



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

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## USER GUIDE

### How to Cite These Data

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

Smith, B., H. A. Fricker, A. Gardner, M. R. Siegfried, S. Adusumilli, B. M. Csathó, N. Holschuh, J. Nilsson, F. S. Paolo, and the ICESat-2 Science Team. 2021. *ATLAS/ICESat-2 L3A Land 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/ATL06.004>. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT [NSIDC@NSIDC.ORG](mailto:NSIDC@NSIDC.ORG)

FOR CURRENT INFORMATION, VISIT <https://nsidc.org/data/ATL06>



National Snow and Ice Data Center

# TABLE OF CONTENTS

1	DATA DESCRIPTION .....	2
1.1	Parameters .....	2
1.2	File Information.....	2
1.2.1	Format.....	2
1.2.2	ATLAS/ICESat-2 Description.....	2
1.2.3	File Contents.....	5
1.2.4	Data Groups.....	6
1.2.5	Naming Convention .....	7
1.3	Spatial Information.....	8
1.3.1	Coverage .....	8
1.3.2	Resolution.....	8
1.3.3	Geolocation.....	9
1.4	Temporal Information .....	9
1.4.1	Coverage .....	9
1.4.2	Resolution.....	9
2	DATA ACQUISITION AND PROCESSING.....	10
2.1	Background .....	10
2.2	Acquisition .....	10
2.3	Processing.....	11
2.4	Quality, Errors, and Limitations .....	12
3	VERSION HISTORY .....	13
4	CONTACTS AND ACKNOWLEDGMENTS .....	14
5	REFERENCES .....	14
5.1	References .....	14
6	DOCUMENT INFORMATION.....	15
6.1	Publication Date .....	15
6.2	Date Last Updated.....	15

# 1 DATA DESCRIPTION

## 1.1 Parameters

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Geolocated land-ice surface heights (above the WGS 84 ellipsoid, ITRF2014 reference frame), plus ancillary parameters that can be used to interpret and assess the quality of the height estimates.

## 1.2 File Information

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### 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 ATL06 data product is described in detail in the Ice, Cloud, and land Elevation Satellite-2 Project Algorithm Theoretical Basis Document for Land-Ice Along-Track Products (ATBD for ATL06 | V04 DOI: [10.5067/TY5QAMS5L65D](#)).

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 ATL06 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. ATL06 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 ATL06 file names, by appending the two-digit cycle number (cc) to the RGT number, e.g. 0001cc to 1387cc.

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 at least 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.

