Description of A-Train Convective object (CO) Database

*Highlighted data products are products that still need to be generated.*

*Updated on December 16, 2022*

This document provides an overview of a convective object database using A-Train measurements, as well as a comprehensive list of all the variables, satellite instruments, and data products used. The database is generated using A-Train observations beginning with Epoch 2 in August 2006 and ends December 2017. Data is stored in NetCDF files (each file is 180.6 MB) and each file corresponds to one CloudSat granule.

**Version 2 Updates**

* The COs are now being detected using an image-processing python function (refer to the outline below for more detail)
* Several new CO features have been updated and added. They are as follows:
  + Identifying multi-layer clouds
  + Identifying distinct cloud regions and their fraction within the CO (e.g., deep convective core, stratiform rain, shallow convection, and non-precipitating fraction)
    - Non-precipitating anvil is separated by thickness according to varying cloud optical depths summed over the vertical column within the anvil cloud
  + Whether or not CALIPSO lidar signal was fully attenuated for each CO profile
  + Full cloud top height and cloud base height columns
  + Information about rain rates and flags from CloudSat (useful for drizzle)
  + Cloud Impact Parameters (CIPs) calculated and averaged over the CO as well as for each cloud region
  + Monthly mean SST and vertical motion at 500 hPa from MERRA2 matched to each CO
* How the COs and their variables are being stored has been updated in that there are no longer several masked values in between each CO in the list. As a result, the nCO (see below) dimension has been reduced. Each list does still have masked values for the sake of keeping the file lengths consistent.
* Naming convention and dimensions have been modified for some of the variables
* Additional updates to specific variables:
  + Latitude and longitudes of COs now have an extra dimension corresponding to narea (see variable dimensions below)
  + Surface flag now includes flag = 4 for CO regions that have a mix of underlying geography (not fully land or ocean, or at least 75% coast)
  + Only the initial and final values of CO pixels are stored
  + Only the initial and final values of CO convective core pixels are stored
  + Reflectivity profile is from the surface to the troposphere (0 km to 18 km) as opposed to the full profile from -4 to 25 km with an example of gridded heights available.
  + Data from MERRA-AUX, an R04 product, were co-located with the updated R05 CloudSat grid, so values might be slightly different (but now correct) in this newer version

**Variable Dimensions**

The data stored in the database are masked arrays pre-defined with the following dimensions:

* nCO: number of COs along a granule ( = 50)
* nCOprof: number of CloudSat profiles for each CO ( = 5000)
* ncore: number of deep convective cores in each CO ( = 75)
* ncoreprof: number of profiles in each core in each CO ( = 360)
* nlayer: number of atmospheric layers between 0 km to 18 km ( = 76)
* nlayerfull: number of atmospheric layers between -4 km to 25 km ( = 125)
* ncldclslayers: number of cloud top and base height levels ( = 10)
* narea: each array along this dimension corresponds to the number of profiles of the CO, CO + 50 profiles on either end, CO + 100 profiles on either end, and CO length + 250 profiles on either end ( = 4)
* ncldtype: cloud types according to precipitating (deep convection, stratiform, shallow convection) and non-precipitating (anvil with three thickness categories) cloud (=6):
  + Precipitating regions:
    - 1) Deep convection defined by 2CPC Conv\_strat\_flag
    - 2) Stratiform rain defined by wherever 2CPC Precip\_flag designated precipitation that was not deep or shallow convection
    - 3) Shallow convection defined by 2CPC Conv\_strat\_flag
  + Non-precipitating anvil:
    - Wherever 2CPC Conv\_strat\_flag flagged no precipitation
    - Anvil separated into three regions according to the cloud optical depth (COD) area vertically summed over each anvil profile: 4) COD area < 1, 5) 1 < COD area < 3, 6) COD area > 3
    - There are some COD values that are missing, so missing data is interpolated using a reference COD value within the CO and scaling it based on the relationship between IWP and COD
* nshear: number of shear calculations for the following layers ( = 4):
  + Total: Surface layer (1000-900 mb) and upper layer (300-150 mb)
  + Low-level: Surface layer (1000-900 mb) and boundary layer (850-700 mb)
  + Mid-level: Boundary layer (850-700 mb) and mid-troposphere (550-450 mb)
  + Upper-level: mid-troposphere (550-450 mb) and upper troposphere (300-150 mb)
* npedestal: number of pedestal regions in CO (= 55)
* nCALIPSO: number of CALIPSO-only detected cloudy regions in CO (= 45)
* nMODpix: number of MODIS aerosol pixels for each CO (= 15000)

