CIPS PMC Level 3C Version 5 Summary Files
Last Updated January 2023

This document describes the CIPS PMC Level 3C data product for retrieval version v5.20, revision 05. This data version is available for all CIPS PMC seasons except for the northern hemisphere (NH) season of 2017 and southern hemisphere (SH) season of 2017-2018, when spacecraft operational anomalies and lack of calibration data prevented PMC retrievals. Significant changes have been made to the content, structure and format of version 5.20 files relative to the previous operational data version, v4.20, revision 06. Users who have used the previous v4.20 data product are encouraged to read this summary description before using the new v5.20 data, since many changes have been incorporated into this new release.

Relative to level 2 data, the level 3C files provide the user with a higher-level summary of the CIPS data for each PMC season. To produce the level 3C summary files, the CIPS level 2 data for each orbit are binned over the longitudes sampled within each one-degree latitude bin from 30 to 89 degrees. The lower latitude limit is extended relative to the old v4.20 files, to accommodate lower latitude sampling of the Level 2 data in later years, as well as the fact that we have removed the solar zenith angle (SZA) screens in the processing, which removed low latitude data in the previous version. The ascending and descending portions of the orbit are binned separately to avoid mixing measurements made at distinct local times.

The screening process applied to the Level 2 data in the latitude binning has changed in the v5.20 data product. All pixels where the retrieved radius is less than 20 nm are omitted from calculations of the average radius and ice water content (IWC) values. This is because the radius and IWC are considered very uncertain when the retrieved radius is less than 20 nm; albedo retrievals are more robust, so the albedos reported in the level 3C files do not include a screening for radius. A minimum retrieval error threshold has also been applied to the input albedo, radius and IWC. Pixels with error bars exceeding accepted minimum values are excluded in the calculation of mean albedo, radius and IWC.

In addition to the standard albedo and ice water content products, the v5.20 Level 3C files also contain albedo and IWC retrieved using the Albedo Ice Regression (AIR) analysis. The interested user is referred to *Thomas et al*. (2019) for a description of the AIR analysis.

To make the summary files more useful for scientific analysis, a process of selective data screening and binning has been implemented. The data are screened using a range of cloud albedo thresholds. In previous versions only three thresholds were used: 1, 2 and 5 G (the shorthand notation 'G' is used for the fundamental CIPS albedo unit, 10^{-6} sr^{-1}). For v5.20 this albedo thresholding has been extended significantly, covering the entire range from 1 to 35 G, in 1-G steps. As described in the level 2 data documentation, each level 2 data pixel is assigned a CLD_PRESENCE value. A value of 1 means the algorithm detected a cloud and successfully retrieved cloud parameters; a 0 indicates no cloud was detected. For the purpose of latitude binning, a cloud point is defined by a CLD_PRESENCE value of 1 ***and a retrieved cloud albedo greater than the threshold***. Thus, a measurement having a CLD_PRESENCE value of 1, but an albedo below the threshold, is interpreted as a non-cloud point. The albedo thresholds provide the user with a full range of options for interpretation based on increasing levels of confidence in the cloud detection. Using the lowest threshold values will give the highest frequencies, but at the likely cost of including more false detections. On the other hand, using the higher thresholds will guarantee that the user is analyzing only the most robust CIPS measurements, even though cloud frequencies will likely be underestimated, as dimmer clouds are missed.

Important to note for v5.20 is that the number of observations included in the level 3C arrays depends on the albedo threshold, because the 3C algorithm considers the cloud detection sensitivity. The CIPS cloud detection sensitivity refers to the capability of CIPS to measure and distinguish between molecular scattering and cloud particle scattering. It can be thought of as the threshold albedo corresponding to a 50% probability of detection. Clouds with albedos smaller than the sensitivity have less than a 50% chance of being identified as clouds, whereas clouds with albedos larger than the sensitivity have a greater than 50% chance of being identified as clouds. Users wishing to calculate the daily cloud frequency, for instance, will choose an albedo threshold and then calculate the number of clouds with albedos that meet or exceed that threshold divided by the number of observations for which the detection sensitivity meets or exceeds that threshold. The number of clouds generally decreases with increasing albedo, but the detection sensitivity increases with increasing albedo. Perhaps counterintuitively, this of course means that the number of observations in the level 3C files (the denominator in a frequency calculation) increases with increasing albedo threshold.

