Seasonal transition of predominant precipitation type and lightning activity over tropical monsoon areas derived from TRMM observations

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[1] Monthly statistics from TRMM-PR and LIS observations for the three years 1998 to 2000 describe large-scale features in rainfall and lightning activity during pre-monsoon and monsoon periods of the Asian and South American summer monsoons. Heavy (~5–10 mm/day) pre-monsoon rainfall in the one or two months before onset was widespread mainly over land. Pre-monsoon rainfall was highly convective and characterized by active lightning, a high ratio of convective rain, and high echo tops. After onset, in contrast, intense rains also occurred over the ocean and land, however, convective intensity over land was diminished. Lightning activity was suppressed over the Amazon basin and Bangladesh during the latter half of the summer monsoon. **Citation:** Kodama, Y.-M., A. Ohta, M. Katsumata, S. Mori, S. Satoh, and H. Ueda (2005), Seasonal transition of predominant precipitation type and lightning activity over tropical monsoon areas derived from TRMM observations, *Geophys. Res. Lett.*, *32*, L14710, doi:10.1029/2005GL022986.

1. Introduction

[2] The Tropical Rainfall Measuring Mission (TRMM) was launched in 1997. This was the first platform from which space-borne radar observations were made with the precipitation radar (PR). Long-term accumulations of data based on TRMM observations describe the climatic features of rainfall and rain types. Such climatic features are determined from vertical profiles and horizontal variations of radar reflectivity. Simultaneous observations from PR and other TRMM sensors such as the Lightning Imaging Sensor (LIS) yield information on cloud physics and convective activity [*Cecil et al.*, 2002, 2005]. *Petersen and Rutledge* [2001] pointed out that vertical structure of precipitation and lightning activity over Amazon and India in wet seasons exhibit characteristics similar to those over tropical oceans, using TRMM PR and LIS observations.

[3] Monsoon rain is one of attractive targets for TRMM observations, because most rainfall in the tropics and subtropics during the summer is in the summer monsoon areas [*Murakami et al.*, 1986]. Monsoon rainfall is a considerable atmospheric heat source that influences the global atmospheric circulation [*Ose*, 1998]. The onset of the summer monsoon is a dramatic event with a large societal impact. Recent studies on monsoon onset have examined pre-monsoon rainfall that falls one or two months before onset. Two seasonal transitions in large-scale atmospheric circulation are known for the Asian summer monsoon. The Tibetan High develops in mid-May, before monsoon onset. The onset of the low-level southwest (SW) monsoon occurs in June [*Yanai et al.*, 1992]. *Ueda et al.* [2003] used Global Energy and Water Cycle Experiment (GEWEX) Asian Monsoon Experiment (GAME) reanalysis data and found large latent and sensible heating over the western Tibetan Plateau in the pre-monsoon period. *Kiguchi and Matsumoto* [2005] showed that pre-monsoon rainfall (and latent heating) over Indochina was strengthened by mid-latitude disturbances passing north of the area. Such heating may contribute to the first transition. *Li and Fu* [2004] found local thermally driven rainfall over the Amazon Basin prior to monsoon onset. An upper anticyclone develops as a response to the heating over the Amazon, as shown by *Gill* [1980]. Moistening of the ground surface by pre-monsoon rainfall promotes monsoon onset. However, these past studies explored pre-monsoon rainfall from a regional perspective only. This study used TRMM-PR and LIS observations for 1998 to 2000 to describe and compare the large-scale distribution, predominant rain types, and lightning activity of pre-monsoon rainfall and monsoon rainfall. Several features were identified that are common to two of the largest summer monsoon systems, the tropical Asian and South American summer monsoons.

2. Data

[4] The climatology of pre-monsoon and monsoon rainfall was investigated using a statistical dataset called the "PRH (PR Heating) grid data." The dataset includes near-surface rain, flash rate, and vertical profiles (e.g., precipitation, latent heating) for 10-day intervals during the three years from 1998 to 2000. These components have the same horizontal resolution of 2.5° (latitude) × 2.5° (longitude) at vertical intervals of 500 m over the TRMM-PR observation domain between 36°S and 36°N. Near-surface rain is the rain in the range bin that is closest to the earth surface and not corrupted by surface clutter. The third and fourth authors processed the PRH grid data. Near-surface rain and profiles of precipitation and latent heating were classified into four rain types based on the PRH algorithm used by *Satoh* [2004]: convective, stratiform, shallow, and anvil.

