ATLAS/ICESat-2 L3A Along Track Inland Surface Water Data, Version 6

USER GUIDE

How to Cite These Data

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

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FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL13

National Snow and Ice Data Center

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1   DATA DESCRIPTION

1.1 Parameters

Along-track surface water products for inland water bodies. Water bodies include lakes, reservoirs, bays, estuaries, and rivers, and a 7 km near-shore buffer. Principal data parameters include the along-track water surface height and standard deviation, subsurface signal (532 nm) attenuation, significant wave height, wind speed, and coarse depth to bottom topography. Water surface heights are provided as both height above the WGS 84 ellipsoid (ITRF2014 Reference Frame) and height above the Earth Gravitational Model 2008 (EGM2008) mean sea level (MSL).

1.2 File Information

1.2.1   Format

Data are provided as HDF5 formatted files.

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 ATL13 data product is described in detail in the ICESat-2 Algorithm Theoretical Basis Document (ATBD) for Along Track Inland Surface Water Data (ATBD for ATL13 | V06, https://doi.org/10.5067/03JYGZ0758UL).

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) 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 ATL13 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 Figure 1). 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, left). 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 1, right). The first yaw flip was performed on 28 December 2018, placing the spacecraft into the backward orientation. ATL13 reports the spacecraft orientation in the sc_orient parameter stored in the /orbit_info/ data group (see Section 1.2.4 Data Groups). 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. During nominal operating conditions onboard software aims the laser beams so that the RGT is 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 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 by appending the two-digit cycle number (cc) to the RGT number, e.g., 0001cc to 1387cc.
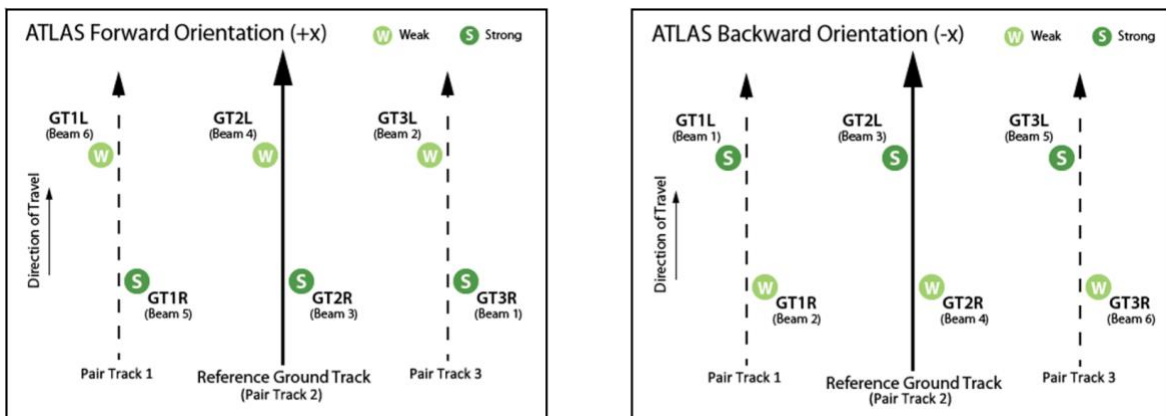

Figure 1. Spot and ground track (GT) naming convention with
ATLAS oriented in the forward (instrument coordinate +x) direction
and backward (instrument coordinate -x) direction.

Under normal operating conditions, data are not 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 PPD and 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 offset at some distance from the RGTs instead of along the nominal RGT. Although not along the nominal RGT, the geolocation information and data quality for these data are 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.

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.

