Characteristics of Precipitation as Observed by TRMM PR

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1. Introduction

Tropical Rainfall Measuring Mission (TRMM) satellite launched in December 1997 is equipped with the first space-borne precipitation radar (PR). There are several advantages of TRMM PR. First of all, it provides three dimensional rainfall structures, which enables more accurate classification of convective and stratiform rains than before. Secondly, since TRMM is unsyncronous with the sun, it can observe diurnal cycle of the precipitation.

Figure 1 shows three-year average diurnal cycles of rain in the equatorial belt of 10N-10S, analyzed separately for those over ocean and those over land (Takayabu, 2002). It was indicated that with a 0.3mm/hr rain-top detection thresholds, convective:stratiform ratio in total rain are 50:50 over ocean, and 63:37 over land at the 2-4km level. Stratiform clouds at these latitudes consists primarily of anvil clouds of mesoscale systems. It was also noticed that convective and stratiform rains over ocean experience almost synchronous diurnal cycle with a maximum in the early morning and a minimum in the afternoon. Over land, on the other hand, a significant afternoon peak in convective rain corresponds to the afternoon shower, but the stratiform rain does not have the corresponding increase in the afternoon but has a maximum in the midnight. These results indicate that rain over ocean is dominated by well organized mesoscale convective systems as shown by previous studies (e.g. Houze, 1977, Nesbitt et al. 2000), while that over land consists of two types of rain; one is the afternoon shower which is not as well organized as mesoscale systems, and the other is organized systems which is enhanced from midnight to early morning. The emphasis of this analysis is on the quantification of precipitation characteristics.

In this report, we aim to examine regional and seasonal variations of rain characteristics, focusing on several indices which became available with TRMM PR; stratiform rain fraction, convective/stratiform rain intensity, convective/ stratiform rain area, etc.

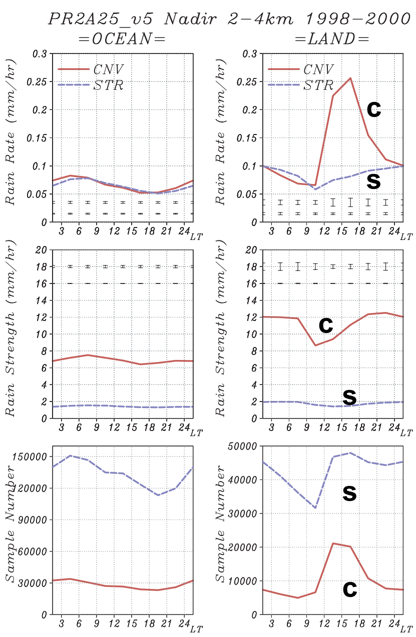

Fig. 1 Mean diurnal variation of the convective rain (solid lines) and of the stratiform rain (broken lines) for the oceanic pixels (left) and for the land pixels (right). The middle panels show the conditional mean diurnal variations under the condition of the pixels are rainy. The bottom panels show the sampled numbersfor each classes. Error bars indicate the 99% confidence intervals but plotted away from the mean values, not to obscure the mean values.

2. Data

In this study, rain rate profiles, rain flags, and method flags obtained from TRMM PR2a25 version 5 archives are utilized. Rain rate data consist of 80 vertical levels from 250m to 20,000m with a vertical resolution of 250m. Classification of rain basically follows rain flags which is determined in the PR2a23 algorithm based both on vertical method with bright-band detections and on horizontal method. Note that an alteration of the flag from the shallow sporadic stratiform rain to shallow convective rain is made, following the indication by Schumacher and Houze (2002, personal communication). Method flags are used to obtain the surface information. Rainy columns are distinguished with a rain-top threshold of 0.3 mm/hr. Most of the statistics in this report are done with only nadir data among 49 rays, except for Fig.2 which consists of all 49 ray data.

Analysis period is three years from 1 January 1998 to 31 December 2000. From January to May 1998 is in the midst of 1997/98 El Nino period. ECMWF operational analysis data for the same period are also utilized to examine the background meteorological conditions.

3. Seasonal Variations in Stratiform Rain Fraction

It has been shown that the stratiform rain fraction is larger over ocean than over land in general (see Fig. 1). However, there are finer variations over ocean as well as over land. In order to examine in details, we divided the analysis period into northern hemisphere monsoon (June -November, referred to as NHM) and southern hemisphere monsoon (December-May; SHM) seasons.

