University of Utah TRMM precipitation and cloud feature database

Description Version 3.0

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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) etc. This database has been updated several times during past decade by Chuntao Liu (Liu et al. 2008). Current version is the newest development based on the TRMM product version 7 (Or GPM product version 1) that reprocessed in 2012.

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

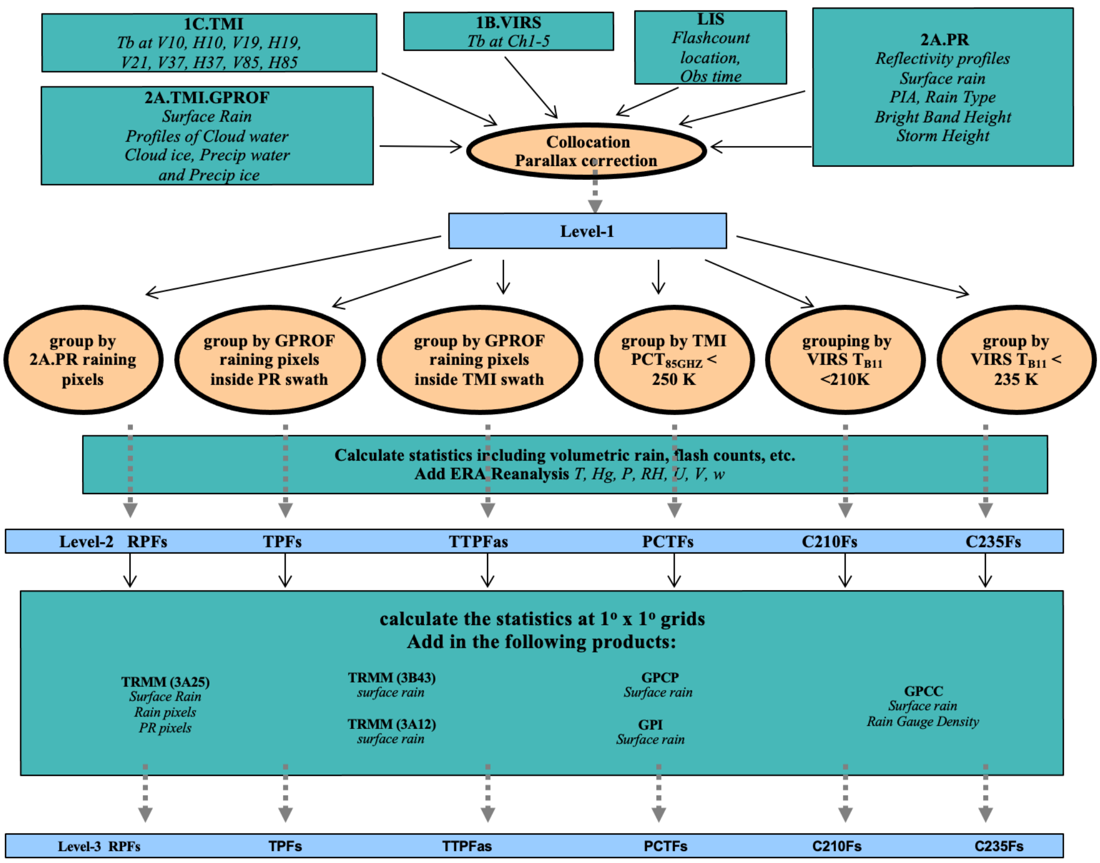

Figure 1. Flow chart of three levels of the University of Utah TRMM feature database.

2. Level-1

As shown in Figure 1, level-1 data are produced with a combination of the version 6 orbital 1B.VIRS, 1B.TMI, 2A.GPROF (Kummerow et al., 2001), 2A.PR (Iguchi et al., 2000), 2B.PRTMI, 2H.SLH, 2H.CSH and LIS granules after TMI-PR parallax correction and TMI-PR-LIS-VIRS nearest neighbor collocation. Where precipitation rate in 2B.PRTMI of combined algorithm and latent heating profiles from 2H are new parameters introduce for the new version. The output data is saved in compressed HDF-4 format for each satellite orbit. The details of these procedures and calculated parameters are introduced in this section.

2.1 Collocation between 1B.TMI and 2A.GPROF

The orbit data stored in TMI 1B.TMI 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 2A.PR and TMI 1B.TMI 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

In the old version of the parallax correction (datasets produced prior 2013), because TMI scans with 52° 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.

In the current reprocessed version, the parallax correction only made for the pixels with PR 2A23 echo top height > 5 km and path integrated attenuation > 0.4 dBZ. In this way, the overcorrection for the shallow precipitations is avoided.

