# ATLAS/ICESat-2 L3A Sea Ice Height, Version 4

## USER GUIDE

**How to Cite These Data**

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

Kwok, R., A. Petty, G. Cunningham, T. Markus, D. Hancock, A. Ivanoff, J. Wimert, M. Bagnardi, N. Kurtz, and the ICESat-2 Science Team. 2021. *ATLAS/ICESat-2 L3A Sea Ice 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/ATL07.004. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL07

National Snow and Ice Data Center

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# 1 DATA DESCRIPTION

## 1.1 Parameters

Along-track sea ice and sea surface height. Sea ice heights are referenced to the time-varying sea surface, which includes ocean tides, inverse barometer effect, and other corrections.

## 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 ATL07 data product is described in detail in the Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Sea Ice Products (ATBD for ATL07/ATL10 | V04, DOI: 10.5067/BHFDVX8Q6FKW).

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 ATL07 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. ATL07 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).

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.

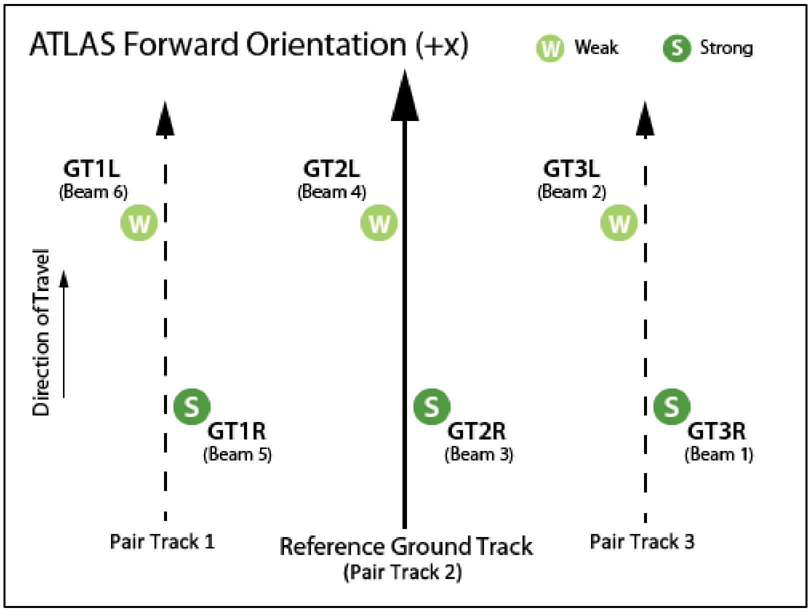


Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

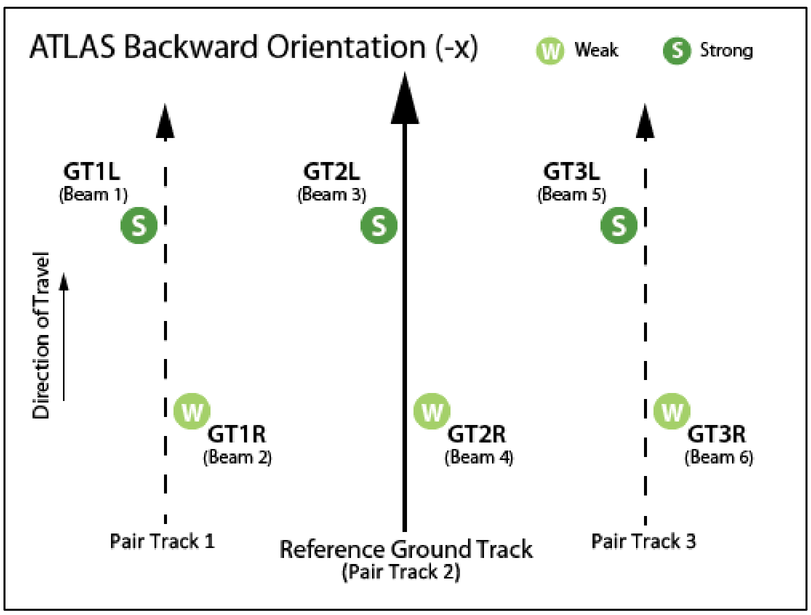


Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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

Data files (granules) contain the sea ice retrievals for one of ATLAS's 1,387 orbits, provided as separate files for Northern Hemisphere and Southern Hemisphere overpasses. Fifteen (and occasionally 16) granules are available per hemisphere per day.

