Intraseasonal Oscillation and the Onset and Retreat Dates
of the Summer Monsoon over East, Southeast Asia
and the Western Pacific Region using
GMS High Cloud Amount Data

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Abstract

The seasonal cycle and the onset and retreat dates in the summer monsoon in East Asia, Southeast Asia and the Western Pacific region are analyzed using 12-year (April 1978–December 1989) means of the 5-day mean 1-degree latitude-longitude gridded GMS high-cloud-amount data. An analysis of these data showed the detailed seasonal cycles of two convective zones (ITCZ and the Baiu front) of the summer monsoon cloud defined by the regions with more than 30 (25 for Baiu front) percent of the mean high-cloud amount. The clouds associated with the ITCZ were observed to increase in Southeast Asia during May and subsequently spread to the South China Sea and the Western Pacific region in a series of sudden expansions during June and July.

The Baiu front branch is preceded by an increase in the high-cloud amount along the polar front located near 30°N just south of Japan around 26 April. During the middle of May, this cloud band rapidly moved south to 20–25°N. This period coincides with the onset of the Baiu season in Okinawa. Subsequently, this cloud band moves north to mainland Japan and the Yellow Sea with a series of sudden northward advances during June and July. These abrupt changes are associated with the phase-locking between the intraseasonal oscillation and the seasonal cycle of the monsoon clouds.

The onset and retreat dates derived from this study fill the major gaps in these dates over Southeast Asia and the adjacent Western Pacific region where the large area of the ocean prevented analysis of the onset (retreat) dates based on rainfall data.

1. Introduction

The onset of the summer monsoon rain is an important event influencing the agriculture of monsoon Asia. When the rainfall data became available, many authorities defined the onset (retreat) dates of the summer monsoon rain based on different criteria (e.g., the Indian Meteorological Department and the Japan Meteorological Agency). Xu and Gao (1962), Kurashima (1968), Ramage (1971) and Tao and Chen (1987) summarized these onset dates in southern and eastern Asia based on the rainfall data. Recently, Kousky (1988) used the satellite OLR data and defined the onset (retreat) dates of the rainy season over South America.

Figure 1a and 1b shows the dates of the onset (retreat) of the monsoon rain in India (based on the Indian Meteorological Department (1943)) and the onset (retreat) dates of the Baiu season in Japan. The dates of the onset are earliest over southern Burma and subsequently move northwest to southern India and Bangladesh by the start of June. In East Asia, countours over Japan are based on the mean onset (retreat) dates of the Baiu season (1951–1980 average) issued annually by the Japan Meteorological Agency. The area over China was left blank, because the Chinese onset dates (e.g., Tao and Chen, 1987) appeared to coincide with the peak of the Baiu rain, which occurs 20 to 25 days after the onset in Japan.

There is a major gap in these dates over Southeast Asia and the adjacent Western Pacific region, where the large area of the ocean prevented the analysis of the onset (retreat) dates based on rainfall data.

In addition to the onset dates, the seasonal cycle and intraseasonal oscillation are important components of the summer monsoon. The 30- to 60-day intraseasonal oscillation first detected by Madden and Julian (1971, 1972) is also analyzed during the northern summer by many authors (Murakami,
Fig. 1. Mean dates of a) the onset b) the retreat of the monsoon rain in India (India Meteorological Department, 1943) and the onset (retreat) dates of the Baiu season (1951-1980 average) in Japan (the dates issued annually by the Japan Meteorological Agency). The contours are drawn every 5 days for the Baiu season in Japan.

Maruyama et al. (1986) showed that the GMS high-cloud amount can be used to estimate the rainfall in the tropical western Pacific region. Nitta (1986, 1987) analyzed this dataset and investigated interannual and intraseasonal variations.

In the present study, the onset (retreat) dates, and seasonal cycle in the summer monsoon clouds and its relationship to phase-locking of the intraseasonal oscillation in East Southeast Asia and the Western Pacific region (40°N–Equator, 90°E–160°E) will be investigated.

