ATLAS/ICESat-2 L3B Weekly and Monthly Gridded Atmosphere, Version 6

USER GUIDE

How to Cite These Data

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

Palm, S. P., Northam, E. T., & Herzfeld, U. C. (2025). *ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere* (ATL16, Version 6). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL16.006 [Date Accessed].

Palm, S. P., Northam, E. T., & Herzfeld, U. C. (2025). *ATLAS/ICESat-2 L3B Monthly Gridded Atmosphere* (ATL17, Version 6). [Data set]. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. https://doi.org/10.5067/ATLAS/ATL17.006 [Date Accessed].

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

FOR CURRENT INFORMATION, VISIT https://nsidc.org/data/ATL16 or https://nsidc.org/data/ATL17

National Snow and Ice Data Center

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1 DATA DESCRIPTION

The ATL16 and ATL17 data products are described in detail in the ICESat-2 Project Algorithm Theoretical Basis Document (ATBD) for Atmosphere Gridded Products (Northam and Palm, 2025).

1.1 Summary

This user guide describes two ICESat-2 data sets: ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere (ATL16) and ATLAS/ICESat-2 L3B Monthly Gridded Atmosphere (ATL17). Both data sets report the same parameters but at different frequencies: weekly (ATL16) and monthly (ATL17). The gridded parameters are global cloud fraction, global combined cloud fraction, global aerosol fraction, global clear fraction, polar cloud fraction, global folded cloud frequency, global total column optical depth, global expanded total column optical depth, polar blowing snow frequency, south polar surface diamond dust frequency, global/polar apparent surface reflectance (ASR), global/polar ASR cloud fraction, and global/polar ground detection frequency.

1.2 File Information

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 Contents

Complete lists of all ATL16 and ATL17 parameters are available in the ATL16 Data Dictionary and ATL17 Data Dictionary, respectively.

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 top level, alongside the `METADATA`, `ancillary_data`, `orbit_info`, and `quality_assessment` data groups:

