ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere, Version 5

USER GUIDE

How to Cite These Data

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

Palm, S. P., E. T. Northam, and U. C. Herzfeld. 2023. *ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere, Version 5*. [Indicate subset used]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL16.005. [Date Accessed].

FOR QUESTIONS ABOUT THESE DATA, CONTACT NSIDC@NSIDC.ORG

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL16

National Snow and Ice Data Center

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1 DATA DESCRIPTION

This user guide describes two ICESat-2 data sets:

- ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere (ATL16)
    - Generated weekly on a 3° latitude x 3° longitude grid for global coverage
    - Generated weekly on a 1° latitude x 3° longitude grid for polar coverage
- ATLAS/ICESat-2 L3B Monthly Gridded Atmosphere (ATL17)
    - Generated monthly on a 1° latitude x 1° longitude grid for global coverage
    - Generated monthly on a 0.5° latitude x 1.5° longitude grid for polar coverage

1.1 Parameters

Both data sets report the same atmospheric parameters:

- Global cloud fraction
- Global aerosol fraction
- Total column optical depth (over ocean and inland water bodies)
- Polar cloud fraction (total, low, mid, and high altitude; transmissive and opaque clouds)
- Blowing snow frequency (low and high rate)
- Apparent surface reflectivity
- Ground detection frequency
- South Polar diamond dust frequency
- Apparent surface reflectance cloud fraction

1.2 File Information

The following sections refer to the Ice, Cloud, and Land Elevation Satellite (ICESat-2) Project Algorithm Theoretical Basis Document (ATBD) for Atmosphere Gridded Products (ATBD for ATL16/17, V5 | https://doi.org/10.5067/1QRLXI6WP717).

1.2.1 Format

Data are provided as HDF5 formatted files.

WARNING: The Global and South Polar data may appear “flipped” across the horizontal axis when plotting in some programs. Specifically, the upper-left coordinates in the file-level metadata appear as the lower-left coordinates of the grid (the y-direction starts in the southern latitudes).

1.2.2 File Naming Convention

ATL16 and ATL17 data are provided as granules (files) that contain data for an observation period of either one week (ATL16) or one month (ATL17). Data files utilize the following naming conventions:

```
ATL16_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5
ATL17_[yyyymmdd][hhmmss]_[ttttccss]_[vvv_rr].h5
```

Examples:

```
ATL16_20190101005132_00550201_005_01.h5
ATL17_20190101005132_00550201_005_01.h5
```

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
`ATL16` *or* `ATL17`	ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere *or* ATLAS/ICESat-2 L3B Monthly Gridded Atmosphere
`yyyymmdd`	Starting date (year, month, day) of data file coverage
`hhmmss`	Starting time (hour, minute, second) of data file coverage (UTC)
`tttt`	Reference Ground Track (RGT) at beginning of data coverage. The ICESat-2 mission has 1,387 RGTs, numbered from 0001 to 1387.
`cc`	Cycle number at beginning of data coverage. Each of the 1,387 RGTs is targeted in the polar regions once every 91 days. The cycle number tracks the number of 91-day periods that have elapsed since ICESat-2 entered the science orbit.
`ss`	Segment number. Not applicable, 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 ATL16 data files span one full orbit, the segment number is 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. As such, 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 science metadata. XML metadata files have the same name as their corresponding `.h5` file, but with `.xml` appended.

1.3 Data Groups

Within data files, similar variables such as science data, instrument parameters, orbit information, and metadata are grouped together according to the HDF model. As shown in the following figure, science data in ATL16 and ATL17 data files are stored at the root-level, alongside the `METADATA`, `ancillary_data`, `orbit_info`, and `quality_assessment` data groups:

Figure 1. Internal structure of an ATL16 data file. ATL17 data files utilize the same structure and variable names.

The primary variables of interest in this data set are described in the "Processing" section below. Additional details are available in "Section 5.0 | Product Formats" of the ATBD for

ATL16/ATL17. Complete parameter lists are available in the ATL16 Data Dictionary and the ATL17 Data Dictionary.

The data groups shown in Figure 1 contain the following information:

1.3.1 METADATA

This group contains ISO19115 structured summary metadata.

1.3.2 ancillary_data

The `ancillary_data` group contains information such as product and instrument characteristics and processing constants. Within `ancillary_data`, the `/atmosphere/` subgroup contains the control parameters `center_weight` and `smooth_grid` (see "Section 4.0 | Smoothing of Images" in the ATBD for ATL16/ATL17) and the day/night data type flag.

1.3.3 orbit_info

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

1.3.4 quality assessment

The quality assessment group contains `qa_granule_pass_fail`, a pass/fail indicator for the granule as a whole, and `qa_granule_fail_reason`, which indicates the reason a granule has failed QA.

