Pre-monsoon rains and onset of monsoon over the Indochina Peninsula

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Abstract

The rainfall phenomena in the pre-monsoon season over the Indochina Peninsula are investigated using geopotential height, wind and moisture fields by the NCEP/NCAR reanalysis, and OLR, precipitation and GPS data during the GAME-IOP year, 1998. The intermittent rainfall events during the pre-monsoon period are brought in wide region over the central part of the Indochina Peninsula. In early and middle April, and early May, the lower OLR regions, representing the heavy convective activity, extend southward from the mid-latitude zone to the Indochina Peninsula. The composite analysis in these three rainfall events show that these rainfall events are brought by the trough passage in the upper troposphere which migrates eastward in the mid-latitude westerlies along the southern periphery of the Tibetan Plateau. The moisture inflow in the lower troposphere related with these rainfall events is found to come mainly from the south and east, which shows sharp contast with the situations of inflow mainly from the west after the monsoon onset in middle May.

Former climatological studies have shown that the summer rainy season starts earlier in the inland area of Thailand and the onset of summer rainy season is prior to the establishment of the summer monsoon circulation over the Indochina Peninsula. Part of such rainfall is shown to be brought by an intermittent rain phenomenon under the mid-latitude westerlies prior to the monsoon onset.

keywords: Pre-monsoon rain, Indochina Peninsula, mid-latitude westerly, moisture flux, wind field

1. Introduction

The appearance of strong convection over the Indochina Peninsula, indicative of the earliest start of the summer monsoon over the Asian continent, has been documented in some recent literatures. The monsoon onset over the Indochina Peninsula occurrs in early or middle May and migrates northward from the southern part of the Bay of Bengal [Wang and LinHo, 2002]. Matsumoto [1997] pointed out that the onset of rainy season is earlier in late April when Indochina is still under the mid-latitude westerly regime in the inland region of the Indochina Peninsula than in the coastal region along the Bay of Bengal. These studies, however, only discussed the onset of the rainy season on a mean field. In general, it is well known that the rainfall phenomena during summer monsoon over the Asian summer monsoon region are produced by the southwesterly monsoon. However, the rainfall phenomena before the establishment of monsoon circulation in each year have not been studied, although they may contribute to the establishment of monsoon circulation. Thus, this paper elaborates on the characteristics of pre-monsoon rains over the Indochina Peninsula during the GAME-IOP (GEWEX (Global Energy and Water Cycle Experiment) Asian Monsoon Experiment - Intensive Observation Period), 1998.

2. Data

The daily rainfall data used in this study are obtained by the GAME-Tropics dataset for the GAME-IOP year, 1998. They are observed and archived by the meteorological departments of Thailand, Laos, and Cambodia. The station distribution is shown in Figure 1.

Moreover, we use the daily mean precipitable water in the atmosphere derived from the Global Positioning System (GPS) observations conducted by the GAME-Tropics

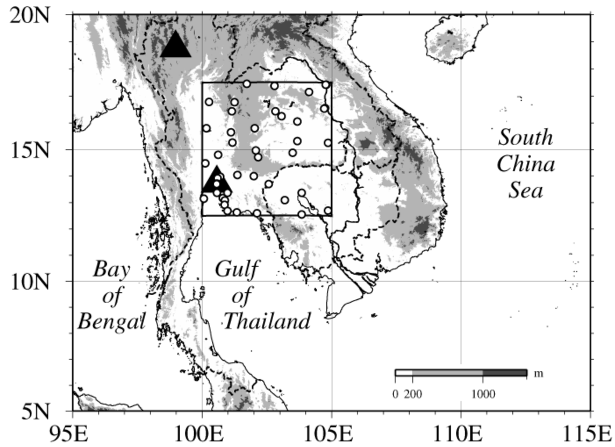

Fig. 1: Map of the study area. Light and dark shadings indicate elevations greater than 200 and 1000 m, respectively. Open circles are the rainfall stations used in this study. Black triangles are the GPS stations used in this study. Northern and southern one indicate Chiang Mai and Bangkok, respectively.

project in the same year. These observation stations are at Bangkok and at Chiang Mai. Furthermore, we investigate the atmospheric conditions using daily mean reanalysis data of various meteorological elements produced by the

National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR). As an indicator of the convective activity, the daily mean interpolated OLR data provided by the National Oceanic and Atmospheric Administration (NOAA) are utilized. The spatial resolution for both data is 2.5degree.

