CIPS RAA Level 2 Data: Orbit-by-Orbit Rayleigh Albedo Anomaly

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1. Introduction

In this document we describe the CIPS v01.00 Level 2 RAA data products and file contents and provide guidance for data users. This product is a new addition to the CIPS primary PMC data products. CIPS Level 2 Rayleigh albedo anomaly (RAA) data files contain derived albedo anomaly on an orbit-by-orbit basis. These files are provided for quantitative analysis of the CIPS data at high spatial resolution. Detailed documentation on the RAA retrieval process is currently in preparation and a link will be provided in the near future. CIPS measures the single-scatter albedo at 265-nm which, in the absence of polar mesospheric clouds (PMC), is due entirely to atmospheric Raleigh scattering. The RAA is defined as the residual difference between the measured Rayleigh albedo and a smooth basic state, expressed in percent. The Rayleigh scattering source function peaks near an altitude of 50 km and the RAA signal therefore provides a direct measure of dynamical perturbations near the stratopause. In particular the occurrence and spatial characteristics of gravity waves (GW) with typical horizontal wavelengths from 15-300 km can be derived from the measured RAA.

Unlike the CIPS PMC data, which cover only the polar summer (~55°–84° latitude), the RAA product is derived using all available dayside CIPS images. This extends the CIPS coverage to lower latitudes, non-PMC seasons (i.e., all year), and into the winter hemisphere where data exist. Full global coverage became possible starting in February 2016 when the CIPS instrument began operating in Continuous Imaging (CI) mode. This mode differs from the nominal PMC mode, used exclusively for the first 9 years of the AIM mission, in that images are taken on a 3-minute cadence rather than the 43-sec PMC imaging cadence. This results in significantly less pixel overlap between successive CIPS images, which adversely affects particle size retrieval in PMC season. Conversely, it offers a significant advantage in that the 30 images obtained per camera are spread out over the entire orbit rather than being localized over the summer pole. Thus full global coverage is obtained and all images obtained on the sunlit portion of the globe are available for deriving RAA data products.

The switch to CI mode was made in response to changes in the AIM orbit. Since the launch of AIM in 2007 the orbit has precessed from a zero β-angle orbit with noon-midnight equator crossings to a high β-angle terminator orbit (β-angle is the angle between the orbit plane and the earth-sun vector). The CI operational mode represents an optimal solution that will continue to extend the CIPS historical PMC measurements into middle latitudes, while at the same time providing RAA/GW data products with global coverage throughout the year. CI mode is the nominal CIPS operating mode since the AIM satellite entered full-sun operations in March 2017.

The RAA processing stream starts with the same v5.10 Level 1A data (soon to be v5.20 Level 1A data) used for PMC data processing (see Lumpe *et al.,* [2013] and related documentation on the CIPS web page) and produces Level 2 RAA files for both scene-by-scene and full orbit strip data, as described in detail below. As of this writing the time period from Feb 2016 to Feb 2017, which includes only CI mode data, has been processed with the RAA algorithm. The CI measurement mode is not a requirement for the RAA algorithm, however; it can just as easily be run on the original PMC mode measurements (43-sec cadence, summer sampling). The entire CIPS data record will soon be reprocessed using v5.20 L1A data, which will yield a complete 10-year record of RAA data products.

Validation of the new CIPS RAA data is still underway, but numerous case studies are available comparing CIPS GW retrievals to near-coincident observations by the Atmospheric Infrared Sounder (AIRS) instrument [Randall *et al.,* 2017; in press at *Geophysical Research Letters*]. These comparisons show good agreement in the location, orientation and horizontal wavelengths of GW features in both the CIPS and AIRS imagery. Additionally, it is evident that CIPS is able to resolve finer scale GW structures than AIRS. The brightness temperature weighting function for the 4.3-μm AIRS data peaks around 35 km, whereas the CIPS weighting function peaks around 50-55 km, indicating coherent upward GW penetration throughout this region. The close correspondence between the CIPS and AIRS measurements supports the utility of the new CIPS data for investigating GW near an altitude of ~50 km.

