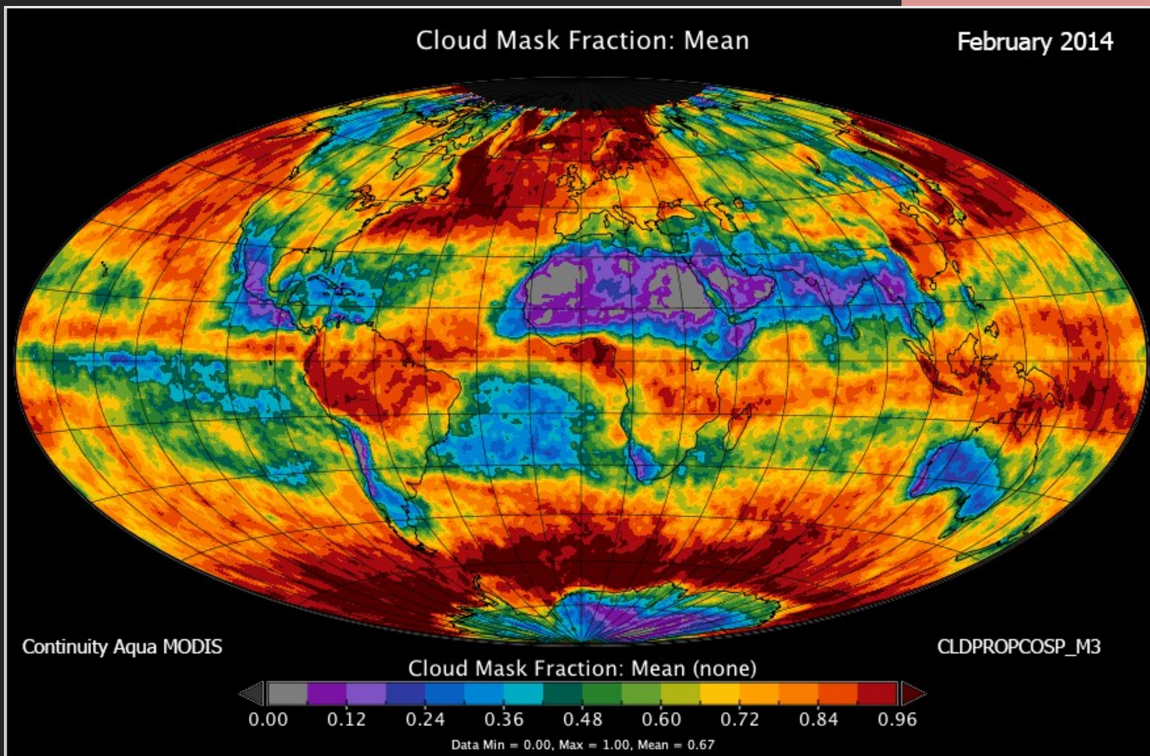
Level-3 CLDPROP COSP Cloud Properties (CLDPROPCOSP_L3)

Continuity MODIS Aqua & VIIRS SNPP Global Gridded Product for Climate Studies

User Guide



Continuity Atmosphere Level-3 CLDPROP COSP
(Continuity L3 MODIS Aqua & VIIRS SNPP)
Global Gridded Products for Daily (D3) and Monthly (M3)
User Guide

L3 CLDPROP COSP User Guide, Version 2.1, 27 Oct 2022

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1.0. Introduction

1.0.1. Background

NASA ushered in a new generation of global imager observations of Earth with MODIS on the EOS Terra and Aqua missions. MODIS provides unique spectral capabilities relative to earlier global imagers, allowing for the retrieval of geophysical parameters key to understanding changes in Earth's land surface, ocean, and atmosphere. To date, these imagers have proved remarkably successful, exceeding their design lives to produce 18-year (Terra) and 16-year (Aqua) climate data records that are expected to continue into the early 2020s.

Nevertheless, detecting climate trends, including those related to clouds, is a multi-decadal endeavor (typically greater than 2-3 decades) given the uncertainties of current sensors [*Wielicki et al.*, 2013]. Therefore, while the EOS Aqua and Terra missions are projected to extend into the early 2020s, those data records alone are not sufficient for establishing climate trends. Extending these EOS data records to new sensors is therefore imperative.

For continuing MODIS-like global cloud records, the only viable imager is VIIRS (375-750 m nadir resolution) on Suomi NPP (SNPP) and the operational NOAA JPSS series (starting with JPSS-1/NOAA-20 in late 2017, with subsequent satellites expected to provide coverage into the mid-2030s). For this reason, a merged MODIS-VIIRS cloud record to serve the science community in the coming decades requires different algorithm approaches than those used for MODIS alone.

Starting in 2013, NASA formed the SNPP Science Team to develop continuity algorithms that would bridge the EOS and SNPP observation era. Due to the differing characteristics between MODIS and VIIRS, the approach taken was to develop a continuity algorithm that uses common (or near-common) logic to be run on both the MODIS and VIIRS data streams.

To advance research on detecting climate trends, including those related to clouds, a new project began development: Level-3 Atmosphere for **C**FMIP (Cloud Feedback Model Intercomparison Project) **O**bservation **S**imulator **P**ackage or **COSP**.

MODIS and/or VIIRS observations provide a valuable source of information for understanding errors in climate models. Retrievals of particle size, in particular, offer a unique view of cloud-aerosol interactions. A "MODIS simulator", part of the COSP package, facilitates the comparison of models and observations by producing synthetic MODIS observations from climate model integrations. Output from the MODIS simulator is part of the formal request for data in the current generation of intercomparison projects (CMIP6). The MODIS request is consistent with similar requests from other platforms and minimizes data volumes, but the output requested unfortunately does not map easily onto standard MODIS Level-3 monthly products.

Thus a new dataset (CLDPROPCOSP) was devised, which is described fully in this User Guide. This new dataset, which reformats regular CLDPROP data (which includes cloud mask, cloud top, and cloud optical retrieval data) from either the MODIS Aqua or VIIRS SNPP instrument over daily and monthly timeframes, provides a set of custom cloud-related parameters, using specific dataset definitions, for better comparison with climate model output. This new dataset is provided in the Network Common Data Format Version 4 (NetCDF4) -- a data format widely used by the climate modeling community.

1.0.2. Level-3 (L3) Atmosphere Data Production & Archive

Level-3 (L3) CLDPROP COSP Atmosphere data users should note that the inputs to COSP are the Continuity L2 CLDPROP (cloud property) products from either MODIS Aqua or VIIRS SNPP. These L2 cloud products have been in production since 2019. However, do note that the L3 CLDPROP COSP product generation has only been produced thus far for the period from March 2012 through present.

Starting sometime in the year 2020, this new L3 CLDPROP COSP product (CLDPROPCOSP) for the 9-year data record (2012-present) will be archived and made available from the LAADS DAAC distribution facility: https://ladsweb.modaps.eosdis.nasa.gov

1.0.3. Definition of "Level"

A quick definition of the "Level" term for those not familiar. The "Level" terminology is used to denote broad categories of satellite data products. Level-0 (L0) denotes raw spectral channel counts, Level-1B (L1B) denotes calibrated and geolocated radiances, Level-2 (L2) denotes orbital-swath science products, typically organized into files with only several minutes of data, and finally Level-3 (L3) denotes global-gridded science products, most commonly compiled on longer time frames like daily or monthly.

1.0.4. Scope of this Document

This document describes the Atmosphere Level-3 (L3) CLDPROP COSP product (CLDPROPCOSP). Topics covered include computational approaches and scenarios, subsampling and gridding characteristics, caveats to be aware of, and finally a breakdown of the parameters and statistics computed in this new L3 product.

1.1. L3 CLDPROP COSP File Characteristics

There are two L3 CLDPROP COSP Cloud products (See Table 1) derived by reformatting two instrument/platform data streams (L2 MODIS Aqua & L2 VIIRS SNPP) at two temporal timeframes (daily & monthly). L3 Daily CLDPROP COSP products are tagged D3, which is short for L3 Daily. L3 Monthly CLDPROP COSP products are tagged M3, which is short for L3 Monthly.

The abbreviation-acronym CLDPROP COSP (used at the beginning of the L3 filename) is a combination of the inputs to the product CLDPROP and the output format COSP.

L3 Daily (D3) CLDPROP COSP products, represented by the violet parallelogram in the center of the figure below, are derived by reformatting L2 Continuity Atmosphere Cloud Data from either Aqua MODIS or VIIRS SNPP. L3 Monthly (M3) CLDPROP COSP products, represented by the violet parallelogram on the far right-hand side of the figure below, are derived directly from the L3 Daily (D3) CLDPROP COSP products only. Monthly (M3) products never read L2 data, only the Daily (D3) products read L2 directly. Table 1 outlines the data processing flow for L3 CLDPROP COSP:

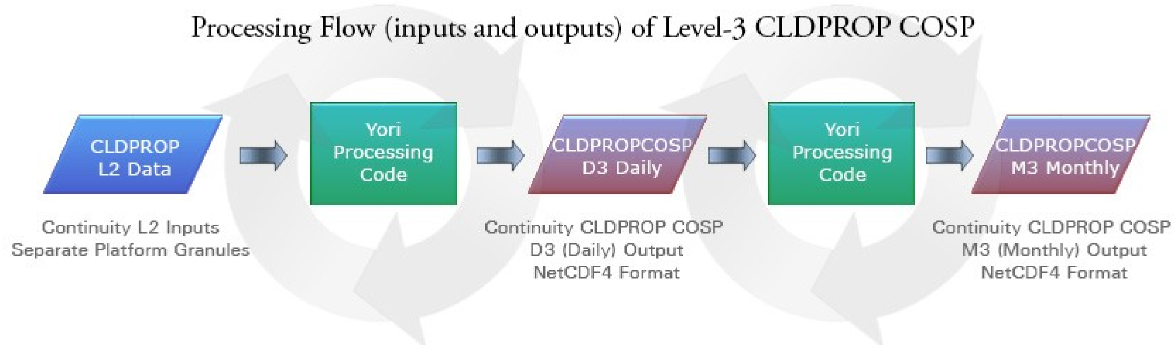


Table 1. CLDPROPCOSP Processing Flow from L2 to L3 Products

1.1.1. File Format

The new CLDPROP COSP Atmosphere products are in NetCDF4 format. L3 CLDPROP COSP NetCDF4 files are organized into (broad) Groups (e.g., Cloud_Top_Pressure) -- and statistics are stored as Variables under that Group (e.g., Mean, Standard_Deviation, Pixel_Counts, etc.).

1.1.2. Resolution

The statistics in L3 CLDPROP COSP files are at 1×1° resolution on a rectangular lat-lon global map. This means that all L3 statistics have an array size of 360 columns by 180 rows (360x180), with each L3 grid cell representing one degree of latitude and longitude.

Note that for the inputs to L3 CLDPROP COSP, each Level-2 atmospheric parameter is retrieved at a spatial resolution determined by the single field of view (FOV) of the key spectral bands of the instrument required to perform the retrieval. Resolutions of L2 Continuity Cloud-related science products are at either 1×1 km or 5×5 km for both MODIS Aqua and VIIRS SNPP. L3 Atmospheric parameters are computed at 1×1° spatial resolution.

1.1.3. Filename Convention

Level-3 (L3) CLDPROP COSP Atmosphere Product NetCDF4 files are named using a standardized convention as displayed below in Table 2. Note that for the sample NetCDF4 file-name shown:

- The first part of the new standardized Product Prefix is the Product Type (CLDPROPCOSP).
- The second part is the Level (D3 for Daily or M3 for Monthly).
- The third part is the Instrument (MODIS or VIIRS)
- The fourth part is the Satellite Platform (Aqua or SNPP)
- The DDD in the date denotes the Day of Year (001-366).
- All times are UTC time, not local time.

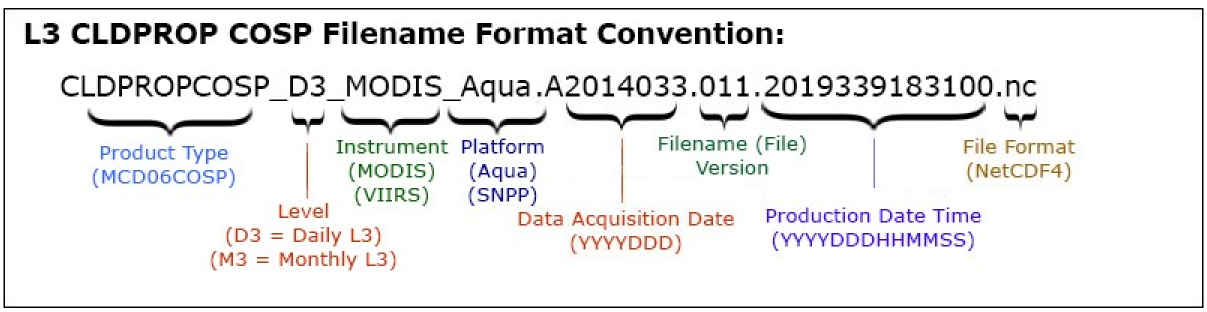


Table 2. The File Naming Convention for the L3 CLDPROP COSP Product

1.1.4. Versioning: The relationship between Filename (File) Version and Data Version

We can discuss versions in two primary ways: a filename version, which is part of the NetCDF4 filename (e.g., 011) shown in Table 2; and a data or collection version, which is a more conventional method of versioning (e.g., Version 1.1), which is generally used in written or verbal communications by the Science Algorithm Teams and in publications.

Note that the first publicly released version of L3 MCD06COSP, processed in 2020, is assigned a data version of 1.1, and is tagged 011 in the filename (see filename version in Table 2).

This Version 1.1 (or 011) for L3 CLDPROPCOSP matches the version of the L2 CLDPROP input, which was reprocessed as Version 1.1 during the Fall of 2019 for the entire data record of the two instrument/platform combinations.

A specific version of data generally stays "current" (is distributed) for anywhere from 1 to as many as 10 years. When reprocessing with an updated CLDPROP COSP algorithm version is undertaken, or when a new version of inputs becomes available, the previous version of data often continues to be distributed while a new version is being processed and distributed. Hence, in some instances in the future, users may encounter two versions of CLDPROP COSP data in the public archive. Users should always attempt to acquire and use the latest version. Currently in year 2020, only Version 1.1 L3 CLDPROP COSP data is available, which corresponds to the latest available L2 Version used as input.

Finally, while most users may think of versions typically incrementing by one (001 to 002) when reprocessing is undertaken -- versions can sometimes increment by *point one* (denoting a more minor update) which leads to unusual increments in the filename version: 001 to 011 (due to the unusual 3-digit filename version convention of the LAADS DAAC, which distributes CLDPROP COSP data). The related (parallel) data version, used by the Science Algorithm Teams, will always follow a more logical (easier to interpret) pattern: v1.0 to v1.1 to v2.0.

During the processing of a particular version, an attempt is made to use the same science algorithm, sometimes known as the Product Generation Executive (PGE). However, occasionally several new PGE's (algorithm updates) are released during a particular data version to fix minor bugs or make improvements to the data. For bug fixes, if the bug is not serious, forward processing will continue with the newly corrected PGE, while old previously processed data (which was produced with an older version algorithm (PGE)) are retained in the archive.

When enough changes or improvements are made to a science algorithm, the entire data record is reprocessed as a new version. Preparation to go to a new version can be a major effort that can take anywhere from a few months to a year or more to prepare and complete.

Note that issues, anomalies, and problems in the Continuity Cloud Product CLDPROP for Version 1.1, which is the input to the L3 CLDPROP COSP Product, are outlined in the Data Issues section of the Atmosphere Imager website as they are discovered:

https://atmosphere-imager.gsfc.nasa.gov/continuity/issues/cldprop_l2

1.1.5. Start Date for the CLDPROP COSP Products Data Record

The start date for CLDPROP COSP product is year 2012 and day 061 (1 March 2012) -- and the data record continues into the present day, until either the MODIS Aqua or VIIRS SNPP instrument data becomes unviable due to instrument aging or malfunction. This first day of the data record corresponds to the first date when VIIRS SNPP data became available.

1.2. L3 CLDPROP COSP File Metrics

1.2.1. Group (Parameter) and Variable (Statistic) Metrics

The current version (Version 1.1) of the L3 CLDPROP COSP Global Product (both Daily and Monthly) contains 114 Variables (Statistics) that are computed for 23 Scientific Groups (Parameters) derived from Level-2 Continuity CLDPROP Products.

All L3 statistics are sorted into 1×1° cells on an equal-angle global grid (see section 2.0). A number of statistical summaries are computed for each of these L3 parameters, depending on the parameter being considered.

Statistics for a given L2 parameter or measurement might include:

- Simple (Mean, Standard_Deviation, Pixel_Count, Sum, and Sum_Squares) statistics
- Parameters of log-normal distributions
- Fraction of pixels that satisfy some condition (e.g., liquid water clouds, ice clouds)
- Joint Histograms derived from comparing one science parameter to another, statistics may be computed for a subset that satisfies some condition.

1.2.2. File Sizes for NetCDF4 Daily and Monthly files

For the current Version 1.1 of L3 CLDPROP COSP Product Files, the Daily (D3) NetCDF4 file is around 32 MB in size, the Monthly (M3) NetCDF4 file is around 44 MB in size. These files used standard packing tools to reduce the file sizes as much as possible to aid users in downloading and storing data.

1.3. L3 COSP Definition of "Day": Time span of the Daily Product

The issue of how to define a *single day of data* in a Daily file is more complex than one might initially think; but before we delve into this topic, let's first review how L2 granules are time stamped.

1.3.1. Time Stamping of L2 Files

The MODIS and VIIRS L2 CLDPROP input data granules (input to L3 Daily CLDPROP COSP) are always time-stamped using Coordinated Universal Time. Coordinated Universal Time is International Atomic Time (TAI) with leap seconds added at irregular intervals to compensate for the Earth's slowing rotation. These added leap seconds allow Coordinated Universal Time (UTC) to track the mean solar time at the Royal Observatory, Greenwich (GMT).

Coordinated Universal Time is abbreviated UTC. The reason for this seemingly unusual abbreviation is the International Telecommunication Union wanted Coordinated Universal Time to have a single abbreviation in all languages. English speakers and French speakers each wanted the initials of their respective language terms to be used internationally: "CUT" for *coordinated universal time* in English, and "TUC" for *temps universel coordonné* in French. This resulted in the final compromise (which likely pleased no one) of using "UTC."

Each L2 MODIS granule (stored in a single NetCDF4 file) contains 5 minutes of data. Each L2 VIIRS granule (stored in a single NetCDF4 file) contains 6 minutes of data. The time stamp (which is part of the L2 NetCDF4 file name) shows the start minute of the data collection time period. For example, a L2 MODIS granule (within a single NetCDF4 file) might have a time stamp of 1430. This means the start time of data acquisition was 14:30:00 UTC and the end time was 14:34:59 UTC. The subsequent NetCDF4 granule would have a time stamp of 1435, which corresponds to an acquisition start time of 14:35:00 UTC.

1.3.2. Definition of "Day" for MODIS Standard Products (MOD08_D3)

In MODIS Standard L3, in Collection 5.1 and earlier, the method to define a "Day" was using a simple 0000 to 2400 UTC period. However, some users complained that this definition led to an unusual pattern of orbital gaps and overlaps (gaps and overlaps on alternating days) near the International Date Line for day, and near the Greenwich Meridian for night. Therefore, starting in Collection 6.0, the definition of "day" was adjusted such that L2 files with time stamps that extended outside of the 24-hour (0000 to 2400 UTC) day were utilized in order to potentially remedy this shortcoming.

In this correction, as much as 3 hours before the start or after the end of a UTC day is included in the L2 data. Then L3 longitudinal map boundaries (the International Dateline for day, and the Greenwich Meridian for night) were used to chop off unnecessary pieces of superfluous data, making a cleaner more well-behaved boundary with no (or at least fewer) orbital gaps and overlaps. For more details and visuals on this method, refer to online documentation at: https://atmosphere-imager.gsfc.nasa.gov/Definition_of_Day_Four_Panel

This modification in the MODIS Standard Products for Collection 6 (and later) was termed the "*Definition of Day Correction for MODIS C6*"

Because of this correction, in the MODIS Standard Collection 6.0 and 6.1 data, one will rarely see large data gaps or data observed (at mid latitudes) nearly 24 hours apart being mixed together in the same geographic region.

Unfortunately, it was later discovered that this "Definition of Day Correction" technique that was implemented for MODIS Standard L3 data, left (in some very specific post-processing scenarios) a visible artifact around the daily global "seams" of the individual days, which were focused around the meridian where the day or night boundary ended or began. And further, it was found that this artifact did not get averaged out over long time periods (annual) aggregations for those very specific cases. One SDS (Scientific Data Set) in particular (Cloud Fraction from Cloud Mask) appeared very sensitive to this issue. The specific scenario that was problematic was when combined Day+Night, and also combined platform (Aqua+Terra) data was merged, but only for Cloud Fraction from Cloud Mask (in the set of SDSs that were studied). It was theorized that the reason that cloud fractions appeared to be more susceptible to this issue, was cloud fractions included clear-data (pixels), while most other L3 SDSs do not, making the relative range of fraction data larger (spanning the full 0% to 100% valid range). Other post-processed MODIS Standard L3 SDSs that did not share this combination of (post-processed) aggregation characteristics: (i) Day+Night, (ii) Terra+Aqua, and (iii) Includes Clear-Sky Pixels, did not appear to be affected (or at least not affected very significantly).

1.3.3. Definition of "Day" for L3 Daily CLDPROP COSP Products (CLDPROPCOSP_D3)

Since the monthly CLDPROP COSP data was deemed the most useful to do climate studies using monthly data, how we define a single-data-day became less of a factor, since the determination of that single-data-day will average out or smear out over a month. A final benefit is the simpler definition of a single-data-day, which is much easier to describe and document. Simpler is often better.

Because of these factors, we decided to revert back to the simpler and easier to describe method of defining a *single day of data* in the CLDPROP COSP products, as a straight-forward 0000 to 2400 UTC period. See Table 3. This simpler (more traditional) definition was also used in MODIS Standard L3 products prior to Collection 6 -- and in the latest Continuity Atmosphere products. See Table 3.

Level-3 (L3) Definition of Day	MODIS Std Atm ≤ Collection 5.1	MODIS Std Atm ≥ Collection 6.0	Continuity Atm ≥ Version 1.1	COSP Atm ≥ Version 1.1
Standard Definition of Day L2 granule times included in a D3 file, span 00:00:00 to 23:59:59 exactly	√		√	√
Definition of Day Correction L2 granule times included in a D3 file, may start before 00:00:00 or end after 23:59:59		√		

Table 3. Users should note the *Definition of Day* in the Daily COSP Products runs from 00:00:00 to 23:59:59 UTC.

Finally, do note there is a new global attribute in the MCD06COSP files called "daily_defn_of_day_adjustment" that can be set to either "true" or "false". If it's set to true, then the product uses the more complex definition of day that was used in MODIS Standard C6.1 products. If it's set to false, then the product uses a more standard definition of day covering the traditional 0000 ot 2400 UTC period. Therefore, this new product has a global attribute of daily_defn_of_day_adjustment = "false" denoting the latter defintion.

2.0. Gridding

All COSP Atmosphere L3 statistics are stored on an equal-angle latitude-longitude grid. The grid cells on this projection are 1×1° in size, which means the COSP Atmosphere L3 output grid is always 360 pixels in width and 180 pixels in height. The left-most boundary of the grid (or map) is located at 180° W longitude, the exact center is the Greenwich Meridian 0°, and the right-most boundary of the grid (or map) is located at 180° E longitude. (See Figure 1).

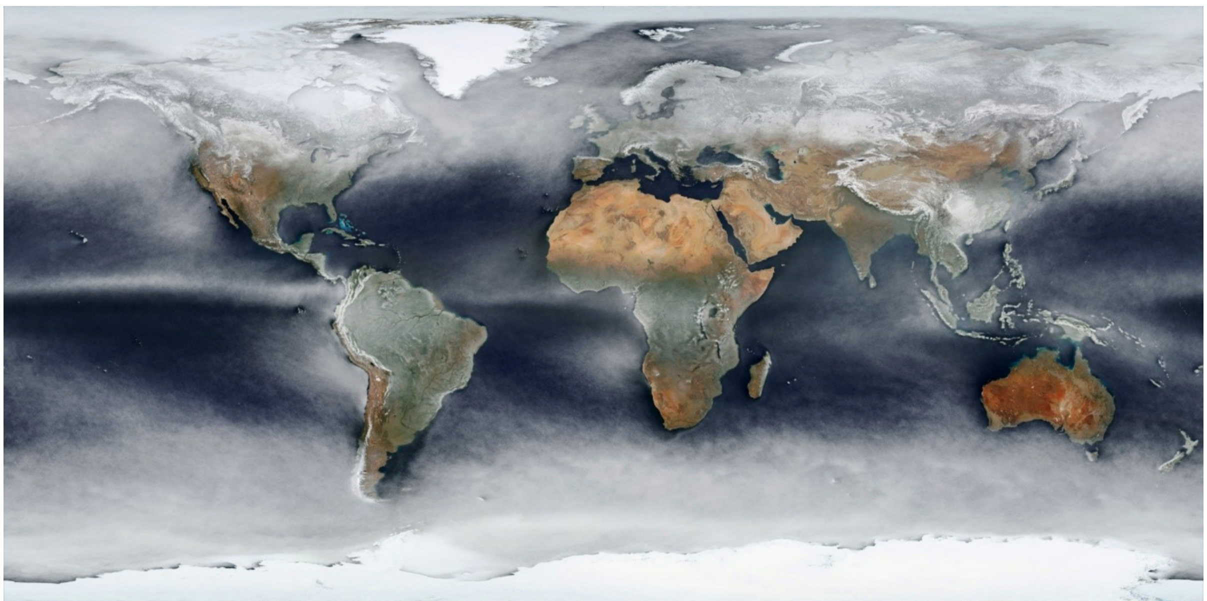


Figure 1. A sample 1x1 degree latitude-longitude rectangular grid. Displayed here is the result of collecting daily RGB Corrected Reflectance satellite data and calculating the per-pixel median over the full year of 2018.

L3 grid cells are indexed (0,0) (since indexing starts at 0 in NetCDF4 files) at the lower left corner of the map and corresponds to a grid box with boundaries of 89° to 90°S latitude and 179° to 180°W longitude. L3 indexing increases as you move up and to the right on the map.

An example of a L3 COSP parameter mapped on this standard 1×1° latitude-longitude grid is shown in Figure 2. Also shown in Figure 2 is a corresponding (matching) Corrected Reflectance image to compare science algorithm results with real-world conditions (views).

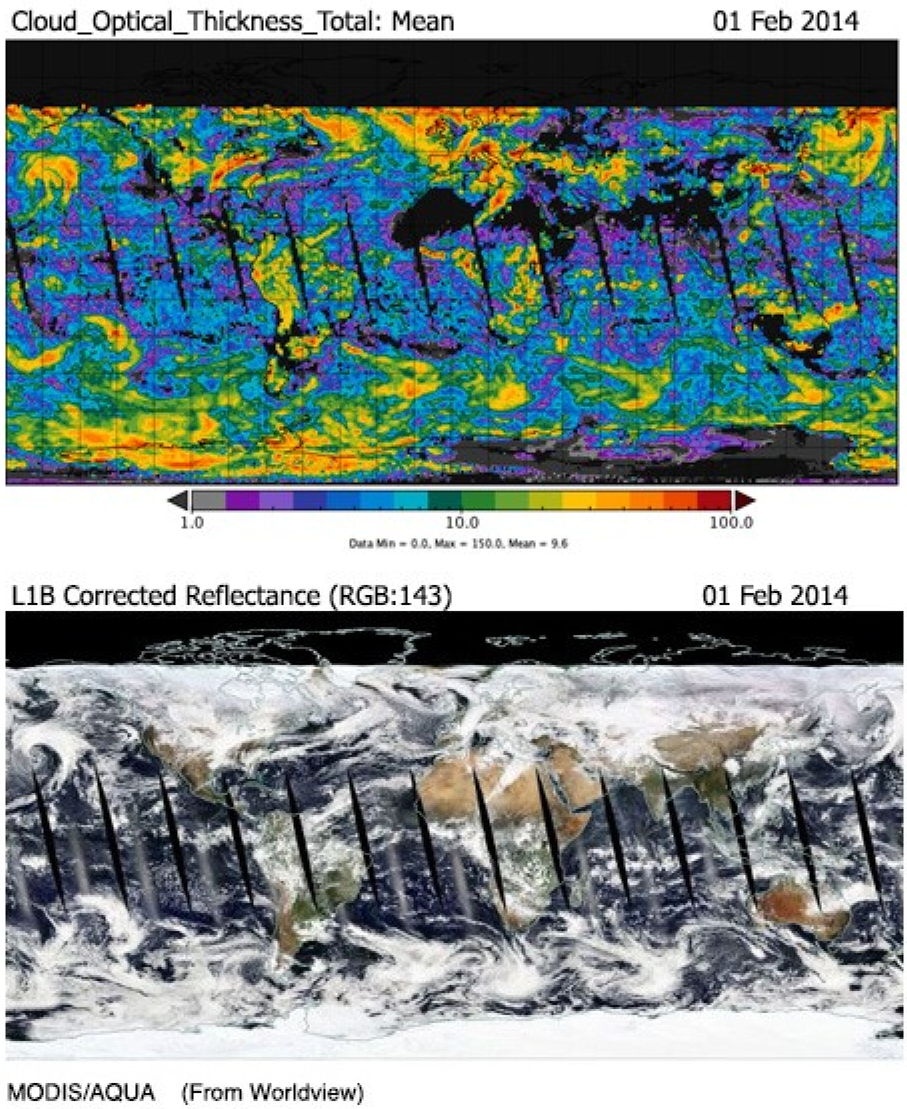


Figure 2. Top is a sample CLDPROP COSP Daily (D3) Cloud Optical Thickness (all clouds) image for MODIS Aqua data shown in its native latitude-longitude projection format. Bottom is a corresponding L3 global image of Corrected L1B Radiances (RGB:143), also for the Aqua platform, for comparison.

The details of how L2 pixels get binned at L3 is important to understand, especially exactly at the boundaries of 1×1° grid cells. The assignment of L2 pixels (to a L3 grid cell) that fall exactly on a 1° L3 grid boundary is performed using the following convention: L2 pixels that fall exactly on the first whole degree boundary 90°S (-90.0) latitude and 180°W (-180.0) longitude are binned in the first L3 grid column and row (0,0). L2 pixels that fall exactly on the second whole degree boundary 89°S (-89.0) and 179°W (-179.0) are binned in the second L3 grid column and row (1,1). The exception to this logic occurs in the last L3 grid row (89° to 90°N), which contains both whole degree latitude boundary pixels (that fall on exactly 89.0 or 90.0). There is no exception for the last L3 grid column or longitude (179°E to 180°E) since +180.0 and -180.0 represent the same physical location (these L2 pixels are binned in the first L3 grid column).

An important property to note when considering L3 gridding occurs due to distortion in the latitude-longitude (rectangular) map projection as one moves poleward. The actual (real-world) size of each 1° × 1° grid box physically shrinks when moving from the equator toward the pole due to the convergence of longitude lines on the globe (see Figure 3). At the equator each 1×1° grid cell is roughly 12,321 km^2 in size. At the pole each 1×1° grid cell is only 107 km^2 or less than 1/100th the size.

Figure 3. Convergence of longitude lines produces shrinking 1×1° rectangular grid cells toward the poles.

Please note that there is also a variation of pixel size in L2 (input) products due to viewing (scan angle) distortion. For example, in 1 km (nadir) resolution L2 data, the L2 pixels expand due to view-angle distortion when moving from nadir towards the limb (high scan angles) of an instrument scan (see Figures 4 and 5).

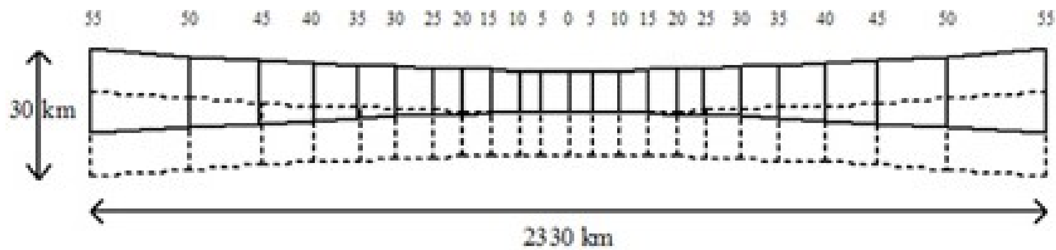


Figure 4. L2 pixel overlap due to scan width growth as a function of scan angle for the MODIS Instrument

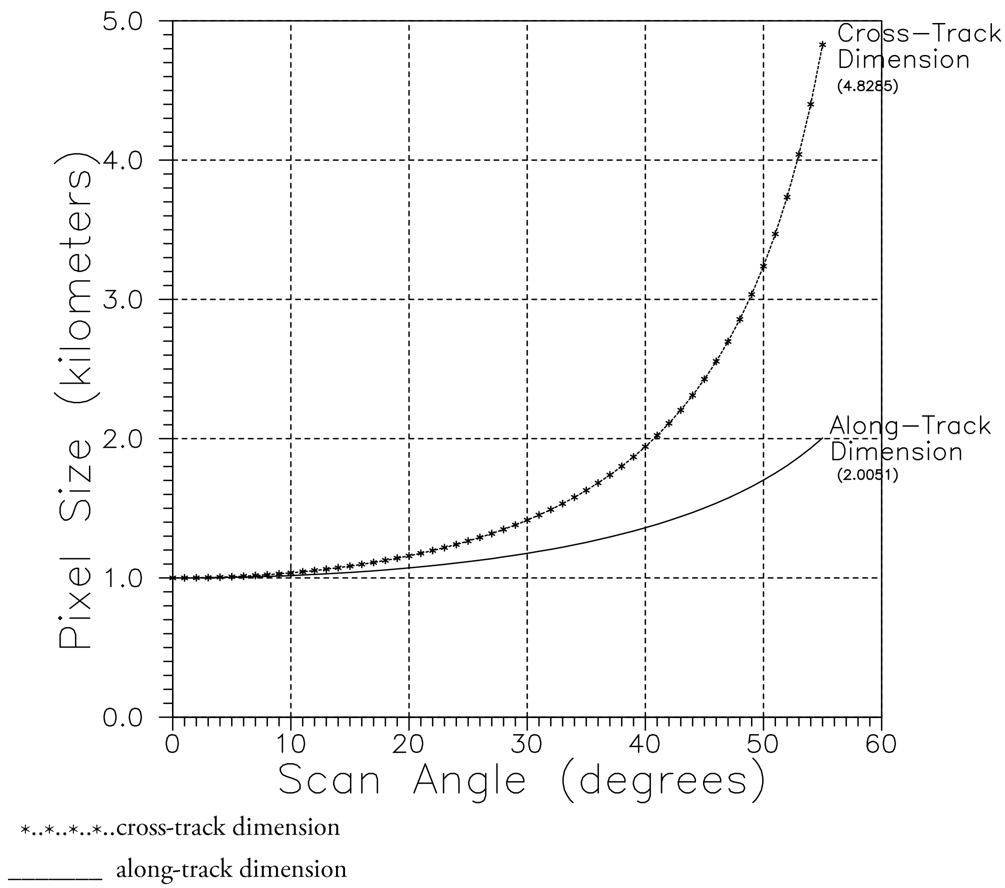


Figure 5. Estimated growth of a 1-km resolution L2 pixel as a function of scan angle for the MODIS Instrument.