2. Data

The data are the 5-day mean 1-degree latitude-longitude grid data of the Geostationary Meteorological Satellite (hereafter called GMS) high-cloud-amount data created by the Meteorological Satellite Center.

The data from April 1978 to the end of 1989 are used in this study. The high cloud amount, expressed as the percent of the total grid area, is defined as the clouds with a cloudtop temperature below the 400 hPa-level climatological temperature based on the upper air observations. The analysis was confined to areas over the ocean, because no data over the land are available prior to March 1987. These data have a few missing periods. These are: 21–25 April 1978, 30 June–4 July 1978 and 1979, 21–25 January 1979, and a one-month period from 31 May to 29 June 1984. The influence of the lower surface temperature in subtropical East Asia (compared to the tropical areas) which is present in the OLR data was removed in this data set. Hence the comparison between the Intertropical convergence zone (ITCZ) and the Baiu front is much easier to make than with commonly-used OLR data.

For each of 73 5-day periods in the calendar year, a 10- to 12-year mean excluding missing data is computed to obtain the climatological mean high-cloud amount. A 1-2-1 filter was then applied to remove the high frequency noise less than about 7.5 days.

3. The summer monsoon season in East Asia, Southeast Asia and the western Pacific regions

Figure 2 shows examples of the annual march of the high-cloud amount for a) 12°N, 115–119°E, b) 8°N, 135–139°E and c) 5°N, 150–154°E. Solid lines show 1-2-1 smoothed data and dotted lines show the smoothed seasonal cycle obtained by filtering the intraseasonal change by the 23-pentad triangular mean. This triangular running mean filters more than 95 percent of the short-term oscillations with a period of less than 60 days (Burroughs, 1978).

In the South China Sea (12°N, 115-119°E), the amplitude of the seasonal cycle is large (near 40 percent), while the intraseasonal oscillation is restricted to the May–October season with an amplitude of
Fig. 2. Mean (1978-89 average) high-cloud amount (percent) for a) 12°N, 115–119°E, b) 8°N, 135–139°E, c) 5°N, 150–154°E. The vertical scale is the cloud amount in percent. The horizontal scale is the months in the calendar year. The solid line shows the 1-2-1 smoothed high-cloud amount. The dotted line shows the seasonal cycle obtained by filtering the intraseasonal change by application of the 23-pentad triangular running mean. Arrows show the monsoon season defined in the text.

near 15 percent. At 8°N, 135–139°E, the amplitude of the seasonal cycle is moderate (near 20 percent), and the amplitude of the intraseasonal oscillation is near 15 percent. Weaker intraseasonal oscillations are observed during winter. Finally, at 5°N, 150–154°E, the seasonal cycle is small (5 percent), and intraseasonal oscillations are observed throughout these years.

Since the monsoon is a seasonal phenomenon, the amplitudes of the seasonal cycle, obtained by filtering the intraseasonal change by the 23-pentad triangular mean (see dotted line in Fig. 2), were computed for East Asia, Southeast Asia and the western Pacific region (Fig. 3). The amplitudes of the seasonal cycle are largest near Burma. Relatively larger values are observed near the Philippines and relatively smaller values are observed east of the Indo-China peninsula. Since summer monsoon winds are predominantly from the southwesterly direction, orographic uplift of this wind contributes to an increase in the cloud amount in Burma and near the Philippines. The smaller values to the east of the Indo-China peninsula can be explained by the orographic downdraft to the lee of the mountains in Laos and Vietnam. A smaller maximum near Japan coincides with the average location of the Bajio-front cloud in June.

The amplitudes of the intraseasonal oscillation are estimated for the region shown in Fig. 3 by subtracting the seasonal cycle from the 1-2-1 filtered data. This operation is equivalent to the 7.5 day-to-60 day band-pass filter. In most of this region, the amplitudes of the intraseasonal oscillation are 15 to 20 percent. Comparison between the amplitude of the seasonal cycle (Fig. 3) and the intraseasonal oscillation suggests that the regions with more than 20 percent of the amplitude of the seasonal cycle (see contours near 20°N and 4°N to 10°N in Fig. 3) are the regions where the amplitudes of seasonal cycle are greater than intraseasonal oscillation. Hence the regions (south of 23°N) with more than 20 percent of the amplitudes of the seasonal cycle are defined as the tropical (ITCZ) monsoon regions. This definition effectively eliminates the regions close to the Equator where the seasonal cycles are small.