The RAA product is provided in two different formats for scientific analysis. Level 2a files contain CIPS RAA data in a scene-by-scene format. A CIPS scene contains simultaneous images from the four CIPS cameras, with a footprint of approximately 2000 km along-track by 900 km cross-track, as described in Lumpe *et al.*, [2013]. In the Level 2b files all the scenes from an orbit are merged together by combining overlapping pixels from different cameras in much the same way as the CIPS Level 2 PMC data products (again see Lumpe *et al.*, [2013]). For each data level multiple netcdf data files are produced for each orbit, in addition to a png image file for Level 2b. The following files are produced and made publicly available on the CIPS web site for each orbit:

Level 2a:

(1) Geolocation file, including variables such as date, time, latitude, longitude, solar zenith angle, etc. The file name extension is _cat.nc.

(2) Albedo anomaly file, including derived Rayleigh albedo anomaly and error, and diagnostics. The file name extension is _alb.nc.

(3) Measurement geometry file, containing satellite view angles and scattering angles for each scene. The file name extension is _ang.nc.

Level 2b:

(1) Geolocation file, including variables such as date, time, latitude, longitude, solar zenith angle, etc. File content is similar to the Level 2a cat file. The file name extension is _cat.nc.

(2) Albedo anomaly file, including derived Rayleigh albedo anomaly and error, and total measured Rayleigh albedo. The file name extension is _alb.nc.

(3) Orbit-strip image of albedo anomaly. The file name extension is _alb.png.

Variables contained in all netcdf files are described in tables at the end of this document. There are ~15 orbits per day. In pre-CI mode each orbit contains 30 PX camera images and 27 images from each of the other three cameras, while in CI mode there are 30 images per camera. Level 2 RAA and associated geolocation variables are provided with 56-km^2 resolution over the entire orbit track (exact resolution is 7.5 km x 7.5 km = 56.25 km^2, shortened to 56 km^2 for simplicity);

resolution elements are 7.5 km × 7.5 km in the nadir, and become elongated away from nadir but remain 56 km^2 in total area covered.

Data arrays in the Level 2 files are reported for all Level 2 pixels, with array dimensions corresponding to the number of elements in the along-track and cross-track directions. For convenience in data handling, the arrays span the entire bounding box defined by a single CIPS scene (Level 2a) or the entire orbit (Level 2b). However roughly half of these elements correspond to locations where no measurements are made and therefore have fill values. Each array element thus corresponds to a unique location (latitude and longitude) that in the Level 2b representation can observed up to ten times with different observation geometries, and thus scattering angles (see Lumpe *et al*. [2013] for a description of the viewing geometry and measurement approach).

The compressed Level 2a geolocation, albedo and measurement geometry netcdf files are ~6.5, 8, and 10 MB in size, respectively. Compressed Level 2b geolocation and albedo netcdf files are ~10 and 5 MB in size, respectively. Uncompressed file sizes are much larger due to the significant fraction of fill (NaN) values in these files.

Documentation and IDL software tools to read the Level 2 RAA netcdf files are available for download from the AIM web site. Netcdf readers for other software packages are available elsewhere (see, for instance, http://www.unidata.ucar.edu/software/netcdf/software.html).

2. Orbit Strip Images

Users interested in a quick, qualitative view of the data for a particular orbit should download the Level 2b albedo image png files (type 3 in the Level 2b list above). These images often show visual evidence of gravity wave features that can then be analyzed more carefully using the data in the netcdf files.

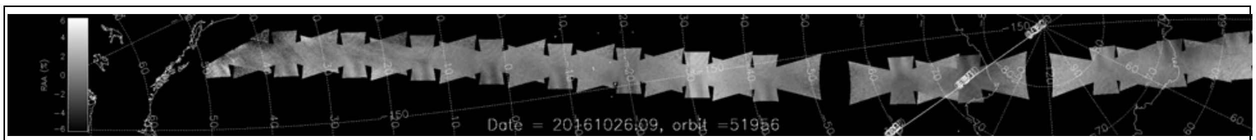

Figure 1. RAA image from CIPS orbit 51956 on 26 October 2016. This data is obtained in CI mode outside of the PMC season.

