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ON THE RELATIONSHIP BETWEEN 100-hPa SOUTH ASIA HIGH AND MEI-YU IN JIANGSU PROVINCE

LIU Mei (刘　梅)[1], PEI Hai-ying (裴海瑛)[2], YU Jian-wei (俞剑蔚)[1], HU Luo-lin (胡洛林)[1]

(1. Jiangsu Meteorological Observatory, Nanjing 210008 China; 2. Nanjing Meteorological Bureau, Nanjing 210008 China)

Abstract: By analyzing the change of an index for the characteristics of South Asia High and variations of upper-air troughs in 2002–2005, we studied the impact of South Asia high on the beginning and ending of the Mei-yu (i.e. sustained rain corresponding to the ripening season of plum) in Jiangsu province. Statistic verification is conducted on the relationships between the index and the Mei-yu season in 1991–2005 to examine the impacts of the SAH characteristics index on a rain intensity index of Mei-yu and regional distribution of a characteristics index for different annual patterns of Mei-yu. Historical composite is performed of the 100-hPa circulation field for these patterns using the 100-hPa geopotential height of Northern Hemisphere from 2002 to 2005 and 45-year NCEP reanalysis to study the difference in the circulation for different patterns of Mei-yu. Diagnostic and statistic conclusions, which share much in common, have been obtained as follows. (1) The characteristics preceding to and the advancement/retreat of SAH and the movement of westerly troughs are the factors that influence the onset time of the Mei-yu season; after the Mei-yu onset, the progression/withdrawal of SAH and how farther east it extends are determining how long the Mei-yu lasts and when it ends. (2) During the Mei-yu, the general 100-hPa circulation situation and average characteristics of the SAH are well corresponding to the characteristics of the season and annual patterns of Mei-yu. In addition, the averages of the SAH ridgeline and east-extending index for June, July and the Mei-yu season have some implications to the forecast of the index of Mei-yu intensity. These conclusions can be served as powerful means in determining the starting/ending dates, duration and annual pattern of the Mei-yu season.

Key words: South Asia High; characteristics index; Mei-yu in Jiangsu province

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1 INTRODUCTION

The Mei-yu, a sustained rain during the ripening season of plum, is a climatic phenomenon in the middle and lower reaches of the Yangtze River. The beginning of the Mei-yu in East Asia is related to the seasonal change of the atmospheric circulation, as pointed out by Tao[1] in the 1950s. Since then, much work has been done in this field to examine the effect of changes in upper- and lower-level circulation patterns on the Mei-yu. With conclusions of important indication, in-depth studies on the relationships between the South Asia High (SAH) and precipitation in flood seasons have been conducted from a number of viewpoints, in order to investigate into the variation of SAH, its interactions with other circulation systems, and its impacts on precipitation in different locations as well as the relationships between its long-term oscillation and drought/floods in China[2-5]. As shown in the studies, the SAH—possessing significant interannual and interdecadal variations—can be used as a clear signal of climatic anomalies[5], especially over China. When the center of SAH stays in one mode of circulation, sustained precipitation anomalies usually occur in the summer precipitation of China. In view of the complicated and changeable processes of Mei-yu over Jiangsu in the past few years, this study attempts to work more intensively on the relationships between the SAH and Mei-yu in the province. The effect of the SAH on precipitation was studied with a numerical experiment on a particular process[6] or from a macroscopic point of view[4, 5, 7]. We discuss the relationships between the variation of the Jiangsu Mei-yu and SAH in the past few years, perform statistic analysis with historical data, and examine the workability of using the SAH in forecasting the Mei-yu and relevant indexes for analysis. As upper-level circulation systems are relatively stable,

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Biography: LIU Mei, engineer, M.S., primarily undertaking short-term forecasting and relevant research.
Corresponding author: LIU Mei, e-mail: lmkerry@163.com

sustainable and preceding, research in this aspect will help forecast the Mei-yu.

2 DATA

This study mainly uses the 100-hPa geopotential height of Northern Hemisphere from 2002 to 2005, 45-year National Centers for Environmental Protection (NCEP, USA) reanalysis, data concerning the characteristics of the beginning and ending of Mei-yu in Jiangsu and the precipitation of this raining season.

