Research Article

Climate Characteristics of High-Temperature and Muggy Days in the Beijing-Tianjin-Hebei Region in the Recent 30 Years

Guohua Zhang,^{1,2} Jian Guan,³ Jingyi Ai,² Jiangtao Zhang,^{1,2} and Xiaoqing Jin²

¹Beijing Institute of Urban Meteorology, China Meteorological Administration, Beijing 100089, China

²Hebei Weather Observatory, Shijiazhuang 050021, China

³College of Geographic Science, Nanjing Normal University, Nanjing 210046, China

Correspondence should be addressed to Guohua Zhang; gzgh2308@163.com

Received 1 September 2014; Revised 16 October 2014; Accepted 2 November 2014

Academic Editor: Zhihua Zhang

Copyright © 2015 Guohua Zhang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The climate characteristics of high-temperature (37°C and above) and muggy days in the Beijing-Tianjin-Hebei region over the past 30 years from 1981 to 2010 are analyzed. The results are summarized as follows. During this period, the years with the most number of high-temperature days are 1997–2005 and 2009 in the Beijing-Tianjin-Hebei region, while high-temperature extremes appear in 1999, 2000, 2002, 2009, and 2010. This disparity between the years with high-temperature extremes and the years with the most number of high-temperature days is located primarily in the central and southern cities of the Beijing-Tianjin-Hebei region. High-temperature extremes in the southern cities appear in June and July, while high-temperature extremes in the other cities appear in July. The years with the most number of muggy days are 1994, 1997, 1998, 2000, and 2010 in the Beijing-Tianjin-Hebei region, but the years with the extreme muggy conditions appear in 1981, 2002, 2005, and 2010. The most number of muggy days are in July, and the muggy days in July and August account for about 90% of the entire summer. Over the 30-year period, no apparent changes are observed in the number of days with precipitation and the annual precipitation amount.

1. Introduction

Global climate change has become a hot issue of common concern to the scientific community, national governments, and public society. High-temperature weather and muggy weather present a serious threat to human comfort, economic development, water resources, and the environment. High temperatures speed up evaporation of soil moisture, aggravate droughts, affect crops growth, lead to forest and grassland fire easily, cause the cyanobacteria in water bodies, and result in water resource pollutions. Under muggy weather conditions, the humidity is high and the diurnal temperature range is small, which, combined with high temperatures, tends to cause heatstroke and induce cardiovascular and cerebrovascular attacks. High-temperature weather and muggy weather can also result in the shortage of urban water and electricity supplies.

Because of rapid urbanization and population growth in China in the past decades, Chinese scientists have

paid more attention to the research on high-temperature weather and muggy weather. For example, Yang et al. [1–3] studied high-temperature conditions in China, East China, and South China, respectively. Guo et al. [4–6] analyzed high-temperature weather events in Chongqing, Wuhan, and Shanghai, respectively. Through an analysis of high-temperature days in North China, Wei and Sun [7] found that, in the 1960s, a high-pressure ridge controlled the most part of North China, leading to a peak of high temperature (not muggy conditions). In the 1990s, North China was controlled by the continental high pressure ridge and the western Pacific subtropical high, thereby causing high-temperature extremes and muggy conditions. Gao et al. [8] analyzed the atmospheric circulation, temperature, humidity, and water vapor transport characteristics of a typical high-temperature and high-humidity weather event in summer in Beijing. Lian and You [9] analyzed the different characteristics, causes, occurrence times, and synoptic systems associated

FIGURE 1: The geographic location of the Beijing-Tianjin-Hebei region (a) and the distribution of the thirteen cities (b).

with high-temperature (dry and heat) and muggy weather in Shijiazhuang.

Most of the above researches focus on the characteristics of high-temperature weather or muggy weather for a certain station only, while there are few studies on high-temperature and muggy days for the entire Beijing-Tianjin-Hebei region.