3. Rainfall during the pre-monsoon period

Figure 2 shows the time series of area averaged station precipitation (44 stations within the box of 12.5-17.5N, 100-105E shown by the rectangular box in Figure 1) for the period from March to May 1998. This region is selected as a representative region of the central area of the Indochina Peninsula. The intermittent rainfall events during the pre-monsoon period are seen in early March (marked by **A**), the period from late March to early April (marked by **B**, and **C**), middle April (marked by **D**) and early May (marked by **E**). According to the distribution of precipitation (not shown), these phenomena are rainfall events in which rainfalls occur not only at some points but also in wide area of research domain.

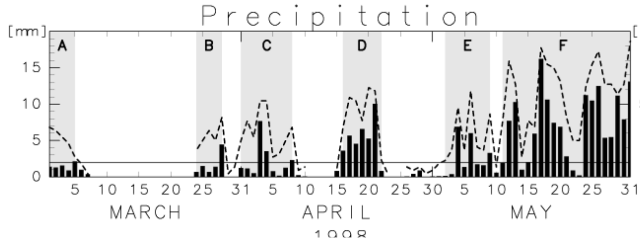

Fig. 2: Area averaged rainfall (black bar) and the ratio of the stations where rainfall is observed (dashed line) from March to May in 1998 based on the daily rainfall amount at 44 stations shown in Figure 1. The dashed line in the non-rain days is neglected. Unit of the rainfall and the ratio are mm/day and %, respectively. The shading indicates the period when the ratio of stations where rainfall is observed is exceeding 10%.

4. Synoptic condition

4.1. Trough passage in the upper troposphere

As a factor of convective activity, we can point out the passage of trough in the upper troposphere that may bring inflow of cold air in the upper troposphere and the upward flow in the troposphere. Then, in order to investigate the relationship between the precipitation phenomena and the trough in the upper troposphere, the temporal changes of geopotential height field at 300 hPa layer are analyzed. The troughs appear during the rainy events in the pre-monsoon period (**A**, **B**, **C**, **D** and **E**).

In order to reveal the wind circulation at 300 hPa layer on rain days, we carry out the composite analysis. Figure 3 shows the composite map of wind field at 300 hPa layer on the rain events(a), that on the non-rain days during the period from March to monsoon onset(b), and the difference between the two(c). The period during the rain events using this composite analysis is the periods **C**, **D** and **E** when the strong convection occurred. It is clear that the trough at 300 hPa stretches from Myanmar to the eastern Bay of Bengal, that is the west of Thailand, on rain events. In contrast, on non-rain days, the strong westerly jet appears over northern part of the Indochina Peninsula and trough is not observed around the Indochina Peninsula. The difference between the rain events and the non-rain days shows that there is a cyclonic anomaly over the Indochina Peninsula. This property of the cyclonic anomaly means the presence of the trough. It is clarified that the existence of the trough in the upper troposphere is important for the convective activity.

Furthermore, in order to show the migration of the trough in the upper troposphere associated with the rainfall events, we compose daily wind circulation at 300 hPa. It is clarified that this trough is generated in the eastern India located in the westerly jet trough in the southern edge of the

