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DISTRIBUTION AND DIURNAL VARIATION OF WARM-SEASON SHORT-DURATION HEAVY RAINFALL IN RELATION TO THE MCSS IN CHINA

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1. INTRODUCTION

Short-duration heavy rainfall (SDHR) is one type of severe convective weather that occurs in China. SDHR events can lead to urban water logging and geological disasters. For example, debris flow resulting from an SDHR event in Zhouqu, Gansu Province on 8 August 2010 caused approximately 2000 deaths. SDHR has therefore become an important focus of weather forecasting in China. The Central Meteorological Office of China defines SDHR as hourly rainfall in excess of 20 mm, while heavy rainfall in China is defined as daily rainfall in excess of 50 mm. In China, both SDHR and heavy rainfall are mainly produced by mesoscale convective systems (MCSs) and accompanied by thunder and lightning. The definition of SDHR emphasizes rain produced by strong convective systems with a short duration. Heavy rain usually lasts a longer time and includes both convective and stratiform precipitation.

2. DATA AND METHODS

The hourly rainfall data are provided by the National Meteorological Information Center of China. The data used in this paper were observed during April–September of 1991–2009. They were collected at 876 observation stations covering mainland China, including almost all of the first- and second-class national stations in China but those in Taiwan. Hourly rainfall refers to one-hour cumulative rainfall accumulated during the previous hour. From these observations, we selected 15 yr of observations taken at 549 stations (Fig. 1).The average distance between two neighboring stations is approximately 100 km. In general, the observation network is densest in eastern China.

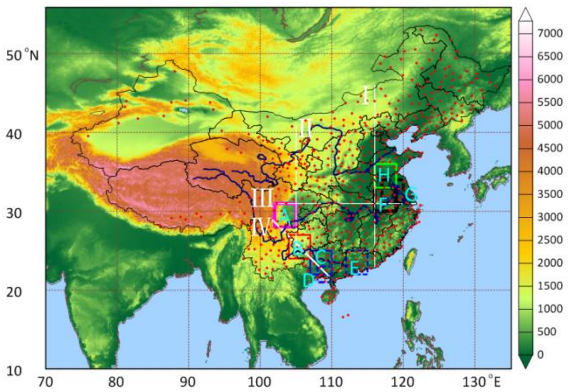

Fig.1 Orography and geography of China (shading), with selected meteorological observation stations (red dots) and analysis regions (white solid lines labeled I, II, III, and IV denote the positions of different cross sections; rectangles labeled A, B, C, D, E, F, G, and H indicate regions used to calculate diurnal cycles of SDHR and TBB≤–52°C; see text for details).

The following methodology is adopted in this paper. Given a specified analysis period and threshold rainfall intensity (for example, 20 mm), the SDHR frequency at any station in China is calculated by dividing the number of hourly data points exceeding the specified threshold intensity by the total number of hourly data points. This frequency is referred to as the frequency of SDHR occurrence. The spatial distribution and average diurnal variations of maximum hourly rainfall are also presented.

Geostationary satellite observations of infrared TBB are used to analyze the diurnal variations of MCSs.

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These diurnal variations are then compared with the diurnal variations of SDHR. The TBB dataset is effectively the same as that used by Zheng et al. (2008), but with temporal coverage from June to August 1996–2007 (excluding 2004). The spatial resolution of the data is 0.1°×0.1° (latitude by longitude). The methodology mirrors that applied by Zheng et al. (2008), in which the frequency of MCSs is calculated for each grid cell as the frequency of TBB ≤ -52° C. The spatial resolution of the TBB data is significantly finer than the spatial resolution of the hourly rainfall data (approximately100 km).

