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Precipitation and streamflow changes in China: Changing patterns, causes and implications

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SUMMARY

Extensive investigation was done on the changes in precipitation and streamflow in both space and time across China based on monthly precipitation data from 590 rainfall stations and on monthly streamflow data from 382 hydrological stations covering 1960–2000. Causes behind the precipitation changes were studied based on NCAR/NCEP reanalysis dataset. Influences of agricultural irrigation on availability and variability of water resources and related implications were also discussed. The results indicate that: (1) decreasing precipitation is found mainly in the regions between 105°E and 115°E and in the northeast China. Scarce precipitation is observed mainly in spring and autumn and winter seems to be wetter; (2) alterations of the East Asian monsoon activities should be the causes behind the spatial patterns of precipitation changes. Large-scale circulation of water vapor flux can well explain the spatial distribution of precipitation changes in China; (3) streamflow changes are mainly the results of precipitation changes. Agricultural irrigation heavily influences the variability and availability of water resources. Increasing water consumption due to booming socio-economy and fast growing population will further deteriorate the water status of China. In this sense, scientific and effective water resource management and advanced agricultural technology are urgently called for to ensure the sustainable socio-economy and social stability of China.

1. Introduction

Global warming being caused by human-induced emission of greenhouse gases is accelerating the global hydrological cycle (Arnell, 1999; Allen and Ingram, 2002; Alan et al., 2003). The accelerated hydrological cycle is altering the spatial–temporal patterns of precipitation resulting in increased occurrences of precipitation extremes (Easterling et al., 2000) and in turn increased occurrences of floods and droughts in many regions of the world (e.g., Easterling et al., 2000; Mirza, 2002), such as China (Zhang et al., 2010a, 2011a; Qiu, 2010a). The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Trenberth et al., 2007) points to different precipitation changes during 1900 and 2005, e.g., significantly wetter climate in eastern North and South America, northern Europe and northern and central Asia, but drier climate in the Sahel, southern Africa, the Mediterranean and southern Asia.

As a vital natural resource, water is fundamental for the sustainable development of economy, ecosystem, and biodiversity. Therefore, water security and related implications for ecosystem and river diversity, especially the variability and availability of regional water resources under the influence of climatic change and human activities (e.g., Kundzewicz, 2004; Xu and Singh, 2004) are warmly discussed in recent years (e.g., Vörösmarty et al., 2010). Nevertheless, it is being increasingly recognized that water resources are deteriorating in many parts of the world. For sustainable water resources planning and management, it is therefore essential to determine the changes in water resources in both space and time and evaluate the influence of climate change and human activities thereon. Of course, this determination heavily relies on adequate hydrological data and information on river flow patterns and availability of water within the catchment to enable quantification of water quality and quantity (e.g., Oyebande, 2001). Adequate data are critical in the design and management of water resources (Birsan et al., 2005; George, 2007; Zhang et al., 2009a).

China, the third largest country in the world in terms of territorial area, has the largest population and booming economy. In 2010 the Editorial board of Nature (Editorial board, 2010) declared that

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producing enough food for the world's population in 2050 at an acceptable cost would depend on research into everything from high-tech seeds to low-tech farming practices. However, China is primarily an agricultural country and its agriculture greatly depends on irrigation (e.g., Cui et al., 2009). Agricultural production in China is heavily dependant on irrigation, and it is particularly the case for the north China (e.g., Liu et al., 1998). Good irrigation is the prerequisite for having good agricultural harvest. Thus, to feed its huge population will, to a large degree, hinge on the availability of water resources. The climatic changes of China are mainly controlled by winter and summer monsoon (Domroes and Peng, 1988). Generally precipitation in southwest China are more than that in northwest China, and this precipitation patterns are decided mainly by the monsoon system and effects of topography of China (Zhai et al., 2005). Rainy seasons in eastern China hinge on progress and retreat of the East Asian summer monsoon. Detailed information of evolution of summer Asian monsoon and associated propagation of rain belt can be found in Ding (1994). Generally speaking, rain belt propagates northward in early May and June and reaches north China from 5 to 25 August. After midsummer, the rain belt retreats rapidly southward, which directly decide precipitation changes across China. There are a lot of researches addressing precipitation changes over China. Becker et al. (2006) analyzed changing trends in monthly precipitation totals in the Yangtze River basin. Wang and Zhou (2005) studied trends in annual and seasonal mean precipitation totals and extreme precipitation events in China during 1961–2001 using linear regression method. Zhai et al. (1999, 2005) reported no significant trend in the annual precipitation over China between 1951 and 1995. Ren et al. (2000) demonstrated an increasing summer precipitation over the middle and the lower Yangtze River and a decreasing trend over the Yellow River basin. Streamflow changes in China mostly based on river basins (e.g., Xu et al., 2002, 2004; Yang and He, 2003; Liu and Zheng, 2004; Wang et al., 2008; Yang et al., 2010). However, the previous researches are mostly based on individual river basin and few reports conduct integrated researches on linkage of precipitation changes to streamflow variations and also discuss implications of these changes on agriculture over China as a whole. What's more, some scientific problems such as water resources, climate changes and implications for agricultural productions are hot in recent decades (e.g., Wisser et al., 2008) and it is particularly true in China (Thomas, 2008). This is the major motivation of this current study.