More specifically, the cloud detection sensitivity varies with the primary factors that determine the overall cloud albedo and the differences between cloud albedo and Rayleigh scattering albedo. These factors include particle radius, scattering angle, solar zenith angle (SZA) and the number of observations comprised by the scattering phase function. For instance, the sensitivity varies with SZA for two reasons: as the solar zenith angle increases the Rayleigh background signal decreases, while at the same time the CIPS sunward (PX) camera samples smaller (more forward) scattering angles. Both of these factors enhance the discrimination between cloud and background contributions in the CIPS measurements, and hence increase detection sensitivity. The scattering angle dependence (phase function) of larger particles is more asymmetric than that of smaller particles, which have phase functions that are more similar to Rayleigh scattering. Scattering phase functions are better constrained with a more broadly sampled range of scattering angles, and thus clouds are more robustly differentiated from Rayleigh scattering signals. Particularly important are the small scattering angles, for which scattering by PMC particles is increasingly peaked as particle size increases.

Table 1 describes the data contained in the L3C files, which are now provided in NetCDF and binary IDLSAVE formats. Each file contains the latitude-binned data, by orbit, for one complete PMC season. The data include the primary CIPS cloud retrieval products – cloud albedo, particle mode radius, ice water content and AIR albedo and ice water content – as well as auxiliary data such as date, UT and local time, longitude and solar zenith angle.

Also included are the total number of valid measurements in each latitude bin and the number of cloud detections (NUM_OBS and NUM_CLD, respectively), from which cloud frequencies can be calculated. In addition to the orbit-by-orbit data, the v5.20 files now also contain daily averaged arrays for all the primary cloud parameter products. These are obtained by averaging over appropriate pixels from all orbits in a day, in each latitude bin. Corresponding versions of the NUM_OBS and NUM_CLD arrays are also included, appropriate for all orbits in a day rather than a single orbit.

A major departure from the previous v4.20 L3C data is that results obtained with different albedo thresholds are no longer saved to separate files. All latitude-binned arrays now have an added dimension reflecting the albedo threshold. In addition, all data are saved in a single file for the season, rather than the old method of binning separately for "CLD", "ALL" and "NOCLD" scenarios. Bin-averaged cloud parameters are calculated using cloud-only pixels, screened by albedo threshold level (equivalent to v4.20 "CLD" file results), while the auxiliary geolocation parameters are generated by averaging all pixels in a bin (equivalent to the v4.20 "ALL" file logic). NUM_OBS and NUM_CLD are, respectively, the total number of valid pixels and the number of pixels exceeding the cloud detection threshold, in each bin.

A fill value of -999 is used when fewer than 25 valid data points (pixels) exist in a given bin. The user will note that some of the lower latitude bins are never populated with non-fill values, particularly early in the mission (pre-2016) before the AIM orbit started changing significantly and CIPS entered continuous imaging mode. Cautions regarding data usage are described in the CIPS Level 2 documentation. In addition, with regard to the L3C summary files described here, users should exercise caution when average parameters are based on only a few cloud pixels (low values of the NUM_CLD array).

The latitude grid is also defined differently in v5.20 compared to previous versions. In place of the old LATLO and LATHI grids there is a single grid called LAT_GRID, dimensioned to NBIN (=120). This grid includes co-latitudes to discriminate between the ascending and descending nodes of the orbit, where values of LAT_GRID > 90° correspond to the ascending part of the orbit. This is exactly analogous to how latitudes are reported in the CIPS Level 2 CAT file. Specifically, LAT_GRID ranges from 30° to 150° in 1° steps (skipping 90°), so the ascending node data are contained in the second half of the array. To calculate true latitude for the ascending node bins simply use LAT = 180 - LAT_GRID. One final difference is that the bin average in v5.20 is now centered on the grid point, e.g., the LAT_GRID = 70° value contains data averaged between 69.5° and 70.5°.

Table 1. Definition of variables in CIPS Level 3C summary file.

