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News & Views

Changes in East Asian summer monsoon and summer rainfall over eastern China during recent decades

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In the East Asian monsoon region over eastern China, east of 100°E, summer rainfall controlled by the East Asian summer monsoon (EASM) is mainly concentrated during June–August. Summer rainfall accounts for more than half of the annual total, or 52 %, according to rainfall observations from 160 meteorological stations in China from 1951 to 2014 over the aforementioned region. A stronger EASM corresponds to more rainfall over northern China, whereas a weaker EASM leads to more rainfall over the Yangtze–Huai River valley. Summer climate changes over eastern China in recent decades have been affected by internal natural factors within the climate system and by external forcing arising from the anthropogenic effects of greenhouse gas (GHG) and aerosol emissions. Therefore, recent research has focused on EASM and summer rainfall variations resulting from natural and anthropogenic factors, which is crucial for providing a better understanding of their roles in the East Asian climate from a global warming perspective.

Similar to the global warming, eastern China has also experienced an increase in summer air temperatures during the period 1951–2014, with a significant trend of 0.1 °C/decade. In terms of data diagnosis, the changing features of EASM and summer rainfall over eastern China under the warming background are well documented. A declining trend in EASM intensity has been observed since the mid-1960s, with decreased rainfall in northern China and increased rainfall in the Yangtze–Huai River basin [1–4]. However, a decadal shift in the East Asian summer climate occurred in the late 1980s [5]. In addition, the recovery of the declining EASM trend was detected during the early 1990s, followed by a subsequent strengthening of EASM and enhanced rainfall in the Huaihe River valley [6]. Based on the observations during the past half-century, both EASM and summer rainfall averaged over eastern China exhibited strong interdecadal variability; summer rainfall over the entire region in eastern China showed no clear trend except for a change in spatial distribution [7, 8]. Compared with the period of 1958–1974, more rainfall was recorded around the middle and lower reaches of the Yangtze River valley in 1975–1989 and moved southward to south of the Yangtze River valley in southern China in 1990–2000; however, rainfall declined in the valley afterward and became negative anomalies in 2001–2008 (Fig. 1).

It appears that the so-called south flood–north drought (SFND) summer climate anomaly, which is defined as more rainfall in southern China and less in the north, existed from the mid-1970s to the late 1990s. During this period, the distribution of additional rainfall also varied, with more precipitation over the Yangtze River valley from the mid-1970s to the late 1980s (Fig. 1a) and over southern China south of the Yangtze River valley from the early to late 1990s (Fig. 1b). From the early to late 2000s, the SFND phenomenon no longer existed because less rainfall was recorded over the Yangtze River valley (Fig. 1c). It is apparent that the EASM and summer rainfall, which accompanied the rising air temperatures over eastern China, did not show a consistent weakening or strengthening trend but instead varied in an interdecadal manner.

In recent decades, changes in the EASM and summer rainfall have been significantly affected by a range of

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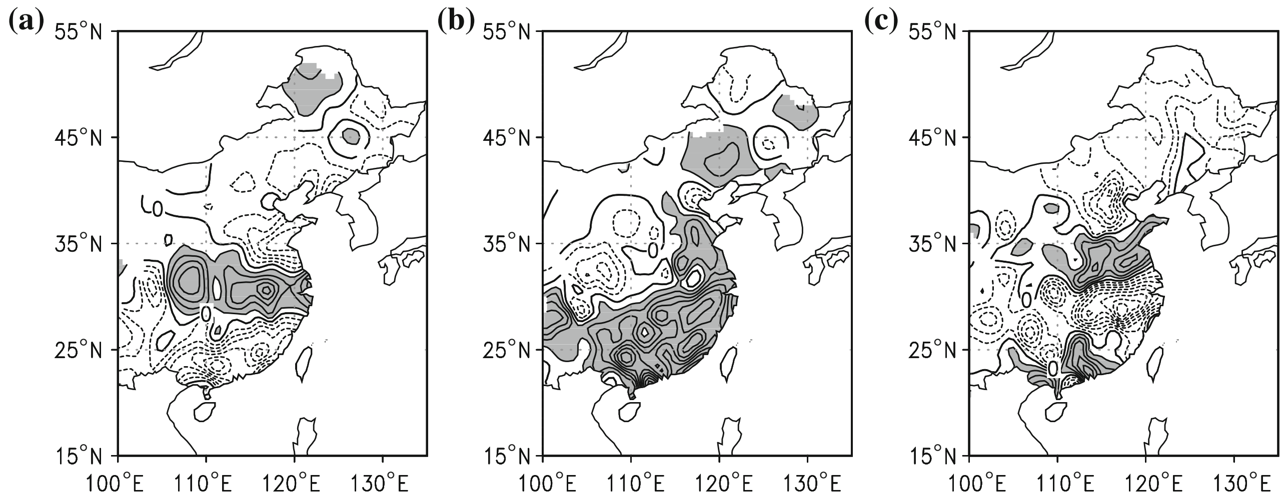

Fig. 1 Differences of summer rainfall between **a** 1975–1989 and 1958–1974, **b** 1990–2000 and 1975–1989, and **c** 2001–2008 and 1990–2000 [8]. The dotted and solid lines represent negative and positive rainfall anomalies, respectively. The line interval is 30 mm, the thick line represents the 0 isoline, and differences larger than 30 mm are indicated by shading

natural factors including such land and oceanic thermal conditions as Eurasian snow cover, Arctic sea ice, and sea-surface temperature anomalies in the Atlantic, western North Pacific, equatorial tropical Pacific, and tropical Indian oceans [8], in addition to internal variability of the coupled oceanic–atmospheric system, such as Pacific decadal oscillation (PDO). Anthropogenic factors may also have had direct impacts. The results of climate models have indicated that although increased GHG has intensified the EASM, the enhanced aerosol content over East Asia had an opposite impact and weakened the EASM [9]. However, the combined effects of anthropogenic GHG and aerosols from the model results may not explain the EASM changes in recent decades [4]. The reversed effects of GHG and aerosols on the EASM are physically understandable. Land–ocean thermal contrast is a basic reason for monsoon formation. The GHG heating effect enlarges the land–ocean thermal contrast and thus leads to EASM intensification. Conversely, the cooling effect of aerosols over the East Asian continent reduces thermal contrast, which results in a weakened EASM. It is not surprising that the model results showed diverse results on the impacts of anthropogenic factors. GHG and aerosol effects on the EASM depend on their relative importance. It appears that if GHG plays a major role, the EASM may strengthen, whereas it could weaken if the aerosols are more important.

Research on the impacts of anthropogenic factors is generally achieved through the use of climate models, the results of which may depend largely on the model sensitivity to such factors. Therefore, the objective reflection of the roles played by GHG and aerosols in the models should be carefully checked, which is crucial for obtaining robust conclusions on the impacts of anthropogenic factors. Particularly in the EASM region, a significant trend of increased summer air temperature is present, although EASM intensity and summer rainfall over eastern China do not show any trend. The relations of the air temperature increasing to EASM intensity and summer rainfall changes remain unclear. Compared with natural factors, the extent to which the East Asian climate is affected by anthropogenic factors remains under debate. It is also necessary to detect and distinguish the contributions of external forcing from the impact of internal variability of the coupled oceanic–atmospheric system. It is noteworthy that although aerosols may influence the East Asian summer climate, their intensity and distribution can also be affected by summer monsoon circulations [10]. Therefore, the interaction of aerosols and meteorological conditions should be considered to fully understand their roles in East Asian climate effects.

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