Centennial Variations and Recent Trends in Summer Rainfall and Runoff in the Yangtze River Basin, China*

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Abstract In recent decades, summer floods in China's Yangtze River basin have become more frequent and severer, threatening the economic development and ecosystem environment in the basin. While great efforts and a large amount of resources have been devoted to minimizing damages and mitigating consequences of floods, several scientific questions are raised: what may have attributed to the increase of the floods, and what may be anticipated of future floods? These questions are addressed in this note from a perspective of natural variability of the region's climate. Major results show that a centennial scale variation of the region's climate has shifted from a dry epoch, from 1910 to the late 1960s, to a wet epoch after the 1960s. Associate with this change are 1) a trend of increase in summer rainfall at an average rate of 30mm per ten years in the eastern portion of the basin, 2) a trend of decrease in summer season surface evaporation at an average rate of 10mm per ten years in the same region, and 3) a combined result of rising surface runoff and flood potential. These trends are speculated to continue because the current wet epoch in the centennial variation will persist in the next few decades.

Keywords: Centennial scale, climate variation, trend, surface, evaporation, runoff, floods, Yangtze River basin

In the last twenty years or so, especially in the 1990s, the Yangtze River basin in southern China suffered frequent and devastating floods [1], while the northern China endured repeated summer droughts. In the Yangtze River basin, the considerable increase in frequency of floods suggests that the summer climate in the basin has become wetter. The wet climate and severe floods have brought adverse effects to the region's economic development and ecosystem environment and, meanwhile, have stimulated great efforts to understand flood development [2] and the region's climate change [3], with a hope to find indications of future flood conditions and develop mitigation strategies to reduce flood impacts. In this note, climate variations of centennial

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scales in the Yangtze River basin are reexamined to provide an interpretation of the recent wet climate and to offer an outlook of future summer climate in the Yangtze River basin. In addition, summer rainfall and surface evaporation in the last 47 years (1954-2000) are examined to show that associated with a shift of the centennial variation from a dry to a wet climate starting in the 1970s and 1980s are trends of increasing summer rainfall and decreasing surface evaporation, and a combined result of an increase in surface runoff and flood potential. These trends are likely to continue in the next few decades because of the persistence of the current wet climate condition sustained by the centennial scale variation.

This note is organized as follows. In the next section, we will discuss major results of Yangtze River basin summer climate variations of centennial scales in terms of wet and dry conditions, and we will show the indications of a shift to wet climate in the 1970s and 1980s in the basin. We will show in section 3 that following this shift are trends in summer rainfall and surface evaporation in recent decades pointing to rising frequency of summer floods. An outlook is given in section 4 for future climate and floods in the Yangtze River basin.

1 Centennial scale wet/dry climate alternations and a recent shift to a wet climate

One of the possible sources that could explain persistent wet or dry climate in a region is the natural variability of the region's climate. Such variability could result from interactions of the atmospheric, land surface, and oceanic processes of a larger environment encompassing the region of interest. With this perception, Hu and Feng[4] investigated the natural variability of the summer climate in both southern and northern China, focusing at the multidecadal to centennial scales. They used the data of five-scale dryness/wetness intensity values from 120 stations in a historical network in eastern China for the period 1470-1997[5-6]. One of their findings is particular intriguing and is presented in Fig. 1. The abscissa in Fig. 1 is time in years from 1500 to 2000, and the ordinate is latitude from 20°N to 45°N, covering the major land areas in China. The contours in Fig. 1 show the wet and dry anomalies of summer climate of each 2.5° latitude bin from 20°N to 45°N between the longitudes 120°E to 140°E. We note that these anomalies are departures of centennial scale variations with period longer than 80 years from the region's long-term average climate condition. Thus, a particular period of dry anomalies, for example, the one started in 1910 and ended in the late 1960s in the latitudinal region between 32°N and 34°N, would indicate that the centennial scale variation contributed dryness to the region's climate. Similarly, the wet anomalies starting in the 1970s and continuing to the most recent year show that the centennial scale variations have been "endowing" wetness to the region's climate in those decades.

