16. THE 2012 NORTH CHINA FLOODS: EXPLAINING AN EXTREME RAINFALL EVENT IN THE CONTEXT OF A LONGER-TERM DRYING TENDENCY

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Introduction. North China, including Beijing (~39°52′N, 116°28′E), Tianjin (~39°10′N, 117°10′E), and part of Hebei Province, experienced severe flooding in the summer of 2012. During 21–22 July, Beijing received a regionally averaged total precipitation of 190.3 mm, and the center of the rainfall event received 460.0 mm; the observations of 11 stations broke the historical records (CMA 2013). The flood-affected area in Beijing was about 16 000 km^2, and the damage-suffering population was estimated at 1.9 million with 77 people dead. The direct economic loss is more than 10 billion Chinese reminbi.

Flooding events are not unusual in China, but have been uncommon in North China in recent decades. The East Asian summer monsoon (EASM) circulation has been weakening since the end of the 1970s, which led to a drying tendency in North China (see Zhou et al. 2009 for a review). The occurrence of the 2012 flood in the context of a multidecadal drying tendency has received great attention. In this study, we analyze the 2012 North China flood in the context of summer monsoon changes in the past 62 years (1951–2012). We examine whether climate change may have played a role in either the 2012 extreme rainfall or the recent multidecadal trend of decreased precipitation in North China.

Observed heavy rainfall in North China. A heavy rainfall occurred on 21–22 July 2012 where the major rain belt extended from Southwest China to North China and was centered in Beijing (Fig. 16.1a). The Beijing area received a regionally averaged rainfall of 190.3 mm, as measured by 20 stations in the area. The Hebei Town station of Fangshan District in the western mountain area of Beijing received the largest amount of rainfall and recorded 460.0 mm within 24 hours (CMA 2013). The 24-hour precipitation accumulation in the western mountain area was nearly equal to the area's

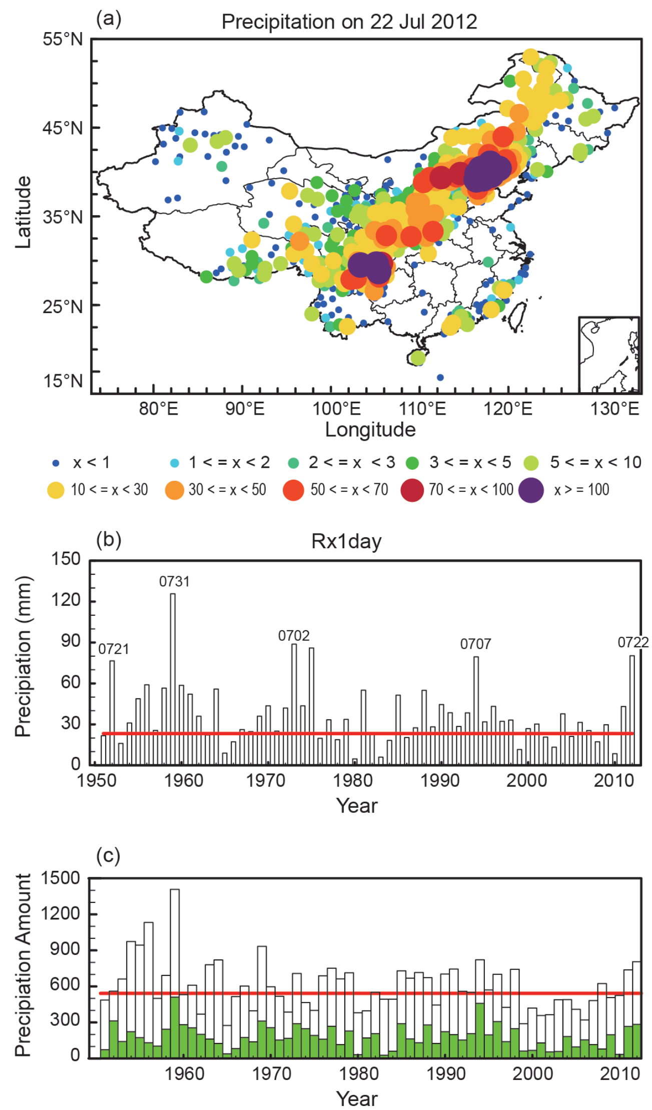

Fig. 16.1. (a) The accumulated precipitation (mm) from 21 July 2012 08:00 China Standard Time (CST) to 22 July 2012 08:00 CST. (b) Time series of the July maximum one-day precipitation (RX1DAY) index in *Beijing station* (station number: 54511). The red solid line is the climatological mean (1981–2000) threshold of the 95th percentile of all precipitation days in July (mm day^{-1}). The text denotes the date when the RX1Day value appeared, e.g., "0721" means the RX1DAY occurred on 21 July. (c) July (green) and annual total (white) precipitation (mm) in *Beijing station*, the red solid line denotes the mean total annual precipitation during 1981–2010.

annual precipitation and far more than the area's average for a single rainfall event. Note, the mean July precipitation for the period 1981–2010 is 160.5 mm, and the mean total annual precipitation is 541.8 mm at *Beijing station* (station number 54511; Fig. 16.1c). The average 24-hour rainfall in the Tianjin area was 98.6 mm, with 294.7 mm of total precipitation at the rainfall center on 21–22. Flooding was observed in part of the Haihe River valley in Hebei province (CMA 2013).