Various reference systems and dynamic processes, or geophysical corrections, occur during an ATLAS/ICESat-2 measurement (Figure 2). Table 1 lists the corrections needed for each surface type and ICESat-2 product. For example, to determine an estimate of the mean sea surface, several well-modeled, time-varying effects must be accounted for.
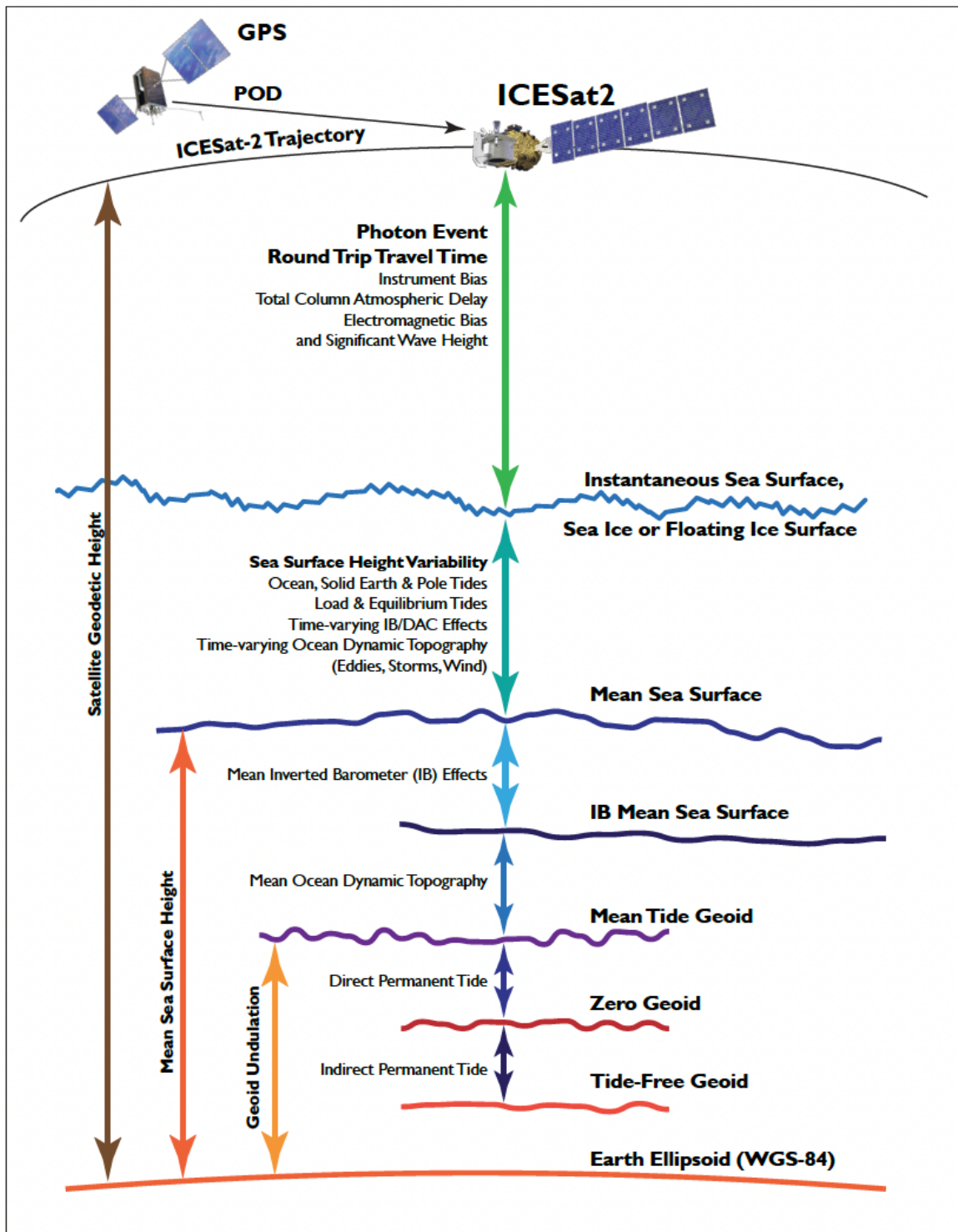
Figure 2. Geophysical corrections used in satellite altimetry. Taken from *ICESat-2 Data Comparison User's Guide for Rel006* available on the ATL03 data set landing page.