**Outline of Convective Object Identification Algorithm**

The main process of the algorithm is to:

1. Identify all of the deep convective pixels along the CloudSat overpass and group the consecutive core pixels as individual “cores”
2. Count the number of “cloudy” pixels (using conditions of reflectivity and cloud top height values) on either side of each convective core and merge the two sides with the core.

Below is an overview of the algorithm flow:

1. Use the 2B-GEOPROF cloud mask to mask reflectivity values along a CloudSat granule that are considered clear-sky, ground clutter, and regions flagged as multi-layer clouds (Z not valid if Z < -28 dBZ, Z > 50 dBZ, or cloud mask < 2 or = 5)
2. Identify convective core pixels using 2C-PRECIP-COLUMN’s convective flags and group contiguous values along CloudSat swath (Conv\_strat\_flag = 1)
3. Fill in CALIPSO-detected cloud with fake Z values (Z = -30 dBZ) between cloud top and cloud base heights from 2B-CLOUDCLASS-LIDAR along CloudSat overpass
   1. If cloud base height of highest cloud is higher than the cloud top height in the layer below then it is deemed as multi-layer --> fill in the cloud layer below the highest cloud
4. Use the skimage Python function from scikit-image for image processing to detect all connecting pixels in 2D space along the CloudSat overpass
   1. Each unique "cloud object" is assigned a label, which is the output of this step
5. Define distinct cores along CloudSat overpass
   1. The vertically lowest unmasked value within the atmospheric column of the first pixel of a convective core becomes a "convective object label"
6. Count the contiguous cloudy pixels on each side of the core
   1. Condition is that the surrounding pixels have the same label as the convective core label and that the pixel has a CTH gradient < 1.5 km
      1. Store the cloud top height indices and create a 3-pixel gradient of cloud top heights from CALIPSO for each pixel
         1. Starting with a pixel and using the counting method from before, if the previous or subsequent gradient is < 1.5 km, then it is included in the cloud object
7. Removing COs
   1. Don't count CO if it's less than 5 or greater than 5000 pixels long
   2. Remove duplicate convective objects created from systems that were already considered because they are multi-core
8. Multi-layer clouds are included in each CO, and flags identifying their location are included

**List of Variables**

**General**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Satellite Instrument (Data product)** | **Description** | **Dimension** | **Units or Type** |
| CloudSat Granule | CloudSat | CloudSat granule number | 1 | Integer |
| Year | CloudSat | Year | 1 | year |
| Julian Day | CloudSat | Julian calendar day of CloudSat overpass | 1 | Julian day (LT) |
| Julian Day in UTC | CloudSat | UTC Julian calendar day of CloudSat overpass | 1 | Julian day (UTC) |
| Time of Day | CloudSat | Boolean recording when CloudSat overpass occurs: daytime = 1 and nighttime = 0 | nCO | Binary |
| Hour (UTC) | CloudSat (2B-GEOPROF) | Hour of A-Train detection of CO | nCO | UTC |
| Minute (UTC) | CloudSat (2B-GEOPROF) | Minutes of A-Train detection of CO | nCO | (UTC) |
| DEM Elevation | CloudSat (2B-GEOPROF) | Surface Digital Elevation Map of the CO | nCO, nCOprof | km |

