



# ATLAS/ICESat-2 L3B Monthly Gridded Atmosphere, Version 4

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## USER GUIDE

### How to Cite These Data

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

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FOR QUESTIONS ABOUT THESE DATA, CONTACT [NSIDC@NSIDC.ORG](mailto:NSIDC@NSIDC.ORG)

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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

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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

## 1.2 File Information

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### 1.2.1 Format

Data are provided as HDF5 formatted files. HDF is a data model, library, and file format designed specifically for storing and managing data. For more information about HDF, visit the [HDF Support Portal](#).

**WARNING:** These data sets are produced using the HDF5 Fortran 2003 interface. The HDF Group includes the following warning about multidimensional arrays written using Fortran on its [HDF5 Fortran User Notes](#) webpage:

When a C application reads data stored from a Fortran program, the data will appear to be transposed due to the difference in the C and Fortran storage orders. For example, if Fortran writes a 4x6 two-dimensional dataset to the file, a C program will read it as a 6x4 two-dimensional dataset into memory. The HDF5 C utilities h5dump and h5ls will also display transposed data, if data is written from a Fortran program.

As such, users who need data within these products' multidimensional arrays **should verify the array order is not transposed**. For a free tool that opens and displays these data sets correctly, NSIDC recommends the [Panoply Data Viewer](#) (Version 4.11.3 **only**).

## 1.2.2 ATLAS/ICESat-2 Description

NOTE: The following brief description of the Ice, Cloud and land Elevation Satellite-2 (ICESat-2) observatory and Advanced Topographic Laser Altimeter System (ATLAS) instrument is provided to help users better understand the file naming conventions, internal structure of data files, and other details referenced by this user guide. The ATL16 and ATL17 data products are described in detail in the ICESat-2 Algorithm Theoretical Basis Document for Atmosphere Gridded Products ([ATBD for ATL16/ATL17, V04 DOI: 10.5067/6DFX3LYR642](#)).

The ATLAS instrument and ICESat-2 observatory utilize a photon-counting lidar 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. The ATL04 data product is organized by ground track, with ground tracks 1L and 1R forming pair one, ground tracks 2L and 2R forming pair two, and ground tracks 3L and 3R forming pair three. Each pair also has a Pair Track—an imaginary line halfway between the actual location of the left and right beams (see figures 1 and 2). 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 1). 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 2). The first yaw flip was performed on December 28, 2018, placing the spacecraft into the backward orientation. ATL16/ATL17 report the spacecraft orientation in the `sc_orient` parameter stored in the `orbit_info/` data group (see Section 1.3 Data Groups). In addition, 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 (cc) to the RGT number, e.g. 0001cc to 1387cc.

Under normal operating conditions, no data are collected along the RGT; however, during spacecraft slews, or off-pointing, some ground tracks may intersect the RGT. Off-pointing refers to a series of plans over the mid-latitudes that have been designed to facilitate a global ground and canopy height data product with approximately 2 km track spacing. 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 had been adequately resolved and the instrument had pointed directly at the reference ground track for at least a full 91 days (1387 orbits).

Users should note that between 14 October 2018 and 30 March 2019 the spacecraft pointing control was not yet optimized. As such, 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.

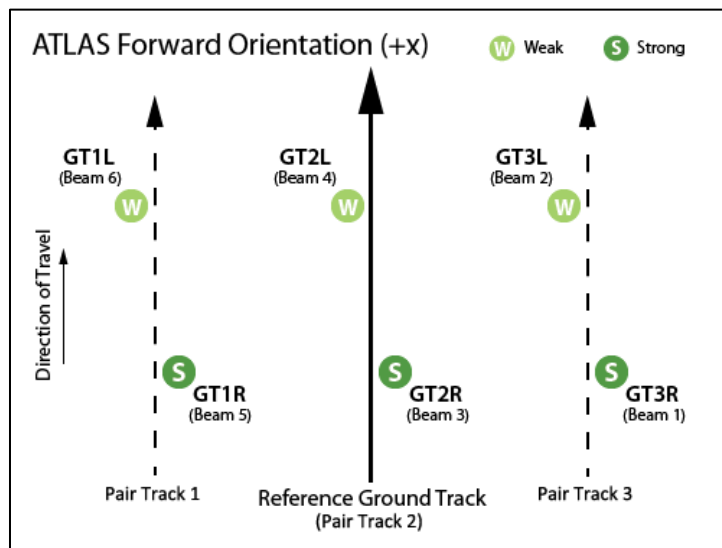


Figure 1. Spot and ground track (GT) naming convention with ATLAS oriented in the forward (instrument coordinate +x) direction.