3 CHARACTERISTICS OF MEI-YU IN JIANGSU AND ANNUAL PATTERNS OF THE RAIN

Generally, documentations about the Mei-yu characteristics include the duration and rainfall. To conduct a comprehensive comparison, this work introduces an index of Mei-yu intensity to categorize the annual patterns of Mei-yu quantitatively. Then, relationships between this quantity and an index of SAH—quantitatively expressed, are studied so as to analyze the links between SAH and the Mei-yu intensity. The index of Mei-yu intensity used in this study—computed with the following formula[8], takes into account the length of Mei-yu and total rainfall, rain rates by region and climatologically averaged state of the characteristics depicting the Mei-yu.

$$M = \frac{L}{\overline{L}} + \frac{1}{2}\frac{\sum R/L}{\sum \overline{R}/\overline{L}} + \frac{\sum R}{\sum \overline{R}}$$

where M is the index of Mei-yu intensity, L the number of days experiencing Mei-yu, $\overline{L}$ the average length of historical Mei-yu, $\sum R$ the average of the total rainfall of Mei-yu in the current years for the four observation stations in Nanjing, Suzhou, Nantong and Huiyin, and $\sum \overline{R}$ the multi-year average of total rainfall of Mei-yu for the four stations in which $\overline{R}$ takes 223 mm. Based on computational results of M over the past 50 years, the Mei-yu intensity is classified as rainy, less rainy, normal, flood, and drought when $M \geq 3.1$, $M \leq 2.0$, $2.0 < M < 3.1$, $M \geq 3.5$, and $M \leq 1.5$, respectively. These criteria are used to categorize the 50 years into different annual patterns of Mei-yu. Following these criteria, droughts occurred in 1959, 1960, 1961, 1964, 1978, 1988, 1992, 1994, and 2005; flood took place in 1954, 1970, 1975, 1980, 1982, 1983, 1986, 1987, 1991, 1996, 1999, and 2003. With the date on which the Mei-yu starts is the only factor to be considered, a summary of Mei-yu situations in the province in 2002–2005 is established (Table 1), together with the input of a statistic study of the starting and ending dates of Mei-yu[9]. According to the table, 2002 is the year in the category of normal rainfall though with a below-normal intensity index. In 2003, concentrated, heavy and sustained rain was recorded which comfirms a typical high Mei-yu year. In 2004, rain centered over the area on the banks of Yangtze River while rainfall was mildly more than normal in the south of the Huaihe River basin. It is a normal Mei-yu year according to the index. Along with 1978, 2005 was one of the two years in the history of meteorological documentation that marked with the shortest Mei-yu season, which was characterized by a late beginning, short duration and light rainfall, a typical less rainy Mei-yu year with a very small M value. It is therefore evident that year-to-year differences can be considerably large so that typical rainy Mei-yu years go with typical less rainy ones, a fact supported by both multi-year historical measurements and recent records in 2002-2005. The occurrence of typical annual patterns of Mei-yu may be related to, inherently, patterns of the atmospheric circulation, climatic conditions, evolution laws of weather systems, and oceanic phenomena over the preceding periods of time. With the variations of SAH at upper levels, this work diagnoses the intrinsic behavioral patterns of Mei-yu and SAH over the past few years, and analyzes the situations associated with historical rainy and less rainy Mei-yu years.

Table 1. Statitistics of Mei-yu in Jiangsu from 2002 to 2005.

Year	Beginning date	Ending date	Duration (days)	Rainfall	Days of heavy rain	Annual pattern	Index of Mei-yu intensity
2002	Jun. 19	Jul. 8	19	Less	7	Low Mei-yu	1.8
2003	Jun. 21	Jul. 12	22	More	13	High Mei-yu	3.5
2004	Jun. 14	Jul. 16	33	More	13	Normal Mei-yu	2.8
2005	Jun. 25	Jun. 29	5	less	5	Low Mei-yu	0.6

4 EFFECTS OF SOUTH ASIA HIGH ON THE BEGINNING AND ENDING DATES OF MEI-YU IN JIANGSU

In this paper, the SAH is mainly depicted through its characteristics index comprising the ridgeline of SAH and east-extending index. The former is used to indicate the latitude at which the east-west axis passing the center of SAH intersects with longitudes 110–120° E while the latter to stand for the longitude on which the easternmost point of the 16760 geopotential meter (gpm) contour touches at 100 hPa (If the SAH is too strong to result in the absence of the 16760-gpm contour, the index of east-extending will be indicated with the longitude on which the easternmost point of the 16800 gpm contour touches at 100 hPa; such replacement happens with the case of 2002). Figs. 1 and 2 give the variation of the SAH characteristics index and the position of an upper-level trough (whose 100-hPa tip reaches the area at 40° N and more southward) in 2002–2005, respectively. Prior to the Mei-yu season, the ridgeline of SAH has been at lower latitudes while advancing northward without crossing 30° N. Of the four years of interest, three witness the start of Mei-yu in the province when the SAH ridgeline reaches 30° N. The east-extending index tends to vary consistently with the ridgeline; when the latter moves north, the index moves east and stays largely west of 120° E prior to the onset of Mei-yu. In addition, the ridgeline and the index also differ much on the interannual basis. In the early Mei-yu year (2004), the overall position of SAH was more southward and westward than normal while the ridegline had significant north-south shifts of position and the index had substantial east-west swings. In comparison, the upper-level trough is more to the west prior to Mei-yu, between 70° –100° E. As it begins to move eastward, however, it signals the beginning of SAH moving both north and east and resulting in Mei-yu in Jiangsu. In the late Mei-yu year (2005), both the east-extending index and ridgeline showed conditions that were completely different from that of the early Mei-yu year. Prior to the raining season, the SAH remained stable and intense for extended time with the bulk significantly more eastward, and the index maintained for a long time east of 110° E without remarkable eastward shift of the upper-level trough or significant northward/eastward progression of SAH. All of these are responsible for the late onset of Mei-yu in 2005. In the normal Mei-yu years (2002 and 2003), both the index and ridgeline are stable, moving northward and eastward while the upper-level trough was evolving steadily from west to east. Such regular variations are conducive to a normal onset of Mei-yu in Jiangsu. As shown in the analysis above, the variation of SAH has some effect on the timing of Mei-yu. As for the years of interest, the dates of the Mei-yu onset were quite normal, around June 20th, as the upper-level trough was located east of 100° E and the bulk of SAH was in steady progression toward the north and east. If the bulk of SAH stays more to the north and east than the average position without much change while the upper-level trough experiences no significant eastward advancement, Jiangsu may have a relatively late start of Mei-yu. If the upper-level trough develops in a westward position but substantial changes take place in the east-extending index and ridgeline, the Mei-yu may begin on an earlier date.

