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

ATL22 Along Track Surface Water Data, Release 003

Algorithm Summary and Known Issues

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Introduction

This document contains algorithm notes and known issues identified by developers of the ICESat-2 ATL22 Release 3 Along Track 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 3 (Jasinski et al., 2023c). The ATL13 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 list of the specific ATL13 output product tables (Chapter 5) and lists of calibration and validation background and opportunities (Chapter 6). The list of all specific products associated with the latest ATL13 version is provided in Table 5.1 of ATL13 ATBD. A summary of the principal updates to each release is provided below in Table 1-1. It 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
ATL13v1	May 2019	Lakes & reservoirs > 10 km² (19,634)	- Continuous, along track surface water products including subsurface attenuation and supporting data. - reported at short segment length - Employs GLWD (Lehner & Doll 2004)
ATL13v2	Nov 2019	Lakes & reservoirs ≥ 10 km² (19,800) Estuaries, bays, and near shore 7 km buffer (~3500)	- Employs HydroLAKES (Messager & 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	Lakes & reservoirs ≥ 0.1 km² (~1,400,000) Estuaries, bays, and near shore buffer (7 km) (~3500) 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
ATL13v4/v5	Apr/Nov 2021	All above water bodies	- Improves photon classification - Improves accuracy of existing data products - Reports additional products
ATL22v2	Dec 2021	All water bodies	- Mean surface water and supporting products including crossing length - Reported for each transect (uninterrupted water crossing)
ATL13v6	Aug 2023	All water bodies	- Improves accuracy of surface products by eliminating anomalous photons - Improves accuracy of subsurface attenuation coefficient deconvolution scheme - Reports additional quality flags
ATL22v3	Aug 2023	All water bodies	- Improves mean surface water product estimates removing anomalies

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 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, ii) covers the global domain with over 1.5 million unique water body shapes including lakes, reservoirs, rivers, estuaries and coasts, embedded within different climate, land cover, and topographic environments, and iii) includes three pairs of high/low energy ATLAS beams.

Summary Features of ATL22 Rel 3 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 loops through the global inland water body database organized within regional basins during each processing period, completely analyzing all the ground tracks of one water body before proceeding to the next. Along- and cross- track data products are computed for all the new ground tracks observed for that water body since the previous processing period. Inland water bodies are delineated by shape files defined for different water body types in the ATL13 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, 100 signal photon short-segment rate. A more recent companion Mean Inland Surface Water Data Product or ATL22 (Jasinski et al., 2023c) includes similar parameters.

The resulting reported short segment resolution is of variable length. Due to water and meteorology conditions, the segment length varies from approximately 30 to 100 meters. Data products are reported throughout the span of the identified water body as shown in Figure 3.3. Lidar 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

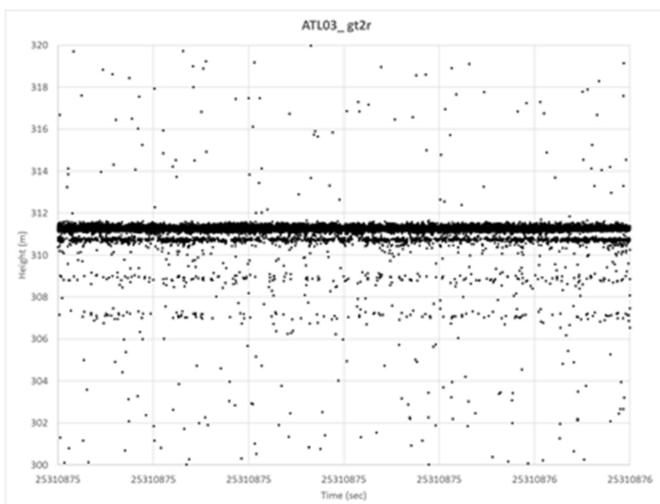
ATBD (Jasinski et al., 2023a), ATL13 products (2023b), and the ATL22 ATBD (Jasinski et al., 2023c).

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. Current known issues that are due to ATL13 processing will be addressed in future product releases. We therefore welcome from all users any questions, feedback, or any new issues so they can be addressed in the future to improve the ATL13 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. Misidentification of subsurface bottom in the presence of instrument effects.

When there is a known afterpulse as mentioned in Issue 1 above, the estimation of subsurface attenuation or bottom elevation can be compromised. There is no current solution for this problem, but it will be addressed with improved photon confidence assignments in Release 7.

Issue 3. 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 4. 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.

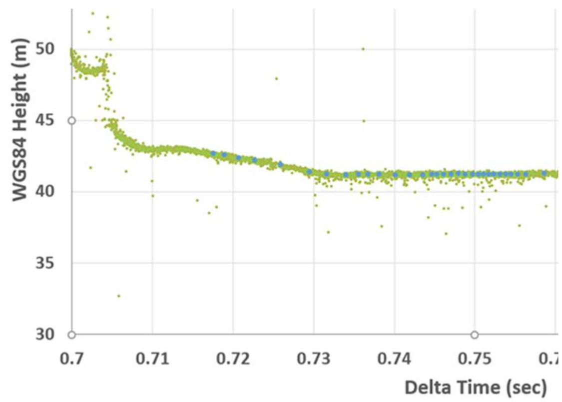
Issue 5. ATL13 overlapping water bodies

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.