2. Data and Methods

High-temperature weather and muggy weather appear primarily from June to August in the Beijing-Tianjin-Hebei region in summer. High-temperature (dry and heat) conditions occur mainly from June to mid-July, the muggy days are observed mostly in August, and both high-temperature weather and muggy weather are seen in July [7, 10, 11]. As such, this study focuses on May through August by utilizing 30-year data from 1981 to 2010. According to the regional distribution characteristics of high-temperature and muggy conditions, five areas covering the Beijing-Tianjin-Hebei region are analyzed. These areas are Beijing and the surrounding cities (Baoding and Langfang), Bohai Rim cities (Tianjin, Qinhuangdao, Tangshan, and Cangzhou), a northwestern city in Hebei province (Zhangjiakou), a northeastern city in Hebei province (Chengde), and southern cities in Hebei province (Shijiazhuang, Xingtai, Handan, and Hengshui), respectively. These five areas are each represented by a city, which are, respectively, Beijing (station number 54511), Tianjin urban climatological station (station number 54517), Zhangjiakou (station number 54401), Chengde (station number 54423), and Shijiazhuang (station number 53698). Data are from the relevant Provincial and Municipal Meteorological Bureau Information Center and the strict quality control is applied (Figure 1).

This research uses the air temperature at 37°C and above to represent high-temperature weather and the muggy index at the second level and above for muggy weather. The muggy

index D is defined as $(T14 - 0.23) \times (U14 + 1.8) - 79.74$, where $T14$ and $U14$, respectively, represent the temperature and relative humidity at 2 pm on a day [12]. The second level and above muggy weather means the muggy index $D \geq -6.0$. The statistics indicate that, under these conditions, heatstroke, collapse, or prostration is likely to occur for prolonged outdoor activities. The higher the D value is, the stronger the muggy extent will be.

3. Climate Characteristics of 37°C and above High-Temperature Days in the Beijing-Tianjin-Hebei Region in the Recent 30 Years

In our analysis, the five representative cities are arranged from south to north and from low altitude to high altitude, which are Shijiazhuang, Tianjin, Beijing, Chengde, and Zhangjiakou. The annual average high-temperature days in the five cities are 5.7, 2.1, 2.1, 1.3, and 0.87, respectively. There are great differences of high-temperature days in each of the 30 years from 1981 to 2010. The years with the most number of high-temperature days in the five cities are Shijiazhuang 17 d (2005), Tianjin 8 d (2000), Beijing 13 d (2000), Chengde 13 d (2000), and Zhangjiakou 6 d (2010). The year with the least number of high-temperature days is 1995, in which high temperatures do not occur in the five cities. The years of the most number of high-temperature days are from 1997 to 2005 in the Beijing-Tianjin-Hebei region in the recent 30 years, and the high temperature in 2000 appears in the northeast of the Beijing-Tianjin-Hebei region. In 2005, the high temperature appears in the south of the Beijing-Tianjin-Hebei region, and the high temperature increases from north to south in 1997 and 2001. The other year of the most number of high-temperature days is 2009. It can be seen that the

FIGURE 2: Interannual variations of high-temperature days in the five representative cities.

cool years (1995 and 2008) are likely followed by the high-temperature years. After 1997, there is a significant tendency of high-temperature days in the five cities. In most years, the high-temperature days in Shijiazhuang are higher than those in Tianjin, Beijing, Chengde, and Zhangjiakou. The high-temperature days fall off as the latitude increases and the surface elevation increases (Figure 2).

In the 30 years, the extreme maximum temperature appearing in Shijiazhuang is 42.9°C on July 15, 2002. Above 40°C high temperatures appear 21 times and they are all appearing in June or July. Among them, the minimum temperature occurs 20 times that day, which are all above 23°C . It can be used as an index to indicate the occurrence of extreme temperatures above 40°C that day in Shijiazhuang. The above 40°C high temperatures have continuous appearing characteristics, such as on July 14 and 15, 2002, on June 24 and 25, 2009, and on July 5 and 6, 2010.

The extreme maximum temperature appearing in Beijing is 41.9°C on July 24, 1999. Above 40°C high temperatures appear three times, which are 1999, 2002, and 2010, respectively, and all occur in July.

The extreme maximum temperature appearing in Tianjin is 41.0°C on July 14, 2002. Above 40°C high temperatures appear three times, which are in 2000, 2002, and 2010, respectively, and all occur in July.

The extreme maximum temperature appearing in Chengde is 43.3°C on July 14, 2000. Above 40°C high temperature appears 3 times, which are July 12, 13, and 14, 2000, as a continuous high-temperature process, with maximum temperatures at 40.1°C , 41.6°C , and 43.3°C , respectively, and minimum temperatures at 21.7°C , 21.3°C , and 22.5°C , respectively. Considering the geographic latitude and altitude, the extreme high temperature in Chengde is higher than that in Shijiazhuang, which is an interesting phenomenon. The daily minimum temperature, on the same day with the extreme high temperature, in Chengde is also lower than that in Shijiazhuang.

