Variation in the Atmospheric Circulation over Asia and the Western Pacific Associated with the 40-day Oscillation of the Indian Summer Monsoon

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Abstract

Through use of the outgoing longwave radiation (OLR) and 700 mb height fields for 1979, an investigation was conducted of the variation of the atmospheric circulation over Asia and the western Pacific associated with the 30–60 day variation of the Indian summer monsoon.

Results of the analysis of the OLR indicate that convection over the northwestern Pacific along 15°N is active slightly before the active phase of the Indian monsoon over central India, while there is a decrease in convective activity prior to the break phase. This active convection (between 140°E and 150°E) propagates southward with a period of 40 days from 15°N to the equatorial zone. The cloudiness to the north of the Tibetan Plateau (around 55°N, 75°E) and over the subtropical high region (southeast of Japan) reaches a minimum slightly before the active phase of the Indian monsoon. Conversely, cloudiness reaches amaximum prior to the break phase of the Indian monsoon.

From the results of the analysis of the 700 mb geopotential heights, it was found that to the north of the Tibetan Plateau the maximum cloudiness corresponds to the stagnation of the trough while the minimum cloudiness is associated with the development of the ridge. The position of the subtropical high shifts northward (along 25–30°N) slightly before the active phase of the Indian monsoon and shifts southward (along 10–20°N) slightly prior to the break phase. The phase of the 30–60 day variation to the north of the Tibetan Plateau precedes that of the subtropical high region.

These results suggest a close association among the 30–60 day variation of the Indian monsoon, the convection over the western Pacific, the westerly-wave movements over the Asian continent and the subtropical high in the western Pacific.

These large scale interactions affect the weather regime around Japan during the Baiu season. The meridional position of the Baiu front (east of 130°E) around Japan shifts from 40°N, when the subtropical high shifts northward, to 30°N when the subtropical high shifts southward. This is due to the variation of the meridional position of the subtropical high, which is associated with the 40 day variation of the monsoon. The meridional position of the Mei-yu front (west of 130°E), in contrast, does not exhibit a cyclical variation.

1. Introduction

Many studies have revealed that the 30–60 day oscillation is a global-scale phenomenon, the structure of which is an eastward propagating wave of zonal wavenumber 1 (Madden and Julian, 1971, 1972; M. Murakami, 1984; Lorenc, 1984; Knutson *et al.*, 1986; Krishnamurti *et al.*, 1985 among others). Yasunari (1979, 1980, 1981) and Sikka and Gadgil (1980) found that cloud bands propagated northward, over the Indian monsoon region from the equatorial zone to the foothills of Himalayas, with a 30–60 day period and that this propagation was associated with active and inactive cycles of the Indian monsoon. In the present study the active phase of the monsoon is defined as that which occurs when the phase of the maximum cloudiness is over northern central India (about 20°N). Conversely, the break phase is defined as when the phase of the minimum cloudiness is over this region. These definitions approximately coincide with those of Krishnamurti and Sabrahmanyam (1982), who made use of the 850mb zonal wind velocity over the Arabian Sea.

Although this fluctuation appears mainly in the tropics, some studies were also conducted on the interaction between low and middle latitudes in the monsoon activity. Raman *et al.* (1980), Raman and Rao (1981) and Tanaka (1983) pointed out that

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the blocking ridge over the Eurasian continent appeared before the break in the monsoon. Moreover, M. Murakami (1984, 1985) showed that the anomalous wind (the 30–60 day component) appeared distinctly in the middle and high latitudes. With respect to these facts, Yasunari (1986) stressed that the meridional movement of the heat source around the Indian monsoon region, as suggested theoretically by Hoskins and Karoly (1981) and Webster (1981, 1982), induces the 30–60 day oscillation in the middle latitudes of the Northern Hemisphere.

On the other hand, Japanese meteolorogists have long been interested in the relationship between the Indian monsoon and the Baiu front. Suda and Asakura (1955) pointed out the parallelism in the starting date of the Indian monsoon and the Baiu.

Recently, some aspects of the relationships between tropical convection and the atmospheric circulation around Japan were investigated. Chen *et al.* (1988) showed that the convergence center of the divergent component field of water vapor transport in the lower layer migrates cyclically between the east coast of China and the area south of Japan. Lau and Chan (1986) investigated the variation in the outgoing longwave radiation (OLR) during the northern summer. It was revealed that the Mei-yu front intensified and the subtropical high pressure area over the western Pacific shifted northwestward when convection became active over central India, being associated with a 40-day variation. It is well known that the weather around Japan during the Baiu season has a close relationship with the variation of the subtropical high (Nakanishi, 1972; Tao and Ding, 1981; Kato, 1989 and others). These facts suggest that the variation of the local weather systems over east Asia is affected by the global 30–60 day oscillation.

As has been shown above, there are probably close relationships between tropical convection over the India-western Pacific and the atmospheric circulation in the middle and high latitudes. This paper will discuss the relationships between the intraseasonal 30–60 day oscillation of the Indian monsoon and variations in the atmospheric circulation over the Asian continent and the northwestern Pacific by use of the outgoing longwave radiation, the 700 mb geopotential heights and synoptic weather charts for the summer of 1979. Special attention is paid to the variation of synoptic weather régimes around Japan (mainly the Baiu) in association with that of the subtropical high.

2. Data and analysis method

Use is made of the twice daily OLR data at grid points separated by 2.5° latitude and 2.5° longitude, derived from the NOAA polar orbiting satellite data, from May to September 1979. These data were averaged to form daily data over the domain of 60–180°E and 10°S–70°N. Missing data were linearly interpolated in time.

In the tropics, low values of OLR can be regarded as masking the existence of deep convection with high cloud top. Care must be taken when examining extratropical OLR data due to low surface temperatures. However, since the analysis period for this study corresponds to the northern summer season, the low values of OLR may be taken as a measure of cloudiness with higher cloud tops, although they may not always be convective clouds.

Use is made of the 700 mb geopotential height data, which were based on the FGGE3b data set produced by the European Center for Medium Range Weather Forecasts (ECMWF). The data were rearranged at the Department of Meteolorogy, Florida State University, to correspond to daily values at global grid points of 11.25° latitude by 11.25° longitude. The region used for the present analysis extends from 56.25–180°E to 11.25°S–67.5°N and covers the period from May 1 through September 30, 1979.

The synoptic charts, produced at the Japan Meteorological Agency (JMA), were also used for determining the positions of cyclones and fronts. The Monthly Bulletin of the Seasonal Weather Forecast and the Monthly Report of Meteorological Satellite Center, which have been published by the JMA, were additionally used.

In order to examine the spatial structure of the intraseasonal oscillation with the 30–60 day period that occurs over the Indian monsoon region through east Asia, a band-pass filter (M. Murakami, 1979) was applied to the OLR and geopotential height data. Figure 1 shows the frequency response of this filter, with half power at 30 and 60 days while full power occurs at about 42 days.

3. Fluctuations in the OLR field

3.1 Average and standard deviation

Figure 2a and b show the spatial distributions of the time average and standard deviation of OLR, respectively, during the period from May 1 to September 30, 1979. In Fig. 2a the shaded areas of lower values (less than 230 W/m^2) in the low latitudes exist over the eastern and southern areas of the Bay of Bengal, the peninsula of Indochina, Borneo, the Philippines and the equatorial zone between 140–160°E. These areas correspond to the active convective areas.