The threshold value for the onset and retreat dates of the tropical summer monsoon season was obtained by comparing the 1-2-1 filtered high-cloud amount with the traditionally-obtained onset (retreat) values (see Fig. 1). Table 1 shows the onset dates for the west coast of Burma. The traditional dates near 13°N (21°N) correspond to values near 40 (30) percent. The Ramage (1971) dates of the onset near 17°N (about 13 May) correspond to a value near 25 percent. Table 2 shows the retreat dates. The traditional date of 15 October (Fig. 1b) near 18°N 94°E corresponds to a value near 23 percent. In the current study, the threshold value of 30 percent in the 1-2-1 filtered data was used to determine the onset and retreat dates of the summer monsoon season in the tropical monsoon region. Hence the first pentad (last pentad) with more than 30 percent of the mean high-cloud amount in the 1-2-1 filtered data was defined to be the onset (retreat) date of
Fig. 3. Amplitude of the seasonal cycle (percent) of the mean (1978-89 average) high-cloud amount obtained by applying the 23-pentad triangular running mean. The thick line shows the value of 20 percent. The scale for the cloud amount is shown on the left.

Table 1. Comparison between the 1-2-1 filtered GMS high-cloud amount along the west coast of Burma and the onset dates shown by the dashed lines based on the Indian Meteorological Department (1943). The solid lines showed the onset dates using a 30 percent threshold value defined for the tropical monsoon in this study. The dates shown on the top row are the last day of each pentad.

Table 2. Same as Table 1, but for the retreat dates. The traditional date published by the Indian Meteorological Department (1943) is 15 October near 18°N, 94°E.

In subtropical regions north of 18°N (23°N) in the South China Sea (western Pacific region), an inspection of the 1-2-1 filtered data showed that the amplitudes of the intraseasonal oscillation are smaller compared to the tropical monsoon region. Hence the amplitudes of the seasonal cycle are greater than the intraseasonal oscillation. The threshold value for the onset and retreat dates of the Baiu season was obtained by comparing the 1-2-1 filtered high-cloud amount to the traditional onset and retreat dates of the Baiu season (Table 3). In this table, the duration between the mean onset and retreat dates for four regions in southern and western Japan are shown by arrows for the respective regions. Except for the onset date for the Okinawa region, the onset and retreat dates correspond to a value near 25 percent. Therefore, a threshold value of 25 percent in the 1-2-1 filtered data was used to determine the Baiu season onset and retreat dates. The duration (at least 3 consecutive pentads) between the onset and retreat dates was defined to be the Baiu season.

In the northern part of the South China Sea
Table 3. Comparison of the 1-2-1 filtered GMS high-cloud amount to the onset and retreat dates of the Baiu season (1951–1980 average) issued by the Japan Meteorological Agency. The arrows show the Baiu season between the onset and retreat dates issued by the Japan Meteorological Agency. The average onset (retreat) dates for each of the four regions are: 7 June (18 July) for Chugoku, 6 June (18 July) for North Kyushu, 1 June (15 July) for South Kyushu, and 11 May (22 June) for Okinawa. The solid lines showed the onset and retreat dates using a 25 percent threshold value defined for the Baiu season in this study. The dates shown on the top row are the last day of each pentad.

<table>
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<th>REGION IN JAPAN</th>
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<th>JUNE</th>
<th>JULY</th>
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<td>21 18 18 23 28 30 29 27 25 27 22 14 13 13 12 14 16 14</td>
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(north of 18°N), two monsoon seasons, the Baiu season during May–June and the tropical monsoon season during August with a distinct dry season between these two monsoons are observed. In the other areas, the regions with the Baiu season and the tropical monsoon season are separated by the subtropical low-cloud region under the influence of the subtropical high pressure system.

