Inter-annual and Inter-decadal Variation of Temperature during 1960-2013 in Dabie Mountain of West Anhui Province

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Abstract: The inter-annual and inter-decadal variation of temperature in Dabie Mountain of West Anhui Province is analyzed according to actually measured data of daily average temperature, maximum temperature and minimum temperature during 1960-2013 in five meteorological stations in Dabie Mountain. Results show: The quarterly and annual average temperature, average maximum temperature and average minimum temperature (except the average maximum temperature in summer) in Dabie Mountain of West Anhui Province are all in a rising tendency. The annual average temperature increases remarkably at an amplitude of 0.165 °C/10 years. The increase amplitude of average minimum temperature is 1-2 times of the average maximum temperature, and the daily range shows obvious reduction. The annual extremely maximum temperature and extremely minimum temperature are both on the rise, and the amplitude of the latter is larger than that of the former. From 1960s, the average temperature, average maximum temperature and average minimum temperature turned rising in Dabie Mountain of West Anhui Province. The abnormally warm years are 1967, 1968, 206, 207, 1998 and 2013, while the abnormally cold years are 1967 and 1981.

1. Introduction
In the past 100 years particularly recent 50 years, the warning in the world and in China is obvious [1-3], and global average surface temperature increased 0.6-0.2 in the 20th century [4]. The events attract great attention of domestic and overseas experts and scholars, and abundant research findings are accumulated. Karl [5] et al. studied land temperature during 1951-1990, and found the rising amplitude of daily minimum temperature on most land area in the northern hemisphere is the triple as that of the daily maximum temperature. Many domestic and overseas scholars paid attention to the issue, and gained abundant achievements. Gao Rong [6] analyzed variation characteristics of temperature in summer in monsoon region according to the average temperature data in summer of 375 monsoon observation station in East China, and pointed out that the summer and annual average temperature in the monsoon region rises at the speed of 0.104 °C/10 years. Hu Liping [7] studied the probability distribution characteristics of minimum temperature during half year of winter in Tianshui, and found the probability of low minimum temperature is reduced, and the probability of warm temperature is increased obviously. Liu Huaxue [8] adopted the data of daily average temperature during 1961-2000, and found the index of extremely low temperature in the past 40 years showed declination as a whole, and the extremely warm index showed an overall rising trend. Tang Hongyu [9] found through analysis that the average maximum temperature in China during 1951-2002 is not changed obviously or
decreasing slightly in South China with main temperature drop area in the south area of the Yangtze River; in North China, the weather is warmer obviously.

This paper applies climatologic statistics method and analyzes the inter-annual and inter-decadal variation of temperature during 1960-2013 in Dabie Mountain of West Anhui area so as to disclose the facts of climate changes.

2. Materials and analysis methodology:

The actually measured data of daily average temperature, maximum temperature and minimum temperature during 1960-2013 in five meteorological stations in Dabie Mountain is adopted in this paper. The quarter-based sequence is generated with December-February as winter, March-May as spring, June-August as summer and September-November as autumn, and then the average value is gained by regions. Then this paper analyzes the inter-annual and inter-decadal variation of average temperature in each season, average maximum temperature, average minimum temperature and daily temperature range, as well as annual extremely maximum temperature and extremely minimum temperature.

2.1 Climate tendency rate

A unitary regression equation $T=a_0+a_1t$ is established with time $t$ as independent variable and temperature $T$ as dependent variable; $a_1*10$ is climate tendency rate, and $a_1$ reflects the rising or declining tendency.

2.2 Wavelet analysis

The wavelet analysis has been successfully applied to periodical analysis of meteorological observation value in the climate field. This paper studies time variation rules of quarterly average temperature during 1960-2013 in Dabie Mountain of West Anhui Province based on Matlabe wavelet analysis method.

3. Analysis results

3.1 Temperature variation trend

| Season | Average temperature | Average maximum temperature | Average minimum temperature | Temperature range |
|--------|---------------------|----------------------------|----------------------------|------------------|
| spring | 0.344**             | 0.221                      | 0.258**                    | 0.092            |
| summer | 0.031               | -0.031                     | 0.177**                    | -0.228**         |
| autumn | 0.189**             | 0.221**                    | 0.247**                    | -0.036           |
| winter | 0.232**             | 0.145                      | 0.326**                    | -0.216*          |
| Year   | 0.165**             | 0.181**                    | 0.25**                     | -0.076           |

Note: items with * passed 95% level test, and items with ** passed 99% level test.

The quarterly and annual average temperature in Dabie Mountain of West Anhui Province is rising at rates of 0.031-0.344°C/10 years (Table 1); the temperature rising amplitude in spring is the highest, at the rate of 0.344°C/10 years (Fig. 1a).

Except summer when the average maximum temperature declines at the speed of 0.031°C/10 years, and the average maximum temperature in other three seasons and the annual average maximum temperature rises at the speed of 0.145°C-0.221°C/10 years; the rising amplitude is the largest in autumn, which is 0.221°C/10 years (Fig. 1b).

