INITIAL ANALYSIS OF AWS-OBSERVED TEMPERATURE

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Abstract

From 2002, in China meteorological observed records by the Automatic Weather Stations (AWS) have been used in scientific research. Using AWS-observed monthly and annual mean temperature in 2000-2004 and the difference between AWS- and man-observed temperature are studied. First, there are the homogeneity test of annual mean temperature and annual mean minimum temperature in 2002 by Cramer's test, of monthly mean temperature and monthly mean minimum temperature in 1996-2005 by maximum likelihood ratio test. Secondly, in order to test drift of AWS instrument, the trend of monthly mean temperature in 2002-2004 is analyzed. The initial results show there is a slight influence on annual mean temperature and annual mean minimum temperature by the change of instrument; there are certain influences on monthly mean temperature and monthly mean minimum temperature by the change of instrument; 2.3 percent of AWS-observed temperature data have trend to change due to instrument drift possibly, which is very little.

key words: AWS temperature homogeneity test

Introduction

The study of climatic change is based on the homogeneous long-period time series reflecting the change of climate. Any inhomogeneous time series may lead to an inaccurate result of research. It has been revealed that in the meteorological time series from long-period observation, such elements as the relocation of stations, the change of instruments, the change of observation times and the gradual change of station environment will make the climatic time series inhomogeneous[1-4]. From the study of meteorologists abroad, the causes bringing inhomogeneity vary in the influence on different climate element data. The relocation of stations, the main reason leading to inhomogeneity, has a significant influence on the inhomogeneity of all weather elements except pressure. The change of observing instrument is also one of the important causes. Since 1980s ASOS has been set throughout USA, and then considerable researches have been made on the influence of observation system change on the data. Those researches show that there exists a significant difference between ASOS data and manual observation data. For example, the daily mean maximum temperature observed by MMTS in American Meteorological Bureau is 0.6℃[5] lower than that from traditional liquid-glass thermograph.

The quality control and quality evaluation of the AWS (automatic weather station)-observed data are the great concern for the meteorological field. There are many documents and papers from WMO and scientists all over the world (6-12). And in recent years studies on AWS-observed data have appeared in China too (13-14). Since 2002, AWS-observed data have become the formal record in China. Automatic observation system is replacing manual observation used in the past 50 years and great changes take place in observational instrument. For example, platinum resistance thermometers are used in automatic observation stations in China, replacing the mercury thermometer used in manual observation. The difference between auto and manual observation is inevitable. In history any change of observation instruments will bring the difference of data, especially the change from manual observation to automatic observation with greatly different observational principles for observation instrument. Then climatic researchers are concerning such questions as the AWS-observed data quality, the continuity between AWS-observed and manual observed data, especially the homogeneity of temperature data. In this paper we try to analyze the AWS-observed data. Since the time series of automatic observation are short in China and the replacement of automatic observation is just starting, so with longer observational time series and more automatic stations further analysis is still needed.

There are two parts in this paper. First there is an analysis on the difference between AWS-observed and manual-observed data, including the homogeneity test of the mean temperature around the year of 2002 and that of the monthly mean temperature in 1996-2005. Second, there is an analysis on the tendency of monthly mean temperature data in 2002-2004 to test whether there exists the observational drift of instruments in automatic stations.

1. Methods and Data

1.1 Method

The official data of auto observation in national base stations have been increasing by year. In 2002, there are 46 automatic weather stations, 60 stations in 2003, 405 stations in 2004, and 629 stations in 2005. It can be seen that the time series of AWS-observed data starting from 2002 are still very short (namely there are only three-year data from 2002 to 2004). It is not very satisfying to have homogeneity test of the time series from 1971 to 2004. So Cramer's test is applied here to test whether there is any interruption in the annual data time series around the year 2002, and then to analyze the difference between AWS-observed and manual observed data in annual time series.

For the monthly time series, the maximum likelihood ratio test is used because there are 120 samples of monthly mean temperature during the ten years of 1996-2005.

