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

# ATL13 Along Track Surface Water Data, Release 005

# Algorithm Notes and Known Issues

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**Introduction**

This document contains algorithm notes and known issues identified by developers of the ICESat-2 ATL13 Release 5 Along Track Inland Surface Water Data product. For a detailed description of the theoretical algorithm and its implementation please refer to the ATL13 Algorithm Theoretical Basis Document (ATBD) Release 5 (Jasinski et al., 2021).

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, and iii) includes six ATLAS beams each with unique performance.

Herein, only the most frequent issues are identified. Current known issues that are due to ATL13 processing and not ATL03 processing will be addressed in future releases of the product. 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.

The ATL13 ATBD Rel 5 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). It supersedes all previous versions and is continually being updated to include new features and capability.

The list of all specific products associated with the latest ATL13 version is provided in the Table 5.1 of ATL13 ATBD.

A summary of the principal updates to each release is provided in Table 1-1 below.

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

| 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) | - <u>Continuous, along track surface water products</u> including subsurface attenuation and supporting data.<br>- reported at short segment length<br>- Employs GLWD (Lehner & Doll 2004) |
| ATL13v2 | Nov 2019 | Lakes & reservoirs ≥ 10 km² (19,800)<br>Estuaries, bays, and near shore 7 km buffer (~3500) | - Employs HydroLAKES (Messager & Lehner, 2016)<br>- Adds transitional waters;<br>   Named Marine Water Bodies (ESRI)<br>   GSHHG Shoreline (Wessel et al, 1996)<br>- Adds significant wave height<br>- coarse bathymetry algorithm<br>- Adds dynamic shore finding |
| ATL13v3 | Mar 2020 | Lakes & reservoirs ≥ 0.1 km² (~1,400,000)<br>Estuaries, bays, and near shore buffer (7 km) (~3500)<br>Rivers ≥ ~50-100 m wide (10,300) | - Adds river mask using GRWL (Allen and Pavelsky, 2018)<br>- Adds wind speed for all crossings<br>- Adds Ice on/off flag from multi-sensor NOAA product<br>- Corrects first photon bias error<br>- Adds cloud confidence flag |
| ATL13v4/v5 | Apr/Nov 2021 | All above water bodies | - Improves photon classification<br>- Improves accuracy of existing data products<br>- Reports additional products |
| ATL22v2 | Dec 2021 | All above water bodies | - <u>Mean surface water products</u> and supporting products including crossing length<br>- Reported for each transect (uninterrupted water crossing) |

## Summary of ATL13 Inland Water Algorithm

The ATL13 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, 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. The future Inland Water Data Product, or ATL22, currently under development, will further include mean transect and associated values as noted in Table 1-2 and in Table 5.2 of the ATBD.

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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., 2021)

## Known Issues

### 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 blow, 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. Future ICESat-s Project Office analyses will further correct this.
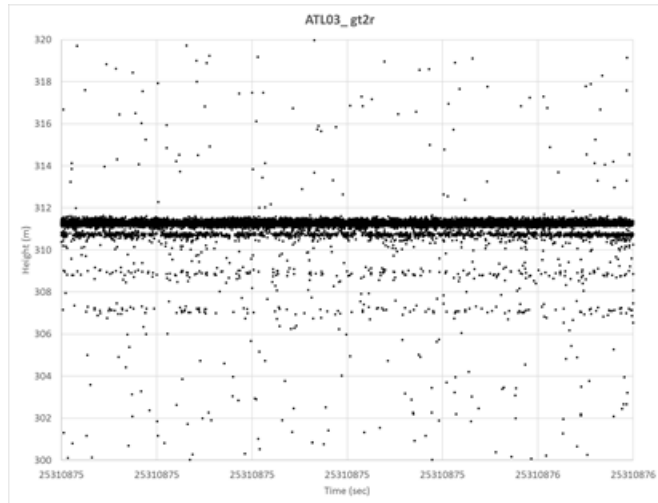
## Issue 2. Occasional miss identification of atmospheric clouds as water surface

Although it is rare, sometimes, in the presence of dense clouds, the true water surface is misidentified as the top of the clouds, as shown in the figure below. There is currently no flag in ATL13 to warn users of this miss identification. This issue has been partly addressed in in ATL13 Ver 4 by selecting a narrow band window based on a known DEM.
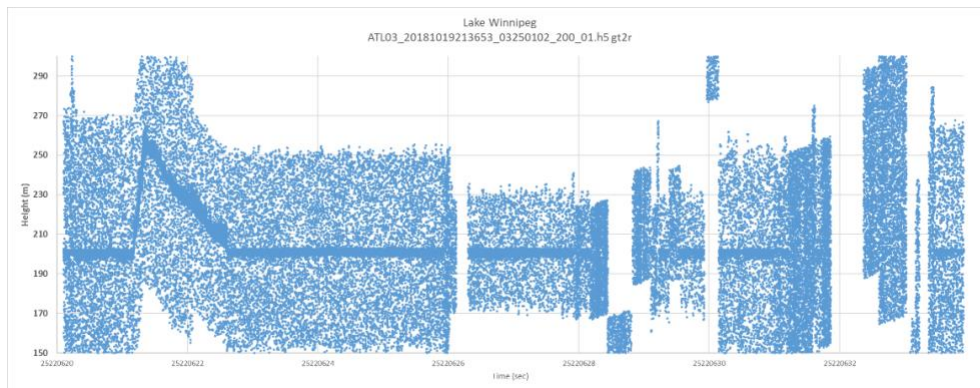


## Issue 3. Snow and ice on water bodies

In ATL13, snow and ice on inland water bodies are not explicitly identified. 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 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.