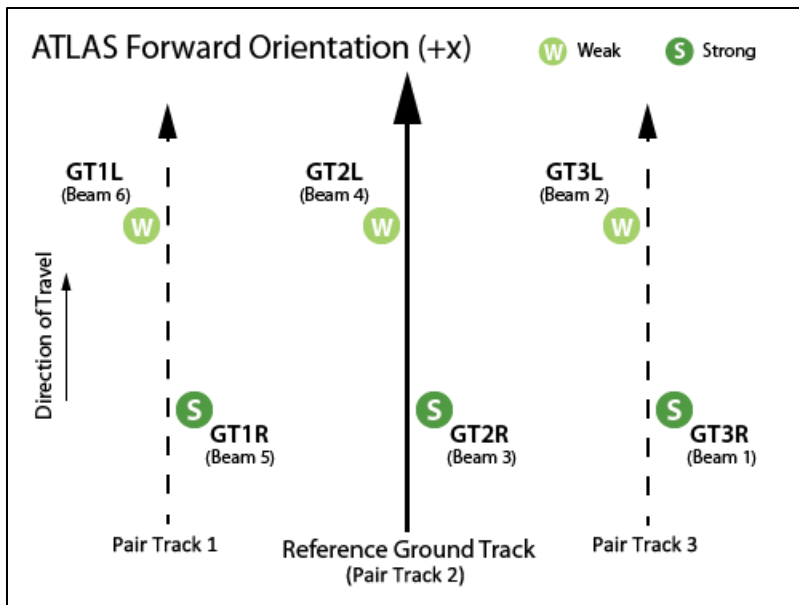


Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

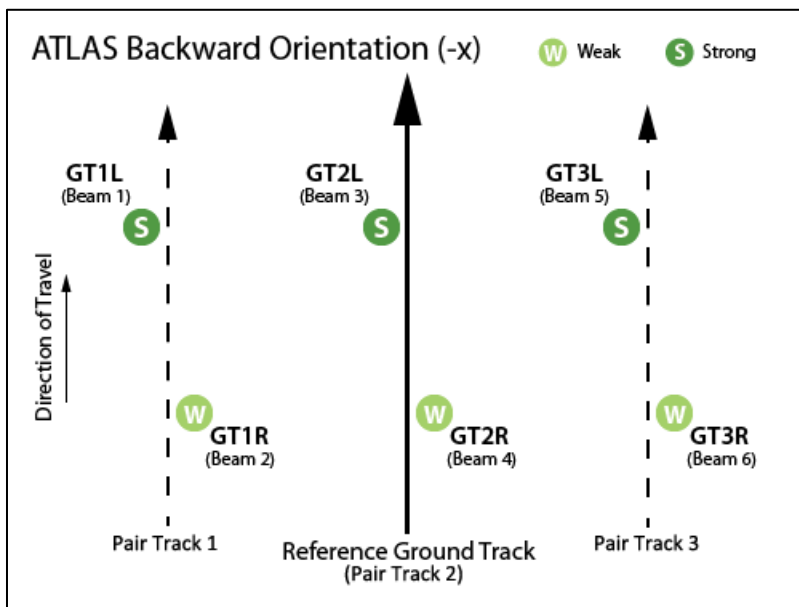


Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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

ATL06 data are provided as granules (files) that span about 1/14<sup>th</sup> of an orbit. Granule boundaries are delineated by lines of latitude that define 14 regions, numbered from 01-14 as shown in Figure 3:

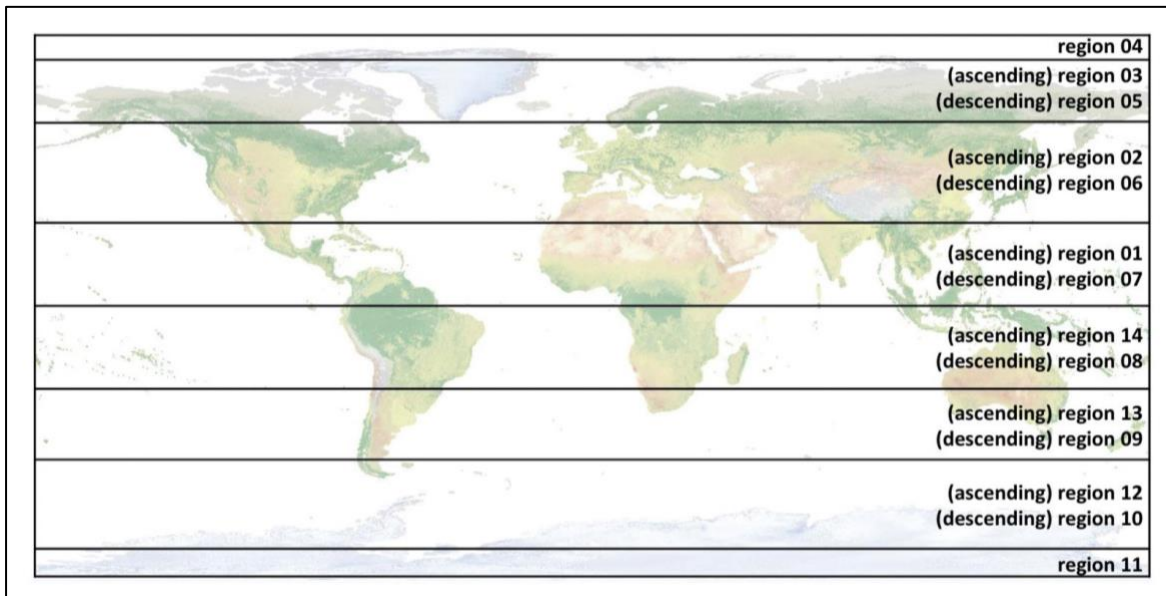


Figure 3. ATL06 region/granule boundaries.

The following table lists latitude bounds and region numbers for all 14 granule regions:

Table 1. ATLAS/ICESat-2 Granule Boundaries and Region Numbers

Region #	Latitude Bounds	Region #	Latitude Bounds
01	Equator → 27° N (ascending)	08	Equator → 27° S (descending)
02	27° N → 59.5° N (ascending)	09	27° S → 50° S (descending)
03	59.5° N → 80° N (ascending)	10	50° S → 79° S (descending)
04	80° N (ascending) → 80° N (descending)	11	79° S (descending) → 79° S (ascending)
05	80° N → 59.5° N (descending)	12	79° S → 50° S (ascending)
06	59.5° N → 27° N (descending)	13	50° S → 27° S (ascending)
07	27° N (descending) → Equator	14	27° S → Equator (ascending)

Note that the Land Ice Height product does not produce data granules for orbital segments that span open ocean only (i.e. do not cross a land surface).

