delta_time) to /quality_assessment. • Added the average DOT for the granule (dot_mean) to /quality_assessment. • Added the standard deviation of DOT for the granule (dot_std) to /quality_assessment. • Added the mean DOT for each 10-degrees of latitude (dot_mean_lat) to /quality_assessment. • Added the standard deviation of DOT for each 10-degrees of latitude (dot_std_lat) to /quality_assessment. • Added the dimension scale for latitude bins center (ds_lat_bincenters) to /quality_assessment. • The overall sigma and the mean DOT and its standard deviation for each 10 degrees of latitude are used for editing on ATL19 but not recorded. The best place for this summary data is in the ATL12 quality_assessment group.
4.0 (retire)	23 Sep 2022	Removed data access for v4.0. Data coverage was 13 Oct 2018 to 15 Jul 2021.
3.0 (retire)	25 Apr 2022	Removed data access for v3.0. Data coverage was 13 Oct 2018 to 11 Nov 2020.
5.0	3 Mar 2022	• Implemented derivation of ice concentration, ice_conc, from Near-Real-Time NOAA/NSIDC Climate Data Record of Passive Microwave Sea Ice Concentration and added ice concentration, gtx/ssh_segments/stats/ice_conc to ATL12 Outputs (ATBD Table 6). This will be particularly useful in ocean areas covered with sea ice and for which ATL07

Version	Date	Description of Changes
		and ATL10 include SSH anomaly measured in leads. In these areas, ATL12 heights will read higher than the actual SSHs in ATL10 by an amount equal to ice and snow freeboard. • Added specification of which values of the podppd_flag the ATL12 data would be processed. As of v5, the podppd_flag will have seven possible values: normal operations vales: 0=NOMINAL; 1=POD_DEGRADE; 2=PPD_DEGRADE; 3=PODPPD_DEGRADE; plus possible calibration maneuver related "CAL" values: 4=CAL_NOMINAL; 5=CAL_POD_DEGRADE; 6=CAL_PPD_DEGRADE; 7=CAL_PODPPD_DEGRADE. For ATL12, we will only use data when the POD/PPD flag indicates nominal normal operations or nominal CAL maneuvers, podppd_flag equal to 0 or 4. For each ocean segment processed, the higher of these two podppd_flag values, 0 or 4, of data used in the ocean segment is reported. This will allow ATL12 users to select whether to use only nominal data (podppd_flag=0), or to accept data during off-pointing calibration maneuvers (ocean scans and round-the-world scans) for which the ICESat-2 program still considers the photon height accuracies to be nominal (podppd_flag=4).
2.0 (retire)	21 May 2021	Removed data access for v2.0. Data coverage was 13 Oct 2018 to 15 Nov 2019.
4.0	13 Apr 2021	• Implemented the usage of the ATL03 orbit and pointing flag (podppd_flag) to only process data with podppd_flag=0. This is done to avoid outputting bad SSHs when the underlying pointing and position data are bad. • Updated the moving average process to consider photons with signal confidence 3 and 4 to be consistent with the ATBD. • Aligned the atmosphere data (layer_flag) collected only for the strong beams by segment_id for the processing of weak beam data. • Changed from surface finding based on the distribution of photon heights to surface finding based on the photon height anomaly relative to a moving bin average of high confidence photon heights. This is done to exclude subsurface returns under the crests of surface waves that otherwise fall inside the histogram of true surface heights. • Added control variables (Table 5 of ATBD) conf_lim, the limiting confidence level to be included in the moving bin average, nphoton, the number of photons either side of a central photon to be included in the moving bin average, e.g., for nphoton=10, a 21-point average is used. • Computed nharms harmonic coefficients, a, and SNR (snr) of along-track heights. These are added features to characterize the surface wave environment in each ocean segment as harmonic coefficients versus wave numbers (wn) in the along-track direction. • Computed correlation length scale from 10 m bin averaged heights, l_scale, the corresponding degrees of freedom, np_effect, and resultant uncertainty, h_uncrtn, in the estimated SSHs. This is to provide an uncertainty estimate for average height over an ocean segment that accounts for the lack of statistical independence between photon heights over surface waves. • Updated to process only data with quality_ph equal to zero to avoid outputting surface heights based on poor quality photon heights as determined in ATL03.
1.0 (retire)	3 Jun 2020	Removed data access for v1.0. Data coverage was 13 Oct 2018 to 3 Feb 2019.
3.0	5 May 2020	• The product now includes 10 m bin average heights and averaged photon rate information from the sea state bias calculation. The new parameters are gt[x]/ssh_segments/heights/xbind, gt[x]/ssh_segments/heights/htybin, gt[x]/ssh_segments/heights/xrbin, and ds_xbin. • 10 m bin average heights are now used in the sea state bias estimation. • A center bin with height = 0 was added ocean histograms to be consistent with the description in the ATBD for ATL12. • New scatter plots were added to the browse product to allow users to better visualize the data. In addition, all height and ground track plots in the browse product (new and preexisting) are now separated by orbit.