This distortion of L2 input pixels means that there are fewer L2 pixels to average in the computation of L3 daily statistics for L3 1×1° grid boxes on a Daily (D3) product map that cover regions of high scan angles in the L2 orbital products, than for those that cover L2 orbital products computed closer to nadir view. For the Monthly (M3) products, this effect is averaged out and is mitigated.

Also note that this "growth" of the L2 pixel also causes some pixel (scene) overlap at high scan angles – meaning that the L2 pixels used to compute L3 daily statistics in these "orbit edge" regions are not as statistically independent as those computed with near-nadir-view pixels. So not only are there fewer L2 pixels to average at high MODIS scan angles, but they are less independent.

A third impact, these high scan-angle L2 pixels may be less reliable in general as they are viewed by the sensor through more atmosphere, which complicates the retrieval process.

A fourth impact is that they could have more inherent geolocation error depending on the local terrain.

Figure 6 shows the predicted orbital track (white lines) for Aqua MODIS for February 1, 2014. L3 gridding issues at the poles (due to very small (area-wise) L3 grid boxes) are exacerbated by MODIS orbital tracks that go no further north or south than roughly 82° – which means the pixels at the poles (90° latitude) are always viewed at higher scan angles. Also, there are 16 overlapping orbits near 82° latitude (each one roughly 98 minutes apart) that cause "time averaging" to occur for daily statistics, for each instrument, computed poleward of about 77° (that is, in polar regions, statistics tend to be daily <u>average</u> statistics). In contrast to those at mid-latitudes (that typically can be pinned down to within 20 minutes of a MODIS instrument overpass), which means CLDPROP COSP statistics are afternoon Aqua or VIIRS snapshots at mid latitudes.

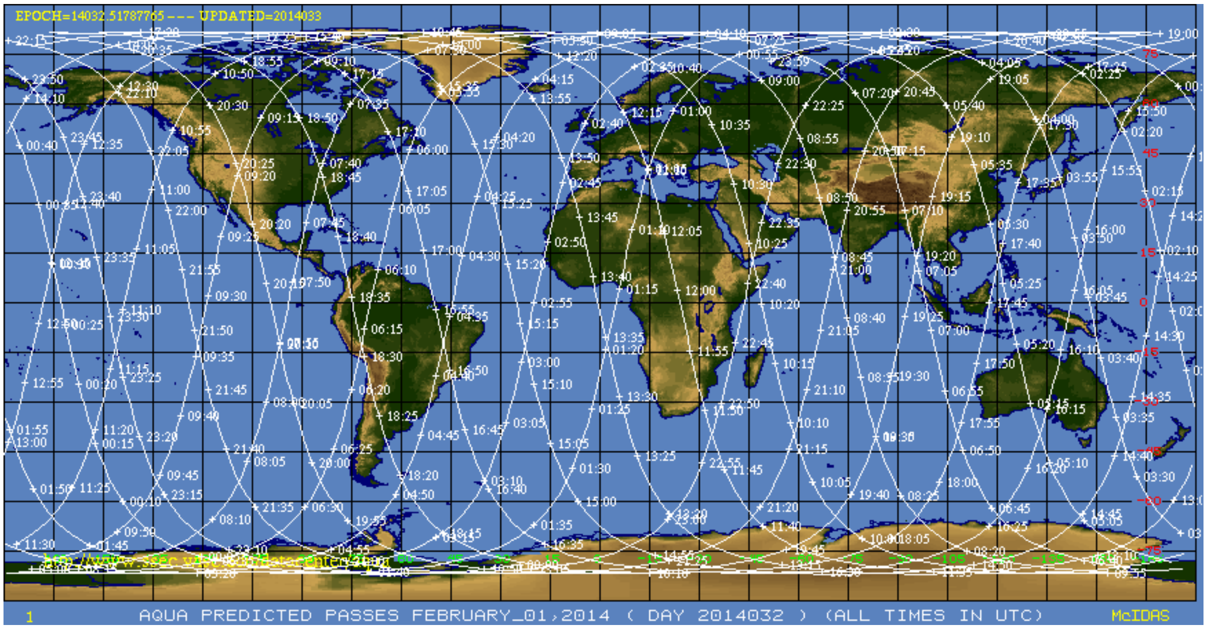


Figure 6. Predicted Aqua MODIS orbit tracks for a particular day (February 1, 2014).

In order to help visualize a typical distribution of L2 pixel counts that are used to compute L3 daily COSP statistics, a sample daily pixel count image is shown in Figure 7. This figure shows the number of L2 pixels that typically go into the computation of statistics in each L3 1×1° grid cell for all (daytime only) Cloud Top Property statistics (1 km resolution at L2).

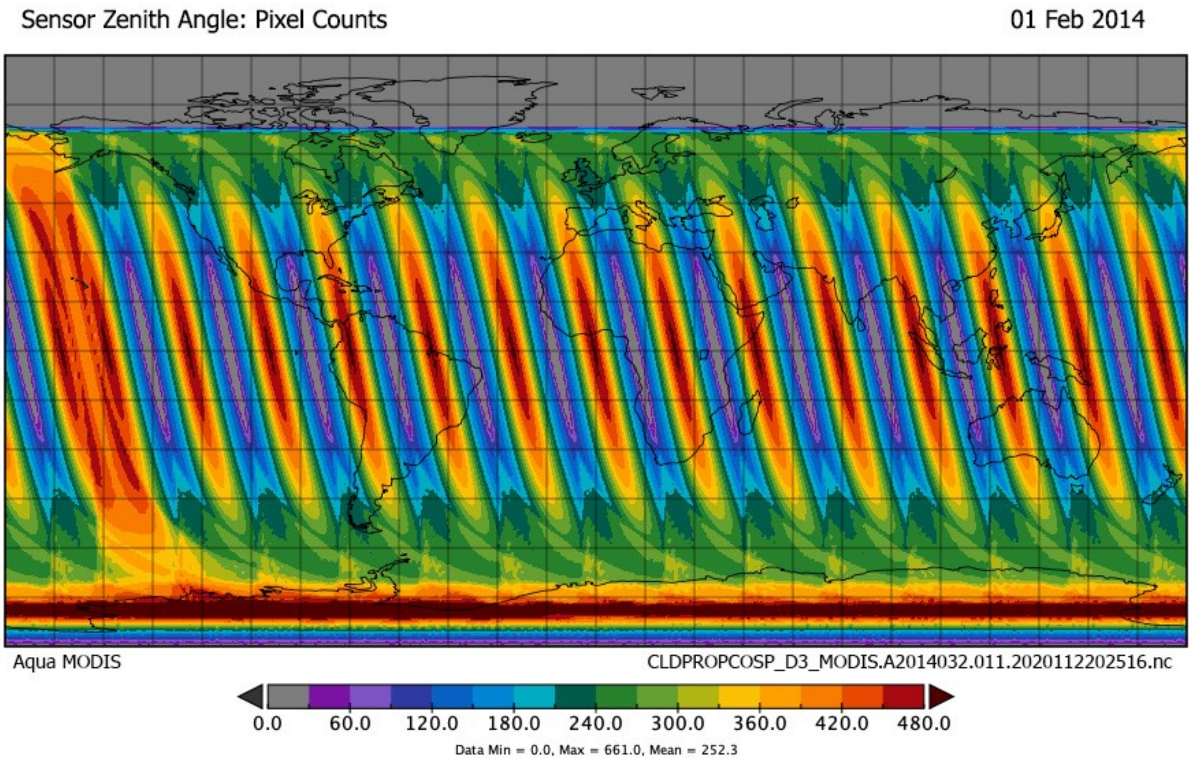


Figure 7. Global distribution of daily MODIS Aqua pixel counts for 1 Feb 2014 (i.e., the number of L2 data pixels per 1×1° L3 grid cell) for 1 km resolution (sampled at 5km) L2 input products (where no aggregation is performed, limiting pixels). Note that this is a daytime-only product. The date of this image is February 1, 2014 (same as the orbit track maps shown in Figure 6). The overlapping orbit tracks around the International Date Line (see the pattern breaks in that region) clearly shows the *definition of day* issue discussed in Section 1.3.

Figure 7 clearly reveals that upwards of over 500 L2 sampled pixels were used to compute L3 statistics for this SDS near nadir (the bright red color at mid latitudes) -- but fewer than 100 L2 pixels were used near the edge of the scans (the purple color at mid latitudes).

Note that the missing or orbital data gap regions on this daytime image are depicted in gray color at the north polar region, where pixel counts are 0.

Pixel counts for MODIS for 1km input data sampled at 5 km, typically range from 0 to 484 (22 × 22) sampled pixels. The number 22 comes from 1 degree of latitude or longitude being roughly 111 km at the equator, so there are typically 22 five-kilometer samples that span that distance.

However, one-degree L3 grid cell pixel counts can exceed this expected (nominal) maximum pixel count numbers where overlapping orbits and near-nadir-views intersect (typically around 82° north latitude in the Summer and 82° south latitude in the Winter). While the reduction of counts in the bottom few rows of latitudes (82°S to 90°S) in Figure 7 is due to count reduction from increasing L2 view-angles (that make the L2 pixels larger) and therefore fewer fall into a given (shrinking, due to Earth geometry) polar L3 1x1° grid cell, since one L2 pixel is only assigned to one L3 grid cell in our mapping system.

So for the first and last few latitude bins (88° to 90° latitude), one has the dual drawback of (i) very small (area-wise) L3 grid cells containing small populations of relatively large input L2 pixels that overlap spatially (due to view-angle distortion) in a single orbital pass; and (ii) multiple orbital passes (up to 16 on a given day for MODIS) that take measurements of the region, which causes the L3 Daily data to be more representative of a daily average instead of a single overpass snapshot at the poles.

Users should note an important property of L3 gridding: in order to simplify the L3 operational production software, each L2 pixel is "located" or placed in the L3 grid cell where its center latitude/longitude falls within the L3 grid cell. In cases where a larger (view-angle distorted) L2 pixel actually covers (or intersects) more than one 1×1° L3 grid cell, (a situation that typically occurs at high L2 scan angles located over higher latitudes), the L2 pixel is still only assigned (placed) in the single L3 grid cell where the geolocated center point of the L2 pixel is located. Although this shortcoming is comparatively minor in the operational L3 software due to the relatively large 1×1° L3 grid size and the much smaller L2 pixel size (750 m or 1km at nadir view), when the code is used in "research mode" to produce products at higher resolution (0.25° or 0.1° for example), it can produce unusual visual effects in the imagery where unnaturally appearing gaps are introduced between adjacent L2 pixels, as illustrated in Figure 8.

Finally, note that most of these pixel-count variation issues are mitigated in the Monthly (M3) product since the orbital gap positions shift from day to day, which allows data from subsequent days to fill in the previous day's gaps. This will tend to provide complete global coverage over these longer time periods.

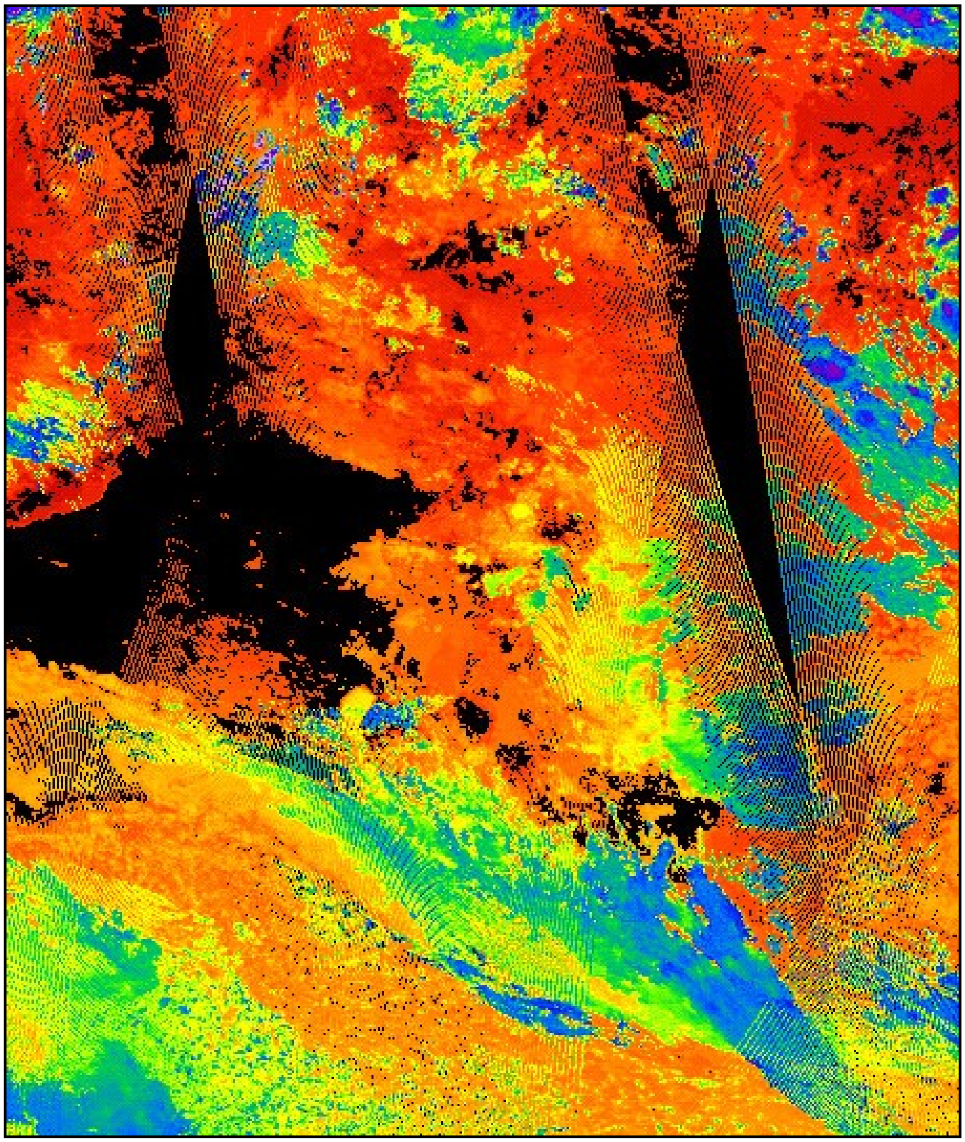


Figure 8. A section of a L3 Cloud Top Temperature image, produced for L3 research purposes at 0.1° × 0.1° resolution, clearly showing the pixel binning limitation (depicted by the moiré pattern visible at the edges of orbits) in the L3 code for grid meshes finer than 1° (the grid resolution currently implemented in operations). This effect is mitigated in the L3 COSP product due to relatively large 1×1 degree bin sizes.

3.0. Sampling

3.1 The Decision to Sample L2 data for L3 Computation

MODIS Standard Level-2 (L2) Cloud Products always have geolocation arrays stored at 5km resolution; however, data arrays can be stored at either 1km (cloud optical properties) or 5km (cloud top properties). Since the L3 grid size (1°) is so much larger than the L2 resolution (1km and 5km), sampling the L2 input data to compute L3 statistics is always performed. The main reason for this is to make the L3 computation faster. In addition, we found in a number of early MODIS studies that sampling 1km L2 data at 5km had little effect on computed L3 statistics, at the L3 operational grid resolution of 1x1°.

3.2 Sampling Technique for L3 MODIS Standard & MODIS Continuity data

3.2.1. Sampling modification to avoid dead detectors for MODIS Aqua

A software modification was introduced in L3 MODIS Standard Collection 5 (and forward) products, which slightly offset the L2 data points sampled (in the 5x5 km L2 space), and was necessary to avoid dead Aqua MODIS detectors for some channels. This patch **only** impacted L3 data that were derived from **sampled** L2 input (that is, where 1km L2 data was sampled at 5km for L3 computations).

In MODIS Standard Collection 4 and earlier, 1km L2 products were sampled in the center grid of the 5x5 km region. The center grid was considered the most representative of the entire 5x5 km region.

When MODIS Aqua suffered a failure of detectors 3 and 8 in band 6 (1.64 μm) just before Collection 5 started, it became necessary to shift the sampled pixels to avoid those dead detectors.

The choice of which alternate pair of detectors to pick [(1 & 6), (2 & 7), (4 & 9), or (5 & 10)] was made to both minimize errors in geolocation as well as inherent detector errors. It turned out, after some study, that detectors 4 and 9 had the dual benefit of: (i) being immediately adjacent to the 5km geolocation pixel so only a 1 km geolocation error was introduced, and (ii) both detectors 4 and 9 were well-behaved and had small residual errors when compared to averages taken over the entire 5 × 5 km area (*Oreopoulos*, 2005). See Figure 9.

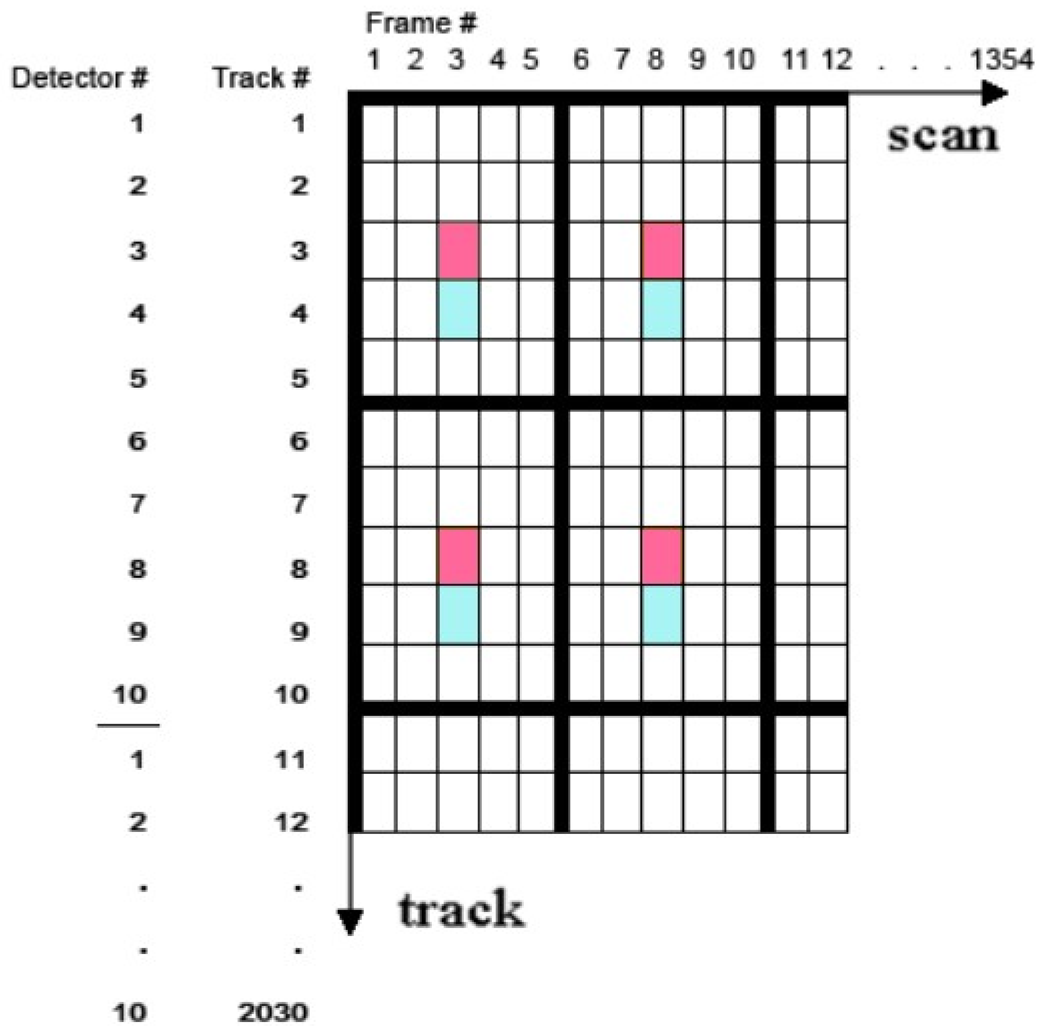


Figure 9. A shift in the L2 "sampling pixel" for L2 input products sampled at 5km was implemented to prevent dead detectors from causing missing L3 data. The pink color is where L3 MODIS Collection 4 was sampled at the center of the 5 × 5 (detector 3, frame 3). The blue color is where L3 MODIS Collection 5 and later collections were sampled (detector 4, frame 3) slightly off center of the 5 × 5 grid box. In other words, for MODIS Collection 4 and earlier, L2 pixels from detectors 3 & 8 were sampled. For MODIS Collection 5 and later, L2 pixels from detectors 4 & 9 were sampled.

Even though the change in start detector (from the 3rd to the 4th) was prompted by the failure of Aqua MODIS detectors 3 and 8 in band 6 (1.64 µm), the change was extended to Terra data as well after a study showed that Terra detector-pairs 4 and 9 provided the most representative results over a 5 km grid cell (*Oreopoulos*, 2005) and it was further thought that matching the logic between Terra and Aqua versions of the L3 software was prudent and simplified L3 processing.

Therefore, for L3 COSP Daily MODIS (CLDPROPCOSP_D3_MODIS), it was necessary to match the sampling technique used in MODIS Standard L3 Daily MODIS (MOD08_D3 and/or MYD08_D3) for consistency and to (once again) avoid dead MODIS Aqua detectors as previously discussed. See the blue squares in Figure 9 showing detectors 4 and 9 being sampled.

3.3. Sampling Technique for VIIRS Continuity Data

For Continuity Atmosphere L3 VIIRS SNPP data, a radically new sampling method had to be implemented, but first let's review properties of the VIIRS L2 data.

VIIRS represents an advancement over MODIS in several respects. For instance, with a sensor scan angle range of ±56.28°, VIIRS views a 3060 km-wide swath on the ground at its nominal altitude of 834 km, allowing for complete daily global coverage free of gaps. MODIS, on the other hand, has gaps between orbital swaths over the tropics, as it only views a 2330 km-wide swath (±55° sensor scan angle range at 705 km altitude).

Figure 10 shows example global RGB imagery from (a) MODIS Aqua and (b) VIIRS SNPP from 10 September 2018. Note the lack of orbital gaps in the VIIRS SNPP image.

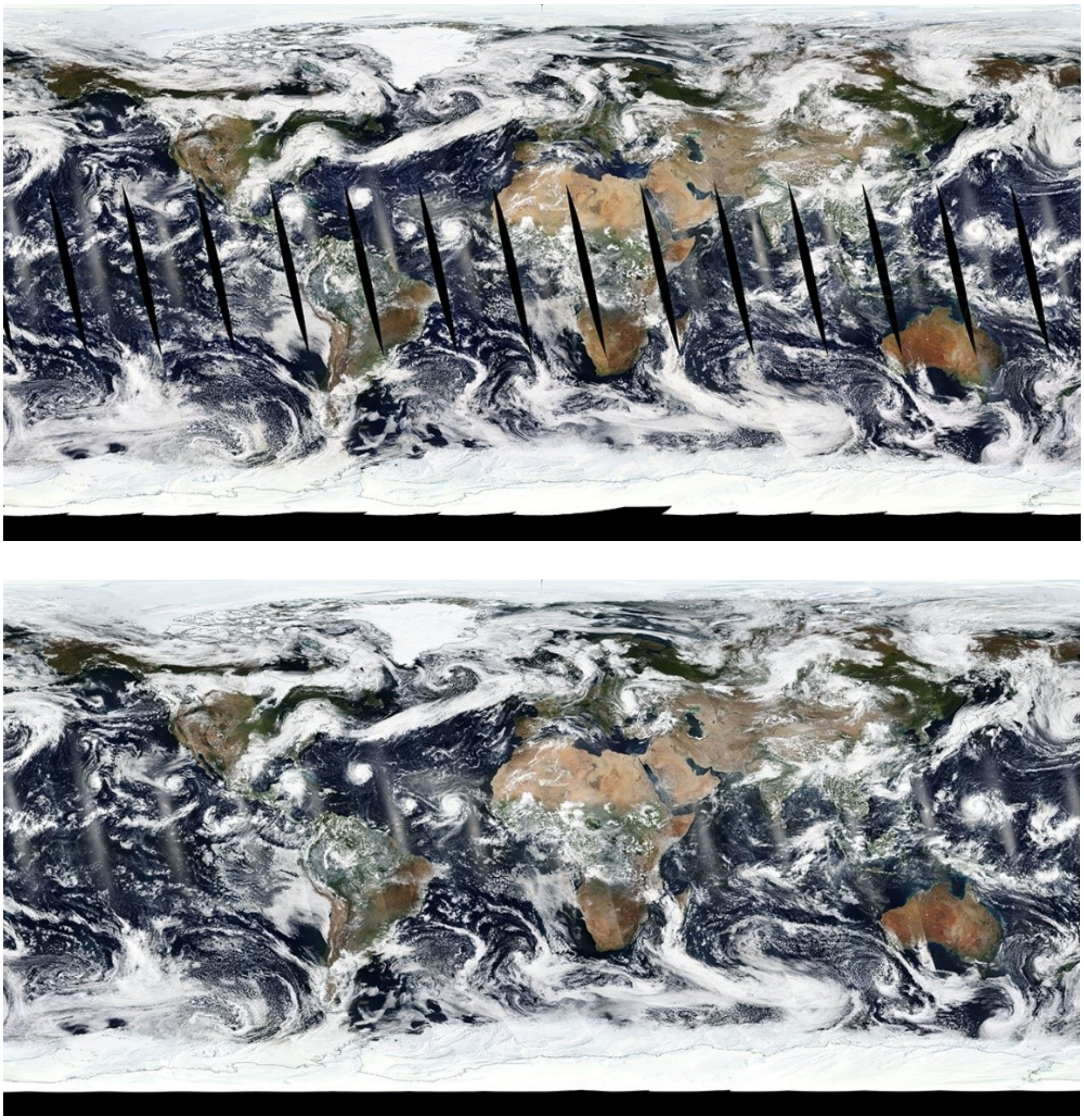


Figure 10. True color corrected reflectance (RGB:143) from September 10, 2018. (a) MODIS Aqua. (b) VIIRS SNPP. The vertical black strips over the tropics in the Aqua-MODIS image (top) are the gaps between MODIS swaths from successive orbits. Note that the VIIRS image does not have these orbital gaps due to its wider swath. Images courtesy of NASA Worldview.

Moreover, while the 750 m nadir pixel size of the VIIRS M-bands is not substantially different from the MODIS 1 km nadir pixel size, VIIRS uniquely employs an on-board detector aggregation scheme that limits along-scan (across-track) pixel growth towards the swath edge. The 16 VIIRS M-band detectors are rectangular with a native footprint size at nadir of 250 m along scan (width) by 750 m along track (length). To achieve the 750 m nadir resolution of the

M-band L1B data, three along-scan detectors are aggregated for observations with sensor scan angles less than 31.72°, two detectors are aggregated for scan angles between 31.72° and 44.86°, and no aggregation is performed beyond 44.86° (see the sample aggregation zones in Figure 11, green text). Thus along-scan pixel width increases roughly to only 1.625 km at scan edge, comparable to the along-track pixel length growth; note that no along-track detector aggregation is performed.

The pixel growth (represented as horizontal sampling interval) in the along-scan and along-track directions is shown by the blue lines in Figure 11. Because the detector aggregation occurs on-board, the native detector data is discarded and only the aggregated data are downlinked. Further information regarding the on-board detector aggregation of the VIIRS M-bands is available in *Section 2.1.1* of the *NOAA VIIRS Sensor Data Record (SDR) User's Guide* [*Cao et al.*, 2013].

MODIS is not designed to allow for such a detector aggregation scheme for all 1 km spectral channels. While channels 1-2 (0.66, 0.86 μm) and 3-7 (0.47, 0.55, 1.24, 1.64, 2.13 μm) are aggregated during L1B processing to 1 km (nadir) pixels from detectors having native nadir resolutions of 250 m and 500 m, respectively, L1B pixel sizes grow from the nominal 1 km at nadir to more than 2×4.9 km at scan edge [*Justice et al.*, 2011].

These differences in sensor swath geometry between MODIS and VIIRS can have profound impacts on the continuity of the cloud products derived from each. The wider swath of VIIRS allows for greater sampling at all latitudes, removing orbital gaps in the tropics while increasing swath overlap at higher latitudes. However, known view-angle-dependent biases, such as artificially increasing cloud fraction towards scan edge or the increased likelihood of viewing the sides of clouds (with implications on cloud top, optical, and microphysical retrievals), are likely larger in these additional VIIRS pixels. Furthermore, the limited pixel size growth of the VIIRS M-bands towards the edge of scan also reduces the impact of sub-pixel cloud heterogeneity and 3D effects that increase as pixel size grows; this behavior has been shown to significantly impact the MODIS cloud optical/microphysical property retrievals under various conditions [e.g., *Zhang and Platnick*, 2011; *Zhang et al.*, 2012; *Cho et al.*, 2015].

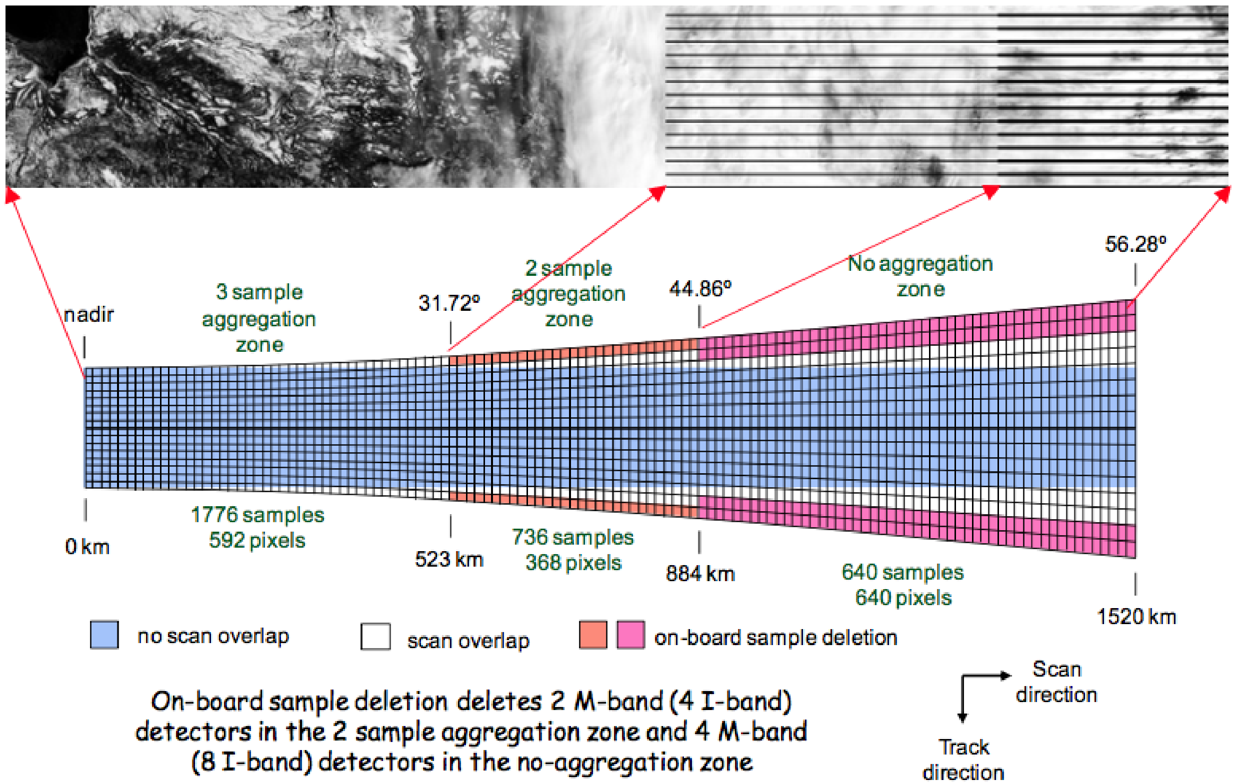


Figure 11. Illustration of VIIRS on-board along-scan detector aggregation zones (green text) and bow-tie pixel deletion. Figure obtained from the *NOAA VIIRS SDR User's Guide* [*Cao et al.*, 2013].

That said, the lack of direct sub-pixel information on VIIRS, available on MODIS from its 250 m VIS/NIR channels, limits the ability to identify and provide useful QA information (via sub-pixel heterogeneity indices, partially cloudy Clear-Sky Restoral tests, etc.) on VIIRS pixels for which sub-pixel heterogeneity may nevertheless be impactful. Quite likely, the VIIRS 375 m I-band (imaging) channels have the potential to provide useful sub-pixel information for the M-bands. However, these channels are not inherently co-located with the M-bands and, because they are coarser than the 250 m MODIS channels and do not map into the M-band 750 m pixels in the same way as the 250 m channels map into the MODIS 1 km pixels, they cannot provide the same level of information on heterogeneity. Further investigation is required to determine the efficacy of the I-bands for assessing M-band sub-pixel heterogeneity.

Due to these many factors described, an optimal sampling technique for VIIRS SNPP data was devised and is shown in Figure 12.

