ATL07/10

Notes to users and known issues

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Most recent update: 08/27/2020
Updated on 06/03/2020 for Release 003
Updated on 09/12/2019 for Release 002

Notes to users and known issues

This document contains notes, which are of use in the analysis of the sea ice products, and issues that are known to the developers, which may be fixed in future releases of these products.

Feedback from the community will be added to future revisions of this document.

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Note 1. ATL07/10 granules

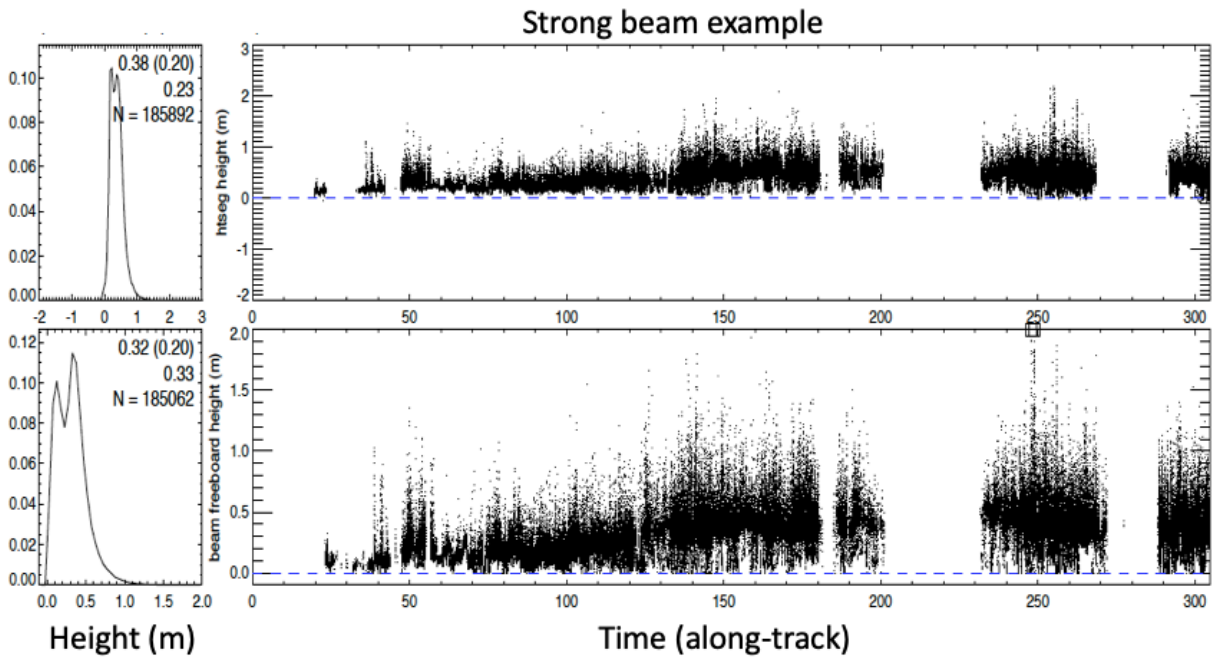


Figure 1

The two panels (above, Figure 1) show the retrieved along-track surface heights (in ATL07, top right panel) and corresponding freeboards (in ATL10, bottom right panel) and their distributions (x-axis in meters, left panels) from a strong beam, in ~300 s (or ~2100 km) of ICESat-2 data. The gaps in the data are due to clouds. Retrievals (though of different resolutions) are available from both the strong and weak beams.

Granules. The ATL07 and ATL10 products each consist of approximately 32 files (granules) per day, 16 for the northern hemisphere and 16 for the southern hemisphere; each granule contains the sea ice retrievals (heights and freeboards) from data acquired over half an orbit. Six ground tracks within each granule span the width of the orbital swath with an across-track distance of 6 km.

Coverage. The ATL07 retrievals contain heights from the ice-covered oceans of the northern and southern hemispheres when the surface is visible (relatively cloud free) and the ice concentration > 15%. The ATL10 products are more restrictive, retrievals are provided only when the ice concentration >50% and 25 km away from the coast.

