

Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2)

ATL22 Along Track Surface Water Data, Release 004

Algorithm Summary and Known Issues

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Introduction

This document contains algorithm notes and possible known issues that may occur in the data product, as identified by developers of the ICESat-2 ATL22 Release 4 Mean Inland Surface Water Data product. For a detailed description of the theoretical algorithm and its implementation please refer to the ATL22 Algorithm Theoretical Basis Document (ATBD) Release 4 (Jasinski et al., 2025). The ATL22 ATBD includes background (Chapter 2) theoretical underpinnings of the algorithms together with their testing on ATLAS or ATLAS prototype data (Chapters 3 and 4), a description of the code and list of the specific ATL22 input and output product tables (Chapter 5), and a list of calibration and validation background and opportunities (Chapter 6). The list of specific variables and products associated with the latest ATL22 version is provided in Tables 5.1 to 5.4. A summary of the principal updates of each release is provided below in Table 1-1 below. ATL22 Rel 4 supersedes all previous versions and is updated with each release to include corrections, new features and capability.

ATL13/22 Version	Release Date	Water Body Types (Number of unique IDs)	Description and Principal Added Features (See details in Change History Log)
ATL13v1	May 2019	Lakes & reservoirs > 10 km ² (19,634)	<u>Continuous, along track surface water products</u> including - subsurface attenuation and supporting data. - reported at short segment length - Employs GLWD (Lehner & Doll 2004)
ATL13v2	Nov 2019	Adds water bodies (count): -Lakes & reservoirs ≥ 10 km ² (19,800) -Estuaries, bays, and 7m near shore buffer (~3500)	- Employs HydroLAKES (Messenger & Lehner, 2016) - Adds transitional waters; Named Marine Water Bodies (ESRI) GSHHG Shoreline (Wessel et al, 1996) - Adds significant wave height, coarse bathymetry algorithm - Adds dynamic shore finding
ATL13v3	Mar 2020	Adds water bodies (count): -Lakes & reservoirs ≥ 0.1 km ² (~1,400,000) -Rivers ≥ ~50-100 m wide (10,300)	- Adds river mask using GRWL (Allen and Pavelsky, 2018) - Adds wind speed for all crossings - Adds Ice on/off flag from multi-sensor NOAA product - Corrects first photon bias error, Adds cloud confidence flag
ATL13 V4 & v5	Apr/Nov 2021	All above water bodies	- Improves photon classification - Improves accuracy of existing data products - Reports additional products
ATL22 v1&2	Dec 2021	All water bodies	- <u>Mean surface water</u> and supporting products including crossing length - Reported for each transect (uninterrupted water crossing)
ATL13v6	Aug 2023	All water bodies	- Improves accuracy by eliminating anomalous photons. Added "2" in Eqn 4.11 & 4.12 to accommodate 2-way attenuation. Reports additional quality flags. - Replaced crossing number algorithm w/winding number. Expanded Table 5-3. Improved deconvolution water profiles Eqn 4.11 & 4.12.
ATL22v3	Aug 2023	All water bodies	- Improves mean surface water product estimates removing anomalies
ATL13v7	Dec 2024	All water bodies	- Added quality flags in Sec 4.8.1.12. Implemented mirroring approach to Sects 4.5.5.2 and 5.3.C. Updated subsurf Equations 4.11/12. Added MLE 4.12b. Included plain language summary in Chap 5. Improved bathymetry calc, removed instrument effects, min number of bathy photons, density thresholds. Updated min mirror count for coastal waters.
ATL22v4	Dec 2024	All water bodies	Added along track slope and rmse, ortho hgt, skew, kurtosis for lakes & reservoirs; mean MLE; crossing slope for rivers; exclusion of invalid slope calcs.

Table 1-1 Summary of Principal Features of the ATL13 and ATL22 Inland Surface Water Data Products

ATL13 reports high resolution along track scattering and altimetry products for each transected water body. Validation of ATL13 and ATL22 is especially challenging given the scope of analyses that i) computes over 25 surface and subsurface inland water outputs and quality flags under a range of atmospheric and water conditions, and ii) covers the global domain with nearly 1.5 million unique water body shapes including lakes, reservoirs, rivers, estuaries and coasts, embedded within different climate, land cover, and topographic environments.