### 1.2.4 Data Groups

Within data files, similar variables such as science data, instrument parameters, and metadata are grouped together according to the HDF model. ATL07 data files contain the top-level groups shown in the following figure.

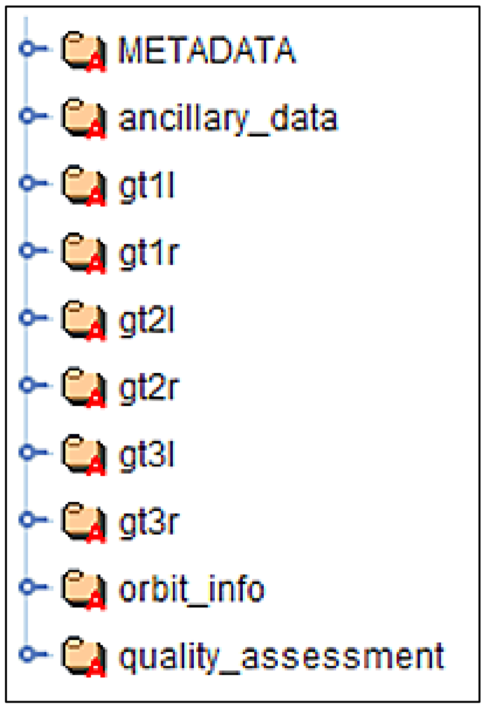


Figure 3. ATL07 top-level data groups shown in HDFView.

The following sections summarize the structure and primary variables of interest in ATL07 data files. Additional details are available in Appendix A of the ATBD for ATL07/10/20. The ATL07 Data Dictionary contains a complete list of all ATL07 parameters.

#### 1.2.4.1 METADATA

ISO19115 structured summary metadata.

#### 1.2.4.2 ancillary_data

Ancillary information such as product and instrument characteristics and processing constants.

#### 1.2.4.3 gt1l – gt3r

Six ground track groups (gt1l – gt3r), each with a sea_ice_segments subgroup that contains the parameters for the specified ATLAS ground track. Parameters include mean segment heights (/heights/height_segment_height); segment surface type (/heights/height_segment_type); segment latitude and longitude; geosegment start and end times; geophysical parameters and corrections (/geophysical/); and parameters related to data quality (/stats/).

#### 1.2.4.4 orbit_info

Orbit parameters that are constant for a granule, such as the RGT number, cycle, and 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.

### 1.2.5 Naming Convention

Data files utilize the following naming convention:

