**National Aeronautics and Space Administration**

**Goddard Earth Sciences Data and Information Services Center (GES DISC)**

# README Document for TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree

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Revision History

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| 09/04/15 | Some rewriting and editing from the original provided by Janice Bytheway | Bill Teng |
| 02/16/16 | Updated Mirador keyword link in Sec. 5.1 | Bill Teng |

# Table of Contents

# 1.0 Introduction

This document provides basic information for using the TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set. This data set was generated with a focus on estimating accumulated precipitation with estimates of its uncertainty.

## 1.1 Data Set Description

The TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set was created as part of the "Developing Consistent Earth System Data Records for the Global Terrestrial Water Cycle" MEaSURES Project. The data set provides estimates of accumulated precipitation from the Tropical Rainfall Measuring Mission (TRMM) and Other Data Precipitation Data set (TRMM 3B42; Huffman et al., 2007), along with estimates of the uncertainty in the TRMM 3B42 made by Bytheway and Kummerow (2013). The data set covers both ocean and land from $50^o$ N-$50^o$ S during the period from 1998-2010 at $0.25^o$ resolution.

The TRMM 3B42 product combines precipitation estimates from both passive microwave and infrared satellite systems, including TRMM Microwave Imager (TMI; Kummerow et al., 1998), Special Sensor Microwave/Imager (SSM/I; Hollinger et al., 1990), Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-E; Kawanishi et al., 2003), Advanced Microwave Sounding Unit-B (AMSU-B; Saunders et al., 1995), and 10.7 µm infrared (IR) data from several internationally-operated geostationary satellites using the TRMM Multi-satellite Precipitation Analysis (TMPA) algorithm (Huffman et al., 2007). Version 7 of the 3B42 data set also includes data from the Special Sensor Microwave Imager/Sounder (SSMIS; Kunkee et al., 2008) and the Microwave Humidity Sounder (MHS; Goodrum et al., 2009; Huffman and Bolvin, 2014). Ground-based data from the Global Precipitation Climatology Centre (GPCC; Schneider et al., 2010) monthly rain gauge analyses are also used to scale the accumulated rainfall on a monthly basis, in order to achieve consistency between the monthly gauge products and monthly accumulated rainfall in the 3B42 product.

## 1.2 Algorithm Background

### 1.2.1 TRMM Multi-satellite Precipitation Analysis (TMPA)

TMPA processing occurs in four stages, described in detail by Huffman et al. (2007).

1. Precipitation from microwave imagers are estimated, using the Goddard Profiling Algorithm (Kummerow et al., 1996; Olson et al., 1999), while precipitation estimates from AMSU-B are provided by the National Environmental Satellite, Data, and Information Service (NESDIS), using the Zhao and Weng (2002) and Weng et al. (2003) algorithms. Precipitation is retrieved at all microwave fields of view (FOVs), and each precipitation estimate is calibrated by a selected reference satellite data set and averaged to a quarter-degree grid. Grid boxes containing more than 40% ambiguous satellite FOVs are set to "missing," and each grid is populated with the "best" data from all available

overpasses. When FOVs from multiple similar instruments (i.e., imagers with imagers and sounders with sounders) are available in the same grid box, the data are averaged.

2. The calibrated and combined microwave precipitation estimates are used to calibrate the precipitation estimates from the infrared sensors, which are from the Climate Prediction Center (CPC) merged IR data set (Janowiak et al., 2001), for the period from February 7, 2000 onward, and from the National Climatic Data Center GridSat-B1 data set (Knapp et al., 2011), for the period from January 1, 1998 to February 7, 2000.
3. The microwave and IR precipitation estimates are combined, using microwave "as is," where available, and filling in with microwave-calibrated IR elsewhere.
4. Monthly rain gauge data from GPCC are used to scale the combined microwave and IR estimates at the monthly scale.

TMPA processing occurs twice, resulting in (1) a "real time" product with climatological calibration (3B42-RT) available approximately 9 hours after real time and (2) a research-quality product (3B42) available about 2 weeks after the end of the month of data collection and with month-to-month calibration. Included in the TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set is the Version 7 TRMM 3B42 product. These data have been found to perform best in convective, heavy rain, warm season regimes, and poorly in midlatitude cool season regimes (Ebert, 2005). Huffman et al. (2007) have found no obvious seasonal cycle in the bias, with a mean absolute monthly bias of 9% for 2004, when compared to an Australian gauge network.