**Convective Object Features**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Name** | **Satellite or Instrument (Data product)** | **Description** | **Dimension** | **Units or Type** |
| Latitudes of CO | CloudSat (2B-GEOPROF) | Latitude coordinates of each CO along CloudSat overpass | nCO, narea, nCOprof | Degree |
| Longitudes of CO | CloudSat (2B-GEOPROF) | Longitude coordinates of each CO along CloudSat overpass | nCO, narea, nCOprof | Degree |
| Surface flag | CloudSat (2B-GEOPROF) | Surface flag: 1 = land, 2 = ocean, 3 = coast, 4 = mixed | nCO | Integer |
| Heights | CloudSat (2B-GEOPROF) | Example height profile from 0-18 km | nlayer | km |
| Mean CO Heights Full | CloudSat (2B-GEOPROF) | Mean height of each vertical column within CO (~-4 to 25 km) | nCO, nlayerfull | km |
| Initial CO Profile Index | CloudSat (2B-GEOPROF, 2CPC) | Initial profile index of each CO along Cloudsat swath | nCO | Integer |
| Final CO Profile Index | CloudSat (2B-GEOPROF, 2CPC) | Final profile index of each CO along Cloudsat swath | nCO | Integer |
| CO Length | CloudSat (2B- GEOPROF, 2CPC) | Length of each CO measured by the number of pixels that make up each object | nCO | Integer |
| Cloud Top Height | CALIPSO (2B-CLDCLASS-LIDAR) | Cloud top heights for each convective object from lidar | nCO, nCOprof, ncldclslayers | km |
| Cloud Base Height | CALIPSO (2B-CLDCLASS-LIDAR) | Cloud base heights for each convective object from lidar | nCO, nCOprof, ncldclslayers | km |
| Full Z Profile | CloudSat (2B- GEOPROF) | Reflectivity profile of CO from 0-18 km | nCO, nCOprof, nlayer | dBZ |
| Column-Integrated Z | CloudSat (2B- GEOPROF) | Reflectivities summed over all atmospheric layers for each profile in CO | nCO, nCOprof | dBZ |
| Volume-Integrated Z | CloudSat (2B- GEOPROF) | Reflectivities summed over all atmospheric layers and profiles in CO | nCO | dBZ |
| Maximum Z | CloudSat (2B- GEOPROF) | Maximum reflectivity value for each convective object | nCO | dBZ |
| Height of Maximum Z | CloudSat (2B- GEOPROF) | Height where maximum reflectivity value is located in the atmosphere | nCO | km |
| Integrated LW Cloud Optical Depth | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | LW estimates of cloud optical depth summed over all atmospheric layers for each profile in CO | nCO, nCOprof | Float |
| Integrated SW Cloud Optical Depth | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | SW estimates of cloud optical depth summed over atmospheric layers for each profile in CO | nCO, nCOprof | Float |
| Convective Fraction | CloudSat (2CPC) | Fraction of deep convective core area over precipitating region: dcc / (dcc + strat + shallow) | nCO | Fraction |
| Convective fraction over CO | CloudSat (2CPC) | Fraction of deep convective flags over full convective object: dcc / length of co | nCO | Fraction |
| Stratiform fraction over CO | CloudSat (2CPC) | Fraction of stratiform raining region within CO | nCO | Fraction |
| Shallow convection fraction over CO | CloudSat (2CPC) | Fraction of shallow convection region within CO | nCO | Fraction |
| Fraction of Anvil with COD lt 1 | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Fraction of non-precipitating anvil with vertically-summed cloud optical depth < 1 | nCO | Fraction |
| Fraction of Anvil with COD gt 1 and lt 3 | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Fraction of non-precipitating anvil with vertically-summed COD > 1 and < 3 | nCO | Fraction |
| Fraction of Anvil with COD gt 3 | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Fraction of non-precipitating anvil with vertically-summed cloud optical depth < 1 | nCO | Fraction |