Looking at water resources in China, the country has about 20% of the world's population but only about 5–7% of global freshwater resources. It is therefore no surprise that water shortage is serious in China (Qiu, 2010b). Thus far, the focus in China has been mostly on regional water resources (e.g., Yang et al., 2004; Wang et al., 2009; Zhang et al., 2009a; Ma et al., 2010). Piao et al. (2010) made a review of climates and water resources in China, but with less than adequate support through quality hydrological and precipitation data. Streamflow data from the Yellow River and the Yangtze River alone cannot represent the status of water resources of the entire country. An acceptable evaluation of water resources needs enough hydro-meteorological data and extensive data-driven analysis. This constituted the motivation for the current study. Further, possible causes of precipitation and water resource variations in China need to be investigated and related implications should be discussed.

The objectives of this study therefore are to: (1) investigate the spatial pattern of precipitation changes and possible causes thereof; (2) determine the spatial distribution of streamflow changes and their relations to precipitation changes; (3) evaluate the influence of human activities (agricultural irrigation) and precipitation on variations of streamflow across China; and (4) discuss the implications of results of study.

2. Data

Monthly precipitation data from 590 rain gauging stations for the period of 1960–2000 were obtained from the National Climate Center (NCC) of China Meteorological Administration (CMA). Monthly streamflow data for the period of 1960–2000 from 382 hydrological stations that cover the territory of China well were

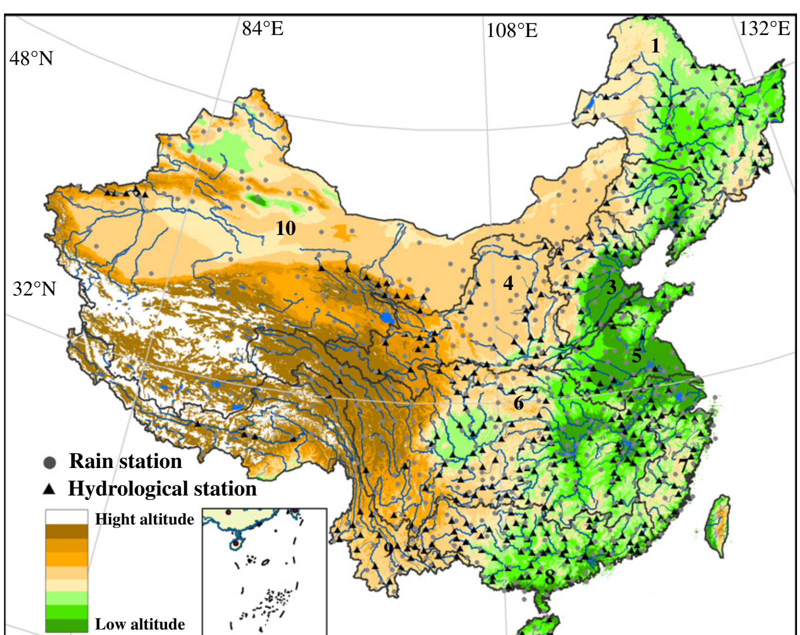

Fig. 1. Locations of 382 hydrological stations and 590 rain gauging stations across China. Numbers denote the 10 drainage basins: 1: Songhuajiang River; 2: Liaohe River; 3: Haihe River; 4: Yellow River; 5: Huaihe River; 6: Yangtze River; 7: SE rivers (rivers in the southeast China); 8: Pearl River; 9: SW rivers (rivers in the southwest China); 10: NW rivers (rivers in the northwest China).