TRMM 3B42 is interpreted as the rain rate effective at the nominal observation time. That is, the rain rate given in each 3-hourly file is valid for ± 90 minutes from the time indicated in the file name. As such, the accumulated rainfall for each three-hour period for the TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set was calculated as the sum of the previous observation's rain rate occurring over 1.5 hours and the current observation's rain rate occurring over 1.5 hours. For example, the accumulated rainfall (in mm) from 3 UTC to 6 UTC at a given location is the 3 UTC rain rate (in mm/hour) x 1.5 hours plus the 6 UTC rain rate x 1.5 hours.

### 1.2.2 Uncertainty Calculation

Uncertainties in the TRMM 3B42 product were calculated using the National Centers for Environmental Prediction (NCEP) Stage IV hourly, 4 km radar-gauge precipitation product (Lin and Mitchell, 2005), available over the United States, as a reference. The Stage IV radar data were averaged onto a 0.25° resolution grid and accumulated for the three hours prior to the nominal 3B42 analysis time, in order to match the resolution of the 3B42 data. There was no accounting for any uncertainty in the radar measurements.

In order to obtain global estimates of the uncertainty in the 3B42 product, we determined the relative uncertainties in the precipitation estimate, related to the characteristics of the precipitation being observed, and related the results over the relatively data-rich United States to similar precipitating systems globally.

Self-similarity of global precipitation regimes was determined using the monthly probability distribution function (PDF) of rainfall in a 0.25-degree 3B42 grid box. The 3-hourly PDFs of accumulated rainfall were calculated by binning the 3B42 rainfall into one of 11 bins. The first bin represents the frequency of occurrence of zero observed precipitation in the grid box. The remaining bins represent the ranges of accumulation where 10% of all non-zero observations from 50° N-S occur over the 4-year period from 2004-2007. The eleven accumulation bins are shown in Table 1. The PDFs were calculated monthly in order to account for seasonal variation in the types and amounts of rainfall in a grid box. Additionally, global PDFs were created encompassing the entire 2004-2007 time period of interest.

Table 1. Accumulation bins used to create PDFs of 3-hourly accumulation for cluster analysis.

| Bin # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Accumulation Range [mm/3hr] | =0.0 | 0.0-0.09 | 0.09 - 0.24 | 0.24 - 0.45 | 0.45 - 0.74 | 0.74 - 1.16 | 1.16 - 1.78 | 1.78 - 2.75 | 2.75 - 4.45 | 4.45 - 8.30 | >8.30 |

Cluster analysis (Anderberg, 1973) was used to group similar PDFs together and was performed on the global 4-year PDFs of 3-hourly precipitation. Five clusters were selected to represent the majority of the global rainfall regimes (Bytheway and Kummerow, 2013). The centroids of the five clusters are shown in Figure 1, and the global distribution of the clusters is shown in Figure 2. The rainfall regimes represented by the five clusters are as follow:

- Cluster 1 (grey) - Orographic: Frequent precipitation occurrence. Mostly low accumulations.
- Cluster 2 (blue) - Mid-latitude: Moderate frequency of occurrence. Approximately equal likelihood for all 3-hourly accumulation bins.
- Cluster 3 (dark blue) - Transitional: Often located between desert and mid-latitude regimes. Somewhat less frequent precipitation than in the mid-latitude cluster. Approximately equal likelihood for all 3-hourly accumulation bins.
- Cluster 4 (light blue) - Desert: Infrequent precipitation. Most precipitation is very light.
- Cluster 5 (green) - Rainforest: Frequent precipitation. Most often moderate to heavy.