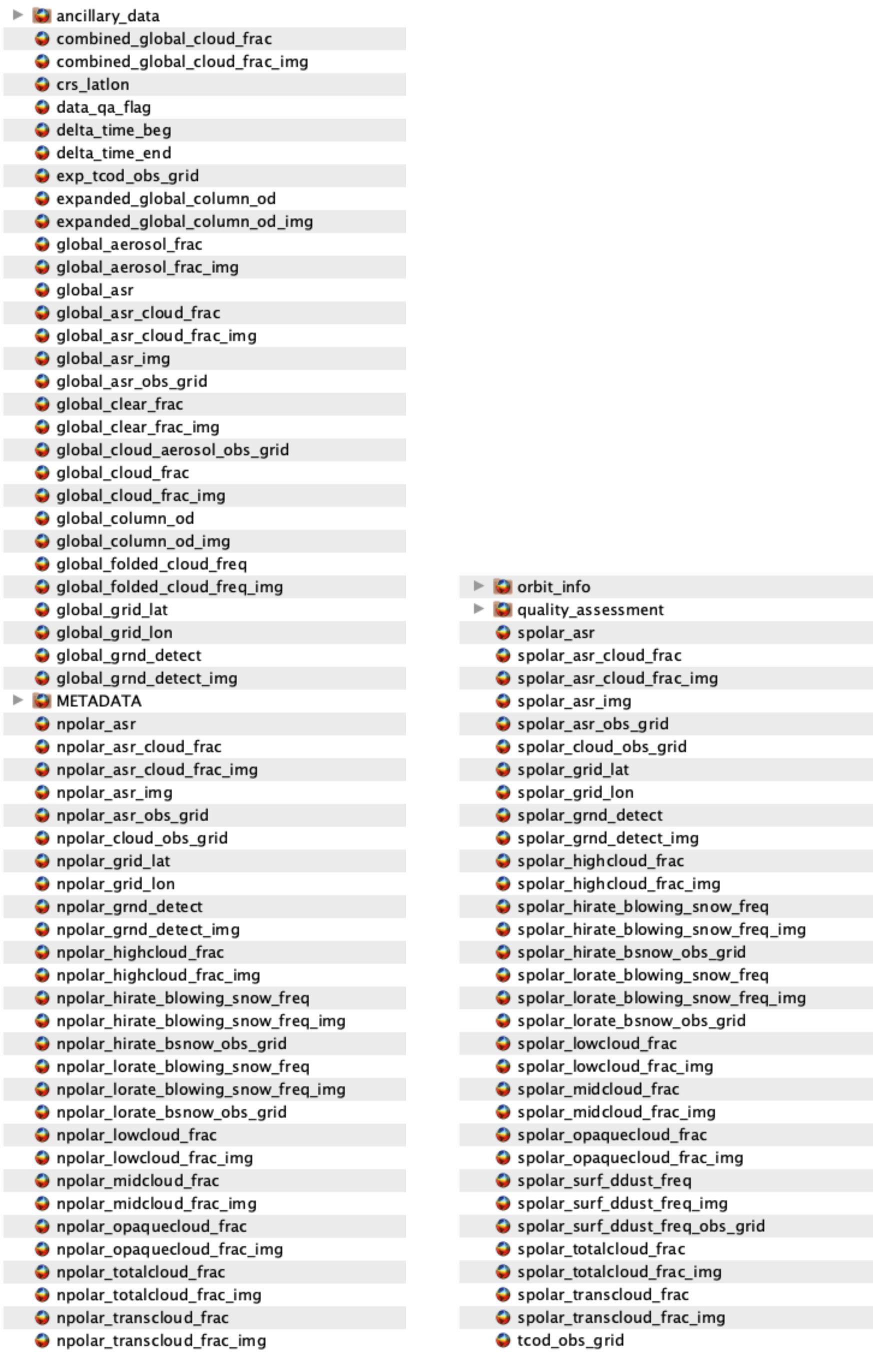


Figure 1. Internal structure of an ATL16 data file. ATL17 data files utilize the same structure and variable names.

1.2.2.1 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) and the day/night data type flag.

1.2.2.2 METADATA

ISO19115 structured summary metadata for the granule, including content that describes the required geospatial information. The version(s) of the input files are included in the file name attribute under the `Lineage` group.

1.2.2.3 orbit_info

Orbit parameters that are constant for a granule, such as the reference ground track (RGT) number, cycle, and spacecraft orientation.

1.2.2.4 quality_assessment

Quality assessment data for the granule as a whole, including a pass/fail flag and a failure reason indicator.

1.2.2.5 Atmospheric parameters

The atmospheric parameters are stored at the top level and described in Section 2.3 of this user guide.