| Fraction of Anvil with Missing COD | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Fraction of non-precipitating anvil with missing COD data | nCO | Fraction |
| Cloud Region Flags | CloudSat/CALIPSO (2CPC, 2B-FLXHR-LIDAR) | Flags according to cloud regions: 1 = deep convection, 2 = stratiform, 3 = shallow convection, 4 = anvil COD < 1, 4 = anvil 1< COD < 3, 5 = anvil COD > 3 | nCO, nCOprof | Integer |
| Mean Freezing Level | CloudSat (2CPC) | Mean freezing level for each convective object | nCO | km |
| Fraction of Heights gt 10 dBZ | CloudSat (2B- GEOPROF) | Fraction of Z > 10 dBZ along convective object | nCO | Fraction |
| Fraction of Heights gt 0 dBZ | CloudSat (2B- GEOPROF) | Fraction of Z > 0 dBZ along convective object | nCO | Fraction |
| Hydrometeor PIA | CloudSat (2CPC) | Hydrometeor path-integrated attenuation (PIA) | nCO, nCOprof | dB |
| Near-surface PIA | CloudSat (2CPC) | Near-surface PIA | nCO, nCOprof | dB |
| PIA uncertainty | CloudSat (2CPC) | PIA percentage uncertainty | nCO, nCOprof | dB |
| Fraction Total Attenuation | CloudSat (2CPC) | Fraction of system where profile is totally attenuated (negative 2CPC rain rates) | nCO | Fraction |
| Multilayer Cloud Flags | CloudSat (2B- GEOPROF) | Flags designating column that contains detached cloud above or below CO: 1 = below CO cloud base, 2 = above CO cloud top, masked if no detection | nCO, nCOprof | Integer |
| Fraction of CO with Cloud Below CO | CloudSat (2B- GEOPROF) | Fraction of CO with cloud detected below CO cloud base | nCO | Fraction |
| Fraction of CO with Cloud Above CO | CloudSat (2B- GEOPROF) | Fraction of CO with cloud detected above CO cloud top | nCO | Fraction |
| 94 GHz Brightness Temperatures | CloudSat (2B-TB94) | 94 GHz brightness temperatures for each pixel in convective object and for convective object +/- 50, 100, and 250 km radii | nCO, narea, nCOprof | K |
| 11-micron Brightness Temperatures | MODIS (MOD06-5KM-AUX) | 11-micron brightness temperatures for each pixel in convective object and for convective object +/- 50, 100, and 250 km radii | nCO, narea, nCOprof | K |
| Anvil-Pedestal Cutoff Height | CloudSat (2B-GEOPROF) | Height that distinguishes the anvil and pedestal regions in each CO | nCO | km |
| Anvil-Pedestal Cutoff Index | CloudSat (2B-GEOPROF) | Index corresponding to full vertical atmospheric height profile (n=125) from TOA to below surface that distinguishes the anvil and pedestal regions in each CO | nCO | Integer |
| Number of Pedestals | CloudSat (2B-GEOPROF) | Number of pedestal regions in each CO | nCO | Integer |
| Initial Pedestal Index | CloudSat (2B-GEOPROF) | Initial pedestal pixel for each pedestal within the CO (indexed by where pedestal is located in the CO) | nCO, npedestal | Integer |
| Final Pedestal Index | CloudSat (2B-GEOPROF) | Final pedestal pixel for each pedestal within the CO (indexed by where pedestal is located in the CO) | nCO, npedestal | Integer |
| Number of CALIPSO-Only Regions | CALIPSO (2B-CLDCLASS-LIDAR) | Number of cloudy regions detected only by CALIPSO within the CO | nCO | Integer |
| Length of CALIPSO-Only Regions | CALIPSO (2B-CLDCLASS-LIDAR) | Length of each CALIPSO-only cloudy region | nCO, nCALIPSO | Integer |
| Initial CALIPSO-Only Region Index | CALIPSO (2B-CLDCLASS-LIDAR) | Initial pixel of each CALIPSO-only cloudy region (indexed by where region is located in the CO) | nCO, nCALIPSO | Integer |
| Final CALIPSO-Only Region Index | CALIPSO (2B-CLDCLASS-LIDAR) | Final pixel of each CALIPSO-only cloudy region (indexed by where region is located in the CO) | nCO, nCALIPSO | Integer |