1.1.1 Cramer's Test [15] for Annual Mean Temperature

To test the hypothesis of equal mean value, we should assume the equality of ensemble variance. First make the test of equal variance, eliminate the stations failing in the test and then make Cramer's test [16].

Cramer's test is similar to t-test, but it is not the comparison between two samples, but the comparison of mean value between sub time series and general time series to see whether there is a significant difference.

①、Make the original hypothesis

Assume there is no significant difference between the mean value of general and sub time series.

②、Construct the t value to test the mean value of the general time series

$$t = \sqrt{\frac{n_1(n-2)}{n - n_1(1+\tilde{l})}} * \tilde{l} \qquad (1)$$

n is the sample length of time series, n_1 is the sub time series sample, and $\tilde{l}$ is given from formula (2). Formula (1) follows the t-distribution with the degree of freedom of n-2.

$$\tilde{l} = \frac{\bar{x}_1 - \bar{x}}{s} \qquad (2)$$

$\bar{x}_1$ and $\bar{x}$ are the mean value of sub time series x_1 and general time series x respectively. s is the mean variance of the general time series.

After the significance level is determined, from the degree of freedom $\gamma = n-2$, refer to the t-distribution. If $|t| \geqslant t$, then the original hypothesis is denied, which indicates there is a significant difference in the mean value of general time series. If there is no interruption in 2002, then divide the year of 2002 into two parts to test.

Before 2002, there are manual observed data and after 2002 there are AWS-observed data. To test the difference between auto and manual observed data is to test whether there is a significant difference in the mean value of sub and general time series in 2002-2004. Starting from 1990, the mean value of 1990-2004 represents the mean value of the general time series, and that of 2002-2004 is the sub time series. Test whether there is a significant difference in the mean value of sub and general time series in 2002-2004.

1.1.2 Maximum Likelihood Ratio Test [17] for the Homogeneity Test of Monthly Mean Temperature

To test whether the temperature of one station is inhomogeneous, one method is to compare the temperature time series of this station with the reference time series. The reference time series is taken by using the mean value of monthly temperature from the neighbor stations which have the similar climatic situation to the tested station.

① Select 5 stations closest to the tested station within two longitudes and latitudes and 300-meter altitude as the reference stations. If there are fewer than 3 qualified stations, then no test is given.

② Calculate the anomaly time series of mean temperature of all months to eliminate the annual period of monthly temperature. The anomaly time series of mean temperature of all months is used as the original time series of the test.

The comparison between the time series of the tested station and its neighboring stations can be illustrated in the following formula.

$$q_i = (y_i - \bar{y}) - \frac{\sum_{j=1}^{k} \rho_j^2 (x_{ji} - \bar{x}_j)}{\sum_{j=1}^{k} \rho_j^2}, i = 1, n \qquad (3)$$

Among it y_i and x_{ji} are the monthly temperature of the tested station and the k neighboring stations respectively, while ρ_j is the correlation coefficient of the tested station and the k neighboring stations. In formula (3) $\bar{y}$ and $\bar{x}$ are obtained by averaging monthly temperature (including all the months in record). So there are 12 values of $\bar{y}$ and 12*k values of $\bar{x}$, which means there are 12 values for each of the k neighboring stations. By weighing the neighboring stations of the tested station with correlation coefficient, we can make these neighboring stations with relative large correlation with the tested station occupy more weighing while making reference time series.

③ To make likelihood ratio test, it is necessary to normalize the q time series.

$$z_i = \frac{(q_i - \bar{q})}{s_q}, i = 1, n \qquad (4)$$

④ Test proceeds.

