Hourly Rainfall Changes in Response to Surface Air Temperature over Eastern Contiguous China

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ABSTRACT

In this study, late-summer rainfall over eastern contiguous China is classified according to hourly intensity and the changes of moderate, intense, and extreme precipitation in response to variation of surface air temperature are analyzed. The e-folding decay intensity ($I_{mi}$) derived from the exponential distribution of rainfall amount is defined as the threshold that partitions rainfall into moderate and intense rainfall, and the double e-folding decay intensity ($I_e$) is used as the threshold to pick out extreme cases. The mean values of $I_{mi}$ and $I_e$ are about 12 and 24 mm h$^{-1}$, respectively. Between the two periods, 1966–85 and 1986–2005, the ratio between moderate and intense rainfall has experienced significant changes. And the spatial pattern of changes in the percentage of moderate rainfall presents a direct relation with that of the surface air temperature. Based on temperature changes, three regimes, regime N (north China), regime C (central eastern China), and regime S (southeastern coastal area of China), are defined. In warming regimes (regimes N and S), the percentage of moderate rainfall exhibits a decreasing trend. In regime C, where the temperature has fallen, the percentage of moderate rainfall increased prominently. In all three regimes there are significant negative (positive) correlations between the percentage of moderate (intense) rainfall and the temperature. The relation between the extreme rainfall and the surface air temperature is far more regionally dependent. With plenty of water supply and little change in relative humidity, the extreme rainfall increased in regime S. Although regime N also shows strong warming trends, there is no significant trend in extreme precipitation due to the lack of water vapor transportation.

1. Introduction

Intensity is one of the most important parameters of precipitation. The knowledge of rainfall intensity is of paramount importance for most meteorologists, hydrologists, climatologists, and even engineers because it is the crucial information either in the study of the global water cycle, energy transformation, or in the validation of numerical weather and climate models, or in engineering structural design to handle storm impacts on highway, bridge, culvert, and other flood-control projects. It is necessary to classify the precipitation into different categories based on intensity and explore the rainfall structure with respect to intensity. However, there is no widely accepted method to define the thresholds to partition moderate, intense, and extreme rainfall. In previous studies, one kind of method is to set a series of thresholds by given values. For example, Sun et al. (2006) classified precipitation into five categories including thresholds of 1, 10, 20, and 50 mm day$^{-1}$. In the analysis of heavy rainfall occurrences in Taiwan, the daily rainfall accumulation of 130 mm was used as a criterion for the extreme heavy precipitation (Chen et al. 2007). Another method is based on the specific percentiles of a distribution, which is often used to define the extreme events. Zhai et al. (2005) defined the extreme events as days with a daily precipitation amount greater than the 95th percentile of all rain days during 1961–90. Wang and Zhou (2005) used 97.5% as the threshold percentile of daily precipitation to find annual extreme events, and the 99th and 99.9th percentiles...
were also used (Lenderink and Van Meijgaard 2008). One purpose of this study is to introduce a method to separate the moderate and intense rainfall.

The relation between temperature and precipitation has received considerable attention, and many studies have shown that climate change has a profound impact on rainfall intensity. Temperature change can directly influence the water-holding capacity of the atmosphere, which is governed by the Clausius–Clapeyron equation. In a warmer climate, the atmospheric moisture content rises and the intensity of heavy rainfall driven by low-level moisture convergence increases at a comparable rate (Trenberth et al. 2003). Studies based on climate models supported that the change in the uppermost quantiles of precipitation distribution are closely related to temperature variation and is constrained by the Clausius–Clapeyron relationship (Allen and Ingram 2002; Pall et al. 2007). Using both satellite observations and model simulations, Allan and Soden (2008) also revealed a distinct link between rainfall extremes and temperature, with heavy rain events increasing during warm periods and decreasing during cold periods. Groisman et al. (2004) found that during the twentieth century both temperature and heavy or intense precipitation have increased in the contiguous United States. A study based on the 99-yr record of hourly precipitation observations from De Bilt, the Netherlands, reveals that 1-h precipitation extremes increase twice as fast as expected from the Clausius–Clapeyron relation when daily mean temperatures exceed 12°C (Lenderink and Van Meijgaard 2008). Analysis of long-term station records in Australia revealed that extreme rainfall positively scales with surface air temperature between 20°C and 26°C and for precipitation duration up to 30 min, and negative scaling is found at higher temperatures (Hardwick Jones et al. 2010). Utsumi et al. (2011) assessed the global relationship between extreme daily precipitation and daily surface air temperature using in situ data. They found that the extreme daily precipitation intensity at midlatitudes increases (decreases) at low (high) temperature. Using subhourly data in Japan, Utsumi et al. (2011) further revealed that the decrease in the extreme daily precipitation intensity at high temperature is caused by the decrease in duration of precipitation events.

