ATLAS/ICESat-2 L3A Sea Ice Freeboard, Version 4

USER GUIDE

How to Cite These Data

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

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL10

National Snow and Ice Data Center

TABLE OF CONTENTS

1 DATA DESCRIPTION

1.1 Parameters

Sea ice freeboard, calculated using three different approaches, plus leads used to establish the reference sea surface.

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 ATL10 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/ATL20 | 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 ATL10 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. ATL10 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.

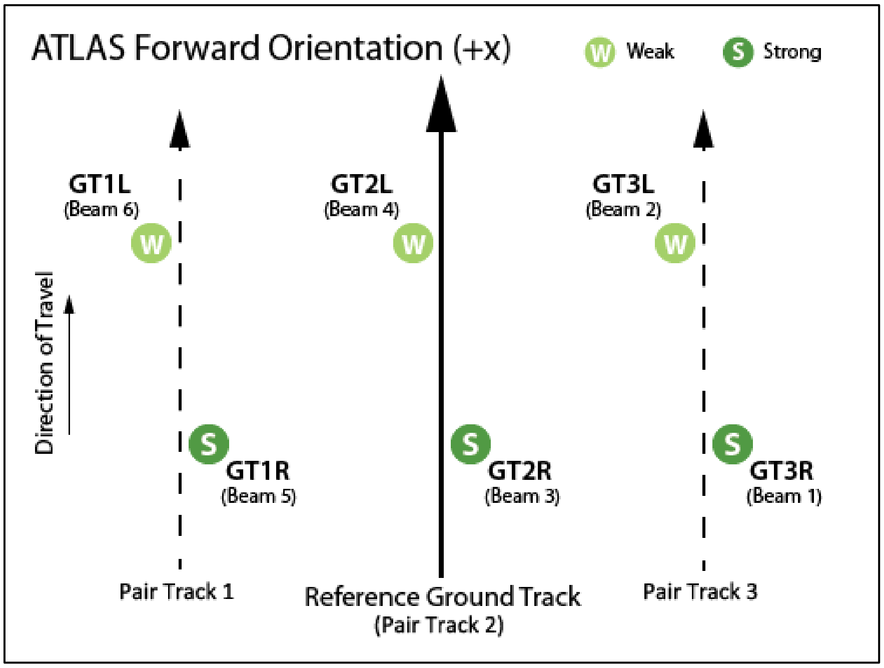

Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

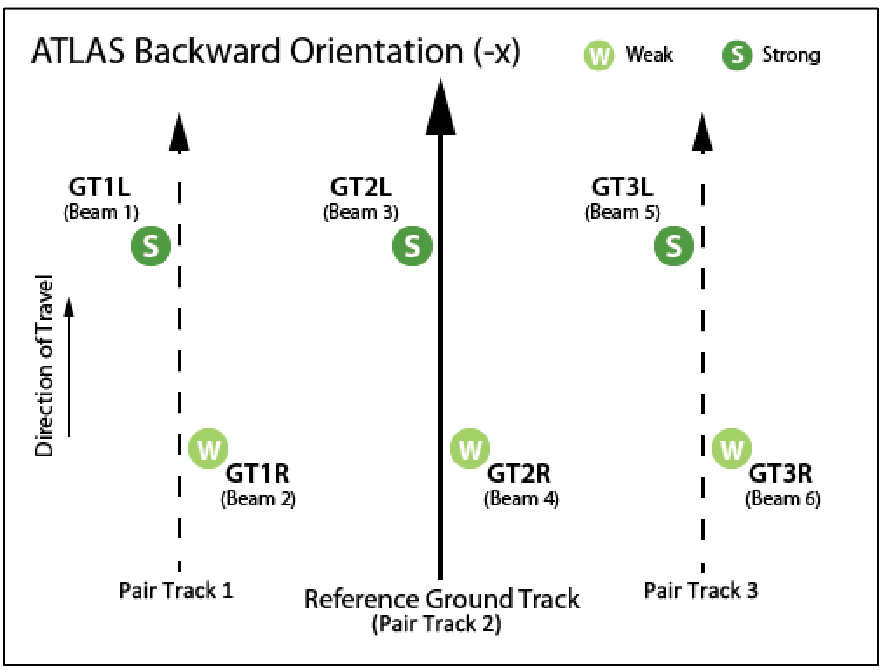

Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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 (freeboard) for one of ATLAS's 1387 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. ATL10 data files contain the top-level groups shown in Figure 3.