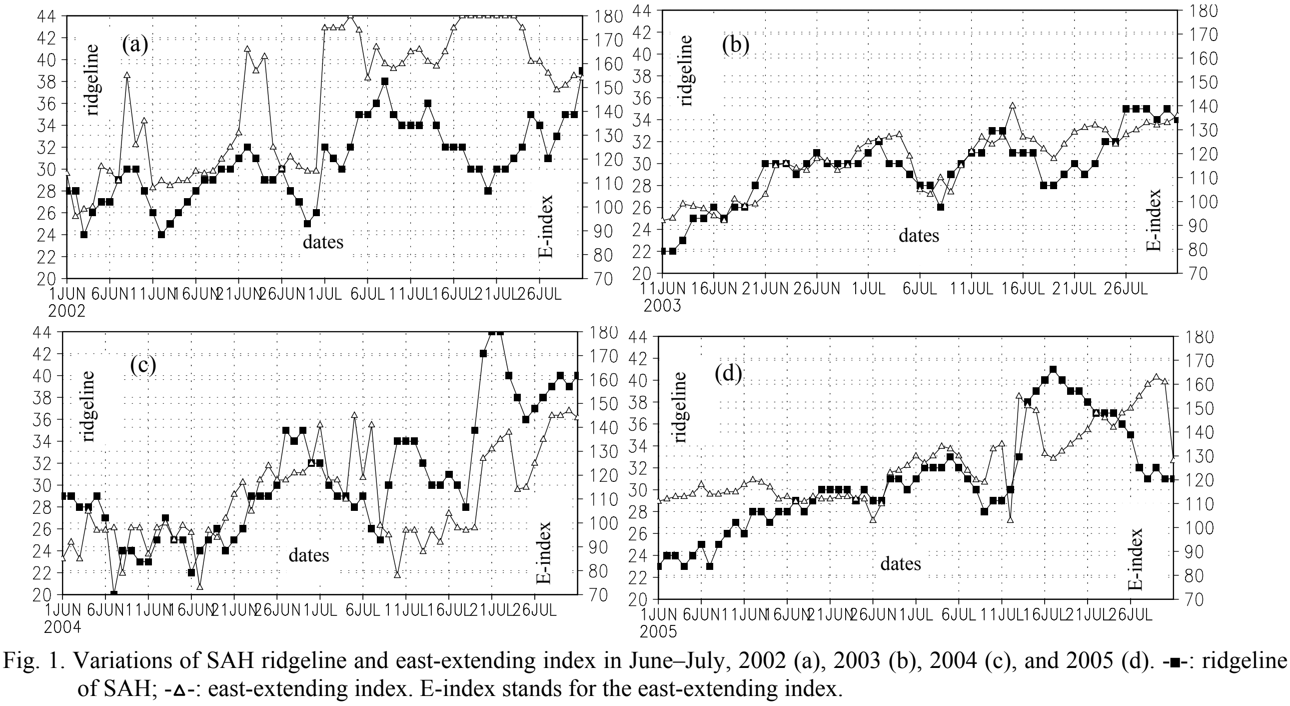

Fig. 1. Variations of SAH ridgeline and east-extending index in June–July, 2002 (a), 2003 (b), 2004 (c), and 2005 (d). -■-: ridgeline of SAH; -▵-: east-extending index. E-index stands for the east-extending index.

