ATLAS/ICESat-2 L3A Ocean Surface Height, Version 4

USER GUIDE

How to Cite These Data

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

Morison, J. H., D. Hancock, S. Dickinson, J. Robbins, L. Roberts, R. Kwok, S. P. Palm, B. Smith, M. F. Jasinski, and the ICESat-2 Science Team. 2021. *ATLAS/ICESat-2 L3A Ocean Surface Height, 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/ATL12.004. [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

1.1 Parameters

Along-track surface height above the WGS 84 ellipsoid (ITRF2014 reference frame), at variable length scales, over the ocean.

1.2 File Information

1.2.1 Format

Data are provided as HDF5 formatted files. HDF is a data model, library, and file format designed specifically for storing and managing data. For more information about HDF, visit the HDF Support Portal.

The HDF Group provides tools for working with HDF5 formatted data. HDFView is free software that allows users to view and edit HDF formatted data files. In addition, the HDF - EOS | Tools and Information Center web page contains code examples in Python (pyhdf/h5py), NCL, MATLAB, and IDL for accessing and visualizing ICESat-2 files.

1.2.2 ATLAS/ICESat-2 Description

NOTE: The following brief description of the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) observatory and Advanced Topographic Laser Altimeter System (ATLAS) instrument is provided to help users better understand the file naming conventions, internal structure of data files, and other details referenced by this user guide. The ATL12 data product is described in detail in the Ice, Cloud, and land Elevation Satellite-2 Project Algorithm Theoretical Basis Document (ATBD) for Ocean Surface Height (ATBD for ATL12 | V04, DOI: 10.5067/R5WRJUFF3RD3).

The ATLAS instrument and ICESat-2 observatory utilize a photon-counting lidar and ancillary systems (GPS and star cameras) 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. The ATL12 data product is organized by ground track, with ground tracks 1L and 1R forming pair one, ground tracks 2L and 2R forming pair two, and ground tracks 3L and 3R forming pair three. Each pair also has a Pair

Track—an imaginary line halfway between the actual location of the left and right beams (see figures 1 and 2). 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 1). 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 2). The first yaw flip was performed on December 28, 2018, placing the spacecraft into the backward orientation. ATL12 reports the spacecraft orientation in the sc_orient parameter stored in the /orbit_info/ data group (see Section 1.2.4 Data Groups). In addition, the current spacecraft orientation, as well as a history of previous yaw flips, is available in the ICESat-2 Major Activities tracking document (.xlsx).

> NOTE: ATL12 includes data from strong beams only. In general, ICESat-2 only downlinks strong beam data over the ocean. Weak beam data are only downlinked in ocean regions that overlap with ice cover or land buffer zones.

The Reference Ground Track (RGT) refers to the imaginary track on Earth at which a specified unit vector within the observatory is pointed. Onboard software aims the laser beams so that the RGT is always 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, for example in file names, by appending the two-digit cycle number (cc) to the RGT number, e.g. 0001cc to 1,387cc.

Under normal operating conditions, no data are collected along the RGT; however, during spacecraft slews, or off-pointing, some ground tracks may intersect the RGT. Off-pointing refers to a series of plans over the mid-latitudes that have been designed to facilitate a global ground and canopy height data product with approximately 2 km track spacing. 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 had been adequately resolved and the instrument had pointed directly at the reference ground track for a full 91 days (1,387 orbits).

Users should note that sometimes, for various reasons, the spacecraft pointing may lead to ICESat-2 data collected not along the nominal RGT, but offset at some distance from the RGTs. Although not along the nominal RGT, the geolocation information and data quality for these data is not degraded. As an example, from 14 October 2018 and 30 March 2019 the spacecraft pointing control was not yet optimized. To identify such time periods, refer to the ICESat-2 Major Activities file.

