Ice, Cloud, and land Elevation Satellite-2 (ICESat-2) Project

Algorithm Theoretical Basis Document (ATBD) for Atmosphere Gridded Products

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Change Log

August 21, 2018: Corrected the logic in Section 3.3.1. Changed the units in Tables 2 and 3 to fraction from percent. [Update note: former Tables 2 and 3 are now contained the current Table 5.]

February 26, 2019: Corrected mistake in blowing snow description, Section 3.4. Changed "if *bsnow_h* is greater than or equal to -2" to "if *bsnow_con* is greater than or equal to -2"

May 2019: in Section 3.1 added the check of "*layer_attr*" when constructing the global cloud fraction grid.

August 2019: Added Section 3.1.1 that defines a new parameter (Global Aerosol Fraction) to be added to ATL16 and ATL17. Added Section 3.8 which defines the new control parameters *week_obs_minimum* and *month_obs_minimum*, and replaced old Section 4.0 with a new section on smoothing of the images that are made from the data grids. In Section 4.0 the new control parameters *smooth_grid* and *center_weight* are described. Changed old Section 4.0 to Section 5.0. Added Section 6.0.

September 2019: ATBD Version 2.1. Added observation grids to both ATL16 and ATL17. Specified that smoothing is to be done only on the data to produce the images. The atmosphere gridded data parameters written on the product are not smoothed.

December 5, 2019: ATBD Version 2.2a. Modifications to certain entries in Section 5.0 Table 2 and Table 3 content. Clarification notes added to Sections 3.1, 3.1.1, and 3.2. Corrections made to text in Section 3.3.1 for definition of low, middle, and high layer altitude boundaries; similar corrections made to Section 5.0 Tables 2 and 3. [Update note: former Tables 2 and 3 are now contained the current Table 5.]

April 30, 2020: ATBD Version 3.0. Section 2: modified the grid sizes for the polar plots for both ATL16 and 17. Modified the grid size of the ATL16 global grid. Added Section 3.10 to identify the data parameters for which the average values would be computed, written to the product and displayed on the image. Tables 2 and 3 updated to show the average values written to the product. Section 3.2: change of title to total column optical depth image. All changes since Version 2.2a are in red font.

May 7, 2020: ATBD Version 3.1 DRAFT. Contains changes to expand Section 3.10 Product Averages from reporting just the parameter average values to become Section 3.10 Product Statistical Values to include the gridded parameter minimum, maximum, and standard deviation values in addition to the average (now the mean) value. The modifications to accommodate the Section 3.10 requirements are also made to Tables 2 and 3 in Section 5.0. [Update note: former Tables 2 and 3 are now contained the current Table 5.]

May 12, 2020: Modifications to Tables 2 and 3 in Section 5.0, to divide the tables into Tables 2.1 and 3.1 containing the original content, and setting up Tables 2.2 and 3.2 to contain the newly added statistical reporting parameters.

June 3, 2020: ATBD Version 3.1b DRAFT. Added sub-section headings 5.1, 5.2, 6.1, and 6.2 for delineating ATL16 and ATL17 product information. Expanded parameter sections to include prototype code statements to illustrate and enumerate the textual specifications. Additional material and annotations are included in this edition, including one additional table (Table 2) that collects together information on monthly and weekly global and polar grid cell sizes and associated array sizes.

References for the monthly and weekly global and polar grid cell size are modified to be expressed as "longitude-size by latitude-size" in degrees (e.g., 1.5x0.5 degrees for ATL17 polar grid cell size). This is done for consistency with grid dimensioning and indexing (i.e., (i,j) where i = the longitude size or index and j = the latitude size or index.

A new table, Table 3, is added for observation grid information. Original Table 2 that was divided into Table 2.1 and 2.2, is relabeled to Tables 4.1 and 4.2. Correspondingly, original Table 3 that was divided into Table 3.1 and 3.2 now becomes Tables 5.1 and 5.2. Original Table 4 becomes Table 6, and Table 5 becomes Table 7.

June 10, 2020: Version 3.1c DRAFT. Prior ATBD review comments are incorporated in this version.

Table 3 has been added to apply the new weekly and monthly global and polar longitude and latitude grid cells sizes to the linear arrays pertinent to longitude and latitude steps.

A major change to this version is changes to polar and global grid sizes for both weekly and monthly (polar only) products. Prior versions used a 1x1 degree grid for all monthly (ATL17) products and a 2x2 degree grid for all weekly products (ATL16). This version incorporates different grid sizes as shown in Table 2.

The Section 1.0 statement that the weekly ATL16 and the monthly ATL17 atmosphere gridded products contained the same parameters at different dimensions and frequencies, the addition of the new Table 2 containing the new grid longitude and latitude size and dimensions, and now the further addition of a new Table 3 showing the impact of the longitude and latitude sizes and dimensions of the linear arrays (i.e., single dimensions), now provide the opportunity to reduce the product description tables in Section 5.0. Consequently, Sub-section headings 5.1 and 5.2 have been removed, and the dual table pairs of Tables 4.1 and 4.2 and 5.1 and 5.2, have been replaced with Tables now numbered as Table 5, Gridded Products List of Gridded and Linear Parameters, Ancillary Data and Images, and Table 6, Gridded Products List of Statistical Parameters.

Table 5 has been expanded to use the ATL16 and ATL17 global and polar grid dimension sizes in Table 2, and the linear array dimension sizes in Table 3 to discriminate the weekly gridded parameter array dimensions and linear array dimensions from those of the monthly gridded parameter arrays and linear arrays in this general table.

The previous Table 3, Gridded Products Observation Grid Parameters has now become Table 4. The previous Table 6, ATL17 Data Product ATL09 Composition by Month has become Table 7, and previous Table 7, ATL16 Data Product ATL09 File Composition by Month and Week has been relabeled as Table 8.

A major change now is the addition of the high-rate blowing snow frequency atmosphere gridded parameter in addition to the existing blowing snow frequency that was based upon usage of the low-rate profile blowing snow height and blowing snow confidence.

June 11, 2020: content changes to Section 3.4 text to clearly indicate the incidence now of both the low-rate and high-rate blowing snow frequency gridded parameters.

June 12, 2020; and June 15, 2020: Version 3.1: Tables 5 and 6 are supplemented with a new table that now becomes Table 6, and the existing Table 6 becomes Table 7. Tables 7 and become Tables 8 and 9.

Statements were added to reference the global parameter array index origin (0,0) to the lower left corner of the grid layout and array. Similar notations were added to reference the South polar parameter array index origin (0,0), also to the lower left corner of the grid layout and array. The North polar parameter array index origin (0,0) mirrors the South polar array with reference at upper left corner of the grid layout and array. Graphic images and text have been added as Attachments A-3, A-4, and A-5.

Control parameters, that had been omitted in the recent set of updates, have been returned in Table. 6. Group identification headers have been added back into Tables 5, 6, and 7. Parameter names from these tables are now included as references within each algorithm description section. Final text additions and comments have been included or addressed.

Removal of red and blue font colors used to designate sets of changed text or added content. Incorporation of font color and type-setting to highlight and increase visibility of formal input ATL09 profile product parameters and output ATL16/ATL17 gridded product parameters.

June 19, 2020: Version 3.1: Added “red” font color back into original state to discriminate changes.

July 16-17, 2020: Version 3.1 [*Interim*]: Changes to Table 4.

July 23, 2020: Version 3.1 [*Interim*]: Changes to Table 4.

August 12, 2020: Version 3.1 [*interim*]: change “asr_obs_grid” to “global_asr_obs_grid” in Table 5. to match the revised entry in Table 4.

January 6, 2021 (January 12, 2021): Version 3.2 [*interim*]: document delivered with revisions proposed to Global Cloud Fraction (Section 3.1) and [Global] Total Column Optical Depth [over Water] (Section 3.2). The changes to Sections 3.1 and 3.2 included the addition of two new control parameters per section. New Section 3.1.2, Global Clear Fraction was added. It is noted that all special color coding under Typographical Conventions was removed.

January 28, 2021: Version 3.2 [*Interim*]: the January 6/January 12, 2021, document edition was modified to restore the color coding under Typographical Conventions. Additional classifications were added to the Typographical Conventions section to accommodate input data, output data, and control data parameters within the red color font paragraphs to clearly delineate input data parameters and output data parameters as well as new control parameters. Global Clear Fraction gridded parameter and image added to Table 5. New control parameters were added to Table 6. Table 7 was updated to include the global clear fraction statistical parameters. Changes to affected proto-code blocks had not been made.

February 1-March 3, 2021: Version 3.2 [DRAFT]: as a result of a review of the January 28, 2021, Version 3.2 [*Interim*] document on that same date, the decision was made to add a new gridded parameter called "Combined Global Cloud Fraction". This parameter supplements the existing Global Cloud Fraction parameter (computed from the output of the DDA to detect clouds directly from the backscatter) with the ASR cloud detection method, which uses the magnitude of ASR and the estimated actual surface reflectance to detect clouds. The algorithm for the new combined global cloud fraction expands the cloud layer counting from ASR in addition to DDA cloud layers. This new combined global cloud fraction (from DDA and ASR) roll-out eliminates the need for the control parameter *include_asr_clouds*.

In addition, a new gridded parameter called Expanded Global Total Column Optical Depth implements code to replace the INVALID over-water ASR optical depth profile values with formulaic estimated values. The addition of the expanded global total column optical depth over water gridded parameter eliminates the need for the control parameter *gen_cloud_od*.

A reorganization of Section 3.1 Global Cloud Fraction with sub-sections 3.1.1 Global Aerosol Fraction and 3.1.2 Global Clear Fraction is submitted to provide an orderly form to now present Global Cloud Fraction (from DDA), Global Aerosol Fraction, and the new Global Clear Fraction and Combined Global Cloud Fraction (from DDA and ASR) as sub-sections under the revised group heading of Global Fractions.

A reorganization of Section 3.2 Total Column Optical Depth will now include subsections Total Column Optical Depth over Water and the Expanded Total Column Optical Depth over Water.

March 9, 2021: Version 3.2 [DRAFT]: repairs to table of Contents indentation; fix several spelling errors.

March 16, 2021, Version 3.2 [DRAFT]: review and invocation of preferred nomenclature, terminology, and references for new products by the ATBD Lead.

March 17, 2021, Version 3.2 [DRAFT]: review and assimilation of March 16, 2021, submitted content changes; completion of in-kind changes not included in the March 16, 2021, revisions. Submitted for "final" disposition consideration.

March 18-19, 2021, Version 3.2 [DRAFT]: update issued to both correct and clarify the function of the Section 3.1.2 Combined Global Cloud Fraction gridded parameter algorithm. Additional content is supplied for Section 3.2 Total Column Optical Depth. Closing statements previously missing added back into the pseudocode blocks.

March 31-April 2, 2021, Version 3.2 [DRAFT]: added content for improved reference and clarity.

April 3-April 9, 2021, Version 3.2 [DRAFT]; continue progression of suggested modifications and clarifications to document content.

April 9-May 11, 2021; Sections 3.1.1, 3.1.2, 3.1.3, 3.1.4, 3.2.1, 3.2.2, 3.3.1, 3.3.2, 3.4, 3.5, 3.6: in response to collection of suggestions to customize the content of the algorithm description sections with a uniform ordering and presentation of key elements at the top of each section or sub-section, an "Atmosphere Gridded Parameter Summary" detailed information block has been inserted at the top of each of the primary section and sub-sections as appropriate.

June 17, 2021; Sections 3.2, 3.2.2: basis ATL09 data test with the v1.3 developmental atlas_l3b_atm PGE demonstrated that current logic for the Expanded Global (Over Water) Total Column Optical Depth algorithm for the replacement of over water (*column_od_asr_qf* () =4, for over water) INVALID ASR column optical depth profile values (*column_od_asr* () = INVALID) as the condition for using the calculation formula to compute an estimated cloud column optical depth (*est_cloud_reflect_loc*) as a replacement value for the INVALID *column_od_asr* profile value would never be performed as the ASR column optical depth profile values (*column_od_asr* ()) will always be VALID when the ASR column optical depth quality flag indicates the profile observation is over water (*column_od_asr_qf* () =4).

June 17, 2021; Sections 3.2, 3.2.2: ATBD Lead submitted Expanded Global (Over Water) Total Column Optical Depth algorithm change: the over ocean surface type profile (*surf_type* (ocean,) =1) is substituted for the over-water ASR column optical depth quality flag (*column_od_asr_qf* () =4), and is now paired with the test for the INVALID ASR column optical depth profile value (*column_od_asr* () = INVALID). The common occurrence of the over ocean surface type profile (*surf_type* (ocean,) =1) and the INVALID ASR column optical depth profile value (*column_od_asr* () = INVALID) are used to invoke the calculation of the estimated cloud column optical depth value as a replacement for the INVALID ASR column optical depth profile value in the accumulation of column optical depth values used in the computation of the average Expanded Global (Over Water) Total Column Optical Depth atmosphere gridded parameter.

June 28, 2021; Sections 3.2, 3.2.2: following examination of Expanded Global (Over Water) Total Column Optical Depth atmosphere gridded data, the decision was made to reduce the size of the control parameter generate cloud column optical depth maximum (*gen_cloud_od_max*) from 100 down to 35 to reduce the magnitude of the resultant expanded_global_column_od (,). The *gen_cloud_od_max* control parameter is used in the calculation formula for the estimated cloud column optical depth value computed as the replacement of the INVALID ASR column optical depth profile value and is used in the accumulation of column optical depth values used in the computation of the average Expanded Global (Over Water) Total Column Optical Depth atmosphere gridded parameter. The scaling for the corresponding product image will be retained at the 0.0 to 25.0 range.

September 1, 2021, Version 3.2 (v3.2) of this ATBD for the Version 1.3 (v1.3) atlas_l3b_atm PGE was delivered to ICESat-2 Data Product Manager Christine ES Sadlik by Atmosphere Team and ATBD Lead scientist Steve Palm.

The delivered ATBD contained a list of three requisite or possible changes for the next PGE (v2.0) and ATBD (V04) deliveries. These were:

1) Complete unfinished addition of a sub-label for control parameter *gen_cloud_od_max* in the format "gen_cloud_od_max=*99*" to the Expanded Global (Over Water) Total Column Optical Depth image expanded_global_column_od_img in the ATL16/ATL17 weekly/monthly atmosphere gridded products with modification the "plot_atl16.py" Python code.
2) Supplement the Expanded Global (Over Water) Total Column Optical Depth module "expanded_global_column_od_mod.f90" to include the "inland water" surface type [*surf_type* (inland_water,)=1] in addition to the existing "ocean" surface type [*surf_type* (ocean,)=1] with the INVALID ASR column optical depth profile parameter [*column_od_asr* ()=INVALID] condition as triggers for the calculation of the estimated cloud column optical depth *est_cloud_reflect_loc* as a replacement value for the INVALID ASR column optical depth profile parameter used in the gridded data accumulation.
3) Add the new global gridded parameter identified as ASR Global Cloud Fraction deriving cloud fraction using the ASR cloud probability profile data, *asr_cloud_probability* ().

JIRA sub-task issue covering item 1) above was created July 2, 2021, as "Implement Changes to Expanded Global Column OD image".

September 17, 2021; "plot_atl16.py" Python code producing and embedding global and polar gridded data images in the ATL16/ATL17 product; email from Jeff Lee requesting change in code for "transparency" constant from the value of 100 to 1. This is required because of the deployment of Python version 3.9 with a change in the alpha factor with a range of 0-1 and not 0-100. Covering JIRA sub-task was created October 13, 2021, as "repair transparency parameter setting in plot_atl16.py".

It is noted that the deployment of Python Version 3.9 (3.9.5) on both the macOS Big Sur 11.6 operating system on the ASAS development Apple Macintosh workstation and laptop computer hardware, as well as, in the Linux operating system on the "gs6141_icesat2-dev1.ndc.nasa.gov" (dev1) resulted in an anomalous presentation of the North and South polar image projections generated and embedded in the ATL16/ATL17 products. In the anomalous renderings both the northern and southern regions polar stereographic projections were now being created off -center and pushed to the left-side and top boundaries of the bounding square black-background area. JIRA sub-task issue covering this activity was created January 3, 2022, as "investigate and clean-up issues with the plot_atl16.py source code".

February 23, 2022; Section 3.2.2: Added sub-label for control parameter *gen_cloud_od_max* in the format "gen_cloud_od_max=*99*" to the Expanded Global (Over Water) Total Column Optical Depth image expanded_global_column_od_img in the ATL16/ATL17 weekly/monthly atmosphere gridded products. This implementation required changes to the "plot_atl16.py" Python code.

ATBD Version 4.0 (ATL16/ATL17 Release 005)

Change Log Notes Pertaining to ATBD Version 4.0 and the Version 2.0 "atlas_l3b_atm" PGE Code

March 9, 2022; notes on filtering of column optical depth from ASR profile data:

- after looking at two months of column optical depth over land profile data, proceed with minimal filtering [this points to items 4) and 5) below expanding the parameters from over-water and over-ocean to over-all-surface-types].
- apply filtering to ATL09 [high-rate] profile parameter column optical depth from ASR *column_od_asr* limiting values to the following range: 0.0 < *column_od_asr* () < 4.0.
- filtering can be applied to over-land and over-water data [applied to all-surface-types per items 4) and 5) below].

list detailing the following "atlas_l3b_atm" PGE code changes and subsequent ATBD modifications and additions:

1) add new level 3B parameter and plot for ASR-based cloud detection using the ASR cloud probability profile data; use cloud probability threshold control parameter = 0.70. [This item clarifies the September 1, 2021, issue number 3) listed above, and will implement the added parameter Global ASR Cloud Fraction and the associated grid image. It will use the existing control parameter *asr_cloud_threshold* from the Combined Global Cloud Fraction.]
2) add new level 3B polar parameter and plot of the frequency of diamond dust reaching the ground over Antarctica, and will implement the added parameter South Polar Surface Diamond Dust Frequency and the associated grid image.
3) change the existing level 3B Combined Global Cloud Fraction cloud probability threshold control parameter constant [i.e., *asr_cloud_threshold*] from 0.8 [i.e., 80 percent] to 0.7 [i.e., 70 percent].
4) change the current Global (Over Water) Total Column Optical Depth parameter and plot from "over-water-only" to now include all surfaces.
5) change the current Expanded Global (Over Water) Total Column Optical Depth parameter and plot [from "over-ocean-only"] to now include all surfaces.

March 10, 2022:

1) enumerates the five modifications and additions from 03/09/2022.
2) supplies the description and algorithm for Global ASR Cloud Fraction parameter and image. It will use the ATL09 high-rate profile parameter *asr_cloud_probability* and the existing level 3B Combined Global Cloud Fraction cloud probability threshold control parameter constant *asr_cloud_threshold* in the filtering and counting. Additionally, the ATL16 or ATL17 minimum observation count control parameter constant *obs_minimum* will be used to limit the gridded parameter computation.
3) supplies the description and algorithm for the fraction of Diamond Dust Reaching the Surface parameter and image. It will use the ATL09 high

rate profile parameter diamond dust from density layer bottom height *ddust_hbot_dens* as the primary input and the ATL09 high rate profile parameters Digital Elevation Model (DEM) height *dem_h*, blowing snow layer thickness (height of layer top above the surface) height *bnsow_h*, and surface bin (vertically aligned, Normalized Relative Backscatter (NRB) bin number of the detected surface return) *surface_bin*, required to filter and calculate the count of diamond dust observation reaching the ground for the Antarctic (i.e., South Polar region) only.

March 10, 2022:

1) in addition to the new Global ASR Cloud Fraction parameter add the North Polar ASR Cloud Fraction and South Polar ASR Cloud Fraction parameters.
2) note: no North Polar diamond dust parameter for now, over Antarctic only (i.e., South Polar Surface Diamond Dust Frequency parameter only).

March 10, 2022: accepting "spolar_surf_ddust_freq" as image name for the South Polar Surface Diamond Dust Frequency plot.

March 10, 2022: additional notes for the filtering process:

- when there is no surface return the *column_od_asr* value will be INVALID,
- INVALID *column_od_asr* values are currently filtered out.
- when the computed [high-rate profile] Apparent Surface Reflectance (ASR) *apparent_surf_reflec* values are greater than the true surface reflectance [high-rate profile] *aclr_true* values (i.e., clear sky ASR; clear sky initial surface reflectance based on GOME climatology or the Cox-Munk model), the *column_od_asr* values will be zeros (0.0).
- currently not filtering out zero (0.0) *column_od_asr* values; these should be filtered out going forward, especially over land with possibly more zero values.
- most important filtering over water is the laser angle; filter out shots where the angle [laser off-nadir angle] is greater than 2 degrees.
- for consistency perform this filtering over all surface types [Global Total Column Optical Depth and Expanded Global Total Column Optical Depth].
- perform filtering on both the column optical depth from ASR value and the laser off-nadir angle limit.
- local laser off-nadir angle [laser_angle] uses ATL09 [high-rate profile] laser beam elevation *beam_elevation* values in the calculation:
  laser_angle () = 90.0 – *beam_elevation* ()
- apply the following filtering:
  if (*column_od_asr* () > 0.0 and
  column_od_asr () < 4.0 and laser_angle () < 2.0) then
  accept the *column_od_asr* () [for processing].
- keep the Global Total Column Optical Depth image scaling at [the current] 0.0 to 1.5.

March 15, 2022: follow-up notes for the expanded global total column optical depth gridded parameter:

- keep the control constant parameter *gen_cloud_od_max* value at 35,
- keep the Expanded Global Total Column Optical Depth gridded parameter image range at 0 to 25 scaling.

March 30, 2022: notes for clarification of the diamond dust parameter:

- windspeed should not be a part of the diamond dust classification.
- diamond dust (reaching the ground) should be defined by high scattering in the bin above the surface and high scattering in each bin above for at least 500 m; if the drop in scattering (i.e., layer top) occurs below 500 m and the wind speed is > 4 m/s, it is blowing snow; if the drop in scattering occurs above 500 m from the surface it is diamond dust that reaches the surface.
- if the drop in scattering occurs below 500 m and the wind speed is less than 4 m/s, it could be classified as diamond dust also, but reluctant to do that; this case is captured in the new blowing snow detection algorithm via a confidence flag.
- there is elevated diamond dust that does not reach the surface, but it is extremely difficult to differentiate it from thin ice crystal (cirrus) clouds; not sure should be trying to detect and classify it as diamond dust.
- DDA is already detecting these elevated layers as part of the normal cloud detection.
- trying to classify elevated diamond dust not reaching the surface would require some signal strength threshold below which it would be diamond dust, and above the threshold cloud.
- diamond dust that reaches the surface (also known as clear-air precipitation) is important from a science perspective.
- when there is diamond dust directly above a blowing snow layer; this case can be considered elevated diamond dust too and the above classification concern applies here as well.
- conclusion:
  - bottom line: take windspeed out of diamond dust detection algorithm,
  - there is no rational for using windspeed as a criteria for the presence of diamond dust.

April 12, 2022: plot_atl16.py source code: request to make thicker country boundaries [lines] particularly on the global parameter plot images.

June 6, 2022: provide fix for discovered BUG in Global (Over Water) Total Column Optical Depth and Expanded Global (Over Water) Total Column Optical Depth parameters [now accumulated over all surface types]:

- BUG: implemented code ignored the ATBD requirement to exclude zero (0.0) column optical depth from ASR [high-rate] profile values [i.e., omit *column_od_asr* () = 0.0] from the solution.
- BUG existing in the original global total column optical depth module was propagated into the expanded global total column optical depth module through code reuse.
- the computed averaged global total column optical depth and expanded global total column optical depth gridded parameter array values are "watered down" by the inclusion of 0.0 *column_od_asr* () profile values in the accumulated summation of the accepted column optical depth from ASR observations in the final parameter computation; the effect here is a reduction in the magnitude of the global_column_od (,) and the expanded_global_column_od (,) grid cell values where the 0.0 *column_od_asr* () profile values have been included in the cell observation summation processing.
- the BUG is present in the Global (Over Water) Total Column Optical Depth gridded parameter in the ATL16 and ATL17 products included in the NSIDC ICESat-2 data archive deliveries identified as Version 2 (V02), Version 3 (V03), and the current Version 4 (V04).
- and is present in the Expanded Global (Over Water) Total Column Optical Depth gridded parameter in the ATL16 and ATL17 products included only in the NSIDC delivery that is the current Version 4 (V04).
- BUG is FIXED with the ATBD V04 and the atlas_l3b_atm PGE v2.0 implementation of the profile value range filtering [i.e., limits: 0.0 < *column_od_asr* () < 4.0] in both modules and gridded parameters.

June 7, 2022: Expanded Global Total Column Optical Depth flow: do compute [random, uniformly distributed, estimated cloud optical depth] OD when *column_od_asr* is INVALID even if laser angle [laser_angle ()] is greater than the limit [laser_angle () > laser_angle_limit].

June 15, 2022: increase the laser angle limit [laser_angle_limit from 2.0 degrees] to 3.0 degrees; make the angle limit a control parameter.

June 16, 2022: clarification on application of the laser angle limit [laser_angle_limit]:
    if (laser_angle () < laser_angle_limit [3.0 degrees] then
        accept the observation for summation and counting

June 17, 2022: regarding the visibility of the 5 degree laser off-nadir scans in the central Pacific ocean: the off-nadir scans of 5 degrees appear in the revised Global Total Column Optical Depth (0-1.5) parameter image and in the revised Global Apparent Surface Reflectance (0-1) parameter image both with the laser angle filtering [i.e., laser_angle () < laser_angle_limit [3.0 degrees]] active, however, the Expanded Global Total Column Optical Depth (0-25) parameter image does not show the Pacific off-nadir scanning data.

June 28, 2022: reduce the South Polar Surface Diamond Dust Frequency image scale currently at (0-1): change the image scale maximum to 0.4 [from 1.0].

June 30, 2022: on the South Polar Surface Diamond Dust Frequency image change in latitude from -90.0 to -60.0 degrees (90S to 60S) down to -90.0 to -65.0 (90S to 65S); clarification to include -65.0 degrees.

June 30, 2022: include South Polar Surface Diamond Dust Frequency observation count parameter. The profile *surface_bin* will be used to check for surface detected; will be INVALID if no surface was detected; surface detected values range from 1 to 700. [Valid *surface_bin* profile values will provide the observation count.]

July 1, 2022: South Polar Surface Diamond Dust Frequency image scaling needs to be changed to 0.0 - 0.4.

August 30, 2022: review of expanded global total column optical depth plots shows the laser incidence angle filtering is <u>not</u> displaying the Pacific Ocean 5 degree off-nadir angle scanning but is showing spuriously high optical depth in this region. Suspicion is that the [random, normally distributed, estimated cloud] optical depths are being calculated. This needs to be changed.

August 31, 2022:

- change the [laser off-nadir] angle limit filtering from 3 to 6 degrees.
- use filtering for [global, northern and southern polar] ASR, [global] total column optical depth, and expanded [global] total column optical depth [parameters and] plots.
- column optical depth [i.e., *column_od_asr*] profile values that exceed the [laser off-nadir] angle limit for the expanded [global] total column optical depth [parameter] <u>should not</u> be replaced with [the random,] normally distributed cloud optical depth [calculated replacement value] and should be skipped.
- changes preferably should be made for next delivered of the L3B products [i.e., the patched and modified v2.0 PGE for redelivery].

cumulative through October 4, 2022:

- additions to "Change Log" section.
- modifications to tables in "Scope" section.
- added Attachment A.6: Documentation Sources Pertaining to the ATBD Version 4.0 Content Changes and the Version 2.0 "atlas_l3b_atm" PGE Code Development Change Log.
- added Attachment A.7: History of Atmosphere Gridded Parameters – ATBD Appearance and NSIDC ATL16/ATL17 Product Archive Version Inclusion.
- changed Section 3.1 title from "Global Fractions" to "Atmospheric Fractions".

	• added Section 3.1.5 "Global and Polar Apparent Surface Reflectance (ASR) Cloud Fraction". • moved Section 3.3 "Polar Cloud Fraction" to become Section 3.1.6 "Polar Cloud Fraction" under Section 3.1 "Atmospheric Fractions". • added Section 3.3 "Polar Precipitation". • changed heading for Section 3.4 "Blowing Snow Frequency" to Section 3.3.1 "Blowing Snow Frequency". • added Section 3.3.2 "South Polar Surface Diamond Dust Frequency". • changed heading for Section 3.5 "Apparent Surface Reflectivity (ASR)" to Section 3.4 "Apparent Surface Reflectivity (ASR)". • changed heading for Section 3.6 "Ground Detection Frequency" to Section 3.6 "Ground Detection Frequency". • changed heading for Section 3.7 "Images of Gridded Fields" to Section 3.6 "Images of Gridded Fields". • changed heading for Section 3.8 "Minimum Number of Observations for Each Grid Box" to Section 3.7 "Minimum Number of Observations for Each Grid Box". • changed heading for Section 3.9 "Observations Grids" to Section 3.8 "Observations Grids". • changed heading for Section 3.10 "Product Statistical Values" to Section 3.9 "Product Statistical Values". • modifications to Section 5.0 "Product Formats", Table 5. "Gridded Products List of Gridded and Linear Parameters, Ancillary Data, and Images", Table 6. "Gridded Products List of Ancillary Control Data", Table 7. "Gridded Products List of Statistical Parameters", and Table 8. "List of Input Parameters from the ATL09 Level-3A Calibrated Backscatter Profile and Atmospheric Layer Characteristics Data" for updated and added parameters, variables, and constants. • additions to table in Section 7.0 "Acronyms and Abbreviations".
September 11, 2023:	• Section 3.3 "Polar Precipitation" renamed to Section 3.3 "Blowing Snow and Diamond Dust".
September 18, 2023:	• cover page modifications including requisite citation with DOI reference. • page numbering scheme change; italicized page number for preface subsections, numerical page numbers for sections. • changes to table for next edition of the ATBD Version 4.1 (ATL16/ATL17 Release 006).

ATBD Version 5 (ATL16/ATL17 Release 005)

<u>Change Log Notes Pertaining to ATBD Version 5 and the Version 2.0 "atlas_l3b_atm" PGE Code</u>

September 25, 2023;	the ICESat-2 Data Product Manager has requested the ATBD document version be changed from Version 4.0 to Version 5 in order to match the NSIDC version number for the documentation that will be Version 5 [also identified as V05]: • changed cover page to read Version 5 and date September 25, 2023; changed citation to read Version 5. • Contents: A.8 Attachment A-8: changed "ATBD Version 4.0" to read "ATBD Version 5". • Change Log: "September 1, 2021, Version 3.2 (v3.2)": changed "ATBD (v4.0) deliveries" to read "ATBD (V04) deliveries". June 6, 2022: changed "current Version 4 (V04)" to read "Version 4 (V04)" [two occurrences]; changed "ATBD v4.0" to read "ATBD V04". added heading ATBD Version 5 (ATL16/ATL17 Release 005) and subheading <u>Change Log Notes Pertaining to ATBD Version 5 and the Version 2.0 "atlas_l3b_atm" PGE Code</u> and a list of changes incorporated September 25, 2023; changed subsequent references under Change Log replacing ATBD V4.0 identification to read Version 5. changed "Summary of Unchanged and Changed Sections within ATBD Version 4.0" to read "Version 5". changed "The ATBD Version 4.0" to read "Version 5" [two entries]. A.8: changed "ATBD Version 4.0" to read "ATBD Version 5"; changed "v4.0 ATBD" to read "V05 ATBD". • Scope: L3B ATM ATBD Version Identification: changed "Version 4.0" to read "Version 5". L3B ATM ATBD Version Date: changed "*September 14, 2023*" to read "*September 25, 2023*". *next* L3B ATM ATBD Version Identification: changed "Version 4.1" to read "Version 6". • 3.1 Atmospheric Fractions: changed "Version 4.0 ATBD dated September 18, 2023" to read "Version 5 ATBD dated September 25, 2023". • 3.1.2 Combined Global Cloud Fraction: changed "ATBD v4.0" to read "ATBD V05". • 3.1.5 Global and Polar ASR Cloud Fraction: NOTE: changed "ATBD v4.0" to read "V05". • 3.2 Total Column Optical Depth: changed "ATBD Version 4.0" to read "ATBD Version 5" [two occurrences].

- 3.2.1 Global Total Column Optical Depth: changed "ATBD Version 4.0" to read "ATBD Version 5".
- 3.2.1.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth: changed "ATBD Version 4.0" to read "ATBD Version 5".
- 3.2.1.4 Deviation from Specification: Failure to Exempt Invalid Values of the ASR Column Optical Depth Quality Flag from Global Total Column Optical Depth: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.2.1.5 Summary of ASR Column Optical Depth Filtering Applied for the Computation of Global Total Column Optical Depth: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.2.2 Expanded Global Total Column Optical Depth: changed "ATBD v4.0" to read "ATBD V05"; changed "ATBD Version 4.0" to read "ATBD Version 5".
- 3.2.2.3 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Expanded Global Total Column Optical Depth: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.2.2.4 Deviation from Specification: Failure to Exempt Invalid Values of the ASR Column Optical Depth Quality Flag from Expanded Global Total Column Optical Depth: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.2.2.5 Summary of ASR Column Optical Depth Filtering Applied for the Computation of Expanded Global Total Column Optical Depth: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.3.2 South Polar Surface Diamond Dust Frequency: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.4.1 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Expanded Global and Polar Apparent Surface Reflectivity: changed "v4.0 ATBD" to read "V05 ATBD".
- 3.8 Observations Grids: changed "ATBD Version 4.0" to read "ATBD Version 5".
- A.8 Attachment A-8: Documentation Sources Pertaining to the ATBD Version 4.0 Content Changes and the Version 2.0 "atlas_l3b_atm" PGE Code Development Change Log: changed "ATBD Version 4.0" to read "ATBD Version 5".
  "Change Log Notes Pertaining to ATBD Version 4.0 and the Version 2.0 "atlas_l3b_atm" PGE Code": changed "ATBD Version 4.0" to read "ATBD Version 5".
  "June 6, 2022, 12:52; "RE: atlas_l3b_atm v2.0 Development Evolution Check from Functional Test Data": changed "current Version 4 (V04)" to

read “Version 4 (V04)” [two occurrences]; changed “ATBD v4.0” to read “ATBD V04”.

- A.9 Attachment A-9: History of Atmosphere Gridded Parameters – ATBD Appearance and NSIDC ATL16/ATL17 Product Archive Version Inclusion: changed “*Version 4.0 November 1, 2022*” to read “*Version 5 September 25, 2023*” [9 occurrences].

Summary of Unchanged and Changed Sections within ATBD Version 5

The ATBD Version 5 document does not change the intent or functionality of the algorithm or the atmosphere gridded parameter in the following section numbers and titles:	
Section No.	Section Title
2.0	Global and Polar Grids
3.1.1	Global Cloud Fraction
3.1.2	Combined Global Cloud Fraction
3.1.3	Global Aerosol Fraction
3.1.4	Global Clear Fraction
3.1.6	Polar Cloud Fraction
3.1.6.1	High, Middle, Low and Total Cloud Fraction
3.1.6.2	Transmissive and Opaque Cloud Fraction
3.3.1	Blowing Snow Frequency
3.6	Images of Gridded Fields
3.7	Minimum Number of Observations for Each Grid Box
3.9	Product Statistical Values
4.0	Smoothing of Images
6.0	Product Production Considerations
6.1	ATL17 Monthly Atmosphere Gridded Product Content Control
6.2	ATL16 Weekly Atmosphere Gridded Product Content Control
A.0	Attachments
A.1	Attachment A-1: Exhibit Rectangular Image with Statistical Data Label
A.2	Attachment A-2: Exhibit Polar Image with Statistical Data Label
A.3	Attachment A-3: Example Global Gridded Parameter Reference Layout
A.4	Attachment A-4: Example North Polar Gridded Parameter Reference Layout
A.5	Attachment A-5: Example South Polar Gridded Parameter Reference Layout

The ATBD Version 5 document does change the intent and functionality of the algorithm and the atmosphere gridded parameter in the following section numbers and titles:		
Section No.	Section Title	Summary
	Items To Be Done	eliminated this preface section
1.0	Introduction	changes only as listed in 1.1 and 1.2 below
1.1	Night-Only Versus Day-and-Night Profile Data Processing Control	number and heading insert only; no content change

The ATBD Version 5 document does change the intent and functionality of the algorithm and the atmosphere gridded parameter in the following section numbers and titles:		
Section No.	Section Title	Summary
1.2	Atmosphere Gridded Data Is Rational	added number, heading, section and section content
3.1	Atmospheric Fractions	heading change from "Global Fraction"; content expanded with insertion of sections 3.1.6, 3.1.6.1, and 3.1.6.2 from the sections formerly numbered 3.3, 3.3.1, and 3.3.2; addition of new section 3.1.5
3.1.5	Global and Polar ASR Cloud Fraction	inserted new section, heading, content, algorithm, and three parameters added
3.1.6	Polar Cloud Fraction	previous Section 3.3 is moved to Section 3.1.6
3.1.6.1	High, Middle, Low and Total Cloud Fraction	previous Section 3.3.1 moved to Section 3.1.6.1
3.1.6.2	Transmissive and Opaque Cloud Fraction	previous Section 3.3.2 moved to Section 3.1.6.2
3.2	Total Column Optical Depth	changes to sections 3.2.1 and 3.2.2 below
3.2.1	Global Total Column Optical Depth	heading change from "Global (Over Water) Total Column Optical Depth", algorithm and parameter changes; formerly over-water-only surface type, now over all valid surface types; sub-sections added
3.2.1.1	Application of Profile Observation Value Filtering for ASR Column Optical Depth	added section, number, heading, algorithm, and content for value range filtering of profile *column_od_asr* changing gridded parameter global_column_od
3.2.1.2	Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth	added section, number, heading, and content describing previous failure to exclude *column_od_asr* zero values from gridded parameter global_column_od computation; fix provided in section 3.2.1.1 above
3.2.1.3	Application of Profile Laser Off-Nadir Angle Limitation Filtering for Global Total Column Optical Depth	added section, number, heading, algorithm, and content for laser beam off-nadir angle limit filtering of profile *column_od_asr* observations changing gridded parameter global_column_od
3.2.1.4	Deviation from Specification: Failure to Exempt Invalid Values of the ASR Column Optical Depth Quality Flag from Global Total Column Optical Depth	added section, number, heading, and content describing previous and current failure to exclude *column_od_asr_qf* INVALID values from gridded parameter global_column_od computation; fix to be included in the next delivery of the "atlas_l3b_atm" PGE to be identified as version 2.1 (v2.1)

The ATBD Version 5 document does change the intent and functionality of the algorithm and the atmosphere gridded parameter in the following section numbers and titles:		
Section No.	Section Title	Summary
3.2.1.5	Summary of ASR Column Optical Depth Filtering Applied for the Computation of Global Total Column Optical Depth	added section, number, heading, and content describing the steps and ordering to perform constraint and filter exclusion of profile values associated with the computation of the gridded parameter global_column_od
3.2.2	Expanded Global Total Column Optical Depth	heading change from "Expanded Global (Over Water) Total Column Optical Depth", algorithm and parameter changes; formerly over-water-only and only-over-ocean surface types, now over all valid surface types; sub-sections added
3.2.2.1	Application of Profile Observation Value Filtering for ASR Column Optical Depth	added section, number, heading, algorithm, and content for value range filtering of profile *column_od_asr* changing gridded parameter expanded_global_column_od
3.2.2.2	Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth	added section, number, heading, and content describing previous failure to exclude *column_od_asr* zero values from gridded parameter expanded_global_column_od computation; fix provided in section 3.2.2.1 above
3.2.2.3	Application of Profile Laser Off-Nadir Angle Limitation Filtering for Expanded Global Total Column Optical Depth	added section, number, heading, algorithm, and content for laser beam off-nadir angle limit filtering of profile *column_od_asr* observations changing gridded parameter expanded_global_column_od
3.2.2.4	Deviation from Specification: Failure to Exempt Invalid Values of the ASR Column Optical Depth Quality Flag from Expanded Global Total Column Optical Depth	added section, number, heading, and content describing previous and current failure to exclude *column_od_asr_qf* INVALID values from gridded parameter expanded_global_column_od computation; fix to be included in the next delivery of the "atlas_l3b_atm" PGE to be identified as version 2.1 (v2.1)
3.2.2.5	Summary of ASR Column Optical Depth Filtering Applied for the Computation of Expanded Global Total Column Optical Depth	added section, number, heading, and content describing the steps and ordering to perform constraint and filter exclusion of profile values associated with the computation of the gridded parameter expanded_global_column_od
3.3	Polar Precipitation	inserted section number and heading
3.3	Blowing Snow and Diamond Dust	section renamed from "Polar Precipitation".

The ATBD Version 5 document does change the intent and functionality of the algorithm and the atmosphere gridded parameter in the following section numbers and titles:		
Section No.	Section Title	Summary
3.3.1	Blowing Snow Frequency	previous Section 3.4 renumbered to Section 3.3.1
3.3.2	South Polar Surface Diamond Dust Frequency	added section, number, heading, algorithm, and content for the new gridded parameter spolar_surf_ddust_freq and associated observation count and statistical value collection
3.4	Apparent Surface Reflectivity (ASR)	previous Section 3.5 renumbered to Section 3.4; modifications to pseudocode blocks
3.4.1	Application of Profile Laser Off-Nadir Angle Limitation Filtering for Global and Polar Apparent Surface Reflectivity	added section, number, heading, algorithm, and content for laser beam off-nadir angle limit filtering of profile *apparent_surf_reflec* observations changing the gridded parameters global_asr, spolar_asr, and spolar_asr.
3.5	Ground Detection Frequency	previous Section 3.6 renumbered to Section 3.5; modifications to pseudocode blocks
3.6	Images of Gridded Fields	previous Section 3.7 renumbered to Section 3.6
3.7	Minimum Number of Observations for Each Grid Box	previous Section 3.8 renumbered to Section 3.7
3.8	Observations Grids	previous Section 3.9 renumbered to Section 3.8; Table 4: some section numbers modified; new observation count grids added
3.9	Product Statistical Values	previous Section 3.10 renumbered to Section 3.9
5.0	Product Formats	Table 5: new gridded parameters and observation grids added, new images added; Table 6: new control constant parameter added; Table 7: new gridded parameters statistical values added; Table 8: new input high-rate profile parameters added
7.0	Acronyms and Abbreviations	added acronyms
A.6	Attachment A-6: ATL17 Monthly Product Images Exhibition	added new attachments section and contents: the set of global and polar gridded parameter PNG images for the ATL17 monthly atmosphere gridded product obtained from the ASAS functional test “func_test_960b1” ATL09 product file set

The ATBD Version 5 document does change the intent and functionality of the algorithm and the atmosphere gridded parameter in the following section numbers and titles:

Section No.	Section Title	Summary
A.7	Attachment A-7: ATL16 Weekly Product Images Exhibition	added new attachments section and contents: the set of global and polar gridded parameter PNG images for the ATL16 weekly atmosphere gridded product obtained from the ASAS functional test "func_test_960b1" ATL09 product file set using the first third of the ATL09 files
A.8	Documentation Sources Pertaining to the ATBD Version 5 Content Changes and the Version 2.0 "atlas_l3b_atm" PGE Code Development Change Log	added new attachments section and contents: collection reference document notes pertinent to the modifications and additions to the "atlas_l3b_atm" PGE v2.0 code as contained in the various section contents in the V05 ATBD
A.9	History of Atmosphere Gridded Parameters – ATBD Appearance and NSIDC ATL16/ATL17 Product Archive Version Inclusion	added new attachments section and contents: table of atmosphere gridded parameters, initial appearance in the ATBD version and date, and series of NSIDC version numbers containing the gridded parameter

Terminology

The term "INVALID" appears throughout the text of this document relative to values encountered in the input process data associated with ICESat-2 ATLAS Level-3A data obtained from the ATL09 standard data product, and the output atmosphere gridded standard data products ATL16 and ATL17. In a generic context INVALID represents missing or empty input profile data, and missing or empty output gridded parameter cells. The class of INVALID values pertaining to missing or empty profile values or missing or empty gridded parameter cell values are identified in the input HDF5 products or output HDF5 products by the Name "_FillValue". In application, INVALID or _FillValue locations contain numerical values that are "huge", i.e., the largest number (not infinity) representable within the 1-byte, 2-byte, and 4-byte integer type, the 32-bit (4-byte) floating point (or real) type, or 64-bit (8-byte) real (or double precision) type. The bottom line here is this, INVALID values should be ignored and exempted from any data usage or algorithm processing consideration.

Used within the product description tables, "N/A" generally means "Not Applicable".

Parentheses "()" are used with the presentation of ATL09 profile parameters to indicate a data array at the profile rate (i.e., 25 Hz for high-rate profile data, or 1 Hz for low-rate profile data). The notation "(,)" or "(,n)" would be used to indicate a 2-dimensional profile parameter array. As examples, the high-rate (25 Hz) profile parameter "*cloud_flag_atm*" will be presented as "*cloud_flag_atm* ()"; the 2-dimesnional profile parameter "*layer_attr*" will be presented as either "*layer_attr* (,n)" or "*layer_attr* (,)".

For the output products ATL16/ATL17, two-dimensional atmosphere gridded parameters will generally be represented with the indices (i,j) or (,). Single-dimensional linear parameter arrays will generally be represented with indices (i) and (j), or simply (). As examples, "global_cloud_frac" will appear as "global_cloud_frac (i,j)", "global_aerosol_frac" may be represented as "global_aerosol_frac (,)", "global_grid_lon" will appear as "global_grid_lon (i)", and "spolar_grid_lat" will appear as "spolar_grid_lat (j)" or "spolar_grid_lat ()".

Typographical Conventions

Italics are used to specifically denote parameters identified from the input ATL09 calibrated backscatter profile and atmospheric layer characteristics data products or to be contained within the output weekly ATL16 or monthly ATL17 atmosphere gridded data products. For example: the *solar_elevation* parameter is obtained from the ATL09 product, and the *data_type_flag* is written out to the ATL16 and ATL17 data products. Note that generic atmosphere gridded parameter references such as "global cloud fraction" are not italicized.

Application of font color and type-setting to highlight and increase visibility (contrast) of formal input ATL09 profile product parameters and generated output ATL16/ATL17 gridded product parameters.

product parameter name forms	color	type set	use	product	dimension	source/destination description
cloud_flag_atm *cloud_flag_atm* ()	blue 0000FF	*italics*	input	ATL09	single-dimension profile array	Level-3A calibrated backscatter profile and atmospheric layer characteristics
layer_attr *layer_attr* (,) *layer_attr* (,n)	blue 0000FF	*italics*	input	ATL09	two-dimension profile array	Level-3A calibrated backscatter profile and atmospheric layer characteristics
data_type_flag	dark green 006600	*italics*	input/ output	control ATL16/ ATL17	single location variable	Level-3B atmosphere gridded products
global_cloud_frac global_cloud_frac (,) global_cloud_frac (i,j)	dark green 006600	none	output	ATL16/ ATL17	two-dimension grid array	Level-3B atmosphere gridded products
global_grid_lon global_grid_lon () global_grid_lon (i)	dark green 006600	none	output	ATL16/ ATL17	single-dimension grid array	Level-3B atmosphere gridded products
est_cloud_reflect_loc	grey 666666	*italics*	local only	none	single variable	internal code use only

It is noted that the usage of font color and type-setting is not applied to the generic atmosphere profile parameters in text such as "solar elevation", "surface signal", or "blowing snow height", generic atmosphere gridded parameters presentation such as "Global Cloud Fraction" or "north polar ground detection frequency", or for the informal generic terms appearing in the pseudocode exhibits such as "low-rate blowing snow detection grid" or "high-rate blowing snow frequency polar grid".

Scope

The scope of the delivery of this edition of the **ICESat-2 Algorithm Theoretical Basis Document for Atmosphere Gridded Products** point to the following ICESat-2 Project element targets:

L3B ATM ATBD Version Identification:	Version 5 (V05)
L3B ATM ATBD Version Date:	*September 25, 2023*
ASAS atlas_l3b_atm PGE Version Identification:	Version 2.0
ASAS atlas_l3b_atm PGE Version Date:	*August 8, 2022*
ASAS ATL16 / ATL17 Product Version Identification:	Version 2.0 (v2.0)
ASAS Delivery Package Version Identification:	ASAS v6.0
ASAS Delivery Package Release:	Release 006
ASAS Delivery Package Version Date:	*updated August 24, 2022*
SIPS Build Version Identification:	SIPS Build 8.0
SDMS ATL16 / ATL17 Data Delivery Identification:	Release 5 (rel005)
NSIDC ATL16 / ATL17 Data Archival Version:	V5 (V05)

This L3B Atmosphere Gridded Products ATBD Version 5 dated *September 25, 2023*, corresponds to the v2.0 ATL16/ATL17 product definitions and the code atlas_l3b_atm PGE v2.0 initially delivered July 6, 2022, for the ASAS v6.0 Release delivery, and then redelivered after patching and modifications and testing September 14, 2022, for the next ASAS v6.0 Release redelivery.