1.2.3 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_20230601012940_10951901_006_01.h5
ATL17_20230601012940_10951901_006_01.h5
```

Table 1. File Naming Convention Variables and Descriptions

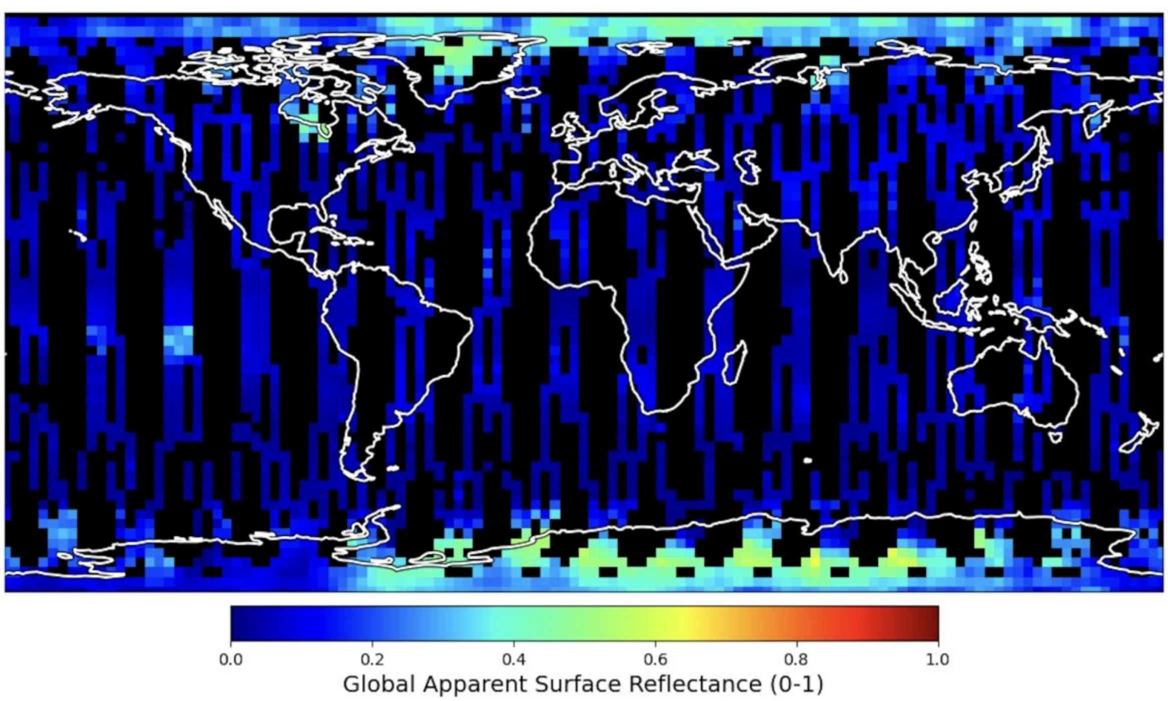
Variable	Description
`ATL16` *or* `ATL17`	ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere *or* ATLAS/ICESat-2 L3B Monthly Gridded Atmosphere
`yyyymmdd`	Starting date (year, month, day) of data file coverage
`hhmmss`	Starting time (hour, minute, second) of data file coverage (UTC)

Variable	Description
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	Region number. This number corresponds to the first of the ICESat-2 along-track regions considered for input into ATL16/17 processing. This region number will always be "01" except when a granule is split along a spacecraft orientation change, in which case, the region number is the last region before the switch and the first region after the switch, in consecutive granules.
vvv_rr	Version and revision number*.

*Occasionally, 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 region 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.

1.2.4 Browse Files

Browse files are provided as JPGs that contain images designed to quickly assess the location and quality of each granule's data. Global Apparent Surface Reflectance and Global Cloud Fraction images are provided for each granule (Figure 2). Browse files utilize the same naming convention as their corresponding data file but with `_BRW` appended.



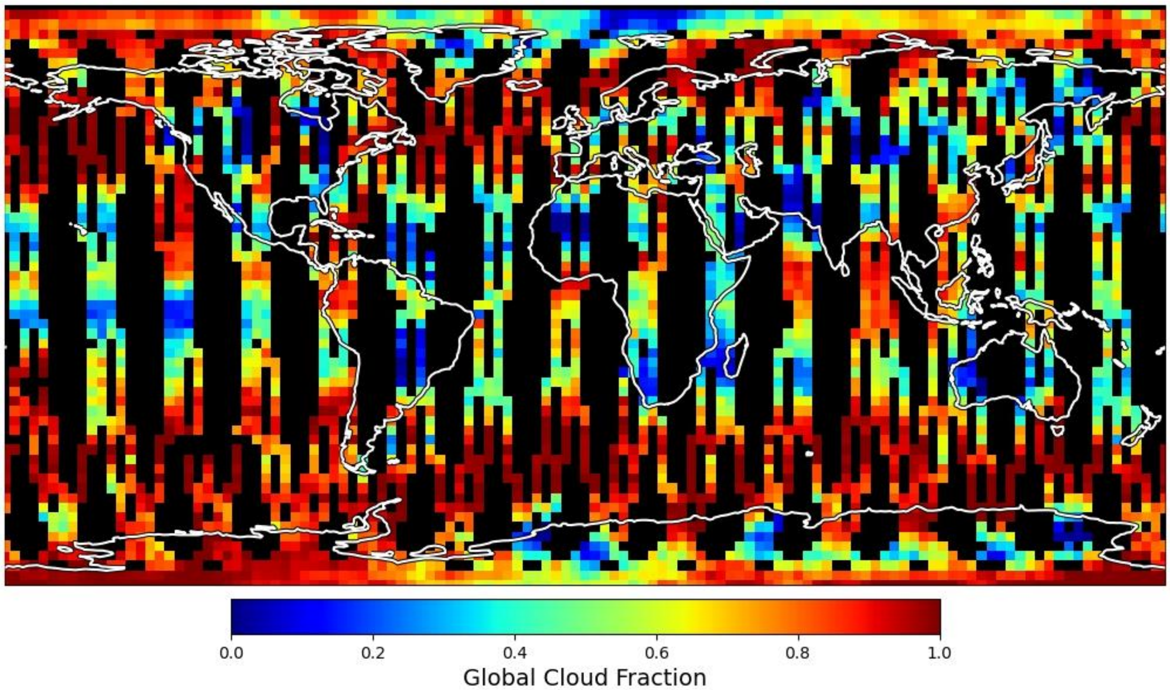


Figure 2. Global Apparent Surface Reflectance (top) and Global Cloud Fraction (bottom) example browse images.

1.3 Spatial Information

1.3.1 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 ATL16/17

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 ≤ 4 km
- Mid: 4 km < h ≤ 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.

1.3.2 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 Region and Polar Region Grid Dimensions

Product	Global Region Grid Resolution	Global Region Grid Dim (row x col)	Polar Regions Grid Resolution	Polar Regions 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

1.3.3 Geolocation

Three pairs of 1D arrays are included in the product that can be used to geolocate the global and polar region 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 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 are defined as geodetic in the WGS 84 geographic coordinate system (EPSG: 4326).

1.4 Temporal Information

1.4.1 Coverage

Temporal coverage is 13 October 2018 through the most current processing.

NOTE: Temporal updates to the product are made available to users a few times per year. The addition of these new files is not reflected in the Version History section of the user guide.

1.4.2 Resolution

1.4.2.1 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.

1.4.2.2 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 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

Atmospheric data acquired from ATLAS is unique because it requires non-standard analysis techniques. For example, the high repetition rate laser limits the vertical extent of the profiles to just 14 km. The gridded ATL16/17 data are useful for atmospheric and climate studies.

