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Flooding 1990s along the Yangtze River, has it concern of global warming?

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Abstract: There were a series of severe floods along the middle to lower reaches of the Yangtze River (Changjiang River) in China during the 1990s. The extensive summer (June, July and August) precipitation is mostly responsible for the flooding. The summer rainfall in the 1980s and the 1990s is much higher than that in the previous 3 decades. The means for 1990-1999 is +87.62 mm above normal, marked the 1990s the wettest decade since the 1950s. Six stations with a time span of 1880-1999 are selected to establish century-long rainfall series. This series also shows that the 1990s is the wettest decade during the last 120 years. In the wettest 12 years, four occurred in the 1990s (1991,1996,1998 and 1999). Both global and China ˇs temperature show there is a relative lower air temperature during the 1960-1970s, and a rapid warming in the 1980-1990s. Comparisons of rainfall between 1960-1979 and 1980-1999 show there are dramatic changes. In the cold period 1960-1979, the summer rainfall along the Yangtze River is 3.8 % to 4.7 % below the normal, during the warm period 1980-1999, over 8.4 % to 18.2 % of summer rainfall occurs. Over the whole eastern China, the summer rainfall shows opposite spatial patterns from the 1960-1970s to 1980-1990s. The consistent trend toward more rainfall with global warming is also presented by the greenhouse scenario modeling. A millennial Drought/flood Index for the middle to lower reaches of the Yangtze River showed that although the surplus summer rainfall in the 1990s is the severest during the past 150 years, it is not outstanding in the context of past millennium. Power spectra of the Drought/flood Index show significant interdecadal periods at 33.3 and 11.8 years. Thus, both the natural inter-decadal variations and the global warming may play important roles in the frequent floods witnessed during the last two decades.

Flooding 1990s along the Yangtze River, has it concern of global warming? GONG Dao-yi1, ZHU Jin-hong2, WANG Shao-wu2 (1. Key Laboratory of Environmental Change and Natural Disaster, Institute of Resources Science, Beijing Normal University, Beijing 100875, China; 2. Department of Geophysics, Peking University, Beijing 100871, China) 1 Introduction Floods occurring along the Yangtze River (Changjiang River) valley make up about 35.8 % of the floods over China[1]. Most noteworthily, a series of severe floods happened along the middle to lower Yangtze River and caused great damages during the past decade. The flood of 1991 afflicted 0.98 million hectares of farmland and resulted in 1,200 loss of life. Severe flood occurred again over this region in 1996. An extremely destructive flood emerged during the summer of 1998, which brought terrible consequence resulting in several thousands of death and up to US$24 billion of economic losses[2]. During the summer of 1999 a relatively notable flood was also observed in much of the lower Yangtze River valley, but with less severity. Although human factors such as deforestation and agricultural activity in lowland area are thought to be partly responsible, the excessive summer precipitation is the most important reason. It is worth noticing that there are upward trends in summer precipitation during the last couple of decades[3]. The abundant rainfall can cause floods more easily. Figure 1 shows the means of summer rainfall anomalies for 1990-1999. Areas with confidence level of 95 % using a t-test are shaded. It is clear that along the middle to lower reaches of the Yangtze River east to about 110?E, about 100 to 200 mm rainfall more than normal has been witnessed. These anomalies are about 20 % - 30 % of the climate normal in magnitude. The purpose of this research is to investigate the variability of summer rainfall in this target region, and to find out how unusual the frequent floods during the 1990s is in the context of centurial and millennial records. Finally, the possible relationship between the surplus summer rainfall during the last 2 decades along the Yangtze River and the global warming is investigated. 2 The 1990s: the wettest

decade on centurial records 2.1 Data Modern networks of weather/climate observing stations are operated beginning in 1951 in China. Among the 160 World Meteorological Organization (WMO) stations in China we chose the 32, which cover t he middle to lower reaches of the Yangtze River with a reasonable uniform distribution, to establish the regional mea n precipitation series. These 32 stations are located east to 105?E, 27-33?N and shown in blank circles in Figure 2. The means of 32 stations summer rainfall are shown in Figure 3 as curve (a). These anomalies show large temporal vari ations with standard deviation of 109.95 mm. To investigate whether the 1990s is anomalous in the context of century history, longer rainfall time series are needed. Six key stations are selected to form a single series representativ e for the middle and lower reaches of the Yangtze River. These stations are Shanghai, Nanjing, Jiujiang, Wuhan, Yicha ng and Changsha. They are shown as black dots in Figure 2. The seasonal precipitation records of these stations have dated back to 1880[4]. The means of 6 stations are shown in Figure 3 as curve (b). The series correlate to the means of 32 stations at 0.94 for the common period 1951-1999. Thus, the 6-station-mean is a