# Tower mast of precipitation over the central Tibetan Plateau summer

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[1] Over the Tibetan Plateau, solar heating often produces strong convective instability in the atmosphere. Using 3 years (1998–2000) of Tropical Rainfall Measuring Mission (TRMM) precipitation radar data, our investigations revealed a tower mast shape of precipitation over the Plateau in both height-longitude and height-latitude cross-sections. High rain rate center over the Plateau is located above 6km as a tower penetrating into the mid-troposphere against the nearby background, implying a unique latent heating source injecting directly to the middle atmosphere. Results indicate that there are more isolated rain cells over the Plateau than its nearby regions, and the strongest diurnal cycle of rainfall existing over the Plateau with a peak around 1600 and a valley around 0500 local time, indicating the dominance of convective clouds caused by solar heating. It is also found that the TRMM algorithm might have misclassified weak convections as stratiform rains. **Citation:** Fu, Y., G. Liu, G. Wu, R. Yu, Y. Xu, Y. Wang, R. Li, and Q. Liu (2006), Tower mast of precipitation over the central Tibetan Plateau summer, *Geophys. Res. Lett.*, *33*, L05802, doi:10.1029/2005GL024713.

## 1. Introduction

[2] Since *Flohn* [1968] pointed out the sensible heat-driven air pump of the Tibetan Plateau from estimated cumulonimbus density using satellite images, studies have revealed many meteorological mysteries of the Plateau, especially in its impact on surrounding circulations [*Yeh and Gao*, 1979; *Wu et al.*, 1997; *Wu and Zhang*, 1998]. In addition to sensible heat, latent heat released by condensation is another important heating source. *Hsu and Liu* [2003] revealed the close correspondence between the interannual variability of the dominant East Asian summer rainfall pattern and the diabatic heating over the Tibetan Plateau in both spring and summer.

[3] Due to the sparse distribution of rain gauges over the Plateau, originally, little was known on the Plateau precipitation. However, the situation has changed since 1979, largely credited to the First and Second Plateau Meteorological Science Experiments conducted in 1979 and 1998, respectively, and the observations by the Tropical Rainfall Measuring Mission (TRMM) satellite launched in 1997 [*Simpson et al.*, 1988]. For instance, *Qian et al.* [1984] found that convective clouds dominate over the Plateau summer; their occurrence frequency is above 60% in most of the Plateau and even over 90% in the central Plateau like along Yarlung Zangbu Valley. *Jiang and Xiang* [1996] pointed out that the initiation and development of severe mesoscale convective systems over the Plateau are mainly driven by its thermo-topographic effect. *Shimizu et al.* [2001] and *Uyeda et al.* [2001] studied the life cycle of convective clouds, and revealed that clouds often develop in daytime to nightfall, and deliver heavy rainfall at night. However, the overall characteristics of the precipitating clouds over the entire Plateau are still unclear. In this study, precipitation characteristics in the central Plateau are investigated using observations by the TRMM precipitation radar (PR). Being the first precipitation radar in space, the TRMM PR provides a unique opportunity to examine precipitation types and structures over the entire tropical belt between 35°S and 35°N [*Kummerow et al.*, 2000; *Iguchi et al.*, 2000; *Liu and Fu*, 2001; *Fu and Liu*, 2001, 2003; *Fu et al.*, 2003].

## 2. Data and Methodology

[4] The data used in this study are the TRMM products 2A25 and 3G68 over 3 summers (June, July and August) of 1998 to 2000 when the TRMM satellite kept the altitude of 350 km. The 2A25 contains rain rate profiles (R), which are calculated from the radar reflectivity (Z) profiles using a Z-R relation based on a hybrid of the Hitschfeld-Bordan method and the surface reference method [*Iguchi and Meneghini*, 1994]. In addition, pixels are classified into three types, convective, stratiform, and "others", based on vertical pattern of the profiles (i.e., V-method [*Awaka et al.*, 1997]) and on horizontal variability of the echo (i.e., H-method [*Steiner et al.*, 1995]). Briefly, a rain profile is classified as stratiform if PR detects a brightband near the freezing level. If no brightband exists and any value of radar reflectivity in the beam exceeds a predetermined value of 39 dBZ, the profile is classified as connective. Profiles are labeled as "others" when they do not meet the definition of either stratiform or convective rain. The 3G68 contains averaged rain rates and the numbers of rainy and total pixels on a common 0.5° × 0.5° grid. Considering the complex topography of the Plateau, our study focuses on the precipitation features in the central Plateau region (80°E–95°E, 30°N–35°N) where the mean altitude is about 5150 m. To contrast the rain properties in the central Plateau with its surroundings, analyses are also conducted for the following three nearby regions: the mid-east plain of China (115°E–120°E, 30°N–35°N), the southeast