Example:

```
ATL07-01_20181016004646_02660101_004_01.h5
```

```
ATL07-02_20181016004646_02660101_004_01.h5
```

```
ATL07-[HH]_[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 |
|---|---|
| ATL07 | ATLAS/ICESat-2 L3A Sea Ice Height product |
| HH | Hemisphere code. Northern Hemisphere = 01, Southern Hemisphere = 02 |
| yyyymmdd | Year, month, and day of data acquisition for the given RGT |
| hhmmss | ICESat-2 data acquisition start time, hour, minute, and second (UTC) for the given RGT (not the start of ATL07 data production) |

| Variable | Description |
|---|---|
| tttt | Four digit Reference Ground Track number. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387. |
| cc | Cycle Number. 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 | Segment number. Not used for ATL07/10. Always 01. |
| vvv_rr | Version and revision number*. |

NOTE: *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 superceded 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.

## 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. The following browse images are available:

### 1.2.6.1 Line plots (beams)

- height of segment
- width of best fit Gaussian
- height segment surface type
- length of segment
- height fit quality flag
- ice concentration
- Apparent Surface Reflectivity (25 Hz)

### 1.2.6.2 Histogram

- height of segment
- width of best fit Gaussian
- length of segment

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

- ATL07-01_20181016004646_02660101_004_01.h5
- ATL07-01_20181016004646_02660101_004_01_BRW.h5

### 1.2.7 File Size

Data files range in size from approximately 5 – 300 MB.

## 1.3 Spatial Information

### 1.3.1 Coverage

Spatial coverage spans the ice-covered oceans of the northern and southern hemispheres with > 15% sea ice concentration.

### 1.3.2 Resolution

The ATLAS instrument transmits laser pulses at 10 kHz. At the nominal ICESat-2 orbit altitude of 500 km, this yields approximately one transmitted laser pulse every 0.7 meters along ground tracks. Note, however, that the number of photons that return to the telescope depends on surface reflectivity and cloud cover (which obscures ATLAS's view of Earth). As such, the spatial resolution varies.

Sea ice heights are derived from segments that vary in length depending on the distance over which 150 signal photons are accumulated, which changes with varying surface types up to a maximum of 150 meters, and the number of available sea surface height segments to derive a reference sea surface. The along track length of the of height segments is stored in gt[x]/sea_ice_segments/heights/height_segment_length_seg.

### 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 | 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 |

| | |
|---|---|
| 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 webpage.

## 1.4 Temporal Information

### 1.4.1 Coverage

14 October 2018 to present

### 1.4.2 Resolution

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

Note that satellite maneuvers, data downlink issues, and other events can introduce data gaps into the ICESat-2 suite of products. As ATL03 acts as the bridge between the lower level, instrumentation-specific data and the higher-level products, the ICESat-2 Science Computing Facility maintains an ongoing list of ATL03 data gaps (.xlsx) that users can download and consult.

# 2 DATA ACQUISITION AND PROCESSING

## 2.1 Background

The ATLAS/ICESat-2 sea ice products are derived from geolocated, time-tagged photon heights plus other parameters passed to them by 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:

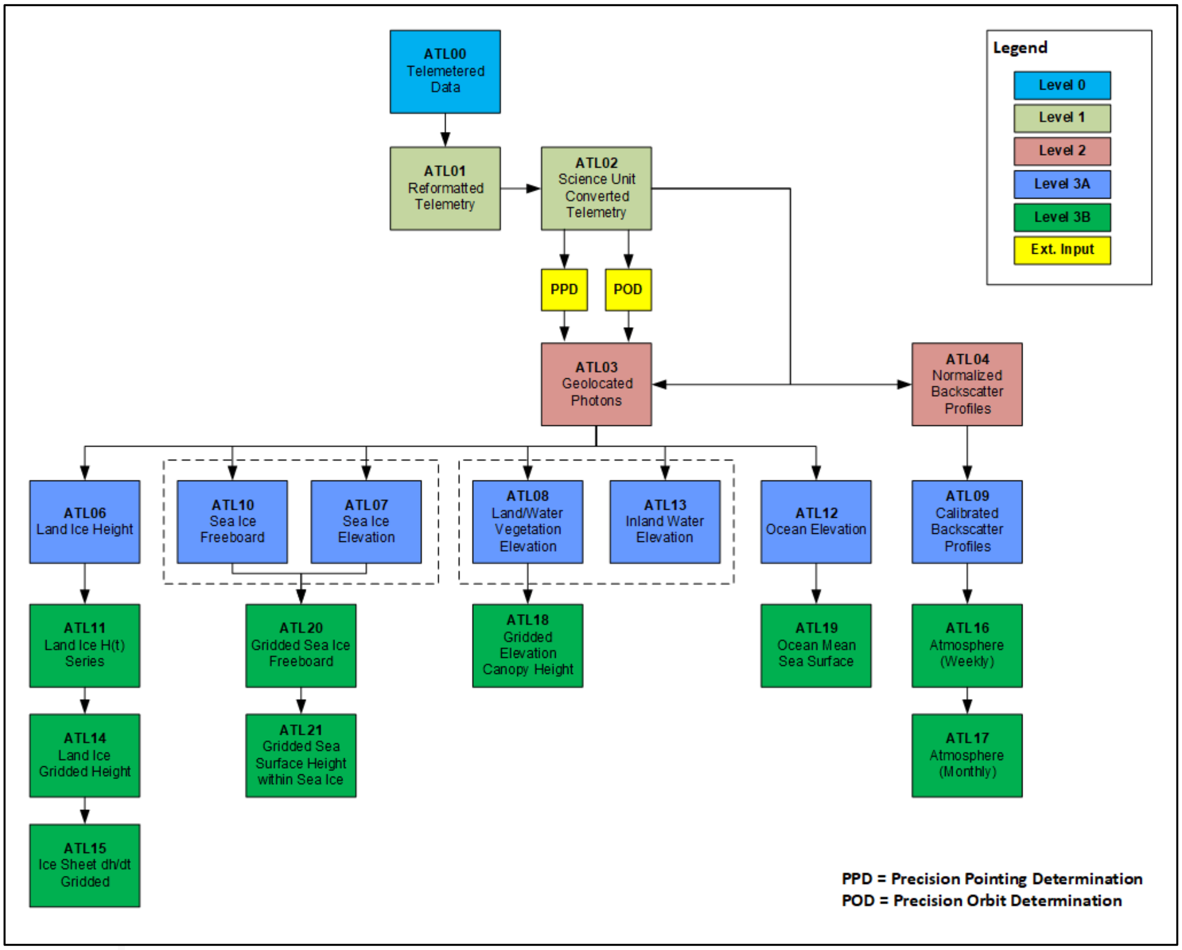


Figure 4. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (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.