The orange-colored grids in Figure 12 represent the L2 750m grids that are being sampled in L3. The red-colored grids are (regularly) sampled grids that are later set to fill-data – this was done to remove the lower quality data that is collected from detector 16 (the last detector) from getting into the L3 statistics. (Actually the data from detectors 1, 2, 15, and 16 are all of lower quality, and are hence excluded in this sampling technique.)

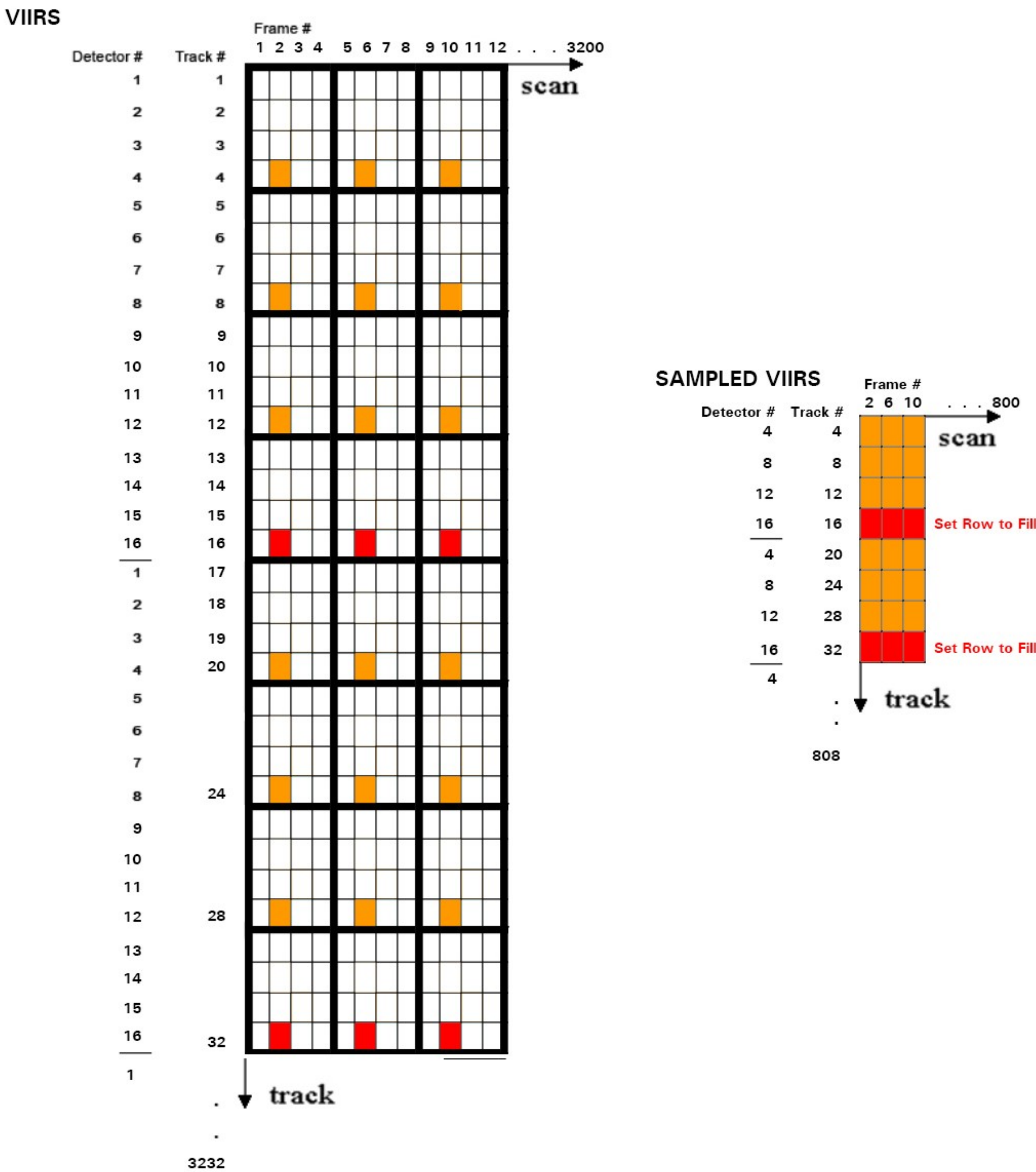


Figure 12. Illustration of the sampling technique used on L2 750m VIIRS data when computing L3 statistics. The orange grids are the sampled grids that are used in L3. The red grids are (regularly) sampled grids that are later set to fill-value in the L3 code, so that lower quality data (from VIIRS detector 16) is not aggregated into L3.

3.4. Summary of Sampling Difference between MODIS & VIIRS

To summarize, Continuity Atmosphere MODIS Aqua data (L2 resolution 1km) is sampled every 5km for L3. The start position for sampling is slightly offset from the center of the 5x5 km grid and instead shifted one detector position (1km) to detector 4, frame 3, in order to avoid dead detectors. So, for MODIS Aqua, the detectors sampled are 4 and 9. (Note that there are 10 detectors in MODIS.) See Figure 13, left.

Continuity Atmosphere VIIRS SNPP data (L2 resolution 750m) is sampled every 3km for L3. Since there is no true middle frame in a 3x3 km grid, frame 2 was arbitrarily chosen as the start position. For VIIRS, the detectors sampled are 4, 8, and 12 (detector 16 is skipped due to lower quality data). (Note that there are 16 detectors in VIIRS.) See Figure 13, right.

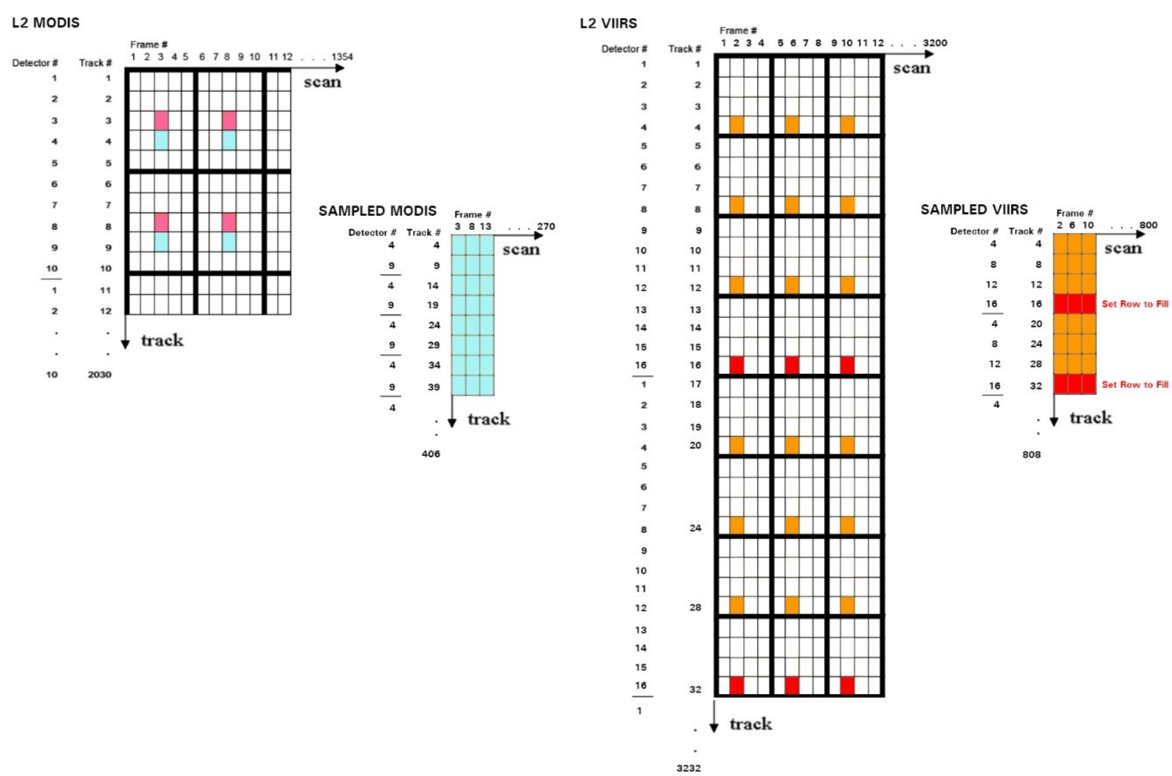


Figure 13. A rehash of earlier sampling figures, (Figures 11 and 14), but now shown side by side. On the left is the MODIS Sampling method, where the blue-colored L2 pixels are sampled in L3. On the right is the VIIRS Sampling method, where the orange-colored L2 pixels are sampled in L3. Red pixels are set to fill-value and not used.

4.0. Computation of L3 Daily Statistics

4.1. Aggregation of Statistics

All Atmosphere L3 products (Daily (D3) and Monthly (M3)) use aggregation capabilities. Aggregation information is typically based upon L2 QA bit flag arrays.

For some parameters, it is useful to aggregate results based on a physical characteristic of the parameter or of the scene. Aggregation refers to the ability to separate L2 input pixel information into various scientifically relevant categories such as liquid water clouds only, ice clouds only, daytime only, etc. These aggregations utilize L2 runtime QA flags that are designed to convey information on retrieval processing path, input data source, and scene characteristics of the physical parameters retrieved.

In addition, this broad group of flags also includes Cloud Mask flags (derived at 1 × 1 km resolution) to determine cloudy/clear or daytime-only scene characteristics.

Aggregated L3 statistics are often identified by a suffix to the Group (Parameter) name such as "_Liquid" or "_Day". However, to simplify the L3 COSP Product, the _Day suffix was dropped since all the Groups in the COSP product reflect daytime-only scenes. Table 4 lists the various aggregations that occur in L3 COSP.

Product Family	Aggregation Property
Cloud Top Properties & Cloud Mask	Daytime Only.
Cloud Optical Properties	Liquid Water, Ice, Total or Combined Phase Clouds. Partly Cloudy (PCL) Scenes vs. Std. Regular Cloudy Scenes.

Table 4. Aggregations that are performed in L3 COSP.

Additional details and documentation about each Group (Parameter) are always provided in the local attribute "long_name" attached to each Group within the NetCDF4 file.

An interesting observation to note is that aggregations of L3 statistics are performed in Yori through the use of true/false (T/F) Masks that are defined in the pre-Yori code and triggered by particular settings in the YAML (Yet Another Markup Language) Configuration File during processing. Multiple Masks may be applied to Statistics in any Group (Parameter).

The Masks which are currently defined in the Yori/YAML code are:

- Mask_Day: Daytime pixels based on the day/night flag
- Mask_CloudMaskDetermined: Cloud mask determined flag
- Mask_Liquid_Water_Phase_Clouds: Liquid water phase cloud retrievals
- Mask_Ice_Phase_Clouds: Ice phase cloud retrievals
- Mask_Undetermined_Phase_Clouds: Undetermined phase cloud retrievals
- Mask_Combined_Phase_Clouds: Combined phase cloud retrievals

4.2. Types of Statistics computed

4.2.1. L3 Statistics Computed by Yori (the L3 Processing System)

Yori is the system/package that is used to process L3 COSP Atmosphere Data. A total of 7 general types of statistics are computed in the COSP Atmosphere L3 products within the Yori Processing System for each 1x1° grid cell. These seven statistics shown below are always found as individual Variables (tagged exactly as shown in the bullets below) under specific Groups within the NetCDF4 file. The Statistics are:

- Mean = the mean of the sampled L2 pixels in each L3 grid
- Standard_Deviation = the standard deviation of the sampled L2 pixels in each L3 grid
- Pixel_Counts = the counts of the sampled L2 pixels in each L3 grid
- Sum = the sum of the values of the L2 pixels in each L3 grid
- Sum_Squares = the sum of the squares of the values of the L2 pixels in each L3 grid
- Histogram_Counts = 1D marginal histogram counts of binned values of the L2 pixels
- JHisto_vs_xxx (where xxx is a secondary Parameter name) = 2D joint histogram counts of binned values of one set of L2 pixels vs. another set of L2 pixels of a different parameter

Note that in the Monthly COSP file (product), the Mean is always weighted by pixel-count, since it's based on Daily values (derived from 06_L2 input) stored as Sum and Pixel_Counts. It is not an unweighted Mean of the Daily Means. Likewise, for Standard_Deviation, it's the standard deviation of the L2 input pixels.

4.2.2. Details of the Math Behind Yori (Section 4.2.2.is from documentation on Yori L3 Gridding Tools)

Since Yori can aggregate files that have already been aggregated (e.g., using 28, 29, 30 or 31 daily files to create a monthly product), it is important to clarify how the aggregation is performed and how the quantities stored in the files are computed. In this section we go through the details of the Yori aggregation phase where statistics are computed, starting from the trivial quantities and then working our way up from there.

4.2.2.1. Computation of Sum, Sum_Squares, and Pixel_Counts

Let's first briefly introduce how sums and sums of squares are computed during the L3 gridding phase. Users may find these definitions fairly obvious but they should help as things progress in the following section.

For any given variable, the **sum** (Sum) represents the sum of its values v_j within a grid cell c and is computed as:

$$s_c = \sum_j v_j \qquad (1)$$

where the subscript j is the j-th pixel and v_j is the value of the quantity under consideration for that pixel j. The summation is performed over all the valid pixels, that is, all those pixels that aren't filtered out via masking in L3.

Similar to eq. (1) we can also compute the **sum of squares** (Sum_Squares), that is, the sum of the squared values of all the valid pixels inside a grid cell:

$$ss_c = \sum_j v_j^2 \qquad (2)$$

where the subscript j denotes the j-th pixel and v_j is the value of the quantity under consideration for that pixel.

The **number of points** (Pixel_Counts) at the L3 gridding stage is simply the count of the number of valid pixels n for any given grid cell c.

During the aggregation phase, the quantities introduced in the previous paragraphs are summed in order to compute what is stored in the aggregated files. Hence, the aggregated **sum** (Sum) **is** derived as:

$$S_c = \sum_i s_{i,c} \qquad (3)$$

where the subscripts i and c represent the i-th file and the c-th grid cell respectively and S_c is the total sum for the cell c. Likewise, the aggregated **sum of squares** (Sum_Squares) SS_c is computed by just replacing $s_{i,c}$ with $ss_{i,c}$ in eq. (3):

$$SS_c = \sum_i ss_{i,c} \qquad (4)$$

Finally, the **number of points** (Pixel_Counts) for any given grid cell c is:

$$N_c = \sum_i n_{i,c} \qquad (5)$$

where, once again, the subscripts i and c indicate the i-th file and the c-th grid cell respectively, so that n is the number of points of the cell c for the file i and N_c is the total number of points for the same cell c.

4.2.2.2. Computation of Mean and Standard_Deviation

In this section we will explain how the mean (Mean) and standard deviation (Standard_Deviation) are computed during the aggregation and computation process. In the following, we omit the subscript c for simplicity's sake but, unless otherwise stated, all quantities refer to a single grid cell.

The **mean** (Mean) M of a quantity is computed as:

$$M = \frac{\sum_i s_i}{\sum_i n_i} = \frac{S}{N} \qquad (6)$$

where the subscript i indicates the i-th file, while S and N are the sum and number of points, respectively, introduced earlier in eqs. (1) and (5).

The **standard deviation** (Standard_Deviation) is derived from:

$$\sqrt{\frac{\sum_i ss_i}{\sum_i n_i} - \left(\frac{\sum_i s_i}{\sum_i n_i}\right)^2} \qquad (7)$$

where, again, i denotes the i-file and s_i, ss_i and n_i are sum, sum of squares and number of points described previously in eqs. (1), (2), and (5), respectively.

By saving sum, sum of squares, and number of points at every stage, and using eqs. (6) and (7), it is possible to correctly compute mean and standard deviation of all the elements within a grid cell without the need to also store all those values (in case further aggregation is required at a later stage).

For instance, this allows deriving monthly aggregations from daily data, which wouldn't be possible if the mean and standard deviation were computed directly from the values provided in the input files.

4.2.3. L3 Statistics computed by manual set-up in the Pre-Yori Step

Some desired L3 statistics were not directly computable by Yori (such as Fractions or Log Statistics). Fortunately, a part of the L3 Yori Processing System is a step called pre-Yori, where

L2 files are "massaged" into a format that can be read by the packaged (canned) routines of Yori (which are mostly fixed and unchanging). Because this pre-Yori step exists, Science Algorithm Developers have the opportunity to create "set up" arrays, which can be used by the relatively basic Yori system to create more interesting and useful statistics. The L3 COSP product uses a pre-Yori step to preprocess or set up new L2 intermediate arrays, which Yori later uses to produce both Fraction (Cloud Fraction) and Log statistics.

4.2.3.1. Cloud Fraction from Cloud Mask

A number of different "flavors" of cloud fractions with different meanings and properties are included in the L3 COSP Product.

The L3 cloud fraction that appears to garner the most interest from L3 Atmosphere data users is cloud fraction derived directly from the L2 cloud mask flags (in the 35_L2 product). Note that these cloud mask flags are duplicated in the L2 Cloud Properties (06_L2) product.

In the L3 COSP product, the following aggregations of Cloud Fraction (from Cloud Mask) are available in the following L3 Groups (or Parameters):

- Cloud_Mask_Fraction (daytime only, all pressure levels (total column))
- Cloud_Mask_Fraction_Low (daytime only, CTP ≥ 680 hPa)
- Cloud_Mask_Fraction_Mid (daytime only, 680 hPa > CTP ≥ 440 hPa)
- Cloud_Mask_Fraction_High (daytime only, CTP < 440 hPa)

The first parameter listed above contains the cloud fraction at all pressure levels computed from daytime retrievals (Solar Zenith Angle (SZA) ≤ 85°). The second through fourth parameters listed above have additional aggregations of atmospheric pressure levels: low-only, mid-level-only, and high-level-only clouds.

Users should note that the daytime cutoff for Cloud Mask (SZA ≤ 85°) is less strict than for Cloud Top or Cloud Optical Properties (SZA ≤ 80°), so the data extends a bit farther poleward for Cloud Mask.

The Yori processing system was not designed to compute fraction statistics directly; an intermediate L2 array called *Cloud_Mask_Cloudiness* is created as a pre-Yori L3 processing step to enable Yori to compute Cloud Fraction from Cloud Mask.

This intermediate array is basically an array filled with 1s (True) and 0s (False). The 1s represent L2 pixels that are true (or cloudy) to compute a particular cloud fraction. The 0s represent L2 pixels that are false (because they were deemed clear or did not meet some other specified criteria).

To compute these 1s and 0s in the intermediate array, two L2 QA flags are read from the Cloud_Mask QA array in L2 COSP. The two L2 QA flags are: the *Cloud Mask Status Flag* and the *Cloud Mask Cloudiness Flag* (see Table 5).

L2 QA Flag	Flag Value	Meaning
Cloud Mask Status Flag	0 1	Undetermined Determined
Cloud Mask Cloudiness Flag	0 1 2 3	Confident Cloudy (or Fill if Status Flag = 0) Probably Cloudy Probably Clear Confident Clear

Table 5. The two key L2 Cloud Mask Flags used to compute the intermediate pre-Yori array *Cloud_Mask_Cloudiness*: and finally, in the final L3 processing step, the Cloud_Fraction parameter in the L3 COSP product.

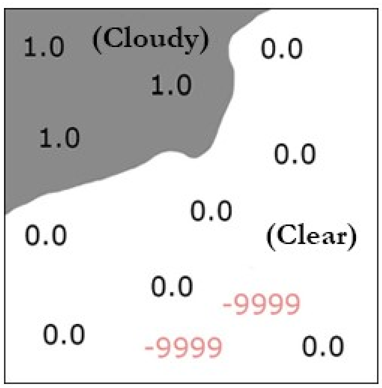
To properly set the 1s and 0s in the intermediate *Cloud_Mask_Cloudiness* array, the following logic is used. If the Cloud Mask Status Flag is set to 1 (determined), then L2 pixels with Cloud Mask Cloudiness Flags set to either 0 (confident cloudy) or 1 (probably cloudy), are assigned a 1 or True. If the Cloud Mask Status Flag is set to 1 (determined), then L2 pixels with Cloud Mask Cloudiness Flags set to either 2 (probably clear) or 3 (confident clear), are assigned a 0 or False.

Finally, the L3 cloud fraction from cloud mask (Cloud_Fraction) is calculated in Yori and written to the L3 COSP product by taking the mean value of the 1s and 0s in the intermediate *Cloud_Mask_Cloudiness* array.

For example, consider the 1x1 degree L3 grid box shown in Figure 14. Then the L3 Yori code does the following:

1. Toss out any Fill Value (-9999) encountered, and
2. with the remaining 1s and 0s (in each 1x1 degree L3 grid box) simply take the Mean of all the values -- that Mean is deemed the cloud fraction for that L3 grid box

In this example of a single L3 1x1 degree grid box shown in Figure 14, there are 2 fill (missing) values (-9999) that are tossed out or ignored. This leaves 10 valid L2 pixels or observations in the L3 Grid Box (0s and 1s). There were 3 pixels or observations assigned cloudy or true (1.0) and 7 pixels or observations assigned clear or false (0.0). The Mean of those 0s and 1s is 0.300.



Mean in the 1x1 degree grid box
3/10 = 0.300

So Cloud_Fraction = 0.300 (or 30%)

Figure 14. A theoretical example of a 1x1 degree L3 grid cell displaying a hypothetical sample of the intermediate Cloud_Mask_Cloudiness array of 1s (true or cloudy) and 0s (false or clear) that are used to compute cloud fractions in L3 by computing the mean of those numbers.

Cloud Fraction = Sum / Pixel_Counts = Mean = 3 / 10 = 0.300 (or 30% cloudy)

So the output Cloud Fraction, in this theoretical 1x1 degree L3 Grid Box, will be 0.300. To complete the job, Yori simply continues to build up the remaining grid cells in the 360 x 180 degree L3 Map in the same manner.

4.2.3.2. Cloud Fraction based on Successful Cloud Optical Property Retrievals (by cloud phase)

The second-most utilized L3 cloud fraction is that derived from the Cloud Optical Properties retrieval. All optical property cloud fractions are computed for **daytime scenes only** (Solar Zenith Angle (SZA) ≤ 81.3731°), which is slightly more restrictive than the definition of daytime for Cloud Mask fractions (SZA ≤ 85°).

The L3 COSP product provides the following aggregations of Cloud Optical Property Cloud Fractions Groups (or Parameters):

- Cloud_Retrieval_Fraction_Liquid
- Cloud_Retrieval_Fraction_Ice
- Cloud_Retrieval_Fraction_Total

The first parameter above represents the cloud retrieval fraction for liquid water phase clouds only; the second, ice phase clouds only; and the third, total or combined phase clouds. Note that the total cloud fraction (Cloud_Retrieval_Fraction_Total) includes Undetermined phase clouds, so it's not just a sum of the Liquid phase and Ice phase.

The optical property cloud fraction is computed in L3 from QA Flags read from a Level-2 Cloud Product (06_L2) SDS called *Quality_Assurance*. These two QA Flags are: the *Primary Cloud Retrieval Phase Flag and the Primary Cloud Retrieval Outcome Flag*. See Table 6.

To compute Cloud Retrieval Fractions (from the Cloud Optical Property Algorithm) using Yori, intermediate L2 arrays are created in the pre-Yori step called *COPR_** (where * is an acronym for the cloud phase).

These intermediate *COPR_** arrays are (as before for the *Cloud_Mask_Cloudiness arrays*) filled with 1s (True) and 0s (False). The 1s represent L2 pixels that are true (or cloudy that also meet some preset requirement specified, e.g., liquid water cloud phase) for the computation of the particular cloud fraction. The 0s represent L2 pixels that are either false (because they were deemed clear) or false (because they did not meet the requirements specified for that particular fraction (e.g., ice phase clouds). Therefore, if one is computing Liquid Water Cloud Fraction, 1s (T) can only be set if the L2 pixel is both cloudy and if the clouds were tagged Liquid Water

Phase.

The logic used was as follows: every sampled L2 grid point that has a *Primary Cloud Retrieval Outcome Flag* = 1 (Retrieval Successful) and a *Primary Cloud Retrieval Phase Flag* of 2 (Liquid Water Cloud), 3 (Ice Cloud), or 4 (Undetermined Phase Cloud) are taken as 100% cloudy for the cloud phase category in question.

L2 QA Flag	Flag Value	Meaning
Primary Cloud Retrieval Phase Flag	0 1 2 3 4	Cloud Mask Undetermined (Missing or Fill) Not Processed (Typically Clear) Liquid Water Cloud Ice Cloud Undetermined Phase Cloud
Primary Cloud Retrieval Outcome Flag	0 1	Retrieval Not Attempted or Unsuccessful Retrieval Successful

Table 6. Two key 06_L2 QA Flags used to compute the Cloud Optical Properties Cloud Fraction.

A key point to remember is that there was a change in how the Cloud Optical Property L3 Cloud Fractions was computed between MODIS Standard Collection 5/51 and Collection 6/61. In MODIS Standard Collection 6 (C6) and later, it was decided to include failed retrievals (in the counts used in the denominator of the L3 cloud fraction computation). This same MODIS Standard C6 logic (to include failed retrievals in this computation as false or 0) is used in L3 COSP.

One note about the *Primary Cloud Retrieval Phase Flag* in Table 6. Flag values of 1 (Not Processed) are counted as clear sky. These retrievals will always have a *Retrieval Outcome Flag* of 0 (Unsuccessful).

In summary, in the MODIS Standard L3 Product files for Collection 6 and later, and in the L3 COSP files, the Cloud Optical Properties Cloud Fraction uses clear pixels, successfully retrieved pixels, **and unsuccessfully retrieved pixels**, to derive the computational denominator. Only successfully retrieved pixels that meet the set cloud-phase aggregation logic are used in the computational numerator.

Keeping in mind the logic described previously for the Cloud Fraction Computation in L3 COSP, the Mean of those T/F pixels are tallied to compute the fraction. See Figure 14.

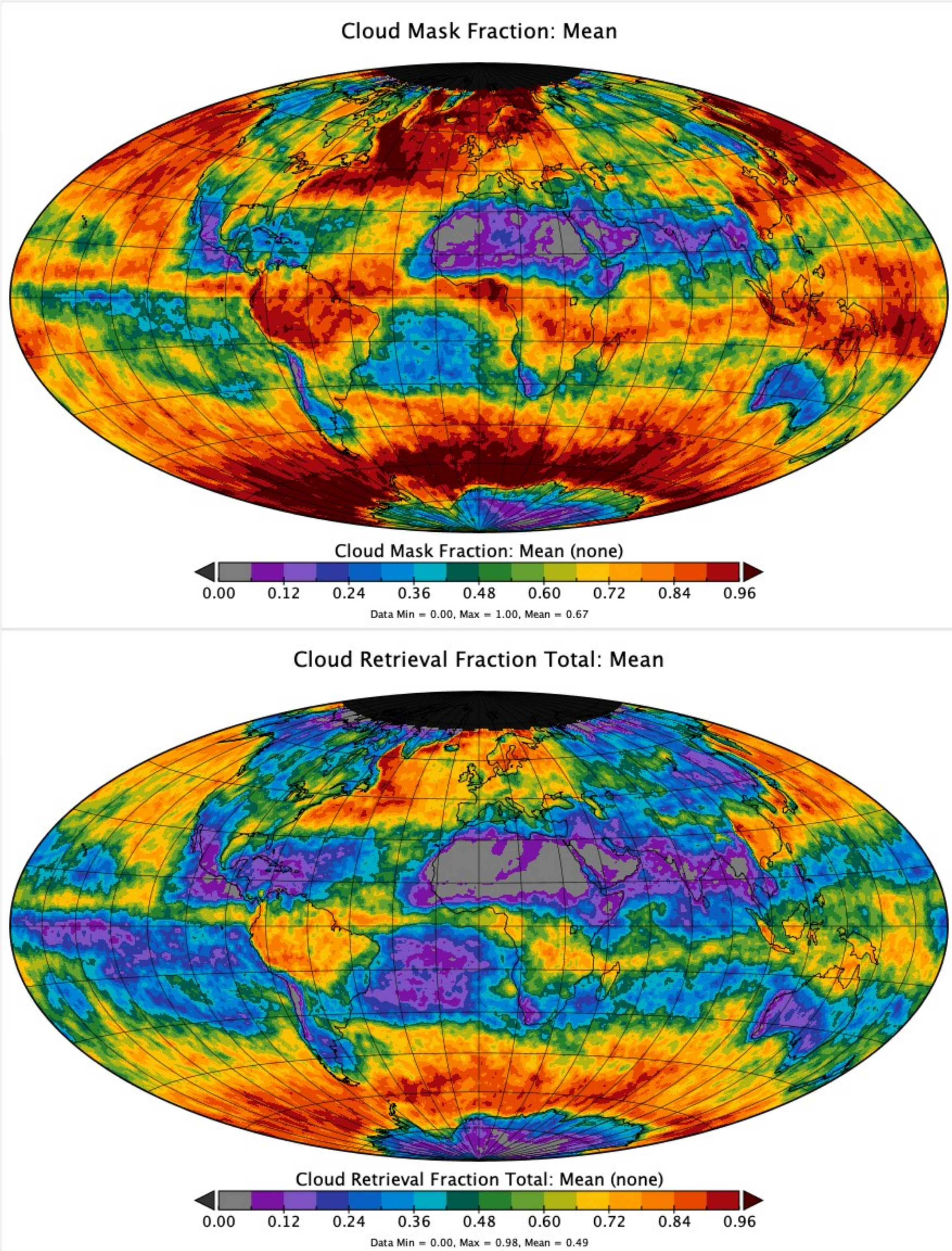


Figure 13. L3 CLDPROP COSP (Aqua MODIS) Monthly Images for Feb 2014 (a) Cloud Fraction from Cloud Mask for Daytime only (b) Successful Cloud Optical Property Retrieval Fraction for Combined Phase Clouds (Daytime) More clouds exist in the top image due to failed retrievals in the bottom image.

4.2.3.3. Logarithm Statistics.

Logarithms are another type of statistic not directly computable by Yori. Again, the pre-Yori step was utilized to pre-process (or set up) new L2 intermediate arrays, which Yori could later use to produce Log statistics.

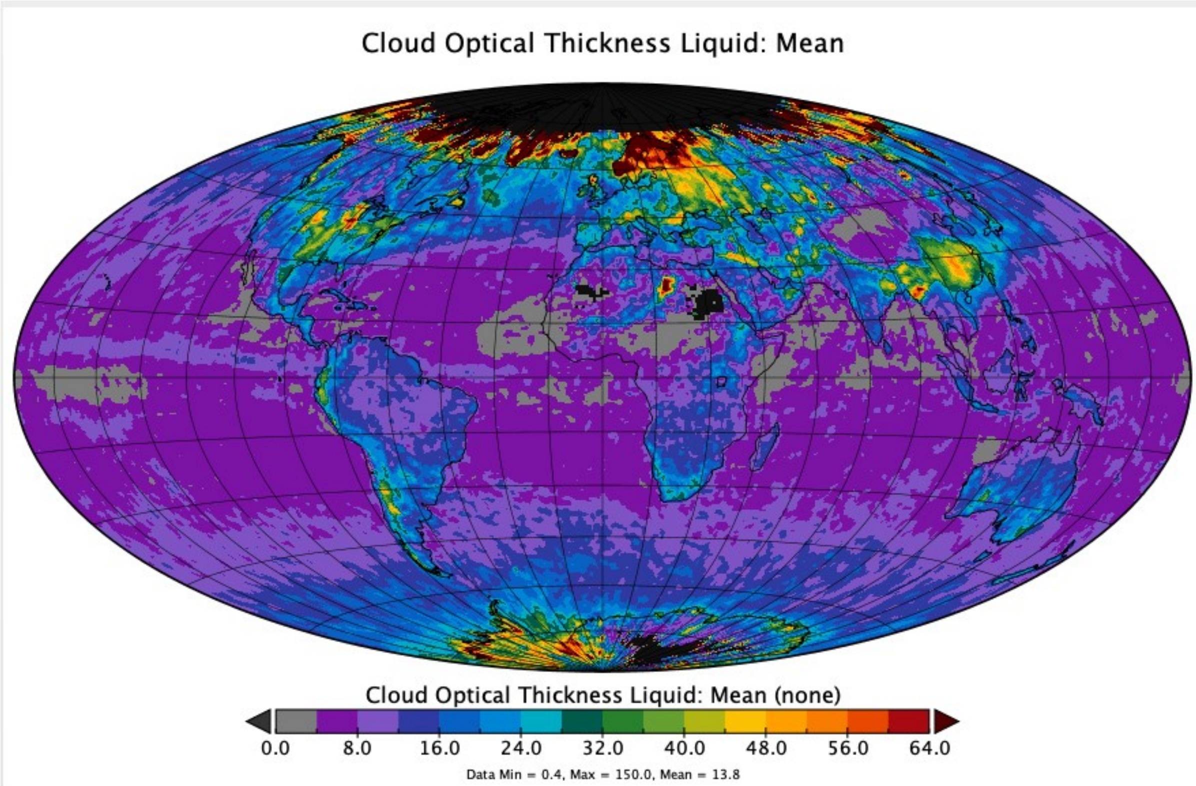
This patch does precipitate a very minor array difference in MODIS Standard (MOD08) vs. COSP (MCD06COSP) products. In the MODIS Standard Products, Log was a 'statistic type'; however, with this patch required in Yori, Log is now an actual new Group (or Parameter) in the L3 COSP product.

Please note that these Log statistics are only computed for cloud optical thickness (τ_c) parameters. The reason for this is as follows: because of the curvature of cloud reflectance as a function of optical thickness, the mean optical thickness of an ensemble of pixels does not correspond to the mean reflectance (or albedo) of those pixels. However, the mean of log(τ_c) approximates the radiatively averaged optical thickness because reflectance plotted as a function of log(τ_c) is linear over a wide range of optical thickness values (excluding small and large values). That is, the mean of log(τ_c) gives an optical thickness that approximately corresponds to the average reflectance of the pixels that comprise the mean. The accuracy of this approximation depends on the nature of the optical thickness probability density function (PDF). Studies on the validity of this approximation for MODIS scenes is reported by Oreopoulos et al. (2007).

Relative to the more complex Cloud Fraction patch noted in the previous section, this pre-Yori Log software patch was much easier to code. The Log set-up arrays were made by simply taking the Log (base 10) of Cloud Optical Thickness and creating a new intermediate input L2 array called *Cloud_Optical_Thickness_Log10*. Next, that new array is simply run through the canned Yori routines to produce the suite of 5 simple Log statistics (Mean, Standard_Deviation, etc.).