4. Seasonal cycle in the summer monsoon cloud amount

Figure 4 shows an example of the latitude-time cross section of the mean high-cloud amounts for the longitude belt from 130°E to 134°E. This longitude belt coincides with the largest amplitude of the seasonal cycle near Japan. The data for land areas of Japan are not available. The top figure (Fig. 4a) shows the 1-2-1 filtered mean high-cloud amount. In the tropical region south of 23°N, phase-locked intraseasonal oscillations are superimposed on the seasonal cycle during June to October. In subtropical latitudes north of 23°N, an increase in the high-cloud amount during the Baiu season is observed. The middle figure (Fig. 4b) shows the seasonal cycle obtained by applications of the 23-pentad triangular running mean.

The bottom figure (Fig. 4c) shows the deviation of the mean high-cloud amount from the seasonal cycle obtained by subtracting Fig. 4b from 4a. This operation is equivalent to the 7.5-day-to-60 day band-pass filter. An inspection of this figure shows that the 30- to 60-day period is large in the low latitudes (Equator to 13°N) from May to October.

The contribution of the intraseasonal oscillation and the seasonal cycle to the total cloud amount are estimated as follows: At 8°N, 135°E (Fig. 2b), the annual mean cloud amount is 23 percent. The value of the seasonal cycle during 20–24 June which coincides with the first peak of the intraseasonal oscillation is 32 percent. The contribution of the seasonal cycle, which is a departure of the seasonal cycle from the annual mean cloud amount, is 9 percent. The contribution of the intraseasonal oscillation, which is the value of the 7.5-day to 60-day band-pass filtered data, is 12 percent. Therefore, enhancement of the high cloud amount by the intraseasonal oscillation was dominant during 20–24 June.

A similar comparison between the contribution of the seasonal cycle and the intraseasonal oscillation for the regions in Fig. 3 showed that the contribution due to the enhancement of the high-cloud amount by the intraseasonal oscillation was greater than the seasonal cycle in late June, early August, and late September to early October in most of the regions to the south of 13°N. The time intervals between these enhancements are between 30 to 60 days.

Figure 4c also shows that north of 13°N, a 20- to 25-day-period oscillation is observed in the Baiu cloud (20–40°N). Similar changes (not shown here) are observed in nearby longitudes from 120°E to 150°E.

Lau et al. (1988) suggested that a 20-day period is dominant north of 25°N during August and a 40-day period is dominant during the Baiu season. In the current study, a 20- to 25-day-period oscillation in the Baiu cloud is shown as the fluctuations in the 7.5 day- to 60-day band-pass filtered high-cloud amount with peaks around 25 May (near 23°N), 15–24 June (near 34°N), and 10–14 July (near 37°N). Among these 3 peaks, the second peak near 15–24
June coincides with the first peak in the 30– to 60-day-period oscillation in the low latitudes south of 13°N. Since the Baiu front moves northward after 16 May with the seasonal cycle, each of these three peaks in the high-cloud amount is observed at the different latitudes.

The horizontal extent of this phase-locked intraseasonal oscillation is investigated by constructing a longitude-time cross section of the deviation of the mean high-cloud amount from the seasonal cycle (Figs. 5 and 6). Figure 5 shows the longitude-time cross section in the latitude band 21–17°N.
Fig. 5. Longitude-time cross section of the phase-locked intraseasonal oscillation for the latitude band 21–17°N. Data are the same as in Fig. 4c). The scale for the cloud amount is the same as shown lower left of Fig. 4.