## 1.2.4 Data Groups

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

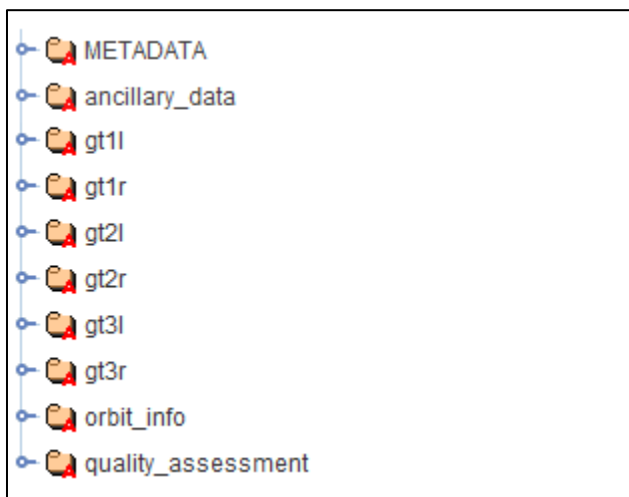


Figure 4. ATL06 data groups shown in HDFView.

The following sections summarize the contents of the data groups and certain parameters of interest. Data groups are described in detail in "Section 4 | ATL06 Data Product Description" in the ATBD for ATL06. A complete list of parameters is available in the [ATL06 Data Dictionary](#).

### 1.2.4.1 METADATA

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

### 1.2.4.2 ancillary\_data

Ancillary information such as product and instrument characteristics and/or processing constants. Data in this group pertain to the granule in its entirety.

### 1.2.4.3 gt1l – gt3r

Each ground track group (six in all) contains three subgroups:

- **land\_ice\_segments:** primary ATL06 derived parameters, e.g. land-ice height (`h_li`), latitude, longitude, standard error and quality measures. Heights represent the mean

surface height, averaged along 40 m segments of ground track spaced 20 m apart, for each of ATLAS's six beams. Data are only provided for segment pairs for which at least one beam has a valid land-ice height measurement. Each reported height has a corresponding segment ID (stored in `segment_ID`), which indicates the second of the two, 20 m ATL03 segments used to generate the 40 m ATL06 height segment.

- **residual\_histogram**: contains histograms of the residuals between photon event heights and the least-squares fit segment heights. Histograms are provided at a 200 m along-track rate.
- **segment\_quality**: contains a record of the success/failure of the surface-finding strategies for every possible segment in the granule, plus locations of the reference points on the reference pair tracks. Data within this group are spaced 20 m apart along-track.

#### 1.2.4.4 orbit\_info

Parameters that are constant for a granule, such as the RGT number and cycle, the spacecraft orientation, and various ATLAS parameters needed by higher-level data products.

#### 1.2.4.5 quality\_assessment

Contains quality assessment data, including QA counters and QA along-track and/or summary data, organized in `gt[x]` subgroups. For more information, see Section 4.0 | Data Product Description in the ATBD for ATL06.

### 1.2.5 Naming Convention

Data files utilize the following naming convention:

Example:

- ATL06\_20181014001920\_02350103\_004\_01.h5
- ATL06\_[yyyymmdd][hhmmss]\_[tttccss]\_[vvv\_rr].h5

The following table describes the file naming convention variables:

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
ATL06	ATLAS/ICESat-2 L3A Land Ice Height product
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Hour, minute, and second of data acquisition (UTC)
tttt	Reference Ground Track. 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.



Variable	Description
ss	Orbital segment (region) number (see Figure 3). ATL06 data files cover approximately 1/14 <sup>th</sup> of an orbit. Orbital segment numbers range from 01-14. Note: data files are not produced for orbital segments that cross open ocean only (i.e. do not cross a land surface). As such, some orbital segments will not be available.
vvv_vv	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 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.

#### 1.2.5.1 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. Images include ground track location, land ice heights, number of photon events used for each beam, and a summary plot that shows height quality and potential problems. Browse files utilize the same naming convention as their corresponding data file, but with \_BRW appended.