Table 1. Geophysical Corrections Applied to ICESat-2 Products

ICESat-2 Products by Surface Type	Geophysical Corrections[1]
Photon-level product (ATL03) (i.e., corrections applicable across all surface types)	Ocean loading Solid Earth tide Solid Earth pole tide Ocean pole tide Total column atmospheric range-delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Inverted barometer (IB)
Ocean (ATL12)	Ocean tide Long period equilibrium ocean tide

[1]For details, see Section 5 of the *ICESat-2 Data Comparison User's Guide for Rel006* available on the ATL03 data set landing page.

1.2.3   File Contents

Data files (granules) contain inland water body surface heights acquired during four of ATLAS's 1,387 orbits.

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. ATL13 data files contain the top-level groups shown in Figure 3:
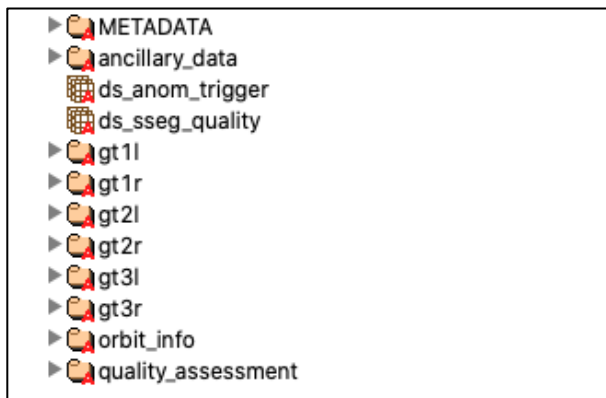

Figure 3. ATL13 data groups shown in HDFView.

The following sections summarize the structure and primary variables of interest in ATL13 data files. For a complete list of parameters, see the ATL13 Data Dictionary, available under Documentation on the data set landing page.

1.2.4.1 METADATA

ISO19115 structured summary metadata for the granule, including content that describes the required geospatial information.

1.2.4.2 ancillary_data

Information that is ancillary to the data product. This may include product and instrument characteristics and/or processing constants.

1.2.4.3 gt1l–gt3r

Six ground track groups (gt1l–gt3r) that contain the per-beam data parameters for the specified ATLAS ground track. Parameters of interest include:

- Water surface height (`ht_water_surf`) above the WGS 84 ellipsoid;
- Orthometric surface height (`ht_ortho`), i.e., height above the EGM2008 MSL;
- Geoid value at short segment reporting location (`segment_geoid`);
- Water body type (`inland_water_body_type`); size (`inland_water_body_size`); shape mask source (`inland_water_body_source`); and water body ID (`inland_water_body_id`). When concatenated, these four values uniquely identify each water body (See "4.7.1.2 | Water Body Reference Identification Scheme" in the ATL13 ATBD).
- Short segment length flag (`qf_sseg_length`);
- Mean latitude (`sseg_mean_lat`), longitude (`sseg_mean_lon`), and time (`sseg_mean_time`) of short segment signal qualified photons
- Short segment, along-track, water-body surface slope (`segment_slope_trk_bdy`)

The gt[x] groups also contain standard deviation, subsurface signal (532 nm) attenuation, significant wave height, wind speed, and coarse depth to bottom topography.

1.2.4.4 orbit_info

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

1.2.4.5 quality_assessment

Quality assessment data for the granule as a whole, including a pass/fail flag and a failure reason indicator.

1.2.5   Naming Convention

Data files utilize the following naming convention:

`ATL13_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5`

Example:

`ATL13_20181019212951_03250101_006_01.h5`

The following table describes the file naming convention variables:

Table 2. File Naming Convention Variables and Descriptions

Variable	Description
ATL13	ATLAS/ICESat-2 L3A Along Track Inland Surface Water Data
yyyymmdd	Year, month, and day of data acquisition
hhmmss	Data acquisition start time, hour, minute, and second (UTC)
tttt	Four-digit RGT number of the first of four tracks in the granule. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
cc	Cycle Number. 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 ATL13. Always 01.[1]
vvv_rr	Version and revision number[2]

[1]Some ATLAS/ICESat-2 products (e.g., ATL03) are provided as files that span 1/14th of an orbit. As such, these products' file names specify a segment number that ranges from 01 to 14. Because ATL13 data files span four full orbits, the segment number is always set to 01.