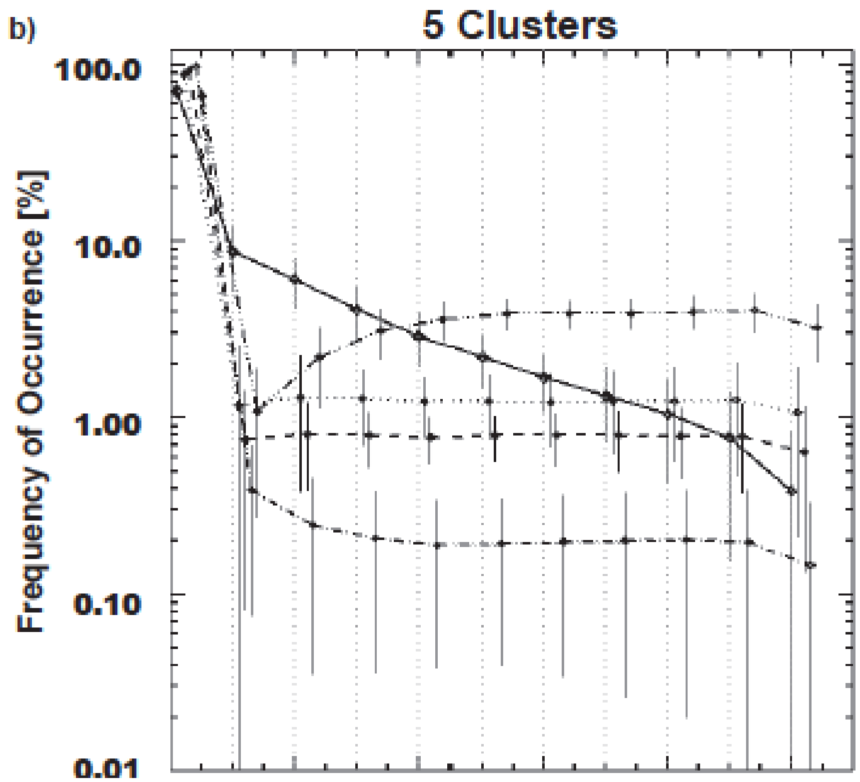


Figure 1. Cluster centroid values for each accumulation bin in Table 1 and the standard deviation of the members of each cluster, for the five clusters used to describe global rainfall regimes.

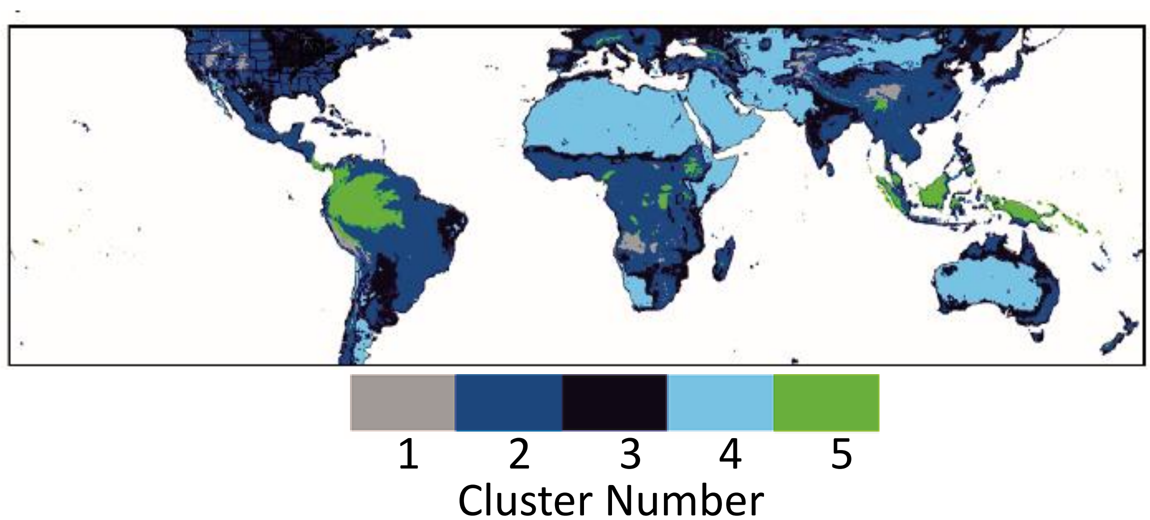


Figure 2. Global distribution of the five clusters used to describe rainfall regimes.