Note 2. Variable segment lengths and spatial statistics

The ATL07 product contains profiles of surface heights of individual height segments along each of the six ground tracks. The variable along-track length of a height segment (L_s), associated with a height estimate, is determined by the ground distance travelled by the pulse footprints (number of pulses × inter-pulse distance) in the time it takes to aggregate 150 photons used for surface finding; thus, this length varies with surface reflectance. That is, the segment length adapts to changes in photon rates from surfaces of different reflectance; height segment lengths (L_s) are longer when the returns are lower and vice versa. The ATL10 freeboards have the same segment lengths as those height segments in ATL07. This is an important characteristic to note in the calculation of spatial statistics.

The calculation of spatial statistics and distributions must account for the non-uniform and variable length sampling of height estimates. For example, the spatial mean ($\overline{h}$) and standard deviation (σ) of heights should be calculated as follows:

$$\overline{h} = \frac{\sum_N L_s^i h_s^i}{\sum_N L_s^i} \qquad \sigma^2 = \frac{\sum_N L_s^i (h_s^i)^2}{\sum_N L_s^i} - \overline{h}^2 \ .$$

That is, the height statistics should be weighted by the corresponding length of the height segment (L_s).

Note 3. ATL10 (July 9 through July 26) not available in R003

ATL10s (freeboard product) will not be available for the period between July 9 and July 26, 2019. These products are on hold pending assessment of data quality during this period.

Surface heights are still available in ATL07.

Note 4. Sea surface designations: SSH flags (0, 1, 2)

In R001 and R002, the SSH flag is set to '1' (in both ATL07 and ATL10) if a particular height segment is a candidate height sample for use in the calculation of sea surface references.

In R003, the SSH flag is incremented from '1' to '2' in ATL10 if that height sample were actually used in the calculation of sea surface references to distinguish the candidate from the selected samples.

Note 5. Increased coverage/sampling of the ice cover (in R003)

There are three changes to the processing software that resulted in increased coverage of both the Arctic and Antarctic sea ice covers (See Figure 2):

1. Handling of returns in regions of overlapping land and sea ice masks

The procedures in R001 and R002 neglected to take into account the additional photons in the larger telemetry window (used for land ice) in the zone of overlap between land and sea ice masks. As a consequence, a large number of shots were treated as saturated and discarded, causing potential gaps in coverage in regions where the two masks overlap. This effect is especially acute in the weak beams and when the solar elevation is high in the spring and summer, and negligible when the sun is below the horizon. This issue was fixed in R003 and an increase in coverage around the coast is expected.

Expected changes: we expect an increase in coverage around coastal Antarctica and the Arctic coastline – especially around the Arctic shelves and in the passages of the Canadian Arctic Archipelago (see Figure 2).

2. Including h_fit_quality_flag=4 in the calculation of ATL10 freeboards

In R001/R002, we included only height segments with *h_fit_quality_flag* ≤ 3 in the calculation of freeboards in ATL10 (low values of *h_fit_quality_flag* are of better quality statistically). In the subsequent investigations, we decided to add height estimates with *h_fit_quality_flag=4* because the smaller population capture the higher freeboards in areas of higher surface roughness. In relaxing this filter, we expect an increase in the number of freeboards in ATL10.

Expected changes: we expect a small increase in overall coverage and only in areas of relatively rough ice (rough as measured by the Gaussian width of the surface finder). In these areas, the quality is low because the broad photon height distributions are noisy realizations of the surface when sampled by a 150 photon-aggregate. They are more random spatially.

Note 6. * Changes in the ATL10 freeboards (in R003) ***

The two changes implemented are described below.