In the middle latitudes, areas of lower values are present over the eastern Tibetan Plateau and eastern Siberia. The lower values over the Tibetan Plateau may be regarded as clouds since the surface temperature over this area is fairly high. The higher values are distributed over the area between 120°E and 180°E along 25°N, which correspond to relatively little cloudiness associated with the sub-

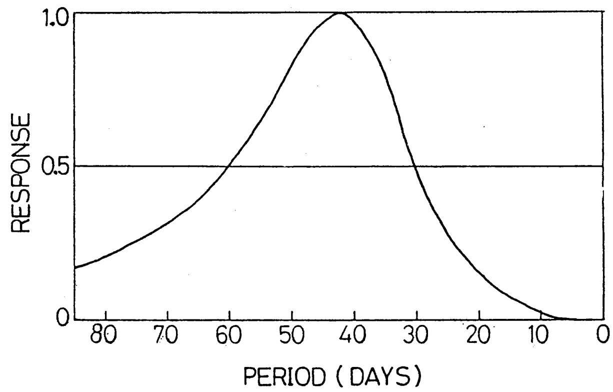

Fig. 1. Response of the band-pass filter (for the case of the 30–60 day oscillation).

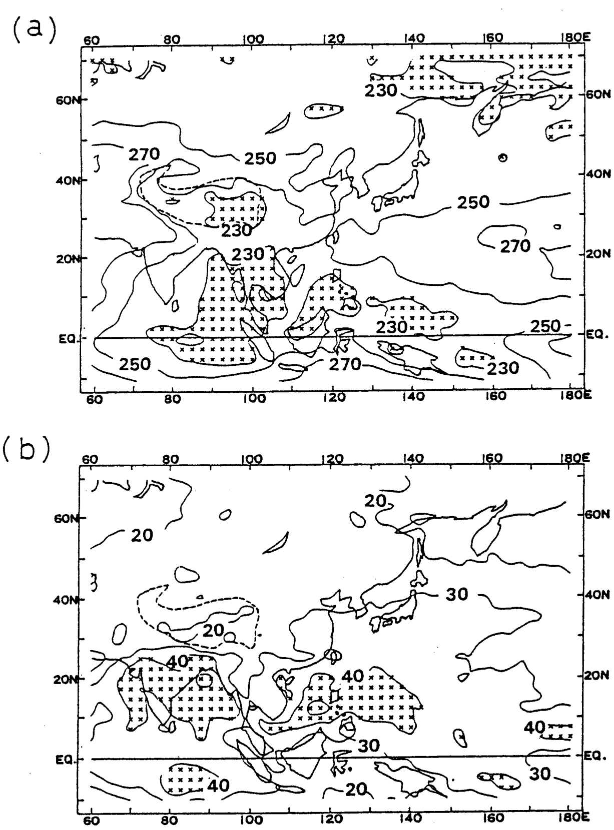

Fig. 2. Spatial distributions of (a) average and (b) standard deviation of the OLR for May 1 to September 30 during 1979. (a) Shaded areas are less than 230 W/m^2. The contour interval is 20 W/m^2. (b) Shaded areas are greater than 40 W/m^2. The contour interval is 10 W/m^2.

tropical high.

In Fig. 2b the areas of large standard deviation tend to be located along the northern rim of lower OLR values found in the northern low latitudes, except those over southern China to the peninsula of Indochina. An area of relatively large standard deviation is also apparent along 30°N, from 110°E to 160°E, *i.e.*, near Japan.

Figure 3 shows the spatial distribution of the ratio of the standard deviation of 30–60 day period component to the total standard deviation. This ratio, defined as R (30–60), is calculated as follows:

$$R(30-60) = (SD(30-60)/SD) \times 100(\%),$$

where SD(30–60) is the standard deviation of the time series of the 30–60 day period component obtained through use of the band-pass filter mentioned above and SD is the standard deviation of the original time series.

In the low latitudes high ratios are distributed along 10°N, especially over the Bay of Bengal and the South China Sea and also in the area centered at 90°E and 5°S.

In the middle latitudes another area of high ratios is noted along 20–30°N over the western Pacific (140–160°E). This area agrees with the northern region of the area of high OLR values (Fig. 2a), *i.e.* the zone of the subtropical high. The fluctuation on this time scale may be, therefore, associated with the strengthening and weakening of the subtropical high. The existence of a 30–60 day oscillation over this area can also be confirmed in the power spectra of OLR by Nakazawa (1986). Takeda and Ikeyama (1985) and Ikeyama and Takeda (1988) found that a period of about 30 days is dominant in the cloudiness field over this area (around 30°N and 150°E) during the summers of 1978 through 1984. Relatively high ratios (>30 %) are also found over the area between 140°E and 150°E, along 40°N and in the area north of the Tibetan Plateau (50–60°N and 70–80°E). Although the 30–60 day oscillation in the OLR field is generally distinct in the low latitudes, it is very important that this variation is also seen in the middle and high latitudes.

3.2 Lagged Correlation Pattern

In order to investigate the variability of the atmospheric circulation in the low and middle latitudes associated with intraseasonal oscillation of the summer Indian monsoon, the reference point at 15°N and 87.5°E (in the Bay of Bengal) was chosen. The filtered time series of OLR at 15°N and 87.5°E (solid line) obtained by an 11-day moving average is shown in Fig. 4. The lagged correlations for the OLR field were computed from *lag*=−21 to +21 days for every three days (not shown here). In this case the band-pass filtered time series, obtained by subtracting the 61-day moving average from the 11-day moving average, were used in order to remove shorter period variations as well as the seasonal trend from each grid point value.

Over the area from India to the Bay of Bengal, the high correlation pattern propagates northward

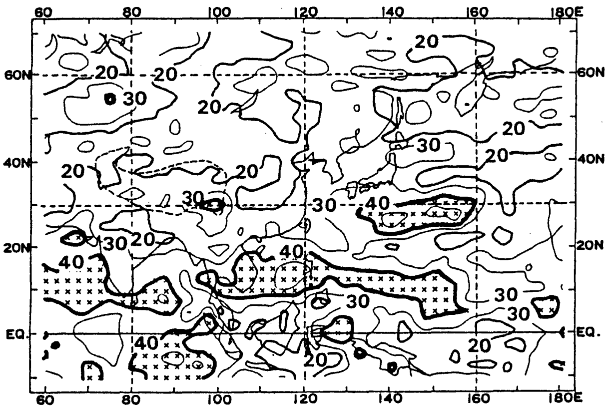

Fig. 3. Spatial distribution of the ratio of the 30–60 day period variance of OLR against the standard deviation for May 1 to September 30, 1979. Shaded areas are greater than 40 %. The contour interval is 10 %.

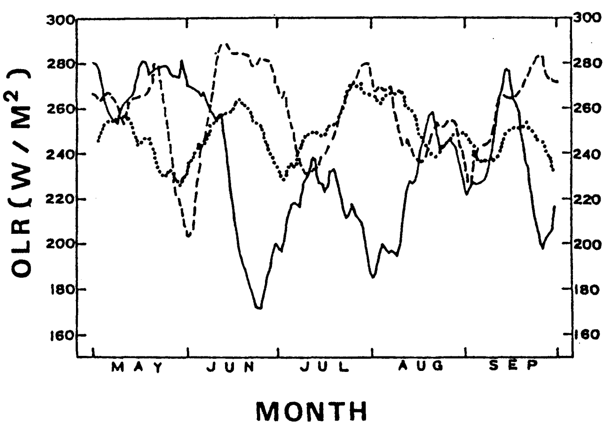

Fig. 4. Time series of the 11-day moving average OLR at 15°N and 87.5°E (reference point, solid line), at 25°N and 147.5°E (broken line) and at 55°N and 75°E (dotted line) for May 1 to September 30, 1979. The unit is W/m^2.

with about a 40-day period. In the middle latitudes the areas of large variation of the correlation coefficient are apparent to the south of Japan (130–160°E along 30°N) and to the north of the Tibetan Plateau (in the vicinity of 55°N and 75°E). The distribution pattern for *lag*=+21(−21) day is opposite to that for *lag*=0. These facts indicate that an oscillation with about a 40-day period occurs in phase with that of the Indian monsoon over the entire domain.

