Seasonal Transition of Summer Rainy Season over Indochina and Adjacent Monsoon Region

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ABSTRACT

The mean onset and withdrawal of summer rainy season over the Indochina Peninsula were investigated using 5-day averaged rainfall data (1975-87). The mean seasonal transition process during onset and retreat phases in Indochina, India and the South China Sea is also examined using 5-day mean OLR (1975-87) and 850 hPa wind (1980-88) data. It was found that the onset of summer rainy season begins earlier in the inland region of Indochina (Thailand) in late April to early May than in the coastal region along the Bay of Bengal. This early onset of rainy season is due to pre-monsoon rain under the mid-latitude westerly wind regime. The full summer monsoon circulation begins to establish in mid-May, causing active convective activity both over the west coast of Indochina and the central South China Sea.

In case of withdrawal, the earliest retreat of summer rainy season is found in the central northern part of Indochina in late September. The wind field, on the other hand, already changes to easterlies in the northern South China Sea in early September. This easterly wind system covers the eastern part of Indochina where post-monsoon rain is still active. In late October, the wind field turns to winter time situation, but post monsoon rain still continues in the southern part of the Indochina Peninsula until late November.

Key words: Seasonal transition, Rainy season, Summer monsoon onset

I. INTRODUCTION

It is well known that the Asian summer monsoon accompanied by abundant rainfall both over India and China advances from south to north in early summer (e.g. India Meteorological Department, 1943; Ramage, 1971; Tao and Chen, 1987). However, the onset maps of rainy season over whole monsoon region by Kurashima (1959), Ramage (1971) and Tao and Chen (1987) were based on several studies applying different onset criteria. The withdrawal map of summer rainy season has rarely been presented for the whole monsoon region except Kurashima (1959). In such preceding maps, no information was presented in the inland region of the Indochina Peninsula. Recently some studies present onset and withdrawal of summer rainy season by using satellite derived cloud data (e.g., Tanaka, 1992; Murakami and Matsumoto, 1994), which provide uniform information over the wide region. According to these studies, the onset of summer rainy season over the Indochina Peninsula is ahead of the advance of the monsoon rainfall over South India. In more than 40 years ago, Yin (1949) tried to explain why summer monsoon rainfall arrives earlier in Burma than in India.

The map in Tao and Chen (1987) indicates that the earliest onset of summer monsoon over the whole monsoon Asia is located in the northwestern part of the South China Sea in early May. Lau and Ding (1995) depicted in the Science Plan of the South China Sea Monsoon Experiment that the onset of East Asian summer monsoon is heralded by the sudden shift of the Intertropical convergence Zone (ITCZ) from the equatorial region to the South

China Sea during mid–May.

As for wind field, Orgill (1967) defined onset of the southwest monsoon over Southeast Asia as that lower tropospheric equatorial westerlies move northward into southern China during the months of May and June. On the basis of upper level wind charts for the period 1936–64, he determined the mean onset of the southwest monsoon in Indochina as 17 May with a range of 33 days. Operationally, the onset of southwest monsoon over this region is sometimes defined as that at both 850 and 700 hPa zonal wind components become positive and stay positive at least 20 days after that date (e.g., Cheang et al., 1988).

Recently, Eguchi (1996) studied the regional characteristics of annual variation of mean precipitation in the western part of the Indochina Peninsula using cluster analysis. However, no studies have revealed the precise situation of onset and withdrawal of summer rainy season in Indochina based on rainfall data. Therefore, the relationship between wind field change and rainfall situation has not been revealed yet.

In the present study, it is attempted to determine the mean onset and withdrawal of summer rainy season over the Indochina Peninsula using 5–day mean precipitation data and tried to reveal the seasonal transition process in the whole South and Southeast Asian monsoon region including India, Indochina and the South China Sea using 5–day mean outgoing long wave radiation (OLR) and wind data.

II. DATA

Datasets utilized in the present research include,

(1) 5–day mean rainfall computed from daily rainfall data, which were provided from meteorological offices of Bangladesh, India, Myanmar (Burma), Thailand, Malaysia, Singapore and Vietnam for the 12–year period (1975–77, 1979–1987) to match the data period of OLR data. The stations with less than 5–year missing data are utilized. This data set is same as utilized in Matsumoto (1992 and 1995), but the data of Myanmar are newly added.

(2) 5–day mean OLR derived from twice daily NOAA satellite observations for the same 12–year period as rainfall data. This data set is same as used in Matsumoto (1992).

(3) 5–day mean zonal and meridional winds mainly at 850 hPa extracted from the ECMWF (European Centre for Medium Range Weather Forecasts) gridded global analysis for a 9–year period of 1980–1988. 12 GMT data are utilized. This data is same as used in Matsumoto (1991a).

The spatial resolution for both data (2) and (3) is $2.5^\circ \times 2.5^\circ$.