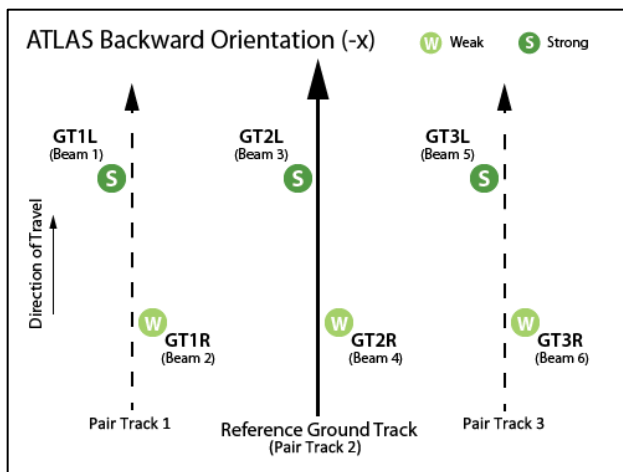


Figure 2. Spot and ground track (GT) naming convention with ATLAS oriented in the backward (instrument coordinate -x) direction.

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.

### 1.2.3 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 convention:

Examples:

ATL16\_20181008010504\_01440101\_004\_02.h5

ATL16\_20181015011226\_02510101\_004\_02.h5

ATL17\_20200301012547\_09980601\_004\_01.h5

ATL17\_20200301012547\_09980601\_004\_01.h5

Description:

ATL16\_ or ATL17\_[yyyymmdd][hhmmss]\_[ttttccss]\_[vvv\_rr].h5

The following table describes the file naming convention variables:

Table 1. File Naming Convention Variables and Descriptions

Variable	Description
ATL16 <i>or</i> ATL17	ATLAS/ICESat-2 L3B Weekly Gridded Atmosphere <i>or</i> 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	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 1387 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 <sup>1</sup> .
vvv_rr	Version and revision number <sup>2</sup> . 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.

**NOTE:**

<sup>1</sup>Some ATLAS/ICESat-2 products (e.g. ATL03) are provided as files that span 1/14<sup>th</sup> of an orbit. As such, these products' file names specify a segment number that ranges from 01 to 14. Because ATL04 and ATL09 data files span one full orbit, the segment number is set to 01.

<sup>2</sup>From time to time, NSIDC receives duplicate, 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 superceded 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 figures, 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 3. Internal structure of an ATL16 data file (Left: top half; Right: bottom half). 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 3 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 available in HDF5 format that contain images designed to quickly assess the quality of each granule's data. Two images are provided: Global Apparent Surface Reflectance (default/default1) and Global Cloud Fraction (default/default2). Browse files utilize the same naming convention as their corresponding data file, but with `_BRW` appended. For example:

```
ATL16_20181008010504_01440101_004_02.h5
ATL16_20181008010504_01440101_004_02.h5_BRW.h5

ATL17_20200301012547_09980601_004_01.h5
ATL17_20200301012547_09980601_004_01.h5_BRW.h5
```

## 1.4 File Size

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ATL16 data files are typically 2 – 4 MB. ATL17 data files are typically 3 – 5 MB. Browse files range from about 300 – 500 KB.

## 1.5 Spatial Information

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### 1.5.1 Coverage

Coverage varies by parameter, provided on either a global grid, separate N/S 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

**Note:** polar cloud fraction for ATL16 and ATL17 is broken out 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:  $4 \text{ km} < h \leq 8$  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.

### 1.5.2 Resolution

Data are provided on rectangular grids of:

- 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, and
- 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

### 1.5.3 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 is defined as geodetic latitude and longitude in the WGS 84 geographic coordinate system (positive values = north). The following table provides information about the WGS 84 geographic coordinate system.