## 2.2 Acquisition

NOTE: The following sections briefly describe the key input data used to generate the ATL07 product. Input sources include ATL03, ATL09 (the ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics product), plus external sources. More detailed information is available in "Section 3.1.3 | Input from IS-2 Products (ATL03 and ATL09)" and "Section 7.4 | Parameters from Ancillary Sources" in the ATDB for ATL07/ATL10/ATL20.

### 2.2.1 ATL03

Input data from ATL03 comprises primarily photons heights, background rates, and geophysical corrections. These corrections include the effects of the atmosphere, as well as tides and solid earth deformation. Although some corrections are applied by default to generate a best estimate of the photon height, by design each of these can easily be removed by the end user if desired.

ATL03 also generates corrections that are not applied by default, so that users may decide whether to apply them or not.

The time-dependent geophysical corrections from ATL03 fall into three categories: (1) corrections that have been applied to the photon ellipsoid heights; (2) corrections that have not been applied, but are provided as reference values; and (3) static reference values provided along with their typical, respective, magnitudes. Geophysical corrections are stored in the gt[x]/sea_ice_elements/geophysical/ group. They are described in detail in Section 6 of the ATBD for ATL03.

#### 2.2.1.1 Corrections applied due to variations in surface bounce point

- Solid Earth tides. Magnitude = ±40 cm (max).
- Ocean loading. Magnitude < 10 cm.
- Solid Earth pole tide deformation. Occurs due to centrifugal effect from small variations in polar motion. Magnitude = ±1.5 cm.
- Ocean pole tide. Global height correction caused by deformational load upon the Earth due to centrifugal effect from small variations in polar motion. Magnitude = ±2 mm amplitude.

#### 2.2.1.2 Corrections provided as reference values but NOT applied

- Ocean tides, including diurnal and semi-diurnal (harmonic analysis) and longer period tides (dynamic and self-consistent equilibrium) tides. Magnitude = ±5 m.

#### 2.2.1.3 Photon round-trip range corrections

- Total column atmospheric delay. Magnitude = -2.6 m to -0.9 m
- Geoid. Static Quantity. Magnitude = -105 m to +90 m (max)

### 2.2.2 ATL09

Inputs from ATL09 consist of atmospheric parameters that are used to assess potential atmospheric impacts including how clouds effect photon returns. Parameters include:

- Relative/calibrated backscatter
- 25-Hz background photon rates
- 25-Hz cloud statistics
- Sea level pressure, 2-m air temperature, 2-m eastward wind, 2-m northward wind

### 2.2.3 External inputs

- Ice concentration (daily fields)
- Mean sea surface (MSS) height from ICESat and CryoSat-2
- Land Mask

- Distance from Land Mask

## 2.3 Processing

NOTE: The following description briefly outlines the product coverage and approach used to generate the ATL07 product. Users seeking a detailed description of the algorithm and processing steps should consult "Section 4 | Algorithm Description: ATL07" of the ATBD for ATL07/ATL10/ATL20.

### 2.3.1 Product Coverage

The marginal ice zone is defined as that part of the ice cover with < 15% ice concentration, determined from daily ice concentration fields from satellite passive microwave brightness temperatures. Returns with ice concentrations < 15% are not processed.

The ATL07 product contains the sea surface height and sea ice height for segments along each of the six ground tracks. The along-track length of these segments is determined by the distance over which approximately 150 signal (surface) photons are accumulated, which changes with varying surface types up to a maximum of 150 meters. Cloudy conditions are identified using parameters input from ATL09 and height estimates are not produced for segments contaminated by clouds.

