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Identification and characteristics analysis of Meiyu in Anhui Province based on the National Standard of Meiyu monitoring indices

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ABSTRACT

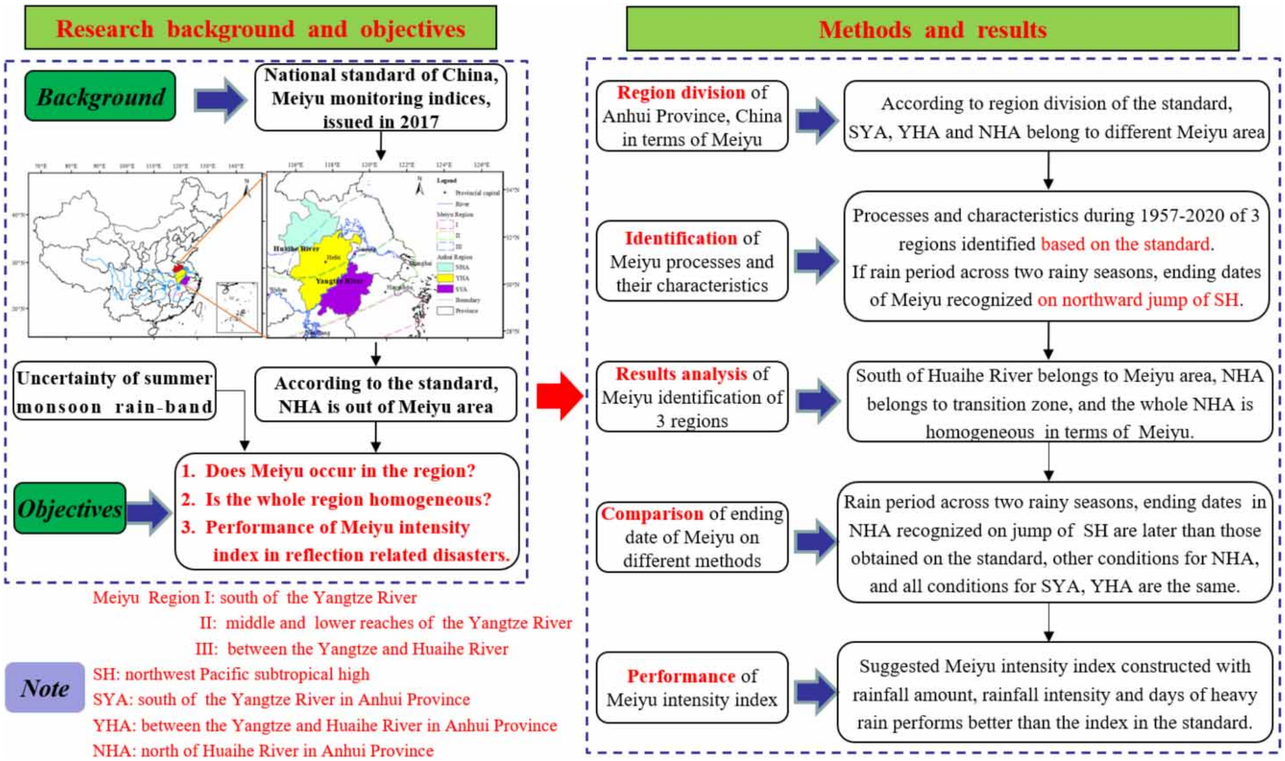
Meiyu is the term used to depict the consecutive rainy weather advancing in the months before the flooding season in East Asia. However, the temporal-spatial climatic characteristics of Meiyu can be differently specified by different evaluation criteria. In this study, we employ both the atmospheric circulation conditions and meteorological factors to identify the spatial characteristics of precipitation of Meiyu in Anhui Province using the collected data of 1957–2020. We further conduct a comparison analysis of the precipitation characteristics in the northern Huaihe River of Aihui province (NHA) with Meiyu rainfall features in two other regions: south of the Yangtze River in Anhui Province (SYA) and the region between the Yangtze River and Huaihe River in Anhui Province (YHA). Finally, the relation between the intensity index between Meiyu and flood or drought is investigated. The results showed that the climatic feature in NHA is a transitional region between Meiyu and non-Meiyu. Also, we proposed a Meiyu intensity index determined by the precipitation amount, intensity, and days of heavy rain. This index performs better than the Meiyu intensity index of National Standard in terms of flood and drought identification.

Key words: flood or drought disaster, Meiyu intensity index, North of Huaihe River in Anhui province, rainy season, ridge of subtropical high

HIGHLIGHTS

- Northern part of Huaihe River in Anhui Province is located in the transition zone between Meiyu region and non-Meiyu region.
- The ending date of Meiyu in the northern part of Huaihe River in Anhui Province should be determined by the northward jump of subtropical high.
- The suggested Meiyu intensity index determined by precipitation amount, intensity, and days of heavy rain performs better.

GRAPHICAL ABSTRACT



INTRODUCTION

Precipitation is the primary influencing factor of the decision-making for operation and scheduling of hydraulic engineering, such as sluices, dams, and hydropower stations. It is also the basis of drought disaster risk analysis. Characteristic analysis of precipitation is very important for flood control (Sun *et al.* 2020) and drought relief work.

At present, the time step for the run theory-based drought process identification depends on the time scale of the observed hydrological data, and usually remains invariable during the whole process (Yuan *et al.* 2013). However, the adopted time step in the identification method does not normally carry clear physical meaning. For example, monthly precipitation drought index may not completely reflect the precipitation process associated with a large-scale weather system longer than one month, which does not begin on the first day nor end on the last day of a month. Consequently, the drought index cannot identify actual drought situations, nor drought events at a time scale shorter than a month. Apart from drought process identification, practical operation and scheduling of a reservoir is also based on the division of precipitation phases according to its formative mechanisms (Harder & Pomeroy 2013), such as Meiyu and typhoons. Thus, characteristic analysis of precipitation is vital to determine the time step adopted in drought processes' identification scientifically, and is also critical to the selection of precipitation phase corresponding to the designed storm. Previous studies generally focused on the statistical characteristics of extreme precipitation during a certain period, such as hourly, daily, and monthly time scales (Li *et al.* 2020). The maximum or average precipitation amount over certain periods, such as the maximum 1-day, consecutive 5-day, monthly, seasonally, yearly precipitation amount, have been used as indices to characterize the spatial-temporal distribution of precipitation. However, few studies have focused on the processes and characteristics of precipitation associated with the large-scale weather systems.

Meiyu is the outcome of seasonal adjustment of atmospheric circulation in the East Asian monsoon region (Liang *et al.* 2007; Zhou *et al.* 2020; Tong *et al.* 2021). With the onset of the South China Sea summer monsoon, and following the northward advance of the East Asian monsoon, the northwest Pacific subtropical high (hereinafter, SH) has three northward jumps (Su & Xue 2011; Ye *et al.* 2014). The corresponding main rain-band of the summer monsoon passes through South China, the Yangtze-Huai River Basin, the Huang-Huai River Basin, North and Northeast China consecutively. The stagnation of rain-band in each river basin forms its rainy season, such as the pre-flood season in Southern China, the Yangtze-Huai Meiyu season, the Huang-Huai rainy season, and the rainy season in North and Northeast China, which is called Meiyu in a broad sense (Liang *et al.* 2007; Lv *et al.* 2012; Janowiak & Xie 2013). However, the classic Meiyu refers to the continuous rainy weather process that occurs in the Yangtze-Huai River Basin, central and southern Japan, and southern Korea during the period between the first and second northward jumps of SH (Geng & Yamada 2007; Qian *et al.* 2009; Su & Xue 2011; Liu *et al.* 2012; Ye *et al.* 2014; Chen & Li 2016; Li *et al.* 2020). The precipitation in the rainy season directly determines the regional drought and flood occurrences (Ye *et al.* 2009; Deng *et al.* 2018; Tian *et al.* 2020). For a long time, the indices and criteria used to identify the Meiyu process and its characteristics varied from place to place. This is not conducive to the analysis of Meiyu characteristics on a national scale. To solve this problem, the Meiyu Monitoring Indices of the National Standard of China was published in 2017 (General Administration of Quality Supervision & Inspection and Quarantine of the PRC 2017). Related studies on the temporal and spatial characteristics of Meiyu have generally focused on the south of Huaihe River (Liu *et al.* 2004; Zhou 2005; Liang *et al.* 2010; Huang *et al.* 2012), while research on Meiyu occurring and its characteristics in the north of the Huaihe River in Anhui Province (NHA) is rare (Wang *et al.* 2018; Zhou *et al.* 2020).