**Convective Core Information**

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| **Name** | **Satellite or Instrument (Data product)** | **Description** | **Dimension** | **Units or Type** |
| Core Latitudes | CloudSat (2B-GEOPROF) | Latitude coordinates of each convective core | nCO, ncore, ncoreprof | Degree |
| Core Longitudes | CloudSat (2B-GEOPROF) | Longitude coordinates of each convective core | nCO, ncore, ncoreprof | Degree |
| Initial Core Index | CloudSat (2CPC) | Initial index of each convective core to index CO profile indices | nCO, ncore | Integer |
| Final Core Index | CloudSat (2CPC) | Final index of each convective core to index CO profile indices | nCO, ncore | Integer |
| No of Convective Cores | CloudSat (2CPC) | Number of convective cores within each convective object from CloudSat convective flags | nCO | Integer |
| Length of Convective Cores | CloudSat (2CPC) | Length of contiguous deep convective core pixels from CloudSat convective flags | nCO, ncore | Integer |
| Z-weighted Core CoG Values | CloudSat (2B-GEOPROF, 2CPC) | Center of Gravity, weighted by Z, for each profile within each convective core | nCO, ncore, ncoreprof |  |
| Z-weighted Mean Core CoG | CloudSat (2B-GEOPROF, 2CPC) | Mean Center of Gravity, weighted by Z, for each convective core | nCO, ncore | km |
| Core Rain Top Height | CloudSat (2CPC) | Mean rain top height for each convective core | nCO, ncore | km |
| Mean Height of Z gt 10 dBZ for Core | CloudSat (2B- GEOPROF, 2CPC) | Conditional mean maximum height where Z > 10 dBZ for each convective core in CO | nCO, ncore | km |
| Mean Height of Z gt 0 dBZ for Core | CloudSat (2B- GEOPROF, 2CPC) | Conditional mean maximum height where Z > 0 dBZ for each convective core in CO | nCO, ncore | km |
| LW COD-weighted Mean CoG | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Center of gravity in optical-depth space, using LW COD, for each profile in CO | nCO, ncore | km |
| SW COD-weighted Mean CoG | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Center of gravity in optical-depth space, using SW COD, for each profile in CO | nCO, ncore | km |

**Precipitation and Water Mass Information**

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| --- | --- | --- | --- | --- |
| **Name** | **Satellite or Instrument (Data product)** | **Description** | **Dimension** | **Units or Type** |
| 2CPC Precip Flags | CloudSat (2CPC) | Precip flags for each profile in CO | nCO, nCOprof | integer |
| CloudSat Rain Rates | CloudSat (2C-Rain-Profile) | CloudSat rain rates for each profile in CO | nCO, nCOprof | mm/hr |
| AMSR Rain Rates | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | AMSR rain rates for each profile in CO | nCO, nCOprof | mm/hr |
| AMSR-CloudSat Mixed Rain Rates | CloudSat (2C-Rain-Profile)  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Whichever rain rate from CloudSat or AMSR-E is greater is chosen in each profile of CO | nCO, nCOprof | mm/hr |
| AMSR-E Mean Rain Rate | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean rain rate for each convective object | nCO | mm/hr |
| AMSR-E Conditional Mean Rain Rate | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean rain rate within each CO’s raining regions | nCO | mm/hr |
| AMSR-E Conditional Mean Convective Rain Rate | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean rain rate within CO’s deep convective region | nCO | mm/hr |
| AMSR-E Conditional Mean Stratiform Rain Rate | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean rain rate within CO’s stratiform region | nCO | mm/hr |
| AMSR-E Conditional Mean Shallow Convective Rain Rate | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean rain rate within CO’s shallow convective region | nCO | mm/hr |
| Mean Column Water Vapor | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean column water vapor for each convective object | nCO | mm |
| Mean Cloud Liquid Water Path | AMSR-E (2007-2010)/ AMSR2 (2011-2018) | Mean cloud liquid water path for each convective object | nCO | mm |
| Column-Integrated Ice Water Path | CloudSat (2C-ICE) | Column-integrated ice water path for each pixel in CO | nCO, nCOprof | g/m2 |
| Column-Integrated Snow Water Path | CloudSat (2C-SNOW-PROFILE) | Column-integrated snow water path for each pixel in CO | nCO, nCOprof | g/m2 |
| Column-Integrated Snow Water Path Uncertainty | CloudSat (2C-ICE) | Column-integrated snow water path fractional uncertainty for each pixel in CO | nCO, nCOprof | Fraction |
| Column-Integrated COD over Anvil Profiles | CloudSat (2B-FLXHR-LIDAR) | Vertically-summed COD within anvil region for each profile in CO | nCO, nCOprof | Float |
| Column-Integrated IWP over Anvil Profiles | CloudSat (2C-ICE) | Ice water path of anvil region for each profile in CO | nCO, nCOprof | g/m2 |