### 2.3.2 Surface Finding

In brief, the algorithm locates the ice and sea surfaces in the photon clouds obtained from ATL03 using a two-step procedure: coarse surface finding, followed by fine. Prior to surface finding, the mean sea surface is removed from the ATL03 data and the inverted barometric (IB) correction is calculated using the sea level pressure from ATL09. Corrected heights are computed as: $h = h_{ph} - h_{mss} - h_{IB}$, where $h_{ph}$ are the ATL03 photon heights; $h_{mss}$ is the mean sea level height; and $h_{IB}$ is the computed IB correction (the sign convention follows that used in ATL03).

The ATL03 product provides photon clouds in 30-m height windows that include the surface return. For the three strong beams, the coarse surface finding algorithm aims to produce an estimate of the mean surface height, within ±0.5 m of the local surface, over an L-km long segment of the orbit; this approach narrows the search space and the computational load of the subsequent fine surface finding process. The fine-tracking algorithm breaks up the coarse segments into N = 150 photon aggregate segments (although this number can be changed. See "Section 4.2.2.3 | Control Parameters" in the ATBD for ATL07/ATL10/ATL20, Release 004). As a result, the last aggregate in the coarse along-track segment may have fewer than N photons; when this occurs, the N < 150 segment is flagged and skipped over. When the coarse-tracking algorithm advances to the next L-km along-track segment, it starts from the location of flagged aggregate segments. Consequently, no valid data are erroneously removed.

For weak beams, coarse height estimates are derived from the results of the fine surface-finding algorithm for the adjacent strong beams. That is, each weak beam is slaved to the fine-tracker output from its corresponding strong beam.

### 2.3.3 Surface Type

Each surface height segment is labeled as belonging to a surface type based on a classification algorithm that determines the most likely surface type from photon and background rates. The surface type of an individual height segment (stored in gt[x]/sea_ice_segments/heights/seg_surf_type) is labeled based on three parameters: surface photon rate, the width of photon distribution (or fitted Gaussian) and the background rate. The combination of these parameters reduces ambiguity in identifying the surface type and the possibility of undetected cloud contamination in that segment. Conceptually, these three parameters are used as follows:

- The surface photon rate (photon returns per pulse) is a measure of the brightness, or apparent surface reflectance, of that height segment. In general, low surface rates indicate water or thin ice in open leads. However, specular and quasi-specular returns have been observed from smooth open-water/thin ice surfaces in both ICESat/GLAS and a pre-launch, airborne testbed instrument. As such, very high observed photon rates are handled differently; specular returns from these surfaces are especially useful since they provide large numbers of photons for surface finding.
- The width of the photon distribution provides a measure of the surface roughness and can be used to partition the height segments within four ranges that correspond to different surface types.
- The background rate provides useful information when the solar elevation is high and sufficient photons are present to yield a relatively accurate rate estimate. For example, for Lambertian surfaces under clear skies, the surface photon rate should be approximately linearly related to the background rate. When it is not, and the solar elevation is high, this indicates shadows (cloud shadows or ridge shadows), specular returns, or possibly, atmospheric effects. In the case of specular returns from a dark lead, the near linear behavior would deviate significantly from expected; that is, the surface photon rate is high but the background rate would be very low. In the shadow case, the background would be lower than expected. When the solar elevation angle is low the uncertainty is the background rate is high, and this parameter is not used for surface type classification.

