Variations of Meiyu Indicators in the Yangtze-Huaihe River Basin during 1954-2003*

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(Received May 13, 2005; revised August 1, 2005)

ABSTRACT

To better understand climate variations of Meiyu, some new indicators for the onset and retreat dates, duration, and Meiyu precipitation in the Yangtze-Huaihe River valley are objectively developed by using observed daily precipitation data from 230 stations in eastern China during 1954-2003.

The rainy season onset and retreat dates in each station can be defined in terms of thresholds for rainfall intensity and persistence. Then, the onset and retreat dates of the Meiyu for the Yangtze-Huaihe River basin have been determined when more than 40% of stations reach the first rainy season thresholds in the study region.

Based on the indicators of Meiyu in the Yangtze-Huaihe River basin, variations of Meiyu rainfall during 1954-2003 are analyzed. The results suggest that Meiyu rainfall in the Yangtze-Huaihe River basin has increased in recent 50 years. In addition, interannual and interdecadal variability of Meiyu is also obvious. All the indicators display a predominant period of about 3 years.

Key words: Yangtze-Huaihe River basin, Meiyu, interannual and interdecadal variability

1. Introduction

The primary physical manifestation of the East Asian summer monsoon is persistent, heavy precipitation identified with a coherent, well-defined rainband. Generally, such rainband movement is characterized by a stepwise northward advance from southern China and the western North Pacific in early-mid May to the Yangtze River valley and southern Japan in mid-June, then to north China and the Yellow Sea as well as the southern Japan Sea in late July (Ding, 1992, 1994; Tao and Chen, 1987; Lau and Li, 1984; Lau et al., 1988; Lau and Yang, 1996). When the monsoon rainband is located in the Yangtze-Huaihe River basin, it is normally called Meiyu. Although there are some definitions of monsoon rainy season in eastern China (Wang and Lin, 2002; Chen et al., 2004; Samel et al., 1999; Chen et al., 2000) including Meiyu (Xu, 1965; Xu et al., 2001; Zhou, 1996), a suite of relatively objective and unified definition of monsoon rainy season has not byet reached a consensus, especially the definition of Meiyu onset and retreat dates in the Yangtze-Huaihe River basin. In the past, the monsoon rainfall, including the Meiyu rainfall, was mainly analyzed based on monthly, dekad or pentad data, and the region was normally applied to the mid-lower reaches of the Yangtze River basin. In this study, the Meiyu definition is extended to the Yangtze-Huaihe River basin by using daily precipitation data. Based on the newly defined Meiyu onset and retreat dates, the characteristics and variations of Meiyu in the Yangtze-Huaihe River basin are further analyzed.

2. Data

The Chinese dataset consisting of observed daily precipitation data of 743 stations during 1951-2003 are utilized in this study. Due to the different beginning period of the observations at each station and the region of interest being at the east of 105°E, the daily precipitation data of 230 stations in eastern China during 1954-2003 are selected in this study. Precipitation at each station is normalized by climatological annual mean amount (reference period of 1971-2000) for that station such that daily values are given as percentage

*Sponsored by the "Interannual and Interdecadal Variations and Their Mechanisms over Yangtze-Huaihe River Basin" of NSFC Key Project under Grant No. 40233037.

of annual mean totals. This normalization eliminates regional difference and uniforms the definition of monsoon precipitation including Meiyu. The spatial distribution of these selected stations is shown in Fig.1.

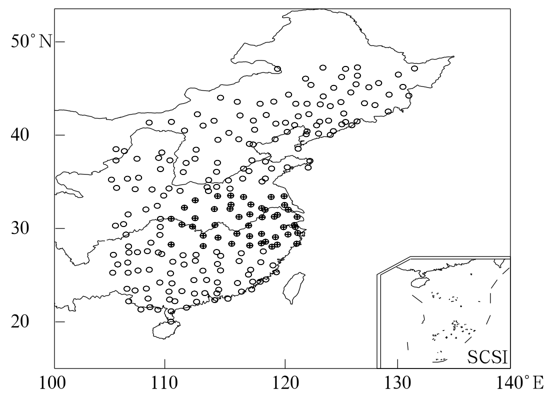

Fig.1. Spatial distribution of stations over eastern China during 1954-2003. ○: 230 stations; ⊕: 46 stations over the Yangtze-Huaihe River basin.