III. DEFINITION OF ONSET AND WITHDRAWAL OF SUMMER RAINY SEASON

It is not very easy to define the onset and withdrawal of summer rainy season by pure objective method. However, in order to compare the large–scale situation, a simple definition is needed. According to Ananthakrishnan et al. (1981), there have been two main ways of determining the onset dates of summer monsoon rain in India. One method is that the onset of each year onset has been determined then the average onset date is determined using frequency distribution of long–term onset dates. For example, Ananthakrishnan and Soman (1988) and Ahmed and Karmakar (1993) used this method to determine the mean onset date of summer monsoon rain in Kerala and in Bangladesh, respectively. Another method is based on long–term averaged daily or 5–day rainfall. In this method, the onset of summer rain can be determined by a sudden and persistent increase of averaged rainfall. The famous map of Indian Meteorological Department (IMD, 1943) was constructed by this method. Ananthakrishnan et al. (1981) also adopted this method for the mean onset date of summer monsoon rain over the Islands of the Bay of Bengal. The two methods should lead to nearly the same results, if the data period is sufficiently long.

In the present study, the latter method is adopted. The definition of the onset (withdrawal) of summer rainy season is that the first (last) pentad when the mean pentad precipitation exceeds annual mean pentad precipitation (Pm = (Annual precipitation) / 73) in at least three consecutive pentads after (before) lowering it in more than three consecutive pentads. Therefore, the threshold value for the onset or withdrawal is different among stations examined. The middle date of thus defined pentad is regarded as onset or withdrawal date. This method is usefull for the region like Indochina where large difference of averaged precipitation is recognized due to orographic effect to the mean monsoonal flow (Fig. 1). Also note that this method is using rainfall data only, so it is not appropriate to consider the results to be applicable directly for the "monsoon onset" which the feature of wind fields must also be examined. In some stations, it is difficult to determine the onset or withdrawal by this method. In particular, winter precipitation maximum is evident along the eastern Pacific coastal region where the distinct between summer and winter rainy season is often difficult using only rainfall data. However, such stations are not considered here because their number and location are limited.

The onset and withdrawal of summer rainy season can easily be determined at most stations over the Indochina Peninsula using the above mentioned criteria. Figure 2 shows an

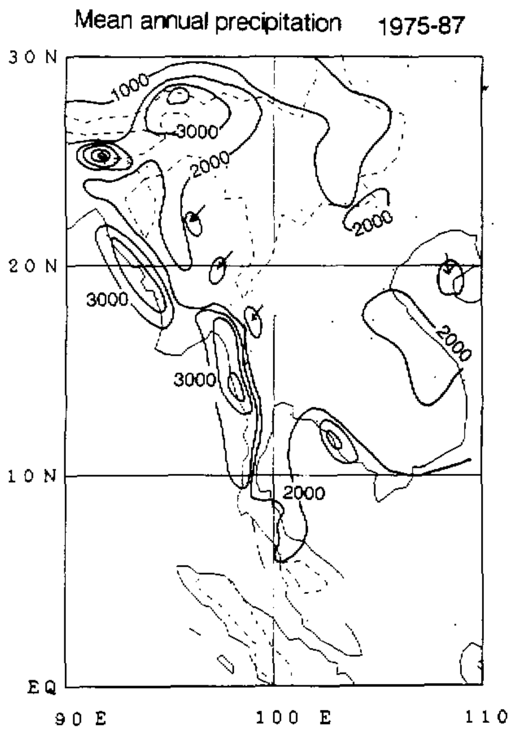

Fig. 1. Mean annual precipitation (mm) in Indochina.

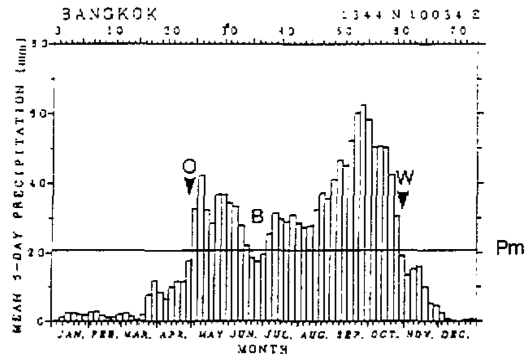

Fig. 2. Time-series of mean pentad precipitation Bangkok. Horizontal line is annual mean pentad precipitation (Pm). 'O' and 'W' indicate the onset and withdrawal pentad of summer monsoon rainfall, respectively. 'B' denotes the period of outstanding break in the monsoon.

example for Bangkok. In some cases, however, there are some 'break' of rainy season when pentad precipitation lowers Pm in more than three consecutive pentads (e.g., Marked 'B' in Fig. 2). These breaks are neglected subjectively by considering the situation of neighboring stations.

IV. FEATURES OF RAINFALL, OLR AND 850 HPA WIND DURING ONSET AND WITHDRAWAL OF SUMMER RAINY SEASON

1. *Onset*

Figure 3 shows the mean onset of summer rainy season in Indochina based on the definition mentioned in the previous section. The earliest onset of rainy season in early April is located in Assam region over Northeast India. The second earliest beginning is found in the inland region of Indochina (Thailand) in late April. It is noted that the onset of rainy season is earlier in the inland region than the coastal region along the Bay of Bengal. This spatial pattern is different from that in the Indian Sub-continent shown in IMD (1943). Also it is noted that such feature is not evident in Myanmar, northern Indochina when summer rainy season advances further northward. It is unknown why such regional differences are generated. The latest onset is located in the northwestern corner of the Indochina Peninsula in late May, which is almost concurrent with the onset of summer monsoon rain over Southern India.