The scope of the delivery information for the next edition of the **ICESat-2 Algorithm Theoretical Basis Document for Atmosphere Gridded Products** are projected in the following ICESat-2 Project element targets:

next L3B ATM ATBD Version Identification:	Version 6
next L3B ATM ATBD Version Date:	*October 1, 2023* [freeze] *November 15, 2023* [PSO]
next ASAS atlas_l3b_atm PGE Version Identification:	Version 2.1
next ASAS atlas_l3b_atm PGE Version Date:	*October 1, 2023*
next ASAS ATL16 / ATL17 Product Version Identification:	Version 2.1 (v2.1)
next ASAS Delivery Package Version Identification:	ASAS v6.1
next ASAS Delivery Package Version Release:	Release 007
next ASAS Delivery Package Version Date:	*December 15, 2023*
next SIPS Build Version Identification:	SIPS Build 9.0 (?)
next SDMS ATL16 / ATL17 Data Delivery Identification:	Release 6 (rel006)
next NSIDC ATL16 / ATL17 Data Archival Version:	V6 (V06)

These dates are derived from the ASAS Release Schedule, a table of events on the ASAS Schedule page within the ASAS space on the ICESat-2 Atlassian Confluence project collaboration site hosted on the project server gs614wphoton.wff.nasa.gov. [NOTE: the next version ATBD and PGE deliveries have been modified to reflect the Proposed ASAS Release Schedule, ASAS DTL Jeffrey Lee, September 18, 2023.]

1.0 Introduction

The atmosphere gridded products consist of the Level-3B (L3B) products ATL16 and ATL17. ATL16 will be a weekly product and ATL17 will be generated monthly. The same atmospheric information will be on both products. The content of both products will include: global cloud fraction, combined global cloud fraction, global aerosol fraction, global total clear fraction, global and polar ASR cloud fraction, polar cloud fraction, global total column optical depth, expanded global total column optical depth, high-rate and low-rate blowing snow frequency, South polar surface diamond frequency, global and polar apparent surface reflectivity, and global and polar ground detection frequency. The polar cloud fraction will be broken into six (6) separate grids representing high, low, middle, transmissive, opaque, and total cloud fraction for each hemisphere.

The Hierarchical Data Format (HDF) product files will contain the gridded fields of the above parameters as 2-dimensional arrays and also images of these fields plotted on a map of the respective region. ATL16 weekly products will be generated on a 3x3-degree global grid and 3x1-degree polar grids (longitude x latitude), and ATL17 monthly products on a 1x1 degree global grid and 1.5x0.5-degree polar grids. Table 1 lists the various atmospheric parameters contained in the L3B products, the type of grid used and the frequency for each. Table 2 provides summary details of the grid cell longitude and latitude sizes and the array dimensions associated with the weekly and monthly global and polar atmosphere gridded parameters. Table 3 applies the grid cell longitude and latitude sizes to weekly and monthly global and polar linear (single-dimensioned) longitude and latitude arrays.

Table 1. Level-3B Atmosphere Gridded Parameters and Grid Type and Frequency

Atmospheric Parameter	Type of Grid	Frequency		Section
		ATL16	ATL17	
Cloud Fraction (DDA)	Global	weekly	monthly	3.1.1
Combined Cloud Fraction (DDA+ASR)	Global	weekly	monthly	3.1.2
Aerosol Fraction	Global	weekly	monthly	3.1.3
Clear Fraction	Global	weekly	monthly	3.1.4
ASR Cloud Fraction (ASR)	Global and Polar	weekly	monthly	3.1.5
Cloud Fraction	Polar	weekly	monthly	3.1.6
Total Column Optical Depth	Global	weekly	monthly	3.2.1
Expanded Total Column Optical Depth	Global	weekly	monthly	3.2.2
Blowing Snow Frequency	Polar	weekly	monthly	3.3.1
South Polar Surface Diamond Dust Frequency	South Polar	weekly	monthly	3.3.2
Apparent Surface Reflectivity	Global and Polar	weekly	monthly	3.5
Ground Detection Frequency	Global and Polar	weekly	monthly	3.6

NOTE: DDA = Density Dimension Algorithm (Atmosphere ATBD), ASR = Apparent Surface Reflectance

Table 2. Level-3B Atmosphere Gridded Products Parameters Grid Sizes and Dimensions

ATM Product	Coverage Period	Grid Type	Grid Size (degrees)			Grid Dimension (i,j) = (lon,lat)
			Longitude	Latitude	Combined	
ATL16	weekly	Global	3.0	3.0	3.0x3.0 *or* 3x3	(120,60)
ATL16	weekly	Polar	3.0	1.0	3.0x1.0 *or* 3x1	(120,30)
ATL17	monthly	Global	1.0	1.0	1.0x1.0 *or* 1x1	(360,180)
ATL17	monthly	Polar	1.5	0.5	1.5x0.5	(240,60)

Table 3. Level-3B Atmosphere Gridded Products Linear Parameters Array Sizes and Dimensions

ATM Product	Coverage Period	Grid Type	Array Size (degrees)		Longitude Dimension (i) = (lon)	Latitude Dimension (j) = (lat)
			Longitude	Latitude		
ATL16	weekly	Global	3.0	3.0	(120)	(60)
ATL16	weekly	Polar	3.0	1.0	(120)	(30)
ATL17	monthly	Global	1.0	1.0	(360)	(180)
ATL17	monthly	Polar	1.5	0.5	(240)	(60)

1.1 Night-Only Versus Day-and-Night Profile Data Processing Control

A control parameter will be installed as a default within the code, with an override read in from the execution control file that will establish whether both night and day data are included in the generation of the product or only night data. The night-only data is determined from the ATL09 parameter *solar_elevation* applied as filter. If it is less than 0.0, then it is considered night data. This control parameter will be included on the product as parameter *data_type_flag* within the product group "/ancillary_data/atmosphere". A value of zero (0) means to use both day and night data to generate the products, and one (1) will mean to use only night data. The coded default value will be zero (0) for processing day and night data; a control file override value of one (1) will process only night data.

This night-only versus day-and-night processing control "filtering" logic is installed as the initial test at the top of each atmosphere gridded parameter profile observation collection in each parameter code module unit.

The following pseudocode content presents how the night-only data selection logic would be generically applied to each global and polar gridded parameter. Section 2.0 addresses the (i,j) array indexing and indices. NOTE: the input high-rate parameter *solar_elevation* () does not contain INVALID values in the profile observations.

the pseudocode below represents the generic (typical) logic for night-only data filtering of ATL09 profile parameter data including selected observations for counting or summation in the numerator grid, and the total available observation count collected in the denominator grid, for all 25 Hz (high-rate) profile observations ():	

for every 25 Hz profile observation ()
  for *data_type_flag* = 1
    for *solar_elevation ()* => 0.0
      next 25 Hz profile observation ()
    else
      for filtering criteria met
        for profile observation counting
          add 1 to parameter counter grid (i,j) [numerator]
        for profile observation running sum
          add parameter to summation grid (i,j) [numerator]
      add 1 to total observation grid (i,j) [denominator]
  next 25 Hz profile observation ()
	
	process night only data
	indicates daylight observation
	skip to next profile observation
	this is night data,
	process this profile observation
	for observation counting
	increment counter grid
	for observation running sum
	add value to summation grid
	increment total observation grid
	cycle through all observations

the pseudocode below represents the generic (typical) logic for filtering of ATL09 profile parameter data including selected observations for summation in the numerator grid, and the filtered available observation count collected in the denominator grid, for all 1 Hz (low-rate) profile observations () in the case of low-rate blowing snow frequency:	
for *data_type_flag* = 1 process night-only data interpolate 25 Hz profile *solar_elevation ()* to 1 Hz profile *lo_rate_solar_elevation* () using 1 Hz *lo_rate_atm_time* ()	

for every 1 Hz profile observation ()
    for *data_type_flag* = 1
        for *lo_rate_solar_elevation* () => 0.0
            next 1 Hz profile observation ()
        else
            for detection filtering criteria met
                add 1 to detection grid (i,j) [numerator]
            for observation filtering criteria met
                add 1 to observation grid (i,j) [denominator]
    next 1 Hz profile observation ()
	
	process night only data
	indicates daylight observation
	skip to next profile observation
	this is night data, process;
	test detection grid criteria
	increment detection grid
	test observation grid criteria
	increment sel. observation grid
	cycle through all observations

1.2 Atmosphere Gridded Data Is Rational

In general, the atmosphere gridded parameters derive from selected parameters collected from the ATL09 Level-3A calibrated backscatter profile and atmospheric layer characteristics data. The gridded parameters are rational, expressed as the ratio of a logically-filtered profile observation count or ATL09 parameter summation as an accumulated numerator value for each cell in a particular grid, divided by a denominator that is total count based primarily on 25 Hz high-rate profile data for each cell or on the accepted observation count for the average atmosphere gridded parameter computation. The cell numerator running counts or running sums are discriminated by logic application of specified flags, attributes, and quality flags. Once all ATL09 dataset input has been assimilated, counted and/or summed within the numerator and denominator grid cells as appropriate, the rational division of numerator cells by denominator cells for the grid parameter array is performed to generate each atmosphere gridded parameter. The cells of the denominator grid consist of the count of valid 25 Hz profile observations, with the filtered count exceptions being the average global total column optical depth, the average expanded global total column optical depth, the average global and polar apparent surface reflectance, the low-rate and high-rate polar blowing snow frequency, and the southern polar surface diamond dust frequency.

Consequently, the atmosphere gridded parameter data formulation is a two-pass operation. In the first pass all of the available valid source profile data is processed either into accumulated observation counts or running summations in each "numerator" grid cell, while all available valid 25 Hz (high-rate) or "filtered" profile observations are "counted" in the accumulated counts comprising the "denominator" grid cells. Once all of the ATL09 files for processing have been assimilated, the second pass is performed, dividing the collected, filtered numerator grid of counts or sums by the collected, filtered denominator grid of counts. NOTE: while the numerator grid cells may contain either profile observation counts or sums the denominator grid will <u>always</u> contain counts of all available valid observations or counts of selected, filtered observations.

For the record, the original blowing snow frequency (ATL16/ATL17) deviated from the 25 Hz observation processing description in that the low-rate 1 Hz profile data is used. Also, it is noted that the set of parameters collected and reported as observation counts in Section 3.9 are actually the denominator total observation count or the number of observations used in the summation grid cell contents. NOTE: with the ATBD Version 3.1 [Interim], August 12, 2020, version, high-rate blowing snow height and confidence profile data is now assimilated for accumulation and computation of the high-rate blowing snow frequency. Correspondingly, the original 1 Hz blowing snow frequency is designated as the low-rate blowing snow frequency.

The fractional or frequency atmosphere gridded parameter expressed as a fraction (0-1) is collected and computed in generic form as:

$$\text{fraction or frequency grid }(i,j) = \frac{\text{filtered profile observation }\underline{\text{counter}}\text{ grid }(i,j)}{\text{total (or filtered total) profile observation }\underline{\text{counter}}\text{ grid }(i,j)}$$

The frequency atmosphere gridded parameter expressed as percentage (%) is collected and computed in generic form as:

$$\text{frequency grid }(i,j) = \frac{\text{filtered profile observation }\underline{\text{counter}}\text{ grid }(i,j)}{\text{total (or filtered total) profile observation }\underline{\text{counter}}\text{ grid }(i,j)} * 100$$

The averaged atmosphere gridded parameter is collected and computed in generic form as:

$$\text{average grid }(i,j) = \frac{\text{filtered profile observation }\underline{\text{summation}}\text{ (total) grid }(i,j)}{\text{total (or filtered total) profile observation }\underline{\text{counter}}\text{ grid }(i,j)}$$

An example of a frequency grid parameter is the high rate (or low rate) blowing snow parameter. This parameter is computed by summing all blowing snow detections (bsnow_h > 0) in a grid cell and dividing it by the total number of observations in the grid cell. An example an average grid parameter is the total column optical depth parameter. This is computed by summing all valid column optical depth retrievals within a grid cell and dividing by the number of such retrievals (i.e., computing the average value of the column optical depth for each grid cell).

2.0 Global and Polar Grids

For the atmosphere gridded products presented here, simple grids are used at various resolutions. For the monthly (ATL17) product, the global grids and the polar grids, the longitude by latitude sizes are included in Table 2. Similarly, the weekly product (ATL16) global grids and the polar grids longitude and latitude sizes are found in Table 2. Some atmospheric fields are produced on a global grid while others are produced on polar grids that cover only the area poleward of 60N or 60S. Three atmospheric parameters, apparent surface reflectance cloud fraction, apparent surface reflectivity, and ground detection frequency, are produced on both global and polar projection arrays. Array dimensions for the monthly global grids (i,j) and the weekly global grids (i,j) are also included in Table 2. Similarly, monthly polar grids (i,j) dimensions and weekly polar grids (i,j) dimensions are supplied in Table 2. The latitudes and longitudes of the various grids will be included on both products as single-dimensioned linear arrays (described in Table 5). NOTE: in the (i,j) grid cell indices, i is the longitude index and j is the latitude index.

The underlying assumptions for global atmosphere gridded algorithms are that longitude goes from -180 to 180 and latitude goes from -90 to 90 degrees; and that the (i,j) indices start at (0,0) for (longitude=-180, latitude=-90). For the global gridded atmosphere parameter array the origin (0,0) occurs at the lower left corner. A graphical illustration of the indexing scheme for an example global gridded array showing the cell layout including the origin and reference is provided in Attachment A-3.

The monthly and weekly **global grid indices** are computed from *longitude* and *latitude* coordinates as follows:

i = int(*longitude*+180.0), j = int(*latitude*+90.0)	for the 1x1 degree grid	global monthly grid, ATL17 product
i = int(*longitude*/3+60.0), j = int(*latitude*/3+30.0)	for the 3x3 degree grid	global weekly grid, ATL16 product

Polar monthly grids and the polar weekly grids will be dimensioned according to Table 2. The longitude span is expressed in the assumptions above. North polar latitude goes from 90 down to 60 degrees. The North polar (i,j) indices start at (0,0) for (longitude=-180, latitude=90). For the North polar gridded atmosphere parameter array the origin (0,0) occurs at the upper left corner. A graphical illustration of the indexing scheme for an example North polar gridded array showing the cell layout including the origin and reference (on a rectangle) is provided in Attachment A-4.

The **North polar grid indices** are computed as:

i = int(*longitude*/1.5+120.0), j = int(180.0-*latitude**2)	for the 1.5x0.5-degree grid, where *latitude* is >= 60.0	North polar monthly grid, ATL17 product
i = int(*longitude*/3.0+60.0), j = int(90.0-*latitude*)	for the 3x1 degree grid, where *latitude* is >= 60.0	North polar weekly grid, ATL16 product

Again, the longitude span is expressed in the assumptions above. South polar latitude goes from -90 up to -60 degrees. The South polar (i,j) indices start at (0,0) for (longitude=-180, latitude=-90). For the South polar gridded atmosphere parameter array the origin (0,0) occurs at the lower left corner. A graphical illustration of the indexing scheme for an example South polar gridded array showing the cell layout including the origin and reference (on a rectangle) is provided in Attachment A-5.

The **South polar grid indices** are computed as:

i = int(*longitude*/1.5+120.0), j = int(180.0+*latitude**2)	for the 1.5x0.5-degree grid, where *latitude* is <= -60.0	South polar monthly grid, ATL17 product
i = int(*longitude*/3.0+60.0), j = int(90.0+*latitude*)	for the 3x1 degree grid, where *latitude* is <= -60.0	South polar weekly grid, ATL16 product

3.0 Product Definitions

3.1 Atmospheric Fractions

In the beginning… there was only Global Cloud Fraction. Close inspection of the derivation of the initial global cloud fraction algorithm revealed the parameter was actually the global cloud and aerosol fraction. Hence the reclassification of the atmosphere gridded parameter as Global Cloud and Aerosol Fraction (as clarified in Version 1.2, February 27, 2019). Then with delivery of the August 21, 2019, Version 2.0 ATBD, the algorithms were differentiated into Global Cloud Fraction (Section 3.1) and Global Aerosol Fraction (Section 3.1.1). With the delivery of the Version 3.2 [*Interim*] ATBD dated January 12, 2021, the new gridded parameter Global Clear Fraction has been introduced as a new Section 3.1.2. Finally, the January 12, 2021, Version 3.2 [*Interim*] ATBD presented modifications to "augment" the existing Global Cloud Fraction by supplementing the profile cloud layer count from the DDA to also include the profile cloud count from as defined by the ATL09 parameter *asr_cloud_probability*. Subsequently, the decision is made to retain the original global cloud fraction algorithm along with the new combined DDA plus ASR global cloud fraction algorithm. Previously, the section was reorganized as the presenting overview under the title Global Fractions hosting the four atmosphere gridded fraction parameters projected on the global grid for both the weekly ATL16 product and the monthly ATL17 product.

With the Version 5 ATBD dated September 25, 2023, the Section 3.1 is retitled from "Global Fractions" to "Atmospheric Fractions". The section has been expanded with the added global and polar apparent surface reflectance cloud fraction parameters. Further, the previous Section 3.3 Polar Cloud Fraction is now "rolled" in under the omnibus "Atmospheric Fractions" as the sub-section, Section 3.1.6 "Polar Cloud Fraction". The organization now covers both the global and polar atmospheric fraction gridded parameter set.

The sub-sections are presented and discriminated as:

- 3.1.1 Global Cloud Fraction [from DDA],
- 3.1.2 Combined Global Cloud Fraction [from DDA plus ASR],
- 3.1.3 Global Aerosol Fraction [from DDA],
- 3.1.4 Global Clear Fraction [from DDA],
- 3.1.5 Global and Polar ASR Cloud Fraction [from ASR],
- 3.1.6 Polar Cloud Fraction [from DDA],
- 3.1.6.1 High, Middle, Low and Total Cloud Fraction [from DDA], and
- 3.1.6.2 Transmissive and Opaque Cloud Fraction [from DDA].

3.1.1 Global Cloud Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	global_cloud_frac (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global Cloud Fraction					
Image parameter:	global_cloud_frac_img	Group: /				
Observation grid:	global_cloud_aerosol_obs_grid (,)	Group: /				
Statistical variables:	*global_cloud_frac_min* *global_cloud_frac_max* *global_cloud_frac_mean* *global_cloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,)	ATL09 Group: /profile_x /high rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_cloud_frac_mod.f90					

This atmospheric parameter ("global_cloud_frac", i.e., from Table 5, typical) is displayed on a global grid. Define a "dda cloud counter grid" [i.e., the numerator grid] and a "total observation grid" [i.e., the denominator grid]. The ATL09 product contains the parameter "*cloud_flag_atm*" which is the number of layers detected for a given 25 Hz profile (note: up to possibly 10 layers). When this parameter is > 0 AND the parameter *layer_attr* = 1 for any layer (i.e., 1=cloud layer attribute), the dda cloud counter grid box associated with the current location (i,j) indices (computed as in Section 2.0 above) is incremented by one (1) for that grid box. The total observation grid box count is incremented by one (1) for every 25 Hz profile regardless of the value of the product parameter *cloud_flag_atm* () or *layer_attr* (,). NOTE: the input parameters *cloud_flag_atm* () and *layer_attr* (,n) do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

NOTE that the "dda cloud counter grid" is incremented only once regardless of the number of cloud layers detected after the first determined cloud layer. The origin of the global cloud fraction is based on the layers derived from "Detection of Atmosphere Layers and Surface Using a Density Dimension Algorithm (DDA)" from the Atmosphere ATBD Part II, Version 11.0, dated February 4, 2020, and the classification of layer type (as cloud or aerosol) as defined in "ICESat-2 Algorithm Theoretical Basis Document for the Atmosphere, Part I: Level 2 and 3 Data Products", Version 3.4, dated January 15, 2021.

the pseudocode below represents the conditional logic for incrementing the "*dda cloud counter grid*", i.e., the numerator grid, for <u>selection</u> from all 25 Hz (high-rate) profile observations ():	
for 25 Hz *cloud_flag_atm* () > 0 and *layer_attr* (,n) = 1 dda cloud counter grid (i,j) = dda cloud counter grid (i,j) + 1 next profile observation	a dda cloud layer is detected only for the first *layer_attr* (,n) = 1

the pseudocode below represents the logic for incrementing the "*total observation grid*", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():
for every 25 Hz profile observation total observation grid (i,j) = total observation grid (i,j) + 1 next profile observation

After reading the input ATL09 files for the period in question, the dda cloud counter grid [the numerator grid] is divided by the total observation grid [the denominator grid] to obtain a global grid of cloud fraction (from DDA). For cases where the number of total observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the global cloud fraction to INVALID.

the pseudocode below represents the conditional logic for calculating the "*global cloud fraction grid*" by division of the "*dda cloud counter grid*", i.e., the numerator grid, by the "*total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:
for total observation grid (i,j) => *_obs_minimum global cloud fraction grid (i,j) = dda cloud counter grid (i,j) / total observation grid (i,j) else global cloud fraction grid (i,j) = INVALID next grid cell
NOTE: *_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

NOTE that the title of the image made from these data was briefly "Global Cloud and Aerosol Layer Fraction" (as implemented with ATBD Version 1.2) and was required to be changed to "Global Cloud Fraction" after the changes with ATBD Version 2.0 were made, which implemented cloud/aerosol discrimination via the *layer_attr* parameter described above. The image label for the global cloud fraction will be "Global Cloud Fraction".

3.1.2 Combined Global Cloud Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Combined Global Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	combined_global_cloud_frac (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Combined Global Cloud Fraction					
Image parameter:	combined_global_cloud_frac_img	Group: /				
Observation grid:	global_cloud_aerosol_obs_grid (,)	Group: /				
Statistical variables:	*combined_global_cloud_frac_min* *combined_global_cloud_frac_max* *combined_global_cloud_frac_mean* *combined_global_cloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *asr_cloud_probability* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*asr_cloud_threshold* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	comb_glob_cloud_frac_mod.f90					

The existing global cloud fraction, based on the cloud layers determined by the backscatter profile layer finding DDA algorithm [identified as the gridded parameter Global Cloud Fraction (from DDA)] is now supplemented with the combined global cloud fraction identified as the new atmosphere gridded parameter Combined Global Cloud Fraction. The combined global cloud fraction includes the DDA detected clouds and increases the detected cloud count with addition of occurrence of clouds from the apparent surface reflectivity (ASR) magnitude algorithm when DDA clouds are not present.

This added atmospheric parameter ("combined_global_cloud_frac") is displayed on a global grid. Define a "dda+asr cloud counter grid" [i.e., the numerator grid] and a "total observation grid" [i.e., the denominator grid]. The ATL09 product contains the parameter "*cloud_flag_atm*" which is the number of layers detected for a given 25 Hz profile (note: up to possibly 10 layers). When this parameter is > 0 AND the parameter *layer_attr* = 1 for any layer (i.e., 1=cloud layer attribute), a cloud layer from DDA has been detected, and the dda+asr cloud counter grid box associated with the current location (i,j) indices (computed as in Section 2.0 above) is incremented by one (1) for that grid box. In addition, if no DDA cloud layer is detected, then do the following: check the ATL09 parameter *asr_cloud_probability*, and if it is greater than or equal to the control parameter *asr_cloud_threshold* (nominal value of 80), an ASR cloud layer has been detected, then increment the dda+asr cloud counter grid box associated with the current location (i,j) indices by one (1) for that grid box. The total observation grid box count is incremented by one (1) for every 25 Hz profile regardless of the value of the product parameter *cloud_flag_atm* () or *layer_attr* (,) or *asr_cloud_probability* (). NOTE: the input parameters *cloud_flag_atm* () and *layer_attr* (,n) and *asr_cloud_probability* () do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

NOTE that the "dda+asr cloud counter grid" is incremented only once regardless of the number of cloud layers detected after the first determined cloud layer from DDA cloud layer determination. If a DDA cloud layer is detected, there will be no further checking for an ASR cloud probability cloud layer for the profile observation. This means there is no redundant, coincident counting of cloud layer occurrences.

<table>
<tr><td colspan="2">the pseudocode below represents the conditional logic for incrementing the "dda+asr cloud counter grid", i.e., the numerator grid, for selection from all 25 Hz (high-rate) profile observations ():</td></tr>
<tr><td>for every 25 Hz profile observation
    if [cloud_flag_atm () > 0 and layer_attr (,n) = 1 OR
        asr_cloud_probability () => asr_cloud_threshold]
          dda+asr cloud counter grid (i,j) =
                    dda+asr cloud counter grid (i,j) + 1
    end if
next profile observation</td><td>test for a DDA cloud layer OR
an ASR cloud layer:
a DDA cloud layer
[first layer_attr (,n) = 1] OR
an ASR cloud layer is detected,
increment dda+asr cloud counter</td></tr>
<tr><td colspan="2">the pseudocode below represents the logic for incrementing the "total observation grid", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():</td></tr>
<tr><td colspan="2">for every 25 Hz profile observation
    total observation grid (i,j) = total observation grid (i,j) + 1
next profile observation</td></tr>
</table>

After reading the input ATL09 files for the period in question, the dda+asr cloud counter grid [the numerator grid] is divided by the total observation grid [the denominator grid] to obtain a combined global grid of cloud fraction (from DDA and ASR). For cases where the number of total observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the combined global cloud fraction to INVALID.

<table>
<tr><td>the pseudocode below represents the conditional logic for calculating the "combined global cloud fraction grid" by division of the "dda+asr cloud counter grid", i.e., the numerator grid, by the "total observation grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:</td></tr>
<tr><td>for total observation grid (i,j) => *_obs_minimum
                                        dda+asr cloud counter grid (i,j)
    combined global cloud fraction grid (i,j) = --
                                            total observation grid (i,j)
else
    combined global cloud fraction grid (i,j) = INVALID
next grid cell</td></tr>
<tr><td>NOTE: *_obs_minimum represents either weekly_obs_minimum or monthly_obs_minimum based on product</td></tr>
</table>

The title of the image made from these data is "Combined Global Cloud Fraction".

With ATBD V05 the nominal value of the control parameter constant *asr_cloud_threshold* is changed from 80 to the value 70 (i.e., 70 percent).

3.1.3 Global Aerosol Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global Aerosol Fraction	Lon	Lat	Lon	Lat	
Product variable:	global_aerosol_frac (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global Aerosol Fraction					
Image parameter:	global_aerosol_frac_img	Group: /				
Observation grid:	global_cloud_aerosol_obs_grid (,)	Group: /				
Statistical variables:	*global_aerosol_frac_min* *global_aerosol_frac_max* *global_aerosol_frac_mean* *global_aerosol_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_aerosol_frac_mod.f90					

This atmospheric parameter ("global_aerosol_frac") is displayed on a global grid. Define a "dda aerosol counter grid" [i.e., the numerator grid] and a "total observation grid" [i.e., the denominator grid]. The ATL09 product contains the parameter "*cloud_flag_atm*" which is the number of layers detected for a given 25 Hz profile (up to 10 layers). When this parameter is > 0 AND the parameter *layer_attr* = 2 for any layer (i.e., 2=aerosol layer attribute), the dda aerosol counter grid box associated with the current location (i,j) indices (computed as in Section 2.0 above) is incremented by one (1) for that grid box. Note that when *cloud_flag_atm* > 1, the *layer_attr* flag must be checked for each of the layers. If any one of them is equal to 2, then the dda aerosol counter is incremented. The total observation count grid box is incremented by one (1) for every 25 Hz profile regardless of the value of the product parameter *cloud_flag_atm* () or *layer_attr* (,). NOTE: the input parameters *cloud_flag_atm* () and *layer_attr* (,n) do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

NOTE: the "dda aerosol counter grid" is incremented only once regardless of the number of aerosol layers detected after the first determined aerosol layer.

the pseudocode below represents the conditional logic for incrementing the "*dda aerosol counter grid*", i.e., the numerator grid, for selection from all 25 Hz (high-rate) profile observations ():	
for 25 Hz *cloud_flag_atm* () > 0 and *layer_attr* (,n) = 2 dda aerosol counter grid (i,j) = dda aerosol counter grid (i,j) + 1 next profile observation	a dda aerosol layer is detected only for the first *layer_attr* (,n) = 2
the pseudocode below represents the logic for incrementing the "*total observation grid*", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():	
for every 25 Hz profile observation total observation grid (i,j) = total observation grid (i,j) + 1 next profile observation	

After reading the input ATL09 files for the period in question, the dda aerosol counter grid is divided by the total observation grid to obtain a global grid of aerosol fraction (from DDA). For cases where the number of total observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the aerosol fraction to INVALID.

the pseudocode below represents the conditional logic for calculating the "*global aerosol fraction grid*" by division of the "*dda aerosol counter grid*", i.e., the numerator grid, by the "*total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:
for total observation grid (i,j) => **_obs_minimum* global aerosol fraction grid (i,j) = dda aerosol counter grid (i,j) / total observation grid (i,j) else global aerosol fraction grid (i,j) = INVALID next grid cell
NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

The title of the image made from these data is "Global Aerosol Fraction".

3.1.4 Global Clear Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global Clear Fraction	Lon	Lat	Lon	Lat	
Product variable:	global_clear_frac (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global Clear Fraction					
Image parameter:	global_clear_frac_img	Group: /				
Observation grid:	global_cloud_aerosol_obs_grid (,)	Group: /				
Statistical variables:	*global_clear_frac_min* *global_clear_frac_max* *global_clear_frac_mean* *global_clear_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_clear_frac_mod.f90					

This atmospheric parameter ("global_clear_frac") is displayed on a global grid. Define a "dda clear counter grid" [i.e., the numerator grid] and a "total observation grid" [i.e., the denominator grid]. The ATL09 product contains the parameter "*cloud_flag_atm*" which is the number of layers detected for a given 25 Hz profile (up to 10 layers). When this parameter is = 0 the dda clear counter grid box associated with the current location (I,j) indices is incremented by one (1) for that grid box. In addition, if the parameter *cloud_flag_atm* is equal to n, where n is > 0, then examine the parameter *layer_attr* for each of the n layers. If *layer_attr* = 2 (aerosol layer) for all of the n layers, then the dda clear counter grid box associated with the current location (I,j) indices is incremented by one (1) for that grid box. The total observation count grid box is incremented by one (1) for every 25 Hz profile regardless of the value of the product parameter *cloud_flag_atm* (). NOTE: the input parameters *cloud_flag_atm* () and *layer_attr* do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

the pseudocode below represents the conditional logic for incrementing the "*dda clear counter grid*", i.e., the numerator grid, for selection from all 25 Hz (high-rate) profile observations ():	

for every 25 Hz profile observation
    if [*cloud_flag_atm* () = 0 OR
      cloud_flag_atm () > 0 and all n *layer_attr* (,n) = 2]
        dda clear counter grid (i,j) =
            dda clear counter grid (i,j) + 1
    end if
next profile observation
	no DDA cloud layers detected OR only aerosol layers detected
	increment clear counter grid

the pseudocode below represents the logic for incrementing the "*total observation grid*", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():
for every 25 Hz profile observation   total observation grid (i,j) = total observation grid (i,j) + 1 next profile observation

After reading the input ATL09 files for the period in question, the clear counter grid [the numerator grid] is divided by the total observation grid [the denominator grid] to obtain a global grid of clear fraction. For cases where the number of total observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the clear fraction to INVALID.

the pseudocode below represents the conditional logic for calculating the "*global clear fraction grid*" by division of the "*dda clear counter grid*", i.e., the numerator grid, by the "*total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

for total observation grid (i,j) => **_obs_minimum*
    global clear fraction grid (i,j)= dda clear counter grid (i,j) / total observation grid (i,j)
else
    global clear fraction grid (i,j)= INVALID
next grid cell

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

The title of the image made from these data is "Global Clear Fraction".

3.1.5 Global and Polar ASR Cloud Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global ASR Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	global_asr_cloud_frac (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global ASR Cloud Fraction					
Image parameter:	global_asr_cloud_frac_img	Group: /				
Observation grid:	global_cloud_aerosol_obs_grid (,)	Group: /				
Statistical variables:	*global_asr_cloud_frac_min* *global_asr_cloud_frac_max* *global_asr_cloud_frac_mean* *global_asr_cloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*asr_cloud_probability* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*asr_cloud_threshold* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_asr_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar ASR Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	npolar_asr_cloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar ASR Cloud Fraction					
Image parameter:	npolar_asr_cloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_asr_cloud_frac_min* *npolar_asr_cloud_frac_max* *npolar_asr_cloud_frac_mean* *npolar_asr_cloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*asr_cloud_probability* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*asr_cloud_threshold* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_asr_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar ASR Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	spolar_asr_cloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar ASR Cloud Fraction					
Image parameter:	spolar_asr_cloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_asr_cloud_frac_min* *spolar_asr_cloud_frac_max* *spolar_asr_cloud_frac_mean* *spolar_asr_cloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*asr_cloud_probability* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*asr_cloud_threshold* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_asr_cloud_frac_mod.f90					

The algorithm for the Global ASR Cloud Fraction has already appeared in the algorithm set for the Combined Global Cloud Fraction (Section 3.1.2) where clouds from the Apparent Surface Reflectance (ASR) are assessed from the ATL09 25 Hz (high rate) profile data in the absence of DDA determined cloud layers. The consideration for this atmosphere gridded parameter appeared as ASR Global Cloud Fraction in the list of "Items To Be Done" in the September 1, 2021, Version 3.2 ATBD as the third item.

This ATL16/ATL17 parameter global asr cloud fraction (global_asr_cloud_frac) will be on a global grid and represents the cloud fraction as obtained from the ratio of the measured apparent surface reflectivity (ASR) to the true surface reflectivity. The *asr_cloud_probability* parameter on ATL09 is defined as:

$$P = (1.0 - ASR/R) * 100.0,$$

where R is the true surface reflectivity (*aclr_true* on ATL09).

When P is greater than or equal to the control parameter *asr_cloud_threshold* (nominal value of 70), an ASR cloud layer has been detected, then increment the asr cloud counter grid box associated with the current location (i,j) indices by one (1) for that grid box. The total observation grid box count is incremented by one (1) for every 25 Hz profile regardless of the value of the product parameter *asr_cloud_probability*. After reading the input ATL09 files for the period in question, the asr cloud counter grid [the numerator grid] is divided by the total observation grid [the denominator grid] to obtain a global grid of cloud fraction (from ASR). For cases where the number of total observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the global asr cloud fraction for that grid box to INVALID.

in addition to the new Global ASR Cloud Fraction parameter, the North Polar ASR Cloud Fraction and the South Polar ASR Cloud Fraction parameters are added as well.

North and South polar grids for cloud fraction from ASR are established at the longitude and latitude grid size resolution and the dimensions for the weekly product, and for the monthly product, according to values contained in Table 2. When the latitude is poleward of 60N or 60S and the parameter *asr_cloud_probability* is greater than or equal to control parameter constant *asr_cloud_threshold* the value of one (1) is added to the polar asr cloud counter grid box at the current location and the corresponding polar total observation grid box is incremented by one (1) for every 25 Hz profile regardless of the value of the product parameter *asr_cloud_probability*. Again, after all ATL09 profile data has been processed, the polar asr cloud counter [numerator] grids asr divided by the polar total observation counter [denominator] grids to obtain the northern and southern polar region grids of cloud fraction from ASR clouds. NOTE: the input parameter *asr_cloud_probability* () does not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

For the global grid:

<table>
<tr><td colspan="2">the pseudocode below represents the conditional logic for incrementing the global "asr cloud counter grid", i.e., the numerator grid, for selection from all 25 Hz (high-rate) profile observations ():</td></tr>
<tr><td>for every 25 Hz profile observation
    if [asr_cloud_probability () => asr_cloud_threshold]
        asr cloud counter grid (i,j) =
            asr cloud counter grid (i,j) + 1
    end if
next profile observation</td><td>test for an ASR cloud layer:
an ASR cloud layer is detected, increment asr cloud counter</td></tr>
<tr><td colspan="2">the pseudocode below represents the logic for incrementing the global "total observation grid", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():</td></tr>
<tr><td colspan="2">for every 25 Hz profile observation
    total observation grid (i,j) = total observation grid (i,j) + 1
next profile observation</td></tr>
</table>

After reading the input ATL09 files for the period in question, the asr cloud counter grid [the numerator grid] is divided by the total observation grid [the denominator grid] to obtain the global grid of cloud fraction (from ASR). For cases where the number of total observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the global asr cloud fraction to INVALID.

the pseudocode below represents the conditional logic for calculating the "*global asr cloud fraction grid*" by division of the "*asr cloud counter grid*", i.e., the numerator grid, by the "*total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

for total observation grid (i,j) => *_obs_minimum
    global asr cloud fraction grid (i,j) = asr cloud counter grid (i,j) / total observation grid (i,j)
else
    global asr cloud fraction grid (i,j) = INVALID
next grid cell

NOTE: *_obs_minimum represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

The title of the image made from these data is "Global ASR Cloud Fraction".

Typically for the northern polar region (90N-60N latitude) or the southern polar region (90S-60S latitude):

the pseudocode below represents the conditional logic for incrementing the two polar regions "*polar asr cloud counter grid*", i.e., the numerator grid, for selection from all 25 Hz (high-rate) profile observations ():	

for every 25 Hz profile observation
    if [*asr_cloud_probability* () => *asr_cloud_threshold*]
        polar asr cloud counter grid (i,j) =
            polar asr cloud counter grid (i,j) + 1
    end if
next profile observation
	test for an ASR cloud layer:
	an ASR cloud layer is detected,
	increment polar asr cloud counter

the pseudocode below represents the logic for incrementing the two regions of "*polar total observation grid*", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():	
for every 25 Hz profile observation polar total observation grid (i,j) = polar total observation grid (i,j) + 1 next profile observation	

After reading the input ATL09 files for the period in question, the polar asr cloud counter grid [the numerator grid] is divided by the polar total observation grid [the denominator grid] to obtain the polar grid of cloud fraction (from ASR). For cases where the number of total observations for a polar region grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the regional polar asr cloud fraction to INVALID.

the pseudocode below represents the conditional logic for calculating the two regions of "*polar asr cloud fraction grid*" by division of the "*polar asr cloud counter grid*", i.e., the numerator grid, by the "*polar total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:
for polar total observation grid (i,j) => *_obs_minimum* polar asr cloud counter grid (i,j) polar asr cloud fraction grid (i,j) = -- polar total observation grid (i,j) else polar asr cloud fraction grid (i,j) = INVALID next grid cell
NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

The title of the images made from these data are "North Polar ASR Cloud Fraction" and "South Polar ASR Cloud Fraction".

NOTE: with ATBD V05 the nominal value of the control parameter constant *asr_cloud_threshold* is changed from 80 to the value 70 (i.e., 70 percent).

3.1.6 Polar Cloud Fraction

3.1.6.1 High, Middle, Low and Total Cloud Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar High Cloud Fraction (> 8km)	Lon	Lat	Lon	Lat	
Product variable:	npolar_highcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar High Cloud Fraction (> 8km)					
Image parameter:	npolar_highcloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_highcloud_frac_min* *npolar_highcloud_frac_max* *npolar_highcloud_frac_mean* *npolar_highcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar High Cloud Fraction (> 8km)	Lon	Lat	Lon	Lat	
Product variable:	spolar_highcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar High Cloud Fraction (> 8km)					
Image parameter:	spolar_highcloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_highcloud_frac_min* *spolar_highcloud_frac_max* *spolar_highcloud_frac_mean* *spolar_highcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Mid Cloud Fraction (> 4km and <=8km)	Lon	Lat	Lon	Lat	
Product variable:	npolar_midcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Mid Cloud Fraction (> 4km and <=8km)					
Image parameter:	npolar_midcloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_midcloud_frac_min* *npolar_midcloud_frac_max* *npolar_midcloud_frac_mean* *npolar_midcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Mid Cloud Fraction (> 4km and <=8km)	Lon	Lat	Lon	Lat	
Product variable:	spolar_midcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Mid Cloud Fraction (> 4km and <=8km)					
Image parameter:	spolar_midcloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_midcloud_frac_min* *spolar_midcloud_frac_max* *spolar_midcloud_frac_mean* *spolar_midcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Low Cloud Fraction (<= 4km)	Lon	Lat	Lon	Lat	
Product variable:	npolar_lowcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Low Cloud Fraction (<= 4km)					
Image parameter:	npolar_lowcloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_lowcloud_frac_min* *npolar_lowcloud_frac_max* *npolar_lowcloud_frac_mean* *npolar_lowcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Low Cloud Fraction (<= 4km)	Lon	Lat	Lon	Lat	
Product variable:	spolar_lowcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Low Cloud Fraction (<= 4km)					
Image parameter:	spolar_lowcloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_lowcloud_frac_min* *spolar_lowcloud_frac_max* *spolar_lowcloud_frac_mean* *spolar_lowcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Total Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	npolar_totalcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Total Cloud Fraction					
Image parameter:	npolar_totalcloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_totalcloud_frac_min* *npolar_totalcloud_frac_max* *npolar_totalcloud_frac_mean* *npolar_totalcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_hmlt_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Total Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	spolar_totalcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Total Cloud Fraction					
Image parameter:	spolar_totalcloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_totalcloud_frac_min* *spolar_totalcloud_frac_max* *spolar_totalcloud_frac_mean* *spolar_totalcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *layer_top* (,)	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_hmlt_cloud_frac_mod.f90					

For each observation period (weekly/monthly) eight (8) separate polar grids are established that cover the latitude range 60N to 90N and 60S to 90S ("npolar_highcloud_frac", "npolar_midcloud_frac", "npolar_lowcloud_frac", "npolar_totalcloud_frac", "spolar_highcloud_frac", "spolar_midcloud_frac", "spolar_lowcloud_frac", and "spolar_totalcloud_frac"). For the polar regions, four (4) cloud fraction grids are created for each hemisphere. Grid 1 will contain the fraction of clouds that occur below and up to and including 4 km altitude. Grid 2 will contain the cloud fraction for clouds above 4 km and up to and including 8 km. Grid 3 will contain the cloud fraction for clouds that occur above 8 km. Grid 4 will represent total cloud fraction. So, there are four (4) grids for each polar region (four (4) North and four (4) South). The grids are populated in the same way as described in Section 3.1, except the low, middle, and high layers are segregated by the altitude of the cloud layer top.

NOTE that *layer_attr* has to be equal to 1 for the layer to be a cloud. The top height of the layers is contained in the ATL09 parameter "*layer_top*", which is dimensioned at 10 but the elements of *layer_top* will only be defined up to the number of layers found. The number of layers found is obtained from the ATL09 parameter *cloud_flag_atm*. Thus, if *cloud_flag_atm* is = 0, that would mean that there were no clouds found in this profile. The *layer_top* (1) up to *layer_top* (*cloud_flag_atm*) are examined to obtain the top heights of the various cloud layers. NOTE: the parameters *cloud_flag_atm* () and *layer_attr* (,n) do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required for these parameters. The parameter *layer_top* (,n) will contain INVALID values in the profile observations. Therefore, INVALID input profile observation exception is required for this parameter.

Assuming *cloud_flag_atm* is > 0, then for each value of x from 1 to *cloud_flag_atm*:

- if any *layer_top (x)* is <= 4 km AND *layer_attr* = 1, then increment the counter for Grid 1.
- if any *layer_top (x)* is > 4 km and <= 8 km AND *layer_attr* = 1, then increment the counter for Grid 2.
- if any *layer_top (x)* is > 8 km AND *layer_attr* = 1, then increment the counter for Grid 3.
- if *cloud_flag_atm* is > 0 AND *layer_attr* = 1 for any layer, then increment the counter for Grid 4.

Note that each of the four (4) counter grids for each polar region are to be incremented (at most) only once per 25 Hz profile. This means if there are two cloud layers, between 4 and 8 km for example, the counter for Grid 2 is incremented only once, not twice.

A separate observation counter grid is established, and the appropriate grid box is incremented for every 25 Hz profile regardless of the value of the value of *cloud_flag_atm*. Typically for the northern hemisphere or the southern hemisphere:

the pseudocode below represents the conditional logic for incrementing the "*low (Grid 1), middle (Grid 2), high (Grid 3), and total (Grid 4) cloud counter grids*", i.e., the numerator grids, for all 25 Hz (high-rate) profile observations ():

for 25 Hz profile *cloud_flag_atm* () > 0
    for x from 1 to *cloud_flag_atm*
        for *layer_top* (,x) <= 4 and *layer_attr* (,x) = 1
            Grid 1 (low cloud) counter grid (i,j) = Grid 1 (low cloud) counter grid (i,j) + 1
        for *layer_top* (,x) > 4 and *layer_top* (x) <= 8 and *layer_attr* (,x) = 1
            Grid 2 (middle cloud) counter grid (i,j) = Grid 1 (middle cloud) counter grid (i,j) + 1
        for *layer_top* (,x) > 8 and *layer_attr* (,x) = 1
            Grid 3 (high cloud) counter grid (i,j) = Grid 3 (high cloud) counter grid (i,j) + 1
    for *layer_attr* (,n) = 1
        Grid 4 (total cloud) counter grid (i,j) = Grid 4 (total cloud) counter grid (i,j) + 1
next profile observation

NOTE: a detected cloud layer counter grid is increment only for the first *layer_attr* (,n) = 1
the pseudocode below represents the logic for incrementing the "*total observation grid*", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():
for every 25 Hz profile   total observation grid (i,j) = total observation grid (i,j) + 1 next profile observation

All four grids are then divided by the total observation grid (where it is > 0) to obtain the various cloud fractions (four (4) cloud fractions for each hemisphere). For cases where the number of observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the specific polar cloud fraction to INVALID.

the pseudocode below represents the conditional logic for calculating the "*low (Grid 1), middle (Grid 2), high (Grid 3)m and total (Grid 4) polar cloud fraction grids*" by division of the "*low (Grid 1), middle (Grid 2), high (Grid 3)m and total (Grid 4) cloud counter grids*", i.e., the numerator grids, by the "*total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

```
for total observation grid (i,j)  => *_obs_minimum
                                                 Grid 1 (low cloud) counter grid (i,j)
    Grid 1 (low) polar cloud fraction grid (i,j)  =  --------------------------------------------------
                                                      total observation grid (i,j)

                                                     Grid 2 (middle cloud) counter grid (i,j)
    Grid 2 (middle) polar cloud fraction grid (i,j)  =  ----------------------------------------------------
                                                         total observation grid (i,j)

                                                  Grid 3 (high cloud) counter grid (i,j)
    Grid 3 (high) polar cloud fraction grid (i,j)  =  ---------------------------------------------------
                                                       total observation grid (i,j)

                                                   Grid 4 (total cloud) counter grid (i,j)
    Grid 4 (total) polar cloud fraction grid (i,j)  =  -------------------------------------------------
                                                        total observation grid (i,j)
else
    Grid 1 (low) polar cloud fraction grid (i,j)  =  INVALID
    Grid 2 (middle) polar cloud fraction grid (i,j)  =  INVALID
    Grid 3 (high) polar cloud fraction grid (i,j)  =  INVALID
    Grid 4 (total) polar cloud fraction grid (i,j)  =  INVALID
next grid cells
```

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

3.1.6.2 Transmissive and Opaque Cloud Fraction

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Transmissive Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	npolar_transcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Transmissive Cloud Fraction					
Image parameter:	npolar_transcloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_transcloud_frac_min* *npolar_transcloud_frac_max* *npolar_transcloud_frac_mean* *npolar_transcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_to_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Transmissive Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	spolar_transcloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Transmissive Cloud Fraction					
Image parameter:	spolar_transcloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_transcloud_frac_min* *spolar_transcloud_frac_max* *spolar_transcloud_frac_mean* *spolar_transcloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_to_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Opaque Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	npolar_opaquecloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Opaque Cloud Fraction					
Image parameter:	npolar_opaquecloud_frac_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_opaquecloud_frac_min* *npolar_opaquecloud_frac_max* *npolar_opaquecloud_frac_mean* *npolar_opaquecloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_to_cloud_frac_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Opaque Cloud Fraction	Lon	Lat	Lon	Lat	
Product variable:	spolar_opaquecloud_frac (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Opaque Cloud Fraction					
Image parameter:	spolar_opaquecloud_frac_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_opaquecloud_frac_min* *spolar_opaquecloud_frac_max* *spolar_opaquecloud_frac_mean* *spolar_opaquecloud_frac_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*cloud_flag_atm* () *layer_attr* (,) *surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_to_cloud_frac_mod.f90					

Four polar grids are established, two for each hemisphere ("npolar_transcloud_frac", "npolar_opaquecloud_frac", "spolar_transcloud_frac", and "spolar_opaquecloud_frac"). As in Section 3.1.6.1, the grids will cover the latitudes 60N to 90N and 60S to 90S. The ATL09 product contains the parameter "*cloud_flag_atm*" which is the number of cloud layers detected for a given 25 Hz profile. When this parameter is > 0, AND the ATL09 parameter "*surface_sig*" is > 0 AND "*layer_attr*" = 1 for any layer, then the current grid box for the transmissive cloud counter grid is incremented. When the parameter "*cloud_flag_atm*" is > 0 AND the parameter "*surface_sig*" is = 0 AND "*layer_attr*" = 1, then the current grid box for the opaque cloud counter grid is incremented. As before, for each observation (25 Hz profile) the current total observation grid box is incremented by one (1). NOTE: the input parameters *cloud_flag_atm* (), *layer_attr* (,n), and *surface_sig* () do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required. Typically for the northern hemisphere or the southern hemisphere:

the pseudocode below represents the conditional logic for incrementing the "*transmissive cloud counter grid*" *and* "*opaque cloud counter grid*", i.e., the numerator grids, for all 25 Hz (high-rate) profile observations ():

for 25 Hz profile *cloud_flag_atm* () > 0
    for *surface_sig* () > 0.0 and *layer_attr* (,n) = 1
        transmissive cloud counter grid (i,j) = transmissive cloud counter grid (i,j) + 1
    for *surface_sig* () = 0.0 and *layer_attr* (,n) = 1
        opaque cloud counter grid (i,j) = opaque cloud counter grid (i,j) + 1
next profile observation

NOTE: a detected cloud layer counter grid is increment only for the first *layer_attr* (,n) = 1
the pseudocode below represents the logic for incrementing the "*total observation grid*", i.e., the denominator grid, for all 25 Hz (high-rate) profile observations ():
for every 25 Hz profile   total observation grid (i,j) = total observation grid (i,j) + 1 next profile observation

When the period in question (weekly/monthly) has been analyzed, divide the transmissive and opaque cloud counter grids by the total observation grid (for all observation grid boxes > 0). For cases where the number of observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the specific polar cloud fraction to INVALID.

the pseudocode below represent the conditional logic for calculating the *"transmissive polar cloud fraction grid"* and "*opaque polar cloud fraction grid*" by respective division of the "*transmissive cloud counter grid*" and "*opaque cloud counter grid*", i.e., the numerator grids, by the "*total observation* grid", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

```
for total observation grid (i,j)  => *_obs_minimum
                                                   transmissive cloud counter grid (i,j)
    transmissive polar cloud fraction grid (i,j)  =  ------------------------------------------------
                                                        total observation grid (i,j)

                                              opaque cloud counter grid (i,j)
    opaque polar cloud fraction grid (i,j)  =  --------------------------------------------
                                                 total observation grid (i,j)
else
    transmissive polar cloud fraction grid (i,j)  =  INVALID
    opaque polar cloud fraction grid (i,j)  =  INVALID
next grid cell
```

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

3.2 Total Column Optical Depth

The Total Column Optical Depth section was reorganized to present both the existing global gridded total column optical depth over water parameter and the new expanded global gridded total column optical depth over water and over ocean parameter with the delivery of the ATBD Version 3.2, September 1, 2021. Now, with the ATBD Version 5 presentation, the section and sub-section content is markedly changed with significant changes to description and data content collection. The profile data collection is now revised from the accumulation of atmosphere column optical depth from apparent surface reflectance (ASR) from only over-water and over-ocean surface types to encompass valid ASR column optical depth from over all valid surface types.