Figure 2 shows stratiform rain fraction maps for four seasons. We can observe clear seasonal variations. Especially when we focus on continental monsoon regions, such as South America, Australia, South Asia, and Africa, it is found that stratiform ratio is larger in rainy seasons and smaller in dry seasons. Over the ocean also, there is a tendency that stratiform ratio is larger over the summer hemisphere than the winter hemisphere. Note that the top panel is for January-May 1998, which is during the ENSO warm event. It is noticeable that the stratiform ratio over the central Pacific is significantly larger than other seasons, which implies that lager portion of rain is associated with well organized systems over the warmer water.

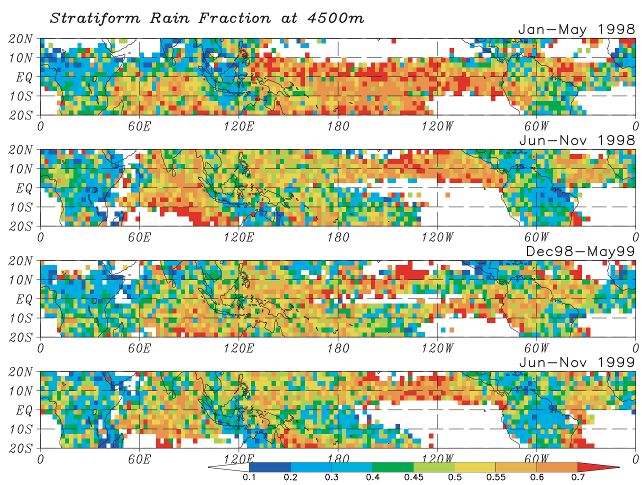

Fig. 2 Maps for the stratiform rain fraction depicted in color shades for four monsoon seasons. SHM, NHM, SHM, NHM from top to bottom. Reddish colors indicate larger fraction of stratiform rain, while bluish colors indicate more convective area. Note that the top panel shows the condition during the warm El Nino event.

Next, in order to understand such seasonal variations in precipitation characteristics in relation to atmospheric conditions, we examined the ECMWF analysis data. Six continental monsoon regions and three oceanic monsoon regions are selected as shown in Fig.3, and regional and 13-day running mean time series are constructed with PR2a25 rain data as well as with ECMWF analysis data. These averaging are necessary to overcome the sampling insufficiency due to the small swath width of PR. Figure 3 shows a scatter plot of stratiform rain fraction against the 500hPa humidity. Significant correlations are found between stratiform rain fraction and mid tropospheric humidity, both for continental monsoon regions (coefficient=0.66) and for oceanic monsoon regions (0.60). Not shown here but mid-to-upper-level humidity fields are well correlated to this stratiform rain fraction.

Considering that mid-to-upper troposphere is moistened mainly by anvil clouds, it is indeed a natural result. Still, we would like to consider two points related to this fact. First, since correlation is quantified, we may induce atmospheric humidity from observations of the stratiform rain fraction. Second point is that in the rainy season when the troposphere is more humid, the optical depth for the long wave radiation is thicker due to larger amount of water vapor. Then the atmospheric radiative cooling becomes top-heavier in the wet season than in the dry season (*e.g.* Fig.4). Since ‘convective heating’ associated with organized mesoscale systems consists of real convective heating and anvil heating, larger stratiform rain fraction results in top-heavier ‘convective heating’. We would like to point out that top-heavier ‘convective heating’ is in the sense of balancing the top-heavier radiative cooling in the rainy season, and the other way round in the dry season.

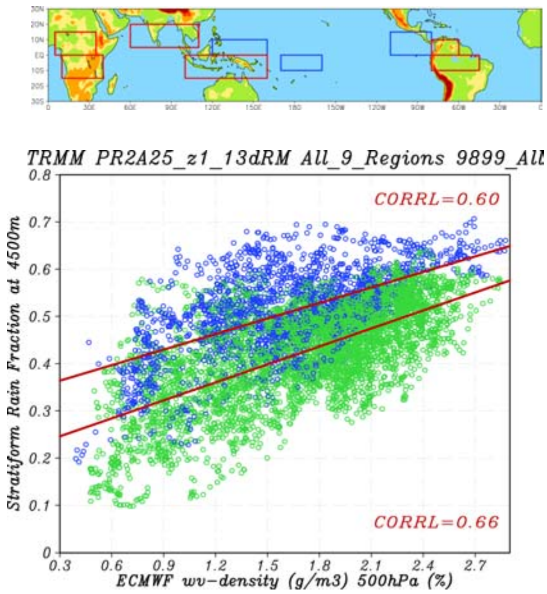

Fig. 3 Scatter diagram between ECMWF humidity (g/m3) and stratiform rain ratio. Both values are applied averaging in the 6 continental and 3 oceanic monsoon regions indicated in the above map and 13-day running means. Green dots indicate those for continental regions and blue dots indicate those for oceanic regions. Correlation coefficients are 0.66 and 0.60 for continental and oceanic data, respectively.