A peak of the Baiu cloud is observed in the second half of May in the northern South China Sea. Two peaks of cloud amount near 20°N, 150°E in late July and August shows propagation toward the west with a period of about 20 to 25 days. Nakazawa (1992), using the OLR data and the 850 hPa level wind, suggested that the sudden increase in cloud amount in late July may be related to tropical cyclone formation with sudden extension of the monsoon westerly wind up to 150°E. Figure 6 shows the longitude-time cross section in the latitude band 11–7°N. The peaks in June, early August and early October are observed at all the longitudes from 90°E to 160°E. Hence these phase-locked intraseasonal oscillations are probably part of the global-scale intraseasonal oscillations found by Madden and Julian (1971, 1972). The peak at longitudes from 90°E to 110°E in May coincides with the onset of the summer monsoon cloud in Southeast Asia.

5. Spatial patterns of the onset sequence of the summer monsoon cloud

Spatial patterns of the onset phase of the summer monsoon cloud from 1 May to 8 August are shown in Figs. 7 to 11. These figures show the change in the 1-2-1 filtered mean high-cloud amount in the left column and the deviation of the mean high-cloud amount from the seasonal cycle, by the same procedure as Fig. 4c, in the right column.

Figure 7 shows the patterns for 1 May to 20 May. In Southeast Asia, the rapid increase in mean high-cloud amount during 6 to 15 May coincides with the onset of the summer monsoon cloud. In the subtropical area, a high-cloud amount of over 25 percent is observed during 1 to 20 May along 30°N just south of Japan. These clouds correspond to the locations of the polar fronts. By 16–20 May, a sudden increase in the high-cloud amount is observed near 20–25°N. This increase coincides with the onset of the Baiu cloud over Okinawa. Hence, southward migration of the cloud band is observed around the onset of the Baiu season. Kato (1985) analyzed the Baiu front and showed that the horizontal temperature gradient across the Baiu front dissipates over China in the second half of May. Ninomiya and Muraki (1986) suggested that the horizontal temperature gradient gradually decreases over the East China Sea and western Japan to the west of 135°E. Hence, a gradual transformation of the frontal structure from the polar front to the Baiu front coincides with the onset of the Baiu season in Okinawa.

Figure 8 shows the patterns from 21 May to 9 June. The peak in the high-cloud amount over Okinawa occurs during the period from 21 May to 4 June. During 5 to 9 June, a rapid northward advance of this cloud band coincides with the onset of the Baiu season in Japan and a simultaneous decrease of the cloud amount near Okinawa. In the southern South China Sea, the onset of the tropical monsoon cloud is observed.

Figure 9 shows the patterns from 10 June to 29 June. A rapid increase in the high-cloud amount is observed in the ITCZ in the Western Pacific region near 10°N. The intraseasonal oscillation, shown in the right column, indicates an eastward propagation with positive cloud anomalies. Simultaneously, the high-cloud amount increases near the Baiu front in Japan. This pattern is best developed during 15 to 24 June and is very similar to the second component of the EOF of the OLR in Lau and Chan (1986). This period coincides with the largest value of the high-cloud amount during the Baiu season. The buildup of the Pacific subtropical high near 20°N is shown by the negative anomalies in the right column of Fig. 9.

This period also coincides with the onset and establishment of the summer monsoon rain in India (Fig. 1a). Kato (1989) suggested that the increased
Fig. 7. Spatial pattern of the 1-2-1 filtered mean high-cloud amount for 1 to 20 May (left column a, b, c, and d) and the phase-locked intraseasonal oscillation for the same period on the right column (d, e, f, and g). The scales for the left and right column are same as upper and lower left of Fig. 4, respectively.
Fig. 8. Same as Fig. 7, but for 21 May to 9 June.
Fig. 9. Same as Fig. 7, but for 10 to 29 June.
low-level pressure gradient between the Pacific sub-tropical high and the area of intensifying monsoon trough low-pressure system over the Asian continent, results in an increased flow of the warm moist southerly flow toward the Baiu front.

Suda and Asakura (1955) showed a parallelism between the onset dates of the Indian monsoon rainfall and the onset dates of the Biau season. Recently, Deshpande et al. (1986) investigated the onset dates of the monsoon rain in Kerala and Bombay for a period from 1901 to 1984. During this period the average date of the onset for Bombay was 10 June, with a standard deviation of 8 days. The average date of the onset of the Biau season published by the Japan Meteorological Agency for Tokyo for a period from 1951 to 1980 was 9 June.

