

## Analysis on Climate Change of Nantong for Nearly 60 Years

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### Abstract

*Nantong is chosen as the object of study in this paper. According to the meteorological observational data for the period from 1951 to 2010 in Nantong, the changes of climate variables on the time series for nearly 60 years are analyzed through estimation of linear tendency and sliding average. It is found that: in the past 60 years, the average temperature is rising at the rate of 0.297 °C/10a, where the warming trend in spring is the most significant, and that in summer is the least. The trends of the min-mean and max-mean temperature are on the rise. The rapidly increasing changes of the extreme minimum and maximum temperature are observed. Over the past 60 years, the tendency of precipitation is generally on the rise with the small rate. The increasing trend of precipitation in summer is the most pronounced, followed by winter. Precipitation in spring and autumn is slightly decreasing. The contribution of the increase in precipitation mainly derives from the addition in summer and winter.*

**Keywords:** climate change; Nantong

### 1. Study Area

Nantong is a city located in the alluvial plain of the downstream of the Yangtze River with about an average altitude of four meters, situated in the region with latitudes ranging from 31°41'N to 32°43'N and longitudes 120°12'E to 121°55'E. Nantong is located in the north subtropical humid environment with the obvious effect of monsoon, four distinct seasons, mild climate, abundant sunshine and rainfall and lone frost-free period. Nantong is also a mid-latitudes city situated in the transition between land and sea, which is a typical meteorological disaster-prone area with the common meteorological disasters such as floods, droughts, plum rains, typhoons, rainstorm, cold wave, high temperature, gale, lightning and hail et al. Statistics show that the annual average temperature in Nantong is around 15°C. The annual average sunshine hours are 2000-2200 hours, and the annual mean precipitation is about 1000-1100 mm with a hot rainy season. The rainfall in summer is about 40-50% of the annual rainfall. Perennial rain day is about 120 days, and the period of mold rain ranges from June to July.

### 2 Data and Methods

#### 2.1. Data

The meteorological data during 1961-2010 is mainly used from the weather stations in Nantong in Jiangsu province. This paper analyzed the weather variables such as average maximum temperature, average minimum temperature, extreme minimum temperature, extreme maximum temperature and precipitation. In this paper, the missing data are filled by using the linear trend interpolation method. The criteria of the classification of seasons are: spring, from March to May; summer, from June to August; autumn, from September to November; winter, January, February and December. The inter-annual division standards are: 1961-1970 considered as the 1960s, 1971-1980 as the 1970s, and so on.

## 2.2. Methods

The changes of climatic variables on the time series for nearly 60 years are analyzed through estimation of linear tendency and sliding average.

### 2.2.1. Estimation of Linear Tendency

Set  $x_i$  to explain a variable of climate which contains the sample size is  $n$ . Set  $t_i$  to denote the time series which mapping the  $x_i$ . According to the relationship between  $x_i$  and  $t_i$ , the linear least squares regression equation is given as:

$$x_i = a + bt_i \quad (i = 1, 2, \dots, n)$$

where  $a$  and  $b$  are regression constant and regression coefficient, respectively. The coefficients  $a$  and  $b$  can be estimated by least squares. It means that the relationship between  $x$  and  $t$  can be expressed by a reasonably straight line.

### 2.2.2. Sliding Average

Sliding average is the most basic method about trend fitting which is equivalent to a low-pass filter, displaying the trends by using the mean values of the determined time series. If the sample size for sequence  $X$  is  $n$ , the moving average sequence is represented as:

$$x_j = \frac{1}{k} \sum_{i=1}^k x_{i+j-1} \quad (j = 1, 2, \dots, n - k + 1)$$

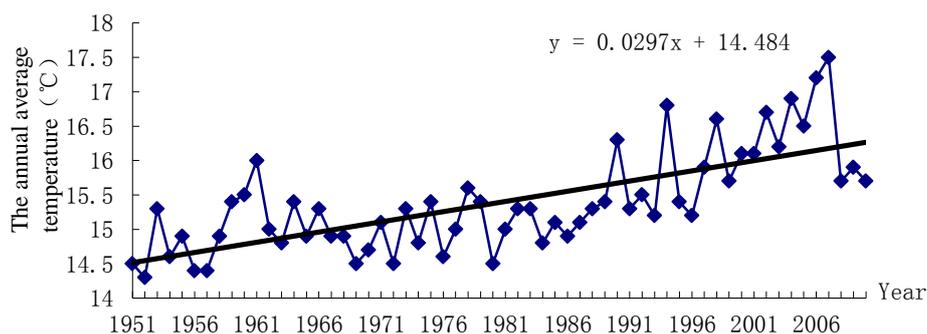
where  $k$  is the sliding length. As a rule,  $k$  had better take an odd number, so that the average values can be added to the time coordinate of the middle of the time series. When  $k$  is an even number, the mean values of each two new sequences through the moving average can be computed in order to align the sliding average values in the middle. It can be proved that through the sliding average, the sequences shorter than the sliding length are cycle cut to highlight the change trends.