The average minimum temperature and annual average minimum temperature both show strong trend of rising, at the speed of 0.177-0.326/10 years; the rising amplitude in winter is the highest, 0.326/10 years (Fig. 1c).

The average daily range rises slightly in spring, and in other three seasons and the annual average value declines at the speed of 0.036-0.228/10 years; the declination in summer is the largest, about -0.228°C/10 years (Fig.1d).

According to the inter-annual variation trend of annual extremely maximum temperature and
minimum temperature (Fig.2). The annual extremely high temperature and extremely low temperature in Dabie Mountain during 1960-2013 shows an increasing trend; the rising amplitude of extremely minimum temperature (0.69°C/10 years) is larger than that of the extremely high temperature (0.05°C/10 years).

Fig. 1 Variation tendency of average temperature in spring (a), average maximum temperature in autumn (b), average minimum temperature (c) and average daily range in summer (d) in Dabie Mountain of West Anhui Province

Table 2 shows the inter-annual variation of annual average temperature, average temperature in winter and summer, maximum temperature and minimum temperature in five periods (recent 54 years, 44 years, 34 years, 24 years and 14 years) in Dabie Mountain.

Table 2. Temperature variation tendency in Dabie Mountain, in West Anhui in different time periods

| Period     | Average temperature | Average maximum temperature | Average minimum temperature | Temperature range | Annual maximum temperature | Annual minimum temperature |
|------------|---------------------|------------------------------|-----------------------------|-------------------|----------------------------|----------------------------|
|            | Year    | summer | winter | Year    | summer | winter | Year    | summer | winter | Year    | summer | winter | Year    | summer | winter |
| 1960-2013  | 0.16*   | 3.031  | 0.232  | 0.181** | 0.031  | 0.145  | 0.25**  | 0.177** | 0.326* | 1960-2013 | 0.16** | 0.031 |
| 1970-2013  | 0.287*  | 3.265* | 0.261  | 0.247*  | 0.253* | 0.302* | 0.253*  | 0.266* | 0.297** | 1970-2013 | 0.16** | 0.205* |
| 1980-2013  | 0.373*  | 3.426* | 0.257  | 0.537** | 0.527* | 0.372* | 0.425** | 0.333* | 0.411* | 1980-2013 | 0.16** | 0.205* |
| 1990-2013  | 0.193*  | 3.337* | -0.313 | 0.377** | 0.588* | 0.293* | 0.418** | 0.174  | 0.425** | 1990-2013 | 0.16** | 0.337* |
| 2000-2013  | -0.255* | 3.382  | -1.103 | 0.328*  | 0.582* | -0.785 | 0.546** | -0.687* | 0.691** | 2000-2013 | 0.16** | 0.337* |

Items with * passed 95% significance test, and items with ** passed 99% significance test.

1) The average temperature, average maximum temperature and average minimum temperature of annual level and in winter and summer are rising obviously, but different in terms of period; the highest rising amplitude in the recent 34 years is almost 2-3 times of that in recent 54 years.

2) The rising of average temperature, average maximum temperature and average minimum temperature of annual level and in winter and summer slows down in recent 24 years. The average temperature, average maximum and minimum temperature in winter shows a downturn, and the
declination amplitude reaches the largest in the recent 14 years.

(3) The annual extremely high and extremely low temperature shows an increasing trend in all periods, and reaches the largest value in recent 24 years and 14 years.

3.2 Inter-decadal variation of temperature

Table 3 lists the inter-decadal variation of average temperature, average maximum temperature, average minimum temperature and daily temperature range in summer and winter in recent 54 years in Dabie Mountain of West Anhui (see Table 3).

| Period     | Average temperature | Average maximum temperature | Average minimum temperature | Temperature range |
|------------|---------------------|-----------------------------|-----------------------------|-------------------|
|            | Year | summer | winter | Year | summer | winter | Year | summer | winter | Year | summer | winter | Year | summer | winter | Year | summer | winter |
| 1961-1970  | -1.133** | -1.102** | -1.375** | -1.466** | -1.335* | -2.255** | -0.382** | -3.22 | -0.464 | 0.891** | -0.774** | -1.977** |
| 1971-1980  | 0.404* | -0.33 | 1.262** | -0.96** | -0.453 | 2.458** | -0.061 | -0.141 | 0.566 | -0.966 | -0.57 | 1.893** |
| 1981-1990  | 0.455** | 0.363 | 1.412** | 0.855** | -7.06 | 0.661 | 0.419** | 0.194 | 1.928 | 0.093** | 0.454 | -1.295** |
| 1991-2000  | 1.199** | 0.619 | 1.732* | 1.162** | 0.629 | 0.195 | 1.405** | 0.903 | 3.0658 | -0.267 | 0.588** |
| 2001-2010  | -0.351 | -0.081 | -0.642 | 0.144 | 0.144 | -0.129 | 0.457** | 0.574** | -0.365 | 0.184** | -0.382 | -0.452 |
| 2011-2013  | 4.697** | 13.18* | 16.3** | 8.65 | 8.65 | 3.82 | 6.019** | -0.154 | 2.22** | 3.606 | 0.262** |

Note: ditto

(1) Since 1960s, the annual average temperature, average maximum temperature and average minimum temperature has turned rising from declining in Dabie Mountain of West Anhui Province. The values showed a down turn in 1960s and half of 1970s; in late 1980s, the values became rising, and the rising amplitude reached the largest in 1980s and 1990s; later, the rising amplitude became larger during 2011-2013.

