ATLAS/ICESat-2 L3A Land and Vegetation Height, Version 1

USER GUIDE

How to Cite These Data

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

Neuenschwander, A. L., S. C. Popescu, R. F. Nelson, D. Harding, K. L. Pitts, and J. Robbins. 2019. *ATLAS/ICESat-2 L3A Land and Vegetation Height, Version 1*. [Indicate subset used]. Boulder, Colorado USA. NSIDC: National Snow and Ice Data Center. doi: https://doi.org/10.5067/ATLAS/ATL08.001. [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL08

National Snow and Ice Data Center

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1 DATA DESCRIPTION

1.1 Parameters

Along-track terrain and canopy height above the WGS 84 ellipsoid (ITRF2014 reference frame).

1.2 File Information

1.2.1 Format

Data are provided as HDF5 formatted files.

HDF5 is a data model, library, and file format designed specifically for storing and managing data. For more information including tools and applications that can help you view, manipulate, and analyze HDF5-formatted data, visit the HDF Group's HDF5 Support Page.

1.2.2 ATLAS/ICESat-2 Description

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 ATL08 data product is described in detail in the Ice, Cloud, and land Elevation Satellite-2 Project Algorithm Theoretical Basis Document for the Land - Vegetation Along-Track Product (ATBD for ATL08). To obtain the most recent version of this ATBD, visit the NASA Goddard Space Flight Center's ICESat-2 Data Products web page.

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 trace out six approximately 14 m wide ground tracks as ICESat-2 orbits Earth. 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 ATL08 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. ATL08 reports the spacecraft orientation in the sc_orient parameter stored in the /orbit_info/ data group (see Section 1.2.4 Data Groups).

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 ATL08 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. Once the ATLAS/ICESat-2 Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions have been adequately resolved and the instrument has pointed directly at the reference ground track for a full 91 days (1387 orbits), the observatory will begin off-pointing data acquisition.

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.

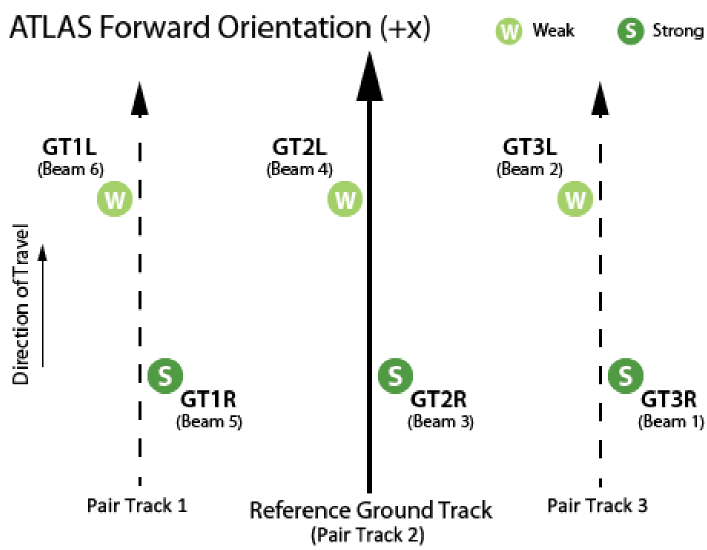

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

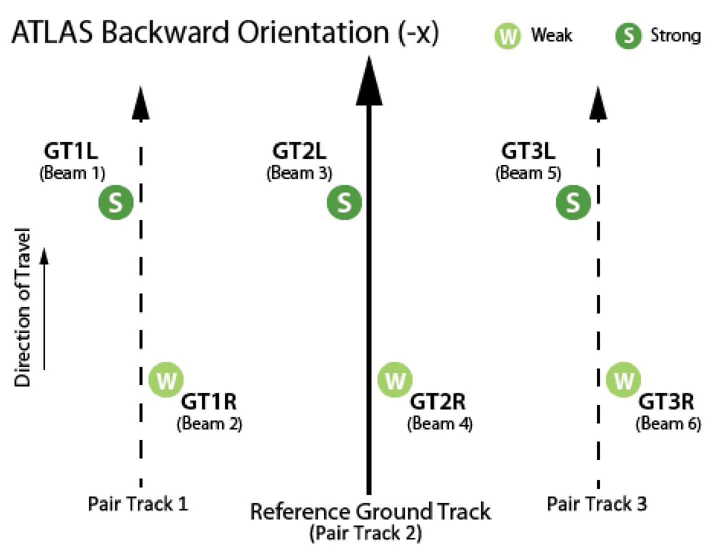

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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