3. Definition of Meiyu over the Yangtze-Huaihe River basin

Summer monsoon rainband has a coherent physical feature associated with the occurrence of heavy and persistent precipitation. Therefore, the onset and retreat monsoon rainfall dates in each station over eastern China are firstly defined in terms of heavy and persistent rainfall. Furthermore, because Meiyu rainfall is a specific regional monsoon rainfall phenomenon over eastern China, we extend the definition in each station to regional Meiyu rainfall.

3.1 *Definition of onset and retreat monsoon rainfall dates in each station*

Referring to Samel et al. (1999), the method of cumulative frequency distribution (CFD) is used to analyze the characteristics of monsoon rainfall over eastern China. The method of CFD indicates a ratio of the absolute frequency to the total number of data points in a frequency and CFD is denoted as

$$\text{CFD} = \frac{F_k}{F_n} \times 100\%, \tag{1}$$

$$F_k = \sum_{i=1}^{k} f_i \qquad i = 1, 2, 3, \ldots, n, \tag{2}$$

where f_i in Eq.(2) indicates absolute frequency, and it is the number of data points which fall within a given class in a frequency distribution. In this study, 90% of the value is used as an approximate statistical threshold.

The onset and retreat monsoon rainfall dates over eastern China are defined by identifying heavy and persistent rainfall. Such concept of heavy and persistent rainfall is applied to daily precipitation data normalized by climatological annual mean totals (1971-2000) from 230 stations during 1954-2003 over eastern China. Firstly, CFDs of daily amount from 230 stations are generated for 4-degree latitudinal bands across eastern China. Each CFD is based on all stations within the zonal band and represents a composite of all days between April and September from 1954 to 2003. Although the regional difference exists, for each rainband, precipitation amounts with approximate 90% of the days are found to be less than 1.5% of annual totals (Fig.2). This threshold is exactly the same as that one given by Samel et al. (1999). Further, for each rainband, heavy rainfall value is defined as the value exceeding 1.5% of annual totals. Similarly to the above method, heavy rainfall is then indicated as 'persistent' when the 1.5% threshold exceeds at least 6 days in a 25-day period that is maximal interval identifying two consecutive heavy rainfall days in a given station and year.

The specific onset and retreat dates are defined according to the characteristics and rainy season of each rainband as well as the minimal number of rain-free days. For a given station and year, the '25-day

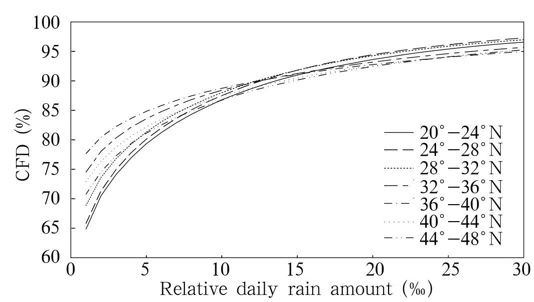

Fig.2. Cumulative frequency distributions (CFDs) of the percentage of days (ordinate) as a function of relative daily rainfall amount (% climatological annual mean total) times 10.

core window' with the maximal number of heavy rainfall days is firstly found by the 25-day running window. Secondly, the daily rainfall time series is analyzed backward (forward) from the first (last) heavy rainfall day until the five rain-free days are encountered. The exact onset (retreat) rainband date is defined to the first day following (preceding) the rain-free period.

3.2 *Definition of onset and retreat dates of Meiyu*

Generally, the Meiyu region ranges from 28°N to 34°N in the east of 110°E, which includes the Yangtze-Huaihe River basin. In terms of the above-mentioned definition, the features and variations of Meiyu rainfall in the the Yangtze-Huaihe River basin are then investigated. The analyses of Meiyu over the mid-lower reaches of the Yangtze River basin as given by Xu (1965), Xu et al. (2001) and Zhou (1996) are referred and further developed.

Firstly, the onset and retreat dates of monsoon rainfall of each station in the study region during 1954-2003 are analyzed. Secondly, the earliest onset and latest retreat dates of all stations in the study region are calculated. Thirdly, the percentages of these stations that enter monsoon rainy season to all stations in the study region are calculated from the earliest onset dates to the latest retreat dates in every year.

