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Effects of atmospheric oscillations at different time scales on persistent autumn rainstorms in Hainan, China

Jiangnan Li[a,*], Qingwen Ye[a], Fangzhou Li[a], Chenghui Ding[a], Youlong Chen[b], Yanbin Huang[b]

[a] *School of Atmospheric Sciences, Sun Yat-Sen University, Guangzhou 510275, PR China*
[b] *Hainan Meteorological Service, Haikou 570203, PR China*

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ABSTRACT

In the autumn of 2008, 2010, and 2011, Hainan experienced anomalously persistent rainstorms. The objective of this study was to examine the roles of atmospheric oscillations at different time scales on these three rainstorm events. A wavelet analysis of daily rainfall data revealed that the 3–10-day synoptic-scale oscillations were the dominant mode in 2008 and 2011 and the 8–15-day quasi-biweekly oscillations were dominant in 2010. These three autumn rainstorm events can be divided into two major periods. Both the synoptic-scale and quasi-biweekly mode influenced the rainstorms, but their oscillation centers and propagation directions were completely different. There is a good corresponding relationship between the two heavy rain periods and the synoptic-scale oscillation cyclones and convection during the autumn of 2008 and 2011. During the first period, moisture mainly came from vapor convergence in the South China Sea (SCS), but during the second period, moisture came from the equatorial Indian Ocean. The major source of the synoptic-scale oscillation was the western North Pacific. The synoptic-scale oscillation cyclones and convection moved northwest to Hainan, resulting in heavy rainfall. Moisture during the first period mainly came from water vapor convergence in the SCS during the autumn of 2010, but moisture in the second period came from western North Pacific. The quasi-biweekly oscillation convection was generated and developed mainly over the equatorial Indian Ocean. Strong convection accompanying oscillation cyclones spread toward the northeast, triggering heavy precipitation in the Hainan region.

1. Introduction

Persistent rainstorms are hazardous because of their long duration, high intensity, and broad extent. There has been a great deal of research on rainfall in southern China (e.g., Li and Li, 1997; Zhang et al., 2009; Zhou et al., 2010; Wu et al., 2012; Pan et al., 2013; Hu and Wu, 2015; Gao et al., 2016), and more and more research on persistent heavy rain there. (e.g., Tang et al., 2006; Chen and Zhai, 2013; Ren et al., 2013; Li and Zhou, 2015). However, most studies focused on rainfall during the April to September flood season in areas such as Guangdong, Guangxi, and Fujian provinces. Hence, few studies have been done on autumn rainstorms or in the Hainan region. Hainan Island (or simply Hainan) in the South China Sea (SCS) is has a special geographic location that makes precipitation there more complex. Agriculture in Hainan is heavily dependent on the characteristics of autumn rainfall; however under the background of global warming, local areas have been experiencing abnormal weather. For example, Hainan has had frequent heavy autumn rainfall in autumn in recent years, but the reason is not very clear. Feng et al. (2013) revealed that the variability of September–October rainfall in Hainan is large and distinct from most of southern China, the Indochina Peninsula, and most of the SCS. But observations show that the late-flood season in Hainan is in September and October, a feature that is closer to the eastern region of the Indochina Peninsula, and that may be related to the SCS summer monsoon withdrawal speed (Chang et al., 2005; Yokoi and Matsumoto, 2008; Chen et al., 2012). Thus, understanding the characteristics and causes of persistent autumn rainstorms in Hainan is very important.

Intraseasonal oscillations (ISO) mainly contain 10–20-day and 30–60-day oscillations, which are major cycle signals impacting tropical atmospheric circulation and precipitation (Mao and Chan, 2005; Sultan et al., 2005; Qiao et al., 2015; Zaitchik, 2017). The precipitation in many areas of China is closely linked to ISO (Zhu et al., 2003; Zeng, 2010; Chen et al., 2015). In addition, many studies have shown that ISO play an important in affecting the climate of the SCS and its surrounding areas. For example, Zhou and Chan (2005) and Shao et al. (2015) noted that the establishment of the SCS summer monsoon is closely tied with ISO. Mao and Chan

* Corresponding author.
E-mail address: essljn@mail.sysu.edu.cn (J. Li).

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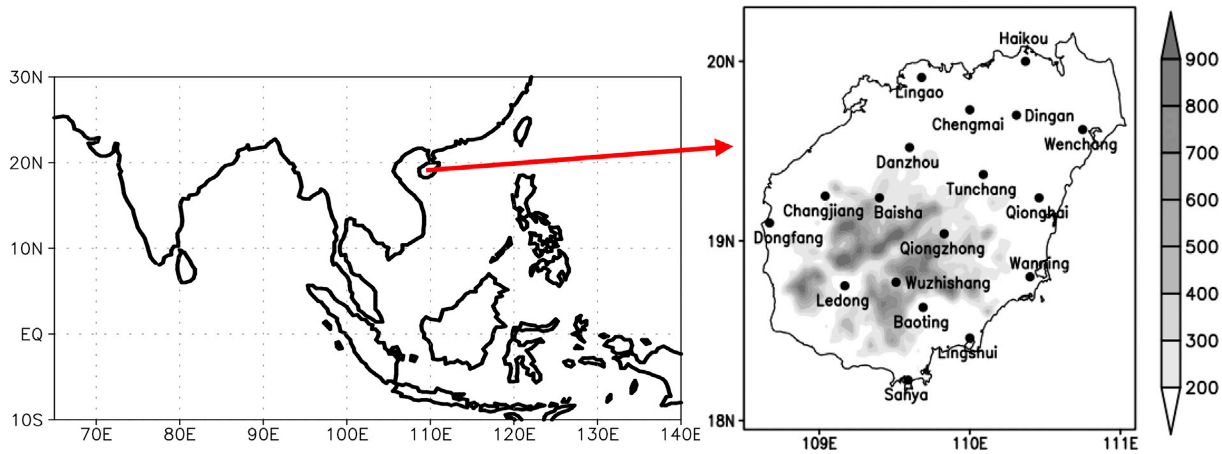

Fig. 1. The location of 18 Hainan meteorological stations and topography (units: m).