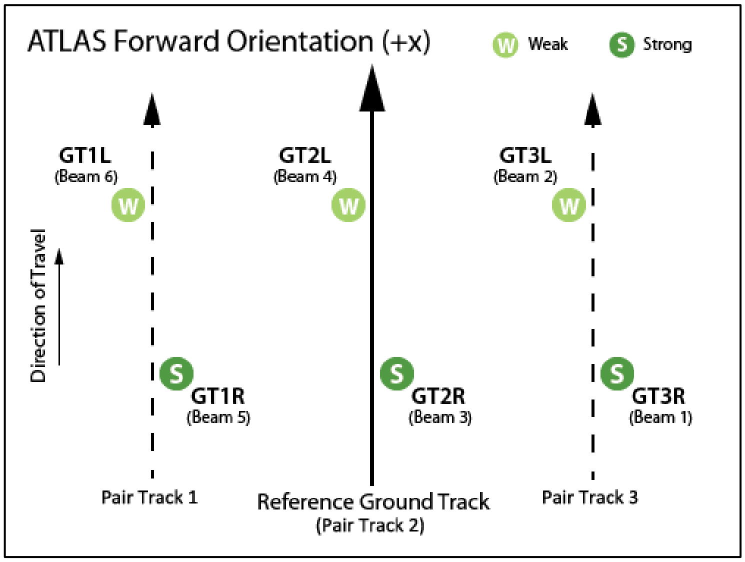

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

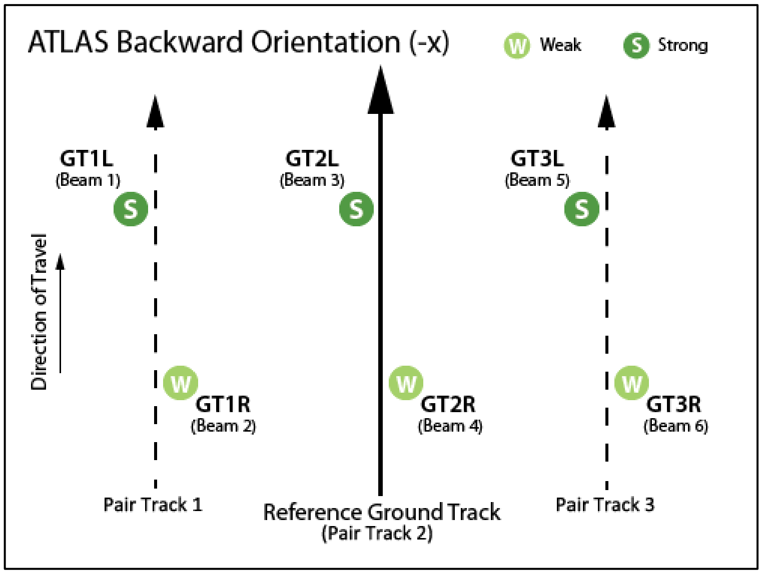

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

NOTE: ICESat-2 reference ground tracks with dates and times can be downloaded as KMZ files from NASA's ICESat-2 | Technical Specs page, below the Orbit and Coverage table.

1.2.3 File Contents

ATL12 data represent surface height at a given point on the ocean at a given time. Data files (granules) contain surface heights acquired during four consecutive orbits, plus parameters needed to assess the quality of the height estimates and to interpret and aggregate the estimates over greater distances. 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 downlinked, processed identically to strong beam data, and output in addition to the strong beam results.

ATL12 processing is designed for open ocean conditions, and as such includes a sea state bias calculation. However, processing is applied to the world ocean including ice-covered regions reported by the ATLAS/ICESat-2 sea ice height and freeboard products ATL07 and ATL10. In these regions, the statistical parameters reported by ATL12 will be valid for the mixed ocean/ice-covered and ice-free surface, however mean heights will include the average sea ice freeboard.

1.2.4 Data Groups

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 Figure 3:

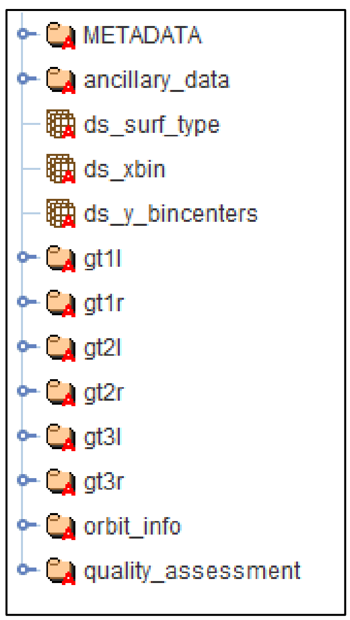

Figure 3. ATL12 data groups shown in HDFView.