3. SPATIAL DISTRIBUTION

Figure 2 shows the spatial distributions of SDHR events exceeding 20 and 50 mm h^{-1} and the spatial distribution of maximum hourly rainfall over China. The spatial distributions of SDHR events exceeding 10, 30, and 40 mm h^{-1} (omitted) are similar to that of SDHR events exceeding 20 mm h^{-1} (Fig. 2a).These distributions are also consistent with that reported by Zhang and Zhai (2011), who based their analysis on hourly rainfall observations over eastern China during the warm seasons of 1961–2000. The spatial distribution of SDHR events exceeding 50 mm h^{-1} (Fig. 2b) is substantially different from the distributions of SDHR events exceeding the lower intensity thresholds. This difference may be because extreme rainfall events with intensity exceeding 50 mm h^{-1} are mainly associated with rare microscale weather systems that have a very low occurrence frequency. This paper focuses mainly on the spatial and temporal distributions of SDHR events exceeding 20 mm $h^{-1}$for consistency with the definition of SDHR given by the Central Meteorological Observatory of China, the threshold for extreme hourly rainfall over eastern China identified by Zhang and Zhai (2011), and the threshold of hourly rainfall intensity typically associated with flash floods in the U.S. (Davis, 2001). This simplification is also supported by the consistency among the spatial distributions of SDHR event frequencies in China when SDHR is defined using intensity thresholds between 10 and 40 mm h^{-1}.

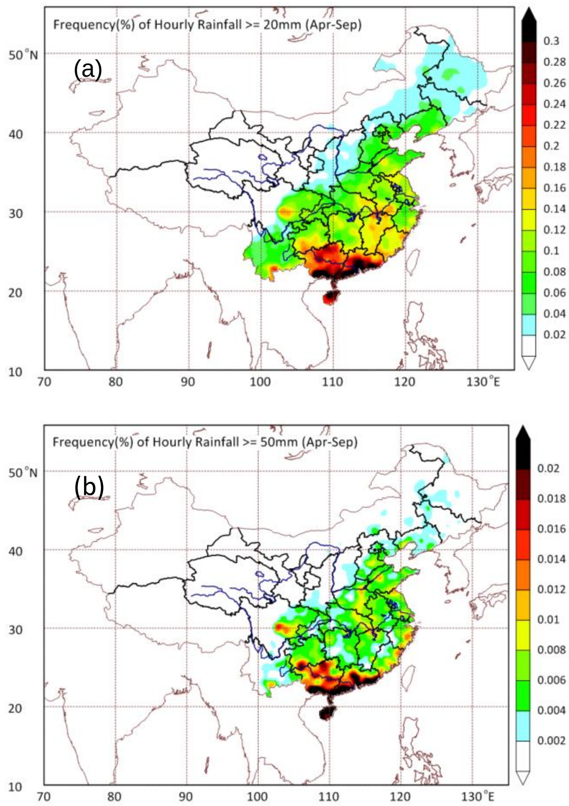


Fig.2 Frequencies of SDHR events (%) exceeding (a) 20 mm h^{-1} and (b) 50 mm h^{-1} during the warm season (April–September)

4. DIURNAL VARIATIONS

No previous studies have characterized the relationships between diurnal variations in SDHR and convection. This section presents the characteristics and propagation patterns of diurnal variations in SDHR over different parts of China, and explores their relationships with diurnal variations in MCSs.

MCSs are defined as regions with TBB ≤ −52°C at a horizontal resolution of 0.1°×0.1°. This definition can identify both meso-α-scale convective systems ($M_{\alpha}CS$) and meso-β-scale convective systems ($M_{\beta}CS$) with horizontal scales exceeding 20 km (Zheng et al., 2007, 2008). These systems comprise a variety of atmospheric convective systems, including weak convective systems (such as isolated thunderstorms and lightning storms) and severe convective systems (such as hailstorms and SDHR with damaging winds).

The spatial resolution of the hourly rainfall data is much coarser than the spatial resolution of the geostationary satellite TBB data.

4.1Mean diurnal variations over China

Figure 3 shows the mean diurnal variations of SDHR frequency and maximum hourly rainfall averaged overall stations in China (excluding Taiwan) during the warm season (April–September).Mean diurnal variations over the active precipitation region within this domain (Anhui, Fujian, Jiangsu, Shandong, Shanghai, Zhejiang, Jiangxi, Heilongjiang, Jilin, Liaoning, Beijing, Hebei, Inner Mongolia, Shanxi, Tianjin, Guangdong, Guangxi, Hainan, Henan, Hubei, Hunan, Yunnan, Guizhou, Sichuan, and Chongqing) are also shown, as are the mean diurnal variations in MCSs during summer (June–August).