2.2 Acquisition

ATL16 and ATL17 are generated primarily from ATL09 data and gridded to the respective grid sizes (see Section 1.3). The Processing section describes how each parameter is generated; the cited section numbers refer to those in the ATBD (Northam and Palm, 2025).

2.3 Processing

2.3.1 Global Cloud Fraction

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 (ATBD Section 3.1.1)

2.3.2 Global Aerosol Fraction

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 (ATBD Section 3.1.3).

2.3.3 Total Column Optical Depth

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 accurate 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. Consequently, the total column optical depth over land surfaces contained in ATL16 and ATL17 is not as accurate as that over water 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 parameter from ATL09, and if an observation is valid, 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 both water and land surfaces.

Global column optical depth is stored in the `global_column_od` variable. An image is provided in `global_column_od_img` (ATBD Section 3.2).

2.3.3.1 Expanded Total Column Optical Depth

The total column optical depth (Section 2.3.3) only includes data for which there is a detectable surface return (i.e., where the ATL09 parameter `column_od_asr` is valid). The expanded total column optical depth does not require `column_od_asr` to be valid. When the value is invalid (i.e., no surface return was detected), a random selection of optical depth between 3.0 and 35.0 is used to represent the column optical depth of that shot and added to the grid box (ATBD Section 3.2.2). If `column_od_asr` is valid, then it is also added to the grid box. The grid box counter is incremented regardless of the value of `column_od_asr` to account for the effect of clouds that totally attenuate the laser beam and thus do not produce a surface return. The `expanded_global_column_od` parameter was added in Version 5.

2.3.3.2 Global Folded Cloud Frequency

The global folded cloud frequency parameter is created from the ATL09 parameter `cloud_fold_flag`, which is a 0/1/2 flag indicating the presence of clouds above 15 km that have been folded down to the -0.5 to 3 km range of the profile (ATBD Section 3.1.7). Such clouds are normally confined to the tropics (30º N to 30º S). To find such occurrences, the signal below ground is examined for a backscatter signal indicative of a cloud and if present, the `cloud_fold_flag` is set to 1. In addition, the GEOS-5 MET data includes the atmospheric pressure of the highest cloud within the current grid box. If, after translating the pressure to height, the cloud height is above 15 km, the `cloud_fold_flag` is set to 2. When `cloud_fold_flag` equals 1 or 2, a fold counter is incremented for the current grid cell. An observation counter is incremented regardless of the value of `cloud_fold_flag`. The folded cloud frequency is then computed by dividing the fold counter by the observation counter for each grid cell. The global cloud fold grid was added in Version 6.

2.3.4 Polar Cloud Fraction

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 (ATBD Section 3.1.6).

