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THE TIMING OF SOUTH-ASIAN HIGH ESTABLISHMENT AND ITS RELATION TO TROPICAL ASIAN SUMMER MONSOON AND PRECIPITATION OVER EAST-CENTRAL CHINA IN SUMMER

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Abstract: The timing of the South Asian High (SAH) establishment over the Indochina Peninsula (IP) from April to May and its relations to the setup of the subsequent tropical Asian summer monsoon and precipitation over eastern-central China in summer are investigated by using NCEP/NCAR daily reanalysis data, outgoing longwave radiation (OLR) data and the daily precipitation data from 753 weather stations in China. It is found that the transitions of the zonal wind vertical shear and convection establishment over tropical Asia are earlier (later) in the years of early (late) establishment of SAH. In the lower troposphere, anti-cyclonic (cyclonic) anomaly circulation dominates the equatorial Indian Ocean. Correspondingly, the tropical Asian summer monsoon establishes earlier (later). Furthermore, the atmospheric circulation and the water vapor transport in the years of advanced SAH establishment are significantly different from the delayed years in Asia in summer. Out-of-phase distribution of precipitation in eastern-central China will appear with a weak (strong) SAH and western Pacific subtropical high, strong (weak) ascending motion in the area south of Yangtze River but weak (strong) ascending motion in the area north of it, and cyclonic (anti-cyclonic) water vapor flux anomaly circulation from the eastern-central China to western Pacific. Accordingly, the timing of the SAH establishment at the upper levels of IP is indicative of the subsequent onset of the tropical Asian summer monsoon and the flood-drought pattern over eastern-central China in summer.

Key words: South-Asian High; Indochina Peninsula; tropical Asian summer monsoon; precipitation over eastern-central China in summer

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1 INTRODUCTION

Also known as the Tibetan Plateau (TP) High, the South Asian High (SAH) is the most powerful and most stable governing circulation system at the upper troposphere in Northern Hemisphere above the TP and its neighboring areas in summer (Mason and Anderson[1]). As an important member of the Asian summer monsoon system, the SAH is closely linked with the circulation systems in the Asian region and even the whole Northern Hemisphere as well as their weather and climate (Zhu et al.[2]; Zhu and He [3]; Luo et al.[4]). The east-west oscillation of its center, variation of its intensity and north-south shift of its ridge all have essential impact on the establishment and progression of the Asian summer monsoon and the distribution of droughts and floods in China as well as in Asia, highly indicative of any changes in the weather and climate (Zhang et al.[5]). As shown in studies concerned, the setup of a summer type of circulation above the TP is ahead of the seasonal variation of the atmospheric circulation in East Asia and the SAH varies with well-defined seasonal rhythms and is precedent enough to serve as a good predictor for the regional climate change (Zhu and Fan[6]; Zhang[7]). According to Ju [8], the location of the SAH center shifting past 15°N corresponds to the onset of the East Asian summer monsoon and that past 25°N is associated with the outbreak of the Indian summer monsoon. In Qian et al.[9], the pentad in which the SAH center passes 20°N is set as the onset time of the South China Sea summer monsoon (SCSSM) and the pentad in which it passes 25°N as the outbreak time of the Indian summer monsoon in the south of the country. Xu et al.[10] argued that the east-west shift of the SAH is well correlated with the intensity of the summer monsoon; when the SAH

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extends to the east, the summer monsoon becomes strong in East Asia and otherwise is true. As Yao and Qian [11] see it, the intensity of SCSSM is closely linked with the location of the SAH in the preceding December; when the SAH is more to the west in preceding time, the SCSSM gets stronger and otherwise it is true. It is now clear that the seasonal migration of the SAH center from winter to summer has close relationships with the setup of the Asian summer monsoon.

The activity of the SAH is also closely associated with large-scale droughts and floods in China. The ridge and central location of the SAH are not only well correlated with the start and end of Meiyu in the basin of Yangtze River (Zhang and Tao[12]; Liu et al.[13]), but also closely related with the beginning and ending of the annually first rainy season in South China, the North China rainy season and the rainfall amount of Northwest China (Chi et al.[14]; Qian et al.[15]). As shown in many studies, the east-west oscillation of the SAH affects the droughts and floods in the east of China; when the SAH is located more eastward, it is relatively wet in the Yangtze River basin but relatively dry in South China and otherwise is true (Luo et al.[4]; Tan et al.[16]; Hu et al.[17]). Huang and Qian [18] also found that the longitude at which the SAH center lies is closely connected with the precipitation in the summer of North China; when the SAH is located more westward in June, precipitation may increase during summer there. Its north-south oscillation is also closely associated with the wetness in the middle and lower reaches of the Yangtze River in China (Sha [19]); when it is more to the north, it will be less rain in these reaches of the river. Conducting model analysis, Wang and You [20] showed that a more southward located SAH is conducive to the appearance and persistence of the Meiyu in the basin of the Yangtze River. Afterwards, the morphology of the SAH during prime time of summer is classified in great detail by Qian et al. [15], who divided the SAH into the Tibetan High and the Iranian High, which are further associated with patterns of eastward and westward location, and discussed the relationships between different types of morphology and summer precipitation in China. On this basis, Zhang et al. [21] studied the links between the dual-mode structure of the SAH (the Tibetan High and the Iranian High) and climate anomalies in East Asia and pointed out that when the SAH shows the mode of Tibetan High, it rains more in the Bay of Bengal region, southern Tibetan Plateau (TP), South China Sea (SCS) and the basin of Yangtze River but less in India and Korean Peninsula; when the SAH shows the mode of Iranian High, the distribution of rainfall anomaly is just the opposite.