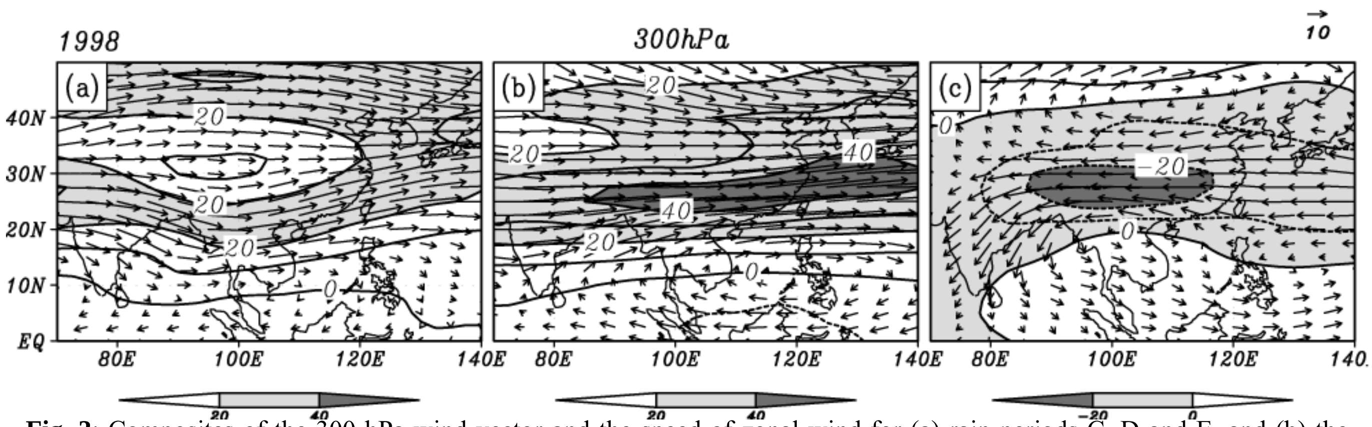

Fig. 3: Composites of the 300 hPa wind vector and the speed of zonal wind for (a) rain periods C, D and E, and (b) the non-rain days from March to mid-May, 1998. The bottom panel (c) shows the difference between (a) and (b). The difference is calculated by subtracting (b) from (a). Contour interval is 10 m/s. Light and dark shadings in (a) and (b) are more than 20 m/s and more than 40 m/s, respectively. And light and dark shadings of (c) are less than 0 m/s and less than 20 m/s, respectively.

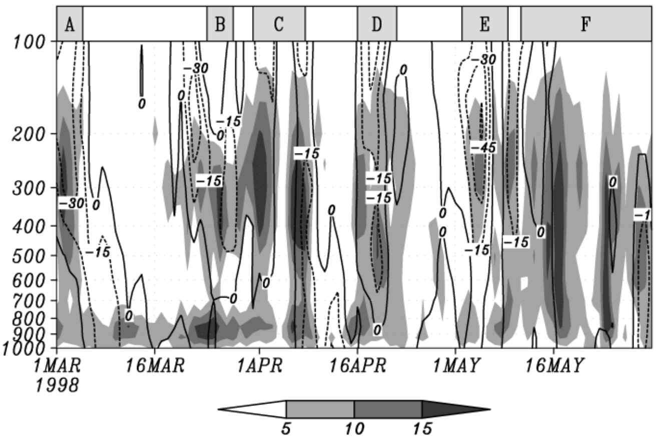

Fig. 4: The vertical-time cross section of height anomaly from the 30-day running mean value (contoured) and ω (shaded) at 15N, 102.5E for the period from March to May in 1998. The unit of height anomaly and ω are m and 10^{-2} Pa/s, respectively. Contour interval of height anomaly is 15 m less than 0 m. Shading is exceeding $5x10^{-2}$ Pa/s. Shading interval is $5x10^{-2}$ Pa/s. Shadings in the upper part of figure indicate the periods when the rainfall events occur.

To reveal the change of the vertical circulation associated with the trough passage in the upper troposphere, the relation between the anomalous geopotential height and the upward flow ω is shown. Figure 4 shows the vertical-time cross section of the anomalous geopotential height and ω. The upward flow is strengthened when the negative value of the anomalous geopotential height indicating the trough passage during the pre-monsoon period. In contrast, the trough passages and upward motion are not coincident after the monsoon onset (during the period **F**). Therefore, it can be said that the upward flow associated with the trough passages in the upper tropospheric westerlies during the pre-monsoon period is strengthened over the central part of the Indochina Peninsula.

From the above analysis, it is clarified that the trough in the upper troposphere moves eastward along the southern edge of Tibetan Plateau.

4.2. Moisture convergence in the lower troposphere

The convergence of moisture is indispensable for the convective activity that brings precipitation. Therefore, we examine distribution and transportation of moisture. We indicate the time series of the precipitable water at Bangkok and Chiang Mai derived from GPS observations (not shown). GPS observation begins from April in 1998. The variations of two kinds of precipitable water data derived from the reanalysis and GPS observations are, in general, similar except for the magnitude of the oscillation, so we utilized the reanalysis data for further discussion.