The extreme maximum temperature appearing in Zhangjiakou is 41.1°C on July 29, 2010. During the 30 years, above 40°C high temperatures only appear once.

FIGURE 3: Interannual variations of muggy days in the five representative cities.

Thus it can be seen by the analysis above that after 1997 urban annual high-temperature days in each area of the Beijing-Tianjin-Hebei region are significantly increasing. The years with high-temperature extremes are 1999, 2000, 2002, 2009, and 2010. For Zhangjiakou and Chengde, those years are also the years with the most number of high-temperature days. For Beijing, Tianjin, and Shijiazhuang, however, the years with the most number of high-temperature days are different from the years with high-temperature extremes. The above 40°C high temperatures tend to appear continuously.

4. Climate Characteristics of the Second Level and above Muggy Weather in the Beijing-Tianjin-Hebei Region in the Recent 30 Years

Over the 30 years, from 1981 to 2010, the annual average days with the second level and above muggy weather in the five cities of Shijiazhuang, Tianjin, Beijing, Chengde, and Zhangjiakou are 26.5 d, 22.4 d, 14.7 d, 4.5 d, and 1.2 d, respectively. The least number of muggy days is in Zhangjiakou, and the second least number of muggy days is in Chengde. The elevation of Zhangjiakou and Chengde, respectively, is 724.2 m and 385.9 m, while the elevation for the other three cities is all below 100 m. Obviously, the least muggy days in Zhangjiakou and Chengde are related to the higher altitude and northern geographic latitude. According to the interannual variations of muggy days (Figure 3), the number of muggy days, in most years, is in decreasing order as follows: Shijiazhuang, Tianjin, Beijing, Chengde, and Zhangjiakou. However, during 1999 to 2001, Tianjin's muggy days are obviously more than Shijiazhuang's, which is due to the fact that the temperature or humidity in Tianjin is higher than that in Shijiazhuang in the three years. Section two of high-temperature analysis shows that Tianjin's high-temperature days are more than those in Shijiazhuang from 1999 to 2000. From 1981 to 1997 (1998), muggy days overall have an increasing tendency in the five cities. From 1997 (1998) to 2004, muggy days overall have a decreasing tendency in the five cities. From 2006 to 2010, muggy days overall show a rising tendency. The years with the most number of muggy

TABLE 1: Analysis of the first-level muggy days in the Beijing-Tianjin-Hebei from 1981 to 2010.

City	Muggy total days (days)	Muggy processes of more than three consecutive days (times)	The longest muggy process (date), process average muggy index	The appearing date and lasting time of the strongest muggy process, process average muggy index	The strongest average muggy index of three consecutive days, appearing time	The strongest muggy index for one day, appearing time
Shijiazhuang	134	6	5 days (05.8.11–15), 1.88	2010.7.28–31, 4 days, 5.72	6.74, 2010.7.29–31	9.34 2010.7.31
Tianjin	116	14	5 days (05.8.11–15), 2.49	2002.8.1–3, 3 days, 6.00	6.00, 2002.8.1–3	7.65 2002.7.12.
Beijing	31	4	4 days (81.7.20–23), 2.51	81.7.20–23, 4 days, 2.51	2.94, 1981.7.20–22	4.37 1981.7.20

days in Shijiazhuang are 1998 (46 times), 1997 (43 times), and 1994 (40 times). The years with the most number of muggy days in Tianjin are 1997 (42 times), 2000 (42 times), and 1994 (39 times). The years with the most number of muggy days in Beijing are 1997 (31 times), 2000 (30 times), and 1994 (27 times). The years with the most number of muggy days in Chengde are 1997 (14 times), 2000 (13 times), and 2010 (12 times). The years with the most number of muggy days in Zhangjiakou are 1981 and 2000 (5 times) and 1999, 2000, and 2010 (4 times). From the above comparison, the years with the most number of muggy days are 1994, 1997, 1998, 2000, and 2010 in the Beijing-Tianjin-Hebei region.

For the monthly distribution of muggy days, the most number of muggy days in each station is in July, and the second most number of muggy days is in August. For Shijiazhuang, Tianjin, and Beijing, the muggy days in July, respectively, are 51.8%, 51.3%, and 56.9% of the total, but the muggy days in August, respectively, are 32.4%, 36.2%, and 35.5% of the total. In contrast, the sum of the muggy days in May and June is about 10% in total. There is no muggy weather in Chengde and Zhangjiakou in May. The sum of muggy days in July and the sum of muggy days in August are 98.5% and 94.2% of the total, respectively.