It is now clear that the existing research is mainly on the relationship between the timing of the SAH shifting northward to the TP in May-June and the onset of the Asian summer monsoon and that between the east-west oscillation of the SAH in June-August and the distribution of summertime droughts and floods in China, and work is relatively little on the relationships between the setup of the SAH in April-May, a key transitory season from spring to summer, and the seasonal change in successive atmospheric circulation in East Asia as well as the distribution of summertime droughts and floods in China. As shown in our previous study, there is significant interannual variation during the establishment of the SAH in April-May over the Indochina Peninsula (Wang and Guo[22]). Then, how is the timing of the SAH establishment over the peninsula during the key seasonal transition related with the successive setup of the Asian tropical monsoon in summer and the simultaneous precipitation in central and eastern China? This is what this study attempts to address.

2 DATA AND METHODOLOGY

2.1 *Selection of data*

The daily reanalysis from NCEP/NCAR (Kalnay et al. [23]) and outgoing longwave radiation (OLR) from NOAA, covering the time from 1979 to 2008 and with horizontal gridpoints at intervals of 2.5°×2.5°, are used in this work. Daily rainfall data from 1959 to 2008, compiled by the National Climate Center, China Meteorological Administration, are also used.

2.2 *Classification of establishment processes*

In this work, the establishment of the SAH over the Indochina Peninsula is classified following a method put forward by Wang and Guo[22], which depends on the timing of the western center of anticyclonic circulation generating over the peninsula: when the western center forms prior to Pentad 5 (in April), the SAH is defined to be in a year of early setup; when it forms after Pentad 5, the SAH is said to occur in a year of late setup; when it forms right in Pentad 5, the SAH is considered to appear in a year of normal setup. See Table 1 for detailed classification.

Table 1. Classification of the establishment of SAH over Indochina Peninsula.

Type	Year
Years of early setup	1984, 1985, 1986, 1990, 1991, 1994, 1996, 1999, 2001, 2002, 2006, 2008
Years of late setup	1983, 1987, 1992, 1993, 1997, 1998, 2003, 2005
Years of normal setup	1979, 1980, 1981, 1982, 1988, 1989, 1995, 2000, 2004, 2007

3 TIMING OF SAH SETUP IN ASSOCIATION WITH TROPICAL SUMMER MONSOON (TSM) IN ASIA

As shown in some studies, the onset of Asian tropical monsoons is closely correlated with the reversal of the direction of meridionally averaged temperature gradients and the vertical shear of the zonal wind in the middle and upper troposphere (He et al.[24]). Following the relation between the thermal wind and the temperature gradient, a monsoon is considered at onset when the vertical shear of the zonal wind changes from upper-level westerlies and lower-level easterlies to upper-level easterlies and lower-level westerlies (Wang and Ding [25]). Fig.1 shows the evolution of the vertical shear of the zonal wind (850 hPa minus 200 hPa) in the low latitudes of Asia (5°–20°N) for the years of early and late SAH setup in April-May. In the Asian tropics from the eastern Bay of Bengal to the SCS, the vertical shear of the zonal wind changes from negative to positive, i.e., upper-level westerlies and low-level easterlies changing to upper-level easterlies and low-level westerlies takes place the earliest in an early SAH onset year but the latest in a late SAH onset year. Specifically, the transformation of the vertical shear of the zonal wind starts at Pentad 3 of April in an early setup year (Fig. 1a), while it begins at Pentad 2 of May in a late setup year (Fig. 1b), in the region from eastern Bay of Bengal to Indochina Peninsula, with the time of transformation starting at Pentad 1 of May for the climatology and normal year (figure omitted). In the SCS region, however, the change from a negative vertical shear of the zonal wind to a positive vertical shear begins at Pentad 6 of April while it starts at Pentad 3 of May in a late year and Pentad 2 of May in the climatology and normal year (figure omitted).

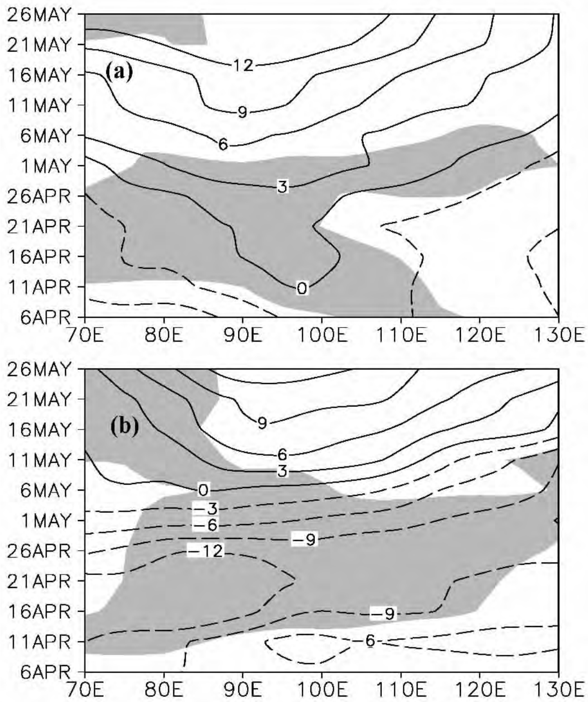

Figure 1. Time-longitude cross sections of the vertical shear of the zonal wind in Asian low latitudes (5°–20° N) in April-May (850 hPa minus 200 hPa, unit: m/s). The ordinate is for the time in the unit of pentad. (a): early SAH setup year; (b): late SAH setup year. The shades stand for the areas in which the t-test passes the 90% confidence level.

The change of direction in the zonal wind at both the upper and lower level of the troposphere is correlated with the state of the atmospheric thermodynamics while the atmospheric state of the Asian tropics is also subject to the regional convection. Fig.2 gives the evolution of OLR with time at 5°–20°N in both the years of early and late SAH setup. In the region from the eastern Bay of Bengal to Indochina Peninsula, the OLR is already less than 240 W/m^2 at Pentad 3 of April in the early year (Fig.2a), indicating that the regional convection becomes active now. In the late year (Fig.2b), however, the OLR is less than 240 W/m^2 as late as at Pentad 1 of May, a sign that shows a late beginning of convection. For the climatology and normal year, convection starts at Pentad 5 of April, generally consistent with the time when the center of an anti-cyclonic circulation forms over the Indochina Peninsula in both types of year[22]. In the year of early SAH setup, convection is also earlier in the SCS area than in the year of late SAH setup.