Table 4. Geolocation Details

<b>Geographic coordinate system</b>	WGS 84
<b>Projected coordinate system</b>	WGS 84
<b>Longitude of true origin</b>	Prime Meridian, Greenwich
<b>Latitude of true origin</b>	N/A
<b>Scale factor at longitude of true origin</b>	N/A
<b>Datum</b>	World Geodetic System 1984
<b>Ellipsoid/spheroid</b>	WGS 84
<b>Units</b>	degree
<b>False easting</b>	N/A
<b>False northing</b>	N/A
<b>EPSG code</b>	4326
<b>PROJ4 string</b>	+proj=longlat +datum=WGS84 +no_defs
<b>Reference</b>	<a href="https://epsg.io/4326">https://epsg.io/4326</a>

## 1.6 Temporal Information

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### 1.6.1 Coverage

13 October 2018 to 1 August 2022

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.

## 1.6.2 Resolution

### 1.6.2.1 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.

### 1.6.2.2 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

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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 family of ICESat-2 data products and the connections between them:

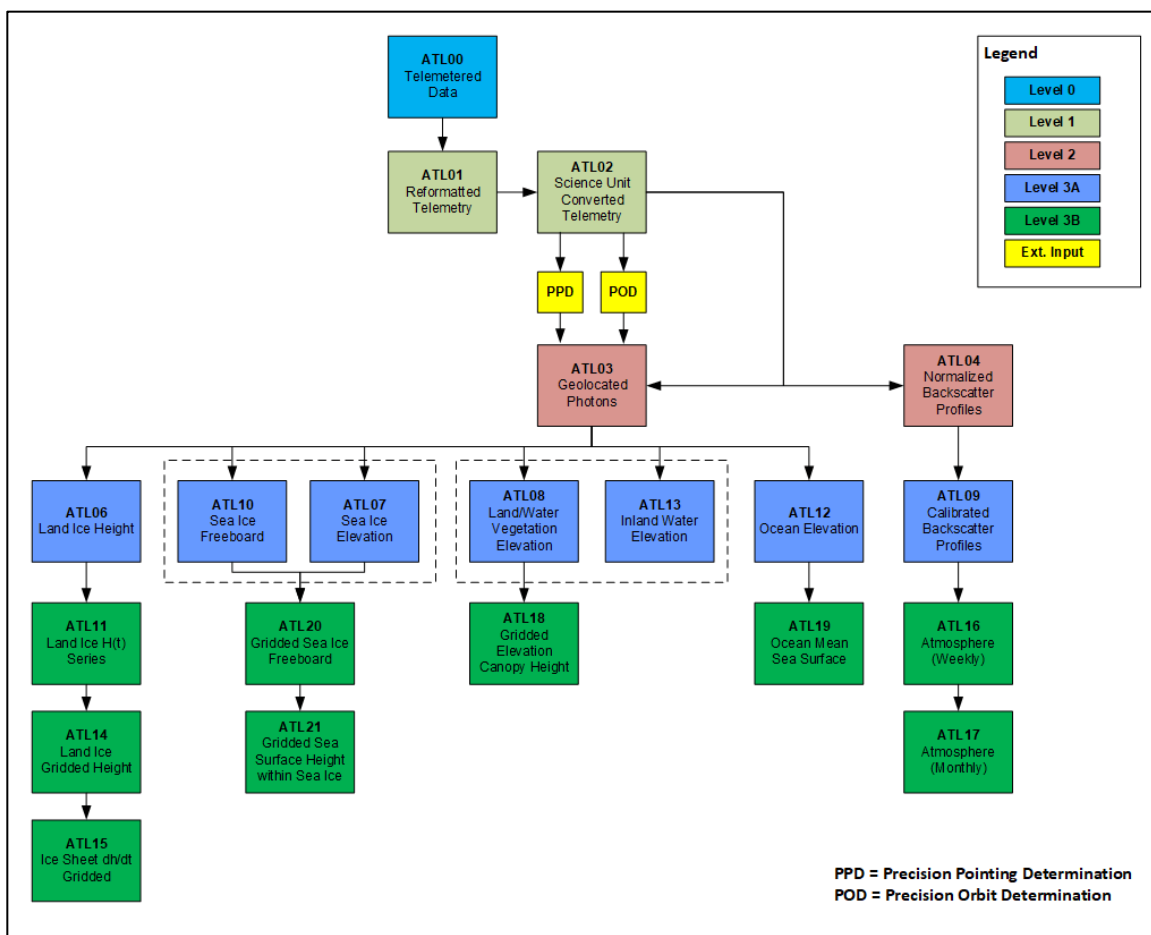


Figure 4. ICESat-2 data processing flow. ATL02 processing converts the ATL01 data to science units and applies instrument corrections. The Precision Pointing Determination (PPD) and Precision Orbit Determination (POD) solutions compute the pointing vector and position of the ICESat-2 observatory.