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## Issue 4. Inter-beam calibration not available.

Currently, ATLAS calibration occurs only at the instrument level, not individual beams. Inter beam height variations in height 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 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 are 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 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 impact on 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.



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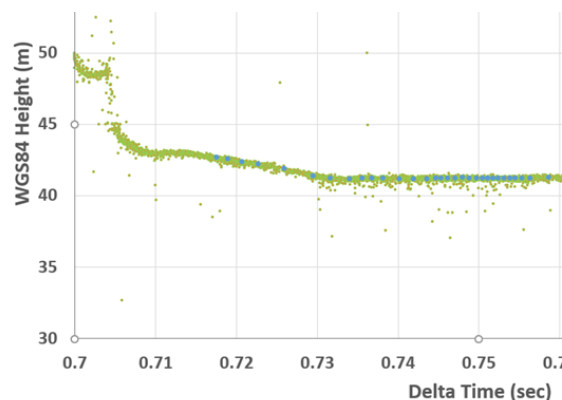
Also, some coastal buffer of narrow inlets and bays caused swaths of land to be included in version 3 of the ATL13 Inland Water Body Mask. In these cases, it is possible that flat land will create enough of a histogram signal to compel the algorithm to process the crossing as if it were water (See example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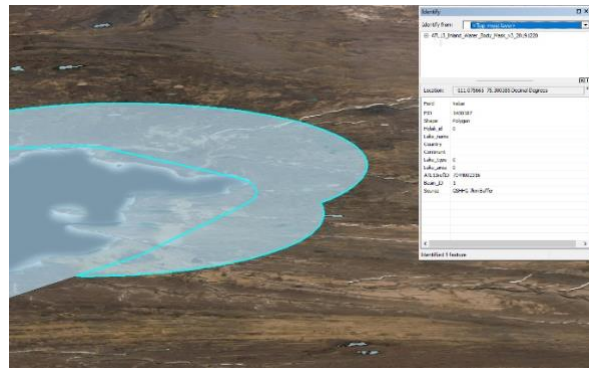


## Issue 7. River crossings with significant adjacent flat land

To ensure the capture of braided and high flow conditions in ATL13 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 5 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 process accordingly.
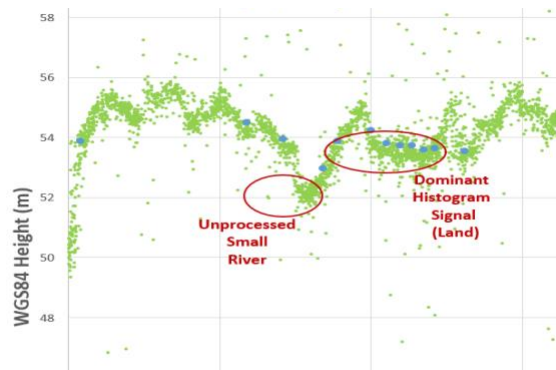


## Issue 8. Detrending at long segment length scales

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.

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**Issue 9.  Inland water quality and classification flags**

Quality and classification flags are provided for key ATL13 output products in the ATBD Section 4.8.  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 Table 5.3 Output Products scheduled for future release are labeled "deferred". The deferred output is either populated with an "invalid" placeholder, or is not provided.


**Issue 11. ATBD citation link/DOI**

The DOI provided by NSIDC for the Inland Water Data Product ATL13 only points to the ICESat-2 data products page, and not to the ATL13 ATBD document itself.  Once reaching the page, please scroll down to see the link to the ATL13 ATBD.

## Issue 12. ATLAS 523nm subsurface attenuation

There is an error in the expression of $\alpha$ and $\beta$ in the subsurface attenuation algorithm, Equation 4.11. This does not affect the surface water height products, but may lead to an overestimation of $\alpha$ by up to 50%.

## Issue 13. Length of partial short segments

The length of partial short segments at the end of water transects can be erroneously reported, as the final photon in the mask transect, rather than the final signal photon in the true water body. This occurs because short segments are defined based on a fixed number of signal photons for a given water body type. If that number is not attained in a transect, the algorithm continues to search until it reaches the end of the ATL13 mask.

## References

M. Jasinski, J. Stoll, D. Hancock, J. Robbins, J. Nattala, T. Pavelsky, J. Morrison, B. Jones, M. Ondrusek, C. Parrish, August 31 2021: *Algorithm Theoretical Basis Document (ATBD) for Along Track Inland Surface Water Data, ATL13, Version 5*, Release Date November 23, 2021, NASA Goddard Space Flight Center, Greenbelt, MD, 125 pp. (August 2021a), DOI: 10.5067/RI5QTGTSVHRZ

M. Jasinski, J. Stoll, D. Hancock, J. Robbins, J. Nattala, August 2021b. *ATLAS/ICESat-2 L3B Mean Inland Surface Water Data, Version 2*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center.* DOI:10.5067/ATLAS/ATL22.001