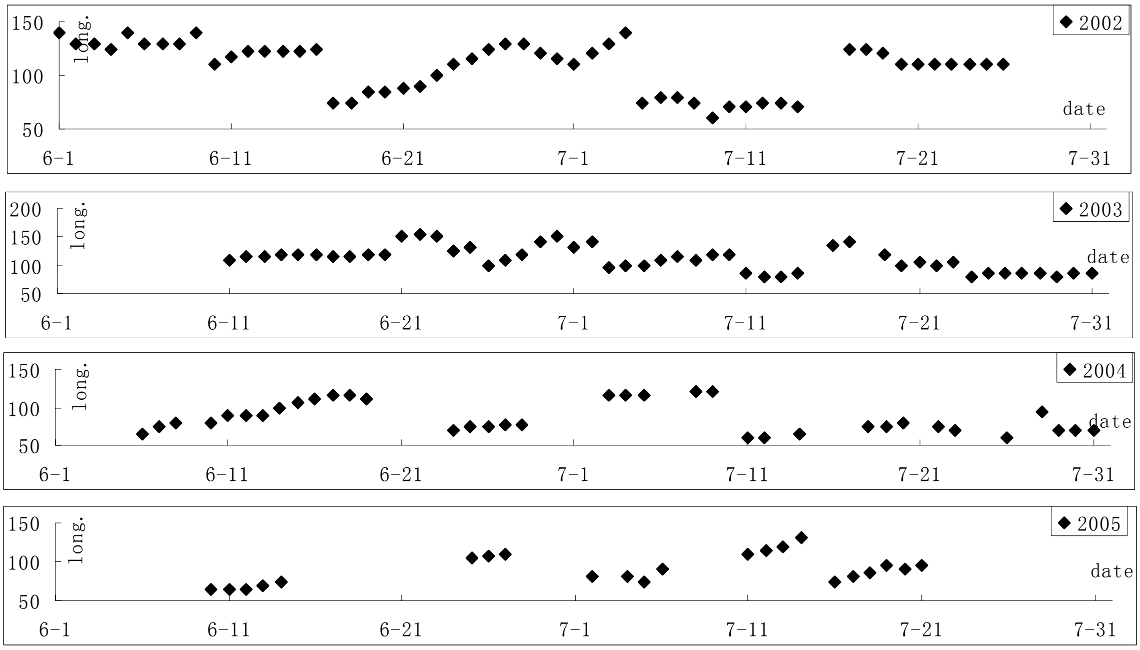

Fig. 2. Variations of the 100-hPa position of the upper-level trough in June and July, 2002–2005.

After the onset of the Jiangsu Mei-yu season in 2002–2005, both the index and ridgeline position experienced some degrees of east-west and north-south shifts in consistent fluctuation; the northward advancement of SAH is accompanied by eastward extension while its southward withdrawal is associated with westward retreat. The position of the upper-level trough also follows some kind of regular patterns. With the eastward shift of the trough, the SAH keeps intensifying until the former arrives at a particular point when the latter becomes weak. The SAH does not move north or east again unless it is subject to another upper-level trough moving eastward, indicating how large the effect of the east-moving upper-level trough is on the SAH. It is during the ongoing movement of the SAH and the trough that is causing the variation of systems at middle- and lower-levels, north-south swings of the continuous precipitation and rain area during the Mei-yu.

Differences exist between the less rainy and rainy Mei-yu year, as shown in examinations of the different annual patterns of Mei-yu and their corresponding characteristics index and upper-level trough positions in 2002–2005. In the years of rainy Mei-yu, the ridgeline of SAH and east-extending index vary considerably, with the ridgeline, east-extending index, and upper-level trough position swinging between 25–35° N, 80–140° E, and 90–130° E, respectively, forming an allocation of positions that is conducive to the meeting of cold and warm air over the area of Jiangsu that results in rain. In the years of less rainy Mei-yu (e.g., 2002), however, the ridgeline is at higher latitudes and the index is usually large (between 120–180° E). The upper-level trough also moves east but with its base located more to the north, being unable of channeling cold air to the area of Jiangsu to bring less rain during the 2002 Mei-yu. The remarkably short duration of Mei-yu in 2005 was caused by an unusually strong SAH that ended the rain much sooner. Interannually, the SAH varies greatly in its characteristics at the time of Mei-yu ending, which is usually marked with a strengthened SAH and a westward located upper-level trough. Because of the eastward advancement of SAH, the subtropical high pressure is now progressing westward while intensifying so that Jiangsu is completely in the control of the high, being free of any impacts from warm, humid air or cold air. Mei-yu thus comes to a halt and is replaced by a span of high temperature in the province.

The variation of SAH characteristics has interesting relationships with the length of corresponding Mei-yu seasons. When SAH varies at normal cycles, the Mei-yu starts and ends on the average dates; when it advances and retreats more frequently, i.e., at shorter cycles, the Mei-yu lasts longer; when it keeps stable and strong and undergoes little change, the Mei-yu starts late and for shorter duration.

