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Probability Distribution of Precipitation Extremes over the Yangtze River Basin

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Abstract: Based on the daily observational precipitation data of 147 stations in the Yangtze River basin for 1960−2005, and the projected daily data of 79 grids from ECHAM5/MPI-OM in the 20th century, time series of precipitation extremes which contain annual maximum (AM) and Munger index (MI) were constructed. The distribution feature of precipitation extremes was analyzed based on the two index series. Research results show that (1) the intensity and probability of extreme heavy precipitation are higher in the middle Mintuo River sub-catchment, the Dongting Lake area, the mid-lower main stream section of the Yangtze River, and the southeastern Poyang Lake sub-catchment; whereas, the intensity and probability of drought events are higher in the mid-lower Jinsha River sub-catchment and the Jialing River sub-catchment; (2) compared with observational data, the averaged value of AM is higher but the deviation coefficient is lower in projected data, and the center of precipitation extremes moves northwards; (3) in spite of certain differences in the spatial distributions of observed and projected precipitation extremes, by applying General Extreme Value (GEV) and Wakeby (WAK) models with the method of L-Moment Estimator (LME) to the precipitation extremes, it is proved that WAK can simulate the probability distribution of precipitation extremes calculated from both observed and projected data quite well. The WAK could be an important function for estimating the precipitation extreme events in the Yangtze River basin under future climatic scenarios.
Key words: precipitation extremes; ECHAM5 model; probability distribution model; Yangtze River basin

Introduction

Twentieth century is the most significant warming period in the last thousand years [1]. Under the circumstance of surface temperature increase, the quickening of water-cycle and the increase in rainfall rate might be expected with the strengthening of atmospheric water holding capacity and potential evaporation capacity. Since changes in frequency and intensity of extreme events have serious impact on the natural and human society systems [1−2], relevant studies have drown much attention from government and the public. China is an area vulnerable to droughts/floods, and the water-related hazards have increased in recent years. Previous studies indicate that precipitation has concentrated evidently at more places in China [3] in the past half century. Besides, the frequency and intensity of rainstorms have shown increasing trends in most parts of eastern China [4], extreme precipitation in the period of meiyu season has also exhibited a significant increase trend in the last half century [5], and further research result also predicts the aggravation of large scale drought hazard for the next few decades [6].

Climatic factors are a kind of random variables, and their extreme values can be expressed as a certain function of these variables. Although it is hard to forecast the extreme events, we can deduce the extreme value in any given return period with the help of frequency analysis [7]. Generalized Extreme Value (GEV), Generalized Pareto distribution (GPD), and Gamma distribution are commonly used to simulate the frequency of extreme heavy rainfull [8−11]. But few distributions deal with drought events in the previous studies. Based on the daily precipitation record of 147 observational stations for 1960−2005 and the modeling data from ECHAM5/MPI-OM of 79 grids for 1941−2000, the spatial-temporal characteristics and frequency distribution of extreme heavy precipitation/droughts over the Yangtze

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River basin were analyzed in current study to seek a scientific method for the estimation of the precipitation extremes under future climate change scenarios.

1 Spatial distribution of observed precipitation extremes

For analyzing precipitation extremes, the annual maximum value is selected for each year to construct the AM series and to define extreme heavy precipitation, and the time series of the longest period of consecutive days with daily precipitation below 1.27 mm — MI series is constructed following the concept of Munger index [12] to analyze the drought situation for flood season (April to September) in the present study.

Based on the observed daily precipitation for flood-season, spatial distributions of the AM and MI indices are displayed in terms of arithmetic mean in 1960–2005 (Fig. 1). As shown in Fig.1 (a), mean AM is higher in the eastern Yangtze River basin than that in the western basin. In most parts of the mid-lower Yangtze reaches, the AM value exceeds 80 mm/d, while in the western upper Yangtze reaches it is below 60 mm/d. There are three heavy precipitation centers, with AM exceeding 100 mm/d, in the mid-lower Mintuo River sub-catchment in the upper Yangtze reaches, the Dongting Lake area, and the Poyang Lake area and the main-stream section of the mid-lower Yangtze reaches. According to the spatial pattern of MI (Fig.1b), it is clear that the drought situation is less severe in the upper reaches than in the mid-lower reaches. Except for Jinsha River sub-catchment, MI is mostly below 16 d over the upper reaches, and the lowest value below 12 d is located in the Mintuo River sub-catchment; while for most parts of the mid-lower reaches, MI exceeds 16 d. Three drought centres with MI above 18 d, lie in the upper and lower Jinsha River sub-catchment; the lower Hanjiang River sub-catchment, the middle main stream section of the Yangtze River and the Dongting Lake sub-catchment; and the lower main stream section of the Yangtze River and the Poyang Lake sub-catchment (Fig. 1b), respectively.