This study aims to investigate the statistical characteristics of precipitation over the periods partitioned based on synoptic background, which will provide theories and data support to drought disaster risk analysis and reservoir operation. The paper is structured as follows. In 'Materials and methods', the data used in this study are briefly described, following which the identification methods of Meiyu process are introduced, then characteristics of the Meiyu process are defined and extracted. In 'Results and discussion', we compare the characteristics of Meiyu in the different regions of Anhui Province and discuss the performance of Meiyu intensity index in reflecting flood and drought disasters. Conclusions are drawn in the final section.

MATERIALS AND METHODS

Study area

Generally, the Yangtze-Huai River Basin is divided into three regions affected by Meiyu, namely, the south of the Yangtze River Meiyu region, the middle and lower reaches of the Yangtze River Meiyu region, and Meiyu region between the Yangtze and Huaihe River. According to the National Standard, the south of the Yangtze River in Anhui Province (SYA) belongs to the middle and lower reaches of the Yangtze River Meiyu region. The region between the Yangtze and Huaihe River in Anhui Province (YHA) belongs to the Meiyu region between the Yangtze and Huaihe River. Therefore, Anhui Province is divided into the SYA, the YHA, and the NHA (Si *et al.* 2009). The location of Meiyu regions and the division of Anhui Province are illustrated in Figure 1. Different from the other two Meiyu dominated regions, the NHA is classified as non-Meiyu dominated region. This classification is different from the previous studies considering the strong interannual swing of Meiyu rain-band. There are 55 Meiyu monitoring representative stations in Anhui Province, which are all located in the south of the Huaihe River.

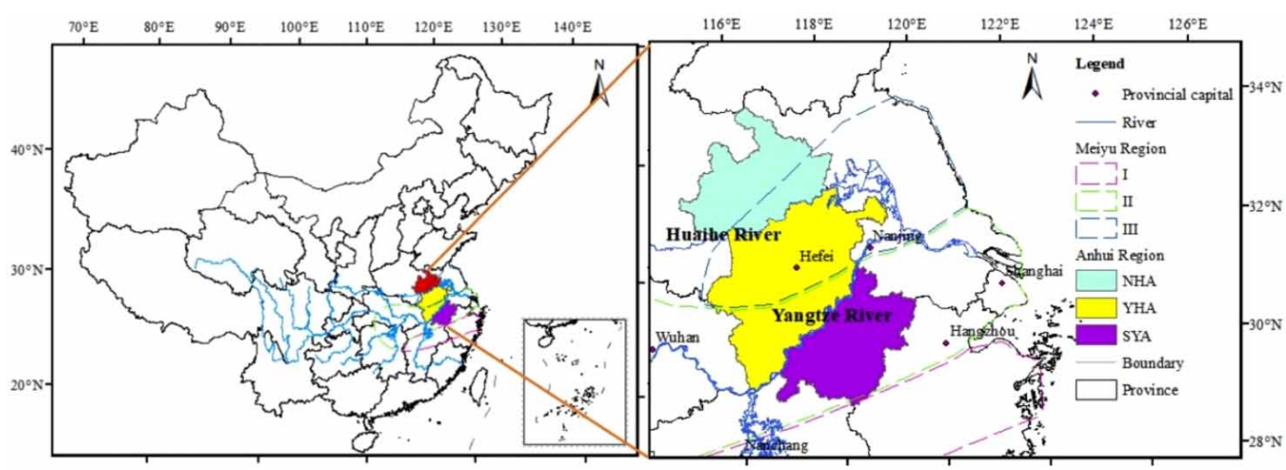


Figure 1 | Location of Meiyu regions of China and the division of Anhui Province.

The Meiyu rain-band is east-west oriented with a width of 200–300 km. It is generally located at 5–8 latitudes north of the SH ridge with a strong interannual swing. Due to the stochastic feature of East Asia monsoon climate (Liang *et al.* 2007; Zhu *et al.* 2013; Rahman & Islam 2019), it is difficult to explicitly specify the size and location of the rain-band (Si *et al.* 2009). The summer monsoon rain-band during Meiyu season may surpass the Huaihe River, and form consecutive rainy weather along the Huaihe River and some areas in the north of Huaihe River. Generally, there will be consecutive rainy days in NHA during the Huang-Huai rainy season. Therefore, the northern region of NHA is affected by Meiyu season but the southern part is also affected by Huang-Huai rainy season. The summer monsoon rain-band can cover NHA during both Meiyu season and Huang-Huai rainy season, which complicated the identification of the precipitation characteristics.

Data

The onset and ending dates of Meiyu are typically determined by the northward jumps of SH. According to the Meiyu Monitoring Indices of China (General Administration of Quality Supervision & Inspection and Quarantine of the PRC 2017), Meiyu is mainly identified with the atmospheric circulation conditions and meteorological factors. The onset and ending dates of Meiyu are determined by both the atmospheric circulation and meteorological factors. Among them, SH ridge is adopted to represent the atmospheric circulation factor; the rainy periods, rainy days, and temperature are used together to characterize the meteorological features. The required data are obtained as follows: the upper-air circulation data of this study use the daily average 500 hPa geopotential height and the zonal wind speed. The data are recorded by the NCEP/NCAR reanalysis project webpage: https://psl.noaa.gov/data/gridded/data.ncep.reanalysis.html. The meteorological data including daily precipitation and average temperature are collected from the 15 meteorological stations of Anhui Province from 1957 to 2020, and the data were downloaded from the China Meteorological Data Network (http://data.cma.cn).

The daily average mean values of precipitation and temperature in SYA, YHA, and NHA are the arithmetic averages of the meteorological stations within the region. The SH ridge on each longitude line is represented by the position of the maximum potential height in the area where the potential height is greater than 5,880 dagpm on the 500 hPa isobaric level. The average position of SH ridge on each longitude within 110–130°E is adopted as the index of the ridge of SH (China Meteorological Administration 2015).

Characteristics of Meiyu

The onset and the ending dates of Meiyu

SH ridge, rainy period, rainy day, and temperature indices are adopted to identify the onset and ending dates of Meiyu based on the National Standard of China. The rainy day is defined when more than one-third of the rain-gauge station in the region has daily rainfall greater than 0.1 mm, and the daily mean precipitation in such a region is not less than 2.0 mm. Following that, the rainy period should satisfy the following conditions: (1) within 10 days after the first rainy day (or 10 days before the last rainy day), the number of rainy days should be greater than 50% of the days from the first (or last) rainy day to the present; (2) there should be at least 4 rainy days in any 10 days; (3) the total number of rainy days during the rainy period should exceed 6, and the total consecutive non-rainy days should be less than 5; (4) the daily rain intensity over the rainy period should exceed 5 mm/d. In addition, there is at least one rainy period in the Meiyu period, and the period between rainy periods is defined as the intermittent rainy period in the National Standard. The rainy period should start before July 20, and end at the first non-rainy day in August. In contrast, some definitions for the rainy period proposed by Liu *et al.* (2004) and Xu (1965) state that after heavy rain, there are at least 4 rainy days within 5 consecutive days or at least 7 rainy days within 10 consecutive days. Moreover, the regional rainy period presented by Liang *et al.* (2007) is specified with at least 4 regional rainy days in every 5 days for 5 consecutive sliding pentads. Compared with the above definition, the condition of rainy period in the National Standard is not difficult to satisfy.

