University of Utah TRMM precipitation and cloud feature database

Description Version 1.0

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1. Introduction

The Tropical Rainfall Measuring Mission (TRMM, Kummerow et al., 1998) is a joint mission between NASA and the National Space Development Agency (NASDA) of Japan designed to monitor and study tropical rainfall. Onboard instruments including Precipitation Radar (PR), TRMM Microwave Imager (TMI), Visible Infrared Radiometers (VIRs), Cloud and Earth Radiant Energy Sensor (CERES) and Lightning Imaging Sensor (LIS) provide invaluable measurements of atmosphere.

One direction of our research is to generalize the precipitation and cloud features from TRMM measurements and study the radar, passive microwave and lightning characteristics of precipitating systems in the Tropics. A database of PR and TMI rain estimates, VIRS IR brightness temperature and LIS lightning data inside and outside the PR swath in these precipitation and cloud features is constructed.

Using this database, many valuable researches have been accomplished, including rainfall estimates validation (Nesbitts et al., 2004), diurnal cycle of precipitation systems (Nesbitt and Zipser, 2003), global distribution of storms with LIS-detected lightning (Cecil et al., 2005), deep convection reaching the tropical tropopause layer (Liu and Zipser, 2005), rainfall production and convective organization (Nesbitt et al. 2006), and the categorization of extreme thunderstorms by their intensity proxies (Zipser et al., 2006).

This document describes the TRMM cloud and precipitation database construction procedures and output parameters in three levels of processing as shown in Figure 1.

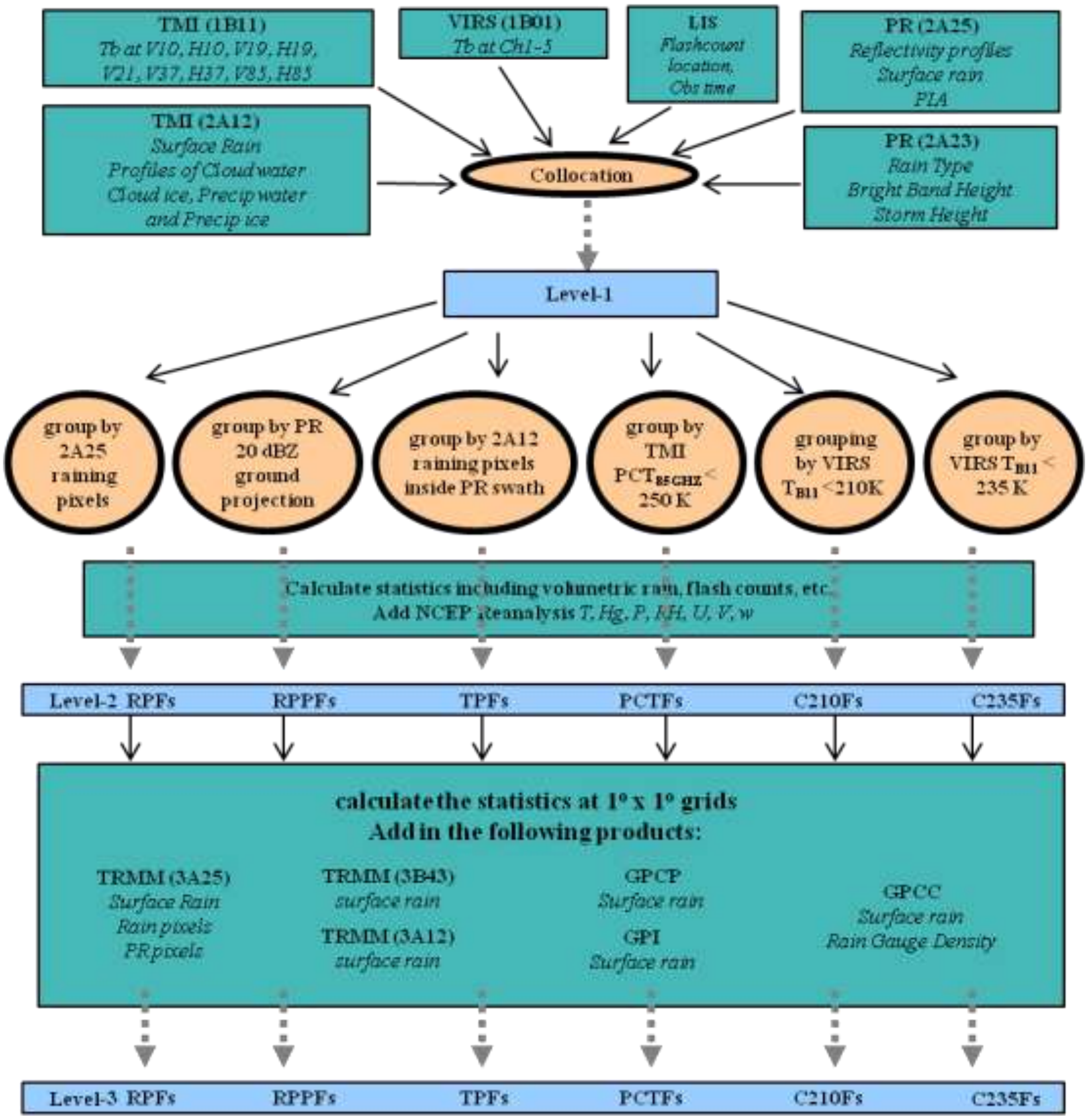

Figure 1. Flow chart of three levels of the University of Utah TRMM feature database.

2. Level-1

As shown in Figure 1, level-1 data are produced with a combination of the version 6 orbital 1B01, 1B11, 2A12 (Kummerow et al., 2001), 2A23, 2A25 (Iguchi et al., 2000) and LIS granules after TMI-PR parallax correction and TMI-PR-LIS-VIRS nearest neighbor collocation. The output data is saved for each satellite orbit. The details of these procedures and calculated parameters are introduced in this section.