Using the 48 monthly PDFs of 3-hourly accumulated precipitation in the United States, each grid box was assigned to one of the five clusters. Then, using the 3-hourly 3B42 and Stage IV radar observations over the contiguous United States, the root mean square error (RMSE) for each cluster was calculated. The calculated RMSE encompasses all of the sources of uncertainty inherent in the satellite measurement, including both the spatial and temporal sampling uncertainty, as well as retrieval and radar errors.

The RMSE for each cluster was calculated with respect to 3-hourly accumulation, with different values calculated for each 1-mm/3-hr accumulation bin. Because we are now describing the behavior of the uncertainty with respect to accumulation, rather than the general characteristics of the rainfall in a given cluster, we switch from the unequal accumulation bins described in Table 1 to this more even distribution. The equation describing the curve that best fits the relationship between the accumulated precipitation and the relative RMSE (defined as the RMSE divided by the average accumulation in that bin) was then used to globally infer the uncertainty of the 3B42 observations.

Figure 3 shows the behavior of the relative RMSE (in percent) of each cluster with respect to accumulation. Each cluster starts out with relative RMSE values in excess of 100%, which decrease with increasing accumulation. As accumulated rainfall exceeds ~10 mm/3 hr, the uncertainty values converge to a range between 75 and 85 percent. At accumulated rainfall greater than 20 mm/3 hr (not shown), uncertainty values continue to decrease, although very slowly. The curves become increasingly noisy towards very high accumulations, where only a small number of data points are available.

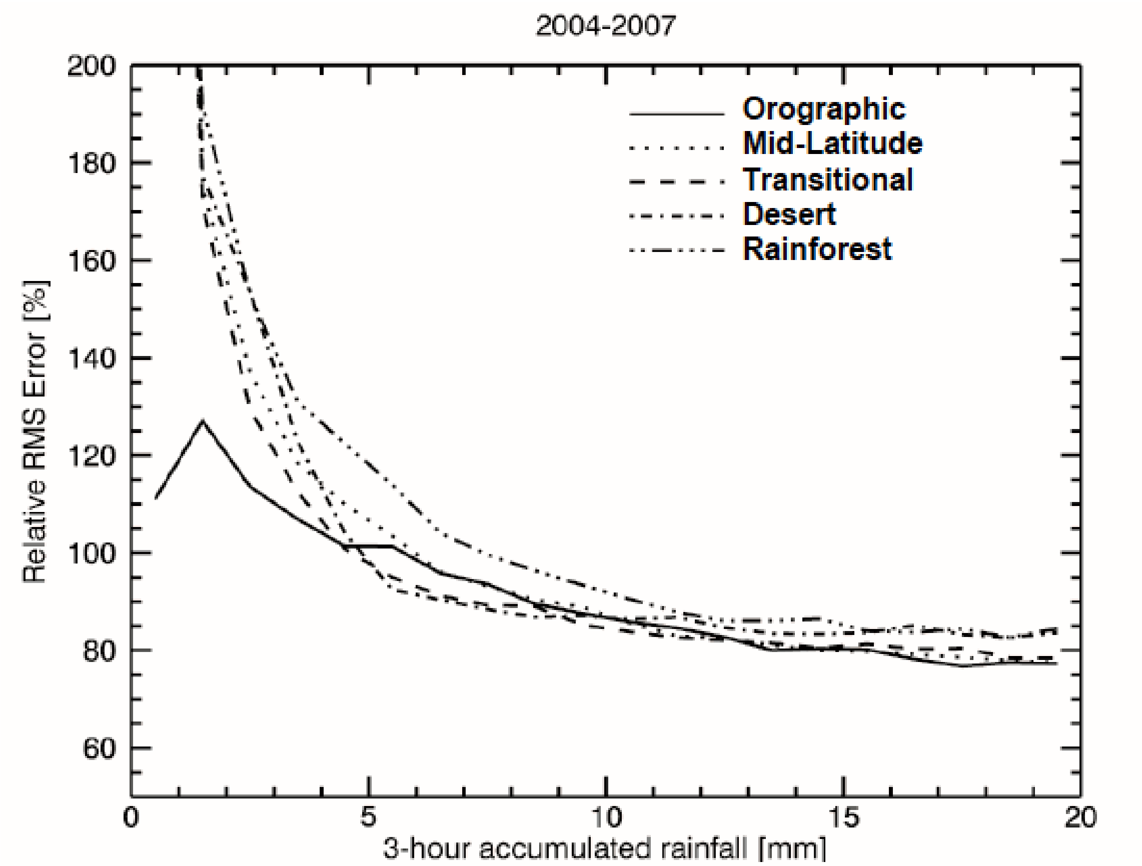


Figure 3. Relative RMSE vs. 3-hourly accumulated rainfall for the five global clusters.

