Transition of the Precipitation Process over the Central Tibetan Plateau during the Summer of 1998

***Hiroyuki YAMADA[1] and Hiroshi UYEDA[1, 2]**
[1: Institute of Observational Research for Global Change (IORGC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC), 2: HyARC, Nagoya University]
*** IORGC, JAMSTEC, 236-0001, 3173-25 Shouwa-machi,**
Kanazawa-ku, Yokohama, Japan. e-mail: yamada@jamstec.go.jp

Abstract

This paper describes the transition of precipitation characteristics, which occurred four weeks after the monsoon onset over the central Tibetan Plateau. This transition occurred when the ground surface became wet and vegetation became active. The daily rainfall amount associated to a plateau-scale heat low increased with the change in the surface condition. This increase in rainfall related to the moistening of sub-cloud layer that suppress the evaporation of precipitation particles. Therefore, this study suggests that the precipitation characteristics over the plateau are sensitive to the change in the ground conditions.

Keyword: Tibetan Plateau, precipitation, land-atmosphere interaction.

1. Introduction

The summer monsoon over the Tibetan Plateau, which usually occurred from June to August, is characterized by deep convective activity (e.g., Murakami 1983; Fujinami and Yasunari 2001). To clarify the precipitation characteristics related to the deep convection, the GAME-Tibet project carried out an intensive field experiment using an X-band Doppler radar during the summer of 1998. Early studies of the GAME-Tibet suggested that there was an interesting transition of precipitation characteristics in early July, which was four weeks after the monsoon onset. The analysis on strong radar echoes by Shimizu et al. (2001) suggested that the activity of deep convection decreased after the middle of July. In contrast, Ueno et al. (2001) showed that monthly rainfall increased remarkably from June (51 mm) to July (134 mm). The cause of the transition was, however, not discussed in these two studies. To clarify the cause of the transition, characterized by the decrease of convective activity and the increase of surface rainfall, this paper describes the transition of precipitation characteristics more in detail, using the data collected during the field experiment in 1998.

2. Change in the surface conditions

The transition mentioned above occurred when the surface conditions changed. Figure 1 shows the time series of surface meteorological elements. To emphasize the change at the early half of July, the analysis period was separated into three sub-periods (labeled as Phases I-III). The mean values in Phase I (dashed lines) were compared with those in Phase III (dash-dotted lines). From Phase I to III, air temperature (*Ta*) decreased from 12.1 to 9.6 ^{o}C (in Phase III). Both the decrease in air temperature and the increase in mixing ratio (*q*, from 7.5 to 8.3 g kg^{-1}) caused a remarkable increase in relative humidity (*RH*, from 48 to 63 %). These changes in atmosphere occurred with the change in the ground conditions: the decrease of ground temperature (*Tg*) from 25 to 15 ^{o}C, and the increase of soil water content from 16 to 42 %. These changes were consistent with the decrease of sensible heat flux and the increase of latent heat flux, which are shown in Tanaka et al. (2001). The observation of ground condition using video camera showed that the color of the grass changed from brown to green (not shown), indicating the activation of vegetation. These changes indicate that the ground surface and the air near the ground became moist during the transition of precipitation characteristics.

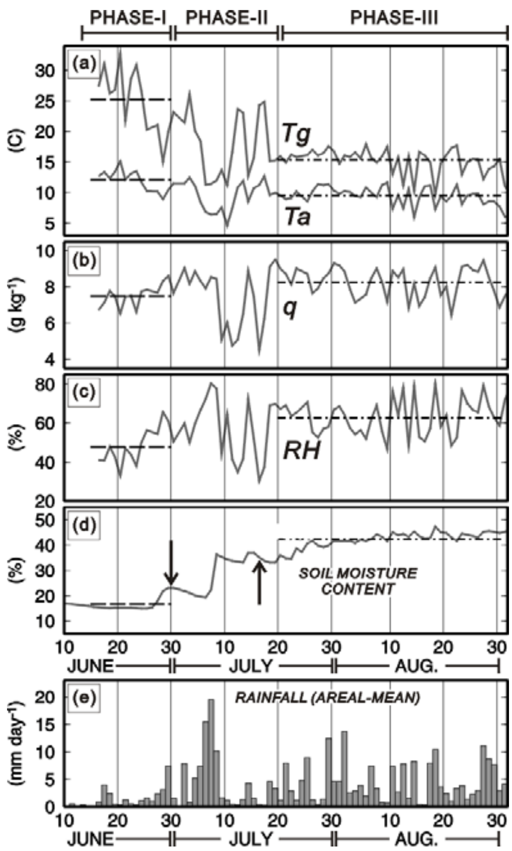

Fig. 1: (a-d) Time series of ground temperature (*Tg*), air temperature near surface (*Ta*), mixing ratio (*q*), relative humidity (*RH*), soil-moisture content at 0.04m below the surface, at Amdo from 10 June to 31 August 1998. (e) Area-mean daily rainfall amount. These elements were averaged in the daytime (00-12 UTC). The dashed line (a dash-dotted line) in each panel is the averaged value during phase I (phase III), respectively.