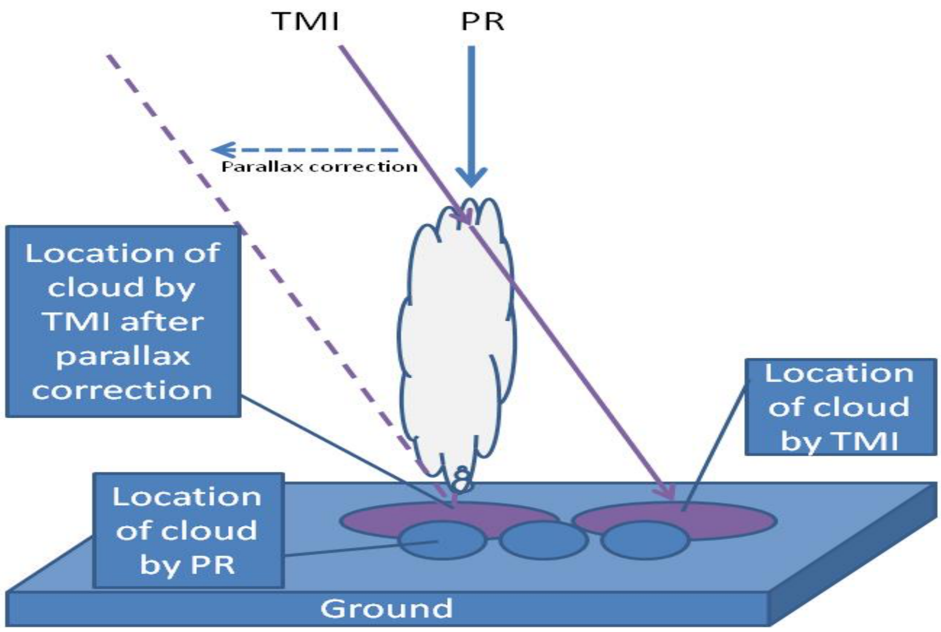

Figure 2. Schematic diagram of parallax correction.

2.3 Collocation between 1B.VIRS and 2A.PR

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 1B.VIRS, 1B.TMI, 2A.PR, 2A.GPROF, and some derived parameters for storing into the level-1 products. These parameters include:

Parameters from PR 2A.PR		
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
Lonpara	Float array (rays, scans)	Longitude with parallax correction
Latpara	Float array (rays, scans)	Latitude with parallax correction
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)
Rain_2b31	Float array (rays,scans)	Liquid form precipitation from 2B31 (mm/hr)
Precip_2b31	Float array (rays,scans)	Total precipitation from 2B31 (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)
LH#	Float array (valid scans, 19)	Latent heating rate from 2H25

		(K/hr)
Q1MQR#	Float array (valid scans, 19)	Q1-Qr (K/hr)
Q2#	Float array (valid scans, 19)	Q2
Colo.hi^	Float array (rays,scans)	Indices of TMI pixels for each PR pixels
Colo.noparallax	Float array (rays,scans)	Indices of TMI pixels for each PR pixels without any parallax correction

*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 2A.GPROF 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 1B.VIRS		
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 1B.TMI		
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 2A.GPROF		
Rain	Float array (hirays,scans)	Liquid form surface rainfall (mm/hr) Note: this parameter only valid over ocean
Surfaceprecip	Float array (hirays,scans)	Surface precipitation (mm/hr)
convprecip	Float array (hirays,scans)	Convective precipitation (mm/hr)
PCT37	Float array (hirays,scans)	37 GHz polarization corrected TB (K)
PCT85	Float array (hirays,scans)	85 GHz polarization corrected TB (K)
Cldwpath	Float array (hirays, scans)	Cloud water path (kg/m^2)
rainwpath	Float array (hirays, scans)	Rain water path (kg/m^2)
icewpath	Float array (hirays, scans)	Ice water path (kg/m^2)
Seasfct	Float array (hirays, scans)	Sea surface temperature (K)
Windspeed	Float array (hirays, scans)	Surface wind speed (m/s)
pbrain	Float array (hirays, scans)	Probability of rain 0-100 (%)
surfaceflag	Float array (hirays, scans)	Surface flag
scorient	Float array (hirays, scans)	Scan orientation

Parameters from LIS		
Tmicoord	Long array(nflash)	TMI pixel index for flash center
Flhcoord	Long array(nflash)	Flash index
Flhlon	Float array(nflash)	Flash center longitude
Flhlat	Float array(nflash)	Flash center latitude
Duration	Float array(nflash)	Flash duration (s)

Area	Float array(nflash)	Flash area (km^2)
eventcount	Float array(nflash)	Flash event count (#)
Radiance	Float array(nflash)	Flash radiance ($\mu Wm^{-2}ster^{-1}\mu m^{-1}$)
Flhtai93	Long array(nflash)	Flash time stamp
Count	Float array (hirays,scans)	Flash count (#)
Effective_obs	Long array (hirays,scans)	Effective observations
Tai93_start	Long array (hirays,scans)	Flash start time stamp

Above parameters are saved into "HDF" format with naming rules as "1Z09.yymmdd.orbit.version.HDF", and there is an IDL program "read_pf_level1_v7_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 additional definitions were developed later (Sep 2006, Liu et al., 2007) by using "pure" information from individual measurements. Currently all TRMM data are processed with both groups of definitions. In 2012, more definitions are introduced in the database. 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_2A.GPROF	Number of PR pixels with 2A.GPROF rainfall (#)
Volrain	Volumetric rain from 2A.PR (km^2mm/hr)
Volrain_2A.GPROF	Volumetric rain from 2A.GPROF 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 2A.PR rain from MCSs in feature (km^2mm/hr)
Rainmcs_2A.GPROF	Volumetric 2A.GPROF 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 Definitions in 2008 version of PF database