## 3. Analysis on Climate Change

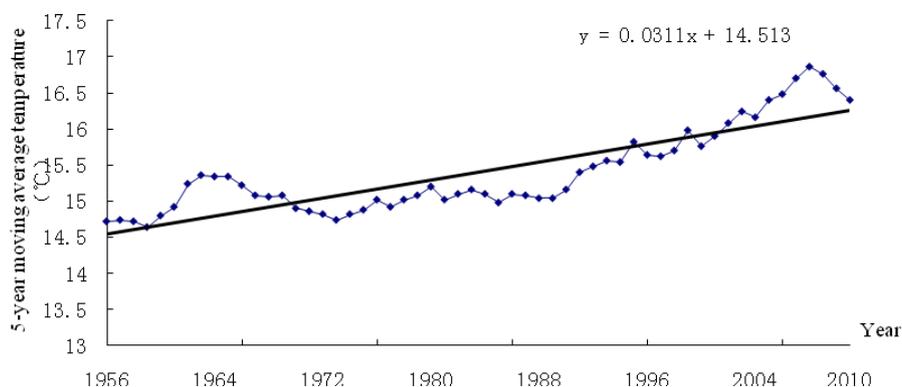
### 3.1. Analysis on Temperature Change

#### 3.1.1. Tendency of Annual Average Temperature

The annual average temperature in Nantong was  $15.4^{\circ}\text{C}$  during 1951 to 2010. In recent 60 years, the annual average temperature in Nantong trend in growth rate of  $0.297^{\circ}\text{C}/10\text{a}$ , the annual average temperature between  $14.3^{\circ}\text{C}$  and  $17.5^{\circ}\text{C}$  (Figure 3-1, Figure 3-2). The sequence of temperature change was in boundary of 1980s, before the late 1980s for the cold period, after the late 1980s for the warm period. Before the late 1980s, except for in 1960, 1964 and 1978, the average temperature is higher than the average value, the rest of the years were low; including temperature in 1952 was  $14.3^{\circ}\text{C}$ ,  $1.1^{\circ}\text{C}$  lower than the annual average. The temperature gradually increased after 80 years into the 21st century, the warming significantly faster, the annual average temperature was  $17.5^{\circ}\text{C}$  in 2007, 1951 is the warmest year in Nantong,  $2.1^{\circ}\text{C}$  higher than the annual average.



**Figure 3-1. The Annual Average Temperature in Nantong 1951~2010**



**Figure 3-2. 5-year Moving Average Temperature in Nantong**

### 3.1.2. Tendency of Seasonal Average Temperature

As shown in Figure 3-3, Figure 3-4, Figure 3-5 and Figure 3-6, the temperature varies linearly rate of Spring, Summer, Autumn and Winter were  $0.395^{\circ}\text{C}/10\text{a}$ ,  $0.219^{\circ}\text{C}/10\text{a}$ ,  $0.343^{\circ}\text{C}/10\text{a}$ ,  $0.322^{\circ}\text{C}/10\text{a}$ . When in spring, autumn and winter, warming magnitude is higher than the annual average temperature linear growth rate, the fastest is in spring while in summer is the slowest. The spring average temperature was  $13.8^{\circ}\text{C}$ , the minimum value was  $12.2^{\circ}\text{C}$ , appeared in 1952, 1956, 1957 and 1970, the maximum value was  $16.5^{\circ}\text{C}$  in 2007; From 50s to 70s, rise tendency of temperature was gentle, but the tendency was negative at the beginning of the 80s, since the 90s, the temperature remained in high level, but the last ten years the temperature dropped slightly. In summer, the average temperature was  $27.9^{\circ}\text{C}$ , minimum value was  $22.1^{\circ}\text{C}$  in 1957, the maximum value was  $27.9^{\circ}\text{C}$  in 2006; Warming fastest in the 1980s and had slowed since the 1990s, but the amount of warming was not large. In autumn, the average temperature was  $17.4^{\circ}\text{C}$ , the minimum value was  $13.2^{\circ}\text{C}$  in 1957, the maximum value was  $19.5^{\circ}\text{C}$ , appeared in 2005 and 2006; Autumn temperature in both the 1950s and 1960s showed a slow downward trend, while in the 1980s and 1990s accelerated warming, but in recent decades showed a slow downward trend again. The winter average temperature was  $4.3^{\circ}\text{C}$ , the lowest point was  $1.8^{\circ}\text{C}$  in 1967, the highest point was  $7.1^{\circ}\text{C}$  in 2007; In recent decades, the winter average temperature showed a slow upward trend.