Since for the Log computation, L2 cloud optical thicknesses (τ_c) are converted to base 10 logs, the following mapping can be laid out. A τ_c of 100 would be converted to a log value of 2.0, a τ_c of 10 would be converted to a log value of 1.0, a τ_c of 1.0 would be converted to a log value of 0, a τ_c of 0.1 would be converted to a log value of –1.0, and finally a τ_c of 0.01 (the smallest reported value in L2) would be converted to a log value of –2.0. So the valid range of this Log statistic would normally be -2.0 to 2.0 (corresponding to regular Cloud Optical Thickness data values ranging from 0.01 to 100). However, at the start of MODIS Standard C6, the maximum reported cloud optical thickness was increased from 100 to 150 in the cloud retrieval algorithm, which means the maximum log value is now 2.176 instead of 2.0. Once the log values of the L2 input pixel data are calculated in the pre-Yori step, a daily mean value of all the log values is computed.

Figure 16 shows an illustrative comparison of traditional (regular linear scale) Cloud Optical Thickness imagery vs. Cloud Optical Thickness **Log** imagery. These images are for the exact same month of data, February 2014.



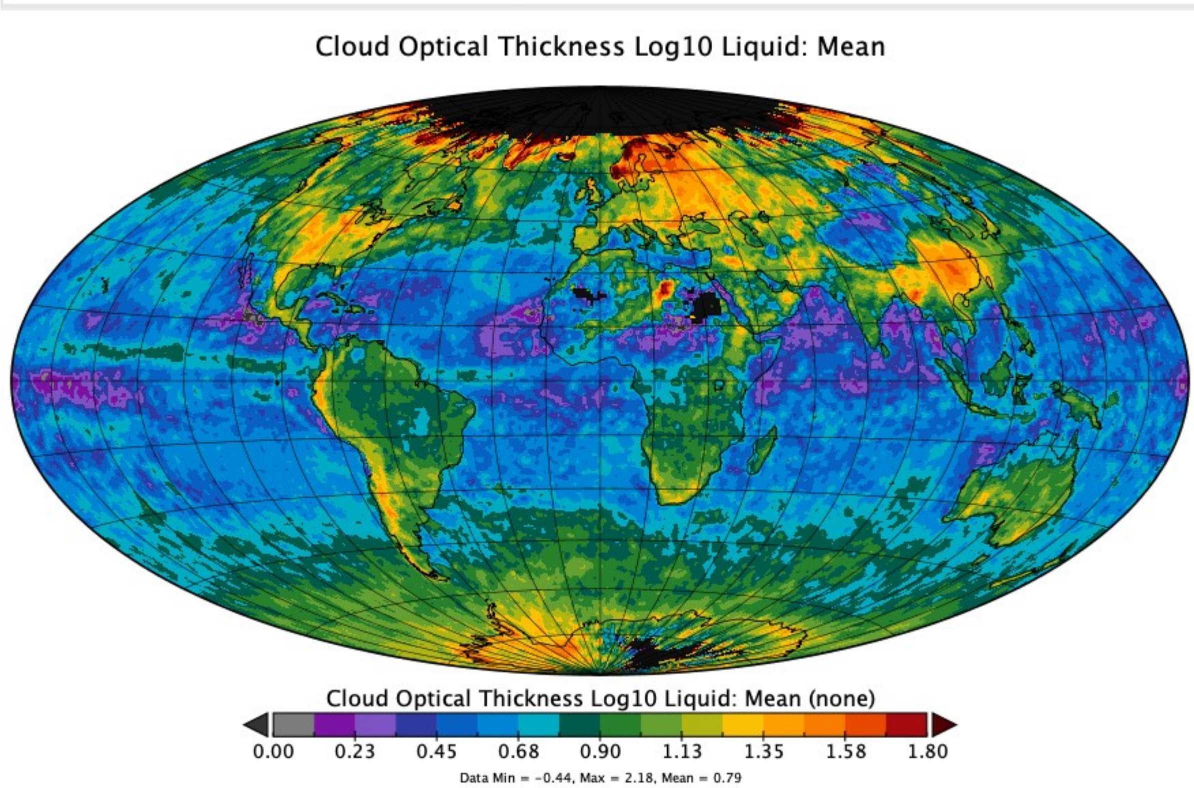


Figure 16. L3 CLDPROP COSP (Aqua MODIS) Monthly Images for Feb 2014 (a) Cloud Optical Thickness for Liquid Water Phase Clouds (full valid range from 0.01 to 150.0) (b) The Logarithm (Log) of that exact same data (full valid range from -2.0 to 2.176). Note that the image scale ranges were tweaked on both images to provide more detail.

5.0. Computation of L3 Monthly Statistics

Since the exact same YAML (Markup Language) Configuration File and Yori Processing System is used to produce both Daily (D3) and Monthly (M3) files, there is little chance of anything going askew in the monthly product only. If the daily product is being computed correctly and producing valid results, then the monthly will follow. That being said, both the daily and monthly products rely on correct and valid upstream L2 input products.

Because of this algorithm-processing matching paradigm, L3 COSP daily and monthly products have identical mapping grids and resolution, identical parameter and statistic inventory lists, and identical histograms and joint histograms (including bin boundary definitions).

It's interesting to note that only the L3 daily files are used as direct input into the monthly product, however because L2-tied quantities Sum and Sum_Squares are carried through the daily and monthly file, statistics in the monthly file continue to reflect the L2 input data directly. This means quantities of standard deviation in the monthly file are actually the standard deviation of the L2 input pixels, which is the most useful and meaningful way to compute standard deviation.

As a bit of background on the standard deviation computation, in the MODIS Standard monthly file (08_M3), there were two different standard deviations computed: 1.) the standard deviation of the daily means, and 2.) the mean of the daily standard deviation; however nowhere in that product was a statistic describing the standard deviation of the L2 input pixels, since the pieces required to compute that information in the monthly file were not available in the daily file. Therefore, the L3 COSP monthly product file is superior to the L3 MODIS Standard monthly product file in that regard.

Users should also note that in L3 MODIS COSP monthly file (as well as daily file), all mean and standard deviation quantities are pixel-count weighted. While in the MODIS Standard monthly file (MOD08_M3, MYD08_M3), some monthly means were pixel-count weighted (cloud optical property-related statistics) and some were unweighted (cloud top property-related statistics).

Also true in the MODIS Standard L3 as well as the COSP L3, there is no "valid_range" check -- only fill value L2 grid cells are universally excluded. Valid_range is reported in the YAML configuration file and in the NetCDF4 file as local attributes attached to each Group, however it's for documentation purposes only.

Finally, users should also note that in L3 COSP monthly file, all mean and standard deviation quantities are pixel-count weighted. While in the MODIS Standard monthly file some monthly means were pixel-count weighted (cloud optical property-related statistics) and some monthly means were unweighted (cloud top property- and cloud mask-related statistics). See Tables 7a and 7b, below.

MODIS Standard Monthly Products MOD08_M3 & MYD08_M3 (Collection 6.1)

Major Parameter Groups	Unweighted Scheme	Pixel-Count Weighted Scheme
Cloud Top Properties / Cloud Mask	√	
Cloud Optical Properties		√

Table 7a. This Table shows the Weighting Scheme used in the MODIS Standard L3 Monthly (08_M3) Products (unwieghted scheme for CTP and CM -related parameters; and pixel-count weighted scheme for COP-related parameters). The weighting scheme used was selected in advance by each science team for their products.

MODIS Starndard Monthly COSP Product MCD06COSP_M3 (Collection 6.1)

Major Parameter Groups	Unweighted Scheme	Pixel-Count Weighted Scheme
Cloud Top Properties / Cloud Mask	n/a	√
Cloud Optical Properties	n/a	√

Table 7b. This Table shows the Weighting Scheme used in the L3 COSP Monthly Products. Users should note the change in the weighting scheme used to compute CTP- and CM-related Monthly (M3) statistics between the Heritage MODIS Standard 08_M3 (Table 7a) and COSP MCD06COSP_M3 (Table 7b). Note that the Unweighted Scheme is not available in the YORI SIPS L3 processing system, so it is not an option for COSP.

Figure 17 shows how these two different monthly weighting schemes (unweighted vs. pixel-count weighted) can affect statistics. The solid line shows MODIS Standard Aqua Daytime Cloud Fractions (60N to 60S) using an unweighted scheme (used in 08_M3), so that each daily mean has the same 1x weight in the computation of the monthly mean.

The dashed line shows MODIS Aqua for the same data using a pixel-count weighted scheme (used in COSP), so that each daily mean is weighted by the number of valid L2 pixels that make up that daily mean, during the computation of the monthly mean. This plot clearly reveals that the weighting scheme used to compute monthly means does make a difference in the values -- for MODIS Aqua data, roughly 1.5%.

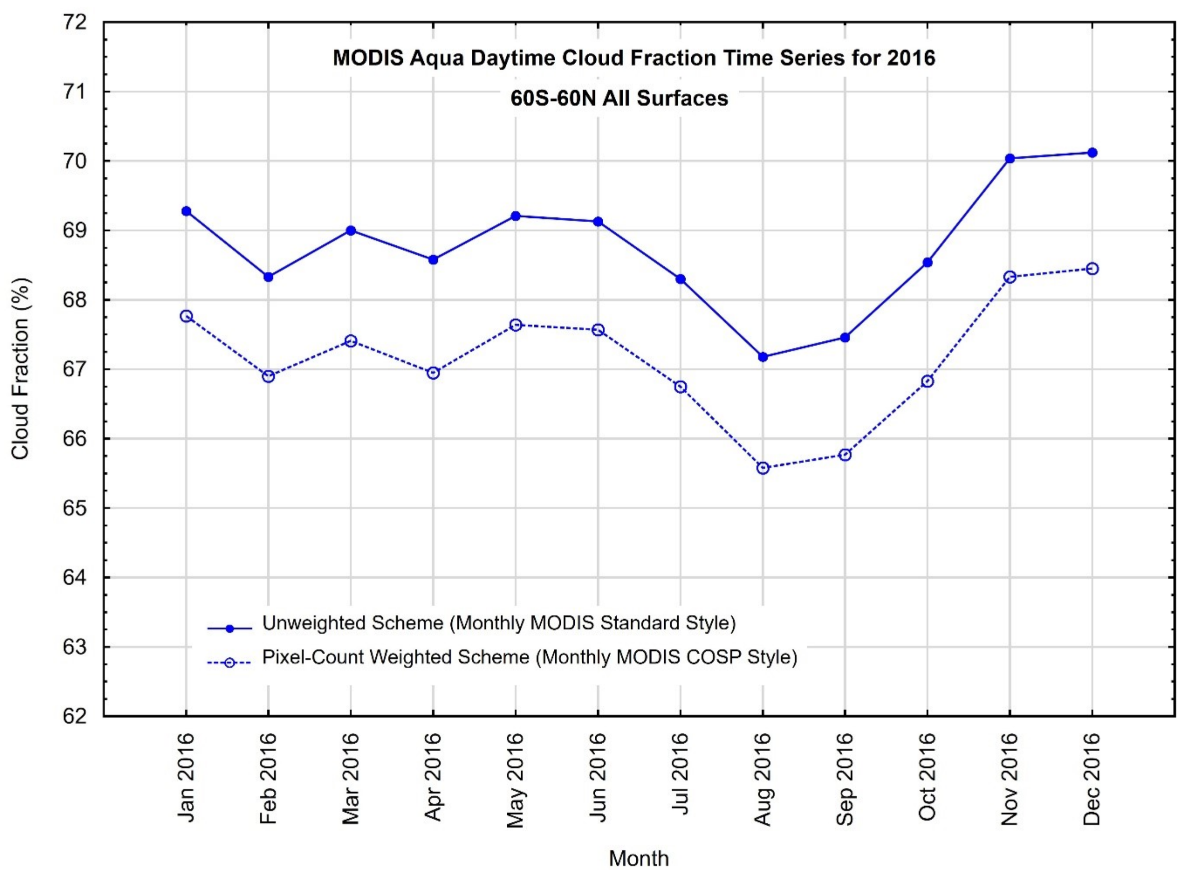


Figure 17. Users should note the change in the weighting scheme used to compute some Monthly (M3) statistics between the Heritage MODIS Standard 08_M3 (Unweighted Scheme) and MODIS COSP MCD06COSP_M3 (Pixel-Count Weighted Scheme). Figure courtesy of Rich Frey, UW SSEC.

6.0. Reading and Unpacking NetCDF4 File Data

NetCDF4 (Network Common Data Form, v4) is a set of software libraries and self-describing, machine-independent, multi-object data formats that support the creation, access, and sharing of array-oriented scientific data. NetCDF was developed by and is maintained at Unidata, which is part of the University Corporation for Atmospheric Research (UCAR) Community Programs (UCP). NetCDF4 is the standard data format for Atmosphere COSP data products.

6.1. Descaling data

The standard NetCDF4 file local attributes "scale_factor" and "add_offset," attached to every Group, would typically only apply to the Mean and Standard_Deviation statistics (which are the only two statistics in L3 COSP that could be realistically packed) and in that case, would be used to convert stored (packed) integer data to geophysical floating point numbers through the use of the following equation:

$$\text{Geophysical Value} = \text{scale\_factor} * (\text{Stored Integer} - \text{add\_offset}) \quad (8)$$

However, in L3 COSP files, the Mean and Standard_Deviation statistics are stored as double-precision real (R*8) numbers that are not natively packed, therefore end-users do not need to unpack. So, for all Groups (Parameters) in L3 COSP, the scale_factor local attribute is set to 1.0 and the add_offset local attribute is set to 0.0.

All L3 count-related statistics (Pixel_Counts, Histogram_Counts, and JHisto_vs_xxx) are stored as 4-byte Integer (I*4) or INT. INT numbers can range up to 2,147,483,647, which provides enough headroom to store any possible real-world count from sampled MODIS instrument data at larger L3 grid sizes, even at longer time-intervals. The Pixel_Counts will always contain the largest numbers of these three count-related statistics, since those counts are not subdivided into data-value bins.

The Sum and Sum_Squares statistics are stored as double-precision Real (R*8), the same format as the Mean and Standard_Deviation. The Sum_Squares numbers can get astronomically large. The Sum and Sum_Squares data is really only provided (available) in order to compute other statistics (e.g.: Mean and Standard_Deviation) as Yori aggregate data, and rarely need to be read by the science or user community.

The scientific measuring units of the geophysical floating-point Mean and Standard Deviation values are indicated by the "units" local attribute that is also provided with each Group.

Valid range local attributes (given as a min (value_min) and max (value_max) number) is also provided with each Group. The two valid range values provided are the expected low and high values of valid (non-fill) L2 input to the L3 statistic data.

Note that **no** valid range screening on the input L2 data or the output L3 data is performed. The reason for this is sometimes absolute valid ranges are difficult to determine in advance and the algorithm developers want to avoid the potential loss of good data. Therefore, users should not be surprised to find non-fill data points that fall outside the documented valid range; however, it should raise a flag for the user to make sure they are unpacking the data correctly.

6.2. Definitions of local attributes

As partially described above, attached to each Group within a NetCDF4 file are a suite of local attributes (some described in the previous section). These local attributes serve as a key to interpret the data, drive the logic in the Yori system, and provide documentation for end users.

6.2.1. Local attributes used in L3 COSP files.

Given below is the full set of local attributes, which can be attached to specific Groups (Parameters) or Variables (Statistics) in the L3 COSP files. Note that not all of these are attached to every Group and Variable (only the local attributes necessary to compute or properly document the statistics in the Group).

- **long_name.** A longer character string description of the Group.
- **units.** Scientific measurement units of the data (if there are no units, "none" is

specified).

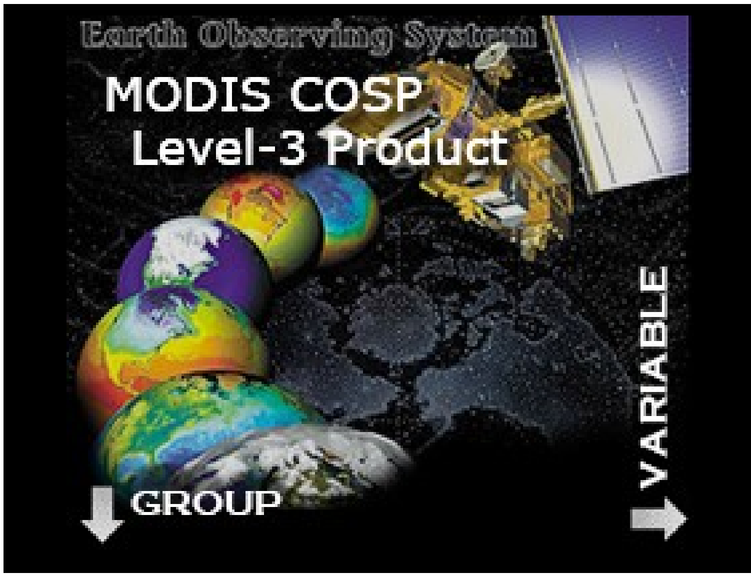
- **valid_min, valid_max.** An array of two numbers that describe the expected low and high values (valid range) of the L2 data (before applying any scale and offset in L2, if L2 data was packed); ignoring the L2 Fill Value.
- **scale_factor.** If the data is packed, this is the scaling factor used to unpack the data. Note for L3 COSP files, this is always set to 1.0 (which means no packing was done).
- **add_offset.** If the data is packed, this is the offset used to unpack the data. Note for L3 COSP files, this is always set to 0.0 (which means no packing was done).
- **_FillValue.** The value of missing or fill data in the Group (Parameter) or Variable (Statistics). Typically set to -9999 in the L3 COSP file.
- **title.** A character array providing a succinct description of what is in the variable. Note that this attribute is attached to all variables in the L3 COSP NetCDF4 file and provides information to various visualization packages (e.g., Panoply) on how to explicitly title images produced from that variable (typically this is a combination of the Group name and the Variable name).
- **Histogram_Bin_Boundaries.** An array of numbers describing the histogram bin boundaries of the primary parameter. (Only used when an optional histogram (Histogram_Count) statistic is defined.)
- **JHisto_Bin_Boundaries.** An array of numbers describing the joint histogram bin boundaries of the primary parameter. (Only used when an optional joint histogram (JHisto_vs_xxx) statistic is defined.)
- **JHisto_Bin_Boundaries_Joint_Parameter.** An array of numbers describing the histogram bin boundaries of any secondary (or jointed) parameter. (Only used when an optional joint histogram (JHisto_vs_xxx) statistic is defined.)

7.0. Complete Group & Variable Inventory of L3 COSP Files

Table 8 (shown on the following page) shows a complete inventory of Groups and Variables in the L3 CLDPROP COSP products. The Groups (or Parameters) are shown in the rows of the table. The Variables (or Statistics) are shown in the columns of the table. Statistics that are computed for each Group are represented by colored dots in the table. A dot means that statistic exists (shown in the column) for that particular parameter (shown in the row).

The color coding of the statistic colums was done to help differentiate groups of statistics. This table was compiled based on L3 COSP Data Version 6.1 (File Version 061), and should remain relatively stable for future versions. This version matches that of the source 06_L2 data.

The number of Groups (Parameters) total 28, the number of possible Variables (Statistics) that can be defined for each Group number 9. The total number of Group/Variable (or Parameter/Statistic) combinations total 114. Of these 114 Parameter/Statistic combinations, 110 are scalar statistics and 4 are 2D Joint Histograms.



	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Cloud_Particle_Size_Liquid (nxm)	JHisto_vs_Cloud_Particle_Size_Ice (nxm)	JHisto_vs_Cloud_Top_Pressure (nxm)

Angles *4 (20)*

01. Solar_Zenith [Day Mask: SZA ≤ 85°]	•	•	•	•	•				
02. Solar_Azimuth [Day Mask: SZA ≤ 85°]	•	•	•	•	•				
03. Sensor_Zenith [Day Mask: SZA ≤ 85°]	•	•	•	•	•				
04. Sensor_Azimuth [Day Mask: SZA ≤ 85°]	•	•	•	•	•				

Cloud Top Properties (CTP) *5 (25)*

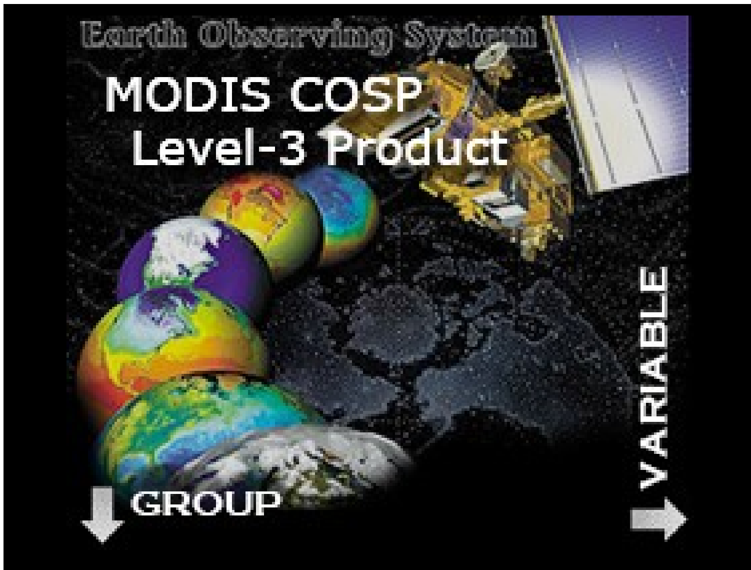
01. Cloud_Top_Pressure [Day Mask: SZA ≤ 85°]	•	•	•	•	•				
02. Cloud_Mask_Fraction [Derived from Cloud Mask]	•	•	•	•	•				
03. Cloud_Mask_Fraction_Low [CTP ≥ 680 hPa]	•	•	•	•	•				
04. Cloud_Mask_Fraction_Mid [680 hPa > CTP ≥ 440 hPa]	•	•	•	•	•				
05. Cloud_Mask_Fraction_High [CTP < 440 hPa]	•	•	•	•	•				

Cloud Optical Properties (COP) *14 (68) JH=3*

3.7µm Retrieval (Regular Cloudy Scenes)

[COP Limit 06_L2 Algo: SZA ≤ 81.3731°]

01. Cloud_Optical_Thickness_Liquid	•	•	•	•	•		•		
02. Cloud_Optical_Thickness_Ice	•	•	•	•	•			•	
03. Cloud_Optical_Thickness_Total [Includes Undetermined Phase]	•	•	•	•	•				•
04. Cloud_Optical_Thickness_Log10_Liquid	•	•	•	•	•				
05. Cloud_Optical_Thickness_Log10_Ice	•	•	•	•	•				
06. Cloud_Optical_Thickness_Log10_Total [Includes Undet. Phase]	•	•	•	•	•				
07. Cloud_Particle_Size_Liquid	•	•	•	•	•				
08. Cloud_Particle_Size_Ice	•	•	•	•	•				
09. Cloud_Water_Path_Liquid	•	•	•	•	•				
10. Cloud_Water_Path_Ice	•	•	•	•	•				



	Mean	Standard_Deviation	Sum	Sum_Squares	Pixel_Counts	Histogram_Counts (n)	JHisto_vs_Cloud_Particle_Size_Liquid (nxm)	JHisto_vs_Cloud_Particle_Size_Ice (nxm)	JHisto_vs_Cloud_Top_Pressure (nxm)
11. Cloud_Retrieval_Fraction_Liquid [COPR derived]	•	•	•	•	•				
12. Cloud_Retrieval_Fraction_Ice	•	•	•	•	•				
13. Cloud_Retrieval_Fraction_Total [Includes Undet. Phase]	•	•	•	•	•				
3.7μm PCL Retrieval (Partly Cloudy Scenes)									
14. Cloud_Optical_Thickness_PCL_Total [Includes Undet. Phase]									•

Table 8. A Complete Inventory of Groups (Parameters) and Variables (Statistics) in the L3 CLDPROP COSP product. There are a total of 23 individual Groups (or Parameters) in the product, shown in the rows of the table. A dot in the table means that the particular Variable (Statistic) exists for that particular Group (Parameter). So, the 123 dots in the table above, represent the 123 group/variable (a.k.a. parameter/statistic) combinations defined in the L3 COSP product. Note that this specification matches exactly between Daily (D3) and Monthly (M3) COSP files.

The CLDPROP COSP NetCDF4 file size is roughly 32 MB for Daily (D3) and 44 MB for Monthly (M3). The file size is slightly larger for monthly since the more completely filled global grids for Monthly (M3) don't compress as well as the less-filled global grids for Daily (D3). Finally, note that the file format and structure is exactly the same between the Daily (D3) and Monthly (M3) NetCDF4 COSP files.

7.1. Mapping Parameter Names from heritage 08_L3 output to new L3 COSP output

There were some slight changes made to the parameter names and keywords between the heritage 08_L3 products and the new L3 COSP products. COSP users should keep these details in mind. Since the COSP product is a daytime-only product, the explicit _Day suffix was dropped on some parameters that previously had that suffix. The parameter Cloud_Fraction was expanded to Cloud_Mask_Fraction in L3 COSP to add clarity. The keyword _Combined, previously used to denote parameters that combine all cloud phases (Liquid Water, Ice, and Undetermined Phase), was changed to _Total in the new L3 COSP product. The previous keyword _Log was changed to _Log10 for L3 COSP. The heritage 08_L3 parameter name Cloud_Effective_Radius was changed to Cloud_Particle_Size for L3 COSP.

Input 06_L2 SDS Name	Heritage 08_L3 Parameter Name	New L3 COSP Group Name
Cloud_Top_Pressure_Day	Cloud_Top_Pressure_Day	Cloud_Top_Pressure
Cloud_Fraction_Day	Cloud_Fraction_Day	Cloud_Mask_Fraction
Cloud_Optical_Thickness	Cloud_Optical_Thickness_Combined	Cloud_Optical_Thickness_Total
Cloud_Optical_Thickness	Cloud_Optical_Thickness_Log	Cloud_Optical_Thickness_Log10
Cloud_Effective_Radius	Cloud_Effective_Radius_Liquid	Cloud_Particle_Size_Liquid
Cloud_Effective_Radius	Cloud_Effective_Radius_Ice	Cloud_Particle_Size_Ice
Cloud_Phase_Optical_Properties	Cloud_Retrieval_Fraction_Combined	Cloud_Retrieval_Fraction_Total

Table 9. Users should note some changes in parameter names between the heritage 08_L3 (orange shading) and L3 COSP (violet shading) in case any comparisons are made between those two products.

8.0. Important Notes, Caveats, and Issues to Consider in L3 COSP

8.1. Cloud Retrieval Fraction Pixels Counts: MOD08 vs. COSP

A difference in the statistics for Cloud Retrieval Fraction-related parameters is noted in the Pixel Counts statistic. In MODIS Standard MOD08, the Cloud Retrieval Fraction Pixel Counts is the numerator of the fraction (the number of cloudy pixels). While in L3 COSP, the Cloud Retrieval Fraction Pixel Counts is the denominator of the fraction (the total number of clear + cloudy pixels). This difference in the meaning of Pixel Counts for Cloud Retrieval Fraction Groups results from the different way this quantity was calculated in MODIS Standard vs. COSP, the former using the heritage L3 Code run at MODAPS, and the latter run with the new YORI L3 Code run at Atmosphere SIPS (computed in the Yori framework). That being said, the actual Fraction statistics will match between MOD08 and COSP (however, do remember that the COSP product combines Terra MODIS and Aqua MODIS, while the M*D08 products are separated by platform).

If a user would like to see the numerator (the total number of cloudy pixels by cloud phase) for Cloud Retrieval Fractions in L3 COSP, simply multiply the Fraction (ranging from 0.0 to 1.0) by the Pixel Counts for that particular parameter, stored in the product.

Note that there is no change in the meaning of Pixel Counts for Cloud Mask Fraction in L3 COSP, because for that parameter, cloud fractions are computed in advance on a 5x5 km grid in the input L2 product (06_L2).

For all other types of Parameters (that are not Cloud Retrieval Fraction), the Pixel Count has the traditional meaning. That is, it's the number of valid or successful L2 sampled retrievals for each particular Parameter.

8.2. Monthly Cloud Top Property (CTP) Weighting: MOD08 vs. COSP

Users comparing CTP-related data in the monthly MODIS COSP file (MCD06COSP) to the MODIS Standard data file (MOD08_M3) should be aware of a difference in how the monthly mean and standard deviation statistics were computed for all Cloud Top Property

(CTP)-related parameters.

The monthly MODIS Standard (MOD08_M3) product uses an *Unweighted Weighting Scheme* to compute Cloud Top Property-related statistics. That is, monthly MODIS Standard (MOD08_M3) CTP-related statistics (e.g.: Cloud_Top_Temperature_Mean_Mean) is an un-weighted *mean of the daily mean* without regard to pixel counts observed on each day.

The monthly COSP (MCD06COSP_M3) product uses a *Pixel Count Weighting Scheme* to compute CTP-related statistics (e.g.: Cloud_Top_Temperature, Mean). So, there is a difference between how the CTP parameters are being computed in a MODIS Standard M3 file (un-weighted) vs. a COSP M3 file (pixel-count weighted). Since the COSP Simulator data uses a pixel-count weighting scheme, it seemed appropriate to switch to that scheme for all Cloud Top Property-related groups.

8.3 Simple Stats most users can ignore: Sum & Sum_Squares

Most L3 COSP Groups contain five standard simple statistics (computed as a set): Mean, Standard_Deviation, Pixel_Counts, Sum, and Sum_Squares. Users can generally ignore the last two statistics in that list (Sum and Sum_Squares) as they are generally not deemed useful to most users. However, they are a required element in Yori to facilitate recomputing the Mean and Standard_Deviation on-the-fly as data is aggregated (spatially and temporally) in L3.

8.4 Pixel_Count Array Initialization: MOD08 vs. COSP

Note that Pixel Count statistics in L3 COSP (produced by the Yori System) are initialized with zero -- and not fill (missing) as was done for MODIS Standard MOD08. This means orbital gaps and day/night boundary regions are shown as 0 and not fill in all count-related data/imagery. In other words, Pixel_Count images will not show (as clearly) data gap (missing data) regions (typically seen between orbital swaths in Daily images for MODIS and over the poles for day- or night-only data).

This statistic initialization rule also applies to histogram count and joint histogram count arrays – so basically, all count arrays are initialized with zero (and not fill) in L3 COSP. If a user wanted to show those missing data gaps on their Pixel_Count images, they would have to mask those images with the fill value from the Mean image in that same group. This visualization issue of fill vs. zero is less important for Histograms and Joint Histograms since those statistics tend not to be displayed on a geographic map -- so initializing with zero is less noticeable.

The L3 Development Team did attempt to get the UW Yori Development Team to change this procedure for initializing Pixel_Counts in Yori, but they seemed set on this decision saying that it made more sense for them to do it that way. Looking back on it now, it probably had a lot to do with how Yori is computing statistics on the fly and simplifying the Yori computational logic.

This issue does not impact the Mean and Standard Deviation statistics because they are initialized with fill-values (missing).

8.5 Histogram Bin Boundary definitions: MOD08 vs. COSP

How bin boundaries are handled has slightly changed between MODIS Standard L3 and COSP L3. For L3 COSP (MCD06COSP), the first through the next-to-last (penultimate) histogram bin includes L2 data points that fall on the lower bin boundary. The last (ultimate) histogram bin includes L2 data points that fall on both the lower and the higher bin boundary.

For L3 MODIS Standard MOD08, the first histogram bin includes L2 data points that fall on both the lower and higher bin boundaries. All subsequent histogram bins include points that fall on the higher bin boundary.

For both streams, any L2 data point that falls outside the specified range of L3 histogram bin boundaries is not counted.

Initially, the L3 Development Team attempted to get the Yori developers to match the old MODIS Standard convention, but eventually, given its minor nature that wouldn't affect any science results, we decided against it. It remains unclear if there is a widely accepted standard for how the binning in histograms and joint histograms is handled.

8.6 Screening occasionally bad L2 CER data < 4.0 microns

In June 2019, we found that the L2 Cloud Optical Property Retrieval algorithm was, very intermittently, producing bad Cloud Effective Radius (CER) < 4.0 microns for liquid water and undetermined phase clouds. We subsequently decided to mask (remove) these bad L2 input CER data from L3 COSP. Note that most of the L3 Cloud Optical Property Groups had to be masked for this issue. This includes all Liquid and Total (Combined) cloud phase Groups in Cloud Optical Properties. Note that Ice cloud phase retrievals did not have an issue. This (more global) masking at L3 was necessary in order to keep the total pixel counts the same between all Cloud Optical Property Parameters. Finally, the L3 *Cloud Retrieval Fraction* parameters required special logic in the pre-Yori code that prevents clear-sky pixels from accidentally being masked out when the "CER ≥ 4.0 is True" mask is applied. So to summarize, this bad L2 input data is still in the MODIS Standard L3 MOD08 data, but has been removed from L3 COSP data. Note that in a later version of the CLDPROP input, this bug was fixed, so the code patch actually no longer does anything to the input L2 data.

8.7. Day/Night Algorithm Cut-Off: MOD06/MOD08 vs. CLDPROP

The Day/Night separation for Cloud Top Parameter-related parameters in MODIS Standard MOD06/MOD08 was based on the L2 Cloud Mask QA Day/Night Flag. Note that this Day/Night Flag uses Solar Zenith Angle ≤ 85 degrees as a daytime cutoff.

However, for the L2 Continuity CLDPROP Cloud Top Properties algorithm, the daytime cutoff was changed from 85 to 80 degrees.

For Cloud Optical Property L2 Continuity CLDPROP products, the daytime cutoff was initially set (early on in development) to 81.3731 degrees, matching the cutoff used in MODIS

Standard MOD06 Products; however by late 2018, it was decided to change that from 81.3731 to 80 degrees to match the Cloud Top Properties Continuity Algorithm. See Table 10.

By early 2019, L2 Cloud Optical Properties Team expressed a desire to eventually have the L2 Cloud Mask Team to change their Cloud_Mask QA Day/Night Flag to match the new day/night cutoff being used for Cloud Top Properties and Cloud Optical Properties (SZA ≤ 80°) -- however there is no formal plan to do that at the present time.