Since the 1963 onset of the Biau season was unusually early (6 May), using these two sources of the onset dates from 1964 showed that the correlation of the onset dates between Bombay and Tokyo for a 21-year period from 1964 to 1984 was +0.29. This low value of the correlation and small values of the interannual variation (standard deviations for this period for Bombay and Tokyo were 6.7 days and 4.5 days, respectively) of the onset dates compared to the period of the 30- to 60-day intraseasonal oscillation suggest that, although the onset dates between Bombay and Tokyo are not correlated on a day-to-day basis in recent years, the difference between these two onset dates is not large in most years.

Figure 10 shows the patterns from 30 June to 19 July. The cloud amount along the ITCZ declined and relative minimum is observed around 15-19 July. The cloud along the Biau front decreases slightly during the period from 30 June to 9 July and moves north. Subsequently, the cloud amount in this cloud band increases and the third peak is observed near the Yellow Sea and the Korean peninsula during 10-14 July.

Figure 11 shows the cloud patterns from 20 July to 8 August. The Biau front dissipates rapidly after 20 July, and a large increase in the high-cloud amount occurs in the tropical Pacific region north of 13°N. By 4 to 8 August, a mid-summer pattern of large cloud amount to the east of the Philippines and a small cloud amount near Japan is observed. A similar analysis was carried out for the period from 9 August to 1 November, which covered the retreat of the summer monsoon.

6. The onset and retreat dates of the summer monsoon clouds in East Asia, Southeast Asia and the West Pacific region

Following the definition of the dates of the onset (retreat) of the summer monsoon clouds in Section 3, the dates of the onset (retreat) of the summer monsoon are determined and are shown in Figs. 12, 13 and 14. The onset dates of the tropical monsoon season are shown in Fig. 12. An inspection of this figure and Figs. 5 and 6 suggests that a rapid northward advance of the onset dates of the tropical summer monsoon season occurs in three distinct stages.

The first stage starts about 6–10 May and lasts until 4 June. This period is the onset phase of the summer monsoon over Southeast Asia. The second stage lasts from 5 June to 29 June. This period is the onset phase of the summer monsoon over the southern part of the South China Sea and the western Pacific region (south of 13°N). The third stage lasts from 30 June to 29 July. This period is the onset phase of the summer monsoon over the western Pacific region north of 13°N.

Following the mid-summer condition which continues until 23 August, the retreat dates of the tropical monsoon season are shown in Fig. 13. An inspection of this figure suggests that the southward migration of the retreat dates of the summer monsoon occurs in two distinct stages. The first stage covers a period starting from 24 August and ending in 27 September. The rapid retreat from 24 August to 7 September coincides with the negative anomalies in the phase-locked intraseasonal oscillation (see Figs. 5 and 6). Further retreats are slow until the end of this stage. The second stage of the retreat covers a period from 28 September to 22 October. The retreat of the summer monsoon is slow until the passage of the peak of the phase-locked intraseasonal oscillation in early October (see Fig. 6). Except for the start date of the first stage of the retreat dates, these dates are very similar to those discussed by Matsumoto (1988).

In subtropical regions, the onset, peak and retreat dates of the Biau season are shown in Fig. 14. Figure 14a shows the onset dates of the Biau season. The Biau season is preceded by the gradual increase in the mean high-cloud amount along the polar front near Japan. Values over 25 percent of the mean high-cloud amount are shown by a black area near Japan. This phase starts between 26–30 April near 30°N, 135°E and subsequently spreads to the entire black area by about 15 May. A sudden southward spread of the cloud to 20–25°N during 16 to 20 May coincides with the onset of the Biau season in Okinawa and southern China. After 4 June, a rapid northward advance of the cloud band coincides with the onset of the Biau season in Japan. The third stage of the northward advance occurs in July over the Yellow Sea and the Korean peninsula.