1.3.5 Browse Files

Browse files are provided as JPGs that contain images designed to quickly assess the location and quality of each granule's data. Two images are provided: Global Apparent Surface Reflectance (`default1`) and Global Cloud Fraction (`default2`). Browse files utilize the same naming convention as their corresponding data file but with `_BRW` appended.

1.4 Spatial Information

1.4.1 Coverage

Coverage varies by parameter, provided on either a global grid, polar grids, or both. Polar grids span the areas poleward of 60° N and 60° S. The following table lists the parameters and their corresponding coverages:

Table 2. Data Grids by Parameter for ATL16/ATL17

Parameter	Grid
Global cloud fraction	Global
Global aerosol fraction	Global
Total column optical depth	Global (over oceans and inland water bodies)
Polar cloud fraction	Polar (see note below)
Blowing snow frequency (low and high rates)	Polar
Apparent surface reflectivity	Global and Polar
Ground detection frequency	Global and Polar
South Polar diamond dust frequency	South Polar
Apparent surface reflectance cloud fraction	Global and Polar

Note: polar cloud fraction for ATL16 and ATL17 is broken into 12 separate polar grids. Two grids (one per hemisphere) report the total polar cloud fraction, while six vertically stacked grids (three per hemisphere) report cloud fractions within the following height ranges:

- Low: $h \leq 4$ km
- Mid: 4 km $< h \leq$ 8 km
- High: $h >$ 8 km

Lastly, four grids are provided that contain the transmissive cloud fraction and opaque cloud fraction in separate grids for each hemisphere.

1.4.2 Resolution

Data are provided on rectangular grids:

- 3° latitude x 3° longitude for ATL16 weekly global coverage
- 1° latitude x 3° longitude for ATL16 weekly polar coverage
- 1° latitude x 1° longitude for ATL17 monthly global coverage
- 0.5° latitude x 1.5° longitude for ATL17 monthly polar coverage

The global and polar grids are dimensioned as shown in the following table:

Table 3. Global and Polar Grid Dimensions

Product	Global Grid Resolution	Global Grid Dim (row x col)	Polar Grid Resolution	Polar Grid Dim (row x col)
ATL16	3° lat (60) x 3° lon (120)	60 x 120	1° lat x 3° lon	30 x 120
ATL17	1° lat x 1° lon	180 x 360	0.5° lat x 1.5° lon	60 x 240

1.4.3 Geolocation

Three pairs of 1D arrays are included in the product that can be used to geolocate the global and polar grids:

- `global_grid_lat, global_grid_lon`
- `npolar_grid_lat, npolar_grid_lon`
- `spolar_grid_lat, spolar_grid_lon`

"Section 2 | Global and Polar Grids" in the ATBD for ATL16/ATL17 contains additional details about the grids, including a simple algorithm for computing global and polar grid indices from latitude and longitude values.

Latitude and longitude in this product are defined as geodetic latitude and longitude in the WGS 84 geographic coordinate system (positive values = north and east). The following table provides information about the WGS 84 geographic coordinate system.

Table 4. 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
Ellipsoid/spheroid	WGS 84
Units	degree
False easting	N/A
False northing	N/A
EPSG code	4326
PROJ4 string	+proj=longlat +datum=WGS84 +no_defs
Reference	https://epsg.io/4326

1.5 Temporal Information

1.5.1 Coverage

13 October 2018 to present

Note that satellite maneuvers, data downlink issues, and other events can introduce data gaps into the ICESat-2 suite of products. As ATL03 acts as the bridge between the lower level, instrumentation-specific data and the higher-level products, the ICESat-2 Science Computing Facility maintains an ongoing list of ATL03 data gaps (.xlsx) that users can download and consult.

1.5.2 Resolution

1.5.2.1 ATL16

ATL16 is generated weekly according to the following rules:

- The first week of data within the month will begin on the first day of the month, end on the seventh day, and contain seven days.
- The second week of data will begin on the eighth day of the month, end on the fourteenth day, and contain seven days.
- The third week of data will begin on the fifteenth day of the month, end on the twenty-first day, and contain seven days.
- The fourth week of data will begin on the twenty-second day of the month and end on either the twenty-eighth, twenty-ninth, thirtieth, or thirty-first day of the month. As such, it will contain either seven, eight, nine, or ten days of data, depending on the calendar month and occurrence of leap years.

1.5.2.2 ATL17

ATL17 is generated monthly. The data month spans the first through the last calendar day of each month.

NOTE: "Section 6.0 | Product Production Considerations" in the ATBD for ATL16/ATL17 contains two tables users may find helpful. The "Weekly ATL16 Product File Content Control Information" table lists the week number, start and end dates, and number of days for each data file, as well as the possible number of ground tracks (i.e., ground track segments contained within the cell) available to generate it. The "Monthly ATL17 Product File Content Control Information" table contains the same information for ATL17 data files.