In order to display the amplitude of variations in precipitation extremes over the Yangtze River basin, the deviation coefficient (the ratio of the standard deviation to the mean) was calculated for each station with the results spatially plotted in Fig. 2. For AM series, the deviation coefficient is less than 0.35 in most parts of the Jinsha River sub-catchment, while greater than 0.45 in heavy rainstorm centers, such as the mid-Mintuo River sub-catchment, the Dongting Lake area, the middle and lower mainstream

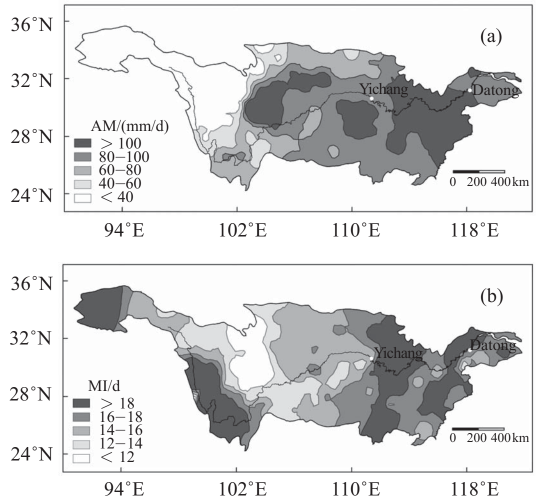

Fig. 1 Spatial distribution of observed precipitation extremes over the Yangtze River basin (a) mean AM, (b) mean MI

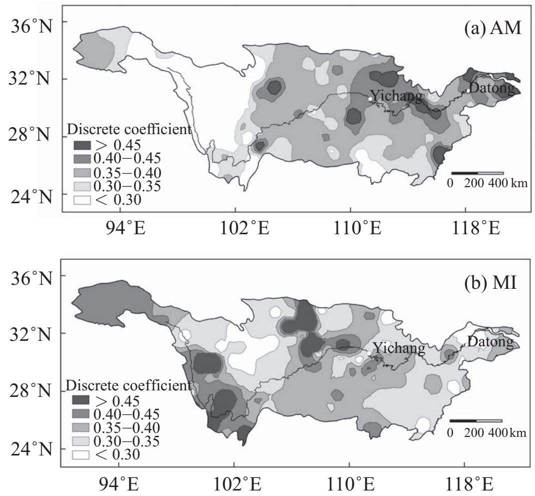

Fig. 2 Spatial distribution of deviation coefficients of observed precipitation extremes over the Yangtze River basin (a) AM series, (b) MI series

section of the Yangtze River, and the southeastern Poyang Lake sub-catchment. The fact that the deviation coefficient is the highest in heavy rainstorm centers means that the probability and intensity of precipitation extremes are higher than their surrounding areas (Fig. 2a). As for MI series, the deviation coefficient is less than 0.35 in the Mintuo River sub-catchment, the upper Jialing River sub-catchment, the lower mainstream section of the Yangtze River, and the Poyang Lake sub-catchment. The areas with a high deviation coefficient of more than 0.45 are located in the mid-lower Jinsha River sub-catchment and the Jialing River sub-catchment, where the probability and intensity of droughts are the highest in the whole Yangtze River basin (Fig. 2b).

2 Probability distribution of observed precipitation extremes

Previous studies have shown that General Extreme Value distribution model (GEV) (including type I, type II, and type III) describes distribution characteristics of the maximum and minimum value very well [13], while, a 5-parameter Wakeby distribution model (WAK) is able to flexibly simulate shapes of most 2- and 3-parameter functions [14]. Thus, the GEV and WAK models are applied to quantify the characteristics of drought/flood events and to analyze the probability distribution of precipitation extremes over the Yangtze River basin in this paper. Their distribution parameters are estimated based on the available sample data using the method of L-moment estimator (LME) [15].

For selecting a robust distribution for precipitation extremes over the Yangtze River basin, Kolmogorov-Smirnov (KS) [15] test is employed to examine whether a sample comes from a population with a specific distribution. In the case when the maximum D_n (differences between empirical distribution $F_n(x)$ and theoretic distribution $F(x)$) is smaller than the critical KS statistic D_n, the simulation result of sample series using the theoretical distribution function can be viewed as being statistically significant. With sample size n = 46 (observational data from 1960 to 2005), critical value of KS statistic is D = 0.177 at significance level α = 0.1.