In recent years, decadal changes in late summer [July and August (JA)] precipitation over eastern China have been studied and are described as the southern flooding and northern drought (SFND) pattern, which refers to the increased rainfall over the midlower reaches of the Yangtze River valley and the decreased rainfall over north China (Hu 1997; Xu 2001; Hu et al. 2003; Yu et al. 2004b; Chen et al. 2004). Based on numerical experiments, Menon et al. (2002) speculated that SFND might be a result of the changes in absorbing black carbon. Qian et al. (2009) also analyzed the aerosol contribution to the precipitation changes in China. They suggested that the increased aerosol concentrations are responsible for the decreased light rain events in China. Yu and Zhou (2007) proposed that the SFND changes in rainfall were linked to significant upper-troposphere cooling covering the area between 30° and 45°N from 90° to 120°E. And, cooling (warming) trends in surface air temperature were found in the Yangtze River valley (north China). Interestingly, studies based on daily rainfall data have shown that the extreme precipitation events in the Yangtze River valley increased dramatically in the last several decades (Wang and Zhou 2005; Zhai et al. 2005) even though the cooling trends dominate this region. The opposite trend between extreme daily precipitation and temperature can be partly ascribed to the following two factors. One is the relatively coarse time resolution of rainfall data. The strong storm dependence on convergence of local moisture only lasts for several hours, or even less than an hour. The daily rainfall data cannot show their real intensity. The other is that most of the JA precipitation changes over eastern China are closely related to changes in circulation. Yu and Zhou stated that the cooling in the upper troposphere is associated with cyclonic (anticyclonic) anomalies in the upper (lower) troposphere. Eastern China is affected by the anomalous northerly wind to the east of the anticyclonic center, which weakens the normal northward progression of the southerly monsoon in JA. This circulation pattern reduces the water vapor supply in north China and keeps the monsoon trough over the mid-to-lower reaches of the Yangtze River valley. Therefore, the large-scale circulation might be more critical than the thermodynamic condition governed by the Clausius–Clapeyron relationship. Therefore, there should be some unique features in the relation between the rainfall structure with respect to intensity and the surface air temperature in this region, which is still an open question. In this paper, 40 years of hourly rainfall data over eastern contiguous China are used to explore the characteristics of this relationship and discuss its possible mechanisms. The analysis in this study is focused on JA because significant changes in precipitation and surface air temperature occur in these two months (Yu et al. 2004b; Yu and Zhou 2007), and JA as a whole can be treated as one phase of the East Asian summer monsoon (Wang et al. 2009).

The other parts of the paper are organized as follows. Section 2 describes the datasets and proposes a method to classify precipitation events based on the intensity.
Change in rainfall structure with respect to intensity and its relation with surface air temperature are investigated in section 3. In section 4, the major points are summarized and the implications of present results are discussed.

2. Data and methodology

The precipitation dataset used in this study was obtained from the National Meteorological Information Centre (NMIC) of the China Meteorological Administration. It consists of quality-controlled hourly rain gauge records during 1954–2007 (Li et al. 2011). The analysis was restricted to the period from 1966 to 2005 to avoid biases caused by missing data. The locations of rain gauge stations are marked by dots in Fig. 1. To reveal the changes in thermal conditions, the daily records of surface air temperature from stations in the national climatic reference network and national weather surface network of China were used. The radiosonde data at stations in eastern contiguous China and the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) Global Reanalysis 1 data (Kalnay et al. 1996) were also analyzed to assess changes in the lower troposphere.

Three stations, marked by green (open) diamonds in Fig. 1, are used as examples to illustrate the method to categorize the moderate, intense, and extreme precipitation. All of the three stations are located between 112° and 113°E. According to their latitudes, these three stations are named as Station North, Station Middle, and Station South, respectively. All July–August hourly rainfall for the period of 1966–2005 is binned by 1 mm h⁻¹ increments. The distributions of rainfall with hourly intensity, shown in Figs. 2a–c by black asterisks, approximately follow an exponential decay pattern. For each station the following exponential function (1) was used to fit the distribution of rainfall amount:

\[ R(I) = A_r e^{-B_r I} . \]  

(1)