2 DATA ACQUISITION AND PROCESSING

2.1 Background

The ATL16 and ATL17 gridded atmosphere products are derived primarily from data in ATL09, the ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics product. The following figure illustrates the suite of ICESat-2 data products:

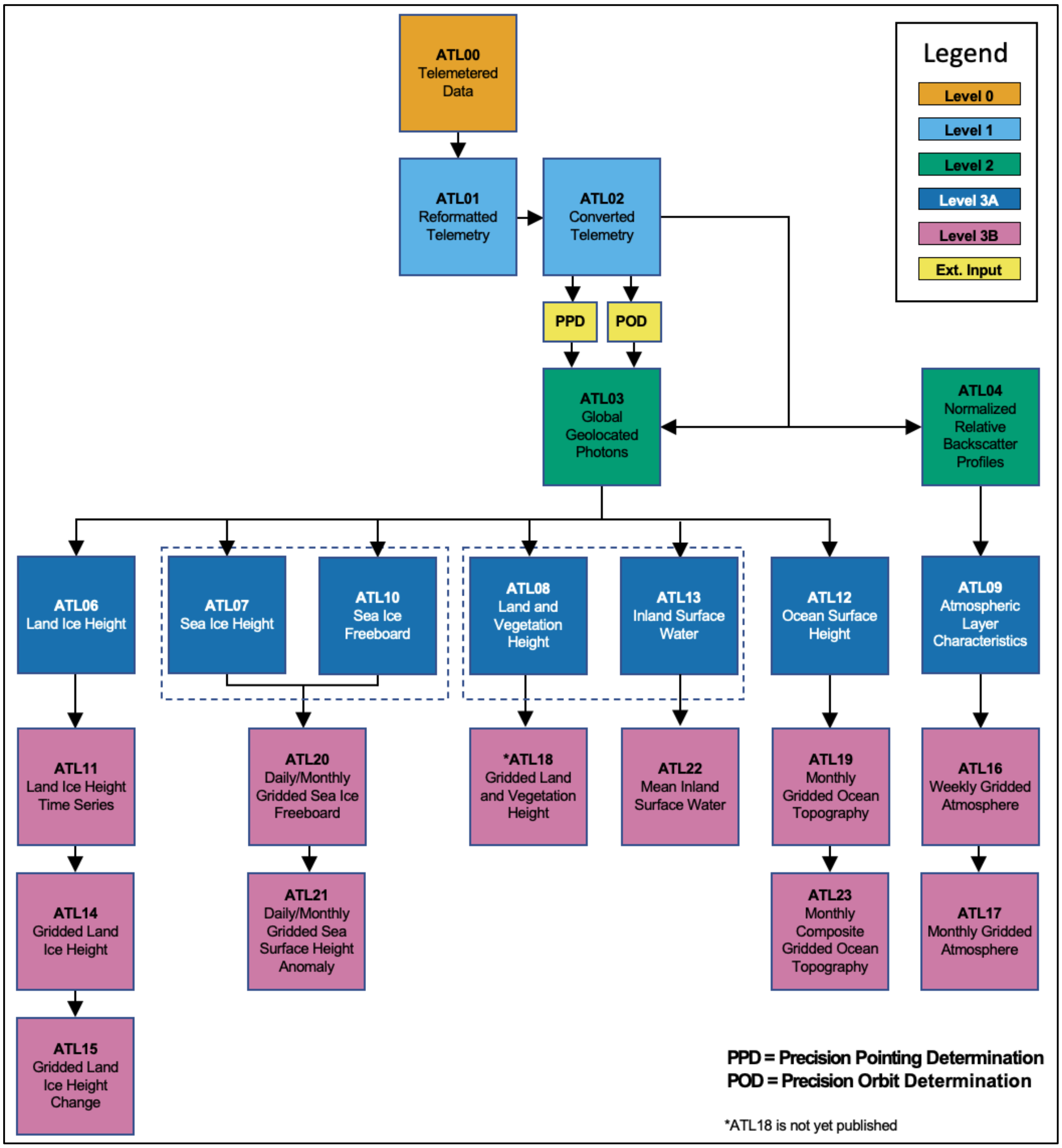

Figure 2. ICESat-2 data processing flow. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory.

2.2 Acquisition

ATL16 and ATL17 are generated primarily from ATL09 data, which are read for the period in question—either weekly or monthly—and gridded to the respective grid sizes. See Section 1.4 for more details on grid sizes. Both data sets report the same parameters. The "Processing" section that follows describes how each parameter is generated.