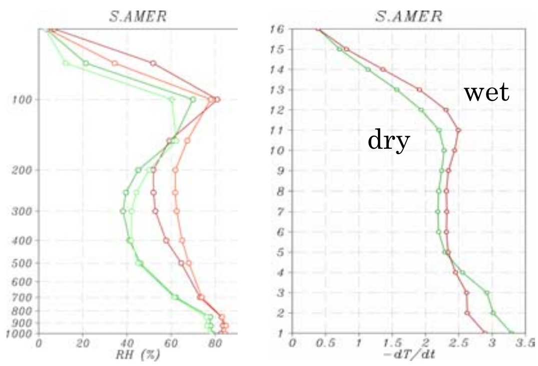

Fig.4 Humidity profiles obtained from ECMWF operational analysis (a) and cloud-free-sky radiative cooling (K/day) profiles calculated with ECMWF atmospheric data (b) over South American monsoon region. Red curves indicate those for wet season and green curves for the dry season.

4. Statistics in Seasonal variation of Precipitation Characteristics

Precipitation characteristics can be also examined with diurnal variations. Figure 5 compares those in the wet season (hereafter summer) and dry season (hereafter winter) for tropical northern hemisphere (20N-Eq, at all longitudes). Over the ocean, convective rain intensity is larger in summer than in winter by factor 1.25 in average (see Table 1), while stratiform rain intensity is not much different. At the same time, the stratiform/convective ratio of the rain area increases by factor 1.27. As a result, total rain amount is larger in summer with a slight increase of stratiform rain fraction. It is notable for the precipitation over ocean, that there is little dependence of the seasonal change on hours of the day (Fig. 6).

On the other hand, over land, summer/winter contrast in convective rain intensity and stratiform/convective area ratio are both found to be smaller (Table 1). Examining the monthly time series (Fig.6), there is considerable seasonal change in the convective intensity but not in the latter. The small contrast for convective intensity in Table 1 is attributable to the definition of two seasons; the value already increases in early summer from April to May which is included in our 'winter'. Significant dependence on seasonal change among the hours of day is found for precipitation characteristics over land (Fig.6). Smaller variations in convective intensity and in stratiform/convective ratio in area are found in the afternoon (15-18LT), while much lager variation is found for early morning (00-03LT) rain. This result may be an indication that nighttime rain has separate origins from afternoon showers.

Note that as seen in Table 1, the stratiform rain fraction is slightly less than 50% over ocean, while slightly less than 40% over land, in general. However, only southern hemispheric summer over land, the value (43%) is larger than usual. It is attributable to Southern American rain which is quite unique in characteristics.

It may be emphasized that there is a tendency that stratiform/convective ratio in area increases in accord with the intensification of convective rain in warmer seasons, especially over the tropical ocean. And it seems to be in the opposite sense from Lindzen et al. (2000)'s iris hypothesis, although not directly addressing the issue. Over the tropical land, characteristics of the afternoon shower vary little with season, while those of night-to-early-morning rain shows similar tendency as those over ocean.

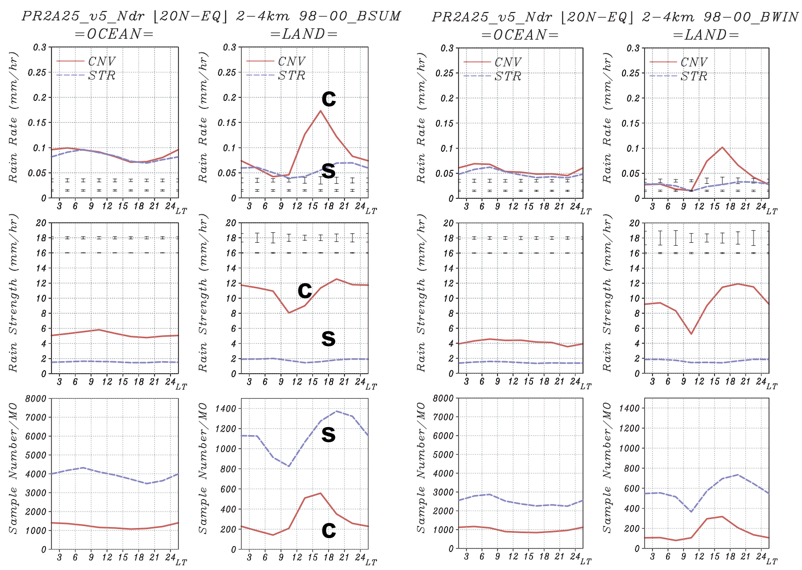

Fig. 5 Same as Fig. 1 but for those over tropical northern hemisphere region (20N-Eq, all longitudes), for NHM (left) and for SHM (right) seasons. NHM composite consists of 18 months: June-November in 1998, 1999, and 2000, while SHM composite consists of 12 months: Dec 1998-May 1999, and Dec 1999-May 2000.