2.3.4.2 Transmissive and Opaque Cloud Fractions

ATL16 and ATL17 also separate 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

As with the polar cloud 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 = 10 m wind speed less than threshold (5 m/s); -1 = backscatter value in first bin above the surface less than threshold; 0 = no top layer found less than 500 m above the surface; 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 count for the 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 (ATBD Section 3.3.1).

2.3.4.4 Apparent Surface Reflectivity

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` (ATBD Section 3.4).

2.3.4.5 Ground Detection Frequency

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 (ATBD Section 3.5).

2.3.4.6 South Polar Diamond Dust Frequency

Diamond dust, also known as clear sky precipitation when it reaches the surface, consists of very small ice crystals that form when the air is extremely cold and supersaturated. This condition frequently occurs over much of the high, East Antarctic plateau. It is most important when it reaches the ground as it can significantly contribute to precipitation in arid regions such as the Antarctic Plateau (Palm et al., 2025). The diamond dust frequency reported here is determined from an elevated backscatter value that occurs within 200 m of the surface in the absence of blowing snow (ATBD Section 3.3.2).

To determine the frequency, 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 m. 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` (ATBD Section 3.3.2).

2.3.4.7 Apparent Surface Reflectance Cloud Fraction

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 (ATBD Section 3.4).

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.

2.4 Quality, Errors, and Limitations

Errors and uncertainties in input sources (e.g., ATL09) and the lower-level 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

Table 4. Version History Summary

Version	Date	Description of Changes
5.1 (retire)	30 Apr 2026	Removed data access for v5.1. Temporal coverage was 15 Oct 2018 to 10 May 2024.
6.0	30 Oct 2025	• Develop atlas_l3b_atm v2.1 • Separate plot limits from valid_min, valid_max. • Add filtering to capture possible INVALID profile column optical depth from ASR quality flag values. • Add Global Folded Cloud Frequency, percent, parameter for gridded cloud_fold_flag implementation • Modify existing global/polar cloud fraction parameters to include layer_attr ()=11 and cloud_fold_flag>0 in first-occurrence detected cloud layer counting • Add daytime-only processing • Implement grid cell observation count threshold control constants
5.1	1 May 2024	Data from 13 Nov 2022 to 26 Oct 2023 were reprocessed using ITRF2014 (replacing ITRF2020) for consistency across the entire data set.
4.0 (retire)	4 Apr 2024	Removed data access for v4.0. Temporal coverage was 13 Oct 2018 to 1 Aug 2022.
5.0	28 Sep 2023	• Added new gridded data parameter called South Polar Diamond Dust Frequency (spolar_surf_ddust_freq), associated image

Version	Date	Description of Changes