1.2.4.1 METADATA

ISO19115 structured summary metadata for the granule, including content that describes the required geospatial information.

1.2.4.2 ancillary_data

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

1.2.4.3 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. No weak beam data are included over the ocean. Mean latitude, longitude, and time plus duration of the segment are stored at the top level of /ssh_segments. The sea surface height distribution and fit parameters are stored in the /heights subgroup. Quality and corrections to the sea surface heights are stored in /stats. Key parameters include:

- sea surface height (stored in /heights/h); variance (/heights/h_var); skewness (/heights/h_skewness); kurtosis (/heights/h_kurtosis)
- significant wave height[1] (/heights/swh)
- sea state bias[1] (/heights/bin_ssbias)
- 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. See Spatial Information/Coverage for details.).

[1]Not valid for ice-covered water.

For a complete list of output parameters, see "Section 5.5 | Output Parameters" in the ATBD for ATL12 or the ATL12 Data Dictionary.

1.2.4.4 orbit_info

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

1.2.4.5 quality_assessment

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

1.2.4.6 Dimension Scales

Three HDF5 dimension scales are stored at the top level alongside the data groups—ds_surf_type, ds_y_bins, and ds_y_bincenters. These dimension scales index the surface type and y-histogram bin and center values, respectively.

1.2.5 Naming Convention

Example:

- ATL12_20181013205512_02330101_004_01.h5
- ATL12_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].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 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	Segment number. Not used for ATL12. Always 01.[1]
vvv_rr	Version and revision number.[2]

NOTE:

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

[2] From time to time, NSIDC receives duplicate, 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.

1.2.6 Browse File

Browse files are provided as HDF5 formatted files that contain images designed to quickly assess the location and quality of each granule's data. Browse images are included (for strong beams) that show each segment's: mean sea surface height; standard deviation of the height distribution; significant wave height; skewness of the height distribution; kurtosis of the height distribution; 2-Gaussian fit parameters.

Browse files utilize the same naming convention as their corresponding data file, but with _BRW appended.

1.3 Spatial Information

1.3.1 Coverage

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

NOTE: Data are processed for areas designated as ocean by the ICESat-2 ocean surface mask. The ocean mask overlaps with all the other surface types in buffer zones up to 20-km wide. As such, ATL12 data may include data collected over low-lying land surfaces which lie close enough to sea level to fall within ±15 m of the geoid. Examples include sea ice surfaces in marginal sea ice zones and low-lying islands. 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. Future releases are slated to incorporate a bathymetric test designed to ensure ATL12 processing occurs over open ocean only.

1.3.2 Resolution

Heights over the sea surface are defined for ocean segments that vary in both length and spacing along the ground track; this strategy is necessary to ensure photon counts are high enough to adequately characterize sea surface heights given the inherently low and variable reflectance of open ocean surfaces.

In general, one photon reflects back to ATLAS from the ocean surface per laser pulse—0.7 m of along-track distance—or approximately 100 photons in a segment length of about 70 m. In practice, the adaptive algorithm outputs heights at length scales between 70 m and 7 km, depending on conditions and assuming clear skies.

1.3.3 Geolocation

Points on Earth are presented as geodetic latitude, longitude, and height above the ellipsoid using the WGS 84 geographic coordinate system (ITRF2014 reference frame). The following table contains details about WGS 84:

Table 2. Geolocation Details

Geographic coordinate system	WGS 84
Projected coordinate system	WGS 84
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
False easting	N/A
False northing	N/A
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

For information about ITRF2014, see the International Terrestrial Reference Frame | ITRF2014 web page.