Version	Date	Description of Changes
		• The width of the received histogram (as determined in fine_sel) is now used to create the y histogram in rm_uncertainty, which is then used in char_rss to create simulated photons that are used in fit2g to determine a 2-Gaussian fit. • The moments of Y are now calculated using the approach described in "Section 5.3.4 | Processing Procedure for Correction and Interpretation of the Surface Height Distribution" in the ATBD for ATL12. This approach allows the moments of the surface height distribution, determined from the 2-Guassian mixture approach, to be checked more easily. • The h_kurtosis calculation has been corrected to match Equation 27 in "Section 4.3.2 | Characterizing the Random Sea Surface" of the ATBD for ATL12. • The length_seg parameter is now calculated as the difference of the along-track x of the first and last signal photons in the ocean segment. This update was made to be consistent with the description in "Section 5.3.3.2 | Harmonic Analysis of Along Track Heights" of the ATBD for ATL12. • A new formula was implemented to calculate the 10 m bin average photon rate. The calculation is now consistent with the ATBD for ATL12 (see "Section 5.3.3 | Processing to Characterize Long Wavelength Waves, Dependence of Sample Rate on Long Wave Displacement, and A Priori Sea State Bias Estimate").
2.0	24 Oct 2019	• The bckgrd_rate parameter (/gt[x]/ssh_segments/stats/) is now read from ATL03 and the mean value for signal photons is written to ATL12 as /gt[x]/ssh_segments/stats/backgr_seg. • The input photon arrays used to estimate sea state bias (x, height, time, ocean-segment, and histogram-bin-index/signal-photon-mask) are now sorted by along-track x. • All data with heights greater than the shore depth (default = -10 m) are not processed as ocean to ensure ocean processing doesn't occur over land. • Changed the processing code and ATL12 template to allow invalid values for significant wave height (/gt[x]/ssh_segments/heights/swh) and sea state bias (/gtx/ssh_segments/heights/bin_ssbias). • Fixed errors that caused segments to be skipped after long gaps and along the boundary between two orbits. • Updated parameter name "ds_y_bins" to "ds_y_bincenters" in the ATL12 product to be consistent with the ATBD and developmental code. • Changed the ocean histogram bin center height edges to eliminate a 0.5 cm ambiguity in histogram statistics. • Corrected the order in which surface types are listed on the surf_type_prcnt parameter description. • Added an ocean photon selection, boxcar smoothing parameter (pts2bin) and assigned it a default value of 21. This value can be overridden in the control file. • Made code updates to modify which residual histogram bins are selected for use. The code now includes a second-pass threshold test based on histogram far tails. • Added a tide_equilibrium_seg parameter in /gt[x]/ssh_segments/stats that is the mean of the ATL03 equilibrium tide values for signal photons. • Updated the SNRc calculation to use the same process as the deconvolution noise filtering. • Shifted the TEP bin center heights to match the fine histogram bin center heights. This allows for better alignment of the surface histogram after Weiner deconvolution of the impulse response.
1.0	10 Jun 2019	Initial release

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5 DOCUMENT INFORMATION

5.1 Publication Date

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5.2 Date Last Updated

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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).