1. Correction of height filter

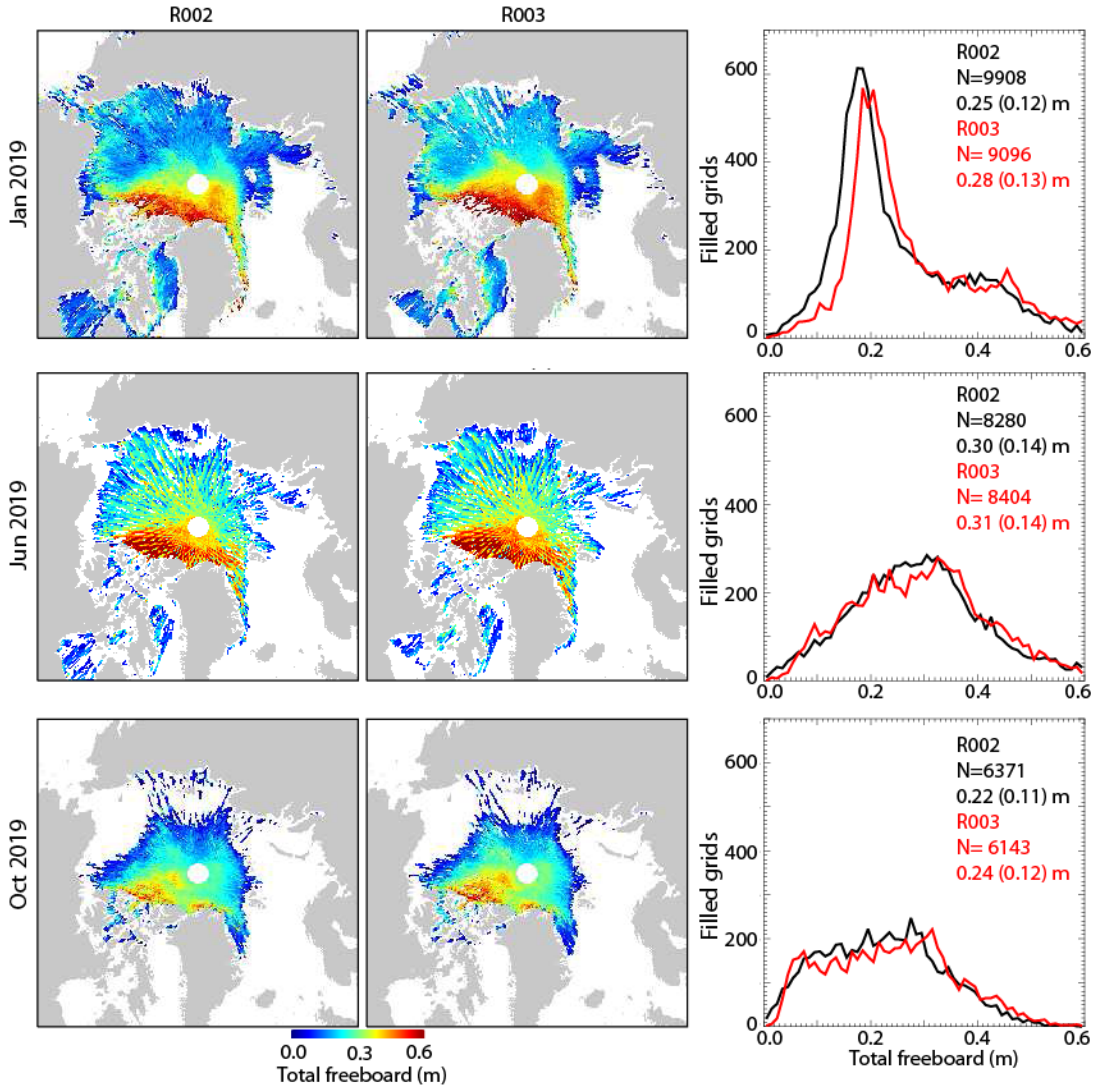
In R001/R002, the height filter used in the selection of reference surfaces for freeboard calculations was set to be overly stringent due to an incorrect parameter setting that eliminated a number of sea surface height segments. This is now fixed in R003.