The maximum one-day precipitation (RX1DAY) index of July during 1951–2012 at Beijing is examined in Fig. 16.1b. Since the original daily precipitation amount is defined as the accumulation of precipitation starting at 20:00 China Standard Time (CST) one day and ending at 20:00 CST the next day, to catch the heavy rainfall that occurred starting 21 July 08:00 CST, a two-day running mean is applied to the original daily data. The RX1DAY of 2012 was the strongest since 1995, but not unprecedented in the past 62 years. RX1DAY indices stronger than the 2012 case are seen in the historical record (Fig. 16.1b). The total July precipitation was more than 30% of the annual precipitation at the Beijing station (Fig. 16.1c).

Was the extreme rainfall of July 2012 due to climate change? Precipitation in North China is known to be directly linked to the strength of the EASM circulation, which is measured by a commonly used index (Guo 1983) and has been weakening since the end of the 1970s (Fig. 16.2a), as reported in previous studies (e.g., Yu et al. 2004; Yu and Zhou 2007; Zhou et al. 2009). The declining trend can also be regarded as an inter-decadal variation due to the short data length. The EASM circulation of 2012 is greater than most years following 1980, but still weaker than the period 1951–79 (Fig. 16.2a,b). Following the decreasing trend of the EASM circulation, the July precipitation in

