STUDY ON THE VARIATION IN THE CONFIGURATION OF SUBTROPICAL ANTICYCLONE AND ITS MECHANISM DURING SEASONAL TRANSITION—PART II: SEASONAL TRANSITION INDICES OVER THE ASIAN MONSOON REGION*

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ABSTRACT

Based on the studies in Part I (see Mao et al. 2003), this paper further examines the relationship between the Asian summer monsoon onset and variation in meridional position of the warm temperature ridge with a zonal orientation in mid-upper troposphere. During the Asian monsoon bursting consequentially over the Bay of Bengal, South China Sea, and South Asia, in addition to the reversal of winds in the lower and upper troposphere and deep convection before and after the onset, the atmospheric meridional temperature gradient (MTG) in the vicinity of the ridge-surface of subtropical high (WEB defined in Part I) exhibits a significant reversal. Since the establishment of temperature structure with higher over north than over south of the WEB in the mid-upper troposphere (200—500 hPa) characterizes the collective essential that the Asian summer monsoon bursts over different areas, the MTG in mid-upper troposphere, based on the thermodynamics associated with the seasonal transition, should be a reasonable index to measure the Asian monsoon onset. The definition for onset date is proposed, and the time series of onset date for different sections are determined. As compared with the onset dates determined by other indices such as 850-hPa zonal wind and OLR, correlation analyses indicate that the 850-hPa zonal wind is only regional index, but the MTG index is applicable universally to the Asian monsoon regime.

Key words: seasonal transition index, meridional temperature gradient, WEB (westerly-easterly boundary)

I. INTRODUCTION

Ye et al. (1958) pointed out that there are only two natural seasons within a year, namely winter and summer. The atmospheric circulation transition from winter to summer patterns exhibits abruptness. The change in structure of easterly and westerly zones in upper troposphere well reflects the seasonal variation. Essentially, this change means the strengthening or weakening of the westerly jet as well as the swing of jet axis in meridional direction. In Part I (Mao et al. 2003), we found that during boreal transition season, the position of the ridge-surface of subtropical high (WEB) shifts evidently from south to

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north, on the other hand, the tilt of the WEB switches from southward to northward, and the changes in tilt of the WEB take place successively from different areas. When meridional temperature gradient (MTG) in the vicinity of the WEB in the troposphere is negative, the subtropical anticyclone exhibits a winter type. While the MTG becomes positive, the subtropical anticyclone manifests a summer pattern. Mao et al. (2003) defined the vertical ridge axis as "seasonal transition axis" (STA), which indicates the displacement of winter monsoon by summer monsoon. The concept "STA" is very important because its occurrence signals the development of the summer subtropical high. The longitudinal location of the STA can also reflect the border where the summer monsoon prevails (see Fig. 4 in Part I). The monsoon circulation transition from winter to summer is closely related to the formation and evolution of the STA. The STA possesses specific physical significance because the structure of the subtropical high depends on the temperature field. The STA represents a critical state that the MTG near the WEB changes from negative to positive, which suggests that the MTG can be used to characterizing the seasonal transition and monsoon onset.

Monsoon is a seasonal reversal of both wind and pressure fields. Previous studies (e.g. Ananthakrishnan et al. 1983; Ananthakrishnan and Soman 1988; Mohanty et al. 1983; Krishnarurti et al. 1981; Krishnarurti 1985; Joseph et al. 1994) have shown that during monsoon onset dramatic changes occur in large-scale atmospheric and oceanic structures over monsoon region. Some of well-known ones associated with the onset are a rise of sea surface temperature over northern Indian Ocean and South China Sea (SCS), a rapid increase of the daily precipitation rate, and an increase in the kinetic energy of the low-level flows. Based on these features, the various indices were therefore proposed to define the monsoon onset date for a particular region. But climatological distributions of onset dates given by different researchers differ greatly due to different indices used and different criteria. The largest discrepancies occur over the eastern Bay of Bengal (BOB) to Indochina Peninsula. Tao and Chen (1987) pointed out that the earliest onset occurs over the SCS in the Asian monsoon regime. But in investigating the 1989 summer monsoon onset, Wu and Zhang (1998) reported that the Asian monsoon onset was composed of three consequential stages and the first was over the BOB. Although the results given by both Lau and Yang (1997) and Webster et al. (1998) showed that the SCS monsoon onset is not the earliest, they did not also indicate that the earliest onset occurs over the eastern BOB.

Based on 19-year data and from the WEB perspective, Mao et al. (2003) pointed out that in climatology, the three stages of the Asian summer monsoon onset well correspond to those of summer subtropical anticyclone establishment. The first onset occurs over eastern BOB-Indochina Peninsula, the second over the SCS, and the third over South Asia. Seasonal transition signifies the replacement of winter circulation by summer circulation. In addition to the circulation replacement, monsoon onset is accompanied by monsoonal precipitation, but occurrence of rainfall does not depend on circulation conditions only. Under circumstances of the climate mean, the establishment of the STA is related to quasi-simultaneous initiation of the local rainy season, so the seasonal transition and monsoon onset can be considered as a same concept. While for a particular year, they may not occur exactly simultaneously.

Since an early or late seasonal transition and monsoon onset are closely related to the more or less subsequent rainfall, determining scientifically monsoon onset date becomes an issue of considerable urgency. At present, the definitions for the SCS monsoon onset are more than those for the other areas such as the BOB and India, but there is not a particular definition widely accepted, let alone the ones suitable for the entire Asian monsoon region.

However, which index is applicable to describe the seasonal transition or monsoon onset? In this paper, the MTG index is proposed, and the seasonal transition dates for individual years are identified. Statistical analyses are carried out to show the advantages of new index as compared with other indices involving 850-hPa zonal wind and OLR.

The data used in this paper are described in Section II. The evolutions of various meteorological parameter fields including temperature, wind, and precipitation are examined in Section III. The definitions regarding the MTG and time series of the seasonal transition date are presented in Section IV. The conclusions are given in Section V.