Figure 14b shows the dates of the peak of the Biau season. In this study, these dates are defined as the dates of the maximum mean high-cloud amount during the Biau season defined by the 25 percent threshold value (see Section 3). Three stages of the dates of the peak are clear, with major jumps in
Fig. 10. Same as Fig. 7, but for 30 June to 19 July.
Fig. 11. Same as Fig. 7, but for 20 July to 8 August.
Fig. 12. Onset dates defined by the threshold value of more than 30 percent of the mean high-cloud amount for the tropical (ITCZ related) monsoon season. The last day of each pentad is shown on the thick contour line defining the northern limit of the area where the mean (1978-89 average) onset dates are observed in a given pentad. The thin contour is the outer boundary of 20 percent in the amplitude of the seasonal cycle which defined the tropical monsoon region in this study. Dashed lines show the dates of the first pentad in June with more than 30 percent of the mean high-cloud amount outside of the monsoon region defined in this study. A black area near Sumatra is the region where the mean high-cloud amount was over 30 percent before 31 March.

Fig. 13. Same as Fig. 12, but for retreat dates of the tropical monsoon.

Fig. 14. a) Onset dates b) peak dates defined by the dates of maximum in the mean high-cloud amount and c) retreat dates of the Biau season. The onset and retreat dates for the Biau season are defined by the threshold value of more than 25 percent of the mean high-cloud amount. The dates on the contours are similar to Fig. 12. Thick lines in b) indicate the boundary of the 3 stages in the peak dates of the Biau season. The dashed lines near the Philippines show the area where the peak of the cloud amount was observed during 20 to 24 June. A black area near Japan shows a region where the polar front is active with over 25 percent of the mean high-cloud amount during 26 April to 15 May.
to 14 July in the Yellow Sea and the Korean peninsula. The first two stages of these maxima have a clear relationship to the phase-locked intraseasonal oscillation in the tropical monsoon. The maximum in Okinawa occurs after the onset of the summer monsoon in Southeast Asia. The second-stage maximum in Japan coincides with a similar peak in the phase-locked intraseasonal oscillation shown by the dashed lines near the Philippines.

Lau and Li (1984), Lau et al. (1988) suggested that monsoon rainfall over East Asia evolves with wave-like progression from south to north from April to September. Abrupt changes caused by the major rainbands are related to the phase-locking between the intraseasonal oscillation and the seasonal cycle. In the current study, both tropical and subtropical (Baiu) branches of the summer monsoon clouds were found to show similar modes of the seasonal evolution with phase-locking between the 30- to 60-day mode near the Equator to 13°N, the 20- to 25-day mode north of 13°N, and the seasonal cycle.

Figure 14c shows the retreat dates of the Baiu season. The sudden retreat after 10 June near 18–24°N, and by 20 July in Japan and the slow northward progression in other periods are the major features. Yoshino (1966) divided the Baiu season into 4 stages based on the rainfall data. A comparison between his divisions and the results of this study suggests that his Stage Ia corresponds to our polar front stage. The three stages of the peak of the Baiu season shown in Fig. 14b correspond to his Stages Ib, II, III–IV, respectively.

7. Summary

An analysis on the 12-year means of the 5-day mean GMS high-cloud amount data revealed the detailed seasonal evolution of the summer monsoon clouds in East Asia, Southeast Asia and the Western Pacific region. The onset and retreat dates derived from this study fill the major gaps in these dates over Southeast Asia and the adjacent western Pacific regions, where the large area of the ocean prevented the analysis of these dates based on the rainfall data. The onset (retreat) of these clouds shows a series of sudden expansions (contractions) which are related to phase-locking between the intraseasonal oscillation such as the 30- to 60-day mode from the Equator to 13°N, the 20- to 25-day modes north of 13°N, and the seasonal cycle. Comparing each stage of the tropical (ITCZ) and subtropical (the Baiu front) branch of the summer monsoon clouds, the summer monsoon season in East Asia, Southeast Asia and the western Pacific ocean region can be divided into 7 stages based on sudden changes of the onset and retreat dates of the summer monsoon cloud and the dates of the peaks in the intraseasonal oscillations:

Stage 1 26 April to 15 May
Polar front cloud increases south of Japan. The onset of the summer monsoon after 6 May in Southeast Asia up to 15°N.