		(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 • Implemented filtering of laser shots with a surface incidence angle greater than six degrees for expanded_global_column_od, global_asr, global_column_od, npolar_asr, spolar_asr • Added new expanded_global_column_od parameter
3.0 (retire)	18 Aug 2022	Removed data access for v3.0. Temporal coverage was 13 Oct 2018 to 1 Jul 2021.
2.0 (retire)	25 Apr 2022	Removed data access for v2.0. Temporal coverage was 13 Oct 2018 to 1 Apr 2020.
4.0	18 Feb 2022	• Added new Global Clear Fraction gridded data parameter (global_clear_frac), associated image and supporting Global Clear Fraction statistical vector parameters: global_clear_frac_max, global_clear_frac_mean, global_clear_frac_min, global_clear_frac_sdev. • Added new module combined_global_cloud_frac_mod to compute the combined global cloud fraction • Added new Combined Global Cloud Fraction gridded data parameter (combined_global_cloud_frac), associated image (combined_global_cloud_frac_img) and supporting Combined Global Cloud Fraction statistical vector parameters: combined_global_cloud_frac_max, combined_global_cloud, frac_mean, combined_global_cloud_frac_min, combined_global_cloud_frac_sdev.

Version	Date	Description of Changes
		• Added new control parameter in support of the Combined Global Cloud Fraction gridded data parameter: the ASR cloud threshold control vector asr_cloud_threshold, used as the minimum value for ASR clouds detected from the profile asr_cloud_probability. • Added new module exp_glob_tot_col_od_mod to compute the expanded global (over water) total column optical depth • Added new Expanded Global (Over Water) Total Column Optical Depth gridded data parameter (expanded_global_column_od), associated image (expanded_global_column_od_img), and supporting Expanded Global (Over Water) Total Column Optical Depth statistical vector parameters: expanded_global_column_od_max, expanded_global_column_od_mean, expanded_global_column_od_min, expanded_global_column_od_sdev. • Added new control parameter in support of the Expanded Global (Over Water) Total Column Optical Depth gridded data parameter: the generate estimated cloud optical depth maximum limit control vector gen_cloud_od_max, used directly in the estimated cloud optical depth value calculation. • Added new observation count grid for the Expanded Global (Over Water) Total Column Optical Depth gridded data parameter, the observation count gridded parameter exp_tcod_obs_grid • Added the Coordinate Reference System (CRS) parameter for WGS84 latitude and longitude reference; includes attributes: cos_wkt, grid_mapping_name, inverse_flattening, longitude_of_prime_meridian, proj4text, semi_majorf_axis, srid.
3.0	29 Apr 2021	• The blowing snow frequency parameter based on the 1 Hz average backscatter data was renamed to low-rate blowing snow frequency and a high-rate blowing snow frequency parameter generated from 25 Hz backscatter data was added. • The grid size for the weekly product (ATL16) changed from 2° x 2° to a 3° latitude x 3° longitude for the global coverage and to a 1° latitude x 3° longitude for the polar coverage. • The grid size for the monthly product (ATL17) changed from 1° x 1° to a 1° latitude x 1° longitude for the global coverage and to a 0.5° latitude x 1.5° longitude for the polar coverage. • Gridded parameter minimum, maximum, and standard deviation values in addition to the average are written on each image and included in the data product