Previously, the expanded parameter incorporated an algorithm for replacing over-water atmospheric column optical depth (OD) from apparent surface reflectance (ASR) INVALID profile data with a calculated estimated cloud optical depth value. The expanded *surf_type* (ocean,) over-ocean INVALID replacement values offered the opportunity to use the invalid values of *column_od_asr* (where ground return was not detected due to opaque clouds) to estimate the optical depth knowing that since the surface return was totally attenuated, the optical depth of the column must be greater than about 3 to 4. With the ATBD Version 3.2 and the "atlas_l3b_atm" PGE Version 1.3 (v1.3), the optical depth used to replace the INVALID values is computed by randomly selecting a value that ranges from 3 to the value of a new control parameter: *gen_cloud_od_max* (nominal value = 35 [default]). In the future this approach will be improved by using cloud optical depth histograms based on MODIS or other satellite-based estimates.

With ATBD Version 3.2, the retained global gridded total column optical depth over water parameter and the new expanded global gridded total column optical depth over water parameter were presented in the following sub-sections:

- Global (Over Water) Total Column Optical Depth and
- Expanded Global (Over Water) Total Column Optical Depth.

Now, with ATBD Version 5, the long-term global gridded total column optical depth over water parameter and the Version 3.2 expanded global gridded total column optical depth over water parameter are presented in the following sub-sections representative of profile observations and calculated replacement values accumulated over all valid surface types:

- Global Total Column Optical Depth and
- Expanded Global Total Column Optical Depth.

3.2.1 Global Total Column Optical Depth

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global Total Column Optical Depth	Lon	Lat	Lon	Lat	
Product variable:	global_column_od (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global Total Column Optical Depth (0-1.5)					
Image parameter:	global_column_od_img	Group: /				
Observation grid:	tcod_obs_grid (,)	Group: /				
Statistical variables:	*global_column_od_min* *global_column_od_max* *global_column_od_mean* *global_column_od_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*column_od_asr* () *column_od_asr_qf* () *beam_elevation* ()	ATL09 Group: /profile_x /high_rate				
Local variable:	*laser_angle* ()	=90.0- *beam_elevation* ()				
Control variable(s)	*laser_angle_limit* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_tot_col_od_mod.f90					

Previously, this legacy observation has been specified from the lineage of Atmosphere Gridded Products ATBD documents Version 1.2, February 27, 2019, through Version 3.2, September 1, 2021, as follows:

> The atmospheric parameter Total Column Optical Depth (Over Water) is displayed on a global grid. On the ATL09 product is a parameter called *column_od_asr* which is the total column optical depth estimated from the apparent surface reflectance. This parameter is computed over the entire globe, but for this product we only want to grid the data over water. Global grids are established as in Section 3.1 above. If the total column optical depth is not INVALID (i.e., it will be INVALID when there is no ground return detected), and if the return is over a water surface (i.e., if the ATL09 product parameter *column_od_asr_qf* is = 4, indicates over water), AND if *column_od_asr* is NOT EQ 0.0, then it (i.e., *column_od_asr*) is added to the total column optical depth grid box [i.e., the numerator grid] corresponding to the current location (i,j) indices (value computed as in Section 2.0 above), and the corresponding over water total observation counter grid box [i.e., the denominator grid] is incremented by one (1). NOTE: the parameters *column_od_asr* () will contain INVALID values and *column_od_asr_qf* () will contain INVALID values in the profile observations. Therefore, INVALID input profile observation exception is required.

The ATBD Version 5 delivery expands the accumulation of the valid total column optical depth estimated from the apparent surface reflectance to produce the averaged global total column optical depth gridded parameter from only over water surface types to now include surface returns for all valid surface types. The ATL09 product profile parameter *column_od_asr_qf* delivers the following range of surface types for the optical depth of the atmosphere based on the apparent and assumed surface reflectance:

column_od_asr_qf () quality flag	
Value	Meaning (Surface Type)
0	no surface signal
1	land
2	sea ice
3	land ice
4	water
INVALID_I1B	missing or invalid

The profile flag *column_od_asr_qf* () with a value of 0 (i.e., no surface return) correlates to the occurrence of the INVALID *column_od_asr* () profile observation. This knowledge is employed to accumulate and count the *column_od_asr* () profile observations for the valid surface type values (1-4). Here, INVALID *column_od_asr* () profile observations are rejected and valid *column_od_asr* () profile observations are accumulated and counted for the valid *column_od_asr_qf* () values of 1, 2, 3, or 4.

The revised atmospheric parameter Total Column Optical Depth remains displayed on a global grid. The key ATL09 product profile parameter remains to be the *column_od_asr* (i.e., the total column optical depth estimated from the apparent surface reflectance). This parameter is now computed over the entire globe for all valid surface types from the qualifying profile parameter *column_od_asr_qf* () (i.e., the surface type flag). The global grid remains as established in Section 3.1 above. If the total column optical depth is not INVALID (i.e., *column_od_asr* () ≠ INVALID; it will be INVALID when there is no ground return detected), and if the return is over any valid surface (i.e., if the ATL09 product parameter *column_od_asr_qf* is = 1, 2, 3, or 4, indicating over land, sea ice, land ice, or water), AND if *column_od_asr* is NOT EQ 0.0, then it (i.e., *column_od_asr*) is added to the total column optical depth grid box [i.e., the numerator grid] corresponding to the current location (i,j) indices (value computed as in Section 2.0 above), and the corresponding over-any-valid-surface-type total observation counter grid box [i.e., the denominator grid] is incremented by one (1). NOTE: again, the parameters *column_od_asr* () will contain INVALID values and *column_od_asr_qf* () can contain INVALID values in the profile observations. Therefore, INVALID input profile observation exception is required.

the pseudocode below represents the logic for selected summation of the valid all-surface-types accumulation global "*total column optical depth grid*", i.e., the numerator grid, and for selected increment of the "*total observation counter grid*", i.e., the denominator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations ():

for 25 Hz profile *column_od_asr* () ≠ INVALID and *column_od_asr* () ≠ 0.0 and
  column_od_asr_qf () ≠ INVALID and *column_od_asr_qf* () > 0
    total column optical depth grid (i,j) = total column optical depth grid (i,j) + *column_od_asr* ()
    total observation counter grid (i,j) = total observation counter grid (i,j) + 1
next profile observation

After all of the ATL09 granules have been read in, the accumulation total column optical depth grid is divided by the all-valid-surface-types total observation counter grid (where the all-valid-surface-types total observation counter grid is > 0) to establish the average global total column optical depth over all valid surface types ("global_column_od") for the period in question. For cases where the number of total all-valid-surface-types observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the average global total column optical depth grid cell to INVALID.

the pseudocode below represents the conditional logic for calculating the over-all-valid-surface-types "*average global total column optical depth grid*" by division of the "*total column optical depth grid*", i.e., the numerator grid, by the "*total observation counter grid*", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

for total observation counter grid (i,j) => **_obs_minimum*
  average global total column optical depth grid (i,j) = total column optical depth grid (i,j) / total observation counter grid (i,j)
else
  average global total column optical depth grid (i,j) = INVALID
next grid cell

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

As indicated in Section 1.0 and Table 2 above, the lower-resolution global grid size and dimensions are used for the ATL16 weekly product, and the higher-resolution global grid size and dimensions are used for the ATL17 monthly product.

NOTE that the 0 to 1.5 range constraint remains to be applied to the image and not to the parameter gridded array values. The title of the product written to the image for this parameter is now "Global Total Column Optical Depth (0-1.5)".

3.2.1.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth

Early in the Version 5 ATBD specification and algorithm information collection process, following Atmosphere Scientist examination of two months of column optical depth over land profile data, in addition to the decision to move to data collection over all surface types, the requirement was levied to proceed with minimal filtering to be applied to the *column_od_asr* (i.e., the column optical depth derived from the apparent surface reflectance) profile data integral to the Global Total Column Optical

Depth and the Expanded Global Total Column Optical Depth gridded parameters beyond the exclusion of INVALID *column_od_asr* profile observations.

This requirement is to apply filtering to the ATL09 [high-rate] profile parameter column optical depth from ASR (*column_od_asr*) limiting the acceptable values to the following range:

0.0 < *column_od_asr* () < 4.0

The filtering is be applied to over-land and over-water data, in fact, now over all surface types with the changes to the Global Total Column Optical Depth and the Expanded Global Total Column Optical Depth gridded parameters. The application of the *column_od_asr* limiting range provides a serendipitous repair to the code omission discussed in the following sub-section heading "Deviation from Specification: Failure to Omit Zero Values of ASR Column OD".

The following represents the amended pseudocode to implement the range filtering requirement:

the modified pseudocode below represents the logic for selected summation of the valid all-surface-types accumulation global "*total column optical depth grid*", i.e., the numerator grid, and for selected increment of the "*total observation counter grid*", i.e., the denominator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations () with the limited range of profile values filtering included:

for 25 Hz profile *column_od_asr* () ≠ INVALID and *column_od_asr* () > 0.0 and
  column_od_asr () < 4.0 and *column_od_asr_qf* () ≠ INVALID and *column_od_asr_qf* () > 0
      total column optical depth grid (i,j) = total column optical depth grid (i,j) + *column_od_asr* ()
      total observation counter grid (i,j) = total observation counter grid (i,j) + 1
next profile observation

The computation of the average global total column optical depth grid (i,j) remains as described in the pseudocode block above in Section 3.2.1 Global Total Column Optical Depth.

3.2.1.2 Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth

The ATBD Version 3.2 (DRAFT), March 3, 2021, augmented the description for the processing of the profile optical depth from ASR (*column_od_asr*) for the 25 Hz data to eliminate the inclusion of zero values (0.0) from the accepted observation summation and counting. In the March 15, 2022, email regarding the filtering of *column_od_asr* profile data, with the move to now include all valid surface types, the increased occurrence of zero (0.0) *column_od_asr* values in the profile data over the land surface types, the importance of removing these zero values was reinforced.

The global total column optical depth Excel workbook for testing the algorithm and the derived pseudocode text already included the elimination of *column_od_asr* () = 0.0 values with the inclusion of the if-then structure to filter the zero values by accepting only profile values greater than zero (i.e., *column_od_asr* () > 0.0).

Unfortunately, the if-then statement excluding the zero *column_od_asr* was omitted from the module: "glob_tot_col_od_mod.f90" source code. Consequently, zero values of *column_od_asr* were included in the observation summations in the numerator grid cells, total column optical depth grid (i,j), and were counted in the denominator grid cells, total observation counter grid (i,j). The inclusion of the zero *column_od_asr* values had the effect of "watering down" or diluting the magnitude of the computed parameter grid cells in the average global total column optical depth grid (i,j) gridded data.

For the record, it is noted that this code omission allowed the occurrences of the zero *column_od_asr* profile values to affect the gridded parameter in all of the previous ATL16 and ATL17 product deliveries archived and available from NSIDC. These included the following:

NSIDC ATL16/ATL17 Version	Initial Date of Appearance
Release 002 (V02)	June 4, 2020
Release 003 (V03)	April 29, 2021
Release 004 (V04)	February 21, 2022

NOTE: Releases are also referred to as Versions.

Because of the inherency of the algorithm and the ATBD text for processing profile *column_od_asr* into the gridded parameter global_column_od using the *column_od_asr_qf* flag in the collection and computation of the global total column optical depth, the same issue occurs in the expanded total column optical depth parameter addressed in Section 3.2.2 Expanded Global Total Column Optical Depth, with the module sharing a common code basis.

The final note for the legacy code failure to exclude the zero-value *column_od_asr* profile observations from accumulation and counting in the gridded parameter global_column_od production in the previous ATL16 and ATL17 product releases, is that, with the deployment of the range-value editing of the *column_od_asr* data in Section 3.2.1.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth above, the zero-value *column_od_asr* profile observations are now excluded from the Version 2.0 (v2.0) ATL16 and ATL17 products Global Total Column Optical Depth gridded parameter that will appear in the NSIDC Release 005 (V05) when posted to the DAAC archive.

3.2.1.3 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Global Total Column Optical Depth

Additional filtering is to be applied to the profile *column_od_asr* data beyond the range value constraint to observation data collection, summation, and counting in both the Global Total Column Optical Depth and Expanded Global Total Column Optical Depth gridded parameters now collected over all surface types. Initial presentation identified this filtering as laser angle and filtering is most important over the water surface, i.e., laser shots should be filtered where the laser angle is greater than about 2 degrees. This has been an oversight previously, but now for consistency this laser angle filtering is to be applied to column optical depth from ASR over all surface types.

The term laser angle may be qualified as being the laser beam off-nadir pointing angle, i.e., with nadir referring to laser pointing perpendicularly incident to the target surface and off-nadir as the angle the laser beam deviates from the perpendicular (zero angle) or zenith angle (zenith being the point at which the signal return is considered the most powerful). The more the laser pointing is off-nadir the more the return signal power is reduced, diminishing the return photon count.

The ATLAS multi-beam laser altimeter pointing angle data from the precision pointing data for the three (3) strong beams obtained from the ATL03 Geolocated Photon Data is delivered in the ATL09 product 25 Hz (high-rate) profile parameters *beam_azimuth* and *beam_elevation*. The profile-rate *beam_elevation* angle in degrees is used to calculate a local profile-rate local laser beam off-nadir angle identified as *laser_angle*. The laser beam off-nadir angle in degrees is calculated from the profile beam elevation with the following formulation:

laser_angle () = 90.0 - *beam_elevation* ()

A control constant value called the laser beam off-nadir angle limiting factor and named *laser_angle_limit* is implemented as the filtering constraint value such that only valid profile data associated with laser off-nadir angle values less than the laser angle limit are allowed to be collected, accumulated, and counted. This filtering is applied as illustrated in the following simplified logic:

```
if (laser_angle () < laser_angle_limit) then
    accept valid profile observation for summation and counting process
    transfer to summation and counting process
else
    reject valid profile observation for summation and counting process
    transfer to process next 25 Hz profile observation
end if
```

Initially the control constant *laser_angle_limit* was implemented and tested at the values of 2.0 degrees and changed to 3.0 degrees. With the final implementation of the "atlas_l3b_atm" PGE v2.0 the control constant is delivered with the default value of 6.0 degrees (i.e., *laser_angle_limit* = 6.0). A control parameter override "asas.l3b_atm.laser_angle_limit" is implemented to enable runtime constant value override entry from the PGE processing control file.

It is noted that requirement has been levied to not only apply the laser beam off-nadir angle filtering to the atmosphere column optical depth from ASR (i.e., *column_od_asr*) for the Global Total Column Optical Depth gridded data but for the same *column_od_asr* profile data filtering in the Expanded Global Total Column Optical Depth gridded parameter as well. Continuing with apparent surface reflectance (ASR) derived 25 Hz profile data, the requirement extends to apply this laser beam off-nadir angle filtering to the high-rate profile apparent surface reflectance profile data from the ATL09 product as the *apparent_surf_reflec* parameter collected, accumulated, and counted in the existing ATL16/ATL17 atmosphere gridded parameters in the Global Apparent Surface Reflectance, North Polar Apparent Surface Reflectance, and South Polar Apparent Surface Reflectance.

3.2.1.4 Deviation from Specification: Failure to Exempt Invalid Values of the ASR Column Optical Depth Quality Flag from Global Total Column Optical Depth

In preparation for finalization and delivery of this V05 ATBD, an audit was performed of the individual gridded parameter specifications intrinsic to the document in comparison to the coded logic deployed in the Fortran source statements in the representative "atlas_l3b_atm" PGE v2.0 modules. Similar to the code omission detailed in Section 3.2.1.2 Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth above, inspection of the pseudocode in Sections 3.2.1 Global Total Column Optical Depth and 3.2.1.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth, both sections presented above, the absence of the filtering code to identify and capture INVALID values of the 25 Hz atmosphere column optical depth from ASR quality flag (i.e., to implement a test for *column_od_asr_qf* () ≠ INVALID).

Although examination of multiple ATL09 product files sampled from the ASAS functional tests func_test_960a6_02 and func_test_960b1 did not reveal the presence of INVALID *column_od_asr_qf* in the 25 Hz profile data. The ATL09 product template HDF5 file and the derived data dictionary file contain the definition for the integer total column optical depth ASR quality flag indicating the accommodation of the constant INVALID_I1B as the FillValue for the profile parameter *column_od_asr_qf*. The test logic in the Excel workbook used to assess the global total column optical depth included the programming to detect and capture the INVALID *column_od_asr_qf* and this function was included in the pseudocode model earlier. Even if the INVALID *column_od_asr_qf* profile value would never occur, the code implementation should at least include accommodation for the INVALID value possibility specified in the ATL09 data dictionary content.

Unfortunately, the omission of the INVALID *column_od_asr_qf* profile observation detection and exemption was not discovered until after the "atlas_l3b_atm" PGE v2.0 source code had already been delivered to SIPS SDMS Team, submitted for the TRR review, and passed on for production testing. Consequently, an issue will be added to the JIRA Task "Develop atlas_l3b_atm v2.1".

3.2.1.5 Summary of ASR Column Optical Depth Filtering Applied for the Computation of Global Total Column Optical Depth

Throughout the "atlas_l3b_atm" PGE v2.0 code development and testing process appertaining to these V05 ATBD specifications it was necessary to clarify the ordering of the logical testing to constrain or filter the profile observations in the collection of the data comprising the gridded data. Documentation providing a summary of the logic order and flow were electronically transmitted for review and approval of the code implementation in a simplified format. A similar composition is included for summarization of the sequence of constraining and filtering testing applied to the *column_od_asr* profile observations for the summation and counting of these data for computation of Global Total Column Optical Depth gridded parameter arrays.

```
! summary of constraining / filtering / testing logic applied in "glob_tot_col_od_mod.f90" code
! performed for all 25 Hz "column_od_asr" observations in the current profile_X (i.e.,
! profile_1, profile_2, profile_3)

for each profile

!   eliminate any INVALID column_od_asr () values
    if (column_od_asr () = INVALID) then
      do next profile
    end if

!   eliminate any zero (0) or INVALID surface quality flag column_od_asr_qf () values
    if (column_od_asr_qf () =0 .or.  column_od_asr_qf () = INVALID) then
      do next profile
    end of

!   eliminate any INVALID index values (i,j) computed for locating profile longitude, lon (),
!   and latitude, lat (), in the gridded parameter numerator summation array and denominator
!   counting array cell locations

    if (i = INVALID .or. j = INVALID) then
      do next profile
    end if

!   eliminate daytime data if processing night-only profile data is selected
    if (night_only = 1) then
!     test sun angle for daylight (daytime) in nighttime only processing and eliminate
      if (solar_elevation () => 0.0) then
        do next profile
      end if
    end if

!   eliminate any "bad" calculated laser_angle values from any possible INVALID beam_elevation
!   profile observations (called the "trap")
    if (laser_angle () < 0.0) then
      do next profile
    end if

!   skip processing for profiles exceeding the laser off-nadir angle limit (laser_angle_limit)
    if (laser_angle () => laser_angle_limit) then
      do next profile
    end if

!   apply range of values filtering to column_od_asr observation
!   note: this test also performs the elimination of zero column_od_asr values
    if (column_od_asr () <= 0.0 .or. column_od_asr () => 4.0) then
      do next profile
    end if
```

```
!   column_od_asr profile observation has passed all constraining / filtering tests
!   accumulate the column_od_asr profile observation in summation numerator grid
    total column optical depth grid (i,j) = total column optical depth grid (i,j)        &
                                              + column_od_asr ()
!   count the column_od_asr profile observation in the accepted profile count denominator array
    total observation counter grid (i,j) = total observation counter grid (i,j) + 1

next profile

! all 25 Hz profiles in profile_x have been processed
```

3.2.2 Expanded Global Total Column Optical Depth

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Expanded Global Total Column Optical Depth	Lon	Lat	Lon	Lat	
Product variable:	expanded_global_column_od (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Expanded Global Total Column Optical Depth (0-25)					
Image parameter:	expanded_global_column_od_img	Group: /				
Observation grid:	exp_tcod_obs_grid (,)	Group: /				
Statistical variables:	*expanded_global_column_od_min* *expanded_global_column_od_max* *expanded_global_column_od_mean* *expanded_global_column_od_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*column_od_asr* () *column_od_asr_qf* () *surf_type* (,) *beam_elevation* ()	ATL09 Group: /profile_x /high_rate				
Local variable:	*laser_angle* ()	=90.0- *beam_elevation* ()				
Control variable(s)	*laser_angle_limit* *gen_cloud_od_max* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	exp_glob_tot_col_od_mod.f90					

Introduced in Version 3.2 of the ATBD, and implemented in the "atlas_l3b_atm" PGE v1.3 code, was the *new* atmospheric parameter Expanded Global (Over Water) Total Column Optical Depth. The collection of profile *column_od_asr* data was previously constrained to valid observations over water-surface-only (from the *column_od_asr_qf* quality flag) or over-ocean-surface-only (from the *surf_type* (ocean,) surface type) profile parameters. The specifications from ATBD v3.2 are retained below for previous parameter historic record keeping:

> The *new* atmospheric parameter Expanded Total Column Optical Depth (Over Water) is displayed on a global grid. The basis of the parameter remains the same algorithm as the existing-TCOD over water with additions to replace INVALID over water profile data. On the ATL09 product is a parameter called *column_od_asr* which is the total column optical depth estimated from the apparent surface reflectance. This parameter is computed over the entire globe, but for this product we only want to grid the data over water. Global grids are established as in Section 3.1 above. If the total column optical depth is not INVALID (i.e., it will be INVALID when there is no ground return detected), and if the return is over a water surface (i.e., if the ATL09 product parameter *column_od_asr_qf* is = 4, indicates over water), AND if

column_od_asr is NOT EQ 0.0, then it (i.e., *column_od_asr*) is added to the expanded total column optical depth grid box [i.e., the numerator grid] corresponding to the current location (i,j) indices (value computed as in Section 2.0 above), and the corresponding expanded over water total observation counter grid box [i.e., the denominator grid] is incremented by one (1). In addition, do the following: If *column_od_asr* is INVALID (i.e. it will be INVALID when there was no ground return detected), AND if the return is over a water surface (i.e., if the ATL09 product parameter surface type *surf_type* (ocean,) = 1, where ocean is the array ocean index, a value of 1 indicates over water), then we randomly chose an optical depth value ranging from 3 to the value of a new control parameter: *gen_cloud_od_max* (nominal value = 35 [default]). This is done by generating a normally distributed random number from 0 to 1 and multiplying it by (*gen_cloud_od_max* - 3) and adding 3. That result is then added to the expanded total column optical depth grid box [i.e., the numerator grid] corresponding to the current location (i,j) indices (value computed as in Section 2.0 above), and the corresponding expanded over water total observation counter grid box [i.e., the denominator grid] is incremented by one (1). NOTE: the parameters *column_od_asr* () will contain INVALID values and *column_od_asr_qf* () will contain INVALID values in the profile observations. The parameter *surf_type* (,) does not contain INVALID values. Therefore, INVALID input profile observation exception is required for the ASR column optical depth and quality flag. Here the INVALID ASR column optical depth profile observation handling is the invocation of the code to replace INVALID over water column optical depth observations with an estimated replacement value. NOTE also that the scaling of the resulting plot will need to be much larger than the global average total column optical depth over water. A guess is that the scaling maximum would be roughly *gen_cloud_od_max* / 4. The value of *gen_cloud_od_max* should be written on the plot.

The ATBD V05 and “atlas_l3b_atm” PGE v2.0 code delivered as part of the ASAS Delivery v6.0 (Release 006) now expand the collection of valid profile *column_od_asr* data over all valid surface types. The existing contribution to the numerator grid summation for the expanded total column optical depth over water is modeled in the following pseudocode. The gridded parameter is now identified as the Expanded Global Total Column Optical Depth, with the previous modifier “(Over Water)” removed. At the module core, the logical data collection of the valid profile *column_od_asr* data continues in the same functionality as with the Global Total Column Optical Depth parameter. And consistently, now collected over all valid surface types.

The ATBD Version 5 delivery expands the accumulation of the valid total column optical depth estimated from the apparent surface reflectance to produce the averaged global total column optical depth gridded parameter from only over water surface types to now include surface returns for all valid surface types. The ATL09 product profile parameter *column_od_asr_qf* delivers the following range of surface types for the optical depth of the atmosphere based on the apparent and assumed surface reflectance:

column_od_asr_qf () quality flag	
Value	Meaning (Surface Type)
0	no surface signal
1	land
2	sea ice
3	land ice
4	water
INVALID_I1B	missing or invalid

The profile flag *column_od_asr_qf* () with a value of 0 (i.e., no surface return) correlates to the occurrence of the INVALID *column_od_asr* () profile observation. This knowledge is employed to accumulate and count the *column_od_asr* () profile observations for the valid surface type values (1-4). The valid *column_od_asr* () profile observations are accumulated and counted for the valid *column_od_asr_qf* () values of 1, 2, 3, or 4, and after summation and counting, the processing moves to process the next available 25 Hz profile data record.

The module also continues to provide the "expanded" functionality that is employed when the INVALID *column_od_asr* profile data value is encountered. The placeholder for future ancillary data supplement continues with the random, normally distributed, estimated cloud optical depth replacement value computation. Previously calculated when the surface type profile parameter indicated the over-ocean surface type, the selection is now expanded to include all valid surface types.

The expanded module code differentiates from the global total column optical depth processing where INVALID *column_od_asr* () profile observations are rejected. Here, encountering the INVALID *column_od_asr* () profile observation pushes processing into the cloud column optical depth synthesis expansion. Valid surface type determination is expanded from the previous ocean surface type to all valid surface type indicators from the ATL09 25 Hz *surf_type* (,) surface type array profile parameter definitions:

surf_type (index,) surface type flag					
flag	index	index	not_type	type	meaning
surf_type (1,)	1	land	0	1	*surf_type* (land,) = 1, land
surf_type (2,)	2	ocean	0	1	*surf_type* (ocean,) = 1, ocean
surf_type (3,)	3	sea_ice	0	1	*surf_type* (sea_ice,) = 1, sea ice
surf_type (4,)	4	land_ice	0	1	*surf_type* (land_ice,) = 1, land ice
surf_type (5,)	5	inland_water	0	1	*surf_type* (inland_water,) = 1, inland water

It is noted that the *surf_type* (index,) surface type array profile parameter may occur in any combination with all five index locations set to "not_type" (i.e., 0) and all five index locations set to "type" (i.e., 1), and all possible combinations in between. In order to meet the definition of the profile observation "occurring over a valid surface" at least one surface type index location must be set to the "type" value (i.e., at least one *surf_type* (index,) =1).

The module expanded code addition for the computation of the random, normally distributed, estimated cloud optical depth replacement value for the INVALID *column_od_asr* profile observation is presented in the following description:

1) Importantly, the random number generator is "seeded" with a numerical value taken from the first ATL09 product and the first profile_x / profile_1 processed. The selection of data record-based values ensures that the seed is data-dependent rather than machine-dependent or operating system dependent. In fact, for the "atlas_l3b_atm" PGE implementation, an integer array of 512 locations (in_seed) is loaded with a scaled set of the first 512 valid *column_od_asr* profile observations from the first profile read from the first ATL09 product in the control file:

```
for:  iout_cnt  from  1 to 512
     if:  column_od_asr () = INVALID  then:
          next profile
     else:
          in_seed (iout_cnt) = int  ((column_od_asr () / 3.0) * 10000.0)
     end if
next iout_cnt
```

   This random number seed processing is performed *only one time* during the program manager initialization activity. Again, only for the first profile (profile_1) from the first ATL09 in the control file processing list.

2) The calculation formula for the local synthesized replacement cloud reflectance estimated value uses the control constant parameter *gen_cloud_od_max* currently value with a nominal value of 35 (i.e., *gen_cloud_od_max* = 35). The computation is modeled as follows:

```
for:  each 25 Hz profile
     if:   column_od_asr () = INVALID  then:
          R  =  random_number ()                    !  normal, Gaussian 0.0 to 1.0 distribution
          est_cloud_reflect_loc  =  R * real (gen_cloud_od_max  -  3)  +  3
          perform expanded  est_cloud_reflect_loc  estimated value summation and counting
     else:
          perform normal  column_od_asr ()  profile summation and counting
     end if
next profile
```

The modified model code for all-valid-surface-type processing follows:

the pseudocode below represents the logic for selected summation of valid all-surface-types accumulation global "*expanded total column optical depth grid*", i.e., the numerator grid, and for selected increment of the "*expanded total observation counter grid*", i.e., the denominator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations ():
for 25 Hz profile *column_od_asr* () ≠ INVALID and *column_od_asr* () > 0.0 and *column_od_asr_qf* () ≠ INVALID and *column_od_asr_qf* () > 0 expanded total column optical depth grid (i,j) = expanded total column optical depth grid (i,j) + *column_od_asr* () expanded total observation counter grid (i,j) = expanded total observation counter grid (i,j) + 1 next profile observation

The expanded algorithm contribution to the numerator grid summation for the expanded total column optical depth over all valid surface types is modeled in the following pseudocode. This also includes initialization to support the estimated replacement value computation for INVALID *column_od_asr* ().

the pseudocode below represents the logic for initiation of parameters to support the estimates of the replacement values for INVALID 25 Hz (high-rate) profile column optical depth from ASR observations ():
rand_seed (randseed); perform random seed for Gaussian (normal) random number generator *od_max_multiplier* = *gen_cloud_od_max* - 3; compute constant multiplier
the pseudocode below represents the logic for estimates of replacement observations for INVALID *column_od_asr* () for over all-surface-type profile values to "expand" the summation of the "*expanded total column optical depth grid*", i.e., the numerator grid, and for selected increment of the "*expanded total observation counter grid*", i.e., the denominator grid, based on both the filtered and accepted 25 Hz (high-rate) profile observations () and the estimated replacement values for the INVALID over-all-surface-types column optical density from ASR observations:
for 25 Hz profile *column_od_asr* () = INVALID and (*surf_type* (land,) = 1 or *surf_type* (ocean,) = 1 or *surf_type* (sea_ice,) = 1 or *surf_type* (land_ice,) = 1 or *surf_type* (inland_water,) = 1) *est_cloud_reflect_loc* = random_number (r) [0,1] * *od_max_multiplier* + 3 expanded total column optical depth grid (i,j) = expanded total column optical depth grid (i,j) + *est_cloud_reflect_loc* expanded total observation counter grid (i,j) = expanded total observation counter grid (i,j) + 1 next profile observation

After all of the ATL09 granules have been read in, the expanded total column optical depth grid is divided by the expanded total observation counter grid (where the expanded total observation counter grid is > 0) to establish the expanded global average total column optical depth over all surface types ("expanded_global_column_od") for the period in question. For cases where the number of expanded total observation counter (over all surface types) for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the expanded global average total column optical depth to INVALID.

the pseudocode below represents the conditional logic for calculating the "*expanded global average total column optical depth grid*" by division of the "*expanded total column optical depth grid*", i.e., the numerator grid, by the "*expanded total observation counter grid*", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

```
for expanded total water observation grid (i,j)  => *_obs_minimum
   expanded global average total column optical depth grid (i,j)  =
                                                        expanded total column optical depth grid (i,j)
                                                       ------------------------------------------------------------
                                                        expanded total observation counter grid (i,j)
else
   expanded global average total column optical depth grid (i,j)  =  INVALID
next grid cell
```

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

As indicated in Section 1.0 and Table 2 above, the low-resolution global grid size and dimension is used for the weekly product and the high-resolution global grid size and dimension is used for the monthly product.

NOTE that the 0 to 25 expanded range constraint based on the *gen_cloud_od_max* control parameter is applied to the image and not to the expanded parameter gridded array values. Note also that the title of the image written to the product for this parameter is to be "Expanded Global Total Column Optical Depth (0-25)". This removes the previous "(Over Water)" modifier from the identification as the averaged, expanded gridded parameter is now computed over all-surface-types. *[NOTE also that the range maximum upper constraint is subject to change.]*

3.2.2.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth

There is the common core in the algorithm and the implemented code primarily operating on the *column_od_asr* (i.e., the column optical depth derived from the apparent surface reflectance), present the Expanded Global Total Column Optical Depth gridded parameter and the predecessor Global Total Column Optical Depth gridded parameter. Consequently, the range of values filtering applied to the Global Total in Section 3.2.1.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth is also applicable to the Expanded Global Total Column Optical Depth gridded parameter as well. As presented in that section:

> Early in the Version 5 ATBD specification and algorithm information collection process, following Atmosphere Scientist examination of two months of column optical depth over land profile data, in addition to the decision to move to data collection over all surface types, the requirement was levied to proceed with minimal filtering to be applied to the *column_od_asr* (i.e., the column optical depth derived from the apparent surface reflectance) profile data integral to the Global Total Column Optical Depth and the Expanded Global Total Column Optical Depth gridded parameters beyond the exclusion of INVALID *column_od_asr* profile observations.

> This requirement is to apply filtering to the ATL09 [high-rate] profile parameter column optical depth from ASR (*column_od_asr*) limiting the acceptable values to the following range:
>
> 0.0 < *column_od_asr* () < 4.0
>
> The filtering is be applied to over-land and over-water data, in fact, now over all surface types with the changes to the Global Total Column Optical Depth and the Expanded Global Total Column Optical Depth gridded parameters. The application of the *column_od_asr* limiting range provides a serendipitous repair to the code omission discussed in the following sub-section heading "Deviation from Specification: Failure to Omit Zero Values of ASR Column OD".

The following represents the amended pseudocode to implement the range filtering requirement:

the modified pseudocode below represents the logic for selected summation of the valid all-surface-types accumulation global "expanded *total column optical depth grid*", i.e., the numerator grid, and for selected increment of the "expanded *total observation counter grid*", i.e., the denominator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations () with the limited range of profile values filtering included:
for 25 Hz profile *column_od_asr* () ≠ INVALID and *column_od_asr* () > 0.0 and *column_od_asr* () < 4.0 and *column_od_asr_qf* () ≠ INVALID and *column_od_asr_qf* () > 0 expanded total column optical depth grid (i,j) = expanded total column optical depth grid (i,j) + *column_od_asr* () expanded total observation counter grid (i,j) = expanded total observation counter grid (i,j) + 1 next profile observation

The computation of the average expanded global total column optical depth grid (i,j) remains as described in the pseudocode block above in Section 3.2.2 Expanded Global Total Column Optical Depth.

3.2.2.2 Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth

Again, the common core in the algorithm and the implemented code primarily operating on the *column_od_asr* (i.e., the column optical depth derived from the apparent surface reflectance), present the Expanded Global Total Column Optical Depth gridded parameter and the predecessor Global Total Column Optical Depth gridded parameter causes an issue of the inheritance of a code omission. The failure to exclude zero (0.0) values occurring in *column_od_asr* profile observations in the Global Total Column Optical Depth gridded parameter was propagated into the Expanded Global Total Column Optical Depth gridded parameter. This deviation from specification for observation filtering was mentioned earlier in the Global Total Section 3.2.2.1 Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth. As presented in that section the description is applicable to the Expanded Global Total Column Optical Depth gridded parameter as well:

> The ATBD Version 3.2 (DRAFT), March 3, 2021, augmented the description for the processing of the profile optical depth from ASR (*column_od_asr*) for the 25 Hz data to eliminate the inclusion of zero values (0.0) from the accepted observation summation and counting. In the March 15, 2022, email regarding the filtering of *column_od_asr* profile data, with the move to now include all valid surface types, the increased occurrence of zero (0.0) *column_od_asr* values in the

profile data over the land surface types, the importance of removing these zero values was reinforced.

The global total column optical depth Excel workbook for testing the algorithm and the derived pseudocode text already included the elimination of *column_od_asr* () = 0.0 values with the inclusion of the if-then structure to filter the zero values by accepting only profile values greater than zero (i.e., *column_od_asr* () > 0.0).

Unfortunately, the if-then statement excluding the zero *column_od_asr* was omitted from the module: "glob_tot_col_od_mod.f90" source code. Consequently, zero values of *column_od_asr* were included in the observation summations in the numerator grid cells, total column optical depth grid (i,j), and were counted in the denominator grid cells, total observation counter grid (i,j). The inclusion of the zero *column_od_asr* values had the effect of "watering down" or diluting the magnitude of the computed parameter grid cells in the average global total column optical depth grid (i,j) gridded data.

Because of the inherency of the algorithm and the ATBD text for processing profile *column_od_asr* into the gridded parameter global_column_od using the *column_od_asr_qf* flag in the collection and computation of the global total column optical depth, the same issue occurs in the expanded total column optical depth parameter expanded_global_column_od addressed in Section 3.2.2 Expanded Global Total Column Optical Depth above, with the module sharing a common code basis.

The logic applied to the Excel workbook and worksheet testing for the global total column optical depth parameter was "duplicated" in the later Excel workbook developed for expanded global total column optical depth code testing. Again, the worksheet logic that identified and excluded the zero values of column optical depth from ASR profile values in the extracted ATL09 test data, was not included in the coded "exp_glob_tot_col_od_mod.f90" module that began as a renamed duplicate of the existing "glob_tot_col_od_mod.f90" module.

For the record, it is noted as *providential* that this code omission allowed the occurrences of the zero *column_od_asr* profile values to affect the gridded parameter in <u>only</u> the <u>last</u> ATL16 and ATL17 product deliveries archived and available from NSIDC. The affected ATL16 and ATL17 product posting is identified as:

NSIDC ATL16/ATL17 Version	Initial Date of Appearance
Release 004 (V04)	February 21, 2022

NOTE: Releases are also referred to as Versions.

The final note for the legacy code failure to exclude the zero-value *column_od_asr* profile observations from accumulation and counting in the gridded parameter expanded_global_column_od production in the <u>last</u> ATL16 and ATL17 product releases, is that, with the deployment of the range-value editing of the *column_od_asr* data in Section 3.2.2.1 Application of Profile Observation Value Filtering for ASR Column Optical Depth above, the zero-value *column_od_asr* profile observations are now excluded from the Version 2.0 (v2.0) ATL16 and ATL17 products Expanded Global Total Column Optical Depth gridded parameter that will appear in the NSIDC Release 005 (V05) when posted to the DAAC archive.

3.2.2.3 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Expanded Global Total Column Optical Depth

The concept of the final level of profile data filtering, that of rejecting the collection of the primary profile observations for computation when the ATLAS laser beam off-nadir angles exceed a limiting angle control constant value, has already been introduced in Section 3.2.1.3 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Global Total Column Optical Depth. The specified deployment of this off-nadir angle filtering has been identified for five (5) of the atmosphere gridded parameters from the v3.2 ATBD and the "atlas_l3b_atm" PGE v1.3 code is incorporated in this V05 ATBD edition and the corresponding "atlas_l3b_atm" PGE v2.0 code– with the Expanded Global Total Column Optical Depth gridded parameter being the second target for this modification. As addressed in Section 3.2.1.3:

> Additional filtering is to be applied to the profile *column_od_asr* data beyond the range value constraint to observation data collection, summation, and counting in both the Global Total Column Optical Depth and Expanded Global Total Column Optical Depth gridded parameters now collected over all surface types. Initial presentation identified this filtering as laser angle and filtering is most important over the water surface, i.e., laser shots should be filtered where the laser angle is greater than about 2 degrees. This has been an oversight previously, but now for consistency this laser angle filtering is to be applied to column optical depth from ASR over all surface types.
>
> The term laser angle may be qualified as being the laser beam off-nadir pointing angle, i.e., with nadir referring to laser pointing perpendicularly incident to the target surface and off-nadir as the angle the laser beam deviates from the perpendicular (zero angle) or zenith angle (zenith being the point at which the signal return is considered the most powerful). The more the laser pointing is off-nadir the more the return signal power is reduced, diminishing the return photon count.
>
> The ATLAS multi-beam laser altimeter pointing angle data from the precision pointing data for the three (3) strong beams obtained from the ATL03 Geolocated Photon Data is delivered in the ATL09 product 25 Hz (high-rate) profile parameters *beam_azimuth* and *beam_elevation*. The profile-rate *beam_elevation* angle in degrees is used to calculate a local profile-rate local laser beam off-nadir angle identified as *laser_angle*. The laser beam off-nadir angle in degrees is calculated from the profile beam elevation with the following formulation:
>
> *laser_angle* () = 90.0 - *beam_elevation* ()
>
> A control constant value called the laser beam off-nadir angle limiting factor and named *laser_angle_limit* is implemented as the filtering constraint value such that only valid profile data associated with laser off-nadir angle values less than the laser angle limit are allowed to be

collected, accumulated, and counted. This filtering is applied as illustrated in the following simplified logic:

```
if (laser_angle () < laser_angle_limit) then
    accept valid profile observation for summation and counting process
    transfer to summation and counting process
else
    reject valid profile observation for summation and counting process
    transfer to process next 25 Hz profile observation
end if
```

Initially the control constant *laser_angle_limit* was implemented and tested at the values of 2.0 degrees and changed to 3.0 degrees. With the final implementation of the "atlas_l3b_atm" PGE v2.0 the control constant is delivered with the default value of 6.0 degrees (i.e., *laser_angle_limit* = 6.0). A control parameter override "asas.l3b_atm.laser_angle_limit" is implemented to enable runtime constant value override entry from the PGE processing control file.

It is noted that requirement has been levied to not only apply the laser beam off-nadir angle filtering to the atmosphere column optical depth from ASR (i.e., *column_od_asr*) for the Global Total Column Optical Depth gridded data but for the same *column_od_asr* profile data filtering in the Expanded Global Total Column Optical Depth gridded parameter as well. Continuing with apparent surface reflectance (ASR) derived 25 Hz profile data, the requirement extends to apply this laser beam off-nadir angle filtering to the high-rate profile apparent surface reflectance profile data from the ATL09 product as the *apparent_surf_reflec* parameter collected, accumulated, and counted in the existing ATL16/ATL17 atmosphere gridded parameters in the Global Apparent Surface Reflectance, North Polar Apparent Surface Reflectance, and South Polar Apparent Surface Reflectance.

3.2.2.4 Deviation from Specification: Failure to Exempt Invalid Values of the ASR Column Optical Depth Quality Flag from Expanded Global Total Column Optical Depth

The downside and negative aspect of specification and testing in code reuse arises in the implemented code omission in the Global Total Column Optical Depth gridded parameter module propagated into the duplicated and renamed as the Expanded Global Total Column Optical Depth gridded parameter.

In preparation for finalization and delivery of this V05 ATBD, an audit was performed of the individual gridded parameter specifications intrinsic to the document in comparison to the coded logic deployed in the Fortran source statements the representative "atlas_l3b_atm" PGE v2.0 modules. Similar to the code omission detailed in Section 3.2.1.2 Deviation from Specification: Failure to Omit Zero Values of ASR Column Optical Depth above, inspection of the pseudocode in Sections 3.2.1 Global Total Column Optical Depth and 3.2.1.1 Application of Profile Observation Value Filtering for ASR Column Optical

Depth, both sections presented above, the absence of the filtering code to identify and capture INVALID values of the 25 Hz atmosphere column optical depth from ASR quality flag (i.e., to implement a test for *column_od_asr_qf* () ≠ INVALID).

Although examination of multiple ATL09 product files sampled from the ASAS functional tests func_test_960a6_02 and func_test_960b1 did not reveal the presence of INVALID *column_od_asr_qf* in the 25 Hz profile data. The ATL09 product template HDF5 file and the derived data dictionary file contain the definition for the integer total column optical depth ASR quality flag indicating the accommodation of the constant INVALID_I1B as the FillValue for the profile parameter *column_od_asr_qf*. The test logic in the Excel workbook used to assess the global total column optical depth included the programming to detect and capture the INVALID *column_od_asr_qf* and this function was included in the pseudocode model earlier. Even if the INVALID *column_od_asr_qf* profile value would never occur, the code implementation should at least include accommodation for the INVALID value possibility specified in the ATL09 data dictionary content.

Unfortunately, the omission of the INVALID *column_od_asr_qf* profile observation detection and exemption was not discovered until after the "atlas_l3b_atm" PGE v2.0 source code had already been delivered to SIPS SDMS Team, submitted for the TRR review, and passed on for production testing. Consequently, an issue will be added to the JIRA Task "Develop atlas_l3b_atm v2.1".