1.4 Temporal Information

1.4.1 Coverage

13 October 2018 to present

1.4.2 Resolution

Each of ICESat-2's 1,387 RGTs is targeted once every 91 days (i.e. the satellite has a 91-day repeat cycle).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The ATL12 product contains sea surface heights at varying length scales, plus other descriptive parameters. These data are derived from geolocated, time-tagged photon heights passed to ATL12, along with other parameters, from the ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03) product. The following figure illustrates the family of ICESat-2 data products and the connections between them:

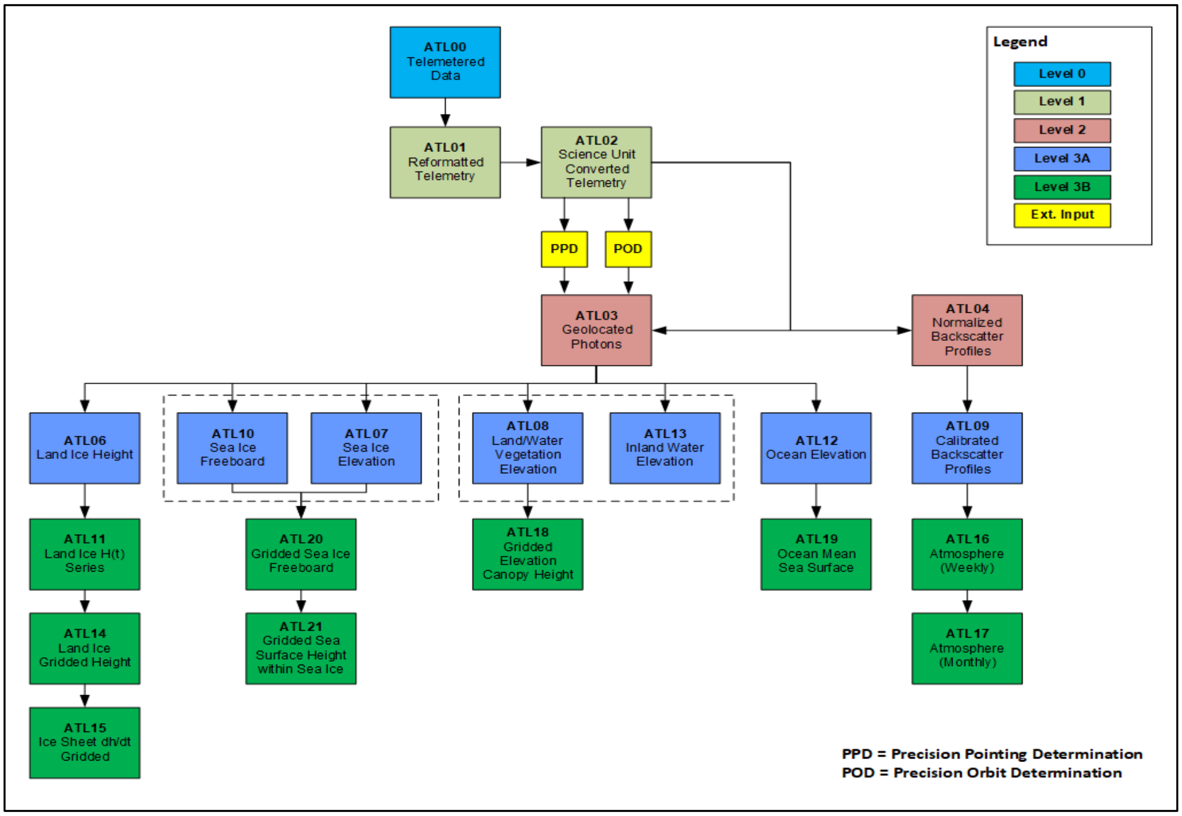

Figure 4. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time. ATL03 acts as the bridge between the lower level, instrumentation-specific products and the higher-level, surface-specific products.

The following sections briefly describe the approach used to generate the sea surface heights and descriptive statistics reported by the ATL12 data product. The approach is detailed in "Section 4 | Algorithm Theory" and "Section 5.0 | Algorithm Implementation" in the ATBD for ATL12.

2.2 Acquisition

Sea surface heights are determined primarily from ATL03 geolocated photon heights. These inputs consist of low-, medium-, and high-confidence signal photons over open ocean combined with a buffer of photons that lie within ±15 m of the EGM2008 geoid. For a complete list of inputs to ATL12, see "Section 5.2 | Input Parameters" in the ATBD for ATL12.