Overall, the seasonal average temperature in the 1950s and 1960s emerged as a low-temperature phase, in addition, with the exception of spring, the average temperature of other quarters had increased in the 1970s and 1980s, and its rate of increase was relatively large. In the 21st century, in addition to a slight rise of summer temperature, the

temperature of the other three seasons tended to decrease.

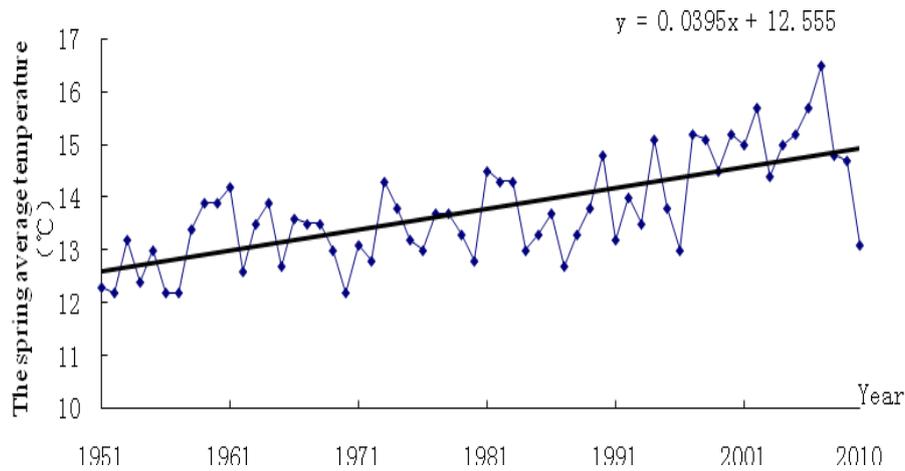