For a certain year, it is found that Meiyu rainfall begins when about 40% of all stations in the study region enter the monsoon rainy season. To avoid abrupt increasing of rainfall in a certain day, the first day is determined as the onset date of Meiyu rainfall when such condition occurs in two consecutive days. Furthermore, we also find that Meiyu rainfall of the region basically terminates when 40% stations in the study region withdraw from the rainy season. Similarly, the retreat date is defined in the preceding the two consecutive days when there are more than 40% stations in the region withdrawing from the rainy season. This definition is consistent with the Meiyu definition in the mid-lower reaches of the Yangtze River basin as given by Xu (1965), Xu et al. (2001), and Zhou (1996).

Based on such a definition, the Meiyu rainfall in 2003 in the Yangtze-Huaihe River basin is depicted in

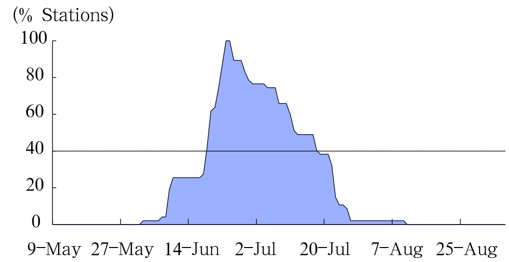

Fig.3. Defined onset and retreat rainfall dates of the Meiyu rainfall in the Yangtze-Huaihe River basin during 2003.

Fig.3. The onset date is June 20 and the retreat date is July 19. This result approximately accords with the rainy season of the Huaihe River basin (from June 21 to July 22) at the normal condition though it slightly differs from the dates of June 21 to July 11 over the mid-lower reaches of the Yangtze River basin as indicated by Zhang et al. (2004). The reason of the difference is that the region of Meiyu in this study includes not only Yangtze River basin but also Huaihe River basin.

4. Variations of Meiyu over the Yangtze-Huaihe River basin

To give a full reflection of climate variability of Meiyu, the onset and retreat dates, total rainfall, and duration are studied.

4.1 *Variations of the onset and retreat dates of Meiyu*

Figure 4 shows that the average onset and retreat dates are about June 17 and July 14, respectively. Noticeably, there exists relatively obvious decadal variation in the onset and retreat dates of Meiyu.

In the 1960s and 1980s, the onset dates of Meiyu over Yangtze-Huaihe River basin are later than the average onset dates. Meanwhile, the onset dates are earlier in the mid-1950s and early 1990s as well as the early 21st century. However, it is relatively late in 2003.

The retreat dates are earlier than the average retreat dates in the early 1960s and mid-1990s as well as. Meanwhile, it is slightly later in the mid-1980s and late 1990s.

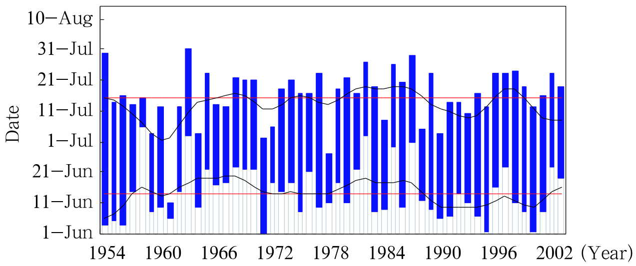

Fig.4. Onset and retreat dates of Meiyu in the Yangze-Huaihe River basin during 1954-2003. (The curve represents 11-yr running mean and the soild lines represent climatological averages.)

4.2 *Variations of Meiyu amount and duration*

The time series of Meiyu amount and duration in the Yangtze-Huaihe River basin are given in Fig.5. Meiyu rainfall anomaly (Fig.5a) indicates that it displays an increasing trend in the recent 50 years. This founding is similar to the result of Meiyu rainfall in the mid-lower reaches of Yangtze River valley (Chen et al., 2004; Wei et al., 2004; Zhu et al., 2001). Meiyu rainfall amount also displays obvious decadal variations. A relatively low Meiyu precipitation appears in the late 1950s, mid-1960s, and late 1970s, but more abundant in the late 1960s and early 1980s as well as late 1990s. However, there is a sudden drop around year 2000 and an abrupt increase in 2003. Meanwhile, the percentage time series of Meiyu amount accounting for summer total rainfall is given in Fig.5c. It shows that the Meiyu contribution to summer rainfall has increased in recent 50 years. Due to summer rainfall totals increasing over the Yangtze River basin (Zhai et al., 2005), the increase of summer totals could be mainly the contribution of Meiyu amount increase in recent 50 years. The contribution of Meiyu amount also displays decadal variations similar to that for the Meiyu rainfall.