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 2A.PR rainfall rate >0
RPPF	PR detected radar echo Projection Feature	Pixels with 20 dBZ above ground
TPF	TMI detected Precipitation Feature	Pixels with 2A.GPROF 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 2A.GPROF 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 2008 version

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_2A.GPROF	Number of PR pixels with valid 2A.GPROF pixels (#)
Npixels_tmi	Number of TMI pixels covered by grouping area (#)
Nrainpixels_2A.PR	Number of PR pixels with 2A.PR rainfall (#)
Nrainpixels_2A.GP	Number of PR pixels with 2A.GPROF rainfall (#)

ROF	
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

* **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 2A.PR and 2A.GPROF 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 New definitions in version 2012

Because of the needs in some special studies focusing on the convective region of storms and sometimes it is necessary to compare PR and TMI rainfall retrievals, new definitions of features are added in the new version of database in 2012.

Acronyms	Definition	Criteria
RTPF	Feature with either PR or TMI surface precipitation	Pixels with 2A.PR rainfall rate >0 or TMI precipitation > 0
CLCONVF	Convective cells by convective pixels	Pixels 2A23 rain type as convective
CL6KM30F	Convective cells by pixels with > 30 dBZ at 6 km	>30 dBZ at 6 km
CL40PF	Convective cells by pixels with 40 dBZ echo in the column	> 40 dBZ within column
CL12KM20F	Convective cells by 20 dBZ at 12 km	> 20 dBZ at 12 km
T200F	Features with 85 GHz PCT < 200 K	Pixels with pct85<200K within TMI swath
TPCTF*	Features with 85 GHz PCT < 250 K	Pixels with pct85<250K within TMI swath

3.6 Additional parameters in version 2012

With additional parameters included in version 7 product, we calculated more variables, e.g. latent heating and 2B31 rainfall. Also the center location of the minimum and maximum values are also included in the new version.

Npixels_20dbz	Number of pixels with 20 dbz
Npixels_tmi	Number of tmi rain pixels
Nrainpixels_2A.PR	Number of PR pixels with 2A.PR rainfall
Nrainpixels_2A.GPROF	Number of TMI pixels with 2A.GPROF rainfall
Nrainarea_2A.GPROF	Number of TMI pixels with 2A.GPROF rainfall > 50% probability
Volrain_20dbz	Volumetric rainfall from area with 20 dBZ
Volrain_2A.GPROF50	Volumetric rainfall from 2A.GPROF > 50% probability
Volrain_2b31	Volumetric rainfall from 2B31
Min85pctlon	Longitude of min value of 85 GHz
Min85pctlat	Latitude of min value of 85 GHz
Min37pctlon	Longitude of min value of 37 GHz
Min37pctlat	Latitude of min value of 37 GHz
N37lt275	Number of pixels with 37 GHz PCT < 275K
N37lt250	Number of pixels with 37 GHz PCT < 250K
N37lt225	Number of pixels with 37 GHz PCT < 225K
Maxnsrain	Maximum 2A.PR nearsurface rainfall rate (mm/hr)
Maxnszlon	Longitude of max value of near surface reflectivity
Maxnszlat	Latitude of max value of near surface reflectivity
N25dbz	Profile of number of pixels > 25 dBZ
N30dbz	Profile of number of pixels > 30 dBZ
N35dbz	Profile of number of pixels > 35 dBZ
N40dbz	Profile of number of pixels > 40 dBZ
N45dbz	Profile of number of pixels > 45 dBZ
N50dbz	Profile of number of pixels > 50 dBZ
Totlh	Profile of total latent heating in feature
Totq1mqr	Profile of total Q1-Qr in feature
Totq2	Profile of total Q2 in feature
Totstratlh	Profile of total LH in stratiform region
Totstratq1mqr	Profile of total Q1-Qr in stratiform region
Totstratq2	Profile of total Q2 in stratiform region
Maxhtlon	Longitude of max value of echo top
Maxhtlat	Latitude of max value of echo top
rpfgrpnum	Group number of RPFs. This parameter could be used by convective cell definitions to find its RPF mother.

3.7 Parameters from NCEP reanalysis (obsolete)

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.
Note: the NCEP parameter is replaced by ERA-Interim for 2012 version.

3.8 Parameters from ERA-5 analysis

Because of better reputation and higher horizontal resolution of ERA-Interim analysis, we have decided to use ERA-Interim analysis to provide the large scale environment for precipitation features in the 2012 algorithm. The vertical profiles are temporally interpolated from 6 hourly ERA-Interim data, then the nearest neighbor method is used to pick the profiles from closest grid. The parameters include:

T	Temperature
HGT	Geopotential height
RH	Relative humidity
U	U
V	V
W	Omega
SP	Surface pressure
TP	Total column water vapor
10U	10 m U wind

10V	10 m V wind
T2M	2 m temperature
D2M	2 m dew point
CBH	Cloud Base Height
DEG0L	Freezing level
CAPE	CAPE
CIN	CIN

The 28 levels of profiles are selected from original 38 levels. The pressure levels are: 1000,975,925,900,875,850,825,800,775,750,700,650,600,550,500,450,400,350,300,250,200,175, 150,125,100,70. Currently only profiles for cloud features of 100 pixels are available.