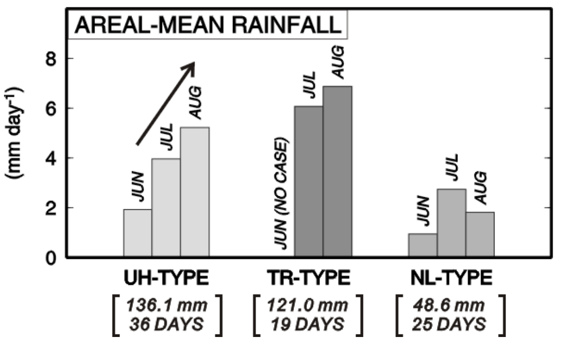

Fig. 2: Monthly variation of daily rainfall amount accumulated for the UH-, TR-, and NL-type rain events.

3. Change in surface rainfall

3.1. Separation of rain events

Many studies have recognized the importance of convective instability due to strong solar heating for the development of convective clouds (e.g., Kuo and Qian 1981; Yanai et al. 1992). On the other hand, Ueno et al. (2001) pointed out that a large-scale frontal disturbance also affects the development of convective clouds. It is, therefore, necessary to separate rainfall events according to the large-scale flow pattern before discussing the precipitation characteristics.

In this study, all rain events were separated into the following three types using the GAME-reanalysis version 1.5 dataset.

- UH-type, which is characterized by a surface heat low and a Tibetan high in the upper troposphere.
- TR-type, characterized by a surface low and a trough in the upper troposphere.
- NL-type, characterized by no surface low.

This separation was accomplished through two methods. First, a surface low was detected using 500-hPa geopotential height. If no low was found, a rain event was classified as NL-type. Second, the detected low was classified according to vortex advection at 250 hPa. If vortex advection was positive, which means the propagation of a trough, a rain event was classified as TR-type. Otherwise (i.e. negative vortex advection), a rain event was classified as UH-type.

3.2. Change in rainfall of three rain types

The differences in rainfall amount among the three types are shown in Fig. 2. Total amounts during the monsoon season (from 13 June to 31 August 1998) are shown under the graph. The amounts of both the UH- and TR-types exceeded 100 mm, and the sum of them was 84 % of the whole amount (305.7 mm). In contrast, the amount by the NL-type was small (48.6 mm), which indicates that most of the rainfall occurred during rain events of both the UH- and TR-types.

The graph of monthly variation in the daily amount shows that intraseasonal change in UH-type rain was remarkable. The daily amount increased from 1.9 mm·day^{-1} in June to 5.2 mm·day^{-1} in August. Such a change is not remarkable for TR-type rain. It is, therefore, necessary to describe the change in the precipitation characteristics associated with UH-type rain in detail

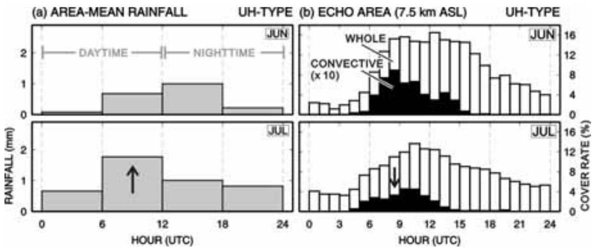

Fig. 3: (a) Diurnal cycles of six-hourly integrated rainfall for UH-type rain events in June and July. An arrow shows remarkable change in amount from the previous month. (b) The same as (a), but for the hourly echo area 7.5 km ASL (3.0 km ARL). The unit of echo is represented as a cover rate (%) to the whole area within the observational range (128 km in radius).