The muggy index $D \geq 0$ can be used as the first-level muggy days. For further analysis, the most number of the first-level muggy days is in July, and the second most number of the first-level muggy days is in August. In the recent 30 years, the first-level muggy conditions are listed in Table 1.

As shown in Table 1, the years with the high-temperature extremes in Shijiazhuang, Tianjin, and Beijing are 2005 and 2000, 2005 and 2002, and 1981, respectively. That is inconsistent with the years with the most number of muggy days. The first-level muggy days in Shijiazhuang are the most, while the times with more than 3 consecutive days of the first-level muggy processes in Tianjin are the most. The longest muggy processes in Shijiazhuang and Tianjin are both five days. The average muggy index of the longest muggy process in Tianjin is higher than that in Shijiazhuang. The highest average muggy index of three consecutive days in Shijiazhuang is higher than that in Tianjin. The highest muggy index of one day in Shijiazhuang is higher than that in Tianjin. There are three first-level muggy processes of four consecutive days (12 days in total) in Tianjin in July 1997,

which is the year with the most number of the first-level muggy days in Tianjin, indicating that the muggy processes between Shijiazhuang and Tianjin are equal. However, from the high-temperature analysis in Section 2, the extreme high-temperature value in Shijiazhuang is higher than that in Tianjin. Therefore, Shijiazhuang's high-temperature weather is stronger than Tianjin's.

The strongest and longest muggy extent occurs from July 28 to 31, 2010. During this episode, Shijiazhuang, Beijing, and Tianjin all reach the first-level muggy category, lasting from July 28 to 31, July 28 to 30, and July 28 to 30, respectively.

Based on the above analysis, the years with muggy extremes are 1981, 2002, 2005, and 2010. These years are inconsistent with the years with the most number of muggy days, which are also different from the years with high-temperature extremes, which are in 1999, 2000, 2002, and 2010. The number of muggy days in July is the most, and the sum of muggy days in July and August is more than 80% of the total. The high-temperature days in Shijiazhuang are greater than those in Tianjin, but the muggy extent between Tianjin and Shijiazhuang is equal, which is probably because Tianjin is the coastal city. The process of the strongest and widest range of muggy extent appears in 2010.

5. Precipitation Characteristics in the Cities of the Beijing-Tianjin-Hebei Region in the Recent 30 Years

5.1. The Number of the Annual Precipitation Days. Figure 4(a) shows that the number of precipitation days per year in Tianjin is obviously less than that in the other four cities. The annual average precipitation days are 61 in Tianjin, 69 in Beijing and Shijiazhuang, 75 in Zhangjiakou, and 73 in Chengde. Over the 30 years, there is no significant increasing or decreasing trend in the number of precipitation days in the five cities. However, there is a stage change: during 1981 and 1990, the number of precipitation days is gradually rising in Shijiazhuang. A rise period is noted in Chengde during 1982 and 1988. There is a significant fluctuation in the number of precipitation days in Beijing from 1985 to 1990. The number of precipitation days is more in Tianjin during 1985 and 1990, and the average value is 70 days, which is 9 days higher than

FIGURE 4: Interannual variations of precipitation in the five representative cities. (a) Annual precipitation days and (b) annual precipitation amount.

the 30-year average. There is a decreasing tendency year by year in Chengde from 1991 to 2000 and Beijing from 1990 to 1995. The tendency in Shijiazhuang is rising year by year from 1992 to 1996 and from 2000 to 2010. There is a decline in Beijing and Shijiazhuang during 2003 and 2007.

5.2. Annual Precipitation. Figure 4(b) shows that the annual precipitation has no obviously rising or declining trend in the five cities from 1981 and 2010. The annual precipitation in Zhangjiakou is significantly less than the other four cities. The 30-year average precipitation in Zhangjiakou is 388.7 mm, while it is between 503 and 532 mm for the other cities, with the most in Beijing and the least in Chengde. The annual precipitation in Beijing is obviously higher than that in the other four cities before 1998. It is suddenly increasing in Shijiazhuang in 1996 (with a daily precipitation reaching 359.3 mm), which is caused by a northward-moving weakened typhoon system.