(2005) have shown that the 10–20-day and 30–60-day oscillations are the main oscillation types controlling SCS summer monsoon activities. Two dominant frequency modes of the summer 2003 heavy rainfall in eastern China are a 10–20-day variation (i.e., quasi-biweekly mode) and a 3–8-day variation (i.e., synoptic-scale mode) (Liu et al., 2014). Li et al. (2013) discovered that ISO signals become active during the summer monsoon period over the SCS, and that the ISO strengthening in the SCS is related to the tropical ISO strengthening in the Indian Ocean. Sea surface temperature (SST) in the SCS is also characterized by ISO (Qiang et al., 2007; Ye and Wu, 2015; Wu and Zhang, 2015). Ding (2007) showed that Asian summer monsoons have 10–20-day and 30–60day oscillations, and Zeng and Wang (2009) showed that the latent heat flux of the SCS mainly experiences 28–35-day and 49–56-day oscillations.

The above studies show that atmospheric oscillations lasting 10 or more days affect everything in the SCS and the surrounding areas, from convection to atmospheric circulation and precipitation. In recent years, some studies have indicated that high-frequency oscillations lasting 10 or fewer days are also closely linked to climate change. For example, Li and Ju (2008) showed that dry and wet regions in eastern China have significant 2–16-day high-frequency oscillations, and Li et al. (2011) demonstrated that the SCS has 2–8-day high-frequency atmospheric oscillations. Thus, convection, cyclones, and precipitation in the SCS and its surrounding areas are closely linked to low- and high-frequency oscillations.

In the autumn of 2008, 2010, and 2011, Hainan experienced anomalously persistent rainstorms. In this study we focus on the following questions: Did atmospheric oscillations take place during the three persistent rainstorm events? If so, what were the spatial distribution characteristics and evolutionary patterns of these oscillations in relation to these rainstorm events? What were the mechanisms by which these oscillations influenced the rainstorm events?

Like Liu et al. (2014), in this paper, we define the 8–15-day oscillation as the quasi-biweekly mode and the 3–10-day oscillation as the synoptic-scale mode. The rest of this paper is organized as follows: Section 2 introduces our study's data and methodology, Section 3 examines the characteristics of precipitation and outgoing longwave radiation (OLR) oscillation, Section 4 investigates the spatial distribution characteristics of atmospheric oscillations, Section 5 explores influence mechanisms of the 3–10-day synoptic-scale oscillation and 8–15-day quasi-biweekly oscillation on rainstorms, and Section 6 provides a summary and discussion.

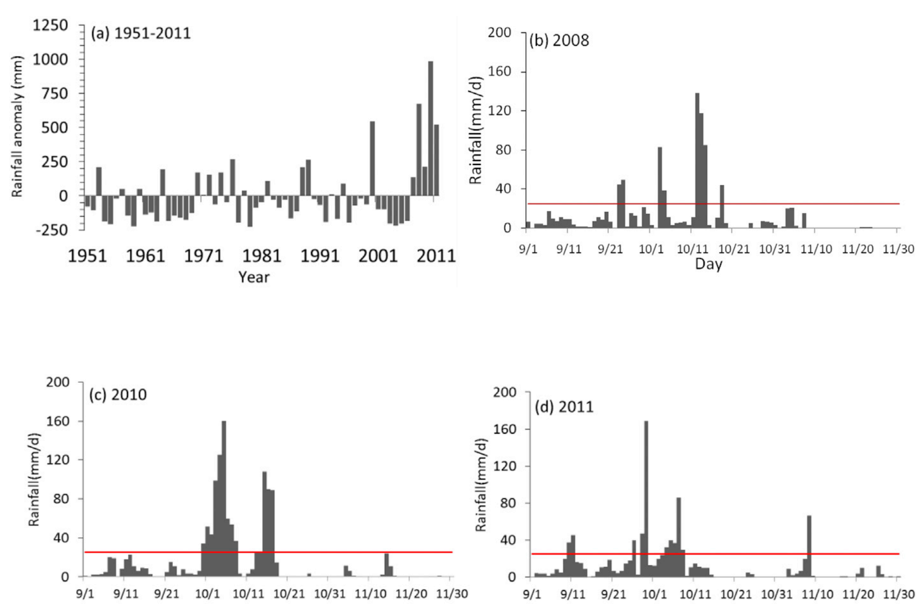

Fig. 2. (a) Interannual variation of precipitation anomalies (units: mm) in October in Haikou, Hainan. Average precipitation daily variation of 18 stations. Daily precipitation variation over Hainan, from September to December (b) 2008; (c) 2010; and (d) 2011. (Horizontal lines represent precipitation of 25 mm day^{-1}).

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