2.1 Collocation between 1B11 and 2A25

The orbit data stored in TMI 1B11 have two resolutions. One is on the low resolution (104 pixels in cross scans) for 10, 19, 21, 37 GHz channels including the brightness temperatures. Another is saved on the high resolution (208 pixels in cross scans) for

85GHz channels. The collocation between PR 2A25 and TMI 1B11 are performed only on the high TMI resolution inside PR swath. The idea is not interpolating the pixels to PR coordinates. Rather, we assign a TMI pixel to each PR pixel. The method of “ the nearest neighbor” is applied to assign these TMI pixels. As the result, each PR pixel has a corresponding TMI pixel. Then we save the indices of these TMI pixels for future use. The collocation for low resolution can be easily obtained by degrading the indices from high resolution grids.

2.2 Parallax correction

Because TMI scans with 52^o conical angle and PR scans nadir, there could be a problem if the microwave scattering signals are from elevated hydrometeors, such as high convective cells. For this reason, we used a simple parallax correction method that simply move the TMI data coordinates data backwards for one scan shown as Figure 2. After this correction, there are better correspondences between PR and TMI measurements for high convective cells. However, the correspondences between PR and TMI for shallow precipitations become worse because of the overcorrection. This could lead to problems when calculate the microwave scattering properties inside a shallow precipitation system defined by PR surface rainfall area.

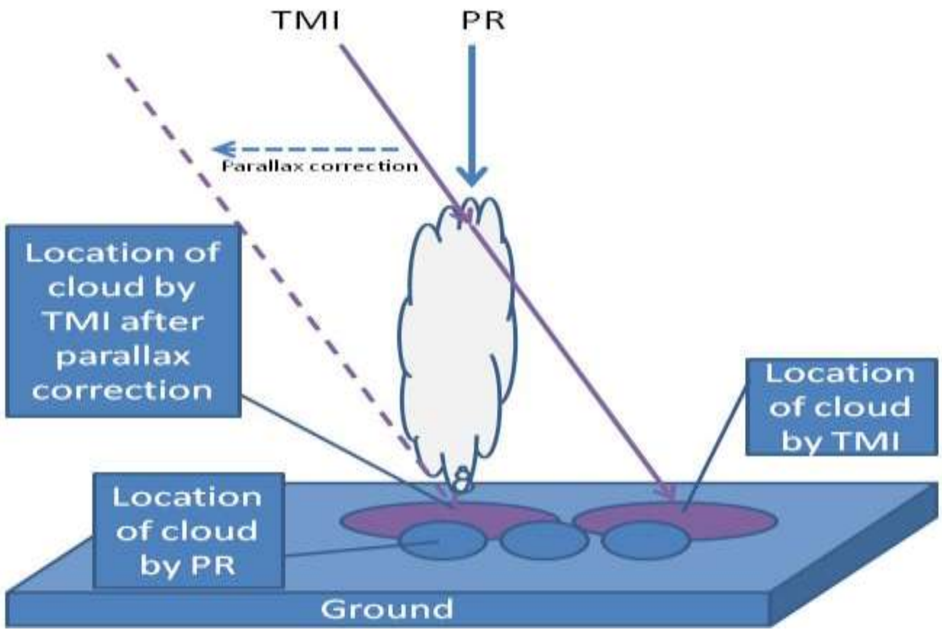

Figure 2. Schematic diagram of parallax correction.

2.3 Collocation between 1B01 and 2A25

Since VIRS scans in nadir, it is relatively easier to collocate VIRS data with PR data. We simply applied the nearest neighbor to degrade the VIRS radiance data onto PR pixel coordinates. Then the brightness temperatures at five VIRS channels at each PR pixel are calculated from radiances at the nearest VIRS pixel.

2.4 LIS data manipulation
LIS data collocation method was developed by Chris West and Dan Cecil in 1999. First, the observation view time is interpolated into 0.1 degree resolution, then use nearest neighbor method to assign each one of the flash event to TMI pixel coordinates. Following the collocation between PR and TMI, each flash can be assigned to a PR pixel for further analysis.

2.5 Output parameters
We have chosen some interesting parameters from 1B01, 1B11, 2A25, 2A12, and some derived parameters for storing into the level-1 products. These parameters include:

Parameters from PR 2A25		
Orbit	1 integer	Orbit number
version	1 float	Version number
rays	1 integer, 49	Number of rays in each scan
scans	1 integer	Number of scans in the orbit
year	Float array (scans)	Year
month	Float array (scans)	Month
day	Float array (scans)	Day
hour	Float array (scans)	Hour
minute	Float array (scans)	Minute
second	Float array (scans)	Second
lon	Float array (rays, scans)	Longitude
lat	Float array (rays, scans)	Latitude
Rangebinnum*	Float array (7,rays,scans)	Range bin number
nearsurfz	Float array (rays,scans)	Near surface reflectivity (0.01 dBZ)
nearsurfrain	Float array (rays,scans)	Near surface rain (mm/hr)
Pia*	Float array (3,rays,scans)	Path integrated attenuation
method	Float array (rays,scans)	Z-R retrieval method
Zrparamnode*	Float array (5,rays,scans)	Z-R retrieval parameters
Scan#	Float array (valid scans)	scan indices of pix with echoes
Ray#	Float array (valid scans)	Ray indices of pix with echoes
Pr_dbz#	Float array (valid scans, 80)	Reflectivity profiles with echoes (0.01 dBZ)
Colohi^	Float array (rays,scans)	Indices of TMI pixels for each PR pixels

*Detail see interface control specification TSDIS.MDL-02.5 volume 4, 1-20
In order to reduce the file size, we only save the reflectivity profiles with valid echoes. For example, one may use lon[ray[i], scan[i]] to obtain the longitude of the reflectivity profiles pr_dbz[i,*].
^ These indices can be used to find the collocated TMI measurements for each PR

pixels. For example, one may use tmi.rain[colohi[I,j]] to find the 2A12 rainfall estimates for PR pixel (i,j) at longitude lon[I,j] and latitude lat[I,j].