II. DATA

The daily mean data used are the NCEP/NCAR reanalysis products for the period 1980—1998. The wind, geopotential height, temperature fields at 12 standard pressure levels are selected with a horizontal resolution of $2.5° \times 2.5°$ grid. Also used are the daily mean outgoing longwave radiation (OLR) data on $2.5° \times 2.5°$ grid from the NOAA satellite observation extracting from 1980 to 1998.

III. EVOLUTIONS OF THE WARM TEMPERATURE RIDGE IN MID-UPPER TROPOSPHERE DURING SEASONAL TRANSITION

1. *Time-Latitude Cross Section*

Figure 1 shows the time-latitude cross sections of 850-hPa winds, OLR, and MTG averaged over different longitudes for three typical monsoon areas. Before the end of April, the BOB is controlled by anticyclone, with northerlies prevailing, and the ridgeline position of subtropical high along with deep convection (less than 230 W/m^2) is located to the lower latitude (Fig. 1a). After the end of April, the southerlies from the equator increase abruptly and migrate into the subtropics over the eastern BOB in such a way that the anticyclonic circulation weakens and dissipates, and the ridgeline first breaks at this place and this time. Thus, the southwesterly flows start to prevail over the BOB, correspondingly, deep convection extends to the north of 10°N, indicating the BOB monsoon onset. By 10 May, deep convection reaches 15°N. The thick solid curve represents not only the zero isoline of the MTG in mid-upper troposphere (200—500 hPa), but also the evolution of the latitudinal location of the warm temperature ridge. It is obvious that this zero isoline is similar and close to that of OLR with 230 W/m^2. These results show that the meridional shift of the warm ridge is an essential feature associated with the BOB monsoon onset.

The SCS monsoon onset exhibits more significant abruptness (Fig. 1b). The warm

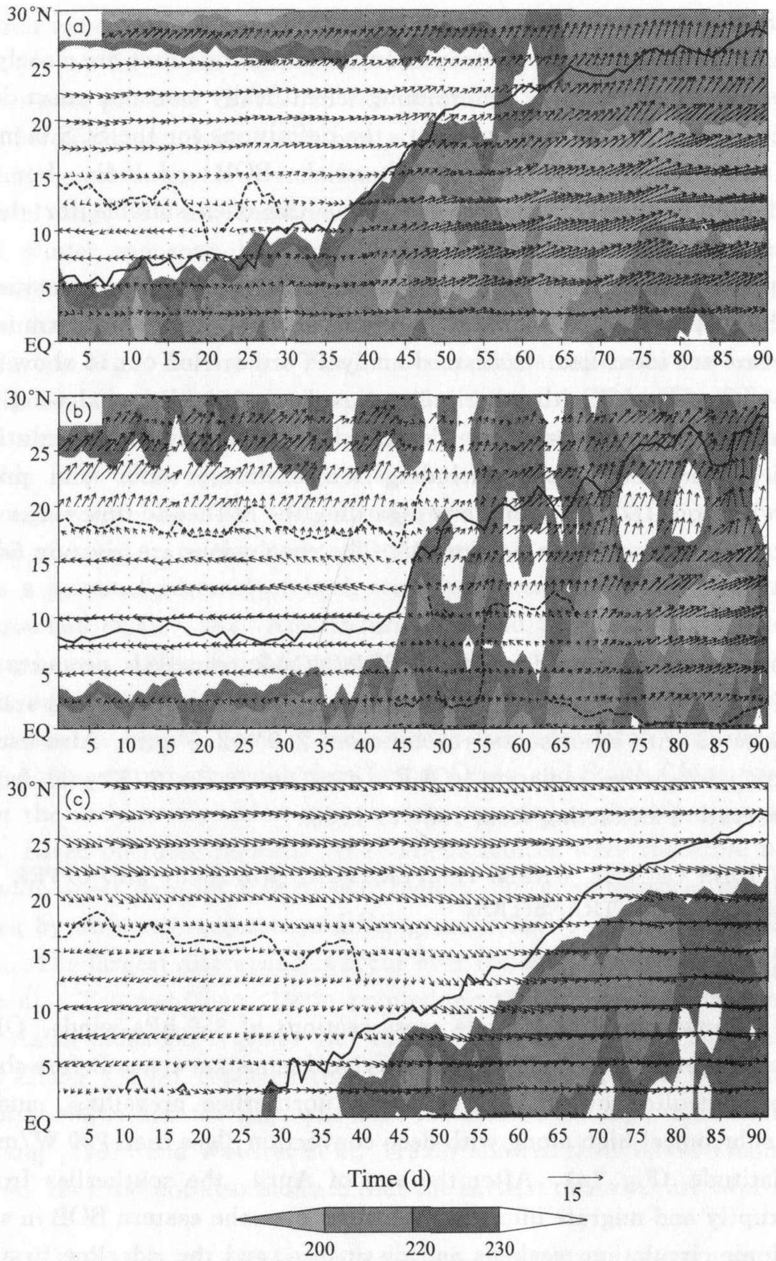

Fig. 1. Time-latitude cross sections of OLR (shading), 850 hPa winds (vectors), 850-hPa subtropical high ridgeline (dashed line), and zero isoline of the mid-upper tropospheric (200—500 hPa) MTG (thick solid line) during seasonal transition. The number along abscissa denotes the day order counted from 1 April. The regions with OLR values less than 200, 220, and 230 W/m^2 are shaded from heavy to light. (a) Eastern BOB (90—100°E), (b) SCS (110—120°E), and (c) South Asia (60—85°E).

ridge jumps from 8°N to 20°N during a short period for 15 — 20 of May, and in lower troposphere, the easterlies are subsequently replaced by southwesterlies over the SCS. Deep convection occurs almost simultaneously over the entire SCS, with the 850-hPa ridgeline retreating out of the SCS.

The summer monsoon onset over South Asia is displayed in Fig. 1c. The zero isoline of the MTG migrates northward since the beginning of May, with deep convection extending northward. During the first dekad of June, deep convection suddenly intrudes northward from 8°N, and the north edge of rainfall is very close to the latitudinal location of the mid-upper tropospheric warm temperature ridge. Note that the low-level westerlies associated with rainfall over South Asia originate from Somali jet.