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	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°x1° grids between 40°S-40°N. 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° x1° 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_2A.PR	Float (80,360,8)	Total number of PR pixels with 2A.PR rain in PR swath (#)
Tot_pix_2A.GPROF	Float (80,360,8)	Total number of PR pixels with 2A.GPROF 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_2A.PR	Float (80,360,8)	Total volumetric 2A.PR rainfall in PR swath (km^2mm/hr)
Tot_volrain_2A.GPROF	Float (80,360,8)	Total volumetric 2A.GPROF 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_2A.PR	Float (80,360,8)	Total number of PR pixels with 2A.PR rain in PR swath (#)
Tot_mcs_pix_2A.GPROF	Float (80,360,8)	Total number of PR pixels with 2A.GPROF 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_2A.PR	Float (80,360,8)	Total volumetric 2A.PR rainfall in PR swath (km^2mm/hr)
Tot_mcs_volrain_2A.GPROF	Float (80,360,8)	Total volumetric 2A.GPROF 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.

In the 2012 version several new parameters are introduced in the level-3 products:

Tot_totlh	Float (80,360,19)	Total latent heating in grid
Tot_totq1mqr	Float (80,360,19)	Total q1-qr in grid
Tot_totq2	Float (80,360,19)	Total q2 in grid
Tot_stratlh	Float (80,360,19)	Total stratiform latent heating in grid
Tot_stratq1mqr	Float (80,360,19)	Total stratiform q1-qr in grid
Tot_stratq2	Float (80,360,19)	Total stratiform q2 in grid
Tot_pixn20dbz	Float (80,360,16)	Total pixels with 20 dBZ at 16 levels
Tot_pixn25dbz	Float (80,360,16)	Total pixels with 25 dBZ at 16 levels
Tot_pixn30dbz	Float (80,360,16)	Total pixels with 30 dBZ at 16 levels
Tot_pixn35dbz	Float (80,360,16)	Total pixels with 35 dBZ at 16 levels

Tot_pixn40dbz	Float (80,360,16)	Total pixels with 40 dBZ at 16 levels

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.

Acknowledgements

Courtesy of Dr. Erich Stocker, all level-1 and old level-2 PF are being processed by TSDIS in near real time. The monthly combination, new definitions processing, NCEP reanalysis profiles extraction, and level-3 data processing are completed at University of Utah.