2.1 *Simulation results of distribution functions*

Applying 3-parameter GEV distribution and 5-parameter WAK distribution to simulate extreme values from 147 stations for 1960–2005 in the Yangtze River basin, we get the KS statistics D_n for AM and MI series, as is shown in Table 1. It can be seen that both of the two distributions can simulate precipitation extremes at sufficient accuracy, and simulation results have reached statistical significance (α=0.1) for 97% of the 147 stations, but WAK distribution is superior to GEV distribution when viewed from the largest difference between empirical distribution $F_n(x)$ and theoretical distribution $F(x)$. Using WAK distribution to simulate AM and MI series, 92% and 68% of the 147 stations reach KS statistics level (D_n<0.09), while using GEV distribution, 87% and 48% of the 147 stations reach the same level, respectively.

2.2 *Spacial distribution of precipitation extremes at recurrence intervals of 50 and 100 years*

One of the main purposes of frequency analyses is to determine peaks at different recurrence intervals [16]. T years return period floods/droughts means extreme events corresponding to cumulative frequency F =1−1/ T. Based on parameters estimated using LME, 50- and 100-year return period precipitation extremes are calculated and the geographical distributions of 50-year return period AM and

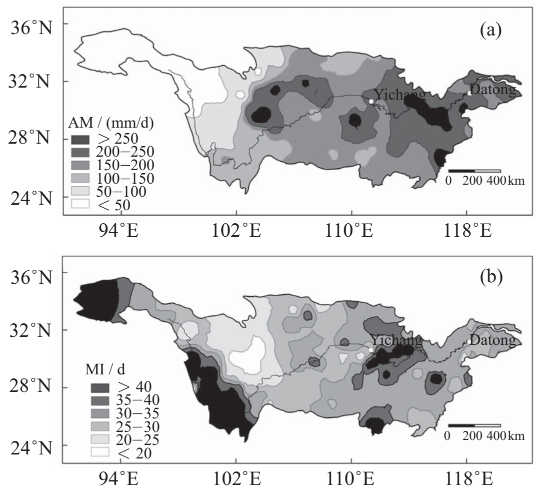

Fig. 3 Spatial distribution of precipitation extremes for a recurrence period of 50 years over the Yangtze River basin (a) maximum daily precipitation, (b) duration of drought period

Table 1 KS statistics for GEV and WAK distributions computed from AM and MI series at 147 stations in the Yangtze River basin (unit: station number)

Series	KS statistics	D_n group						
		<0.03	0.03–0.06	0.06–0.09	0.09–0.12	0.12–0.15	0.15–0.17	>0.17
AM	GEV	0	48	80	15	0	0	4
	WAK	0	73	63	6	2	0	3
MI	GEV	0	6	65	53	17	1	5
	WAK	0	13	87	32	9	1	5

MI from WAK function are displayed in Fig. 3, respectively. It is seen that general spatial patterns of Fig. 3 and Fig. 1 are resemble to each other, but with different quantity levels. The 50-year return period AM is greater than 200 mm/d in the heavy precipitation region of the Yangtze River basin, and even more than 250 mm/d (250−335 mm/d) at centers (Fig. 3a). The 50-year return period MI is greater than 35 d in the upper-lower Jinsha River sub-catchment, the middle main stream section of the Yangtze River, the upper Dongting Lake sub-catchment and the Poyang Lake area, and even more than 40 d (40−56 d) at centers (Fig. 3b). Compared with Fig. 3a, the area with AM > 200 mm/d in the geographical distribution of 100-year return period AM (Figure omitted) is expanded and the center value of heavy precipitation also increased (300−410 mm/d). On the other hand, for the 100-year return period MI (Figure omitted), the area with MI > 30 d is expanded obviously, and the drought lasts more than 45 d (45−65 d), or even 65 d in the upper-lower Jinsha River sub-catchment, the middle main stream section of the Yangtze River, the upper Dongting Lake sub-catchment and the Poyang Lake area.

3 Probability distribution of precipitation extremes projected by ECHAM5

Trends of extreme events under climate warming are often studied by climatic model [17]. Ensemble simulations with ECHAM5/MPI-OM of the 20th century climate scenarios were analyzed by calculating the multi-year mean and deviation coefficient of AM for 1941−2000. It is shown in Fig. 4 (a) that high value (>130 mm/d) areas of AM series based on the projected data are located in the upper Mintuo River and Jialing River sub-catchment, the mid-lower mainstream section of the Yangtze River, the Hanjiang River sub-catchment, and the Poyang lake area and its south-eastern tributaries. While low value (<70 mm/d) areas of AM series are located in the Jinsha River sub-catchment. The variation of projected AM series is gentle with a deviation coefficient generally less than 0.25. Areas with the deviation coefficient greater than 0.21 mainly