Here \( I \) represents hourly rainfall intensity and \( R(I) \) is for the accumulated rainfall amount. The parameters, \( A_r \) and \( B_r \), are determined by least squares fitting of Eq. (2), which is derived by taking the natural logarithm of both sides of Eq. (1):

\[ \ln[R(I)] = \ln A_r - B_r I . \]  

(2)

The logarithm of rainfall amount and the corresponding fit lines are shown by blue triangles and blue lines, respectively. The logarithm of rainfall amount decreases linearly when the intensity is not too high. The exponential decay curve gives an \( e \)-folding (double \( e \)-folding) decay intensity when hourly rainfall intensity reaches 1/\( B_r \), (2/\( B_r \)), as marked by red vertical lines in Figs. 2a–c. The \( e \)-folding decay intensity (1/\( B_r \), referred to as \( I_{mi} \)) is defined as the threshold that divides the moderate and intense hourly rainfall. The double \( e \)-folding intensity (2/\( B_r \), referred to as \( I_e \)) is defined as the threshold of extreme hourly rainfall. It is to be noted that, in this paper, the extreme precipitation is included as part of the intense precipitation. As shown in Figs. 2a–c, the blue triangles on the left side of the \( I_e \) lines show a much better linear pattern than those on the right side. Deviation from the climatic exponential decay pattern can be regarded as an important feature of extreme rainfall events.

The mean \( I_{mi} \) of all stations shown in Fig. 1 is 11.9 mm h⁻¹, and large regional differences exist in the distribution of \( I_{mi} \) values. As shown in Fig. 3a, the \( I_{mi} \) values are small (<8 mm h⁻¹) in the northwestern part of the figure and increase in a sharp gradient toward the southeast. Over the northern part of the coastal region from 32° to 40°N, the \( I_{mi} \) values are high and at many stations they exceed 16 mm h⁻¹. To the south of this high value region, southeastern China shows relatively low \( I_{mi} \) values (<12 mm h⁻¹) compared to the surrounding areas. Along 30°N there are two high value centers,
located west of 106°E around 116°E, and another high value center in Fig. 3a exists south of 23°N. Interestingly, the spatial distribution of $I_{mi}$ is similar to that of the mean hourly rainfall intensity, shown in Fig. 3b. All large value centers match quite well. The pattern correlation between the two fields is as high as 0.94. At each station the $I_{mi}$ is around five times of its climatic hourly intensity. This relationship indicates that the new defined thresholds, which are identified based on the climatic rainfall amount distribution with hourly intensity, has certain physical significance.

The moderate rainfall defined by this method is shaded gray in Figs. 2a–c, and it accounts for around two-thirds of the total rainfall amount. The other one-third comes from intense precipitation, half of which is defined as extreme rainfall. The specific percentages of moderate, intense, and extreme precipitation of the three sample stations are listed in Table 1. A remarkable feature is that, although the percentage of intense rainfall increases from north to south, the contribution of extreme rainfall is larger at Station North and smaller at Station South.

**FIG. 2.** The 1966–2005 accumulated rainfall amount of July–August (JA) precipitation with different hourly intensity (black asterisks) and its exponential distribution fit line (black curve line) for (a) Station North, (b) Station Middle, and (c) Station South. The blue triangles and blue lines are for the logarithm of rainfall amount at all stations. The e-folding and double e-folding of the exponential distribution are marked by red vertical lines. The 95th and 99th percentile hourly rainfall intensity are labeled by black dashed vertical lines. (d)–(f) As in (a)–(c), but for rainfall frequency.
The rainfall frequency distribution with intensity (black asterisks) and the logarithm of it (blue triangles) are also shown (Figs. 2d–f). The total frequency of rainfall less than 1 mm h\(^{-1}\) is too high and the frequency drops dramatically as intensity increases at all three stations. As a result, the exponential distribution line (black line) does not fit the black asterisks on the left side of the plot. Correspondingly, the distribution of blue triangles presents a curve pattern left of 24 mm h\(^{-1}\) and it systematically deviates from the linear fit line (blue line). Comparison between Figs. 2a–c and 2d–f reveals that the rainfall amount obeys the exponential decay law much better than frequency. Therefore, the rainfall amount distribution is used to define the threshold values.