## 2.2 Acquisition

ATL16 and ATL17 are generated primarily from ATL09 data, which is read for the period in question — either weekly or monthly — and gridded to the respective grid sizes. See Section 1.5.2 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 (global\_cloud\_frac)

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

Global cloud fraction is computed from two parameters on the ATL09 product: `ccloud_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 `ccloud_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<sup>1</sup>; the total observation count is incremented regardless of the `ccloud_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  $< \text{obs\_minimum}$ . 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 stored in the `global_cloud_frac` variable. The data are also provided as an image in `global_cloud_frac_img`.

<sup>1</sup>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 (`global_aerosol_frac`)

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

Global aerosol fraction is computed via the same approach described above for global cloud fraction. Using the `ccloud_flag_atm` and `layer_attr` parameters from ATL09, if `ccloud_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<sup>1</sup>; the total observation count is incremented regardless of the `ccloud_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  $< \text{obs\_minimum}$ . 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`.

<sup>1</sup>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 (`global_column_od`)

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

Total column optical depth 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  $< \text{obs\_minimum}$ . 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 3.3 | 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  $60^\circ$  N and  $60^\circ$  S. In addition to the total polar cloud fraction, cloud fractions are also determined for three different height ranges:  $h \leq 4$  km (low),  $4 \text{ km} < h \leq 8$  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` 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  $\leq 4$  km AND `layer_attr = 1`, increment the counter for low cloud fraction;  
 If any `layer_top(x)` is  $> 4$  km and  $\leq 8$  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  $< \text{obs\_minimum}$ , 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:

### Northern

- `npolar_totalcloud_frac`
- `npolar_lowcloud_frac`
- `npolar_midcloud_frac`
- `npolar_highcloud_frac`

### Southern

- `spolar_totalcloud_frac`
- `spolar_lowcloud_frac`
- `spolar_midcloud_frac`
- `spolar_highcloud_frac`

<sup>1</sup>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  $< \text{obs\_minimum}$  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:

#### Northern

- `npolar_transcloud_frac`
- `npolar_opaquecloud_frac`

#### Southern

- `spolar_transcloud_frac`
- `spolar_opaquecloud_frac`

### 2.3.4.3 Blowing snow frequency

(see "Section 3.4 | 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 the previous version of ATL16 and ATL17 only low-rate data was used to produce blowing snow frequency. In this updated version both high-rate (25 Hz) and low-rate (1Hz) blowing snow height is 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 3.5 | ATBD for ATL16/ATL17")

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_refl` parameter on ATL09. If `apparent_surf_refl` 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 3.6 | 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 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

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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](#).

## 2.5 Version History

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Version 4 (February 2022) is produced from ATL09 Version 5.

Changes for this version include mostly additions of parameters and data groups. All changes are listed below:

- 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; the module accumulates cloud layer counts from the existing profile DDA layer type = 1 (cloud occurrences) as a first pass; then a second pass "combines" in

additional data, with the addition of profile ASR determined clouds, based on profile ASR cloud probability exceeding the new ASR cloud threshold control parameter (set to 80).

- 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`.
- 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; the module accumulates the existing profile ASR column optical depth over-water occurrences as a first pass; then a second pass "expands" the parameter with additional data from the estimated cloud optical depth, the estimated cloud optical depth for over-ocean surface type is calculated when the profile ASR column optical depth is INVALID and the estimated cloud optical depth is accumulated in the gridded array used to compute the average 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_major_axis`, `srid`.

Version 4 of this data set was retired in April 2024.

## 3 CONTACTS AND ACKNOWLEDGMENTS

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## 4 DOCUMENT INFORMATION

### 4.1 Publication Date

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### 4.2 Date Last Updated

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