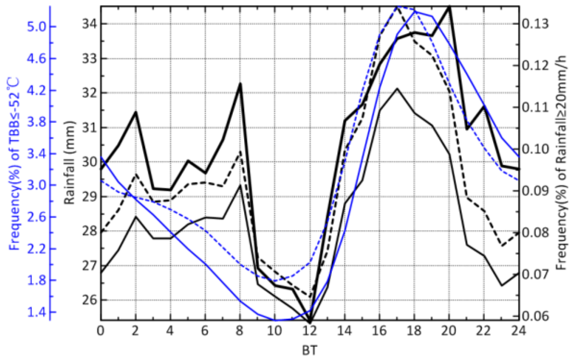


Fig.3 Diurnal variations in mean frequency and maximum hourly rainfall for SDHR events with rainfall ≥ 20 mm h^{-1} and brightness temperatures (TBB) less than –52°C. Diurnal variations in the mean frequencies are shown for SDHR averaged over all of China (thin black solid line), SDHR averaged over the active precipitation region (black thick dashed line), TBB ≤ –52°C averaged over all of China (blue solid line), and TBB ≤ –52°C averaged over the active precipitation region (blue dashed line). The thick black solid line shows the maximum hourly rainfall averaged over all of China. The blue *y*-axis indicates the frequency of TBB ≤ –52°C (unit: %), the black *y*-axis on the left indicates hourly rainfall (unit: mm), and the black y-axis on the right indicates SDHR frequency (unit: %).