[2]From time to time, NSIDC receives 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. 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 file level 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 JPGs that contain images designed to quickly assess the location and quality of each granule's data. Browse images include water surface orthometric height (`ht_ortho`) and granule ground track location and coverage (`groundtrack`).

Browse files utilize the same naming convention as their corresponding data file but with "_BRW"
and descriptive keywords appended.

1.3 Spatial Information

1.3.1 Coverage

Spatial coverage spans approximately 88° N latitude to 88° S; however, the focus of ATL13 is high-
latitude terrestrial regions where the convergence of the ICESat-2 orbits provides spatially dense
observations in the pan-Arctic region. Water surface height processing is constrained by an inland
water mask (see Section 2.3.1 Water Masks).

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 individual signal photons varies.

Inland water heights are processed in segments that contain a minimum of approximately
100 signal photons, except rivers which only require 75. As such, the segments vary in length from
approximately 30 m to several hundred meters, depending on factors such as signal quality
and water and atmospheric conditions.

1.3.3 Geolocation

Latitudes and longitudes refer to the WGS 84 coordinate system. Water surface heights are
provided as both heights above the WGS 84 ellipsoid (ITRF2014 Reference Frame) and as heights
above mean sea level (EGM2008). 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 ensemble
Ellipsoid/spheroid	WGS 84

Geoid	EGM2008
Units	degrees
False easting	N/A
False northing	N/A
EPSG codes	4326 (WGS 84) 3855 (EGM2008)
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326 (WGS 84) https://epsg.io/3855 (EGM2008)

For information about ITRF2014, see the International Terrestrial Reference Frame | ITRF2014 webpage.