ATL08 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:

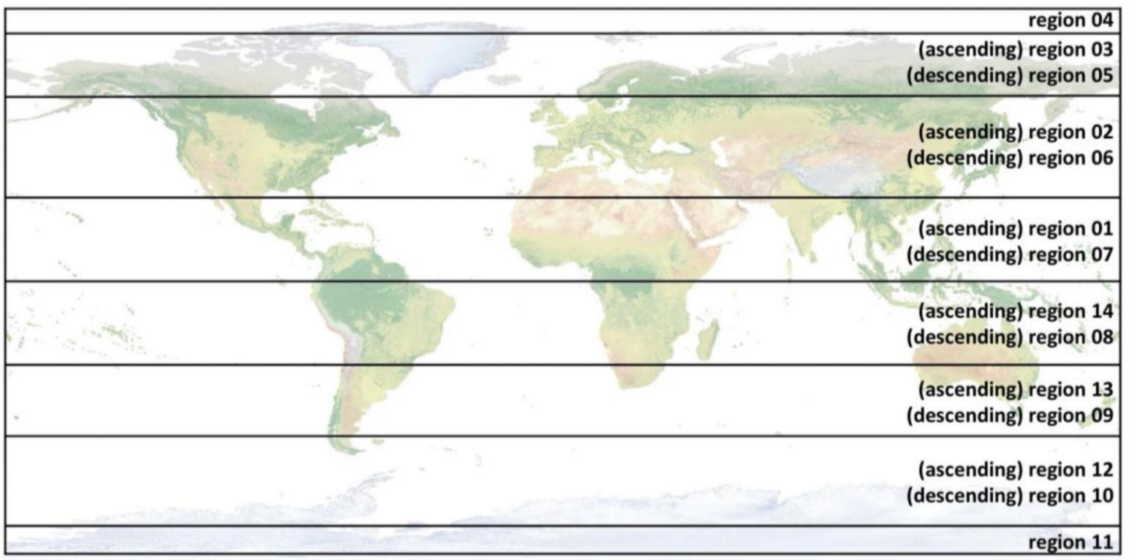

Figure 3. ATL08 region/granule boundaries.

The following table lists the 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 and Vegetation 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 files, similar variables such as science data, instrument parameters, altimetry data, and metadata are grouped together according to the HDF model. ATL08 data files contain the top-level groups shown in Figure 4:

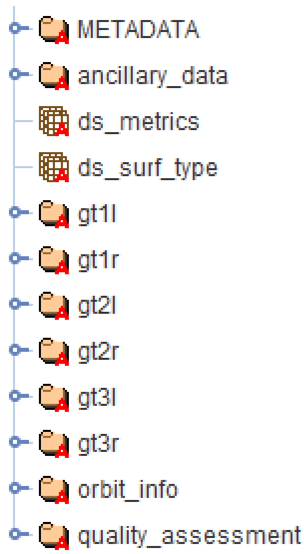

Figure 4**.** ATL08 data groups shown in HDFView.

The following sections summarize the structure and primary variables of interest in ATL08 data files. Additional details are available in "Section 2 | ATL08 Data Product" of the ATBD for ATL08. To obtain the most recent version of this ATBD, visit the NASA Goddard Space Flight Center's ICESat-2 Data Products web page. A complete list of parameters is available in the ATL08 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

Information that is ancillary to the data product. This may include product characteristics, instrument characteristics and/or processing constants. This group also contains the /land/ subgroup, which houses constants specific to the land/vegetation product.