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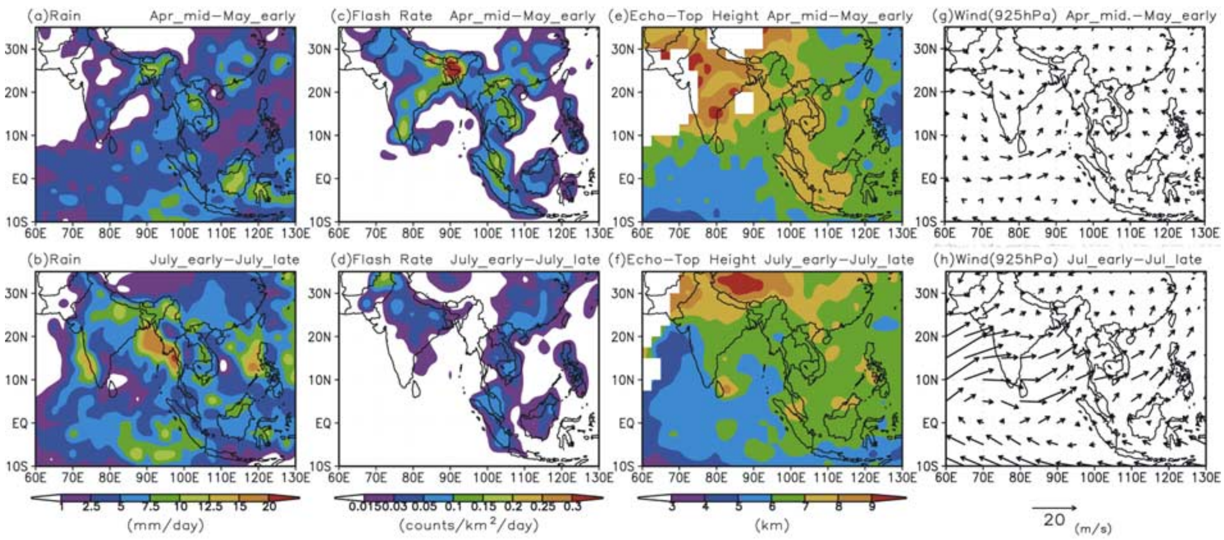

Figure 1. (a) and (b) Near-surface rain, (c) and (d) flash ratio, (e) and (f) mean echo-top height (defined as an upper limit the 17 dBZ contour in the reflectivity profiles), and (g) and (h) low-level winds over south and southeastern Asia for the (top) pre-monsoon and the (bottom) monsoon periods derived from TRMM-PR and TRMM-LIS observations and averaged for 1998 to 2000. Echo top is averaged only for footprints in which precipitation was detected. Echo top is not shown for grid boxes where rainfall was detected less than 0.3 % of total number of the footprints.

Near-surface rain was classified as shallow when echo tops are lower than the 0°C height. The shallow thus includes both convective and stratiform rain. For example, shallow, isolated rain observed by TRMM-PR, which is convective [*Schumacher and Houze*, 2003], is classified into the shallow in the PRH grid data. Near-surface rain other than the shallow was defined as convective or stratiform as determined by vertical and horizontal variations in radar reflectivity, including the existence of a bright band, following definitions in 2A25 version 5 (http://daac.gsfc.nasa.gov/hydrology/TRMM_README/TRMM_README_V5/TRMM_2A25_readme.shtml). Echo-top was derived from the top range bin of portion of at least three consecutive range bins whose echo intensity exceeds the noise level (17 dBZ). Flash rates were normalized with view time of TRMM-LIS, which is larger in higher latitude.

3. Results

[5] Figure 1 shows three-year averages of near-surface rainfall, flash counts, mean echo-top height and 925 hPa winds over south and southeast Asia for the pre-monsoon