1.4 Temporal Information

1.4.1 Coverage

13 October 2018 to present

1.4.2 Resolution

Repeat observations for any given water body depend on its size and geographic location. The frequency at which ATLAS/ICESat-2 crosses inland water bodies depends on how often the spacecraft's orbital pattern intersects with the water body mask. For high-latitude polar regions (approximately ±65°), the mission requirements mandate repeat observations every 91 days along the precisely established reference tracks (i.e., the satellite has a 91 day repeat cycle). However, starting with cycle 04 (28 June 2019), ATLAS/ICESat-2 began conducting a systematic off-pointing scenario at lower latitudes that is designed to achieve approximately 2 km global spacing after two years of data acquisition.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The ATL13 product is derived primarily from geolocated, time-tagged photon heights and other parameters passed from the ATLAS/ICESat-2 L2A Global Geolocated Photon Data (ATL03) product. The following figure illustrates the suite of ICESat-2 data products:
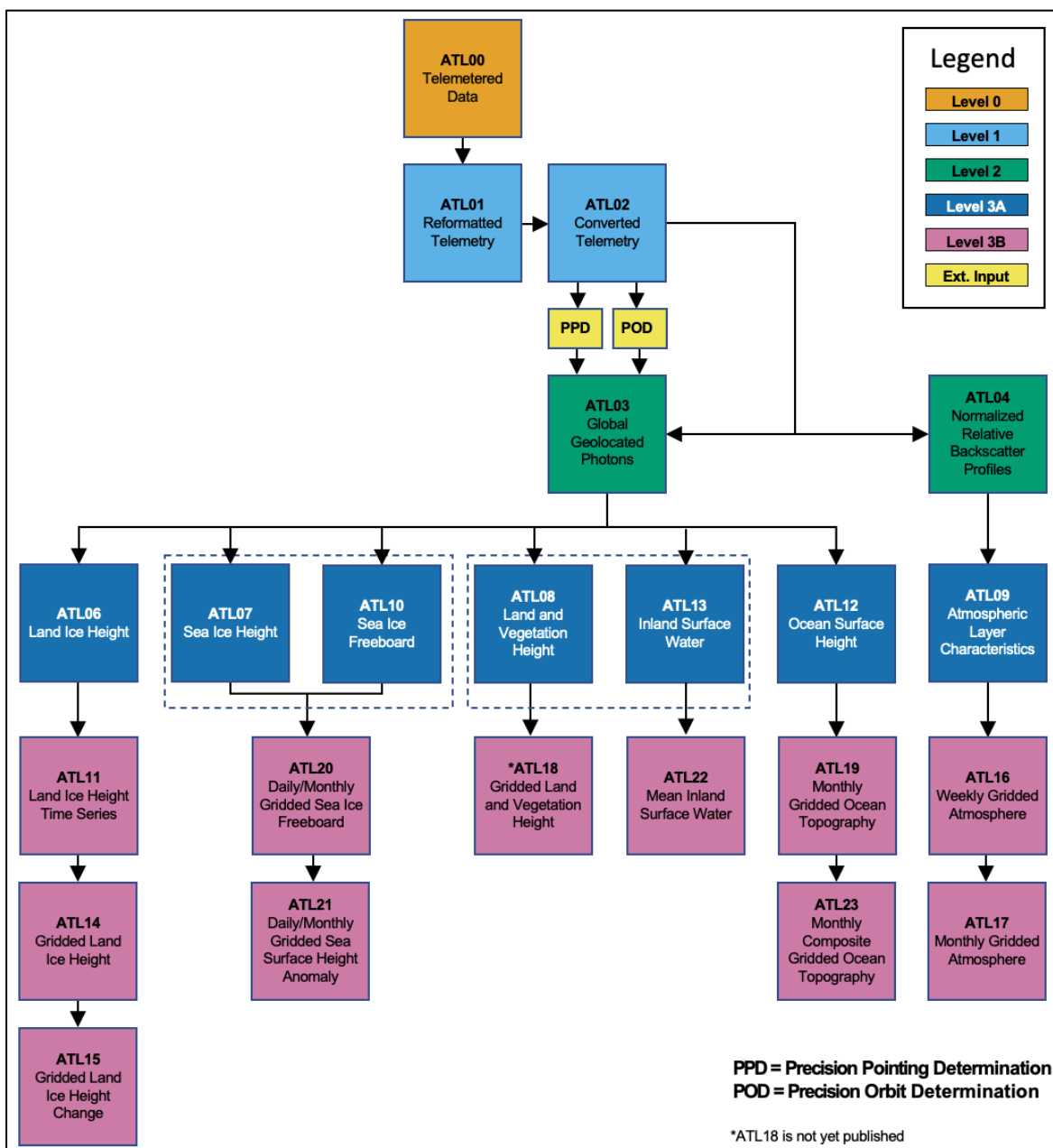
Figure 4. ICESat-2 data processing flow. The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time. ATL03 acts as the bridge between the lower level, instrumentation-specific products and the higher-level, surface-specific products.

2.2 Acquisition

Inputs from ATL03 product include precise latitude, longitude, and height for every received photon, plus applied geophysical corrections such as Earth tides and atmospheric delays. Each

photon is also classified as signal or background and by surface type (land ice, sea ice, land, ocean, and inland water).

> NOTE: The following sections summarize the approach used to generate the ATL13 product. For a complete description of the theory and algorithm, consult the ATBD for ATL13.

2.3 Processing

2.3.1   Water Masks

Water masks help organize the inland water data and constrain processing to only those land and coastal regions that possess water bodies. ATL13 relies on three types of hydrologic masks:

- ATL03 Inland Water Mask (applied to input data)
- ATL13 Regional Basin Mask
- ATL13 Inland Water Body Mask