(a) (b)

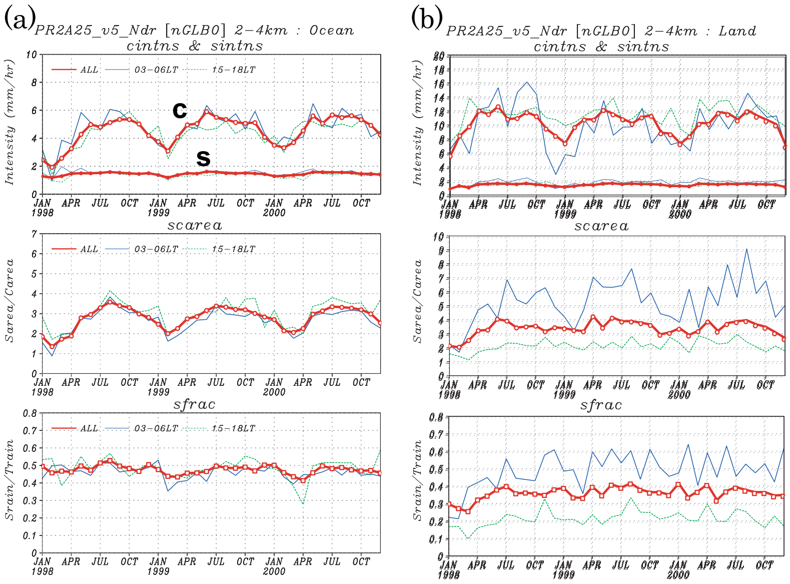

Fig. 6 Monthly mean time series for indices representing precipitation characteristics. Values are, convective and stratiform rain intensity (upper), stratiform / convective rain area ratio (middle), and stratiform rain fraction in the total rain amount (bottom), over the tropical northern hemispheric ocean (a), and land (b). Thick lines with dots indicate those for daily mean values, while solid lines are for 03-06LT, dotted lines are for 15-18LT.

Table 1 Statistics of precipitation obtained from TRMM PR2a25 data. Values are average contribution of convective rain to total rain rate, same for stratiform rain, convective rain intensity, stratiform rain intensity, convective/stratiform intensity ratio, and stratiform/convective area ratio, from top to bottom. Note that the values for stratiform area and stratiform intensity are sensitive to the threshold of rain detection, while others are not.

	Ocean	**Ocean**	**Land**	**Land**
20N-Eq, all longitudes	**Summer(NHM)**	**Winter(SHM)**	**Summer**	**Winter**
meanConv (mm/hr)	0.087 (51%)	0.056 (53%)	0.093 (62%)	0.048 (64%)
meanStrat (mm/hr)	0.082 (49%)	0.049 (47%)	0.057 (38%)	0.027 (36%)
C-intensity (mm/hr)	5.27 [1.25*w]	4.20	11.1 [1.09*w]	10.2
S-intensity (mm/hr)	1.54 [1.08*w]	1.43	1.82 [1.08*w]	1.68
Cintns/Sintns	3.42 [1.16*w]	2.94	6.09 [1.00*w]	6.08
Sarea/Carea	3.23 [1.27*w]	2.54	3.70 [1.08*w]	3.42
Eq-20S, all longitudes	**Summer(SHM)**	**Winter(NHM)**	**Summer**	**Winter**
meanConv (mm/hr)	0.065 (53%)	0.035 (54%)	0.100 (57%)	0.061 (64%)
meanStrat (mm/hr)	0.058 (47%)	0.030 (46%)	0.076 (43%)	0.034 (36%)
C-intensity (mm/hr)	4.38 [1.48*w]	2.96	10.4 [0.95*w]	11.0
S-intensity (mm/hr)	1.50 [1.13*w]	1.33	1.77 [1.00*w]	1.76
Cintns/Sintns	2.92 [1.31*w]	2.23	5.85 [0.94*w]	6.24
Sarea/Carea	2.59 [1.33*w]	1.95	4.44 [1.29*w]	3.44

References

Houze R. A., Jr., and A. K. Betts, 1981: Convection in GATE, Rev. Geophys., 19, 541-576.

Lindzen, R. S., M. D. Chou, and A. Y. Hou, 2001: Does the earth have an adaptive infrared iris? Bull. Amer. Meteor. Soc., 82, 417-432.

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, 4087-4016.

Takayabu, Y. N., 2002: Spectral representation of rain profiles and diurnal variations observed with TRMM PR over the equatorial area.