2.0	3 June 2020	Initial release
1.0	N/A	Generated for evaluation purposes only; not released

4 REFERENCES

Magruder, L. A., Brunt, K., Neumann, T., Klotz, B., & Alonzo, M. (2020). Passive ground-based optical techniques for monitoring the on-orbit ICESat-2 altimeter geolocation and footprint diameter. *ESS Open Archive*. https://doi.org/10.1002/essoar.10504571.1

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Palm, S. P., & Yang, Y. (2025). ICESat-2 lidar estimates of clear-sky precipitation over the East Antarctic Plateau. *Journal of Geophysical Research: Atmospheres*, 130, e2025JD044120. https://doi.org/10.1029/2025JD044120

5 DOCUMENT INFORMATION

5.1 Publication Date

October 2025

5.2 Date Last Updated

April 2026

APPENDIX A – ICESAT-2/ATLAS DESCRIPTION

The ICESat-2 observatory utilizes a photon-counting lidar (the ATLAS instrument) and ancillary systems (GPS, star tracker cameras, and ground processing) to measure the round-trip time a photon takes to travel from ATLAS to Earth and back again. The time-of-flight, absolute time, spacecraft location and pointing are used to determine the reflected photon's geodetic height, latitude, and longitude.

The ATLAS instrument uses a single laser and a beam splitter to illuminate six different “spots” that each trace out a ~11 m wide track (Magruder et al., 2020) as ICESat-2 orbits Earth (Figure A - 1). Three of the spots are considered “strong” (spots 1, 3, and 5) and the other three “weak” (spots 2, 4, and 6). Three independent Photon Counting Electronics (PCEs) record the photons returned to the telescope, each for a single pair of strong/weak spots. PCE1 records spots 1 and 2; PCE2 records spots 3 and 4; and PCE3 records spots 5 and 6.

Higher-level ATLAS/ICESat-2 data products are organized by ground track (GT), with GT1L and GT1R forming pair one, GT2L and GT2R forming pair two, and GT3L and GT3R forming pair three. Each GT is numbered according to the relative location of the laser spot that generates it, with GT1L on the far left and GT3R on the far right. Left/right beams within each pair are approximately 90 m apart in the across-track direction and 2.5 km in the along-track direction.

The mapping between the strong and weak spots of ATLAS, and their relative positions 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 (Figure A - 1, left), with the weak spots leading the strong spots. In the backward orientation, ATLAS travels along the -x coordinate in the instrument reference frame, with the strong spots leading the weak spots (Figure A - 1, right). Atmospheric profiles are generated from strong spots only, and the instrument orientation determines which GT label ("gtx") corresponds to which profile. The spacecraft orientation is tracked in the ICESat-2 Major Activities document (.xlsx).

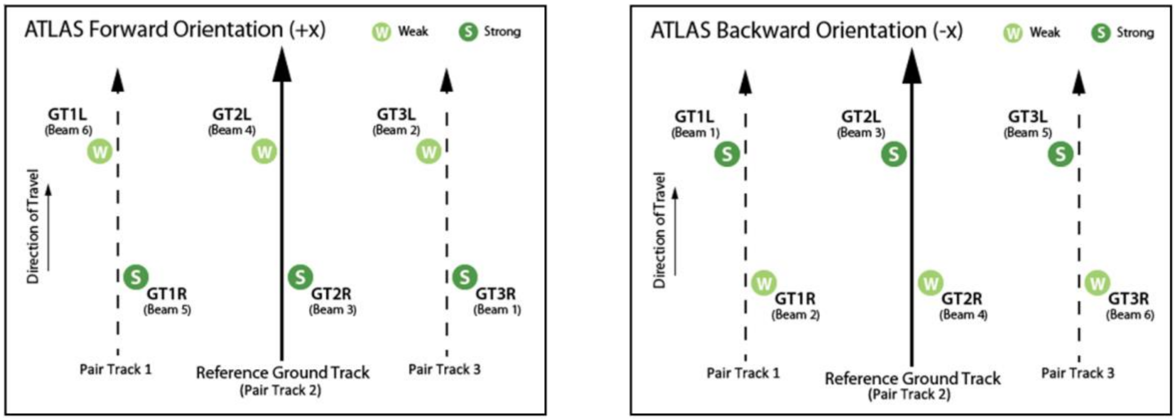

Figure A - 1. Spot and Ground Track (GT) naming convention.