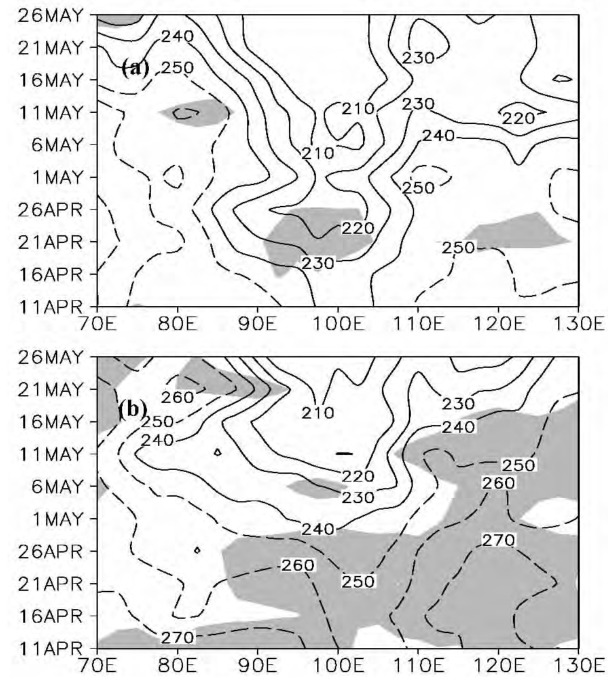

Figure 2. Time-longitude cross sections of OLR averaged at 5°–20°N in April-May. The solid curves encircle the areas where OLR<240 W/m^2. Other captions are the same as in Fig.1.

As far as the circulation pattern is concerned, the SAH at the upper troposphere moves to the north and west from above the waters over the east of Philippines islands to the Indochina Peninsula, the western Pacific subtropical high at the middle troposphere breaks off and withdraws to the east, the Bay of Bengal trough generates and a cross-equatorial flow develops over Somali at the lower troposphere. The enhancement and rapid eastward and northward expansion and propagation of the westerlies in the equatorial Indian Ocean are the large-scale characteristics of the establishment of tropical monsoons in Asia (He et al.[24]; Li and Qu[26]; Ding et al.[27]). The early (late) establishment of the SAH indicates the early (late) movement of the SAH to the west and north from waters east of the Philippines islands to Indochina Peninsula. At 500 hPa, the middle level of the troposphere (figure omitted), the break-off and the eastward retreat of the subtropical high in the western Pacific and the formation of a Bay of Bengal trough are also the earliest in the early year but the latest in the late year.

In the lower troposphere, however, the equatorial Indian Ocean is dominated by an anti-cyclonic anomalous circulation that enhances the development of the cross-equatorial flow in Somali and equatorial westerlies in the Indian Ocean, as shown in the 850-hPa anomalous flow field in April-May in the years of early SAH setup in Fig.3a. It then increases the westerly flow in the Bay of Bengal to southern SCS and is conducive to the establishment and eastward advancement of the TSM in Asia. After entering the southern SCS, the westerly anomaly flow joins with a northeasterly flow in the SCS area, which comes from northern China, to trigger a full setup of the regional convection (Wen et al.[28]). In the year of late SAH setup (Fig.3b), however, the equatorial Indian Ocean is dominated by cyclonic anomaly circulation that weakens the cross-equatorial flow in Somali and the equatorial Indian Ocean westerlies, unfavorable for the TSM to set up and move eastward.

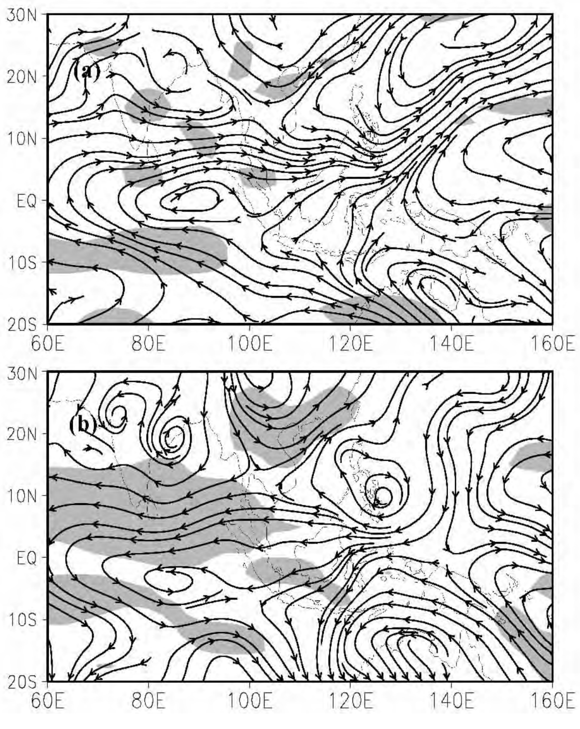

Figure 3. Anomalous flow field at 850 hPa in April-May. (a): year of early setup; (b): year of late setup. The shades have the meaning as in Fig. 1.

In summary, significant differences exist between the years of early and late SAH setup in the atmospheric thermodynamics and the seasonal change of the atmospheric circulation in tropical Asia, as well as the establishment of the TSM. The SAH sets up earlier than the TSM, which can be used as a precursory signal at the upper level to foresee the establishment of the TSM later. In the early (late) year of SAH setup, the TSM has an early (late) onset in Asia.