Parameters from PR 2A23		
version	1 float	Version number
Raintype2a23	Integer array (rays, scans)	Rain type 100-153: strat 200-293: convective
HBB2A23	Integer array (rays, scans)	Height of bright band (m)
HFREEZ2A23	Integer array (rays, scans)	Height of freezing level (m)
Stormh	Integer array (rays, scans)	Storm height (m)

*Detail see interface control specification TSDIS.MDL-02.5 volume 4, 1-9

Parameters from PR 1B01		
boost	1 integer	0: before, 1: after boost
Ch1	Float array (rays, scans)	0.63 micron TB at PR pixels (K)
Ch2	Float array (rays, scans)	1.6 micron TB at PR pixels (K)
Ch3	Float array (rays, scans)	3.75 micron TB at PR pixels (K)
Ch4	Float array (rays, scans)	10.8 micron TB at PR pixels (K)
Ch5	Float array (rays, scans)	12.0 micron TB at PR pixels (K)
Lon	Float array (261,*)	Longitude of full VIRS swath (K)
Lat	Float array (261,*)	Latitude of full VIRS swath (K)
Ch4_rain	Float array (261,*)	10.8 micron TB of full VIRS swath (K)

Parameters from 1B11		
Orbit	1 integer	Orbit number
version	1 float	Version number
hiRays	1 integer (208)	Number of high res rays in each scan
loRays	1 integer (104)	Number of low res rays in each scan
Scans	1 integer	Number of scans in the orbit
year	Float array (scans)	Year
month	Float array (scans)	Month
day	Float array (scans)	Day
hour	Float array (scans)	Hour
minute	Float array (scans)	Minute
second	Float array (scans)	Second
lonHI	Float array (hirays, scans)	High resolution longitude
latHI	Float array (hirays, scans)	High resolution latitude
Lonlo	Float array (lorays, scans)	low resolution longitude
latlo	Float array (lorays, scans)	low resolution latitude
V10	Float array (lorays,scans)	10 GHz vertical polarization TB (K)
H10	Float array (lorays,scans)	10 GHz horizontal polarization TB (K)
V19	Float array (lorays,scans)	19 GHz vertical polarization TB (K)
H19	Float array (lorays,scans)	19 GHz horizontal polarization TB (K)

V21	Float array (lorays,scans)	21 GHz vertical polarization TB (K)
V37	Float array (lorays,scans)	37 GHz vertical polarization TB (K)
H37	Float array (lorays,scans)	37 GHz horizontal polarization TB (K)
V85	Float array (hirays,scans)	85 GHz vertical polarization TB (K)
H85	Float array (hirays,scans)	85 GHz horizontal polarization TB (K)

Parameters from PR 2A12		
Rain	Float array (hirays,scans)	TMI surface rainfall (mm/hr)
Confidence*	Float array (hirays,scans)	Confidence of retrieval
Surfaceflag*	Float array (hirays,scans)	Surface flag
PCT37	Float array (hirays,scans)	37 GHz polarization corrected TB (K)
PCT85	Float array (hirays,scans)	85 GHz polarization corrected TB (K)
Cld_water*	Float array (valid pix, 14)	Cloud water profile (mg/m^3)
Cld_ice*	Float array (valid pix, 14)	Cloud ice profile(mg/m^3)
Precip_water*	Float array (valid pix, 14)	Precipitation water profile (mg/m^3)
Precip_ice*	Float array (valid pix, 14)	Precipitation ice profile (mg/m^3)
Profile_ray#	Float array (valid pix)	Indices of rays with surface rain
Profile_scan#	Float array (valid pix)	Indices of scans with surface rain

*Detail see interface control specification TSDIS.MDL-02.5 volume 4, 1-1
In order to reduce the file size, we only save the hrdrometeor profiles over rainfall area. For example, one may use lonhi[profile_ray[i],profile_ scan[i]] to obtain the longitude of the cloud water profiles cld_water[i,*].

Above parameters are saved into “HDF” format with naming rules as “1Z99.yymmdd.orbit.version.HDF”, and there is an IDL program “read_pf_level1_hdf.pro” for access these level-1 files.

3. Level-2

The first step to create the level-2 data is to define the features. There are two groups of feature definitions with development of the database. The old-definition (1999-2005, Nesbitt et al., 2000) is a “hybrid definition” using information from both PR and TMI. The new definition was developed recently (Sep 2006, Liu et al., 2007) by using “pure” information from individual measurements. Currently all TRMM data are processed with both groups of definitions. This section will introduce these definitions separately.

3.1 Old definition

The first TRMM Precipitation Feature (PF) was developed by Dan Cecil, Steve Nesbitt and Ed Zipser around 1998-1999 (Nesbitt et al., 2000). The concept was to use the information from both TMI and PR, and defined the PFs with area of PR pixels with 20 dBZ at near surface or TMI 85GHz Polarization Corrected Temperature (PCT, Spence et al., 1989) colder than 250 K. Then summarize the precipitation, convective properties inside the PF area. By using this definition, many valuable research have been accomplished (Nesbitts et al., 2004, Nesbitt and Zipser, 2003, Cecil et al., 2005, Liu and Zipser, 2005, Nesbitt et al. 2006, Zipser et al., 2006).

3.2 Parameters in old definitions

After grouping the pixels with PR 20 dBZ near surface reflectivity or 85 GHz PCT < 250 K, the indices of pixels for each feature are identified within PF swath from collocated level-1 data. Using these indices, the total number of pixels, maximum echo tops, and minimum brightness temperatures inside features are calculated and saved as level-2 product. The parameters for each feature in level-2 product are listed below:

Orbit	Orbit number
Grpnum	Group number in the orbit
Year	Year
Month	Month
Day	Day
Hour	Float number of hour in UTC
Lat	Geographical center latitude (degree)
Lon	Geographical center longitude (degree)
Altrk	Along track center location (# pixels)
actrk	Cross track center location (#pixels)
Elev	Ground elevation (m)
Npixels	Number of PR pixels (#)
Npixels_2a12	Number of PR pixels with 2A12 rainfall (#)
Volrain	Volumetric rain from 2A25 (km^2mm/hr)
Volrain_2a12	Volumetric rain from 2A12 inside feature(km^2mm/hr)
Min85pct	Minimum 85 GHz polarization correction TB (K)
Min37pct	Minimum 37 GHz polarization correction TB (K)
Nlt275	Number of PR pixels with 85 GHz PCT < 275 K (#)
Nlt250	Number of PR pixels with 85 GHz PCT < 250 K (#)
Nlt225	Number of PR pixels with 85 GHz PCT < 225 K (#)
Nlt200	Number of PR pixels with 85 GHz PCT < 200 K (#)
Nlt175	Number of PR pixels with 85 GHz PCT < 175 K (#)
Nlt150	Number of PR pixels with 85 GHz PCT < 150 K (#)
Nlt125	Number of PR pixels with 85 GHz PCT < 125 K (#)
Nlt100	Number of PR pixels with 85 GHz PCT < 100 K (#)
Minir	Minimum VIRS CH4 10.8 Micron TB (K)
Maxnsz	Maximum near surface reflectivity (dBZ)
Max6km	Maximum reflectivity at 6 km (dBZ)
Max9km	Maximum reflectivity at 9 km (dBZ)
Maxht	Maximum height with 15 dBZ echo (km)
Maxht20	Maximum height with 20 dBZ echo (km)
Maxht30	Maximum height with 30 dBZ echo (km)

Maxht40	Maximum height with 40 dBZ echo (km)
Nmcs	Number of MCSs inside feature (#)
Nint	Number of intensive MCSs inside feature (#)
Rainmcs	Volumetric 2A25 rain from MCSs in feature (km^2mm/hr)
Rainmcs_2a12	Volumetric 2A12 rain from MCSs in feature (km^2mm/hr)
Npixelsmcs	Number of pixels from MCSs (#)
Npixelsint	Number of pixels from Intensive MCSs (#)
Landocean	0: over ocean. 1: over land
Nstrat	Number of pixels with stratiform rainfall (#)
Nconv	Number of pixels with convective rainfall (#)
Rainstrat	Stratiform volumetric rain (km^2mm/hr)
Rainconv	Convective volumetric rain (km^2mm/hr)
Anv	Number of pixels with 85GHz PCT < 250K without rain
Snow	0: not a snow case. 1: snow case
Boost	0: before boost. 1: after boost
R_lon*	Center location longitude of fitted ellipse
R_lat	Center location latitude of fitted ellipse
R_major	Major axis of ellipsis (km)
R_minor	Minor axis of ellipsis (km)
R_orientation	Orientation angle (degree)
R_solid	Percentage filled by rainfall area
C_lon*	Center location longitude
C_lat	Center location latitude
C_major	Major axis of ellipsis (km)
C_minor	Minor axis of ellipsis (km)
C_orientation	Orientation angle (degree)
C_solid	Percentage filled by rainfall area
Flashcount	Total flash counts in feature (#)
Flashcount_plusborder	Total flash counts in feature considering TMI swath
Flashtotal	Total flashes in the orbit
Viewtime	View time of feature (second)
Beyond_swath	Flashes outside PR swath

* The morphology of the feature can be represented by major, minor axes, orientation angle of fitted ellipse. Here R_xxx are the parameters fitted for whole feature, C_xxx are the parameters fitted for the area with convective rainfall.

The similar PF definitions of features by grouping by 85 GHz PCT < 250 K inside TMI swath and PR swath are also applied to the TRMM dataset. All the calculated parameters for each one of PFs are saved in a Level-2 product file in “HDF format” for each orbit with naming rules as “2Z99.yymmdd.orbit.version.HDF”. There is an IDL program “read_pf_level2_hdf.pro” for accessing these level-1 files.

Because there are about 15 orbits per day, it is difficult to build statistics by accessing many files at the same time. The orbital level-2 files were combined monthly for convenience. The monthly combined files are compatible to the level-2 products and can be accessed through the same reading program.

3.3 New definitions

The old PF definition was very successful in the research. However, this definition has some disadvantages that limit its applications. First, the old precipitation features (Nesbitt et al., 2000) exclude some shallow rain area with surface reflectivity less than 20 dBZ and TMI 85 GHz PCT > 250 K. Also some features can be defined over the non raining area with cold 85GHz PCT due to low surface emissivity over high terrain. Second, the precipitating area usually is only the small part of a cloud system. There are large areas of cold anvil clouds neither with surface radar echoes, nor with cold ice scattering signals (Liu et al., 2007). Thus, the precipitation features definition cannot be used to study the whole cloud system, especially the relation between the precipitation and the radiation impacts by these cloud systems. Third, it is difficult to compare the rainfall estimates from PR and TMI in the feature defined using information from both PR and TMI measurement. In fact, any single feature definition by itself would not cover all the aspects.

So we decided to improve the database by introducing the “pure” definitions by using single properties. These new definitions include both precipitation features and cold cloud features (Liu et al., 2007) and listed below:

Acronyms	Definition	Criteria
RPF	PR detected Precipitation Feature	Pixels with 2A25 rainfall rate >0
RPPF	PR detected radar echo Projection Feature	Pixels with 20 dBZ above ground
TPF	TMI detected Precipitation Feature	Pixels with 2A12 rainfall rate > 0
PCTF	TMI cold 85 GHZ PCT feature	Pixels with 85 GHZ PCT < 250 K
C210F	Cloud Features with 210 K	VIRS T_{B11} < 210 K
C235F	Cloud features with 235 K	VIRS T_{B11} < 235 K
C273F	Cloud features with 273 K	VIRS T_{B11} < 235 K
TTPF*	TMI detected Precipitation Feature	Pixels with 2A12 rainfall rate > 0 within TMI swath

All above features are defined within PR swath except TTPFs. This provides a good opportunity for the inter-comparisons among these definitions. For example, by subtracting the total rainfall inside C273Fs from total rainfall from RPFs, we may easily obtain the “warm” rainfall under clouds without ice.