Following a concrete, diagnostic analysis of the cases of 2002–2005 and taking into account the representation of conclusions, this study compares and analyzes diurnal characteristics of SAH and Mei-yu in Jiangsu for June and July in a period of 15 years (1991–2005, e.g. Fig. 3). At 100 hPa, the ridgeline and index gradually begin to move northward and eastward in June and July. Of these 15 years, three out of the four years of early Mei-yu (1991, 1996, 1999 and 2004) were marked with a southward position of the ridgeline in early June (south of 22° N) followed by a sudden northward shift, while the remaining year (1999) was with a northward location of the ridgeline in early June (28° N). For the early Mei-yu years, the east-extending index is also much eastward. For the late years of Mei-yu (1992, 1997 and 2005), however, the ridgeline of SAH corresponding to the early period of Mei-yu is usually southward and stays stable for a long time, while the index maintains an eastward position, usually east of 110° E. The normal years of Mei-yu are usually accompanied with the ridgeline gradually progressing northward prior to mid-June and reaching around 28° N on June 15th–25th. The east-extending index does not have regular patterns of variation and is therefore a poor indicator.

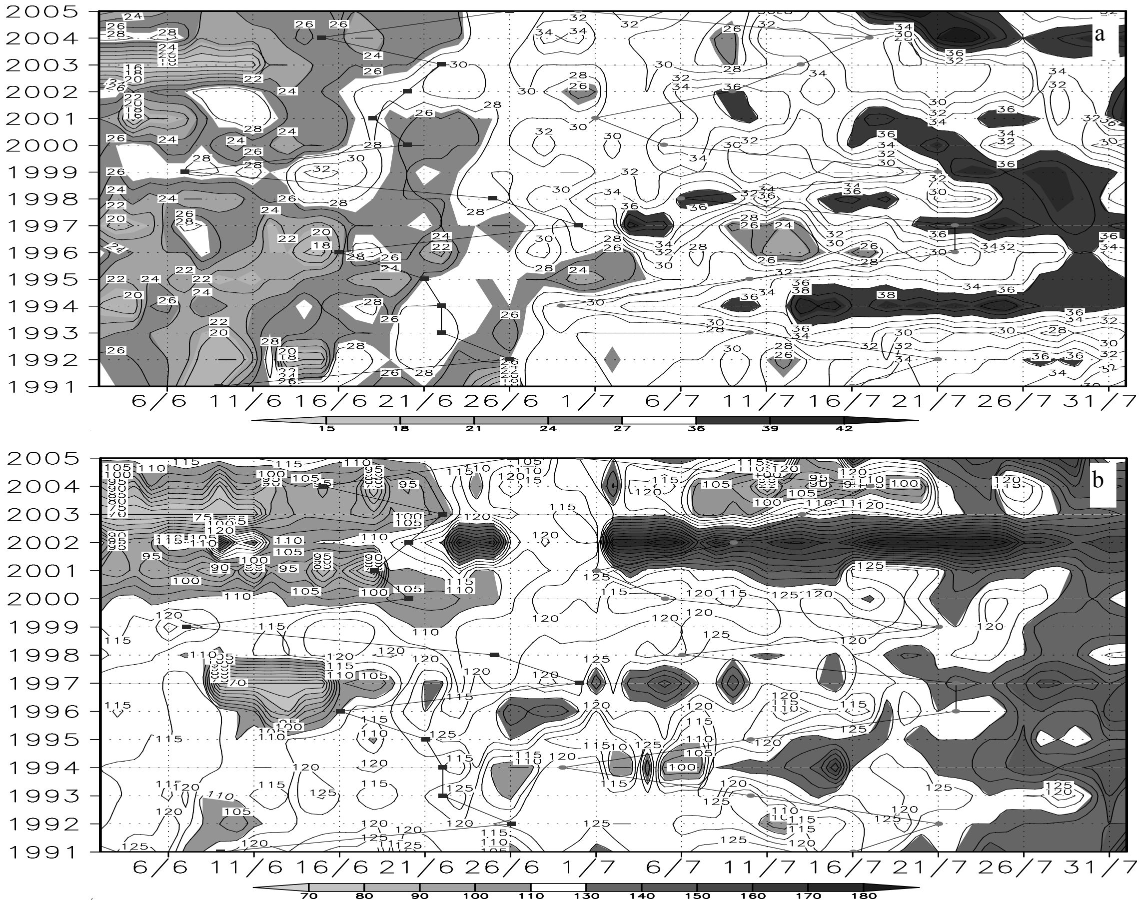

Fig. 3. Distribution of the characteristics index of SAH and the dates of the Mei-yu start and ending in June and July, 1991–2005 (a: SAH ridgeline; b; east-extending index).

In the years of early Mei-yu ending (1994, 2000, 2001 and 2005), the SAH's northward and eastward advancement was early and significant; usually, the ridgeline was at 32° N and the index was east of 120° E rather quickly. In the years of late Mei-yu ending (1992, 1996, 1997, 1999 and 2004), however, the SAH maintained a relatively long period of north-south and east-west zigzags during the Mei-yu until both the ridgeline and index settled in areas north of 32° N and east of 120° E, leading Jiangsu out of the raining season into spans of high-temperature weather. In the years of normal Mei-yu, both the ridgeline and index are, after the onset of Mei-yu, stable and free from frequent shifts in position. The former moves to 32° N and the latter to areas east of 120° E, in the usual case, till the raining season ends. From a tendency of variation over the past 15 years, it is observed that if the Mei-yu starts early, it ends on a relatively late, instead of early, date; if it starts on a late or normal date, it ends either early or late.