2.3 Processing

2.3.1 Global cloud fraction

("Section 3.1.1 | ATBD for ATL16/ATL17")

Global cloud fraction (`global_cloud_frac`) is computed from two parameters in the ATL09 product: `cloud_flag_atm`, which reports the number of layers detected for a given 25 Hz profile; and `layer_attr`, which indicates whether any detected layers are cloud (1), aerosol (2), or unknown (3).

The global cloud fraction algorithm reads input files from ATL09 and establishes two grids — one that counts the number of cloud observations and another that counts the total number of observations. If `cloud_flag_atm` is > 0 (i.e., layers are present) and `layer_attr` = 1 (i.e., cloud) *for any layer*, the cloud counter grid box associated with the current location is incremented[1]; the total observation count is incremented regardless of the `cloud_flag_atm` or `layer_attr` value. After all the input files are read for the week (ATL16) or month (ATL17) in question, the algorithm checks the minimum number of observations (`/ancillary_data/atmosphere/obs_minimum`) and sets the cloud fraction to "invalid" if the total number of observations is < `obs_minimum`. Otherwise, the cloud fraction is calculated by dividing the cloud counter in each grid box by its corresponding total number of observations.

Global cloud fraction is also provided as an image in `global_cloud_frac_img`.

[1]The cloud counter is incremented only once — after the first cloud layer has been detected — regardless of the number of cloud layers that are present.

2.3.2 Global aerosol fraction

("Section 3.1.3 | ATBD for ATL16/ATL17")

Global aerosol fraction (`global_aerosol_frac`) is computed via the same approach described above for global cloud fraction. Using the `cloud_flag_atm` and `layer_attr` parameters from

ATL09, if cloud_flag_atm is > 0 (i.e. layers are present) and layer_attr = 2 (i.e. aerosol) *for any layer*, the aerosol counter grid box associated with the current location is incremented[2]; the total observation count is incremented regardless of the cloud_flag_atm or layer_attr value. As with global cloud fraction, once all the input files are read for the week (ATL16) or month (ATL17) in question, the algorithm checks the required minimum number of observations (/ancillary_data/atmosphere/obs_minimum) and sets the aerosol fraction to "invalid" if the total number of observations is < obs_minimum. Otherwise, the aerosol fraction is calculated by dividing the aerosol counter in each grid box by its corresponding total number of observations.

Global aerosol fraction is stored in the global_aerosol_frac variable. An image is provided in global_aerosol_frac_img.

[2]The aerosol counter is incremented only once — after the first aerosol layer has been detected — regardless of the number of aerosol layers that are present.

2.3.3 Total column optical depth

("Section 3.2 **|** *ATBD for ATL16/ATL17")*

Total column optical depth (global_column_od) is determined from the ATL09 parameter column_od_asr, which is an estimate of the total column optical depth based on the apparent surface reflectance (ASR). ATL09 computes total column optical depth from ASR over the entire globe, however this estimate is only valid if the actual surface reflectance is well known, and this criterion is only met over ocean and inland water bodies where the surface reflectance can be computed from wind speed. As such, ATL16 and ATL17 only report total column optical depth over these surfaces.

Total column optical depth is determined using the same gridding approach described above for global cloud and aerosol fraction. The algorithm reads the column_od_asr and column_od_asr_qf parameters from ATL09, and if an observation is valid and over a water surface (column_od_asr_qf = 4), the column_od_asr value is added to the grid box at the current location and the corresponding counter grid box is incremented. After all the ATL09 input files have been read for the week (ATL16) or month (ATL17) in question, the algorithm checks the minimum number of observations (/ancillary_data/atmosphere/obs_minimum) and sets the total column optical depth to "invalid" if the total number of observations is < obs_minimum. Otherwise, the total column optical depth grid is divided by the counter grid (where the counter grid is > 0) to compute the average total column optical depth over the oceans and inland water bodies.

Global column optical depth is stored in the global_column_od variable. An image is provided in global_column_od_img.

2.3.4 Polar cloud fraction

("Section 3.1.6 | ATBD for ATL16/ATL17")

2.3.4.1 High, Middle, Low, and Total Cloud Fractions

High, middle, low, and total polar cloud fractions are determined in the same manner as global cloud fraction, except cloud fractions are computed using polar grids that span the regions poleward of 60° N and 60° S. In addition to the total polar cloud fraction, cloud fractions are also determined for three different height ranges: h ≤ 4 km (low), 4 km < h ≤ 8 km (mid), and h > 8 km (high). As such, ATL16 and ATL17 each contain eight polar cloud fraction grids (four per hemisphere).