2.3 Processing

Because the sea surface is in constant motion, surface finding requires searching ATL03 photon heights for a representative sea surface height distribution. The algorithm treats every ATL03 photon height passed as input to ATL12 as an individual surface-height point measurement, spaced on average less than one meter apart, but with an x-y location uncertainty on the order of 10 m. Figure 5 shows ATL03 photon heights collected over 7-km of ocean surface. Note that the dense cloud of surface-reflected photons clearly stands out from the noise photons above and below.

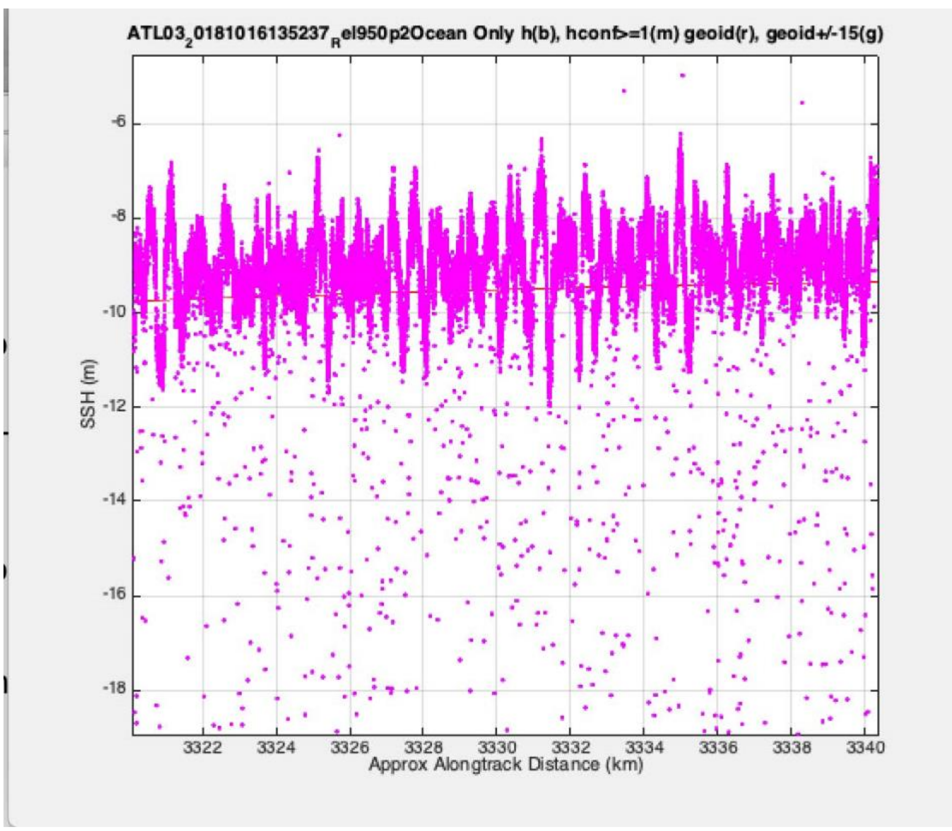

Figure 5. ATL03 photon heights (magenta) from Oct. 16, 2018 over the Pacific Ocean. Waves in the dense photon cloud are apparent as well as subsurface and atmospheric noise photons. Image from ATL12 Ocean Surface Height Release 004 Application Notes and Known Issues.

From the population of ATL03 input heights, the ATL12 algorithm accumulates photons returns that likely fall within the sea surface height distribution, until it traverses 7 km of along-track distance or tallies 8000 photons. The accumulated photons over the resulting ocean segment are then filtered to select heights in the histogram at levels above the background rate. After one iteration, a linear trend and average height are removed and then the data are filtered a second time (the trend and average height are retained and output with the ocean segment statistics).

The trimmed, detrended surface photon histogram is then: 1) deconvolved with an ATLAS instrument impulse response histogram[1] to produce a surface height distribution; and 2) fit with a 2-Gaussian mixture model to produce the first four moments of the surface height distribution (see Figure 6).