Figure 3-3. The Spring Average Temperature in Nantong 1951~2010

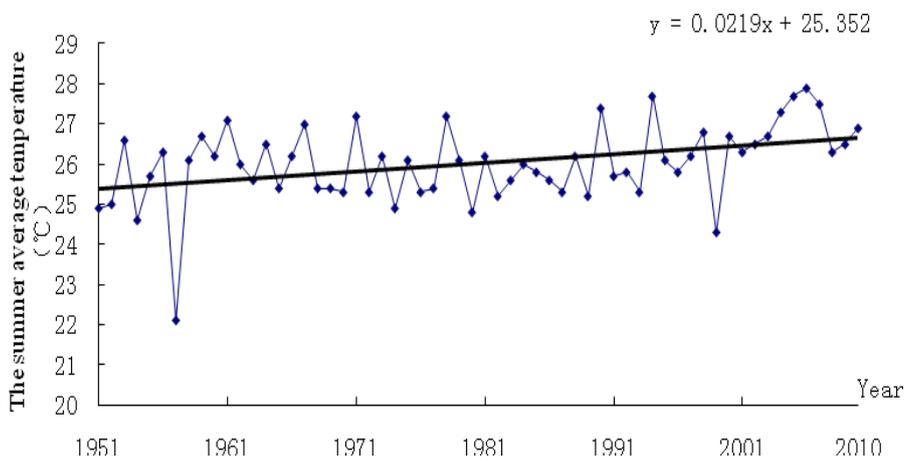


Figure 3-4. The Summer Average Temperature in Nantong 1951~2010

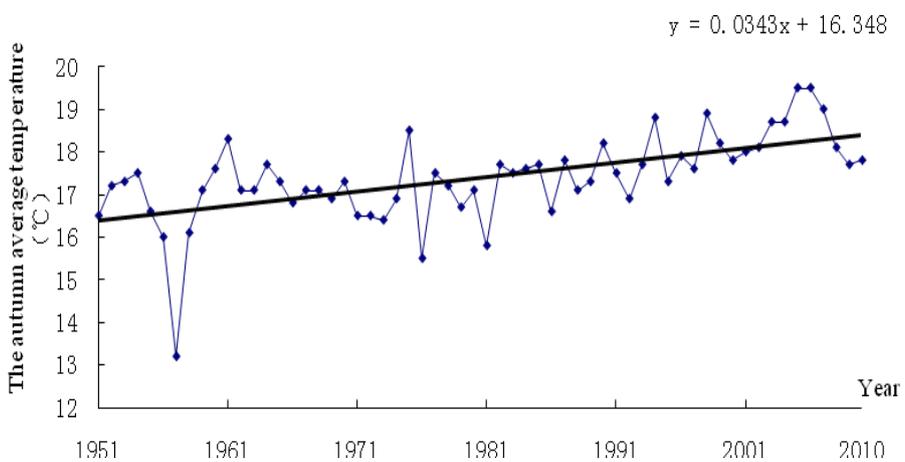
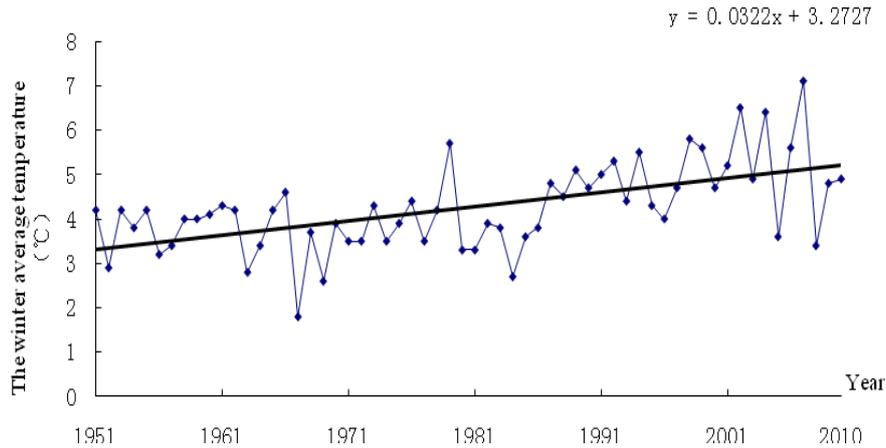


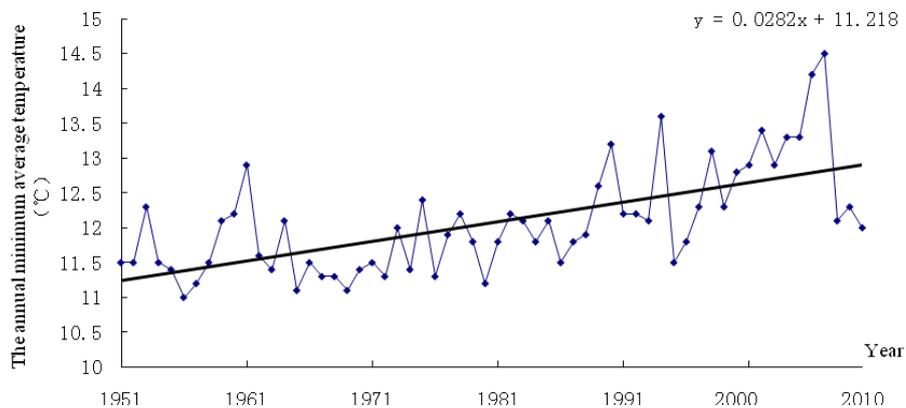
Figure 3-5. The Autumn Average Temperature in Nantong 1951~2010



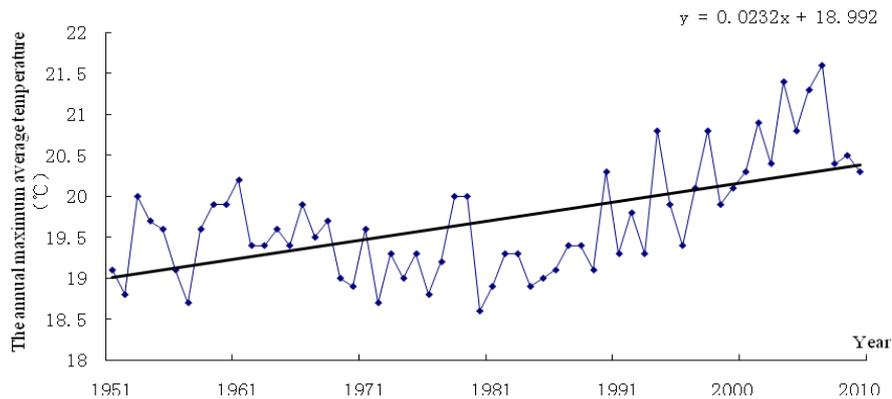
**Figure 3-6. The Winter Average Temperature in Nantong 1951~2010**