#### 1.2.5.2 File Size

Data files range in size from approximately 2 MB to 120 MB.

## 1.3 Spatial Information

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### 1.3.1 Coverage

The ICESat-2 mission acquires data along 1,387 different reference ground tracks. However, this product does not produce data granules for orbital segments that span open ocean only (i.e. do not cross a land surface). As such, some granules/orbital segments will not be available.

### 1.3.2 Resolution

Land ice heights represent the mean land ice surface height averaged along 40 m segments of ground track and spaced 20 m apart.

### 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 3. Geolocation Details

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

For information about ITRF2014, see the International Terrestrial Reference Frame | [ITRF2014 webpage](#).

## 1.4 Temporal Information

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### 1.4.1 Coverage

14 October 2018 to present

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.

### 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).

## 2 DATA ACQUISITION AND PROCESSING

### 2.1 Background

ATL06 height estimates are derived from geolocated, time-tagged photon heights plus other parameters passed to ATL06 by the ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03) product. Figure 5 illustrates the family of ICESat-2 data products and the connections between them:

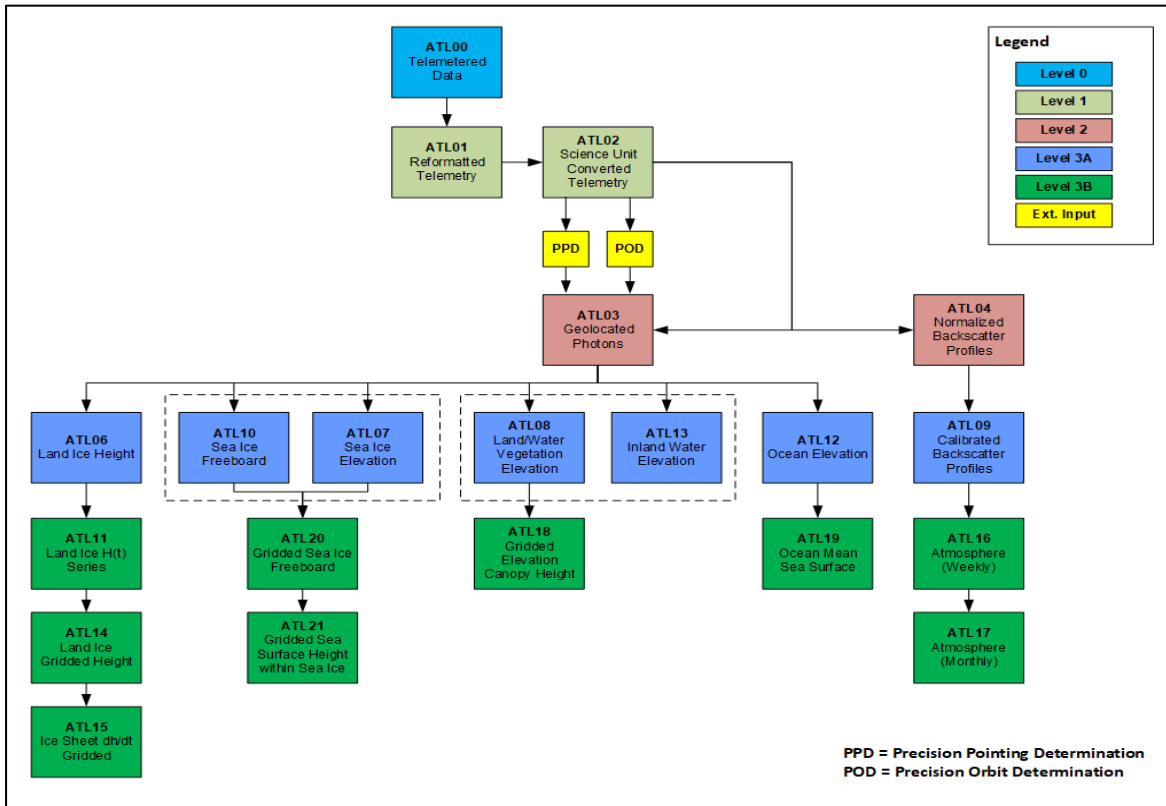


Figure 5. Schematic of the ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level-0 data and converts it into engineering units. ATL02 processing converts ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time.