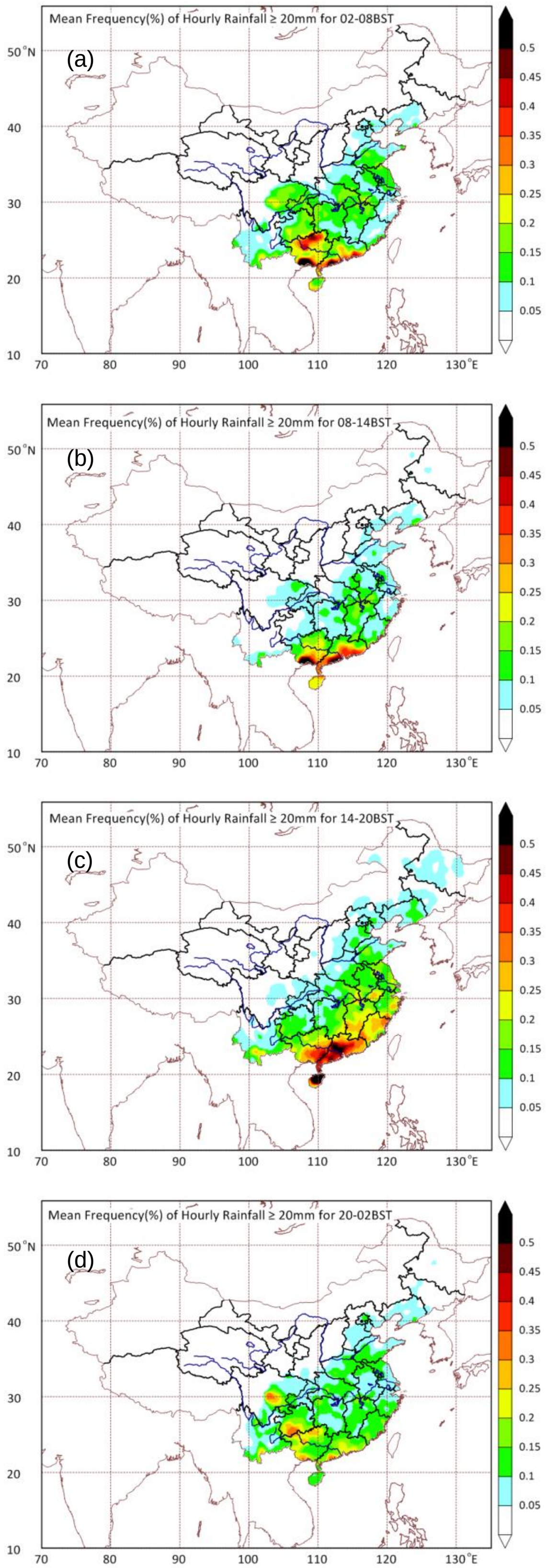


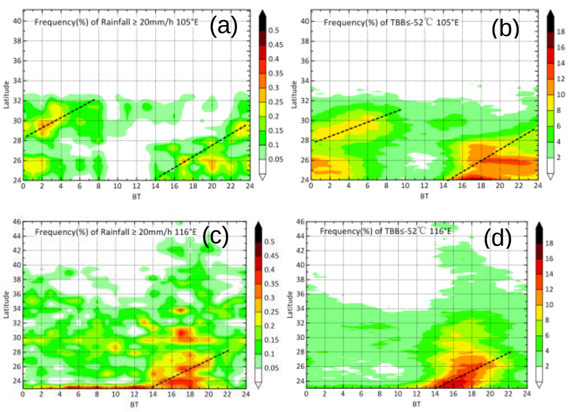
Fig.4 Diurnal variations of the frequency (unit: %) of SDHR with hourly rainfall ≥ 20 mm $h^{-1}$for (a) 0200–

0800 BT, (b) 0800–1400 BT, (c) 1400–2000 BT, and (d) 2000–0200 BT.

Figure 4 shows distributions of SDHR frequency for different times of day. As in Fig. 3, SDHR events occur most often in the afternoon (1500–2000 BT) and least often in the morning (0900–1400 BT), but periods of high SDHR activity in China differ by region. Moreover, diurnal variations in SDHR activity appear to propagate in characteristic ways.

4.2Diurnal variations over different regions

Differences in diurnal variations of SDHR and MCSs over different regions are examined using time–latitude cross-sections along the105° and 116°E meridians, time–longitude cross-sections along the31°N parallel, and cross-sections along a straight line from southwestern Sichuan to southeastern Guangxi (Fig. 5). The positions of all cross-sections are indicated by white lines in Fig. 1. Diurnal variations in SDHR and MCSs are very similar, but diurnal variations in MCSs are smoother and more continuous, and the MCSs propagate more clearly. These differences result from differences in the underlying observations. Observations of TBB (which are used to identify MCS anvil clouds) are instantaneous rather than hourly, and TBB is a more continuous quantity than precipitation.



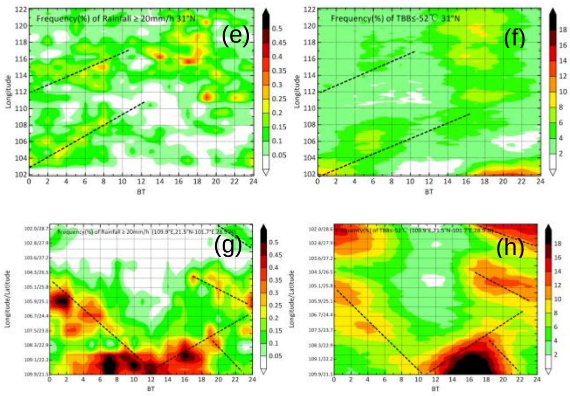


Fig.5 Temporal cross-sections of diurnal variations in the frequencies (unit: %) of SDHR (hourly rainfall ≥ 20 mm; left column) and MCSs (TBB ≤–52°C; right column) along (a, b) the 105°E meridian, (c, d) the 116°E meridian, (e, f) the 31°N parallel, and (g, h) the straight line (28.9°N, 101.7°E) –(21.5°N, 109.9°E).