3.4 Additional parameters in new definitions

In addition to the parameters calculated for the old PFs, some new parameters are introduced for various research directions. They are listed below:

Maxdbz	Maximum reflectivity profile with 0.5 km interval (0.01dBZ)
N20dbz	Profile of number of pixels with 20 dBZ with 1km interval (#)
Npixels_2a12	Number of PR pixels with valid 2A12 pixels (#)
Npixels_tmi	Number of TMI pixels covered by grouping area (#)
Nrainpixels_2a25	Number of PR pixels with 2A25 rainfall (#)
Nrainpixels_2a12	Number of PR pixels with 2A12 rainfall (#)
Npixels_pr	Number of PR pixels (#)
Volrain_20dbz	Volumetric rainfall over 20 dBZ area (km^2mm/hr)
Maxht	Storm height from 2A23 (km)
Nch4le210	Number of PR pixels with 10.8 micron TB <=210 K (#)
Nch4le235	Number of PR pixels with 10.8 micron TB <=235 K (#)
Nch4lt273	Number of PR pixels with 10.8 micron TB <273 K (#)
Nch4ge273	Number of PR pixels with 10.8 micron TB >273 K (#)
Nrpf	Number of raining cells inside feature
Medch1	median value of Tb at VIRs ch1 (K)
Medch2	median value of Tb at VIRs ch2 (K)
Medch3	median value of Tb at VIRs ch3 (K)
Medch4	median value of Tb at VIRs ch4 (K)
Medch5	median value of Tb at VIRs ch5 (K)
Medrefch1*	median value of reflectance at 0.63 micron for ch4 < 210K
Medrefch2*	median value of reflectance at 1.6 micron for ch4 < 210K
Medrefch3*	median value of reflectance at 3.75 micron for ch4 < 210K
Medref210235ch1*	median value of reflectance at 0.63 micron for 235K > ch4 > 210K
Medref210235ch2*	median value of reflectance at 1.6 micron for 235K > ch4 > 210K
Medref210235ch3*	median value of reflectance at 3.75 micron for 235K > ch4 > 210K
Med20dbz10kmch1	median value of 10 km 20dbz pixels Tb at VIRs ch1 (K)
Med20dbz10kmch2	median value of 10 km 20dbz pixels Tb at VIRs ch2 (K)
Med20dbz10kmch3	median value of 10 km 20dbz pixels Tb at VIRs ch3 (K)
Med20dbz10kmch4	median value of 10 km 20dbz pixels Tb at VIRs ch4 (K)
Med20dbz10kmch5	median value of 10 km 20dbz pixels Tb at VIRs ch5 (K)
Medref20dbz10kmch1*	median value of 10 km 20dbz pixels ch1 reflectance for ch4<210k
Medref20dbz10kmch2*	median value of 10 km 20dbz pixels ch2 reflectance for ch4<210k
Medref20dbz10kmch3*	median value of 10 km 20dbz pixels ch3 reflectance for ch4<210k

Med20dbz14kmch1-5	Similar to Med20dbz10kmch1 but for 14km
Medref20dbz14kmch1-3*	Similar to Medref20dbz10kmch1 but for 14km

* **These variables are still in testing stage and not reliable at the time.**

In this list, we introduced not only some new parameters useful in inter-comparison between 2A25 and 2A12 rainfall, but also two new profile parameters (maxdbz and n20dbz) that describes the vertical structure of the cloud or precipitation system. Note that in TRMM 3A25, there is no information about the reflectivity occurrence at different altitude.

3.5 Parameters from NCEP reanalysis

In order to study the environment of the cloud and precipitation systems, vertical profiles of temperature, geopotential height, wind and humidity are extracted from NCEP 2.5x2.5 6 hour interval reanalysis dataset (Kistler et al., 2001) for each feature with at least 4 PR pixels. The NCEP parameters include:

T	Temperature profile (K)
H	Geopotential height (m)
Omega	Omega (pa/s)
U	U wind speed (m/s)
V	V wind speed (m/s)
RH	Relative humidity at 8 lower levels (%)
Tropopause_T	Tropopause temperature (K)
Tropopause_P	Tropopause pressure (hPa)
Surface_T	Surface temperature (K)
Surface_P	Surface pressure (Pa)
Surface_RH	Surface relative humidity (%)
Precip_water	Precipitable water (kg/m^2)

Where profiles are temporal and spatial interpolated from standard pressure levels: 1000, 925, 850, 700, 600, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, 10 hPa. Currently only profiles for old PF definition, RPFs, RPPFs, TPFs, and C210Fs with at least 4 pixels have been extracted and added into the level-2 products.

4. Level-3

One important application of level-2 feature data is to generate the climatology of precipitation, convective intensity etc. Level-3 product is just an example and application of generating the physically meaningful statistics from TRMM cloud and precipitation features. There are many other statistics can be done and not included in the current level-3 processing. This section introduces the current procedure of the level-3 products.

4.1 precipitation data

The original motivation of the TRMM is the rainfall measurements over tropics. Thus, the climatology of the precipitation is at the top of the list in level-3 data processing. To validate the contribution of precipitation from features defined, climatology of rainfall in tropics is needed. Here we not only combine TRMM TSDIS processed level-3 precipitation product, but also incorporate the rainfall estimates from some other resources for comparison. They include:

Products	Source	Retrieval method
TRMM 3A25	http://disc.sci.gsfc.nasa.gov/data/datapool/TRMM/	Purely from TRMM Precipitation radar
TRMM 3A12	Same as above	Purely from TRMM TMI
TRMM 3B43	Same as above	From Microwave+IR+Rain gauges
GPCP	http://www.ncdc.noaa.gov/oa/wmo/wdcamet-ncdc.html	Combined precipitation estimates retrieved from microwave and IR
GPI	ftp://ftp.ncep.noaa.gov/pub/precip/gpi/	Estimates from IR measurements
GPCC	http://www.dwd.de/en/FundE/Klima/KLIS/int/GPCC/GPCC.htm	Purely from rain gauges

Original GPI (Joyce and Arkin, 1997), GPCC (Rudolf, 1993), and GPCP (Huffman et al., 2001) data are not in the same format. So the first step is to convert these dataset into a common format (IDL save files). Then we degrade the monthly mean precipitation onto 1^ox1^o grids between 40^oS-40^oN. Besides the monthly rainfall rate, number of rain gauges used in GPCC, and total sampled and raining pixels from TRMM 3A25 and 3A12 are also kept for the future references.