Compared with the widely used percentile method (Jenkinson 1977), \(I_{mi}\) is slightly larger than the 95th percentile (black dashed lines labeled P95 in Figs. 2a–c). The mean value of P95 at all stations is 9.6 mm h\(^{-1}\). The 99th percentile intensity (black dashed lines labeled P99 in Figs. 2a–c) is located between \(I_{mi}\) and \(I_e\). The mean value of P99 at all stations is 18.6 mm h\(^{-1}\). Thus, the \(I_e\) is a more strict criterion compared to the 99th percentile intensity when defining the extreme events based on hourly rainfall data.

### 3. Results

Previous studies based on daily rainfall data revealed that during the last several decades the extreme precipitation has significantly increased in the midlower reaches of the Yangtze River valley and changes in frequency and intensity of torrential rain have contributed to the formation of the southern flooding–northern drought (SFND) pattern (Li et al. 2008; Zhai et al. 2005). However, using hourly rainfall data, Yu et al. (2010) proposed that the SFND pattern over eastern China is mostly attributed to changes in precipitation with relatively low intensity. They found that changes in precipitation weaker than 10 mm h\(^{-1}\) account for 65% (96%) of the “flooding” (“drought”) in the midlower reaches of Yangtze River valley (north China) and changes in rainfall stronger than 20 mm h\(^{-1}\) are fairly small. Following Yu et al., the period 1966–2005 is separated into 1966–85 and 1986–2005 to analyze the decadal changes. Figure 4 shows the difference in 105°–118°E zonally averaged precipitation between the latter (1986–2005) and former (1966–85) 20 years as a function of intensity. To distinguish the moderate, intense, and extreme precipitation, the zonally averaged \(I_{mi}\) \((I_e)\) value is presented by black solid (dashed) line. The curves of

<table>
<thead>
<tr>
<th>Station</th>
<th>Moderate</th>
<th>Intense</th>
<th>Extreme</th>
</tr>
</thead>
<tbody>
<tr>
<td>North</td>
<td>66.14</td>
<td>33.86</td>
<td>17.42</td>
</tr>
<tr>
<td>Middle</td>
<td>63.31</td>
<td>36.69</td>
<td>15.14</td>
</tr>
<tr>
<td>South</td>
<td>62.92</td>
<td>37.08</td>
<td>13.61</td>
</tr>
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95th (gray solid line) and 99th (gray dashed line) percentile intensity are also shown in Fig. 4 for reference. One striking feature presented in both rainfall amount (Fig. 4a) and frequency (Fig. 4b) is the SFND pattern. Moreover, as the intensity increases, both negative and positive centers decay and the boundary between them shifts southward. The major part of the dipole is confined to the left of the black solid curve, indicating that the dominant contribution comes from the moderate precipitation. The intense rainfall does not show a noticeable SFND pattern, and changes in extreme precipitation are totally independent of the dipole. In the region south of 24°N, although the decadal changes in both the amount and frequency of moderate precipitation are small, negative values appear in the low intensity section, especially for frequency.

The uneven distribution of rainfall changes against intensity (Fig. 4) indicates that the intensity-related structure of precipitation has been reshaped at stations in eastern China. Figure 5 shows the changes in the percentage of moderate precipitation at each station. The changes in rainfall amount (Fig. 5a) and frequency (Fig. 5b) present similar patterns. In most areas of north China, the percentage of moderate rainfall has decreased in the last several decades. Along and south of the Yangtze River valley, there are positive centers that indicate the portion of moderate rainfall has increased. Another distinctive feature shown in Fig. 5 is the decreasing trends in the southeastern coastal areas. The inland area and the coastal region are distinctly divided by the thick zero line, except for a gap around 25°–26°N. Since the precipitation process is complex and is sensitive to lots of factors, the statistical calculation based on each single station might be influenced by the randomness due to limited sample size, which leads to low significance at some stations. However, the continuous large areas with the same sign, such as north China, the Yangtze River valley, and the southeastern coastal areas, do exhibit scientifically informative changes in precipitation.

Figure 6 shows the changes in the JA surface air temperature in the last several decades. There are three key regions in both daily mean temperature (Fig. 6a) and the daily maximum (Fig. 6b). The stations north of 35°N present strong warming trends. The positive values are also found in the southeastern coastal regions. Between these two warming regions, cooling trends exist in central China. This cooling is spatially continuous and covers a large area in eastern China. Since the cooling appears in the global warming background and is influenced by anthropogenic warming, its magnitude is reduced and the statistical significance is weakened. Nevertheless, this cooling is an important and physically reliable signal. The spatial pattern of surface air temperature change is correlated to the changes in moderate precipitation.
between the 1986–2005 mean and the 1966–85 mean (figure not shown). The pattern correlation between the shifts of the mean (maximum) temperature and changes in moderate rainfall frequency reaches $-0.57$ ($-0.61$).