The grids are populated using the approach described for global cloud fraction, except the ATL09 parameter `layer_top`[3] is used to segregate the data by height. Assuming that `cloud_flag_atm` = some value x > 0, then for each value from 1 to x:

If any `layer_top(x)` is <= 4 km AND `layer_attr` = 1, increment the counter for low cloud fraction;
If any `layer_top(x)` is > 4 km and <= 8 km AND `layer_attr` = 1, increment the counter for mid-level cloud fraction;
If any `layer_top(x)` is > 8 km AND `layer_attr` = 1, increment the counter for high cloud fraction;
If `cloud_flag_atm` is > 0 AND `layer_attr` = 1 for *any layer*, increment the counter for total cloud fraction.

Note that each counting grid is incremented (at most) only once per 25 Hz profile, even if multiple layers are found within, say, the same height range. For example, if two cloud layers lie between 4 km and 8 km, the mid-level counter is only incremented once.

As with total cloud fraction, a separate grid is maintained to count total observations (incremented only once per 25 Hz profile regardless of the value of the value of `cloud_flag_atm`). After all the ATL09 input files have been read for the week (ATL16) or month (ATL17) in question, all four grids are divided by the total observation grid (where it is > 0) to obtain cloud fractions for all grids. As described previously, if the number of observations for a grid box is < `obs_minimum`, the cloud fraction in that box is set to "invalid".

Total, low, mid, and high polar cloud fractions are stored in the following variables. The data are also provided as images using the same variable names with "`_img`" appended:

- `npolar_totalcloud_frac`
- `npolar_lowcloud_frac`

- npolar_midcloud_frac
- npolar_highcloud_frac
- spolar_totalcloud_frac
- spolar_lowcloud_frac
- spolar_midcloud_frac
- spolar_highcloud_frac

[3]The ATL09 layer_top parameter reports the height of the top of detected layers.

2.3.4.2 Transmissive and Opaque Cloud Fractions

ATL16 and ATL17 also break out polar cloud fractions by whether the detected cloud layers are transmissive or opaque based on the presence of photon returns in the surface bin (ATL09 parameter surface_sig).

Using the same approach described above, if the cloud_flag_atm > 0 (i.e., layers are present), AND surface_sig is > 0 (photons are present in the surface bin), AND layer_attr = 1 (i.e., clouds) *for any layer*, then the counting grid box for transmissive cloud at that location is incremented. If the same conditions are met but surface_sig = 0, the grid box for the opaque cloud is incremented. As described previously, the transmissive and opaque cloud grids are divided by the total observation count to obtain the transmissive and opaque cloud fractions, and all grid boxes in which the total number of observations < obs_minimum are set to "invalid".

Transmissive and opaque cloud fractions are stored in the following variables. The data are also provided as images using the same variable names with "_img" appended:

- npolar_transcloud_frac
- npolar_opaquecloud_frac
- spolar_transcloud_frac
- spolar_opaquecloud_frac

2.3.4.3 Blowing snow frequency

(see "Section 3.3.1 | *ATBD for ATL16/ATL17")*

As with the polar snow fractions discussed previously, blowing snow frequency for ATL16 and ATL17 is generated using two polar grids: one to count the occurrence of blowing snow and another to count the total number of observations. In previous versions of ATL16 and ATL17, only low-rate data was used to produce blowing snow frequency. In this version, both high-rate (25 Hz) and low-rate (1Hz) blowing snow heights are used to produce two separate blowing snow frequencies.

Generally, the presence of blowing snow is determined from the ATL09 parameter `bsnow_h`, which records the height above the ground of the top of the blowing snow layer and is only > 0 when blowing snow has been detected. The total number of observations is counted using the ATL09 parameter `bsnow_con`, a blowing snow confidence flag that estimates blowing snow detection confidence using the following integer coding scheme: -3 = surface not detected; -2 = no surface wind; -1 = no scattering layer found; 0 = no top layer found; 1 = none–little; 2 = weak; 3 = moderate; 4 = moderate–high; 5 = high; 6 = very high.

The blowing snow frequency algorithm reads the input ATL09 files and if `bsnow_h` is valid > 0 the blowing snow grid box associated with the current location is incremented. If `bsnow_con` is valid > -3, the observation grid box is incremented at the current location (with or without the presence of blowing snow). After all the input files are read for the week (ATL16) or month (ATL17) in question, blowing snow frequency is calculated by dividing the blowing snow counter in each grid box by the corresponding total number of observations and multiplying by 100 to obtain a percent (blowing snow frequency is the only parameter reported as a percent). Grid boxes in which the total number of observations is less than `obs_minimum` is set to "invalid".

Blowing snow frequency is stored in the npolar_hirate_blowing_snow_freq, spolar_hirate_blowing_snow_freq, npolar_lorate_blowing_snow_freq, and spolar_lorate_blowing_snow_freq variables. These parameters are also provided as images in the variables npolar_hirate_blowing_snow_freq_img, spolar_hirate_blowing_snow_freq_img, npolar_lorate_blowing_snow_freq_img, and spolar_lorate_blowing_snow_freq_img.