4.2 Cloud and precipitation feature processing

Since TRMM satellite is not sun synchronizing, its measurements include the information of diurnal variation of precipitation and properties of cloud and precipitation systems. For this reason, we categorize cloud and precipitation features into 8 time period daily and calculate monthly totals on the same 1^o x1^o grids. In this way, the capability of calculating the monthly means is kept by summing parameters from all 3-hour bins. With all different rainfall estimates and the accumulated properties from defined features, level-3 monthly products include following parameters:

Year	Integer	Year
Month	Integer	Month
Days	Integer	Number of days processed
Lon	Float (80,360)	Longitude
Lat	Float (80,360)	Latitude
Rain_3B43	Float (80,360)	Monthly rainfall from TMM 3B43 (mm/month)
Rain_GPCC	Float (80,360)	Monthly rainfall from GPCC (mm/month)
Rain_gpcc_num_gauges	Float (80,360)	Number of rain gauges used in GPCC (#)
Rain_GPCP	Float (80,360)	Monthly rainfall from GPCP (mm/month)
Rain_GPI	Float (80,360)	Monthly rainfall from GPI (mm/month)
Rain_3A12	Float (80,360)	Monthly rainfall from TMM 3A12 (mm/month)
Pix_3A12	Float (80,360)	Total sample pixels used in 3A12 (#)
Rain_pix_3A12	Float (80,360)	Total raining pixels used in 3A12 (#)
Rain_3A25	Float (80,360)	Monthly accumulative rainfall from TMM 3A25 (mm/month)
Pix_3A25	Float (80,360)	Total sample pixels used in 3A25 (#)
Rain_pix_3A25	Float (80,360)	Total raining pixels used in 3A25 (#)
Tot_pix_pr	Float (80,360,8)	Total number of PR pixels in features (#)
Tot_pix_20dbz	Float (80,360,8)	Total number of PR pixels with 20 dBZ in features (#)
Tot_pix_tmi	Float (80,360,8)	Total number of TMI pixels involved in features (#)
Tot_pix_2a25	Float (80,360,8)	Total number of PR pixels with 2A25 rain in PR swath (#)
Tot_pix_2a12	Float (80,360,8)	Total number of PR pixels with 2A12 rain in PR swath (#)
Tot_pix_nlt275	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 275K (#)
Tot_pix_nlt250	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 250K (#)
Tot_pix_nlt225	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 225K (#)
Tot_pix_nlt200	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 200K (#)
Tot_pix_nlt175	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 175K (#)
Tot_pix_nlt150	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 150K (#)
Tot_pix_nlt125	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 125K (#)

Tot_pix_nlt100	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 100K (#)
Tot_pix_n20dbz	Float (80,360,8,16)	Total number of PR pixels with 20 dBZ at 0-15 km (#)
Tot_pix_ch4le210	Float (80,360,8)	Total number of PR pixels with VIRS CH4 < =210 K (#)
Tot_pix_ch4le235	Float (80,360,8)	Total number of PR pixels with VIRS CH4 <= 235 K (#)
Tot_pix_ch4lt273	Float (80,360,8)	Total number of PR pixels with VIRS CH4 < 273 K (#)
Tot_pix_ch4ge273	Float (80,360,8)	Total number of PR pixels with VIRS CH4 >=273 K (#)
Tot_pix_strat	Float (80,360,8)	Total number of PR pixels with 2A23 stratiform rain (#)
Tot_pix_conv	Float (80,360,8)	Total number of PR pixels with 2A23 convective rain (#)
Tot_pix_sample_pr	Float (80,360,8)	Total number of PR pixels sampled in PR swath (#)
Tot_pix_sample_tmi	Float (80,360,8)	Total number of TMI pixels sampled in TMI swath (#)
Tot_volrain_2a25	Float (80,360,8)	Total volumetric 2A25 rainfall in PR swath (km^2mm/hr)
Tot_volrain_2a12	Float (80,360,8)	Total volumetric 2A12 rainfall in PR swath (km^2mm/hr)
Tot_volrain_20dbz	Float (80,360,8)	Total volumetric rainfall with 20 dBZ near surface (km^2mm/hr)
Tot_volrain_strat	Float (80,360,8)	Total volumetric stratiform rainfall (km^2mm/hr)
Tot_volrain_conv	Float (80,360,8)	Total volumetric convective rainfall (km^2mm/hr)
Tot_flashcount	Float (80,360,8)	Total flash counts in all features (#)
Tot_feature	Float (80,360,8)	Total number of features
Min_85pct	Float (80,360,8)	Minimum of min85pct from all features (K)
Min_37pct	Float (80,360,8)	Minimum of min37pct from all features (K)
Min_ir	Float (80,360,8)	Minimum of minch4 Tb from all features (K)
Max_dbz	Float (80,360,8,40)	Maximum reflectivity from 0-19.5km (0.01 dBZ)
Max_ht	Float (80,360,8)	Maximum echo top from 2A23 storm height (km)
Max_ht15	Float (80,360,8)	Maximum 15 dBZ height (km)
Max_ht20	Float (80,360,8)	Maximum 20 dBZ height (km)
Max_ht30	Float (80,360,8)	Maximum 30 dBZ height (km)
Max_ht40	Float (80,360,8)	Maximum 40 dBZ height (km)