1.2.4.3 gt1l – gt3r

Six gt[x] groups, each of which contains the parameters for one of the six ATLAS ground tracks. Each gt[x] top-level group contains the following subgroups:

- **/land_segments/** contains parameters related to 100 m land segments. Key parameters include time, latitude, and longitude of the centermost signal photon; the number of signal photons in the segment (n_seg_ph); a night flag; land, snow, and water masks; and descriptive statistics. This group also contains the following subgroups:
  - /canopy/ that contains parameters generated by the canopy finding algorithm, including canopy heights and statistics for the segment;
  - /terrain/ that contains terrain parameters aggregated at 100 m.
- **/signal_photons/** contains parameters related to individual photons, including the classification flag for each photon (noise, ground, canopy, or canopy top) and indexes to trace photons back to ATL03 source product.

1.2.4.4 orbit_info

Parameters that are constant for a granule, such as the RGT number and cycle, the spacecraft orientation, and elapsed time.

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

Two HDF5 dimension scales are stored at the top level alongside the data groups—ds_metrics and ds_surf_type—which index the surface type and metrics arrays.

For details about how the parameters are organized in the ATL08 product, see "Section 2 | ATL08: Data Product" in the ATBD for ATL08.

1.2.5 Naming Convention

Data files utilize the following naming convention:

Example:

```
ATL08_20181014092931_02410101_001_01.h5
```

```
ATL08_[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
ATL08	ATLAS/ICESat-2 L3A Land and Vegetation Height product
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Data acquisition start time, hour, minute, and second (UTC)
tttt	Four digit Reference Ground Track number. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle Number. Each of the 1387 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	Orbital segment (region) number (see Figure 3). ATL08 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_rr	Version and 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. Images include track location, canopy heights, and terrain and canopy photon counts for each ground track. 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 approximately 88° N latitude to 88° S. However, data files are not produced for orbital segments that cross open ocean only (i.e. do not cross a land surface).

ATL08 data can be referenced by numbered geographical regions, unique to the ATL08 product, which are roughly prescribed by continent—Greenland is assigned to its own region and Antarctica is divided into four, for a total of 11 regions (see Figure 5). The ATL08 regions encompassed by the ATL03 input granule are stored in \ancillary_data\land\atl08_region.

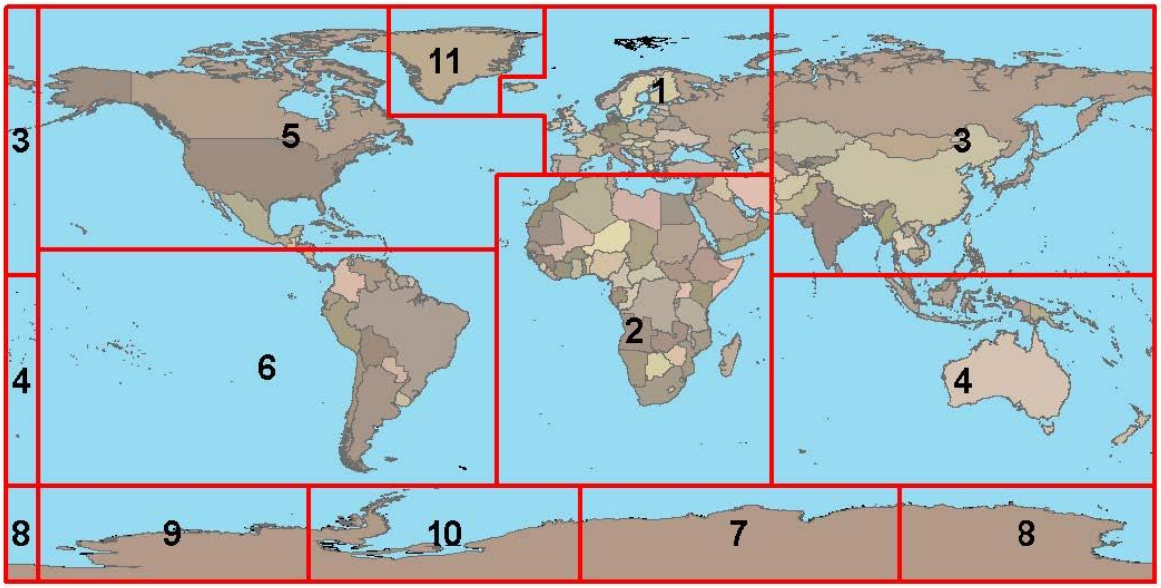

Figure 5. ATL08 Geographic Regions

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 of signal photons varies.

For ATL08, the canopy and ground surfaces are processed in fixed 100 m data segments, which typically contain more than 100 signal photons (however, some may contain fewer). For Version 1, the science team has determined that fewer than 50 signal photons in a 100 m segment does not accurately represent the surface. As such, segments with fewer than 50 photons (gt[x]/land_segments/n_seg_ph) report all height fields as invalid (except for interpolated height surfaces).

1.3.3 Geolocation

The following table contains details about WGS 84:

Table 3. 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 14 January 2019

1.4.2 Resolution

Data are reacquired along each of ATLAS/ICESat-2's 1387 RGTs every 91 days (i.e. the satellite has a 91-day repeat cycle).

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The ATL08 product contains heights for both terrain and canopy in the along-track direction, plus other descriptive parameters. These data are derived from geolocated, time-tagged photon heights passed to ATL08, 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:

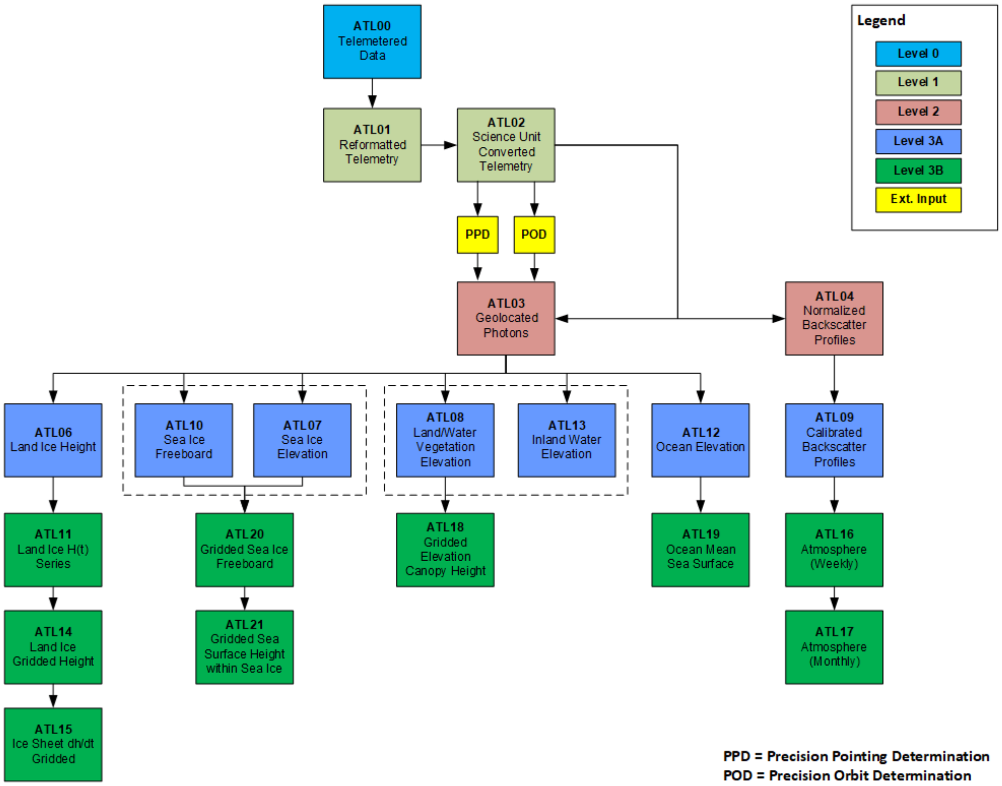

Figure 6. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (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

Input sources used to generate the ATL08 product consist primarily of medium- and high-confidence signal photon events from ATL03 plus the Landsat Tree Cover Continuous Fields data set (2000 epoch) available from the Global Land Cover Facility at the University of Maryland.

2.3 Processing

To detect both the canopy surface and the underlying topography, the ATL08 software has been designed to accept multiple approaches to capture both the upper and lower surface signal photons. For Version 1, the algorithm utilizes iterative photon filtering in the along-track direction, which best preserves signal photons returned from the canopy and topography while rejecting noise photons. The following sections outline the approach implemented by the algorithm. More detailed descriptions are available in "Section 3 | Algorithm Methodology" and "Section 4 | Algorithm Implementation" of the ATBD for ATL08. To obtain the most recent version of this ATBD, visit the NASA Goddard Space Flight Center's ICESat-2 Data Products web page.

2.3.1 Noise Filtering