Figure 1 shows a sample image for an orbit of data obtained on 26 October 2016 when the instrument was operating in CI mode. Each "bowtie" shape is a single scene, with successive scenes overlapping only in the fore and aft (PX and MX) cameras. The noticeable gaps in the image sequence at ~55°S and 80°S correspond to the locations of dark images. These diagnostic images are required for calibration and are taken twice per orbit, replacing a normal science image. The image is aligned along the center longitude of the orbit, as defined by the bounding box, thus minimizing the area needed for the image.

Figure 2 shows an image from an orbit just 11 days earlier, when the instrument was temporarily operating in PMC measurement mode for a short period. This sampling is representative of the first 8 years of the mission (e.g., see all PMC orbit image strips prior to February 2016). Data obtained in this mode are characterized by dense along-track overlap between the 27 sequential scenes and concentration of the images in the summer polar region, in this case extending down to ~ 20° latitude in the Southern Hemisphere.

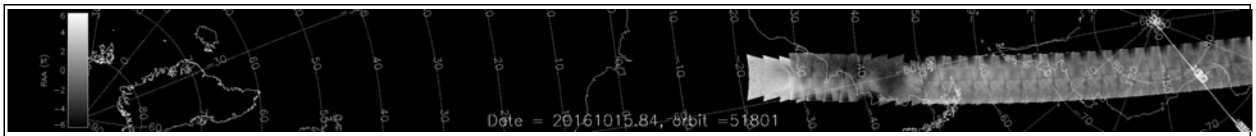

Figure 2. RAA image from CIPS orbit 51801 on 15 October 2016. This image is also outside of PMC season, but the data are obtained using the PMC measurement sequence, and thus limited to high latitudes in the summer (Southern) hemisphere.

The remainder of this section describes some anomalies or artifacts that occasionally occur and that users should be aware of in the RAA png file images. Some of these are simply results of the observing geometry, but others are caused by retrieval artifacts or PMC contamination. If images are found to exhibit suspicious behavior that is not described here, we would very much appreciate being informed (please send an email to aimsds@lasp.colorado.edu).

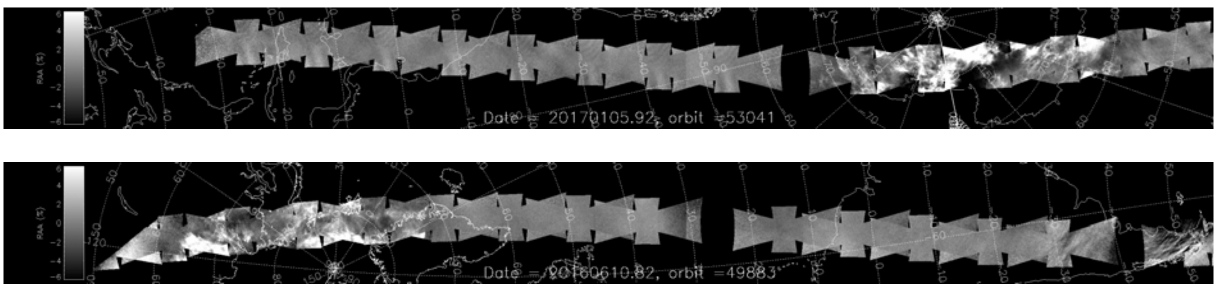

Figure 3. Two CIPS RAA images obtained during peak PMC season. The top image is from CIPS orbit 53401 on 5 January 2017. Bright artifacts due to extensive PMCs are evident throughout the polar region in the Southern Hemisphere. The bottom image is from orbit 49883 on 10 June 2016. This image shows PMCs throughout the Northern Hemisphere polar region, but also includes clear evidence of gravity wave at the lowest Southern Hemisphere latitudes (rightmost scene in the image).