It is obvious that the variations in structure of temperature field play an important role in the summer monsoon establishment. Monsoon onset is closely related to the northward migration of local mid-upper tropospheric warm ridge. Therefore, the mid-upper tropospheric MTG can indicate the Asian summer monsoon onset.

2. *Time-Pressure Cross Section*

Since the start dates of seasonal transition are different from area to area, the domain for defining monsoon onset must be delimited. Based on the latitudinal position of the WEB, location of the STA, and northward shift of mid-upper tropospheric warm ridge, the domains of three typical monsoon areas are demarcated (see Fig. 2): BOB (5—15°N, 90—100°E), SCS (5—20°N, 110—120°E), and IDO (10—20°N, 60—85°E, India and Arabian Sea). In this sub-section, the vertical structure associated with monsoon onset is first discussed, and definitions for onset are then conducted.

The BOB summer monsoon bursts around the first dekad of May (Fig. 3). Before 1 May, the MTG is positive below 700 hPa and above 200 hPa, which is the manifestation that the MTG lower than 3 km between 60°E and 110°E reverses in April (Mao et al. 2003). However, the MTG in atmospheric column between 700—200 hPa is negative (Fig. 3a). In addition to the shallow westerlies near the boundary surface, the easterlies exist below 300 hPa (Fig. 3b). The dynamical structure exhibits the upper divergence and lower weak convergence (Fig. 3c), with descending motion and suppressed convection (not

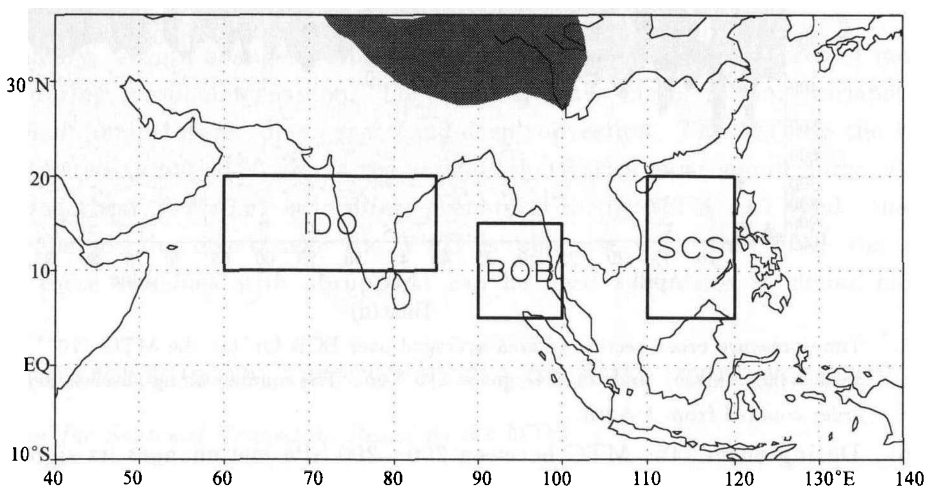

Fig. 2. Three demarcated domains: BOB (5—15°N, 90—100°E), SCS (15—20°N, 110—120°E), and IDO (10—20°N, 60—85°E). Shaded area indicates the terrain above 3000 m.