This onset pattern is basically similar to the results obtained by the OLR field (Murakami and Matsumoto, 1994). However, more precise regional characteristics are obvious by using station-based rainfall data. To further elaborate on the field of convective activity, the 5-day mean OLR distribution over the whole South Asian monsoon region including both India, Indochina and the South China Sea regions is presented in every two pentads (Fig. 4).

In early April (Fig. 4-a), almost whole region in 10-20°N zone is under OLR value higher than 240 Wm^{-2}, indicating hot pre-monsoon dry season. While in mid- to late April (Figs. 4-b and 4-c), the OLR value in the inland region of the Indochina Peninsula gradually decreases indicating start of rainy season, although the minimum OLR value in this longitudinal zone is still located over northern Sumatra Island. In early May (Fig. 4-d), the

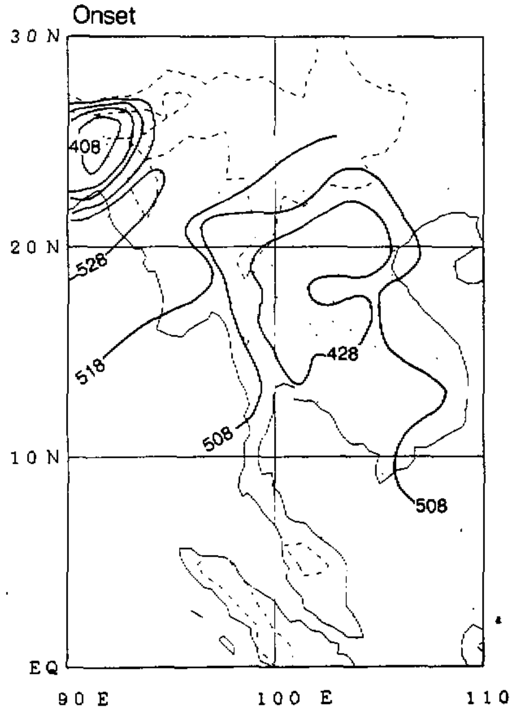

Fig. 3. Mean onset of summer rainy season in Indochina. Numeral indicates the middle date of onset pentad of summer rainy season.

minimum OLR region first appears along the southern coast of Thailand implying the effect of southwest monsoon. After mid-May (Fig. 4-e), the minimum OLR region begins to migrate northward in Indochina along the coast of the Bay of Bengal to reach the north rim of the Bay in early June (Fig. 4-g). Also convection over the South China Sea suddenly enhanced after mid-May (Fig. 4-e). Therefore, it is clear that the convection over the inland Indochina Peninsula is ahead of that over the South China Sea. After late May (Figs. 4-f and 4-g), the low OLR regions also move northward along the west coast of India, presenting beginning of summer monsoon rain in South India.

When we look at the wind field, easterly wind dominates in 7.5-12.5°N zone and mid-latitude westerlies are located to the north of this wind system before mid-April (Figs. 5-a and 5-b). In late April to early May (Figs. 5-c and 5-d), the easterlies in the southern part of the South China Sea between Borneo and the Malay Peninsula begin to weaken, and they are completely replaced by the monsoonal southwesterly in mid-May (Fig. 5-e). The southwesterly wind also expands northward in the Bay of Bengal and South China Sea during the same period and finally it merges into the mid-latitude westerlies to the north in mid-May (Fig. 5-e). In northern part of the Indochina Peninsula, the wind system is already southwesterly in April both at 850 and 700 hPa. Therefore, Orgill's (1967) definition of monsoon onset cannot be applied here. It is difficult to distinguish the monsoon and mid-latitude