Comparing Fig. 5 and Fig. 6, one common feature of changes in the moderate rainfall percentage and temperature is the northern–central–southeastern tripole pattern. Based on this feature, three station groups are

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**FIG. 5.** The 20-yr mean changes (1986–2005 minus 1966–85) in the percentage of JA moderate rainfall (a) amount and (b) frequency. Regions where the changes are statistically significant at the 10% confidence level according to a Student’s $t$ test are shaded. The contour intervals are 3% in (a) and 0.5% in (b).

**FIG. 6.** The 20-yr mean changes (1986–2005 minus 1966–85) in the JA (a) mean daily surface air temperature and (b) daily maximum surface air temperature. Regions where changes are statistically significant at the 10% confidence level according to a Student’s $t$ test are shaded; contour intervals are 0.2°C.
defined according to temperature changes. In northern China (32°–42°N, 105°–125°E), the stations at which the daily maximum temperature difference between the 1986–2005 mean and the 1966–85 mean in excess of 0.1°C are classified as regime N (marked by red dots in Fig. 1). The stations presenting a cooling in daily maximum temperature shift greater than −0.1°C and located south of 37°N and east of 105°E are defined as regime C (blue dots in Fig. 1). In southern China (20°–32°N, 105°–125°E), the warming stations (daily maximum temperature change greater than 0.1°C) are defined as regime S (pink dots in Fig. 1).

For each regime the 20-yr mean (1966–85 and 1986–2005) JA rainfall amount is binned by intensity and is fitted to the exponential decay function. Figure 7 shows the logarithm of $e^{-Br t}$; the term $Ar$ is removed for a better comparison. From top to bottom, there are regimes S (blue lines), C (green lines), and N (sienna lines). Based on the slope of lines, it can be deduced that regime S has the largest percentage of intense precipitation, regime C less, and the ratio of intense rainfall in regime N is the smallest. Comparing the lines of the former (dashed line) and the latter (solid line) 20 years, regimes N and S exhibit uplift trends, while the line of regime C drops. This suggests that in the warming regimes (N and S) the contribution of intense rainfall has increased, while in the cooling regime C the portion of moderate rainfall has expanded.

Figure 8 shows the changes in percentage of rainfall binned by intensity. In regime N (sienna solid lines), the regime mean $I_{mi}$ (9.9 mm h$^{-1}$) divides the smoothed line (thick solid) into negative and positive parts. The percentage of moderate (intense) rainfall has decreased (increased) in the past several decades. As part of the intense rainfall, the extreme precipitation portion also shows an upward trend. The blue dotted lines are for regime S, analogous to the changes of regime N. As the intensity increases, the percentage change shifts from negative to positive. One prominent difference between the thick dotted line and the thick solid line is that the dotted line rises to zero at a much stronger intensity, coinciding with the higher mean $I_{mi}$ (14.0 mm h$^{-1}$) in regime S. The changes of regime C are shown by green dashed lines, which present a pattern nearly opposite to regimes N and S. The moderate precipitation has increased, while the percentage of rainfall with intensity around 20–35 mm h$^{-1}$ has reduced.

Both Figs. 7 and 8 show that the warming regime and the cooling regime have experienced different changes in the intensity-related structure of rainfall. The results indicate that there might be a relationship between the surface air temperature and the rainfall structure with respect to intensity. Figure 9 presents the 1966–2005 series of the regime mean JA temperature (red solid line) and the percentage of moderate rainfall (light blue solid line) and extreme rainfall (dark blue dashed line). In regime N (Fig. 9a) the surface air temperature has significantly risen by 0.85°C during the period from 1966 to 2005. The percentage of moderate rainfall is negatively correlated with temperature (correlation coefficient: $-0.45$). Accompanying the decrease of moderate rainfall percentage ($-3.99$%, significant at the 5% confidence level), the portion of extreme rainfall has significantly increased by 2.77%. Nevertheless, there is no significant change in the actual amount and frequency of extreme precipitation over regime N, which is consistent with the results shown in Fig. 4. Figure 9b presents a slight cooling trend in regime C. The correlation coefficient between the JA temperature and the moderate rainfall percentage reaches $-0.58$ in this regime. Regime S (Fig. 9c) experienced a prominent warming of 0.58°C, which is statistically significant at the 1% confidence level. The moderate rainfall percentage in this regime is also negatively correlated with temperature (correlation coefficient $-0.70$).
moderate and intense rainfall has experienced significant changes during the period from 1966 to 2005. The shift in the intensity-related rainfall structure is closely correlated with the variation of surface air temperature. In the warming regimes (regimes N and S) the percentage of moderate rainfall has decreased. In the cooling regime (regime C) the percentage of moderate rainfall exhibits an increasing trend. In all three regimes the percentage of moderate rainfall is negatively correlated with the surface air temperature. Significant trends of extreme precipitation amount and frequency are only found in regime S.