With this citation, we now examine changes of the centennial scale variations in the last 500 plus years. Scanning through Fig. 1 from the left to the right in the latitude span of the Yangtze River basin, 25°-34°N, we find large amplitude alternations of dry and wet climate anomalies in the last five centuries. The average period of the alternation is about 130 years albeit this "period" has varied in the range from 110 to 160 years. According to this alternation, the centennial variation went through a period of dryness from about 1910 through the late 1960s in the Yangtze River basin and has entered a wet phase or wet epoch in the 1970s and 1980s. In addition, the wet anomalies first appeared in northern section of the river basin and have since been expanding southward. Because each of the wet or dry epochs in the centennial variations has persisted for a number of decades, it is unlikely that this recently emerging wet epoch in the variation could terminate abruptly and be replaced by dry epoch. Thus, this wet epoch and its contribution to wetness in the region's climate shall be anticipated to continue in the next few decades especially in the southern portions of the river basin.

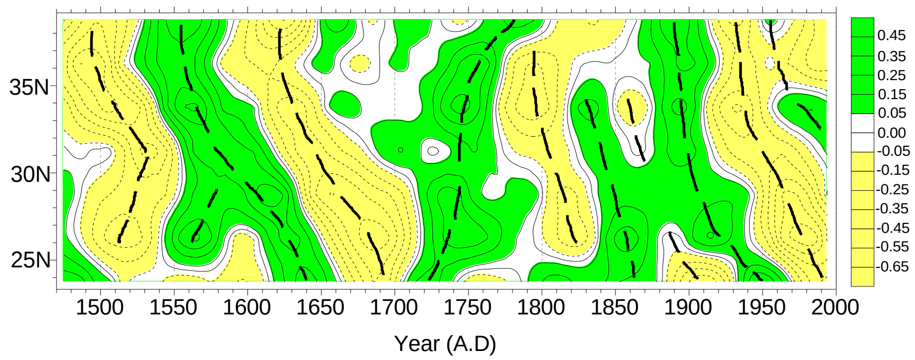

Fig. 1 Time-latitude section of centennial scale variations in dryness/wetness in central and eastern China. Dark-shaded (or green-colored) areas indicate wet and light-shaded (or yellow-colored) areas indicate dry anomalies (intensity of the anomalies is indicated by the scales on the right side of the figure). Clear (or white) areas are neutral or normal conditions

Indeed, even though the centennial scale variations are found explaining a substantial portion of the total variance in the observed rainfall variation [4], the centennial scale variation is only one component contributing to the Yangtze River basin's summer rainfall variation, which also is affected by numerous other components of, for example, shorter time scales from interannual to decadal. A summary of those components and their possible roles in summer rainfall variations of the Yangtze River basin can be found in Qian et al [7]. The synthesized and integrated outcome of these components could be a condition different from that suggested by a particular component, including the centennial scale variation. Hence, it is necessary to examine the actual summer rainfall variation from available data and evaluate the rainfall anomalies in different epochs of the centennial variation. A connection of the actual rainfall and the centennial variation could be useful for estimating future rainfall and flood anomalies by using the tendency and persistency of the centennial scale variation. In addition, surface evaporation and water storage also interact with rainfall frequency, intensity, and duration to determine flood development. These surface processes need to be evaluated, and together with rainfall variations, they will assist our understanding of the surface runoff and floods. For this reason, we examine in the next section variations in summer rainfall, surface evaporation, and runoff in the Yangtze River basin and delineate their trends in recent wet epoch of the centennial climate variation.

2 Variations of the summer rainfall, surface evaporation, and runoff in recent decades

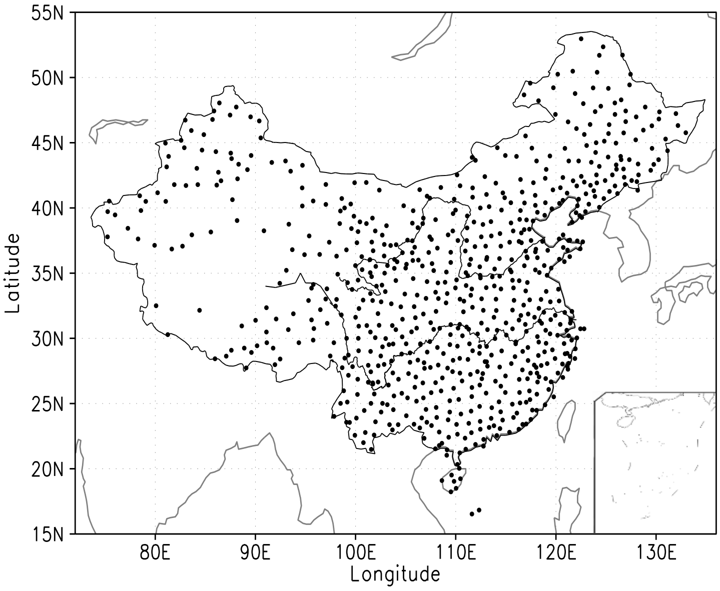

Fig. 2 Distribution of surface meteorological stations whose data are used in this study