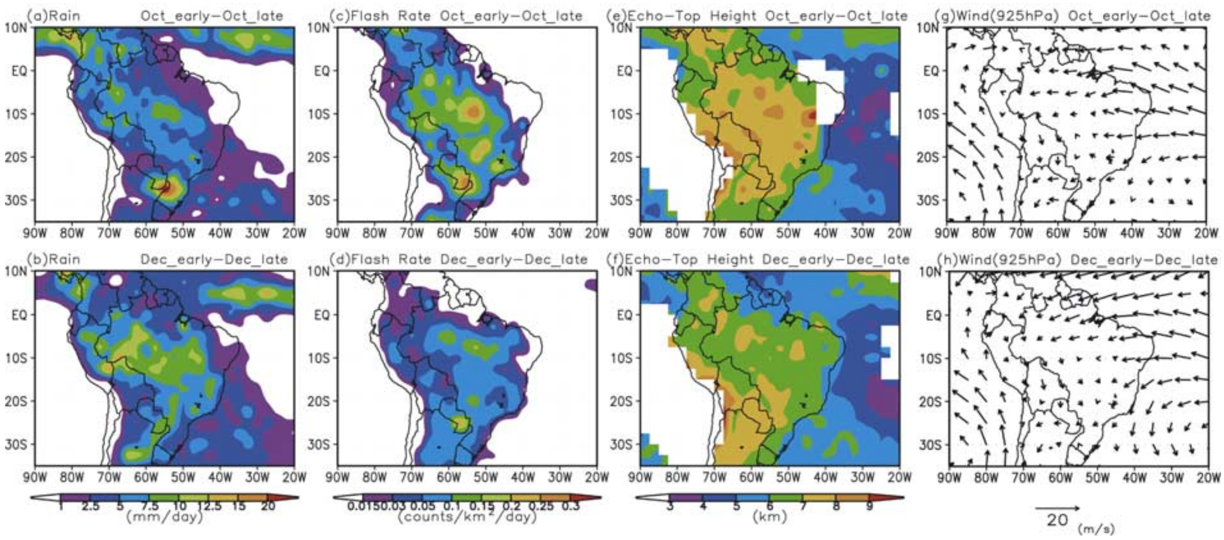

Figure 2. As in Figure 1 except over the South America.

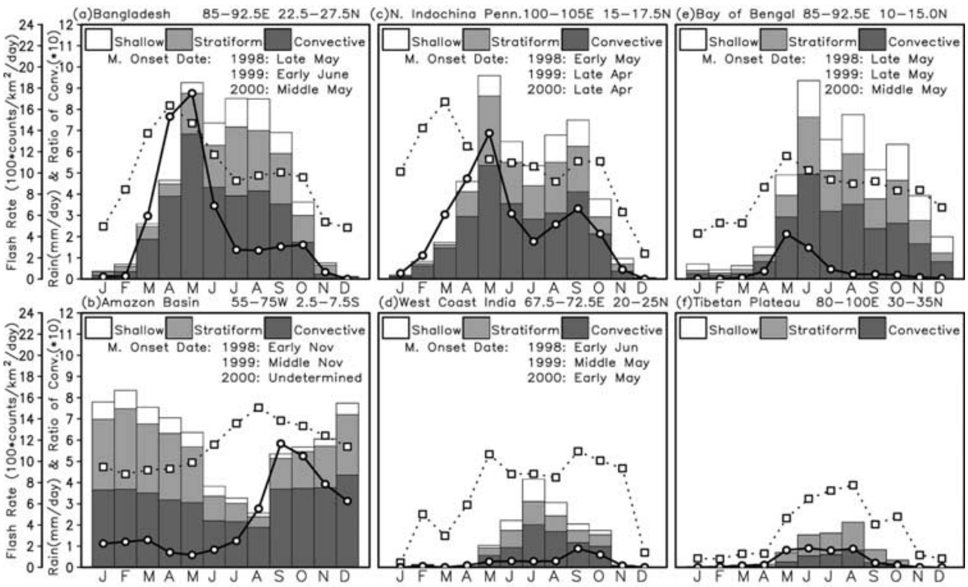

Figure 3. Three-year (1998–2000) averaged monthly precipitation categorized into three types over (a) Bangladesh, (b) the Amazon basin, (c) the northern part of the Indochina Peninsula, (d) the west coast of India, (e) the Bay of Bengal, and (f) the Tibetan Plateau. White bars, light shaded bars, and dark shaded bar indicate shallow rain, stratiform rain, and convective rain, respectively. Thick and dotted lines indicate flash ratio observed by TRMM-LIS and the ratio of convective rain to the total rain, respectively. Except over the Tibetan Plateau, onset dates for the summer monsoon in each year were determined from 925 hPa level winds.

period from 11 April to 10 May and for the monsoon in July. Figure 2 shows the variables over South America for the pre-monsoon period (in October) and the monsoon (in December). The onset of the summer monsoon varies spatially (e.g., *Tao and Chen* [1987] for the Asian monsoon) and interannually. We defined that onset dates of the summer monsoon for each year are the first ten days of the monsoon period as determined by 925-hPa winds. The monsoon period was defined to be characterized by wind directions within ±45 degrees of the mean direction of the summer monsoon and wind speeds larger than 80% of mean wind speed of the summer monsoon. Onset occurred when those two conditions were met continuously except for intermittent interruptions that were shorter than 10 days. Seasonal changes in wind direction are obscured over the Amazon by barrier effects associated with the Andes cordillera [*Figueroa et al.*, 1995]. Monsoon periods there were thus referenced for the 925–hPa wind in a valley between the Andes and Guiana Highlands, where cross–equatorial northerly winds prevail in monsoon period [*Wang and Fu*, 2002]. The pre–monsoon and monsoon periods selected for these figures were selected to avoid transitional periods in monsoon areas following the monsoon onset. Low–level circulations characterizing the summer monsoon occurred only in the selected monsoon periods. For example, the SW monsoon was over the Indian Ocean and south and southeast Asia (Figure 1h), and cross–equatorial northerly winds were between the Andes and the Guiana Highlands (around 70°W on the Equator) (Figure 2h). These circulations were not present in pre–monsoon wind fields, (Figures 1g and 2g). The selected pre-monsoon and monsoon periods are thus reasonable.