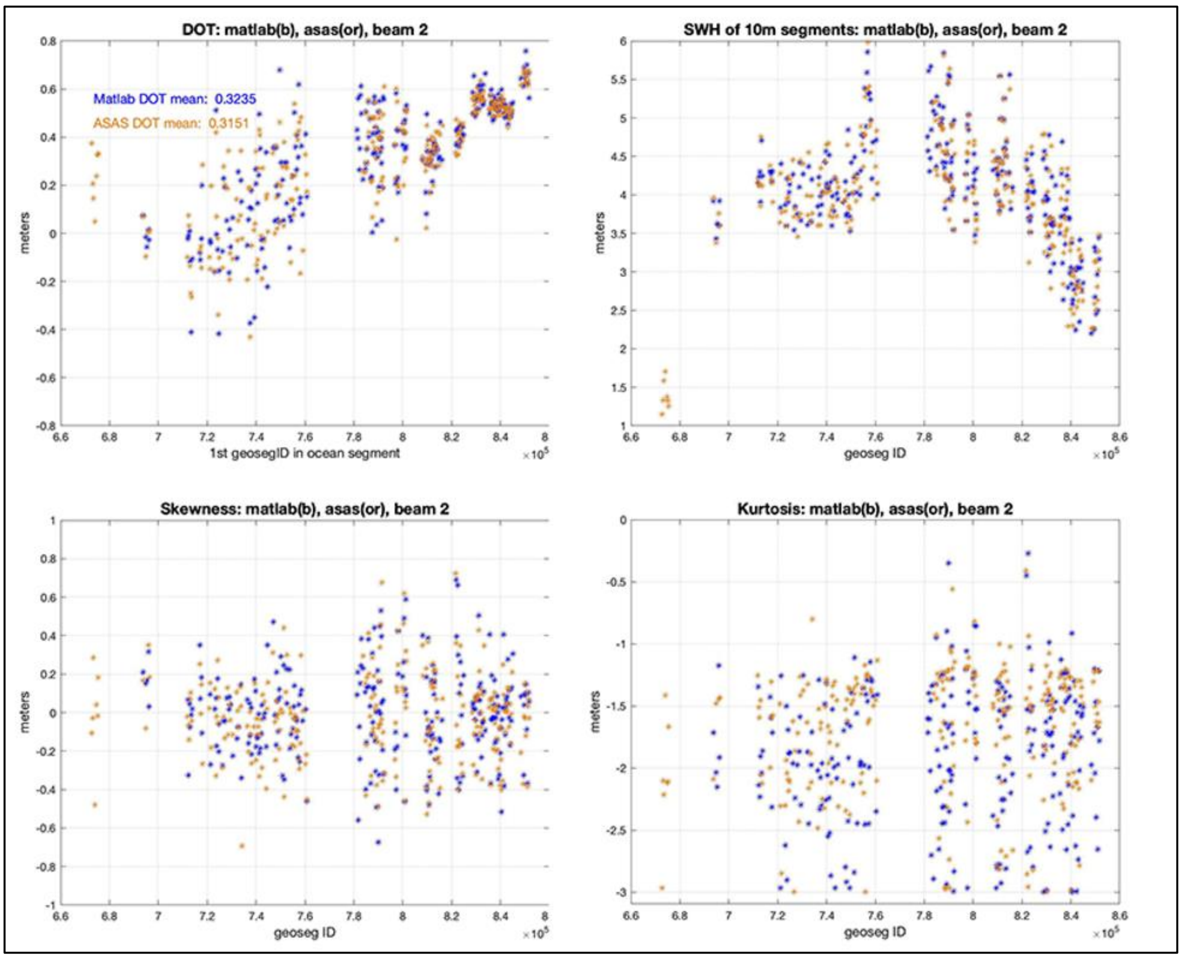

Figure 6. ATL12 ocean segment statistics. Upper left: Mean dynamic ocean topography (DOT) = SSH (moment 1) - geoid (EGM2008); upper right: significant wave height (SWH) = 4 x standard deviation (moment 2); lower left: skewness of sea surface height (moment 3); lower right: kurtosis of sea surface height (moment 4). Yellow DOTS are ATL12, Version 1 (revision 1) and blue dots are from ATL12 Science Team MATLAB developmental code applied to ATL03, which generally does not segment the data the same as ATL12. The agreement is better where segments are more closely matched.

