ATLAS/ICESat-2 L3A Land Ice Height, Version 3

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. 2020. *ATLAS/ICESat-2 L3A Land Ice Height, Version 3*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/ATLAS/ATL06.003. [Date Accessed].

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

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

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

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

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 | V03).

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 between 14 October 2018 and 30 March 2019 the spacecraft pointing control was not yet optimized. As such, ICESat-2 data acquired during that time do not lie along the nominal RGTs, but are offset at some distance from the RGTs. Although not along the RGT, the geolocation information for these data is not degraded.

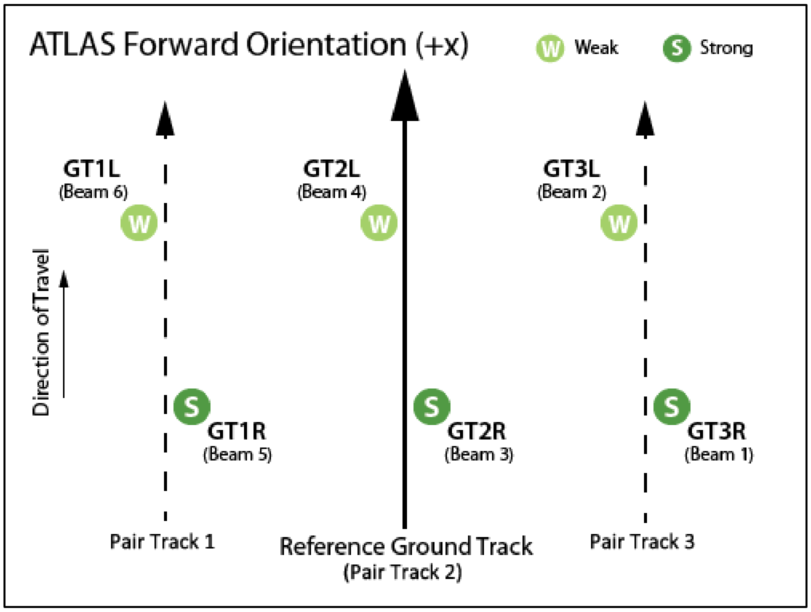

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

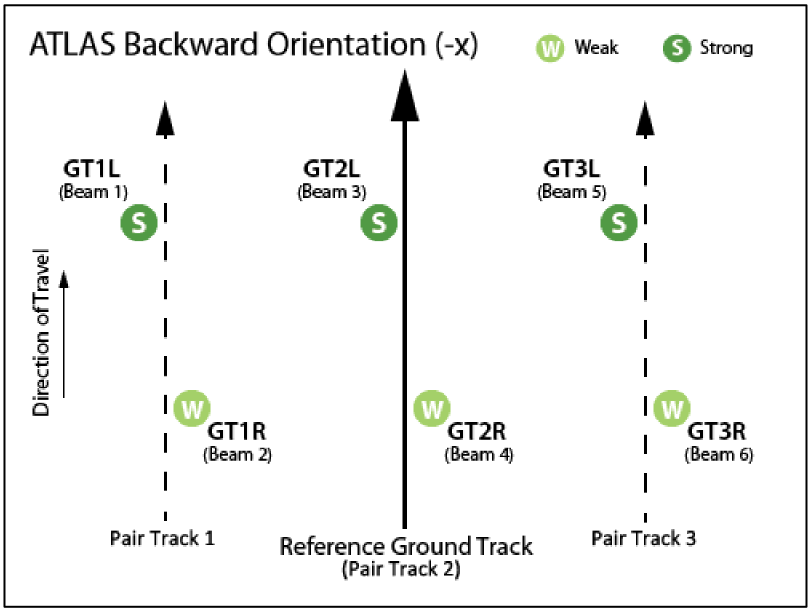

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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 1/14th of an orbit. Granule boundaries are delineated by lines of latitude that define 14 regions, numbered from 01-14 as shown in Figure 3:

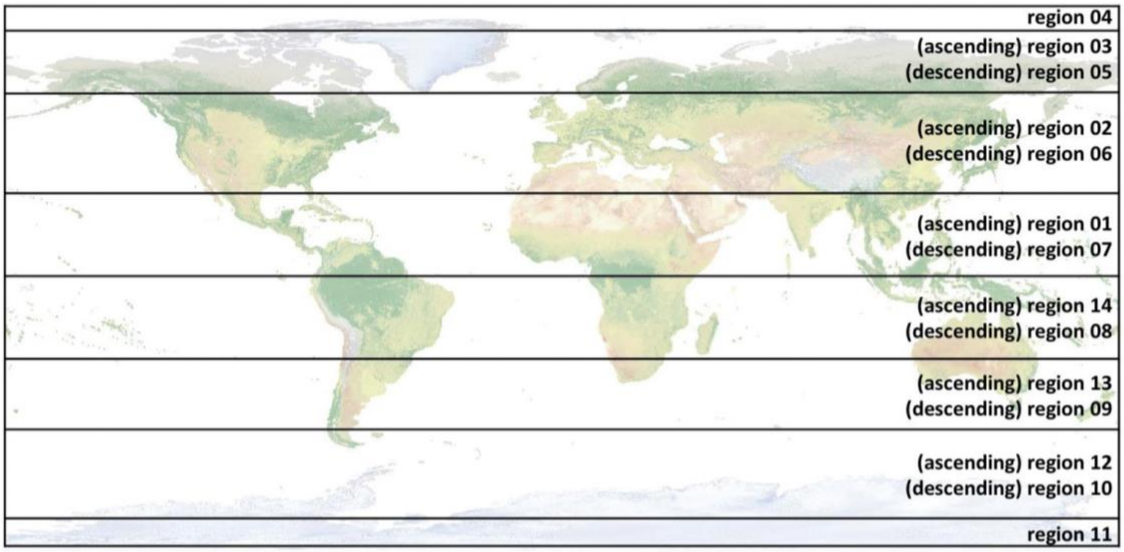

Figure 3. ATL06 region/granule boundaries.

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:

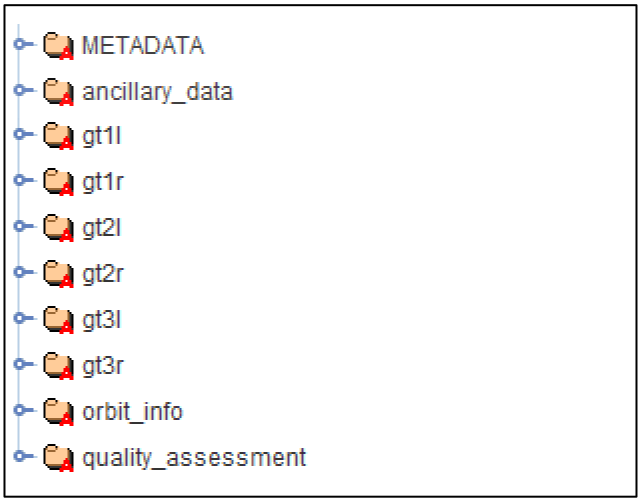

Figure 4. ATL06 data groups shown in HDFView.

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_001_01.h5
- ATL06_[yyyymmdd][hhmmss]_[ttttccss]_[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 1/14th 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 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

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 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

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 webpage.

1.4 Temporal Information

1.4.1 Coverage

14 October 2018 to 11 November 2020

Note that satellite manuevers, 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:

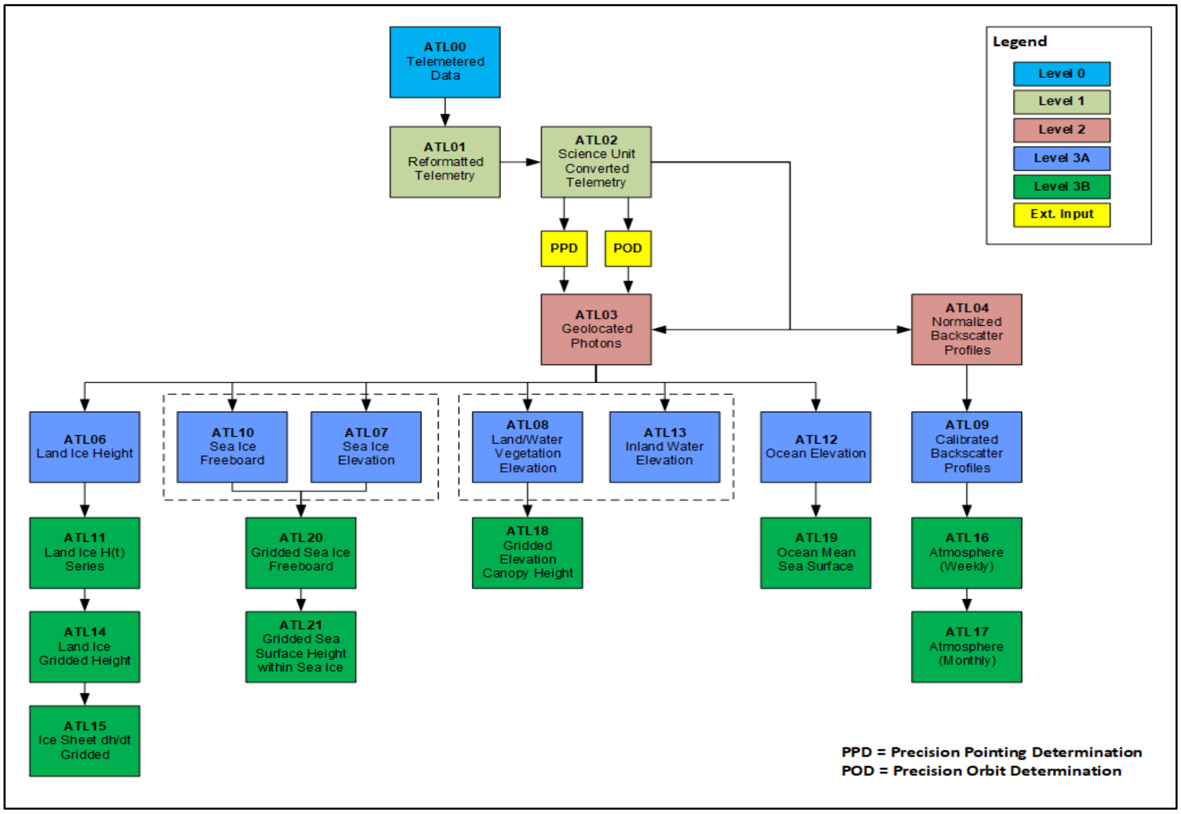

Figure 5. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Dete

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

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 Esimator, 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

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 3 (May 2020)

Changes for this version include:

- ATL09 pass-through cloud flags are now written to the ATL06 product. This fixes a bug in earlier versions.
- The ATL09 layer flag was added to ATL06 (gt[x]/land_ice_segments/geophysical/layer flag). If two ATL09 flags intersect an ATL06 segment, only the higher flag value is used. The layer_flag parameter is an important tool for predicting forward scattering.
- The large DEMs previously required are no longer rneeded for processing. If they are provided in the processing control file, values are queried as in previous releases; if the DEMs are not provided in the control file, the values from ATL03 are used. This change simplifies the ATL06 calculation and provides a consistent DEM value across product levels.
- Molecular transmission is now read from ATL09 and used as input to compute the effective background. Previous versions used a default value.
- Radial orbit error from ATL03 (sigma_h) was added to the ATL06 product as gt[x]/land_ice_segments/ground_track/sigma_geo_r. This value is useful in propagating systematic errors in ICESat-2 data.
- ATL06 processing and product generation algorithms now ignore ATL03 data where the podppd_flag is non-zero. This ensures that land ice data are only created from ATL03 data with a high degree of confidence in the geolocation accuracy.
- The residual histograms were change to range from -50 m to +50 m with varying bin sizes. Residual histogram bins that are not fully encompassed by at least one of the two possible telemetry band range windows are marked as invalid. The histograms were enlarged to encompass the full potential vertical range of forward-scattering returns below the surface and to allow sampling of backscatter from blowing snow above the surface.
- Corrected the long names for sigma_geo_at and sigma_geo_xt on the ATL06 product.
- Residual histograms are now centered on h_mean instead of h_li. This change yields a better representation of the segment-to-segment statistics of the residuals.

4 CONTACTS AND ACKNOWLEDGMENTS

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6 DOCUMENT INFORMATION

6.1 Publication Date

23 May 2019

6.2 Date Last Updated

25 January 2022