This means that as long as L3 CLDPROP is using the Cloud_Mask Day/Night QA Flag cutoff (SZA ≤ 85°) to aggregate day and night Cloud Top Property-related products in L3, some of the Cloud Top Property L3 Groups tagged "_Day" will have some nighttime pixels (that is, pixels that the Cloud Top Properties algorithm is tagging as night) included (mixed in) near the edge of the day/night boundary.

Since Cloud Optical Property (COP) Parameters are never aggregated as Day vs. Night (since the COP algorithm is only run in the daytime), this issue will not affect COP parameters.

Algorithm	**MODIS Standard Atmosphere** Day/Night Cutoff	**Continuity Atmosphere** Day/Night Cutoff
Cloud Mask Algorithm	Solar Zentih ≤ 85°	Solar Zentih ≤ 85°
Cloud Top Property Algorithm	Solar Zentih ≤ 85°	Solar Zentih ≤ 80°
Cloud Optical Property Algorithm	Solar Zentih ≤ 81.3731°	Solar Zentih ≤ 80°

Table 10. The different ways the three Cloud Algorithm Teams (Cloud Mask, Cloud Top, and Cloud Optical) have defined the Day/Night Cutoff for both the MODIS Standard Products (MOD06, MOD08), shown in the middle column; and for the later Continuity Products (CLDPROP), shown in the far right column. The Solar Zenith Angles shown in the table are used to define daytime; everything else would fall into nighttime.

8.8. File format tweaks to improve interaction with Visualization Tools (e.g.: Panoply)

Early in the development of L3 COSP products, Panoply (a popular visualization and analysis tool) did not handle NetCDF4 files as expected in creating optimal image titles by default.

The primary reason for this was the new Group/Variable format of L3 COSP vs. the old standalone Scientific Data Set (SDS) format of L3 MODIS Standard MOD08.

When Panoply generates titles for images from a NetCDF4 file with the Group/Variable structure, the Group information is ignored, and instead, Panoply uses information attached to the Variable only. In this paradigm, Panoply creates image titles based on the following list of items, any of which may be associated with a specific variable -- in descending order of priority: 1.) the *long_name* attribute, 2.) the *title* attribute, 3.) the *standard_name* attribute, and 4.) the variable's *simple name*. The first three items in the list are defined through the use of local attributes attached to the variable.

Option 1, the *long_name* attribute, which is, by default, attached to the Group as a group attribute in the L3 COSP NetCDF4 file, was too wordy and long-winded to use as an image title, so we decided not to transfer (or pass-through) that string to a local attribute attached to variables in that Group (so that Panoply would "pick it up" when it read each variable). Option 4, the variable's *simple name*, was too short (too cryptic) with not enough information included -- it's simply the name of the variable (e.g.: Mean).

This left only two options on the table to remedy this shortcoming. The *title* attribute (option 2) and the *standard-name* attribute (option 3).

The *title* attribute is described in the NetCDF4 User Guide as *a character array providing a succinct description of what is in the variable*. The *standard_name* attribute is described in the NetCDF4 User Guide as *a long descriptive name for the variable taken from a controlled vocabulary of variable names*.

Of these two remaining choices, we chose option 2, the ***title*** attribute, to solve our titling problems in Panoply. We made this choice for three primary reasons. First, the ***title*** attribute was a higher priority than the ***standard_name*** attribute in Panoply's internal rankng system – and we thought it was prudent to use the higher ranking vehicle. Second, we found the name of the keyword itself, "title", the most descriptive, since this whole process was done to fix how Panoply *titles* images from L3 COSP files -- so why not use an attribute name that captures that meaning literally. (This also facilitates users to determine what that attribute means without added documentation). Third, when we read the meaning of the ***title*** attribute in the NetCDF User Guide, it used the word *succinct* (meaning a concise and compact description). So a ***title*** local attribute is defined as a shorter laconic string (while still defining the variable fully), and therefore felt it would best fit in the limited space available for most image titles, while retaining enough information to fully describe the variable.

Therefore, in our final production version of the L3 COSP NetCDF4 file, an attribute called ***title*** is attached to **all** variables and provides information that can be passed to various visualization packages (e.g.: Panoply) informing the package how to explicitly title images produced from that variable. Under most circumstances, these ***title*** local attributes are a simple combination of the Group name and the Variable name, which matches fairly closely with how images were generally titled for variables (statistics) imaged from MODIS Standard Products. This new ***title*** local attribute was implemented in Yori Software version 1.3.8 and later, which was launched on 9 July 2019, and is reflected in all L3 COSP files.

Note that custom software tools, manually written in Python, IDL, or other languages, by individual users, can be designed to do this sort of Group and Variable combining on the fly to make well-behaved image titles, however we were looking for a way to standardize how our files were going to pass titling information to pre-packaged commercial or standardized (widely distributed) visualization tools (like Panoply).

8.9. Internal Structure Change between L3 COSP NetCDF4 and L3 MOD08 HDF4

Note the internal structure of the files in L3 COSP NetCDF4 is slightly different from L3 MOD08 HDF4. In NetCDF4, we use Groups (e.g., Cloud_Optical_Thickness_Liquid) and Variables (e.g., Mean, Sum, etc.), which are part of that group. In HDF4, there were separate SDSs, whose names are created by appending the statistic suffix name to the parameter prefix name (e.g., Cloud_Optical_Thickness_Mean).

8.10. Data Types of Variables with the L3 COSP NetCDF4 file

All the statistics in this L3 (except for Pixel_Counts, Histograms, and Joint_Histograms) are stored in Floating-Point Double-Precision Real in the final gridded NetCDF4 COSP output file (by default) – that is, R*8 output is hardcoded within the Yori processing system for those statistics. For all the "count"-related statistics such as Pixel_Counts, Histogram_Counts, and Joint Histograms, they are stored in Integer I*4.

The new NetCDF4 format and advanced compression tools pose no issues with file size. Note that the Fill Value in these new NetCDF4 files is hardwired to -999.0 and is documented in the local attributes of the file itself.

9.0. Using the newly redesigned Atmosphere-Imager web site

The original MODIS-Atmosphere web site (developed in 1999) was initially designed for MODIS Standard Products, such as MOD06_L2 (L2 Cloud Product) and MOD08_M3 (L3 Global Gridded Monthly Product). This site was completely redesigned in 2018 (using the state-of-the-art Drupal framework) and adapted to include the new Continuity Products. (Screen-captures in Figures 18 through 21.) The redesigned website was renamed the **Atmosphere-Imager** (AI) website and can be viewed at: https://atmosphere-imager.gsfc.nasa.gov

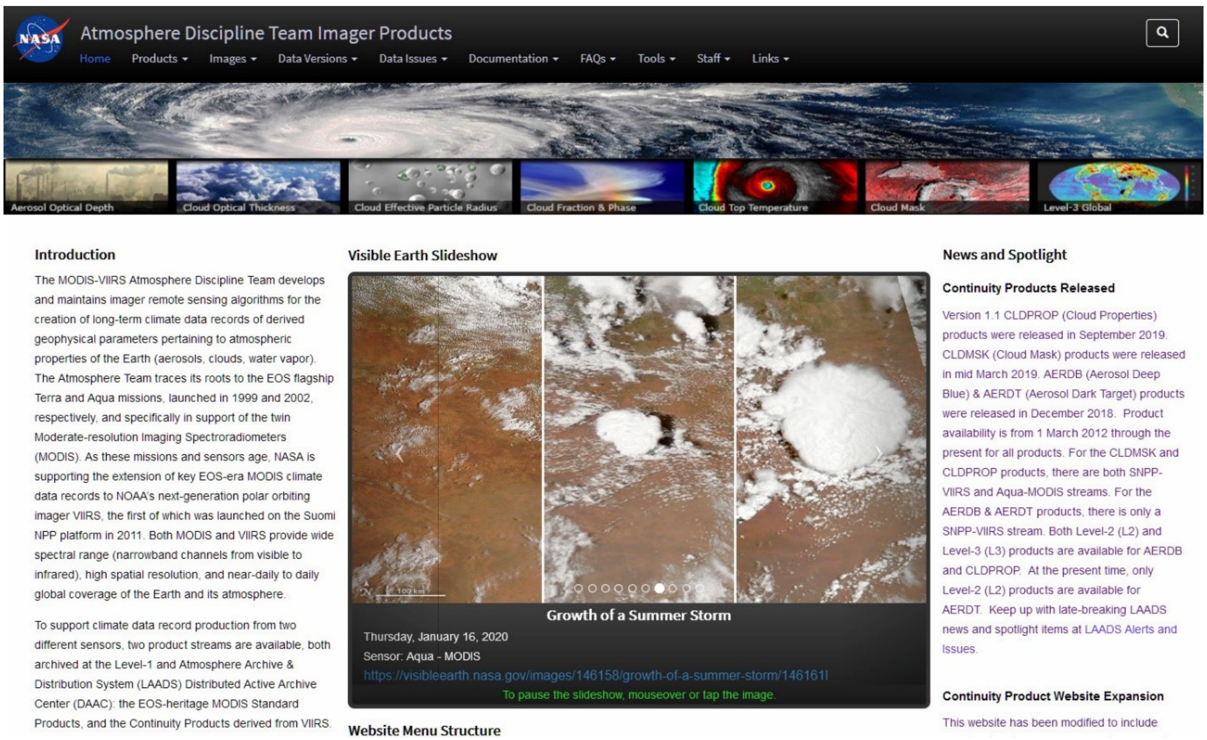


Figure 18. A capture of the new Atmosphere Imager website that was redesigned with a split navigation bar, allowing visitors to view both MODIS Standard content as well as new Continuity content.

The Atmosphere-Imager website has a new user-friendly navigation interface that provides access to content from both MODIS Standard and newer Continuity products.

Note that the COSP Product (CLDPROP COSP), relates directly to the Continuity

CLDPROP_L2 content, which is the direct input to the L3 CLDPROP COSP product.

Users can find this navigation *split* via the *pull-down* from the main topic links displayed atop all pages. The main topic-links that have this navigation *split* are: 1.) Products, 2.) Images, 3.) Data Versions, 4.) Data Issues, 5.) Documentation, and 6.) FAQs.

By selecting the "Continuity" option on any of these main topic pulldown menus, one branches into sections of the website geared towards the Atmosphere Continuity Products (such as CLDPROP_L2, which is the input to L3 COSP (CLDPROPCOSP_L3).

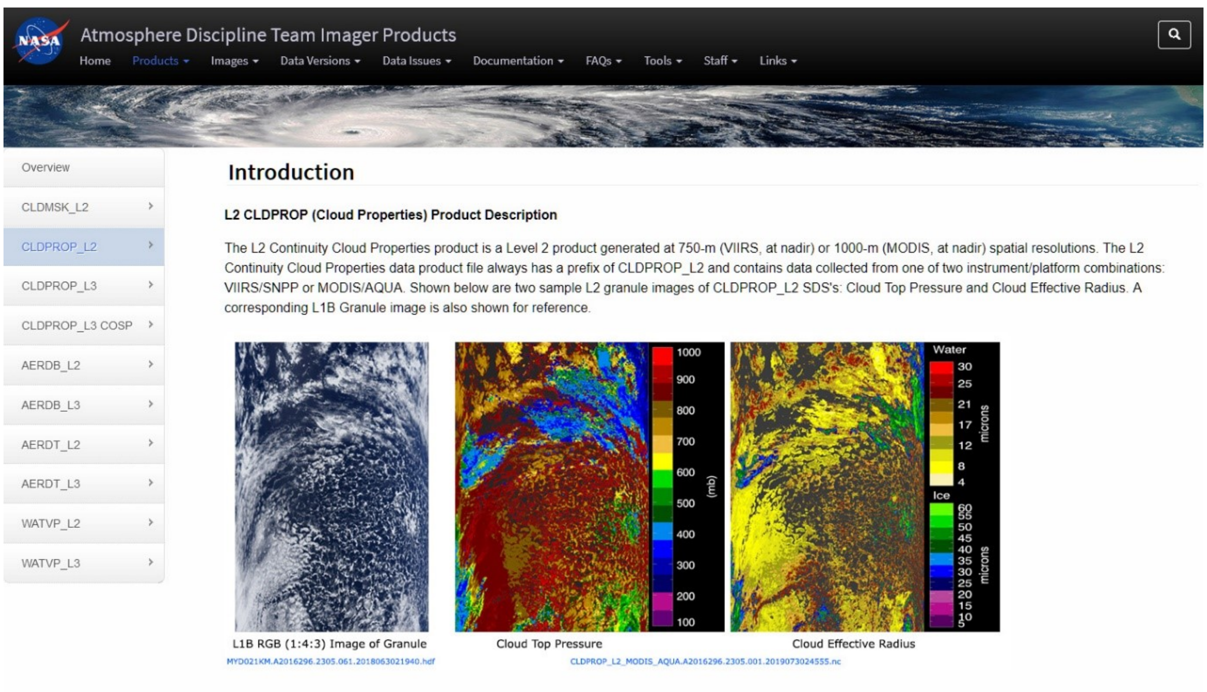


Figure 19. A capture of the Products > Continuity > CLDPROP_L2 page. A pull-down sub menu on the left-hand side, allows visitors to view more sub pages related to the CLDPROP Cloud Product

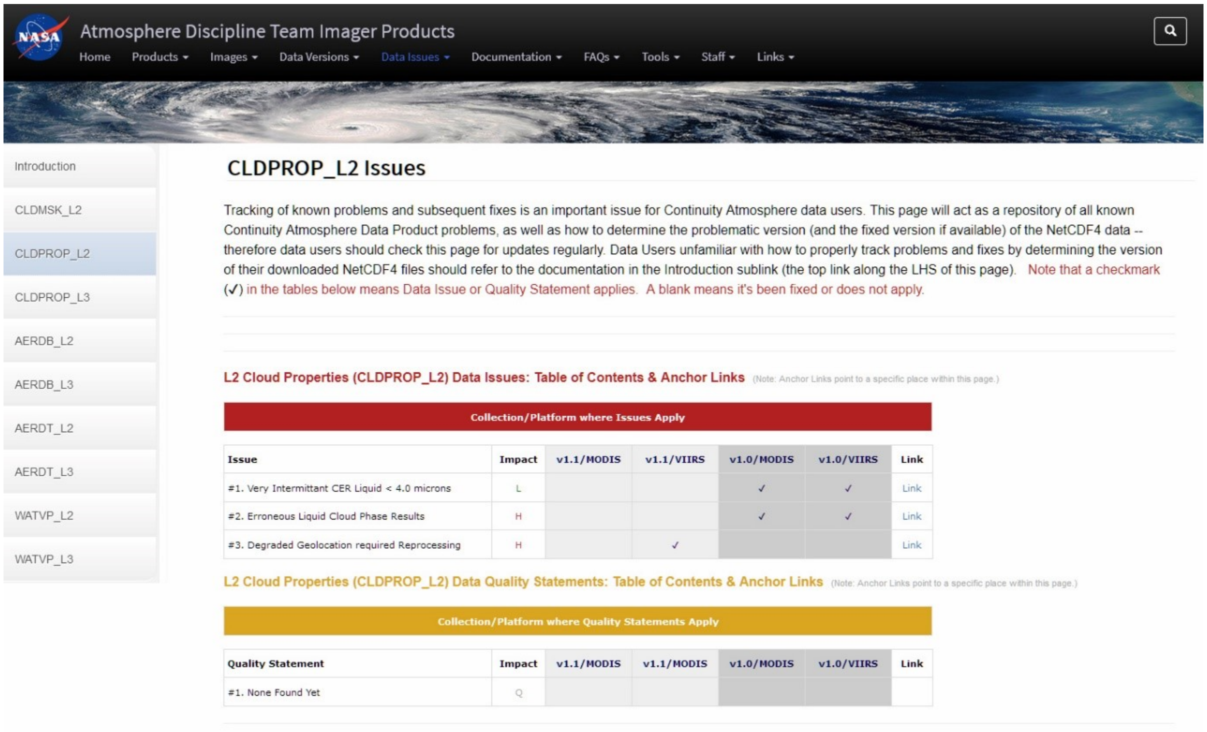


Figure 20. A capture of the Data Issues > Continuity > CLDPROP_L2 page. As problems or issues are discovered in the CLDPROP_L2 data, they are posted here to alert the user community. Also provided are fixes (where possible) as well as a graphical *Impact Meter* to give a quick overview as to whether an issue has Low, Medium, or High Impact. A table of contents with jump-links to the relevant part of the page below is included at the top of the page for easy navigation.

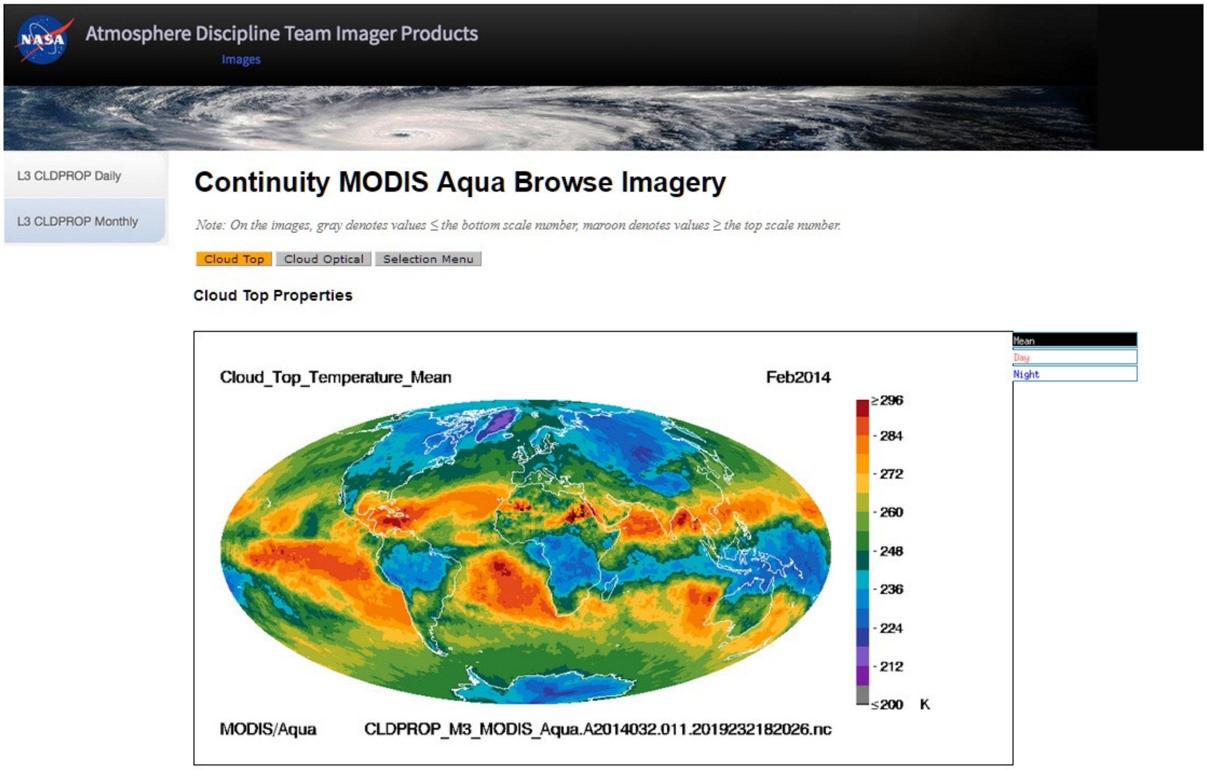


Figure 21. A capture of the Images > Continuity > L3 CLDPROP Monthly page. Here, users can find browse images for L3 CLDPROP_D3 and CLDPROP_M3 Products. Note that the images on this page are separately provided for MODIS Aqua and VIIRS SNPP.

For L3 **Daily** products, images are only available in the native equal-angle lat-lon grid. For L3 **Monthly** products, images can be projected in both the native lat-lon grid, as well as an equal-area Hammer-Aitoff grid.

10.0. Interpretation of Data: Frequently Asked Questions

Since the release of L3 Continuity Atmosphere data, users have asked the L3 development team and associated Atmosphere staff a number of questions. This section summarizes the most commonly asked questions and their answers.

10.1. What is the difference between Cloud Fraction (i) from Cloud Mask, and (ii) from Cloud Optical Property Retrievals?

In order for users to appreciate the meaning of the two basic cloud fractions in L3 COSP products, they should understand how cloud fraction is defined and computed in each L3 cloud fraction parameter. Most simply, L3 cloud fraction is the number of cloudy L2 pixels (that fit pre-determined criteria, such as daytime-only or liquid-water-clouds-only) divided by the total number of non-fill L2 pixels within a 1×1° L3 grid box. The key detail is how each parameter defines a pixel as "cloudy" and what domain of pixels is used to compute the denominator. L3 COSP files have two primary types of cloud fractions.

10.1.1. Cloud Fraction from Cloud Mask

The L3 cloud fraction that garners the most interest from Atmosphere data users is Cloud Fraction derived directly from the Cloud Mask. These L3 COSP cloud mask cloud fractions have the Group names:

- Cloud_Fraction
- Cloud_Fraction_Day
- Cloud_Fraction_Night

The first parameter listed above contains both day and night retrievals, the second parameter contains daytime-only retrievals (solar zenith angle less than or equal to 85°), and the third parameter contains nighttime-only retrievals.

The cloud mask cloud fraction is computed in L3 using the Cloud Mask Status Flag and the Cloud Mask Cloudiness Flag, both parts of the Quality_Assurance SDS in L2 COSP. See

Table 11.

L2 QA Flag	Flag Value	Meaning
Cloud Mask Status Flag	0 1	Undetermined Determined
Cloud Mask Cloudiness Flag	0 1 2 3	Confident Cloudy (or Fill if Status Flag = 0) Probably Cloudy Probably Clear Confident Clear

Table 11. Two L2 Cloud Mask Flags used to compute the L3 Cloud Mask Cloud Fraction.

In the computation of the L3 cloud mask cloud fraction, the first two flags are assigned 100% cloudy and the last two flags 100% clear. Then in each 1x1 degree L3 grid, the mean L2 cloudiness is computed based on those results.

10.1.2. Cloud Fraction from Cloud Optical Property Retrievals

The second-most utilized L3 cloud fraction is the one derived from the Cloud Optical Properties retrieval. All optical property cloud fractions are computed for **daytime-only scenes** (solar zenith angle ≤ 80°).

These L3 COSP cloud optical property cloud fractions have the Group names:

- Cloud_ Retrieval_Fraction_Liquid
- Cloud_ Retrieval_Fraction_Ice
- Cloud_ Retrieval_Fraction_Undetermined
- Cloud_Retrieval_Fraction_Combined

The first parameter represents the cloud fraction for the liquid water cloud phase only; the second, ice phase clouds only; the third, undetermined phase clouds only; and the fourth, combined (all) cloud phase clouds.

The optical property cloud fraction is computed in L3 using the Primary Cloud Retrieval Phase Flag and the Primary Cloud Retrieval Outcome Flag, both parts of the Quality_Assurance SDS in L2 COSP. See Table 12.

Every sampled L2 grid point that has a Primary Cloud Retrieval Outcome Flag = 1 (Retrieval Successful) and a Primary Cloud Retrieval Phase Flag of 2 (Liquid Water Cloud), 3 (Ice Cloud), or 4 (Undetermined Phase Cloud) are taken as 100% cloudy for the cloud phase category in question. Then in each 1x1 degree L3 grid, the mean L2 cloudiness is computed based on those results.

L2 QA Flag	Flag Value	Meaning
Primary Cloud Retrieval Phase Flag	0	Cloud Mask Undetermined (Missing or Fill)
	1	Not Processed (Typically Clear)
	2	Liquid Water Cloud
	3	Ice Cloud
	4	Undetermined Phase Cloud
Primary Cloud Retrieval Outcome Flag	0	Retrieval Not Attempted or Unsuccessful
	1	Retrieval Successful

Table 12. Two L2 Quality Assurance Flags used to compute the L3 Cloud Optical Properties Cloud Fraction.

10.1.3. Formula to recover the total number of cloudy (or true) pixels in L3 COSP

To retrieve the numerator of the cloud fraction, that is, the number of cloudy (or true) pixels (the fraction numerator) in L3 COSP fraction groups, simply multiply the Pixel_Counts by the Mean (Fraction) in the particular cloud fraction group under consideration.

10.2. What is the Cloud Optical Property Retrieval "Flavor" or "Type" used in L3 COSP?

L3 COSP data users should keep in mind that the Cloud Optical Properties (COP) retrieval algorithm has 4 different flavors or types. They include: COP Retrievals based on 2.1 micron radiance data, retrieval based on 1.6 micron radiance data, retrievals based on 3.7 micron radiance data, and retrievals based on 1.6–2.1 micron radiance data. For L3 COSP, only one of these flavors is used: retrievals based on 3.7 micron radiance data. The reason for this is the COSP model uses the *Look Up Tables* (LUTs) for 3.7 micron in the code.

10.3. What is the meaning of Undetermined and Total (Combined) Cloud Phases?

The undetermined cloud phase means the cloud optical properties retrieval algorithm could not make a determination of the cloud phase (liquid water or ice). This may have been caused by viewing anomalies in the retrieval (sunglint), contamination of the scene by aerosol, or a multi-layer cloud with mixed phases (e.g., thin cirrus overlying liquid water clouds). For these undetermined retrievals the liquid water libraries are used in the cloud optical properties retrievals, but the retrievals are considered to be of lower confidence (and quality) than those that are placed in one of the other primary phase categories (liquid water and ice). The total or combined phase is simply a combination of all cloud phase categories: liquid water, ice, and undetermined.

L3 COSP (MCD06COSP) data users should remember that there is no separate aggregation (Groups) of Undetermined Phase Clouds, however those Undetermined Phase Clouds are included in the Total or Combined Cloud Phase Groups.

10.4. What is the meaning of Partly Cloudy (PCL) Cloud Optical Property parameters?

L3 COSP files contain one PCL (Partly Cloudy) Cloud Optical Property Group or Parameter, which has the string "_PCL" in the Group name. These are slightly less reliable than the regular cloudy retrievals, which are used in all other Groups in the L3 COSP file -- therefore, this PCL Retrieval data was separated into a stand-alone Group so that users could decide either to mix them in with the regular retrievals or exclude them.

10.5. What is the meaning of Low, Mid, & High Cloud aggregations in Cloud Mask Fraction Groups?

The L3 COSP Product contains a Cloud Mask Fraction Group, which is a Cloud Fraction based on the Cloud Mask. This variable is for daytime only and for all pressure levels (total column):

- Cloud_Mask_Fraction (daytime only, all pressure levels)

Next, there are aggregations of that same data for Low, Mid, and High Clouds. The definitions of these aggregations are based on Cloud Top Pressure data. Those aggregations are defined as follows

- Cloud_Mask_Fraction_Low (daytime only, CTP $\geq$ 680 hPa)
- Cloud_Mask_Fraction_Mid (daytime only, 680 hPa $>$ CTP $\geq$ 440 hPa)
- Cloud_Mask_Fraction_High (daytime only, CTP $<$ 440 hPa)

10.6. Why do Joint Histogram bin boundaries sometimes exceed the valid range of data?

L3 COSP data users may notice that some of the Joint Histogram bin boundaries exceed the valid range of the input MODIS data. This occurs because the COSP model and other climate models have certain standardized histogram bin boundaries that are required as input into models. In these cases, the valid range of the data is ignored and joint histograms default to those standardized bin boundaries.

For example, in Cloud Top Pressure, the L3 COSP upper Joint Histogram bin boundary is set to 10,000 hPa or mb. This greatly exceeds real-world values or the valid range of the L2 MODIS input data, which maxes out at 1,100 hPa or mb.

Another example is from Liquid Water Cloud Particle Size (a.k.a. Cloud Effective Radius for Liquid Water Clouds), where the L2 MODIS input data has a valid range of 4 to 30 microns, however the L3 COSP Joint Histogram ranges from 0 to 30. Similarly for Ice Water Cloud Particle Size, the L2 MODIS input data has a valid range of 6 to 60 microns, however the L3 COSP Joint Histogram ranges from 0 to 90 microns.

A final example is from Cloud Optical Thickness, where the L2 MODIS input data has a valid range of 0.01 to 150.0, however the L3 COSP Joint Histogram goes from 0 to 10,000.

The following explanation was offered to account for the difference between the Joint Histogram's bin range and L2 MODIS data's valid range: One can see the boundaries used by the COSP model (and also with ISCCP) in this online reference:

https://github.com/CFMIP/COSPv2.0/blob/master/src/cosp_config.F90

All units are in MKS (meters, kilograms, seconds) except pressure is in hPa/mb instead of Pa:

```
tau_binBounds = (/0.0, 0.3, 1.3, 3.6, 9.4, 23., 60., 10000./)
pres_binBounds = (/0., 180., 310., 440., 560., 680., 800., 10000./)
reffLIQ_binBounds = (/0., 8e-6, 1.0e-5, 1.3e-5, 1.5e-5, 2.0e-5, 3.0e-5/)
reffICE_binBounds = (/0., 1.0e-5, 2.0e-5, 3.0e-5, 4.0e-5, 6.0e-5, 9.0e-5/)
```

Given that the original source information is from MODIS, an argument exists to change the particle size boundaries to match the valid range of MODIS data; but the consensus views it as more important to have the boundaries in the L3 COSP data match what the COSP model reports. We may see these bin boundaries revised in a future revision.

10.7. What is the best way to display or visualize 2D joint histogram data?

Common ways to display Joint Histogram data are (i) 3D lego plots, (ii) smoothed contour plots, and (iii) color-coded histogram bin plots.

Some graphics packages render Lego plots (Figure 22); however it’s often difficult to read the exact height of each lego block, and some (or most) viewing orientations may cause some blocks to remain hidden behind larger blocks in front of them.

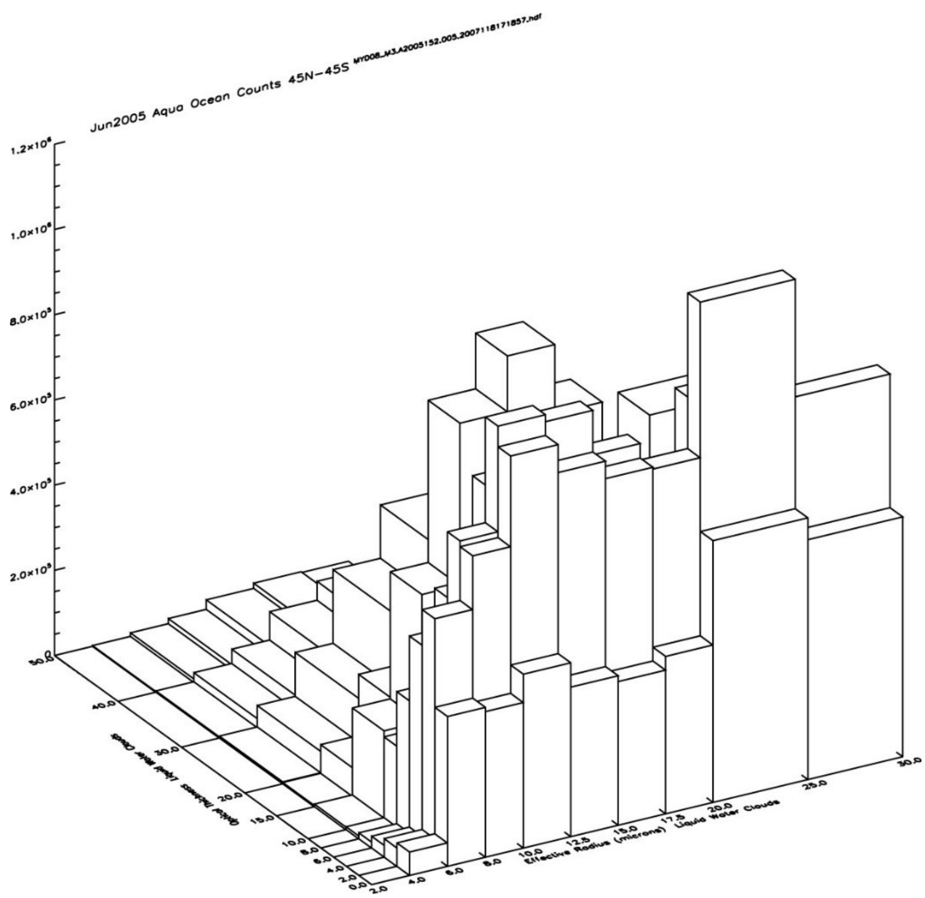


Figure 22. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a “3D lego plot” with post-

processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The height of each Lego bar represents the number of counts in each bin. Orienting all bins to render lego plots visible is often difficult to impossible.

Smoothed contour plots (Figure 23) are useful as they allow quick visual interpretation of data (without an intimate knowledge of the color bar scale) and therefore lend themselves well to time-series animations, where the time to view each joint histogram movie frame is short. However, smoothing options can be difficult to fine-tune, and the result is always a plot that shows a distorted (smoothed) view of the actual data.