### 3.1.3. Tendency of Annual Maximum and Minimum Average Temperature

According to statistics of Nantong, the annual minimum average temperature was 12.1°C, the maximum value was 14.5°C, appeared in 2007, the minimum value was 11°C, appeared in 1956. And the annual maximum average temperature was 19.7°C, the maximum value was 21.6°C, appeared in 2007, the minimum value was 18.6°C, appeared in 1980. Since 1951, the change rate of the annual minimum average temperature in Nantong was 0.282°C/10a, with relatively stable upward trend, and declined slightly in the 1960s, as one of the coldest period; There was a quick growth in the 1980s, but slowed down in the 1990s. Since enter into the 21st century, the minimum temperature decreased (Figure 3-7). The annual maximum temperature had two large fluctuations in the 1950s, but tends to upward overall; and the maximum temperature decreased when was the lowest period of the maximum temperature; It began a slow rise in the 1970s, and in the 1980s the temperature was low, that appeared the minimum value of the maximum temperature in 1980, but its warming speed seemed to be significantly faster; Large fluctuations of the maximum temperature were appeared in the 1990s, with the fastest warming speed; Into the 21st century, the maximum temperature is still rising, but its speed has slow down (Figure 3-8).



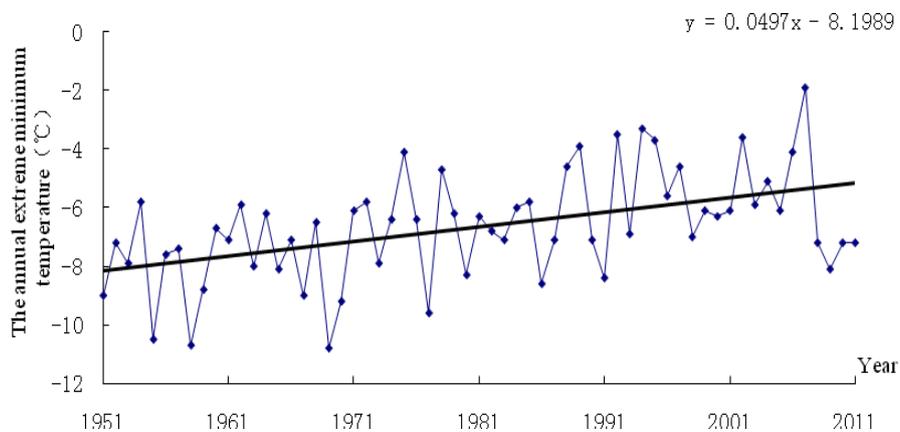
**Figure 3-7. The Annual Minimum Average Temperature in Nantong 1951~2010**



**Figure 3-8. The Annual Maximum Average Temperature in Nantong 1951~2010**

### 3.1.3. Tendency of Extreme Temperature

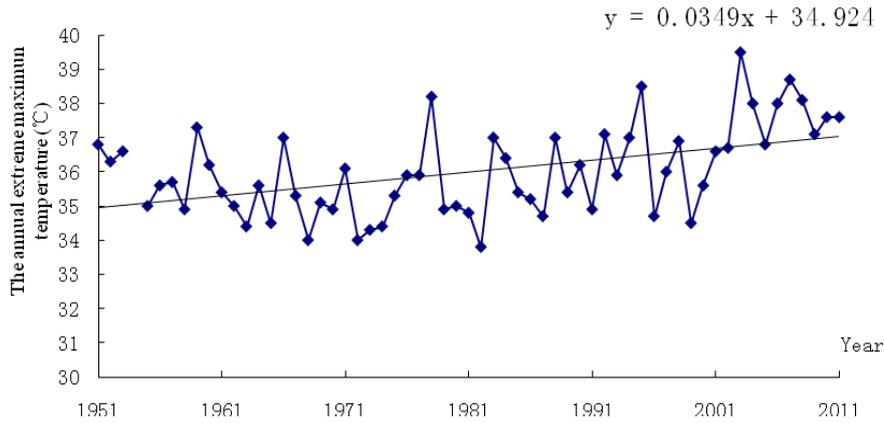
Annual extreme minimum temperature is one value of the lowest minimum temperature of the year. The average of annual extreme minimum temperature in Nantong was  $-6.6^{\circ}\text{C}$  in recent 60 years. The extreme minimum temperature increased  $0.497^{\circ}\text{C}/10\text{a}$ , that its variation trend was larger than the annual average temperature and average winter temperature (Figure 3-9). The lowest value of extreme minimum temperature appeared during the 1950s and 1960s, except in 1954, 1962 and 1964; but began to increase since the 1970s, and the annual extreme minimum temperature rose faster especially in the 1990s, but declined again from 2008 to 2010.