Large negative values are found to the south of Japan and to the north of the Tibetan Plateau for *lag*=−6 days, whereas large positive values appear in these regions for *lag*=+15 days. The spatial distribution of the correlation coefficient for *lag*=−6 days is shown in Fig. 5. That is, when the cloud band which propagates northward arrives around 10°N in the region over India to the Bay of Bengal, the cloudiness is at a minimum over above two areas. This feature is clearly seen in the time series (11-day moving average) of OLR at 25°N and 147.5°N (broken line) in Fig. 4, which is negatively correlated to that of the reference point with several days lag. In this region, the maximum values denote the development or northward shift of the subtropical high, while the minimum values denote a dissipation or southward shift.

The areas of large positive values mainly expand in the low latitudes of the northern hemisphere, which suggests that the variation of convective activity along the ITCZ over the northwestern Pacific is positively correlated to that of the Indian monsoon with several days lag. Another positive area is apparent along 35–55°N east of 120°E, which may suggest that the activity of the extratropical cyclones over this area is also associated with the oscillation of the Indian monsoon. These coherent fluctuations of OLR around Japan may be associated with the variation in the Baiu front (*i.e.* the eastern part of the frontal zone). These facts will be further investigated in Section 4.3 through the use of synoptic fields.

3.3 Time sequence of the OLR anomalies

In the above subsection it was suggested that a cyclic variation in the atmospheric circulation associated with the Indian monsoon occurs around Japan and also to the north of the Tibetan Plateau. In this subsection an investigation is made of the variation in the spatial pattern of the 30–60 day component, with special note of the evolution of this pattern in the seasonal cycle.

In order to examine the meridional variations, latitude-time sections of the longitudinal mean 30–60 day component of OLR are composed for 85–90°E and 145–150°E, as shown in Fig. 6a and 6b, respectively. Figure 6a shows the section of the Indian monsoon region. The onset of the monsoon in central India during 1979 occurred on June 19 (Sikka and Grossman, 1980). In mid June the active convective areas, propagating northward, arrive between 10°N and 20°N. Although the active convection with a 40-day period occurs four times in the equatorial zone, the northward propagation occurs three times, *i.e.* in June, late July to August and in late September. After the second northward propagation, in late August, the 40-day cycle breaks down. This is known as the monsoon withdrawal (Ding *et al.*, 1982). It is also interesting to note that the convection zone does not propagate northward during early May, in spite of the considerable intensity of the convective activity. This feature of the northward propagation agrees well with those of the filtered wind fields at 850 mb examined by

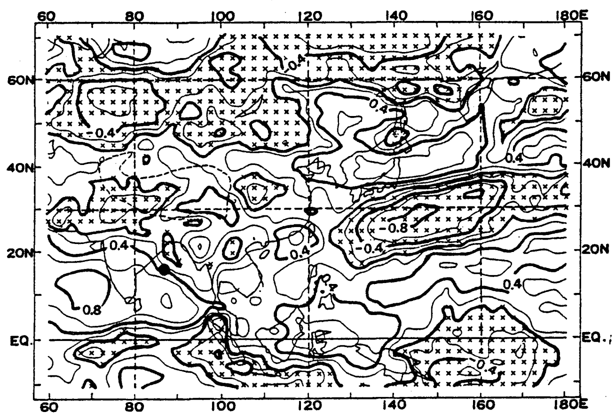

Fig. 5. Spatial distribution of correlation coefficients of OLR for *lag*=6 days. The reference point is found at 15°N and 87.5°E (shown by •). Shaded areas are negative values. The contour interval is 0.2.

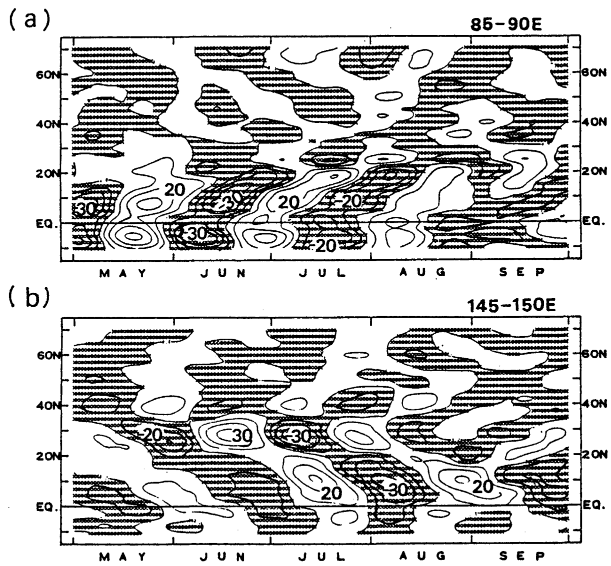

Fig. 6. Latitude-time sections of the standardized anomalies of the 30–60 day period of OLR for longitudinal means (a) over 85–90°E and (b) over 145–150°E. Shaded areas are negative anomalies. The contour interval is 10 W/m^2.

Krishnamurti and Subrahmanyam (1982).

Figure 6b shows the section of the subtropical high region around Japan. The variations, with a 40-day period, of the areas along 40°N and along 25°N are out of phase. That is, the frontal activity around Japan in the Baiu season is closely associated with the 40-day oscillation in the tropics. The anomaly pattern seems to represent the southward propagation from 40°N to the equatorial zone, especially south of 20°N. In order to confirm this southward propagation of the actual convection field, the latitude-time section of low-pass filtered OLR along the longitudes of 145–150°E is shown in Fig. 7. This

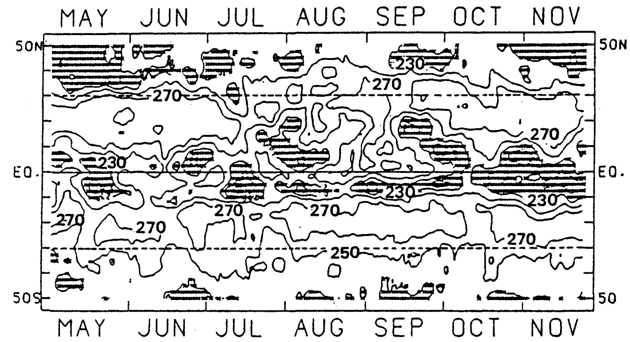

Fig. 7. Latitude-time section of the 11-day moving average OLR for the longitudinal mean over 145–150°E for May to November, 1979. Shaded areas are less than 230 W/m^2. The contour interval is 20 W/m^2.

propagation is very distinct during August and late September to October while indistinct in June. The southward propagation was also obtained for the 30-day period of cloud amount during 1980 by Takeda and Ikeyama (1985). It was also shown by M. Murakami (1984) that a northward propagation of the active convective area between 120°E and 130°E, was concurrent with that over India to the Bay of Bengal. It is very interesting to investigate the difference of the dynamical processes between the regions west and east of approximately 130°E.