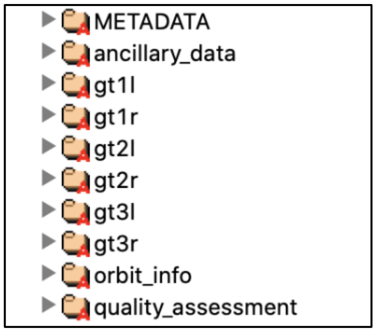

Figure 3. ATL10 top-level data groups shown in HDFView.

The following sections summarize the structure and primary variables of interest in ATL10 data files. Additional details are available in "Section 5.2 | Output of Freeboard Estimation Algorithm" and Appendix A of the ATBD for ATL07/ATL10. The ATL10 Data Dictionary contains a complete list of all ATL10 parameters.

1.2.4.1 METADATA

ISO19115 structured summary metadata.

1.2.4.2 ancillary_data

Information ancillary to the data product such as product and instrument characteristics and processing constants.

1.2.4.3 freeboard_swath_segment

WARNING: The freeboard_swath_segment group is not included in Version 4 of this product. The Science Team plans to add this group in a future version.

Parameters at the freeboard swath segment rate related to quality and corrections to the freeboard values.

1.2.4.4 gt[x]/sea_ice_segments

Six ground track groups (gt1l – gt3r), each with /freeboard_beam_segment/ and /leads/ subgroup:

- /freeboard_beam_segment/beam_freeboard/ contains the freeboard estimate and associated height segment parameters for the specified ground track. Data within this group are stored at the variable segment rate. Parameters include freeboard height for the beam (beam_fb_height); acquisition time, latitude and longitude, and distance from the equator to the segment center (seg_dist_x); plus quality indicators for the freeboard estimate.
- /leads/ contains parameters associated with the leads (sea surface height segments) used to compute the reference sea surface and local freeboard. Parameters include: acquisition times, latitudes and longitudes, lengths, heights, standard deviations, and the number and indices of height segments used as leads.

1.2.4.5 orbit_info

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

1.2.4.6 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:

- ATL10-01_20181016004646_02660101_004_01.h5
- ATL10-02_20181016004646_02660101_004_01.h5
- ATL10-[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
ATL10	ATLAS/ICESat-2 L3A Sea Ice Freeboard product
HH	Hemisphere code. Northern Hemisphere = 01, Southern Hemisphere = 02

Variable	Description
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)
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	Segment number. Not used for ATL07/ATL10. 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.

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. The following browse images are available:

1.2.6.1 Line plots (beams)

- estimate of freeboard height for the entire swath
- estimate of freeboard height for individual beams
- Number of leads (per swath)
- Number of leads (per beam)
- reference mean surface (per swath)
- reference mean surface (per beam)

1.2.6.2 Histogram

- freeboard height distribution (swath)
- freeboard height distribution (per beam)
- distribution of reference mean surface (swath)
- distribution of reference mean surface (per beam)

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

- ATL10-01_20181016004646_02660101_004_01.h5
- ATL10-01_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 includes regions in the ice-covered oceans of the Northern and Southern Hemispheres that have > 50% sea ice concentration and lie > 25 km away from the coast.

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.

Freeboard is estimated from ATL07 sea ice height segments that vary in length depending on the distance over which approximately 150 signal photons are accumulated and the availability of a reference sea surface. The along track length of these of input height segments is stored in gt[x]/freeboard_beam_segment/height_segments/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 15 July 2021

1.4.2 Resolution

Each of ICESat-2's 1387 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:

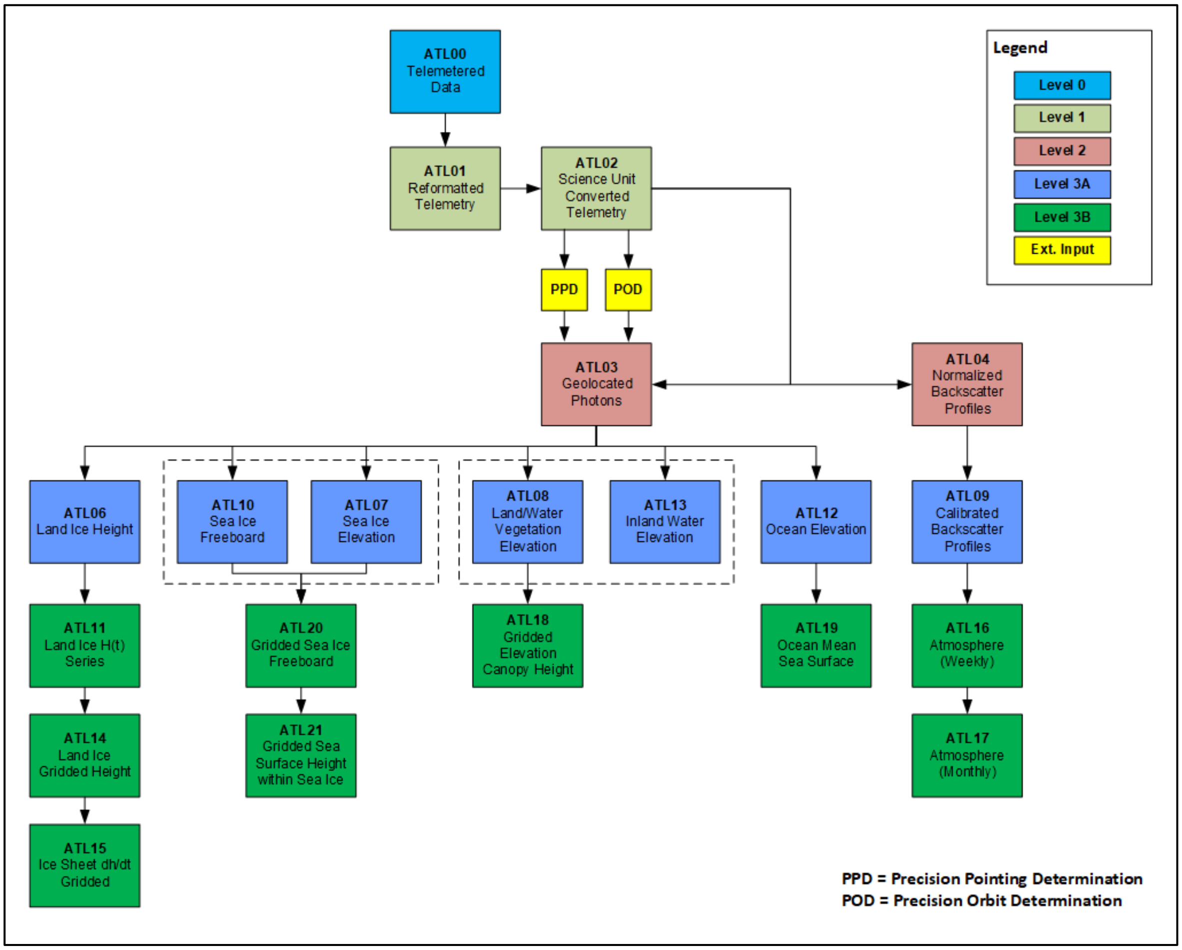

Figure 4. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination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

NOTE: The following description briefly outlines the inputs, product coverage, and approach used to generate the ATL10 product. ATL10 is derived predominantly from ATL07, the ATLAS/ICESat-2 L3A Sea Ice Height product. Users seeking a detailed description of how ATL10 along-track freeboard is generated should consult "Section 4 | Algorithm Description: ATL07" and "Section 5 | Algorithm Description: ATL10" of the ATBD for ATL07/ATL10/ATL20.

2.2 Acquisition

Along-track, sea ice freeboard is estimated for every sea ice height segment computed in ATL07. These segments are passed to ATL10 along with available sea surface height segments (leads) that are flagged by ATL07 as suitable for establishing a local, reference sea surface height that can be used to compute freeboard. The along-track length of the ATL07 sea ice segments is determined by the distance over which approximately 150 signal 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 (the ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics data product) and height estimates are not produced for segments contaminated by clouds.

2.3 Processing

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 in ATL07/ATL10.

2.3.2 Freeboard Estimation

The ATL10 product contains sea ice freeboard calculated in three different ways, each determined inside swath segments that are 10 km along-track (nominally) and 6 km across-track (the span of the six beams). These freeboard swath segments contain the leads that are used to establish a sea surface reference for each type of freeboard calculation. The first type is a mean freeboard height (/freeboard_swath_segment/fbswath_fb_height) for the entire freeboard swath, based on a reference surface computed as the weighted mean of all the leads within that freeboard swath. The second type is a freeboard height for each ATL07 sea ice height segment within the freeboard swath (across all six beams) based on the same reference surface (/freeboard_swath_segment/gt1l/swath_freeboard/fbswath_fb_height). The third is a freeboard height computed for each ATL07 sea ice height segment based on a beam reference surface (/gt[x]/freeboard_beam_segment/beam_freeboard/beam_fb_height) determined by using only the leads along the beam (each beam has its own reference surface). For convenience, ATL10 also maintains the ATL07 segment heights used for the freeboard calculations. (see "Section 5.1 | Basis for freeboard estimation" and "Appendix K | Organization of lead data in ATL10" in the ATBD for ATL07/ATL10 for details).