Removing solar background photons represents one of the biggest challenges with photon counting lidar data. The ATL03 signal finding approach uses a histogramming strategy, that places photons into vertical bins along a consistent horizontal span and then assumes the signal lies within the bins that contain the highest number of photons. This method works well over simple surfaces such as ice sheets; however, photons that are reflected from the top of the canopy in vegetated areas are not always flagged as signal. As such, before surface finding commences in ATL08, the input from ATL03 is passed through an additional signal finding method referred to as DRAGANN (Differential, Regressive, and Gaussian Adaptive Nearest Neighbor), which was developed specifically to identify and remove noise photons from histogrammed photon point clouds.

DRAGANN assumes that signal photons will be closer together in space than random noise photons and implements an adaptive, nearest neighbor search, which can apply different thresholds for variable levels of background noise and changing surface reflectance along the data profile. The search finds an effective radius by computing the probability of finding a specified number of points (P) within a search area. However, to account for certain cases, e.g. nighttime acquisitions when the solar background noise will be considerably lower, the value of P adapts dynamically based on estimations of the signal and noise rates from the photon cloud.

Once the radius has been computed, DRAGANN counts the number of points within the radius for each point and histograms that set of values. The distribution of the number of points in each bin contains two distinct peaks—a noise peak and a signal peak. DRAGANN then utilizes an iterative process of Gaussian curve fitting and statistical evaluation to determine a threshold that can be used to separate noise from signal. Once the signal photons have been identified by DRAGANN, they are combined with the coarse signal finding output from ATL03. This process is described in detail in "Section 3.1.1 | DRAGANN" in the ATDB for ATL08.

2.3.2 Surface Finding

For Version 1, the surface finding approach utilizes one algorithm to find the ground surface and canopy surface (as noted previously, the science team anticipates that future releases will combine multiple approaches to better distinguish individual photons as ground, canopy, top of canopy, or noise.).

Figure 7 shows a flowchart of the signal finding approach in ATL08. The sections that follow briefly describe the steps in the surface finding algorithm. The process is detailed in "Section 3.2 | Surface Finding" of the ATBD for ATL08.

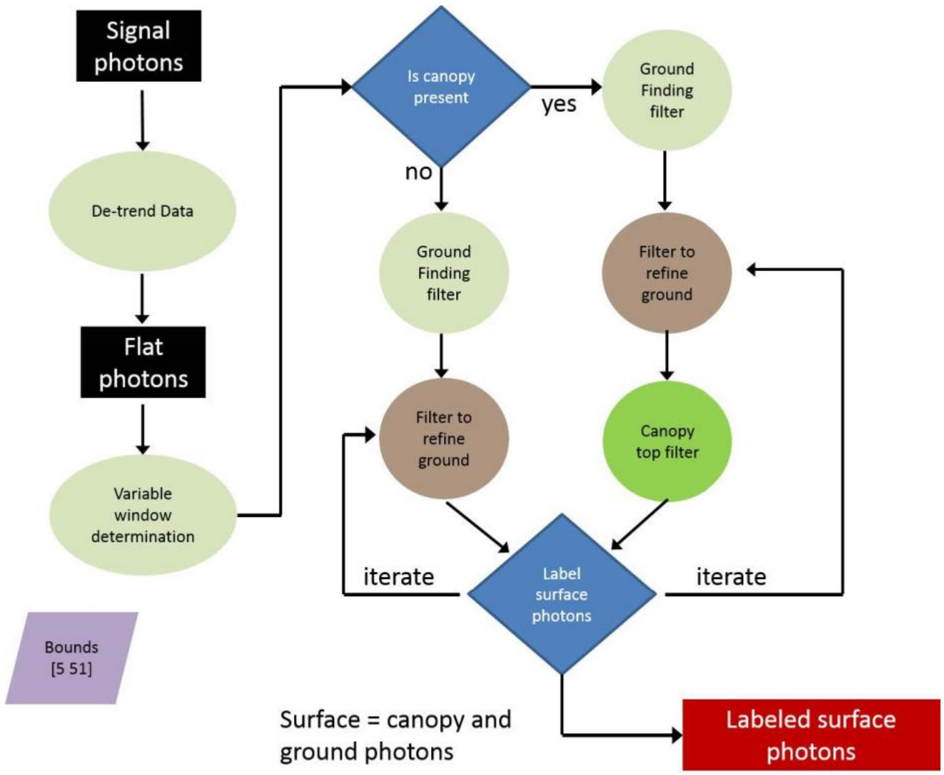

Figure 7. Flowchart of ATL08 Surface Finding.

2.3.2.1 Signal Photon De-trending

The effect of topography on the input data is removed to improve the performance of the algorithm. To achieve this, the input signal photons are de-trended by subtracting a heavily smoothed representation of the surface. Essentially, this surface is a low pass filter of the original data; most of the analysis to detect the canopy and ground are applied to a high pass filter of the data. The amount of smoothing, i.e. the window size, depends on the underlying relief. For example, for segments with high relief the smoothing window is decreased to ensure topography isn't filtered out (Section 3.1.1, ATBD for ATL08).

2.3.2.2 Canopy Determination

The success of the surface finding algorithm relies heavily on correctly identifying the presence of canopy along any given L-km length segment. Due to the large volume of data ATLAS generates, this process is automated so that the algorithm can apply the appropriate surface finding methodology. For Version 1, the Landsat Tree Cover Continuous Fields data set (2000 epoch) is used to set a canopy flag within the ATL08 algorithm.