3.2.2.5 Summary of ASR Column Optical Depth Filtering Applied for the Computation of Expanded Global Total Column Optical Depth

In similar manner to Section 3.2.1.5, in the "atlas_l3b_atm" PGE v2.0 code development and testing process relative to the results from V05 ATBD specifications it was necessary to clarify the ordering of the logical testing to constrain or filter the profile observations in the collection of the data comprising the gridded data. Documentation providing a summary of the logic order and flow were electronically transmitted for review and approval of the code implementation in a simplified format. A similar composition is included for summarization of the sequence of constraining and filtering testing applied to the *column_od_asr* profile observations for the summation and counting of these data for computation of Expanded Global Total Column Optical Depth gridded parameter arrays. The expanded code logic relevant to the estimated cloud optical depth values as replacements for the INVALID *column_od_asr* profile observations is included as well.

```
! summary of constraining / filtering / testing logic applied in "exp_glob_tot_col_od_mod.f90"
! code performed for all 25 Hz "column_od_asr" observations in the current profile_X (i.e.,
! profile_1, profile_2, profile_3)

for each profile
```

```
!   eliminate any INVALID index values (i,j) computed for locating profile longitude, lon (),
!   and latitude, lat (), in the gridded parameter numerator summation array and denominator
!   counting array cell locations

    if (i = INVALID .or. j = INVALID) then
      do next profile
    end if

!   eliminate daytime data if processing night-only profile data is selected
    if (night_only = 1) then
!     test sun angle for daylight (daytime) in nighttime only processing and eliminate
      if (solar_elevation () => 0.0) then
        do next profile
      end if
    end if

!   eliminate any "bad" calculated laser_angle values from any possible INVALID beam_elevation
!   profile observations (called the "trap")
    if (laser_angle () < 0.0) then
      do next profile
    end if

!   skip processing for profiles exceeding the laser off-nadir angle limit (laser_angle_limit)
    if (laser_angle () => laser_angle_limit) then
      do next profile
    end if

!   eliminate any INVALID column_od_asr () values
    if (column_od_asr () = INVALID) then
      transfer to calc_est_cloud_reflect_loc
    end if

!   eliminate any zero (0) or INVALID surface quality flag column_od_asr_qf () values
    if (column_od_asr_qf () =0 .or.  column_od_asr_qf () = INVALID) then
      do next profile
    end of

!   apply range of values filtering to column_od_asr observation
!   note: this test also performs the elimination of zero column_od_asr values
    if (column_od_asr () <= 0.0 .or. column_od_asr () => 4.0) then
      do next profile
    end if

!   valid and acceptable column_od_asr observation into expanded global total column optical
!   depth gridded parameter data collection
!   column_od_asr profile observation has passed all constraining / filtering tests
!   accumulate the column_od_asr profile observation in summation numerator grid
    total column optical depth grid (i,j) = total column optical depth grid (i,j)         &
                                          + column_od_asr ()
!   count the column_od_asr profile observation in the accepted profile count denominator array
    total observation counter grid (i,j) = total observation counter grid (i,j) + 1

next profile
```

```
calc_est_cloud_reflect_loc:    ! label
!   perform filtering specific to the random, normally distributed, estimated cloud optical
!   depth replacement value for the occurrence of the INVALID column_od_asr value
!   test the surface type profile array surf_type (,) for at least one valid surface type
!   indicated; if no valid surface type detected proceed to next profile observation
!   initialize valid surface type count
    val_srf_typ_ct = 0
    for index = 1, 5
      if (surf_type (index,) = 1) then
        val_srf_typ_ct = val_srf_typ_ct + 1
      end if
    next index
!   all five surface types in the surf_type (,) array have been tested
!   test valid surface type count for one or more valid surface types detected,
!   i.e., surf_type (index,) would equal one (1)
!   if valid surface type count equals zero (0) then no valid surface types were detected
!   then go to process next profile
    if (val_srf_typ_ct <= 0) then
      do next profile
    end if

!   calculate estimated cloud optical depth replacement value
    R = random_number ()     ! return random, Gaussian, normally distributed number => 0.0 and
                             ! <= 1.0
    est_cloud_reflect_loc = R * real (gen_cloud_od_max -3) + 3
!
!   accumulate the calculated est_cloud_reflect_loc replacement value in summation numerator
grid
    total column optical depth grid (i,j) = total column optical depth grid (i,j)         &
                                          + est_cloud_reflect_loc
!   count the est_cloud_reflect_loc replacement value in the accepted profile count denominator
array
    total observation counter grid (i,j) = total observation counter grid (i,j) + 1

next profile

! all 25 Hz profiles in profile_x have been processed
```

3.3 Blowing Snow and Diamond Dust

3.3.1 Blowing Snow Frequency

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Low-Rate Blowing Snow Frequency	Lon	Lat	Lon	Lat	
Product variable:	npolar_lorate_blowing_snow_freq (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Low-Rate Blowing Snow Frequency (percent)					
Image parameter:	npolar_lorate_blowing_snow_freq_img	Group: /				
Observation grid:	npolar_lorate_bsnow_obs_grid (,)	Group: /				
Statistical variables:	*npolar_lorate_blowing_snow_freq_min* *npolar_lorate_blowing_snow_freq_max* *npolar_lorate_blowing_snow_freq_mean* *npolar_lorate_blowing_snow_freq_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*bsnow_h* () *bsnow_con* ()	ATL09 Group: /profile_x /low_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_lorate_blosnow_freq_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Low-Rate Blowing Snow Frequency	Lon	Lat	Lon	Lat	
Product variable:	spolar_lorate_blowing_snow_freq (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Low-Rate Blowing Snow Frequency (percent)					
Image parameter:	spolar_lorate_blowing_snow_freq_img	Group: /				
Observation grid:	spolar_lorate_bsnow_obs_grid (,)	Group: /				
Statistical variables:	*spolar_lorate_blowing_snow_freq_min* *spolar_lorate_blowing_snow_freq_max* *spolar_lorate_blowing_snow_freq_mean* *spolar_lorate_blowing_snow_freq_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*bsnow_h* () *bsnow_con* ()	ATL09 Group: /profile_x /low_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_lorate_blosnow_freq_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar High-Rate Blowing Snow Frequency	Lon	Lat	Lon	Lat	
Product variable:	npolar_hirate_blowing_snow_freq (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar High-Rate Blowing Snow Frequency (percent)					
Image parameter:	npolar_hirate_blowing_snow_freq_img	Group: /				
Observation grid:	npolar_hirate_bsnow_obs_grid (,)	Group: /				
Statistical variables:	*npolar_hirate_blowing_snow_freq_min* *npolar_hirate_blowing_snow_freq_max* *npolar_hirate_blowing_snow_freq_mean* *npolar_hirate_blowing_snow_freq_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*bsnow_h* () *bsnow_con* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_hirate_blosnow_freq_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar High-Rate Blowing Snow Frequency	Lon	Lat	Lon	Lat	
Product variable:	spolar_hirate_blowing_snow_freq (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar High-Rate Blowing Snow Frequency (percent)					
Image parameter:	spolar_hirate_blowing_snow_freq_img	Group: /				
Observation grid:	spolar_hirate_bsnow_obs_grid (,)	Group: /				
Statistical variables:	*spolar_hirate_blowing_snow_freq_min* *spolar_hirate_blowing_snow_freq_max* *spolar_hirate_blowing_snow_freq_mean* *spolar_hirate_blowing_snow_freq_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*bsnow_h* () *bsnow_con* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_hirate_blosnow_freq_mod.f90					

On the ATL09 product is the parameter blowing snow layer thickness, *bsnow_h* (i.e., height above the surface in meters to the top of the blowing snow layer), at both high-rate (i.e., 25 Hz) and low-rate (i.e., 1 Hz). Originally stated in the ATBD: to create the blowing snow frequency, the low-rate (1 second) blowing snow height will be used. Previous releases of ATL16 and ATL17 only contained blowing snow frequency computed using the low-rate profile data. Now with this version two detection grids and two observation grids are collected to cover the polar regions (poleward of 60 degrees North and South). The low-rate profile data continues to be used for the production of both North and South polar low-rate blowing snow frequency. The additional high-rate profile data in the new high-rate detection and observation grids is now used for the production of the new North and South polar high-rate blowing snow frequency gridded parameters.

In general, blowing snow height, *bsnow_h*, will only be > 0.0 (and not INVALID) when there is a detected blowing snow layer. Thus, when the latitude is poleward of 60N or 60S and whenever *bsnow_h* > 0.0 (and not INVALID), increment the grid box of the detection grid corresponding to the current latitude/longitude by one (1). If blowing snow confidence, *bsnow_con* is greater than or equal to -2 (but not INVALID), then increment the observation grid box of the current location by one (1). If *bsnow_con* is less than -2, it indicates that the surface was not detected. In this case do not consider it an observation and thus do not increment the observation grid (denominator). NOTE: the input parameters *bsnow_h* () and *bsnow_con* () will contain INVALID values in the profile observations. Therefore, INVALID input profile observation exception is required for these parameters.

With the requirement to produce both low-rate and high-rate blowing snow frequency as gridded parameters ("npolar_lorate_blowing_snow_freq", "spolar_lorate_blowing_snow_freq", "npolar_hirate_blowing_snow_freq", and "spolar_hirate_blowing_snow_freq"), inputs and outputs must be discriminated into low-rate (lorate_) and high-rate (hirate_) input sources and output destinations.

Typically for the northern hemisphere or the southern hemisphere, the low-rate blowing snow profile data is processed as follows:

the pseudocode below represents the conditional logic for incrementing the "*low-rate blowing snow detection grid*", i.e., the numerator grid, based on the filtered and accepted 1 Hz (low-rate) profile observations ():

for every 1 Hz profile occurrence of *lorate_bsnow_h* () ≠ INVALID
    for *lorate_bsnow_h* () > 0.0
        low-rate blowing snow detection grid (i,j) = low-rate blowing snow detection grid (i,j) + 1
next 1 Hz profile observation

a low-rate blowing snow layer has been detected
the pseudocode below represents the conditional logic for incrementing the "*low-rate blowing snow observation grid*", i.e., the denominator grid, based on the filtered and accepted 1 Hz (low-rate) profile observations ():

for every 1 Hz profile occurrence of *lorate_bsnow_con* () ≠ INVALID
    for *lorate_bsnow_con* () => -2
        low-rate blowing snow observation grid (i,j) = low-rate blowing snow observation grid (i,j) + 1
next 1 Hz profile observation

Similarly, typical for the northern hemisphere or the southern hemisphere, the high-rate blowing snow profile data is processed as follows:

the pseudocode below represents the conditional logic for incrementing the "*high-rate blowing snow detection grid*", i.e., the numerator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations ():
for every 25 Hz profile occurrence of *hirate_bsnow_h* () ≠ INVALID for *hirate_bsnow_h* () > 0.0 high-rate blowing snow detection grid (i,j) = high-rate blowing snow detection grid (i,j) + 1 next 25 Hz profile observation
a high-rate blowing snow layer has been detected
the pseudocode below represents the conditional logic for incrementing the "*high-rate blowing snow observation grid*", i.e., the denominator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations ():
for every 25 Hz profile occurrence of *hirate_bsnow_con* () ≠ INVALID for *hirate_bsnow_con* () => -2 high-rate blowing snow observation grid (i,j) = high-rate blowing snow observation grid (i,j) + 1 next 25 Hz profile observation

After all ATL09 files for the period in question have been processed in this way, the blowing snow frequency grid is obtained by dividing the detection grid by the observation grid (where the observation count equals or exceeds the product observation count minimum), and then multiplying by 100 to obtain percent. For cases where the number of observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the blowing snow frequency to INVALID.

For the northern hemisphere or the southern hemisphere, the low-rate blowing snow frequency gridded parameter is obtained as follows:

the pseudocode below represents the conditional logic for calculating the "*low-rate blowing snow frequency polar grid*" in percent by division of the "*low-rate blowing snow detection grid*", i.e., the numerator grid, by the "*low-rate blowing snow observation grid*", i.e., the denominator grid, then multiplying by 100, for either the weekly or the monthly atmosphere gridded data product:
for low-rate blowing snow observation grid (i,j) => *_obs_minimum* low-rate blowing snow frequency polar grid (i,j) = (low-rate blowing snow detection grid (i,j)) / (low-rate blowing snow observation grid (i,j)) X 100 else low-rate blowing snow frequency polar grid (i,j) = INVALID next grid cell
NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

For the northern hemisphere or the southern hemisphere, the high-rate blowing snow frequency gridded parameter is obtained as follows:

the pseudocode below represents the conditional logic for calculating the "*high-rate blowing snow frequency polar grid*" in percent by division of the "*high-rate blowing snow detection grid*", i.e., the numerator grid, by the "*high-rate blowing snow observation grid*", i.e., the denominator grid, then multiplying by 100, for either the weekly or the monthly atmosphere gridded data product:
for high-rate blowing snow observation grid (i,j) => **_obs_minimum* high-rate blowing snow frequency polar grid (i,j) = high-rate blowing snow detection grid (i,j) / high-rate blowing snow observation grid (i,j) X 100 else high-rate blowing snow frequency polar grid (i,j) = INVALID next grid cell
NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

3.3.2 South Polar Surface Diamond Dust Frequency

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Surface Diamond Dust Frequency	Lon	Lat	Lon	Lat	
Product variable:	spolar_surf_ddust_freq (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Surface Diamond Dust Frequency					
Image parameter:	spolar_surf_ddust_freq_img	Group: /				
Observation grid:	spolar_surf_ddust_freq_obs_grid (,)	Group: /				
Statistical variables:	*spolar_surf_ddust_freq_min* *spolar_surf_ddust_freq_max* *spolar_surf_ddust_freq_mean* *spolar_surf_ddust_freq_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*ddust_hbot_dens* () *dem_h* () *bsnow_h* () *surface_bin* ()	ATL09 Group: /profile_x /high_rate				
Local variable:	*ddust_bot_ht*	= *ddust_hbot_dens* () - *dem_h* ()				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_surf_ddust_freq_mod.f90					

The initial transmitted descriptive text for this new V05 ATBD and "atlas_l3b_atm" PGE v2.0 algorithm for implementation included the following:

> Original Title: Diamond Dust Reaching the Surface.
>
> This ATL16/17 parameter (spolar_surf_ddust_freq) will be a polar plot over Antarctica only and represent the fraction of time that diamond dust reaches the surface. Diamond dust consists of small ice particles and can exist at any height within the troposphere. It is most important when it reaches the surface where it is known as clear-air precipitation. In some places in Antarctica, it represents up to 80% of the precipitation that falls. However, little is known about its spatial and temporal frequency since it is invisible to radar remote sensing like CloudSat. On the ATL09 product (v005 and later) the parameter *ddust_hbot_dens* represents the bottom height (above the ellipsoid) of the diamond dust layer if detected. If diamond dust was not detected, *ddust_hbot_dens* will be invalid. We are interested in times when diamond dust reaches the surface, but blowing snow is not present.
>
> The first step is to convert the bottom height of the diamond dust layer (*ddust_hbot_dens*) from above the ellipsoid to above the surface:
>
> *ddust_bot_ht* = *ddust_hbot_dens* () - *dem_h* ()

Where *dem_h* is the DEM surface height value. The next step is to filter the diamond dust observations to include those where the bottom height of the layer is less than 200 meters, and the surface return was detected and there was no blowing snow present, and the surface height is greater than 500 meters. If the surface return was detected, the ATL09 parameter *surface_bin* will have a value less than 700. If it was not detected it will have an INVALID value. If blowing snow was not detected, the ATL09 parameter *bsnow_h* will be INVALID. If it was detected, *bsnow_h* will always be less than or equal to 500.0.

An example (assumes latitudes of all "n" profile observations are less than -65.0 degrees [65S]):

```
for each ith observation of "n" profiles:
    do  i  =  1, n
        {
        add 1 to the geolocated ddust total observation grid cell (denominator grid)
        If  (ddust_bot_ht  <  200.0  .and.  bsnow_h (i)  >  500.0  .and.        &
            surface_bin (i)  >  700.0  .and. dem_h (i)  >  500.0)  then
          add 1 to the geolocated ddust counter grid cell (numerator grid)
        end if
        }
    end do
```

After reading the input ATL09 files for the period in question, the ddust counter grid [the numerator grid] is divided by the ddust total observation grid [the denominator grid] to obtain the fraction of diamond dust reaching the ground.

For cases where the number of ddust total observations for a grid box is less than the *week_obs_minimum* (ATL16) or the *month_obs_minimum* (ATL17), set the spolar_surf_ddust_freq for that grid box to INVALID.

Further transmitted descriptive text for the surface diamond dust frequency included the following clarification narrative:

Windspeed should <u>not</u> be a part of diamond dust classification.

Diamond dust (reaching the ground) should be defined by high scattering in the bin above the surface and high scattering in each bin above for at least 500 meters. If the drop in scattering (i.e., layer top) occurs below 500 meters and the wind speed is greater than 4 meters/second, it is blowing snow. If the drop in scattering occurs above 500 meters from the surface it is diamond dust that reaches the surface. I suppose one could say if the drop in scattering occurs below 500 meters and the wind speed is less than 4 meters/second, we could classify it as diamond dust too, but I am a bit reluctant to do that. This case is captured in my new blowing snow detection algorithm via a confidence flag.

Of course, there is elevated diamond dust that does not reach the surface. But it is extremely difficult to differentiate it from thin ice crystal (cirrus) clouds. So, I am not sure if we should be trying to detect and classify it as diamond dust. Remember, the DDA is certainly already detecting these elevated layers as part of the normal cloud detection. If we do try to classify it, we would need some signal strength threshold below which it would be diamond dust, and above the threshold cloud. From a science perspective, it is the diamond dust that reaches the surface that is important. This is known as clear-air precipitation.

The other case is when there is diamond dust directly above a blowing snow layer. This case can be considered elevated diamond dust too and my above concern applies there as well.

The bottom line is let's take windspeed out of the diamond dust detection algorithm. There is no rationale I can see for using windspeed as a criteria for the presence of diamond dust.

To recount the ATL09 25 Hz (high-rate) profile data used as input in the resolution of the south polar surface diamond dust frequency gridded parameter, the following parameters and description are required:

ATL09 input profile parameter	long name	description / INVALID value
ddust_hbot_dens ()	Diamond Dust Density Layer Bottom Height	Diamond dust from density layer bottom height. / INVALID_R4B
bsnow_h ()	Blowing Snow Layer Thickness	Blowing snow layer thickness (height of top above surface). / INVALID_R4B
dem_h ()	DEM Height	Best available Digital Elevation Model (DEM) [in priority of Arctic/Antarctic/Global/MSS] value at the geolocation point. / INVALID_R4B
surface_bin ()	Surface Bin	Vertically aligned, Normalized Relative Backscatter (NRB) bin number of the detected surface return. / INVALID_I4B

After testing and refinement of the algorithm for the diamond dust reaching the surface in the south polar (Antarctic) region, the 25 Hz (high-rate) diamond dust related profile data is processed as follows:

the pseudocode below represents the conditional logic for incrementing the "*diamond dust observation grid*", i.e., the denominator grid, and for incrementing the "*diamond dust counter grid*", i.e., the numerator grid, based on the filtered and accepted 25 Hz (high-rate) profile observations ():

```
for every 25 Hz profile occurrence of lat () <= -65.0
    if ( surface_bin () ≠ INVALID )  then
      ! increment denominator grid array cell
      diamond dust observation grid (i,j) = diamond dust observation grid (i,j) + 1
    else
      next 25 Hz profile observation
    end if
    if ( ddust_hbot_dens () ≠ INVALID .and. dem_h () ≠ INVALID )  then
      ! convert the bottom height from above the ellipsoid to above the surface
      ddust_bot_ht = ddust_hbot_dens () - dem_h ()
    else
      next 25 Hz profile observation
    end if
    if  (ddust_bot_ht < 200.0 .and. bsnow_h () ≠ INVALID .and. bsnow_h () > 500.0 .and.
       surface_bin () < 700.0 .and. dem_h () > 500.0 ) then
      ! a surface diamond dust density layer has been detected
      ! increment numerator grid array cell
      diamond dust counter grid (i,j) = diamond dust counter grid (i,j) + 1
    else
      next 25 Hz profile observation
    end if
next 25 Hz profile observation
```

After all of the ATL09 files for the period in question have been processed in this way, the south polar surface diamond dust frequency gridded parameter is obtained as follows:

the pseudocode below represents the conditional logic for calculating the "*surface diamond dust frequency grid*" in percent by division of the "*diamond dust counter grid*", i.e., the numerator grid, by the "*diamond dust observation grid*", i.e., the denominator grid, for either the weekly or the monthly atmosphere gridded data product:

```
for diamond dust observation grid (i,j)  => *_obs_minimum
                                               diamond dust counter grid (i,j)
   surface diamond dust frequency grid (i,j)  =  -----------------------------------------------
                                               diamond dust observation grid (i,j)
else
   surface diamond dust frequency grid (i,j)  =  INVALID
next grid cell
```

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

As indicated in Section 1.0 and Table 2 above, the low-resolution polar grid size and dimension is used for the weekly product and the high-resolution polar grid size and dimension is used for the monthly product– with the exception of constraining the computation and the downstream image from -90.0 degrees to less than or equal to -65.0 degrees [90S – 65S].

The title of the image written to the product for this parameter is to be "South Polar Surface Diamond Dust Frequency". The graphic image, spolar_surf_ddust_freq_img, of the south polar gridded parameter is to be limited to the range from 0.0 to 0.4, rather than the normal 0.0 to 1.0 frequency fractional value range.

3.4 Apparent Surface Reflectivity (ASR)

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global Apparent Surface Reflectance	Lon	Lat	Lon	Lat	
Product variable:	global_asr (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global Apparent Surface Reflectance (0-1)					
Image parameter:	global_asr_img	Group: /				
Observation grid:	global_asr_obs_grid (,)	Group: /				
Statistical variables:	*global_asr_min* *global_asr_max* *global_asr_mean* *global_asr_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*apparent_surf_reflec* () *beam_elevation* ()	ATL09 Group: /profile_x /high_rate				
Local variable:	*laser_angle* ()	=90.0- *beam_elevation* ()				
Control variable(s)	*laser_angle_limit* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_asr_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Apparent Surface Reflectance	Lon	Lat	Lon	Lat	
Product variable:	npolar_asr (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Apparent Surface Reflectance (0-1)					
Image parameter:	npolar_asr_img	Group: /				
Observation grid:	npolar_asr_obs_grid (,)	Group: /				
Statistical variables:	*npolar_asr_min* *npolar_asr_max* *npolar_asr_mean* *npolar_asr_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*apparent_surf_reflec* () *beam_elevation* ()	ATL09 Group: /profile_x /high_rate				
Local variable:	*laser_angle* ()	=90.0- *beam_elevation* ()				
Control variable(s)	*laser_angle_limit* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_asr_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Apparent Surface Reflectance	Lon	Lat	Lon	Lat	
Product variable:	spolar_asr (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Apparent Surface Reflectance (0-1)					
Image parameter:	spolar_asr_img	Group: /				
Observation grid:	spolar_asr_obs_grid (,)	Group: /				
Statistical variables:	*spolar_asr_min* *spolar_asr_max* *spolar_asr_mean* *spolar_asr_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*apparent_surf_reflec* () *beam_elevation* ()	ATL09 Group: /profile_x /high_rate				
Local variable:	*laser_angle* ()	=90.0- *beam_elevation* ()				
Control variable(s)	*laser_angle_limit* *weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_asr_mod.f90					

Apparent Surface Reflectivity (ASR) represents the true surface reflectivity modified by the two-way atmospheric transmission. It will generally be a number between 0 and 1. ASR is related to the ratio of the received energy to the transmitted energy and assumes a Lambertian surface reflectance. North and South polar grids and a global grid are established at the longitude and latitude grid size resolution and the dimensions for the weekly product, and for the monthly product, according to values contained in Table 2. The parameter *apparent_surf_reflec* on ATL09 will have a value of 0.0 unless there was a signal detected from the surface (i.e., correspondingly, *surface_sig* > 0.0). For the polar grids when the latitude is poleward of 60N or 60S and the parameter *apparent_surf_reflec* is greater than 0.0, it (i.e., *apparent_surf_reflec*) is added to the ASR (summation) grid box at the current location and the corresponding ASR observation grid box is incremented. If the ASR is equal to 0.0, do nothing. NOTE: the input parameters *apparent_surf_reflec* () and *surface_sig* () do not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

For the global grid, and typically for the northern hemisphere or the southern hemisphere:

the pseudocode below represents the logic for selected accumulation of the "*ASR (summation) global grid*" and the "*ASR (summation) polar grid*", i.e., the numerator grids, and for selected increment of the corresponding "*global ASR observation grid*" and "*polar ASR observation grid*", i.e., the denominator grids, based on the filtered and accepted 25 Hz (high-rate) profile observations ():

for 25 Hz profile *apparent_surf_reflec ()* > 0.0
    ASR (summation) global grid (i,j) = ASR (summation) global grid (i,j) + *apparent_surf_reflec ()*
    ASR (summation) polar grid (i,j) = ASR (summation) polar grid (i,j) + *apparent_surf_reflec ()*
    global ASR observation grid (i,j) = global ASR observation grid (i,j) + 1
    polar ASR observation grid (i,j) = polar ASR observation grid (i,j) + 1
next profile observation

After the period in question has been processed, the ASR grid is divided by the observation grid to get the average ASR grid ("global_asr", "npolar_asr", and "spolar_asr"). For cases where the number of observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the ASR to INVALID. For the global grid, and typically for the northern hemisphere or the southern hemisphere:

the pseudocode below represents the conditional logic for calculating the "*average ASR global grid*" and the "*average ASR polar grid*" by respective division of the "*ASR (summation) global grid*" and "*ASR (summation) polar grid*", i.e., the numerator grids, by the "*global ASR observation grid*" and "*polar ASR observation grid*", i.e., the denominator grids, for either the weekly or the monthly atmosphere gridded data product:

for all grid cells
    if (global observation grid (i,j) => **_obs_minimum*) then
        average ASR global grid (i,j) = ASR (summation) global grid (i,j) / global observation grid (i,j)
    else
        average ASR global grid (i,j) = INVALID
    end if
    if (polar observation grid (i,j) => **_obs_minimum*) then
        average ASR polar grid (i,j) = ASR (summation) polar grid (i,j) / polar observation grid (i,j)
    else average ASR polar grid (i,j) = INVALID
    end if
next grid cell

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

It is further noted here that generic polar grid representations above are discriminated in implementation to north polar and south polar parameters.

3.4.1 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Expanded Global and Polar Apparent Surface Reflectivity

The concept of the profile data filtering, that of rejecting the collection of the primary profile observations for computation when the ATLAS laser beam off-nadir angles exceed a limiting angle control constant value, has already been introduced in Section 3.2.1.3 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Global Total Column Optical Depth, and Section 3.2.2.3 Application of Profile Laser Off-Nadir Angle Limitation Filtering for Expanded Global and Polar Apparent Surface Reflectivity. The specified deployment of this off-nadir angle filtering has been identified for five (5) of the atmosphere gridded parameters from the v3.2 ATBD and the "atlas_l3b_atm" PGE v1.3 code is incorporated in this V05 ATBD edition and the corresponding "atlas_l3b_atm" PGE v2.0 code– with the Global Apparent Surface Reflectance gridded parameter being the third target, the North Polar Apparent Surface Reflectance gridded parameter the fourth target, and the South Polar Apparent Surface Reflectance gridded parameter the fifth target, for these modifications.

Data filtering is now to be applied to the profile *apparent_surf_reflec* data, augmenting the existing observation data collection, summation, and counting in the averaged Global Apparent Surface Reflectance, the averaged North Polar Apparent Surface Reflectance, and the averaged South Polar Apparent Surface Reflectance gridded parameters. As initially presented in Section 3.2.1.3:

> The term laser angle may be qualified as being the laser beam off-nadir pointing angle, i.e., with nadir referring to laser pointing perpendicularly incident to the target surface and off-nadir as the angle the laser beam deviates from the perpendicular (zero angle) or zenith angle (zenith being the point at which the signal return is considered the most powerful). The more the laser pointing is off-nadir the more the return signal power is reduced, diminishing the return photon count.
>
> The ATLAS multi-beam laser altimeter pointing angle data from the precision pointing data for the three (3) strong beams obtained from the ATL03 Geolocated Photon Data is delivered in the ATL09 product 25 Hz (high-rate) profile parameters *beam_azimuth* and *beam_elevation*. The profile-rate *beam_elevation* angle in degrees is used to calculate a local profile-rate local laser beam off-nadir angle identified as *laser_angle*. The laser beam off-nadir angle in degrees is calculated from the profile beam elevation with the following formulation:
>
> *laser_angle* () = 90.0 - *beam_elevation* ()
>
> A control constant value called the laser beam off-nadir angle limiting factor and named *laser_angle_limit* is implemented as the filtering constraint value such that only valid profile data associated with laser off-nadir angle values less than the laser angle limit are allowed to be collected, accumulated, and counted. This filtering is applied as illustrated in the following simplified logic:
>
> if (*laser_angle* () < *laser_angle_limit*) then
> *accept valid profile observation for summation and counting process*

```
            transfer to summation and counting process
        else
            reject valid profile observation for summation and counting process
            transfer to process next 25 Hz profile observation
        end if
```

Initially the control constant *laser_angle_limit* was implemented and tested at the values of 2.0 degrees and changed to 3.0 degrees. With the final implementation of the "atlas_l3b_atm" PGE v2.0 the control constant is delivered with the default value of 6.0 degrees (i.e., *laser_angle_limit* = 6.0). A control parameter override "asas.l3b_atm.laser_angle_limit" is implemented to enable runtime constant value override entry from the PGE processing control file.

It is noted that requirement has been levied to not only apply the laser beam off-nadir angle filtering to the atmosphere column optical depth from ASR (i.e., *column_od_asr*) for the Global Total Column Optical Depth gridded data but for the same *column_od_asr* profile data filtering in the Expanded Global Total Column Optical Depth gridded parameter as well. Continuing with apparent surface reflectance (ASR) derived 25 Hz profile data, the requirement extends to apply this laser beam off-nadir angle filtering to the high-rate profile apparent surface reflectance profile data from the ATL09 product as the *apparent_surf_reflec* parameter collected, accumulated, and counted in the existing ATL16/ATL17 atmosphere gridded parameters in the Global Apparent Surface Reflectance, North Polar Apparent Surface Reflectance, and South Polar Apparent Surface Reflectance.

Now modified for the global grid, and typically for the northern hemisphere or the southern hemisphere:

the modified pseudocode incorporating the laser angle limit below represents the logic for selected accumulation of the "*ASR (summation) global grid*" and the "*ASR (summation) polar grid*", i.e., the numerator grids, and for selected increment of the corresponding "*global ASR observation grid*" and "*polar ASR observation grid*", i.e., the denominator grids, based on the filtered and accepted 25 Hz (high-rate) profile observations ():

```
for each 25 Hz profile
    if (laser_angle () < laser_angle_limit) then
      if (apparent_surf_reflec () > 0.0) then
        ASR (summation) global grid (i,j) = ASR (summation) global grid (i,j) + apparent_surf_reflec ()
        ASR (summation) polar grid (i,j) = ASR (summation) polar grid (i,j) + apparent_surf_reflec ()
        global ASR observation grid (i,j) = global ASR observation grid (i,j) + 1
        polar ASR observation grid (i,j) = polar ASR observation grid (i,j) + 1
      end if
    end if
next profile observation
```

The computation of the Global Apparent Surface Reflectance, the North Polar Apparent Surface Reflectance, and the South Polar Apparent Surface Reflectance gridded parameters remain as described in the pseudocode block above in Section 3.4 for the average ASR global grid (i,j) and average ASR polar grid (i,j).

3.5 Ground Detection Frequency

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	Global Ground Detection Frequency	Lon	Lat	Lon	Lat	
Product variable:	global_grnd_detect (,)	3.0	3.0	1.0	1.0	deg
Product group:	Group: /	120	60	360	180	dim
Image label:	Global Ground Detection Frequency (fraction)					
Image parameter:	global_grnd_detect_img	Group: /				
Observation grid:	global_cloud_aerosol_obs_grid (,)	Group: /				
Statistical variables:	*global_grnd_detect_min* *global_grnd_detect_max* *global_grnd_detect_mean* *global_grnd_detect_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	glob_grnd_detect_freq_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	North Polar Ground Detection Frequency	Lon	Lat	Lon	Lat	
Product variable:	npolar_grnd_detect (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	North Polar Ground Detection Frequency (fraction)					
Image parameter:	npolar_grnd_detect_img	Group: /				
Observation grid:	npolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*npolar_grnd_detect_min* *npolar_grnd_detect_max* *npolar_grnd_detect_mean* *npolar_grnd_detect_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	npol_grnd_detect_freq_mod.f90					

Atmosphere Gridded Parameter Summary		ATL16		ATL17		
Long Name:	South Polar Ground Detection Frequency	Lon	Lat	Lon	Lat	
Product variable:	spolar_grnd_detect (,)	3.0	1.0	1.5	0.5	deg
Product group:	Group: /	120	30	240	60	dim
Image label:	South Polar Ground Detection Frequency (fraction)					
Image parameter:	spolar_grnd_detect_img	Group: /				
Observation grid:	spolar_cloud_obs_grid (,)	Group: /				
Statistical variables:	*spolar_grnd_detect_min* *spolar_grnd_detect_max* *spolar_grnd_detect_mean* *spolar_grnd_detect_sdev*	Group: /quality_assessment /atmosphere				
ATL09 variable(s):	*surface_sig* ()	ATL09 Group: /profile_x /high_rate				
Control variable(s)	*weekly_obs_minimum* → *obs_minimum* (ATL16) *monthly_obs_minimum* → *obs_minimum* (ATL17)	Group: /ancillary_data /atmosphere				
PGE module:	spol_grnd_detect_freq_mod.f90					

For ground detection frequency ("global_grnd_detect", "npolar_grnd_detect", and "spolar_grnd_detect"), the ATL09 high-rate parameter *surface_sig* (i.e., surface signal count, the number of photons in the surface bin) should be used. This will be 0.0 unless the surface signal was detected. North and South Polar grids and a global grid are set up as in Section 3.5 above, and when *surface_sig* is > 0.0, the surface signal detection grid box at the current location is incremented. The corresponding observation grid box is incremented regardless of the value of *surface_sig*. NOTE: the input parameter *surface_sig* () does not contain INVALID values in the profile observations. Therefore, no INVALID input profile observation testing is required.

For the global grid and typically for the northern hemisphere or the southern hemisphere:

the pseudocode below represents the conditional logic for incrementing the "*surface signal detection global grid*" and the "*surface signal detection polar grid*", i.e., the numerator grids, for all 25 Hz (high-rate) profile observations ():

for 25 Hz profile *surface_sig* () > 0.0
    surface signal detection global grid (i,j) = surface signal detection global grid (i,j) + 1
    surface signal detection polar grid (i,j) = surface signal detection polar grid (i,j) + 1
next profile observation

the pseudocode below represents the logic for incrementing the "*global observation grid*" and "*polar observation grid*", i.e., the denominator grids, for all 25 Hz (high-rate) profile observations ():

```
for every 25 Hz profile
    global observation grid (i,j) = global observation grid (i,j) + 1
    polar observation grid (i,j) = polar observation grid (i,j) + 1
next profile observation
```

After the period in question has been processed, the ground detection frequency is calculated by dividing the surface signal grid by the observation grid for values of the observation grid equal to or exceeding the product observation minimum count value. For cases where the number of observations for a grid box is less than *week_obs_minimum* (ATL16) or *month_obs_minimum* (ATL17), set the ground detection frequency to INVALID.

the pseudocode below represents the conditional logic for calculating the "*ground detection frequency global grid*" and the "*ground detection frequency polar grid*" by respective division of the "*surface signal detection global grid*" and "*surface signal detection polar grid*", i.e., the numerator grids, by the "*global observation grid*" and "*polar observation grid*", i.e., the denominator grids, for either the weekly or the monthly atmosphere gridded data product:

```
for all grid cells
    if (global observation grid (i,j)  => *_obs_minimum) then
                                                        surface signal detection global grid (i,j)
        ground detection frequency global grid (i,j)  =  ----------------------------------------------------
                                                             global observation grid (i,j)

    else
        ground detection frequency global grid (i,j)  =  INVALID
    end if

    if (polar observation grid (i,j)  => *_obs_minimum) then
                                                       surface signal detection polar grid (i,j)
        ground detection frequency polar grid (i,j)  =  ----------------------------------------------------
                                                            polar  observation grid (i,j)

    else
        ground detection frequency polar grid (i,j)  =  INVALID
    end if

next grid cell
```

NOTE: **_obs_minimum* represents either *weekly_obs_minimum* or *monthly_obs_minimum* based on product

It is further noted here that generic polar grid representations above are discriminated in implementation to north polar and south polar parameters.

3.6 Images of Gridded Fields

Included on both products will be images of selected atmospheric variables. The global and polar atmosphere gridded parameters' grid images will overlay map images showing continental and country boundaries. Polar stereographic projection is used for the polar plots and equirectangular projection for the global images. The images can be either jpeg or png format. See the bottom of Table 5 for a list of images to be included on the products. The images have the same root name as the atmosphere gridded parameters with the added suffix "_img". For example, for the gridded parameter "global_cloud_frac" will be incorporated as the image "global_cloud_frac_img". NOTE that the list of images contained in Table 5 is not meant to be definitive. It is acceptable if images of other data fields are included.

NOTE: the image labels are included with the HDF5 product templates for the ATL16 and ATL17 products. These labels are embedded are part of the global (rectangular) projection images and the polar (stereographic) projection images in the weekly ATL16 or the monthly ATL17 atmosphere gridded data products. For the images listed in Table 5, the contents of the Description fields are the actual label character strings that are included in the product templates and will be applied to the generated gridded parameter global and polar projection images.

3.7 Minimum Number of Observations for Each Grid Box

In the computation of the various data fields, the data are divided by the number of observations in each grid box. For the ATBD Version 2.2a, we introduce two new control parameters called *week_obs_minimum* and *month_obs_minimum*. If the number of observations for a given grid box is less than *week_obs_minimum* for ATL16, then the value of that grid box is set to INVALID. It would be as if there were no observations at all for that grid box. If the number of observations is less than *month_obs_minimum* for ATL17, then the value of that grid box is set to INVALID. The nominal values for these parameters are: *week_obs_minimum* = 2 and *month_obs_minimum* = 4. These values are implemented within the code as constants and defaults. Control file execution overrides for these parameters will be available for replacement of these default values.

3.8 Observations Grids

For Version 2.1 of this ATBD the following five (5) observation grids were added to the products:

South Polar Blowing Snow Frequency – new parameter "spolar_bsnow_obs_grid" *[now Low-Rate below]*
Global ASR – new parameter "asr_obs_grid"
Global (Over Water) Total Column Optical Depth - "tcod_obs_grid"
Global Cloud or Aerosol Fraction - "global_cloud_aerosol_obs_grid"

With ATBD Version 3.1c DRAFT, the two existing (low-rate profile) polar blowing snow frequency observation count grids are expanded and renamed as a result of the addition of the high-rate profile polar blowing snow frequency observation count grids. Subsequently, the following four (4) polar blowing snow observation count grids replace the previous two (2) count grids:

North Polar Low-Rate Blowing Snow Frequency – new parameter "npolar_lorate_bsnow_obs_grid"
South Polar Low-Rate Blowing Snow Frequency – new parameter "spolar_lorate_bsnow_obs_grid"
North Polar High-Rate Blowing Snow Frequency – new parameter "npolar_hirate_bsnow_obs_grid"
South Polar High-Rate Blowing Snow Frequency – new parameter "spolar_hirate_bsnow_obs_grid"

NOTE: the parameters "npolar_bsnow_obs_grid" and "spolar_bsnow_obs_grid" included in the Version 2 ATL16/ATL17 products are now renamed to "npolar_lorate_bsnow_obs_grid" and "spolar_lorate_bsnow_obs_grid" observation grid parameters to clearly discriminate from the new high-rate profile data polar blowing snow frequency grid count parameters.

With the ATBD Version 3.2 DRAFT, 17 March 2021, an observation count grid has been added for the Expanded Global Total Column Optical Depth (Over Water):

Expanded Global (Over Water) Total Column Optical Depth - "exp_tcod_obs_grid"

With the ATBD Version 5, the following existing observation count definitions have been modified:

Global Total Column Optical Depth - "tcod_obs_grid"
Expanded Global Total Column Optical Depth - "exp_tcod_obs_grid"

and the following observation count definition has been added:

South Polar Surface Diamond Dust Frequency - "spolar_surf_ddust_freq_obs_grid"

These observation grids are loaded from a selected set of "denominator grids" representing the logically filtered observation counter grids or the total observation grids collected in earlier sections above for the following parameters listed in Table 4 below:

Table 4. Atmosphere Gridded Products Observation Grid Parameters, Sources, Applicable Parameters

observation [count] grid parameter	Section	atmosphere gridded parameter algorithm source: count	applicable to atmosphere gridded parameters
global_cloud_aerosol_obs_grid (i,j)	3.1, 3.1.1, 3.1.2, 3.1.3, 3.1.4, 3.6	global cloud fraction: count of every 25 Hz profile observation	global_cloud_frac (i,j), combined_global_cloud_frac (i,j), global_aerosol_frac (i,j), global_clear_frac (i,j), global_grnd_detect (i,j)
tcod_obs_grid (i,j)	3.2, 3.2.1	[global] total column optical depth: count of every valid 25 Hz profile apparent surface reflectance column optical depth [*column_od_asr* () > 0.0 and < 4.0] and valid quality flag [*column_od_asr_qf* () > 0] for observations over all surface types, and laser off-nadir angle [*laser_angle* () < *laser_angle_limit*]	global_column_od (i,j)
exp_tcod_obs_grid (i,j)	3.2, 3.2.2	expanded [global] total column optical depth: count of every valid 25 Hz profile apparent surface reflectance column optical depth [*column_od_asr* () > 0.0 and < 4.0] and valid quality flag [*column_od_asr_qf* () > 0] observations, plus estimated cloud optical depth for asr values for [*column_od_asr* () = INVALID] and valid surface types [any *surf_type* (,) = 1] for expanded global average total column optical depth over all surface types, and laser off-nadir angle [*laser_angle* () < *laser_angle_limit*]	expanded_global_column_od(i,j)
global_asr_obs_grid (i,j)	3.5	[global] apparent surface reflectance (ASR): count of every 25 Hz profile surface signal detected ASR [*apparent_surf_reflec* () > 0.0] observation, and laser off-nadir angle [*laser_angle* () < *laser_angle_limit*]	global_asr (i,j)
npolar_lorate_bsnow_obs_grid (i,j)	3.4	[north polar low-rate] blowing snow frequency: count of every valid 1 Hz blowing snow layer detected confidence [*bsnow_con* () >= -2] observation in the northern polar region	npolar_lorate_blowing_snow_freq (i,j)
spolar_lorate_bsnow_obs_grid (i,j)	3.4	[south polar low-rate] blowing snow frequency: count of every valid 1 Hz blowing snow layer detected confidence [*bsnow_con* () >= -2] observation in the southern polar region	spolar_lorate_blowing_snow_freq (i,j)

observation [count] grid parameter	Section	atmosphere gridded parameter algorithm source: count	applicable to atmosphere gridded parameters
npolar_hirate_bsnow_obs_grid (i,j)	3.4	[north polar high-rate] blowing snow frequency: count of every valid 25 Hz blowing snow layer detected confidence [*bsnow_con* () >= -2] observation in the northern polar region	npolar_hirate_blowing_snow_freq (i,j)
spolar_hirate_bsnow_obs_grid (i,j)	3.4	[south polar high-rate] blowing snow frequency: count of every valid 25 Hz blowing snow layer detected confidence [*bsnow_con* () >= -2] observation in the southern polar region	spolar_hirate_blowing_snow_freq (i,j)
npolar_cloud_obs_grid (i,j)	3.1, 3.3.1, 3.6	[north] polar total cloud fraction: count of every 25 Hz profile observation in the northern polar region	npolar_lowcloud_frac (i,j), npolar_midcloud_frac (i,j), npolar_highcloud_frac (i,j), npolar_totalcloud_frac (i,j), npolar_transcloud_frac (i,j), npolar_opaquecloud_frac (i,j), npolar_grnd_detect (i,j)
spolar_cloud_obs_grid (i,j)	3.1, 3.3.1, 3.6	[south] polar total cloud fraction: count of every 25 Hz profile observation in the southern polar region	spolar_lowcloud_frac (i,j), spolar_midcloud_frac (i,j), spolar_highcloud_frac (i,j), spolar_totalcloud_frac (i,j), spolar_transcloud_frac (i,j), spolar_opaquecloud_frac (i,j), spolar_grnd_detect (i,j)
npolar_asr_obs_grid (i,j)	3.5	[north polar] apparent surface reflectance (ASR): count of every 25 Hz profile surface signal detected ASR [*apparent_surf_reflec* () > 0.0] observation in the northern polar region, and laser off-nadir angle [*laser_angle* () < *laser_angle_limit*]	npolar_asr (i,j)
spolar_asr_obs_grid (i,j)	3.5	[south polar] apparent surface reflectance (ASR): count of every 25 Hz profile surface signal detected ASR [*apparent_surf_reflec* () > 0.0] observation in the southern polar region, and laser off-nadir angle [*laser_angle* () < *laser_angle_limit*]	spolar_asr (i,j)

3.9 Product Statistical Values

For each product gridded parameter for which an image is made, a set of statistical values of the data, consisting of the data minimum, maximum, mean, and standard deviation values, will be displayed on the grid image, and will be written to the atmosphere gridded product. The statistical values will be included on the image in the proximity of the image parameter label, centered below the label. For example, on the global cloud fraction image, a character string sub-label with the format "Min = x.xxxxxx, Max = x.xxxxxx, Mean = x.xxxxxx, StdDev = x.xxxxxx" will be displayed below the image label: "Average Global Cloud Fraction" (centered below the label). The statistical values of the various data product gridded parameters identified in Table 6 are to be written to the product within the quality assessment group. The statistical values contained in the atmosphere gridded product quality_assessment/atmosphere group will be supplied to the image generation code to prepare the image statistical label. [NOTE: example graphics of a typical global (rectangular projection) image and a polar (polar stereographic projection) image with the statistical values label are included as Attachments A-1 and A-2 at the end of this ATBD.)

4.0 Smoothing of Images

For Version 2.0 of this ATBD, two control parameters are introduced, called *smooth_grid* and *center_weight*. If the control parameter *smooth_grid* is equal to 1, then it means to apply the smoothing algorithm below to either the weekly product (ATL16) images, or the monthly product (ATL17) images, based on the product being generated by the PGE. NOTE that the smoothing algorithm is to be applied only to the data to produce the images and not to the gridded data fields that are written to the products. The nominal [default] value of *smooth_grid* is 1. The *center_weight* control parameter is a real value from 0.0 to 1.0 with a nominal [default] value of 0.6. NOTE that the *center_weight* control parameter is not active when image smoothing is deselected (overridden with *smooth_grid* = 0). These control parameter values are installed in the program code as constants [defaults], and may be replaced by override statements included in the execution processing control file. The algorithm below shall be used in the smoothing of the gridded data fields.

Smoothing shall be applied in the following manner. Let imax be the number of longitude points in a given grid and jmax the number of latitude points. Let the addressing indices go from 1 to imax (i.e., not 0 to imax-1) and let Grid represent a gridded data parameter. The source gridded data may contain INVALID data.

NOTES: the smoothing algorithm code below is to be functionally implemented in the source code for the graphics image production for the ATL16/ATL17 products. If the smoothing algorithm for images is specified, the product parameter grid array data is smoothed locally within the imaging code using internal buffered data– and the source gridded parameter data in the product is not modified.

model code represents the logic for implementing the atmosphere gridded image data smoothing algorithm

```
smooth_grid(*,*) = INVALID

for j= 2, jmax-1 do begin
  for i= 2, imax-1 do begin
      cnt = 0.0
      sum = 0.0
      for ii= i-1, i+1 do begin
          for jj= j-1, j+1 do begin
              if (jj ne j or ii ne i) then begin
                  if (grid (ii,jj) ne INVALID) then begin
                      cnt++
                      sum = sum + Grid (ii,jj)
                  endif
              endif
          endfor
      endfor


      avg = 0.0
      if (cnt gt 0.0) then avg = sum / cnt
      pix = 0.0
      weight = 0.0
      if (grid (i,j) ne INVALID) then begin
          weight = center_weight
          pix = Grid (i,j)*weight
      endif
      spix = avg * (1.0 – weight) + pix
      if (spix ne 0.0) then smooth_grid (i,j) = spix
  endfor
endfor

for i= 1, imax do begin
  if (Grid (i,1) ne INVALID and Grid (i,2) ne INVALID) then &
      smooth_grid (i,1) = (Grid (i,1) + Grid (i,2)) / 2.0
  if (Grid (i,jmax-1) ne INVALID and Grid (i,jmax) ne INVALID) then &
      smooth_grid (i,jmax) = (Grid (i,jmax-1) + Grid (i,jmax)) / 2.0
endfor


for j= 1, jmax do begin
  if (Grid (1,j) ne INVALID and Grid (2,j) ne INVALID) then  &
      smooth_grid (1,j) = (Grid (1,j) + Grid (2,j)) / 2.0
  if (Grid (imax,j) ne INVALID and Grid (imax-1,j) ne INVALID) then &
      smooth_grid (imax,j) = (Grid (imax-1,j) + Grid (imax,j)) / 2.0
endfor
```

5.0 Product Formats

As mentioned in Section 1.0, ATL16 and ATL17 contain the same atmosphere gridded variables. The only difference between the products is the resolution of the grids, the resolution of the linear latitude and longitude arrays, and the frequency that they will be produced. Tables 2 and 3, also in Section 1.0, provide the global and polar grid sizes and the linear array sizes for the weekly-produced ATL16 and the monthly-produced ATL17 atmosphere gridded products represented in Table 5. Table 6 lists the added Section 3.10 product statistical values as a separate table. The statistical parameters are common to both the ATL16 and ATL17 products.