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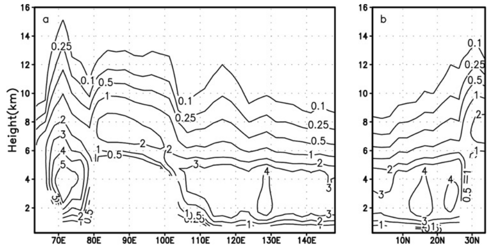


**Figure 1.** (a) Height-longitude cross-section averaged between 30°N and 35°N and (b) height-latitude cross-section averaged between 85°E and 90°E. Averaging is performed for rain-only bins at each level of the profiles. The averaging period covers June, July and August of three years from 1998 to 2000. (unit: mm/h).

upland of China (115°E–120°E, 25°N–30°N), and the Bangladesh bay (85°E–95°E, 15°N–20°N).

## 3. Results

[5] In order to visualize the unique distribution of precipitating clouds over the Plateau, mean rain rate is plotted in Figure 1a, which shows the height-longitude cross-section from 60°E to 150°E averaged between 30°N and 35°N. The mean rain rate is calculated by averaging rain-only bins at each level of the profiles. Figure 1b is the same as Figure 1a, but for height-latitude cross-section between the Equator and 35°N averaged between 85°E and 90°E. It is shown that precipitation top elevation increases westward from the mid-east plain of China (Figure 1a) and northward from Indian Ocean (Figure 1b). The distribution for rain rates higher than 2 mm/h in the central Plateau is like a precipitating cloud tower mast, well-lifted and well-penetrated into the middle troposphere over the region, which implies a unique and huge latent heating source injecting directly to the middle atmosphere over the Plateau. There are four significant maxima with rain rate greater than 4 mm/h in the low troposphere. They are located at East China Sea (126°E ~ 130°E), to the west of the Plateau (70°E ~ 78°E), the Bay of Bengal (12°N and 19°N), and the Hindustan Plain (22°N and 26°N), respectively. Among the four maxima, the deepest precipitation layer appears to the west of the Plateau, which may represent the strongest monsoon rainfall in the globe.

[6] The dominance of convective clouds over the Plateau summer has been observed by ground-based and satellite observations. The convective nature of the clouds should result in more isolated or scattered precipitating cells over the Plateau. To confirm this, we calculate the ratio of surface rain pixels to total pixels in each 0.5° × 0.5° grid over the central Plateau and the other three regions. Figure 2 shows the frequency distribution of the ratio for the four regions. The result indicates that there is a frequency peak of about 20% at the ratio being 0.3, and more than 65% of the frequencies correspond to the ratio smaller than 0.5 over the central Plateau. In contrast, in the other three regions the frequency peaks at ratio being 1.0, and 70% of total frequencies correspond to ratio greater than 0.5. These statistics indirectly indicate that more isolated precipitating clouds occur in the central Plateau. A typical precipitating cloud of such isolated cell detected by the PR on August 18, 1999 is shown in Figure 3. This cell has a dimension of ~40 km in length (from C to D) and ~30 km in width (from A to B). Its top reaches above 17 km altitude.

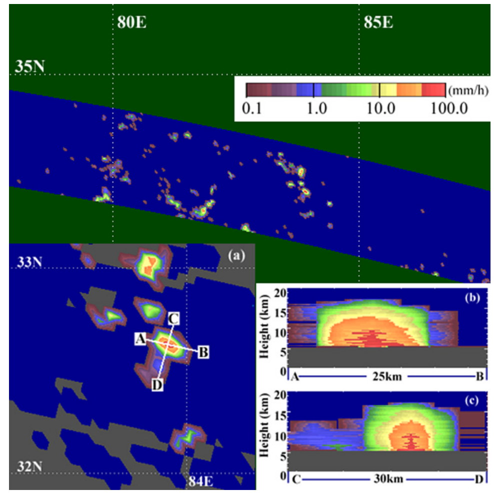


**Figure 3.** An example of isolated convective tower on August 19, 1999.

[7] The strong diurnal cycle of precipitation is another noticeable feature of rains in the central Plateau summer. Figure 4 shows rain pixel number (or area) and rain amount percentages at each hour of local standard time (LST) over the four regions defined earlier. Figure 4 indicates a peak near 1600 LST and a low near 0500 LST for both rain area