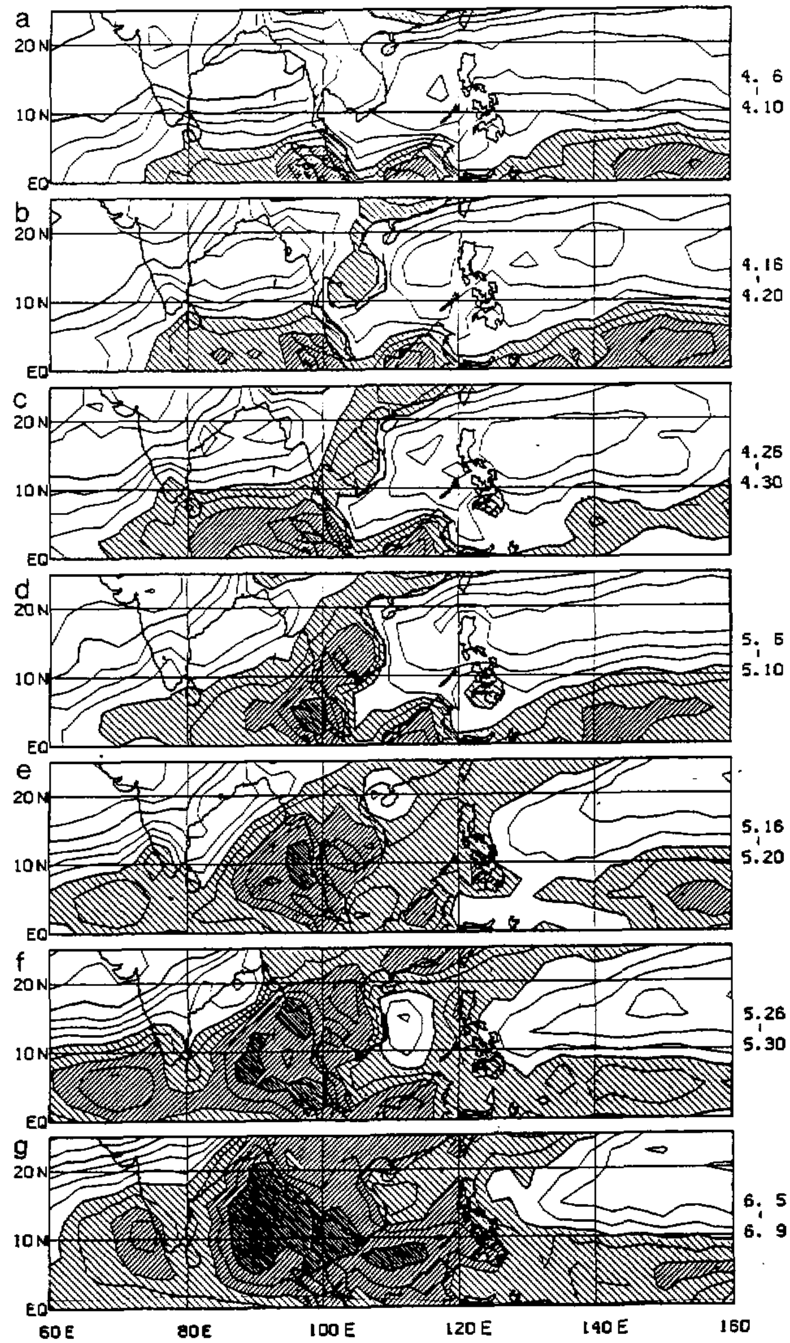

Fig. 4. Pentad mean OLR during onset phase of summer monsoon. Contour interval is 10 Wm^{-2} Hatching is less than 240 Wm^{-2}.

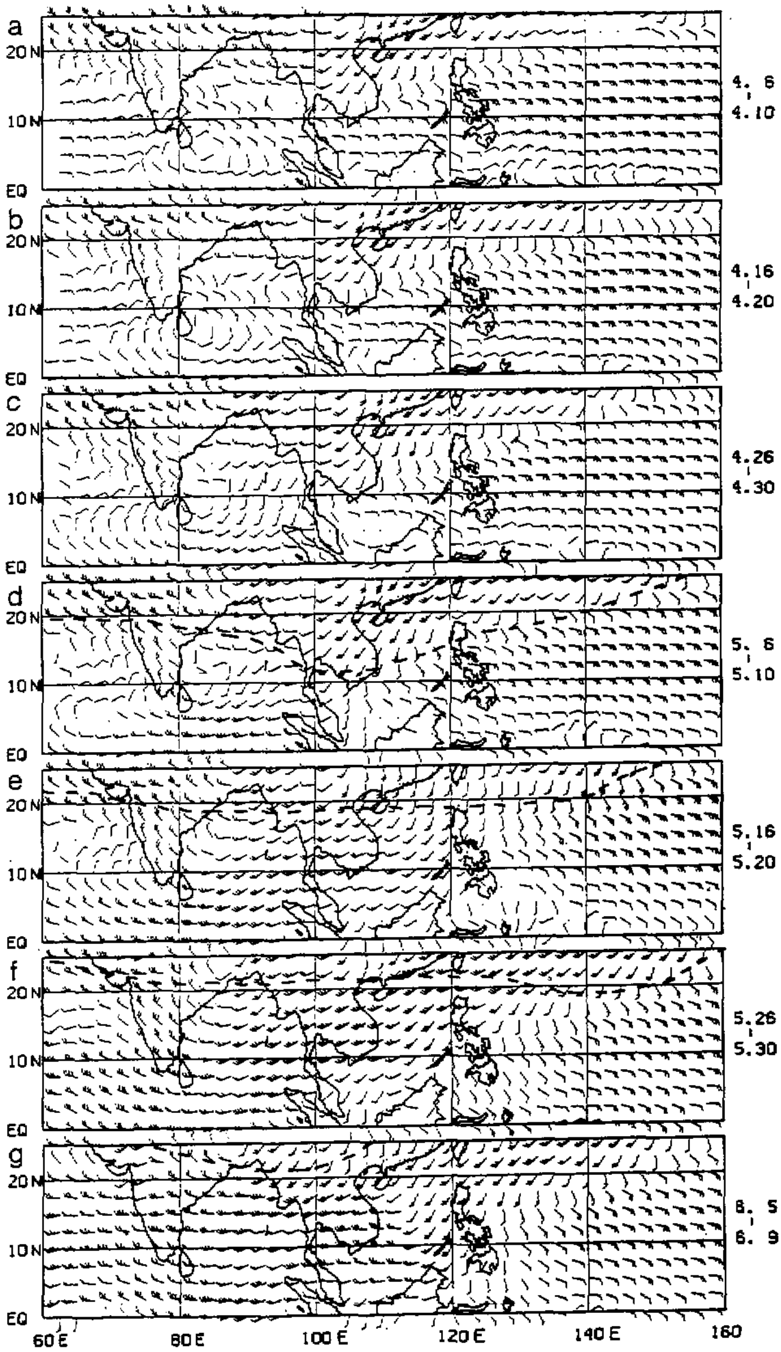

Fig. 5. Pentad mean circulation at 850 hPa during onset phase of summer monsoon (half bar: 1 ms^{-1}, full bar: 2 ms^{-1}). Dotted line indicates the boundary between mid-latitude westerlies and monsoon westerlies.