Figure 8 shows the series of spatial distributions of the normalized OLR anomalies of the 30–60 day component for June 7 through August 16, for every 10 days. The negative anomaly areas are shaded, which generally agree with the large cloudiness areas. To the south of Japan, the negative anomalies (July 7–17 and August 16–21) appear when the positive anomaly band is present along 10°N over the India to the Bay of Bengal, *i.e.* slightly before the break phase of the Indian monsoon. Conversely, the positive anomalies (June 12–22 and July 27–August 1) appear when the negative anomaly band is present along 10°N over that region, *i.e.* slightly before the active phase. The fact that the amplitudes of the variation to the south of Japan and in the area along 40°N are large to the east of 130°E indicates that the cyclic variation with a 40-day period is present in the activity of the subtropical high and the Baiu front but not in the Mei-yu front. The change of the horizontal structure of the subtropical high during the middle of June pointed out by Kato (1989) and Kato and Kurihara (1989) seems to be associated with the change of the anomalies, from negative to positive, to the south of Japan. The positive anomalies between July 27 and August 1 seems to be associated with the end of the Baiu.

To the north of the Tibetan Plateau, the positive and negative anomalies appear alternately with a 40-day period. The phase of the variation over this

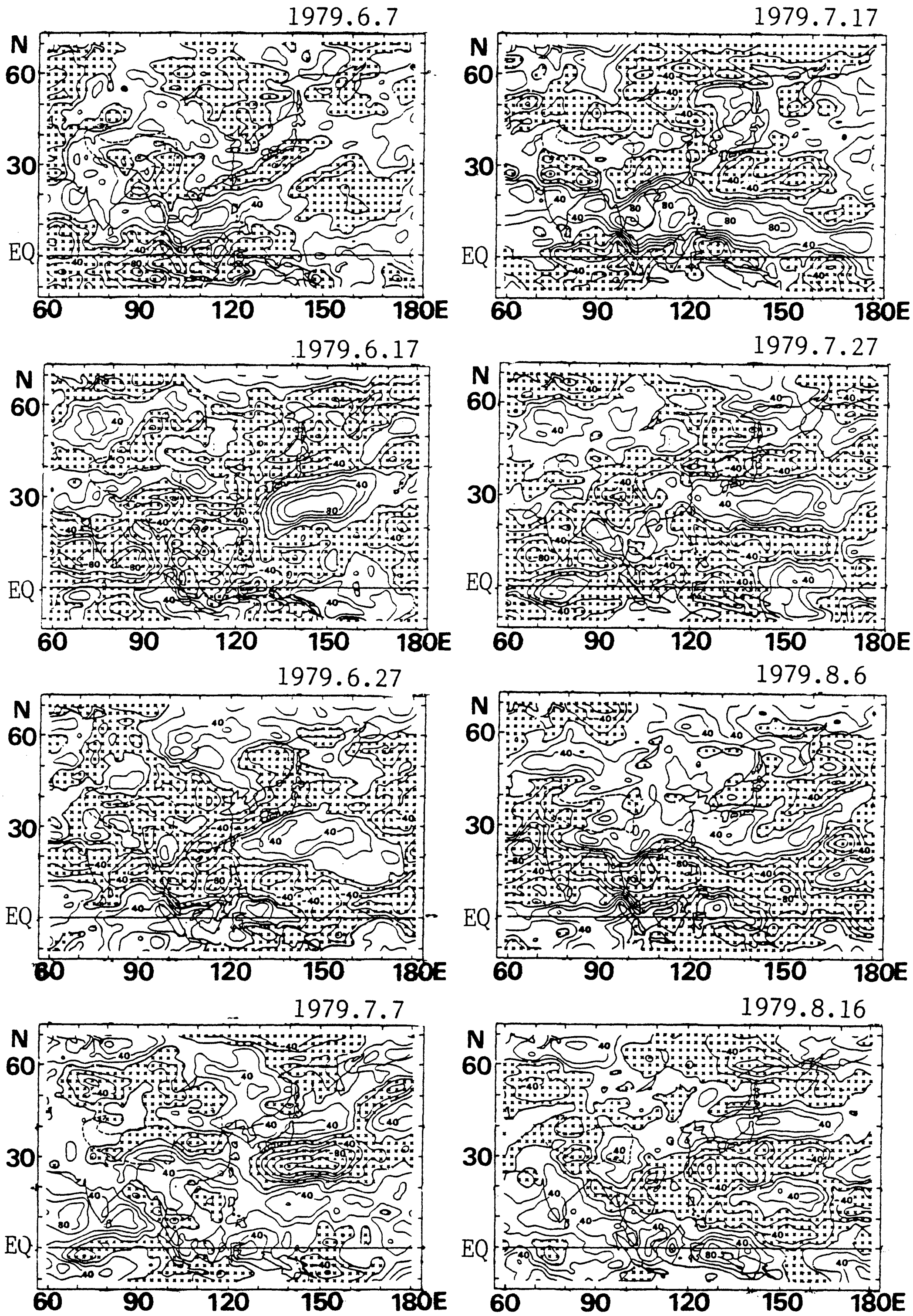

Fig. 8. Spatial distributions of the normalized anomalies of the 30–60 day period of OLR (through use of the band pass filter) for June 7 to August 16, for every 10 days. Shaded areas are negative anomalies. The contour interval is 0.2. A hundred times value of the contour is shown in figure.

area (dotted line in Fig. 4) appears to slightly precede the phase to the south of Japan (broken line in Fig. 4).

Over the southern region of the Tibetan Plateau the 30–60 day period is also dominant. When active convection appears along 10°N over India to the Bay of Bengal, the convection over the southeastern part of the Tibetan Plateau also becomes active. However, the relationship between the convective activity over this region and that associated with the

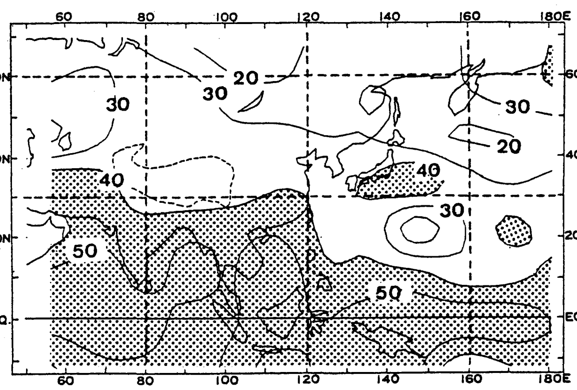

Fig. 9. Spatial distribution of the ratio of the 30–60 day period variance of the 700 mb geopotential heights against the standard deviation for May 1 to September 30, 1979. Shaded areas are greater than 40 %. The contour interval is 10 %.