According to the National Standard, the following two conditions are defined for the Meiyu season of SYA (YHA): the first is that the SH ridge surpasses 19°N (20°N), and the second is that every 5 days of SH ridge lies between 19 and 26°N (20–27°N). Following that, the first rainy day with an average daily temperature higher than 22 °C is defined as the onset date of Meiyu. In the National Standard, there are no special regulations on the amount of daily precipitation for the onset of Meiyu. Liu *et al.* (2004) have specified the daily precipitation amount for the onset of Meiyu, as well as the identification criteria of the onset of Meiyu. Generally, the onset of Meiyu should start from a heavy rain day with the daily precipitation amount not less than 25 mm. In practice, if a certain rainy period fulfilling the atmospheric circulation and temperature conditions for Meiyu and the start date of the rainy period is earlier than the heavy rainy day, then the start date of the rainy period should be set as the onset of Meiyu. Therefore, in this study, the first rainy day of the rainy period is identified as the onset of Meiyu, when the atmospheric circulation and temperature conditions of Meiyu are met.

With the second northward jump of SH, the Yangtze-Huai rainy season ends and the Huang-Huai rainy season begins. Consequently, the precipitation significantly increases in NHA, and there is very little precipitation in SYA. Generally, during the Yangtze-Huai rainy season, the summer monsoon rain-band covers SYA and YHA. However, according to previous climatic data records, the summer monsoon rain-band could reach NHA. During the Huang-Huai rainy season, NHA is on the front of the summer monsoon rain-band. The southern front of the rain-band may also cover YHA, whereas SYA is not affected by the summer monsoon rain-band. The ending date of Meiyu defined in Provision 3.2.6 of the National Standard is the following day after the ending of the rainy period in Meiyu season. Thus, according to Provision 3.2.6, the ending date of Meiyu in NHA and YHA may occur in Huang-Huai rainy season, especially in the years with the rainy period in NHA or YHA covering the two rainy seasons with a long rainy period in Huang-Huai rainy season. This is inconsistent with the definition of Meiyu in the previous study (continuous rainy process associated with the second northward jump of SH is identified as Meiyu). However, the ending date of Meiyu in SYA generally is consistent with the date of the first northward jump of SH.

Provision 3.2.8 of the National Standard stipulates that the atmospheric circulation condition for the ending of Meiyu is that every 5 days of average position of the SH ridge surpasses the corresponding northern boundary for Meiyu season by two latitudes. Meanwhile, there should be no rain in the following days. As a large-scale continuous rainy process, the ending date of Meiyu is determined by circulation conditions, rainy days, and temperature proposed in Provision 3.2.8 is consistent with the ending date of Meiyu defined as the end of the last rainy period according to Provision 3.2.6. However, when the study area is smaller than the Meiyu region, due to the spatial heterogeneity of the Meiyu precipitation, the Meiyu region may be still in the rainy period, although the rainy period in the study area has ended. In this condition, the ending date of Meiyu identified with Provision 3.2.6 may be earlier than that of the data with Provision 3.2.8. That is, there may exist an intermittent rainy period between the ending date of Meiyu season. Therefore, the end of the rainy period is preliminarily identified as the potential latest ending date of Meiyu according to Provision 3.2.8, while the day after the last rainy day before the northward jump of SH is specified as the potential earliest ending date of Meiyu. From the back to the front, the next day of the rainy day belonging to a rainy period is specified as the ending date of Meiyu. The ending dates of Meiyu in NHA or YHA are compared with the date of the second northward jump of SH in the years with the rainy period covering the Meiyu and Huang-Huai rainy seasons. Also, with the comparison analysis of the similarities and differences of the Meiyu characteristics along the Huaihe River in Anhui Province and that in the northern part of Huaihe River in Anhui Province, the occurrence of Meiyu in NHA is investigated. Precipitation of the region along the Huaihe River in Anhui Province is represented by Shouxian, Fuyang, and Bengbu rain-gauge stations, while that in the northern part of Huaihe River is represented by Bozhou, Suxian, and Dangshan rain-gauge stations. Locations of the precipitation stations are shown in Figure 2.

Characteristics of Meiyu process

In addition to the onset and the ending dates of Meiyu, the length of Meiyu season (hereinafter, Meiyu length), the daily average precipitation during Meiyu season (hereinafter, Meiyu precipitation), the number of rainy periods, the number of rainy days, and precipitation during the concentrated period of Meiyu represent the characteristics of the Meiyu process from different perspectives. Among them, the indices of rainy days and precipitation during the concentrated period of Meiyu represent the cumulative number of rain days and the cumulative precipitation of one or more rainy periods during the Meiyu season, respectively. Thus, the rain days and precipitation in the intermittent period of the Meiyu season are not included in the above indices. When the SH ridge lies within 19–26°N (20–27°N), if there is no rainy period in SYA (YHA), the corresponding year is recognized as empty Meiyu year. The Meiyu precipitation over the empty year in SYA (YHA) is defined as the amount of precipitation during the period from the first rainy day after the SH ridge stably reaches 19°N (20°N) to the last rainy day before the SH ridge stably surpasses 26°N (27°N).

Zhou (1996) defined the length and precipitation of the concentrated period of Meiyu, and the average daily precipitation during Meiyu season as the index for the sub-item calculation of the Meiyu intensity, which is the same as the National Standard. Yu *et al.* (2008) used the length and precipitation of the concentrated period of Meiyu, the proportion of the Meiyu precipitation in annual precipitation, and the number of rainstorm days during Meiyu season as the index to calculate