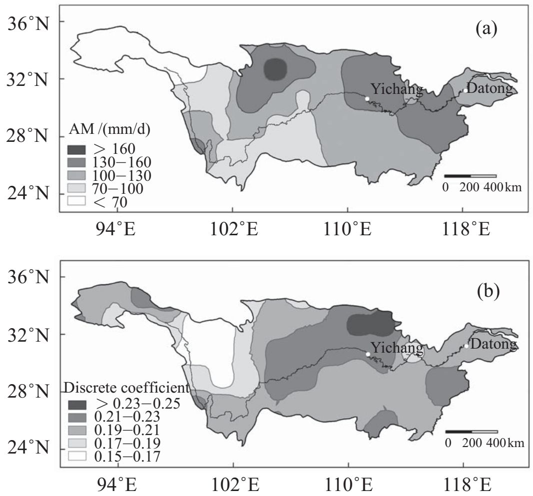

Fig. 4 Spatial distribution of precipitation extremes computed from ECHAM5 climatic model over the Yangtze River basin
(a) mean value, (b) deviation coefficient

lie in the upper mainstream section of the Yangtze River and the mid-lower Jialing River sub-catchment, and the middle mainstream section of the Yangtze River and the Hanjiang River sub-catchment. However, the deviation coefficient is less than 0.17 in the middle Jinsha River sub-catchment and the upper Mintuo River sub-catchment (Fig. 4b). Compared with the spatial distributions of the mean value (Fig.1a) and the deviation coefficient (Fig. 2a) of AM series calculated from the observed data, the projected AM series is overestimated in mean value, but underestimated in the amplitude of variations in general. Besides, the maximum value centers of the mean value and deviation coefficient of AM in the projected data also lie further north of the observed positions.

The differences between the projected and the observed data have shown that the ECHAM5/MPI-OM model still can not capture the precipitation extremes well over the Yangtze River basin. But the simulated data can provide a theoretical background for studying climate change in the Yangtze River basin. To detect the possibility of future precipitation extremes, the frequency distribution

Table 2 KS statistics for GEV and WAK distributions computed from AM series at 79 grids in the Yangtze River basin (unit: number of grid points)

	D_n group						
KS statistics	<0.03	0.03−0.06	0.06−0.09	0.09−0.12	0.12−0.15	0.15−0.17	>0.17
GEV	0	37	37	4	0	0	1
WAK	0	57	20	0	0	0	2

of extreme precipitation events simulated by ECHAM5/MPI-OM was analyzed. Table 2 shows KS statistics D_n for GEV and WAK distribution computed from AM series for 1941−2000 at 79 grids. It is obvious that simulation results of GEV and WAK distribution reach the 0.1 significance level for 97% of the investigated grids. But the maximum difference between experimental distribution $F_n(x)$ and theoretic distribution $F(x)$ further indicates that simulation results of WAK are superior to those of GEV, since the maximum D_n is lower in WAK cases. Similar results in Table 2 and Table 1 suggest that the WAK distribution is more suitable for describing the frequency distribution of precipitation extremes over the Yangtze River basin.

4 Conclusions

Distribution characters of precipitation extremes over the Yangtze River basin were analyzed based on the daily observational data at 147 stations for 1960−2005 and the ECHAM5/ MPI-OM simulated data at 79 grids for 1941−2000. Time series for maximum daily precipitation and the longest period of consecutive days with low rainfall within each year were constructed to define the extremely heavy precipitation and drought events, respectively. The following conclusions are drawn from the current study.

(1) The spatial distribution of observed precipitation extremes has shown that the mean value and deviation coefficient of AM are high in the middle Mintuo River sub-catchment, the Dongting Lake area, the mid-lower main stream section of the Yangtze River, and the southeastern Poyang Lake sub-catchment, while the deviation coefficient of MI is high in the mid-lower Jinsha River sub-catchment, and the Jialing River sub-catchment. That is to say, the intensity and probability of precipitation extremes are the highest over these areas.

(2) The spatial distribution of AM data simulated by ECHAM5/MPI-OM model has shown that the mean value is much higher while deviation coefficient is much lower than the observed data in general, and the locations of the heavy precipitation centers are also shifted northwards. The differences between the simulated and the observed data indicate that the ECHAM5/MPI-OM model still can not capture the precipitation extremes very well over the Yangtze River basin.

(3) According to the KS test, the 5-parameter WAK distribution can describe the probability distribution of precipitation extremes from both observational and simulated data at a sufficient accuracy. WAK could be an important function for estimating the future precipitation extremes under climate warming.

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