The ATL08 algorithm compares the midpoint location of an ATLAS L-km length segment with the midpoint locations of the Landsat tiles to find the closest tile that encompasses the segment. Each signal photon's X-Y location is mapped to the corresponding Landsat pixel within the tile. Multiple instances of the same pixels for the L-km length segment are discarded. The algorithm then produces an average canopy cover percentage for the segment by averaging the percentage canopy values for those Landsat pixels determined to lie along the L-km length segment.

If the average canopy cover for a segment is greater than 5%, the canopy flag (gt[x]/land_segments/canopy/canopy_flag) is set (1). When this flag is set for a segment, the ATL08 algorithm assumes the presence of canopy in the segment and applies an approach designed to identify both ground and vegetation photons. If the canopy flag is not set (0), the algorithm assumes no canopy and uses a simplified calculation to locate ground photons only. Over Antarctica (regions 7, 8, 9, 10) and Greenland (region 11), the algorithm identifies ground photons only (Section 3.2.2, ATBD for ATL08).

2.3.2.3 Variable Window Determination

For both the canopy/no canopy cases, the surface finding algorithm uses a window of varying size (i.e. span) to compute statistics and smooth and filter the data. The window size is determined using Savitzky-Golay smoothing/median filtering, bound appropriately to prevent over-filtering. To apply this method, the algorithm uses an empirically determined shape function that sets the window size based on the number of photons in the L-km length segment. Note that the window size varies for each L-km length segment but remains constant within a segment (Section 3.2.3, ATBD for ATL08).

2.3.2.4 Compute Descriptive Statistics

A moving window is used to compute descriptive statistics on the de-trended input data to help characterize it and initialize certain parameters used in the surface finding algorithm. The moving window is the same width as the smoothing function described in the preceding section and slides one quarter of its size with each step, to allow a large overlap between windows and to ensure that the approximate ground location is returned. Mean height, minimum and maximum height, and standard deviation of the heights are computed for each step.

The statistics used to estimate the ground height depends on the amount of vegetation within the each window. The standard deviation of photon heights is used to classify the vertical spread of the photons within a window and assign it to one of four classes—open, canopy level 1, canopy level 2, or canopy level 3—which range from areas with little or no signal photon spread to areas with a high spread in photon heights (Section 3.2.4, ATBD for ATL08).

2.3.2.5 Ground-Finding Filter

The ground-finding algorithm uses an iterative median filtering approach to retain/eliminate photons when canopy is present. The approach assumes that when canopy exists a smoothed line will lie somewhere between the canopy top and the ground. Once this line is established, the algorithm iteratively labels points above the line as canopy. This process is repeated five times to eliminate points that fall above the estimated surface as well as noise points that fall below the ground (Section 3.2.5, ATBD for ATL08).

2.3.2.6 Top of Canopy Finding Filter

The same approach used to find the ground is applied to locate the top of canopy. The de-trended data are effectively 'flipped' by multiplying the photons heights by -1 and adding the mean of all the heights back in. The same procedure described in the preceding section is then applied to locate points at the top of the canopy (Section 3.3, ATBD for ATL08).

2.3.2.7 Photon Classification