credible representative of the middle to lower basin. These anomalies also show large temporal variations, with standard deviation of 122.39 mm whic h is greater than the 32-station-mean since fewer stations are used here. Figure 3 Summer rainfall anomalies. Curve (a) is the means of 32 stations, (b) is the means of 6 stations, referring to 1961-1990. Two curves correlate at 0.9 2 during the period 1951-1999 2.2 Wettest decade during the past 120 years Table 1 presents the decadal means of the summer rainfall anomalies (only 9 years available for the 1950s). The summer rainfall in the 1980s and the 1990s is m uch higher than that in the previous 3 decades. The means for 1990-1999 is 87.62 mm, which is the highest. Thus, the 1990s experienced the wettest period since the 1950s. The decadally averaged summer rainfall for the 6 stations is al so shown in Table 1. The decadal value of the 1990s and the 1980s stands out for the first and third highest ones, wi th the value of 118.19 and 56.15 mm respectively, and the 1910s the second. Obviously, the recent two decades experie nced the rapidest increasing in summer rainfall during the past century. The continuing upward trend makes 1980-1999 the wettest periods during the last 120 years. Analysis indicates that the mean summer rainfall of the middle to lowe r Yangtze River valley during 1990-1999 is the highest since 1880 too. Table 1 Decadal means of the summer rainfall a nomalies over the middle to lower reaches of the Yangtze River Given the probability of once every 10 years, 12 wette st and driest summers are obtained and presented in Table 2. This criterion matches approximately the anomaly above 4 0 % of the normal for wet conditions, and below 30 % of the normal for dry conditions. Average anomalies for these 1 2 wettest and driest summers are 56.27 % and -35.89 % respectively. All these values presented in Table 2 exceed the span of one standard deviation. The top five wettest summers go beyond the value of two standard deviations or even m ore. Standard deviation of the whole series is 122.39 mm. Table 2 The classification of 12 wettest and driest summer s for the target region The increasing rainfall would bring much higher risk of floods. The recently rapid increasin g in summer rainfall would have shown powerful influence in enhancing the intensity and frequency of the extremely se vere floods. In the top 12 wet summers, four occurred in the 1990s. It is doubtlessly unprecedented since the late 19 th century. Figure 4 Summer rainfall anomalies during 1960-1979 (a) and 1980-1999(b) (in mm, with respect to 1961-199 0) 3 Comparison of summer rainfall between the cold and warm periods 3.1 Comparison of rainfall between 1960-1970s an d 1980-1990s The potential relationship between the hemispheric or global warming and precipitation, particularly th e regional precipitation, have been given more attention recently as the global warming becomes a hotter topic[5-8]. Especially, the possible changes in extreme rainfall events associated with the global changes are highlighted[9-1 1]. The coincident changes for trends in summer rainfall over China and global warming have been investigated recentl y[12-15]. Some studies also indicated that the changed surface thermal condition would influence the Asia monsoon rai nfall[16]. Regarding of the rainfall data availability and the magnitude of the global warming, we compare the most r ecent two 20-year segments, i.e., the relatively cold period 1960-1979 and the much warmer period 1980-1999. As demon strated in Table 2, it can be found that the extremely wet events during the 1980-1990s account for 41.7 % of the tot al events (5 in 12 summers). During the 1960-1970s, the northern hemispheric surface temperature is much lower than t hat of recent 20 years, average annual temperature anomalies for 1960-1979 and 1980-1999 is -0.04?C and +0.26?C respe ctively according to the Jones ˇ [17] updated series. It is interesting to note that the extremely dry events also occ urred 5 times in the relatively cold 1960-1970s. It is clear that the frequency of extreme events have changed dramat ically from the cold period to the warm phase. As expected, the 20-year means of the summer rainfall also exhibit exc iting transition. Figure 4 shows the average summer rainfall anomalies for these two periods. In the 1960-1970s, nega tive anomalies spread along the Yangtze River westward to about 105?E, the centres almost ride on the Yangtze River. On the contrary, the outstanding positive anomalies predominate over the Yangtze River valley east to 105?E. This obv ious rainfall transition is of interest regarding that the similar changes in the global temperature trends. 3.2 Asso ciated changes in 500hPa heights The atmospheric circulation controls regional weather and climate directly. What ar