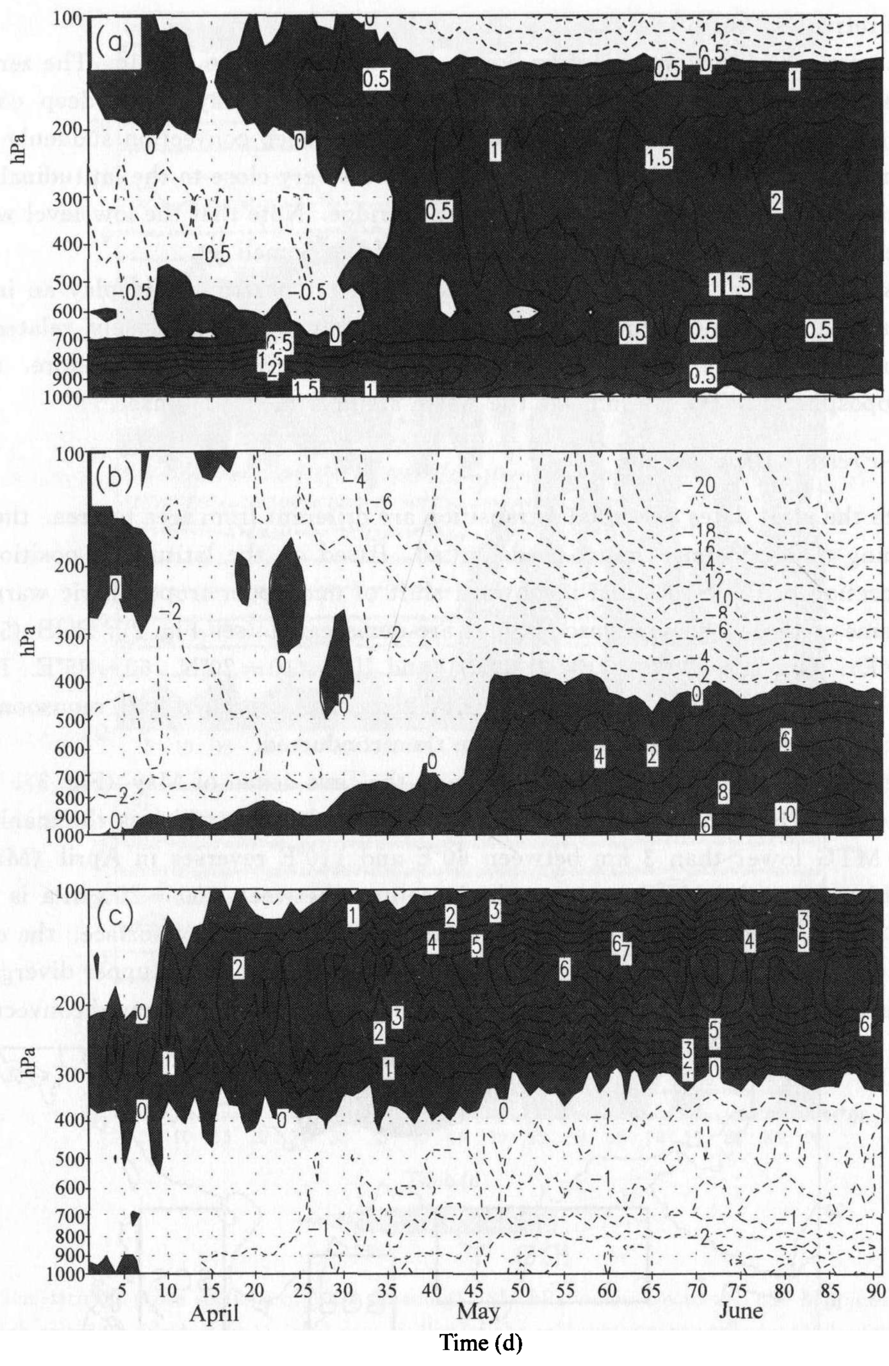

Fig. 3. Time-pressure cross section of area-averaged over BOB for (a) the MTG (10^{-3} K/km), (b) zonal winds (m/s), and (c) divergence (10^{-6}/s). The number along abscissa denotes the day order counted from 1 April.

shown). During onset, the MTG between 700—200 hPa just changes its sign on the first pentad of May (Fig. 3a). Both the lower tropospheric westerlies (divergence) and upper tropospheric easterlies (convergence) strengthen (Figs. 3b and 3c), and OLR abruptly drops to below 220 W/m^2. Noteworthy is that the time when the MTG changes sign is slightly earlier than that when OLR drops to threshold of 230 W/m^2, which suggests that the BOB monsoon onset occurs till the reversal of the mid-upper tropospheric MTG. After the onset, the low-level cyclonic circulation is enhanced as an asymmetric Rossby wave response to deep convective heating over the BOB (Gill 1980). As a result, the air temperature rises over the northern SCS due to latent heating release, causing the reversal of the MTG and northward tilt of the WEB over the SCS. Moreover, based on thermal adaptation theory (Wu and Liu 2000; Wu et al. 1999; Liu et al. 1999), if latent heating strengthens with increasing height, it is favorable for the developing of positive vorticity in mid-lower troposphere. Therefore, the ridgelines at 700, 500, and 400 hPa split on the fourth pentad of May.

Figure 4 shows that the SCS monsoon onset occurs in 16—20 May. Before the onset, the MTG below 200 hPa is negative (Fig. 4a), and the easterlies prevail in mid-lower levels while the westerlies exist in upper levels (Fig. 4b). Weak divergence exists between 200—500 hPa (Fig. 4c), and convection is suppressed with OLR values more than 260 W/m^2 (not shown). During the onset, the zero isoline of the MTG is almost vertical from surface to 200 hPa, the reversals in upper and lower winds are also distinct. After the onset, the upper tropospheric divergence becomes stronger than the lower tropospheric convergence.

The monsoon onset over the IDO (Fig. 5) is different from that over the BOB and SCS. The IDO monsoon bursts around the first two pentads of June. Before the onset, although the MTG below 700 hPa has been positive since April due to sensible heating near the surface, the MTG between 200—700 hPa remains negative. There are the easterlies only between 600—850 hPa, and the contrast between strong convergence in upper level and divergence in low-level is evident. During the onset, the reversal of the MTG between 200—500 hPa has a lead one pentad compared with that of the MTG between 500—700 hPa. After the onset, the easterlies are above 600 hPa, and the westerly maximum is close to the surface layer. The divergent layer is also shallow and lower than 850 hPa.

In summary, abrupt changes occur in thermal and dynamical structures of monsoon circulation during seasonal transition. The reversal takes place in some variable fields including wind, temperature, divergence, and deep convection. The MTG in the vicinity of the WEB between 200—500 hPa is the variable that varies most significantly. Because the zonal wind shear ($\partial U/\partial z$) is in direct proportion to the MTG ($\partial T/\partial y$), the zonal wind shear before the onset near the WEB is opposite with that after the onset. Therefore, these variables with abruptness can be used as indices to define monsoon onset.

IV. DEFINITION FOR SEASONAL TRANSITION OVER THE ASIAN MONSOON REGION

1. *Definition for Seasonal Transition Based on the MTG*

Rainfall and winds are commonly considered as two indices to define summer monsoon onset. There are various definitions proposed for the SCS monsoon onset (Tao and Chen 1987; Xie et al. 1996; Chen et al. 1999; Jin 1999; Dai et al. 2000; Li and Qu 2000), but