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/trmm/

D. Full description of the level-2 product in the IDL code for 2012 algorithm.
For definitions within PR swath, level2_pr_description.pro:

```
pro level2_pr_description,description
description={ orbit:'Orbit number',                    $
    grpnum:'feature number in the orbit data',                    $
    boost:'0: before boost, 1: after boost',$
    lat:'Geographical center latitude ',   $
    lon:'Geographical center longitude ',   $
    altrk:'number of pixels along track',   $
    actrk:'number of pixels across track',   $
    elev:'ground elevation (km)', $
    year:'UTC year',$
    month:'UTC month',$
    day:'UTC day',$
    hour:'UTC hour',$
    npixels_pr:'number of pr pixels inside feature',          $
    npixels_20dbz:'number of pr pixels inside feature with 20dBZ',          $
    npixels_tmi:'number of tmi pixels inside feature',          $
    nrainpixels_2A.PR:'number of pr raining pixels', $
    nrainpixels_2A.GPROF:'number of tmi raining pixels', $
    nrainarea_2A.GPROF:'number of tmi raining pixels with pbrain > 50%', $
    volrain_2A.PR:'volumetric rain from 2A.PR (mm/hr*km^2)',          $
    volrain_20dbz:'volumetric rain from 2A.PR for 20dBZ pixels (mm/hr*km^2)',          $
    volrain_2A.GPROF:'volumetric rain from 2A.GPROF (mm/hr*km^2)', $
    volrain_2A.GPROF50:'volumetric rain from 2A.GPROF with more than 50% 
prob(mm/hr*km^2)', $
```

```
volrain_2b31:'volumetric rain from 2b31 (mm/hr*km^2)', $
min85pct:'minimum 85GHz PCT (K)',          $
min85pctlon:'lon of minimum 85GHz PCT',          $
min85pctlat:'lat of minimum 85GHz PCT ',          $
min37pct:'minimum 37GHz PCT (K)',          $
min37pctlon:'lon of minimum 37GHz PCT ',          $
min37pctlat:'lat of minimum 37GHz PCT ',          $
nlt275:'number of PR pixels with 85GHz PCT < 275 K',             $
nlt250:'number of PR pixels with 85GHz PCT < 250 K',             $
nlt225:'number of PR pixels with 85GHz PCT < 225 K',             $
nlt200:'number of PR pixels with 85GHz PCT < 200 K',             $
nlt175:'number of PR pixels with 85GHz PCT < 175 K',             $
nlt150:'number of PR pixels with 85GHz PCT < 150 K',             $
nlt125:'number of PR pixels with 85GHz PCT < 125 K',             $
nlt100:'number of PR pixels with 85GHz PCT < 100 K',             $
n37lt275:'number of PR pixels with 37GHz PCT < 275 K',             $
n37lt250:'number of PR pixels with 37GHz PCT < 250 K',             $
n37lt225:'number of PR pixels with 37GHz PCT < 225 K',             $
n37lt200:'number of PR pixels with 37GHz PCT < 200 K',             $
n37lt175:'number of PR pixels with 37GHz PCT < 175 K',             $

minir:'minimum 10.8 um Tb (K)',              $
minirlon:'lon of minimum 10.8 um Tb ',               $
minirlat:'lat of minimum 10.8 um Tb ',              $
maxnsz:'maximum near surface reflectivity (dBZ)',             $
maxnsrain:'maximum near surface rainrate (mm/hr)',             $
maxnszlon:'lon of maximum near surface reflectivity ',             $
maxnszlat:'lat of maximum near surface reflectivity ',             $
maxdbz:'maximum 1km reflectivity at 0.5-20km by 0.5km interval (dBZ)',             $
n20dbz:'number of pr pixels greater or equal to 20 dBZ at 1-16 km by 1km interval',        $
n25dbz:'number of pr pixels greater or equal to 25 dBZ at 1-16 km by 1km interval',        $
n30dbz:'number of pr pixels greater or equal to 30 dBZ at 1-16 km by 1km interval',        $
n35dbz:'number of pr pixels greater or equal to 35 dBZ at 1-16 km by 1km interval',        $
n40dbz:'number of pr pixels greater or equal to 40 dBZ at 1-16 km by 1km interval',        $
n45dbz:'number of pr pixels greater or equal to 45 dBZ at 1-16 km by 1km interval',        $
n50dbz:'number of pr pixels greater or equal to 50 dBZ at 1-16 km by 1km interval',        $
totlh:'total lh within feature at 0-0.5,0.5-1,1-2.....17-18 layers (k/hr) ',        $
totq1mqr:'total q1mqr within feature at 0-0.5,0.5-1,1-2.....17-18 layers (k/hr)',        $
totq2:'total q2 within feature at 0-0.5,0.5-1,1-2.....17-18 layers (k/hr)',        $
totstratlh:'total stratiform lh within feature at 0-0.5,0.5-1,1-2.....17-18 layers (k/hr) ',        $
totstratq1mqr:'total stratiform q1mqr within feature at 0-0.5,0.5-1,1-2.....17-18 layers (k/hr)',
$
totstratq2:'total q2 stratiform within feature at 0-0.5,0.5-1,1-2.....17-18 layers (k/hr)',        $
maxht:'maximum height of the feature from 2A23 storm height (km)',              $
```

```
maxhtlon:'lon of maximum height of the feature from 2A23 storm height ',              $
maxhtlat:'lat of maximum height of the feature from 2A23 storm height ',              $
maxht15:'maximum height reached by the feature with 15 dBZ (km)',           $
maxht20:'maximum height reached by the feature with 20 dBZ (km)',           $
maxht20lon:'lon of maximum height reached by the feature with 20 dBZ ',           $
maxht20lat:'lat of maximum height reached by the feature with 20 dBZ ',           $
maxht30:'maximum height reached by the feature with 30 dBZ (km)',           $
maxht30lon:'lon of maximum height reached by the feature with 30 dBZ ',           $
maxht30lat:'lat of maximum height reached by the feature with 30 dBZ ',           $
maxht40:'maximum height reached by the feature with 40 dBZ (km)',           $
maxht40lon:'lon of maximum height reached by the feature with 40 dBZ ',           $
maxht40lat:'lat of maximum height reached by the feature with 40 dBZ ',           $
nch4le210:'number of pr pixels with 10.8 um TB <= 210 K',           $
nch4le235:'number of pr pixels with 10.8 um TB <= 235 K',           $
nch4lt273:'number of pr pixels with 10.8 um TB < 273 K',           $
nch4ge273:'number of pr pixels with 10.8 um TB >= 273 K',           $
landocean:'0: over ocean      1:over land',$
nstrat_2A.PR:'number of pr pixels with stratiform rain',$
nconv_2A.PR:'number of pr pixels with convective form rain',$
rainstrat_2A.PR:'stratiform volumetric rain (mm/hr*km^2)',$
rainconv_2A.PR:'convective form volumetric rain (mm/hr*km^2)',$
nrpf:'number of radar precipitation features inside',$
  r_lon:'center longitude of the ellipses',$
  r_lat:'center latitude of the ellipses',$
  r_major:'major axle (km)',$
  r_minor:'minor axle (km)',$
  r_orientation:' orientation angle (degree)',$
  r_solid:' percent filled ',$
  flashcount:'flash counts (#)',$
  viewtime:'flash view time ', $
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)',$
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 ch4 >210 and <235',$
medref210235ch2:'median value of reflectance at 1.6 micron for ch4 >210 and <235',$
medref210235ch3:'median value of reflectance at 3.75 micron for ch4 >210 and <235',$
medch4:'median value of Tb at VIRs ch4 (K)',$
medch5:'median value of Tb at VIRs ch5 (K)',$
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)',$
```

```
        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',$
        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)',$
        med20dbz14kmch1:'median value of 14 km 20dbz pixels Tb at VIRs ch1 (K)',$
        med20dbz14kmch2:'median value of 14 km 20dbz pixels Tb at VIRs ch2 (K)',$
        med20dbz14kmch3:'median value of 14 km 20dbz pixels Tb at VIRs ch3 (K)',$
        medref20dbz14kmch1:'median value of 14 km 20dbz pixels ch1 reflectance for ch4<210K ',$
        medref20dbz14kmch2:'median value of 14 km 20dbz pixels ch2 reflectance for ch4<210K ',$
        medref20dbz14kmch3:'median value of 14 km 20dbz pixels ch3 reflectance for ch4<210K ',$
        med20dbz14kmch4:'median value of 14 km 20dbz pixels Tb at VIRs ch4 (K)',$
        med20dbz14kmch5:'median value of 14 km 20dbz pixels Tb at VIRs ch5 (K)' $
         }
end
```