Summary Features of ATL22 Rel 4 Inland Surface Water Algorithm

The ATL22 algorithm processes global inland water body height products and associated products from georeferenced photons obtained from ATL03. The algorithm processes the global ATL13 and ATL22 inland water body algorithms for each orbit, completely analyzing all the ground tracks of one water body before proceeding to the next. Inland water bodies are delineated by shape files defined for different water body types in the ATL13/22 Water Body Shape mask.

The principal data product for each water body type consists of along-track mean height, significant wave height, slope, wind speed, 532nm attenuation coefficient and bottom anomaly (if observed), and other products, for short segment lengths of each strong and weak beam. All ATL13 data products are reported for each beam at the along track, short-segment rate. Products are generally processed in segments of 75-100 returned signal photons. Due to water and meteorology conditions, the resulting reported products of segment length varies from approximately 30 to 150 meters.

The companion ATL22 Mean Inland Surface Water Data products (Jasinski et al., 2025) are computed for each uninterrupted crossing segment, reporting similar only those relative to the mean crossing scale. Water elevation data products are analyzed in orthometric units. Thus, data obtained from ATL03 in WGS84 ellipsoid reference data are converted to the EGM2008 Geoid.

Water bodies often have irregular shapes including dendritic or branching patterns. When an ATLAS transect crosses over one branch of a given water body (completely entering and exiting), then crosses another branch of the same water body (completely entering and exiting), the ATL13 analyses treats and reports each beam crossing as separate (not connected to the first crossing), even though the water body ID is the same.

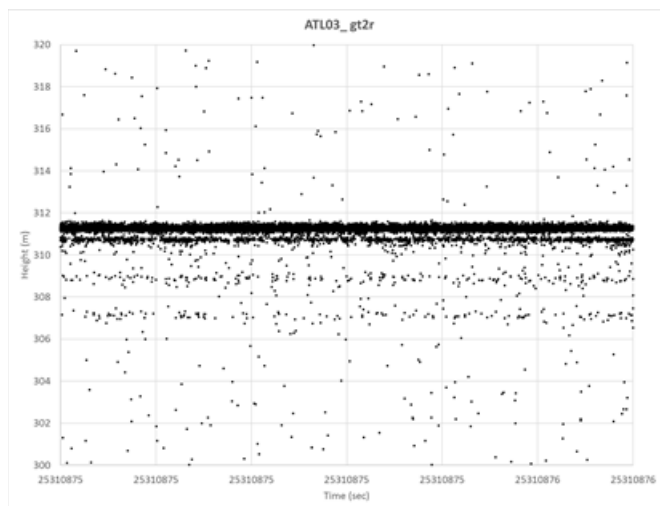
Analyses occurs as follows: The heights of long segment lengths equaling 10 sequential short segments (~1000 signal photons) are computed including deconvolution of the satellite IRF and apparent observed water body height histogram. The true height of each short segment is estimated based on the mean deconvolved height plus all electromagnetic and fit biases. Very long segments composed of 30 subsequent short segments (~3000 signal photons) are required for estimation of the subsurface attenuation. For additional details, please refer to the ATL13 ATBD (Jasinski et al., 2025a), ATL13 products (2025b), and the ATL22 ATBD (Jasinski et al., 2025c) and ATL22 products (2025d).

Known Issues

Herein, only the more frequent “known” issues are identified. Even these, however, occur in less than a few percent of the transects. Most transects provide a highly accurate suite of data products. Current known issues that are due to ATL13 processing may be addressed in future product releases, although this is not currently envisioned. The ATBD authors therefore welcome from all users any questions, feedback, or any new issues regarding this product.

Issue 1. Distorted surface return over some water bodies with very high reflectance due to first photon bias and dead time.