Max_flashcount	Float (80,360,8)	Maximum flash counts (#/feature)
Tot_mcs_pix_pr	Float (80,360,8)	Total number of PR pixels in features (#)
Tot_mcs_pix_20dbz	Float (80,360,8)	Total number of PR pixels with 20 dBZ in features (#)
Tot_mcs_pix_tmi	Float (80,360,8)	Total number of TMI pixels involved in features (#)
Tot_mcs_pix_2a25	Float (80,360,8)	Total number of PR pixels with 2A25 rain in PR swath (#)
Tot_mcs_pix_2a12	Float (80,360,8)	Total number of PR pixels with 2A12 rain in PR swath (#)
Tot_mcs_pix_nlt275	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 275K (#)
Tot_mcs_pix_nlt250	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 250K (#)
Tot_mcs_pix_nlt225	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 225K (#)
Tot_mcs_pix_nlt200	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 200K (#)
Tot_mcs_pix_nlt175	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 175K (#)
Tot_mcs_pix_nlt150	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 150K (#)
Tot_mcs_pix_nlt125	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 125K (#)
Tot_mcs_pix_nlt100	Float (80,360,8)	Total number of PR pixels with 85 GHz PCT < 100K (#)
Tot_mcs_pix_n20dbz	Float (80,360,8,16)	Total number of PR pixels with 20 dBZ at 0-15 km (#)
Tot_mcs_pix_ch4le210	Float (80,360,8)	Total number of PR pixels with VIRS CH4 <=210 K (#)
Tot_mcs_pix_ch4le235	Float (80,360,8)	Total number of PR pixels with VIRS CH4 <= 235 K (#)
Tot_mcs_pix_ch4lt273	Float (80,360,8)	Total number of PR pixels with VIRS CH4 < 273 K (#)
Tot_mcs_pix_ch4ge273	Float (80,360,8)	Total number of PR pixels with VIRS CH4 >=273 K (#)
Tot_mcs_pix_strat	Float (80,360,8)	Total number of PR pixels with 2A23 stratiform rain (#)
Tot_mcs_pix_conv	Float (80,360,8)	Total number of PR pixels with 2A23 convective rain (#)
Tot_mcs_pix_sample_pr	Float (80,360,8)	Total number of PR pixels sampled in PR swath (#)

Tot_mcs_pix_sample_tmi	Float (80,360,8)	Total number of TMI pixels sampled in TMI swath (#)
Tot_mcs_volrain_2a25	Float (80,360,8)	Total volumetric 2A25 rainfall in PR swath (km^2mm/hr)
Tot_mcs_volrain_2a12	Float (80,360,8)	Total volumetric 2A12 rainfall in PR swath (km^2mm/hr)
Tot_mcs_volrain_20dbz	Float (80,360,8)	Total volumetric rainfall with 20 dBZ near surface (km^2mm/hr)
Tot_mcs_volrain_strat	Float (80,360,8)	Total volumetric stratiform rainfall (km^2mm/hr)
Tot_mcs_volrain_conv	Float (80,360,8)	Total volumetric convective rainfall (km^2mm/hr)
Tot_mcs_flashcount	Float (80,360,8)	Total flash counts in all features (#)
Tot_mcs_feature	Float (80,360,8)	Total number of features
Min_mcs_85pct	Float (80,360,8)	Minimum of min85pct from all features (K)
Min_mcs_37pct	Float (80,360,8)	Minimum of min37pct from all features (K)
Min_mcs_ir	Float (80,360,8)	Minimum of minch4 Tb from all features (K)
Max_mcs_dbz	Float (80,360,8,40)	Maximum reflectivity from 0-19.5km (0.01 dBZ)
Max_mcs_ht	Float (80,360,8)	Maximum echo top from 2A23 storm height (km)
Max_mcs_ht15	Float (80,360,8)	Maximum 15 dBZ height (km)
Max_mcs_ht20	Float (80,360,8)	Maximum 20 dBZ height (km)
Max_mcs_ht30	Float (80,360,8)	Maximum 30 dBZ height (km)
Max_mcs_ht40	Float (80,360,8)	Maximum 40 dBZ height (km)
Max_mcs_flashcount	Float (80,360,8)	Maximum flash counts (#/feature)
Mean_mcs_85pct	Float (80,360,8)	Mean minimum 85GHz PCT in MCSs (K)
Mean_mcs_37pct	Float (80,360,8)	Mean minimum 37GHz PCT in MCSs (K)
Mean_mcs_ht	Float (80,360,8)	Mean maximum echo top in MCSs (km)
Mean_mcs_ht20	Float (80,360,8)	Mean maximum 20 dBZ top in MCSs (km)
Mean_mcs_ht40	Float (80,360,8)	Mean maximum 40 dBZ top in MCSs (km)

In the above calculation, MCSs are defined by features with area of 2000 km^2. The level-3 processing has been applied to all the level-2 products.
Note that volumetric rain and area inside each feature are assigned to the grid with feature center. Due to small grid interval, this could be problematic because some volumetric rain and raining area from large MCSs are assigned to a small grid. However, given enough samples, this effect could be compensated by other large MCSs happened around. However, this can be serious if there is a systemic center location of large systems over some regions, for example, some terrain invoked cloud and precipitation systems.

4.3 Combined level-3 products

All the level-3 products are initially processed monthly. There are requirements for annual, seasonal and longer climatology. So we combined the monthly data into annual, before boost, after boost, seasonal (DJF, MAM, JJA, SON), and 8 year products. The combination rules can be simply summarized as following:

Rainfall estimates (i.e. rain_3a25)	Average through monthly data
Min estimates (i.e. min_85pct)	Find minimum though monthly data
Max estimates (i.e. max_ht20)	Find maximum though monthly data
Total estimates (i.e tot_pix_pr)	Sum from all the selected monthly data
Mean estimates (i.e mean_mcs_ht40)	Average through monthly data

As the results, we may obtain some maximum and minimum values through all 8 years of observations, as well as the total 8 year sampled pixels and mean values of precipitations etc. Currently the combination has only been completed for old PFs, RPFs, RPPFs, TPFs, and C210Fs.

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5. References

Cecil, D.J., E.J. Zipser, and S.W.Nesbitt, 2002: Reflectivity, ice scattering, and lightning characteristics of hurricane eyewalls and rainbands. Part I: Quantitative description**.** *Mon Wea. Rev.,***130**, 769-784.

Cecil, D.J., E.J. Zipser, and S.W.Nesbitt, 2002: Reflectivity, ice scattering, and lightning characteristics of hurricane eyewalls and rainbands. Part II: Intercomparison of observations. *Mon. Wea. Rev*., **130**, 785-801.