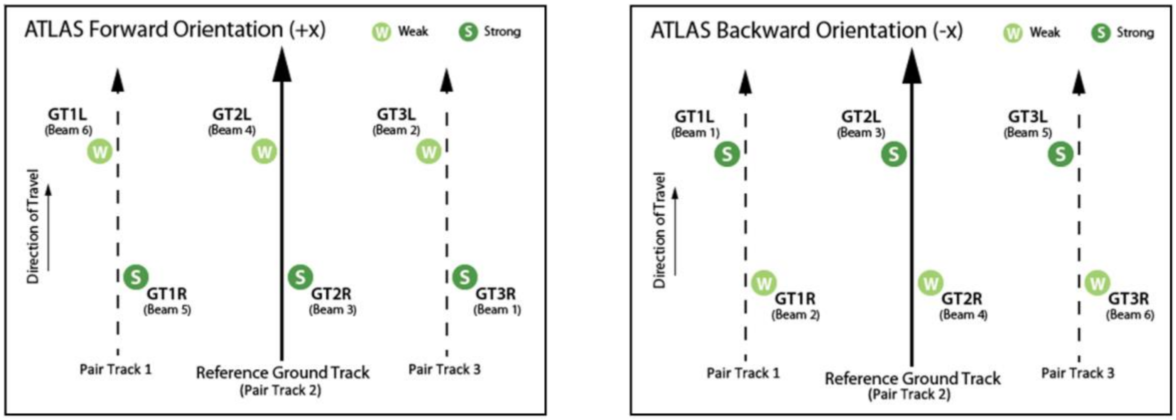

Figure A - 1. Spot and Ground Track (GT) naming convention.

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.

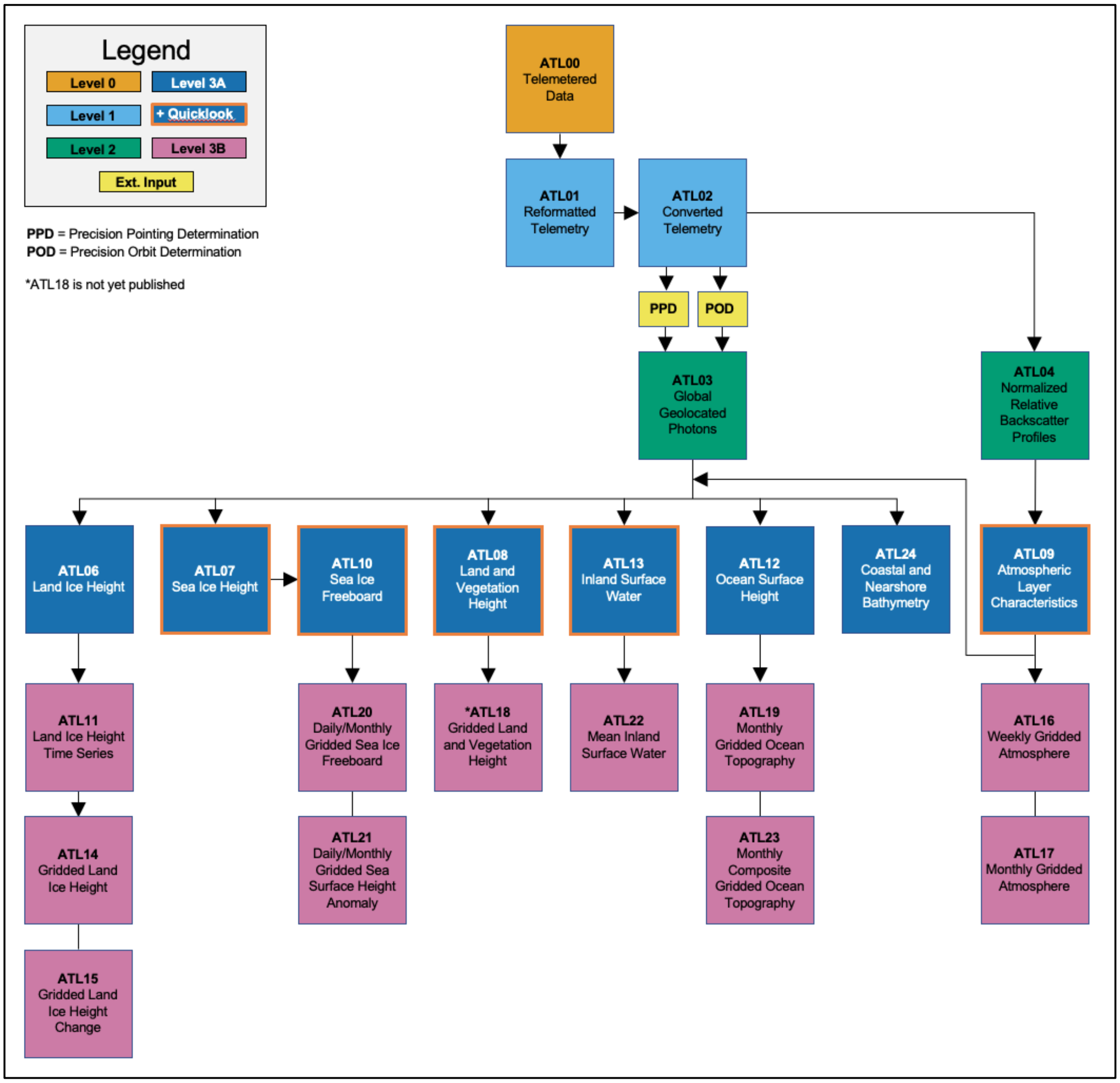

Figure A - 2. Schematic of ICESat-2 data processing and data products.