The precipitable water increases ahead of the periods **B**, **C**, **D** and **E**. The moisture amount over the Indochina Peninsula increases before the occurrence of active convection. From the time series of vertically integrated moisture inflow from each direction, the relationship between the moisture inflow from the east and rain events is focused. The moisture inflow from the east is positive value during the periods **A**, **B**, **C**, and **E**. The moisture inflow from the west and east become weak for the period **D**. In contrast, the moisture inflow mainly from the west and south during the period **F**. On the other hand, the meridional moisture inflow is almost from the south during the period from March to May. There is the strengthening of moisture convergence before the appearance of strong convection for the periods **B**, **C** and **D**. It is thought that the strengthening of moisture convergence produces the increase of precipitable water. As shown in the above analysis, it is seen that the moisture convergence during the rain events is brought by the moisture inflow from the east and south.

To reveal whether the moisture inflow from which direction contributes to intermittent rain events during the pre-monsoon period quantitatively, the composite analysis of the vertically integrated moisture inflow into the study area from each direction is carried out. Figure 5 shows the composite map of the vertically integrated moisture inflow on rain events (during the periods **C**, **D** and **E**) (a) and on non-rain days for the period from March to the date of monsoon onset (b), respectively. According to the above composite analysis, it is

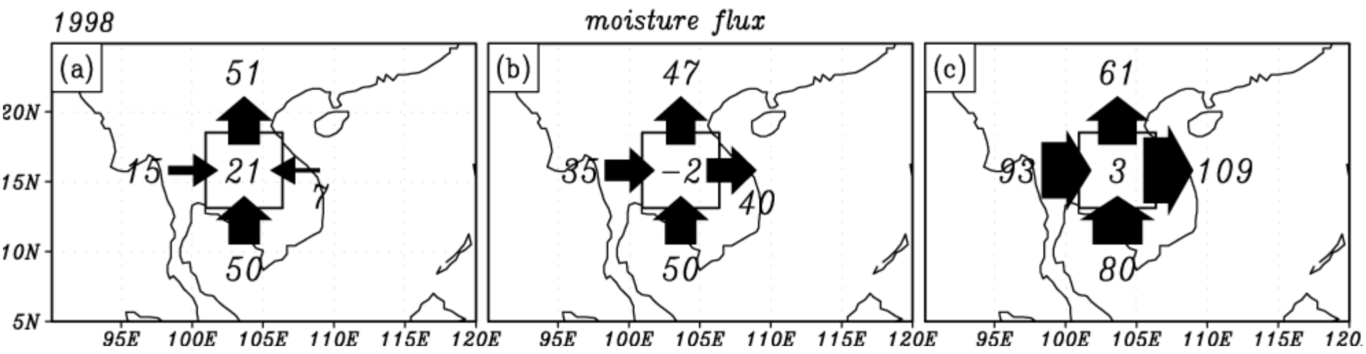

Fig. 5: Composites of the vertical integration of zonal and meridional moisture fluxes passing across boundaries of the box (12.5-17.5N, 100-105E) and the precipitable water in this box on (a) the periods **C**, **D** and **E**, (b) the non-rain days from March to May, and (c) the period of **F**. Arrows indicate the direction of flux. The numeral written in the center of the box is the precipitable water in the box. The unit of the moisture flux and that of the precipitable water are 10^6 Kg/s and 10^6 Kg/m^2, respectively.