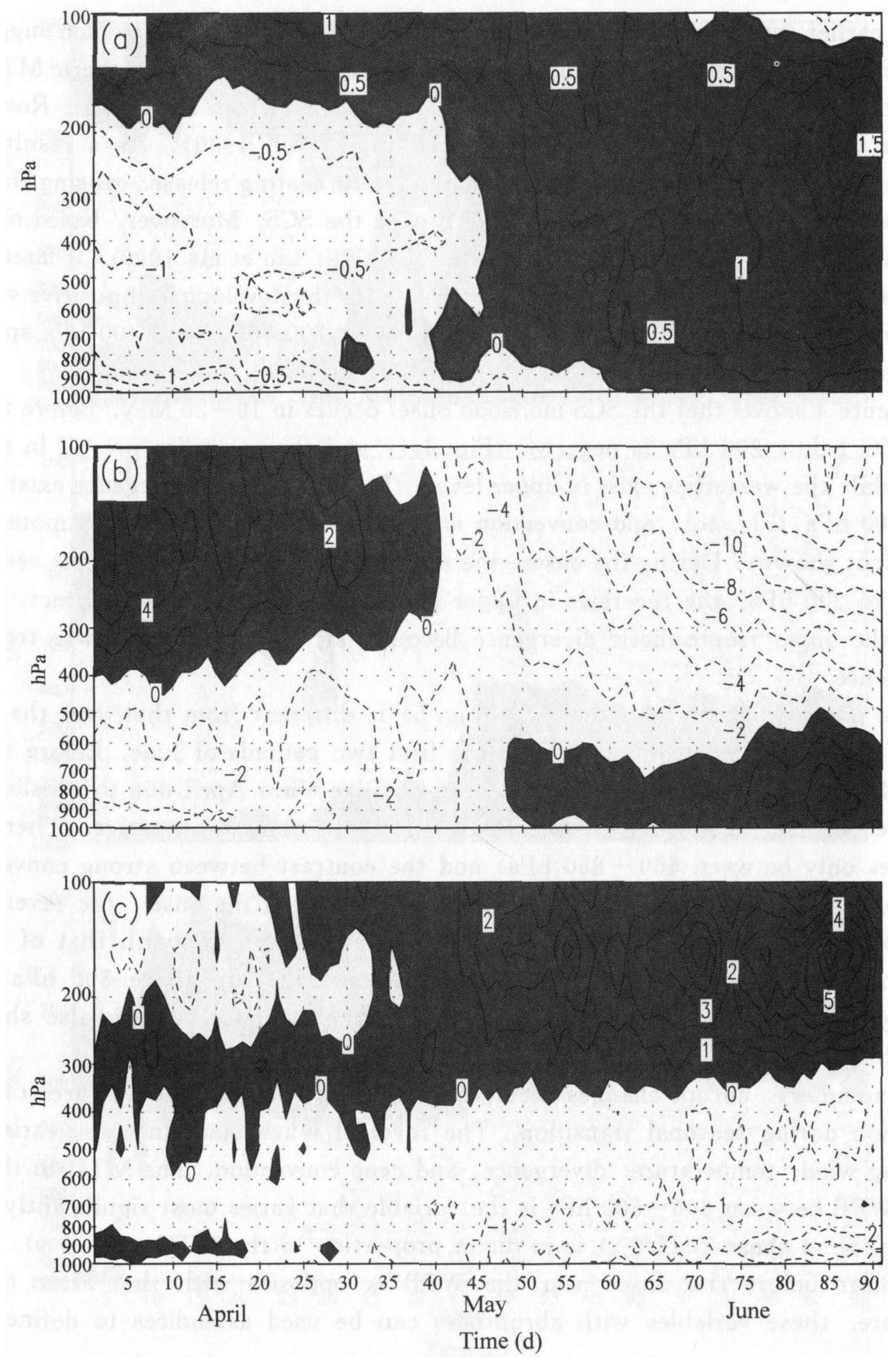

Fig. 4. As in Fig. 3, except for the SCS.

for the IDO and BOB-Indochina Peninsula monsoon. the definition is mainly based on the observational precipitation (Ananthakrishnan et al. 1988; Zhang et al. 2002). The above analyses and results in Mao et al. (2003) indicate that the tilt of the WEB depends on the MTG, namely, the thermal basis of seasonal transition is the reversal of the MTG near the WEB.

The climatological seasonal transition date can be identified for each of three areas