**Figure 3-9. The Annual Extreme Minimum Temperature in Nantong 1951~2010**

Annual extreme maximum temperature is one value of the highest maximum temperature of the year. The average of annual extreme maximum temperature in Nantong was  $36^{\circ}\text{C}$  since 1951.

The extreme maximum temperature increased  $0.34^{\circ}\text{C}/10\text{a}$ , that its variation trend was larger than the annual average temperature and average summer temperature (Figure 3-10). The annual extreme maximum temperature was declining during the 1950s and 1960s, began to rise from the 1970s to 1980s, reached the lowest value in 1982 was  $33.8^{\circ}\text{C}$ ; Since the 1990s, the annual extreme maximum temperature increased faster, that above  $36^{\circ}\text{C}$  from 2000 to 2010, and reached the highest value in 2003 was  $39.5^{\circ}\text{C}$ .

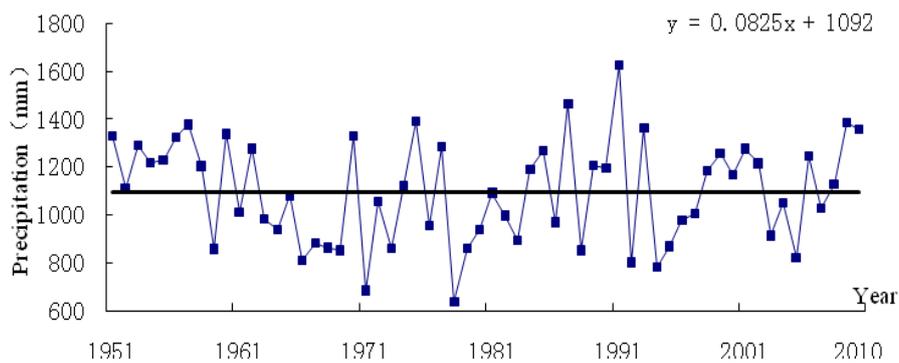


**Figure 3-10. The Annual Extreme Maximum Temperature in Nantong 1951~2010**  
(Note: the value in 1954 was Missing)

### 3.2. Precipitation Change

#### 3.2.1. Annual Scale

From Figure 3-11, it can be observed that the average precipitation in Nantong is 1094.6mm, and the fluctuation is relatively large. In the 1950s, the tendency of precipitation is rising with the rate of 8.25mm/10a. The trend is gradually reducing in the 1960s, and the rainfall in the 1970s is at the bottom in recent decades. The lowest precipitation in recent decades appears in 1979, only 637.4mm, which is 58.2% of annual mean precipitation. In the 1980s, the increasing trend of precipitation is significant, and the maximum precipitation, 1626.8mm, appears in 1991, which is about 1.5 times of the annual mean precipitation. In the 1990s, the trend declines. In recent ten years, the rising tendency of precipitation is the most obvious after 1951 with the rate of 203.8mm/10a.