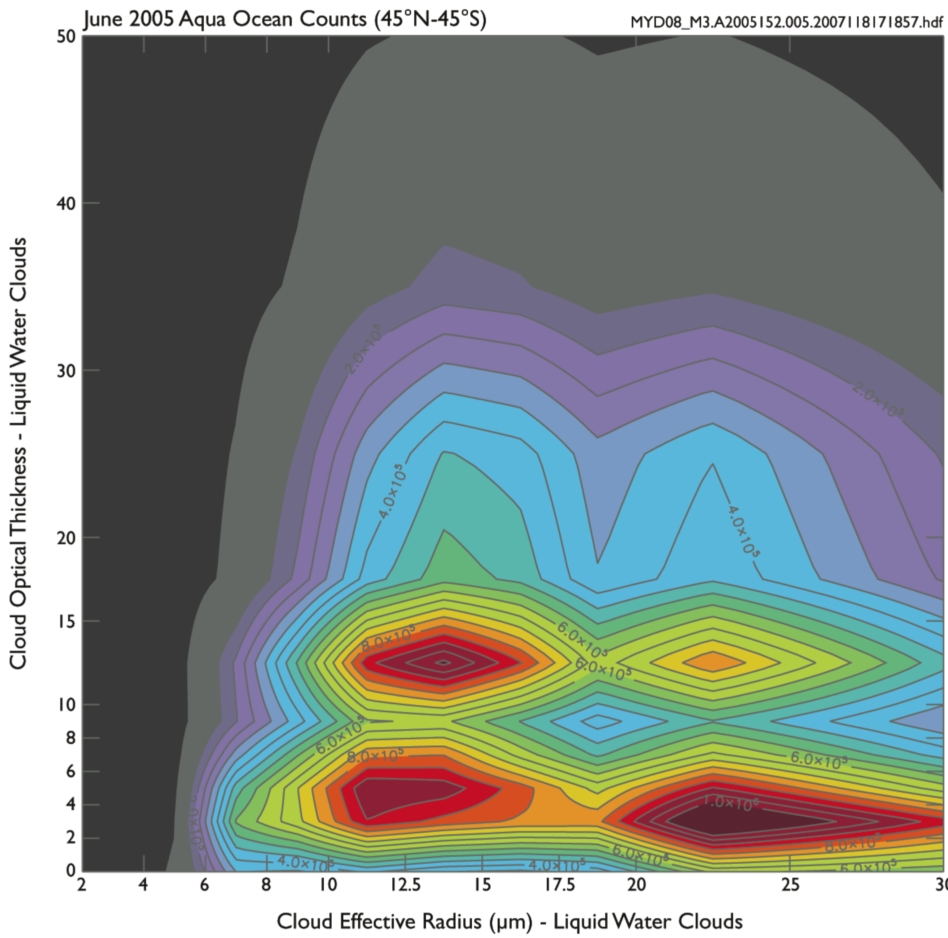


Figure 23. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a "colored contour plot" with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The contour colors represent the number of counts in each bin (low is grey, high is red). Contour plots show a distorted (smoothed) view of the data stored in the joint histogram.

The third option, color-coded histogram bin plots (Figure 24), work best in most cases and have fewer drawbacks; however, some graphics packages cannot produce these plots without expert knowledge of the language and some user programming. The pros of this final method are there is no distortion (smoothing) of data in the x-y plane (as is the case with smoothed contour plots) and all cells (bins) are viewable without any visual obstruction (as is the case with lego plots). Figures 17, 18, and 19 show identical MODIS L3 joint histogram counts data plotted using these three described techniques.

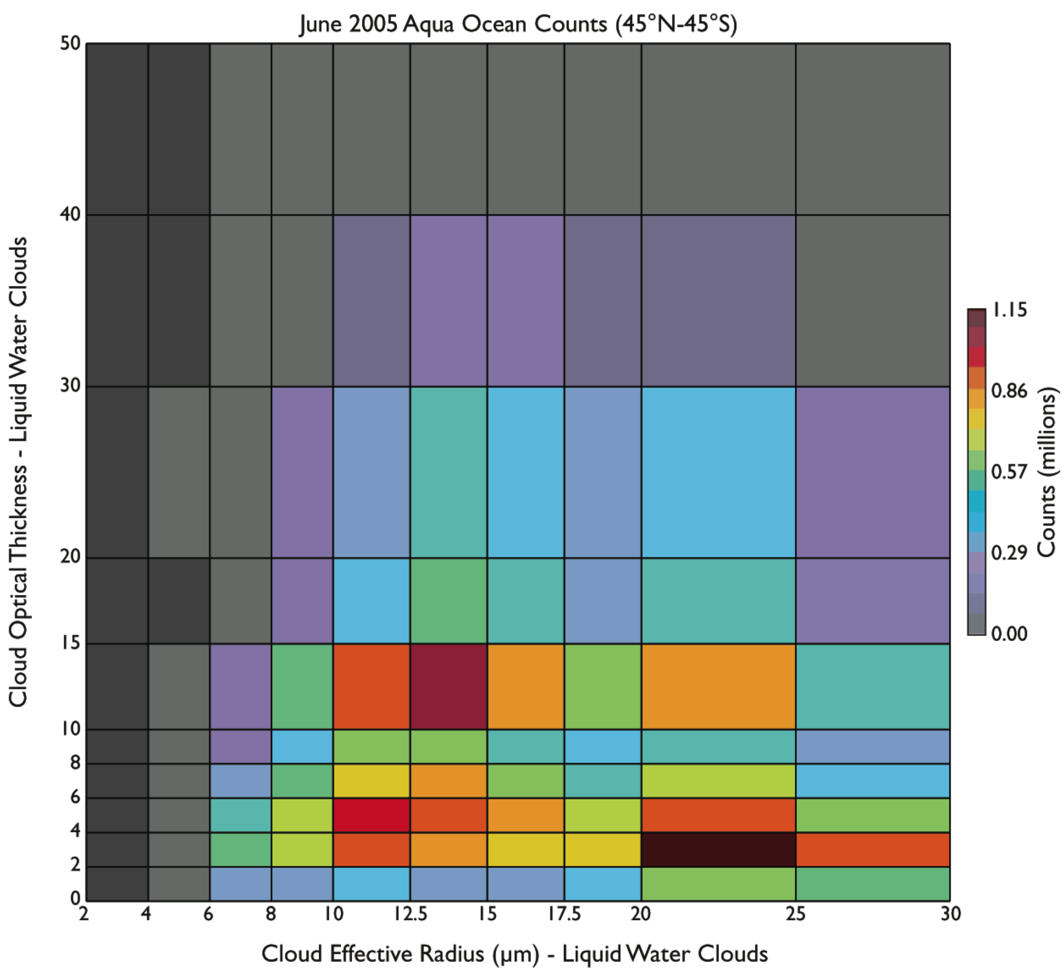


Figure 24. A June 2005 MYD08_M3 Counts Joint Histogram of cloud optical thickness (y-axis) vs. cloud effective radius (x-axis) for liquid water clouds displayed as a "colored histogram bin plot" with post-processing to limit the data to ocean-only L3 grid cells that range from 45°N to 45°S. The top bin of cloud optical thickness from 50 to 100 was chopped off. The bin colors represent the number of counts in each bin (low is grey, high is red).

For optimal display, it's best to have the graphics package print tick marks and labels at the exact histogram bin boundaries on both axes, so that the bin boundaries and sizes are clear to the viewer. These bin boundaries can be obtained from local attributes attached to each Joint Histogram variable (statistic) within the L3 COSP file. They are also provided in Appendix A of this User Guide for convenience.

Since all L3 joint histograms are stored as 4D arrays (Lat, Lon, Parameter1Bin, Parameter2Bin), MODIS data users can read (and view) a unique joint histogram for every L3 1° × 1° grid cell. This allows users to easily perform post-processing to narrow the application of the joint histogram to specific global regions to show more focused scientific results.

Users can apply a latitude/longitude screen to the 1°×1° gridded histograms so a newly computed (summed) joint histogram applies to a specified range of latitudes and longitudes only.

Users can also apply land-only or ocean-only masks when summing individual 1° × 1° gridded histograms so the newly summed joint histogram applies to land-only or ocean-only regions.

Occasionally, users may also find it advantageous to delete (remove) the highest bin along one or both data axes (which typically have a large data range and fewer counts) when displaying joint histograms in order to show more detail in other more scientifically relevant bins.

Users are reminded that they can plot "counts" (which is how the data are stored in the L3 HDF file) in each bin; or sometimes it is more useful to normalize the data by taking into account the bin sizes and then plot "normalized probability" in each bin. This normalized probability calculation is performed as follows:

$$\text{Normalized Probability} = (\text{bin\_box\_counts}) / (\text{bin\_box\_area} * \text{total\_counts}) \qquad (5)$$

Converting the counts to normalized probabilities removes the visual anomalies that occur when comparing bins of different sizes in joint histogram plots. Figure 25 shows how the representation in Figure 24 changes when going from raw counts to normalized probability (where an adjustment is made for bin sizes). Clearly, normalizing the data can really change one's perspective of the results.

Finally, some users ask, what do the Probability Density Function (PDF) numbers computed for each histogram bin in Figure 25 actually (physically) represent? If a normalized one-dimensional histogram plot means the area under the curve equals one; then a normalized joint histogram PDF plot means the volume under the surface equals one. (The surface being defined as z-axis heights or PDF values in each bin.) If one calculates the (area of bin) x (height of bin) or, alternatively (area of bin) × (PDF value of bin) then a "volume of the block" calculation is actually being performed. When one sums all the block volumes, one ends up with the volume under the surface, which for the normalized JPDF surface is 1.0 or 100%.

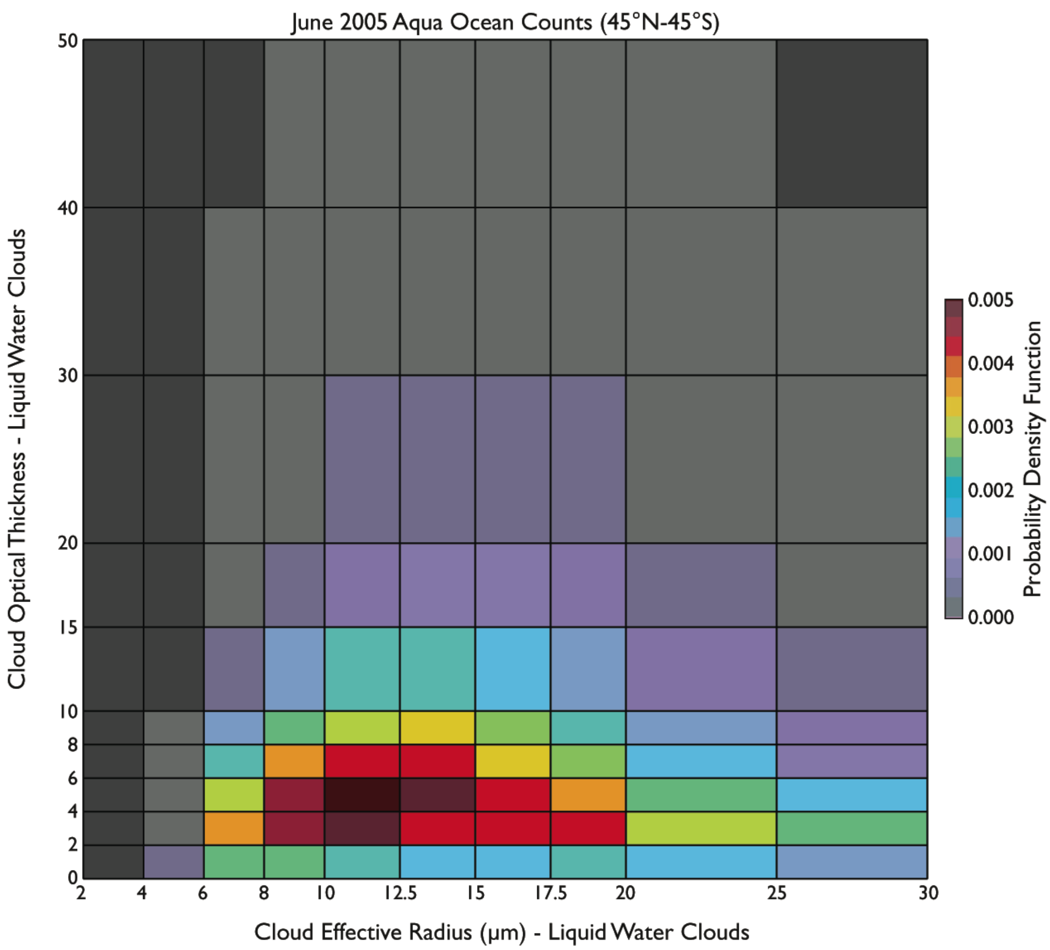


Figure 25. A June 2005 MYD08_M3 Normalized Probability Density Function (PDF) Joint Histogram of Cloud Optical Thickness (y-axis) vs. Cloud Effective Radius (x-axis) for Liquid Water Clouds displayed as a "colored histogram bin plot" with post-processing to limit the data to Ocean-only L3 grid cells that range from 45N to 45S. The top bin of Cloud Optical Thickness from 50 to 100 was removed. The bin colors represent the PDF in each bin (low probability is grey, high

probability is red).

For example, the peak PDF histogram bin value shown in Figure 25 is 0.005. If you take this number and multiply by the area of the bin (2.5 × 2.0 = 5.0), one gets a bin (block) volume of 0.025. This means that 2.5% of the total volume under the surface of the entire plot fell in this bin (block). You can also interpret this as the probability of any one pixel falling in this peak joint histogram bin box as 2.5%. If you perform this calculation for every bin (block), and sum them, you end up with 1.0 or 100%.

Note that for the joint histogram in Figures 17 through 20, the top bin (50 < Optical Thickness ≤ 100) was cut off in order to show (allow) more visual detail in the remaining bins. In order to get the proper summed value of 1.0 (100%), you need to include this deleted bin in the calculation.

11.0. References

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Appendix A:

Joint Histogram Statistics
&
Bin Boundaries

Joint Histogram Statistics and Bin Boundaries

Identical in Daily & Monthly Products

LIQUID WATER PHASE CLOUDS

Description:
Cloud Optical Thickness vs. Cloud Particle Size for Liquid Water Phase Clouds

Group (Parameter) Name:
Cloud_Optical_Thickness_Liquid

Variable (Statistic) Name:
JHisto_vs_Cloud_Particle_Size_Liquid

Bin Boundaries for Liquid Water Cloud Optical Thickness:
[0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 10000.0] (7 bins)
(Note Valid Range of MODIS Liquid Water COT Data is 0.01 to 150.0)

Bin Boundaries for Liquid Water Cloud Particle Size Radius:
[0, 8, 10, 13, 15, 20, 30] (6 bins)
(Note Valid Range of MODIS Liquid Water CPSR Data is 4.0 to 30.0)

ICE PHASE CLOUDS

Description:
Cloud Optical Thickness vs. Cloud Particle Size for Ice Phase Clouds

Group (Parameter) Name:
Cloud_Optical_Thickness_Ice

Variable (Statistic) Name:
JHisto_vs_Cloud_Particle_Size_Ice

Bin Boundaries for Ice Cloud Optical Thickness:
[0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 10000.0] (7 bins)
(Note Valid Range of MODIS Ice COT Data is 0.01 to 150.0)

Bin Boundaries for Ice Cloud Particle Size Radius:
[0, 10, 20, 30, 40, 60, 90] (6 bins)
(Note Valid Range of MODIS Ice CPSR Data is 6.0 to 60.0)

TOTAL (COMBINED) PHASE CLOUDS

Description:
Cloud Optical Thickness vs. Cloud Top Pressure for All Phase Clouds in fully Cloudy Scenes

Group (Parameter) Name:
Cloud_Optical_Thickness_Total

Variable (Statistic) Name:
JHisto_vs_Cloud_Top_Pressure

Bin Boundaries for All Phase Cloud Optical Thickness in fully Cloudy Scenes
[0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 10000.0] (7 bins)
(Note Valid Range of MODIS COT Data is 0.01 to 150.0)

Bin Boundaries for All Phase Cloud Top Pressure:
[0, 180, 310, 440, 560, 680, 800, 10000] (7 bins)
(Note Valid Range of MODIS CTP Data is 1.0 to 1100.0)

Description:
Cloud Optical Thickness vs. Cloud Top Pressure for All Phase Clouds in Partly Cloudy Scenes

Group (Parameter) Name:
Cloud_Optical_Thickness_PCL_Total

Variable (Statistic) Name:
JHisto_vs_Cloud_Top_Pressure

Bin Boundaries for All Phase Cloud Optical Thickness for Partly Cloudy Scenes
[0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 10000.0] (7 bins)
(Note Valid Range of MODIS COT PCL Data is 0.01 to 150.0)

Bin Boundaries for All Phase Cloud Top Pressure
[0, 180, 310, 440, 560, 680, 800, 10000] (7 bins)
(Note Valid Range of MODIS CTP Data is 1.0 to 1100.0)

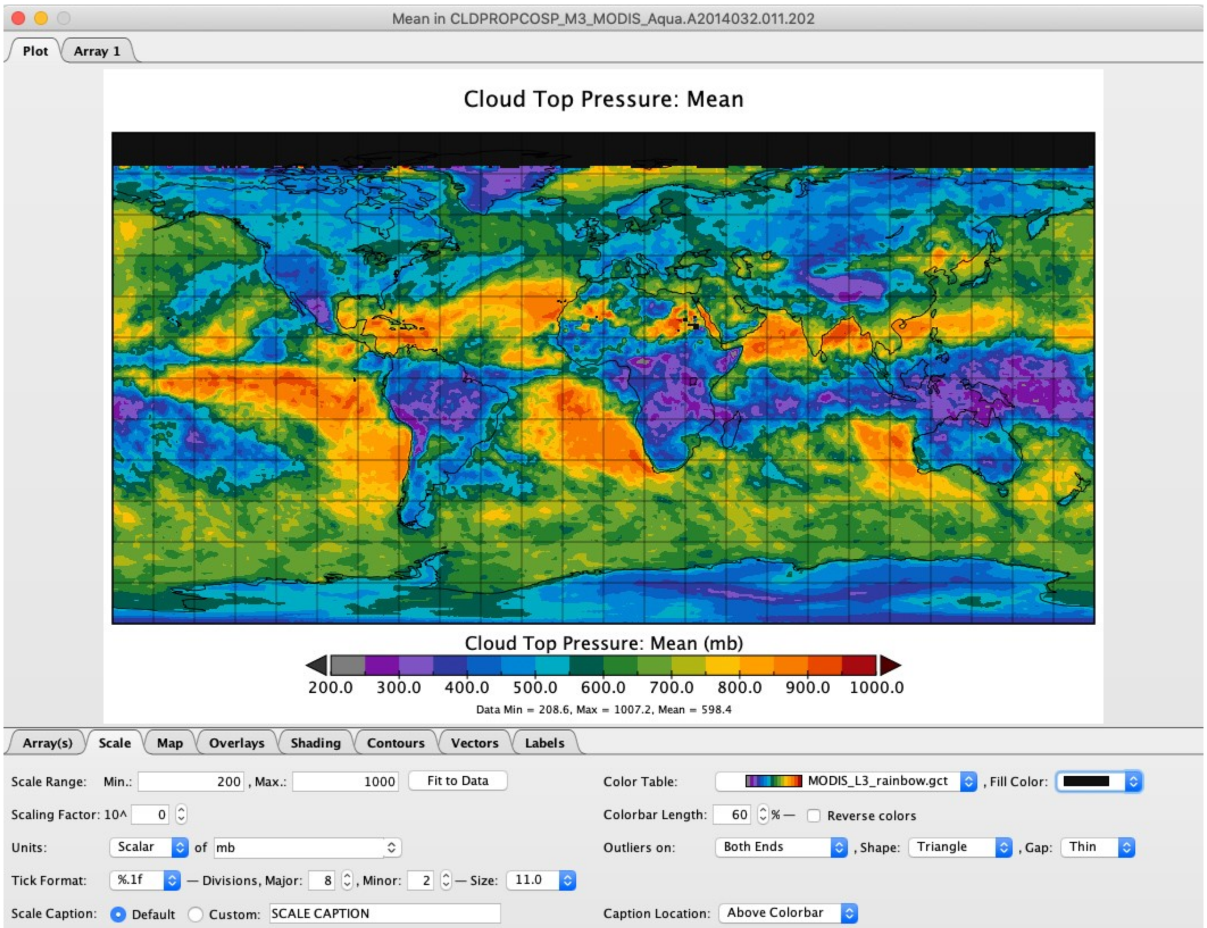
* Bin Boundary Handling: For L3 COSP Joint Histograms, the first through the penultimate histogram bin includes L2 pixel values equal to the lower bin boundary. The **last bin** includes L2 pixel values equal to both the lower and higher bin boundaries. This is slightly different from MODIS Standard MOD08, where the **first bin** included L2 pixel values equal to both the lower and higher bin boundaries.

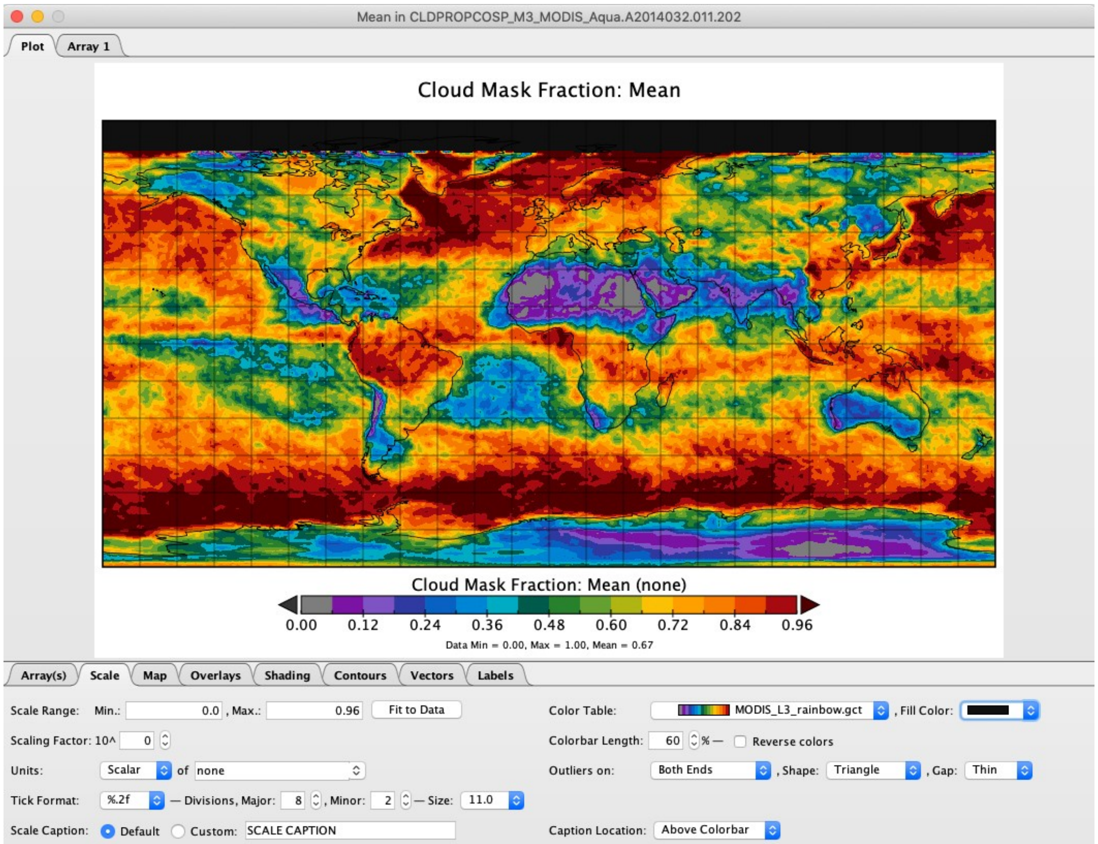
Appendix B:

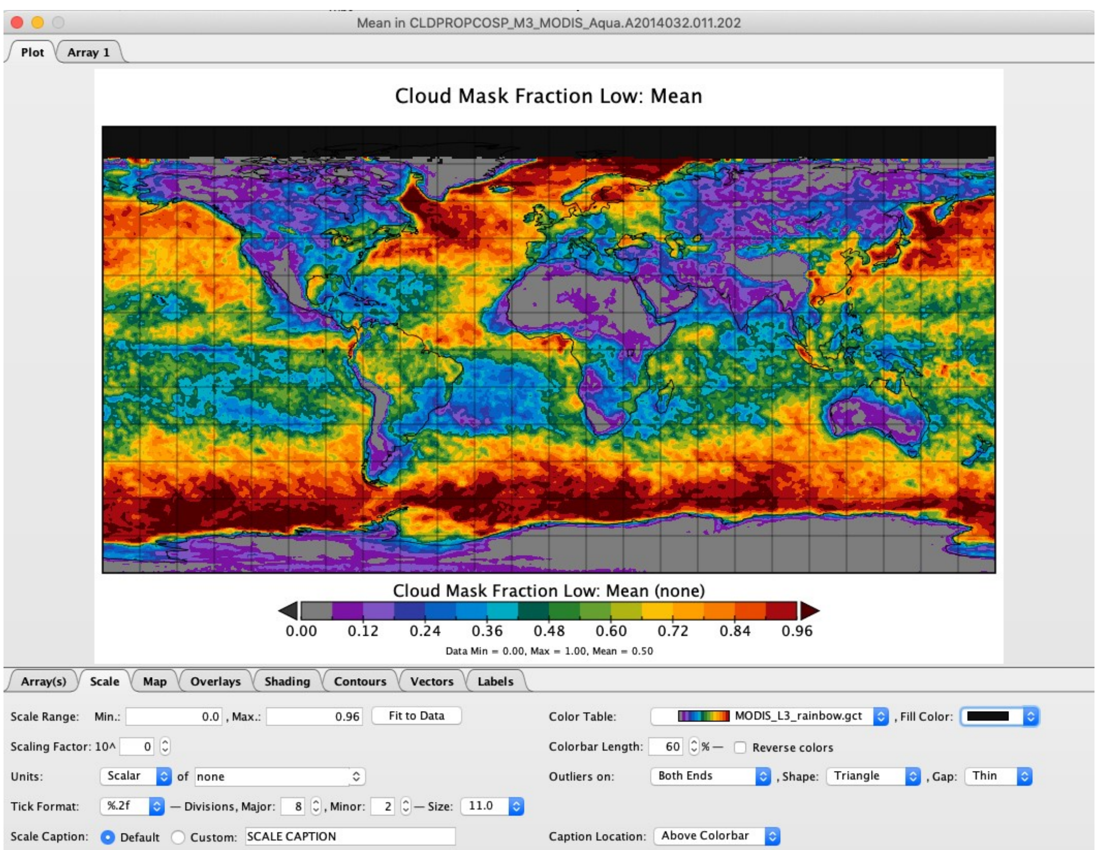
Mean Statistic Images from a Sample L3 CLDPROP COSP File

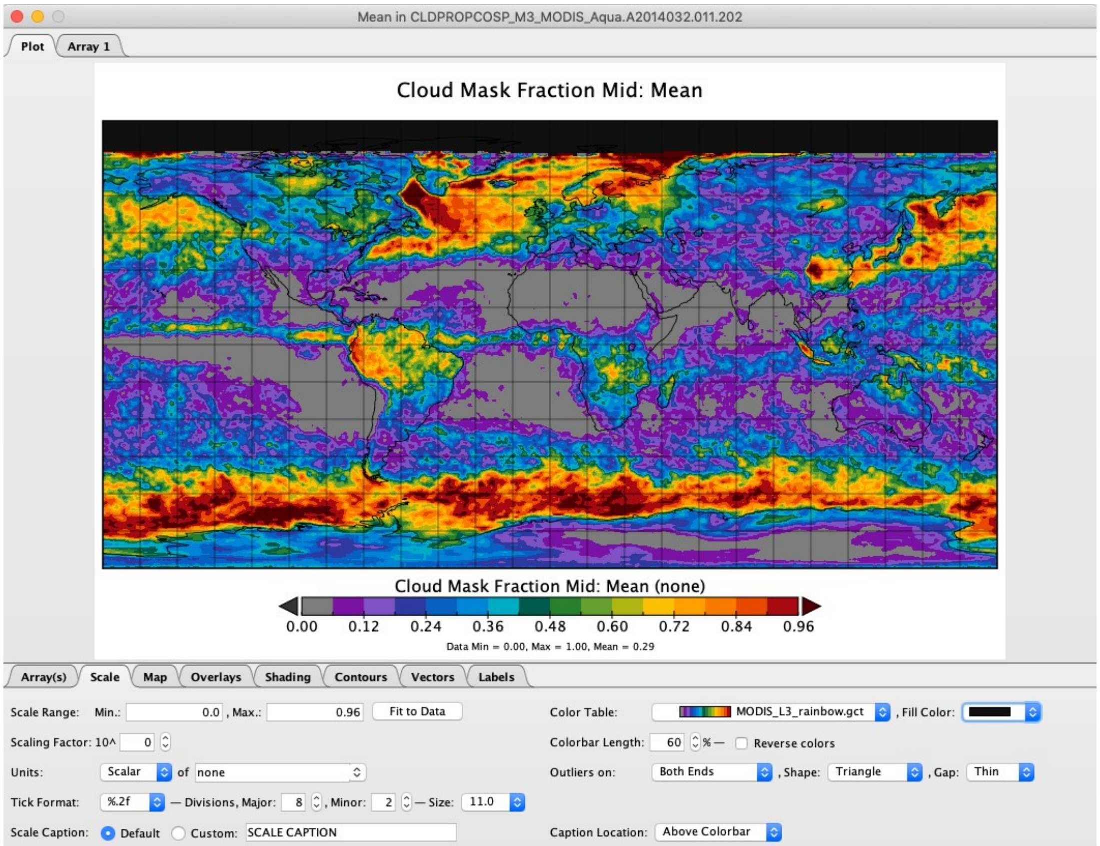
Continuity CLDPROP COSP for MODIS Aqua (Feb 2014)

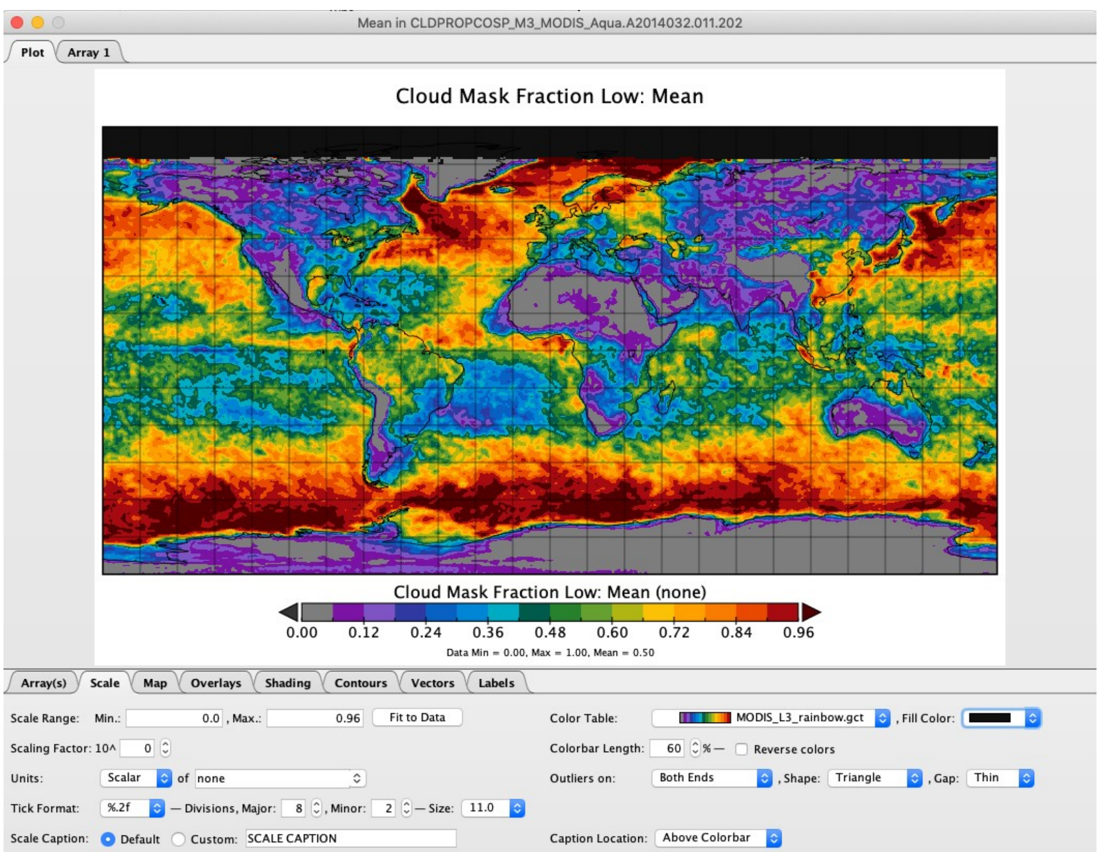
This Appendix shows mean statistic images for a number of groups in a L3 monthly CLDPROP COSP file. The file being displayed is the L3 monthly COSP file for February 2014. Images were produced using the Panoply tool with a custom high contrast rainbow color bar. The color bar scale range was optimized for each image to show enhanced detail.