"Section 4 | Algorithm Description: ATL07" in the ATBD for ATL07/ATL10/ATL20 (Release 004) contains a complete description of algorithm strategy and implementation. Of particular interest, sections 4.2.1.8 through 4.2.1.10 detail expected uncertainties associated with the surface height retrieval and describe a number of statistical quality metrics computed during product generation.

"Section 7 | Algorithm Implementation Considerations" in the ATBD discusses implementation details including how surface finding and classification are applied to ATLAS/ICESat-2's multibeam architecture; product coverage; and the parameters, internal and external. required to produce the sea ice products.

## 2.4 Quality, Errors, and Limitations

"Section 9 | Data Quality in the ATBD for ATL07/ATL10/ATL20" (Release 003) lists all the parameters and statistics used to assess data quality in the sea ice products as well as their locations within various data groups in the ATL07 and ATL10 data files.

The /gt[x]/sea_ice_segments/heights/ subgroups contain key segment quality indicators, such:

- height_segment_confidence, based on the number of photons, background rate, and error analysis;
- height_segment_fit_quality_flag, which describes the quality of the along-track fit from 1 (best) to 5 (poor);
- height_segment_quality, a binary indicator (1 = good, 0 = bad) of segment quality;
- height_segment_surface_error_est, which stores a quantatative error estimate (meters) for the surface height.

Errors in height retrievals from photon counting lidars like ATLAS can arise from a variety of sources. For example:

- Sampling error: ATLAS height estimates are based on random point samplings of the surface height distribution;
- Background noise: sampled photons include some random outliers that are not from the surface;
- Misidentified photons: the retrieval algorithms do not always utilize the correct photons as surface photons when estimating surface height;
- Atmospheric forward scattering: photons traveling downward through a cloudy atmosphere may be scattered through small angles and yet still be reflected by the surface within the ATLAS field of view. As such, these photons will be delayed and produce an apparently lower surface;
- Subsurface scattering: photons may be scattered many times within ice or snow before returning to the detector, and as such may yield surface height estimates with a low bias.
- First-photon bias: this error, inherent to photon-counting detectors, results in a high bias in the mean detected photon height that depends on signal strength.

Error sources, corrections, and mitigation strategies are also discussed throughout the ATBD. In particular, users may wish to consult "Section 2.2.5 | Potential Error Sources" and "Section 4 | Algorithm Description: ATL07."

# 3 VERSION HISTORY

Version 4 (April 2021)

Changes for this version include:

- Confirmed that invalid parameters from ATL03 to ATL09 are properly marked, including ocean tide. The routine used to average sea ice parameters has been tested to properly average, including checking for any invalids. If an invalid is found, the average for the segment is set to invalid.
- Meteorological data from ATL09 for the weak beam has been properly aligned with the strong beam by using distance instead of time.
- Removed geolocation segments with poor orbit or poor pointing quality from being used by using the podppd_flag from ATL03.
- Dynamically converted MSS values to the tide-free system.
- Dynamically adjusted sea ice coarse track height filters for the tide-free system.
- Read the free2mean parameters from ATL03 and averaged them to a sea ice segment rate in to ATL07.
- Fixed error in calculation of sea ice segment length to correctly measure length and remove negative results.
- Fixed error in the computation of first photon bias.

# 4 CONTACTS AND ACKNOWLEDGMENTS

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# 5 DOCUMENT INFORMATION

## 5.1 Publication Date

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## 5.2 Date Last Updated

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