4 TIMING OF SAH ESTABLISHMENT IN ASSOCIATION WITH SUMMER PRECIPITATION IN CENTRAL AND EASTERN CHINA

Since the timing of SAH setup over Indochina Peninsula can be used as a precursory signal from the upper level to indicate with comfortable margin the successive establishment of summer monsoon in tropical Asia, then, how does this variation feature affect the distribution of rainfall in the summer of the central and eastern China? More study will be done in the text that follows.

Figure 4 gives the composite of rainfall difference between the early and late years of SAH in the summer (June to August) in China. In the years of early SAH setup (Fig.4a), the precipitation is negatively anomalous in most areas north of the Yangtze River and south of the Yellow River, especially in the eastern part of the Sichuan Basin where there is a zone of large negative anomalies. Meanwhile, the early year is accompanied with positive rainfall anomalies in the eastern Northeast China Plain, central and eastern Yunnan province and extensive area south of the Yangtze River—from Hunan province to coastal South China, with an area of large positive anomalies in South China. In the year of late SAH setup (Fig.4b), rainfall is negatively anomalous in the northern part of North China Plain, central and eastern Yunnan, Hunan and southern South China. At the same time, the rainfall is positively anomalous in northeastern Inner Mongolia Region, Northeast China Plain, the area north of the middle and upper reaches of the Yangtze River and Zhejiang province area south of the lower reach of the Yangtze River, with the area of large positive anomalies in Zhejiang and eastern Sichuan Basin.

Generally speaking, there is reversed-phase distribution of summer precipitation in central and eastern China in the early and late years of the SAH establishment. In the early year, precipitation is less in the areas north of the Yangtze River and south of the Yellow River but more in central and eastern Yunnan and extensive areas south of the Yangtze River from Hunan to coastal South China. In the late year, precipitation is less in central and eastern Yunnan, Hunan and southern South China but more in Zhejiang and areas north of the upper and middle reaches of the Yangtze River.

Figure 4. Differences between the June-August precipitation amount and the multi-year mean for summer

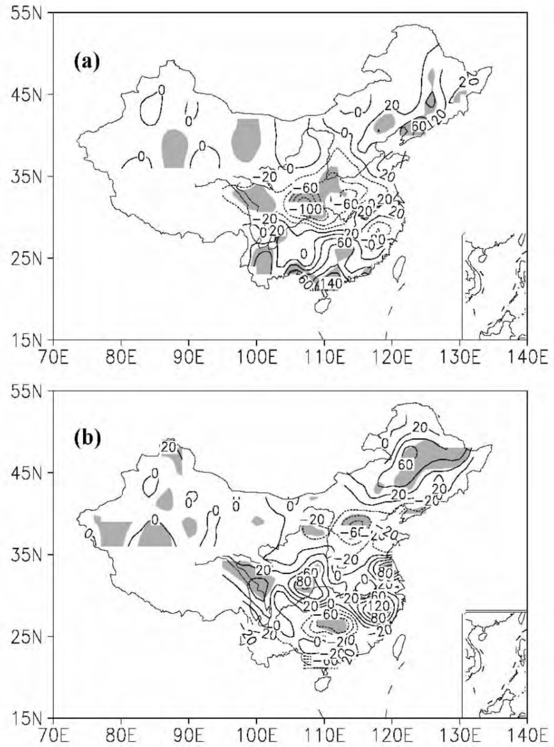

Figure 4. Differences between the June-August precipitation amount and the multi-year mean for summer in the early and late years of SAH setup. The solid (dashed) line stands for the area more (less) than 0 and the unit is mm. Other captions are the same as in Fig.3.

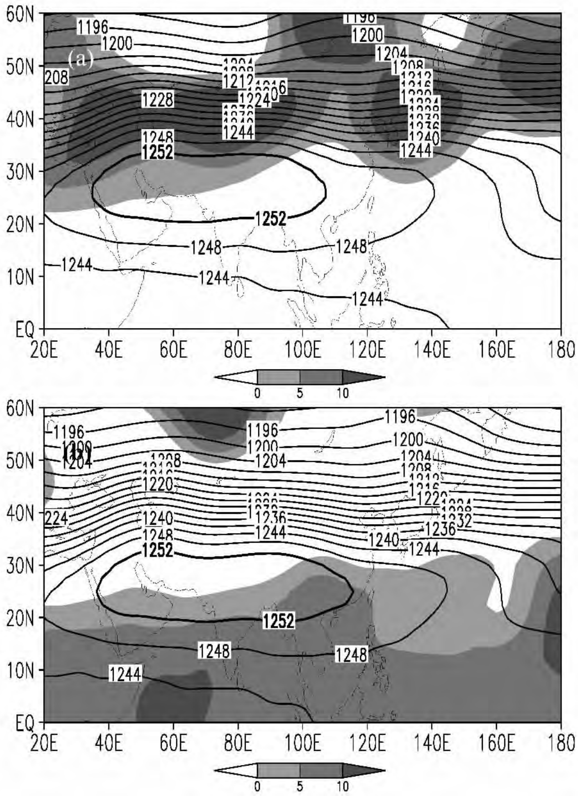

Figure 5. Distribution of geopotential height field (contours, units: dagpm) and geopotential height anomalies (shaded areas, units: gpm) at 200 hPa in June-August. (a): early years of SAH setup; (b): late years of SAH setup.

in the early and late years of SAH setup. The solid (dashed) line stands for the area more (less) than 0 and the unit is mm. Other captions are the same as in Fig.3.

Figure 5 gives the composite distribution of the 200-hPa geopotential height field for the early and late SAH setup years. In the early setup years (Fig.5a), the easternmost point of the ridge of the 1 252 dagpm characteristic contour is located near 110°E, which is westward than usual, and negative anomalous geopotential height is over the area south of 30°N in China, suggesting that the SAH is relatively weak there. In the late setup year (Fig.5b), this point has now moved to 120°E, which is eastward than usual, and positive anomalous geopotential height is over this area, indicating a stronger-than-usual SAH.