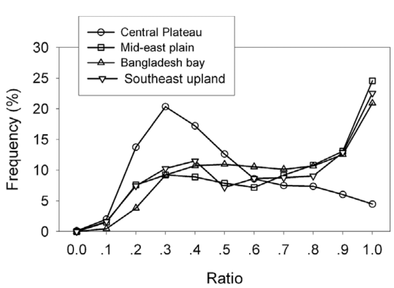


**Figure 2.** Frequency distribution of the ratio of surface rain pixels to total pixels in each 0.5° × 0.5° grid.

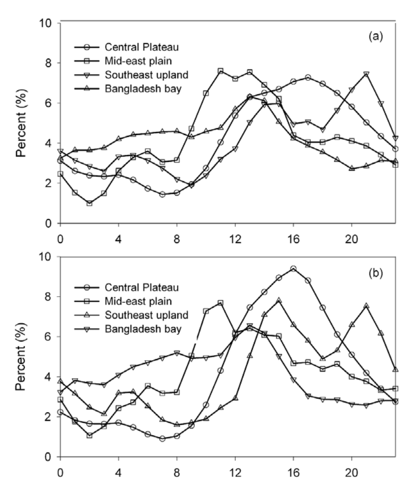


**Figure 4.** Diurnal cycle of (a) surface rain pixel percentage and (b) rain amount percentage.

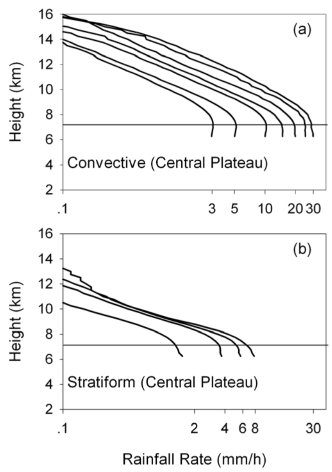


**Figure 5.** (a) Convective and (b) stratiform mean profiles at each given surface rain rate in the central Plateau.

and rain amount in the central Plateau. In the mid-east plain, the maximum of rain area or rain amount appears around 1100 LST. There are two peaks at 1500 and 2100 LST, respectively, in the southeast upland of China. The latter peak reflects convective activities in the southeast upland region before midnight. In the Bay of Bengal, the peak of rain area and rain amount occurs at 1300 LST, which may represent a feature of summer monsoon rainfall in the region. Relatively, the amplitude of rainfall diurnal variation is weak in the Bay of Bengal compared to other regions.

[8] In the tropics and East Asia, studies have found that there are four characteristic layers for convective and three characteristic layers for stratiform rains based on the vertical variation of their rain rate profiles [*Liu and Fu*, 2001; *Fu and Liu*, 2001; *Fu et al.*, 2003]. However, mean profiles of convective and stratiform rains based on the TRMM classification show similar patterns over the central Plateau (Figure 5). According to variation of the mean profiles at each given surface rain rate, only two layers, divided by the $\sim$7.5 km altitude, can be identified for both rain types. Below the altitude is the bottom layer with $\sim$1.5 km in depth. Convective rain rate decreases (increases) toward the surface for less (greater) than 10 mm/h surface rain rate profiles, suggesting an evaporation (coalescence) process when raindrops falling toward the ground (Figure 5a). The layer above 7.5 km is nearly 9 km deep without significant change in slope. For stratiform rain profiles in the central Plateau, Figure 5b shows that no brightband exists, which is the biggest difference between stratiform rains in the Plateau and in the plain. Rather, the stratiform profiles are much similar to the convective profiles over the Plateau. The two key points, no brightband and pattern similarity, open up the possibility that stratiform rains in the central Plateau classified by TRMM algorithm are weak convective rains with echo less than 39 dBZ. This deduction is consistent with the fact that most clouds in the Plateau are convective ones as classified by surface observers.

## 4. Conclusion

[9] Our studies based on TRMM PR observations find that during summer the deep precipitation layer over the central Tibetan Plateau, with more than 2.0 mm/h rain rate centered above 6 km, appears as a tower penetrating into the middle troposphere. The tower mast of precipitation can be seen from both height-longitude and height-latitude cross-sections, which implies a unique latent heating directly to the middle atmosphere over the Plateau. The ratio of rain pixels to total pixels in each $0.5° \times 0.5°$ grid indicates more isolated rainfall occurring over the central Plateau than other regions. Analysis also revealed the strongest diurnal cycle of precipitation occurring over the central Plateau with a peak at about 1600 LST and a low at about 0500 LST, which indirectly indicates that most rain events are convective in the Plateau summer. Mean rain rate profiles show that convective and stratiform rains have a similar vertical distribution, and no brightband identifiable for stratiform rains in the central Plateau, which signifies that the stratiform rains classified by TRMM algorithm may be weak convective rains.

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