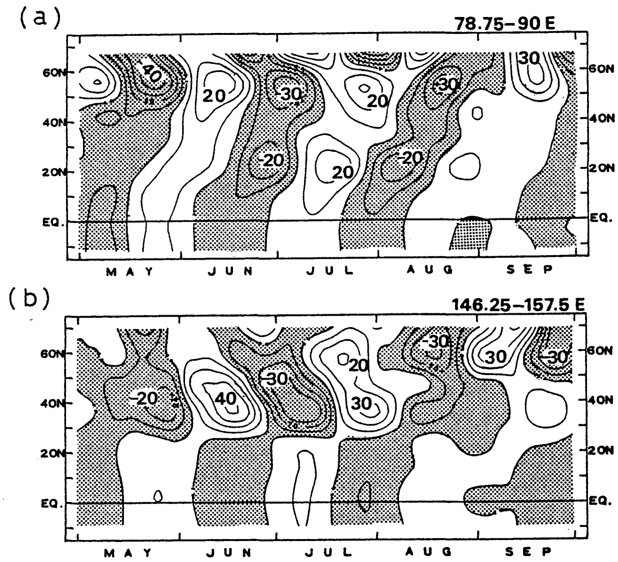

Fig. 10. Latitude-time sections of anomalies of the 30–60 day period variation of the 700 mb geopotential height for longitudinal means (a) over 78.75–90°E and (b) 146.25–157.5°E. Shaded areas are negative anomalies. The contour interval is 10 m.

northward propagations is not clear.

It was shown in this section that cloudiness is a minimum to the south of Japan (the subtropical high region) and to the north of the Tibetan Plateau (centered at 55°N and 75°E) when active convection exists along 10°N over the Indian monsoon region. Conversely, there is maximum cloudiness over these areas when minimum cloudiness exists along the 10°N region. Since the amplitude of the variation of the OLR field around Japan is large to the east of 130°E, this variation may be closely associated with the intraseasonal variation of the Baiu front and the subtropical high. On the other hand, the Mei-yu front does not show an intraseasonal variation of this time scale. Moreover, it should be noted that this 40-day oscillation becomes indistinct simultaneously over these three areas after late August (not shown). These facts strongly suggest the link of the intraseasonal fluctuations among these regions and also the strong modulation of this fluctuation in the seasonal cycle.

4. Fluctuations in the 700 mb geopotential height

It was indicated in the above section that the 30–60 day oscillation of the OLR, which was well correlated with the variation of the Indian monsoon, existed over a broad area. In this section it will be shown that the variation of the 700 mb geopotential height is one of the characteristics of the atmospheric circulation which exhibits such an oscillation.

Figure 9 shows the spatial distribution of the ratio of the standard deviation of the 30–60 day component of 700 mb geopotential height to the total standard deviation. This ratio was calculated in the same manner as that of the OLR (Section 3.1). The areas of greater than 40 % are shaded and the contour interval is 10 %.

Large values of the ratio are found in the low latitudes, especially over the equatorial zone, where relatively low ratios are apparent in the OLR field (Fig. 3a). In the extratropical regions large values of the ratio are apparent to the southeast of Japan, which is located to the north of the high ratios in the OLR field. High values also found in the vicinity of 60°N, 180°E. The high ratios over the area to the southeast of Japan are probably due to the variation in both the Baiu front and the subtropical high pressure area.

Figure 10a and 10b show latitude-time sections of anomalous 700 mb heights having a 30–60 day periods for longitudinal means over 78.75–90°E and over 146.25–157.5°E, respectively. The negative anomalous areas are shaded. In Fig. 10a the anomalies appear to propagate northward from the equatorial zone to 55°N. Although the alternate northward propagation of anomalous ridge and trough patterns from the equatorial zone to the foothills of Himalayas correspond well to those of the OLR data, the northward propagation from 30°N to 55°N is not confirmed in the OLR data.

In Fig. 10b the anomalies propagating southward from 60°N to 30°N appear from June to early August. In low latitudes, the anomalies of the OLR show a southward propagation but those of the 700 mb geopotential heights exhibit a standing-type oscillation with a node at about 25°N rather than a meridional propagation.

Figure 11 exhibits the spatial pattern of anomalies

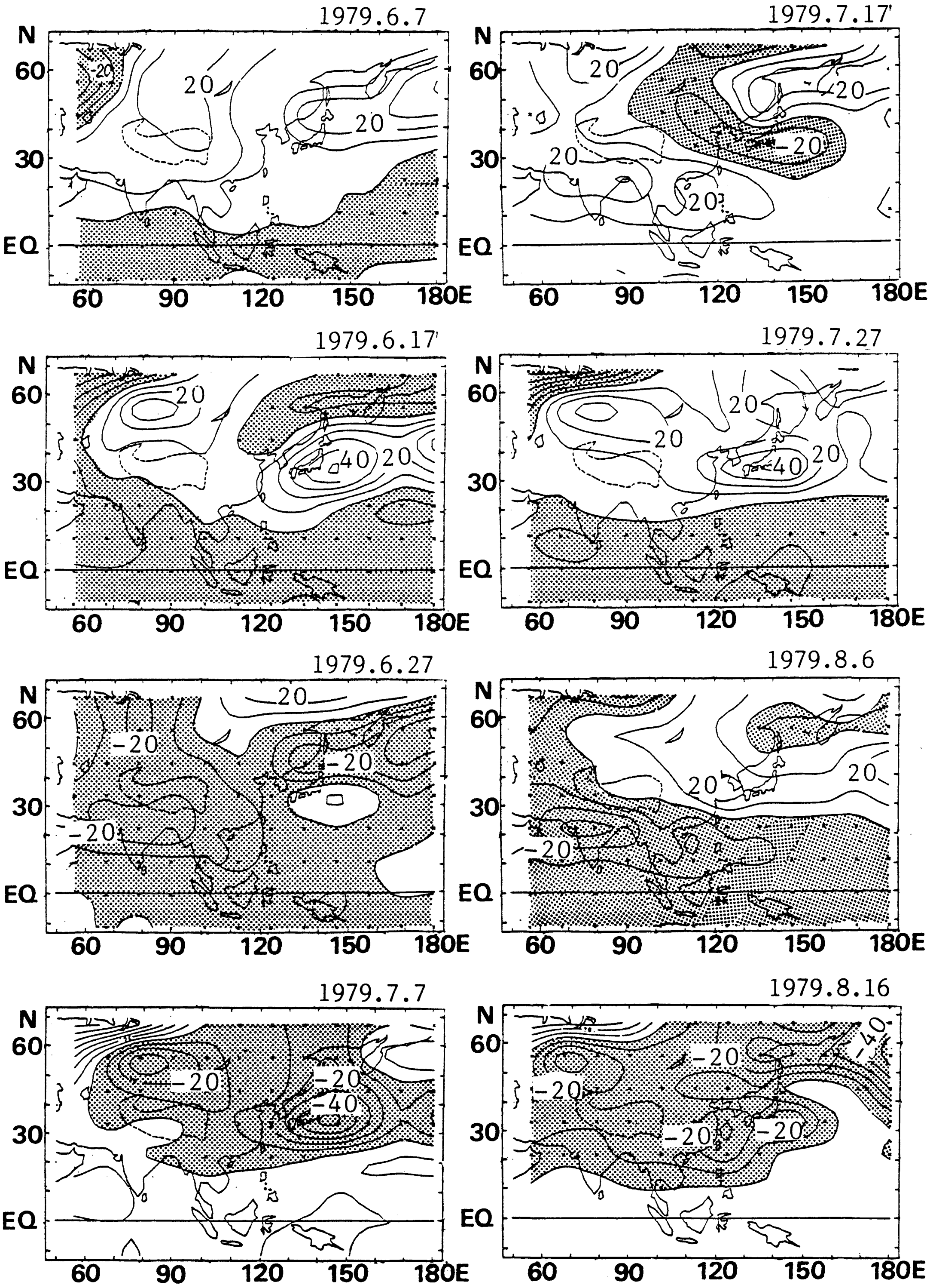

Fig. 11. Spatial distributions of anomalies of the 30–60 day period variation of the 700 mb geopotential height (through use of the band-pass filter) for June 7 to August 16, for every 10 days. Shaded areas are negative anomalies. The contour interval is 10 m.

for the 30–60 day period for June 7 to August 16 for every 10 days. The positive (negative) height anomalies correspond well to the positive (negative) OLR anomalies (Fig. 8), particularly over the region of the Indian monsoon, to the north of the Tibetan Plateau and to the southeast of Japan.