Figure 6 presents the anomalous distribution of the 500-hPa geopotential height field in the early and late years of SAH setup. In the early year (Fig.6a), the western Pacific south of 30°N is dominated by negatively anomalous geopotential height and the western Pacific subtropical high is broken-off and becomes small. At mid- and higher-latitudes, the area east of Ural Mountains and west of Lake Baikal is covered with significantly negative anomalies of the geopotential height while the area from Lake Baikal to Sea of Okhotsk is dominant with positive anomalies of geopotential height. The positions of such negative and positive centers of the anomaly wavetrain are generally consistent with the

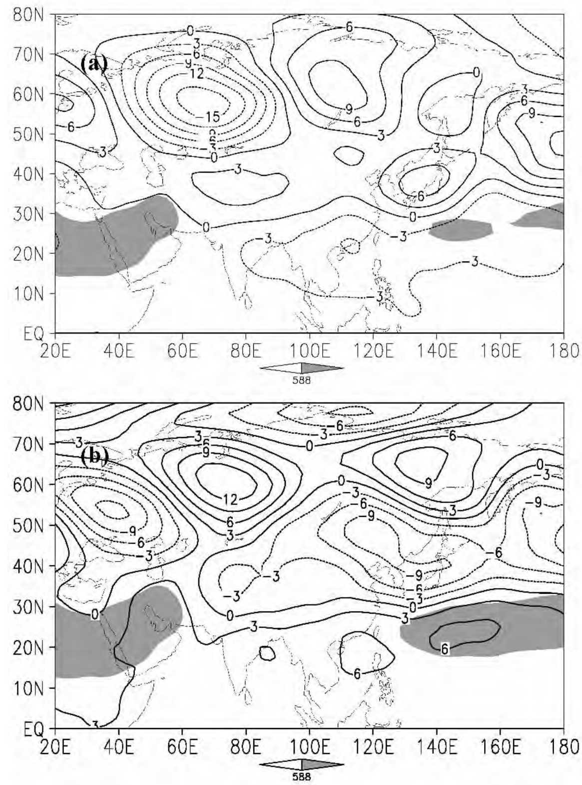

Figure 6. Anomalies of 500-hPa geopotential height (contours, units: gpm) and area enclosed by the 5 880 gpm (shading) in June-August. Other captions are the same as in Fig.5.

mean positions of troughs and ridges, strengthening the mean troughs and ridges to help the meridional circulation develop. As a result, the cold air from the north can reach farther south in the southern part of China to increase the precipitation in most of the area south of the Yangtze River. In the year of late SAH setup (Fig. 6b), the western Pacific south of 30°N is controlled by positive anomalies of the geopotential height and the westernmost point of the subtropical high ridge is around 125°E, westward than usual, with its size larger than in the early year. In the mid- and higher-latitudes, the positions of the positive and negative centers of the anomalous wavetrains are just the opposite of those of the mean troughs and ridges, weakening the mean troughs and ridges, making the mid- and higher-latitude circulation zonally oriented, and consequently making it less likely for the cold air to move southward to reduce precipitation in most of the area south of the Yangtze River (Li et al.[29]). It is seen from jointly examining Figs.5 and 6 that the SAH is either going with or away from the western Pacific subtropical high (Ren et al.[30]; Chen and Li[31]; Han et al.[32]).

It is shown in the longitude-geopotential height cross sections of the vertical velocity anomalies for the early and late years of SAH setup (Fig.7) that an area of positive anomalies of vertical velocity is at levels above 925 hPa in the early years (Fig.7a), suggesting that ascending motion is relatively strong and provides favorable dynamic conditions for the increase of rainfall, and an area of negative anomalies of vertical velocity is at levels above 850 hPa over the area in the late years (Fig.7b), indicative of relatively weak ascending motion that does not help in increasing the rainfall, over the area south of the Yangtze River. It is also known that in the early year (Fig.7c), an area of negative anomalies spreads over the entire region north of the Yangtze River and south of the Yellow River, weakening the ascending motion to make it unlikely for rainfall to increase, and in the late year (Fig.7d), an area of positive anomalies is dominant in 100°–110°E, which is consistent with the location of an area of large positive anomalies of rainfall in the eastern part of the Sichuan Basin, and an area of positive anomalies in 115°–120°E is also favorable for the increase of rainfall there.