It is noted for the product images listed in Table 5 that the Description column contains the actual labels to be applied to the embedded graphic for each imaged parameter.

Table 5. Gridded Products List of Gridded and Linear Parameters, Ancillary Data, and Images

Group: /					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
start_time	double precision	(1)	(1)	seconds since 2018-01-01	start time/date of data used to make product
end_time	double precision	(1)	(1)	seconds since 2018-01-01	end time/date of data used to make product
data_qa_flag	integer	(1)	(1)		TBD
npolar_grid_lat	float	(30)	(60)	degrees	latitudes of north polar grid
spolar_grid_lat	float	(30)	(60)	degrees	latitudes of south polar grid
npolar_grid_lon	float	(120)	(240)	degrees	longitudes of north polar grid
spolar_grid_lon	float	(120)	(240)	degrees	longitudes of south polar grid
global_grid_lat	float	(60)	(180)	degrees	latitudes of global grid
global_grid_lon	float	(120)	(360)	degrees	longitudes of global grid
npolar_lorate_bsnow_obs_grid	float	(120,30)	(240,60)	N/A	the number of low-rate blowing snow confidence observations used in the computation of low-rate blowing snow frequency for the Arctic
spolar_lorate_bsnow_obs_grid	float	(120,30)	(240,60)	N/A	the number of low-rate blowing snow confidence observations used in the computation of low-rate blowing snow frequency for the Antarctic
npolar_hirate_bsnow_obs_grid	float	(120,30)	(240,60)	N/A	the number of high-rate blowing snow confidence observations used in the computation of high-rate blowing snow frequency for the Arctic
spolar_hirate_bsnow_obs_grid	float	(120,30)	(240,60)	N/A	the number of high-rate blowing snow confidence observations used in the computation of high-rate blowing snow frequency for the Antarctic

Group: /					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
spolar_surf_ddust_freq_obs_grid	float	(120,30)	(240,60)	N/A	the number of diamond dust layer observations reaching the surface used in the computation of the surface diamond dust frequency for the Antarctic
global_asr_obs_grid	float	(120,60)	(360,180)	N/A	the number of observations used to compute the average global apparent surface reflectance (ASR)
tcod_obs_grid	float	(120,60)	(360,180)	N/A	the number of observations used to compute the average global total column optical depth over water
exp_tcod_obs_grid	float	(120,60)	(360,180)	N/A	the number of observations used to compute the average expanded global total column optical depth over water
global_cloud_aerosol_obs_grid	float	(120,60)	(360,180)	N/A	the number of total observations available to compute the global cloud fraction and the global aerosol fraction
global_cloud_frac	float	(120,60)	(360,180)	fraction	global cloud fraction
combined_global_cloud_frac	float	(120,60)	(360,180)	fraction	*combined* global cloud fraction
global_aerosol_frac	float	(120,60)	(360,180)	fraction	global aerosol fraction
global_clear_frac	float	(120,60)	(360,180)	fraction	global clear fraction
global_asr_cloud_frac	float	(120,60)	(360,180)	0 - 1	global ASR cloud fraction
npolar_asr_cloud_frac	float	(120,30)	(240,60)	0 - 1	north polar ASR cloud fraction
spolar_asr_cloud_frac	float	(120,30)	(240,60)	0 - 1	south polar ASR cloud fraction
npolar_lowcloud_frac	float	(120,30)	(240,60)	fraction	north polar low (<= 4 km) cloud fraction
spolar_lowcloud_frac	float	(120,30)	(240,60)	fraction	south polar low (<= 4 km) cloud fraction
npolar_midcloud_frac	float	(120,30)	(240,60)	fraction	north polar mid (> 4 km and <= 8 km) cloud fraction
spolar_midcloud_frac	float	(120,30)	(240,60)	fraction	south polar mid (> 4 km and <= 8 km) cloud fraction

Group: /					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
npolar_highcloud_frac	float	(120,30)	(240,60)	fraction	north polar high (> 8 km) cloud fraction
spolar_highcloud_frac	float	(120,30)	(240,60)	fraction	south polar high (> 8 km) cloud fraction
npolar_totalcloud_frac	float	(120,30)	(240,60)	fraction	north polar total cloud fraction
spolar_totalcloud_frac	float	(120,30)	(240,60)	fraction	south polar total cloud fraction
npolar_transcloud_frac	float	(120,30)	(240,60)	fraction	north polar transmissive cloud fraction
spolar_transcloud_frac	float	(120,30)	(240,60)	fraction	south polar transmissive cloud fraction
npolar_opaquecloud_frac	float	(120,30)	(240,60)	fraction	north polar opaque cloud fraction
spolar_opaquecloud_frac	float	(120,30)	(240,60)	fraction	south polar opaque cloud fraction
global_column_od	float	(120,60)	(360,180)	unitless	global (over water) total column optical depth
expanded_global_column_od	float	(120,60)	(360,180)	unitless	expanded global (over water) total column optical depth
npolar_lorate_blowing_snow_freq	float	(120,30)	(240,60)	percent	low-rate blowing snow frequency for the northern hemisphere polar region
spolar_lorate_blowing_snow_freq	float	(120,30)	(240,60)	percent	low-rate blowing snow frequency for the southern hemisphere polar region
npolar_hirate_blowing_snow_freq	float	(120,30)	(240,60)	percent	high-rate blowing snow frequency for the northern hemisphere polar region
spolar_hirate_blowing_snow_freq	float	(120,30)	(240,60)	percent	high-rate blowing snow frequency for the southern hemisphere polar region
spolar_surf_ddust_freq	float	(120,30)	(240,60)	fraction	south polar surface diamond dust frequency
global_asr	float	(120,60)	(360,180)	0 - 1	global apparent surface reflectance
npolar_asr	float	(120,30)	(240,60)	0 - 1	north polar apparent surface reflectance
spolar_asr	float	(120,30)	(240,60)	0 - 1	south polar apparent surface reflectance
global_grnd_detect	float	(120,60)	(360,180)	fraction	global ground detection frequency

Group: /					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
npolar_grnd_detect	float	(120,30)	(240,60)	fraction	north polar ground detection frequency
spolar_grnd_detect	float	(120,30)	(240,60)	fraction	south polar ground detection frequency
global_cloud_frac_img	image			fraction	Global Cloud Fraction
combined_global _cloud_frac_img	image			fraction [3]	Combined Global Cloud Fraction [3]
global_clear_frac_img	image			fraction	Global Clear Fraction
global_aerosol_frac _img	image			fraction	Global Aerosol Fraction
global_asr_cloud_frac _img	image			fraction [3]	Global ASR Cloud Fraction [3]
npolar_asr_cloud_frac _img	image			fraction	North Polar ASR Cloud Fraction
spolar_asr_cloud_frac _img	image			fraction	South Polar ASR Cloud Fraction
npolar_lowcloud_frac _img	image			fraction	North Polar Low Cloud Fraction (<= 4km)
spolar_lowcloud_frac _img	image			fraction	South Polar Low Cloud Fraction (<= 4km)
npolar_midcloud_frac _img	image			fraction	North Polar Mid Cloud Fraction (> 4km and <= 8km)
spolar_midcloud_frac _img	image			fraction	South Polar Mid Cloud Fraction (> 4km and <= 8km)
npolar_highcloud_frac _img	image			fraction	North Polar High Cloud Fraction (> 8km)
spolar_highcloud_frac _img	image			fraction	South Polar High Cloud Fraction (> 8km)
npolar_totalcloud_frac _img	image			fraction	North Polar Total Cloud Fraction
spolar_totalcloud_frac _img	image			fraction	South Polar Total Cloud Fraction
npolar_transcloud_frac _img	image			fraction	North Polar Transmissive Cloud Fraction
spolar_transcloud_frac _img	image			fraction	South Polar Transmissive Cloud Fraction
npolar_opaquecloud _frac_img	image			fraction	North Polar Opaque Cloud Fraction
spolar_opaquecloud _frac_img	image			fraction	South Polar Opaque Cloud Fraction
global_column_od _img	image			0 - 1.5	Global Total Column Optical Depth (0-1.5)

Group: /					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
expanded_global _column_od_img	image			0 - 25 [1],[2]	Expanded Global Total Column Optical Depth (0-25) [1],[2]
npolar_lorate_blowing _snow_freq_img	image			percent	North Polar Low-Rate Blowing Snow Frequency (percent)
spolar_lorate_blowing _snow_freq_img	image			percent	South Polar Low-Rate Blowing Snow Frequency (percent)
npolar_hirate_blowing _snow_freq_img	image			percent	North Polar High-Rate Blowing Snow Frequency (percent)
spolar_hirate_blowing _snow_freq_img	image			percent	South Polar High-Rate Blowing Snow Frequency (percent)
spolar_surf_ddust_freq _img	image			0 – 0.4	South Polar Surface Diamond Dust Frequency
global_asr_img	image			0 - 1	Global Apparent Surface Reflectance (0-1)
npolar_asr_img	image			0 - 1	North Polar Apparent Surface Reflectance (0-1)
spolar_asr_img	image			0 - 1	South Polar Apparent Surface Reflectance (0-1)
global_grnd_detect _img	image			fraction	Global Ground Detection Frequency (fraction)
npolar_grnd_detect _img	image			fraction	North Polar Ground Detection Frequency (fraction)
spolar_grnd_detect _img	image			fraction	South Polar Ground Detection Frequency (fraction)

NOTE: for the images the Description field contains the label for the projection graphic.
NOTES: [1] Expanded Global Total Column Optical Depth (0-25) upper range constraint may be subject to change. [2] the control parameter *gen_cloud_od_max* is to be displayed on the image. [3] the control parameter *asr_cloud_threshold* is displayed on the image.

Table 6. Gridded Products List of Ancillary Control Data

Group: /ancillary_data/atmosphere					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
data_type_flag	integer	(1)	(1)	0, 1	tells whether night only data was used to make product. 0=no, 1=yes [default = 0]
polar_grid_lon_scale	float	(1)	(1)	degrees	polar grid projection cell longitude resolution (size) [defaults: ATL16 = 3.0, ATL17 = 1.5]
polar_grid_lat_scale	float	(1)	(1)	degrees	polar grid projection cell latitude resolution (size) [defaults: ATL16 = 1.0, ATL17 = 0.5]
global_grid_lon_scale	float	(1)	(1)	degrees	global grid projection cell longitude resolution (size) [defaults: ATL16 = 3.0, ATL17 = 1.0]
global_grid_lat_scale	float	(1)	(1)	degrees	global grid projection cell latitude resolution (size) [defaults: ATL16 = 3.0, ATL17 = 1.0]
obs_minimum	integer	(1)	(1)	N/A	minimum acceptable selected observation count from control constant [defaults: ATL16 = 2, ATL17 = 4]
smooth_grid	integer	(1)	(1)	0, 1	use smoothed grid data to generate parameter grid images: 0=generate images without smoothing, 1=generate images with smoothing applied [default = 1]
center_weight	float	(1)	(1)	N/A	weight factor used to scale each cell in the smoothed image production [default = 0.6]

Group: /ancillary_data/atmosphere					
Parameter	Type	ATL16 Dim.	ATL17 Dim.	Units	Description
asr_cloud_threshold	integer	(1)	(1)	N/A	when generating combined_global_cloud_frac, *asr_cloud_probability* () will be used to increase the cloud count when it meets or exceeds *asr_cloud_threshold*, that is the minimum value to increment the cloud counter grid box, nominal value = 70 [default = 70]
gen_cloud_od_max	integer	(1)	(1)	N/A	for the expanded global total column optical depth over water, when calculating an estimated value to replace INVALID *column_od_asr* () over water profile values, the parameter *gen_cloud_od_max* provides the maximum value, i.e., the ranging upper limit, for the calculation; the nominal value is 35 [default = 35]
laser_angle_limit	float	(1)	(1)	degrees	laser beam off-nadir angle limiting value for filtering the computation of global total column optical depth, expanded global total column optical depth, global, north and south polar ASR; the constant values have been 2.0 and 3.0 degrees; the nominal [and default] value is now 6.0 degrees

NOTES: The values indicated in this document are listed as control defaults above; execution overrides are provided for replacement of these control parameters within the production environment. The parameters "*global_grid_lon_scale*" and "*polar_grid_lon_scale*" now replace the Version 2 ATL16/ATL17 parameter "*lon_scale*". Similarly, the parameters "*global_grid_lat_scale*" and "*polar_grid_lat_scale*" now replace the Version 2 ATL16/ATL17 parameter "*lat_scale*".

Table 7. Gridded Products List of Statistical Parameters

Group: /quality_assessment/atmosphere			
Parameter	Type	Units	Description
global_cloud_frac_min	float	fraction	global cloud fraction minimum
global_cloud_frac_max	float	fraction	global cloud fraction maximum
global_cloud_frac_mean	float	fraction	global cloud fraction mean
global_cloud_frac_sdev	float	fraction	global cloud fraction standard deviation
combined_global_cloud_frac_min	float	fraction	combined global cloud fraction minimum
combined_global_cloud_frac_max	float	fraction	combined global cloud fraction maximum
combined_global_cloud_frac_mean	float	fraction	combined global cloud fraction mean
combined_global_cloud_frac_sdev	float	fraction	combined global cloud fraction standard deviation
global_aerosol_frac_min	float	fraction	global aerosol fraction minimum
global_aerosol_frac_max	float	fraction	global aerosol fraction maximum
global_aerosol_frac_mean	float	fraction	global aerosol fraction mean
global_aerosol_frac_sdev	float	fraction	global aerosol fraction standard deviation
global_clear_frac_min	float	fraction	global clear fraction minimum
global_clear_frac_max	float	fraction	global clear fraction maximum
global_clear_frac_mean	float	fraction	global clear fraction mean
global_clear_frac_sdev	float	fraction	global clear fraction standard deviation
global_asr_cloud_min	float	fraction	global ASR cloud fraction minimum
global_asr_cloud_max	float	fraction	global ASR cloud fraction maximum
global_asr_cloud_mean	float	fraction	global ASR cloud fraction mean
global_asr_cloud_sdev	float	fraction	global ASR cloud fraction standard deviation
npolar_asr_cloud_min	float	fraction	north polar ASR cloud fraction minimum
npolar_asr_cloud_max	float	fraction	north polar ASR cloud fraction maximum
npolar_asr_cloud_mean	float	fraction	north polar ASR cloud fraction mean
npolar_asr_cloud_sdev	float	fraction	north polar ASR cloud fraction standard deviation
spolar_asr_cloud_min	float	fraction	south polar ASR cloud fraction minimum
spolar_asr_cloud_max	float	fraction	south polar ASR cloud fraction maximum
spolar_asr_cloud_mean	float	fraction	south polar ASR cloud fraction mean
spolar_asr_cloud_sdev	float	fraction	south polar ASR cloud fraction standard deviation

Group: /quality_assessment/atmosphere			
Parameter	Type	Units	Description
npolar_lowcloud_frac_min	float	fraction	north polar low (<= 4 km) cloud fraction minimum
npolar_lowcloud_frac_max	float	fraction	north polar low (<= 4 km) cloud fraction maximum
npolar_lowcloud_frac_mean	float	fraction	north polar low (<= 4 km) cloud fraction mean
npolar_lowcloud_frac_sdev	float	fraction	north polar low (<= 4 km) cloud fraction standard deviation
spolar_lowcloud_frac_min	float	fraction	south polar low (<= 4 km) cloud fraction minimum
spolar_lowcloud_frac_max	float	fraction	south polar low (<= 4 km) cloud fraction maximum
spolar_lowcloud_frac_mean	float	fraction	south polar low (<= 4 km) cloud fraction mean
spolar_lowcloud_frac_sdev	float	fraction	south polar low (<= 4 km) cloud fraction standard deviation
npolar_midcloud_frac_min	float	fraction	north polar mid (> 4 km and <= 8 km) cloud fraction minimum
npolar_midcloud_frac_max	float	fraction	north polar mid (> 4 km and <= 8 km) cloud fraction maximum
npolar_midcloud_frac_mean	float	fraction	north polar mid (> 4 km and <= 8 km) cloud fraction mean
npolar_midcloud_frac_sdev	float	fraction	north polar mid (> 4 km and <= 8 km) cloud fraction standard deviation
spolar_midcloud_frac_min	float	fraction	south polar mid (> 4 km and <= 8 km) cloud fraction minimum
spolar_midcloud_frac_max	float	fraction	south polar mid (> 4 km and <= 8 km) cloud fraction maximum
spolar_midcloud_frac_mean	float	fraction	south polar mid (> 4 km and <= 8 km) cloud fraction mean
spolar_midcloud_frac_sdev	float	fraction	south polar mid (> 4 km and <= 8 km) cloud fraction standard deviation
npolar_highcloud_frac_min	float	fraction	north polar high (> 8 km) cloud fraction minimum
npolar_highcloud_frac_max	float	fraction	north polar high (> 8 km) cloud fraction maximum
npolar_highcloud_frac_mean	float	fraction	north polar high (> 8 km) cloud fraction mean
npolar_highcloud_frac_sdev	float	fraction	north polar high (> 8 km) cloud fraction standard deviation
spolar_highcloud_frac_min	float	fraction	south polar high (> 8 km) cloud fraction minimum

Group: /quality_assessment/atmosphere			
Parameter	Type	Units	Description
spolar_highcloud_frac_max	float	fraction	south polar high (> 8 km) cloud fraction maximum
spolar_highcloud_frac_mean	float	fraction	south polar high (> 8 km) cloud fraction mean
spolar_highcloud_frac_sdev	float	fraction	south polar high (> 8 km) cloud fraction standard deviation
npolar_totalcloud_frac_min	float	fraction	north polar total cloud fraction minimum
npolar_totalcloud_frac_max	float	fraction	north polar total cloud fraction maximum
npolar_totalcloud_frac_mean	float	fraction	north polar total cloud fraction mean
npolar_totalcloud_frac_sdev	float	fraction	north polar total cloud fraction standard deviation
spolar_totalcloud_frac_min	float	fraction	south polar total cloud fraction minimum
spolar_totalcloud_frac_max	float	fraction	south polar total cloud fraction maximum
spolar_totalcloud_frac_mean	float	fraction	south polar total cloud fraction mean
spolar_totalcloud_frac_sdev	float	fraction	south polar total cloud fraction standard deviation
npolar_transcloud_frac_min	float	fraction	north polar transmissive cloud fraction minimum
npolar_transcloud_frac_max	float	fraction	north polar transmissive cloud fraction maximum
npolar_transcloud_frac_mean	float	fraction	north polar transmissive cloud fraction mean
npolar_transcloud_frac_sdev	float	fraction	north polar transmissive cloud fraction standard deviation
spolar_transcloud_frac_min	float	fraction	south polar transmissive cloud fraction minimum
spolar_transcloud_frac_max	float	fraction	south polar transmissive cloud fraction maximum
spolar_transcloud_frac_mean	float	fraction	south polar transmissive cloud fraction mean
spolar_transcloud_frac_sdev	float	fraction	south polar transmissive cloud fraction standard deviation
npolar_opaquecloud_frac_min	float	fraction	north polar opaque cloud fraction minimum
npolar_opaquecloud_frac_max	float	fraction	north polar opaque cloud fraction maximum
npolar_opaquecloud_frac_mean	float	fraction	north polar opaque cloud fraction mean
npolar_opaquecloud_frac_sdev	float	fraction	north polar opaque cloud fraction standard deviation

Group: /quality_assessment/atmosphere			
Parameter	Type	Units	Description
spolar_opaquecloud_frac_min	float	fraction	south polar opaque cloud fraction minimum
spolar_opaquecloud_frac_max	float	fraction	south polar opaque cloud fraction maximum
spolar_opaquecloud_frac_mean	float	fraction	south polar opaque cloud fraction mean
spolar_opaquecloud_frac_sdev	float	fraction	south polar opaque cloud fraction standard deviation
global_column_od_min	float	unitless	global total column optical depth minimum
global_column_od_max	float	unitless	global total column optical depth maximum
global_column_od_mean	float	unitless	global total column optical depth mean
global_column_od_sdev	float	unitless	global total column optical depth standard deviation
expanded_global_column_od_min	float	unitless	expanded global total column optical depth minimum
expanded_global_column_od_max	float	unitless	expanded global total column optical depth maximum
expanded_global_column_od_mean	float	unitless	expanded global total column optical depth mean
expanded_global_column_od_sdev	float	unitless	expanded global total column optical depth standard deviation
npolar_lorate_blowing_snow_freq_min	float	percent	low-rate blowing snow frequency for the northern hemisphere polar region minimum
npolar_lorate_blowing_snow_freq_max	float	percent	low-rate blowing snow frequency for the northern hemisphere polar region maximum
npolar_lorate_blowing_snow_freq_mean	float	percent	low-rate blowing snow frequency for the northern hemisphere polar region mean
npolar_lorate_blowing_snow_freq_sdev	float	percent	low-rate blowing snow frequency for the northern hemisphere polar region standard deviation
spolar_lorate_blowing_snow_freq_min	float	percent	low-rate blowing snow frequency for the southern hemisphere polar region minimum
spolar_lorate_blowing_snow_freq_max	float	percent	low-rate blowing snow frequency for the southern hemisphere polar region maximum

Group: /quality_assessment/atmosphere			
Parameter	Type	Units	Description
spolar_lorate_blowing_snow_freq_mean	float	percent	low-rate blowing snow frequency for the southern hemisphere polar region mean
spolar_lorate_blowing_snow_freq_sdev	float	percent	low-rate blowing snow frequency for the southern hemisphere polar region standard deviation
npolar_hirate_blowing_snow_freq_min	float	percent	high-rate blowing snow frequency for the northern hemisphere polar region minimum
npolar_hirate_blowing_snow_freq_max	float	percent	high-rate blowing snow frequency for the northern hemisphere polar region maximum
npolar_hirate_blowing_snow_freq_mean	float	percent	high-rate blowing snow frequency for the northern hemisphere polar region mean
npolar_hirate_blowing_snow_freq_sdev	float	percent	high-rate blowing snow frequency for the northern hemisphere polar region standard deviation
spolar_hirate_blowing_snow_freq_min	float	percent	high-rate blowing snow frequency for the southern hemisphere polar region minimum
spolar_hirate_blowing_snow_freq_max	float	percent	high-rate blowing snow frequency for the southern hemisphere polar region maximum
spolar_hirate_blowing_snow_freq_mean	float	percent	high-rate blowing snow frequency for the southern hemisphere polar region mean
spolar_hirate_blowing_snow_freq_sdev	float	percent	high-rate blowing snow frequency for the southern hemisphere polar region standard deviation
spolar_surf_ddust_freq_min	float	0 – 1	south polar surface diamond dust frequency minimum
spolar_surf_ddust_freq_max	float	0 – 1	south polar surface diamond dust frequency maximum
spolar_surf_ddust_freq_mean	float	0 – 1	south polar surface diamond dust frequency mean
spolar_surf_ddust_freq_sdev	float	0 – 1	south polar surface diamond dust frequency standard deviation
global_asr_min	float	0 - 1	global apparent surface reflectance minimum
global_asr_max	float	0 - 1	global apparent surface reflectance maximum
global_asr_mean	float	0 - 1	global apparent surface reflectance mean

Group: /quality_assessment/atmosphere			
Parameter	Type	Units	Description
global_asr_sdev	float	0 - 1	global apparent surface reflectance standard deviation
npolar_asr_min	float	0 - 1	north polar apparent surface reflectance minimum
npolar_asr_max	float	0 - 1	north polar apparent surface reflectance maximum
npolar_asr_mean	float	0 - 1	north polar apparent surface reflectance mean
npolar_asr_sdev	float	0 - 1	north polar apparent surface reflectance standard deviation
spolar_asr_min	float	0 - 1	south polar apparent surface reflectance minimum
spolar_asr_max	float	0 - 1	south polar apparent surface reflectance maximum
spolar_asr_mean	float	0 - 1	south polar apparent surface reflectance mean
spolar_asr_sdev	float	0 - 1	south polar apparent surface reflectance standard deviation
global_grnd_detect_min	float	fraction	global ground detection frequency minimum
global_grnd_detect_max	float	fraction	global ground detection frequency maximum
global_grnd_detect_mean	float	fraction	global ground detection frequency mean
global_grnd_detect_sdev	float	fraction	global ground detection frequency standard deviation
npolar_grnd_detect_min	float	fraction	north polar ground detection frequency minimum
npolar_grnd_detect_max	float	fraction	north polar ground detection frequency maximum
npolar_grnd_detect_mean	float	fraction	north polar ground detection frequency mean
npolar_grnd_detect_sdev	float	fraction	north polar ground detection frequency standard deviation
spolar_grnd_detect_min	float	fraction	south polar ground detection frequency minimum
spolar_grnd_detect_max	float	fraction	south polar ground detection frequency maximum
spolar_grnd_detect_mean	float	fraction	south polar ground detection frequency mean
spolar_grnd_detect_sdev	float	fraction	south polar ground detection frequency standard deviation

NOTE: the atmosphere gridded parameters statistical data will be located within the product "/quality_assessment/atmosphere" group.

Table 8. List of Input Parameters from the ATL09 Level-3A Calibrated Backscatter Profile and Atmospheric Layer Characteristics Data

Group: /ancillary_data			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
end_delta_time	double	seconds since 2018-01-01	ATLAS End Time (Actual) / Number of GPS seconds since the ATLAS SDP epoch at the last data point in the file. The ATLAS Standard Data Products (SDP) epoch offset is defined within /ancillary_data/atlas_sdp_gps_epoch as the number of GPS seconds between the GPS epoch (1980-01-06T00:00:00.000000Z UTC) and the ATLAS SDP epoch. By adding the offset contained within atlas_sdp_gps_epoch to delta time parameters, the time in gps_seconds relative to the GPS epoch can be computed. / None
start_delta_time	double	seconds since 2018-01-01	ATLAS Start Time (Actual) / Number of GPS seconds since the ATLAS SDP epoch at the first data point in the file. The ATLAS Standard Data Products (SDP) epoch offset is defined within /ancillary_data/atlas_sdp_gps_epoch as the number of GPS seconds between the GPS epoch (1980-01-06T00:00:00.000000Z UTC) and the ATLAS SDP epoch. By adding the offset contained within atlas_sdp_gps_epoch to delta time parameters, the time in gps_seconds relative to the GPS epoch can be computed. / None

Group: /profile_x/high_rate			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
apparent_surf_reflec ()	float	1	Apparent Surface Reflectance / Apparent Surface Reflectance (ASR). Atmosphere ATBD (Equation 4.7). / None
asr_cloud_probability ()	float	1	ASR Cloud Probability / Probability of the occurrence of cloud based on the magnitude of the apparent surface reflectivity. Atmosphere ATBD, part 1 (Section 4.6.2.3). / None
beam_elevation ()	float	degrees	Beam Elevation / Elevation angle of each ATLAS laser beam incident to the surface (from precision pointing determination, ATL03 ATBD). / INVALID_R4B

Group: /profile_x/high_rate			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
bsnow_con ()	integer _1	1	Blowing Snow Confidence / Blowing snow confidence. -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. Atmosphere ATBD. Meanings: [-3 -2 -1 0 1 2 3 4 5 6]) (Values: ['surface_not_detected', 'no_surface_wind', 'no_scattering_layer_found', 'no_top_layer_found', 'none_little', 'weak', 'moderate', 'moderate_high', 'high', 'very_high']). / INVALID_I2B
bsnow_h ()	float	meters	Blowing Snow Layer Thickness / Blowing Snow layer thickness (height of top above surface). Atmosphere ATBD. / INVALID_R4B
cloud_flag_atm ()	integer _1	1	Cloud Flag Atm / Number of layers found from the backscatter profile using the DDA layer finder. Atmosphere ATBD. / None
column_od_asr ()	float	1	Optical Depth from ASR / Optical depth of atmosphere column based on apparent surface reflectance and the assumed actual surface reflectance. Atmosphere ATBD. / INVALID_R4B
column_od_asr_qf ()	integer _1	1	Optical Depth ASR Quality / Total column optical depth from ASR quality flag. The total atmosphere column particulate optical depth can be computed from the apparent surface reflectance if the actual surface reflectance is well known. The flag indicates the surface type over which the flag is computed in the order from unable to compute (0 - no_surface_signal) to best quality (4=water). Atmosphere ATBD. (Meanings: [0 1 2 3 4]) (Values: ['no_signal', 'land', 'sea_ice', 'land_ice', 'water']). / INVALID_I1B
ddust_hbot_dens ()	float	meters	Diamond Dust Density Layer Bottom Height / Diamond dust from density layer bottom height. For *bsnow_dens_flag* () = 2 the bottom is one atmosphere bin (30 meters) above the top of the blowing snow. For *bsnow_dens_flag* () = 3 or 4 the bottom is one atmosphere bin (30 meters) above the surface. Surface is defined as *surface_h_dens* () if valid, otherwise *surface_height* () if valid, otherwise *dem_h* (). Atmosphere ATBD. / INVALID_R4B

Group: /profile_x/high_rate			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
delta_time ()	double	seconds since 2018-01-01	Elapsed GPS Seconds / Number of GPS seconds since the ATLAS SDP epoch. The ATLAS Standard Data Products (SDP) epoch offset is defined within /ancillary_data/atlas_sdp_gps_epoch as the number of GPS seconds between the GPS epoch (1980-01-06T00:00:00.000000Z UTC) and the ATLAS SDP epoch. By adding the offset contained within atlas_sdp_gps_epoch to delta time parameters, the time in gps_seconds relative to the GPS epoch can be computed. Atmosphere ATBD. / None
dem_h ()	float	meters	DEM Height / Best available Digital Elevation Model (DEM) (in priority of Arctic/Antarctic/Global/MSS) value at the geolocation point. Atmosphere ATBD. / INVALID_R4B
latitude ()	double	degrees_north	Latitude of the ATM Histogram / Latitude at the top of the ATM histogram, WGS84, North=+, Derived from the geolocation of the ATM range window. ATL03g ATBD. / None
layer_attr (,)	integer_1	1	Layer Attribute Flag / Layer attribute flag for each of the possible 10 layers. Indicates (0) no_layer (1) cloud, (2) aerosol or (3) unknown. Atmosphere ATBD. (Meanings: [0 1 2 3]) (Values: ['no_layer', 'cloud', 'aerosol', 'unknown']). / None
layer_top (,)	float	meters	Height Layer Tops / Height of top of detected layers. Atmosphere ATBD. / INVALID_R4B
longitude ()	double	degrees_east	Longitude of the ATM Histogram / Longitude at the top of the ATM histogram, WGS84, East=+, derived from the geolocation of the ATM range window. Atmosphere ATBD. / None
segment_id ()	integer	1	Along-Track Segment ID Number / A 7-digit number identifying the along-track geolocation segment number. These are sequential, starting with 1 for the first segment after an ascending equatorial crossing node. ATL03 ATBD (Section 3.1). / None

Group: /profile_x/high_rate			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
solar_elevation ()	float	degrees	Solar Elevation / Solar Angle above or below the plane tangent to the ellipsoid surface at the laser spot. Positive values mean the sun is above the horizon, while negative values mean it is below the horizon. The effect of atmospheric refraction is not included. This is a low precision value, with approximately TBD degree accuracy. ATL03g ATBD. / None
surf_type (,)	integer_1	1	Surface Type / Flags describing which surface types this interval is associated with. 0=not type, 1=is type. Order of array is land, ocean, sea ice, land ice, inland water. ATL03 ATBD (Section 4). (Meanings: [0 1]) (Values: ['not_type', 'is_type']). / None
surface_bin ()	integer	1	Surface Bin / Vertically aligned, Normalized Relative Backscatter (NRB) bin number of the detected surface return. Atmosphere ATBD (Section 3.3.5). / INVALID_I4B
surface_sig ()	float	counts	Surface Signal Count / Number of photons in the detected surface bin. Atmosphere ATBD (Section 3.3.5). / None

Group: /profile_x/low_rate			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
bsnow_con ()	integer_1	1	Blowing Snow Confidence / Blowing snow confidence. -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. Atmosphere ATBD. Meanings: [-3 -2 -1 0 1 2 3 4 5 6]) (Values: ['surface_not_detected', 'no_surface_wind', 'no_scattering_layer_found', 'no_top_layer_found', 'none_little', 'weak', 'moderate', 'moderate_high', 'high', 'very_high']). / INVALID_I2B
bsnow_h ()	float	meters	Blowing Snow Layer Thickness / Blowing Snow layer thickness (height of top above surface). Atmosphere ATBD. / INVALID_R4B

Group: /profile_x/low_rate			
Parameter	Type	Units	Long Name / Description / Invalid Value (optional)
delta_time ()	double	seconds since 2018-01-01	Elapsed GPS Seconds / Number of GPS seconds since the ATLAS SDP epoch. The ATLAS Standard Data Products (SDP) epoch offset is defined within /ancillary_data/atlas_sdp_gps_epoch as the number of GPS seconds between the GPS epoch (1980-01-06T00:00:00.000000Z UTC) and the ATLAS SDP epoch. By adding the offset contained within atlas_sdp_gps_epoch to delta time parameters, the time in gps_seconds relative to the GPS epoch can be computed. Atmosphere ATBD. / None
latitude ()	double	degrees _north	Latitude of the ATM Histogram / Latitude at the top of the ATM histogram, WGS84, North=+, Derived from the geolocation of the ATM range window. ATL03g ATBD. / None
longitude ()	double	degrees_east	Longitude of the ATM Histogram / Longitude at the top of the ATM histogram, WGS84, East=+, derived from the geolocation of the ATM range window. Atmosphere ATBD. / None

6.0 Product Production Considerations

List of ATBD Lead suggestions regarding the date/time span for production of atmosphere gridded data products:

- the monthly product will begin on the first day of the month.
- the monthly data product will end on the last day of the month.
- the first weekly data product within the month will begin on the first day of the month, end on the seventh day of the month, and contain seven days.
- the second weekly data product within the month will begin on the eighth day of the month, end on the fourteenth day of the month, and contain seven days.
- the third weekly data product within the month will begin on the fifteenth day of the month, end on the twenty-first day of the month, and contain seven days.
- the fourth weekly data product within the month will begin on the twenty-second day of the month, end on either the twenty-eighth, twenty-ninth, thirtieth, or thirty-first day of the month, and will contain either seven days, eight days, nine days, or ten days, respectively, depending on the calendar month and leap year.

The following tables supply the beginning and ending dates for the control file generation for production of monthly ATL17 and weekly ATL16 atmosphere gridded data products.

6.1 ATL17 Monthly Atmosphere Gridded Product Content Control

Monthly ATL17 Product File Content Control Information
(Used to control the collection and specification of ATL09 files to compose the product)

Month	Beginning Date	Ending Date	Number of Days	Possible Number of Files (RGTs)
January	January 01	January 31	31	474
February	February 01	February 28	28	428
February (leap year)	February 01	February 29	29	443
March	March 01	March 31	31	474
April	April 01	April 30	30	459
May	May 01	May 31	31	474
June	June 01	June 30	30	459
July	July 01	July 31	31	474
August	August 01	August 31	31	474
September	September 01	September 30	30	459
October	October 01	October 31	31	474
November	November 01	November 30	30	459
December	December 01	December 31	31	474

Table 9. Monthly ATL17 Data Product ATL09 File Composition by Month

6.2 ATL16 Weekly Atmosphere Gridded Product Content Control

Weekly ATL16 Product File Content Control Information
(Used to control the collection and specification of ATL09 files to compose the product)

Month	Week	Beginning Date	Ending Date	Number of Days	Possible Number of Files (RGTs)
January	01	January 01	January 07	07	107
January	02	January 08	January 14	07	107
January	03	January 15	January 21	07	107
January	04	January 22	January 31	10	153
February	01	February 01	February 07	07	107
February	02	February 08	February 14	07	107
February	03	February 15	February 21	07	107
February	04	February 22	February 28	07	107
February (leap year)	04	February 22	February 29	08	123
March	01	March 01	March 07	07	107
March	02	March 08	March 14	07	107
March	03	March 15	March 21	07	107
March	04	March 22	March 31	10	153
April	01	April 01	April 07	07	107
April	02	April 08	April 14	07	107
April	03	April 15	April 21	07	107
April	04	April 22	April 30	09	138
May	01	May 01	May 07	07	107
May	02	May 08	May 14	07	107
May	03	May 15	May 21	07	107
May	04	May 22	May 31	10	153
June	01	June 01	June 07	07	107
June	02	June 08	June 14	07	107
June	03	June 15	June 21	07	107
June	04	June 22	June 30	09	138
July	01	July 01	July 07	07	107
July	02	July 08	July 14	07	107
July	03	July 15	July 21	07	107
July	04	July 22	July 31	10	153
August	01	August 01	August 07	07	107
August	02	August 08	August 14	07	107
August	03	August 15	August 21	07	107
August	04	August 22	August 31	10	153
September	01	September 01	September 07	07	107
September	02	September 08	September 14	07	107
September	03	September 15	September 21	07	107
September	04	September 22	September 30	09	138

Month	Week	Beginning Date	Ending Date	Number of Days	Possible Number of Files (RGTs)
October	01	October 01	October 07	07	107
October	02	October 08	October 14	07	107
October	03	October 15	October 21	07	107
October	04	October 22	October 31	10	153
November	01	November 01	November 07	07	107
November	02	November 08	November 14	07	107
November	03	November 15	November 21	07	107
November	04	November 22	November 30	09	138
December	01	December 01	December 07	07	107
December	02	December 08	December 14	07	107
December	03	December 15	December 21	07	107
December	04	December 22	December 31	10	153

Table 10. Weekly ATL16 Data Product ATL09 File Composition by Month and Week

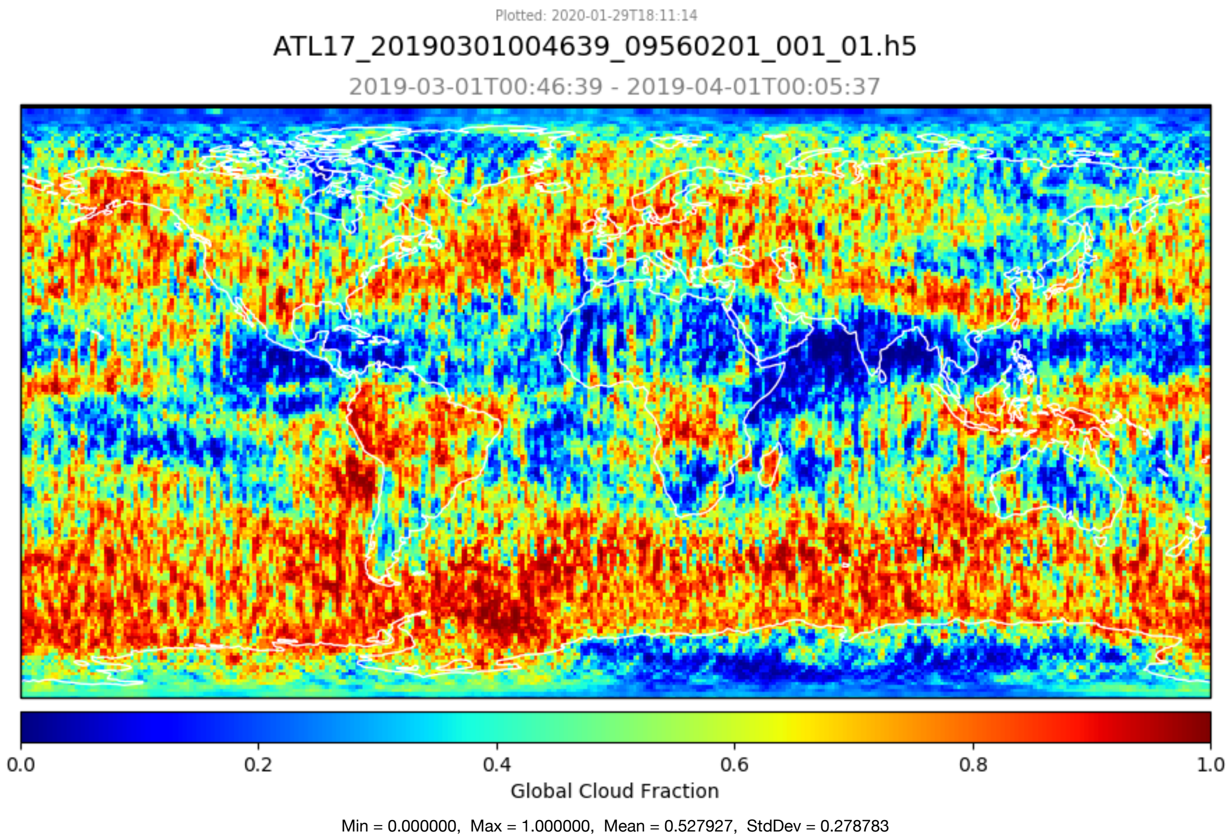
7.0 Acronyms and Abbreviations

Acronym / Abbreviation	Expansion / Definition
ASR	Apparent Surface Reflectance, Apparent Surface Reflectivity
ATBD	Algorithm Theoretical Basis Document
DDA	Density Dimension Algorithm
DEM	Digital Elevation Model
HDF	Hierarchical Data Format
HDF5	Hierarchical Data Format Version 5
Hz	Hertz
L3A	Level-3A
L3B	Level-3B
N/A	Not Applicable
NRB	Normalized Relative Backscatter
NSIDC	National Snow and Ice Data Center
OD	Optical Depth
PGE	Product Generation Executive
TCOD	Total Column Optical Depth

A.0 Attachments

A.1 Attachment A-1: Exhibit Rectangular Image with Statistical Data Label

Attachment A-1 Exhibit "atlas_plot" Application ATL17 Product Python Code Generated Rectangular Projection Global Parameter Image with Added Grid Statistical Data Sub-Label.



The graphic above presents the rectangular projection image of the Global Cloud Fraction parameter produced by the Python code application "atlas_plot.py" using the ATL16/ATL17 product specific "plot_atl16.py" Python code. The image extracted from the monthly ATL17 atmosphere gridded product for the month of March 2019 has been edited to apply the statistical data label showing the gridded data minimum, maximum, mean, and standard deviation values, positioned as a character text string sub-label

Min = 0.000000, Max = 1.000000, Mean = 0.527927, StdDev = 0.278783

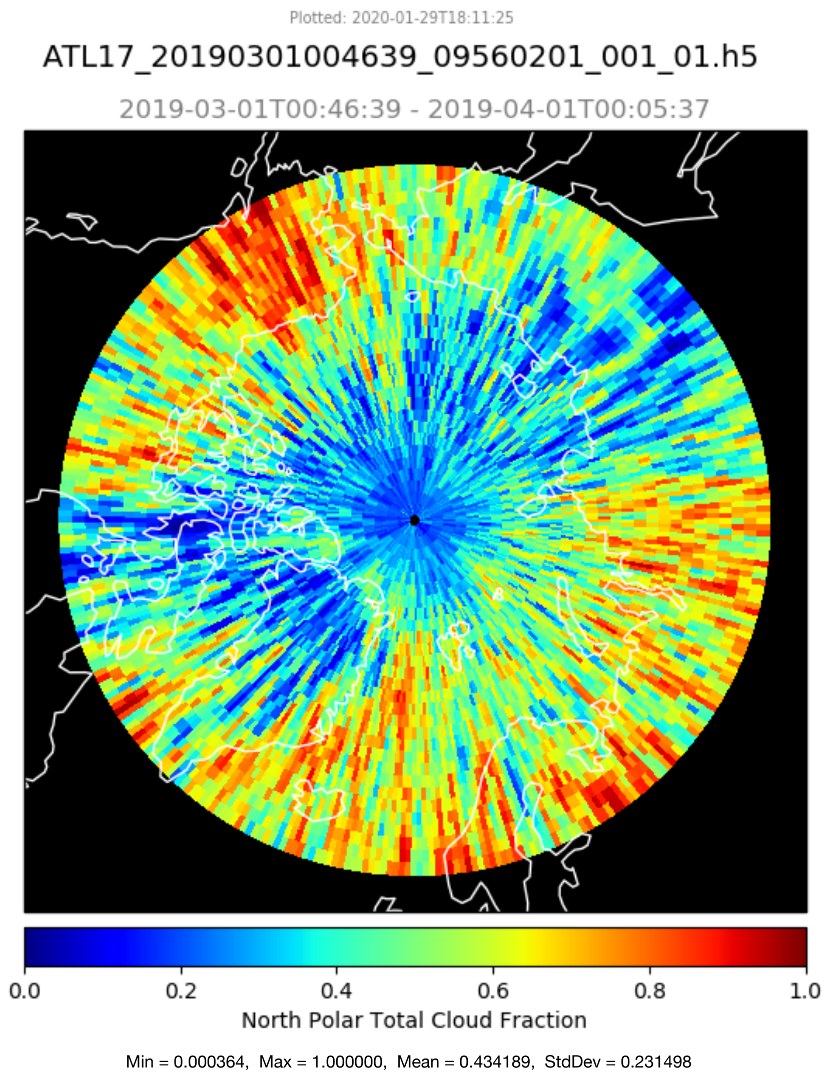
centered below the image parameter label

Global Cloud Fraction

The statistical date values for this example parameter image (and the other global and polar parameter images) will be obtained from the ATL17 product quality assessment data group by the image-generating Python code application. The basis for this image implementation is found in Section 3.10.

A.2 Attachment A-2: Exhibit Polar Image with Statistical Data Label

Attachment A-2 Exhibit “atlas_plot” Application ATL17 Product Python Code Generated Polar Stereographic Projection Polar Parameter Image with Added Grid Statistical Data Sub-Label.