e the atmospheric circulation features with respect to the anomalous precipitation along the Yangtze River? Figure 5 shows the correlation coefficients between the summer rainfall of the target region and large scale 500hPa geopotential heights. The 500 hPa heights used here are NCEP/NCAR (National Centers for Environmental Prediction/National Centers for Atmospheric Research) reanalysis data covering 1958-1999. Associated with the rich rainfall along the middle to lower reaches of the Yangtze River, there are two positive centres locating in central Asian continent, western Pacific, and a negative centre locating over Korea and Japan in the middle troposphere geopotential heights. This regime implies that with the strengthened Western Pacific Subtropic High, northward warm moist air along the western edge of the Subtropic High would be enhanced. At the same time, the stronger anticyclone pattern in central Asian continent and the adjacent cyclone pattern over Korea and Japan would bring more cold air southward. All of these would result in abundant rainfall along the middle to lower reaches of the Yangtze River. The result presented by Figure 5 is also generally consistent with Hu[18] and Nitta and Hu[19]. Considering aforementioned changes in summer rainfall during the relatively cold 1960-1979 and the much warmer 1980-1999, it is of interest to check the simultaneous changes in 500hPa geopotential heights during these two most recent periods. As expected, the spatial patterns during the two periods show reverse regimes generally. During the recent two warm decades, the 20-year-mean anomalies are reasonably consistent with the relationship as shown in the correlation coefficients in Figure 5. Especially, the positive anomalies in 500 hPa heights over the middle to higher latitude continent are particularly prominent. As shown in Figure 6, during the cold period 1960-1979 the 500 hPa heights differ much from that for 1980-1999, and the much lower 500 hPa heights over the Asian continent is also impressive. The changes in troposphere heights over Eurasia during the recent several decades is dramatic, and during these decades the observed surface air temperature also show significant change and switch from a coldness to much higher warmth in the late 1970s. The coincidence strongly suggests the possibility that the recent global warming would have been altering the summer rainfall over the Yangtze River through the changing atmospheric circulation. However, the details and proofs remain to be examined further. Figure 5 Correlation between summer rainfall and 500hPa heights. (1958-1999, target region shaded). The 95 % and 99 % confidence levels (degree of freedom is 40) march approximately 0.30 and 0.39 respectively Figure 6 Comparison of 500 hPa heights between 1960-1979(a) and 1980-1999(b). Both shown as the average anomalies with respect to 1961-1990 (in gpm) 3.3 Modeling results It is now widely recognized that changes in the global temperature will result in more moisture content in atmosphere and more precipitation. However, the associated change in precipitation is by no means of uniform. As IPCC[20] report indicates, most GCMs (General Circulation Models) yield the rising trends in global mean precipitation under the greenhouse scenarios, and the more precipitation is mostly expectable in tropic and high latitudes. The regional impacts of global warming on rainfall must be very complicated, especially, over East Asia[7,21]. Does the precipitation in the Yangtze River show consistent secular trend with the global warming? The modeling results provide an alternative to examining or sorting out the signal of global warming in rainfall. IPCC˘s data used are obtained from the IPCC Data Distribution Center (IPCC-DDC). Here we analyze five models˘ results, including ECHAM4 (German Climate Research Center, GGA1), HadCM2 (The UK Hadley Center for Climate Prediction and Research, only GGA1), GFDL-R15 (The US Geophysical Fluid Dynamics Laboratory, GGA1), CGCM1 (The Canadian Center for Climate Modeling and Analysis, GGA1), and CSIRO-Mk2 (The Australian Commonwealth Scientific and Industrial Research Organization, GGA1). All used scenarios are greenhouse gases increase +1% annually. Statistics of these results are presented in Table 3. The summer rainfall over the middle to lower reaches of the Yangtze River are calculated for three time segments 2010-2039, 2050-2069 and 2070-2099, and the changes compared to model climate (1961-1990) are also listed at the bottom line. All modeling results show the same significant warming trend in surface air temperature with a little difference among models. Under the imposed greenhouse warming, the summer rainfall in the Yangtze River shows much greater dependence on models than temperature does. On the average, for all models and all time segments, the summer rainfall would increase by 5.8mm during the 2010-2090s. It is generally consistent with the above-mentioned feature of warm/wet condition. But, the magnitude of rainfall changes is much lower than the observations during the recent decades. Possible causes include the lack of capability of simulating rainfall, especially on a regional scale, and some other factors such as low frequent variability on a rainfall would be involved. Table 3 Simulated rainfall changes under the greenhouse warming (in mm, data from IPCC-DDC) 4 Interdecadal variability in the millennial records 4.1 Drought/flood Index Variability in interdecadal time scale is of increasing interest to us. Much work has been done on these variations as climatologists attempted to sort natural variability from possible anthropogenic forcing. Are there interdecadal variations in the Yangtze River summer rainfall? And has the recent trend toward surplus summer rainfall been masked by the natural low frequent variation? Here we would investigate the millennial Drought/flood Index series. Figure 7 Decadally averaged Drought/flood Index (a) and summer rainfall (b) anomalies. In curve a, the anomalies are with respect