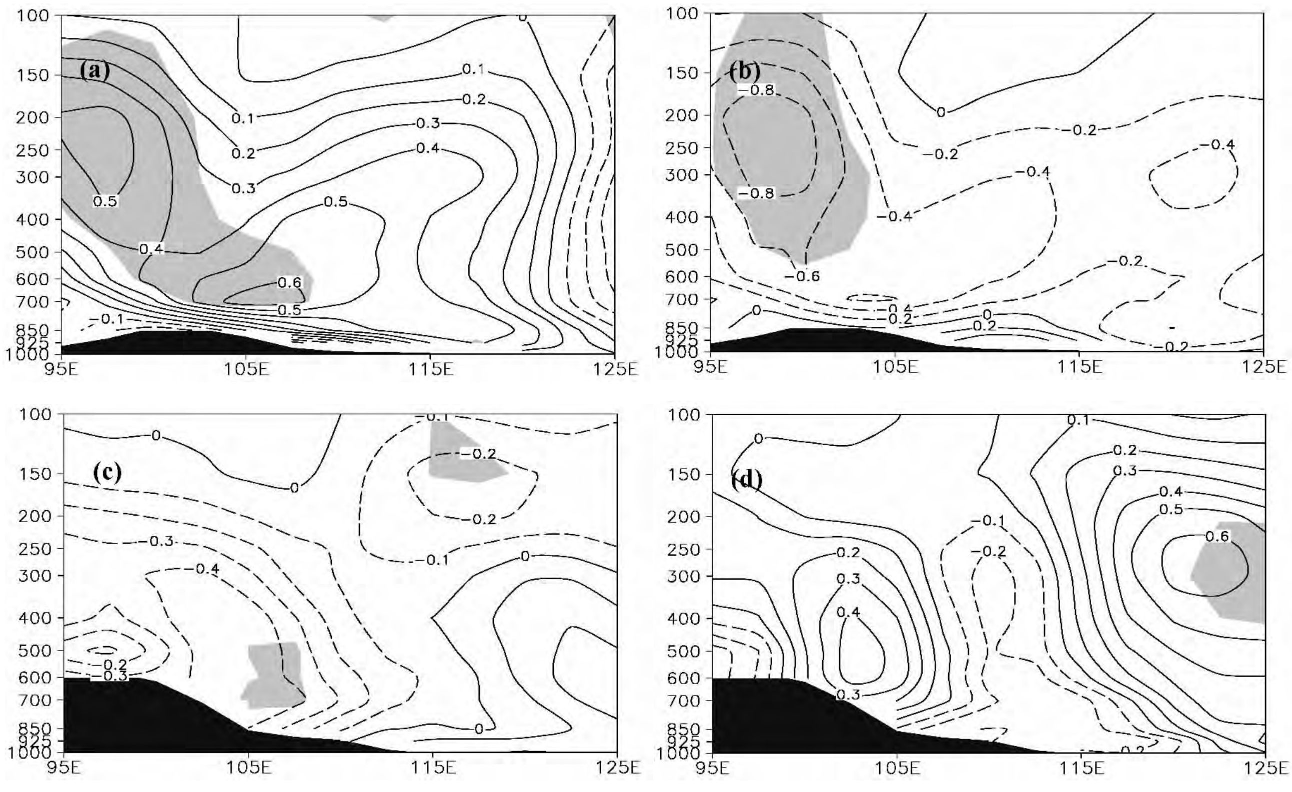

Figure 7. Mean longitude-geopotential height cross sections ($-\omega$ 10^{-2}, units: Pa/s) of vertical velocity anomalies on 22°–27°N (a, b) and 30°–35°N (c, d) for June-August in the early SAH setup (a, c) year and late SAH setup (b, d) year. Captions for the grey shades are the same as in Fig. 1 and the deep shades are the terrain.

The transport of water vapor is examined next. Fig. 8 gives the distribution of the anomaly and divergence of water vapor flux in the early and late SAH setup years. In the early year (Fig.8a), the area from the central and eastern part of China to the western Pacific is dominated by anomalous circulation of cyclonic water-vapor flux while the Bay of Bengal area is prevalent with the anomaly of westerly water-vapor flux that increases the transport of water vapor and causes it to converge in South China and northern SCS, increasing the rainfall there. It is consistent with the location of an area of large positive anomaly of rainfall in South China. By contrast, in most of the area north of the Yangtze River and south of the Yellow River, the transport of water vapor is divergent to reduce the rainfall.

In the late year (Fig.8b), the area from the central and eastern part of China to the western Pacific is dominated by anomalous circulation of anticyclonic water-vapor flux while the Bay of Bengal area is prevalent with the anomaly of easterly water-vapor flux that decreases the transport of water vapor and causes it to diverge in Hunan and southern South China, decreasing the rainfall there. By contrast, in the Sichuan Basin and the coastal area of the lower reach of the Yangtze River, the transport of water vapor is convergent, which is consistent with the location of an area of large positive anomaly of rainfall in Zhejiang and eastern Sichuan Basin.

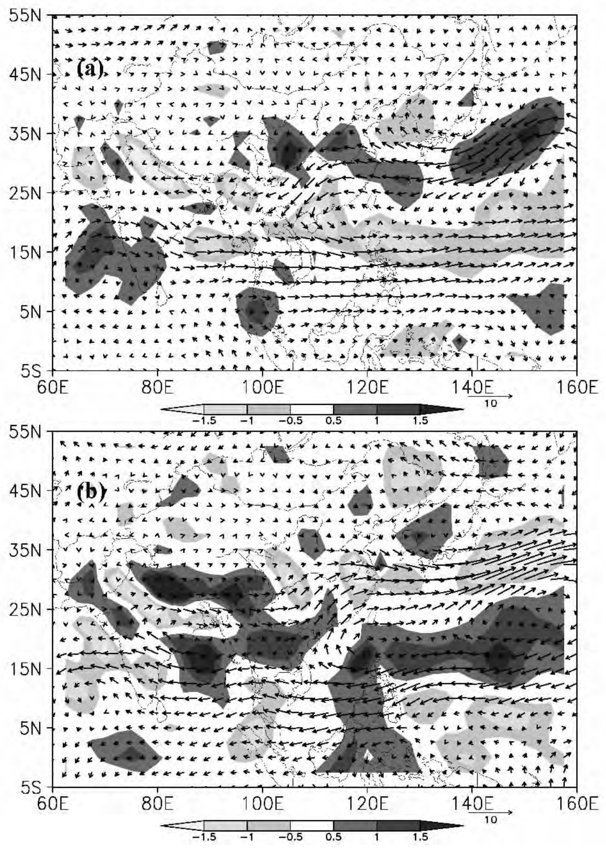

Figure 8. Anomalies of water vapor flux (units: g/(cm·hPa·s)) and water vapor divergence (shading, units: 10^{-6}g/(cm^2·hPa·s)) that are integrated throughout the whole column (to 300 hPa) for June-August. (a): early setup year; (b): late setup year.