The trend of Meiyu duration anomaly during 1954-2003 (Fig.5b), as reflected by deference between the retreat date and onset date, is quite similar to that of Meiyu amount. The correlation coefficient between Meiyu duration and amount is 0.85, which is statistically significant at 99% confidence level. This indicates that the duration tends to be longer and the Meiyu amount is more plenty.

To further reflect variations of Meiyu amount and duration, periodical distributions of Meiyu indicators are further investigated by use of Morlet wavelet transform analysis. A red noise process and chi-square test

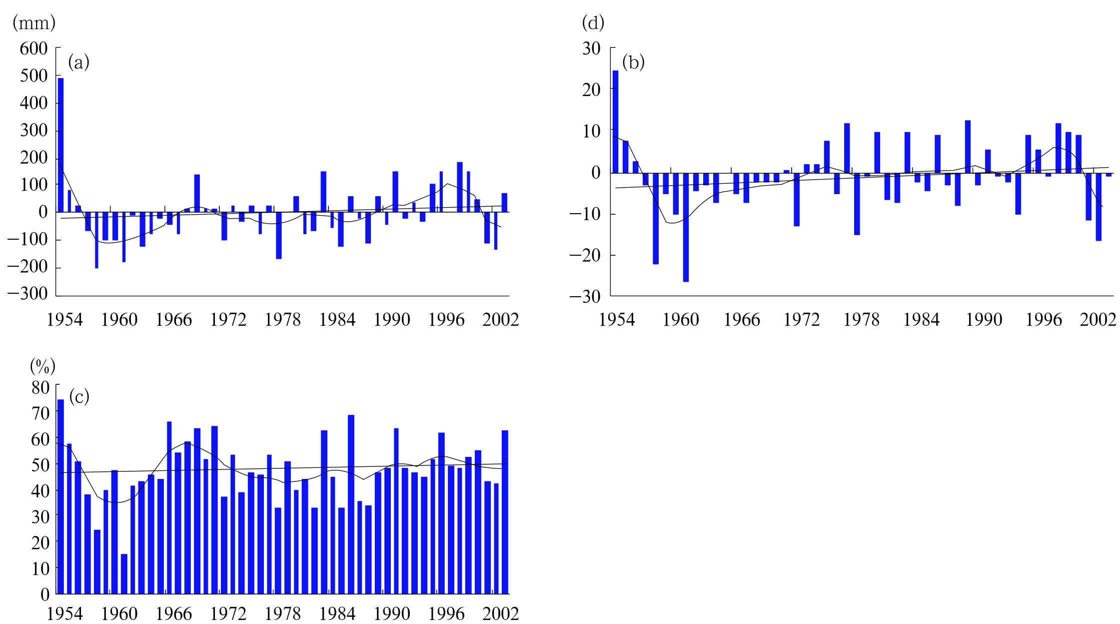

Fig.5. Variations of Meiyu indicators for Meiyu amount anomaly (mm) (a), Meiyu duration anomaly (day) (b), and the contribution of Meiyu amount to summer total rainfall (%) (c). (Bars, dashed and solid lines indicate Meiyu indicator values, 11-yr running means and linear trends, respectively.)

method as discussed by Torrence and Compo (1998) are applied to detect the statistical significance of the dominant periods.

Figure 6 shows periodical distributions of Meiyu amount and duration. Obviously, there exist about a 20-yr and 11-yr long period as well as a 3-6−yr short period in the Meiyu amount (Fig.6a). The significant period is about 3-6−yr. The period in the late 1950s and early-mid 1980s is relatively shorter (Fig.6b). Similarly, the duration shows an about 20-yr long period and a 3-6-yr period (Fig.6c). The statistically significant period about 3 yr mainly occurs in the late 1970s and 1980s as well as in the early 1960s. However, 4-yr significant period happens in the late 1990s from the wavelet power spectrum (Fig.6d).