[1] The impulse response function represents the height uncertainty associated with the lidar transmit pulse width and other instrumental factors.

In addition, the algorithm analyzes the spatial series of surface photon heights to characterize surface waves and to calculate the photon return rate and surface height correlation that constitutes the electromagnetic (EM) sea state bias (SSB) in the mean sea surface height. Thus, the ATL12 ocean product includes histograms and statistics of sea surface height over variable lengths.

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 for ATL12. In addition, users should consult "Section 9.0 | Constraints, Limitations, and Assumptions" in the ATBD for ATL12. 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 sea surface height of 1 cm or better, under typical sea states. However, due its utilization of 532 nm, visible light, 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 will necessarily carry through to the ATL12 product. In particular, subsurface returns represent a significant concern because the ATLAS 532 nm laser penetrates water, and the higher subsurface density of photons apparent in Figure 5 may be due in part to subsurface scattering in the ocean. However, the ATL12 Science Team has noted similarly enhanced subsurface densities over clear, deep ocean waters (and even over land) where subsurface backscatter does not apply. At this time, the ICESat-2 Science Team believes that the subsurface noise level stems from forward scattering delays in the atmosphere. To eliminate subsurface returns masked by the true surface distribution, future releases will adopt a scheme that selects photons based on a histogram of height anomalies about a moving, 11 photon average of high confidence photon heights. This histogram is much narrower than the surface height histogram and has a more distinct negative-side noise tail that will facilitate deletion of subsurface returns under the surface wave crests.

In addition, the ATL12 Science Team has found larger ocean segment-to-segment variation in average DOT = SSH - Geoid (e.g., see Fig. 6 upper left, ±0.1 to 0.3 m in) than expected from instrumental factors. If every one of the approximately 8,000 photon heights in an ocean segment were independent, even with a SWH = 2.5 m (t_h = .625 m), the uncertainty in estimates of the mean should be less than 1 cm. However, the height measurements over long ocean waves are not independent, and the degrees of freedom can approach the number of wavelengths in the ocean segment. To address this problem, future ATL12 releases will include harmonic analyses of surface height for each ocean segment and the option to use a zero wave-number amplitude to represent SSH. In addition, the spectral analysis will be used to derive measures of the effective number of degrees of freedom for each ocean segment. These measures will be output as an ATL12 parameter in order to optimally combine ATL12 ocean segment heights and produce the lowest uncertainties in the planned gridded SSH product (ATL19).

As this sea surface height product is being developed and evaluated on an ongoing basis, users should consult the most recent version of "ATL12 Ocean Surface Height Application Notes and Known Issues." This document is located on the Technical References tab of the ATL12 data set landing page. This document will be updated with each new release.

3 VERSION HISTORY

Version 4 (April 2021)

Changes for this version include:

- 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 putting out bad sea surface heights 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 (wave direction is not accounted for at this time).
- 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 sea surface heights. 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.

4 CONTACTS AND ACKNOWLEDGMENTS

James H. Morison

Applied Physics Laboratory

University of Washington

Seattle, WA 98105

David Hancock

NASA Goddard Space Flight Center

Mail Code: 615

Greenbelt, MD 20771

Suzanne Dickinson

Applied Physics Laboratory

University of Washington

Seattle, WA 98105

John Robbins

NASA Goddard Space Flight Center

Mail Code: 615

Greenbelt, MD 20771

Leeanne Roberts

KBR, Inc

Greenbelt, MD 20770

Ron Kwok

Jet Propulsion Laboratory

California Institute of Technology

Pasadena, CA 91109

Steve Palm

Science Systems and Applications, Inc.

NASA Goddard Space Flight Center

Greenbelt, MD 20771

Ben Smith

Applied Physics Lab

Polar Science Center
University of Washington
Seattle, WA 98105

Mike Jasinski
NASA Goddard Space Flight Center
Mail Code: 617
Greenbelt, MD 20771

Bill Plant
Applied Physics Laboratory
University of Washington
Seattle, WA 98105

Timothy Urban
Center for Space Research
University of Texas at Austin
Austin, TX 78705

5 DOCUMENT INFORMATION

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