The graphic above presents the polar stereographic projection image of the North Polar Total Cloud Fraction parameter produced by the Python code application “atlas_plot.py” using the ATL16/ATL17 product specific “plot_atl16.py“ Python code. The image extracted from the monthly ATL17 atmosphere gridded product for the month of March 2019 has been edited to apply the statistical data label showing the gridded data minimum, maximum, mean, and standard deviation values, positioned as a character text string sub-label

Min = 0.000364, Max = 1.000000, Mean = 0.434189, StdDev = 0.231498 centered below the image parameter label

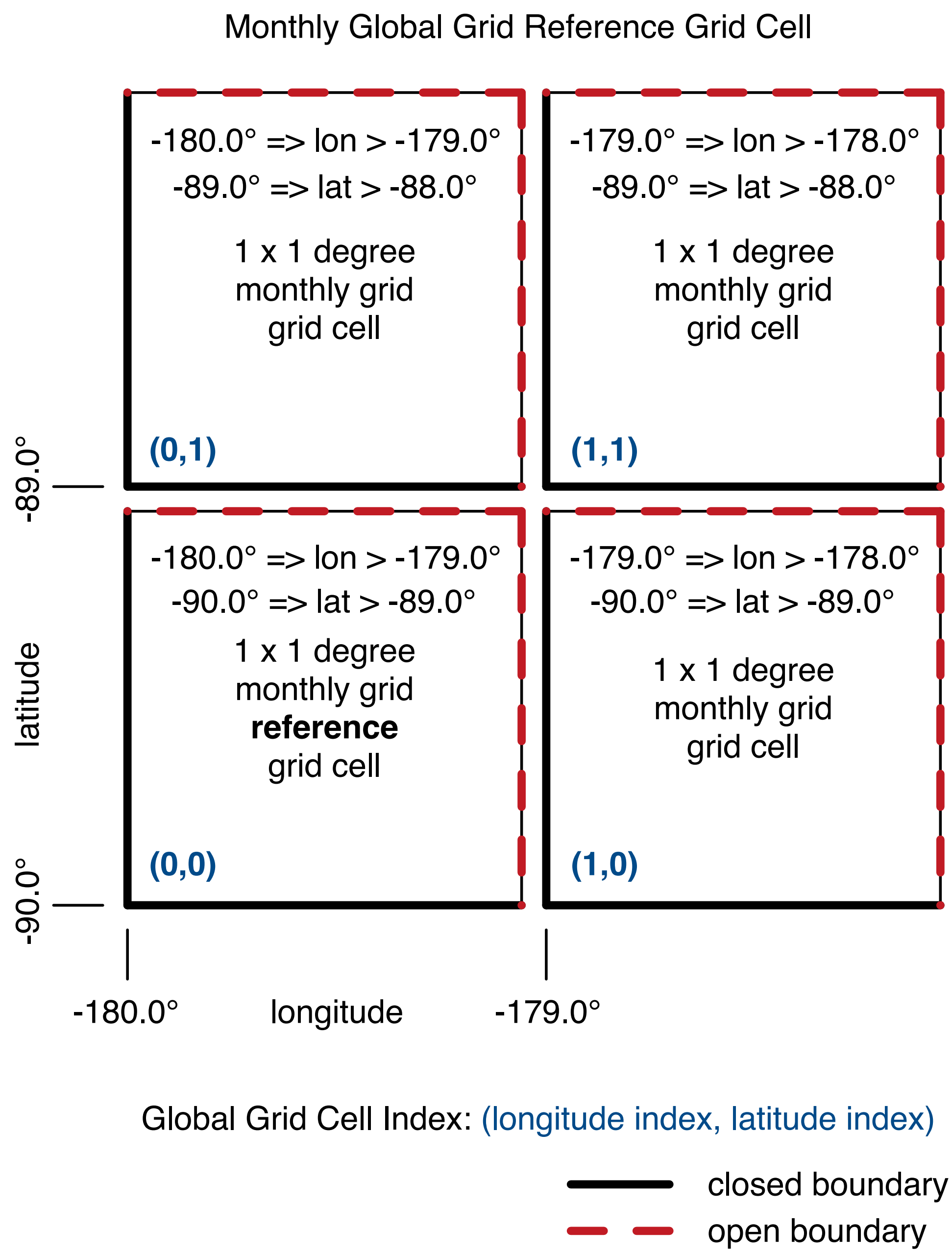
North Polar Total Cloud Fraction

The statistical date values for this example parameter image (and the other global and polar parameter images) will be obtained from the ATL17 product quality assessment data group by the image-generating Python code application. The basis for this image implementation is found in Section 3.10.

NOTE that the above exhibit images are generated with “atlas_l3b_atm” version 1.1 PGE using the monthly polar grid cell size of 1 degree by 1 degree. The Version 1.2 PGE will generate the polar grid projection with a cell size of 1.5 degrees longitude by 0.5 degrees latitude.

A.3 Attachment A-3: Example Global Gridded Parameter Reference Layout

Example Global Gridded Parameter Reference Layout
Grid Cell Index Formula Application for Profile Data Gridding



Reference index point: (0,0) = (-180,-90) = the <u>lower left corner</u>
Product: ATL17 – monthly gridded product (global parameters)
Grid size: global (rectangular projection): 1 degree longitude by 1 degree latitude

Attachment A-3 Graphical Image Illustrating Section 2.0 Global Grid Application and Index Computation for the ATL17 Monthly Gridded Atmosphere Product Parameter.

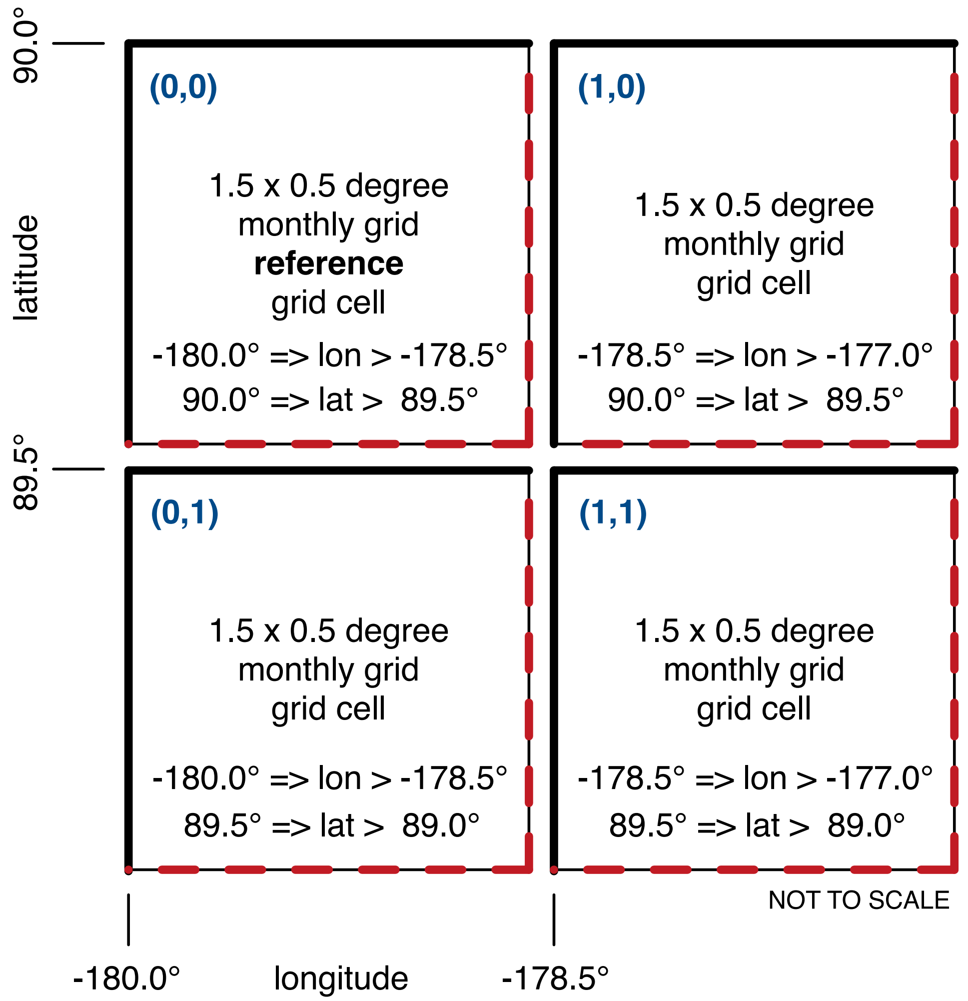
This graphic provides an example image to depict application of the Section 2.0 Global (rectangular projection) 1-degree longitude by 1-degree latitude grid cell size and indexing formula for the ATL17 monthly product grid cell mapping with open and closed boundaries indicated for the cells from the grid origin (reference) cell. For the global atmosphere gridded parameter array, the origin reference (longitude, latitude) = (i,j) index pair of (0,0) is equivalent to (-180°,-90°) and occurs at the lower left corner of the grid array.

A.4 Attachment A-4: Example North Polar Gridded Parameter Reference Layout

Example North Polar Gridded Parameter Reference Layout

Grid Cell Index Formula Application for Profile Data Gridding

Monthly North Polar Grid Reference Grid Cell



North Polar Grid Cell Index: (longitude index, latitude index)

closed boundary

open boundary

Reference index point: (0,0) = (-180,90) = the upper left corner

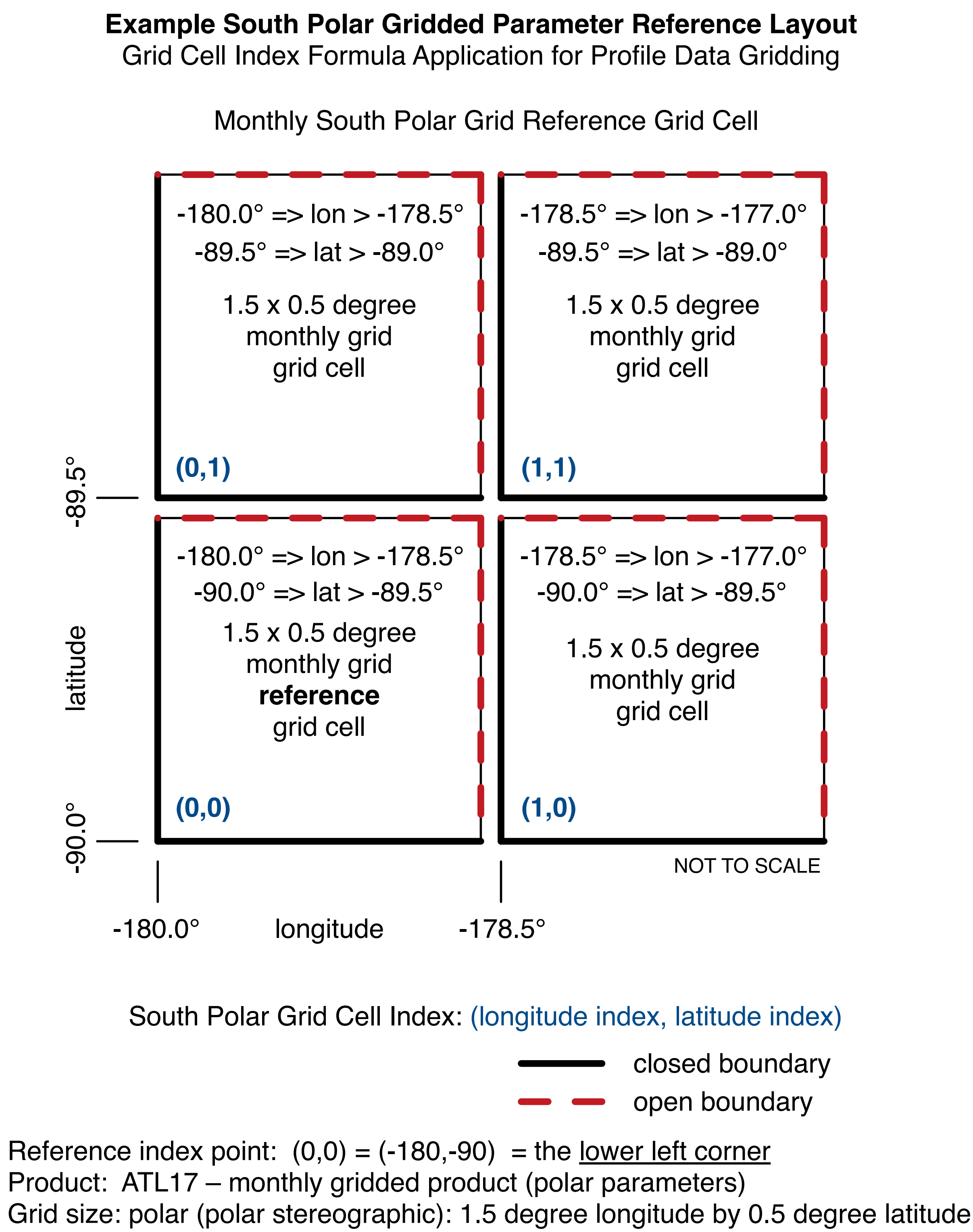
Product: ATL17 – monthly gridded product (polar parameters)

Grid size: polar (polar stereographic): 1.5 degree longitude by 0.5 degree latitude

Attachment A-4 Graphical Image Illustrating Section 2.0 North Polar Grid Application and Index Computation for the ATL17 Monthly Gridded Atmosphere Product Parameter

This graphic provides an example image to depict application of the Section 2.0 North Polar (polar stereographic projection) 1.5-degree longitude by 0.5-degree latitude grid cell size and indexing formula for the ATL17 monthly product grid cell mapping with open and closed boundaries indicated for the cells from the grid origin (reference) cell. For the North polar atmosphere gridded parameter array, the origin reference (longitude, latitude) = (i,j) index pair of (0,0) is equivalent to (-180°,90°) and occurs at the upper left corner of the grid array.

A.5 Attachment A-5: Example South Polar Gridded Parameter Reference Layout



Attachment A-5 Graphical Image Illustrating Section 2.0 South Polar Grid Application and Index Computation for the ATL17 Monthly Gridded Atmosphere Product Parameter

This graphic provides an example image to depict application of the Section 2.0 South Polar (polar stereographic projection) 1.5-degree longitude by 0.5 degrees latitude grid cell size and indexing formula for the ATL17 monthly product grid cell mapping with open and closed boundaries indicated for the cells from the grid origin (reference) cell. For the South polar atmosphere gridded parameter array, the origin reference (longitude, latitude) = (i,j) index pair of (0,0) is equivalent to (-180°,-90°) and occurs at the lower left corner of the grid array.

A.6 Attachment A-6: ATL17 Monthly Product Images Exhibition

This appendix section presents the ATL17 monthly atmosphere gridded product parameter images extracted with the Python utility program “hdf2png”. The ATL17 product is the result of processing of the ASAS functional test “func_test_960b1” (a.k.a., 960b1) as the acceptance test for the “atlas_l3b_atm” PGE v2.0. The processing sequence also includes the supplemental utility program executions on the ATL17 product. These utility programs, in order of execution are: “atl17_qa_util” v2.0, “atlas_meta” v5.0, “atlas_brw” v3.0, and “atlas_plot” v3.0 (using “plot_atl16” v1.4).

The ATL17 is a saturated product having been produced from the processing of the set of 556 ATL09 “ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics” product HDF5 files comprising the “func_test_960b1” input files. It is noted that a nominal ATL17 product is operationally produced from a set of 428 minimum to 474 maximum ATL09 product files. The functional test dataset covers ATLAS data for various dates for seventeen (17) cycle and reference ground track (rgt) collected granules (orbits).

NOTE: All images have been scaled with the exception of the final image in Exhibit 32.

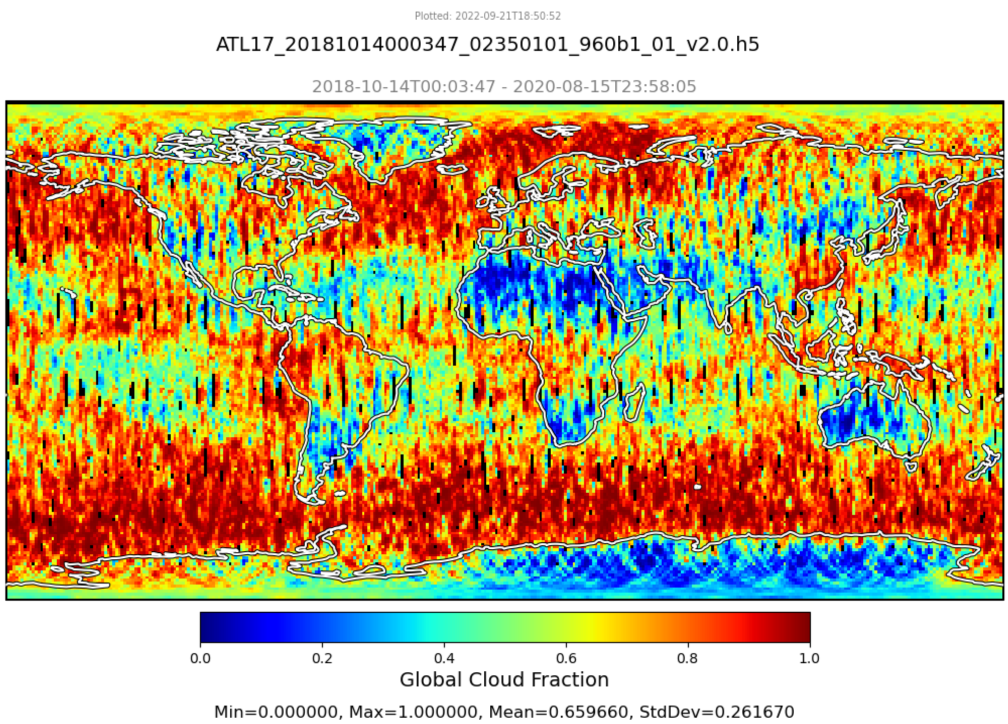


Exhibit 1: ATL17 “global_cloud_frac_img.png”

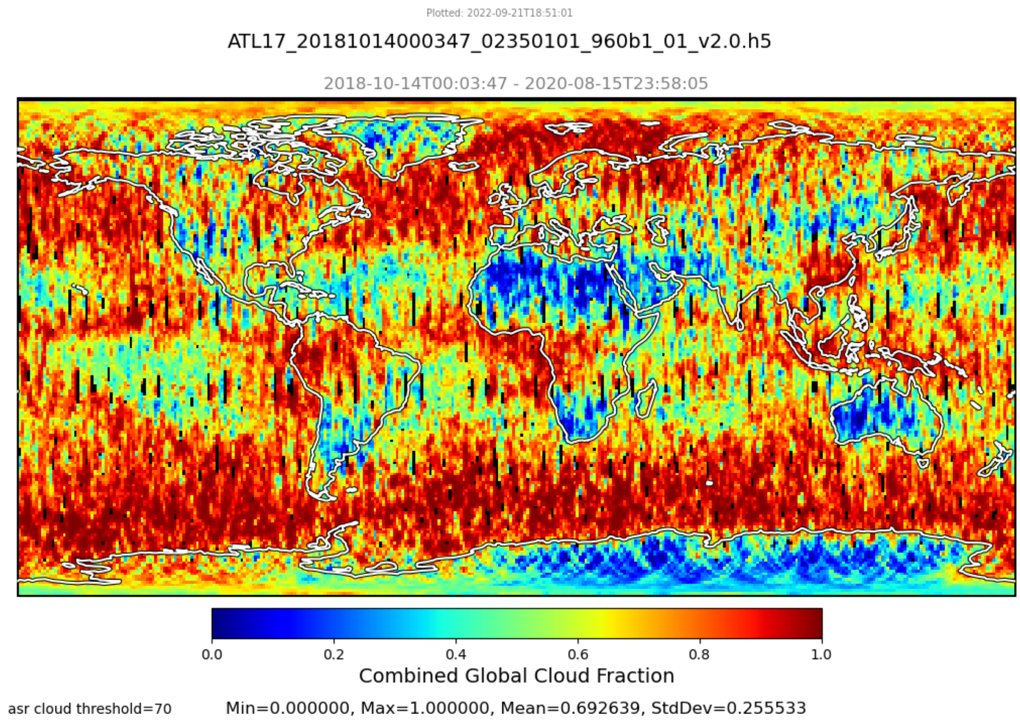


Exhibit 2: ATL17 "combined_global_cloud_frac_img.png"

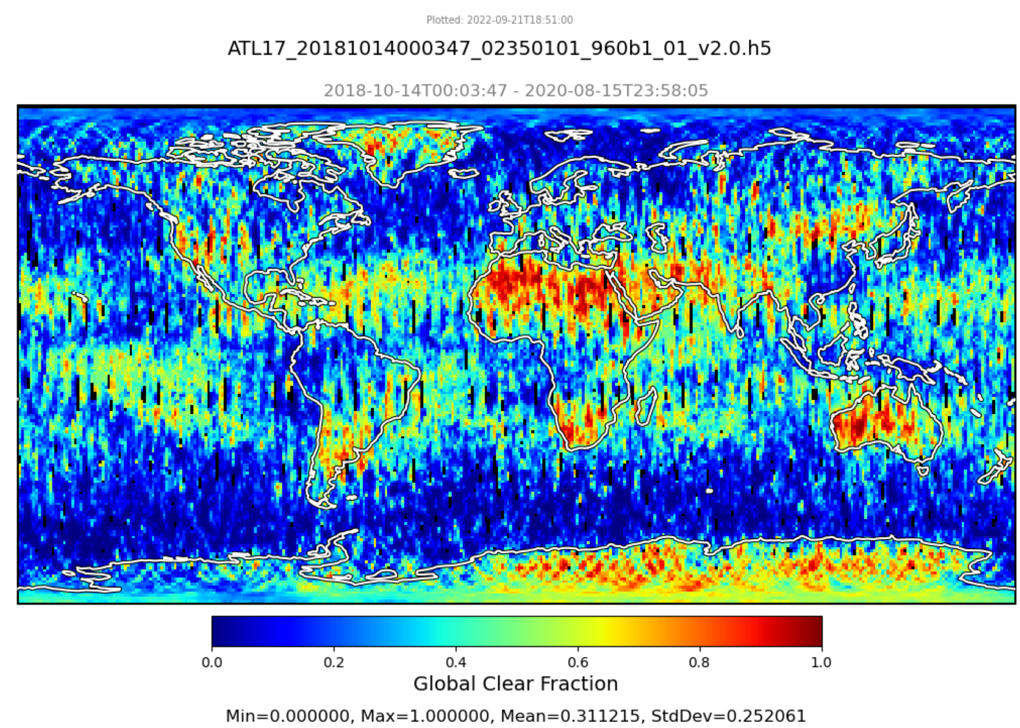


Exhibit 3: ATL17 "global_clear_frac_img.png"

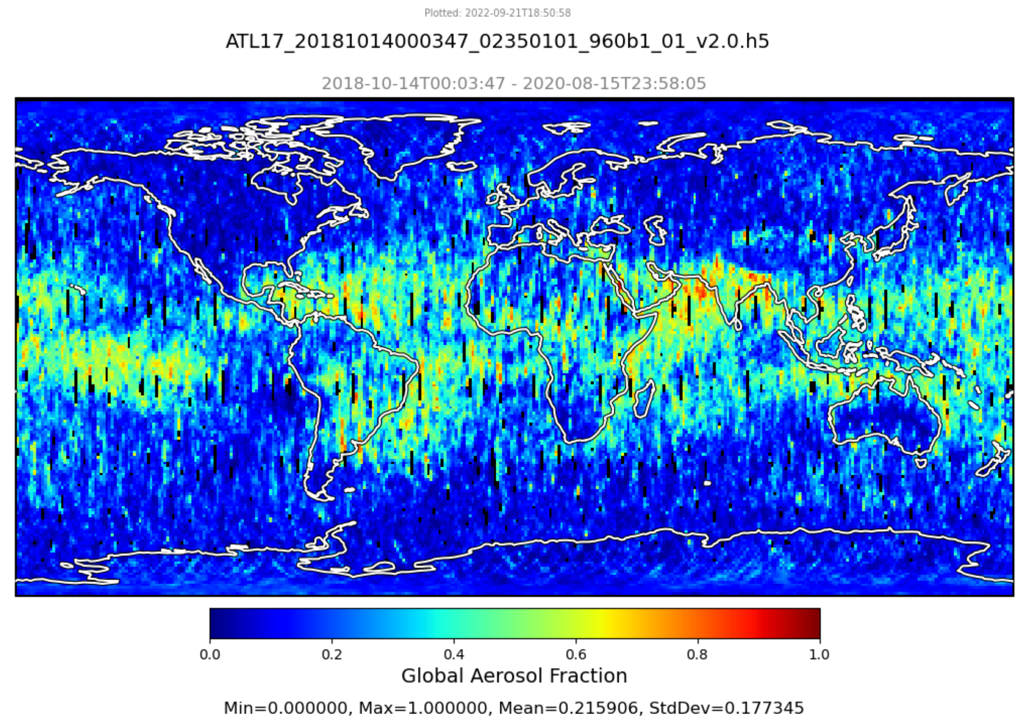


Exhibit 4: ATL17 “global_aerosol_frac_img.png”

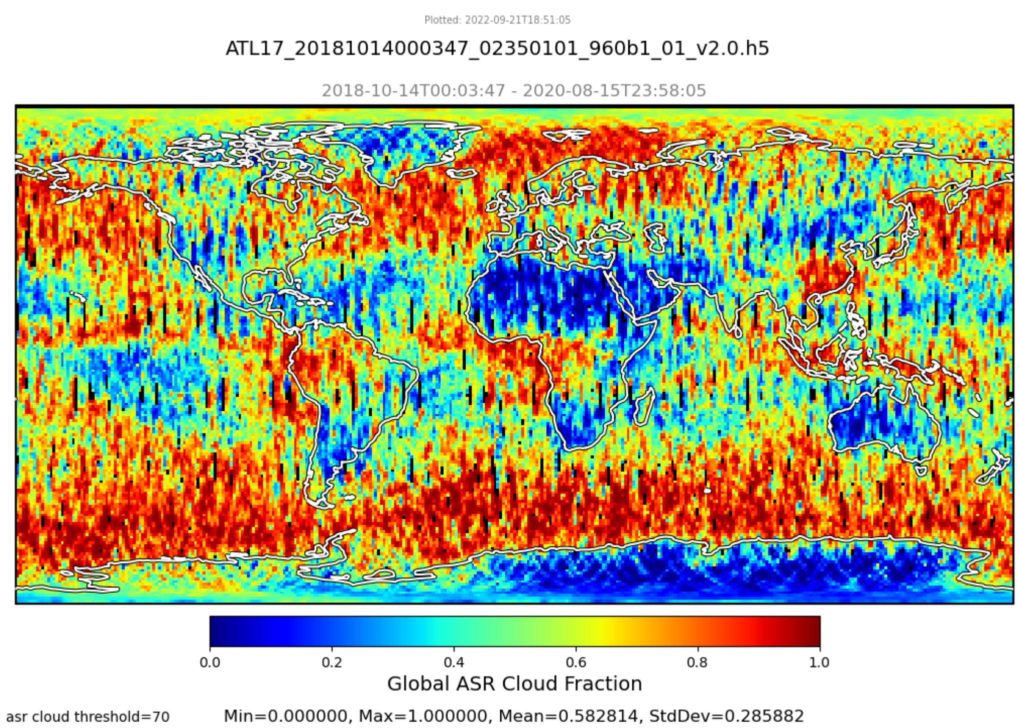


Exhibit 5: ATL17 “global_asr_cloud_frac_img.png”

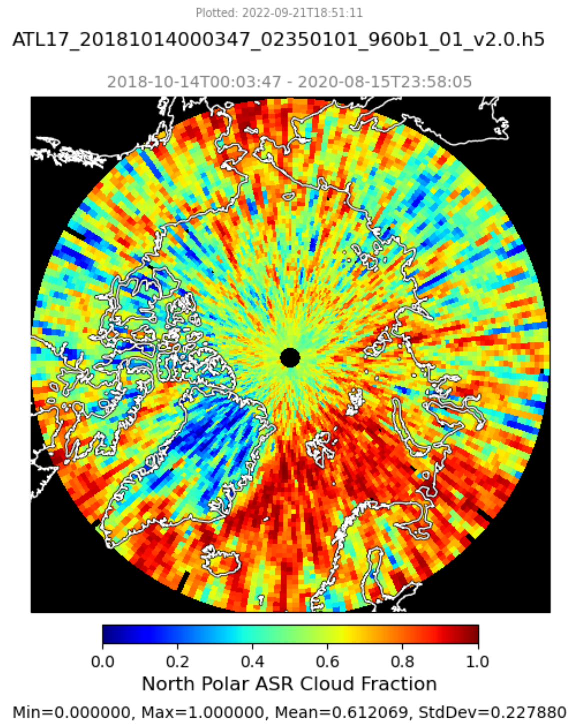


Exhibit 6: ATL17 "npolar_asr_cloud_frac_img.png"

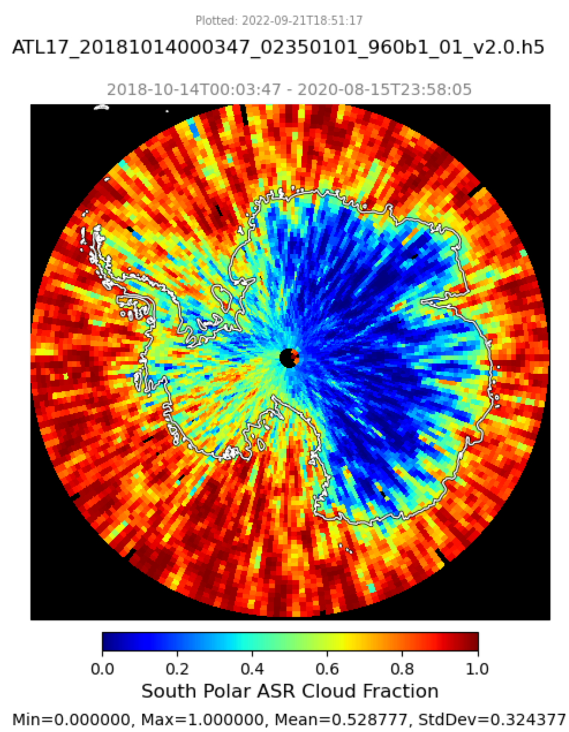


Exhibit 7: ATL17 "spolar_asr_cloud_frac_img.png"

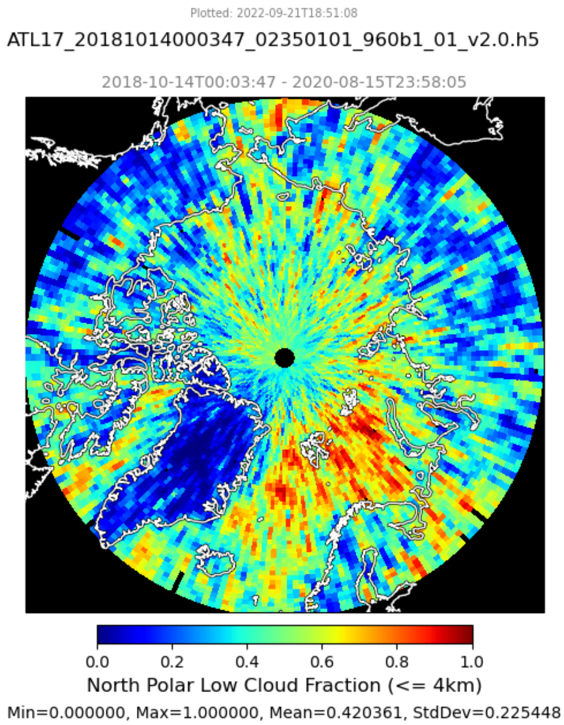


Exhibit 8: ATL17 “npolar_lowcloud_frac_img.png”

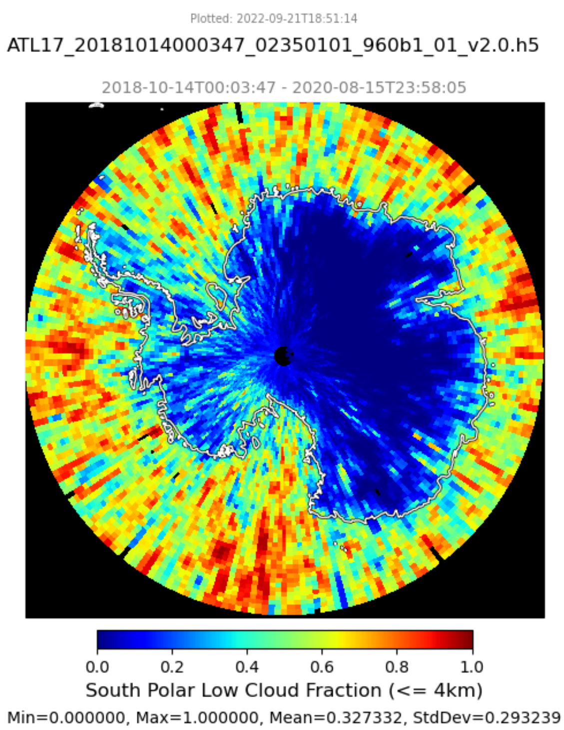


Exhibit 9: ATL17 “spolar_lowcloud_frac_img.png”

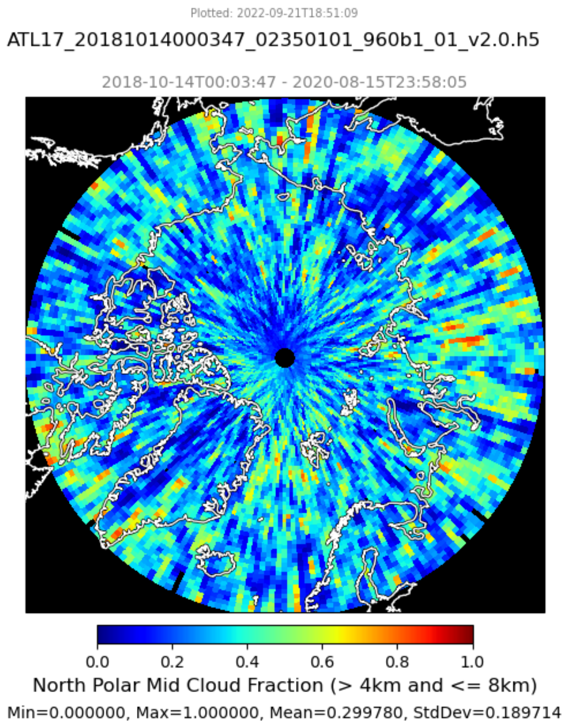


Exhibit 10: ATL17 "npolar_midcloud_frac_img.png"

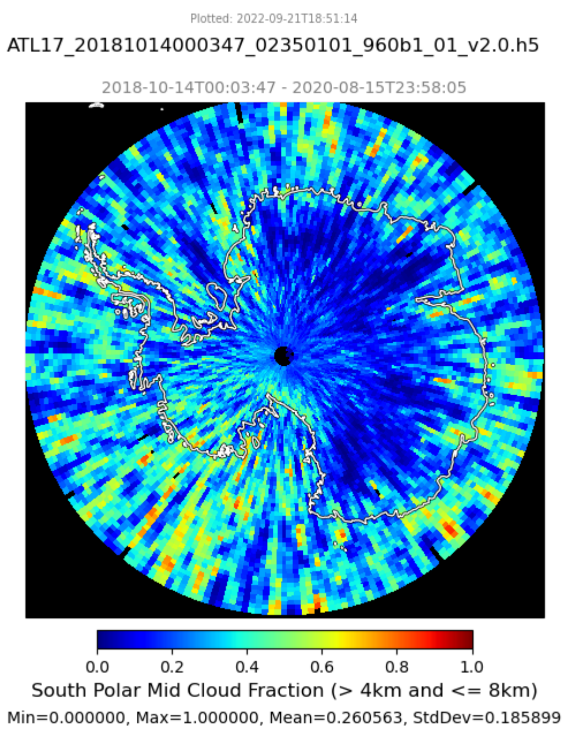


Exhibit 11: ATL17 "spolar_midcloud_frac_img.png"

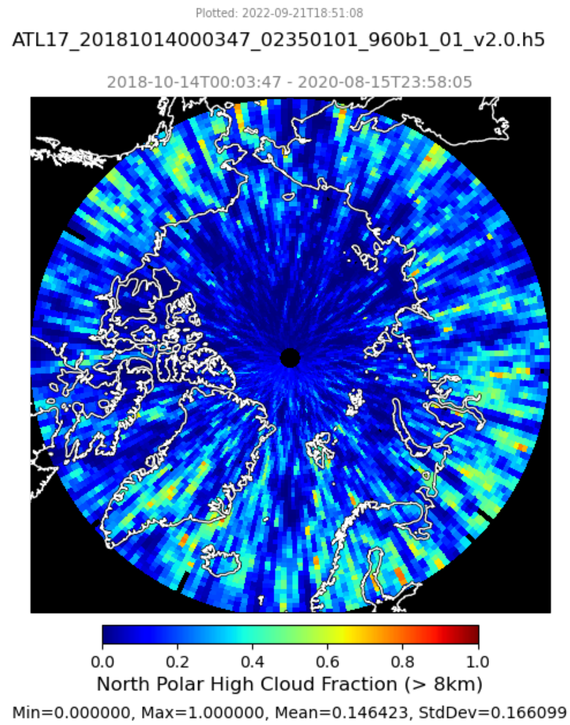


Exhibit 12: ATL17 "npolar_highcloud_frac_img.png"

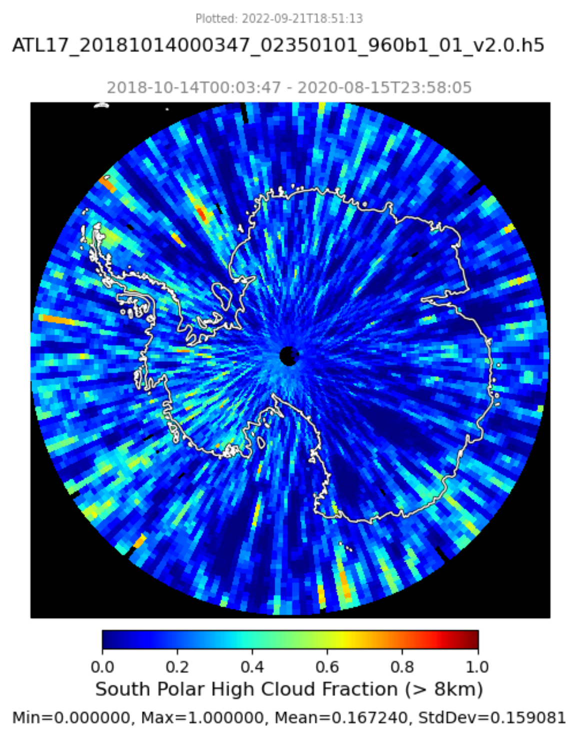


Exhibit 13: ATL17 "spolar_highcloud_frac_img.png"

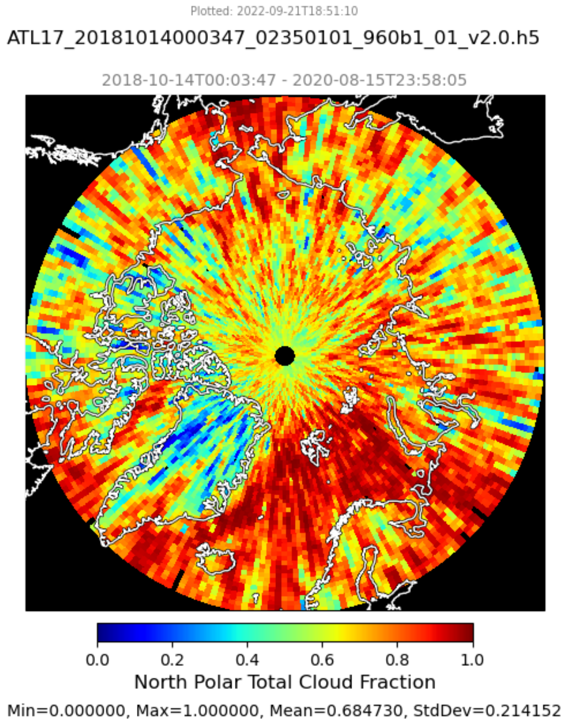


Exhibit 14: ATL17 “npolar_totalcloud_frac_img.png”

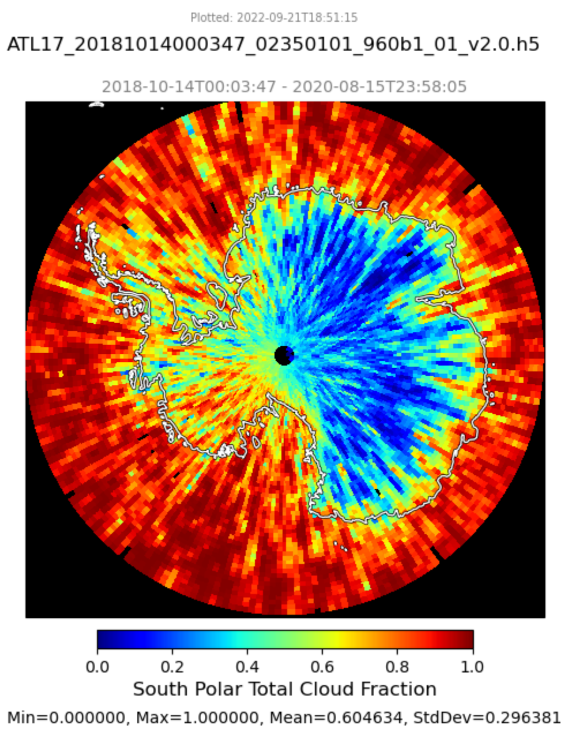


Exhibit 15: ATL17 “spolar_totalcloud_frac_img.png”

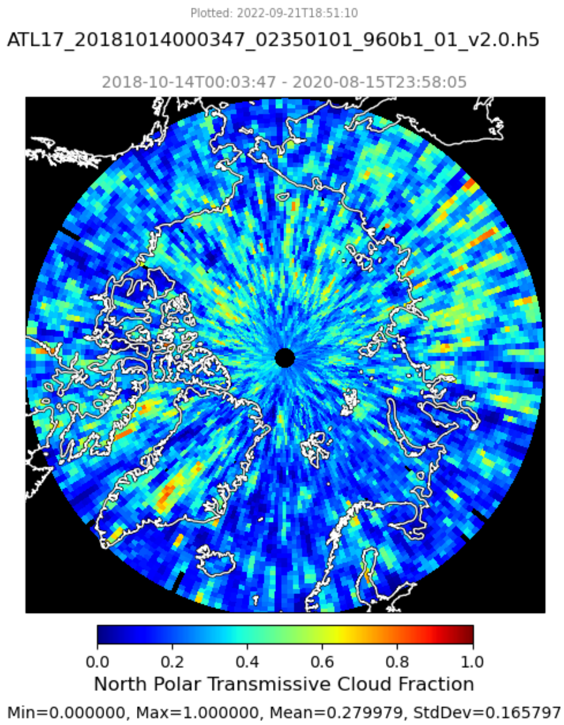


Exhibit 16: ATL17 “npolar_transcloud_frac_img.png”

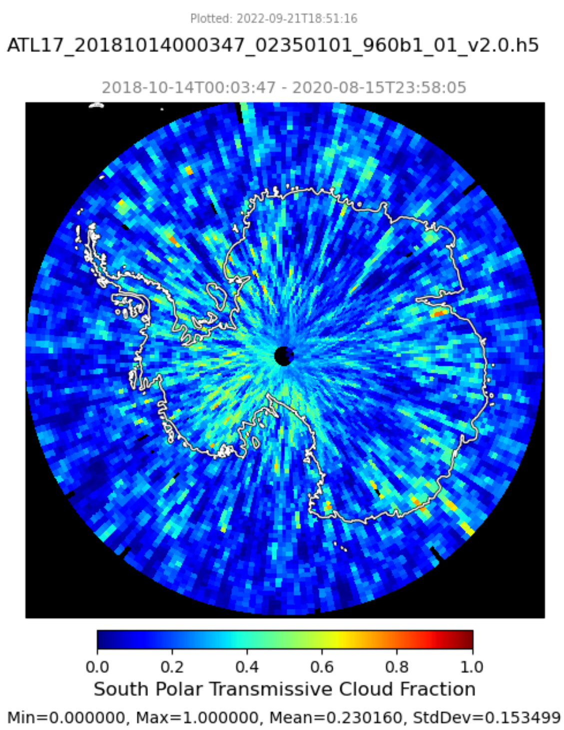


Exhibit 17: ATL17 “spolar_transcloud_frac_img.png”

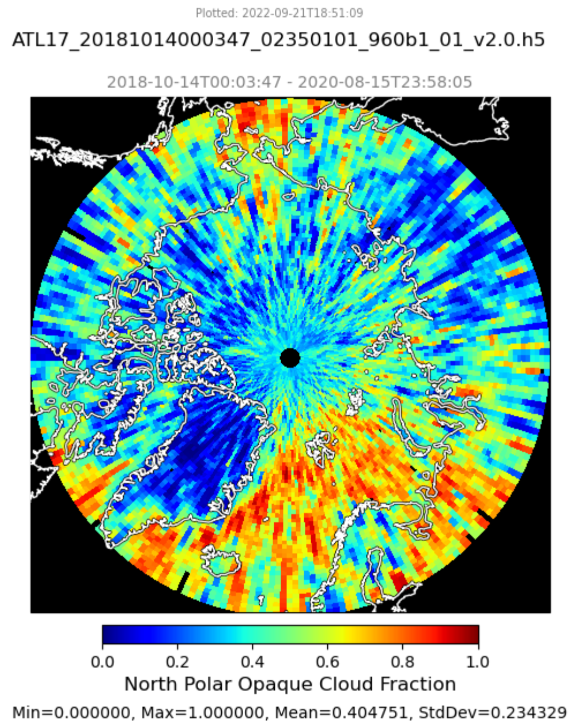


Exhibit 18: ATL17 “npolar_opaquecloud_frac_img.png”

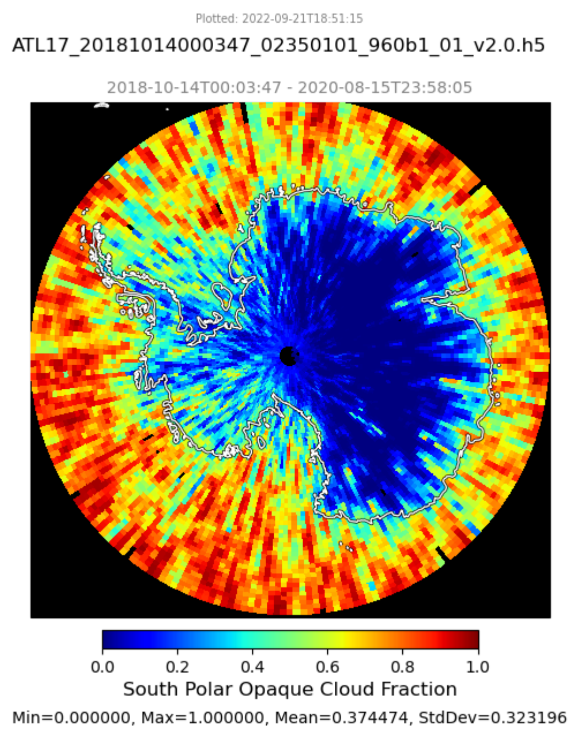


Exhibit 19: ATL17 “spolar_opaquecloud_frac_img.png”

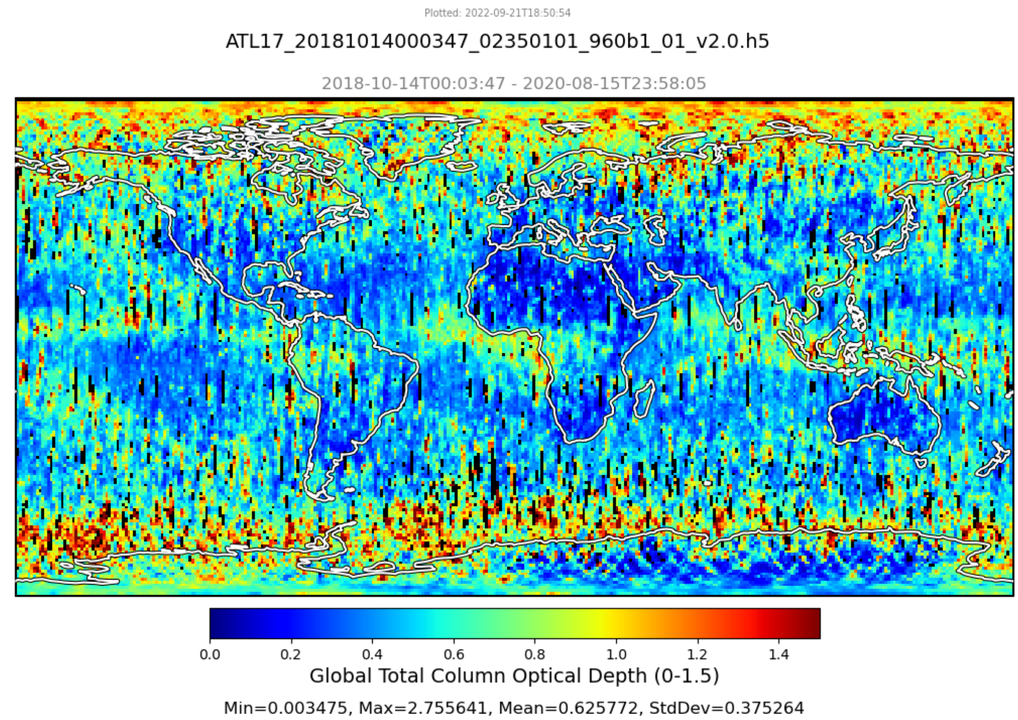


Exhibit 20: ATL17 "global_column_od_img.png"