The **ATL03 Inland Water Mask**, shown in Figure 1, extracts data for analysis only from those areas required for inland water analysis (Section 3.4, ATBD for ATL13).
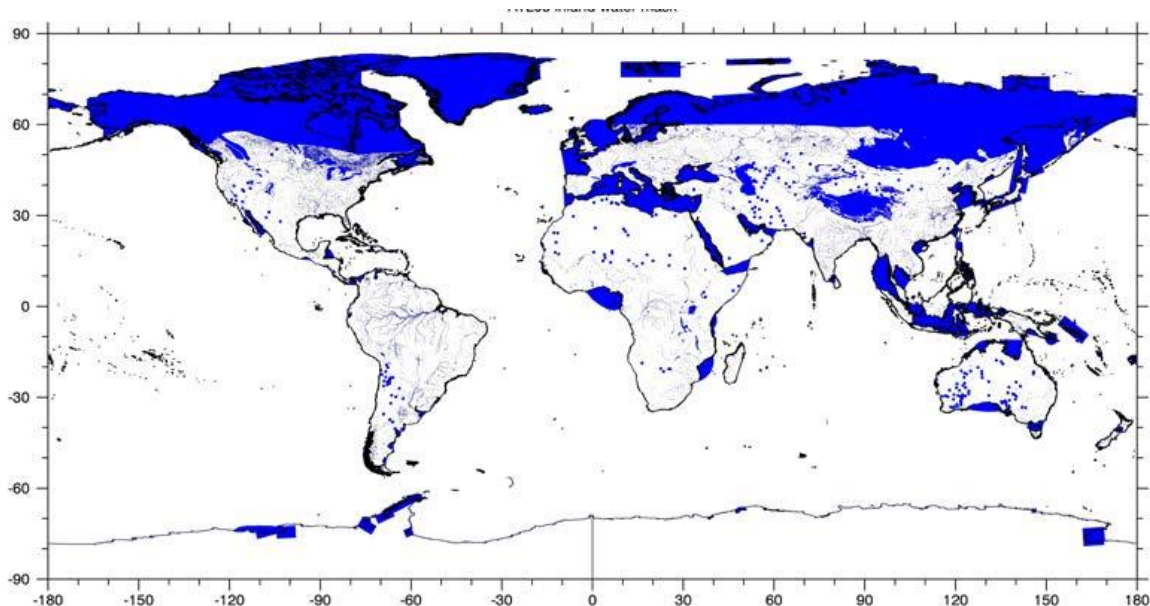

Figure 1. ATL03 Inland Water Mask. Observations that fall within shaded areas (blue) are flagged as water bodies.

This 0.1 km^2 gridded mask was developed from a number of coastline and inland water databases including the Global Self-consistent, Hierarchical, High-resolution Geography (GSHHG) coastlines database and various lake shapefiles, including ephemeral lakes, permafrost extent, and custom shapes created to close larger bays in locations not otherwise addressed.

The **ATL13 Regional Basin Mask** comprises polygons that represent principally the outline of entire large river basins plus some adjacent intervening area. Each polygon contains all the lakes and rivers within that river basin and logically organizes the ATLAS data used to produce the hydrologic products (Section 3.5, ATBD for ATL13).

The **ATL13 Inland Water Body Mask** identifies ICESat-2 crossings over individual water bodies. It was designed to delineate the shape and spatial distribution of contiguous individual water bodies, such as lakes, reservoirs, and rivers, and is applied as a shapefile—unlike the gridded ATL03 mask flag described above. The shape mask consists of polygons that each represent an entire single lake, reservoir, river segment and tributaries, bay, or 7 km wide coast segment. An approximately 100 m buffer is extended over land to clearly distinguish the land/water interface. Each water body is identified by a unique number, latitude and longitude, and local name if available (Section 3.6, ATBD for ATL13).

2.3.2   Surface Height Algorithm

The goal of ATL13 is to estimate the mean water surface height in short, statistically representative segments (75–100 signal photons) for each ATLAS beam that crosses a water body in the along-track direction. Thus, computing inland water heights requires distances of at least 100 m, depending on atmospheric, solar, and water conditions. In addition, although the majority of the signal photons that return to ATLAS from a given water body are reflected from the surface, typically a percentage comprise subsurface backscatter. As such, prior to computing the short segments, the algorithm analyzes longer segments (1 to 3 km), which contain a sufficient number of subsurface photons to estimate the volume scattering parameters. The ATL13 product combines physical and statistical modeling approaches to characterize key physical processes related to open water surface dynamics and light propagation and to retrieve inland water heights from (primarily) ATL03 data.