**Radiative Response Information\***

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| --- | --- | --- | --- | --- |
| **Name** | **Satellite/Instrument/Reanalyses (Data product)** | **Description** | **Dimension** | **Units or Type** |
| LW CRE | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Longwave CRE for each profile in CO | nCO, nCOprof | W/m2 |
| SW CRE | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Shortwave CRE for each profile in CO | nCO, nCOprof | W/m2 |
| Net CRE | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Net CRE for each profile in CO | nCO, nCOprof | W/m2 |
| Mean LW CRE | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean longwave CRE for each CO and CO +/- 50, 100, and 250 km radii | nCO, narea | W/m2 |
| Mean SW CRE | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean shortwave CRE for each CO and CO +/- 50, 100, and 250 km radii | nCO, narea | W/m2 |
| Mean Net CRE | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean net CRE for each CO and CO +/- 50, 100, and 250 km radii | nCO, narea | W/m2 |
| Fraction of NET CRE gt 0 | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Fraction of net CRE > 0 for each CO | nCO | Fraction |
| Fraction of NET CRE lt 0 | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Fraction of net CRE < 0 for each CO | nCO | Fraction |
| CO Mean Upwelling LW Fluxes at TOA | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky upwelling LW fluxes at top-of-atmosphere | nCO | W/m2 |
| CO Mean Upwelling LW Fluxes at TOA no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky upwelling LW fluxes at top-of-atmosphere | nCO | W/m2 |
| CO Mean Upwelling LW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky upwelling LW fluxes at surface | nCO | W/m2 |
| CO Mean Upwelling LW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky upwelling LW fluxes at surface | nCO | W/m2 |
| CO Mean Downwelling LW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky downwelling LW fluxes at surface | nCO | W/m2 |
| CO Mean Downwelling LW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky downwelling LW fluxes at surface | nCO | W/m2 |
| CO Mean Upwelling SW Fluxes at TOA | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky upwelling SW fluxes at top-of-atmosphere | nCO | W/m2 |
| CO Mean Upwelling SW Fluxes at TOA no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky upwelling SW fluxes at top-of-atmosphere | nCO | W/m2 |
| CO Mean Downwelling SW Fluxes at TOA | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky downwelling SW fluxes at top-of-atmosphere | nCO | W/m2 |
| CO Mean Downwelling SW Fluxes at TOA no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky downwelling SW fluxes at top-of-atmosphere | nCO | W/m2 |
| CO Mean Upwelling SW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky upwelling SW fluxes at surface | nCO | W/m2 |
| CO Mean Upwelling SW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky upwelling SW fluxes at surface | nCO | W/m2 |
| CO Mean Downwelling SW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky downwelling SW fluxes at surface | nCO | W/m2 |
| CO Mean Downwelling SW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky downwelling SW fluxes at surface | nCO | W/m2 |
| Component Mean Upwelling LW Fluxes at TOA | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky top-of-atmosphere upwelling LW flux averaged over each cloud type (listed at the top under dimensions) | nCO, ncldtype | W/m2 |
| Component Mean Upwelling LW Fluxes at TOA no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky top-of-atmosphere upwelling LW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Upwelling LW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky surface upwelling LW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Upwelling LW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky surface upwelling LW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Downwelling LW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky surface downwelling LW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Downwelling LW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky surface downwelling LW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Upwelling SW Fluxes at TOA | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky top-of-atmosphere upwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Upwelling SW Fluxes at TOA no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky top-of-atmosphere upwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Downwelling SW Fluxes at TOA | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky top-of-atmosphere downwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Downwelling SW Fluxes at TOA no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky top-of-atmosphere downwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Upwelling SW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky surface upwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Upwelling SW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky surface upwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Downwelling SW Fluxes at SFC | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean all-sky surface downwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| Component Mean Downwelling SW Fluxes at SFC no cloud | CloudSat/CALIPSO (2B-FLXHR-LIDAR) | Mean clear-sky surface downwelling SW flux averaged over each cloud type | nCO, ncldtype | W/m2 |
| CO Mean Cloud Greenhouse Effect | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | G: cloud greenhouse effect averaged over CO (CIPs) | nCO | Fraction |
| CO Mean Cloud Albedo Effect | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | A: cloud albedo effect averaged over CO (CIPs) | nCO | Fraction |
| CO Mean Ratio of Cloud Albedo to Greenhouse | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | N: ratio of cloud albedo effect to greenhouse effect averaged over CO (CIPs) | nCO | Fraction |
| CO Mean SW Cloud Radiative Efficiency at sfc | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RC,SW: SW cloud radiative efficiency at the surface averaged over CO (CIPs) | nCO | Fraction |
| CO Mean LW Cloud Radiative Efficiency at sfc | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RC,LW: LW cloud radiative efficiency at the surface averaged over CO (CIPs) | nCO | Fraction |
| CO Mean Cloud Radiative Efficiency at sfc | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RC: net cloud radiative efficiency (RC,SW+RC,LW) at the surface averaged over CO (CIPs) | nCO | Fraction |
| CO Mean Cloud Radiative Efficiency in atm | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RH: cloud radiative efficiency in the atmosphere averaged over CO (CIPs) | nCO | Fraction |
| Component Mean Cloud Greenhouse Effect | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | G: cloud greenhouse effect averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |
| Component Mean Cloud Albedo Effect | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | A: cloud albedo effect averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |
| Component Mean Ratio of Cloud Albedo to Greenhouse | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | N: ratio of cloud albedo effect to greenhouse effect averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |
| Component Mean SW Cloud Radiative Efficiency at sfc | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RC,SW: SW cloud radiative efficiency at the surface averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |
| Component Mean LW Cloud Radiative Efficiency at sfc | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RC,LW: LW cloud radiative efficiency at the surface averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |
| Component Mean Cloud Radiative Efficiency at sfc | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RC: net cloud radiative efficiency (RC,SW+RC,LW) at the surface averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |
| Component Mean Cloud Radiative Efficiency in atm | CloudSat/CALIPSO (2B-FLXHR-LIDAR, 2C-RAIN-PROFILE);  AMSR-E (2007-2010)/ AMSR2 (2011-2018) | RH: cloud radiative efficiency in the atmosphere averaged over each cloud type (CIPs) | nCO, ncldtype | Fraction |

**\*** The radiative fluxes and cloud impact parameters averaged over the full CO are also calculated and averaged over each distinct cloud type. These variables are stored with the same name, but instead of “CO Mean” in the variable name, it is “Component Mean”. Each of these variables have dimension = nCO, ncldtype.