Figure 3 shows two orbits that are representative of CIPS observations in the middle of the PMC season; the Southern and Northern Hemisphere PMC seasons in the top and bottom panels, respectively. Here we see the obvious signature of PMC contamination evident in the very bright features at high latitudes in the summer hemisphere. Clearly the RAA retrieval breaks down in this circumstance and PMC-contaminated data is not useful for GW detection or science. We recommend careful, or complete, screening of all data above 50 degrees latitude in the summer hemisphere during PMC seasons (May 1 to August 31 in the North and Nov 1 – Feb 28 in the South). Note that the bottom image, obtained from orbit 49883 on 10 June 2016, also shows GW features at high Southern Hemisphere latitudes.

Figures 4 through 6 show examples of both real and apparent GW signatures in the Level 2b orbit strip png images. These figures are intended to alert data users of the need to use caution in the interpretation of wave patterns. Users must first examine the orbit strip for repeating patterns in adjacent scenes. Figure 4 provides an example of *apparent* GW caused not by the atmosphere but by the retrieval method. See, for example, what appears to be GW off the coast of Vietnam (in the top part of the camera scene marked with the letter “A”). These wave patterns are likely artifacts since they are also present in adjacent camera scenes (see the top part of the camera scenes given by the letters A through F). Users are advised to be cautious and to look in adjacent camera scenes when they see GW patterns in the CIPS RAA L2b orbit strips. If the same wave patterns (wave fronts that have the same horizontal spacing and orientation) occur in multiple neighboring scenes then this is an indication of artifacts.

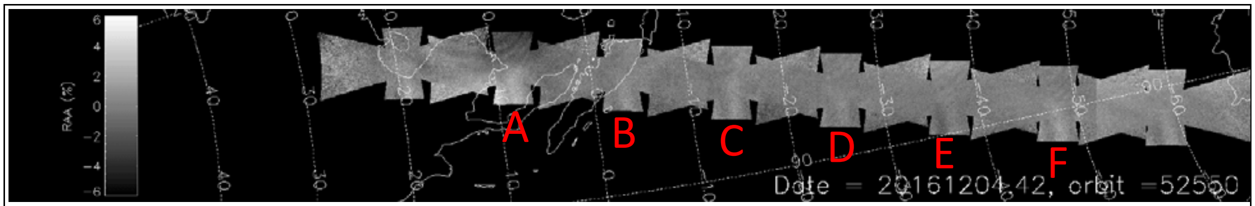

Figure 4. A portion of the png image for orbit 52550 on 4 Dec 2016 that extends from Indonesia (left) over the Indian Ocean (right). Letters A-F denote the MX and MY camera pictures sampled along the orbit track.

Figure 5 demonstrates the presence of both real GW and GW artifacts in a single orbit strip. Apparent wave patterns occur in the top part of scenes denoted by the letters A though F. Indications that these wave patterns are artifacts are that they have the same spacing and phase orientation in neighboring MX cameras. Compare the appearance of these artifacts with real GW located east of Fiji (just above the letter “D”). Since the GW near Fiji do not appear in the other scenes this gives confidence that they are real.

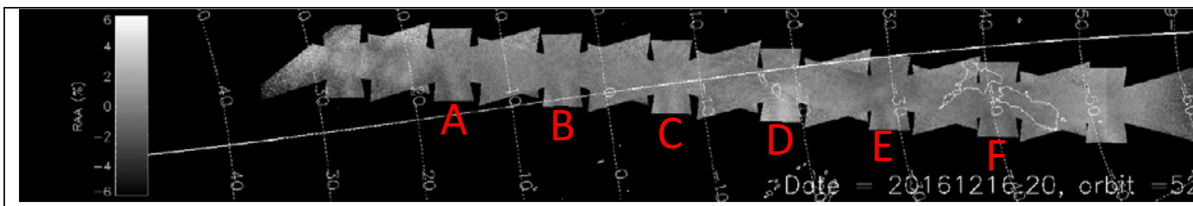

Figure 5. A portion of the png image for orbit 52728 on 16 Dec 2017 that extends across the Pacific Ocean. Letters A-F denote the MX and MY camera pictures sampled along the orbit track.

Figure 6 shows both real GW and GW artifacts in another orbit strip. Real GW over Madagascar (above the letter “D”) are differentiated from artifacts in that they do not repeat from scene to scene.