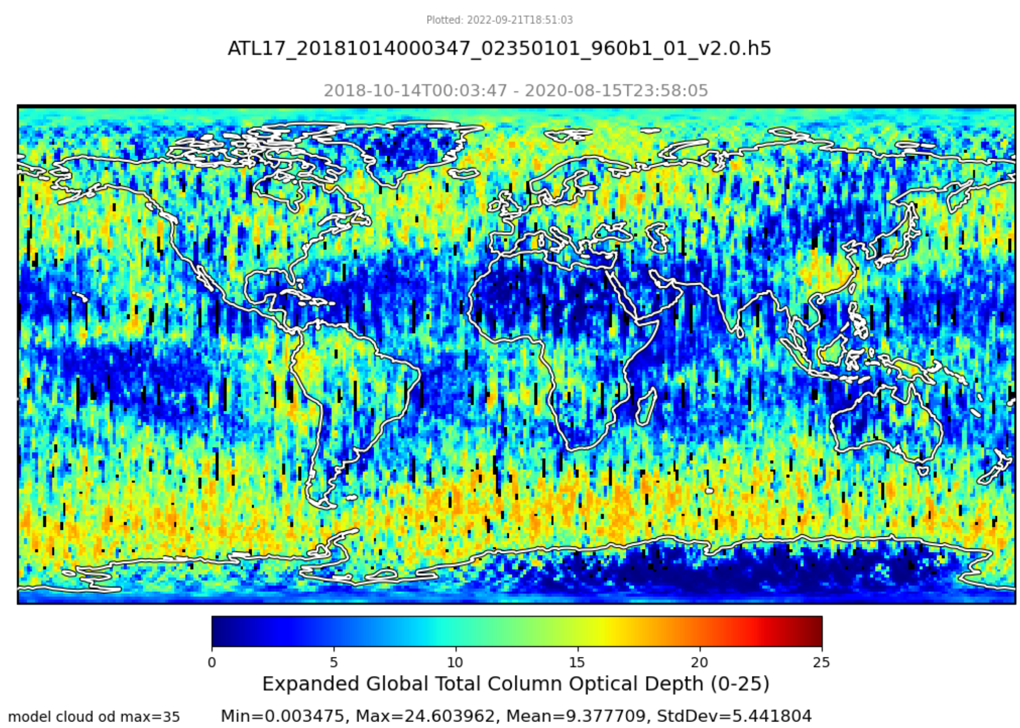


Exhibit 21: ATL17 "expanded_global_column_od_img.png"

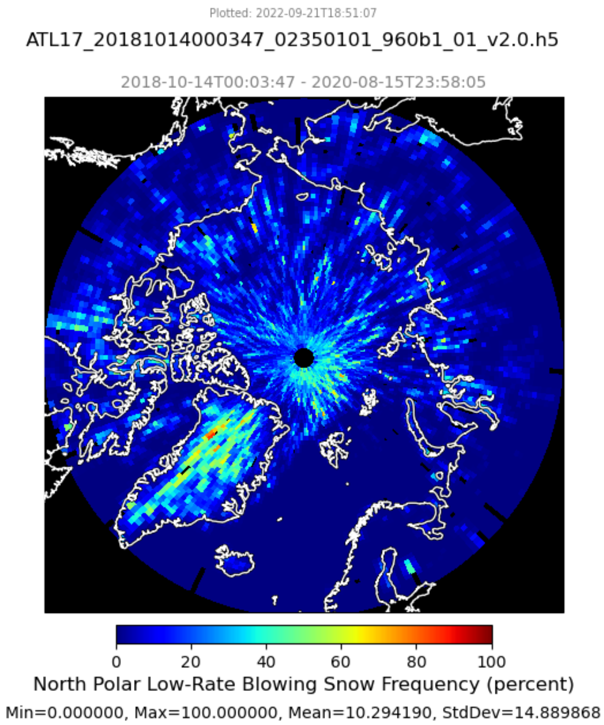


Exhibit 22: ATL17 "npolar_lorate_blowing _snow_freq_img.png"

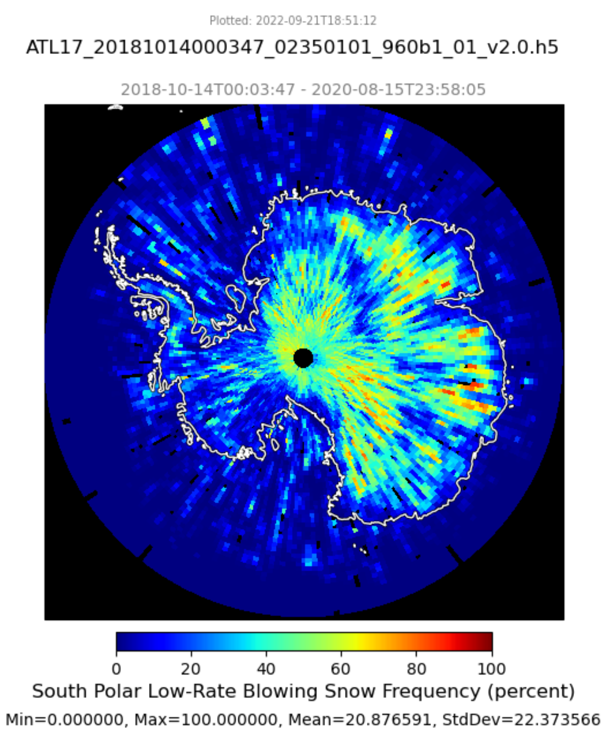


Exhibit 23: ATL17 "spolar_lorate_blowing _snow_freq_img.png"

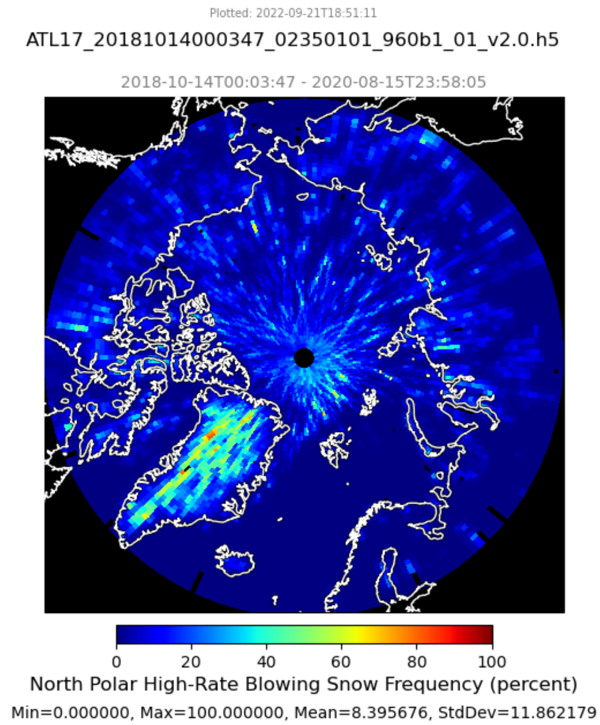


Exhibit 24: ATL17 “npolar_hirate_blowing _snow_freq_img.png”

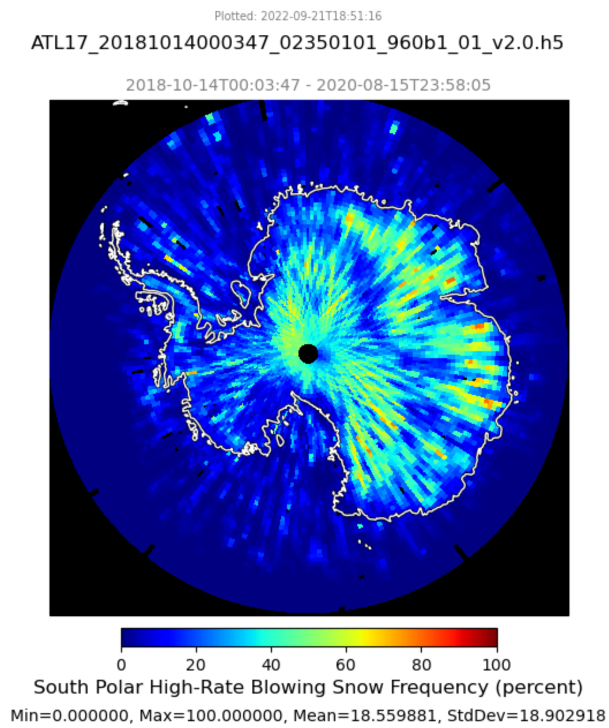


Exhibit 25: ATL17 “spolar_hirate_blowing _snow_freq_img.png”

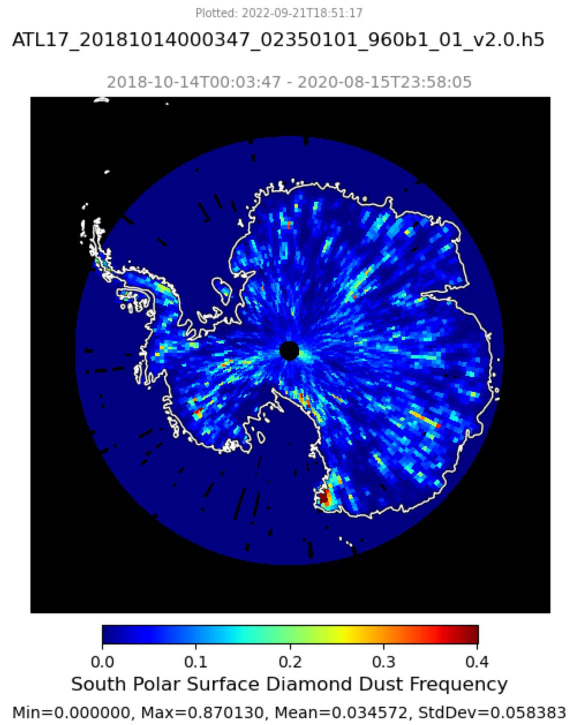


Exhibit 26: ATL17 “spolar_surf_ddust_freq_img.png”

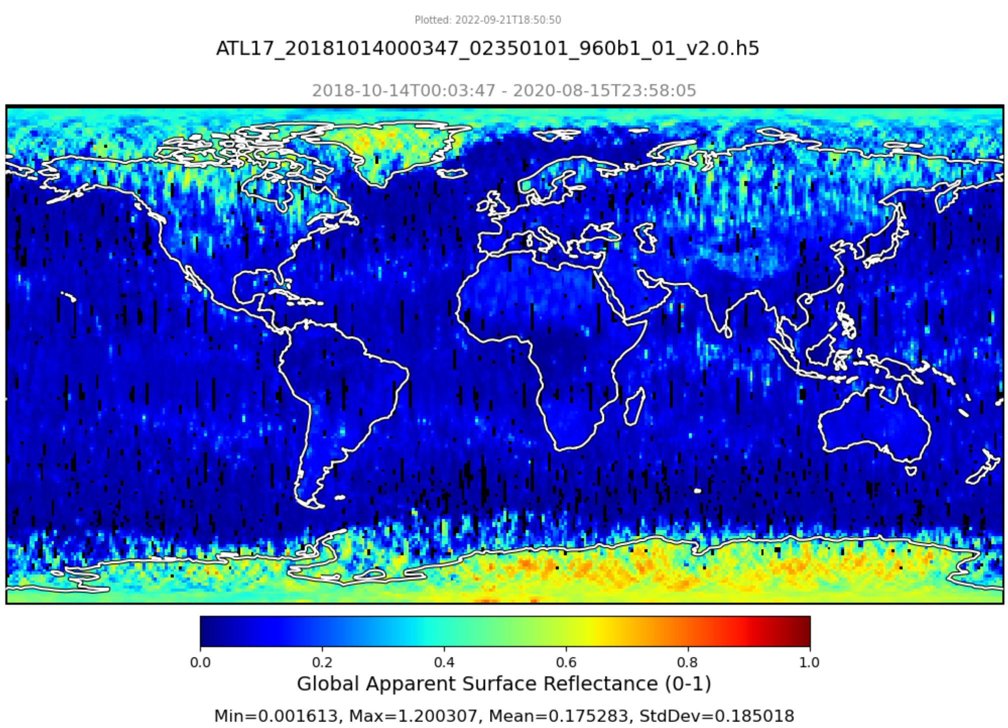


Exhibit 27: ATL17 “global_asr_img.png”

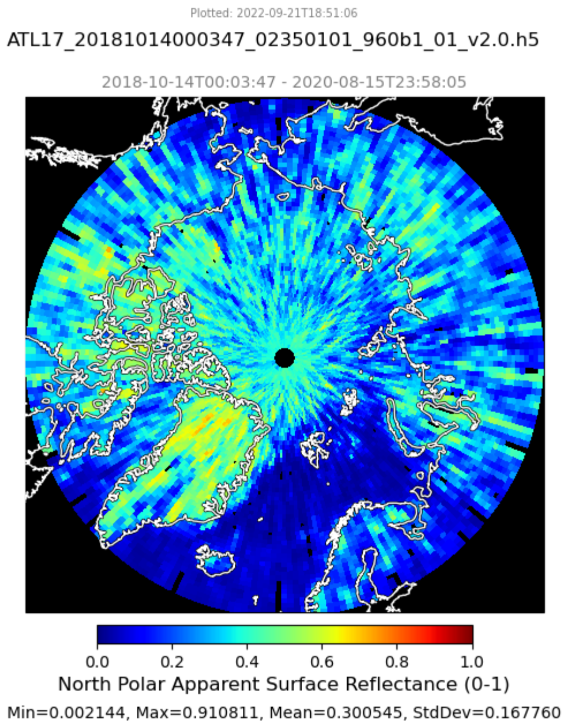


Exhibit 28: ATL17 “npolar_asr_img.png”

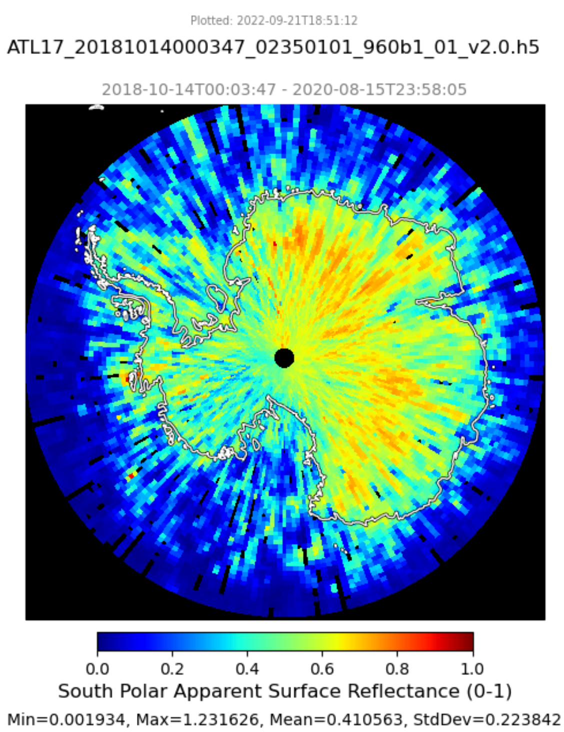


Exhibit 29: ATL17 “spolar_asr_img.png”

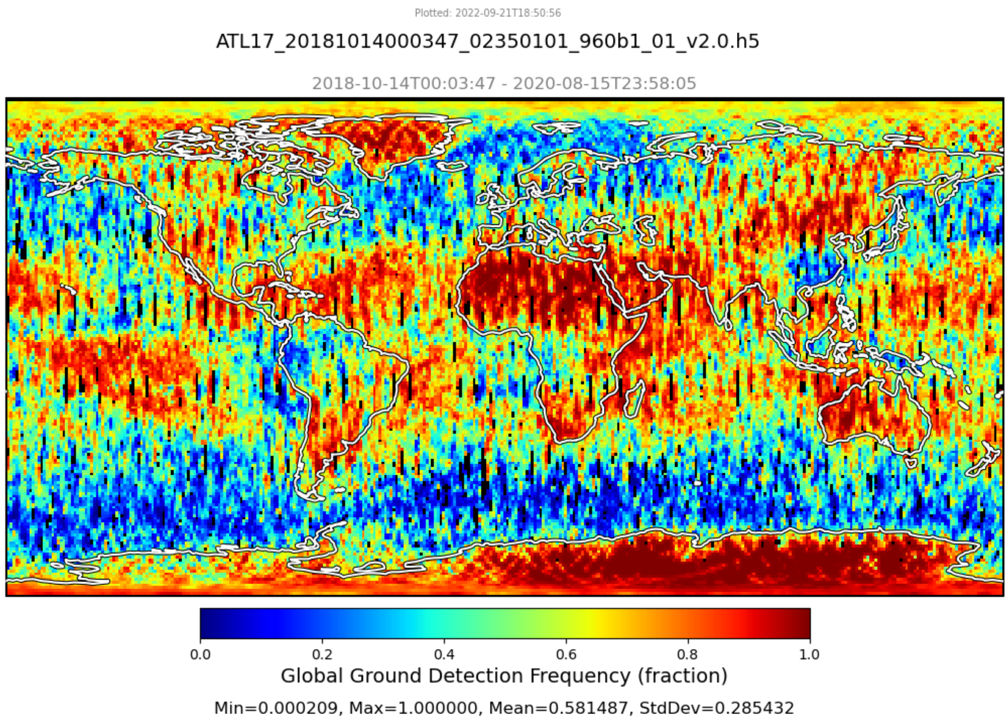


Exhibit 30: ATL17 “global_grnd_detect_img.png”

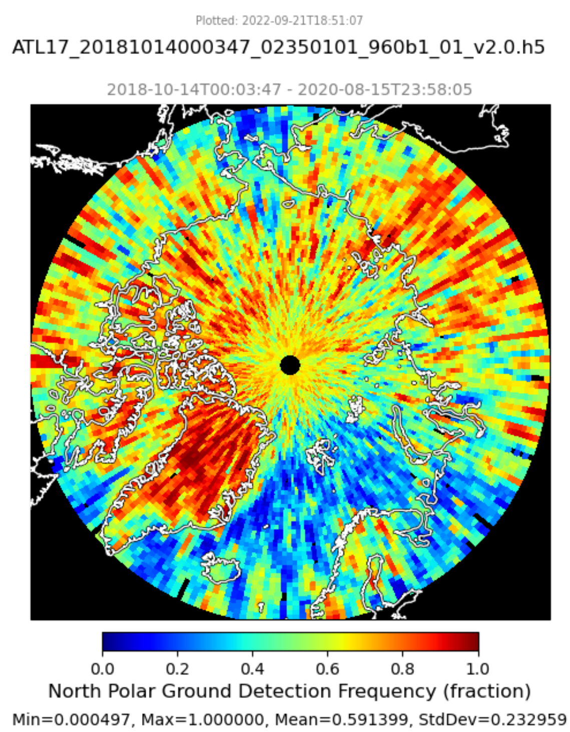


Exhibit 31: ATL17 “npolar_grnd_detect_img.png”

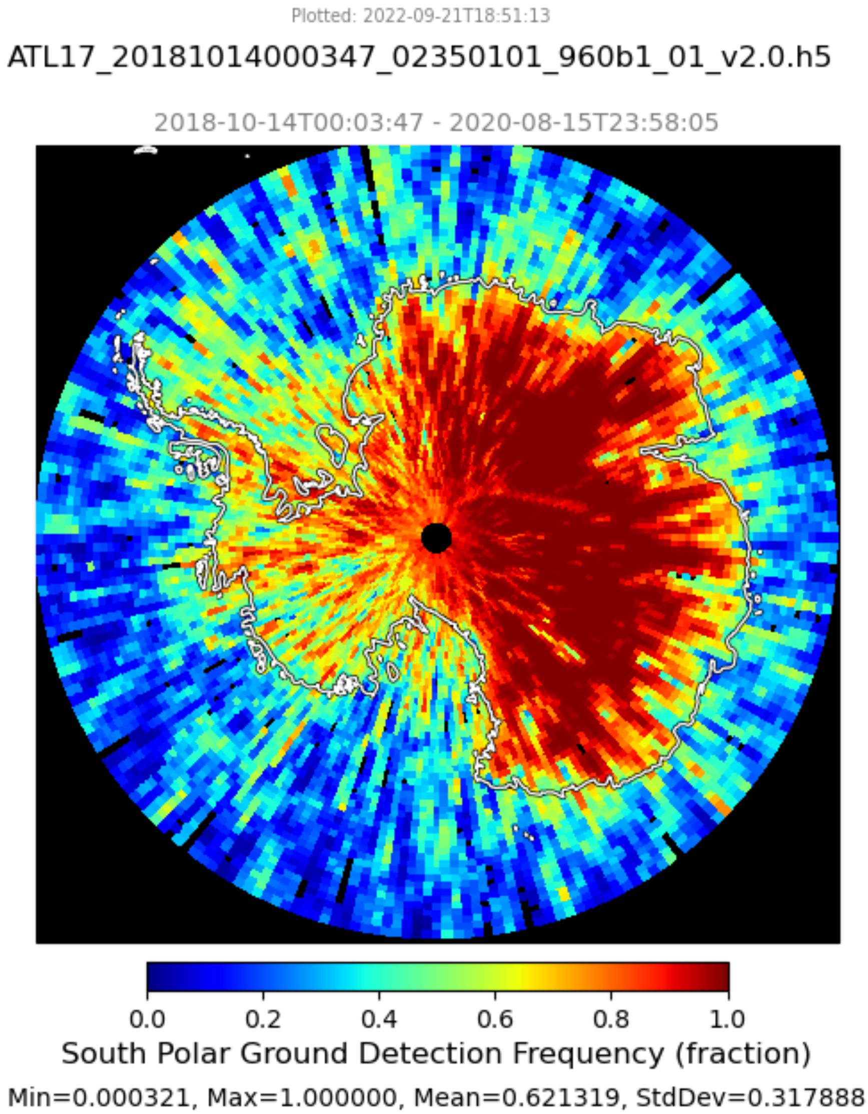


Exhibit 32: ATL17 “spolar_grnd_detect_img.png”

A.7 Attachment A-7: ATL16 Weekly Product Images Exhibition

This appendix section presents the ATL16 weekly atmosphere gridded product parameter images extracted with the Python utility program “hdf2png”. The ATL16 product is the result of processing of the ASAS functional test “func_test_960b1” (a.k.a., 960b1) as the acceptance test for the “atlas_l3b_atm” PGE v2.0. The processing sequence also includes the supplemental utility program executions on the ATL16 product. These utility programs, in order of execution are: “atl16_qa_util” v2.0, “atlas_meta” v5.0, “atlas_brw” v3.0, and “atlas_plot” v3.0 (using “plot_atl16” v1.4).

The ATL16 is a saturated product having been produced from the processing of first 185 files from the set of 556 ATL09 “ATLAS/ICESat-2 L3A Calibrated Backscatter Profiles and Atmospheric Layer Characteristics” product HDF5 files comprising the “func_test_960b1” input files. It is noted that a nominal ATL16 product is operationally produced from a set of 107 minimum to 153 maximum ATL09 product files [153 ATL09 files represents the last week as ten (10) days in a thirty-one (31) day month. The functional test dataset covers ATLAS data for various dates for seventeen (17) cycle and reference ground track (rgt) collected granules (orbits).

NOTE: All images have been scaled with the exception of the final image in Exhibit 32.

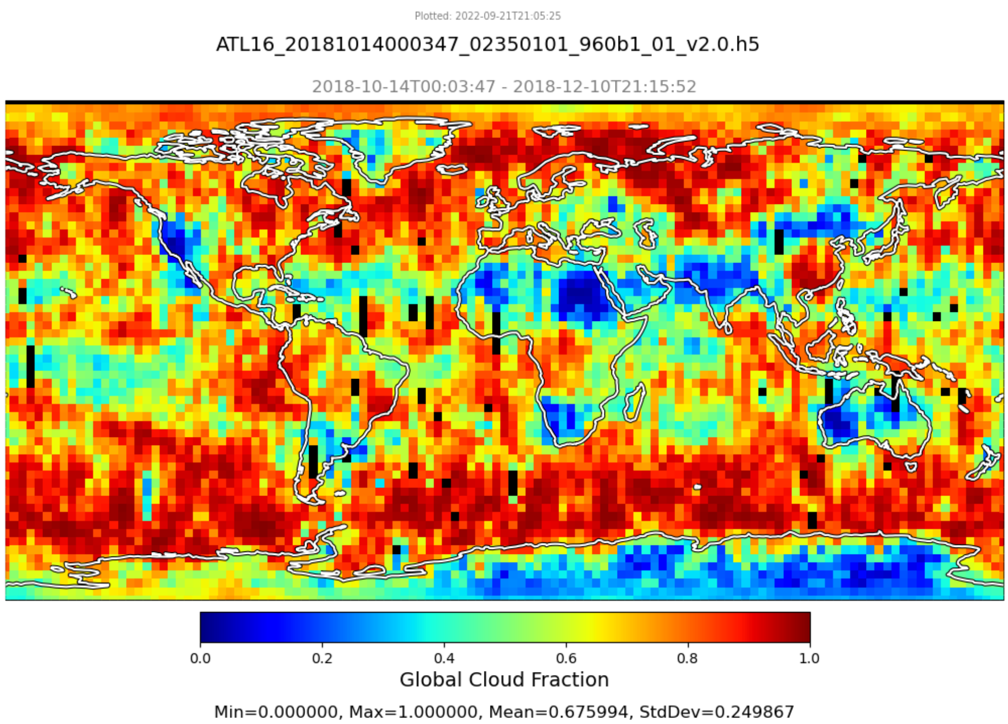


Exhibit 1: ATL16 “global_cloud_frac_img.png”

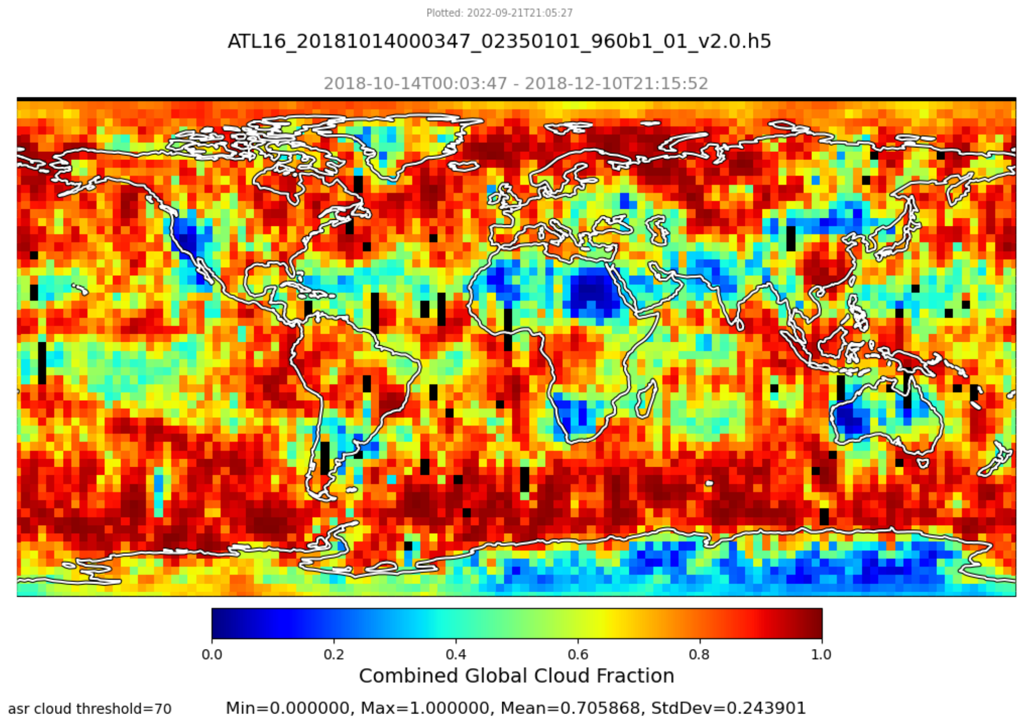


Exhibit 2: ATL16 “combined_global_cloud_frac_img.png”

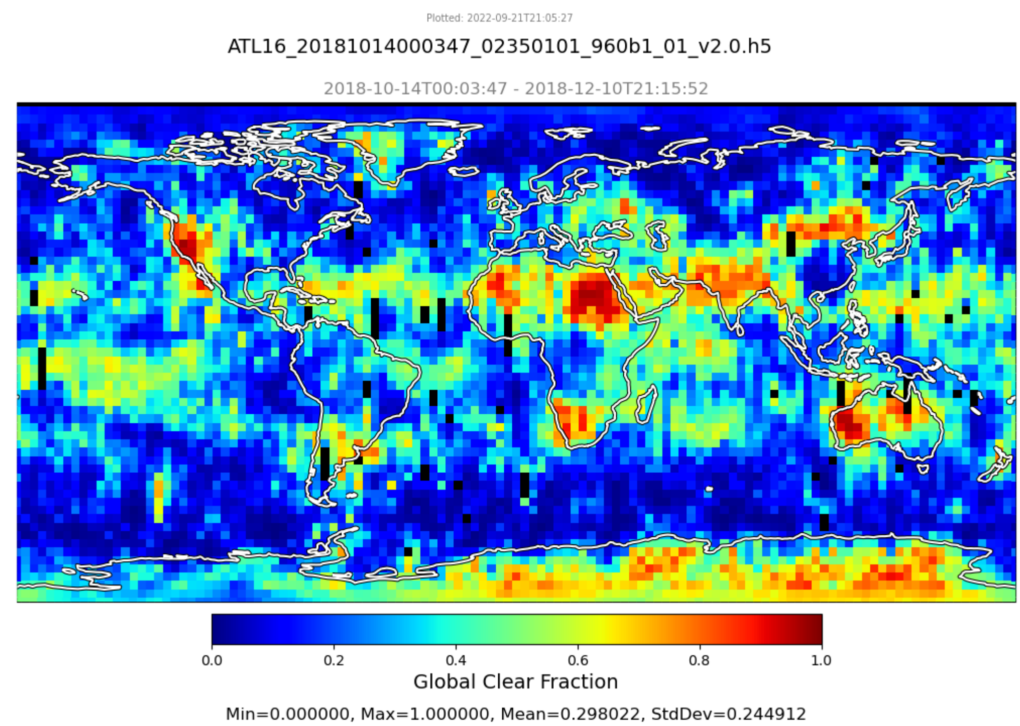


Exhibit 3: ATL16 “global_clear_frac_img.png”

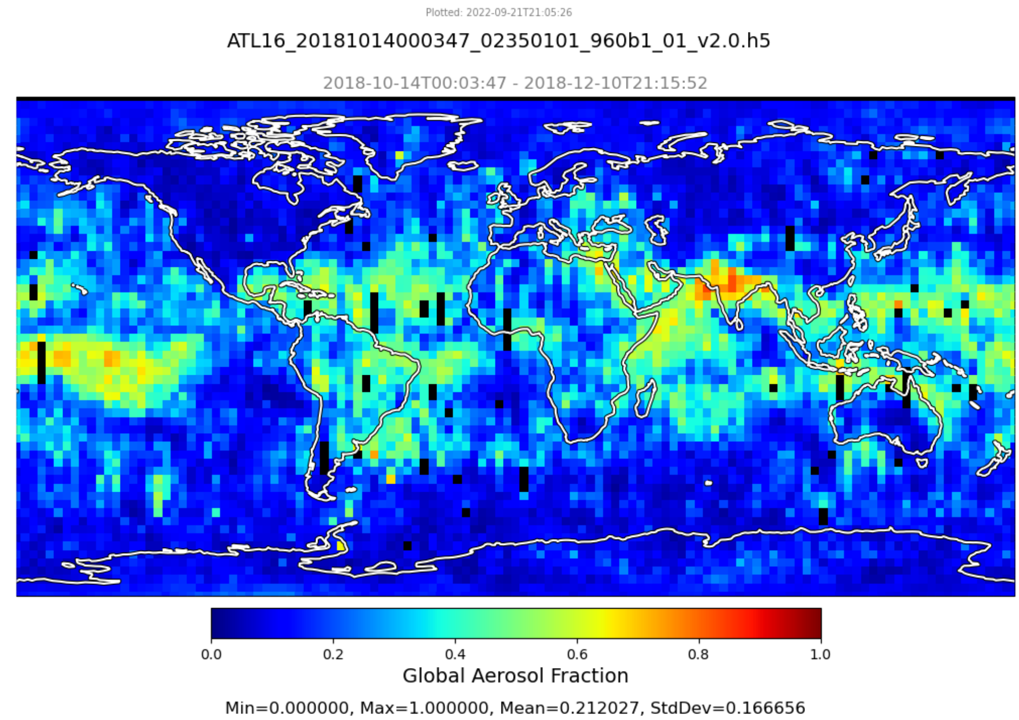


Exhibit 4: ATL16 "global_aerosol_frac_img.png"

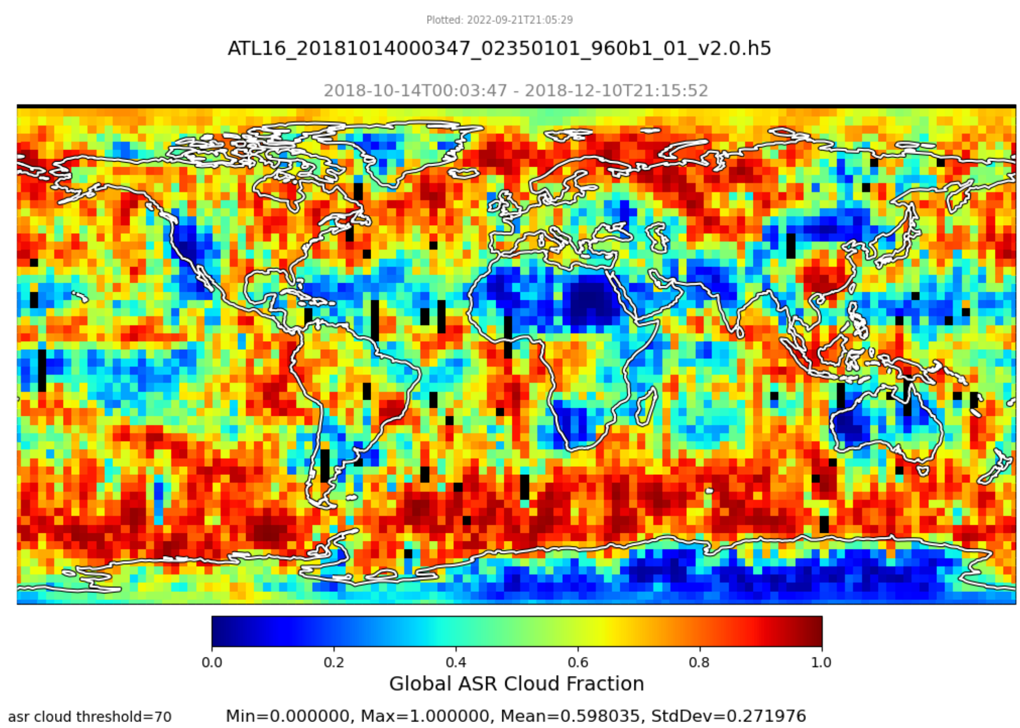


Exhibit 5: ATL16 "global_asr_cloud_frac_img.png"

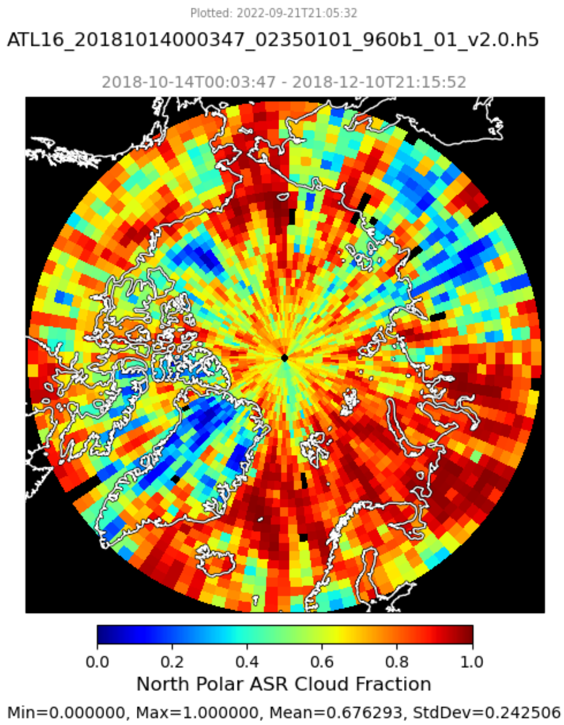


Exhibit 6: ATL16 "npolar_asr_cloud_frac_img.png"

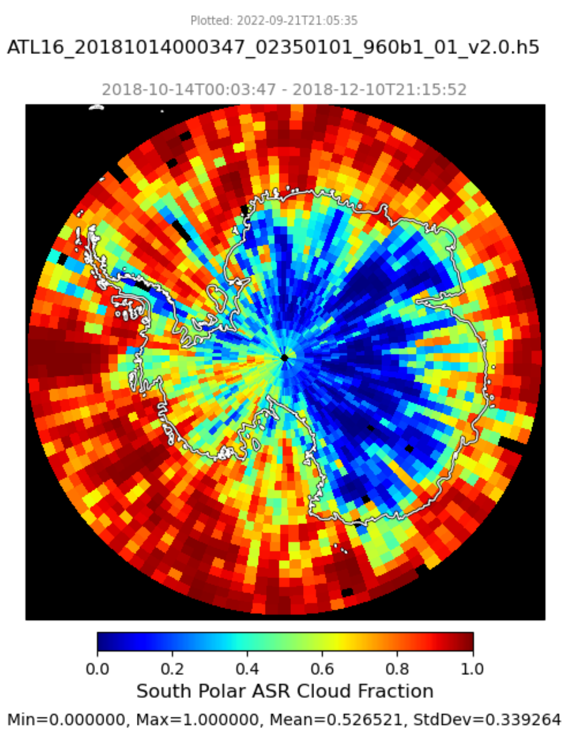


Exhibit 7: ATL16 "spolar_asr_cloud_frac_img.png"

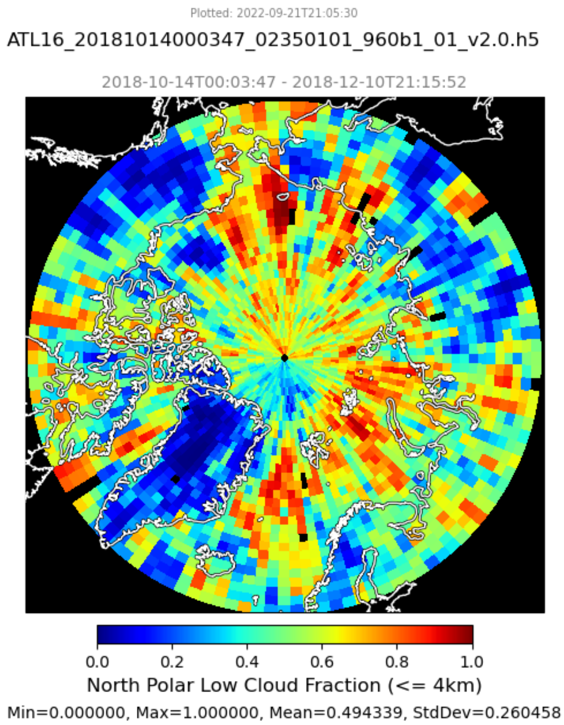


Exhibit 8: ATL16 “npolar_lowcloud_frac_img.png”

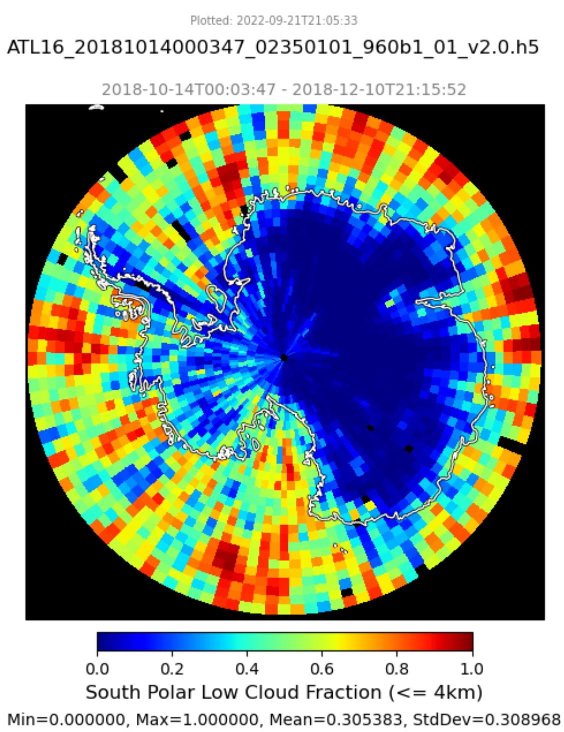


Exhibit 9: ATL16 “spolar_lowcloud_frac_img.png”

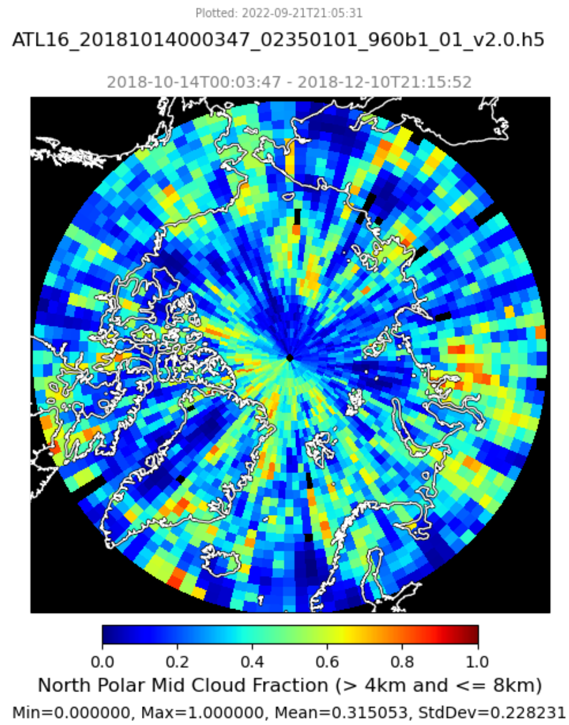


Exhibit 10: ATL16 “npolar_midcloud_frac_img.png”

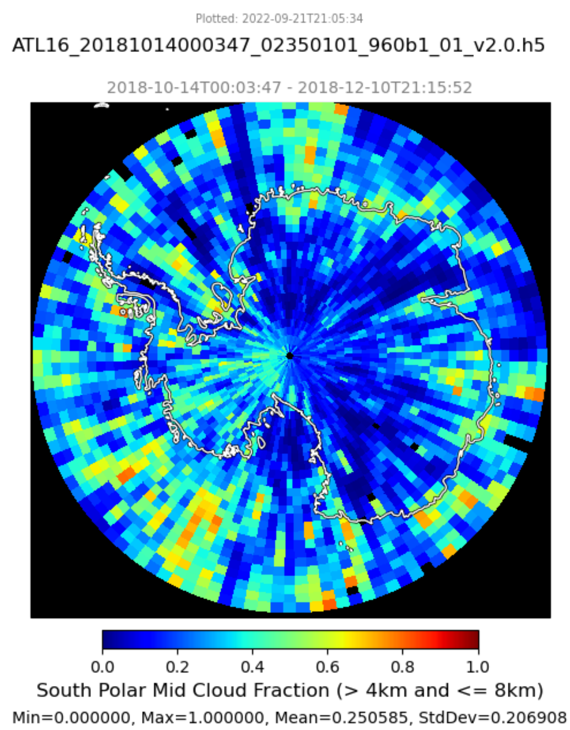


Exhibit 11: ATL16 “spolar_midcloud_frac_img.png”

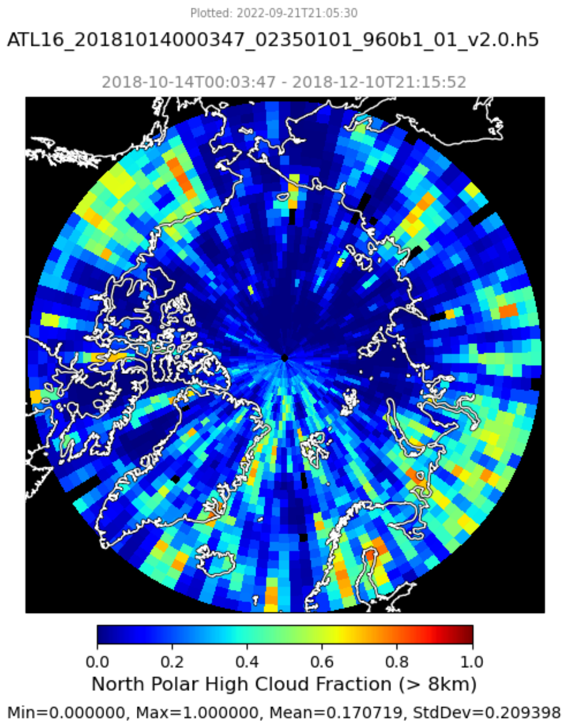


Exhibit 12: ATL16 “npolar_highcloud_frac_img.png”

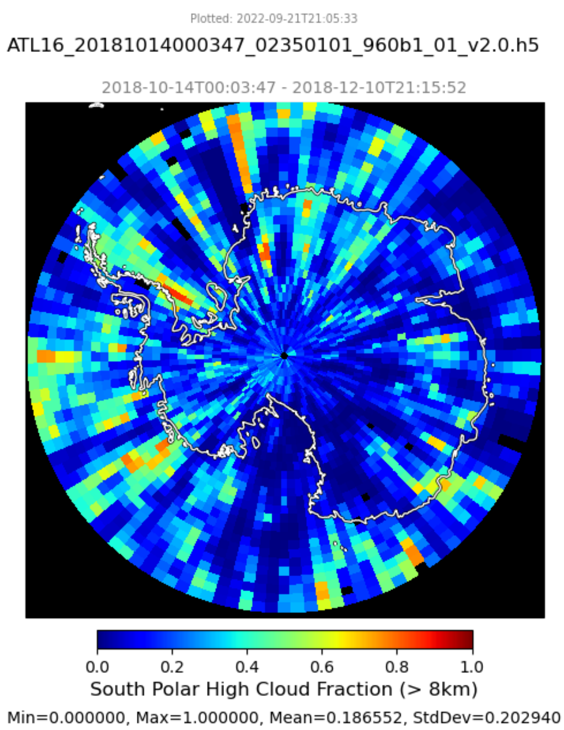


Exhibit 13: ATL16 “spolar_highcloud_frac_img.png”

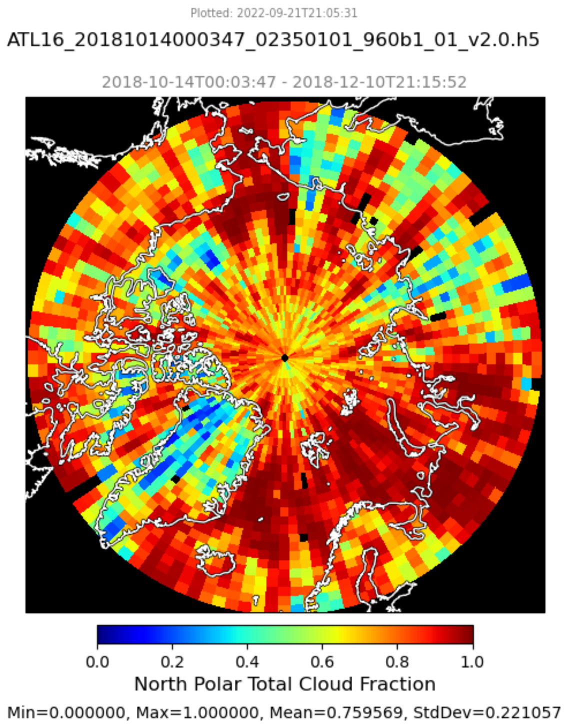


Exhibit 14: ATL16 “npolar_totalcloud_frac_img.png”

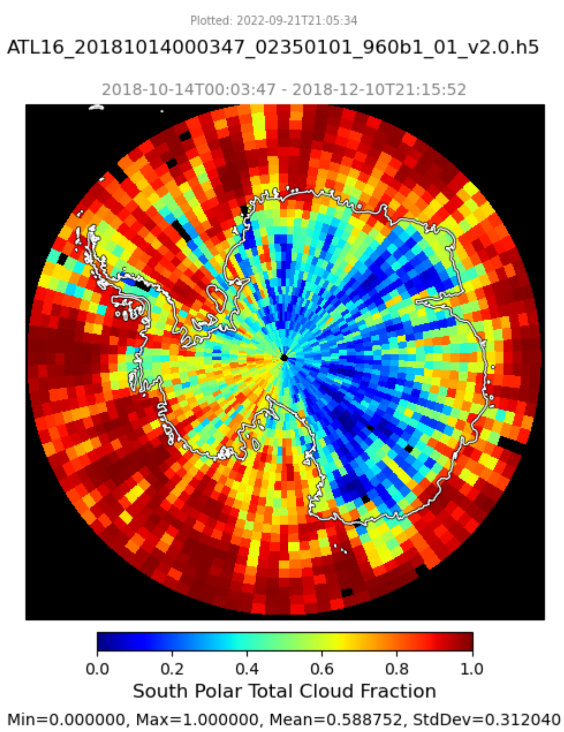


Exhibit 15: ATL16 “spolar_totalcloud_frac_img.png”