Occasionally, over calm or highly reflective water surfaces, there is a high photon surface return that ATLAS can only partially record due to detector limitations, leading to striping of the returns. In the figure below, the gap just under the top surface return is attributed to dead time, while the deeper striping is due to instrument afterpulses. The gap in the true full surface return usually occurs about 1 m below the surface, in both the weak and strong beams, resulting in a positive bias of the surface elevation. Also, often occurring in these situations are faint afterpulses at depths of about 2.2 and 3.9m. ATL13 partially corrects the height using the ATL03 CAL19 first photon bias correction algorithm. The ICESat-2 Project Office analyses are addressing this issue by assigning confidence values in the ATL03 photon product. Future ATL13 and ATL22 processing will incorporate these confidences as they are made available.



Issue 2. Snow and ice on water bodies

In ATL13, snow and ice on inland water bodies are not explicitly identified, which impacts on ATL22. Thus, the retrievals apply the same inland water algorithm throughout. While not

corrected, to offset this issue, ATL13 does provide a NOAA-derived snow and ice flag, retrieved from ATL09 and resampled at the ATL13 short segment rate. The NOAA map is based on published daily Interactive Multisensor Snow reports. Users who download ATL13 and 22 water body heights during a period when snow and ice is possible should check the ATL13 Snow and Ice flag (snow_ice_ATL09) reported in the ATL13 output. When the flag is set at 2 or 3, ATL13 results should be regarded with caution as they may not represent open water.

Issue 3. Inter-beam calibration not available

Currently, ATLAS calibration occurs only at the instrument level, not individual beams. Inter beam variations in height over level surfaces on the order of centimeters are known to exist but have not been fully evaluated by the ICESat-2 Project Office, especially in the lower and mid latitudes.

Issue 4. ATL13 overlapping water bodies

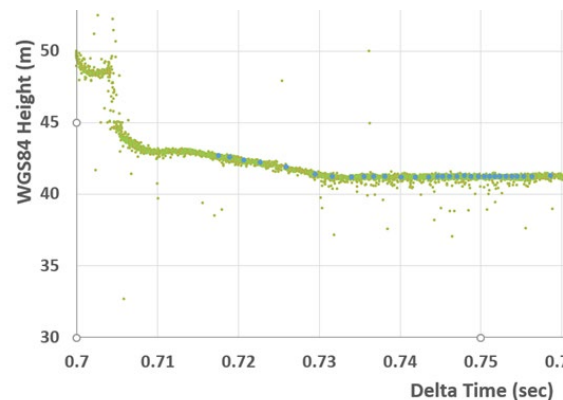
The ATL13 Inland Water Body Shape Mask, also used by ATL22, facilitates identification of ICESat-2 crossings over individual water bodies, by delineating the shape and spatial distribution of contiguous individual water bodies. It is a composite mask derived from various published sources, and includes lakes, reservoirs, rivers, and transitional waters including estuaries and bays, and near shore coastal waters. Details are provided in the ATL13 ATBD.

While the mask works very well in most cases, in areas of high water body density (E.g. multiple small lakes within a few tens of square kilometers), the buffering of bodies and different interpretation of boundaries by different sources can cause shapes in the ATL13/22 Inland Water Body Mask to overlap. River overlaps of lakes were specifically removed to allow the lakes in those cases to be seen in their entirety, but in the cases of other body type overlaps, Body 1 will be fully processed and then the processing of Body 2 will begin only after Body 1 was exited. Thus, the overlapped portion of Body 2 may be incorrectly assigned as the final transect(s) in Body 1 and/or not processed at all depending on the nature of the terrain. Both overlaps and interruption might also cause a broken flow in the output for an individual water body where, for example, a lake in the middle of a river shape might cause the report of two transects of the river to be separated by that of a lake in between them. Still, this occurrence is rare.

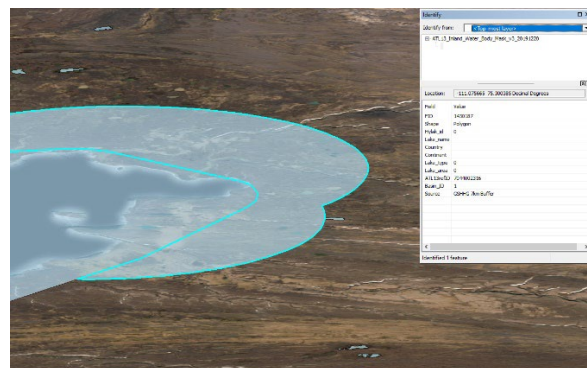
Issue 5. Land area adjacent to water bodies

Occasionally, ATL13 will incorrectly identify land along the edge of a water body as water surface which will produce ATL13 output over the land and thus impact the ATL22 mean height. This may occur when the adjacent land is less than several tens of cms higher than the true water surface. This release does not include a flag indicating the likelihood of a body edge segment being land. However, a user can in most cases make an accurate determination based

on the edge height relative to a segment located further inside the body. Further, the most recent ATL22 rel004 mean analysis includes a filter to remove most of these occurrences.