[6] Rainfall was more intense during the monsoon over tropical Asia, especially over western India, the Bay of Bengal, and west of Luzon Island. However, heavy rain (∼5–10 mm/day) fell over land during the pre-monsoon period in many places, especially Bangladesh, northern Indochina, the east coast of India, south China, and the southern and southwestern Tibetan highlands. The pre-monsoon rainfall over land was weaker and accompanied by more frequent lightning than that during the monsoon period. After the monsoon onset, rainfall intensified both over land and ocean. Lightning activity decreased over land, except around Pakistan and the Tibetan Plateau.

[7] Similar differences between pre-monsoon and monsoon periods for rainfall and lightning also occurred over South America. The rainfall over the Amazon basin was weaker and accompanied by more frequent lightning during the pre-monsoon period than the monsoon period. Heavy rains around 30°S in the pre-monsoon period originated from mid-latitude disturbances.

[8] The height of the echo top shows the vertical extent of precipitation and can be used as an activity index for deep convection. Figures 1 and 2 show the mean echo top height averaged for footprints where rainfall was detected. Echo top heights are not shown for grid boxes in which rainfall occurred in less than 0.3% of the total footprints. Mean echo top height in areas with rain was higher during the pre-monsoon than during the monsoon. Convection was deeper and more intense during the pre-monsoon.

[9] Figure 3 shows three-year averages of monthly variations in flash counts and near-surface rain classified by rain types for Bangladesh, northern Indochina, the west coast of India, the Amazon basin, the Bay of Bengal, and

the Tibetan Plateau. The figure highlights the seasonal transition of rainfall and lightning activity around the monsoon onset. The onset of the summer monsoon for each year was determined using the methods described previously for each panel in Figure 3, except for the Tibetan Plateau, where 925 hPa winds could not be observed.

[10] Over Bangladesh, northern Indochina, and the Amazon basin, rainfall and flash counts increased during the one or two months before monsoon onset, although rainfall was weaker than after monsoon onset. Pre-monsoon rainfall was characterized by more convective rain, consistent with the active lightning. Maximum flash counts occurred between one and two months before monsoon onset. After monsoon onset, stratiform and shallow rains became more common. Lightning decreased in the latter half of the summer monsoon, especially over wet lands such as Bangladesh and the Amazon basin. *Mohr et al.* [1999] noted that rainfall over the Amazon resembles rainfall over the ocean. Over the Bay of Bengal and the west coast of India, where rains start after monsoon onset, lightning activity and the ratio of convection was as low as over the land regions during the monsoon period examined above. After monsoon onset, rainfall type and lightning activity over both land and oceans were similar. Rainfall over the Tibetan Plateau started in May, before monsoon onset, and intense lightning activity was not observed.

4. Conclusion

[11] Pre-monsoon rainfall (~5–10 mm/day) was widespread over tropical monsoon areas, especially over land, from one to two months before monsoon onset. Pre-monsoon rainfall was highly convective, i.e., characterized by a high ratio of convective rain, high echo tops, and frequent lightning flashes, but it was weaker in intensity defined for accumulated precipitation than monsoon-period rainfall. Greater lightning intensity and higher echo tops suggest that deep convection is enhanced over land during the pre-monsoon period. Pre-monsoon rainfall may serve as a deep atmospheric heat source and strengthen land–ocean heat contrasts in the atmosphere. *Kawamura et al.* [2002] noted that strong land–sea heat contrasts around Australia may be related to high sea surface temperatures (SSTs) north of continent. These SSTs support a convectively unstable layer that forces a rainfall burst at the monsoon onset. Future studies should produce quantitative descriptions of differential latent heating between land and ocean and examine the roles of enhanced land-sea heat contrast in monsoon onset.

[12] Convective activity is suppressed over land, especially over wet lands, after monsoon onset despite increases in rainfall intensity. Rainfall characteristics such as composition of rain types and lightning activity are similar over land and ocean after monsoon onset. These results are consistent with those over Amazon and India in wet seasons presented by *Petersen and Rutledge* [2001]. An inverse relationship between rainfall and lightning activity has recently been noted over the maritime continental regions at various time-scales, i.e., on Madden Julian Oscillation (MJO) scales by Prof. Y. Takayabu (personal communication) and on ENSO scales [*Hamid et al.*, 2001]. The global nature of this relationship is not well documented, and the underlying mechanisms are unclear. Further study is warranted.

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