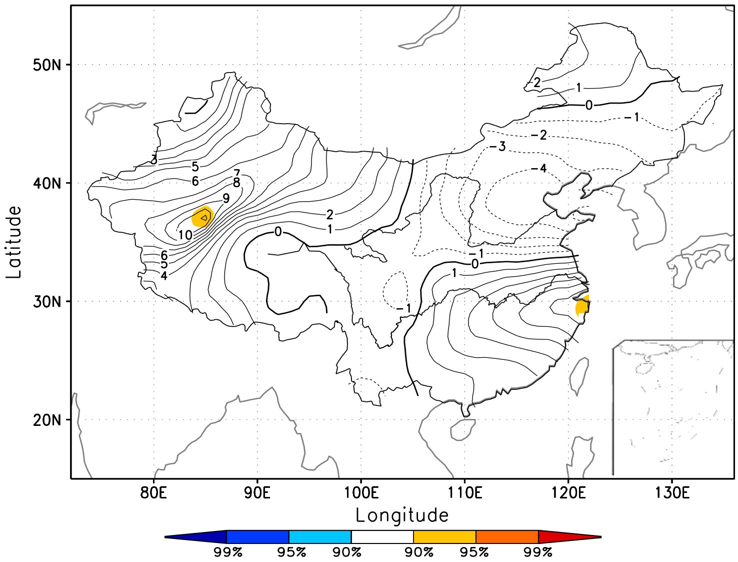

Fig. 3 Trend of summer rainfall based on the stations' data from 1954 to 2000. Solid (dashed) contour lines show the trend of increase (decrease) in percentage of the 47-year mean. Contour interval is 1%. Statistical significance of the increase or decrease is shaded according to the confidence level given in the scale bar underneath the figure

Daily rainfall in summer months (June, July, and August) from 726 weather stations in mainland China (Fig. 2) was obtained for the period 1954-2000. Also in the stations data are relative humidity, surface temperature, wind speed and direction, and barometric pressure, which are used with radiation data to calculate surface evaporation and runoff. The daily rainfall data were examined for their quality before summed to get summer total rainfall at each station. After obtaining the summer rainfall, we calculated its trend of variation for the period 1954-2000. The results and their prominent features are shown in Fig. 3. First, the eastern half of the Yangtze River basin has a trend of increasing summer rainfall in the last 47 year. The average rate of the increase is higher in the coastal regions of the basin and reaches to more than 6% of the 47-year average summer rainfall of 500mm in every 10 years. To the north and in the Yellow River basin, an opposite is shown with a trend of decrease in summer rainfall, although the magnitude of the decrease is not large. Besides these changes in the central and eastern China, another feature in Fig. 3, worthy of mentioning, is the large rate of increase in summer rainfall in western China, including Xinjiang province and western Tibetan Plateau [1,8] (also see Hu et al. 2002; The maximum of rising rainfall is found in the northwestern slopes of the Kunlun Mountains, and is at a rate of 10% of the summer average of about 50mm in every 10 years. The trend of the increasing summer rainfall in the Yangtze River basin in the last 47 years is consistent with the transition in the late 1960s from a dry to a wet epoch in variation of the centennial scale component in the region's climate, a result also supported by the findings in [9]. Who showed that the centennial scale variation usually possesses a large portion of the total climate variation energy and often sets up a dry or wet norm for actual rainfall.

After confirming the rainfall increase associated with the wet phase in the centennial climate variation, we calculated the surface evaporation using the revised Penman method described in Qui et al[10]. which has been shown relevant to the conditions in eastern and southern China,

$$AE = 1.251\frac{\Delta}{\Delta+\gamma}(R_n - G) - 1.522\frac{\gamma}{\Delta+\gamma}E_a \tag{1}$$

In (1), AE is the actual evaporation in mm, R_n is the net radiation energy at the surface, G is the fraction of R_n absorbed and stored in soils, and E_a is the evaporation that would occur at air temperature of the reference height. The two parameters, Δ and γ, are slope of the saturation vapor pressure curve and the psychrometric constant, respectively. The two coefficients of the two terms on the right side of (1) are derived in Qui et al[10]. for China's condition.