**Environmental Conditions**

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| **Name** | **Satellite/Instrument/Reanalyses (Data product)** | **Description** | **Dimension** | **Units or Type** |
| MERRA SST | MERRA (MERRA-AUX 2006-2010)/ MERRA 2 (MERRA2-AUX 2006-2018) | Instantaneous sea surface temperature for each profile in CO | nCO, nCOprof | K |
| MERRA CAPE | MERRA (MERRA-AUX 2006-2010)/ MERRA 2 (MERRA2-AUX 2006-2018) | Instantaneous CAPE for each profile in CO | nCO, nCOprof | J/kg |
| MERRA Vertical Motion | MERRA (MERRA-AUX 2006-2010)/ MERRA 2 (MERRA2-AUX 2006-2018) | Instantaneous vertical motion at 500 hPa for each profile in CO | nCO, nCOprof | Pa/s |
| Monthly Mean MERRA2 Omega 500 | MERRA 2 monthly-mean data (2006-2018) | Monthly-mean vertical motion at 500 hPa matched to coordinates of largest integrated core CoG in CO | nCO | Pa/s |
| Monthly Mean MERRA2 SST | MERRA 2 monthly-mean data (2006-2018) | Monthly-mean surface temperature matched to coordinates of largest integrated core CoG in CO | nCO | K |
| ECMWF Magnitudinal Vertical Wind Shear | ECMWF (ECMWF-AUX) | Magnitude difference in layer-averaged winds between two layers for the layers defined above averaged over CO (shear = (u2+v2)1/2) | nCO, nshear | m/s |
| ECMWF Directional Vertical Wind Shear | ECMWF (ECMWF-AUX) | Geometric relation between horizontal wind angles (theta = arctan[v/u]) for the layers defined above averaged over CO | nCO, nshear | Degree |
| ECMWF U-Wind Shear | ECMWF (ECMWF-AUX) | U-wind shears calculated for the layers defined above (e.g., ushear = ulayer1 – ulayer2) | nCO, nshear, nCOprof | m/s |
| ECMWF V-Wind Shear | ECMWF (ECMWF-AUX) | V-wind shears calculated for the layers defined above (e.g., vshear = vlayer1 – vlayer2) | nCO, nshear, nCOprof | m/s |

**Aerosol information from MODIS MYD08\_D3 Collection 6 Daily 1x1 deg Grid Data**

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| --- | --- | --- | --- | --- |
| **Name** | **Satellite/Instrument/Reanalyses (Data product)** | **Description** | **Dimension** | **Units or Type** |
| Mean AOD | MODIS (MYD08\_D3) | Mean Aerosol Optical Depth (AOD) interpolated over CO | nCO | Float |
| AOD Values | MODIS (MYD08\_D3) | AOD values for every MODIS pixel found in CO | nCO, nMODpix | Float |
| Mean AOD Longitude | MODIS (MYD08\_D3) | Mean longitude where mean CO AOD is located | nCO | degrees |
| AOD Longitude Values | MODIS (MYD08\_D3) | List of longitudes for each AOD in CO | nCO, nMODpix | degrees |
| Mean AOD Latitude | MODIS (MYD08\_D3) | Mean latitude where mean CO AOD is located | nCO | degrees |
| AOD Latitude Values | MODIS (MYD08\_D3) | List of latitudes for each AOD in CO | nCO, nMODpix | degrees |
| Mean Aerosol Index (AI) | MODIS (MYD08\_D3) | Mean AI calculated from a grid of Angstrom exponents and effective optical depths over ocean-only COs | nCO | Float |
| AI Values | MODIS (MYD08\_D3) | AI values for every MODIS pixel found in ocean-only COs | nCO, nMODpix | Float |
| Mean AI Longitude | MODIS (MYD08\_D3) | Mean longitude where mean ocean-only CO AI is located | nCO | degrees |
| AI Longitude Values | MODIS (MYD08\_D3) | List of longitudes for each AI in ocean-only CO | nCO, nMODpix | degrees |
| Mean AI Latitude | MODIS (MYD08\_D3) | Mean latitude where mean ocean-only CO AI is located | nCO | degrees |
| AI Latitude Values | MODIS (MYD08\_D3) | List of latitudes for each AI in ocean-only CO | nCO, nMODpix | degrees |