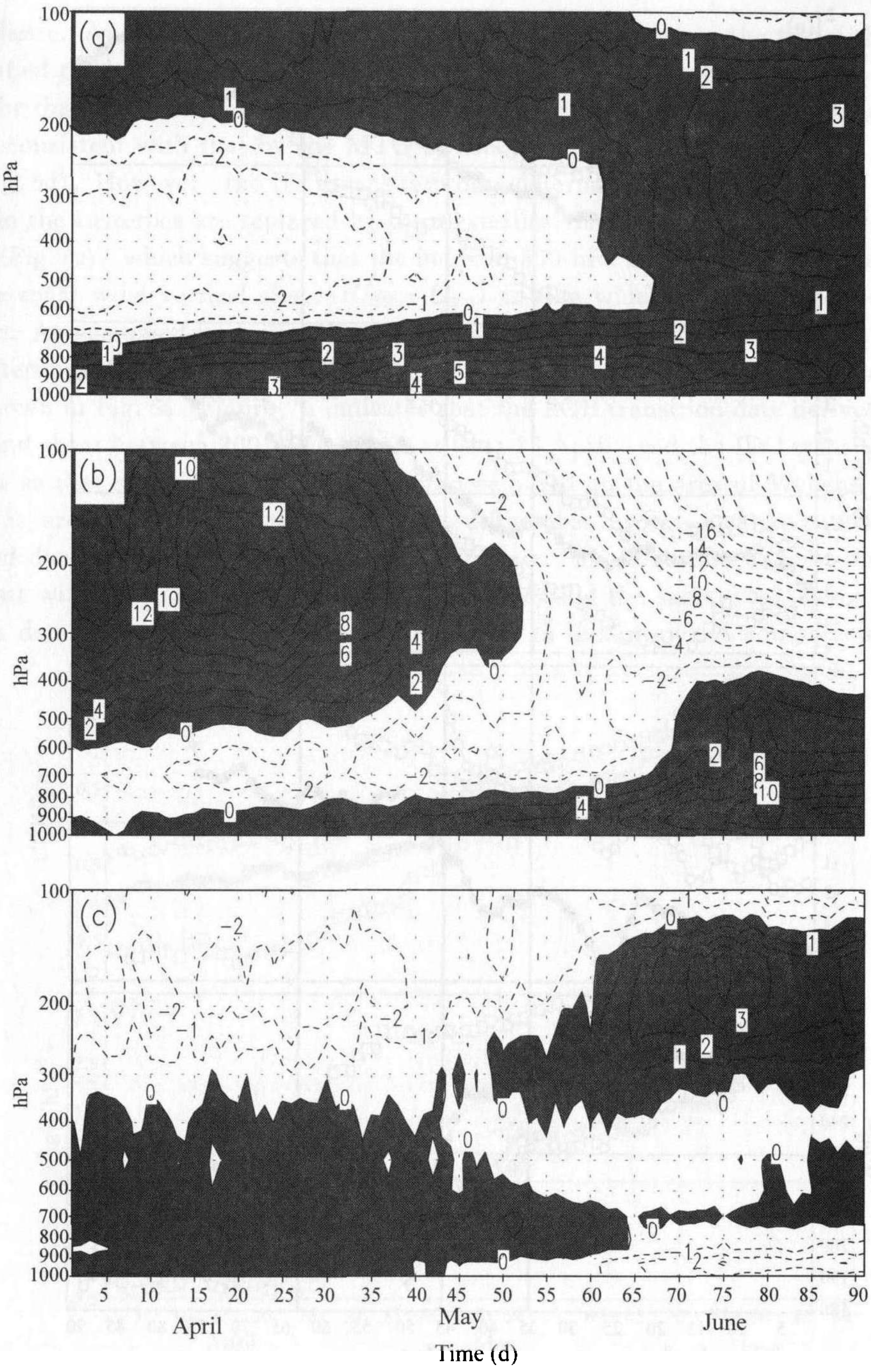

Fig. 5. As in Fig. 3, except for the IDO.

from Fig. 6. Figure 6a illustrates that the MTG evolves from negative to positive for each area. If the day when the MTG equals zero is defined as seasonal transition date, the climatological transiton dates for the BOB, SCS, and IDO are 6 May, 15 May, and 1 June, respectively.

The evolutions of zonal wind vertical shear (Fig. 6b) are similar to those of the MTG, which indicates the relationship between wind and temperature fields satisfies the thermal

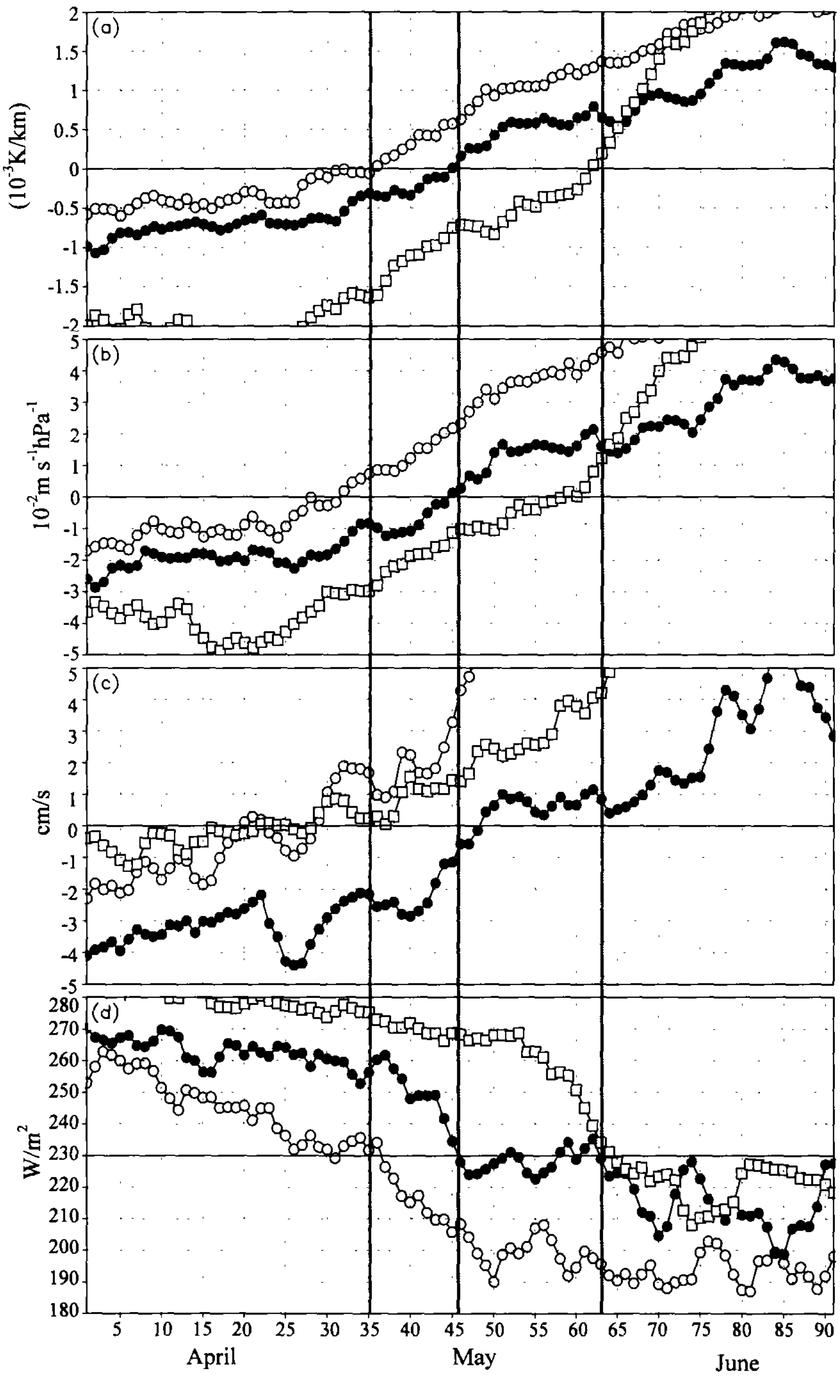

Fig. 6. Evolutions of climatological (a) mid-upper tropospheric (200—500 hPa) MTG (10^{-3} K/km), (b) zonal wind vertical shear between 200 hPa and 500 hPa (10^{-2} m s^{-1}hPa^{-1}), (c) 850-hPa zonal wind (m/s), and (d) OLR (W/m^2). The number along abscissa denotes the day order counted from 1 April. Open circles denote the BOB (5—15°N, 90—100°E), solid circles represent the SCS (5—20°N, 110—120°E), and open squares denote the IDO (10—20°N, 60—85°E).

wind balance. At the same time, the theoretical analyses regarding the tilt of the WEB is also verified to be correct.