The other two Meiyu indicators (the onset and retreat Meiyu dates, not shown) illustrate that there exist a 20-yr and 15-yr long period respectively while both have nearly a 3-yr and a 6-7-yr short period in two indicators. The 3-yr and 6-7-yr periods are statistically significant at 95% confidence level. The 3-yr period in the time series of the onset and retreat dates is more obvious in the late 1950s to mid-1960s and the late 1970s to 1980s. The 6-7-yr period of the onset date mainly appears in the late 1950s to mid-1960s as well as the late 1990s. However, the 6-7-yr period of the retreat date only appears in the late 1950s to mid-1960s.

5. Conclusions

A new definition of onset and retreat dates of rainy season of each station is proposed and then the regional Meiyu indicators over the Yangtze-Huaihe River basin are further developed. Variations of Meiyu indicators are therefore conducted in this study.

To detect the features of monsoon rainfall, heavy and persistent rainfall is defined when the 1.5% threshold persists at least 6 days in a 25-day period. The onset (retreat) monsoon rainfall dates are determined according to 5 consecutive rain-free days following or preceding dates. Based on the newly developed definition of monsoon rainy season over each station, the onset and retreat dates of Meiyu over the Yangtze-Huiahe River basin are given as follows: The first day is defined as the onset date when more than or equal to 40% of all stations in the study region enter rainy season, while the retreat date is defined when more than 40% of the stations withdraw from the rainy season.

Variations of Meiyu rainfall in the Yangtze-Huaihe River basin show there exists an increasing trend. Also, interannual and interdecadal variations are obvious in four Meiyu indicators. A 3-yr period is significant for all the four Meiyu indicators. In addition, there exist a 6-7-yr period in the onset and retreat Meiyu dates, and a 5-6-yr period in Meiyu

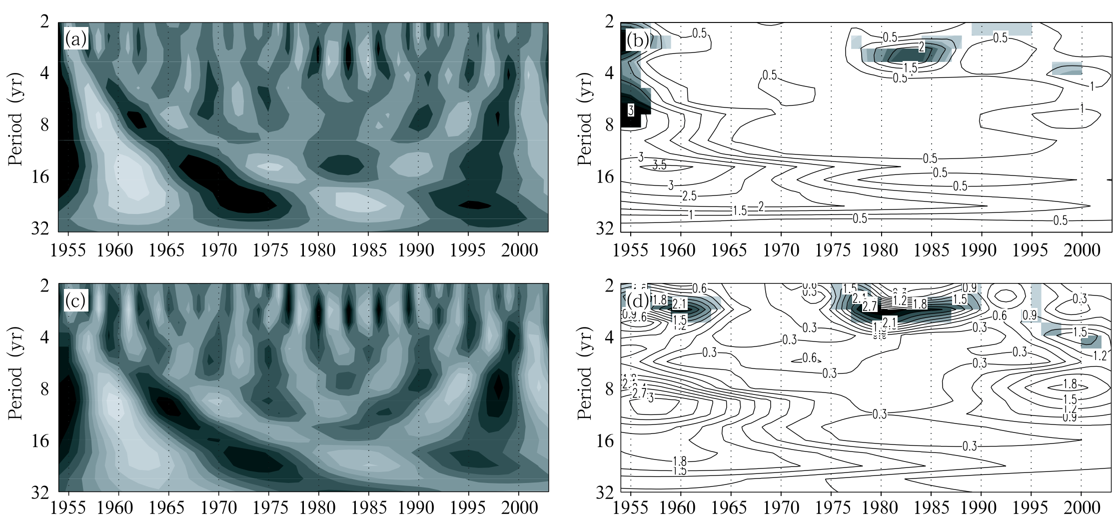

Fig.6. Morlet wavelet period of Meiyu: (a) amount and (c) duration, (b) and (d) represent local wavelet power spectrum of Meiyu amount and duration, respectively, and the shaded contours enclose regions of greater than 95% confidence level for a red-noise process.

amount.

Compared with early studies on Meiyu in the mid-lower reaches of the Yangtze River basin (Xu, 1965; Xu et al., 2001; Zhou, 1996; Zhang et al., 2004) based on 5 representative stations, the definition of Meiyu dates in this study not only is objective but also extends to a wider region. Such a concept can be further extended to the Meiyu in the Huaihe River basin and Meiyu in the region south to the Yangtze River valley.

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