**Figure 3-11. The Annual Average Precipitation in Nantong 1951~2010**

#### 3.2.2. Seasonal Scale

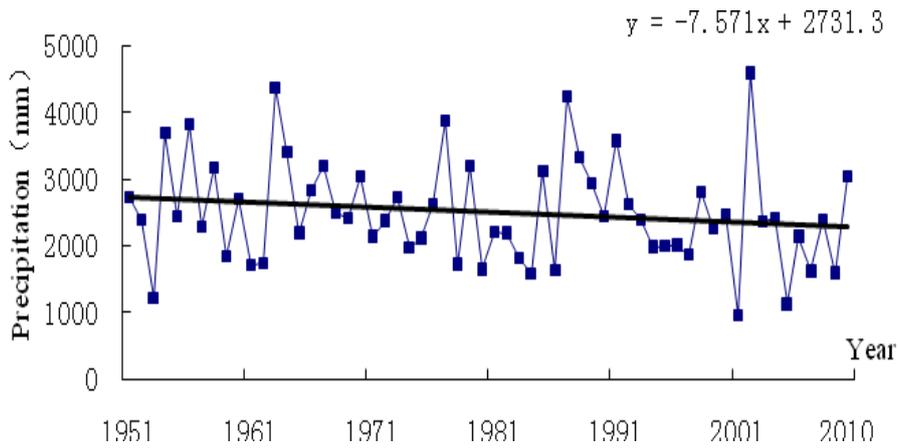
According to Figure 3-12, a downward trend is in the precipitation in spring with the declining rate of 7.571mm/10a. The mean precipitation in spring is 250mm, accounting for 22.8% of the annual mean precipitation. The precipitation in 2001, 96.4mm, is the least, and the rainfall in 2002, 459.7mm, is the most. Maximum precipitation in spring appears in the 1960s, and the upward trend is also the most obvious. The precipitation decreased since the 1990s, and the rainfall in spring in recent ten years is minimal in each

decade.

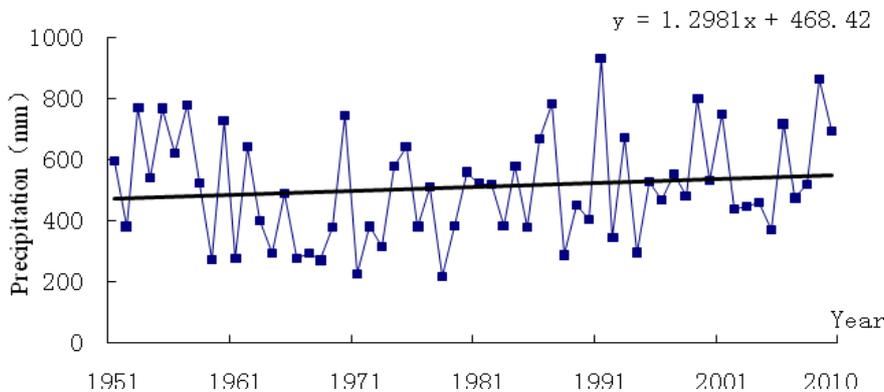
Through Figure 3-13, it can be observed that the increasing tendency of the precipitation in summer is significant with the rate of 12.981mm/10a. In seasonal precipitations, summer is the most, 508mm, accounting for 46.4% of the annual mean precipitation. The precipitation in 1991, 930.8mm, is the most and the rainfall in 1978, 216.2mm, is the least. Precipitation in the 1950s is the most while precipitation in the 1960s is the least. Hereafter the trend of precipitation in each decade is on the rise. At the early 20th century, the increasing tendency of precipitation is the most significant.

Seeing Figure 3-14, the decreasing rate of precipitation in autumn is 6.694mm/10a. The average precipitation is 209.4mm which accounts for 19.1% of the annual mean precipitation. The precipitation in autumn in 1961, 479.8mm, is the most and the precipitation in 1995, 49.7mm, is the least. From 1950s to 1970s, the change of rainfall in autumn is flat. In the 1980s, precipitation increased rapidly. Rainfall reached the lowest in the 1990s and has increased in recent ten years.

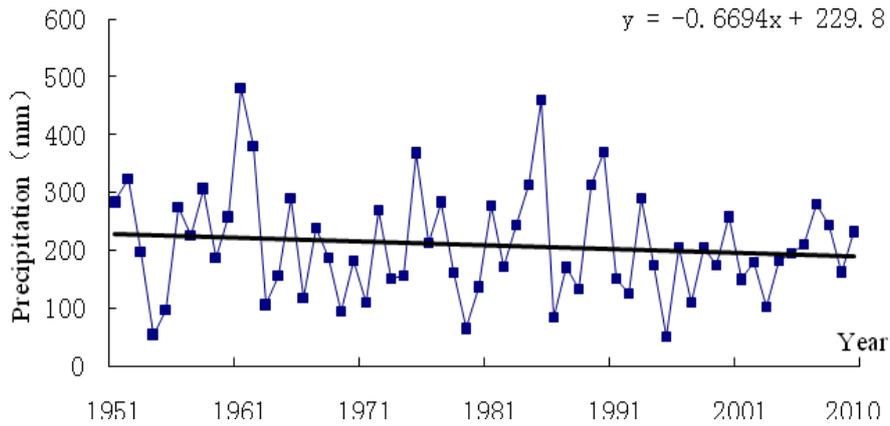
In Figure 3-15, it can be found that the increasing rate of precipitation in winter is 3.703mm/10a. The average precipitation is 128.7mm, holding only 11.8% of the annual precipitation. The precipitation in winter in 2001, 281.6mm, is the most and the precipitation in 1967, only 30.9mm, is the least. Rainfall in winter in the 1960s is the lowest. Precipitation increased in the 1970s and began to reduce in the 1980s. After the 1990s, the precipitation is continuously increasing. Rainfall in winter in recent ten years is the most.