westerlies in 850 hPa maps, but by using the wind field of upper level (700, 500, 300 and 200 hPa levels, figures not shown), it can be determined that monsoon westerlies are overlaid by upper easterlies, while mid–latitude westerlies are also westerlies in the upper layers. The boundary between these two wind systems thus determined is shown in Figs. 5–d to 5–g. It is noted that the wind system in early May (Fig. 5–d) over the Indochina Peninsula is basically mid–latitude westerlies, while it is replaced by monsoon westerlies in mid–May (Fig. 5–f). The same thing can be observed over the northern South China Sea north of 12.5°N. The wind speed of monsoon westerlies particularly strengthens by early June (Fig. 5–g) both in the Bay of Bengal and Arabian Sea.

In summary, rainfall and OLR begin to show summer rainy season over the inland Indochina Peninsula from late April under mid–latitude westerlies. After that, the summer monsoon circulation covers both over Indochina and the central South China Sea in mid–May, when the convective activity over the South China Sea abruptly begins to enhance. Therefore, mid–May is an important turning point of the onset of summer monsoon over Indochina and the South China Sea. This result is consistent with He et al. (1987), Matsumoto (1991b) and Hirasawa et al. (1995), which recognized large–scale abrupt seasonal changes in this period over Indochina.

2. *Withdrawal*

In case of withdrawal (Fig. 6), the earliest retreat of summer rainy season is found in the central northern part of the Indochina Peninsula in late September. The withdrawal phase seems to experience two stepwise changes with high speed southward migration in mid–October and eastward migration in early November. The latest retreat is located along central east coast of Vietnam in late November.

When looking at the OLR field (Fig. 7), OLR value gradually increases over Indian sector from northwest during September to early October (Figs. 7–a to 7–d). Over the Indochina Peninsula and the Bay of Bengal, OLR value increases apparently in mid–September (Fig. 7–b). The minimum OLR region along the coast of the Gulf of Thailand begins to weaken in early October (Fig. 7–d). The OLR over northern part of Indochina gradually increases from early October to late October, while in southern part, OLR continuously below 240 Wm^{-2} as late as mid–November (figure not shown). The convective activity over the northern South China Sea weakens from early October (Fig. 8–d). After late October (Fig. 7–f), the OLR minimum over India field from summer to winter monsoon system, which will be shown in the followings.

As for 850 hPa wind (Fig. 8), the monsoon westerlies are already replaced by easterlies in the northern part of the South China Sea in early September, while monsoonal westerlies are still dominant over the Indochina Peninsula (Fig. 8–a). The eastern part of the Indochina Peninsula suddenly is covered by the easterlies from mid–September (Fig. 8–b). On the other hand, western part of the peninsula is dominated by westerlies until mid–October (Fig. 8–e). Mid–latitude westerlies begins to retreat southward from late September (Fig. 8–c) at the northern head of the Bay of Bengal. The wind shift from westerlies to easterlies occurs in India and the Arabian Sea in mid–October (Fig. 8–e). After late October (Fig. 8–f), the wind field in the 10–20°N zone is almost easterlies indicating the end of the summer monsoon over South Asia. This is also consistent with the OLR distribution in Fig. 7–f, thus late October is an important turning period between summer and winter monsoon circulation. This result is concurrent with the study of monsoon retreat by the author (Matsumoto, 1988 and 1991b).

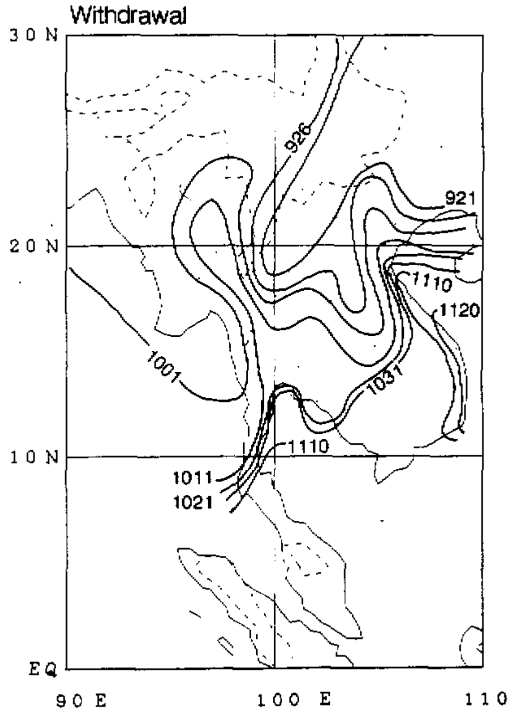

Fig. 6. Mean withdrawal of summer rainy season in Indochina. Numeral indicates the middle date of withdrawal pentad of summer rainy season.