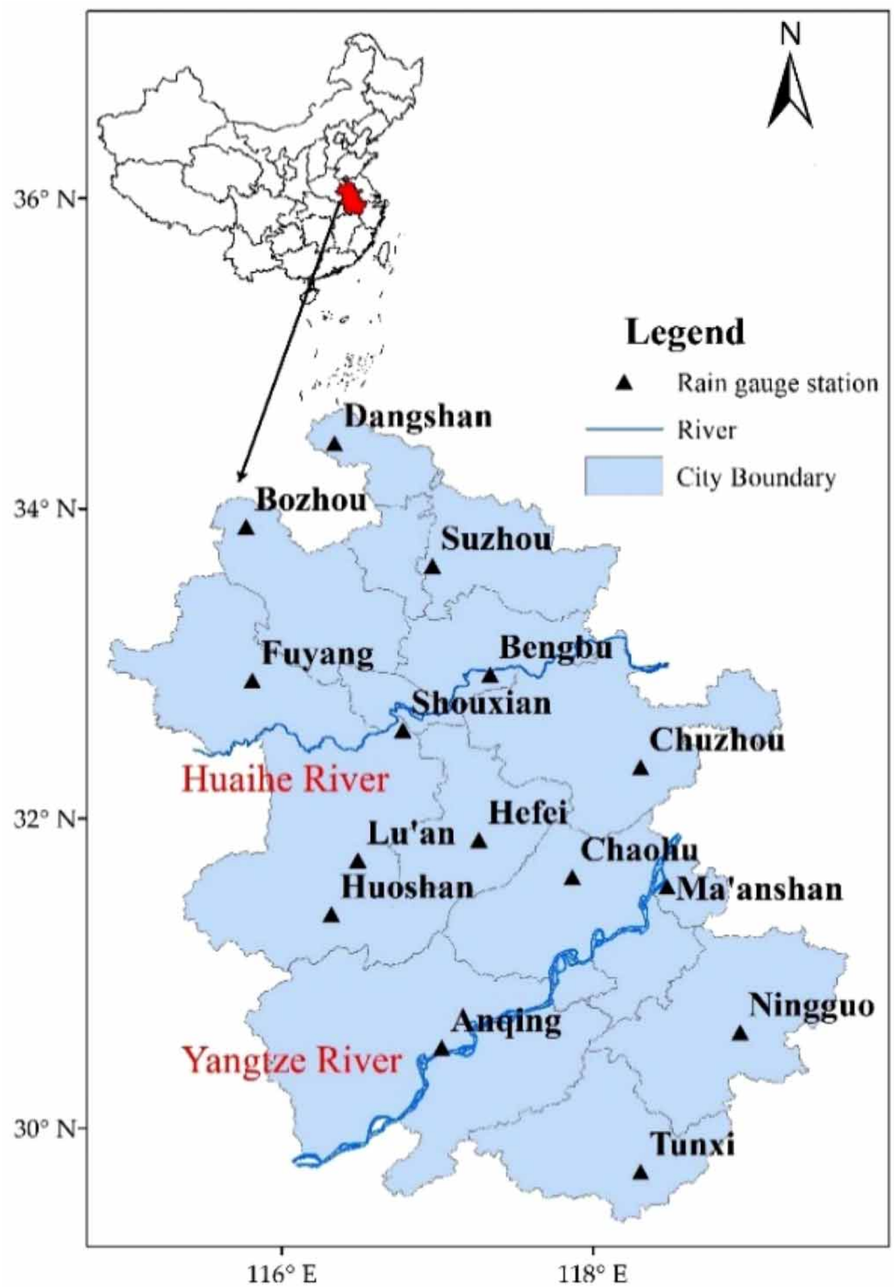


Figure 2 | Location of the study area and the distribution of precipitation stations.

Meiyu intensity. When calculating the Meiyu intensity index, Zhou (1996) and Yu *et al.* (2008) defined Meiyu precipitation and Meiyu length as the characteristics of the concentrated period of Meiyu, instead of the characteristics of the whole Meiyu season (Hu *et al.* 2008). In this study, the characteristics of the whole Meiyu season and the concentrated period of Meiyu are both used to calculate the Meiyu intensity index M:

$$M = \frac{L}{L_0} + 0.5\frac{R/L}{R_0/L_0} + \frac{R}{R_0} - 2.5 \tag{1}$$

where L and L_0 represent Meiyu length and the corresponding average value of the past years, respectively; R and R_0 represent the Meiyu precipitation and the corresponding average value of the past years. According to Equation

(1), the Meiyu intensity index M is calculated to analyze its performance of reflecting the regional flood and drought disasters.

RESULTS AND DISCUSSION

Identification results of the Meiyu process in Anhui Province

Occurrence of the rainy period and the ending date of Meiyu

The three stations in Anqing, Ningguo, and Tunxi are used to calculate the precipitation characteristics of SYA. The observation data of Anqing station from 2017 to 2020 are replaced with the data of Ma'anshan station because there are no observation data during this period. The six stations in Chaohu, Hefei, Chuzhou, Lu'an, Huoshan, and Shouxian are used to identify the Meiyu characteristics in YHA. The five stations in Fuyang, Bengbu, Bozhou, Suzhou, and Dangshan are used in NHA. The data of each station are provided by China Meteorological Data Network. Based on the daily precipitation during 1957–2020, the process characteristics of the identified rainy period covering Meiyu and Huang-Huai rainy seasons in YHA and NHA are shown in Table 1. (The ending date of Meiyu in the NHA was defined based on the definition of ending date of Meiyu in the YHA in the standard. When the SH ridge stably surpasses 27°N, the Meiyu in the NHA ends. The ending date of Meiyu is the following day after the ending of the rainy period in Meiyu season).

Table 1 shows that the Meiyu seasons of 1957, 1965, 1969, and 1970 in YHA and the Huang-Huai rainy season are consecutive as one rainy period. According to the northward jump of SH, 1965 is an empty Meiyu year, and the identified ending date of Meiyu in 1957, 1969, and 1970 is consistent with the results from Xu & Zhang (2007). The ending date of Meiyu in 1957, 1965, 1969, and 1970 resulting from the National Standard are respectively 4, 6, 6, and 4 days later than those identified by the northward jump of SH. In other years, the ending date of Meiyu identified by the National Standard is the same as those identified by the northward jump of SH. However, there is less than 6 days difference between the ending date of Meiyu and those identified by the northward jump of SH when rainy days of the two rainy seasons are consecutive. Since the probability of the rainy season covering two rainy seasons is 6.25%, i.e., 4 out of 64 years, the National Standard can be used to identify the ending date of Meiyu in YHA.

Table 1 | Precipitation and ending date of Meiyu in NHA and YHA during the rainy period covering two rainy seasons

Region	Year	Start and end	Precipitation	Ending date of Meiyu (based on jump of SH)	Ending date of Meiyu (based on the Standard)
YHA	1957	6.30–7.09–7.12	149.7–23.3–173.0	7.10	7.13
	1958	/	/	6.30	6.30
	1960	/	/	6.30	6.30
	1963	/	/	7.13	7.13
	1965	6.30–7.07–8.04	47.6–199.3–246.9	7.08 (Empty Meiyu)	7.14
	1969	7.01–7.17–7.23	413.9–17.6–431.5	7.18	7.24
	1970	7.09–7.22–7.26	178.7–14.6–193.3	7.23	7.27
	2003	/	/	7.12	7.12
	2004	/	/	7.14	7.14
	2008	/	/	7.03	7.03
NHA	1957	7.01–7.09–7.31	67.7–237.1–304.8	7.10 (Empty Meiyu)	7.18
	1958	6.26–6.29–7.14	54.1–202.9–257.0	6.30 (Empty Meiyu)	7.08
	1960	6.19–6.29–7.12	124.8–95.0–219.8	6.30	7.04
	1963	6.30–7.12–8.27	184.6–454.7–639.3	7.13	7.13
	1965	6.30–7.07-8.04	190.6–478.4–669.0	7.08	7.17
	1969	7.11–7.17–7.24	95.5–138.5–234.0	7.18 (Empty Meiyu)	7.25
	1970	7.16–7.22–7.27	83.0–45.9–128.9	7.23 (Empty Meiyu)	7.28
	2003	6.20–7.12–7.22	392.7–109.2–501.9	7.13	7.18
	2004	7.06–7.14–7.27	70.0–179.4–249.4	7.14	7.21
	2008	6.30–7.04–7.18	44.3–6.5–120.8	7.05 (Empty Meiyu)	7.12

Note: The dates in the 'start and end' column represent the onset of Meiyu, ending date of Meiyu, and ending date of Huang-Huai rainy season, respectively. Precipitation refers to the amount in the two rainy seasons and total amount during the rainy period covering two rainy seasons.