to the whole period AD1000-1999 There are plenty of documents on floods and droughts in China. These historical documents were examined in detail in the 1970s and the early 1980s[22]. As a result a series of drought/flood maps for the last 500 years were published[23], in which each of the about 120 stations˘ drought/flood classes were depicted on the maps with 1 to 5 from AD1470 to 1979. The category 1 denotes ¨the severe flood〃, 2 ¨the flood〃, 3 ¨the normal〃, 4 ¨the drought〃 and 5 ¨the severe drought〃. The probability of these 5 categories is 1/8, 1/4, 1/4, 1/4 and 1/8 respectively. Wang et al.[24] and Wang and Chen[25] have published the drought/flood classes maps for the five stations along the middle to lower reaches of the Yangtze River for the period AD 1000 to 1469. The principle used in the studies for this period was identical to that for the period 1470-1979. Finally, a regional mean series of Drought/flood Index was obtained, the definition of the regional mean is depicted in Table 4. The Drought/flood Index for each summer is updated to 1999 in this study. The decadally averaged Drought/flood Index anomalies are shown in Figure 7. 4.2 Power spectral analysis The millennial Drought/flood Index for the middle to lower reaches of the Yangtze River show that although the surplus summer rainfall in the 1990s is the severest during the past 150 years, it is not outstanding in the context of past millennium. As Figure 7 demonstrated, there are some longer periods during which both wetter than the 1980-1990s and drier than the 1960-1970s conditions has been witnessed, showing some features of low frequent variability. Details are analyzed below. Table 4 Definition of the regional mean Drought/flood Index (Wang et al. 1993) Figure 8 Power spectra of the Drought/flood Index. Time series are normalized prior to analyzing. The periods are given in years for each significant peak. Dashed line is the 95 % confidence level We used spectral analysis to establish the significant dominant periods at which variance occurs in the Drought/flood Index. The spectrum was estimated from 300 lags of the autocorrelation function. With this number of lags (30% of the series length), we set a reasonable balance between high resolution and moderate stability. Figure 8 shows the spectrum for the summer Drought/flood Index. It is clear, spectral variance is not only concentrated at higher frequencies, but also appeared at lower frequencies. Peaks that exceed the 95% confidence limit are observed at 2.2-2.3, 2.9-3.0, 5.1-5.6 and 6.8 years on the annual time scale. Obvious interdecadal peaks are also observed at 11.8 and 33.3 years. These interdecadal periods are also studied by some previous researches, for example, Wang[26] indicated there are 36 years cycle in annual precipitation of Shanghai. Wang and Zhao[27] reported that 36 years cycle also predominated at least for the last 400-year period, and later Liang et al.[28] indicated the decadal cycles decrease from north (about 47 years) to south (about 21 years) in the station˘s Drought/flood Index. Thus, the natural interdecadal variations in summer moisture condition may play an important role in the frequent floods during the last two decades. It is hard to separate the contribution of greenhouse warming and natural low frequent variation in the rainfall series. It seems that recent changes in rainfall would be attributed to both of the above-mentioned two factors. 5 Concluding remarks During the recent two decades, frequent severe floods along the Yangtze River have been witnessed. The extensive summer precipitation is mostly responsible for the flooding. The summer rainfall in the 1980s and the 1990s is much higher than that in the previous 3 decades (1950-1970s). The means of anomalies for the 1990-1999 is +87.62 mm, marked the 1990s the wettest decade since 1951. Six stations with centurial records are selected to establish long rainfall series. The six-station-mean series correlate to the means of 32 stations at 0.94 for the common period 1951-1999. Thus, the 6-station-mean is a credible representative of the middle to lower basin average. Analysis also shows that the 1990s is the wettest decade during the last 120 years. To investigate the possible relationship with global warming, the difference in rainfall between the cold and warm period is investigated. The comparison of 1960-1979 and 1980-1999 shows there are dramatic changes. The 20-year means of the summer rainfall exhibit exciting transition. The average summer rainfall anomalies for the 1960-1970s show that the rainfall deficit spread along the Yangtze River westward to about 105?E. On the contrary, the outstanding positive anomalies predominate over the Yangtze River valley east to 105?E for of the period 1980-1990s. Associated with the rainfall changes the 500hPa heights show concord variation. The greenhouse scenario modeling result also presents the consistent trend toward more rainfall with global warming. A millennial Drought/flood Index for the middle to lower reaches of the Yangtze River shows that although the surplus summer rainfall in the 1990s is the highest during the past 150 years, it is not outstanding in the context of past millennium. Power spectra of the Drought/flood Index indicate significant interdecadal periods of 33.3 and 11.8 years. These low frequent variabilities were also observed by other studies. Thus, both the natural inter-decadal variations and the global warming may play an important role in the frequent floods witnessed during the last two decades. 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关键词： summer rainfall; Yangtze River; global warming; interdecadal variation