Suppose (4) follows normal distribution, we can use zero hypothesis H_0 and hypothesis H_1 to check the abnormality in the data (that is, y time series).

$$H_0 : z_i \to N(0,1), i = 1, n \qquad H_1 : \left\langle \begin{array}{c} z_i \to N(\mu_1, 1), i = 1, a \\ z_i \to N(\mu_2, 1), i = a+1, n \end{array} \right\rangle$$

Here N (g, h) is the normal distribution of the mean value g and the standard deviation. If H_0 is denied and H_1 is approved, then it means there is a significant change in the y time series. The likelihood ratio test can be shown in the following.

$$T = 2 \ln \left[\frac{L(H_0)}{L(H_1)} \right] \qquad (5)$$

Here what among the parentheses is the ratio of likelihood function, obtained from the following formula.

$$\frac{L(H_0)}{L(H_1)} = \frac{\exp\left[\frac{1}{2}\left(\sum_{i=1}^{a}(z_i-\mu_1)^2 + \sum_{i=a+1}^{n}(z_i-\mu_2)^2\right)\right]}{\exp\left[\frac{1}{2}\sum_{i=1}^{n} z_i^2\right]} \quad (6)$$

Here the numerator and the denominator have the direct ratio with standard probability density function of z time series. If in (6) the ratio is over the critical value, then in can be assumed that the mean value i=(1,a) is different from the mean value of i=(a+1,n) in the y time series. From (5) and (6), the maximum likelihood estimator is the sample average of $\bar{z}_1$ and $\bar{z}_2$. The denying standard is shown in the following.

$$T = a\bar{z}_1^2 + (n-a)\bar{z}_2^2 > C \quad (7)$$

Here C is the critical value of the selected significance level. Determine the critical value C in the significance level 0.05. If one or more T>C, then there is probably a significant change in the y time series.

1.1.3 Testing Method for the Changing Trend of monthly data

(1) Testing Procedure for the Data Changing Trend

① Establish the mean value time series of the reference station. Find 5 stations closest to the tested station within two longitudes and latitudes and 300-meter altitude, and get the mean value of the 5 stations in each month as the mean value of the reference station.

② Establish the contrast value time series of the mean value of the tested station and the reference station, used as the tested time series.

③ Determine the trend by using linear tendency estimation and the trend test of cumulative contrast value of rank statistics. If both tests are passed, then it can be assumed that the tested station may have the changing trend.

④ If the reference station of the tested station also has the changing trend, then check the tested station again after eliminating the reference station to see whether there is a changing trend.

⑤ Analyze the trend. If it exceeds the order of magnitudes of climate change, then it probably has the changing trend.

(2) Linear Tendency Estimation and the Trend Test of Cumulative Rank Statistics

Linear Tendency Estimation:

Establish the univariate linear regression of the tested time series and the time of all months. The regression coefficient (b) indicates the trend. x_i represents the anomaly of each month, t_i represents the months corresponding to x_i. Then establish the univariate linear regression equation.

$$\hat{x}_i = a + bt_i \qquad (i=1, 2, \cdots\cdots 12 \text{ or } 36) \quad (8)$$

It shows the relation between x and time t. Here regression coefficient b shows the trend of the tested time series. b＞0 means x has a rising tendency with the increase of t, and b＜0 means x has a declining tendency with the increase of time t. At the same time the value of b will reflect the speed of the increasing or decreasing.

The formulae to calculate regression coefficient b and the constant number a are omitted.

In order to analyze the linear correlation of x and time t, we calculate the correlation coefficient of time t and x.

The significance test of correlation coefficient is made to see whether there is a significant change in the trend. If $|\gamma| > \gamma$, then x has a significant changing trend with the change of time t, otherwise there is no significant changing trend.

If the significance test with the correlation coefficient $\alpha = 0.05$ has been passed, then it is regarded to have a trend.

Trend Test of Cumulative Contrast Value of Rank Statistics

x_i indicates the contrast value of each month, and y_i is the cumulative contrast value of each month.

$$y_i = y_{i-1} + x_i \qquad (i = 1, 2, 3, \ldots\ldots, 12 \text{ or } 36)$$

when $i=1$, $y_1 = x_1$

For y_i, in the time of i, when $i=1$, 2, ……, n−1, then

$$r_i = \begin{cases} 1 & \text{when } y_j > y_i \\ 0 & \text{others} \end{cases} \qquad (j = i+1, \ldots\ldots, n) \qquad (9)$$

Namely rank r_i is the number of samples with the value y_j, $j=i+1, \ldots\ldots, n$ more than the value of y_i after the time of i.