The three regimes analyzed in this study have different features in climate change and provide a good platform for studies on the relation between precipitation and surface air temperature.

In contrast to the global warming, regime C presents a weak cooling trend. The strongest negative correlation (−0.73) between moderate rainfall amount and surface air temperature is found in this regime. This is consistent with the positive feedback between cloud and temperature. Yu et al. (2004a) found that over central China, the strong cloud radiative forcing fundamentally influences the local surface air temperature, which in turn modulates the lower-tropospheric relative humidity and stratification and then changes the cloud amount. Since a large portion of the moderate rainfall over this region could come from deep stratus clouds, the high correlation between the moderate precipitation amount and surface air temperature is easy to understand. It can be explained by the unique climatic feature of deep continental stratus clouds and the positive feedback between clouds and surface air temperature over regime C.

Surrounding the southeast border of the cooling regime, regime S presents a considerable warming trend. Regime N, which is north of regime C, is also a warming regime. However, despite the uniform trends in both temperature and the percentage of moderate precipitation, there is an important difference between these two warming regimes. Regime N does not show a significant trend in actual extreme precipitation, but in regime S the extreme rainfall has increased prominently. This difference can be partly ascribed to the moisture conditions in these two regimes. Figure 10 illustrates the changes in the near-surface specific humidity (Fig. 10a) and relative humidity (Fig. 10b) derived from the NCEP reanalysis data. In regime N, accompanying the surface warming, both specific humidity and relative humidity at 1000 hPa have decreased. Taking into account both possible biases of the reanalysis data in describing the decadal changes of hydrological variables and the limited significant areas in north China, the 40-yr European Centre for Medium-Range Weather Forecasts Re-Analysis (ERA-40) data is used to verify the changes in north China and it shows

4. Summary and discussion

This paper describes a new method to classify the moderate, intense, and extreme precipitation based on hourly rainfall data. The thresholds, $I_m$ and $I_c$, are determined from the climatic distribution of rainfall amount as a function of hourly intensity. The ratio of the

![Fig. 9. Time series of regime-mean JA temperature (red solid line), percentage of moderate rainfall (light blue solid line), and extreme rainfall (dark blue dotted line) for (a) regime N, (b) regime C, and (c) regime S.](image-url)
significant trends (1966–2002) in the near-surface specific and relative humidity (figure not shown). Furthermore, the relative humidity derived from station sounding data is shown (solid line in Fig. 10c), which confirms the decreasing trend of relative humidity in the lower troposphere over regime N. Despite the increase in atmospheric water-holding capacity, it becomes drier in regime N due to the unfavorable large-scale circulation changes (Yu and Zhou 2007). Since most water vapor reaching north China comes from the Indian Ocean, the Indochina Peninsula, the South China Sea, and the southeastern region of mainland China (Shinoda et al. 2005), the monsoon circulation, rather than the thermal condition, plays a crucial role in modulating the local moisture and precipitation. In regime S, which is close to the sea and has a plentiful water vapor supply, the specific humidity has increased significantly. The variation of specific humidity is closely related to surface air temperature. The correlation coefficient between them reaches 0.54. In contrast, the relative humidity does not show significant changes both in the NCEP
data (Fig. 10b) and sounding data (dotted line in Fig. 10c). This indicates that the water-holding capacity associated with the temperature is the dominant factor influencing the moisture condition in this coastal regime.

Based on these three regimes and the classification of moderate, intense, and extreme precipitation, the relationship between temperature and rainfall can be further studied in detail. Instead of studying total rainfall amount and frequency, separating rainfall events according to their mechanisms, such as thermal-induced local convection, large-scale precipitation associated with the monsoon rainbelt, and tropical cyclone rainfall, should be investigated. Different kinds of rainfall events would have different relationships with temperature changes.

Another point that needs to be considered in following studies is the influences of urbanization on temperature and the formation of light precipitation. Data at stations in the same regime but having different local environmental changes (near or far from an urbanization center) should be compared to identify and distinguish local anthropogenic influences.

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