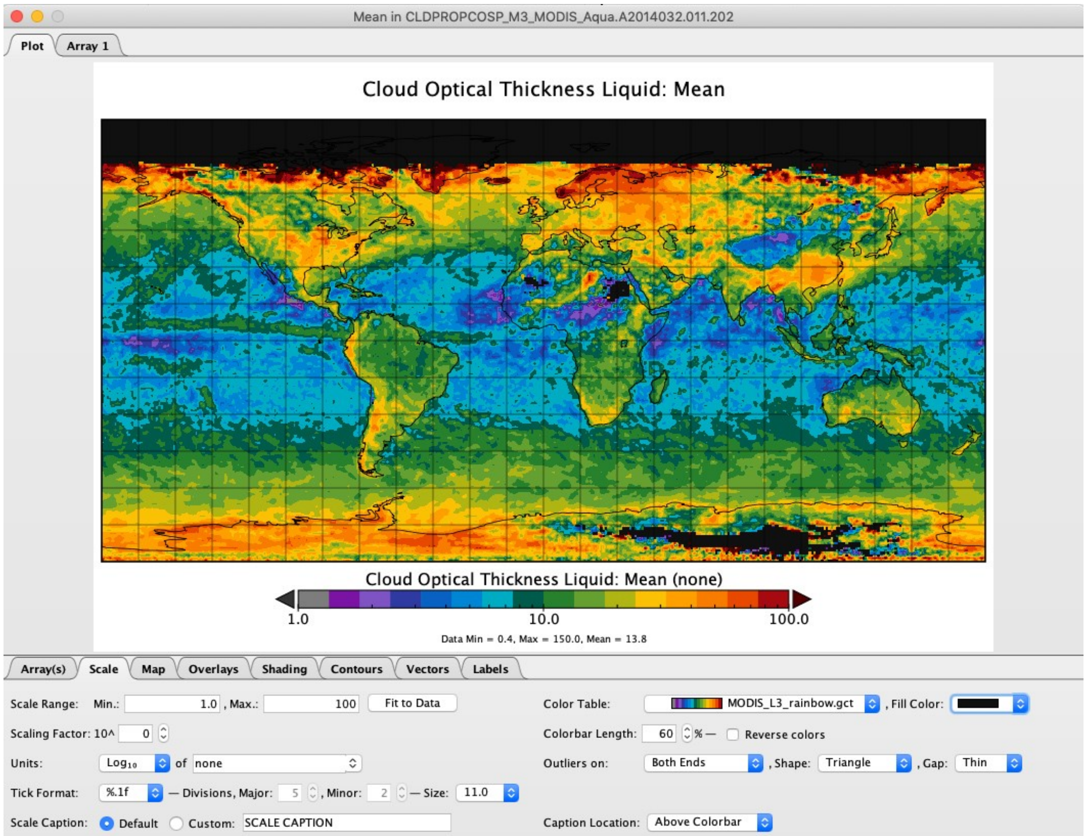


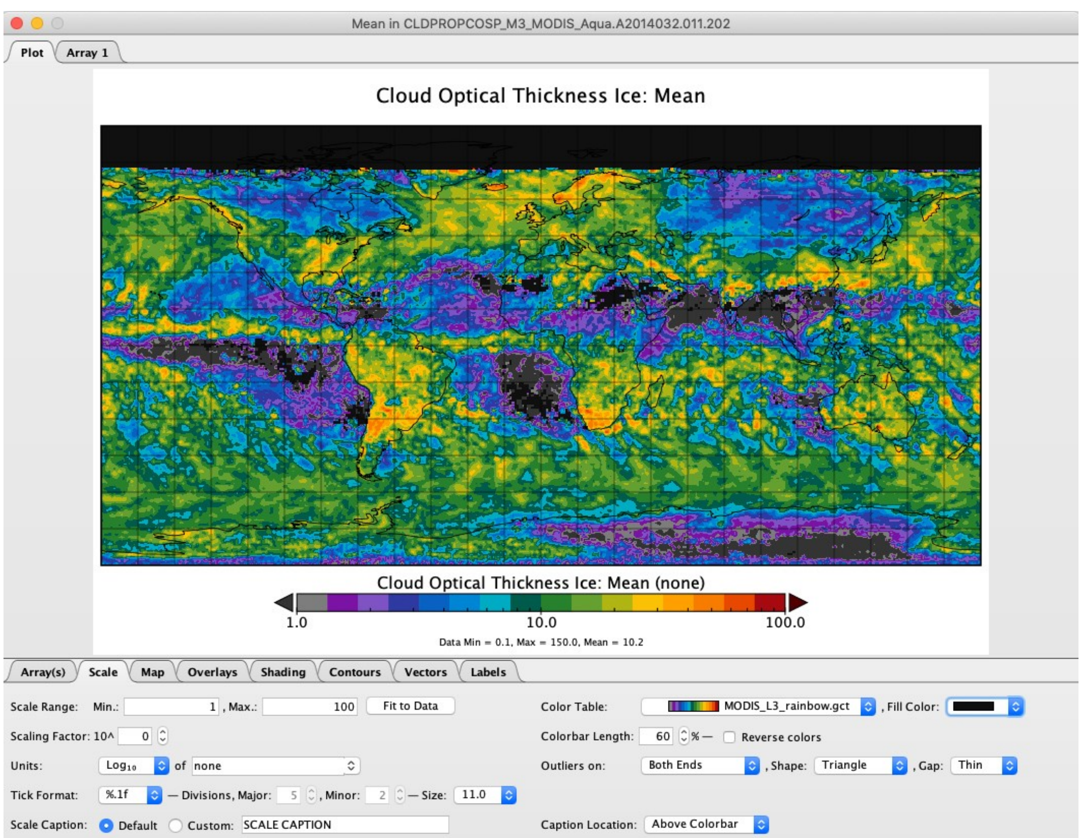

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Mask Fraction: Mean
Cloud Mask Fraction: Mean (none)
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84 0.96
Data Min = 0.00, Max = 1.00, Mean = 0.67
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0.0 , Max.: 0.96 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

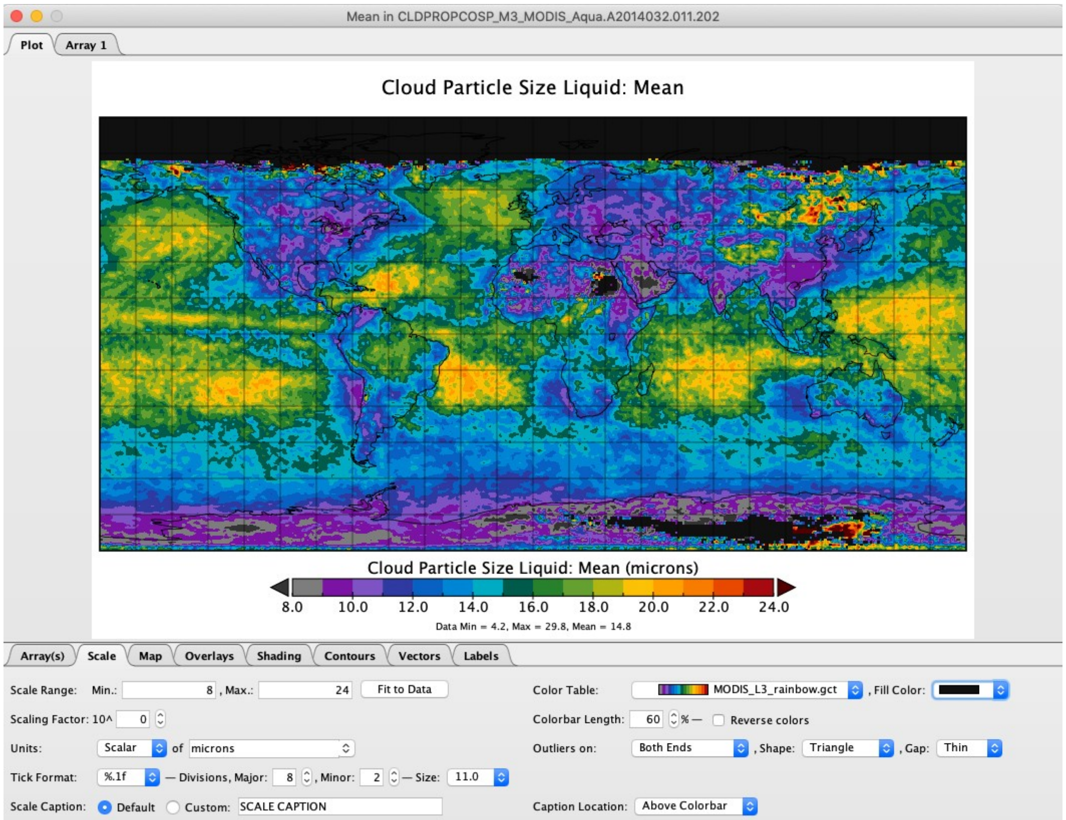

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Mask Fraction Low: Mean
Cloud Mask Fraction Low: Mean (none)
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84 0.96
Data Min = 0.00, Max = 1.00, Mean = 0.50
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0.0 , Max.: 0.96 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

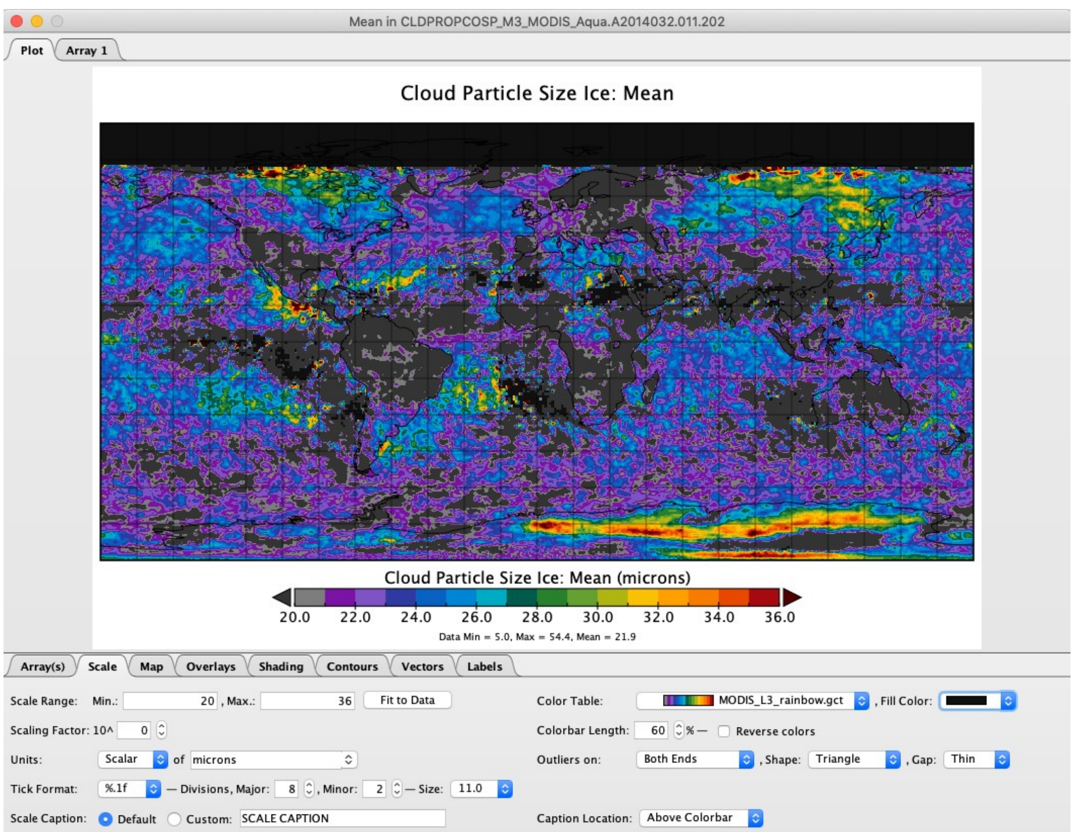

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Mask Fraction Mid: Mean
Cloud Mask Fraction Mid: Mean (none)
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84 0.96
Data Min = 0.00, Max = 1.00, Mean = 0.29
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0.0 , Max.: 0.96 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

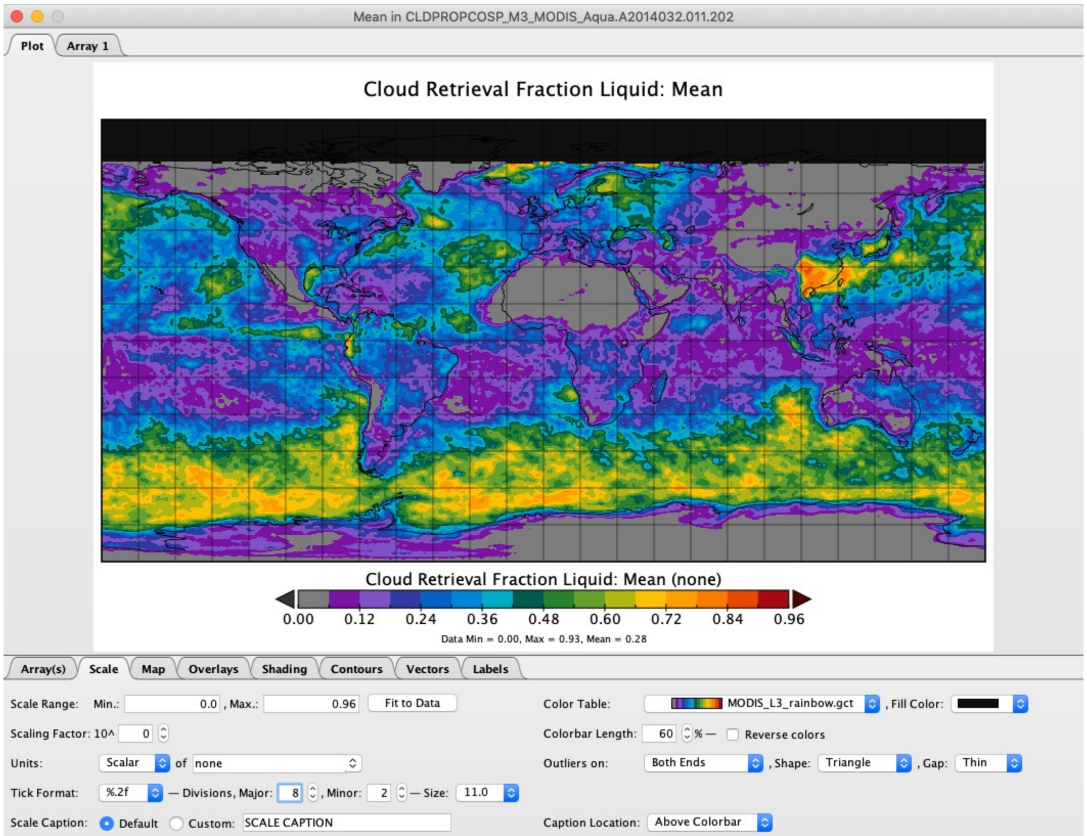

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Mask Fraction Low: Mean
Cloud Mask Fraction Low: Mean (none)
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84 0.96
Data Min = 0.00, Max = 1.00, Mean = 0.50
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0.0 , Max.: 0.96 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

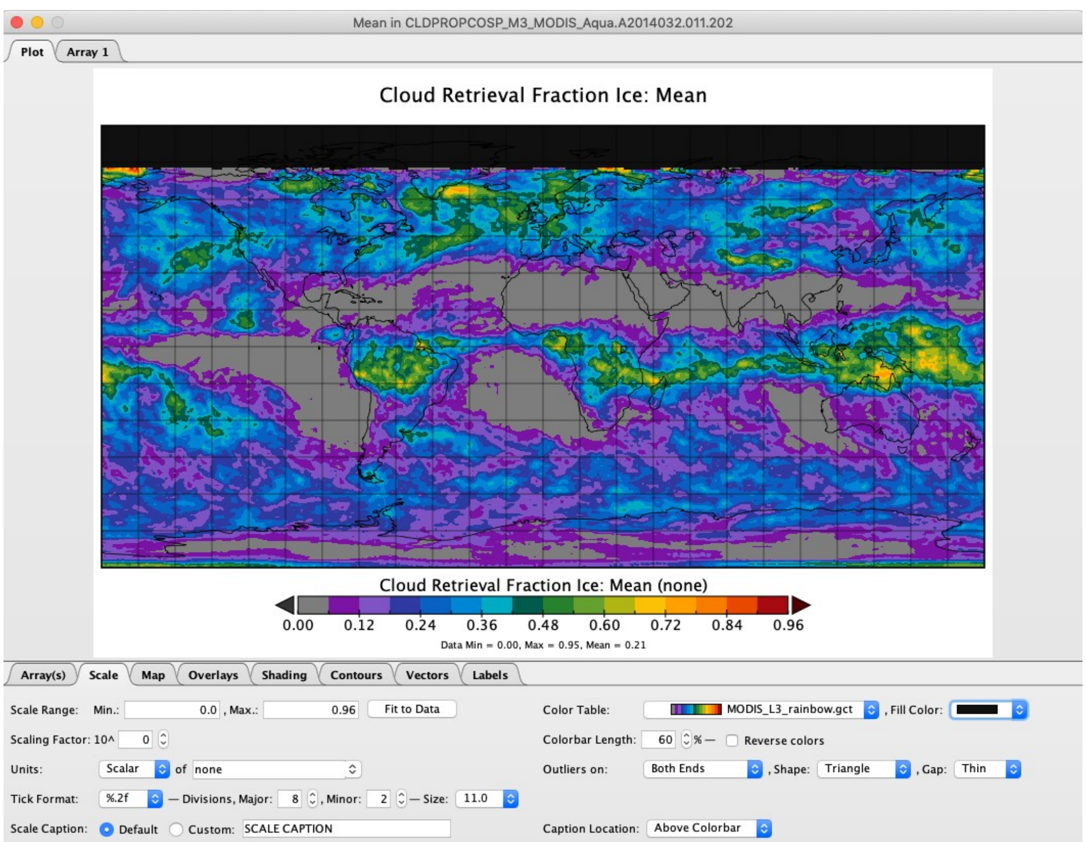

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Optical Thickness Liquid: Mean
Cloud Optical Thickness Liquid: Mean (none)
1.0
10.0
100.0
Data Min = 0.4, Max = 150.0, Mean = 13.8
Array(s)
Scale
Map
Overlays
Shading
Contours
Vectors
Labels
Scale Range: Min.: 1.0 , Max.: 100
Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Log10 of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.1f — Divisions, Major: 5 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

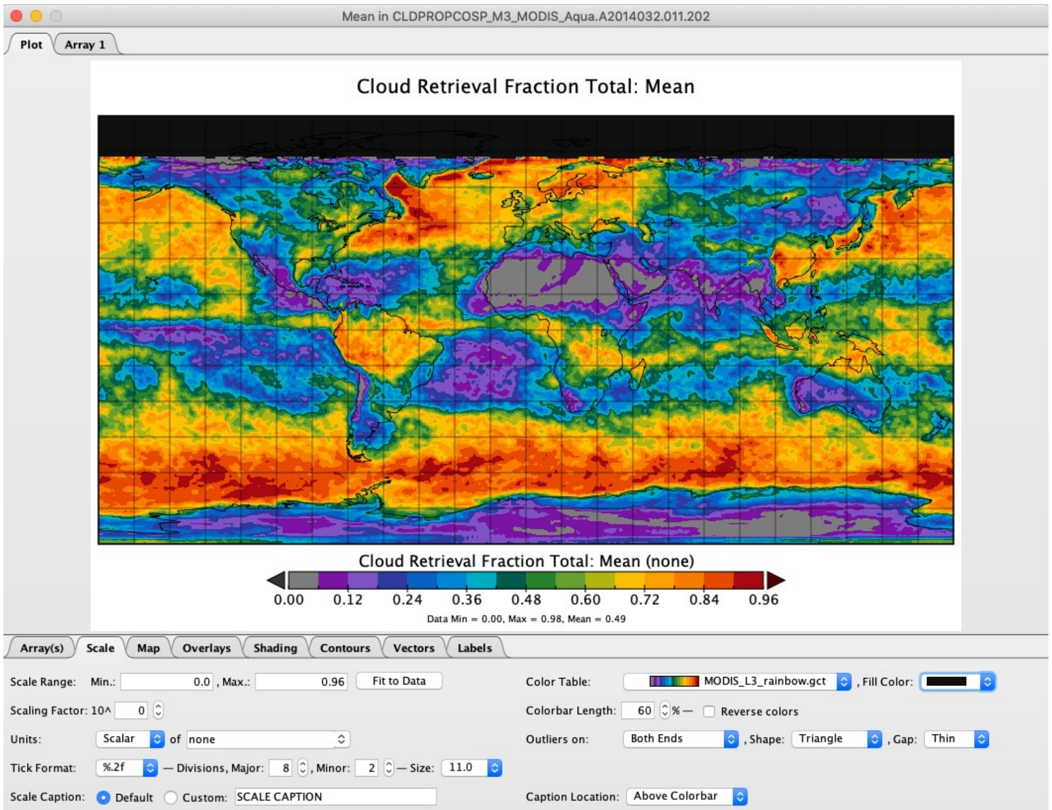

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Optical Thickness Ice: Mean
Cloud Optical Thickness Ice: Mean (none)
1.0
10.0
100.0
Data Min = 0.1, Max = 150.0, Mean = 10.2
Array(s)
Scale
Map
Overlays
Shading
Contours
Vectors
Labels
Scale Range: Min.: 1 , Max.: 100
Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Log10 of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.1f — Divisions, Major: 5 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar


Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Particle Size Liquid: Mean
Cloud Particle Size Liquid: Mean (microns)
8.0 10.0 12.0 14.0 16.0 18.0 20.0 22.0 24.0
Data Min = 4.2, Max = 29.8, Mean = 14.8
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 8 , Max.: 24 Fit to Data
Scaling Factor: 10^ 0
Units: Scalar of microns
Tick Format: %.1f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Colorbar Length: 60 % — Reverse colors
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Caption Location: Above Colorbar

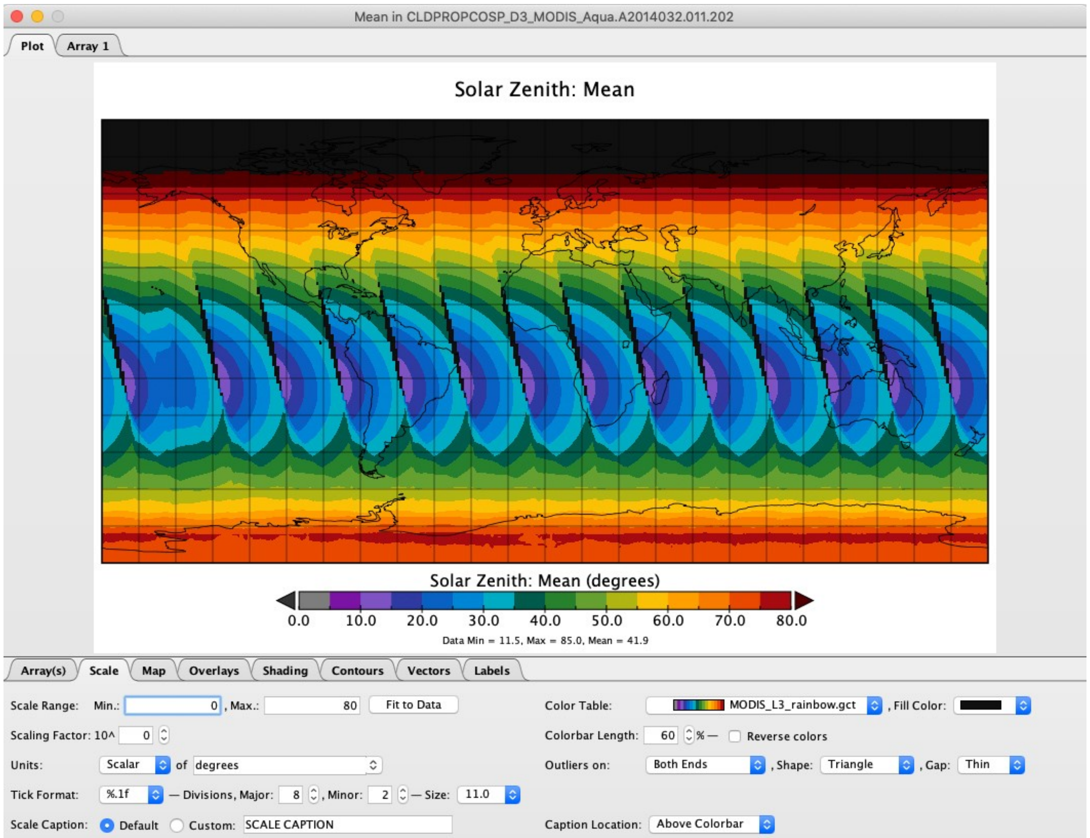

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Particle Size Ice: Mean
Cloud Particle Size Ice: Mean (microns)
20.0 22.0 24.0 26.0 28.0 30.0 32.0 34.0 36.0
Data Min = 5.0, Max = 54.4, Mean = 21.9
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 20 , Max.: 36 Fit to Data
Scaling Factor: 10^ 0
Units: Scalar of microns
Tick Format: %.1f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Colorbar Length: 60 % — Reverse colors
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Caption Location: Above Colorbar

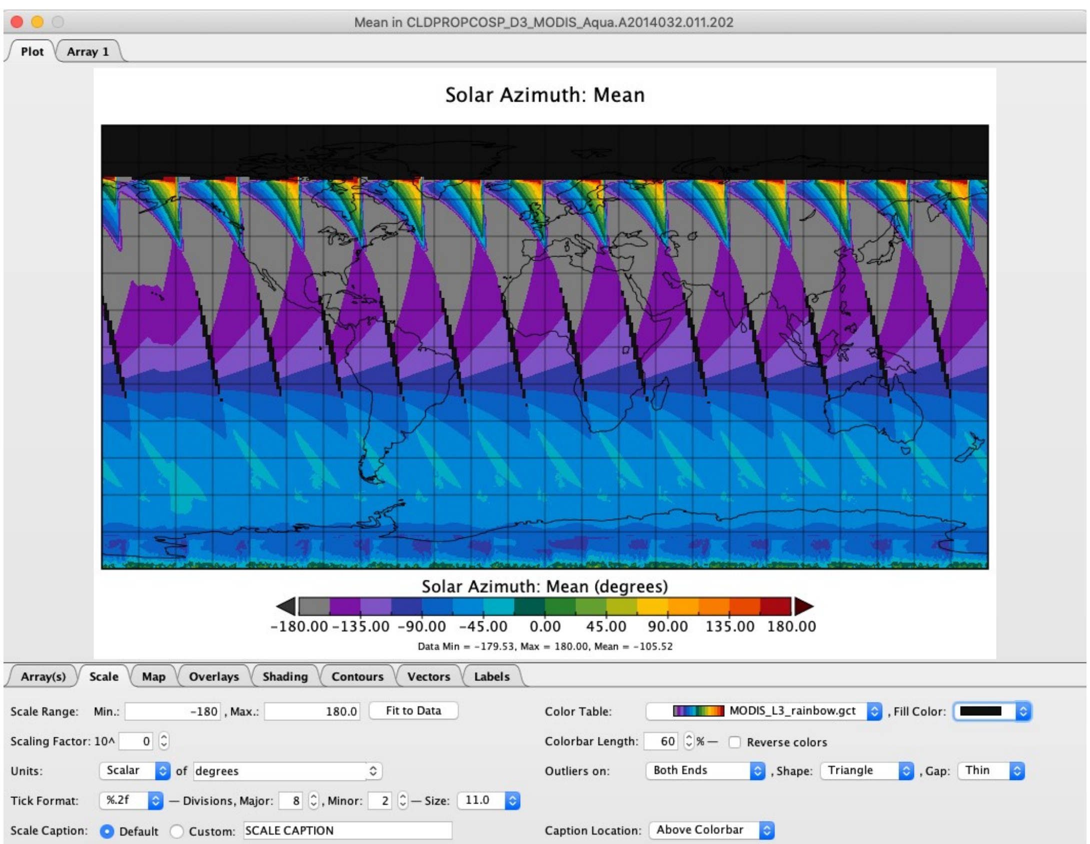

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Retrieval Fraction Liquid: Mean
Cloud Retrieval Fraction Liquid: Mean (none)
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84 0.96
Data Min = 0.00, Max = 0.93, Mean = 0.28
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0.0 , Max.: 0.96 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

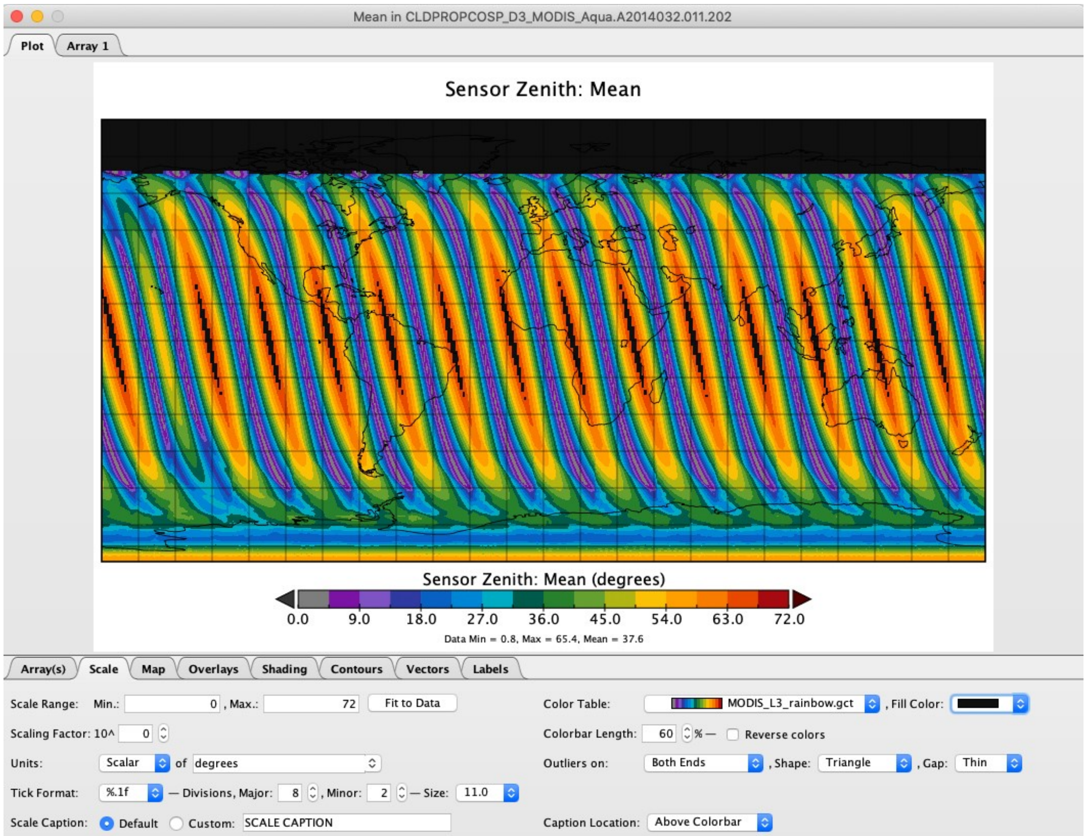

Mean in CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Cloud Retrieval Fraction Ice: Mean
Cloud Retrieval Fraction Ice: Mean (none)
0.00 0.12 0.24 0.36 0.48 0.60 0.72 0.84 0.96
Data Min = 0.00, Max = 0.95, Mean = 0.21
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0.0 , Max.: 0.96 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of none
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

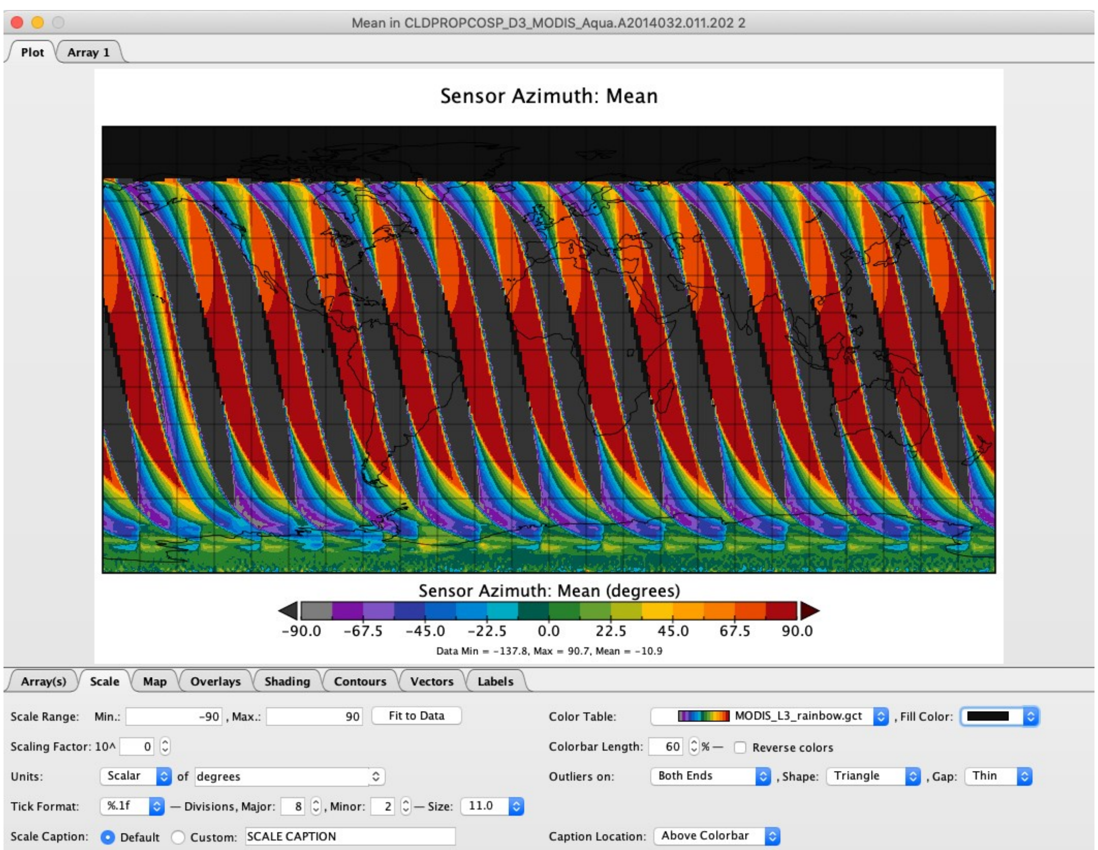


IMPORTANT NOTE: For the following 4 Solar and Sensor Angle images, the COSP file being visualized was switched to a Daily L3 COSP File for data collected on 1 Feb 2014. The Monthly COSP data, visualized in previous images, is too chaotic in the monthly-averaged Angle images to see well-behaved patterns that are easily understandable.