### 2.2 Acquisition

The ATLAS instrument on ICESat-2 determines the range between the satellite and Earth’s surface by measuring the two-way time delay of short pulses of laser light that it transmits in six beams. ATLAS pulses are short—about 1.6 ns—and are transmitted every 0.1 ms (10 kHz). As the satellite travels along its orbit, this fast repetition yields spots whose centers are separated by about 0.7 m

in the along-track direction. Each pulse illuminates an approximately circular area on the ground about 14 m in diameter. ATLAS's strong beams generate at most 12 reflected photons from each transmitted pulse. Great care is taken to detect only photons with the same wavelength as the transmitted laser pulse and to limit the field of view of the detectors to a region that is just slightly larger than the illuminated spot. As such, ground-return photon events (PEs) are clustered in time and may readily be distinguished from solar, background PEs, which are distributed evenly in time and arrive much less frequently.

## 2.3 Processing

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The following section summarizes the approach used to generate the ATL06 data product. For a more complete description, consult the [ATBD for ATL06](#).

ATL06 processing computes land ice surface heights and stores them by ground track so that subsequent measurements on the same reference pair track (RPT) can be easily compared. It also uses information from each strong/weak beam pair to estimate across-track slope. Additional parameters are also provided that indicate the quality of the surface-height estimates and the signal and noise levels associated with the measurement. The heights represent the mean surface height averaged along 40 m segments of ground track, spaced 20 m apart, for each of ATLAS's six beams. Segments within adjacent beams are aligned to facilitate estimation of the across-track surface slope. Segments are also aligned from orbit to orbit so that height estimates in subsequent repeat tracks lie at nearly the same location on the surface, thereby simplifying the task of computing height changes through time.

The algorithm utilizes an iterative process to select a small surface window that includes the majority of the signal photon events (PEs) with as few as background PEs as possible. The surface height is then expressed as the median of the PE heights within the surface window, because the median is less sensitive to sampling error for distributions that contain a statistically uniform, background component. To estimate the spread of a distribution of PE heights, the algorithm uses the Robust Dispersion Estimator, which is equal to half the difference between the 16th and the 84th percentiles of a distribution. For Gaussian-distributed data, this statistic is approximately equal to the standard deviation, and for data containing a mixture of a large fraction of signal and a small fraction of noise, it provides an estimate of the spread of the signal that is relatively insensitive to the noise.

Land ice height is defined as the estimated surface height of the segment center for each reference point, using median-based statistics. The algorithm calculates this as the sum of the least-squares height fit, the first-photon-bias median correction, and the pulse-truncation median correction. Height increment values are provided with the product that allow removal of the correction and the

calculation of the segment mean height and first-photon-bias and pulse-truncation corrections corresponding to the segment mean.

The following steps outline the procedure used to generate land ice surface heights for each along-track reference point:

1. All PEs are collected from the current cycle that fall into the along-track bin for the along-track point.
2. The initial height and along-track slope are estimated for each beam in the pair.
3. The heights and surface windows are iteratively refined for each beam in the pair.
4. Corrections for subsurface scattering, first-photon bias, median offsets, and error estimates are calculated for each beam based on the edited PEs.
5. The across-track slope is calculated.

For a complete description of the ATL06 height derivation theory and implementation, see Section 3 | Algorithm Theory: Derivation of ATL06 Land Ice Height Parameters in the ATBD for ATL06.

## 2.4 Quality, Errors, and Limitations

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Errors in ATLAS land-ice products can come from a variety of sources:

1. Sampling error: ATLAS height estimates are based on a random sampling of the surface height distribution;
2. Background noise: Random-noise PEs are mixed with the signal PEs, so sampled PEs will include random outliers;
3. Complex topography: The along-track linear fit and across-track polynomial fit do not always resolve complex surface topography.
4. Misidentified PEs: The ATL03 product will not always identify the correct PEs as signal PEs;
5. First-photon bias: This is an error inherent to photon-counting detectors that results in a high bias in the mean detected PE height that depends on signal strength;
6. Atmospheric forward scattering: Photons traveling downward through a cloudy atmosphere may be scattered through small angles but still be reflected by the surface within the ATLAS field of view; these will be delayed, producing an apparently lower surface;
7. Subsurface scattering: Photons may be scattered many times within ice or snow before returning to the detector; these will be delayed, producing a surface estimate with a low bias.

Each of these errors are treated differently during the ATL06 processing:

- 1 and 2 (above) are treated as random errors and their effects are quantified in the error estimates associated with the product.
- 3 and 4 will produce relatively large errors that will need to be addressed with consistency checks when higher-level products are generated.
- 5 will be corrected routinely during ATL06 processing.