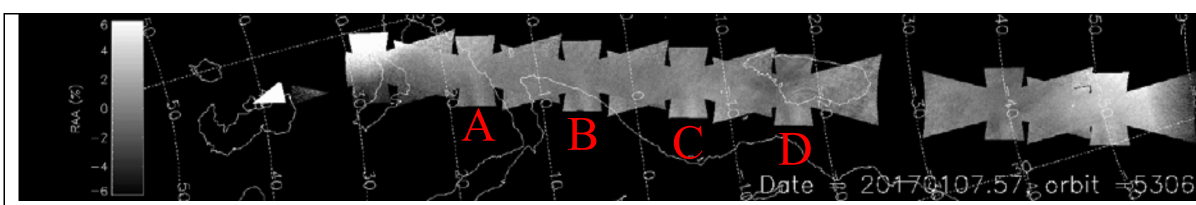

Figure 6. A portion of the png image for orbit 53066 on 7 Jan 2017 that extends from the Persian Gulf (left) along the east coast of Africa. Letters A-D denote the MX and MY camera pictures sampled along the orbit track.

3. Guidance for NetCDF files

The NetCDF files listed in Section 1 enable users to quantitatively analyze the data plotted in the orbit strip images. Tables 1-5 below summarize the contents of each data file and provide a description of all parameters and arrays along with explicit values from a single representative CIPS orbit.

Finally, a note about the file name convention: Each file has a day-of-year included in the file name. This is the day corresponding to the ascending node equator crossing time (definition of orbit start time). When the equator crossing time is near midnight UT, some or all of the data in the file may occur on the day after the day in the filename.

Table 1. Variables in the CIPS RAA level 2a geolocation file. Fill value is NaN.

Variable Name	Units	Type/Dimension	Description / Example*
AIM_Orbit_Number		Integer / 1	Integer orbit number to which all data in the file applies / 53104
Version		String / 1	Data version number / 1.00
Revision		String / 1	Data revision number / 03
Product_Creation_Time		String / 1	String containing UT time at which data file was produced / Thu Feb 9 15:51:27 2017
UT_Date	yyyyddd	Long / 1	UT date / 20170110
UT_Time	day	Double / [Nscenes]	UT time for each element (fractional date) / range: 20170110.07241-20170110.10574
JD_Time	Julian day	Double / [Nscenes]	UT time for each element (fractional Julian day) / range: 2457763.57241 - 2457763.60574
Orbit_Start_Time	microseconds	Double / 1	GPS start time of orbit (microseconds from 0000 UT on 6 Jan 1980) / 1.1701958e+15
Orbit_Start_Time_UT	yyyy/doy-hh:mm:ss	String / 1	Start time of orbit / 2017/010-01:05:01
Orbit_End_Time	microseconds	Double / 1	GPS end time of orbit (microseconds from 0000 UT on 6 Jan 1980) / 1.1680512e+15
Nscenes		Long/ 1	# of scenes in the orbit / 15
XDim		Long / 1	Number of along-orbit-track elements in the scene data arrays / 293
YDim		Long / 1	Number of cross-orbit-track elements in the scene data arrays / 145
KM_Per_Pixel	km	Float / 1	Linear dimension of square pixel occupying area of Level 2 resolution element / 7.50
Bbox	Index	Long / [4,Nscenes]	Bounding Box of each scene: Bottom-Left and Top-Right indices of the smallest rectangle which both circumscribes a set of cells on a grid and is parallel to the grid axes / [-1317, 1, 293, 145] (scene 1)
Center_Lon	Degrees	Double / 1	Center longitude of the orbit / 127.80141
Latitude	Degrees	Float / [Xdim,Ydim,Nscenes]	Latitude of each element / [293,145,15], range: 20.428 to 41.606 (scene 1)
Longitude	Degrees	Float / [Xdim,Ydim,Nscenes]	Longitude of each element; ranges from -180 to 180 / [293,145,15], range: -135.956 to -119.739 (scene 1)