2.3.4.4 Apparent surface reflectivity

(see "Section 3.4 **|** *ATBD for ATL16/ATL17")*

ASR is defined as the true surface reflectivity modified by the two-way atmospheric transmission and is in general a number between 0 and 1. Using the previously described approach, ASR is determined for both global and polar grids by reading the `apparent_surf_reflec` parameter in ATL09. If `apparent_surf_reflec` is greater than 0, the value is added to the grid boxes (i.e., global and polar) at the corresponding location and the observation counters are incremented. After all the input files are read for the week (ATL16) or month (ATL17) in question, the running total in each ASR grid box is divided by the corresponding number of observations to obtain the average ASR. Grid boxes are set to "invalid" if the total number of observations is less than `obs_minimum`.

ASR is stored in the following variables: `global_asr, npolar_asr,` and `spolar_asr`. These parameters are also provided as images in the variables `global_asr_img, npolar_asr_img`, and `spolar_asr_img`.

2.3.4.5 Ground detection frequency

(see "Section 3.5 | *ATBD for ATL16/ATL17")*

Ground detection frequency is determined for both global and polar grids using the same approach described previously and the ATL09 parameter `surface_sig`, which reports the number of photons detected in the surface bin and is only greater than 0 if a surface signal was detected. The algorithm reads the ATL09 input files and if `surface_sig` is > 0, the surface signal grid boxes (i.e., global and polar) at the current location are incremented. The corresponding observation grid box is incremented regardless of the value of `surface_sig`. After all the input files are read for the week (ATL16) or month (ATL17) in question, the ground detection frequency is calculated by dividing the surface signal grids by the corresponding observation grids (where they are > 0). Grid boxes are set to "invalid" if the total number of observations is less than `obs_minimum`.

Ground detection frequency is stored in the following variables: `global_grnd_detect`, `npolar_grnd_detect`, and `spolar_grnd_detect`. These parameters are also provided as images in the `global_grnd_detect_img`, `npolar_grnd_detect_img`, and `spolar_grnd_detect_img` variables.

2.3.4.6 South Polar Diamond Dust Frequency

("Section 3.3.2 | *ATBD for ATL16/ATL17")*

For each south polar grid cell, South Polar Diamond Dust Frequency (`spolar_surf_ddust_freq`) represents the ratio of the number of valid detected diamond dust density layers above the digital elevation model (DEM) surface height from all available 25 Hz observations to the number of all 25 Hz profile observations regardless of the values of the profile bottom height of the diamond dust density layer above the ellipsoid (`ddust_hbot_dens`). The observations are converted to a local bottom height of the diamond dust density layer above the surface.

The filtering test conditions are 1) `ddust_bot_ht` < 200.0, 2) `hirate_bsnow_h` = INVALID or `hirate_bsnow_h` > 500.0, 3) `surface_bin` < 700.0 and 4) `dem_h` < 500.0. All conditions being satisfied, the south polar surface diamond dust density layer observation count numerator array cell is increment by one and the denominator array cell is incremented for all 25 Hz observations.

South Polar Diamond Dust Frequency is also stored as an image in `spolar_surf_ddust_freq_img`.

2.3.4.7 Apparent Surface Reflectance Cloud Fraction

("Section 3.4 | *ATBD for ATL16/ATL17")*

For each identified ASR cloud probability observation count grid cell (north polar, south polar, or global), Apparent Surface Reflectance Cloud Fraction represents the number of 25 Hz observations determined from the ATL09 ASR cloud probability when the observation equals or exceeds a control constant. The gridded parameter represents the ratio of the clouds counted from ASR to the number of all 25 Hz observations in the cell. An ASR cloud fraction value of 0.0 represents a completely cloud-free grid cell; an ASR cloud fraction value of 1.0 indicates the grid cell is completely covered with clouds from ASR.

Apparent Surface Reflectance Cloud Fraction is stored in `npolar_asr_cloud_frac`, `spolar_asr_cloud_frac`, and `global_asr_cloud_frac`. These parameters are also provided as images in the `npolar_asr_cloud_frac_img`, `spolar_asr_cloud_frac_img`, and `global_asr_cloud_frac_img` variables.

2.3.4.8 Image Smoothing

The images stored in ATL16 and ATL17 data files are smoothed versions of the underlying (unsmoothed) gridded data fields. The smoothing algorithm and criteria for applying it are described in "Section 4.0 | Smoothing of Images" in the ATBD for ATL16/ATL17.

2.4 Quality, Errors, and Limitations

Errors and uncertainties in input sources such as ATL09, and the lower lever products from which ATL09 is produced, can propagate into ATL16 and ATL17. Users interested in these products' error sources should consult the product documentation for ATL02, ATL03, and ATL09.