For definitions within TMI swath, level2_tmi_description.pro:

```
pro level2_tmi_description,description
description={ orbit:'Orbit number',                    $
        grpnum:'feature number in the orbit data',                    $
        boost:'0: before boost, 1: after boost',$
        lat:'Geographical center latitude ',    $
        lon:'Geographical center longitude ',    $
        altrk:'number of pixels along track',    $
        actrk:'number of pixels across track',    $
        elev:'ground elevation (km)', $
        year:'UTC year',$
        month:'UTC month',$
        day:'UTC day',$
        hour:'UTC hour',$
        npixels_pr:'number of pr pixels inside feature',           $
        npixels_20dbz:'number of pr pixels inside feature with 20dBZ',           $
        npixels_tmi:'number of tmi pixels inside feature',           $
        nrainpixels_2A.PR:'number of pr raining pixels', $
        nrainpixels_2A.GPROF:'number of tmi raining pixels', $
        nrainarea_2A.GPROF:'number of tmi raining pixels with pbrain > 50% ', $
        volrain_2A.PR:'volumetric rain from 2A.PR (mm/hr*km^2)',           $
        volrain_20dbz:'volumetric rain from 2A.PR for 20dBZ pixels (mm/hr*km^2)',           $
        volrain_2A.GPROF:'volumetric rain from 2A.GPROF (mm/hr*km^2)', $
        min85pct:'minimum 85GHz PCT (K)',         $
        min85pctlon:'lon of minimum 85GHz PCT ',         $
        min85pctlat:'lat of minimum 85GHz PCT ',         $
        min37pct:'minimum 37GHz PCT (K)',         $
        min37pctlon:'lon of minimum 37GHz PCT ',         $
```

```
min37pctlat:'lat of minimum 37GHz PCT ',          $
nlt275:'number of TMI pixels with 85GHz PCT < 275 K',            $
nlt250:'number of TMI pixels with 85GHz PCT < 250 K',            $
nlt225:'number of TMI pixels with 85GHz PCT < 225 K',            $
nlt200:'number of TMI pixels with 85GHz PCT < 200 K',            $
nlt175:'number of TMI pixels with 85GHz PCT < 175 K',            $
nlt150:'number of TMI pixels with 85GHz PCT < 150 K',            $
nlt125:'number of TMI pixels with 85GHz PCT < 125 K',            $
nlt100:'number of TMI pixels with 85GHz PCT < 100 K',            $
volrain_lt250:'volumetric rain from 2A.GPROF over pixels of 85 GHz PCT < 250 K',$
volrain_lt200:'volumetric rain from 2A.GPROF over pixels of 85 GHz PCT < 200 K',$
volrain_lt150:'volumetric rain from 2A.GPROF over pixels of 85 GHz PCT < 150 K',$
n37lt275:'number of TMI (hires) pixels with 37GHz PCT < 275 K',            $
n37lt250:'number of TMI (hires) pixels with 37GHz PCT < 250 K',            $
n37lt225:'number of TMI (hires) pixels with 37GHz PCT < 225 K',            $
n37lt200:'number of TMI (hires) pixels with 37GHz PCT < 200 K',            $
n37lt175:'number of TMI (hires) pixels with 37GHz PCT < 175 K',            $
volrain_37lt250:'volumetric rain from 2A.GPROF over pixels of 37 GHz PCT < 250 K',$
volrain_37lt200:'volumetric rain from 2A.GPROF over pixels of 37 GHz PCT < 200 K',$

minir:'minimum 10.8 micron Tb (K)',              $
maxnsz:'maximum near surface reflectivity (dBZ)',            $
maxht:'maximum height of the feature from 2A23 storm height (km)',              $
maxht15:'maximum height reached by the feature with 15 dBZ (km)',          $
maxht20:'maximum height reached by the feature with 20 dBZ (km)',          $
maxht30:'maximum height reached by the feature with 30 dBZ (km)',          $
maxht40:'maximum height reached by the feature with 40 dBZ (km)',          $
nch4le210:'number of pr pixels with 10.8 um TB <= 210 K',           $
nch4le235:'number of pr pixels with 10.8 um TB <= 235 K',           $
nch4lt273:'number of pr pixels with 10.8 um TB < 273 K',           $
nch4ge273:'number of pr pixels with 10.8 um TB >= 273 K',           $
landocean:'0: over ocean      1:over land',$
  flashcount:'flash counts inside TMI swath(#)',$
  viewtime:'flash view time inside TMI swath' $
  }
end
```