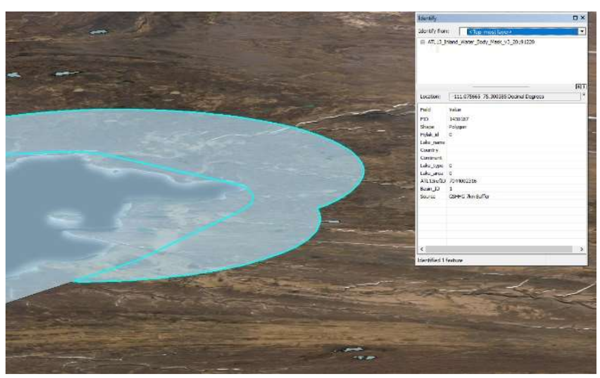
While the mask works very well in most cases, there can be several issues. First, in areas of high-density water bodies, the buffering of bodies and different interpretation of boundaries by different sources can cause shapes in the ATL13/22 Inland Water Body Mask to overlap. River overlaps of lakes 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.

Issue 6. 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 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 rel003 mean analysis includes a filter to remove most non-water effects.

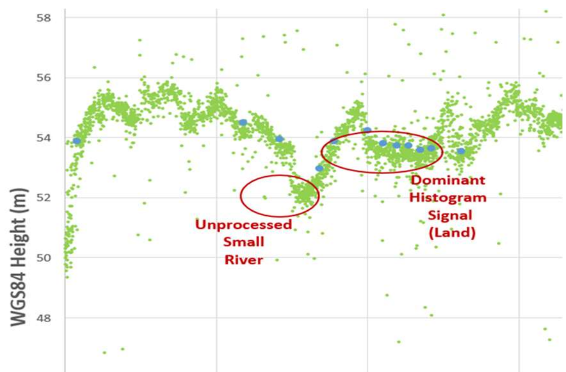


Also, some coastal buffer of narrow inlets and bays caused swaths of land to be included in version 3 of the ATL13 Inland Water Body Mask. In these cases, it is possible that flat land will create enough of a histogram signal to compel the algorithm to process the crossing as if it were water (See example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



Issue 7. River crossings with significant adjacent flat land

To ensure the capture of braided and high flow conditions in ATL13 and 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 6 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 process accordingly.



Issue 8. Detrending at long segment length scales

Along track inland water body slopes are processed for long segments within the detrending algorithm. The reported slope may not be representative of the true slope due to the current ATL03 signal photon classification process. Impacts to the water surface elevation is thought to be minimal.

Issue 9. Inland water quality and classification flags

Quality and classification flags are provided for key ATL13 output products in the ATL13 ATBD Section 4.8 that can be useful for understanding ATL22 mean results. They show the range of a variable's magnitude for an initial indication of a product's behavior. Current ATL13 ATBD flags are:

4.8.1 Inland Water Segment Processing Flag: This flag describes the level of processing using to estimate the surface and subsurface parameters.

4.8.2 Background Flag: This flag describes the intensity of the background rate in each short segment. The flags are:

4.8.3 Bias Fit Flag: Indicates the range of bias in the Gaussian fit

4.8.4 EM Bias Flag: Indicates theoretical range of bias due surface wave slope:

4.8.5 Short Segment Length Flag: Indicates length range of short segments,

4.8.6 Long Segment Length Flag: Indicates length range of long segments

4.8.7 Clouds Flag : Cloud confidence flags derived in ATL09 and resampled to convert to ATL13 short segment rates, for Cloud_Flag_ASR, Cloud_Flag_Atm and Layer_Flag.

4.8.8 Flags Associated with Snow and Ice: The ATL13 snow and ice flags are (snow_ice_ATL09), obtained from the ATL09 Snow_Ice flag and the NOAA GMASI product, are assigned at the short segment rate as: 0 = ice free water, 1 = snow free land, 2 = snow, and 3 = ice. When there is more than one overlap, they are assigned the greatest value.

4.8.9 Flags Associated with Surface Temperature: ATL13 reports the ATL09 MET surface (skin) temperature at the short segment rate based on a linear interpolated nearest neighbor approach.

Issue 10. "Deferred" ATL13 Products

Several of the ATL13 Table 5.3 Output Products scheduled for future release are labeled "deferred" and are also not available in ATL22. The deferred output is either populated with an "invalid" placeholder or is not provided.

Issue 11. ATLAS 523nm subsurface attenuation

The depth (d) in Equation 4.11 of ATL13 has not been fully corrected for refraction at this point. This does not affect the surface water height products but may lead to an overestimation of up to 30% in the ATL22 attenuation values. This has been corrected for ATL13 Rel 007 and ATL22 Rel 004 expected in late 2023.

Issue 12. Transects with Interrupted Water

Interrupted water due to the presence of islands or data gap is not accounted for short and long segment construction and analysis. This issue is being addressed in ATL13 Rel 7 for late 2023.

References

Jasinski, M., Stoll, J., Hancock, D., Robbins, J., Nattala, J., Pavelsky, T., Morrison, J., Jones, B., Ondrusek, M., Parrish, C., Carabajal C., and the ICESat-2 Science Team (2023a). *ICESat-2 Algorithm Theoretical Basis Document (ATBD) for Along Track Inland Surface Water Data, ATL13, Release 6*. ICESat-2 Project, NASA Goddard Space Flight Center, Greenbelt, MD, 178pp. DOI: 10.5067/03JYGZ0758UL.

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Jasinski, M., Stoll, J., Hancock, D., Robbins, J., Nattala, J., Carabajal, C., 2023c, ICESat-2 Algorithm Theoretical Basis Document (ATBD) for Mean Inland Surface Water Data, ATL22, Release 3, ICESat-2 Project, NASA Goddard Space Flight Center, Greenbelt, MD, 42 pp.

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