2. Use of only height segments with specular returns for reference height estimation

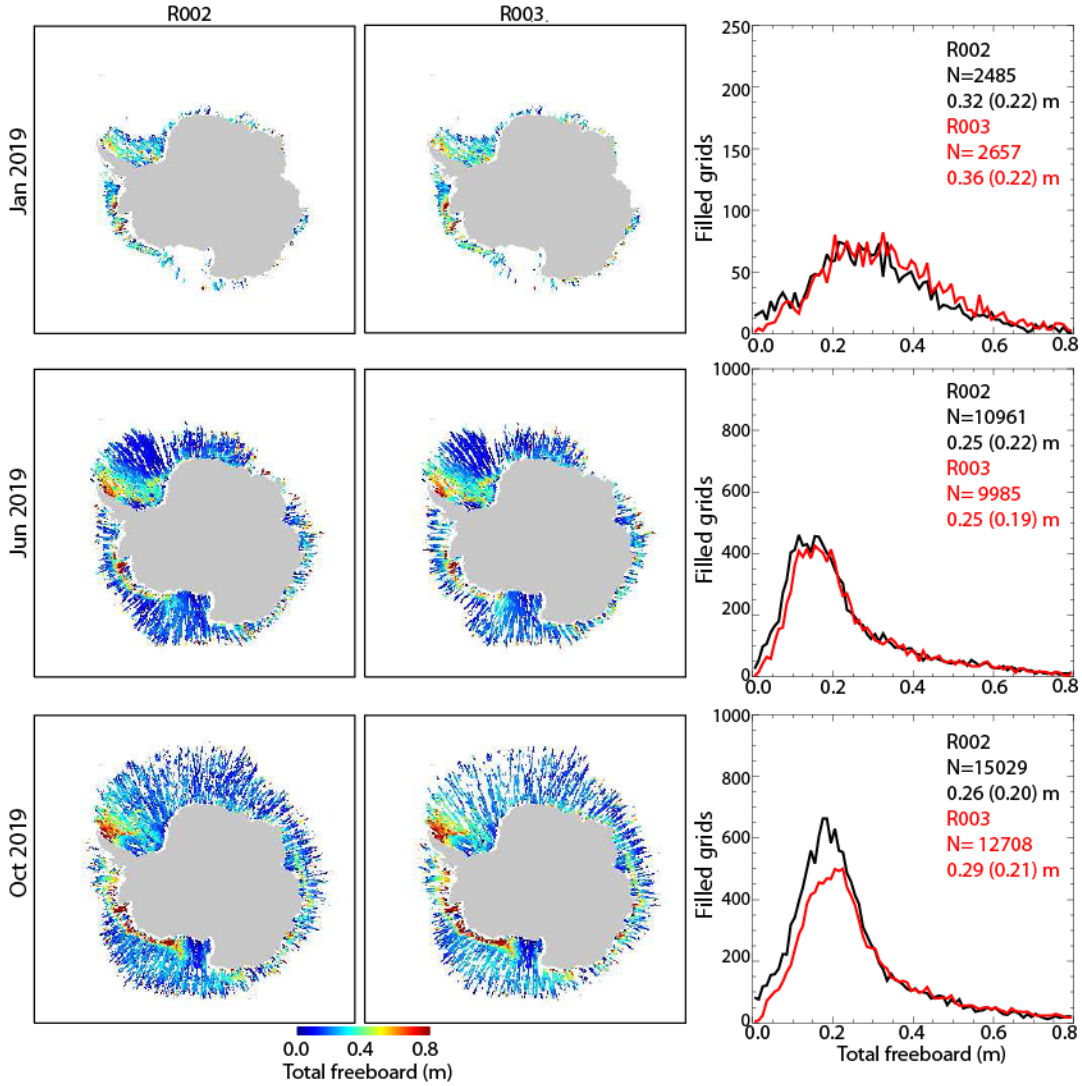
In R001/R002, candidate height segments that were selected to estimate reference heights for freeboard calculations included surface types 2 to 7. Surface types 2-5 are height segments with specular returns and types 6-7 are segments with smooth surfaces and low surface reflectance (dark leads). We found that the photon rates, used as a proxy for surface reflectance, are attenuated due to clouds (leading to incorrect classification of dark leads) and surface heights from dark leads are less reliable than those of specular returns without a cloud filter; the consequence is a higher reference surface and a lowering the estimated freeboards. Cloud flags from ATL09 are low resolution (~400 m) and thus not an effective filter at the lengths scale of potential leads detected by the sea ice classifier.

In R003, we have modified the surface reference calculations so that only leads with specular returns (surface type 2-5) are used. The consequence of the changes can be seen in the freeboard composites of the Arctic Ocean (N6-Figure 1) and of the Antarctic (N6-Figure). Broadly, coverages have decreased by ~10-20% because there are fewer leads (by excluding the dark leads), and the composite means have increased by 0-3 cm because of the use of higher quality surface heights (i.e., closer to the local sea surface) in freeboard calculations. A more detailed accounting and rationale for these changes – a refinement of freeboard calculations – will be reported in a publication that is being prepared at this time (Kwok et al., 2020). Also, an alternate approach to filtering the cloud contaminated surfaces has been tested and may be implemented in future releases.