In summary, the summer monsoon westerlies first retreat from the northern part of the South China Sea in early September, then retreat from northeastern part of the Indochina Peninsula in early to mid-September. From late September, the rainy season also retreats southward. Therefore, rainfall is abundant in eastern Indochina during latter half of September under mean easterly wind condition. The monsoon westerlies survive longer along the northwest coast of the Bay of Bengal in the Indochina Peninsula as late as mid-October, whild rainfall is decreased here by early October. After late October, the circulation system turns from summer to winter condition, but rainfall or convection over the southern part of the Indochina Peninsula is still active until late November.

V. TIME SECTIONS

In order to further elaborate on the seasonal change process of OLR and low level wind fields, time-latitude sections are prepared along 102.5°E. Figure 9 presents the OLR section. It is clearly shown that from mid- to late April the OLR value decreases in the 10-15°N zone separated from that to the south of 5°N. After mid-May, these two minimum OLR regions merge together, and continue to be a minimum center during summer monsoon season until early October. Another OLR minimum is obvious after mid-June in 15-20°N zone. This region experiences sudden increase of OLR in early September (Fig. 10) concurrent with the wind shift shown later.

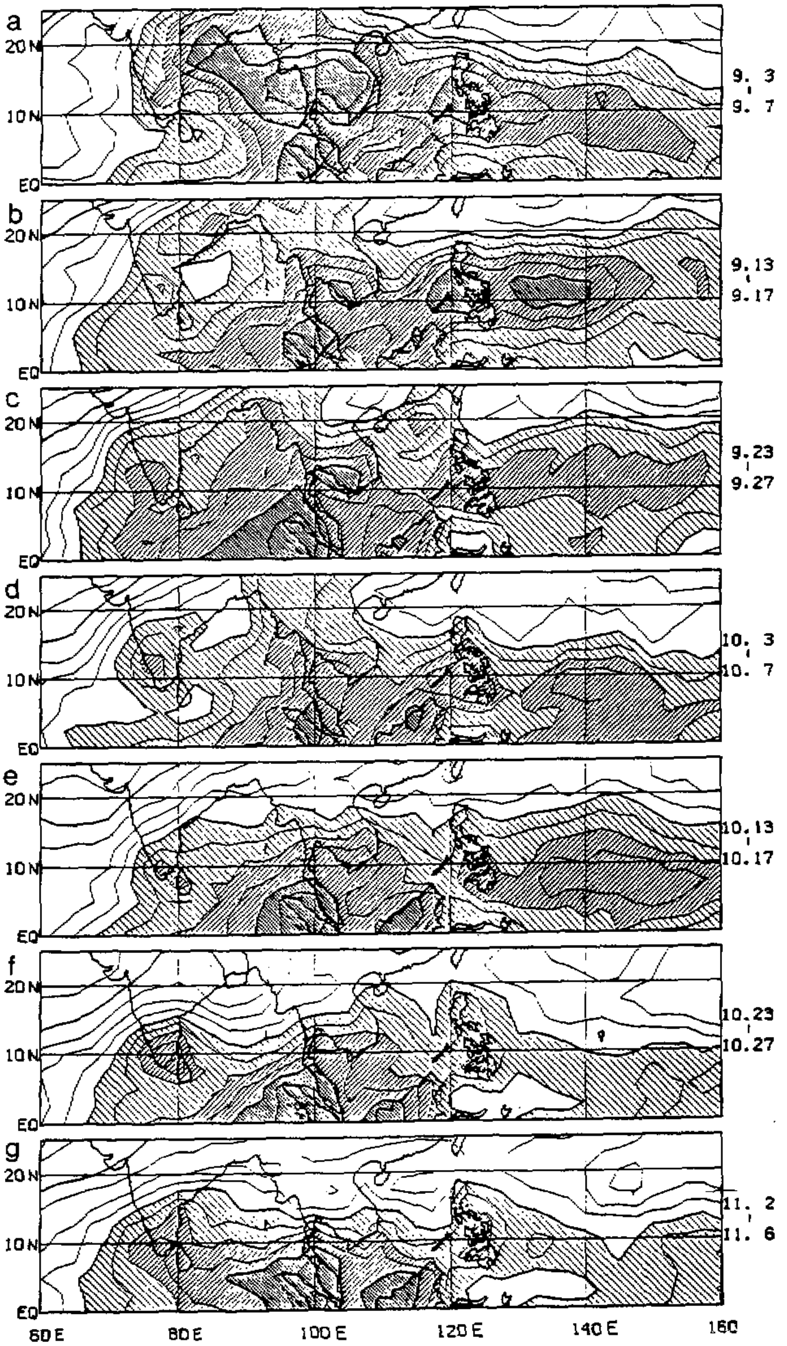

Fig. 7. As in Fig. 4 but for withdrawal phase.