The Reference Ground Track (RGT) is an imaginary track on Earth through the six-spot pattern that is used to point the observatory. 1,387 RGTs are sampled over the course of 91 days, allowing seasonal height changes to be detected. Onboard software aims the laser beams so that the RGT is between GT2L and GT2R (i.e., coincident with Pair Track 2). Nominal RGT pointing occurs over the oceans and polar regions and is periodically adjusted over vegetated land areas to broaden global coverage. 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 (cc) to the RGT number.

Over lower latitudes, the satellite points slightly off the RGT during most cycles to measure canopy and ground heights. Off-pointing began on 1 August 2019 with RGT 518 after the ATLAS/ICESat-2 Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions were adequately resolved, and the instrument had pointed directly at the RGT for at least a full 91 days (1,387 orbits).

NOTE: ICESat-2 RGTs with dates and times can be downloaded as KML files from NASA's ICESat-2 | Technical Specs page, below the Orbit and Coverage table. Pointing plans summarized by cycle and off-pointing angle are posted in the ICESat-2 Major Activities document.

The ATLAS data and data collected from ancillary systems are telemetered to the ground and processed into several data products (Figure A - 2). The ATL01 algorithm reformats and unpacks the Level 0 data and converts it into engineering units. ATL02 processing converts ATL01 data to science units, applies instrument corrections, and produces photon time-of-flight data. The PPD and POD solutions compute the pointing vector and position of the ICESat-2 observatory as a function of time. ATL02, PPD, and POD are used to produce the global geolocated photon data of ATL03 and the normalized relative backscatter profiles of ATL04, which are the base products for all higher-level data sets.

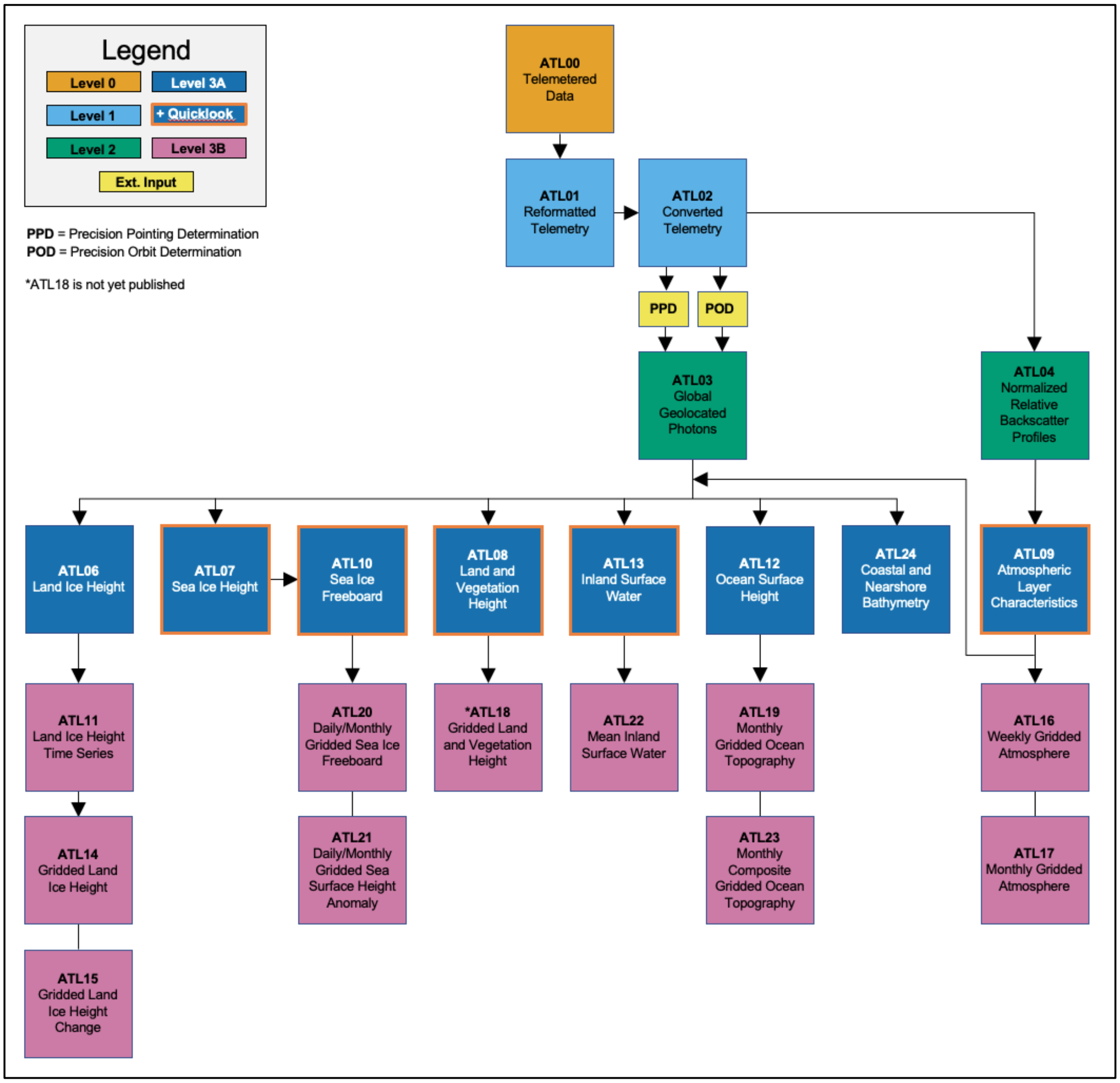

Figure A - 2. Schematic of ICESat-2 data processing and data products.

In satellite altimetry, the reflection point of an emitted signal occurs on an instantaneous and often dynamic planetary surface (Figure A - 3). For ICESat-2, reflective surfaces include oceans, inland water bodies, solid ground, ice, vegetation, and manmade structures. Depending on the product and surface type, geophysical corrections are applied to measurements to account for various time-varying processes (Table A - 1). Upper-level products may undergo additional height corrections, including corrections for pulse shape and instrument characteristics. For more information, refer to the data product's ATBD.

Table A - 1. 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 delay
Land Ice, Land, and Inland Water (ATL06, ATL08, and ATL13)	*No geophysical corrections beyond ATL03*
Sea Ice (ATL07 and ATL10)	ATL03 corrections Referenced to mean sea surface Ocean tide Long period equilibrium ocean tide Dynamic atmosphere correction
Ocean (ATL12)	ATL03 corrections Ocean tide Long period equilibrium ocean tide

[1]For details, see Section 5 of the *ICESat-2 Data Comparison User's Guide for Rel007* available on the ATL03 data set landing page.

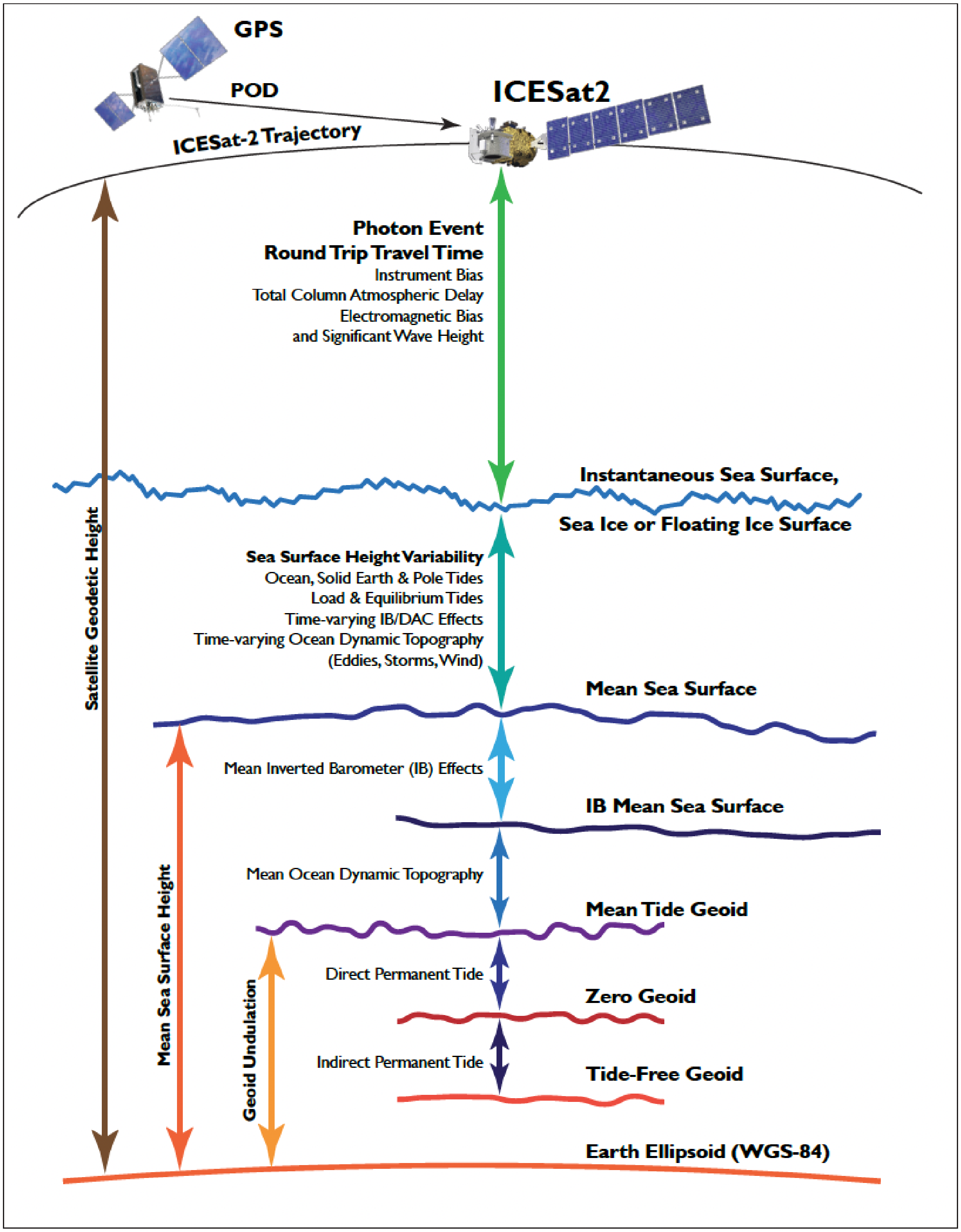

Figure A - 3. Geophysical corrections used in satellite altimetry (Source: *ICESat-2 Data Comparison User's Guide for Rel007,* available on the ATL03 data set landing page).