According to diagnostic analysis of the Mei-yu in the years of interest, and historical statistics of multiple years, its starting dates and duration are linked to the 100-hPa SAH high and westerly troughs, and the preceding features of SAH and its advancement/retreat and the westerly troughs affect the timing of the Mei-yu onset. After the onset, however, the frequency of the SAH advancement/retreat and the degree of its northward and eastward extension in turn affect the length and ending dates of Mei-yu. It is therefore important for the upper-level situation to be correctly predicted in order to have good forecast of the starting and ending dates of Mei-yu.

5 100-hPa CIRCULATION DURING MEI-YU

AND ITS ANNUAL PATTERNS

To investigate the relationships between the 100-hPa SAH and the whole background of circulation with the rainfall during the Mei-yu in Jiangsu, we seek averaging of the 100-hPa geopotential height field during Mei-yu in 2002–2005 with the results presented in Fig. 4. For different annual patterns of Mei-yu, the SAH at the level of 100 hPa and the general situation of circulation vary significantly. For example, differences are large in the average 100-hPa geopotential height field between the late and short Mei-yu season (2005) and that of 2002, 2003, and 2004. This field is an extensive area of troughs in the middle and higher latitudes without obvious alternation of troughs and ridges. It puts the province in the control of a weak high-pressure ridge, keeping the cold air from reaching it. In the years with normal Mei-yu start and ending (2002, 2003, and 2004), however, the geopotential height field is dominated by a high-pressure ridge in the middle- and higher-latitudes with troughs clearly alternating with ridges and northwesterly flows in the northeast of SAH. It is noted that there is substantial difference in the circulation between the rainy and less rainy Mei-yu years, which is typical for the years in which Mei-yu is with normal start and ending. In 2002 (with a less rainy Mei-yu), the bulk of SAH was quite strong with the centre at 16880 gpm and the 16800-gpm contour extended to the area of Jiangsu. Meanwhile, the main portion of the ridge, distributed widely across the middle- and higher-latitude region, was more eastward and a trough zone to its east was over Japan through the northeast of China, a situation that made it hard for the cold air to penetrate into the province and to result in much rain. By contrast, the SAH centre was weaker in 2003 and 2004 (with a rainy Mei-yu) without much eastward extension of the 16500-gpm contour. In the areas west of 100° E, the bulk of a northwest-southeast-oriented high-pressure ridge covering vast areas of the middle- and higher-latitudes was located more to the east, making it easy for the cold air to reach the east of China and intrigue precipitation easily. Under the conditions of either extended troughs or a strong high-pressure ridge in the middle-and higher-latitudes, a less rainy Mei-yu is likely to occur, depending chiefly on the position of the ridge and whether there is cold air in the area of Jiangsu due to the ridge's effect. If a widespread area of troughs exists in the middle- and higher-latitudes, a less rainy Mei-yu is likely to happen; if a high-pressure ridge takes control of these regions while the SAH is strong and significantly extended to the east with its bulk covering Japan and surrounding areas, a less rainy Mei-yu is also likely the outcome for the province. On the other hand, when troughs and ridges alternate at the 100-hPa level of the middle- and higher-latitudes with the bulk of a high pressure located more to the west and the east-extending 16800-gpm contour off the province, cold air is able to travel there to result in rainfall, causing a rainy Mei-yu to appear. It can then be concluded that the average characteristics of the entire 100-hPa circulation and SAH are well corresponding to the start/ending dates and annual patterns of Mei-yu.