- 6 and 7 are not quantified in ATL06. They require information about cloud structure and ice-surface conditions that are not available when ATL06 is processed. Correcting for these errors remains an active avenue of research.

Potential error sources and mitigation strategies are detailed in Section 3.0 | ATBD for ATL06.

## 3 VERSION HISTORY

Version 4 (April 2021)

Changes for this version include removal and addition of parameters as well as changed values for several parameter descriptions. All changes are listed according to their group within the hdf5 files here:

- Group: /ancillary\_data/land\_ice
  - Deleted parameter: /ancillary\_data/land\_ice/maxiter
  - Deleted parameter: /ancillary\_data/land\_ice/sigma\_tx
  - Deleted parameter: /ancillary\_data/land\_ice/t\_dead
  - Added parameter: / ancillary\_data/land\_ice/txp\_maxiter
- Group: /gtx/land\_ice\_segments/dem
  - Changed /gtx/land\_ice\_segments/dem/dem\_flag/description value from "Indicates source of the DEM height. Values: 0=None, 1=Arctic, 2=GMTED, 3=MSS, 4=Antarctic." to "Indicates source of the DEM height. Values: 0=None, 1=Arctic, 2=Global, 3=MSS, 4=Antarctic."
  - Changed /gtx/land\_ice\_segments/dem/dem\_flag/flag\_meanings value from "[ 'none', 'arctic', 'gmted', 'mss', 'antarctic' ]" to "[ 'none', 'arctic', 'global', 'mss', 'antarctic' ]"
  - Changed /gtx/land\_ice\_segments/dem/dem\_h/description value from "Height of the DEM, interpolated by cubic-spline interpolation in the DEM coordinate system to the PE location. (Best available DEM value in priority of Arctic/Antarctic/GMTED/MSS)" to "Height of the DEM, interpolated by cubic-spline interpolation in the DEM coordinate system to the PE location. (Best available DEM value in priority of Arctic/Antarctic/Global /MSS)"
- Group: /gtx/land\_ice\_segments/geoid
  - Changed /gtx/land\_ice\_segments/dem/geoid\_h/description value from "Geoid height above WGS-84 reference ellipsoid (range -107 to 86m)," to "Geoid height above WGS-84 reference ellipsoid (range -107 to 86m) in the tide-free system."
- Group: /gtx/land\_ice\_segments/geophysical
  - Changed /gtx/land\_ice\_segments/geophysical/tide\_earth/description value from "Solid Earth Tides" to "Solid earth tides in the tide-free system."
- Group: /gtx/land\_ice\_segments/fit\_statistics
  - Changed /gtx/land\_ice\_segments/fit\_statistics/signal\_selection\_source\_status/description value from "Indicates the status of the last signal selection algorithm attempted (see signal\_selection\_source). The definition of flag is different for each source and are defined in each of the signal\_selection\_status flags. (See Land Ice ATBD

Table 3-2)." to "Indicates the status of the last signal selection algorithm attempted (see signal\_selection\_source). The definition of flag is different for each source and are defined in each of the signal\_selection\_status flags. (See Land Ice ATBD Table 3-2)."

- Group: /gtx/segment\_quality/signal\_selection\_status
  - Changed  
/gtx/segment\_quality/signal\_selection\_status/signal\_selection\_status\_all/description value from "Indicates confidence of the signal-selection algorithm using all ATL03-flagged PEs. 0=Signal selection succeeded using all ATL03-flagged PEs (or algorithm not attempted); 1=Signal selection using all ATL03-flagged PEs failed the 20-meter-spread test; 2=Signal selection using all ATL03-flagged PEs failed the 10-photon-count test; 3=Signal selection using all ATL03-flagged PEs failed both tests" to "Indicates confidence of the signal-selection algorithm using all ATL03-flagged PEs. 0=Signal selection succeeded using all ATL03-flagged PEs (or algorithm not attempted); 1=Signal selection using all ATL03-flagged PEs failed the 20-meter-spread test; 2=Signal selection using all ATL03-flagged PEs failed the 10-photon-count test; 3=Signal selection using all ATL03-flagged PEs failed both tests"

## 4 CONTACTS AND ACKNOWLEDGMENTS

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## 6 DOCUMENT INFORMATION

### 6.1 Publication Date

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### 6.2 Date Last Updated

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