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Review

Natural and human-induced changes in summer climate over the East Asian monsoon region in the last half century: A review

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Abstract

In the last half century, a significant warming trend occurred in summer over eastern China in the East Asian monsoon region. However, there were no consistent trends with respect to the intensity of the East Asian summer monsoon (EASM) or the amount of summer rainfall averaged over eastern China. Both of the EASM and summer rainfall exhibited clear decadal variations. Obvious decadal shifts of EASM occurred around the mid- and late 1970s, the late 1980s and the early 1990s, and the late 1990s and early 2000s, respectively. Summer rainfall over eastern China exhibited a change in spatial distribution in the decadal timescale, in response to the decadal shifts of EASM. From the mid- and late 1970s to the late 1980s and the early 1990s, there was a meridional tri-polar rainfall distribution anomaly with more rainfall over the Yangtze River valley and less rainfall in North and South China; but in the period from the early 1990s to the late 1990s and the early 2000s the tri-polar distribution changed to a dipolar one, with more rainfall appearing over southern China south to the Yangtze River valley and less rainfall in North China. However, from the early 2000s to the late 2000s, the Yangtze River valley received less rainfall.

The decadal changes in EASM and summer rainfall over eastern China in the last half century are closely related to natural internal forcing factors such as Eurasian snow cover, Arctic sea ice, sea surface temperatures in tropical Pacific and Indian Ocean, ocean–atmospheric coupled systems of the Pacific Decadal Oscillation (PDO) and Asian–Pacific Oscillation (APO), and uneven thermal forcing over the Asian continent. Up to now, the roles of anthropogenic factors, such as greenhouse gases, aerosols, and land usage/cover changes, on existing decadal variations of EASM and summer rainfall in this region remain uncertain.

Keywords: East Asian summer monsoon; Summer rainfall over eastern China; Natural change; Human-induced change; The last half century

1. Introduction

The eastern region of China is affected by the East Asian monsoon; the area to the east of 100°E is usually referred to as the East Asian monsoon region (Tao and Chen, 1987; Zhang et al., 1996; Wang et al., 2004). Over eastern China in the East Asian monsoon region, rainfall mainly occurs in the summer season (June, July and August). Based on the climatological mean of 1951–2014 observed from 160 meteorological stations over eastern China to the east of 100°E, summer rainfall accounts for more than half (52%) of the total annual rainfall (Zhang, 2015). The distribution and the amount of summer rainfall over eastern China are mainly controlled by the intensity of the East Asian summer monsoon (EASM). A strong EASM corresponds to more rainfall over northern China, and a weak EASM is associated with more rainfall over the Yangtze–Huaihe River valley (Ding, 1994). The temporal variations of EASM and summer rainfall over the East Asian

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monsoon region are characterized by clear features of multi-timescales ranging from synoptic to interdecadal timescales (Wang et al., 2005; Huang et al., 2012; Qin et al., 2012).

Eastern China is one of the regions in the world with the densest population and fastest economic development in recent decades. Consequently, regional summer climate is being affected by both internal natural factors within the climate system through ocean−land−atmosphere interactions and external forcing arising from anthropogenic factors such as greenhouse gases (GHGs), aerosols, and land usage/cover changes (LUCC). Therefore, changes in EASM and summer rainfall resulting from natural and anthropogenic factors have been a research focus in recent years. Finding out what roles natural and anthropogenic factors play in influencing EASM and summer rainfall is crucial for understanding East Asian climate change.

The present study provides a comprehensive review on the up-to-date researches on the changes in EASM and summer rainfall over eastern China as well as their causes in the last half century. Section 2 presents the changing features of EASM and summer rainfall over eastern China. The effects of natural and anthropogenic factors are addressed in sections 3 and 4, respectively. Concluding remarks are given in section 5, in which the unsolved issues concerning the changes in EASM and summer rainfall over eastern China are discussed.