In NHA, the rainy days of the Meiyu season and the Huanghuai rainy season are consecutive for the following ten years: 1957, 1958, 1969, 1970, 2008, 1960, 1963, 2003, 2004, and 1965. In 1957, 1958, 1969, 1970, and 2008, there was no rainy period during the rainy season. According to the National Standard, the ending dates of Meiyu in empty Meiyu years are later than those identified by the northward jump of SH, which were 8, 8, 7, 5, 7 days later in the corresponding years. According to the northward jump of SH, the ending dates of Meiyu in 1960, 1963, 2003, and 2004 are consistent with the data of Xu & Zhang (2007) and Huang *et al.* (2012). However, according to the National Standard, the ending dates of Meiyu are 4, 4, 5, and 7 days later, respectively. In 1965, there are 6 rainy days before the northward jump of SH, fulfilling the requirement of the rainy period; therefore, it is identified as a Meiyu year. It is slightly different from empty Meiyu in that year identified by Xu & Zhang (2007). According to the National Standard, the ending date of Meiyu in 1965 was July 17, which is 9 days later than the northward jump of SH. In these ten years, there are nine years with the ending date of Meiyu identified by the National Standard later than the results of the northward jump of SH. Therefore, the ending date of Meiyu in NHA should be identified from the northward jump of SH.

Identification results and analysis of the Meiyu process

The Meiyu process and characteristics in SYA, YHA, and NHA evaluated with the National Standard are shown in Table 2. Following the starting date of Meiyu and rainy period identified by the National Standard, the ending dates of Meiyu in NHA and YHA are determined by the position of the SH ridge and the precipitation characteristics in the three regions with the northward jumps of SH.

As illustrated in Table 2, there are six empty Meiyu years in SYA (i.e., 10% of all years), and 13 empty Meiyu years in YHA (20% of all years), indicating that SYA and YHA belong to the Meiyu region. There are 29 empty Meiyu years in NHA. Moreover, during the concentrated period of Meiyu, there is one year with a length of 6 days, and seven years with daily precipitation less than 100 mm. There are 37 years that are almost empty Meiyu years, which accounts for about 60% of all years. The daily average mean precipitation during the Meiyu season including the empty Meiyu years is 166.2 mm, and the precipitation during the normal Meiyu year is 238.2 mm. The normal Meiyu year was only 40% of all years for NHA, implying that NHA is a transition zone between Meiyu and non-Meiyu regions. Precipitation during the Meiyu season in normal Meiyu years accounts for about 75% of the multi-year average precipitation during June to July in NHA, indicating it is an important factor of the summer precipitation forecast.

Three rain-gauge stations, Shouxian, Fuyang, and Bengbu, are selected to represent the region along the Huaihe River, while three stations, i.e., Bozhou, Suzhou, and Dangshan, are used to represent the northern region of NHA. The Meiyu processes in the region along the Huaihe River and northern part of NHA are identified in 29 empty Meiyu years in NHA. Results show that there is no rainy period in the above 29 years. It also demonstrates that the whole region of NHA is homogeneous regarding the occurrence of Meiyu. Therefore, within the regions of Huaihe River, SYA and YHA are both identified as the Meiyu regions, but NHA is the transition zone between the Meiyu and non-Meiyu regions.

Table 2 shows that the ending date of Meiyu is July 11 in all three regions, and the onset of Meiyu in SYA is June 15, compared with June 18 in YHA and NHA. When the empty Meiyu year is not taken into account, the onset of Meiyu in SYA, YHA, and NHA is June 14, June 19, and June 22, respectively, and the corresponding ending dates are July 12, July 13, and July 14. In short, the onset and ending dates of Meiyu show an increasing tendency from the south to north regions, which reflects the moving characteristics of the main rain-band of the summer monsoon.

When the empty Meiyu year is not considered, the Meiyu precipitation in SYA, YHA, and NHA is 376.4 mm, 270.7 mm, and 238.2 mm, respectively, which accounts for about 83, 79, and 75% of the precipitation from June to July. The Meiyu length is 27.5 days, 23.7 days, and 21.6 days in SYA, YHA, and NHA, respectively, and the corresponding length of the concentrated precipitation period is 25.2 days, 20.7 days, and 17.9 days, and the difference between the precipitation in the concentrated precipitation period and that in the Meiyu season is 3.2 mm, 7.7 mm, and 10.5 mm, respectively. It shows that the Meiyu precipitation is the most important part of precipitation in Anhui Province during June to July. The precipitation during the intermittent period of the Meiyu is relatively small. Moreover, the length of the Meiyu season and the concentrated precipitation period decreases from south to north.

Meiyu intensity index M is divided into three levels in the National Standard. When $M > 1.25$, the strong level is defined; $0.375 < M < 1.25$ denotes a slight strong level, and the normal level is specified with $-0.375 < M < 0.375$. The M values in the precipitation concentration period and the whole Meiyu season in Table 2 are consistent, and the positive and negative values of the two types of the period are almost the same in SYA. In 1972, 1974, 1979, 1984, and 2004 of YHA, the positive and