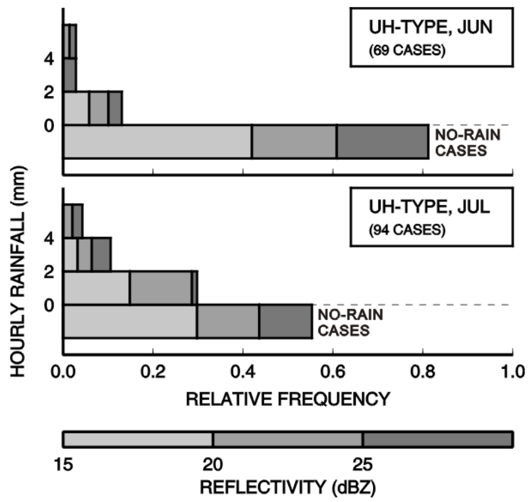

Fig. 4: Histograms of hourly rainfall in the daytime (00-12 UTC) during UH-type events in June and July. Each bar is stratified according to the maximum value of area-averaged reflectivity at 7.5 km ASL in the same hour. The cases observed at six stations within the radar observational area were used.

4. Transition of precipitation characteristics in UH-type rain

Since convective activity over the plateau in summer shows obvious diurnal variation (e.g., Uyeda et al. 2001), it is necessary to examine the change in the diurnal cycles of rainfall and radar echo during UH-type rain events. Diurnal cycles of six-hourly integrated rainfall (Fig. 3a) show that rainfall in the afternoon (i.e., between 6 and 12 UTC, marked by arrows) increased from June to July.

The diurnal cycles of hourly radar-echo area are shown in Fig. 3b. The areas of convective echo were separated using the method similar to the one used in Steiner et al. (1995). Diurnal cycle of convective echo area is characterized by a peak in the afternoon and almost zero in the late half of the night. By comparing the diurnal variations between June and July, it is found that convective echo in the afternoon (6-12 UTC) decreased after June.

To clarify the relationship between the decrease of convective-echo area and increase of rainfall amount in the afternoon, hourly-measured rainfall amount was compared with reflectivity above the rain gauge (Fig. 4). The important point to emphasize here is the cases that no rainfall was measured whereas radar echoes existed over the rain gauge. Frequency of occurrence of no-rain cases decreased from June to July. This result indicates that precipitation particles from convective clouds sometimes did not reach the ground in June. It is suggested that the atmospheric conditions in June were suitable for the evaporation of precipitation particles. This evaporation is probably the reason why the daily rainfall was very small in June. The moistening of sub-cloud layer after June was confirmed from the analysis of upper-air sounding data (not shown).

5. Summary and discussion

This study describes the transition of precipitation characteristics that occurred over the central plateau after the monsoon onset. This transition is characterized by the following points:

- Change in the ground condition (i.e., moistening of ground surface and activation of vegetation), and moistening of air near the surface.
- The increase of daily rainfall amount in the UH-type rain, which occurred under the condition characterized by a heat low near the surface and a high in the upper troposphere.

These results suggest that the transition of precipitation characteristics associated with the UH-type rain events was related to the changes in the surface conditions. Figure 5 shows a schematic illustration of the transition. Both the moistening of the ground and the activation of grass may have caused the moistening and cooling of air in the sub-cloud layer. This moistening of lower troposphere may have suppressed evaporation of precipitation particles that fall from deep convective clouds in the afternoon. As a result of the suppression, precipitation particles could reach to the ground, and rainfall amount measured by rain gauge may have increased. Therefore, this study suggests the importance of the ground conditions as a prevailing factor for the convective activity and precipitation characteristics over the plateau in summer.

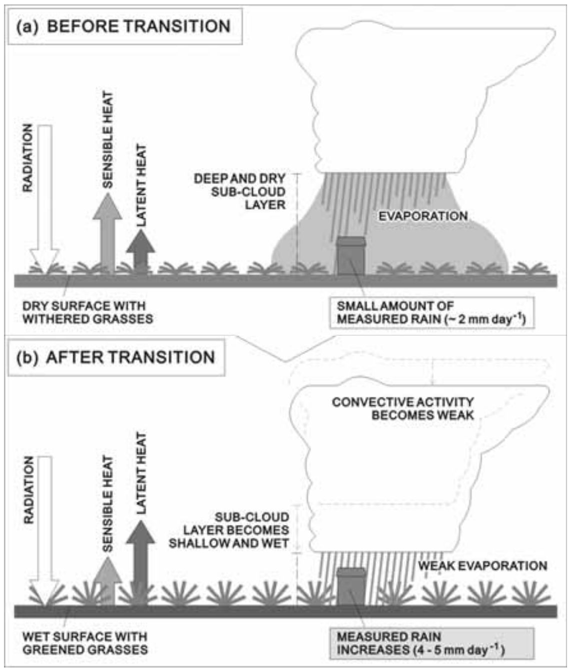

Fig. 5: Schematic illustration showing the transition of the convective precipitation process in a UH-type rain event due to changes in the ground conditions.

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