The algorithm first finds the leads—collections of height segments flagged[1] by ATL07 as sea surface—and then uses the leads to estimate the height of a reference surface for computing the local freeboard over a region of 10-km extent. To construct the reference surface, each L-km long segment is first estimated for each beam and the results then synthesized across all six beams to

[1]gt[x]/freeboard_beam_segment/height_segment_ssh_flag=1

create a single L-km long reference surface for each L-km segment. Freeboards are then calculated from the individual height-segments using the sea surface references (per beam and for all the beams). The output is a swath segment that contains freeboards and freeboard distributions from all six beams (i.e. 3 beam pairs). The relationship between sea surface height segments (SSHseg), leads, and the reference surface (refsurf) is shown in the following figure:

Erroneous reference surfaces are filtered out by identifying the conditions where the reference surface observations are near to land and/or in areas of low ice concentration (sea state influences the reference surface near the ice edge, resulting in surfaces that can be many 10s of centimeters below the local mean sea surface). This filtering procedure is designed to use collections of reference surfaces within ATLAS sub-regions (approximately 20 degrees of latitude). As multiple ATL03 granules can be processed into one ATL07 and ATL10 granule, the algorithm uses the defined latitude boundaries and increasing/decreasing latitudes (i.e., ascending/descending tracks) in time to delineate these regions.

Analysis of reference surfaces in the Northern Hemisphere are performed within the following latitudinal bounds:

- 27° < latitude < 60° and Δlatitude increasing (ascending tracks);
- 60° < latitude < 80° and Δlatitude increasing (ascending tracks);
- Latitude > 80°;
- 60° < latitude < 80° and Δlatitude decreasing (descending tracks);
- 27° < latitude < 60° and Δlatitude decreasing (descending tracks).

Analysis of reference surfaces in the Southern Hemisphere are performed within:

- -79° < latitude < -50° and Δlatitude decreasing (descending tracks);
- -79° < latitude < -50° and Δlatitude increasing (ascending tracks).

Further details about the filtering procedure are provided in Section 5 of the ATBD for ATL07/ATL10 under the unnumbered heading "Procedure to Filter and Fill Missing Surface Reference (refsurf) Estimates Along Track." For a list of parameters output by the freeboard algorithm, see "Section 5.2 | Output of Freeboard Estimation Algorithm" in the ATBD for ATL07/ATl10.

2.4 Quality, Errors, and Limitations

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.

For additional details, see "Section 2.2.5 | Potential Error Sources in the ATBD for ATL07/ATL10/ATL20."

3 VERSION HISTORY

Version 4 (April 2021)

Changes for this version include:

- Implemented freeboard beam along-track slope for ATL10; referenced surface along-track slope is now reported on ATL10.
- The default value of the controllable parameter height_segment_fit_quality_flag_max has been updated/set to 4.
- The default values of upper and lower bounds of the freeboard reference surface and ht_thresh2 have been updated to match the ATBD for ATL07/ATL10/ATL20 V04 ATBD.
- Mean sea surface, geoid, and height data products are placed into a consistent tide-free system. Free-to-mean tided conversion factors are included to easily change to mean tide system.

4 CONTACTS AND ACKNOWLEDGMENTS

Ron Kwok

Jet Propulsion Laboratory

California Institute of Technology

Pasadena, CA 91109

Alek Petty

NASA Goddard Space Flight Center

Greenbelt, MD 20771

Glenn Cunningham

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Thorsten Markus

NASA Goddard Space Flight Center
Greenbelt, MD 20771

David Hancock

NASA Goddard Space Flight Center
Greenbelt, MD 20771

Alvaro Ivanoff

ADNET Systems, Inc.
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Jesse Wimert

Stinger Ghaffarian Technologies, Inc
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Marco Bagnardi

NASA Goddard Space Flight Center
Greenbelt, MD 20771

Nathan Kurtz

NASA Goddard Space Flight Center
Greenbelt, MD 20771

5 DOCUMENT INFORMATION

5.1 Publication Date

13 April 2021

5.2 Date Last Updated

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