Table 2 | The characteristics of Meiyu during 1957–2020 in SYA, YHA, and NHA

Year	Onset and ending date of Meiyu in SYA	Concentrated period			The whole season		Onset and ending date of Meiyu in YHA	Concentrated period			The whole season		Onset and ending date of Meiyu in NHA	Concentrated period			The whole season	
		L	R	M	R	M		L	R	M	R	M		L	R	M	R	M
1957	6.20–7.10	20	299.9	−0.41	299.9	−0.33	6.30–7.13	13	173.0	−0.68	173.0	−0.56	6.20–7.10*				90.9	−0.80
1958	6.22–6.30				10.5	−2.12	6.22–6.30				33.3	−1.81	6.22–6.30*				54.1	−1.17
1959	6.16–7.07	21	203.8	−0.80	203.8	−0.77	6.26–7.02	6	58.9	−1.59	58.9	−1.52	6.26–7.09	13	62.3	−1.32	62.3	−1.27
1960	6.08–6.25	17	230.6	−0.76	230.6	−0.70	6.07–6.30	23	252.1	0.01	252.1	0.10	6.19–6.30*	11	124.8	−0.91	124.8	−0.60
1961	6.07–6.15	8	142.0	−1.22	142.0	−1.13	6.06–6.16				91.4	−1.24	6.06–6.16				12.0	−1.92
1962	6.16–6.27	11	137.1	−1.29	163.2	−1.07	6.15–7.10	25	258.5	0.10	258.5	0.18	6.14–7.09	12	66.9	−1.33	175.0	0.07
1963	6.16–7.12	26	185.5	−0.73	185.5	−0.72	6.22–7.13	21	177.1	−0.48	177.1	−0.43	6.30–7.13*	13	184.6	−0.43	184.6	0.03
1964	6.18–7.01	13	291.9	−0.46	291.9	−0.34	6.24–7.02	8	75.8	−1.45	75.8	−1.37	6.17–7.01				38.1	−1.49
1965	6.18–7.08				127.4	−1.14	6.18–7.08*				58.2	−1.24	6.30–7.08*	8	190.6	−0.32	190.6	0.43
1966	6.16–7.13	27	429.6	0.25	429.6	0.33	6.16–7.14				166.1	−0.29	6.16–7.14				83.7	−0.59
1967	6.15–7.06	21	208.6	−0.78	208.6	−0.74	6.24–7.06	12	58.7	−1.50	58.7	−1.49	6.26–7.05	9	204.9	−0.24	204.9	0.50
1968	6.23–7.21	28	169.3	−0.73	169.3	−0.73	6.25–7.20	25	326.2	0.47	326.2	0.60	6.26–7.21	25	311.6	0.73	311.6	1.22
1969	6.24–7.18	24	569.4	0.76	569.4	0.91	7.01–7.18*	17	417.4	0.89	417.4	1.18	6.24–7.18*				164.7	−0.04
1970	6.18–7.21	28	460.2	0.39	460.9	0.58	7.09–7.23*	14	178.7	−0.63	178.7	−0.52	7.16–7.23*				189.5	0.54
1971	6.09–6.27	14	126.4	−1.31	130.1	−1.18	6.09–6.27	11	178.8	−0.64	201.2	−0.33	6.09–6.26	14	142.2	−0.71	168.7	−0.14
1972	6.20–7.02	12	113.0	−1.41	113.0	−1.37	6.20–7.04	14	261.5	−0.08	261.5	0.11	6.19–7.05	16	257.5	0.13	257.5	0.72
1973	6.16–7.14	28	314.9	−0.17	314.9	−0.13	6.16–7.15	29	229.7	0.09	229.7	0.12	6.25–7.06	23	203	0.01	203.0	0.26
1974	6.10–7.20	33	501.0	0.65	502.4	0.91	6.09–7.22	22	213.6	−0.24	228.7	0.61	6.09–7.22				103.7	0.16
1975	6.17–7.17	30	418.9	0.27	418.9	0.35	6.17–7.16	21	317.1	0.32	334.7	0.74	7.01–7.12	11	78.4	−1.27	78.4	−1.12
1976	6.16–7.15	25	186.4	−0.76	187.9	−0.63	6.17–7.16	14	102.7	−1.14	146.1	−0.37	6.15–7.16				154.7	0.09
1977	6.09–7.02	23	355.6	−0.12	355.6	−0.04	6.09–7.03				52.1	−1.12	6.09–7.03				16.3	−1.31
1978	6.08–6.24				45.4	−1.66	6.08–6.24				33.4	−1.56	6.08–6.24				15.1	−1.65
1979	6.19–7.24	29	363.3	0.04	364.1	0.25	6.19–7.22	21	228.0	−0.19	319.0	0.76	6.29–7.22	23	284.3	0.50	284.3	0.96
1980	6.06–7.17	41	405.2	0.54	405.2	0.57	6.17–7.22	35	454.8	1.44	454.8	1.58	6.16–7.21	35	239.4	0.77	239.4	0.89
1981	6.27–7.03	6	237.7	−0.32	237.7	−0.12	6.22–7.02	10	98.7	−1.25	98.7	−1.17	6.19–6.29	10	118.9	−0.97	118.9	−0.63
1982	7.11–7.26	15	198.7	−0.94	198.7	−0.87	7.09–7.24	15	366.8	0.60	366.8	0.88	7.09–7.26	17	284	0.32	284.0	0.96
1983	6.09–7.17	38	705.3	1.51	705.3	1.63	6.11–7.19	38	359.6	1.08	359.6	1.14	6.09–7.17				169.9	0.46
1984	6.07–7.07	20	395.9	0.01	402.8	0.28	6.06–7.06	20	222.7	−0.24	225.1	0.13	6.04–7.12	22	170	−0.23	185.6	0.58
1985	6.24–7.06	12	167.7	−1.11	167.7	−1.05	6.22–7.06				88.0	−1.21	6.22–7.06				28.1	−1.60
1986	6.16–7.08	22	408.4	0.08	408.4	0.18	6.15–7.24	21	179.5	−0.46	179.5	−0.41	6.15–7.08				58.7	−0.98
1987	6.29–8.01	33	314.4	−0.03	314.4	0.00	7.02–7.31	20	269.7	0.03	288.5	0.47	7.05–7.29	8	111.6	−1.04	205.2	0.30
1988	6.11–6.30	12	256.4	−0.63	256.9	−0.55	6.11–6.30				89.4	−1.06	6.11–6.30				9.3	−1.58
1989	6.03–7.14	36	429.3	0.47	430.4	0.66	6.03–7.15	25	342.9	0.56	380.2	1.38	6.03–7.16	24	359.6	0.98	368.8	2.12
1990	6.14–7.03	19	215.0	−0.80	215.0	−0.75	6.14–7.03	19	136.4	−0.78	136.4	−0.75	6.14–7.03	15	108.2	−0.92	113.7	−0.62
1991	5.19–7.14	46	677.8	1.63	677.8	1.99	5.18–7.15	49	951.8	4.26	959.5	4.88	5.18–7.17	33	481.2	2.01	512.0	3.73
1992	6.14–7.14	30	295.0	−0.19	295.0	−0.16	7.06–7.21	15	93.2	−1.17	93.2	−1.15	7.10–7.23	13	104.6	−1.01	104.6	−0.82

(*Continued*)

Table 2 | Continued

Year	Onset and ending date of Meiyu in SYA	Concentrated period			The whole season		Onset and ending date of Meiyu in YHA	Concentrated period			The whole season		Onset and ending date of Meiyu in NHA	Concentrated period			The whole season	
		L	R	M	R	M		L	R	M	R	M		L	R	M	R	M
1993	6.12–7.09	27	435.7	0.27	435.7	0.36	6.20–7.08	18	143.8	−0.77	172.7	−0.52	6.14–7.09				68.9	−0.82
1994	6.08–6.28	20	360.3	−0.15	360.3	−0.05	6.07–6.28				110.2	−0.86	6.07–6.28				103.3	−0.66
1995	6.20–7.08	18	401.6	0.03	401.6	0.15	6.11–7.10	29	239.2	0.14	239.2	0.18	6.17–7.17				56.5	−0.73
1996	6.02–7.24	47	1,021.5	2.82	1,022.8	3.11	6.03–7.22	49	559.9	2.45	559.9	2.56	6.16–7.27	37	533.4	2.45	533.7	3.29
1997	6.30–7.16	16	200.1	−0.92	200.1	−0.86	6.30–7.17	17	141.2	−0.81	141.2	−0.76	6.29–7.14				69.0	−1.15
1998	6.12–8.02	33	626.6	1.12	629.4	1.68	6.25–7.04	9	169.5	−0.67	169.5	−0.49	6.29–7.05	6	162.3	−0.44	162.3	0.37
1999	6.08–7.19	35	1,017.9	2.58	1,022.1	2.88	6.23–7.18	15	189.6	−0.55	226.1	−0.17	6.07–7.18				167.6	0.55
2000	6.20–6.30				84.2	−1.57	6.20–6.30	10	75.5	−1.43	75.5	−1.38	6.21–6.30	9	308.8	0.64	308.8	1.82
2001	6.09–6.27	18	195.3	−0.90	195.3	−0.86	6.09–6.20	11	66.4	−1.48	66.4	−1.45	6.09–6.27				65.1	−1.10
2002	6.18–6.29	11	226.2	−0.78	226.2	−0.67	6.19–6.29	10	188.1	−0.55	188.1	−0.37	6.18–6.29				122.1	−0.62
2003	6.23–7.12	14	219.4	−0.84	219.4	−0.73	6.20–7.12	22	513.1	1.45	513.1	1.75	6.20–7.13*	23	392.7	1.15	392.7	1.90
2004	6.14–7.15	14	240.0	−0.74	314.6	−0.06	6.14–7.14	20	214.3	−0.29	230.1	0.16	7.06–7.14*	8	70	−1.42	70.0	−1.20
2005	6.25–7.18				225.1	−0.65	7.06–7.17	11	193.1	−0.53	193.1	−0.36	6.25–7.18	23	283.9	0.50	283.9	0.96
2006	6.22–7.12	13	247.5	−0.69	248.0	−0.58	6.21–7.12	21	228.1	−0.18	228.1	−0.10	6.21–7.11	14	320.4	0.55	320.9	1.27
2007	6.13–7.30	40	283.9	0.08	284.0	0.31	6.23–7.29	32	354.3	0.83	354.9	1.05	6.19–7.27	38	549.4	2.58	549.4	3.34
2008	6.08–7.03	20	225.8	−0.73	241.7	−0.51	6.17–7.04				143.9	−0.74	6.17–7.04*				93.2	−0.86
2009	6.17–7.02	15	177.8	−1.04	177.8	−0.99	6.17–7.05				118.6	−0.89	6.17–7.05				73.7	−1.02
2010	6.20–7.18	28	484.6	0.48	484.6	0.58	7.03–7.24	21	283.8	0.13	283.8	0.27	6.20–7.16				40.0	−1.03
2011	5.27–7.21	55	710.1	2.01	710.1	2.08	6.04–7.21	39	385.6	1.24	387.2	1.59	5.27–7.04				57.1	−0.40
2012	6.26–7.18				210.9	−0.71	6.26–7.15	19	178.2	−0.53	178.2	−0.46	6.29–7.17	18	226.8	−0.02	226.8	0.41
2013	6.16–7.08	22	337.5	−0.22	337.5	−0.14	6.16–7.08				242.6	0.02	6.16–7.08				88.8	−0.76
2014	6.17–7.18	31	499.8	0.60	499.8	0.69	6.25–7.13	11	178.5	−0.64	217.4	−0.21	6.20–7.18				42.1	−0.93
2015	6.07–7.27	50	617.6	1.55	617.6	1.61	6.15–7.25	35	478.6	1.56	482.0	1.87	6.15–7.24	22	226.2	0.11	299.4	1.48
2016	6.15–7.20	35	653.3	1.26	653.3	1.38	6.20–7.22	32	488.8	1.51	488.8	1.70	7.13–7.22	10	87.8	−1.23	87.8	−0.99
2017	6.19–7.11	15	172.3	−1.06	210.5	−0.71	6.30–7.11	11	86.9	−1.32	86.9	−1.27	7.01–7.11	10	81.5	−1.28	81.5	−1.08
2018	6.19–7.11	22	335.5	−0.22	335.5	−0.15	7.02–7.11	9	137.8	−0.93	137.8	−0.79	7.04–7.11	7	90.7	−1.22	90.7	−0.87
2019	6.17–7.23	36	484.5	0.67	484.5	0.74	6.17–7.19				155.8	−0.20	6.17–7.19				61.8	−0.61
2020	6.03–7.29	56	1,059.3	3.19	1059.3	3.33	6.10–8.01	44	936.0	4.03	945.6	4.64	6.10–8.01	45	548.4	2.88	550.1	3.73
Ave	6.15–7.11	25.2	373.2	0	352.1	0	6.18–7.11	20.7	263.0	0	237.3	0	6.18–7.11	17.9	227.7	0	166.2	0