(2) In the first decade of the 21st century, the average temperature, maximum temperature and minimum temperature in winter showed a down trend under the background of global warming; the daily temperature range in winter was abnormal and in a rising trend.

3. 3 Analysis on temperature anomaly

In line with the judgment standards proposed by TMO for climate anomaly, the temperature anomaly in Dabie Mountain is analyzed based on the standard of twice out of standard of anomaly (Table 4).

| Year | Average temperature | Average maximum temperature | Average minimum temperature | Year | Average temperature | Average maximum temperature | Average minimum temperature |
|------|---------------------|-----------------------------|-----------------------------|------|---------------------|-----------------------------|-----------------------------|
| 2007 | 2007 (+)            |                             |                             |      |                     |                             |                             |
| 1967 | 1967 (+) 213 (+)    | 1967 (+) 1968 (+)           | 2013 (+)                    |      |                     |                             |                             |
| 1981 | 1981 (-) 1998 (+)   | 2005 (+)                    |                             |      |                     |                             |                             |
| 1967 | 1967 (-) 1998 (+)   | 1998 (+) 1981 (-)           |                             |      |                     |                             |                             |

Note: Item with “+” means abnormally warm, and with “-” means abnormally cold.

(1) The annual average minimum temperature experiences three peak periods in 1998, 2006 and 2007.

(2) The average temperature in spring in 2007 is abnormally high.

(3) The average temperature and average maximum temperature in 1967 in summer is abnormally high; the average temperature and average minimum temperature in the summer of 2013 is abnormally high. The maximum temperature in 1968 is abnormally high only in summer.
(4) The average temperature and average maximum temperature in 1998 in autumn is abnormally high; the average temperature and average maximum temperature in 1998 is abnormally low.

(5) The average temperature, average maximum temperature and average minimum temperature in the winter of 1998 are all abnormally high, and that winter is a typical warm winter. The average temperature in 1967 is abnormally low; the average maximum temperature in 1981 is abnormally low.

3.4 Wavelet analysis on temperature

The Matlab wavelet analysis shows the 1-2 years and quasi-35 years oscillation periods of average temperature in spring in Dabie Mountain of West Anhui during 1960-2013. The average temperature shows a 1-2 years period in summer, 1-2 years period and quasi-35 years oscillation period in autumn, 1-2 years period in winter; but the 20 years oscillation period is in 1960s; and there is a 10-year oscillation period in the 22 years during 1978-1990, and a quasi-8-year oscillation period during 1996-2010. The annual average temperature shows 4-year, 10-year, 22-year and 33-year periods.

(a- spring, b- summer, c- autumn, d- winter, e- Year)

Fig.2 Wavelet analysis of average temperature during 1960-2013 in Dabie Mountain of West Anhui
4. Conclusions

This paper analyzes the inter-annual and inter-decadal variation of temperature during 1960-2013 in West Anhui area according to climate statistics method, and the following conclusions are drawn.

(1) For the quarterly and annual average temperature in Dabie Mountain of West Anhui, the average minimum temperature shows remarkably rising trend; only the average temperature rising trend in summer failed to pass the significance test. Except the slight declination in summer, the average maximum temperature on the annual basis and in other three seasons is rising; however, only the average maximum temperature in autumn and on the annual basis passed the significance test.

(2) The quarterly and annual average maximum temperature and average minimum temperature in Dabie Mountain of West Anhui are all in a rising tendency (except the average maximum temperature in summer). The rising amplitude of the average minimum temperature is above 1-2 times of the maximum temperature; the asymmetric temperature increase leads to declination of the daily temperature range in three reasons except spring and on the annual basis.

(3) The annual average maximum temperature and minimum temperature shows a declination trend in 1960s in Dabie Mountain of West Anhui; declines and rises half of the years each in 1970s; increases after 1980s, and the rising amplitude is the largest in 1980s and 1990s; later, rises more during 2011-2013; the average temperature, maximum temperature and minimum temperature in winter declines, and daily temperature range rises, which is abnormal.

(4) The average minimum temperature in Dabie Mountain is rising abnormally only in 2006 and 2007. The annual average temperature in spring in 2007 is abnormally high. The temperature is abnormally high in summer in 1967, 1968 and 2013. The years with abnormally high temperature in autumn are 1998 and 2005; the year with abnormally low temperature is 1981. The temperature in winter is extremely high in 1998 and extremely low in 1967 and 1981.

(5) According to the wavelet analysis, there are 1-2 years and quasi-35 years oscillation periods in spring and 1-2 years period in summer in Dabie Mountain of West Anhui during 1960-2013. There is a 1-2 years period in winter, a quasi-20 years period in 1960s, and quasi-10 years period during 1978-1990. The annual average temperature is stable in periods of 4 years, 10 years, 22 years and 33 years.

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