If the threshold criterion of OLR is chosen to be 230 W/m^2, the transition date by this index is consistent with that by the MTG or zonal wind vertical shear for each individual area (Fig. 6d). However, the IDO transition date determined by 850-hPa zonal wind (the day when the easterlies are replaced by the westerlies) is different from that by the above indices (Fig. 6c), which suggests that the index of 850-hPa zonal wind is a regional index.

The zonal wind vertical shear ($U_{850}-U_{200}$) is also widely used to describe seasonal variation. As compared with Fig. 6, Fig. 7a shows that except for the SCS, the transition dates determined by the MTG between 200—850 hPa for the BOB and IDO are earlier than those shown in Fig. 6a. Figure 7b indicates that the BOB transition date derived from the zonal wind shear between 200—850 hPa is at least 26 April, and the IDO transition date is the same as that of the SCS. The transition date based on the area of Webster and Yang (1992) is around 5 May, but the regional differences in seasonal transition time are concealed due to too large domain selected by them. These results are not obviously in agreement with practical facts. Although Liu (2000) did the same work using the $U_{850}-U_{200}$, his domains selected are different from those in this study. A comparison of Fig. 6

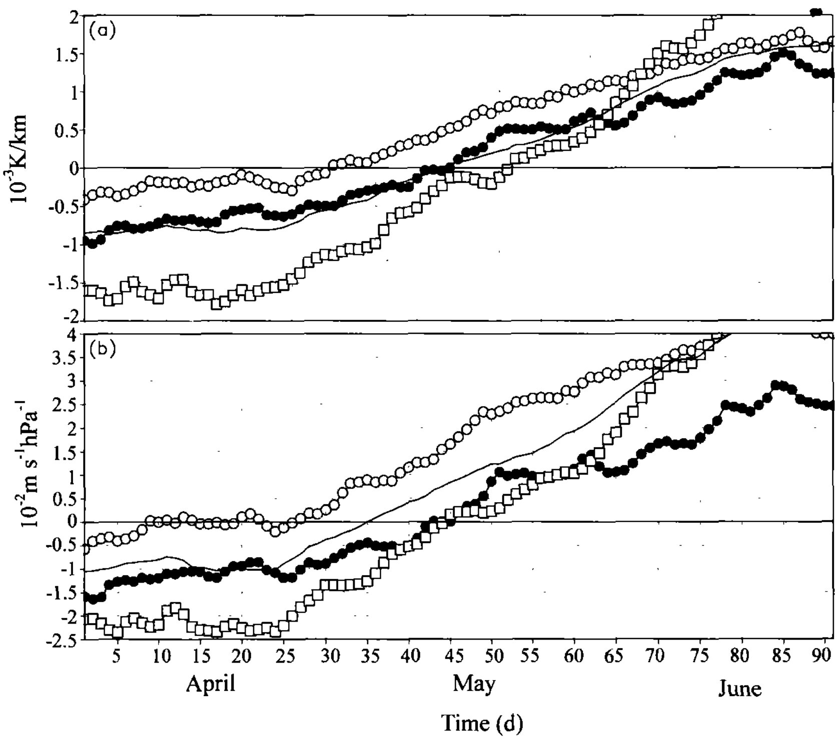

Fig. 7. Evolutions of climatological (a) lower-upper tropospheric (200—850 hPa) MTG (10^{-3} K/km) and (b) zonal wind vertical shear between 200 hPa and 850 hPa (10^{-2} m s hPa^{-1}). The number along abscissa denotes the day order counted from 1 April. Open circles denote the BOB (5—15°N, 90—100°E), solid circles represent the SCS (5—20°N, 110—120°E), open squares denote the IDO (10—20°N, 60—85°E), and solid line denotes the area chosen by Webster and Yang (1992).

with Fig. 7 shows that the MTG or zonal wind vertical shear between 200—850 hPa is not suitable for defining the monsoon onset for all different areas, instead, the MTG or zonal wind vertical shear between 200—500 hPa has potential in practice.

Table 1. The Seasonal Transition and Monsoon Onset Dates over the BOB (month-day)

Year	MTG	U_{850}	OLR	Combination
1980	5-11	5-03	5-09	5-11
1981	5-07	5-10	5-13	5-13
1982	4-22	4-21	4-23	4-23
1983	5-16	5-19	5-23	5-23
1984	4-13	4-15	4-15	4-15
1985	4-17	4-18	4-20	4-20
1986	5-09	5-03	5-09	5-09
1987	5-03	5-02	5-25	5-25
1988	5-02	4-29	4-27	5-02
1989	4-28	4-20	5-08	5-08
1990	5-14	5-11	5-14	5-14
1991	4-25	4-25	5-20	5-20
1992	5-14	5-14	5-10	5-14
1993	5-19	5-18	5-14	5-19
1994	5-01	4-30	4-24	5-01
1995	5-09	5-09	5-07	5-09
1996	4-25	4-25	4-21	4-25
1997	5-17	5-16	5-11	5-17
1998	5-18	5-15	5-12	5-18
Mean	5-05	5-03	5-07	5-08
Standard deviation (d)	10.56	10.46	11.32	11.21

Generally, climatological transition dates determined by the MTG between 200—500 hPa, zonal wind vertical shear and OLR are well consistent for each of the three areas. The BOB transition date derived from 850-hPa zonal wind is slightly earlier than those by the above three indices, while it is slightly later for the SCS. For the IDO area, however, the transition date from 850-hPa zonal wind is largely different from those by other indices, because this westerly component is involved in the northwesterly flows (see Fig. 1c). It is no surprise that the Indian monsoon is accustomed to use the local rainfall to define the onset. After having examined the performances of different indices, it is found that the MTG between 200 — 500 hPa is applicable to define the monsoon onset for different areas in the Asian monsoon regime.

Based on the above results, here the seasonal transition or monsoon onset date for each individual year is defined as the day when the following criteria are first satisfied: (1) the area-averaged mid-upper tropospheric (200 — 500 hPa) MTG changes from negative to positive; and (2) the MTG remains positive for more than 7 days within the next 10 consecutive days.