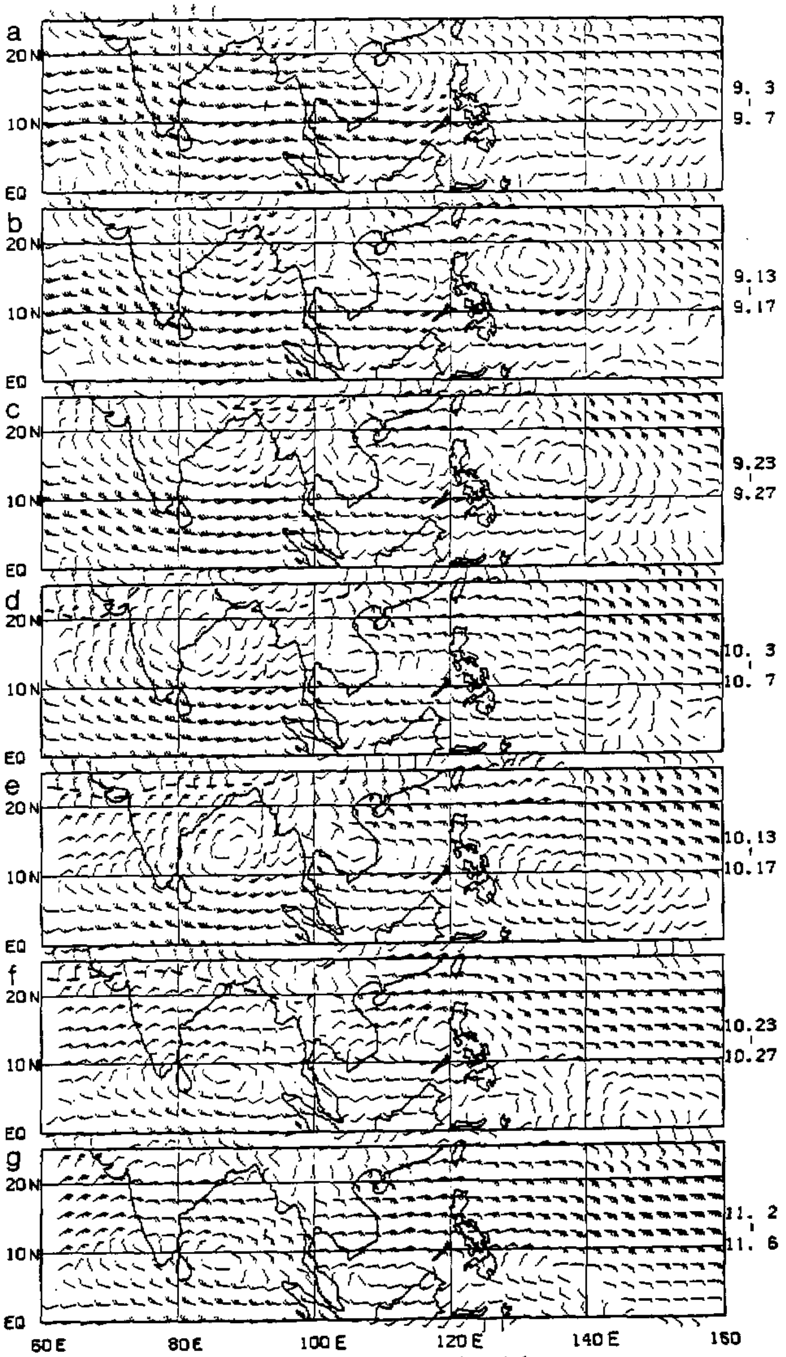

Fig. 8. As in Fig. 5 but for withdrawal phase.

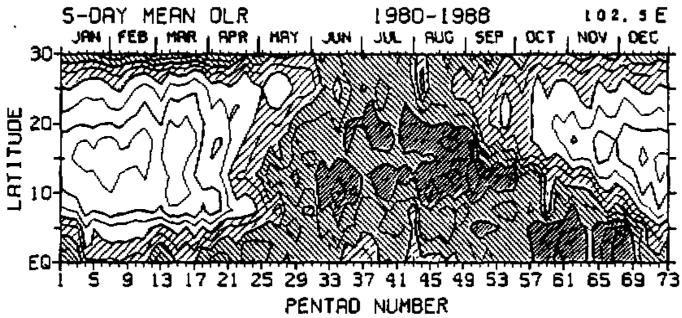

Fig. 9. Time-latitude section of pentad mean OLR along 102.5°E. Contour interval is 10 Wm^{-2}. Hatching is less than 240 Wm^{-2}.

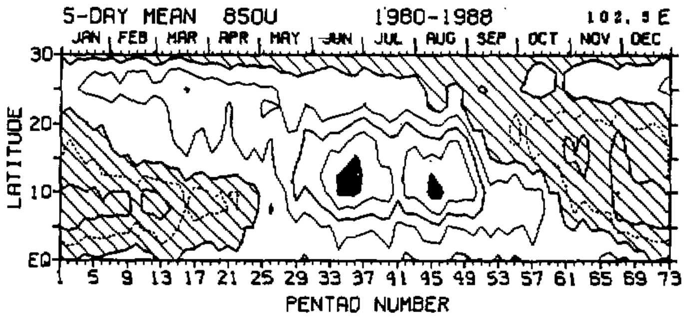

Fig. 10. Time-latitude section of pentad mean 850 hPa zonal wind along 102.5°E. Contour interval is 2.5 ms^{-2}. Light hatching is easterly wind, while heavy hatching is westerly wind of more than 10 ms^{-1}.