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.

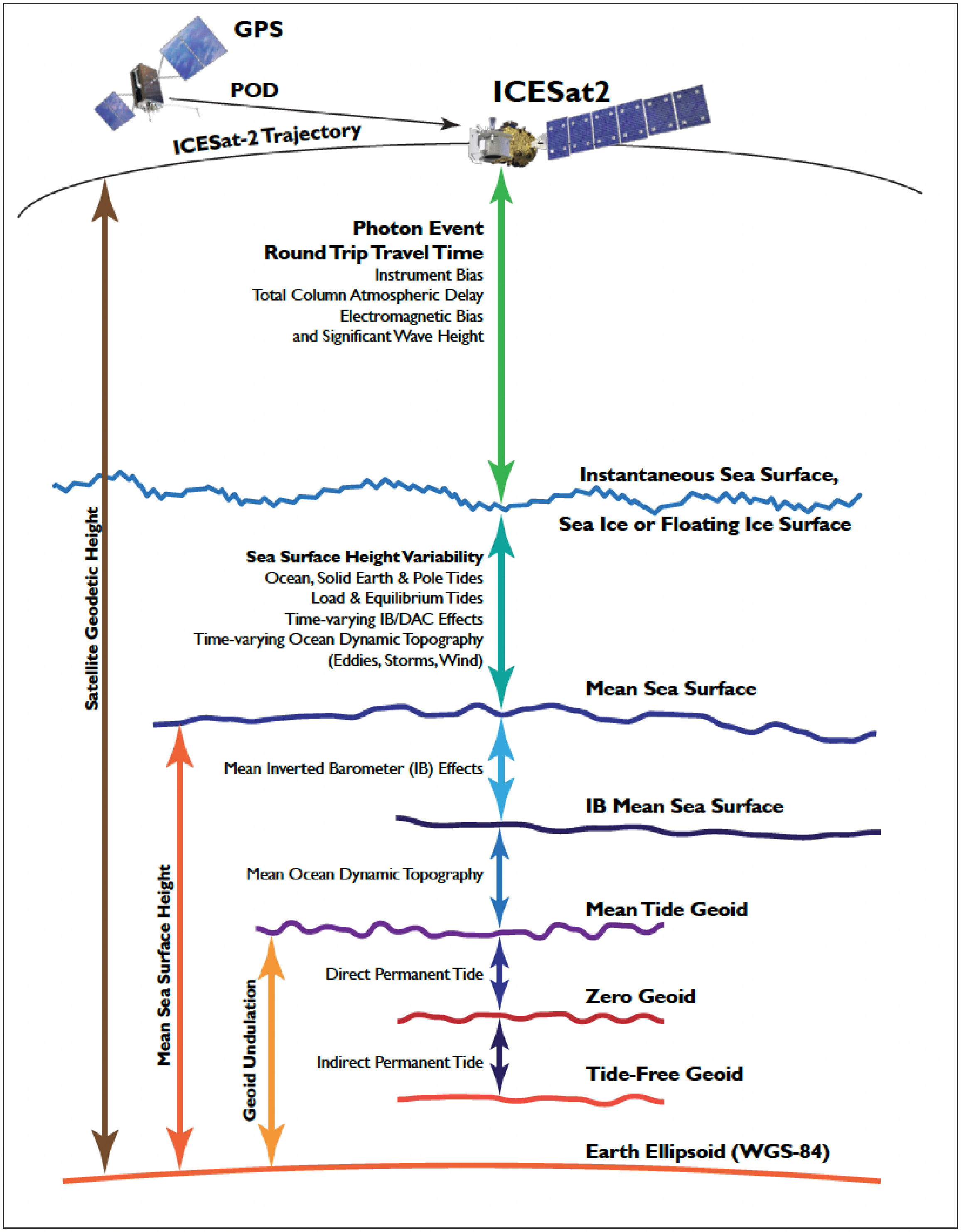

Figure A - 3. Geophysical corrections used in satellite altimetry (Source: *ICESat-2 Data Comparison User's Guide for Rel007,* available on the ATL03 data set landing page).