### 1.3 Data Disclaimer

The TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set was produced as part of the NASA MEaSUREs program. It follows the TRMM Multisatellite Precipitation Analysis (TMPA) (Huffman et al., 2007), with the addition of uncertainty estimates as a function of precipitation rate and regime characteristics. Because the TRMM 3B42 product, based on TMPA, requires a number of passive microwave sensors in orbit simultaneously, it is available only from 1998 onward. Before January 1998, there are insufficient data for 3-hourly products, and only daily precipitation is available.

## 2.0 Data Organization

The 3-hourly precipitation estimates from TRMM 3B42 are packed into daily files, each containing the center latitude and longitude of 0.25° grid boxes and two 8 (time) x 720 (lat) x 1440 (lon) arrays of, respectively, the 3-hourly accumulated rainfall and the estimates of RMSE.

### 2.1 File Naming Convention

File names are formatted as follows:

WC_MULTISEN_PREC_025_L3_V001_YYYYMMDDT00Z.nc4

where

- WC_MULTISEN_PREC expands to **W**ater **C**ycle **MULTISEN**sor **PREC**ipitation
- 025 indicates 0.25$^o$ spatial resolution
- L3 indicates Level-3 gridded data
- V001 indicates version 1 of data product
- YYYYMMDD indicates date of data acquisition
- T00Z indicates starting time (hour) for data contained in the file
- .nc4 indicates netCDF4 file format

Filename example: WC_MULTISEN_PREC_025_L3_V001_20100601T00Z.nc4

### 2.2 File Format and Structure

TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data files are in netCDF4 (http://www.unidata.ucar.edu/software/netcdf/docs/), which facilitates the creation, access, and sharing of array-oriented data in a form that is self-describing and portable.

Each daily file contains geolocation information (latitude and longitude of grid box centers), starting and ending accumulation times for each 3-hourly field, and two data fields, each of which contains data for all eight 3-hourly periods.

- prec - 3-hourly accumulated precipitation (mm) from TRMM 3B42 (Sec. 1.2.1). Each 24-hour file starts at the nominal file time, i.e., accumulation begins at 21 UTC on the day preceding that indicated in the file name.
- rmse - Root Mean Square Error (mm) of the precipitation estimates (Sec. 1.2.2). Grid boxes with zero rainfall indicated by 3B42 are assigned an RMSE of 3.0 mm.

There is also a set of global attributes defining the metadata for the data set. More details are provided in Section 3.0.

## 3.0 Data Contents

### 3.1 Dimensions

3-hourly multisensor precipitation data and uncertainty estimates are stored in 3-dimensional arrays with dimensions (time, lat, lon), where time = 8, corresponding to the eight 3-hourly accumulation periods; lat = 720, the number of grid boxes in the north-south direction; and lon = 1440, the number of grid boxes in the east-west direction.

### 3.2 Global Attributes

In addition to SDS (Scientific Data Sets) arrays containing variables and dimension scales, global metadata are also stored in the files. Some metadata are required by standard conventions; some are included to meet data provenance requirements; and others are provided as a convenience to users of the TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set. A summary of global attributes present in all files is shown in Table 2.