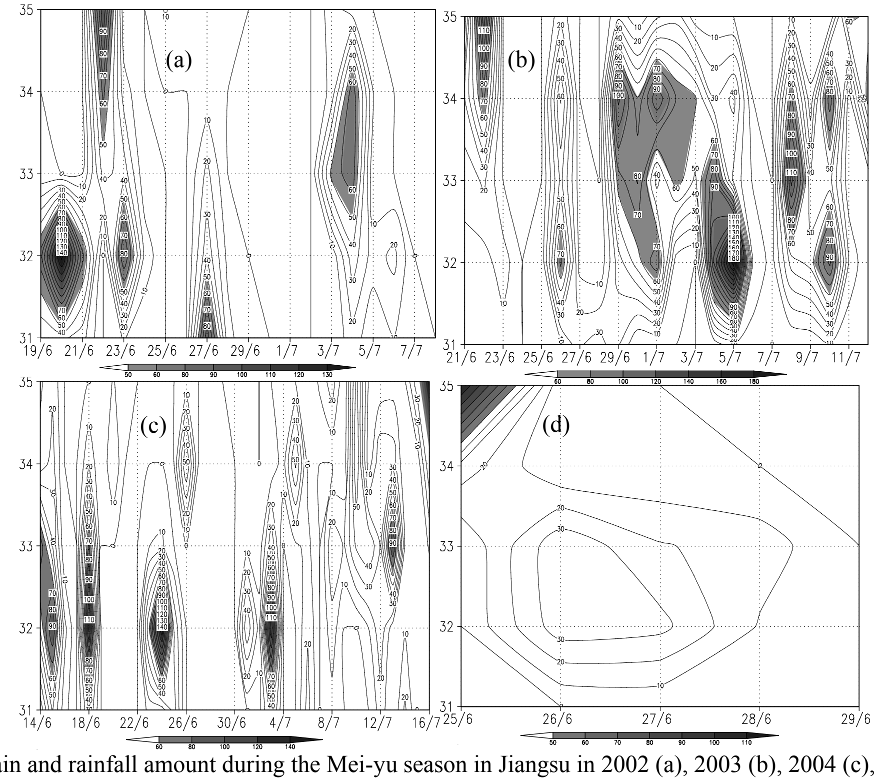

Fig. 4. Area of rain and rainfall amount during the Mei-yu season in Jiangsu in 2002 (a), 2003 (b), 2004 (c), and 2005 (d).

Based on diagnostic results from the study of these few years and in conjunction with the annual patterns characterized by the Mei-yu intensity index over the past 50 years, this study does a composite analysis of historical years of rainy Mei-yu (1970, 1975, 1980, 1982, 1983, 1986, 1987, 1991, and 1996) and historical years of less rainy Mei-yu (1958, 1959, 1960, 1961, 1964, 1978, 1988, 1992, and 1994). Results showed that differences could be found in the average 100-hPa circulation field between the two types of years, though not as much as those on the interannual scale. Examination of multi-year averages suggest that the SAH, a dominant system at 100 hPa south of 50° N, is stronger in the rainy than in the less rainy Mei-yu year, with the centre at 16840 versus 16900 gpm. For the annual patterns of Mei-yu, differences in the span of latitude are less significant as that of longitude as far as the SAH is concerned. While its average east-extending index is greater than 120° E in the rainy Mei-yu year, it is less than 115° E. It is now clear that both the SAH intensity and east-extending index are contributing in some way to the annual patterns of Mei-yu in Jiangsu.

The Mei-yu intensity is somewhat related to the SAH. To access the effect of SAH on the annual Mei-yu patterns in the province, the averages of SAH ridgeline and east-extending index in June and July as well as those for the season of Mei-yu are used for the past 15 years to study the impacts on the intensity of Mei-yu in the province. No significant correlation is found between the intensity index of Mei-yu and the characteristics index of SAH, though the latter's impacts show some regional pattern, as indicated in Fig. 5. When the average SAH ridgeline for June and July is less than 29° N or more than 31° N, as shown in Fig. 5a, a rainy Mei-yu is likely to occur, a possibility that is supported by a 15-year long statistics that points to the absence of a single less rainy Mei-yu. When this ridgeline lies between 29–31° N over the same months, a typical pattern of a less rainy, instead of a rainy, Mei-yu takes place, with the intensity index less than 2.0. The average index of Mei-yu intensity, either less than 110° E or more than 130° E, is favourable for the occurrence of a rainy Mei-yu pattern, while an east-extending index averaged between 110–130° E is accompanied by both rainy and less rainy Mei-yu years. When the two June–July indexes, one for the characteristics and the other for east-extending, are taken into account together, typical annual patterns of less rainy Mei-yu appear, mostly, when the average falls inside the box of Fig. 5a, and typical patterns of rainy Mei-yu occur, mostly, when it is outside the box. The area distribution with regard to the effect of the average characteristics index of SAH on the Mei-yu intensity index, as shown in Fig. 5b, is slighly different from that shown in Fig. 5a. When the averages of the indexes are inside the box of 110–125° E, 27–30° N, the annual pattern of extreme Mei-yu, composing both rainy and less rainy seasons (each seen in half of the 15-year-long period of interest), is likely to appear. When the characteristics index of SAH is outside the box, the index of Mei-yu intensity is all less than 3.0, an indication of a normal annual pattern of Mei-yu. It is then known that the former index is somewhat indicative of the latter.