Zenith_Angle	Degrees	Float / [Xdim,Ydim,Nscenes]	Solar zenith angle (SZA) of each element. The value is specified at the altitude of the maximum contribution to the Rayleigh background. Generally around 55 km but increasing with increasing SZA. / [293,145,15], range: 81.360 to 97.651 (scene 1).
Orbit_Track_X_Axis		Double / 3	X axis of the orbit track ECEF coordinates used for binning grid / [-0.58685432, -0.37111988, -0.71963327]
Orbit_Track_Y_Axis		Double / 3	Y axis of the orbit track ECEF coordinates used for binning grid / [0.48878327, 0.54618836, -0.68027140]
Orbit_Track_Z_Axis		Double / 3	Z axis of the orbit track ECEF coordinates used for binning grid / [0.64551756, -0.75096492, -0.13913581]
Orbit_Track_Epoch	microseconds	Double / 1	GPS time at which the orbit track axis approximately matches the true orbit track (microseconds from 0000 UT on 6 Jan 1980) / 1.1680491e+15
Data_Product		String	Description of data product in this file / 'Rayleigh Albedo Anomaly Level 2A (scenes)'
Notes		String	Any additional notes. / Blank.

* Examples are from cips_raa_2a_orbit_53104_2017-010_v01.00_r03_cat.nc.

Table 2. Variables in the CIPS RAA level 2a albedo anomaly file. Fill value is NaN.

Variable Name	Units	Type/Dimension	Description / Example*
Rayleigh_Albedo_Anomaly	Percent	Double / [Xdim,Ydim,Nscenes]	Albedo Anomaly / [293,145,15], range: -9.334 to 4.082 (scene 2)
Rayleigh_Albedo_Anomaly_Unc	Percent	Double / [Xdim,Ydim,Nscenes]	Uncertainty in Albedo Anomaly due to noise / [293,145,15], range: 0.313 to 1.853 (scene 2)
Rayleigh_Albedo	10^{-6} sr^{-1}	Double / [Xdim,Ydim,Nscenes]	Total observed albedo / [293,145,15], range: 56.957 to 287.049 (scene 2)
Overlap_Offset	Percent	Double / [4,Nscenes]	Camera normalization factor added to RAA for each image / [4,15], [0.2192, -0.5246, 0.6391, -0.3338] (scene 2)
Overlap_Error	Percent	Double / [5,Nscenes]	Residual median camera differences after overlap offset / [5,15], [0.29, -0.29, 0.345, 0.049, -0.049] (scene 2)
Overlap_Error0	Percent	Double / [5,Nscenes]	Residual median camera differences before overlap offset / [5,15], [0.716, -0.849, -0.628, 1.213, 0.142] (scene 2)

* Examples are from cips_raa_2a_orbit_53104_2017-010_v01.00_r03_alb.nc.

Table 3. Variables in the CIPS RAA level 2a measurement geometry file. Fill value is NaN.

Variable Name	Units	Type/Dimension	Description / Example*
View_Angle	Degrees	Double / [Xdim,Ydim,Nscenes]	Satellite view angle / [293,145,15], range: XXX to YYY (scene 1)
Scattering_Angle	Degrees	Double / [Xdim,Ydim,Nscenes]	Solar scattering angle / [293,145,15], range: XXX to YYY (scene 1)
View_Angle_Derivative	Degrees/km	Double / [Xdim,Ydim,Nscenes]	Derivative of view angle with altitude along line of sight / [293,145,15], range: -0.028 to 8.83e-05 (scene 1)
Zenith_Angle_Derivative	Degrees/km	Double / [Xdim,Ydim,Nscenes]	Derivative of zenith angle with altitude along line of sight / [293,145,15], range: -0.0232 to 0.0224 (scene 1)

* Examples are from cips_raa_2a_orbit_53104_2017-010_v01.00_r03_ang.nc.

Table 4. Variables in the CIPS RAA level 2b geolocation file. Fill value is NaN.