Variable Name	Units	Type (Dimension)	Description
NTHRESH	NA	INTEGER (SCALAR)	Number of albedo threshold values (=35).
NBIN	NA	INTEGER (SCALAR)	Number of latitude bins (=120).
NREV	NA	LONG (SCALAR)	Total number of orbits in the season.
THRESHOLD	10^{-6} sr^{-1}	FLOAT (NTHRESH)	Albedo threshold
LAT_GRID	Degrees	INTEGER (NBIN)	Center latitude of bin
REV	NA	LONG (NREV)	AIM orbit number
DATE	NA	LONG (NREV)	Date in YYYYMMDD format
DFS	NA	LONG (NREV)	Days from solstice

These quantities come from ALL pixels in the bin:			
NUM_OBS	NA	INTEGER (NTHRESH, NREV, NBIN)	Total number of valid pixels in bin.
NUM_CLD	NA	INTEGER (NTHRESH, NREV, NBIN)	Number of cloud pixels in bin above threshold.
UT	Hours	FLOAT (NTHRESH, NREV, NBIN)	Mean UT time in bin.
LTIME	Hours	FLOAT (NTHRESH, NREV, NBIN)	Mean local time in bin.
LON	Degrees	FLOAT (NTHRESH, NREV, NBIN)	Mean longitude in bin.
SZA	Degrees	FLOAT (NTHRESH, NREV, NBIN)	Mean solar zenith angle in bin.
These quantities come from cloud pixels in the bin:			
ALB	10^{-6} sr^{-1}	FLOAT (NTHRESH, NREV, NBIN)	Mean cloud albedo.
ALB_STD	10^{-6} sr^{-1}	FLOAT (NTHRESH, NREV, NBIN)	Cloud albedo standard deviation.
IWC	g/km^2	FLOAT (NTHRESH, NREV, NBIN)	Mean ice water content.
IWC_STD	□g/m^2	FLOAT (NTHRESH, NREV, NBIN)	Ice water content standard deviation.
RAD	nm	FLOAT (NTHRESH, NREV, NBIN)	Mean particle radius
RAD_STD	nm	FLOAT (NTHRESH, NREV, NBIN)	Particle radius standard deviation.
ALB_AIR	10^{-6} sr^{-1}	FLOAT (NTHRESH, NREV, NBIN)	Mean AIR cloud albedo.
ALB_AIR_STD	10^{-6} sr^{-1}	FLOAT (NTHRESH, NREV, NBIN)	AIR cloud albedo standard deviation.
IWC_AIR	g/km^2	FLOAT (NTHRESH, NREV, NBIN)	Mean AIR ice water content.
IWC_AIR_STD	g/km^2	FLOAT (NTHRESH, NREV, NBIN)	AIR ice water content standard deviation.
Daily average quantities:			
NDAYS	NA	LONG/SCALAR	Total number of days in the season.
DATE_DAILY	NA	LONG (NDAYS)	Unique dates in YYYYMMDD format
DFS_DAILY	NA	LONG (NDAYS)	Days from solstice
NUM_OBS_DAILY	NA	LONG (NTHRESH, NDAYS, NBIN)	Total number of valid pixels in bin.
NUM_CLD_DAILY	NA	LONG (NTHRESH, NDAYS, NBIN)	Number of cloud pixels in bin above threshold.
ALB_DAILY	10^{-6} sr^{-1}	FLOAT (NTHRESH, NDAYS, NBIN)	Daily mean cloud albedo.
IWC_DAILY	g/km^2	FLOAT (NTHRESH, NDAYS, NBIN)	Daily mean ice water content.
RAD_DAILY	nm	FLOAT (NTHRESH, NDAYS, NBIN)	Daily mean particle radius.

ALB_AIR_DAILY	10^{-6} sr^{-1}	FLOAT (NTHRESH, NDAYS, NBIN)	Daily mean AIR cloud albedo.
IWC_AIR_DAILY	g/km^2	FLOAT (NTHRESH, NDAYS, NBIN)	Daily mean AIR ice water content.

References:

Thomas, G., C. E. Randall, J. D. Lumpe, and C. Bardeen (2019). Albedo-Ice regression method for determining ice water content of Polar Mesospheric Clouds using ultraviolet observations from space, Atmospheric Measurement Techniques, 12, 1755-1766, doi:10.5194/amt-12-1755-2019.

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