E. Full description of the level-3 product in the IDL code for 2012 algorithm.

```
;   This program creats the PF level-3 grid level products
;             description
;                     chuntao liu
;                             9/2012
```

```
pro level3_description,description
  description={$
        year:'year ',$
        month:'month ',$
        lon:'longitude ',$
        lat:'latitude ',$
        days:'number of days in the month',$
        rain_3b43:'monthly rainfall rate from TRMM 3B43 (mm/day)',$
        rain_gpcc:'GPCC monthly rain (mm/day)',$
        rain_gpcc_num_gauges:'GPCC rain gauge numbers (#)',$
;       rain_gpcp:'GPCP monthly rain (mm/month)',$
;       rain_gpi:'GPI monthly rain (mm/month)',$
        rain_3a12:'TRMM 3A12 monthly rain (mm/day)',$
        pix_3a12:'TRMM 3A12 total pixels (#/month)',$
        rain_pix_3a12:'TRMM 3A12 raining pixels (#/month)',$
        rain_3a25:'TRMM 3A25 monthly rain (mm/month)',$
        pix_3a25:'TRMM 3A25 total pixels (mm/month)',$
        rain_pix_3a25:'TRMM 3A25 raining pixels (mm/month)',$
        tot_pix_pr:'Total number of pr pixels in features (#)',$
        tot_pix_20dbz:'Total number of near surface pixels with 20 dBZ in features (#)',$
        tot_pix_tmi:'Total number of TMI pixels in features (#)',$
        tot_pix_2A.PR:'Total number of 2A.PR raining    pixels in features (#)',$
        tot_pix_2A.GPROF:'Total number of pr pixels with 2A.GPROF rain in features (#)',$
        tot_pix_nlt275:'Total number of pr pixels with 85PCT < 275K in features (#)',$
        tot_pix_nlt250:'Total number of pr pixels with 85PCT < 250K in features (#)',$
        tot_pix_nlt225:'Total number of pr pixels with 85PCT < 225K in features (#)',$
        tot_pix_nlt200:'Total number of pr pixels with 85PCT < 200K in features (#)',$
        tot_pix_nlt175:'Total number of pr pixels with 85PCT < 175K in features (#)',$
        tot_pix_nlt150:'Total number of pr pixels with 85PCT < 150K in features (#)',$
        tot_pix_nlt125:'Total number of pr pixels with 85PCT < 125K in features (#)',$
        tot_pix_nlt100:'Total number of pr pixels with 85PCT < 100K in features (#)',$
        tot_pix_n20dbz:'Total number of pr pixels with 20 dBZ from 1km-16km with 1km intervals in features (#)',$
        tot_pix_n25dbz:'Total number of pr pixels with 25 dBZ from 1km-16km with 1km intervals in features (#)',$
        tot_pix_n30dbz:'Total number of pr pixels with 30 dBZ from 1km-16km with 1km intervals in features (#)',$
        tot_pix_n35dbz:'Total number of pr pixels with 35 dBZ from 1km-16km with 1km intervals in features (#)',$
        tot_pix_n40dbz:'Total number of pr pixels with 40 dBZ from 1km-16km with 1km intervals in features (#)',$
        tot_pix_n45dbz:'Total number of pr pixels with 45 dBZ from 1km-16km with 1km intervals in features (#)',$
        tot_totlh:'total latent heating (k/hr)',$
```

tot_totq2:'total Q2 ',$
tot_totq1mqr:'total Q1-Qr (k/hr)',$
tot_stratlh:'total stratiform latent heating (k/hr)',$
tot_stratq2:'total stratiform Q2',$
tot_stratq1mqr:'total Q1-QR (k/hr)',$
tot_pix_ch4le210:'Total number of pr pixels with CH4 Tb <= 210K in features (#)',$
tot_pix_ch4le235:'Total number of pr pixels with CH4 Tb <=235K in features (#)',$
tot_pix_ch4lt273:'Total number of pr pixels with CH4 Tb <273K in features (#)',$
tot_pix_ch4ge273:'Total number of pr pixels with CH4 Tb >=273K in features (#)',$
tot_pix_strat:'Total number of pr pixels with stratiform rain in features (#)',$
tot_pix_conv:'Total number of pr pixels with convective rain in features (#)',$
tot_pix_sample_pr:'Total number of PR pixels in the box (#)',$
tot_pix_sample_tmi:'Total number of TMI pixels in the box (#)',$
tot_volrain_2A.PR:'Total 2A.PR volumetric rain (mm/hour*km^2)',$
tot_volrain_2A.GPROF:'Total 2A.GPROF volumetric rain (mm/hour*km^2)',$
tot_volrain_20dbz:'Total 2A.PR volumetric rain from 20 dBZ area (mm/hour*km^2)',$
tot_volrain_strat:'Total 2A.PR stratiform volumetric rain (mm/hour*km^2)',$
tot_volrain_conv:'Total 2A.PR convective volumetric rain (mm/hour*km^2)',$
tot_flashcount:'Total flashcounts (#)',$
tot_feature:'Total number of features (#)',$
min_85pct:'Minimum 85 GHz PCT (K)',$
min_37pct:'Minimum 37 GHz PCT (K)',$
min_ir:'Minimum CH4 Tb (K)',$
max_dbz:'Maximum reflectivity at 0-19.5km with 0.5 km interval (dBZ)',$
max_ht:'Maximum storm height (km)',$
max_ht15:'Maximum height of 15 dBZ (km)',$
max_ht20:'Maximum height of 20 dBZ (km)',$
max_ht30:'Maximum height of 30 dBZ (km)',$
max_ht40:'Maximum height of 40 dBZ (km)',$
max_flashcount:'Maximum flashcounts (#)',$