Stage 2 16 May to 4 June
Continued northward advance of the summer monsoon in Southeast Asia. The onset and the peak of the Baiu season in Okinawa and southern China. This peak is the first peak of the 20- to 25-day mode in the Baiu cloud.

Stage 3 5 June to 29 June
Rapid onset of the summer monsoon in the Southern South China Sea and the Western Pacific region south of 13°N. This is followed by the first peak of the 30- to 60-day mode in the western Pacific region south of 13°N which occurs around 20 to 24 June. The onset and the peak of the Baiu season in Japan and central China. This peak is the second peak of the 20- to 25-day mode in the Baiu cloud. The Baiu season ends in Okinawa and southern China.

Stage 4 30 June to 29 July
Rapid onset of the summer monsoon in the western Pacific region after 19 July to north of the 13°N. The first peak of the 20- to 25-day mode near 20°N, 150°E occurs around 25 to 29 July. The onset and the peak of the Baiu season in the Yellow Sea and the Korean peninsula. This peak is the third peak of the 20- to 25-day mode in the Baiu cloud. Toward the end of this stage, the Baiu season ends in East Asia.

Stage 5 30 July to 23 August
A mid-summer condition. Large area of the cloud amount greater than 30 percent to the east of the Philippines. The second peak of the 30- to 60-day mode in the western Pacific region south of 13°N which occurs around 4 to 8 August. The second peak of the 20- to 25-day mode near 20°N, 150°E which occurs around 14 to 18 August. Relative minimum in the cloud amount near Japan.

Stage 6 24 August to 27 September
Rapid retreat of the summer monsoon in the western Pacific region north of 13°N until 7 September. Followed by the very slow southward retreat.

Stage 7 28 September to 22 October
The third peak of the 30- to 60-day mode in the Western Pacific region south of 13°N around 3 to 7 October. This peak is followed by a rapid retreat of the summer monsoon in Southeast Asia and the western Pacific region south of 13°N.

The foregoing results are exploratory, since they are based only on the GMS high-cloud-amount data.
Further studies are needed to investigate the nature of the phase-locking between the intraseasonal oscillation and the seasonal cycle in the summer monsoon using the rainfall, wind and geopotential height data.

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GMS 上層雲量による東アジア・東南アジア・西太平洋上における
夏のモンスーンの開始と季節変化

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5 日平均 GMS 上層雲量 (1°×1°メッシュ) データ (1978 年 4 月から 1989 年 12 月) を利用して東アジア・東南アジア・西太平洋上における夏のモンスーンの開始と季節変化を調査した。夏のモンスーンに伴う雲は ITCZ による熱帯モンスーンと、梅雨前線による亜熱帯モンスーンに分けられる。熱帯モンスーンに伴う雲は、5 月に東南アジアで増加し、雨期が始まる。その後、6・7 月にかけて数回の急速な北上で南シナ海・西太平洋上に広がる。

梅雨の走りは 4 月 26 日以降に日本のすぐ南方の 30°N 付近で寒帯前線帯の雲量の増加として始まる。5 月 16 日ごろからこの雲ベルトは南下し 20-25°N 付近で雲が急速に増加し、沖縄で梅雨が始まる。6 月 5 日-9 日ごろこの雲は急速に北上し、日本で梅雨が始まる。7 月に入ると梅雨は黄海・朝鮮半島に北上する。

これらの雲量の急速な変化は 30-60 日及び 20-25 日の周期の季節内変動と、60 日以上の周期の季節変化の位相の同期によると考えられる。東南アジア・西太平洋上では広大な海洋のため降水量による雨期の開始（終了）の日の調査は十分でなかった。しかし GMS 上層雲量データによる調査によってこの地域での雨期の開始から終了までの季節変化が明らかになった。