The positive (negative) extremes of anomalies in the extratropics, which are centered to the north of the Tibetan Plateau and to the south of Japan, are evident from mid June to mid August. It should

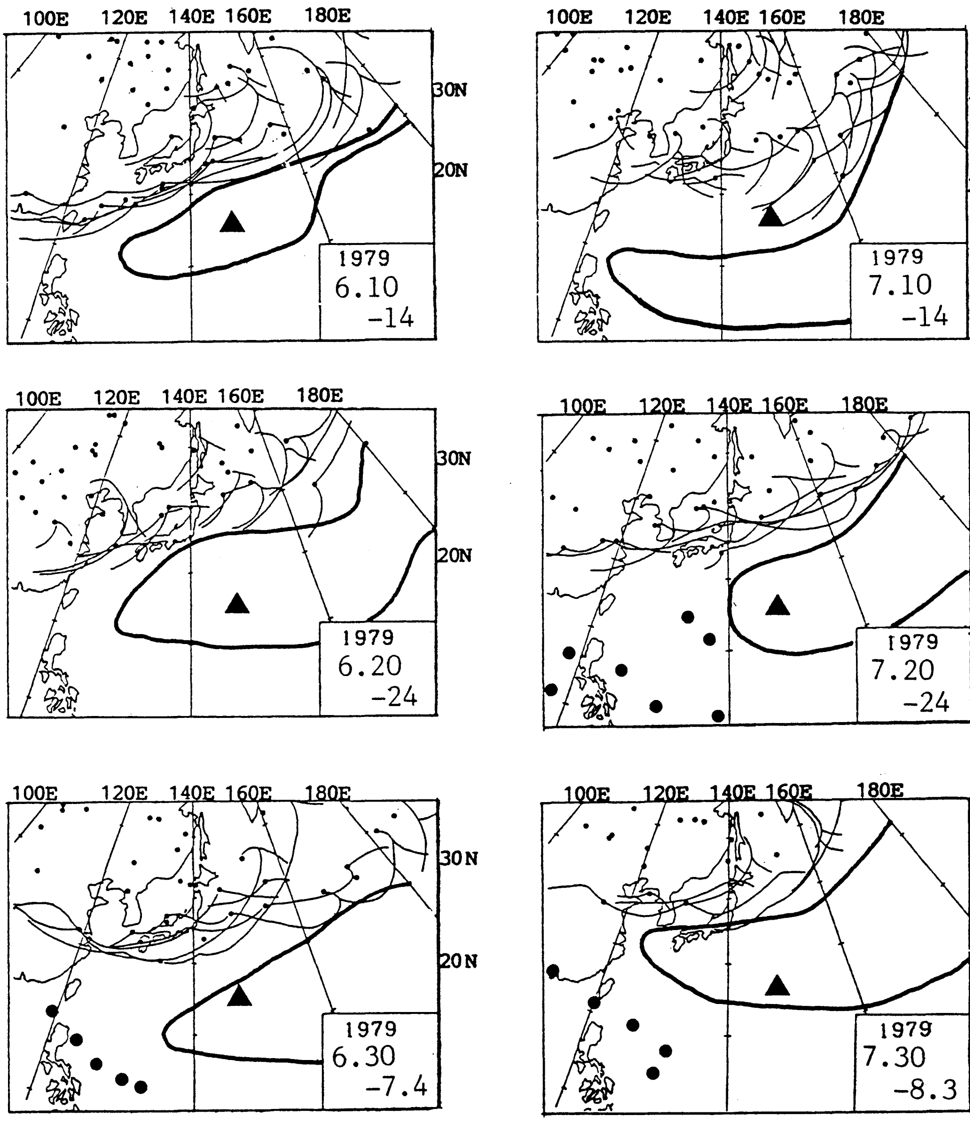

Fig. 12. Composite maps of the fronts and the centers of both tropical (•) and extratropical (·) cyclones for a pentad, with an interval of a pentad for June 10 to August 3, 1979. The thick line is 3175 m contour of 700 mb geopotential height, averaged for a pentad, and black triangle indicates the point at 25°N and 147.5°E.

be noted that extratropical variations of this type are distinct only during the period when the convective area repeats the northward propagation over the India—Bay of Bengal region, *i.e.* the season of the Indian monsoon. As seen in Fig. 11, the anomalies to the north of the Tibetan Plateau slightly precede those near and to the south of Japan. This phenomenon may be at least partly related to the eastward propagation of the 30–60 day mode along the equator as shown in studies by Lorenc (1984), Chan (1987) and the others.

The southward propagation, seen in Fig. 10b, occurs east of 130°E from 60°N to 30°N, while the anomalies propagate northward from the equatorial zone to 55°N west of 130°E. The propagation pattern of the anomalies exhibits a clockwise rotation.

In this section it is confirmed that a 40-day oscillation is present in the atmospheric circulation field in the same manner as in the OLR field. A large-amplitude area to the southeast of Japan indicates the evident 40-day variation of the subtropical high during the Baiu season. It was also shown by Nakanishi (1972) that the 30–60 day component was one of periodicities of the variation of the subtropical high during the Baiu season.

5. Frequency of extratropical cyclones

In this section the investigation of the cyclic variation in the anomalies of the OLR and 700 mb geopotential heights around Japan is accomplished by use of synoptic weather charts, in order to examine the relationship between the variation of the subtropical high and that of the real weather régimes around Japan. Figure 12 exhibits the composite maps of fronts and the centers of both tropical and extratropical cyclones for a pentad, with an interval of a pentad, based on JMA's synoptic charts. The thick line is a contour of 3175 m of 700 mb geopotential height, averaged for every pentad, and the black triangle is the point of 25°N and 147.5°E.

In mid June (upper left panel in Fig. 12), the Baiu front is established off the southern coast of Japan, which first develops in late May and shifts gradually northward (not shown). This gradual shift is associated with the slow development of the subtropical high (see Fig. 4). When the OLR indicates maximum values around June 20, the frontal zone shifts further north (middle left panel). In the OLR field (see Fig. 8) the positive anomalies appear south of Japan while the negative anomalies simultaneously appear along 40°N. At this time the area enclosed by the 3175 m contour line is spread. It continued to be hot and sunny in the middle of Japan until June 27, when the frontal zone again shifts to the south coast of Japan. Here, this phase is defined as the break phase of Baiu over the southern part of the Japan Islands. From early July to mid July the values of the OLR are small south of Japan, while the frontal zone shifts southward and stagnates along the southern coast of Japan (lower left and upper right panels). The negative anomalies to the south of Japan and the positive anomalies along 40°N are seen during July 7 in Fig. 8. Severe local rainstorms are often observed in the western region of Japan during this period. This Baiu event finished with the second development of the subtropical high in late July (middle and lower right panels), *i.e.* the area enclosed by 3175 m contour shifts northward. These results indicate that the 40-day variation of OLR at 25°N and 147.5°E is induced by the meridional shift of the frontal zone and the subtropical high. Chen and M. Murakami (1988) also pointed out the north-south movement of deep convective clouds over the western Pacific during this period.