tot_mcs_pix_pr:'Total number of pr pixels in MCSs (#)',$
tot_mcs_pix_20dbz:'Total number of near surface pixels with 20 dBZ in MCSs (#)',$
tot_mcs_pix_tmi:'Total number of TMI pixels in MCSs (#)',$
tot_mcs_pix_2A.PR:'Total number of 2A.PR raining pixels in MCSs (#)',$
tot_mcs_pix_2A.GPROF:'Total number of pr pixels with 2A.GPROF rain in MCSs (#)',$
tot_mcs_pix_nlt275:'Total number of pr pixels with 85PCT < 275K in MCSs (#)',$
tot_mcs_pix_nlt250:'Total number of pr pixels with 85PCT < 250K in MCSs (#)',$
tot_mcs_pix_nlt225:'Total number of pr pixels with 85PCT < 225K in MCSs (#)',$
tot_mcs_pix_nlt200:'Total number of pr pixels with 85PCT < 200K in MCSs (#)',$
tot_mcs_pix_nlt175:'Total number of pr pixels with 85PCT < 175K in MCSs (#)',$
tot_mcs_pix_nlt150:'Total number of pr pixels with 85PCT < 150K in MCSs (#)',$
tot_mcs_pix_nlt125:'Total number of pr pixels with 85PCT < 125K in MCSs (#)',$
tot_mcs_pix_nlt100:'Total number of pr pixels with 85PCT < 100K in MCSs (#)',$

```
tot_mcs_pix_n20dbz:'Total number of pr pixels with 20 dBZ from 1km-16km with 1km intervals in MCSs (#)',$
tot_mcs_pix_ch4le210:'Total number of pr pixels with CH4 Tb <= 210K in MCSs (#)',$
tot_mcs_pix_ch4le235:'Total number of pr pixels with CH4 Tb <=235K in MCSs (#)',$
tot_mcs_pix_ch4lt273:'Total number of pr pixels with CH4 Tb <273K in MCSs (#)',$
tot_mcs_pix_ch4ge273:'Total number of pr pixels with CH4 Tb >=273K in MCSs (#)',$
tot_mcs_pix_strat:'Total number of pr pixels with stratiform rain in MCSs (#)',$
tot_mcs_pix_conv:'Total number of pr pixels with convective rain in MCSs (#)',$
tot_mcs_volrain_2A.PR:'Total 2A.PR volumetric rain in MCSs (mm/hour*km^2)',$
tot_mcs_volrain_2A.GPROF:'Total 2A.GPROF volumetric rain in MCSs (mm/hour*km^2)',$
tot_mcs_volrain_20dbz:'Total 2A.PR volumetric rain from 20 dBZ area in MCSs (mm/hour*km^2)',$
tot_mcs_volrain_strat:'Total 2A.PR stratiform volumetric rain in MCSs (mm/hour*km^2)',$
tot_mcs_volrain_conv:'Total 2A.PR convective volumetric rain in MCS (mm/hour*km^2)',$
tot_mcs_flashcount:'Total flashcounts in MCSs(#)',$
tot_mcs_feature:'Total number of MCSs (#)',$
tot_mcs_withflashfeature:'Total number of MCSs with flashes(#)',$
min_mcs_85pct:'Minimum 85 GHz PCT in MCSs (K)',$
min_mcs_37pct:'Minimum 37 GHz PCT in MCSs (K)',$
min_mcs_ir:'Minimum CH4 Tb in MCSs (K)',$
max_mcs_dbz:'Maximum reflectivity in MCSs at 0-19.5km with 0.5 km interval (dBZ)',$
max_mcs_ht:'Maximum 2A23 storm height in MCSs (km)',$
max_mcs_ht15:'Maximum height of 15 dBZ in MCSs (km)',$
max_mcs_ht20:'Maximum height of 20 dBZ in MCSs (km)',$
max_mcs_ht30:'Maximum height of 30 dBZ in MCSs (km)',$
max_mcs_ht40:'Maximum height of 40 dBZ in MCSs (km)',$
max_mcs_flashcount:'Maximum flashcounts in MCSs (#)',$
mean_mcs_min85pct:'Mean minimum 85 GHz PCT in MCSs (K)', $
mean_mcs_min37pct:'Mean minimum 37 GHz PCT in MCSs (K)', $
mean_mcs_maxht:'Mean maximum 2A23 storm height in MCSs (km)', $
mean_mcs_maxht20:'Mean maximum height of 20 dBZ in MCSs (km)', $
mean_mcs_maxht40:'Mean maximum height of 40 dBZ in MCSs (km)' $
}
end
```