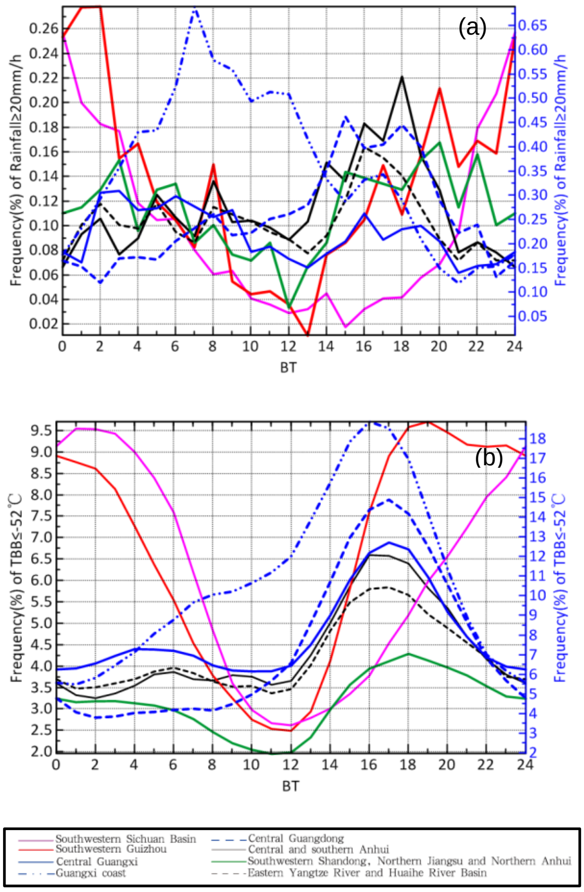


Fig. 6. Diurnal variations infrequencies (unit: %) of (a) SDHR (hourly rainfall ≥ 20 mm)and (b) MCSs (TBB ≤–52°C). The blue curves (for central Guangxi, the

coastal area of Guangxi, and central Guangdong) use the blue (right) ordinate axes; the curves for other regions use the black (left) ordinate axes.

Figure 6 shows the diurnal variations of the mean frequencies of SDHR (hourly rainfall ≥ 20 mm) and the MCSs (TBB ≤–52°C) over active precipitation areas. These results highlight the dependence of these diurnal variations on the underlying surface. The areas (which are indicated by rectangles in Fig. 1) include the southwestern Sichuan Basin (rectangle A; 28°–31°N, 102°–105°E), southwestern Guizhou (rectangle B; 24°–27°N, 104°–107°E), central Guangxi (rectangle C; 22°–25°N, 107°–110°E), the coastal area of Guangxi (rectangle D; 21°–23°N, 108°–110°E), central Guangdong (rectangle E; 22°–25°N, 112°–115°E , central and southern Anhui (rectangle F; 30°–33°N, 116°–119°E), southwestern Shandong, northern Jiangsu and northern Anhui (rectangle H; 33°–36°N, 116°–119°E), and the eastern Yangtze–Huaihe River Basin (rectangle G; 31°–34°N 117°–120°E). Note that two vertical axes are used in both panels of Fig. 6 to better highlight the diurnal variations of SDHR and MCSs in regions with lower frequencies.

5. CONCLUSIONS

In general, the spatial distributions of SDHR in China defined using thresholds of 10, 20, 30,or 40 mm h^{-1} are very similar to the distribution of heavy rainfall with intensity ≥ 50 mm day^{-1}. By contrast, the spatial distribution of SDHR with intensity ≥ 50 mm h^{-1} is more scattered, with a stronger similarity to the spatial distribution of heavy rainfall with intensity ≥ 100 mm day^{-1}. The heaviest hourly rainfall observed in China during this period was more than 180mm. Although SDHR with intensity ≥ 50 mm h^{-1} is rare, it has been observed to occur even in regions with very weak SDHR activity.

The mean diurnal cycles of SDHR frequency and maximum hourly rainfall averaged over China as a whole are trimodal. The primary maximum in this diurnal cycle occurs during the afternoon (1600–1700 BT); this peak is consistent with the primary maximum in the diurnal cycle of MCS activity. There are also two secondary peaks during the midnight and early morning hours (0100–0200 and 0700–0800 BT, respectively), which do not appear in the diurnal cycle of MCS activity. SDHR frequency averaged over all of China is minimum in the morning. Changes in the mean SDHR frequency are more gradual after midnight.

The mean diurnal cycles of SDHR averaged within different regions of China have several different characteristic types (including single-peak, double-peak, and multiple-peak). The main periods and relative durations of SDHR differ substantially over different underlying surfaces. Diurnal variations in SDHR and MCSs have many common features over most regions of China, but often differ significantly after midnight.

The diurnal variations of SDHR and MCSs along various transects in southern China show that the SDHR indicate that these convective system often propagate according to characteristic patterns. MCSs frequently propagate over the Sichuan Basin, the region of Hubei and Anhui provinces near 31°N, and from the southeastern part of the Sichuan Plateau to the coastal area of Guangxi via the northeast Yunnan–Guizhou Plateau (southwestern Guizhou).

6. REFERENCES

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