Note: The blank part of the value of *M* in the column 'concentration period' denotes an empty Meiyu year; The onset and ending dates of Meiyu in empty Meiyu are the beginning day of SH ridge fulfilling the requirement of Meiyu season and the day next to the ending date of SH ridge fulfilling the requirement of Meiyu, respectively; '*' denotes the year in which the rainy period is covering Meiyu and Huang-Huai rainy seasons.

negative values are different. The grade of M values in the concentration period is normal in the above-mentioned five years. However, the grade of M values in the Meiyu season is relatively strong in 1974 and 1979, and normal in 1972, 1984, and 2004. In NHA, there is a large difference in precipitation between the concentrated precipitation period and the Meiyu season. Moreover, there are eight years in which the positive and negative values of M in the two periods are inconsistent, nor at the same level. The M value during the concentrated period of Meiyu in the three regions is shown in Figure 3.

Taking 1990 as the division in Figure 3, the M values before 1990 in all three regions are relatively small. The M values reach 1.25 only in 1980 and 1983, which is classified as a strong level. Severe drought occurred in Anhui Province during 1958–1968, and 1976–1978; afterwards, the probability of M values exceeding 1.25 significantly increased in the three regions. In 1991, 1996, 1998, 1999, 2003, 2016, and 2020, Anhui Province experienced severe floods. In general, the M value shows an increasing trend, which is consistent with the upward trend of the Meiyu intensity index along the Huaihe River analyzed by Yu *et al.* (2008). In Table 3 and Figure 3, the synchronization of M values in SYA and YHA is better, followed by that in YHA and NHA. The poor synchronization of M values in SYA and NHA regions indicates that Meiyu is zonal distributed (Wang *et al.* 2018).

Meiyu intensity index and its reflection of flood and drought disasters

The Meiyu intensity index is smallest in the empty Meiyu year, during which, Meiyu precipitation or the average precipitation intensity is small. Among the six empty Meiyu years in SYA (shown in Table 2), the Meiyu precipitation in three years is less

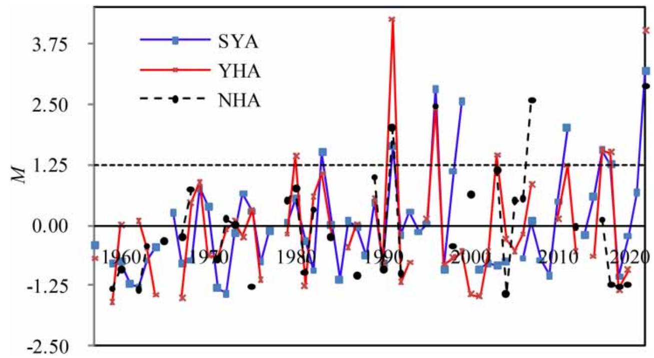


Figure 3 | Meiyu intensity index during the concentrated period of Meiyu in SYA, YHA, and NHA from 1957 to 2020.

Table 3 | Meiyu intensity index M and precipitation and rainfall intensity during the concentrated period of Meiyu precipitation in SYA, YHA, and NHA regions

	M			**Precipitation (mm)–rainfall intensity (mm/h)–heavy rain days(d)**		
Years	**SYA**	**YHA**	**NHA**	**SYA**	**YHA**	**NHA**
1969	0.76	0.89		569.4–23.7–8	417.4–24.6–8	164.7–6.9–3
1980	0.54	1.44	0.77	405.2–9.9–3	454.8–13.0–6	239.4–6.8–1
1983	1.51	1.07		705.3–18.6–10	359.6–9.5–5	169.9–4.5–3
1989	0.47	0.56	0.98	430.4–10.5–5	380.2–9.1–6	368.8–8.6–5
1991	1.63	4.26	2.01	677.8–12.1–7	959.5–16.5–13	512.0–8.5–6
1996	2.82	2.45	2.45	1,022.8–19.7–13	559.9–11.4–6	533.7–13.0–9
1999	2.58	– 0.55		1,022.1–24.9–15	226.1–15.1–3	167.6–4.1–3
2003	– 0.84	1.45	1.15	219.4–11.5–4	513.1–23.3–6	219.4–15.7–5
2011	2.01	1.24		710.1–12.9–10	387.2–8.2–4	57.1–1.5–0
2015	1.55	1.56	0.11	617.6–12.4–7	482.0–12.1–8	299.4–7.7–5
2016	1.26	1.51	– 1.23	653.3–18.7–8	488.8–15.3–5	87.8–9.8–1
2020	3.19	4.03	2.88	1,059.3–18.9–15	945.6–18.2–12	550.1–10.6–7

than 100 mm, and the average precipitation intensity in the other three years is less than 10 mm/d. In 8 of the 13 empty Meiyu years in YHA, the precipitation is less than 100 mm, and the average precipitation intensity in the remaining four years, except 2013, less than 6 mm/d. The precipitation in the above period is 242.6 mm, which is close to the mean value of Meiyu. Among the 29 empty Meiyu years in NHA, the precipitation in 21 years is less than 100 mm, the precipitation in seven of the remaining eight years is less than 10 mm/d, and the precipitation in the remaining one year is 11 mm/d. SYA and YHA experienced severe droughts in empty Meiyu years. NHA encountered severe droughts during the rainless Huang-Huai rainy season after empty Meiyu, such as 1966, 1978, 1994, 2001, and 2019.