Because for time scales longer than one year the net storage of energy in soils, G, is zero, AE can be computed from known R_n and E_a. To get R_n, we used the method of Allen et al[11]. and observed sunshine duration data, and calculated E_a using individual weather stations' air temperature, humidity, wind speed, and barometric pressure. Results of the calculated surface evaporation are shown in Fig. 4. Because the validity of (1) is limited to the conditions in the central and eastern China, we have plotted only the surface evaporation and will restrict our discussion for those areas. According to Fig. 4, there is a significant trend of decrease in surface evaporation in the eastern two thirds of the Yangtze River basin. Larger rates of decreasing evaporation are shown in the east coast areas in the basin, and the average rate is -3% (of the average summer season evaporation of about 300mm) in every 10 years. In the western one third of the basin, surface evaporation has decreased by a little. To the north of the basin, surface evaporation has increased slightly in the majority of the Yellow River basin although the change is not as significant as in the Yangtze River basin.

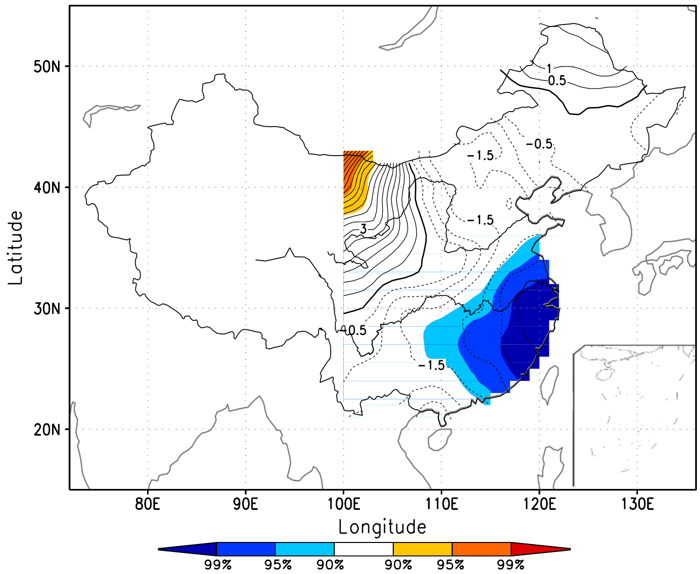

Fig. 4 Trend of summer surface evaporation calculated using stations' data from 1954 to 2000. Solid (dashed) contour lines show the trend of increase (decrease) in percentage of the 47-year mean. Contour interval is 0.5%. Statistical significance of these increase or decrease is shaded according to the confidence level given in the scale bar

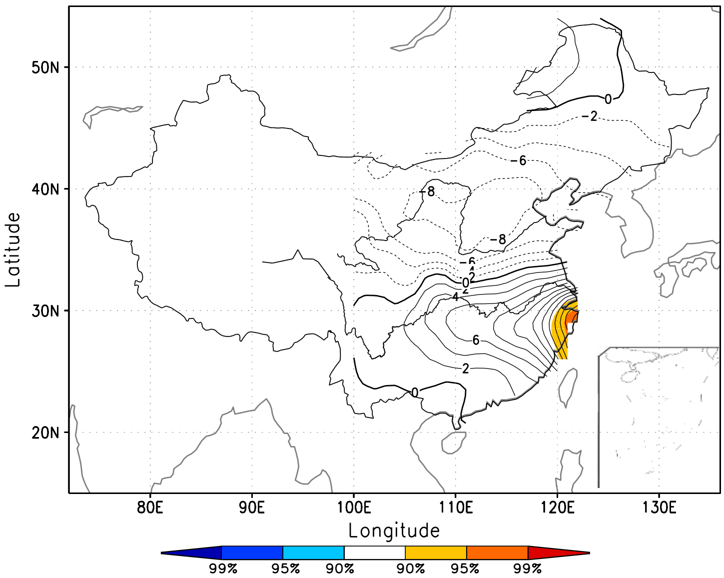

Fig. 5 Same as Fig. 4 but for the surface runoff. Contour interval is 2%

With respect to surface runoff and flood development, the trend of increase in the summer rainfall and the concurrent decrease of surface evaporation in the Yangtze River basin describe a tendency of increase in the surface runoff and rise in the flood potential (Fig. 5). Moreover, because the rainfall increases and the evaporation decreases at a larger rate in the eastern part of the basin the runoff is larger and flood potential higher in that part of the basin. The average runoff increase in the eastern part of the basin reaches a rate of 16% of the average runoff of 200mm per 10 years.