Mean in CLDPROPCOSP_D3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Solar Zenith: Mean
Solar Zenith: Mean (degrees)
0.0 10.0 20.0 30.0 40.0 50.0 60.0 70.0 80.0
Data Min = 11.5, Max = 85.0, Mean = 41.9
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: 0 , Max.: 80 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of degrees
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.1f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar


Mean in CLDPROPCOSP_D3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Solar Azimuth: Mean
Solar Azimuth: Mean (degrees)
-180.00 -135.00 -90.00 -45.00 0.00 45.00 90.00 135.00 180.00
Data Min = -179.53, Max = 180.00, Mean = -105.52
Array(s) Scale Map Overlays Shading Contours Vectors Labels
Scale Range: Min.: -180 , Max.: 180.0 Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of degrees
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.2f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar


Mean in CLDPROPCOSP_D3_MODIS_Aqua.A2014032.011.202
Plot
Array 1
Sensor Zenith: Mean
Sensor Zenith: Mean (degrees)
0.0
9.0
18.0
27.0
36.0
45.0
54.0
63.0
72.0
Data Min = 0.8, Max = 65.4, Mean = 37.6
Array(s)
Scale
Map
Overlays
Shading
Contours
Vectors
Labels
Scale Range: Min.: 0 , Max.: 72
Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of degrees
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.1f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar


Mean in CLDPROPCOSP_D3_MODIS_Aqua.A2014032.011.202 2
Plot
Array 1
Sensor Azimuth: Mean
Sensor Azimuth: Mean (degrees)
-90.0
-67.5
-45.0
-22.5
0.0
22.5
45.0
67.5
90.0
Data Min = -137.8, Max = 90.7, Mean = -10.9
Array(s)
Scale
Map
Overlays
Shading
Contours
Vectors
Labels
Scale Range: Min.: -90 , Max.: 90
Fit to Data
Color Table: MODIS_L3_rainbow.gct , Fill Color:
Scaling Factor: 10^ 0
Colorbar Length: 60 % — Reverse colors
Units: Scalar of degrees
Outliers on: Both Ends , Shape: Triangle , Gap: Thin
Tick Format: %.1f — Divisions, Major: 8 , Minor: 2 — Size: 11.0
Scale Caption: Default Custom: SCALE CAPTION
Caption Location: Above Colorbar

Appendix C:

CLDPROP COSP File Spec

Header Dump, Global Attributes, and Parameter Specification in a L3 CLDPROP COSP File

This Appendix provides users an idea of the kind and scope of information available at the top of any given NetCDF4 L3 CLDPROP COSP file.

netcdf CLDPROPCOSP_M3_MODIS_Aqua.A2014032.011.2020112203433 {

dimensions:
    latitude = 180 ;
    longitude = 360 ;
    histo_cloud_optical_thickness_liquid_7 = 7 ;
    jhisto_vs_cloud_particle_size_liquid_6 = 6 ;
    histo_cloud_optical_thickness_ice_7 = 7 ;
    jhisto_vs_cloud_particle_size_ice_6 = 6 ;
    histo_cloud_optical_thickness_total_7 = 7 ;
    jhisto_vs_cloud_top_pressure_7 = 7 ;
    histo_cloud_optical_thickness_pcl_total_7 = 7 ;

variables:
    double latitude(latitude) ;
        latitude:_FillValue = -999. ;
        latitude:units = "degrees_north" ;
    double longitude(longitude) ;
        longitude:_FillValue = -999. ;
        longitude:units = "degrees_east" ;

// global attributes:

        :_NCProperties = "version=1|netcdflibversion=4.4.1|hdf5libversion=1.8.17" ;
        :YAML_config = "grid_settings:\n gridsize: 1\n projection: conformal\n lat_in:
latitude\n lon_in: longitude\n lat_out: latitude\n lon_out: longitude\n fill_value: -
999\n\nvariable_settings:\n\n - name_in: Solar_Zenith\n   name_out: Solar_Zenith\n   attributes:
\n   - name: long_name\n   value: Solar Zenith Angle (Cell to Sun) for Daytime Scenes\n   -
name: units\n   value: degrees\n   - name: _FillValue\n   value: -999.0\n   - name: valid_min\n
value: 0.0\n   - name: valid_max\n   value: 180.0\n   - name: scale_factor\n   value: 1.0\n   -
name: add_offset\n   value: 0.0\n   masks:\n   - Mask_Day\n   - Mask_VZA_65p5\n\n -
name_in: Solar_Azimuth\n   name_out: Solar_Azimuth\n   attributes: \n   - name: long_name\n
value: Solar Azimuth Angle (Cell to Sun) for Daytime Scenes\n   - name: units\n   value: degrees\n
- name: _FillValue\n   value: -999.0\n   - name: valid_min\n   value: -180.0\n   - name:
valid_max\n   value: 180.0\n   - name: scale_factor\n   value: 1.0\n   - name: add_offset\n
value: 0.0\n   masks:\n   - Mask_Day\n   - Mask_VZA_65p5\n\n - name_in: Sensor_Zenith\n
name_out: Sensor_Zenith\n   attributes: \n   - name: long_name\n   value: Sensor Zenith Angle
(Cell to Sensor) for Daytime Scenes\n   - name: units\n   value: degrees\n   - name: _FillValue\n
value: -999.0\n   - name: valid_min\n   value: 0.0\n   - name: valid_max\n   value: 180.0\n   -
name: scale_factor\n   value: 1.0\n   - name: add_offset\n   value: 0.0\n   masks:\n   -
Mask_Day\n   - Mask_VZA_65p5\n\n - name_in: Sensor_Azimuth\n   name_out: Sensor_Azimuth\n
attributes: \n   - name: long_name\n   value: Sensor Azimuth Angle (Cell to Sensor) for Daytime
Scenes\n   - name: units\n   value: degrees\n   - name: _FillValue\n   value: -999.0\n   - name:
valid_min\n   value: -180.0\n   - name: valid_max\n   value: 180.0\n   - name: scale_factor\n
value: 1.0\n   - name: add_offset\n   value: 0.0\n   masks:\n   - Mask_Day\n   -
Mask_VZA_65p5\n\n\n - name_in: Cloud_Top_Pressure\n   name_out: Cloud_Top_Pressure\n
attributes: \n   - name: long_name\n   value: Cloud Top Pressure for Daytime Scenes\n   - name:

units\n value: mb\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 1.0\n - name: valid_max\n value: 1100.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Day\n - Mask_VZA_65p5\n\n\n - name_in: Cloud_Mask_Cloudiness\n name_out: Cloud_Mask_Fraction\n attributes: \n - name: long_name\n value: Cloud Fraction from Cloud Mask for Daytime Scenes\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Day\n - Mask_VZA_65p5\n\n - name_in: Cloud_Mask_Cloudiness\n name_out: Cloud_Mask_Fraction_Low\n attributes: \n - name: long_name\n value: Cloud Fraction from Cloud Mask (Low, CTP GE 680 hPa) for Daytime Scenes\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Day\n - Mask_Low\n - Mask_VZA_65p5\n\n - name_in: Cloud_Mask_Cloudiness\n name_out: Cloud_Mask_Fraction_Mid\n attributes: \n - name: long_name\n value: Cloud Fraction from Cloud Mask (Mid, 680 hPa GT CTP GE 440 hPa) for Daytime Scenes\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Day\n - Mask_Middle\n - Mask_VZA_65p5\n\n - name_in: Cloud_Mask_Cloudiness\n name_out: Cloud_Mask_Fraction_High\n attributes: \n - name: long_name\n value: Cloud Fraction from Cloud Mask (High, CTP LT 440 hPa) for Daytime Scenes\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Day\n - Mask_High\n - Mask_VZA_65p5\n\n\n\n\n\n\n\n - name_in: Cloud_Optical_Thickness_37\n name_out: Cloud_Optical_Thickness_Liquid\n attributes: \n - name: long_name\n value: Cloud Optical Thickness for Liquid Water Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 150.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n 2D_histograms:\n - name_out: JHisto_vs_Cloud_Particle_Size_Liquid\n primary_var:\n edges: [0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 150.0]\n joint_var:\n name_in: Cloud_Effective_Radius_37\n edges: [4.0, 8.0, 10.0, 13.0, 15.0, 20.0, 30.0]\n masks:\n - Mask_Liquid_Water_Phase_Clouds\n - Mask_VZA_65p5\n\n - name_in: Cloud_Optical_Thickness_37\n name_out: Cloud_Optical_Thickness_Ice\n attributes: \n - name: long_name\n value: Cloud Optical Thickness for Ice Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 150.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n 2D_histograms:\n - name_out: JHisto_vs_Cloud_Particle_Size_Ice\n primary_var:\n edges: [0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 150.0]\n joint_var:\n name_in: Cloud_Effective_Radius_37\n edges: [5.0, 10.0, 20.0, 30.0, 40.0, 50.0, 60.0]\n masks:\n - Mask_Ice_Phase_Clouds\n - Mask_VZA_65p5\n\n \n - name_in: Cloud_Optical_Thickness_37\n name_out: Cloud_Optical_Thickness_Total\n attributes: \n - name: long_name\n value: Cloud Optical Thickness for Combined (LiquidWater+Ice+Undetermined) Phase Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 150.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n 2D_histograms:\n - name_out: JHisto_vs_Cloud_Top_Pressure\n primary_var:\n edges: [0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 150.0]\n joint_var:\n name_in: Cloud_Top_Pressure\n edges: [0.0, 180.0, 310.0, 440.0, 560.0, 680.0, 800.0, 10000.0]\n masks:\n - Mask_Combined_Phase_Clouds\n - Mask_VZA_65p5\n\n\n - name_in: Cloud_Optical_Thickness_37_PCL\n name_out: Cloud_Optical_Thickness_PCL_Total\n only_histograms:\n attributes: \n - name: long_name\n value: Cloud Optical Thickness for Combined (LiquidWater+Ice+Undetermined) Phase Clouds (3.7 micron Retrieval for Partly Cloudy (PCL) Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 150.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n 2D_histograms:\n - name_out: JHisto_vs_Cloud_Top_Pressure\n primary_var:\n edges: [0.0, 0.3, 1.3, 3.6, 9.4, 23.0, 60.0, 150.0]\n joint_var:\n name_in: Cloud_Top_Pressure\n edges: [0.0, 180.0, 310.0, 440.0, 560.0, 680.0, 800.0, 10000.0]\n masks:\n - Mask_Combined_Phase_Clouds\n - Mask_VZA_65p5\n\n\n\n\n\n\n - name_in: Cloud_Optical_Thickness_37_Log\n name_out: Cloud_Optical_Thickness_Log10_Liquid\n attributes: \n - name: long_name\n value: Cloud Optical Thickness Log10 for Liquid Water Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: -2.0\n - name: valid_max\n value: 2.176\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Liquid_Water_Phase_Clouds\n - Mask_VZA_65p5\n\n - name_in: Cloud_Optical_Thickness_37_Log\n name_out: Cloud_Optical_Thickness_Log10_Ice\n attributes: \n - name: long_name\n value: Cloud Optical Thickness Log10 for Ice Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: -2.0\n - name: valid_max\n value: 2.176\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Ice_Phase_Clouds\n - Mask_VZA_65p5\n\n \n - name_in: Cloud_Optical_Thickness_37_Log\n name_out: Cloud_Optical_Thickness_Log10_Total\n attributes: \n - name: long_name\n value: Cloud Optical Thickness Log10 for Combined (LiquidWater+Ice+Undetermined) Phase Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: -2.0\n - name: valid_max\n value: 2.176\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Combined_Phase_Clouds\n - Mask_VZA_65p5\n\n\n\n - name_in: Cloud_Effective_Radius_37\n name_out: Cloud_Particle_Size_Liquid\n attributes: \n - name: long_name\n value: Cloud Effective Radius for Liquid Water Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: microns\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 4.0\n - name: valid_max\n value: 30.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Liquid_Water_Phase_Clouds\n - Mask_VZA_65p5\n\n - name_in: Cloud_Effective_Radius_37\n name_out: Cloud_Particle_Size_Ice\n attributes: \n - name: long_name\n value: Cloud Effective Radius for Ice Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: microns\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 5.0\n - name: valid_max\n value: 60.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Ice_Phase_Clouds\n - Mask_VZA_65p5\n\n\n\n\n - name_in: Cloud_Water_Path_37\n name_out: Cloud_Water_Path_Liquid\n attributes: \n - name: long_name\n value: Cloud Water Path for Liquid Water Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: g/m^2 \n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 3000.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Liquid_Water_Phase_Clouds\n - Mask_VZA_65p5\n\n - name_in: Cloud_Water_Path_37\n name_out: Cloud_Water_Path_Ice\n attributes: \n - name: long_name\n value: Cloud Water Path for Ice Clouds (3.7 micron Retrieval for Cloudy Scenes)\n - name: units\n value: g/m^2\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 6000.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_Ice_Phase_Clouds\n - Mask_VZA_65p5\n\n\n\n\n\n - name_in: COPR_37_Liquid\n name_out: Cloud_Retrieval_Fraction_Liquid\n attributes: \n - name: long_name\n value: Cloud Optical Properties 3.7 Retrieval Fraction (Liquid Water Clouds)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n -

name: add_offset\n value: 0.0\n masks:\n - Mask_VZA_65p5\n\n - name_in: COPR_37_Ice\n name_out: Cloud_Retrieval_Fraction_Ice\n attributes: \n - name: long_name\n value: Cloud Optical Properties 3.7 Retrieval Fraction (Ice Clouds)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_VZA_65p5\n\n - name_in: COPR_37_Combined\n name_out: Cloud_Retrieval_Fraction_Total\n attributes: \n - name: long_name\n value: Cloud Optical Properties 3.7 Retrieval Fraction (Combined (LiquidWater+Ice+Undetermined) Phase Clouds)\n - name: units\n value: none\n - name: _FillValue\n value: -999.0\n - name: valid_min\n value: 0.0\n - name: valid_max\n value: 1.0\n - name: scale_factor\n value: 1.0\n - name: add_offset\n value: 0.0\n masks:\n - Mask_VZA_65p5\n\n\n\n\n" ;

```
		:Yori_version = "1.3.13" ;
		:input_files =
"CLDPROPCOSP_D3_MODIS_Aqua.A2014051.011.2020112202625.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014050.011.2020112202626.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014047.011.2020112202627.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014046.011.2020112202626.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014049.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014048.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014043.011.2020112202635.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014042.011.2020112202630.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014045.011.2020112202629.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014044.011.2020112202626.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014056.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014057.011.2020112202630.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014058.011.2020112202633.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014059.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014052.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014053.011.2020112202629.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014054.011.2020112202630.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014055.011.2020112202627.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014041.011.2020112202626.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014040.011.2020112202629.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014037.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014036.011.2020112202626.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014039.011.2020112202628.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014038.011.2020112202629.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014033.011.2020112202519.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014032.011.2020112202516.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014035.011.2020112202626.nc,CLDPROPCOSP_D3_MODIS_Aqua.A2014034.011.2020112202627.nc" ;
		:daily = "False" ;

group: Solar_Zenith {
  variables:
	double Mean(longitude, latitude) ;
		Mean:_FillValue = -999. ;
		Mean:title = "Solar_Zenith: Mean" ;
		Mean:units = "degrees" ;
	double Standard_Deviation(longitude, latitude) ;
		Standard_Deviation:_FillValue = -999. ;
		Standard_Deviation:title = "Solar_Zenith: Standard_Deviation" ;
		Standard_Deviation:units = "degrees" ;
	double Sum(longitude, latitude) ;
		Sum:_FillValue = -999. ;
		Sum:title = "Solar_Zenith: Sum" ;
	int Pixel_Counts(longitude, latitude) ;
		Pixel_Counts:_FillValue = -999 ;
		Pixel_Counts:title = "Solar_Zenith: Pixel_Counts" ;
	double Sum_Squares(longitude, latitude) ;
```

```
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Solar_Zenith: Sum_Squares" ;

  // group attributes:
                :long_name = "Solar Zenith Angle (Cell to Sun) for Daytime Scenes" ;
                :units = "degrees" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 180. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Solar_Zenith

group: Solar_Azimuth {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Solar_Azimuth: Mean" ;
                Mean:units = "degrees" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Solar_Azimuth: Standard_Deviation" ;
                Standard_Deviation:units = "degrees" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Solar_Azimuth: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Solar_Azimuth: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Solar_Azimuth: Sum_Squares" ;

  // group attributes:
                :long_name = "Solar Azimuth Angle (Cell to Sun) for Daytime Scenes" ;
                :units = "degrees" ;
                :_FillValue = -999. ;
                :valid_min = -180. ;
                :valid_max = 180. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Solar_Azimuth

group: Sensor_Zenith {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Sensor_Zenith: Mean" ;
                Mean:units = "degrees" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Sensor_Zenith: Standard_Deviation" ;
                Standard_Deviation:units = "degrees" ;
```

```
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Sensor_Zenith: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Sensor_Zenith: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Sensor_Zenith: Sum_Squares" ;

  // group attributes:
                :long_name = "Sensor Zenith Angle (Cell to Sensor) for Daytime Scenes" ;
                :units = "degrees" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 180. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Sensor_Zenith

group: Sensor_Azimuth {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Sensor_Azimuth: Mean" ;
                Mean:units = "degrees" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Sensor_Azimuth: Standard_Deviation" ;
                Standard_Deviation:units = "degrees" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Sensor_Azimuth: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Sensor_Azimuth: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Sensor_Azimuth: Sum_Squares" ;

  // group attributes:
                :long_name = "Sensor Azimuth Angle (Cell to Sensor) for Daytime Scenes" ;
                :units = "degrees" ;
                :_FillValue = -999. ;
                :valid_min = -180. ;
                :valid_max = 180. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Sensor_Azimuth

group: Cloud_Top_Pressure {
  variables:
        double Mean(longitude, latitude) ;
```

```
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Top_Pressure: Mean" ;
                Mean:units = "mb" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Top_Pressure: Standard_Deviation" ;
                Standard_Deviation:units = "mb" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Top_Pressure: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Top_Pressure: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Top_Pressure: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Top Pressure for Daytime Scenes" ;
                :units = "mb" ;
                :_FillValue = -999. ;
                :valid_min = 1. ;
                :valid_max = 1100. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Top_Pressure

group: Cloud_Mask_Fraction {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Mask_Fraction: Mean" ;
                Mean:units = "none" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Mask_Fraction: Standard_Deviation" ;
                Standard_Deviation:units = "none" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Mask_Fraction: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Mask_Fraction: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Mask_Fraction: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Fraction from Cloud Mask for Daytime Scenes" ;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 1. ;
```

```
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Mask_Fraction

group: Cloud_Mask_Fraction_Low {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Mask_Fraction_Low: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Mask_Fraction_Low: Standard_Deviation" ;
                    Standard_Deviation:units = "none" ;
          double Sum(longitude, latitude) ;
                    Sum:_FillValue = -999. ;
                    Sum:title = "Cloud_Mask_Fraction_Low: Sum" ;
          int Pixel_Counts(longitude, latitude) ;
                    Pixel_Counts:_FillValue = -999 ;
                    Pixel_Counts:title = "Cloud_Mask_Fraction_Low: Pixel_Counts" ;
          double Sum_Squares(longitude, latitude) ;
                    Sum_Squares:_FillValue = -999. ;
                    Sum_Squares:title = "Cloud_Mask_Fraction_Low: Sum_Squares" ;

  // group attributes:
                    :long_name = "Cloud Fraction from Cloud Mask (Low, CTP GE 680 hPa) for Daytime
Scenes" ;
                    :units = "none" ;
                    :_FillValue = -999. ;
                    :valid_min = 0. ;
                    :valid_max = 1. ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Mask_Fraction_Low

group: Cloud_Mask_Fraction_Mid {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Mask_Fraction_Mid: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Mask_Fraction_Mid: Standard_Deviation" ;
                    Standard_Deviation:units = "none" ;
          double Sum(longitude, latitude) ;
                    Sum:_FillValue = -999. ;
                    Sum:title = "Cloud_Mask_Fraction_Mid: Sum" ;
          int Pixel_Counts(longitude, latitude) ;
                    Pixel_Counts:_FillValue = -999 ;
                    Pixel_Counts:title = "Cloud_Mask_Fraction_Mid: Pixel_Counts" ;
          double Sum_Squares(longitude, latitude) ;
                    Sum_Squares:_FillValue = -999. ;
```

```
                    Sum_Squares:title = "Cloud_Mask_Fraction_Mid: Sum_Squares" ;

  // group attributes:
                    :long_name = "Cloud Fraction from Cloud Mask (Mid, 680 hPa GT CTP GE 440 hPa) 
for Daytime Scenes" ;
                    :units = "none" ;
                    :_FillValue = -999. ;
                    :valid_min = 0. ;
                    :valid_max = 1. ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Mask_Fraction_Mid

group: Cloud_Mask_Fraction_High {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Mask_Fraction_High: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Mask_Fraction_High: Standard_Deviation" ;
                    Standard_Deviation:units = "none" ;
          double Sum(longitude, latitude) ;
                    Sum:_FillValue = -999. ;
                    Sum:title = "Cloud_Mask_Fraction_High: Sum" ;
          int Pixel_Counts(longitude, latitude) ;
                    Pixel_Counts:_FillValue = -999 ;
                    Pixel_Counts:title = "Cloud_Mask_Fraction_High: Pixel_Counts" ;
          double Sum_Squares(longitude, latitude) ;
                    Sum_Squares:_FillValue = -999. ;
                    Sum_Squares:title = "Cloud_Mask_Fraction_High: Sum_Squares" ;

  // group attributes:
                    :long_name = "Cloud Fraction from Cloud Mask (High, CTP LT 440 hPa) for Daytime 
Scenes" ;
                    :units = "none" ;
                    :_FillValue = -999. ;
                    :valid_min = 0. ;
                    :valid_max = 1. ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Mask_Fraction_High

group: Cloud_Optical_Thickness_Liquid {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Optical_Thickness_Liquid: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Optical_Thickness_Liquid: Standard_Deviation" ;
```

```
                Standard_Deviation:units = "none" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Optical_Thickness_Liquid: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Optical_Thickness_Liquid: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Optical_Thickness_Liquid: Sum_Squares" ;
        int JHisto_vs_Cloud_Particle_Size_Liquid(longitude, latitude,
histo_cloud_optical_thickness_liquid_7, jhisto_vs_cloud_particle_size_liquid_6) ;
                JHisto_vs_Cloud_Particle_Size_Liquid:_FillValue = -999 ;
                JHisto_vs_Cloud_Particle_Size_Liquid:title = "Cloud_Optical_Thickness_Liquid:
JHisto_vs_Cloud_Particle_Size_Liquid" ;
                JHisto_vs_Cloud_Particle_Size_Liquid:JHisto_Bin_Boundaries = 0., 0.3, 1.3, 3.6, 9.4,
23., 60., 150. ;
                JHisto_vs_Cloud_Particle_Size_Liquid:JHisto_Bin_Boundaries_Joint_Parameter = 4.,
8., 10., 13., 15., 20., 30. ;

  // group attributes:
                :long_name = "Cloud Optical Thickness for Liquid Water Clouds (3.7 micron Retrieval
for Cloudy Scenes)" ;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 150. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_Liquid

group: Cloud_Optical_Thickness_Ice {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Optical_Thickness_Ice: Mean" ;
                Mean:units = "none" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Optical_Thickness_Ice: Standard_Deviation" ;
                Standard_Deviation:units = "none" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Optical_Thickness_Ice: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Optical_Thickness_Ice: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Optical_Thickness_Ice: Sum_Squares" ;
        int JHisto_vs_Cloud_Particle_Size_Ice(longitude, latitude,
histo_cloud_optical_thickness_ice_7, jhisto_vs_cloud_particle_size_ice_6) ;
                JHisto_vs_Cloud_Particle_Size_Ice:_FillValue = -999 ;
```

```
                JHisto_vs_Cloud_Particle_Size_Ice:title = "Cloud_Optical_Thickness_Ice:
JHisto_vs_Cloud_Particle_Size_Ice" ;
                JHisto_vs_Cloud_Particle_Size_Ice:JHisto_Bin_Boundaries = 0., 0.3, 1.3, 3.6, 9.4,
23., 60., 150. ;
                JHisto_vs_Cloud_Particle_Size_Ice:JHisto_Bin_Boundaries_Joint_Parameter = 5., 10.,
20., 30., 40., 50., 60. ;

  // group attributes:
                :long_name = "Cloud Optical Thickness for Ice Clouds (3.7 micron Retrieval for
Cloudy Scenes)" ;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 150. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_Ice

group: Cloud_Optical_Thickness_Total {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Optical_Thickness_Total: Mean" ;
                Mean:units = "none" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Optical_Thickness_Total: Standard_Deviation" ;
                Standard_Deviation:units = "none" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Optical_Thickness_Total: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Optical_Thickness_Total: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Optical_Thickness_Total: Sum_Squares" ;
        int JHisto_vs_Cloud_Top_Pressure(longitude, latitude, histo_cloud_optical_thickness_total_7,
jhisto_vs_cloud_top_pressure_7) ;
                JHisto_vs_Cloud_Top_Pressure:_FillValue = -999 ;
                JHisto_vs_Cloud_Top_Pressure:title = "Cloud_Optical_Thickness_Total:
JHisto_vs_Cloud_Top_Pressure" ;
                JHisto_vs_Cloud_Top_Pressure:JHisto_Bin_Boundaries = 0., 0.3, 1.3, 3.6, 9.4, 23.,
60., 150. ;
                JHisto_vs_Cloud_Top_Pressure:JHisto_Bin_Boundaries_Joint_Parameter = 0., 180.,
310., 440., 560., 680., 800., 10000. ;

  // group attributes:
                :long_name = "Cloud Optical Thickness for Combined
(LiquidWater+Ice+Undetermined) Phase Clouds (3.7 micron Retrieval for Cloudy Scenes)" ;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
```

```
                    :valid_max = 150. ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_Total

group: Cloud_Optical_Thickness_PCL_Total {
  variables:
          int JHisto_vs_Cloud_Top_Pressure(longitude, latitude,
histo_cloud_optical_thickness_pcl_total_7, jhisto_vs_cloud_top_pressure_7) ;
                    JHisto_vs_Cloud_Top_Pressure:_FillValue = -999 ;
                    JHisto_vs_Cloud_Top_Pressure:title = "Cloud_Optical_Thickness_PCL_Total:
JHisto_vs_Cloud_Top_Pressure" ;
                    JHisto_vs_Cloud_Top_Pressure:JHisto_Bin_Boundaries = 0., 0.3, 1.3, 3.6, 9.4, 23.,
60., 150. ;
                    JHisto_vs_Cloud_Top_Pressure:JHisto_Bin_Boundaries_Joint_Parameter = 0., 180.,
310., 440., 560., 680., 800., 10000. ;

  // group attributes:
                    :long_name = "Cloud Optical Thickness for Combined
(LiquidWater+Ice+Undetermined) Phase Clouds (3.7 micron Retrieval for Partly Cloudy (PCL)
Scenes)" ;
                    :units = "none" ;
                    :_FillValue = -999. ;
                    :valid_min = 0. ;
                    :valid_max = 150. ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_PCL_Total

group: Cloud_Optical_Thickness_Log10_Liquid {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Optical_Thickness_Log10_Liquid: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Optical_Thickness_Log10_Liquid:
Standard_Deviation" ;
                    Standard_Deviation:units = "none" ;
          double Sum(longitude, latitude) ;
                    Sum:_FillValue = -999. ;
                    Sum:title = "Cloud_Optical_Thickness_Log10_Liquid: Sum" ;
          int Pixel_Counts(longitude, latitude) ;
                    Pixel_Counts:_FillValue = -999 ;
                    Pixel_Counts:title = "Cloud_Optical_Thickness_Log10_Liquid: Pixel_Counts" ;
          double Sum_Squares(longitude, latitude) ;
                    Sum_Squares:_FillValue = -999. ;
                    Sum_Squares:title = "Cloud_Optical_Thickness_Log10_Liquid: Sum_Squares" ;

  // group attributes:
                    :long_name = "Cloud Optical Thickness Log10 for Liquid Water Clouds (3.7 micron
Retrieval for Cloudy Scenes)" ;
```

```
                    :units = "none" ;
                    :_FillValue = -999. ;
                    :valid_min = -2. ;
                    :valid_max = 2.176 ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_Log10_Liquid

group: Cloud_Optical_Thickness_Log10_Ice {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Optical_Thickness_Log10_Ice: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Optical_Thickness_Log10_Ice:
Standard_Deviation" ;
                    Standard_Deviation:units = "none" ;
          double Sum(longitude, latitude) ;
                    Sum:_FillValue = -999. ;
                    Sum:title = "Cloud_Optical_Thickness_Log10_Ice: Sum" ;
          int Pixel_Counts(longitude, latitude) ;
                    Pixel_Counts:_FillValue = -999 ;
                    Pixel_Counts:title = "Cloud_Optical_Thickness_Log10_Ice: Pixel_Counts" ;
          double Sum_Squares(longitude, latitude) ;
                    Sum_Squares:_FillValue = -999. ;
                    Sum_Squares:title = "Cloud_Optical_Thickness_Log10_Ice: Sum_Squares" ;

  // group attributes:
                    :long_name = "Cloud Optical Thickness Log10 for Ice Clouds (3.7 micron Retrieval
for Cloudy Scenes)" ;
                    :units = "none" ;
                    :_FillValue = -999. ;
                    :valid_min = -2. ;
                    :valid_max = 2.176 ;
                    :scale_factor = 1. ;
                    :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_Log10_Ice

group: Cloud_Optical_Thickness_Log10_Total {
  variables:
          double Mean(longitude, latitude) ;
                    Mean:_FillValue = -999. ;
                    Mean:title = "Cloud_Optical_Thickness_Log10_Total: Mean" ;
                    Mean:units = "none" ;
          double Standard_Deviation(longitude, latitude) ;
                    Standard_Deviation:_FillValue = -999. ;
                    Standard_Deviation:title = "Cloud_Optical_Thickness_Log10_Total:
Standard_Deviation" ;
                    Standard_Deviation:units = "none" ;
          double Sum(longitude, latitude) ;
                    Sum:_FillValue = -999. ;
```

```
                Sum:title = "Cloud_Optical_Thickness_Log10_Total: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Optical_Thickness_Log10_Total: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Optical_Thickness_Log10_Total: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Optical Thickness Log10 for Combined
(LiquidWater+Ice+Undetermined) Phase Clouds (3.7 micron Retrieval for Cloudy Scenes)" ;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = -2. ;
                :valid_max = 2.176 ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Optical_Thickness_Log10_Total

group: Cloud_Particle_Size_Liquid {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Particle_Size_Liquid: Mean" ;
                Mean:units = "microns" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Particle_Size_Liquid: Standard_Deviation" ;
                Standard_Deviation:units = "microns" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Particle_Size_Liquid: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Particle_Size_Liquid: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Particle_Size_Liquid: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Effective Radius for Liquid Water Clouds (3.7 micron Retrieval
for Cloudy Scenes)" ;
                :units = "microns" ;
                :_FillValue = -999. ;
                :valid_min = 4. ;
                :valid_max = 30. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Particle_Size_Liquid

group: Cloud_Particle_Size_Ice {
  variables:
        double Mean(longitude, latitude) ;
```

```
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Particle_Size_Ice: Mean" ;
                Mean:units = "microns" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Particle_Size_Ice: Standard_Deviation" ;
                Standard_Deviation:units = "microns" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Particle_Size_Ice: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Particle_Size_Ice: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Particle_Size_Ice: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Effective Radius for Ice Clouds (3.7 micron Retrieval for Cloudy
Scenes)" ;
                :units = "microns" ;
                :_FillValue = -999. ;
                :valid_min = 5. ;
                :valid_max = 60. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Particle_Size_Ice

group: Cloud_Water_Path_Liquid {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Water_Path_Liquid: Mean" ;
                Mean:units = "g/m^2" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Water_Path_Liquid: Standard_Deviation" ;
                Standard_Deviation:units = "g/m^2" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Water_Path_Liquid: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Water_Path_Liquid: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Water_Path_Liquid: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Water Path for Liquid Water Clouds (3.7 micron Retrieval for
Cloudy Scenes)" ;
                :units = "g/m^2" ;
                :_FillValue = -999. ;
```

```
                :valid_min = 0. ;
                :valid_max = 3000. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Water_Path_Liquid

group: Cloud_Water_Path_Ice {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Water_Path_Ice: Mean" ;
                Mean:units = "g/m^2" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Water_Path_Ice: Standard_Deviation" ;
                Standard_Deviation:units = "g/m^2" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Water_Path_Ice: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Water_Path_Ice: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Water_Path_Ice: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Water Path for Ice Clouds (3.7 micron Retrieval for Cloudy
Scenes)" ;
                :units = "g/m^2" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 6000. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Water_Path_Ice

group: Cloud_Retrieval_Fraction_Liquid {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Retrieval_Fraction_Liquid: Mean" ;
                Mean:units = "none" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Retrieval_Fraction_Liquid: Standard_Deviation" ;
                Standard_Deviation:units = "none" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Retrieval_Fraction_Liquid: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Retrieval_Fraction_Liquid: Pixel_Counts" ;
```

```
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Retrieval_Fraction_Liquid: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Optical Properties 3.7 Retrieval Fraction (Liquid Water Clouds)"
;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 1. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Retrieval_Fraction_Liquid

group: Cloud_Retrieval_Fraction_Ice {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Retrieval_Fraction_Ice: Mean" ;
                Mean:units = "none" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
                Standard_Deviation:title = "Cloud_Retrieval_Fraction_Ice: Standard_Deviation" ;
                Standard_Deviation:units = "none" ;
        double Sum(longitude, latitude) ;
                Sum:_FillValue = -999. ;
                Sum:title = "Cloud_Retrieval_Fraction_Ice: Sum" ;
        int Pixel_Counts(longitude, latitude) ;
                Pixel_Counts:_FillValue = -999 ;
                Pixel_Counts:title = "Cloud_Retrieval_Fraction_Ice: Pixel_Counts" ;
        double Sum_Squares(longitude, latitude) ;
                Sum_Squares:_FillValue = -999. ;
                Sum_Squares:title = "Cloud_Retrieval_Fraction_Ice: Sum_Squares" ;

  // group attributes:
                :long_name = "Cloud Optical Properties 3.7 Retrieval Fraction (Ice Clouds)" ;
                :units = "none" ;
                :_FillValue = -999. ;
                :valid_min = 0. ;
                :valid_max = 1. ;
                :scale_factor = 1. ;
                :add_offset = 0. ;
  } // group Cloud_Retrieval_Fraction_Ice

group: Cloud_Retrieval_Fraction_Total {
  variables:
        double Mean(longitude, latitude) ;
                Mean:_FillValue = -999. ;
                Mean:title = "Cloud_Retrieval_Fraction_Total: Mean" ;
                Mean:units = "none" ;
        double Standard_Deviation(longitude, latitude) ;
                Standard_Deviation:_FillValue = -999. ;
```

```
		Standard_Deviation:title = "Cloud_Retrieval_Fraction_Total: Standard_Deviation" ;
		Standard_Deviation:units = "none" ;
	double Sum(longitude, latitude) ;
		Sum:_FillValue = -999. ;
		Sum:title = "Cloud_Retrieval_Fraction_Total: Sum" ;
	int Pixel_Counts(longitude, latitude) ;
		Pixel_Counts:_FillValue = -999 ;
		Pixel_Counts:title = "Cloud_Retrieval_Fraction_Total: Pixel_Counts" ;
	double Sum_Squares(longitude, latitude) ;
		Sum_Squares:_FillValue = -999. ;
		Sum_Squares:title = "Cloud_Retrieval_Fraction_Total: Sum_Squares" ;

  // group attributes:
		:long_name = "Cloud Optical Properties 3.7 Retrieval Fraction (Combined
(LiquidWater+Ice+Undetermined) Phase Clouds)" ;
		:units = "none" ;
		:_FillValue = -999. ;
		:valid_min = 0. ;
		:valid_max = 1. ;
		:scale_factor = 1. ;
		:add_offset = 0. ;
  } // group Cloud_Retrieval_Fraction_Total
}
```