Once a composite ground surface is determined, photons are labeled as ground photons if they fall within the point spread function of the surface—approximately 35 cm rms. Signal photons that are not labeled as ground and are below the ground surface (buffered with the point spread function) are labeled as noise, but retain the signal label. The top of canopy photons that are identified are used to generate an upper canopy surface by applying a shape-preserving surface fitting method. All signal photons that are not labeled ground, and lie above the ground surface (buffered with the point spread function) and below the upper canopy surface, are labeled as canopy photons. Signal photons that lie above the top of canopy surface are labeled as noise, but retain their signal label. Signal photon classifications are stored in gt[x]/signal_photons/classed_pc_flag and use the following values: noise (0), ground (1), canopy (2), and top of canopy (3) (Section 3.4, ATBD for ATL08.)

2.3.2.8 Refining the Photon Classifications

During the first surface finding iteration, the algorithm may mislabel some photons (most likely classifying noise as canopy). After the first iteration, the algorithm then rejects photons as mislabeled based on set of criteria designed to identify statistically unlikely and unphysical canopy classifications.

In addition, photons labeled as ground are evaluated and reassigned as needed, based on the how the ground surface was determined and whether canopy photons have been detected. If no canopy photons are present for an L-km length segment, the final ground surface is interpolated from the identified ground photons and the segment receives a final round of median filtering and smoothing. If canopy photons are present, the final ground surface is interpolated based on the amount of canopy at that location along the segment and constructed iteratively as a composite of various intermediate surfaces. The ground and the canopy refinement criteria are detailed in "Section 3.5 | Refining the Photon Labels" of the ATBD for ATL08.

2.3.2.9 Canopy Height Determination

Once the final ground surface is determined, canopy heights for individual photons are computed by removing the ground surface height for that photon's latitude/longitude. These relative canopy photon height values are then used to compute the canopy statistics on the ATL08 data product. Vegetation parameters are derived at the fixed segment length of 100 m, to ensure that canopy (and terrain) metrics are consistent between segment (Sections 3.6 and 3.7, ATBD for ATL08).

3 QUALITY, ERRORS, AND LIMITATIONS

A variety of factors contribute to the accuracy of ATLAS elevation measurements and, as such, ATLAS-derived data products. These factors include the ranging precision of the instrument, orbital and geolocation uncertainties, forward scattering in the atmosphere, and uncertainty in the tropospheric path delay. ATLAS/ICESat-2 was designed to have a radial orbital uncertainty of less than 4 cm and a tropospheric path delay uncertainty of approximately 3 cm. Based on prelaunch testing, the ranging precision for flat surfaces is expected to have a standard deviation of approximately 25 cm. Note, however, that these error estimates will evolve as more ATLAS data are acquired and analyzed.

Uncertainty in computed terrain height estimates depends on the uncertainties in the ATL03 data passed to the algorithm combined with any local uncertainties within each 100 m segment, beginning with the number of photons classified as terrain photons. Potential error sources in ATL08 height retrievals are detailed in sections 1.5 — 1.8 of the ATBD of ATL08. Topics include vertical sampling error, background noise, misidentified photons, complex topography, dense vegetation, and dense and sparse canopies.

4 VERSION HISTORY

Version 1

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6 DOCUMENT INFORMATION

6.1 Publication Date

23 May 2019

6.2 Date Last Updated

25 November 2020