Table 2. Global metadata attributes associated with each SDS of the TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set.

| **Global Attribute** | **Type** | **Description** |
|---|---|---|
| Title | String | Full data set title |
| ProcessingCenter | String | Location of data set production |
| ContactPersonName<br>ContactPersonRole<br>ContactPersonEmail<br>ContactPersonAddress | String | Contact information for data set producers |
| Source | String | Algorithm basis for the 3-hourly Multisensor Precipitation with Uncertainty Estimates data set |
| ProductReference1<br>ProductReference2<br>ProductReference3 | String | Citation information for references on TRMM 3B42 data set and uncertainty estimate methodology |
| Identifier_product_doi | String | Digital object identifier of data set |
| Identifier_product_doi_authority | String | Digital object identifier host |
| ShortName | String | Product short name |
| ProcessingDate | String | Date of file creation, yyyy-mm-dd |
| VersionID | String | Product version number |
| Conventions | String | CF conventions followed |
| LocalGranuleID | String | File name |
| Format | String | File format |
| RangeBeginningDate | String | Start date of the data in the file |
| RangeBeginningTime | String | Time stamp of first temporal field |
| RangeEndingDate | String | End date of the data in the file |
| RangeEndingTime | String | Time stamp of final temporal field |
| NorthBoundingCoordinate | String | Center latitude of northernmost grid box |
| SouthBoundingCoordinate | String | Center latitude of southernmost grid box |
| EastBoundingCoordinate | String | Center longitude of easternmost grid box |
| WestBoundingCoordinate | String | Center longitude of westernmost grid box |

A list of key metadata fields can be found in Table 3. Global attributes in a TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data file can be viewed with the *ncdump* software: ncdump –h -c <file>

Table 3. Key metadata fields

| **Name** | **Type** | **Description** |
|---|---|---|
| FillValue | float32 | Floating-point value used to denote missing data |
| long_name | String | Long descriptive variable name |
| standard_name | String | Standard description of the variable as defined in CF conventions |
| Units | String | Units of a variable |

# 4.0 Options for Reading the Data

The following are a few of the many command line and visualization tools available for reading netCDF4 format data, such as the TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data files. For more comprehensive lists of tools, please see the following:

https://www.unidata.ucar.edu/software/netcdf/docs/netcdf_tools.html

https://www.hdfgroup.org/products/hdf5_tools/

## 4.1 Command Line Utilities

### 4.1.1 ncdump (free)

The ncdump tool generates the CDL (Common Data Language) text (ASCII) representation of a netCDF or compatible file and writes to standard output. The tool can also be used as a simple browser for netCDF files, to display the dimension names and lengths; variable names, types, and shapes; attribute names and values; and, optionally, the values of data for all variables or selected variables. A common use of ncdump is with the –h option, with which only the header information is displayed. The ncdump tool comes with the netCDF library as distributed by Unidata.

http://www.unidata.ucar.edu/downloads/netcdf/

### 4.1.2 h5dump (free)

The h5dump tool enables users to examine the contents of an HDF5 file and dump those contents to an ASCII file or, optionally, as XML or binary outputs. It can display the contents of the entire HDF5 file or selected objects, which can be groups, data sets, a subset of a data set, links, attributes, or datatypes. The h5dump tool is included with the HDF5 distribution from The HDF Group.

https://www.hdfgroup.org/HDF5/release/obtain5.html

### 4.1.3 NCO (free)

The netCDF Operator (NCO) (http://nco.sourceforge.net/) toolkit manipulates and analyzes data stored in netCDF-accessible formats, including DAP, HDF4, and HDF5.

### 4.1.4 CDO (free)

CDO (Climate Data Operators) (https://code.zmaw.de/projects/cdo) is a collection of command line operators to manipulate and analyze climate and Numerical Weather Prediction (NWP) model data.

## 4.2 Visualization Tools

### 4.2.1 Ncview (free)

Ncview is a quick and easy way to visualize the contents of netCDF files.

http://meteora.ucsd.edu/~pierce/ncview_home_page.html

### 4.2.2 ncBrowse (free)

ncBrowse is a Java application that provides flexible, interactive graphical displays of data and attributes from a wide range of netCDF data file conventions.

http://www.epic.noaa.gov/java/ncBrowse/

### 4.2.3 Panoply (free)

Panoply is a Java application, developed by the NASA Goddard Institute for Space Studies (GISS), that plots geo-referenced and other arrays from netCDF, HDF, GRIB, and other data types. Among other capabilities, Panoply enables one to slice and plot geo-referenced latitude-longitude, latitude-vertical, longitude-vertical, time-latitude, or time-vertical arrays from larger multidimensional variables; combine two geo-referenced arrays in one plot by differencing, summing, or averaging; plot maps using various map projections; and access remote catalogs to retrieve data files.