It is apparent that obvious differences exist in the (generally reversed-phase) distribution of summer precipitation in the central and eastern part of China between the early and late years of SAH establishment. In the early year, negatively anomalous geopotential heights of the mid- and higher-troposphere are in the area south of 30°N in China, the upper-level SAH is relatively westward, the mid-level western Pacific subtropical high is broken off and relatively small in size. Besides, the circulation of the mid- and higher-latitudes is such that it facilitates the southward progression of the cold air. The ascending motion is strong in the area south of the Yangtze River but weak in the area north of it and south of the Yellow River. The transport of water vapor is convergent in South China and northern SCS but divergent in most of the area north of the Yangtze River and south of the Yellow River, resulting in less rain in the latter area but more rain in the central and eastern part of Yunnan and Hunan as well as the coastal area of South China. In the late year, however, positively anomalous geopotential heights of the mid- and higher-troposphere are in the area south of 30°N in China, the upper-level SAH is relatively eastward, the mid-level western Pacific subtropical high strengthens and extends westward. In addition, the circulation of the mid- and higher-latitudes is such that it is unfavorable for the cold air to travel southward. The ascending motion is weak in the area south of the Yangtze River but strong in the area north of it and south of the Yellow River. The transport of water vapor is divergent in Hunan and the coastal area of South China but convergent in the Sichuan Basin and the coastal area of the lower reach of the Yangtze River, resulting in less rain in the central and eastern part of Yunnan and Hunan as well as the southern part of South China but more rain in Zhejiang and the area north of the middle and upper reaches of the Yangtze River. Therefore, the early or late establishment of the SAH can also be used as a good upper-level precursory for indicating successive distribution of summer rainfall in the central and eastern part of China.

According to a successive study of this work (Guo [33]), the distribution is almost reversed-phase between the intensity of the Walker cell and the SST in the tropical Pacific in preceding winter and spring in the early and late years of SAH setup, suggesting that significant differences also exist in the air-sea interaction of tropical Asia between the early and late years of SAH setup, which may be one of the reasons for the reversed-phase distribution of precipitation in the subsequent summer rainfall in the central and eastern China.

5 CONCLUSIONS

(1) In the early (late) year of SAH establishment, the zonal wind of tropical Asia has an early (late) change in the direction of the vertical shear and early (late) onset of convection and the lower troposphere of the equatorial Indian Ocean has anticyclonic (cyclonic) anomalous circulation. The associated tropical monsoon also differs in the establishment of the tropical monsoon in Asia, which sets up early (late) in the early (late) year of SAH setup.

(2) During the summer (June-August), when the SAH sets up early (late), the SAH and western Pacific subtropical high are weak (strong), the mid- and higher-latitude circulation pattern is favorable (unfavorable)

for the cold air to move to the south, ascending motion is strong (weak) in the area south of the Yangtze River but weak (strong) in the area north of the Yangtze River and south of the Yellow River, and the area from the central and eastern China to the western Pacific is controlled by cyclonic (anti-cyclonic) anomalous circulation of water vapor, in that year. Consequently, much difference is found in the distribution, which is roughly reversed-phase, of summer precipitation in the central and eastern China. In the year of early SAH setup, rain is less in most of the area north of Yangtze River and south of the Yellow River but more in central and eastern Yunnan as well as the area south of the Yangtze River from Hunan to coastal South China. In the year of late SAH setup, rain is more in the central and eastern Yunnan, Hunan and the southern part of South China but more in Zhejiang and the area north of the middle and lower reaches of the Yangtze River.

It is known then that the April-May variations of the SAH, a planetary scale circulation itself, can be taken as a precursory signal at the upper level to indicate the establishment of successive summer monsoon in tropical Asia and the distribution of summer precipitation in the central and eastern part of China.

REFERENCES:

[1] MASON R B, ANDERSON C E. The development and decay of the 100mb summertime anticyclone over southern Asia [J]. Mon Wea Rev, 1958, 91(1): 3-12.

[2] ZHU Fu-kang, LU Long-hua, CHEN Xian-ji, et al. The South Asian High [M]. Beijing: Science Press, 1980 (in Chinese).

[3] ZHU Qian-gen, HE Jin-hai. On features of the upper circulation in the establishment of Asian monsoon in 1979 and its medium-range oscillation [J]. J Trop Meteorol, 1985, 1 (1): 9-18 (in Chinese).

[4] LUO Si-wei, QIAN Zheng-an, WANG Qian-qian. The climatic and synoptical study about the relation between the Qinghai-Xizang High Pressure on the 100mb surface and the flood and drought in East China in summer [J]. Plateau Meteorol, 1982, 1(2): 1-10 (in Chinese).

[5] ZHANG Qiong, QIAN Yong-fu, ZHANG Xue-hong. Interannual and interdecadal variations of the South Asia High [J]. Chin J Atmos Sci, 2000, 24(1): 67-78 (in Chinese).

[6] ZHU Fu-kang, FAN Yun. The features of the diabatic heating and the kinetic energy budget over the Qinghai-Xizhang Plateau during the early summer 1979 [J]. Acta Meteorol Sinica, 1987, 45(2): 219-228 (in Chinese).

[7] ZHANG Qiong. Evolution patterns, mechanisms of the South Asian High and its impact on regional climate [D]. Nanjing: Nanjing University, 1999: 149 (in Chinese).

[8] JU Jian-hua. Simulation of the precipitation during Yunnan rainy season with the UGAMP GCM [J]. J Yunnan Univ, 1994, 16 (Suppl): 53-57 (in Chinese).

[9] QIAN Yong-fu, JIANG Jing, ZHANG Yan, et al. The earliest onset area of the tropical Asian summer monsoon and its mechanisms [J]. Acta Meteorol Sinica, 2004, 62 (2): 129-139 (in Chinese).

[10] XU Xiang-de, YIN Shu-xin, SHEN Jian-guo, et al. Numerical experiments of the correlation between drought-flood in East China and East Asian zonal stationary waves [J]. J Nanjing Inst Meteorol, 1992, 15 (2): 12-20 (in Chinese).