Cecil, D.J., S.J.Goodman, D.J.Boccippio, E.J.ZIpser, and S.W.Nesbitt, 2005: Three years of TRMM precipitation features. Part 1: Radar, radiometric, and lightning characteristics. *Mon Wea. Rev*., **133**, 543-566.

Huffman, G., R. Adler, M. Morrissey, D. Bolvin, S. Cuttis, R. Joyce, B. McGavock and J.Susskind, 2001: Global precipitation at one degree resolution from multi satellite observations. *J. Hydrometeor.,* **2**, 36-50.

Iguchi, T., T. Kozu., R. Meneghini, J. Awaka, and K. Okamoto, 2000: Rain-profiling algorithm for the TRMM precipitation radar. *J. Appl. Meteor.*, **39**, 2038-2052.

Joyce, R., and P. A. Arkin, 1997: Improved estimates of tropical and subtropical precipitation using the GOES Precipitation Index. *J. Atmos. Ocean. Tech.*, **10**, 997-1011.

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. bisuzaki, M. Kanamitsu, V. Kousky, H. Dool, R. Jenne and M. Fiorino, 2001: The NCEP-NCAR 5—year reanalysis: monthly means CD-ROM and documentation. *Bull. Amer. Meteor. Soc.* **82**, 247-267.

Kummerow, C., W. Barnes, T. Kozu, J. Shiue, and J. Simpson, 1998: The Tropical Rainfall Measuring Mission (TRMM) sensor package. *J. Atmos. Oceanic Tech.*, **15**, 809–817.

Kummerow, C., 23 coauthors, and E. J. Zipser, 2000: The status of the Tropical Rain Measuring Mission (TRMM) after 2 years in orbit. J. Appl. Meteor., 39, 1965-1982

Liu, C. and E.J. Zipser, 2005: Global distribution of convection penetrating the tropical tropopause. *J.Geophys. Res.-Atm*, **110**, doi:10.1029/2005JD00006063.

Liu, C., E,J,Zipser, and S.W.Nesbitt, 2007: Global distribution of tropical deep convection: Differences using infrared and radar as the primary data source. *J. Climate*, **20**, 489-503, DOI:10.1175/JCLI4023.1.

Nesbitt, S.W., E. J. Zipser, and D.J. Cecil, 2000: A census of precipitation features in the tropics using TRMM: Radar, ice scattering, and lightning observations. *J. Climate*, **13** (23), 4087-4106

Nesbitt, S.W., and E.J.Zipser, 2003: The diurnal cycle of rainfall and convective intensity according to three years of TRMM measurements. J. Climate, 16 (10), 1456-1475

Nesbitt, S.W., E.J. Zipser, and C.D. Kummerow, 2004: An examination of Version-5 rainfall estimates from the TRMM Microwave Imager, Precipitation Radar, and rain gauges on global, regional, and storm scales. *J. Appl. Meteor.,* **43**, 1016-1036.

Rudolf, B., 1993: Management and analysis of precipitation data on a routine basis. *Proc. Int. WMO/IAHS/ETH Symp. on Precipitation and Evaporation*, Bratislava, Slovakia, Slovak Hydromet. Inst., 69–76

Spencer, R. W., H. G. Goodman, and R. E. Hood, 1989: Precipitation retrieval over land and ocean with the SSM/I: identification and characteristics of the

scattering signal. *J. Atmos. Oceanic Tech.*, **6**, 254-273.
Zipser, E.J., D.J.Cecil, C.Liu, S.W.Nesbitt. and D.P.Yorty, 2006: Where are the most intense thunderstorms on earth? *Bull, Amer. Meteor. Soc.*, **87**, 1057-1071.

6. Appendix

A. Other by-products

There are several by-products when we process the TRMM cloud and precipitation feature database. Here we introduce two important ones:

First one is the dataset of the PR, TMI and VIRs measurements at flash locations. The parameters include: near surface reflectivity, rainfall, minimum detectable, 15 dBZ, 20 dBZ, 30dBZ, 40 dBZ top from PR, 85 GHz PCT from TMI, CH3 and CH4 brightness temperatures from VIRS. These dataset may be useful helping us understanding the lightning mechanism.

Second one is the nadir only level-1 product. This product saved the selected parameters for nadir only pixels. This largely reduced the file size. Also it reduced the possible altitude calibration due to non-nadir scan. The nadir only PR data is organized like a cross section similar to CloudSat. This dataset provides a unique base for comparing the climatology of precipitation radar and cloud radar observations in the future.

B. websites

There is an old website providing access the level-2 products of old MCS definitions (Nesbitt et al., 2000) during 1998-2005
http://www.met.utah.edu/zipser/pub/projects/trmm/
Some level-3 products can be accessed through
http://www.met.utah.edu/zipser/pub/projects/trmm/level_3/
We are planning to build a new website that provides access to all the dataset described above depending on the funding situations.

C. Reading programs

Read_pf_level1_hdf.pro
This program reads Level-1 UU TRMM data.
Usage:
IDL > read_pf_level2_hdf,'1Z99.19980101.537.6.HDF',f
Here f is a structure storing all the level-1 variables.

Read_pf_level2_hdf.pro
This program reads all old definition Level-2 products, including the combined monthly data.

Usage:

```
IDL>    read_pf_level2_hdf,'199801.level2.v6.HDF',f,o,i
```

Here f is a structure with all the variables of old

Read_sds.pro

This program reads all the science data from HDF-4 format file and save into a structure. This program can be used to access level-2 products with new definitions and all level-3 products.

Usage example:

```
IDL>    read_sds,'example.HDF',f        ; f is a structure variable with all the parameters
```

Show_sds.pro

This program list all the science data variables from HDF-4 format file.

Usage:

```
IDL> show_sds,'example.HDF'
```

Read_sds_one.pro

This program reads in one variable from HDF-4 format file

Usage:

```
IDL>    read_sds_one,'example.HDF','var1',var
```

All these IDL programs can be downloaded at:

ftp://www.met.utah.edu/ezipser/liuct/for_trmm/