3 VERSION HISTORY

A summary of the version history is provided in Table 5, followed by a detailed list of changes for the current version.

Table 5. Version History Summary

Version	Release Date
V2*	June 2020
V3	April 2021
V4	February 2022
V5	September 2023

* Note that Version 1 of ATL16 and ATL17 was generated for evaluation purposes only and never released. Version 2 is the first version of these products that was released to the public.

Changes for Version 5 are as follows:

- Added new gridded data parameter called South Polar Diamond Dust Frequency (`spolar_surf_ddust_freq`), associated image (`spolar_surf_ddust_freq_img`**),** and supporting statistical vector parameters: `spolar_surf_ddust_freq _max`**,** `spolar_surf_ddust_freq_mean`**,** `spolar_surf_ddust_freq_min`**,** `spolar_surf_ddust_freq_sdev`
- Added new North Polar Apparent Surface Reflectance Cloud Fraction gridded data parameter (`npolar_asr_cloud_frac`), associated image (`npolar_asr_cloud_frac_img`**),** and supporting North Polar Apparent Surface Reflectance Cloud Fraction statistical vector parameters: `npolar_asr_cloud_frac_max`, `npolar_asr_cloud_frac_mean`, `npolar_asr_cloud_frac_min`, `npolar_asr_cloud_frac_sdev`
- Added new South Polar Apparent Surface Reflectance Cloud Fraction gridded data parameter (`spolar_asr_cloud_frac`), associated image (`spolar_asr_cloud_frac_img`**),** and supporting South Polar Apparent Surface Reflectance Cloud Fraction statistical vector parameters: `spolar_asr_cloud_frac_max`, `spolar_asr_cloud_frac_mean`, `spolar_asr_cloud_frac_min`, `spolar_asr_cloud_frac_sdev`
- Added new Global Apparent Surface Reflectance Cloud Fraction gridded data parameter (`global_asr_cloud_frac`), associated image (`global_asr_cloud_frac_img`**)** and supporting Global Apparent Surface Reflectance Cloud Fraction statistical vector parameters: `global_asr_cloud_frac_max`, `global_asr_cloud`, `frac_mean`, `global_asr_cloud_frac_min`, `global_asr_cloud_frac_sdev`
- For the following parameters, implemented filtering of laser shots with a surface incidence angle greater than six degrees:
    - Expanded Global Total Column Optical Depth (`expanded_global_column_od`)
    - Global Apparent Surface Reflectance (`global_asr`)
    - Global Total Column Optical Depth (`global_column_od`)
    - North Polar Apparent Surface Reflectance (`npolar_asr`)
    - South Polar Apparent Surface Reflectance (`spolar_asr`)

4 DOCUMENT INFORMATION

4.1 Publication Date

September 2023

4.2 Date Last Updated

February 2024

APPENDIX A: ATLAS/ICESAT-2 DESCRIPTION

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. Each pair also has a Pair Track—an imaginary line halfway between the actual location of the left and right beams (see Figure A1). 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 A1, 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 A1, right). The first yaw flip was performed on December 28, 2018, placing the spacecraft into the backward orientation. 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 (i.e., the satellite has a 91-day repeat cycle) 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 to the RGT number, e.g., 000103 (RGT 0001, cycle 03) or 138705 (RGT 1387, cycle 05).

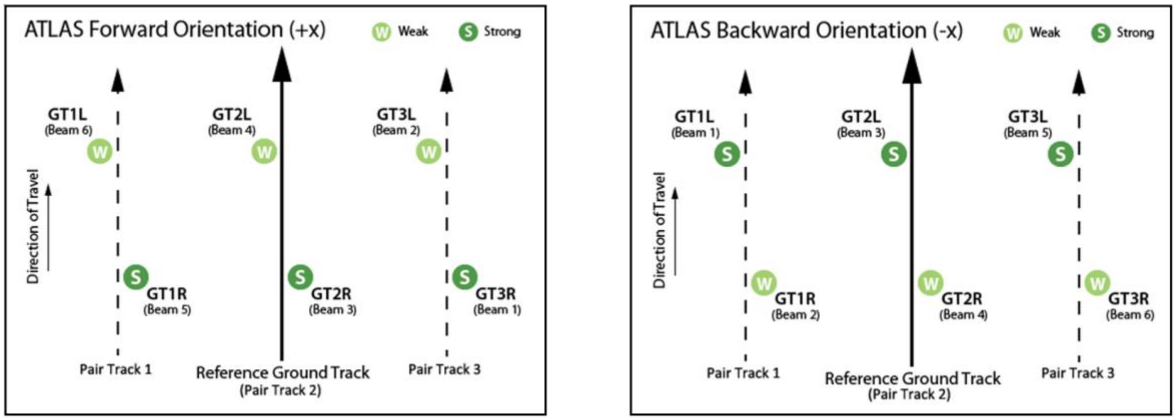

Figure A1. Spot and ground track (GT) naming convention with
ATLAS oriented in the forward (instrument coordinate +x) direction
and backward (instrument coordinate -x) direction.