2. Changing features of EASM and summer rainfall

Under the global warming background, eastern China (east of 100°E) has also experienced an significant increase in summer air temperature, with an increasing trend of 0.1 °C per decade between 1951 and 2014, based on observations from 160 meteorological stations in China (Zhang, 2015). A lot of studies have been done on the changing features of East Asian summer climate, which have been well documented (Zhou et al., 2009a; Zhang et al., 2013; Hsu et al., 2014; Zhang, 2015). A declining trend in the intensity of EASM was observed since the mid-1960s, with decreased rainfall in northern China and increased rainfall in the Yangtze−Huaihe River basin (Yan et al., 1990; Huang et al., 1999; Wang, 2001; Gong and Ho, 2002; Hu et al., 2003; Yu et al., 2004; Jiang and Wang, 2005). However, a decadal climate shift of EASM occurred in the late 1980s (Zhang et al., 2008). It was reported that a recovery of the declining trend occurred in the early 1990s and, since then, the EASM has become strengthened with enhanced rainfall in the Huaihe River valley (Liu et al., 2012). After the early 1990s, South China experienced more rainfall (Kwon et al., 2005; Zhang et al., 2008; Ding et al., 2008; Wu et al., 2010; Huang et al., 2011; Zhang et al., 2013), and between the late 1990s and the late 2010s, rainfall decreased over the lower−middle reaches of the Yangtze River (Zhang et al., 2013; Xu et al., 2015).

As mentioned above, both EASM and summer rainfall over eastern China exhibited strong decadal variability. By using an index of the western North Pacific−East Asian summer monsoon (WNP−EASM) (Wang et al., 2001), Zhang et al. (2013) demonstrated that the WNP−EASM index varied with a pronounced decadal variability in the period from 1958 to 2011. Corresponding to the decadal variation of the WNP−EASM index, the summer rainfall averaged over eastern China showed no trend in recent decades, but exhibited a change in its spatial distribution (Li et al., 2010b; Zhang et al., 2013). Compared to 1958−1974, more rainfall appeared around the middle and lower reaches of the Yangtze River valley in 1975−1989 (Fig. 1a), and moved southward to the south of the Yangtze River valley in 1990−2000 (Fig. 1b). Relative to the period of 1990−2000, the amount of rainfall increased in both the southernmost area in China and around the north of the Yangtze River valley, and declined in the Yangtze River valley in 2001−2008 (Fig. 1c).

It seems that the so called south flood and north drought summer climate anomaly in eastern China (i.e., more rainfall in southern China and less rainfall in northern China) (Yu and Zhou, 2007), existed only from the mid-1970s to the late 1990s, during which the distribution of rainfall anomalies was also different. From the mid-1970s to the late 1980s, there was

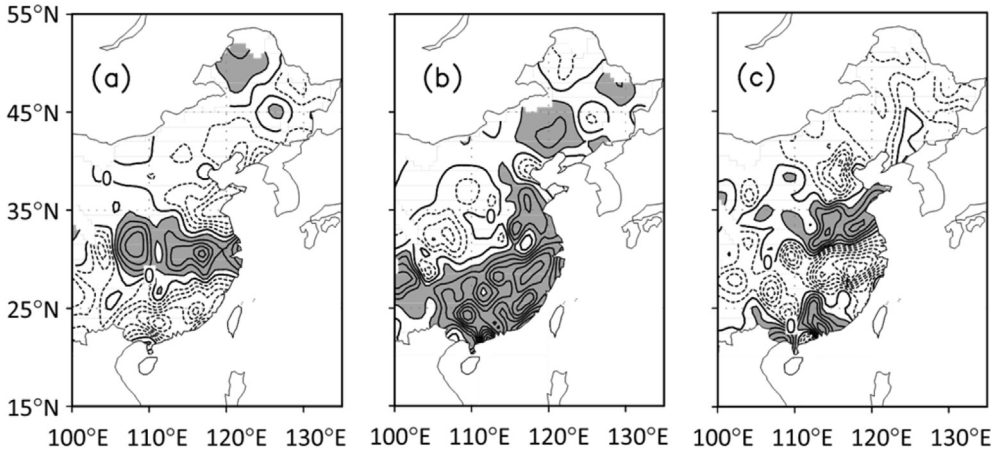

Fig. 1. Averaged summer rainfall differences, (a) 1975−1989 minus 1958−1974, (b) 1990−2000 minus 1975−1989, and (c) 2001−2008 minus 1990−2000. The dotted and solid lines represent the negative and positive anomalies, respectively. The line interval is 30 mm. The thick line is the 0 isoline. Differences larger than 30 mm is shaded (Zhang et al., 2013).