The Persistent Heavy Rainfall over Southern China in June 2010: Evolution of Synoptic Systems and the Effects of the Tibetan Plateau Heating

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ABSTRACT

This study investigates influencing weather systems for and the effect of Tibetan Plateau (TP)'s surface heating on the heavy rainfall over southern China in June 2010, focusing on the four persistent heavy rainfall events during 14–24 June 2010. The major weather systems include the South Asian high, midlatitude trough and ridge, western Pacific subtropical high in the middle troposphere, and shear lines and eastward-moving vortices in the lower troposphere. An ensemble of convection-permitting simulations (CTL) is carried out with the WRF model for these rainfall events, which successfully reproduce the observed evolution of precipitation and weather systems. Another ensemble of simulations (SEN) with the surface albedo over the TP and its southern slope changed artificially to one, i.e., the surface does not absorb any solar heating, otherwise it is identical to CTL, is also performed. Comparison between CTL and SEN suggests that the surface sensible heating of TP in CTL significantly affects the temperature distributions over the plateau and its surroundings, and the thermal wind adjustment consequently changes atmospheric circulations and properties of the synoptic systems, leading to intensified precipitation over southern China. Specifically, at 200 hPa, anticyclonic and cyclonic anomalies form over the western and eastern plateau, respectively, which enhances the southward cold air intrusion along the eastern TP and the divergence over southern China; at 500 hPa, the ridge over the northern plateau and the trough over eastern China are strengthened, the southwesterly flows along the northwestern side of the subtropical high are intensified, and the positive vorticity propagation from the plateau to its downstream is also enhanced significantly; at 850 hPa, the low-pressure vortices strongly develop and move eastward while the southwesterly low-level jet over southern China strengthens in CTL, leading to increased water vapor convergence and upward motion over the precipitation region.

Key words: persistent heavy rainfall over southern China, convection-permitting ensemble simulation, circulation and weather systems, Tibetan Plateau's heating effect


1. Introduction

Covering about a quarter of the Chinese territory, the mean elevation of the Tibetan Plateau (TP) is more than 4000 m above sea level. Because of its special location, large size, and high elevation, the TP’s dynamic and heating effects can exert great influences on weather and climate in China, East Asia, and even throughout the globe (Ye and Gu, 1955; Flohn, 1957). The diabatic heating of the TP has a significant impact on the planetary-scale circulation and summer monsoon circulation (Hahnd and Manabe, 1975; Huang,
The air over the TP sinking in winter and rising in summer acts like a huge “air pump” that affects surrounding and global atmospheric circulations. In summer, the plateau is a heat source on average compared to the atmosphere over the plateau (Ye and Gao, 1979). The surface sensible heat flux, which is large near the northern and southern flanks of the TP, appears to be the major driving source. This “sensible heat pump” (Wu et al., 2006) regulates the development, advance, and retreat of the East Asian rainband (Xu et al., 2010). Research has also indicated that the lower sensible heating flux of TP in spring will delay the seasonal conversion of the land-sea thermal contrast in East Asia, and weaken the East Asian summer monsoon circulation. In contrast, a larger sensible heating flux in spring can lead to an earlier onset of the East Asian summer monsoon and strengthen the monsoon circulation (Duan et al., 2012).

The generation and development of the weather systems over the TP are significantly affected by the plateau’s surface thermal conditions. For example, the plateau’s surface sensible heating can reduce atmospheric stability, increasing the boundary perturbation (Wang, 1987). This effect plays an important role in the generation of the low-pressure vorticity over the plateau and its southeastern margin near the Sichuan basin (Luo et al., 1991; Luo and Yang, 1992; Chen et al., 1996; Li et al., 2002; Li and Liu, 2006). By comparing adiabatic processes, diabatic processes, presence and absence of surface sensible heating and latent heating, respectively, in a series of numerical experiments, some scholars concluded that the formation of the plateau vortex is mainly caused by diabatic processes. Within the diabatic processes, they concluded that the plateau surface sensible heating effect is much more important than the surface latent heating (Luo and Yang, 1992). Subsequent case studies also found that if there is no surface sensible heating effect, the plateau vortex will not form (Chen et al., 1996). Moreover, the strengthening and developing of the TP vortex after its formation is generally considered to be closely related to the release of latent heating, and the convectively generated latent heating feedback effect is more important than the large-scale latent heating (Chen et al., 1996). The surface sensible heating also plays an important role in the development of the plateau vortex, depending on the configuration of the vortex center and the sensible heating center. When the two centers are appropriately located, greater differences in temperature create a more conducive environment for the development of the vortex (Li et al., 2002).

In recent years, persistent heavy rainfall events have attracted increasing attention, and some progress has been made on the impact of TP on the persistent rainfall over southern China. Some researchers pointed out that the existence of the southwest wind center over the southeastern edge of the plateau is the main climatic cause of persistent precipitation in southeastern China (Wan and Wu, 2007; Wan et al., 2009). In spring, TP is a weak heating source. TP heating-forced low-level cyclonic winds can strengthen the southwest flows over its southeastern margin, transporting warm air to South China. Meanwhile, the plateau’s bypassing effect strengthens the southward movement of northern cold air. The warm and cold air masses converge over South China, increasing spring precipitation thereby (Liang et al., 2005; Wan and Wu, 2007; Wan et al., 2009). The plateau’s strong surface heating effect can maintain from spring to summer, turning the summer plateau into a strong atmospheric heating source (Wang et al., 2013). In summer, the TP’s heating effect is a main factor causing lower-level cyclonic circulation and higher-level anticyclonic circulation over the plateau and its surrounding areas (Wu and Liu, 2000; Wu et al., 2002). The TP’s thermal forcing can strengthen the South Asian high, with its center moving northwestward (Liang et al., 2005). It can also lead to a Rossby wave train downstream. A cyclonic response over the northeastern plateau strengthens the lower-level northerly over the northern China, and an anticyclonic response over the western Pacific enhances the subtropical high and the lower-level southerly along its west. Warm and cold air flows converge over the Huaihe River basin, strengthening summer rainfall in the region. In summer, the TP’s sensible heating strengthens the warm center of