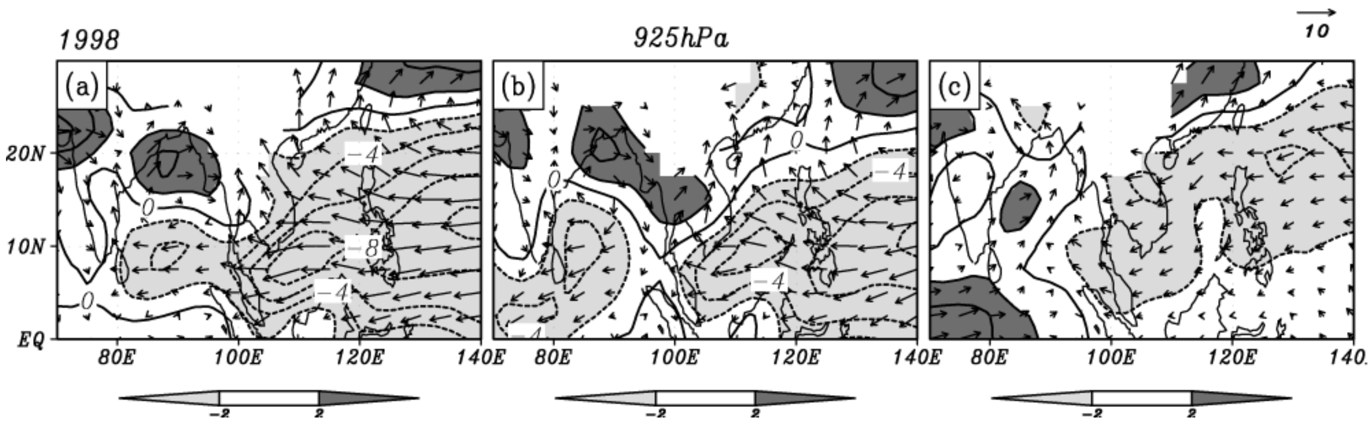

Fig. 6: Same as Figure 3, but for the 925 hPa. Contour interval is 2 m/s. Light and dark shadings is less than -2 m/s and more than 2 m/s, respectively.

clarified that the moisture convergence becomes strengthened on the rain events. In contrast, Figure 5(b) indicates that there is the moisture divergence on non-rain days. The moisture inflow from the south and north is almost the same amount in both rain events (Figure 5(a)) and non-rain days (Figure 5(b)). But the characteristics of the inflow from the zonal direction are drastically different between them. On non-rain days, the amount of moisture outflow to the east is higher than that of moisture inflow from the west. Although amount of moisture inflow is different, such characteristic is similar to that after the monsoon onset (Figure 5(c)). It is suggested that equatorial westerly and mid-latitude westerly are distinguished over the Indochina Peninsula in summer monsoon season and in non-rain days, respectively. In contrast, convergence of zonal direction occurs on rain days. This result indicates that the moisture convergence when intermittent rain events occur is produced by the strengthening of inflow from the east.

To investigate the atmospheric circulation field related to strengthening of easterly, the composite map of the wind field in the lower troposphere is constructed. The line indicating the boundary between westerly and easterly is located at approximately 100E on rain events. It is clear that southeasterly flows into the inland region of the Indochina Peninsula. In contrast, the westerly is dominant over the Indochina Peninsula on non-rain days. The features are more clearly shown by taking the difference between (a) and (b). Figure 6(c) is a subtraction of (b) from (a). We can see that anomalous easterly on rain events covers from the western North Pacific Ocean to the Indochina Peninsula.

5. Conclusions

In this study, the conditions when the intermittent rainfall during the pre-monsoon period occurred in 1998 are revealed using daily mean reanalysis data. It is indicated that the intermittent rainfall events during the pre-monsoon season are accompanied by the passage of the westerly trough in the upper troposphere and the moisture inflow from the south and east in the lower troposphere. The westerly trough in the upper troposphere moves eastward along the southern edge of the Tibetan Plateau. The boundary between westerly and easterly is located in the central region of the Indochina Peninsula just before the rain events and the easterly from the South China Sea is strengthened from the start of the rain events.

The analysis of this study is carried out only in 1998. To reveal the generality of the results in these analyses, the investigation of rainfall during the pre-monsoon period for longer period is needed. The present study clarified that the intermittent rain events during the pre-monsoon period are produced by the trough passage in the upper troposphere and the moisture convergence in the lower troposphere. To understand the mechanism of rainfall phenomena, we should be clarified using the regional numerical model in future. In this sutdy, it is not clear whether the rainfall events during the pre-monsoon period influence the establishment of monsoon circulation. The heat budget analysis over the Indochina Peninsula during the pre-monsoon period should be carried out. Furthermore, the role of the air-land interaction for the monsoon onset shoud be investigated in the future.

References

Matsumoto, J., The seasonal changes in Asian and Australian monsoon regions, *Adv. Atmos. Sci.*, **14**, 231-245, 1997.

Wang, B., and LinHo, Rainy season of the Asian--Pacific summer monsoon, *J. Climate*, **15**, 386-398, 2002.