In 850 hPa zonal wind field (Fig. 11), the sudden change from easterlies to westerlies over wide region between 5–12.5°N is apparent in late April. In case of windrawal, the wind shift is rather gradual, but two stepwise changes are clear from westerlies to easterlies to the north of 15°N in early September and between 5–15°N in late October.

Also time-longitude section of OLR field is prepared for 15°N (Fig. 11). It is clear that OLR value decreases lower than 240 Wm^{-2} first in mid- to late April in 100–110°E, where the Indochina Peninsula is located. OLR value then decreases both in the Bay of Bengal and the South China Sea in mid-May. In early June, it decreases also over India.

Compared with onset phase, the change in the withdrawal is gradual. OLR value begins to increase higher than 240 Wm^{-2} in early October over India, then in the Bay of Bengal in mid-October, in the Indochina Peninsula in late October, and finally in the South China Sea west of 120°E in early November.

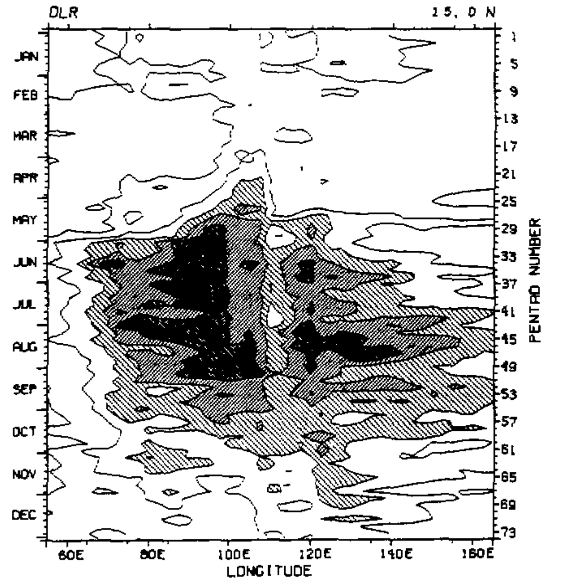

Fig. 11. Time–longitude section of pentad mean OLR along 15°N. Contour interval is 10 Wm^{-2}. Hatching is less than 240 Wm^{-2}.

VI. CONCLUSIONS

It was found that the earliest onset of summer rainy season is in early April in Assam region over northeast India. The second earliest beginning is located in the inland region of the Indochina Peninsula (Thailand) from late April to early May. The onset of rainy season is earlier in the inland region of Thailand than the coastal region along the Bay of Bengal. Such early onset occurs under mid–latitude wind system, thus can be called as "pre–monsoon rain."

This rain may have more localized feature than the subsequent summer monsoon rainfall. The full summer monsoon circulation begins to establish in mid–May, causing active convective activity both over the west coast of the Indochina Peninsula and the central South China Sea. This is the onset of summer monsoon over Indochina and the South China Sea. It seems both monsoons start concurrently. The latest onset is located in the northwestern corner of the Indochina Peninsula in late May, which is almost concurrent with the onset over southern India.

This result is not the same as the previous studies like IMD (1943), Kurashima (1959), Ramage (1971) and Tao and Chen (1987). It is probably because new data in the inland region is added in this study. But the separation of premonsoon and monsoon rain, not conducted in this study, may also affect the result. Further study is needed on this separation. On the other hand, the onset of summer monsoon over Indochina in mid–May is just similar to the result of Orgill (1967). The role of early pre–monsoon rain in inland region in the establishment of full monsoon system is a future problem.

In case of withdrawal, the earliest retreat of summer rainy season is found in the central northern part of the Indochina Peninsula in late September. The wind field, on the other hand, already changes to easterlies in the northern South China Sea as early as early September. These easterlies cover the eastern part of the Indochina Peninsula during mid–September to mid–October. But rainfall and covective activity are still active there during this period, therefore, such rainfall can be called as "post–monsoon rain". In late October, the wind field turns to winter time situation, but post monsoon rain still continues in the southern part of the Indochina Peninsula. The latest retreat is located along central east coast of Vietnam in late November.

In the present study, the sequence of pre–monsoon, summer monsoon and post monsoon rainfall in India, Indochina and the South China Sea monsoon regions is minutely described on the averaged field. This is the first comprehensive description for the onset and withdrawal of summer rainy season in Indochina. However, the rainfall data of Laos and Cambodia should be added in order to complete the onset and withdrawal maps of rainy season in Indochina.

As for the seasonal transition, it is clear that the seasonal transition process is not a reversal image in onset and withdrawal cases. In onset case, the fast evolution of convective activity is apparent over inland Indochina where no pronouced mountains are located. The heating over land area will be related to such early onset of rain in the inland region, but further study is needed on the physical mechanism of this phenomenon. The relationship between synoptic condition and rainfall features should also be examined. These studies will solve the problem why summer rain begins earlier in the inland region of Indochina in Thailand and why such feature is not obvious in case of Myanmar or India.

This study presents only averaged condition. The role of disturbances and year to year variations should be investigated in the future. Such further studies are expected in the GAME (GEWEX Asian Monsoon Experiment) and SCSMEX (South China Sea Monsoon Experiment) projects.

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