In brief, the algorithm 1) identifies the beginning and ending edges where individual ATLAS beams intersect a contiguous water body; 2) models the reflectance components that contribute to the integrated signal return from the water body; 3) analyzes models of the surface water height statistical distributions, subsurface volume attenuation, and their relation to the distribution of the signal photons from water surface facets; 4) removes background photons to extract the true representation of water reflectance and height; 5) deconvolves the ATLAS instrument response function from the observations; 6) computes along-track statistics (surface water height, subsurface attenuation, coarse-resolution water depth, significant wave height, and the mean and maximum along-track water surface slope and azimuth from the two adjacent strong beams), and 7) evaluates the accuracy and quality of the measurement.

The following sections outline the major components used to estimate inland water heights in ATL13. For additional details, consult the referenced sections in the ATBD for ATL13. The algorithm implementation is described in Section 4.0.

2.3.2.1 Inland Water Backscatter

"Section 4.2 | Satellite Inland Water Backscatter Model" in the ATBD for ATL13 describes the approach used to model inland water backscatter. It includes sections that discuss the water surface specular model (4.2.1), the water surface foam model (4.2.2), the volume scattering model (4.2.3), bottom reflectance (4.2.4), the relative magnitude of anticipated returns (4.2.5), and required atmospheric and meteorological inputs (4.2.6).

2.3.2.2 Water Surface Height

"Section 4.3 | Water Surface Height Model" discusses the approach used to differentiate signal photons associated with water height, including subsections that address removing signal photons not associated with water surface height (4.3.1), estimating the background and signal to background noise ratio (4.3.2), estimating water surface height and slope (4.3.3), and estimating the water surface slope variance (4.3.4).

2.3.2.3 ATLAS Instrument Response Function

"Section 4.4 | Instrument Response Function (Transmitted Pulse Shape)" and "Section 4.5 | Deconvolution of Instrument Response from Lidar Returns" describe the approach used to deconvolve the instrument response function (or histogram) from the observed histogram to extract the actual water response histogram.

2.4 Quality, Errors, and Limitations

Data quality in this product depends largely on the precision of the georeferenced photons input from ATL03 and associated products evaluated prior to use by the ATL13 algorithm. The overall ensemble error per 100 inland water photons is estimated to be 6.1 cm. This calculation is detailed in "Section 4.9.1 | ICESat-2 Precision" in the ATBD for ATL13.

The Inland Water Team will be evaluating error in this product as more data are acquired. "Section 4.9.2 | Data Product Evaluation" in the ATBD describes the Inland Water Team's plan to assess ATL13 data quality in conjunction with relevant U.S. agencies, organizations, and university researchers.

3   VERSION HISTORY

A summary of the version history is provided in Table 4.

Table 4. Version History Summary

Version	Release Date	Description
V1	May 2019	Initial release
V2	October 2019	Refer to V2 User Guide
V3	June 2020	Refer to V3 User Guide
V4	July 2021	Refer to V4 User Guide
V5	December 2021	Refer to V5 User Guide
V6	June 2023	• Modified the computations of the deconvolution of subsurface backscatter profile (Section 4.5.3, ATBD for ATL13) and deconvolution of surface water profile (Section 4.5.4, ATBD for ATL13) • Expanded iteration range of subsurface parameters within deconvolution scheme and added quality flags • Added surface quality flags (Section 4.8.12, ATBD for ATL13) • Defined end of partial short segments as the final signal photon • To avoid inadvertently capturing subsurface photons associated with bottom reflection and machine error, such photons are further screened and removed from processing using a mirroring approach applied to the water surface • Replaced "crossing-number" algorithm with "winding number" algorithm for better determination of ICESat-2 transects within the inland water mask shapes
V6.1	May 2024	Data from 13 November 2022 to 26 October 2023 were reprocessed using ITRF2014 (replacing ITRF2020) for consistency across the entire data set.

4   DOCUMENT INFORMATION

4.1 Publication Date

June 2023

4.2 Date Last Updated

May 2024