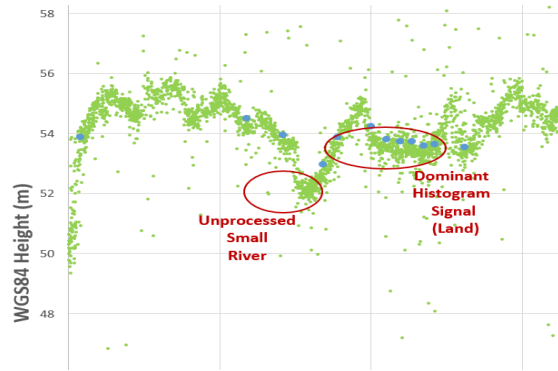


Also, some coastal buffer of narrow inlets and bays caused swaths of land to be included in version 3 of the ATL13 Inland Water Body Mask. In these cases, it is possible that flat land will create enough of a histogram signal to compel the algorithm to process the crossing as if it were water (See example below).



Issue 6. River crossings with significant adjacent flat land

To ensure the capture of braided and high flow conditions in ATL13/22 rivers, a wide buffer was provided in the masks of certain river shapes. Because of this approach, land segment heights are often incorrectly reported as water surfaces. It is possible but rare that extensive flat floodplains are dominated by land rather than open water. ATL13 Ver 7 makes every effort to exclude land anomalies. However, when braided rivers are expected, users should also visually examine the ATL13 short segment for anomalous land segments and ATL22 means accordingly.



Issue 7. Detrending at long segment length scales

Along track inland water body slopes are processed for long segments within the ATL13 detrending algorithm. The accuracy of the reported mean ATL22 slope may be compromised due to possible updates in the current ATL03 signal photon classification process. Impacts to the water surface elevation is thought to be minimal.

References

Citation for this ATL13 ATBD Release 7:

M. Jasinski, J. Stoll, D. Hancock, J. Robbins, J. Nattala, T. Pavelsky, J. Morrison, B. Jones, M. Ondrusek, C. Parrish, and the ICESat-2 Science Team, January 2025a: *Algorithm Theoretical Basis Document (ATBD) for Along Track Inland Surface Water Data, ATL13, Release 7*, January 2025, NASA Goddard Space Flight Center, Greenbelt, MD, 190 pp.
DOI: 10.5067/46BO943W5S2X

Citation when using ATL13 Inland Water data products from NSIDC:

M. Jasinski, J. Stoll, D. Hancock, J. Robbins, J. Nattala, T. Pavelsky, J. Morrison, B. Jones, M. Ondrusek, C. Parrish, and the ICESat-2 Science Team, 2025b. *ATLAS/ICESat-2 L3A Along Track Inland Surface Water Data, Release 7*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center.
DOI:10.5067/ATLAS/ATL13.007

Citation for this ATL22 ATBD Release 004:

M. Jasinski, J. Stoll, D. Hancock, J. Robbins, J. Nattala and C. Carabajal (January 2025c) *Algorithm Theoretical Basis Document (ATBD) for Mean Inland Surface Water Data, ATL22, Release 4*, NASA Goddard Space Flight Center, Greenbelt, MD, 48 pp.
DOI: 10.5067/ONG3H30DUFEL

Citation when using ATL22 Release 4 Inland Water data products from NSIDC:

M. Jasinski, J. Stoll, D. Hancock, J. Robbins, J. Nattala and C Carabajal (January 2025d). *ATLAS/ICESat-2 L3B Mean Inland Surface Water Data, Release 4*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. DOI:10.5067/ATLAS/ATL22.004