3 Concluding remarks

These results partially explain the recent rising frequency and intensity of floods in the Yangtze River basin from the perspective of natural (vs. anthropogenic effects on) variations in the region’s climate. In addition, by showing the coherent trends in summer rainfall and surface evaporation in the wet epoch of the centennial variation, the results indicate that the current trends in rainfall and surface evaporation would continue while the wet epoch persists in the next few decades. Of course, this outlook is not eliminating individual dry years or even dry spells of a couple of consecutive dry years from occurring in the basin. However, such dry spells would be “outliers” to the wet norm in the coming decades. This tendency of rising floods will be quite challenging for management of water resources in the Yangtze River basin especially because the rising surface temperature from anthropogenic causes might worsen the wet condition and amplify the flood magnitude [12]. To reduce the adverse impacts of floods, prevention and mitigation strategies need to be designed, and use of climate and weather predictions must be properly integrated in those strategies so that skills of using forecasts by decision makers will be developed to improve decisions and minimize flood damages.

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References

1 Shi Y, Shen Y, Li D, et al. *An Assessment of the Issues of Climatic Shift from Warm-dry to Warm-wet in Northwest China*. Beijing: Meteorology Press, 2003:124

2 Jiang T, Shi Y. Global climatic warming, the Yangtze floods and potential loss. *Advance in Earth Sciences*, 2003,18(2): 276-284

3 Nitta T, Hu Z. Summer climate variability in China and its association with 500hPa height and tropical convection. *J Meteor Soc* ,1996, 74: 425-445

4 Hu Q, Feng S. A southward migration of centennial scale variations of drought/flood in eastern China and the western United States. *J Climate*, 2001, 14: 1323-1328

5 Peking University, Central Meteorological Institute, Nanking University. The drought and flood charts of China from 1470 to 1979. Beijing: Atlas Press, 1981: 332

6 Wang S W, Zhao Z C. Droughts and floods in China, 1470-1979. In: T M L, Wigley M J, Ingrasham, Eds: *Climate and History*.

Cambridge University Press, 1981:171-288

7 Qian W, Hu Q, Zhu Y. et al. Centennial-scale dry-wet variations in East Asia. *Climate Dynamics*, 2003,21: 77-89

8 Hu R J, Jiang F Q, Wang Y. A climate shift from dry to wet in Xinjiang, China. *Dry-Land Geography*, 2002, 25: 194-200

9 Hameed S, Yeh WM, Li M T, et al. An analysis of periodicities, 1983 in the 1470 to 1974 Beijing precipitation record. *Geophys Res Lett*, 10: 436-439

10 Qui X, Cao Y, Maio Q, et al. Methods for calculating annual surface evaporation using routine weather stations data. *Science in China* (Series D), 2003, 46: 281-288

11 Allen R G, Pereira L S, Raes D, et al. Crop evapotranspiration: Guidelines for computing crop water requirements. FAO irrigation and drainage paper, 1998, No. 56, FAO, Rome: 300

12 Shi Y, Zhu J, Xie Z, et al. Prediction and prevention of the impacts of sea level rise on the Yangtze River Delta and its adjacent areas. *Science in China (Series D)*, 2000,(4): 412-422

长江流域夏季降水与气温百年尺度变化及近期趋势

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摘 要

在最近的 30a 里，中国长江流域夏季洪水频繁,直接影响该流域经济发展和生态环境.在致力于解决洪水灾害和努力减轻其影响的同时，我们常面临如下三个问题：洪水频繁发生的原因,将来几十年的洪水频率将如何变化,还会这样频繁吗?本文将从局部气候的自然变化规律中来试图回答这三个问题.文中报告主要结果指出：长江流域夏季降水具有一个明显的自然尺度的变化，且该变化最近由一个偏干的气候态（从 1910 年到 60 年代末期）转化为一个偏湿的气候态（自 60 年代末以来）.伴随着这种变化，长江流域夏季降水表现出增加趋势（平均增加率为 30mm/10a），夏季地表水蒸发呈现出减少趋势（平均减少率为 10mm/10a）,以及这两种作用共同造成的地表水增加和洪水频繁. 由于目前偏湿的气候态将持续，预计在今后 10-20a 里这些变化以及相联系的频繁洪水的趋势将在长江流域持续.

关键词 世纪尺度 气候变化 趋势 地表蒸发 径流 洪水 长江流域

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