http://www.giss.nasa.gov/tools/panoply/

### 4.2.4 HDFView (free)

HDFView is a Java-based visual tool created by The HDF Group for browsing and editing HDF4 and HDF5 files. It allows users to view all objects in an HDF file hierarchy, which is represented as a tree structure, and create, add, delete, and modify object contents and attributes.

https://www.hdfgroup.org/products/java/hdfview/

### 4.2.5 IDL netCDF tools (commercial)

Users familiar with the IDL programming language (http://www.exelisvis.com/ProductsServices/IDL.aspx) can use the netCDF functions available with the IDL software package to read and visualize the data.

#### 4.2.6 GrADS netCDF tools (free)

Users familiar with the GrADS programming language (http://iges.org/grads/) can use the netCDF functions available with the GrADS software package to read and visualize the data.

#### 4.2.7 NCL (free)

The NCAR Command Language (NCL) (http://www.ncl.ucar.edu/) is a free interpreted language designed specifically for scientific data processing and visualization.

## 5.0 Data Services

### 5.1 Mirador

Mirador is a GES DISC earth science data search and download tool. It provides a simple interface for users to make basic keyword, temporal, and spatial searches. More advanced, event-based searches are also possible. An interactive shopping cart offers various download options.

http://mirador.gsfc.nasa.gov/

The TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set can be keyword searched with "precipitation" or accessed via Mirador's "Projects" view.

http://mirador.gsfc.nasa.gov/cgi-bin/mirador/collectionlist.pl?keyword=WC_MULTISEN_PREC_025

### 5.2 OPeNDAP

The Open-source Project for a Network Data Access Protocol (OPeNDAP) provides a means for requesting and accessing data across the internet, in a form usable by OPeNDAP clients, i.e., clients that can remotely access OPeNDAP-served data (e.g., Panoply, IDL, MATLAB, GrADS, IDV, McIDAS-V, Ferret). OPeNDAP provides the ability to retrieve subsets of files and to aggregate data from several files in one transfer operation.

The TMPA/TMI/TRMM Precipitation and Uncertainty 3-Hourly Level-3 0.25-degree data set is available from the GES DISC through OPeNDAP:

http://measures.gsfc.nasa.gov/opendap/TerrestrialWaterCycle/WC_MULTISEN_PREC_025.001/contents.html

## 6.0 More Information

### 6.1 Other Precipitation Resources

For other precipitation and related data available at the GES DISC, please see

http://disc.sci.gsfc.nasa.gov/precipitation

For other precipitation and related data available elsewhere, please search NASA's Global Change Master Directory (GCMD) at

http://gcmd.nasa.gov/

### 6.2 Point of Contact

Name: GES DISC Help Desk
URL: http://disc.sci.gsfc.nasa.gov/
E-mail: gsfc-help-disc@lists.nasa.gov
Phone: 301-614-5224
Fax: 301-614-5268
Address: Goddard Earth Sciences Data and Information Services Center
Attn: Help Desk
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USA

### 6.3 Acronyms

| | |
|---|---|
| AMSR-E: | Advanced Microwave Scanning Radiometer - Earth Observing System |
| AMSU-B: | Advanced Microwave Sounding Unit –B |
| CPC: | Climate Prediction Center |
| FOV: | Field of View |
| GPCC: | Global Precipitation Climatology Centre |
| IR: | Infrared |
| MEaSUREs: | Making Earth System Data Records for Use in Research Environments |
| NCEP: | National Centers for Environmental Prediction |
| PDF: | Probability Distribution Function |
| RMSE: | Root Mean Square Error |
| SSM/I: | Special Sensor Microwave/Imager |
| SSMIS: | Special Sensor Microwave Imager/Sounder |
| TMI: | TRMM Microwave Imager |
| TMPA: | TRMM Multisatellite Precipitation Analysis |
| TRMM: | Tropical Rainfall Measuring Mission |

## 7.0 Acknowledgments

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