Variable Name	Units	Type/Dimension	Description / Example*
AIM_Orbit_Number		Integer / 1	Integer orbit number to which all data in the file applies / 53104
Version		String / 1	Data version number / 1.00
Revision		String / 1	Data revision number / 03
Product_Creation_Time		String / 1	String containing UT time at which data file was produced / Thu Feb 9 15:51:36 2017
UT_Date	yyyyddd	Long / 1	UT date / 20170110
UT_Time	yyyymmdd.xx	Double / [Xdim,Ydim]	UT time for each pixel (fractional day) / [3600,320], range: 20170110.07241 - 20170110.10574
JD_Time	Days from epoch	Double / [Xdim,Ydim]	JD time for each pixel (fractional Julian day) / [3600,320], range: 2457763.57241 - 2457763.60574
Orbit_Start_Time	microseconds	Double / 1	GPS start time of orbit (microseconds from 0000 UT on 6 Jan 1980) / 1.1680455e+15
Orbit_Start_Time_UT	yyyy/doy-hh:mm:ss	String / 1	Start time of orbit / 2017/010-01:05:01
Orbit_End_Time	microseconds	Double / 1	GPS end time of orbit (microseconds from 0000 UT on 6 Jan 1980) / 1.1680512e+15
XDim		Long / 1	Number of along-orbit-track elements in the data arrays / 3600
YDim		Long / 1	Number of cross-orbit-track elements in the data arrays / 320
KM_Per_Pixel	km	Float / 1	Linear dimension of square pixel occupying area of Level 2 resolution element / 7.50
Bbox	Index	Long / [4]	Bounding Box: Bottom-Left and Top-Right indices of the smallest rectangle which both circumscribes a set of cells on a grid and is parallel to the grid axes / [-1800, -160, 3600, 320]
Center_Lon	Degrees	Double / 1	Center longitude of the orbit / 127.80141
NLayers		Integer / [Xdim,Ydim]	Number of observations at the location of each element; each observation corresponds to a different observing geometry and thus scattering angle in the phase function / [3600,320], range: 1 to 2.
Latitude	Degrees	Float / [Xdim,Ydim]	Latitude of each element / [3600, 320], range: -89.9804 to 74.8148

Longitude	Degrees	Float / [Xdim,Ydim]	Longitude of each element; ranges from -180 to 180 / [3600, 320], range: -180.0 to -180.0
Zenith_Angle	Degrees	Float / [Xdim,Ydim]	Solar zenith angle (SZA) of each element. The value is specified at the altitude of the maximum contribution to the Rayleigh background. Generally around 55 km but increasing with increasing SZA. / [3600, 320], range: 50.5209 to 99.6370
Orbit_Track_X_Axis		Double / 3	X axis of the orbit track ECEF coordinates used for binning grid / [-0.586, -0.371, -0.719]
Orbit_Track_Y_Axis		Double / 3	Y axis of the orbit track ECEF coordinates used for binning grid / [0.488, 0.546, -0.680]
Orbit_Track_Z_Axis		Double / 3	Z axis of the orbit track ECEF coordinates used for binning grid / [0.646, -0.751, -0.139]
Orbit_Track_Epoch	microseconds	Double / 1	GPS time at which the orbit track axis approximately matches the true orbit track (microseconds from 0000 UT on 6 Jan 1980) / 1.1680491e+15
Data_Product		String	Description of data product in this file / 'Rayleigh Albedo Anomaly Level 2B (scenes)'
Notes		String	Any additional notes. / Blank.

* Examples are from cips_raa_2b_orbit_53104_2017-010_v01.00_r03_cat.nc.

Table 5. Variables in the CIPS RAA level 2b albedo anomaly file. Fill value is NaN.

Variable Name	Units	Type/Dimension	Description / Example*
Rayleigh_Albedo_Anomaly	Percent	Double / [Xdim,Ydim]	Albedo Anomaly / [3600,320], range: -6498.4895 to 2686.5918
Rayleigh_Albedo_Anomaly_Unc	Percent	Double / [Xdim,Ydim]	Uncertainty in Albedo Anomaly due to noise / [3600,320], range: 0.00 to 462.239
Rayleigh_Albedo	10^{-6} sr^{-1}	Double / [Xdim,Ydim]	Total observed albedo / [3600,320], range: -1.204 to 495.023

* Examples are from cips_raa_2b_orbit_53104_2017-010_v01.00_r03_alb.nc.

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