Users should note that between 14 October 2018 and 30 March 2019, the spacecraft pointing control was not yet optimized. Thus, ICESat-2 data acquired during that time do not lie along the nominal RGTs but are offset at some distance from the RGTs. Although not along the RGT, the geolocation information for these data is not degraded.

Various reference systems and dynamic processes, or geophysical corrections, occur during an ATLAS/ICESat-2 measurement (Figure A2). Table A1 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.

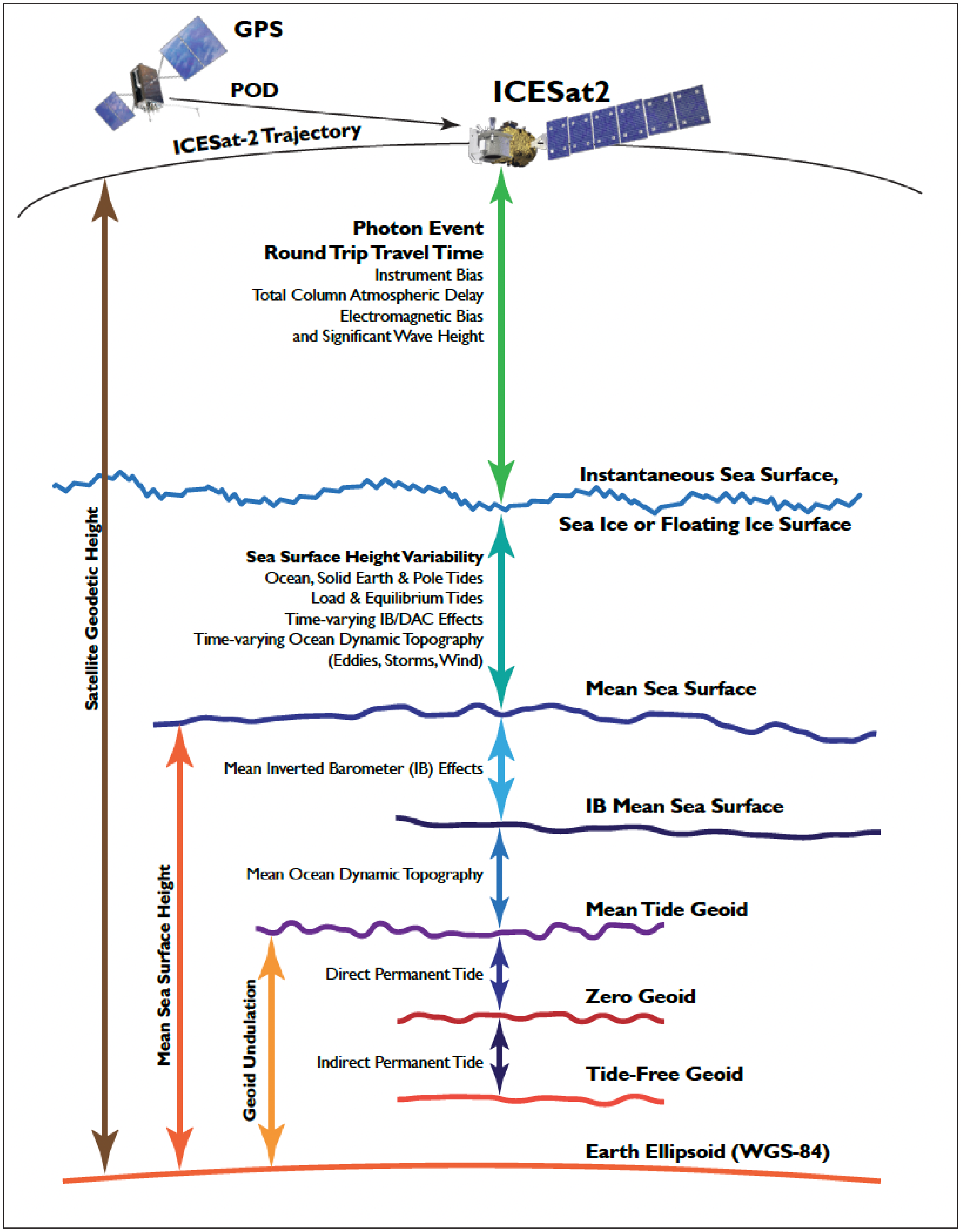

Figure A2. Geophysical corrections used in satellite altimetry.
Taken from *ICESat-2 Data Comparison User's Guide for Rel006*
available on the ATL03 data set landing page.

Table A1. 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.

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.