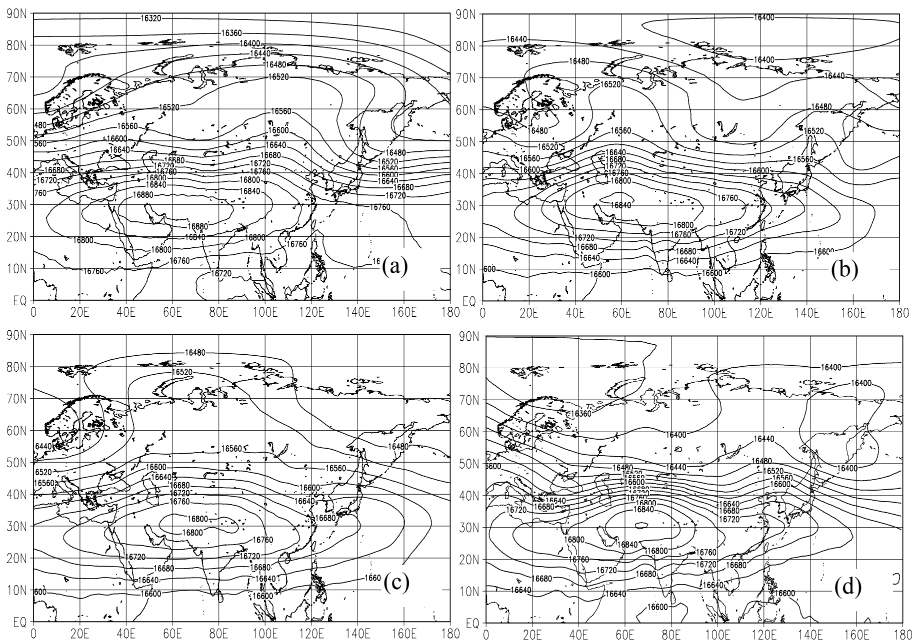

Fig. 5. Average 100-hPa geopotential height fields during the Mei-yu season in Jiangsu in 2002 (a), 2003 (b), 2004 (c), and 2005 (d).

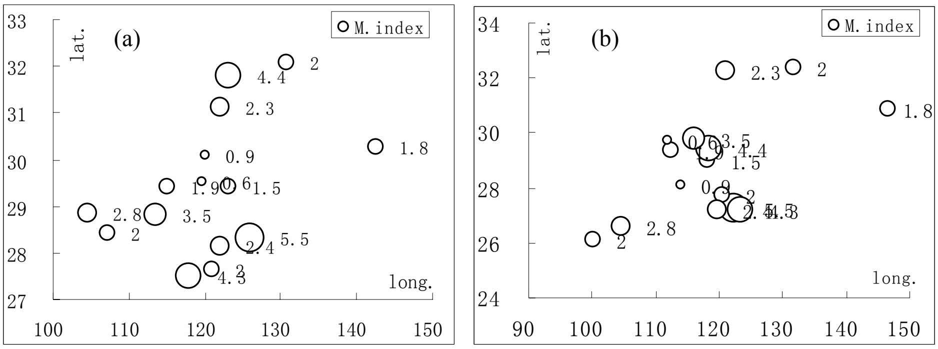

Fig. 6. Distribution of the characteristics index of SAH and Mei-yu intensity index in June and July and during the Mei-yu in 1991–2005 (a: June and July; b: Mei-yu season)

6 CONCLUSIONS

Based on our analysis of the relationships between Mei-yu in Jiangsu and SAH, the following conclusions can be made:

(1) The preceding characteristics and advancement/retreat of SAH and the movement of westerly troughs are the factors that have impacts on the onset time of the Mei-yu season; after the Mei-yu onset, the progression/withdrawal of SAH and how farther east it extends are determining how long the Mei-yu lasts and when it ends. For the years of early Mei-yu start, the east-extending index usually shows signs of obvious eastward advancement. For those with a late onset, however, the ridgeline of SAH, prior to the onset, is usually more southward and remains stable for an extended time. The index is normally east of 110° E. In the years with early Mei-yu ending, the SAH abruptly shifts northward and eastward on earlier dates, with the ridgeline usually at 32° N and east-extending index over areas east of 120° E, promptly. In the years with late Mei-yu ending, the SAH has repeated processes of north-south and east-west swings within the Mei-yu season until it is both settled north of 32° N and east of 120° E.

(2) The general 100-hPa circulation situation and average characteristics of the SAH are well corresponding to the characteristics of the season and annual patterns of Mei-yu. If the middle-and higher-latitude region is in the control of an extensive trough, a less rainy Mei-yu is likely to happen. If it is dominated with a high-pressure ridge, together with an intense, much eastward-extended SAH—whose bulk reaches Japan and nearby areas, a less rainy Mei-yu is also a likely outcome. Both the SAH intensity and east-extending index have some kind of impact on the annual patterns of Mei-yu in Jiangsu. The index is larger than 120° E in the rainy Mei-yu year but smaller than 115° E in the less rainy Mei-yu year, on average. The SAH intensity in the rainy Mei-yu year is greater than that in the less rainy Mei-yu year.

(3) The averages of the SAH ridgeline and east-extending index for June, July and the Mei-yu season have some implications to the forecast of the index of Mei-yu intensity.

(4) The above conclusions drawn on the basis of diagnoses and statistics need to be verified and improved in routine operation in order to further and enrich the achievements in this field of research.

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