[11] YAO Yong-hong, QIAN Yong-fu. The relationship of the South China Sea monsoon with the South Asia High and its characteristics of seasonal or interannual variations [J]. Adv Atmos Sci, 2003, 17 (Suppl. 1): 57-70.

[12] ZHANG Qing-yun, TAO Shi-yan. The anomalous subtropical anticyclone in western Pacific and their association with circulation over East Asia during summer [J]. Chin J Atmos Sci, 2003, 27(3): 369-380 (in Chinese).

[13] LIU Mei, PEI Hai-ying,YU Jian-wei, et al. On the relationship between 100-hPa South Asia High and Mei-yu in Jiangsu province [J]. J Trop Meteorol, 2011, 17(3): 302-309.

[14] CHI Yan-zhen, HE Jin-hai, WU Zhi-wei. Features analysis of the different precipitation periods in the pre-flood season in South China [J]. J Nanjing Inst Meteorol, 2005, 28(2): 163-171 (in Chinese).

[15] QIAN Yong-fu, ZHANG Qiong, ZHANG Xue-hong. The South Asian High and its effects on China's mid-summer climate abnormality [J]. J Nanjing Univ (Nat Sci), 2002, 38(3): 295-307 (in Chinese).

[16] TAN Jing, YANG Hui, SUN Shu-qing, et al. Characteristics of the longitudinal oscillation of South Asia High during summer [J]. J Nanjing Inst Meteorol, 2005, 28(4): 452-460 (in Chinese).

[17] HU Jing-gao, TAO Li, ZHOU Bing. Characteristic of South Asia High activity and its relation with the precipitation of East China in summer [J]. Plateau Meteorol, 2010, 29(1): 128-136 (in Chinese).

[18] HUANG Ying, QIAN Yong-fu. Relationships between South Asian High and summer rainfall in North China [J]. Plateau Meteorol, 2003, 22(6): 602-607 (in Chinese).

[19] SHA Wen-yu. Circulation feature of 100mb in Northern Hemisphere and its spectral analysis during a transitional period of anomalous Meiyu season [J]. J Nanjing Univ (Nat Sci Edit), 1985, 21(2): 394-404 (in Chinese).

[20] WANG An-yu, YOU Li-yu. A study of the effects of the anomalies of the subtropical high in the western Pacific region on the floods in the middle and lower reaches of the Yangtze River [J]. Acta Sci Nat Univ Sunyatseni, 1993, 32(2): 68-74 (in Chinese).

[21] ZHANG Qiong, WU Guo-xiong, QIAN Yong-fu. The bimodality of the 100hPa South Asia High and its relationship to the climate anomaly over East Asia in summer [J]. J Meteorol Soc Japan, 2002, 80(4): 733-744.

[22] WANG Li-juan, GUO Shuai-hong. Interannual variability of the South-Asian high establishment over the Indo-china Peninsula from April to May and its relation to southern Asian summer monsoon [J]. Trans Atmos Sci, 2012, 35(1): 10-23 (in Chinese).

[23] KALNAY E, KANAMITSU M, KISTLER R, et al. The NCEP/NCAR 40-year reanalysis project [J]. Bull Amer Meteorol Soc, 1996, 77(3): 437-470.

[24] HE Jin-hai, XU Hai-ming, ZHOU Bing, et al. Large scale features of SCS summer monsoon onset and its possible mechanism [J]. Clim Environ Res, 2000, 5 (4): 333-344 (in Chinese).

[25] WANG Qi, DING Yi-hui. Climatological aspects of evolution of summer monsoon over the northern South Chi-

na Sea [J]. Acta Meteorol Sinica, 1997, 55 (4): 466-483 (in Chinese).

[26] LI Chong-yin, QU Xin. Large scale atmospheric circulation evolutions associated with summer monsoon onset in the South China Sea [J]. Chin J Atmos Sci, 2000, 24(1): 1-14 (in Chinese).

[27] DING Yi-hui, LI Chong-yin, HE Jin-hai, et al. South China Sea monsoon experiment (SCSMEX) and the East-Asian monsoon [J]. Acta Meteorol Sinica, 2004, 62 (5): 561-586 (in Chinese).

[28] WEN Min, HE Jin-hai, XIAO Zi-niu. Impact of the convection over the Indo-china Peninsula on the onset of SCS summer monsoon [J]. Chin J Atmos Sci, 2004, 28 (6): 864-875 (in Chinese).

[29] LI Yan, WANG Ya-fei, WEI Dong. Effects of anomalous SST in tropical Indian Ocean and Pacific Ocean on next June rainfall over the Yangtze River basin and area south of the basin [J]. Acta Meteorol Sinica, 2007, 65 (3): 393-405 (in Chinese).

[30] REN Rong-cai, LIU Yi-min, WU Guo-xiong. Impact of South Asia High on the short-term variation of the subtropical anticyclone over western Pacific in July 1998 [J]. Acta Meteorol Sinica, 2007, 65(2): 183-197 (in Chinese).

[31] CHEN Yong-ren, LI Yue-qing. The variations of polar vortex and South Asia High and characters of northern atmosphere circulations at 100 hPa [J]. J Trop Meteorol, 2008, 24(5): 519-526 (in Chinese).

[32] HAN Jie, GUAN Zhao-yong, LI Ming-gang. Comparisons of circulation anomalies between the daily precipitation extreme and non-extreme events in the middle and lower reaches of Yangtze River in boreal summer [J]. J Trop Meteorol, 2015, 21(2): 131-142.

[33] GUO Shuai-hong. Interannual variability of the South-Asian High establishment over the Indo-China Peninsula from April to May: Data analysis and numerical simulation [D]. Nanjing: Nanjing University of Information of Science and Technology, 2012 (in Chinese).

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