Kwok, R., A. A. Petty, M. Bagnardi, N. T. Kurtz, G. F. Cunningham, A. Ivanoff (2020), Refining the sea surface identification approach for determining freeboard in the ICESat-2 sea ice products, *The Cryosphere Discuss*, doi:10.5194/tc-2020-174.



N6-Figure 1. Changes in coverage and freeboard distributions of the Arctic Ocean sea ice cover in monthly composites of Jan, Jun, and Oct 2019. N is the number grid cells (25 by 25 km) that contains freeboard estimate. Numerical values are the mean (standard deviation) of the distributions. The distributions are not normalized and show actual population counts and provide an indication of the loss and gain of samples in each of the distribution bins.



N6-Figure 2. Same as previous figure except for the Antarctic.

Issue 1. Multi-beam freeboards calculations disabled (ATL10)

Currently the multi-beam freeboard calculations are switched off as the beams have not been leveled relative to each other. Only single-beam freeboards are available in ATL10. That is, freeboards are not calculated using the local sea level from other beams.

Issue 2. Sea surface heights (SSH, cross-beams and absolute SSH levels)

SSHs across the beams have not been leveled relative to each. Although the relative SSH within each beam seems usable, they require further evaluation. And, the quality of absolute sea surface heights have not been assessed.

Issue 3. Lower transmitted energy in Beam 3 (Strong Beam)

The transmit energy of Beam 3 (Strong beam 2R or 2L, depending on orientation of the ICESat-2 observatory) is approximately 80% that of Beam 1 and Beam 5. Thus, the segment lengths and photon return statistics are and will be different from the other two strong beams.

Issue 4. *Layer_flag* in ATL07 and ATL10

The computation of the *layer_flag*, which combines the information in *cloud_flag_atm*, *cloud_flag_asr* and *bsnow_con* into a consolidated flag for indication of cloud coverage, was implemented incorrectly in the current release (R001 - ASAS 5.1). DO NOT USE.

Issue 5. High freeboard samples (near the ice margins) due to sea state

The reference sea surfaces used to calculate freeboards are based on sea surface heights identified in ATL07. Near the ice edge, the reference surfaces within the ice cover are affected by sea state, likely due to scattering from the troughs of waves propagating into the ice cover, resulting in surfaces that may be tens of centimeters below the local mean sea level. This results in higher freeboards, and affect one or perhaps two 10-km freeboard segments. Most of these anomalous retrievals have been filtered out but they still occur.

Issue 6. Gaps in coverage near the coast especially in the weak beams (resolved in R003)

The procedures in R001 and R002 neglected to take into account the additional photons in the larger telemetry window in the zone of overlap between land and sea ice masks. As a consequence, a large number of shots were treated as saturated and discarded, causing a gap in coverage in the overlapping land ice/sea ice masks. This effect is especially acute in the weak beams and when the solar elevation is high in the spring and summer, and negligible when the sun is below the horizon.

Issue 7. Data from July 2019

Data collected between 9-26 July 2019 have a small timing bias resulting from an erroneous Earth orientation parameter uploaded during the spacecraft's return to operations following a safehold event on 26 June 2020. This caused an error in spacecraft pointing, resulting in an extra approximately 1 degree of forward pitch, and shifted the onboard attitude control system interpretation of spacecraft time by roughly 19 seconds. The primary manifestation of this issue

is telemetry band errors at steep coastal areas, at times resulting in loss of surface returns. We note that there may be some increased height errors from data collected during this time period, those errors are generally within the conservative estimates of geolocation and height uncertainty currently provided on the ATL03 product.

Issue 8. Negative segment lengths

The segment lengths in r001 to r003 ATL07/10 data are calculated using the difference in distance between the first and last photon in a given height segment. Because the photon distance measurements are not provided in sequential along-track distance order, this can cause erroneous behavior, including negative segment lengths in some rare cases. The problem was fixed by finding the difference of the max and min of the along-track distances instead of the start and end, which will be included in r004 data.