For comparison, an identical definition is applied to the 850-hPa zonal wind and OLR, except for that the threshold of OLR is 230 W/m^2. The onset dates for the period 1980—1998 and for three areas are listed in Tables 1 to 3. The date in last column by the combination means when the two or three afore-listed indices all satisfy the definition.

2. Correlation among the MTG, U_{850}, and OLR

It is found from Tables 1—3 that in a large number of individual years, the dates determined by the MTG are consistent with those by OLR and U_{850}. In a few years, there are large differences. For example in 1991, the MTG has reversed since 28 April and persists to 25 May, but deep convection occurs till 4 June. Due to this, we call provisionally the MTG as seasonal transition index. Table 4 lists the correlation coefficients among various indices. The MTG between 200—500 hPa is well correlated with OLR for three areas. The confidence levels for the BOB and IDO have exceeded 0.01, and in the SCS the confidence level also reaches 0.05. Note that the MTG exhibits a better correlation with the combination except for the SCS. These results indicate that the reversal of the mid-upper tropospheric (200—500 hPa) MTG can reflect the collective essential feature for different areas in the Asian monsoon region. Besides, 850-hPa zonal wind is only a regional index.

Table 2. The Seasonal Transition and Monsoon Onset Dates over the SCS (month-day)

Year	MTG	U850	OLR	Combination
1980	5-13	5-14	5-16	5-16
1981	5-10	5-10	6-03	6-03
1982	5-06	4-30	6-04	6-04
1983	5-22	5-19	6-05	6-05
1984	4-27	4-27	4-28	4-28
1985	5-24	5-26	5-27	5-27
1986	5-10	5-10	5-14	5-14
1987	5-20	6-08	6-05	6-08
1988	5-20	5-20	5-20	5-20
1989	5-15	5-17	5-16	5-17
1990	5-15	5-16	5-14	5-16
1991	4-28	6-08	6-04	6-09
1992	5-15	5-21	6-08	6-08
1993	5-30	6-16	6-15	6-16
1994	5-03	5-02	5-03	5-03
1995	5-15	6-04	5-30	6-04
1996	5-06	5-13	5-12	5-13
1997	5-17	5-17	5-20	5-20
1998	5-19	5-20	5-19	5-20
Mean	5-14	5-19	5-23	5-24
Standard deviation (d)	8.43	13.12	12.62	13.14

It is also found that the mean seasonal transition dates listed in Tables 1—3, which are averaged mathematically from all individual years, are in well agreement with those shown in Fig. 6, and also verify that the MTG index is reasonable.

The standard deviations in Tables 1—3 show the large interannual variability of seasonal transition and monsoon onset. The range between the earliest and latest start dates (for BOB, 13 April—19 May; SCS, 28 April—30 May; IDO, 6 May—15 June) exceeds one month. The interannual variability and its influences will be explored later.

Table 3. The Seasonal Transition and Monsoon Onset Dates over the IDO (month-day)

Year	MTG	OLR	Combination
1980	6-01	6-01	6-01
1981	5-27	5-30	5-30
1982	6-03	6-14	6-14
1983	6-15	6-15	6-15
1984	5-24	5-27	5-27
1985	5-27	5-24	5-27
1986	6-04	6-04	6-04
1987	6-03	6-01	6-03
1988	5-21	6-06	6-06
1989	5-19	6-03	6-03
1990	5-12	5-23	5-23
1991	6-05	6-01	6-05
1992	6-11	6-11	6-11
1993	6-09	6-03	6-09
1994	6-05	5-28	6-05
1995	6-06	6-09	6-09
1996	5-06	6-05	6-05
1997	6-15	6-08	6-15
1998	6-07	6-13	6-13
Mean	6-01	6-04	6-05
Standard deviation (d)	8.90	6.44	6.56

Table 4. Correlation Coefficients among Various Indices (Statistical confidence levels exceeding 0.05, 0.01, and 0.001 are marked with one, two, and three asterisks respectively)

Area	Index	MTG	U_{850}	OLR	Combination
BOB	MTG	1.000	0.957***	0.682**	0.779***
	U_{850}		1.000	0.666**	0.760***
	OLR			1.000	0.975***
	Combination				1.000
SCS	$\partial T/\partial y$	1.000	0.554*	0.499*	0.468*
	U_{850}		1.000	0.668**	0.720***
	OLR			1.000	0.993***
	Combination				1.000
IDO	$\partial T/\partial y$	1.000	0.318	0.615**	0.796***
	U_{850}		1.000	0.266	0.161
	OLR			1.000	0.920***
	Combination				1.000

V. CONCLUSIONS

(1) Seasonal transition and monsoon onset are closely related to the variations in the structure of the subtropical high. The monsoon onset is associated with the abrupt northward migration of local mid-upper tropospheric warm temperature ridge. During seasonal transition, the abrupt changes occur in thermal and dynamical structures of monsoon circulation. The reversals take place in some variable fields including wind, temperature, divergence, and deep convection. The MTG in the vicinity of the WEB between 200—500 hPa is the variable that varies most significantly.

(2) Since the thermal basis of seasonal transition is the reversal of the MTG near the WEB, such essential feature should be emphasized in defining for monsoon onset, and the other variables with abruptness are also considered. It is found that the reversal of the mid-upper tropospheric (200—500 hPa) MTG can reflect the collective essential feature for different areas in the Asian monsoon region. The results verify that the MTG between 200—500 hPa is applicable to measure the Asian monsoon onset.

(3) Based on the MTG index, the seasonal transition dates for individual years are identified quantitatively, the time series of transition dates and associated with monsoon onset dates for the period 1980—1998 are thus obtained. Over the BOB and SCS, the MTG between 200—500 hPa is well correlated with 850-hPa zonal wind, and the confidence levels have exceeded 0. 01 and 0. 05, respectively. But the correlation is weak over the IDO. Therefore, 850-hPa zonal wind is only a regional index.

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