6. Conclusions

- (1) Based on our analysis period from 1981 to 2010, the years with the most number of high-temperature days are from 1997 to 2005 and 2009. However, the years with high-temperature extremes are 1999, 2000, 2002, 2009, and 2010; for the northern cities, those are also years of the most number of high-temperature days. For the central, southern, and coastal cities, the years with high-temperature extremes and the years with the most number of high-temperature days are inconsistent. After 1997, the urban annual high-temperature days are significantly increasing in each area of the Beijing-Tianjin-Hebei region. The high-temperature extremes in the southern cities appear in June and July, and the other cities are in July. After the cool years, the years of high temperature are likely occurring.
- (2) The years with the most number of muggy days are 1994, 1997, 1998, 2000, and 2010, the years with the muggy extremes are 1981, 2002, 2005, and 2010, and

these years are inconsistent. The years with high-temperature extremes and the years with the muggy extremes are both in the 2000s, but the specific years are inconsistent. The number of muggy days in July and August accounts for above 80% of the muggy days of the entire summer. The strongest and widest range of the muggy extent appears in 2010.

- (3) The high-temperature extent of the southern inland cities (the representative station is Shijiazhuang) is stronger than that of the coastal city (Tianjin), but the muggy extent of the coastal cities is weaker than that of the inland cities.
- (4) Despite short-term fluctuations, there is no apparent trend in the number of precipitation days per year and the annual precipitation amount. The number of precipitation days in Tianjin is clearly less than that in the other four cities. The annual precipitation amount in Zhangjiakou is notably less than that in the other four cities. The precipitation amount in Beijing is notably greater than that in the other cities before 1998.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

This work was supported by Grants from the Urban Meteorological Scientific Research Foundation (UMRF200905) and the Special Scientific Research Fund of Public Welfare Profession (Meteorology) (GYHY201106053).

References

- [1] P. Yang, W. Liu, Q. Wang et al., "The climatic change trend and seasonal characteristics of daily temperature extremes in China

- for the latest 40 years,” *Journal of Applied Meteorological Science*, vol. 21, no. 1, pp. 29–35, 2010 (Chinese).
- [2] J. Shi, Y. Ding, and L. Cui, “Climatic characteristics of extreme maximum temperature in East China and its causes,” *Journal of Atmospheric Sciences*, vol. 33, no. 2, pp. 347–358, 2009 (Chinese).
 - [3] Y. Wang, P. Zhai, and H. Tian, “Extreme high temperature in Southern China in 2003 under the background of climate change,” *Meteorological Monthly*, vol. 32, no. 10, pp. 27–33, 2006 (Chinese).
 - [4] Q. Guo, W. Sun, B. Cheng et al., “Analyses on climatic characteristics of high temperature and circulation situation in recent 48 years in Chongqing City,” *Resources and Environment in the Yangtze Basin*, vol. 18, no. 1, pp. 52–59, 2009.
 - [5] Y. He, W. Chen, C. Li et al., “Climatic characteristics, causes and prediction of mid-summer high-temperature in Wuhan,” *Meteorological Science and Technology*, vol. 35, no. 6, pp. 809–813, 2007 (Chinese).
 - [6] L. Cui, J. Shi, and W. Zhou, “Characteristics of extreme temperature variations and their response to urbanization in Shanghai,” *Scientia Geographica Sinica*, vol. 29, no. 1, pp. 93–97, 2009.
 - [7] J. Wei and J. Sun, “The analysis of summer heat wave and sultry weather on North China,” *Climatic and Environmental Research*, vol. 12, no. 3, pp. 453–463, 2007.
 - [8] S. Gao, Y. Zhou, T. Lei et al., “Beijing city summer hot and humid weather process analysis and dynamic identification,” *Science in China, Series D: Earth Sciences*, vol. 35, pp. 107–114, 2005.
 - [9] Z. Lian and F. You, “Prediction of high temperature and muggy in Shijiazhuang, Hebei Province,” *Meteorological Monthly*, vol. 31, no. 6, pp. 17–21, 2005 (Chinese).
 - [10] Y. Wang, G. Ge, and Z. Tao, “Climatic characteristics of estival muggy weather in Beijing related to 2008 olympics,” *Meteorological Monthly*, vol. 29, no. 9, pp. 23–27, 2008 (Chinese).
 - [11] Y. Shi, Y. Gu, and Y. Lin, “Analysis of the temporal and spatial distribution and circulation features of high temperatures in Beijing, Tianjin and Hebei,” *Meteorological Monthly*, vol. 35, no. 6, pp. 63–69, 2009 (Chinese).
 - [12] S. Zhao and S. Che, “High temperature and muggy weather in Shijiazhuang city,” *Meteorological Monthly*, vol. 27, no. 9, pp. 23–25, 2001 (Chinese).