Especially in SYA and YHA, which are located in the main rain-band of Meiyu, during the concentrated period of Meiyu, the greater the precipitation amount and intensity, the higher chance of serious floods. For SYA and YHA, when the grade of *M* values lies at a little strong level or one of the regions is reaching a strong level, the characteristics of the concentrated period of Meiyu in three regions are shown in Table 3.

In Table 3, in 1991, 1996, 2015, 2016, and 2020, the grades of *M* values in SYA and YHA had a strong level, and severe floods occurred in the Yangtze River Basin in Anhui Province. Among them, the grades of *M* value in NHA were also strong in 1991, 1996, and 2020. In 2020, the Meiyu precipitation and length in SYA were the highest since records, and the number of heavy rain days was also the highest. The Meiyu precipitation and the number of heavy rain days in YHA both ranked second, only less than those in 1991, while precipitation intensity was stronger than that in 1991. The Meiyu precipitation in NHA was highest since records began in 1957, and the number of heavy rain days ranked the second. In that year, both the Yangtze River Basin and the Huaihe River Basin in Anhui Province experienced catastrophic floods. The water level of Chaohu Lake exceeded the highest water level in history, and the water level of Zhengyangguan station in the Huaihe River ranked second on record. The circumstances in 1996 were similar to those in 2020, but the Meiyu precipitation in YHA in 1996 was significantly less than that in 2020. In 1991, the precipitation in YHA and NHA was similar to that in 2020, but the precipitation in SYA in 1991 was significantly lower than that in 2020. In 2016, SYA and YHA both had heavy rain during the Meiyu season, but precipitation during the Meiyu season in NHA was very small. In that year, severe floods occurred in the Yangtze River Basin in Anhui Province. In 2015, the *M* value in SYA and YHA was greater than that in 2016, but the floods in 2016 were significantly heavier than those in 2015. The Meiyu precipitation and its intensity in 2016 were both larger than that in 2015, and only the Meiyu length was shorter than that in 2015. It shows that Meiyu length as a sub-item of the *M* value may produce *M* value of the Meiyu process with the same precipitation amount and longer duration, but the flood disaster caused by the rainfall with the same rainfall amount and longer duration is generally less severe. Since the greater the amount and intensity of the precipitation process, the more serious the flood is; moreover, the Meiyu precipitation and the average intensity during the Meiyu season have indirectly reflected the Meiyu length. Therefore, the duration should be removed, and only Meiyu precipitation and intensity used to calculate Meiyu intensity index. The larger Meiyu intensity index corresponds to the precipitation process with higher rainfall and rain intensity, and it can better reflect the disaster response of the precipitation process and can consider the effect of the Meiyu characteristics on the flood disaster.

As shown in Table 3, the *M* values in SYA and YHA in 2016 were both lower than those in 2015. The intensity of the Meiyu precipitation in 2016 was higher than in 2015, the number of heavy rain and heavy rainstorm days in 2015 was 8 and 5, respectively, while it was 7 and 2, respectively, in 2016. Although the number of heavy rain and rainstorm days during the Meiyu season in 2016 was 5 and 2, respectively, it was slightly lower than that in 2015 which was 8 and 3, respectively. There was a heavy rainstorm day with precipitation of 151.1 mm in 2016, which was only 75.6 mm in 2015, indicating that heavy rain and rainstorm days are also key factors affecting floods. The *M* value in SYA and YHA in 2011 was relatively large due to the longer rainy period. When looking at the two items of amount and intensity, or at the three items of amount, intensity, and heavy rain days, the *M* value in that year was not very strong, which is closer to the actual circumstances of floods. In 1969, the *M* values in SYA and YHA were not large, but the Meiyu intensity index was very strong from the perspective of amount and intensity, which corresponded to the severe disaster in that year. The *M* values in 1980 and 1989 were not large. From the perspective of amount and intensity, or amount, intensity, and number of heavy rain days, the Meiyu intensity index in the two years was not large, which was close to the actual disaster.

In Table 3, the values of *M* in SYA and YHA were relatively high in 1983, and severe floods occurred in the Yangtze River Basin in Anhui Province that year. In addition to the high precipitation amount and intensity, the disaster in that year was also closely related to the continuous high water level in the Anhui section of the Yangtze River from June to July. The precipitation amount and the intensity of Meiyu in SYA in 1998 were similar to those in 1983. The severe floods in the Chaohu Basin of Anhui Province were also related to the continuous high water level in the Anhui section of the Yangtze River during the Meiyu season. From July to September of that year, the flow of Chaohu into the Yangtze River was zero. In 1999, the amount of Meiyu precipitation in SYA was equivalent to that in 2020 and 1996, while the Meiyu precipitation in YHA was lower than its average value, and it was an empty Meiyu year in NHA. In that year, SYA, such as Qingyi River and Shuiyang River in Anhui Province, experienced a super-historical flood. When using precipitation amount and intensity, or amount, intensity, and number of heavy rain days to calculate the M values in 1996, 1999, and 2020, the M values are very large. It can be seen that Meiyu intensity index of the National Standard based on precipitation amount, intensity, and duration is a good indicator of water disasters. The Meiyu intensity index calculated with precipitation amount, intensity, and heavy rain days as factors may better characterize the impact of precipitation on flood and drought disasters.

CONCLUSIONS

Following the definition of the onset and ending dates of Meiyu with the consideration of the atmospheric circulation, precipitation, and temperature in the National Standard of China, the Meiyu processes and characteristics in SYA, YHA, and NHA during 1957–2020 are identified. In the years with the rainy period covering Yangtze-Huai and Huang-Huai rainy seasons, similarities and differences of ending dates of Meiyu in YHA and NHA are specified by comparison between the northward jump of SH and the National Standard. The performance of Meiyu intensity index for the identification of flood and drought disasters was also analyzed. In summary, the main conclusions are given as follows:

1. With the Huaihe River as the boundary, SYA and YHA are located in the Meiyu region, while NHA is located in the transition zone between Meiyu and non-Meiyu regions. The whole region of NHA is homogeneous in terms of the occurrence of Meiyu.
2. The ending dates of Meiyu identified by the National Standard and the northward jump of SH are consistent in SYA and YHA. However, the ending date of Meiyu identified by the National Standard is generally later than that resulting from the northward jump SH in NHA.
3. The Meiyu season and the Huang-Huai rainy season cannot be consecutive as one rainy period in SYA, while there are about 6 and 16% years in which the rainy period covers two rainy seasons in YHA and NHA, respectively. In these years, ending dates of Meiyu specified by the northward jump of SH are earlier than the date from the National Standard within 6 and 9 days in SYA and NHA, respectively. The northward jump of SH should be used as the criterion to identify the ending date of Meiyu in NHA.
4. The Meiyu intensity index based on Meiyu precipitation amount, intensity, and duration can well reflect flood and drought disasters. For example, the grades of M values in SYA in 2020 had a strong level, the Meiyu precipitation and length in SYA in 2020 were the highest since records began, and the number of heavy rain days was also the highest. In addition, the suggested Meiyu intensity index has better performances regarding the relations between Meiyu and flood or drought disasters.
5. Excluding the empty Meiyu year, the onset of Meiyu in SYA, YHA, and NHA is June 14, June 19, and June 22, respectively. The ending date of Meiyu is July 12, July 13, and July 14, respectively. The Meiyu length in SYA, YHA, and NHA is 27.5 days, 23.7 days, and 21.6 days, respectively. The lengths of the precipitation concentration period in these regions are 25.2 days, 20.7 days, and 17.9 days, respectively. Precipitation during the Meiyu season is 376.4 mm, 270.7 mm, and 238.2 mm, respectively, while precipitation during the concentration period is 373.2 mm, 263.0 mm, and 227.7 mm, accounting for more than three-quarters of the precipitation from June to July.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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