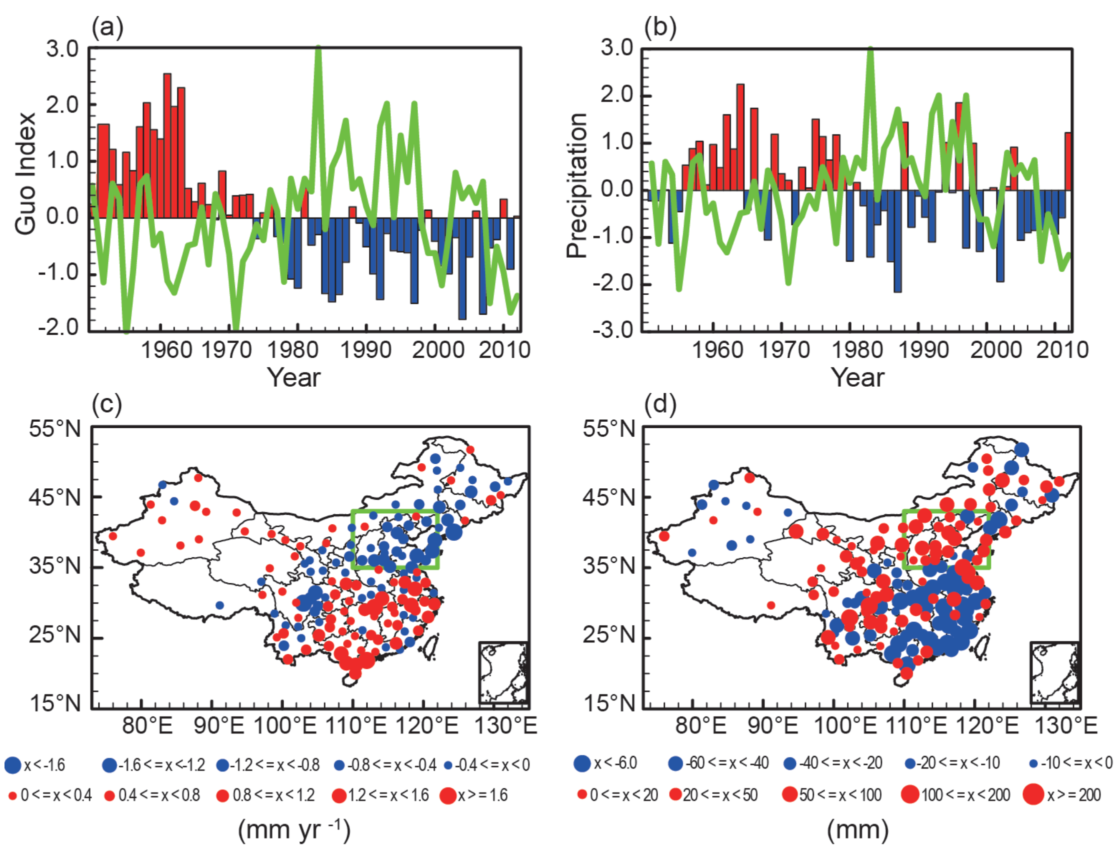

Fig. 16.2. (a) Normalized Jul EASM index derived from NCEP/NCAR reanalysis based on Guo (1983). The green line indicates the PDO index derived from http://jisao.washington.edu/pdo/PDO.latest. (b) Normalized Jul precipitation amount averaged over North China (35°N–43°N, 110°E–122°E; 23 stations included; dimensionless). The green line indicates the PDO. (c) Linear trends of July precipitation during 1951–2011 (mm yr^{-1}; the absolute values of anomolies larger than 0.4 are statically significant at the 5% level), the green box indicates the North China region (35°N–43°N, 110°E–122°E). (d) Anomalies of Jul precipitation in 2012 relative to 1981–2010.

North China has also been decreasing since the end of 1970s. However, as with only five other Julies in the last 30 years, July 2012 was above normal. More importantly, July 2012 was the strongest event in the last 15 years (Fig. 16.2b).

While North China precipitation and the EASM circulation index are directly correlated, they are inversely correlated with the phase of the Pacific Decadal Oscillation (PDO), or "Inter-decadal Pacific Oscillation" (IPO; Power et al. 1999). A negative phase of the PDO corresponds to a stronger EASM circulation (Fig. 16.2a) and more precipitation in North China (Fig. 16.2b). The PDO affects the EASM circulation through changing land-sea thermal contrast (Li et al. 2010). The recent transition of the PDO from a positive to a negative phase (Zhu et al. 2011; Liu et al. 2012) provides a large-scale background for the stronger summer monsoon in 2012.

The precipitation anomaly of July 2012 is compared to the long-term trend in Fig. 16.2c. Following the weakening tendency of the EASM circulation (Fig. 16.2a), decreasing precipitation trends are seen in most stations of North China (Fig. 16.2c). The extreme precipitation of July 2012 is in contrast to the long-term trend, and most stations in North China witnessed a positive July 2012 precipitation anomaly (Fig. 16.2d). There is insufficient data to conclude whether this indicates a recovery of the EASM after experiencing a weakening stage since the end of the 1970s (Liu et al. 2012).

Following the declining trend of the EASM circulation, the average rainfall amount and frequency have significantly decreased but the rainfall intensity has increased in North China (Yu et al. 2010). July 2012 is in contrast to the long-term trend in rainfall amount but consistent with rainfall intensity trends.

To understand the relationship of the July North China rainfall event with climate change, the July precipitation averaged in North China derived from the historical simulation and Representative Concentration Pathway (RCP) projection of 39 Coupled Model Intercomparison Project Phase 5 (CMIP5) models are analyzed (Supplementary Fig. S16.1). The models show an increasing trend from 1950–2000, in contrast to the decreasing trend observed during this period. The inability of CMIP5 models to replicate the observations is partly due to the inconsistency of PDO phase transition, since the CMIP5 models were not initialized with contemporary observations and, therefore, would not reproduce the observed phase transition of the PDO event. Under RCP4.5 and RCP8.5 scenarios, the July precipitation in North China is projected to increase in the future by CMIP5 models. However, the credibility of the projection is reduced due to the weakness of historical simulation. Due to the inability of climate models to reproduce the observed trend, it is difficult to make any conclusions about the role of climate change in the trend of decreasing (increasing) precipitation amount (intensity) observed in North China over the last three decades. In addition, the performance of global models in reproducing regional precipitation changes in North China may be limited by their low resolutions. Whether a dynamical downscaling using a higher resolution regional model can improve the simulation deserves further study

Concluding remarks. Although the damage caused by the 2012 floods in North China was large, the amount of precipitation was not unprecedented in the past 62 years. The flood occurred in the background of a longer-term drying tendency. Since the late 1970s, the total summer rainfall amounts have significantly decreased, but the rainfall intensity of single events has increased in North China associated with the weakening tendency of the EASM circulation partly due to the phase transition of the PDO. We are unable to confirm or reject the role of climate change in the 21–22 July 2012 rainfall event due to the inability of the CMIP5 models to accurately replicate observations in this region of China. The CMIP5 models show an increasing trend from 1950 to 2000, in contrast to the decreasing trend observed during this period. Both the mean and extreme precipitation in North China are projected to increase in the future, but the creditability of the projection is limited by the weakness of models to simulate the climatology of EASM and the design of CMIP5 projection experiments, which were not initialized with contemporary ocean observations and would not be able to reproduce the observed phase transition of the PDO.

In addition, we should note that the inability of CMIP5 models to replicate the observations is not due entirely to the unmodelled phase transition of the PDO. The trend of the PDO during 1971–2012 is nearly zero, but the precipitation trend in North China is nonzero, which is -1.44 mm day^{-1} and statistically significant at the 5% level. This suggests an underlying trend caused by processes other than the PDO. Further studies are needed to understand the underlying processes.