From the results in this section, it is suggested that the meridional position of the Baiu front varies in association with the 40-day oscillation of the subtropical high. This variation of the meridional position is closely associated with the change of weather around Japan during the Baiu season.

6. Summary and remarks

This papaer investigated the intraseasonal variation (30–60 day) in the OLR and 700 mb geopotential height anomalies over the Asian continent through the western Pacific associated with the Indian monsoon activity. Large anomalies are found in some phases of the monsoon cycle over the area to the north of the Tibetan Plateau and around Japan. The features of this variation over these areas are summarized as follows:

The strengthening and weakening of the subtropical high pressure area (20–30°N and 130–160°E) was associated with the intraseasonal variation of the Indian monsoon. It was also shown that the meridional shift of the Baiu front was associated with the strengthening and weakening of the subtropical high. Namely, when the subtropical high shifts northward slightly prior to the active phase of the Indian monsoon, cloud bands do not exist over the southern part of Japan, and vice versa. Lau and Chan (1986) have shown similar results for the relationship between the subtropical high and Indian monsoon for 1975 to 1982. In contrast to their results, the position of the subtropical high in the present study shifts further northward. Since the present analysis is made for the single year of 1979, this difference may be at least partly due to the interannual variation. The subtropical high in this region during summer seems to be modulated by the large scale convection in the tropical western Pacific by means of the Rossby wave response, rather than a northern branch of the Hadley cell, as suggested by Kurihara and Tsuyuki (1987) and Nitta (1986, 1988). The position and strength of the subtropical high is, therefore, very sensitive to the fluctuation of ITCZ to the south. This sensitive difference in the meridional position may be very important for weather around Japan during the Baiu season. In practice, Lau and Chan pointed out that it was during the active phase of the Mei-yu trough when the subtropical high shifted northward, contrary to the present results.

In addition, the difference of the meridional variation of Baiu (east of 130°E) and Mei-yu (west of 130°E) fronts is found in this study. The difference of the characteristics of the circulation fields of these two front was also pointed out (Kurashima and Hiranuma, 1971; Akiyama, 1973).

It has also been confirmed clearly that the phase of the 40-day oscillation over the area centered at 55°N and 75°E precedes that over the subtropical high region by several days.

Figure 13 schematically shows the results mentioned above. Figure 13a represents a snapshot just prior to the active phase of Indian monsoon. The contours are the 700 mb geopotential heights of an 11 day average centered on June 17. The shaded area represents values less than 3100 m, with a contour interval of 25 m. The major convective zones are located along 10°N over the Bay of Bengal and along 15°N over the western Pacific. Over the area to the north of the Tibetan Plateau the ridge is strengthened. The subtropical high develops and shifts northward while the frontal zone also shifts northward around Japan. This phase corresponds to the break and the ending phase of the Baiu around the southern part of the Japan Islands. Figure 13b shows a schematic snapshot just prior to the break phase of the Indian monsoon (July 7). The ma-

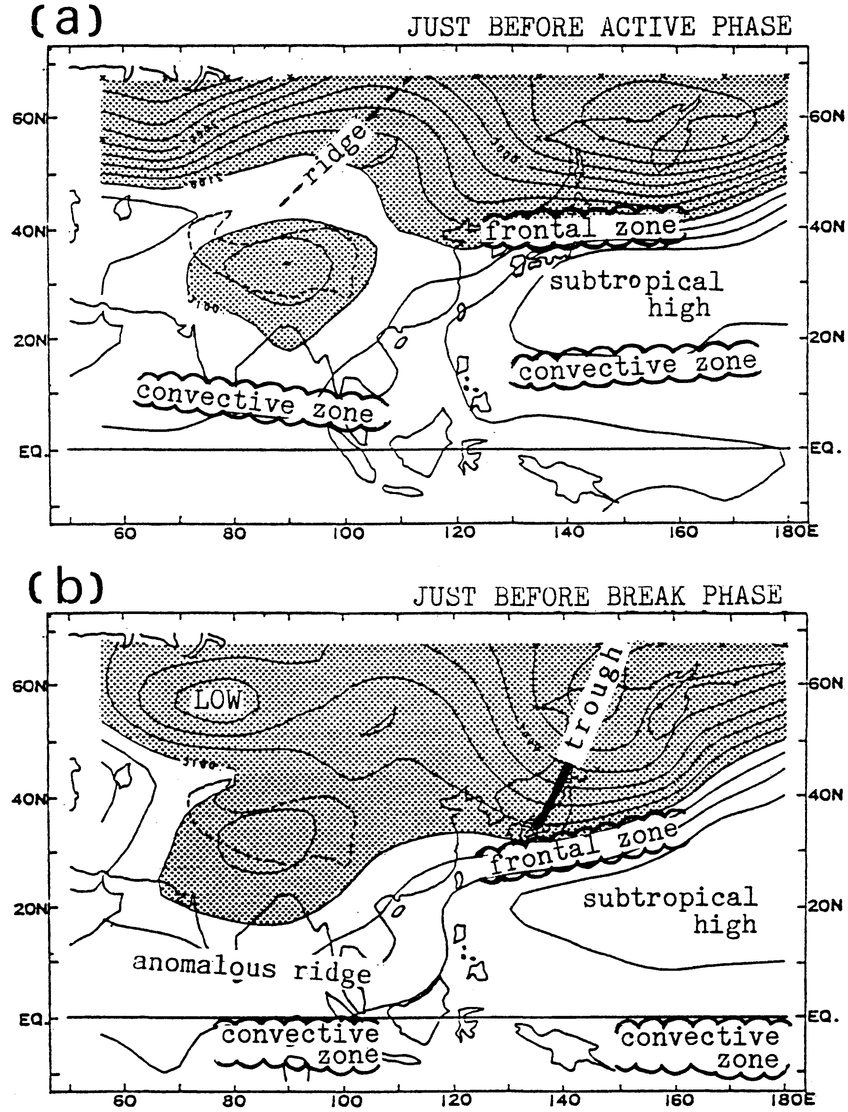

Fig. 13. Schematic pattern of circulation and cloudiness for the 40-day oscillation. (a) pattern slightly prior to the active phase of monsoon over central India (June 17). (b) pattern slightly before the break phase of monsoon over central India (July 7). The contour represent the 700 mb geopotential heights of an 11 day average centered on June 17 and July 7, respectively. The contour interval is 25 m.

jor areas of convection are located over the equatorial Indian and the western Pacific Ocean, and the anomalous ridge remains over the Indian Ocean along 10°N. The trough deepens to the north of the Tibetan Plateau. The subtropical high weakens and shifts southward. This phase corresponds to the active phase of the Baiu around the southern part of Japan Islands.

Here, the association of the regional scale feature in the present results to the evolution of the global aspect of the 40-day oscillation is briefly examined by using the time series of the 700 mb geopotential height during the northern summer. The global composite maps for category 1, 3, 5 and 7 are shown in Fig. 14. Here, categories 1 and 5 correspond to the active phase (June 27 and August 6 in Fig. 11) and the break phase (July 17 in Fig. 11) of monsoon over central India, respectively. The map on June 17 and July 27 in Fig. 11 (the break phase of the Baiu) correspond to category 7 and that on July 7 (the active phase of the Baiu) correspond to category 3.

The wavenumber-1 structure is dominant over the equatorial zone and near both poles, especially near the north pole. It should be noted that the area of large anomalies to the north of 70°N appears to propagate westward.