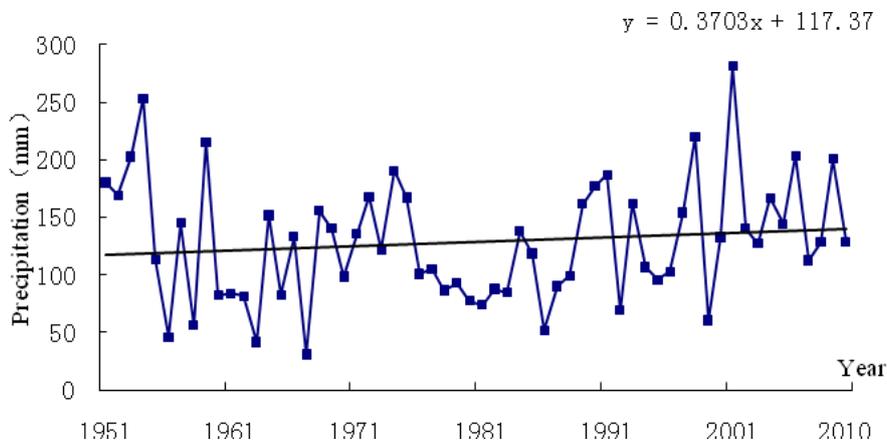
**Figure 3-12. The Spring Average Precipitation in Nantong 1951~2010**



**Figure 3-13. The Summer Average Precipitation in Nantong 1951~2010**



**Figure 3-14. The Autumn Average Precipitation in Nantong 1951~2010**



**Figure 3-15. The Winter Average Precipitation in Nantong 1951~2010**

#### 4. Conclusions

(1) In the past 60 years, the trend of the average temperature in Nantong is on the rise with the warming rate of  $0.297^{\circ}\text{C}/10\text{a}$ . The warming trend is obvious in the 1980s. The increasing rate is generally negative over the ten years in the 21<sup>st</sup> century. The turning point appears in 2008 where the temperature decreased obviously. The mean temperature in recent three years is lower than that in the previous seven years of about  $1^{\circ}\text{C}$ . But the average temperature in recent ten years is  $16.4^{\circ}\text{C}$ , which is higher than that in the 1990s,  $15.8^{\circ}\text{C}$ .

(2) In the past 60 years, the trends of the average temperature in four seasons are on the rise, where the increasing trend in spring is the most significant and that in summer is the smallest. Except warming in spring beginning from the 1990s, warming in summer, autumn and winter mainly start from the 1980s. In recent ten years, the trends of warming have slowed. Except the temperature in summer increasing slightly, the temperatures in other three seasons tend to decrease.

(3) The trends of the min-mean temperature and the max-mean temperature are on the rise, and the increasing rate of the min-mean temperature ( $0.282^{\circ}\text{C}/10\text{a}$ ) is slightly higher than the max-mean temperature ( $0.232^{\circ}\text{C}/10\text{a}$ ).

(4) There are rapidly rising trend in extreme minimum temperature and extreme maximum temperature. The increasing rate of extreme minimum temperature ( $0.497^{\circ}\text{C}$

/10a) is significantly higher than extreme maximum temperature ( $0.34^{\circ}\text{C}/10\text{a}$ ), and both of the warming rates are faster than that of the average temperature.

(5) In the past 60 years, the tendency of precipitation is generally on the rise, but the increasing rate, only  $8.25\text{mm}/10\text{a}$ , is small. The 60s and 70s are the periods of relatively drought in history.

(6) The increasing trend of precipitation in summer is the most pronounced, followed by winter. Precipitation in spring and autumn is slightly decreasing. The contribution of the increase in precipitation mainly derives from the addition in summer and winter.

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