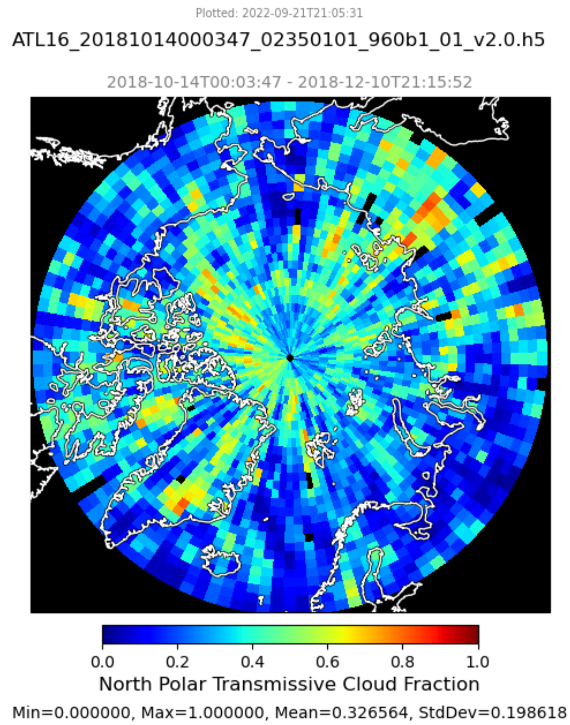


Exhibit 16: ATL16 “npolar_transcloud_frac_img.png”

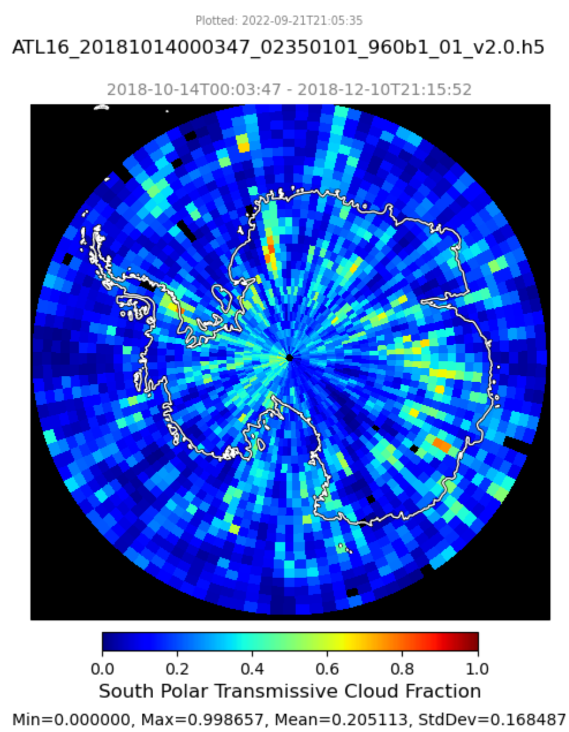


Exhibit 17: ATL16 “spolar_transcloud_frac_img.png”

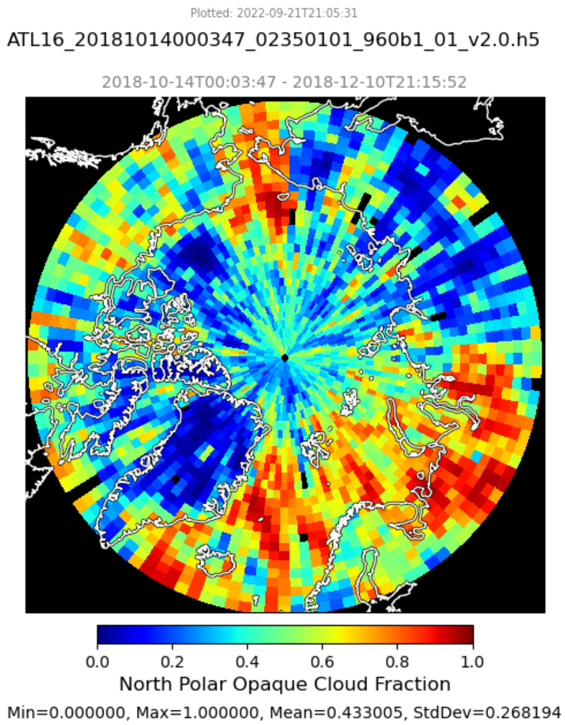


Exhibit 18: ATL16 “npolar_opaquecloud_frac_img.png”

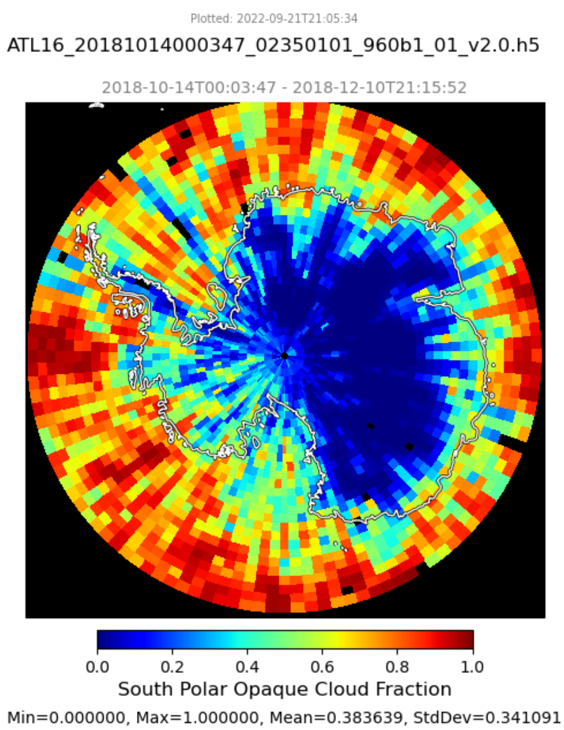


Exhibit 19: ATL16 “spolar_opaquecloud_frac_img.png”

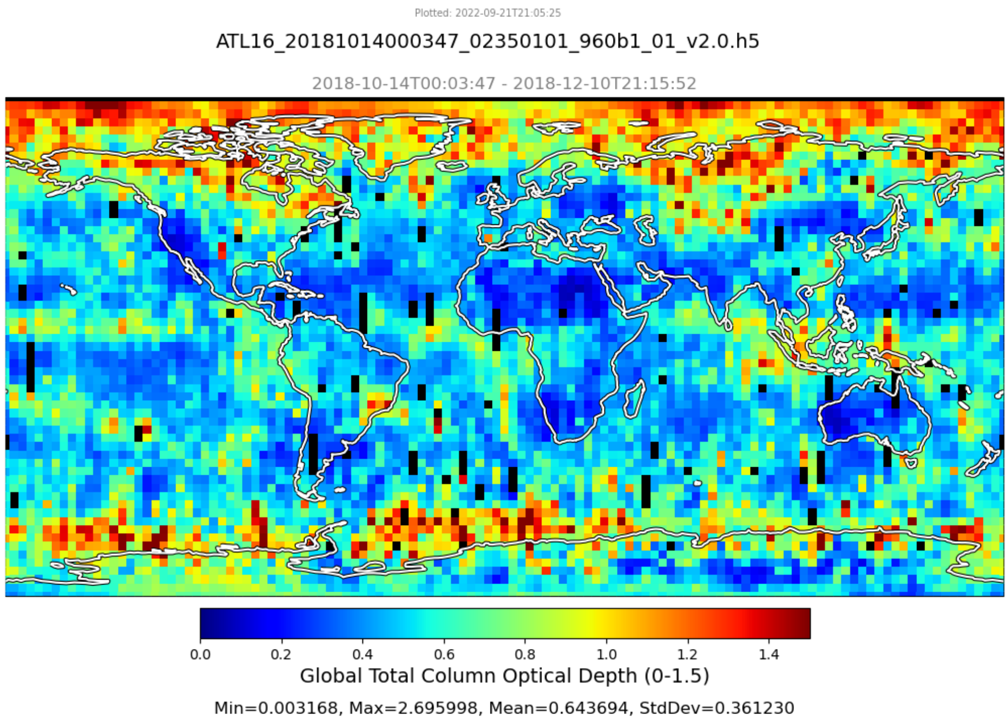


Exhibit 20: ATL16 “global_column_od_img.png”

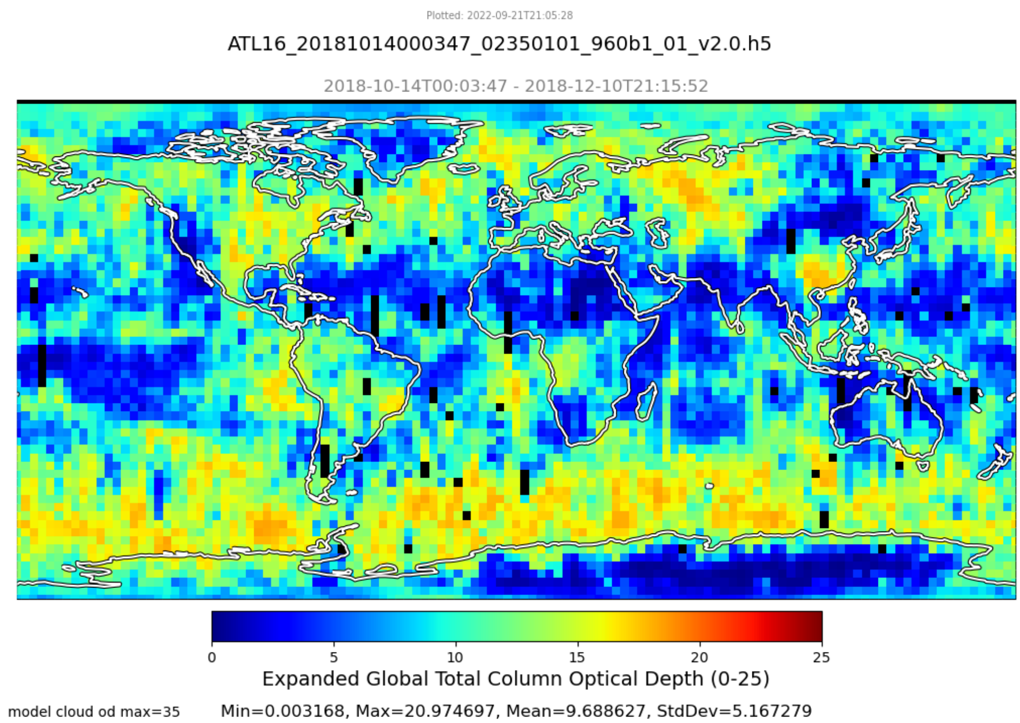


Exhibit 21: ATL16 “expanded_global_column_od_img.png”

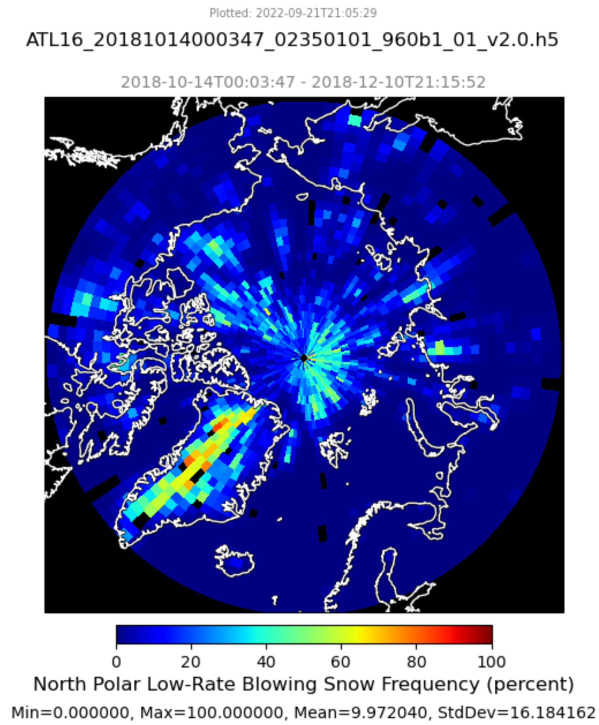


Exhibit 22: ATL16 “npolar_lorate_blowing _snow_freq_img.png”

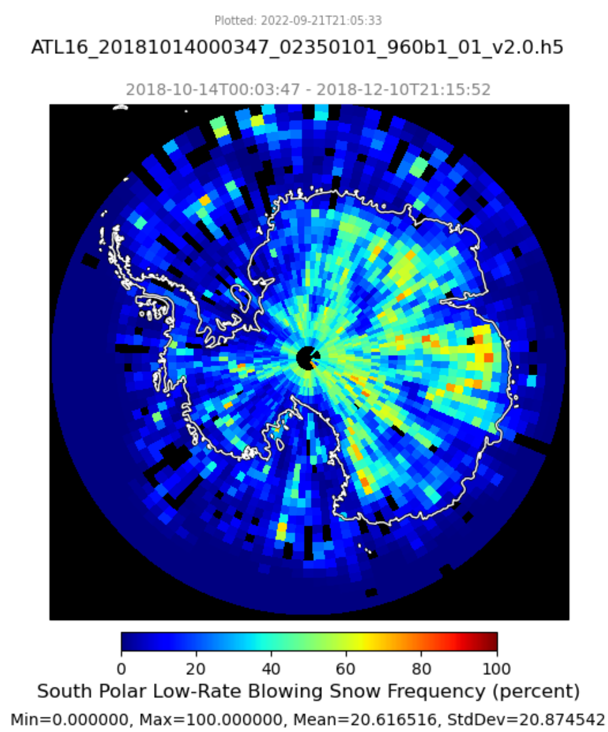


Exhibit 23: ATL16 “spolar_lorate_blowing _snow_freq_img.png”

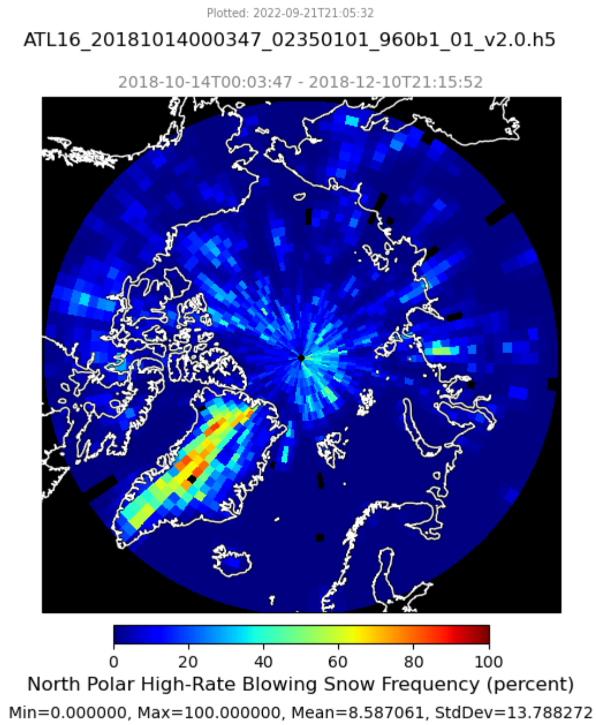


Exhibit 24: ATL16 “npolar_hirate_blowing _snow_freq_img.png”

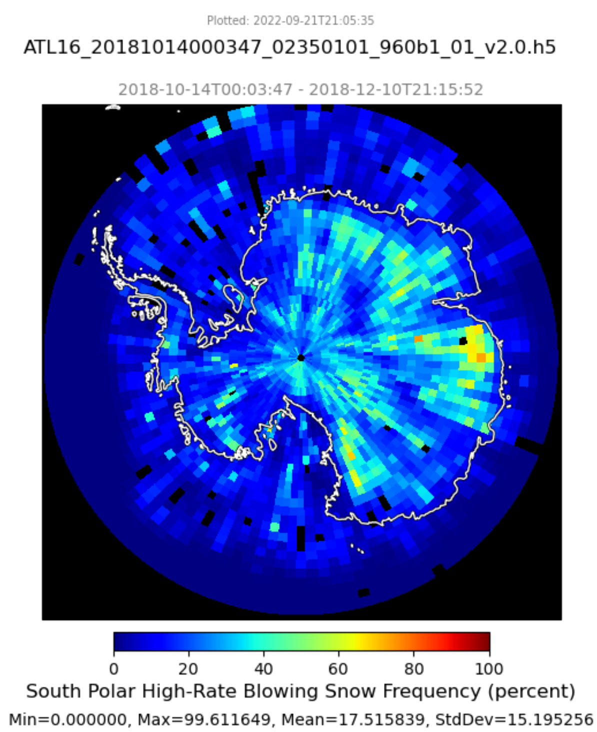


Exhibit 25: ATL16 “spolar_hirate_blowing _snow_freq_img.png”

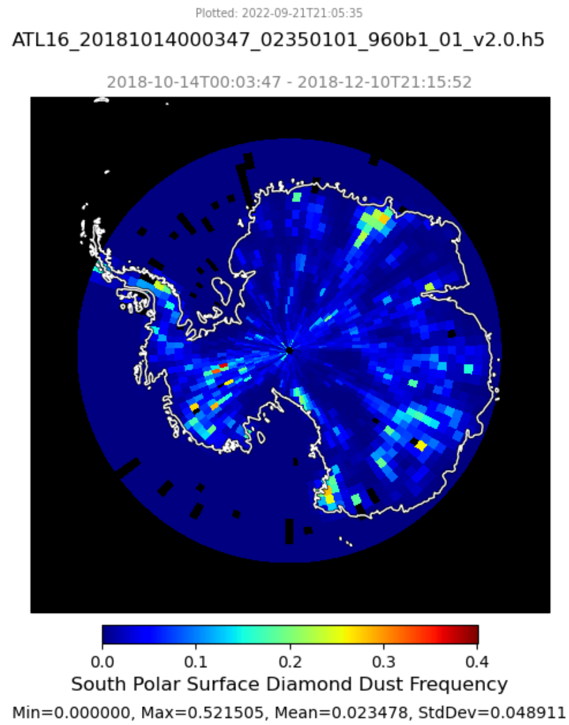


Exhibit 26: ATL16 “spolar_surf_ddust_freq_img.png”

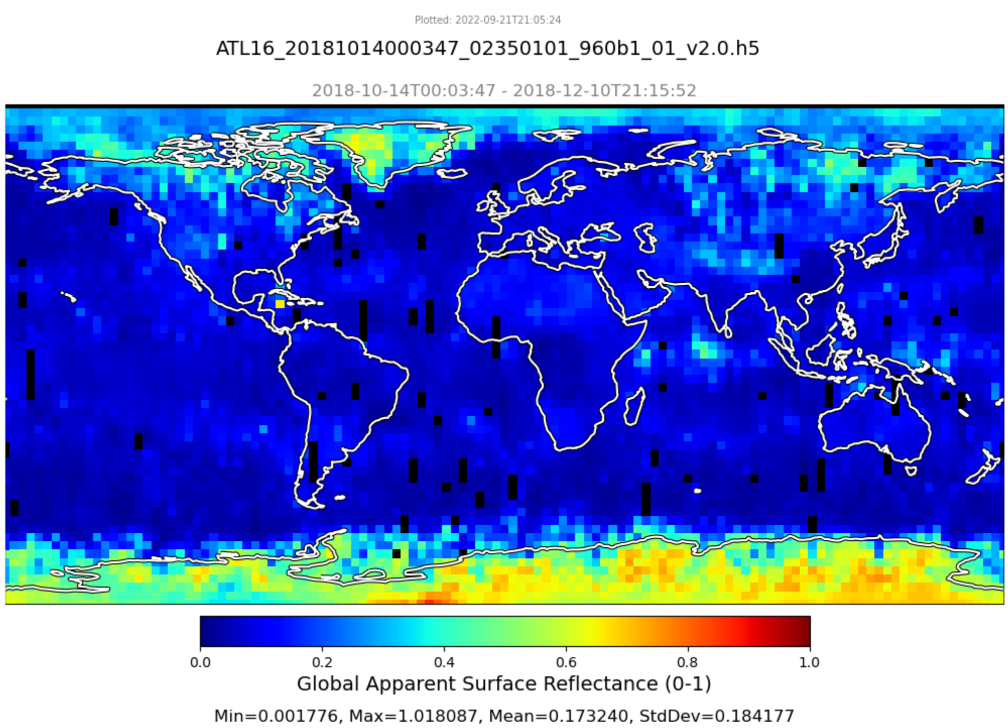


Exhibit 27: ATL16 “global_asr_img.png”

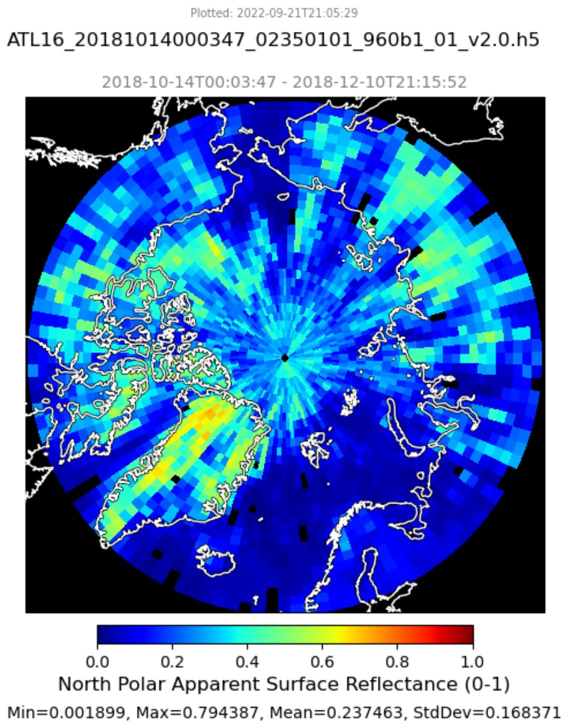


Exhibit 28: ATL16 “npolar_asr_img.png”

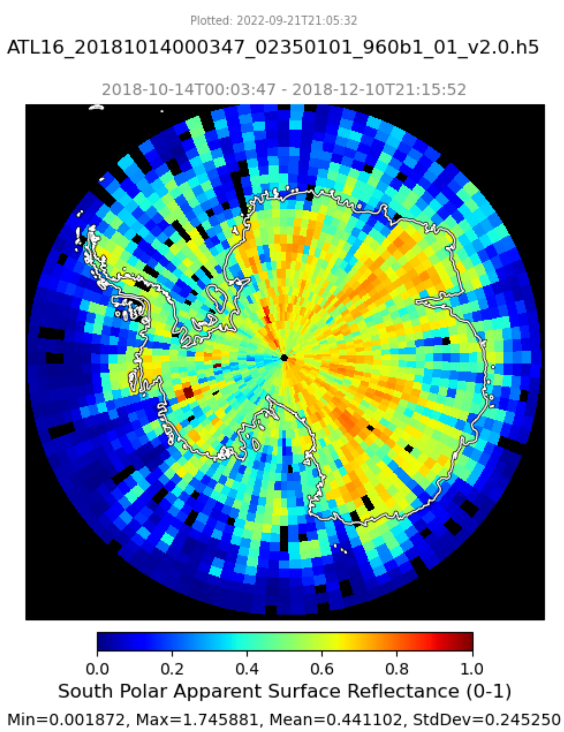


Exhibit 29: ATL16 “spolar_asr_img.png”

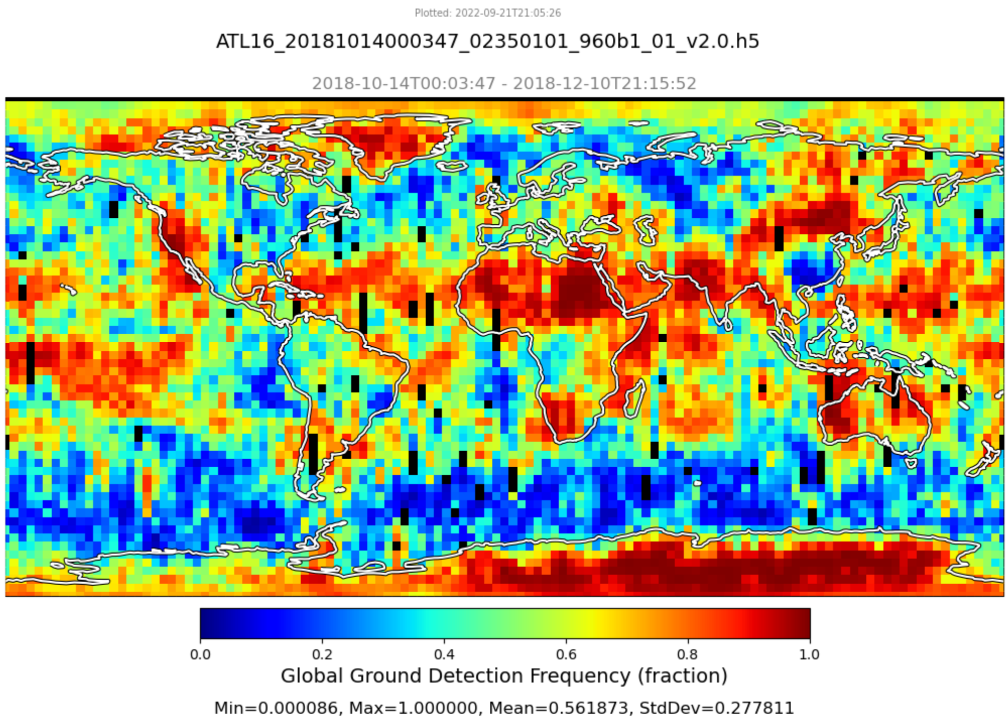


Exhibit 30: ATL16 “global_grnd_detect_img.png”

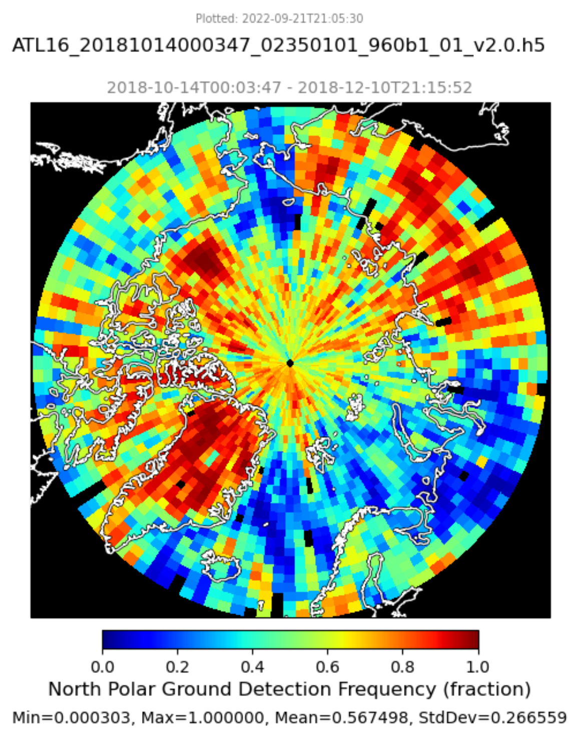


Exhibit 31: ATL16 “npolar_grnd_detect_img.png”

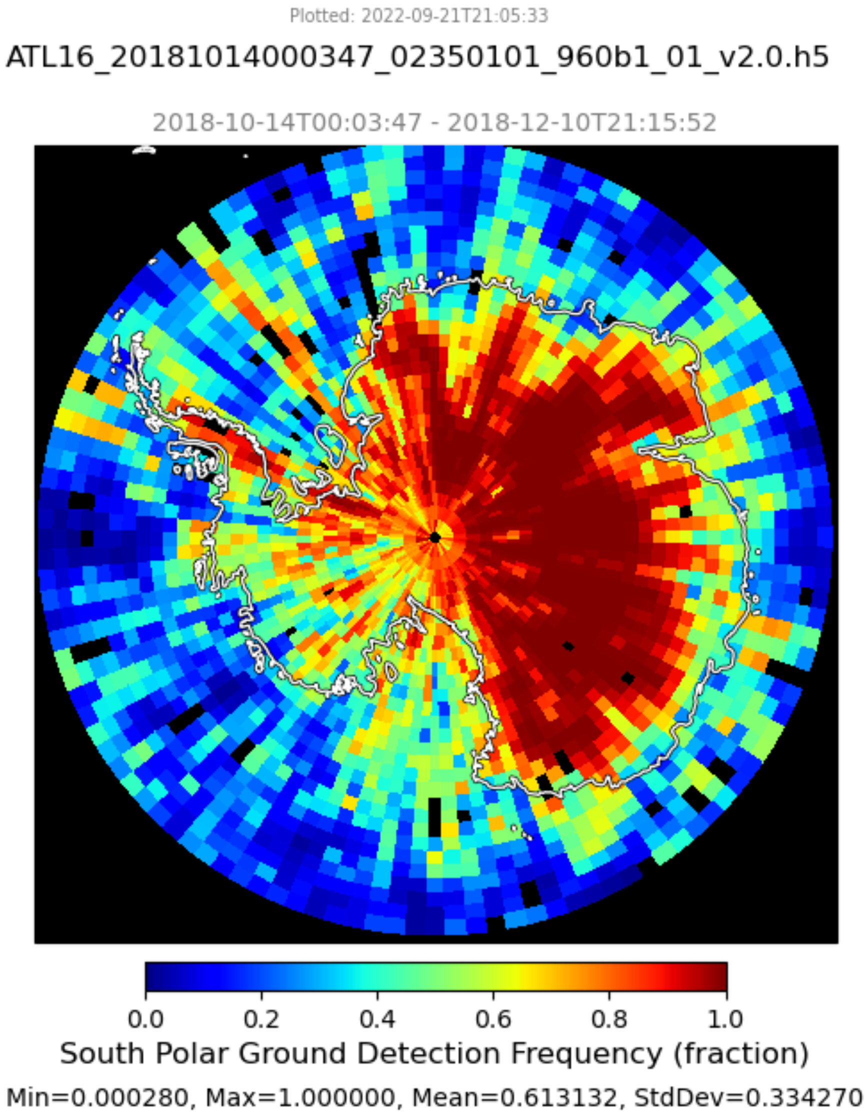


Exhibit 32: ATL16 “spolar_grnd_detect_img.png”

A.8 Attachment A-8: Documentation Sources Pertaining to the ATBD Version 5 Content Changes and the Version 2.0 "atlas_l3b_atm" PGE Code Development Change Log

Change Log Notes Pertaining to ATBD Version 5 and the Version 2.0 "atlas_l3b_atm" PGE Code

March 9, 2022, 16:24; "RE: 09Mar22 Atmos Telecon Notes"; following the Atmosphere Team teleconference on this date the ATBD Lead delivered an email message reply with filtering notes and the "Atmos Telecon notes" listing the L3B PGE code changes. The following notes on filtering were included:

- after looking at two months of column optical depth over land profile data, will proceed with minimal filtering [this points to items 4) and 5) below expanding the parameters from over-water and over-ocean to over-all-surface-types],
- apply filtering to ATL09 [high-rate] profile parameter column optical depth from ASR *column_od_asr* limiting values to the following range: 0.0 < *column_od_asr* () < 4.0,
- filtering can be applied to over-land and over-water data [applied to all-surface-types per items 4) and 5) below].

Included list detailing the following "atlas_l3b_atm" PGE code changes and subsequent ATBD modifications and additions:

1) add new level 3B parameter and plot for ASR-based cloud detection using the ASR cloud probability profile data; use cloud probability threshold control parameter = 0.70. [This item clarifies the September 1, 2021, issue number 3) listed above, and will implement the added parameter Global ASR Cloud Fraction and the associated grid image. It will use the existing control parameter *asr_cloud_threshold* from the Combined Global Cloud Fraction.]
2) add new level 3B polar parameter and plot of the frequency of diamond dust reaching the ground over Antarctica, and will implement the added parameter South Polar Surface Diamond Dust Frequency and the associated grid image.
3) change the existing level 3B Combined Global Cloud Fraction cloud probability threshold control parameter constant [i.e., *asr_cloud_threshold*] from 0.8 [i.e., 80 percent] to 0.7 [i.e., 70 percent].
4) change the current Global (Over Water) Total Column Optical Depth parameter and plot from "over-water-only" to now include all surfaces.
5) change the current Expanded Global (Over Water) Total Column Optical Depth parameter and plot [from "over-ocean-only"] to now include all surfaces.

March 10, 2022, 15:25; "RE: 09Mar22 Atmos Telecon Notes"; email message reply from the ATBD Lead with Word document attachment "09Mar22 Atmos Telecon notes.docx":

1) enumerates the five modifications and additions from the 03/09/2022 email message.
2) supplies the description and algorithm for Global ASR Cloud Fraction parameter and image. It will use the ATL09 high-rate profile parameter *asr_cloud_probability* and the existing level 3B Combined Global Cloud Fraction cloud probability threshold control parameter constant

asr_cloud_threshold in the filtering and counting. Additionally, the ATL16 or ATL17 minimum observation count control parameter constant *obs_minimum* will be used to limit the gridded parameter computation.

3) supplies the description and algorithm for the fraction of Diamond Dust Reaching the Surface parameter and image. It will use the ATL09 high rate profile parameter diamond dust from density layer bottom height *ddust_hbot_dens* as the primary input and the ATL09 high rate profile parameters Digital Elevation Model (DEM) height *dem_h*, blowing snow layer thickness (height of layer top above the surface) height *bnsow_h*, and surface bin (vertically aligned, Normalized Relative Backscatter (NRB) bin number of the detected surface return) *surface_bin*, required to filter and calculate the count of diamond dust observation reaching the ground for the Antarctic (i.e., South Polar region) only.

March 10, 2022, 18:45; "RE: 09Mar22 Atmos Telecon Notes"; email message reply from the ATBD Lead with added details expanding the 03/09/2022 email message list:

1) in addition to the new Global ASR Cloud Fraction parameter add the North Polar ASR Cloud Fraction and South Polar ASR Cloud Fraction parameters.
2) noted no North Polar diamond dust parameter; for now, over Antarctic only (i.e., South Polar Surface Diamond Dust Frequency parameter only).

March 10, 2022, 18:49; "RE: 09Mar22 Atmos Telecon Notes"; email message reply from the ATBD Lead accepting "spolar_surf_ddust_freq" as image name for the South Polar Surface Diamond Dust Frequency plot.

March 15, 2022, 13:42; "RE: Clarification for Filtering of column_od_asr Profile Data"; email message reply from the ATBD Lead with additional notes for the filtering process:

- when there is no surface return the *column_od_asr* value will be INVALID,
- INVALID *column_od_asr* values are currently filtered out.
- when the computed [high-rate profile] Apparent Surface Reflectance (ASR) *apparent_surf_reflec* values are greater than the true surface reflectance [high-rate profile] *aclr_true* values (i.e., clear sky ASR; clear sky initial surface reflectance based on GOME climatology or the Cox-Munk model), the *column_od_asr* values will be zeros (0.0).
- currently not filtering out zero (0.0) *column_od_asr* values; these should be filtered out going forward, especially over land with possibly more zero values.
- most important filtering over water is the laser angle; filter out shots where the angle [laser off-nadir angle] is greater than 2 degrees.
- for consistency perform this filtering over all surface types [Global Total Column Optical Depth and Expanded Global Total Column Optical Depth].
- perform filtering on both the column optical depth from ASR value and the laser off-nadir angle limit.

- local laser off-nadir angle [laser_angle] uses ATL09 [high-rate profile] laser beam elevation *beam_elevation* values in the calculation:
  laser_angle () = 90.0 – *beam_elevation* ()
- apply the following filtering:
  if (*column_od_asr* () > 0.0 and *column_od_asr* () < 4.0 and laser_angle () < 2.0) then
  accept the *column_od_asr* () [for processing].
- keep the Global Total Column Optical Depth image scaling at [the current] 0.0 to 1.5.

March 15, 2022, 20:59; "RE: Clarification for Filtering of column_od_asr Profile Data"; email message reply from the ATBD Lead with follow-up notes for the expanded global total column optical depth gridded parameter:

- keep the control constant parameter *gen_cloud_od_max* value at 35,
- keep the Expanded Global Total Column Optical Depth gridded parameter image range at 0 to 25 scaling.

March 30, 2022, 22:45; "RE: [EXTERNAL] zoom link for today"; email message reply from the ATBD Lead to Ground System Manger with notes for clarification of the diamond dust parameter:

- windspeed should not be a part of the diamond dust classification.
- diamond dust (reaching the ground) should be defined by high scattering in the bin above the surface and high scattering in each bin above for at least 500 m; if the drop in scattering (i.e., layer top) occurs below 500 m and the wind speed is > 4 m/s, it is blowing snow; if the drop in scattering occurs above 500 m from the surface it is diamond dust that reaches the surface.
- suppose one could say if the drop in scattering occurs below 500 m and the wind speed is less than 4 m/s, could classify it as diamond dust too, but am a bit reluctant to do that.
- this case is captured in the new blowing snow detection algorithm via a confidence flag.
- there is elevated diamond dust that does not reach the surface, but it is extremely difficult to differentiate it from thin ice crystal (cirrus) clouds; not sure if should be trying to detect and classify it as diamond dust.
- the DDA is certainly already detecting these elevated layers as part of the normal cloud detection.
- if do try to classify it, would need some signal strength threshold below which it would be diamond dust, and above the threshold cloud.
- from a science perspective, it is the diamond dust that reaches the surface that is important; this is known as clear-air precipitation.
- the other case is when there is diamond dust directly above a blowing snow layer; this case can be considered elevated diamond dust too and the above concern applies there as well.
- conclusion:
  - the bottom line is to take windspeed out of the diamond dust detection algorithm.
  - there is no rational for using windspeed as a criteria for the presence of diamond dust.

April 12, 2022, 11:05; "RE: Approval request for ASAS – 2696 Investigate and clean-up issues with the plot_atl16.py source code"; email message reply from the ATBD Lead with request to make thicker country boundaries [lines] particularly on the global parameter plot images.

June 6, 2022, 12:52; "RE: atlas_l3b_atm v2.0 Development Evolution Check from Functional Test Data"; email message reply from the PGE developer indicating discovery of a BUG in the code during implementation of the *column_od_asr* value range filtering [i.e., limits: 0.0 < *column_od_asr* () < 4.0]:

- original ATBD Section 3.2.1 for the Global (Over Water) Total Column Optical Depth gridded parameter specified the exclusion of zero (0.0) column optical depth from ASR [high-rate] profile values [i.e., omit *column_od_asr* () = 0.0] from the solution.
- while the filtering of *column_od_asr* () = 0.0 values was included in the test prototype code in the Excel workbook implementation, the important if-then test logic to exclude these values was inadvertently omitted from the Fortran code implementation in the module "glob_tot_col_od_mod.f90".
- consequently, the computed averaged global (over water) total column optical depth gridded parameter array values are "watered down" by the inclusion of 0.0 *column_od_asr* () profile values in the accumulated summation of the accepted column optical depth from ASR observations in the final parameter computation; the effect here is a reduction in the magnitude of the global_column_od (,) grid cell values where the 0.0 *column_od_asr* () profile values have been included in the cell observation summation processing.
- the effect of this BUG is present in the Global (Over Water) Total Column Optical Depth gridded parameter in the ATL16 and ATL17 products included in the NSIDC ICESat-2 data archive deliveries identified as Version 2 (V02), Version 3 (V03), and the Version 4 (V04).
- as the code from the module "glob_tot_col_od_mod.f90" was used as the basis for development of the Expanded Global (Over Water) Total Column Optical Depth gridded parameter code, the BUG allowing inclusion of the 0.0 *column_od_asr* () profile values in the computation was propagated into the module "exp_glob_tot_col_od_mod.f90".
- in the same manner as the computed averaged global (over water) total column optical depth gridded parameter array values, the computed averaged expanded global (over water) total column optical depth gridded parameter array values are also "watered down" by the inclusion of 0.0 *column_od_asr* () profile values in the accumulated summation of the accepted column optical depth from ASR observations in the final parameter computation; again, the effect here is a reduction in the magnitude of the expanded_global_column_od (,) grid cell values where the 0.0 *column_od_asr* () profile values have been included in the cell observation summation processing.
- the effect of this BUG is also present in the Expanded Global (Over Water) Total Column Optical Depth gridded parameter in the ATL16 and ATL17 products included in the NSIDC ICESat-2 data archive; since this parameter was introduced with the v3.2 ATBD and included in the atlas_l3b_atm PGE v1.3, the NSIDC deliveries have included only the Version 4 (V04).

- the BUG is FIXED with the ATBD V04 and the atlas_l3b_atm PGE v2.0 implementation of the profile value range filtering [i.e., limits: 0.0 < *column_od_asr* () < 4.0] in both modules and gridded parameters.

June 7, 2022, 17:33; "RE: Modified Flow for Expanded Global Total Column Optical Depth"; email message reply from the ATBD Lead to developer: do compute [random, uniformly distributed, estimated cloud optical depth] OD when *column_od_asr* is INVALID even if laser angle [laser_angle ()] is greater than the limit [laser_angle () > laser_angle_limit].

June 15, 2022, 14:30; "RE: Approve of ASAS-2719, 2720 and 2743"; email message reply from the ATBD Lead to the Ground System Manager: increase the laser angle limit [laser_angle_limit from 2.0 degrees] to 3.0 degrees; make the angle limit a control parameter.

June 16, 2022, 07:37; "RE: Approve of ASAS-2719, 2720 and 2743"; email message reply from the ATBD Lead to the developer: clarification on application of the laser angle limit [laser_angle_limit]:

```
if (laser_angle () < laser_angle_limit [3.0 degrees] then
    accept the observation for summation and counting
```

June 17, 2022, 09:58; "RE: Test of 960a5 with the laser_angle_limit Change from 2.0 to 3.0 degrees"; email message reply from the ATBD Lead to the Ground System Manager: regarding the visibility of the 5 degree laser off-nadir scans in the central Pacific ocean: the off-nadir scans of 5 degrees appear in the revised Global Total Column Optical Depth (0-1.5) parameter image and in the revised Global Apparent Surface Reflectance (0-1) parameter image both with the laser angle filtering [i.e., laser_angle () < laser_angle_limit [3.0 degrees]] active, however, the Expanded Global Total Column Optical Depth (0-25) parameter image <u>does not</u> show the Pacific off-nadir scanning data.

June 28, 2022, 15:40; "RE: Next Look at the New South Polar Surface Diamond Dust Frequency Gridded Parameter from atlas_l3b_atm PGE v2.0dev with 960a5"; email message reply from the ATBD Lead to the developer regarding a reduction in the image scale on the South Polar Surface Diamond Dust Frequency currently at (0-1): change the image scale maximum to 0.4 [from 1.0].

June 30, 2022, 08:02; "Re: questions/docs"; email message reply from the Ground System Manager to the developer regarding question on the South Polar Surface Diamond Dust Frequency image change in latitude from -90.0 to -60.0 degrees (90S to 60S) down to -90.0 to -65.0 (90S to 65S) to include -65.0 degrees: clarification is to include -65.0 degrees.

June 30, 2022, 09:10; "RE: Questions on Diamond Dust Algorithm Implementation and Wednesday's Attempted Discussion"; email message reply from the ATBD Lead to the Ground System Manager: include South Polar Surface Diamond Dust Frequency observation count parameter. The profile *surface_bin* will be used to check for surface detected; will be INVALID if no surface was detected; surface detected values range from 1 to 700. [Valid *surface_bin* profile values will provide the observation count.]

July 1, 2022, 13:54; "RE: Approval request for ASAS-2723 diamond dust fraction"; email message reply from the ATBD Lead to the Ground System Manager and developer: South Polar Surface Diamond Dust Frequency image scaling needs to be changed to 0.0 - 0.4.

August 30, 2022, 22:52; "RE: ATL04/09/16/17 Acceptance Review"; email message reply from ATBD Lead to developer and others: review of expanded global total column optical depth plots shows the laser incidence angle filtering is <u>not</u> displaying the Pacific Ocean 5 degree off-nadir angle scanning but is showing spuriously high optical depth in this region. Suspicion is that the [random, normally distributed, estimated cloud] optical depths are being calculated. This needs to be changed.

August 31, 2022, 14:18; "L3B Status"; email message from ATBD Lead to developer and Ground System Manager:

- change the [laser off-nadir] angle limit filtering from 3 to 6 degrees.
- filtering is used for [global, northern and southern polar] ASR, [global] total column optical depth, and expanded [global] total column optical depth [parameters and] plots.
- the column optical depth [i.e., *column_od_asr*] profile that exceed the [laser off-nadir] angle limit for the expanded [global] total column optical depth [parameter] <u>should not</u> be replaced with [the random,] normally distributed cloud optical depth [calculated replacement value]; such profiles should be skipped.
- preferably, these changes should be made for next delivered of the L3B products [i.e., the patched and modified v2.0 PGE for redelivery].

A.9 Attachment A-9: History of Atmosphere Gridded Parameters – ATBD Appearance and NSIDC ATL16/ATL17 Product Archive Version Inclusion

Atmosphere Gridded Parameter	Initial ATBD Version and Date	NSIDC ATL16/ATL17 Product Inclusion
Combined Global Cloud Fraction	Version 3.2 September 1, 2021	Version 04 (V04) *Version 05 (V05)*
Expanded Global (Over Water) Total Column Optical Depth [over ocean surface type *only*]	Version 3.2 September 1, 2021	Version 04 (V04)
Expanded Global Total Column Optical Depth [over all surface types, *column_od_asr* filtered, laser angle filtered]	*Version 5* *September 25, 2023*	*Version 05 (V05)*
Global Aerosol Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
Global Apparent Surface Reflectance	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04)
Global Apparent Surface Reflectance [laser angle filtered]	*Version 5* *September 25, 2023*	*Version 05 (V05)*
Global Apparent Surface Reflectance Cloud Fraction	*Version 5* *September 25, 2023*	*Version 05 (V05)*
Global Cloud and Aerosol Fraction	Version 1.2 February 27, 2019	Version 01 (V01) [not delivered]
Global Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
Global Total Column Optical Depth Global (Over Water) Total Column Optical Depth [over water surface type *only*]	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04)
Global Total Column Optical Depth [over all surface types, *column_od_asr* filtered, laser angle filtered]	*Version 5* *September 25, 2023*	*Version 05 (V05)*
Global Ground Detection Frequency	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Apparent Surface Reflectance	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04)
North Polar Apparent Surface Reflectance [laser angle filtered]	*Version 5* *September 25, 2023*	*Version 05 (V05)*

Atmosphere Gridded Parameter	Initial ATBD Version and Date	NSIDC ATL16/ATL17 Product Inclusion
North Polar Apparent Surface Reflectance Cloud Fraction	*Version 5* *September 25, 2023*	*Version 05 (V05)*
North Polar Blowing Snow Frequency [low-rate *only*]	Version 2.2 December 5, 2019	Version 02 (V02)
North Polar Ground Detection Frequency	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar High Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar High-Rate Blowing Snow Frequency	Version 3.1 [Interim] August 12, 2020	Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Low-Rate Blowing Snow Frequency	Version 3.1 [Interim] August 12, 2020	Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Low Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Mid Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Opaque Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Total Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
North Polar Transmissive Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Apparent Surface Reflectance	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04)
South Polar Apparent Surface Reflectance [laser angle filtered]	*Version 5* *September 25, 2023*	*Version 05 (V05)*
South Polar Apparent Surface Reflectance Cloud Fraction	*Version 5* *September 25, 2023*	*Version 05 (V05)*

Atmosphere Gridded Parameter	Initial ATBD Version and Date	NSIDC ATL16/ATL17 Product Inclusion
South Polar Blowing Snow Frequency [low-rate *only*]	Version 2.2 December 5, 2019	Version 02 (V02)
South Polar Ground Detection Frequency	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar High Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar High-Rate Blowing Snow Frequency	Version 3.1 [Interim] August 12, 2020	Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Low-Rate Blowing Snow Frequency	Version 3.1 [Interim] August 12, 2020	Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Low Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Mid Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Opaque Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Surface Diamond Dust Frequency	*Version 5* *September 25, 2023*	*Version 05 (V05)*
South Polar Total Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*
South Polar Transmissive Cloud Fraction	Version 2.2 December 5, 2019	Version 02 (V02) Version 03 (V03) Version 04 (V04) *Version 05 (V05)*

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