Over the northern middle latitudes, a wavenumber-3 structure is dominant during the active and break phase of the monsoon (category 1, 5) while a wavenumber-1 structure is dominant between the active and break phase (category 3, 7). The large amplitude anomalies over the area to the north of the Tibetan Plateau and in the subtropical high region emerge at the latter phases (category 3,7).

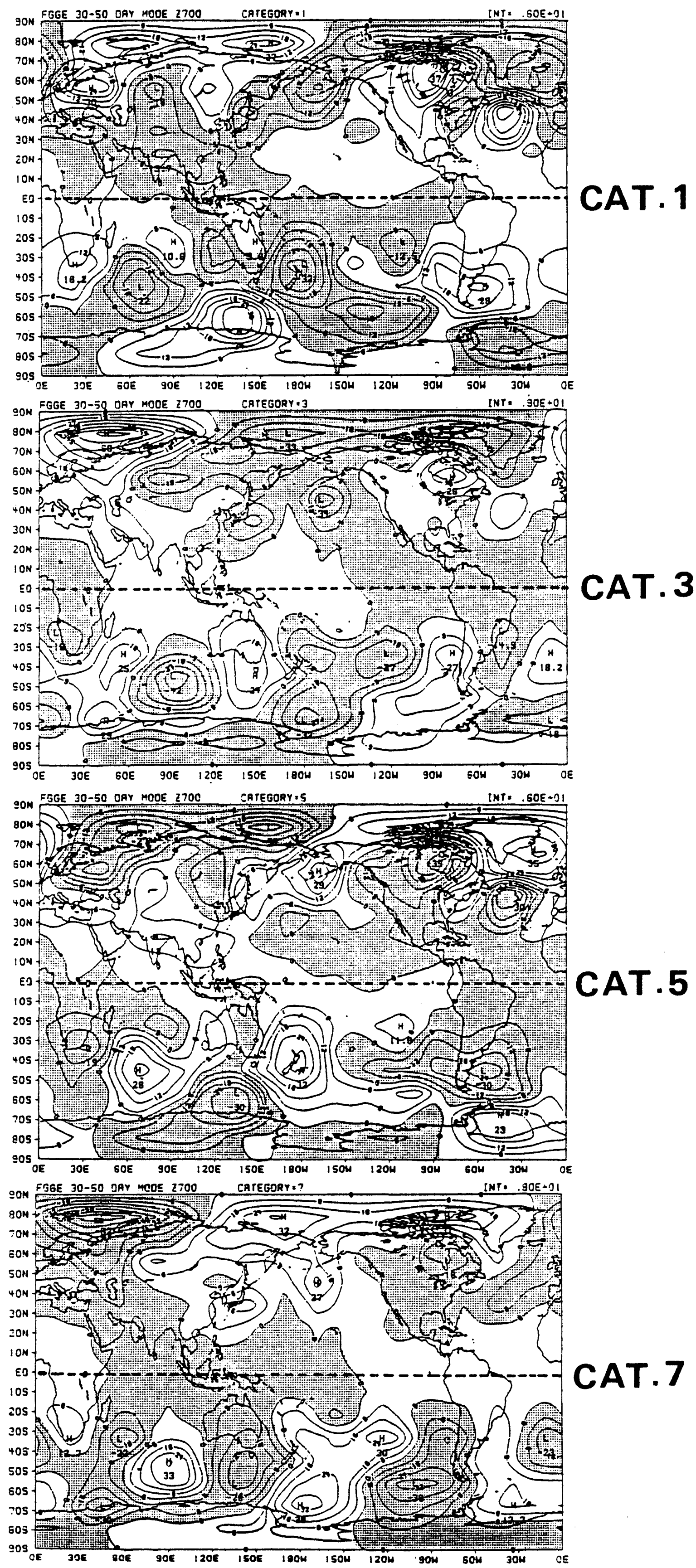

Fig. 14. Category 1, 3, 5 and 7 of global composite maps of the 30–50 day mode in the 700 mb geopotential heights (One cycle of the Indian monsoon is divided into 8 categories). Shaded areas are negative anomalies. Category 1 and 5 correspond to the active and break phase of the monsoon, respectively.

Therefore, it is confirmed that the variations over these two areas are part of the local characteristics of the global variation (wavenumber-1), associated with the variation in the Indian monsoon.

The intraseasonal variation of the trough-ridge system over the two area (*i.e.* to the north of the Tibet and to the south of Japan) is distinct during the period from the onset to the withdrawal of the Indian monsoon. Although Krishnamurti and Gadgil (1985) showed that the 30–50 day mode was also present at higher latitudes throughout the FGGE year in the wind and temperature fields, the results here indicate that the feature of the circulation pattern in the Indian monsoon season seems to be largely different from that in any other seasons. That is, in the Indian monsoon season the heat source moves northward cyclically, while in other seasons it does not show a meridional fluctuation. Thus the present results fundamentally seem to have confirmed the hypothesis by Yasunari (1986) which suggests that the intraseasonal circulation changes in the mid latitudes are induced by the different types of responses to a slowly northward-moving monsoon heat source, though some questions still remain (*e.g.* Though the feature in Fig. 13b looks like the response in the "advective limit", the heat source seems to shift most northward in the active phase over northern India, *i.e.* before the phase of Fig. 13b.).

Further studies of interannual variability are needed with respect in the relationships among the variation of the Indian monsoon, the trough-ridge system over the Eurasian continent through the western Pacific including the Mei-yu and Baiu fronts, and the ITCZ over the western Pacific.

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インドモンスーンの30–60日振動に関連したアジア～西太平洋における大気循環の変動

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1979年のOLRと700 mb高度場の資料を用いて、インドモンスーンの30–60日周期変動と関連したアジアから太平洋における大気循環場の変動について調べた。

OLRの30–60日周期成分の解析から以下のことがわかった。西太平洋上の北緯15度付近では、インド中央部がモンスーンの活発期（不活発期）にはいる直前に、対流活動が活発期（不活発期）となる。この西太平洋上（東緯140度～150度）の雲量極大域（極小域）は40日の周期で北緯15度付近から赤道へと南に伝播していくモードを持っている。チベット高原北方（北緯55度、東緯75度付近）と亜熱帯高気圧域（日本の南東）の雲量は、インド中央部がモンスーンの活発期（不活発期）にはいる直前に、極小期（極大期）になる。700 mb高度場の30–60日周期成分の解析から以下のことがわかった。チベット高原北方で

は、雲量極大期とトラフの停滞、雲量極小期とリッヂの強化が対応している。亜熱帯高気圧の位置は、インド中央部がモンスーンの活発期にはいる直前に最も北偏し（北緯 25–30 度）、不活発期にはいる直前に最も南偏する（北緯 10–20 度)。また、チベット高原北方の 30–60 日振動の位相は亜熱帯高気圧域の位相に比べ数日先行する。これらの結果は、インドモンスーン、西太平洋上の対流活動、アジア大陸上の偏西風波動、亜熱帯高気圧が密接な関係を持ちながら季節内変動をしていることを示唆している。

これら大規模場の 30–60 日振動に関連した相互作用は梅雨期において日本付近の天候に大きく影響を与えている。梅雨前線（東経 130 度以東の部分）は亜熱帯高気圧が北に偏った時に北緯 40 度付近に、また、亜熱帯高気圧が南に偏った時に北緯 30 度付近にと南北変動をする。メイ・ユ前線（東経 130 度以西の部分）は梅雨前線のような周期的な南北変動は示さない。