Calculate the statistics.

$$Z = \frac{4\sum_{i=1}^{n-1} r_i}{n(n-1)} - 1 \qquad (10)$$

Set the significant level. Suppose $\alpha = 0.05$, then

$$Z_{0.05} = 1.96 \times \left[\frac{4n+10}{9n(n-1)}\right]^{\frac{1}{2}} \qquad (11)$$

If $|Z| > Z_{0.05}$, then it can be assumed that the trend is significant in the significance level $\alpha = 0.05$.

1.2 Data

There are obvious difference in the observational instruments between manual and automatic observation of mean minimum temperature and mean temperature, changing from minimum thermometer and dry-bulb thermometer to platinum resistance thermometer. The two elements are typical, chosen to test and analyze the difference in temperature observation. The mean value of 4 observations a day is taken for both manual and automatic stations instead of 24 times of observation because only the influence of instrument change is the purpose of study.

Since 2002, 46 automatic stations have functioned, among which the station 57462 (Sanxia station) is not involved in the test due to its short time series, so the data from altogether 45 stations are used in the test of annual time series.

In the homogeneous test of monthly men temperature and monthly mean minimum temperature in 1996-2005, the monthly data last till the June of 2005 and data from July to December of 2005 are missing.

In the test of monthly mean temperature changing tread for 36 months in 2002-2004, station 57458 (Wufeng station) and station 58437 (Huangshan station) are not included in the test since there is no reference station, so altogether 43 stations are taken in this test.

All the data are based on the annual and monthly values in 1971-2005 from the database of National Meteorological Information Center with quality control.

2. Results of Differences Between Automatic and Manual Observed Temperature

2.1 Test of Annual Mean Minimum Temperature

Cramer's test is applied to test the annual mean minimum temperature in 618 stations in 1990-2004. On the significance level of 0.05, altogether 73 stations have changes (i.e. relocation or the start of automatic station) in 1990s or around 2002, among which 7 stations (excluding the influence of station relocation) are included in the 45 automatic stations since 2002. Further test shows that there is no interruption of neighboring stations around the 7 stations, which means the significant difference of these stations is not caused by the climate change of minimum temperature rising. Then the significant difference of annual mean minimum temperature and long-period time series in 2002-2004 in the 7 stations is caused by the change of instruments in automatic stations, and it accounts for 15.6% of all the 45 automatic stations from 2002.

The result of the significance level 0.05 (which is there are 15.6% of automatic stations starting from 2002 having interruptions in 2002) shows that the change of instruments in automatic stations has a certain influence on the annual mean minimum temperature.

Table1: automatic weather stations from 2002 with significant difference with long time series in annual mean minimum temperature

Province	Station Code	contrast value with long time series
Liaoning	54339	0.76
Liaoning	54337	0.52
Liaoning	54342	0.89
Anhui	58236	0.73
Hubei	57545	0.51
Hubei	57583	0.51
Hubei	58407	0.55

2.2 Test of Annual Mean Temperature

The annual mean temperature is tested by the same method and procedure as testing the annual mean minimum temperature. The result shows that on the significance level of 0.05, altogether 62 stations have changes (i.e. relocation or the start of automatic station) in 1990s or around 2002. Excluding the influence from the station relocation and climate change, there are 5 stations (without the influence of station relocation) in the 45 automatic stations starting from 2002. Then the significant difference of annual mean temperature and long-period time series in 2002-2004 in the 5 stations is caused by the change of instruments in automatic stations, and it accounts for 11.1% of all the 45 automatic stations from 2002.

Table2: automatic weather stations from 2002 with significant difference with long time series in annual mean temperature

Province	Station Code	contrast value with long time series
Liaoning	54339	0.63
Liaoning	54337	0.48
Liaoning	54342	0.64
Hubei	57545	0.44
Jiangsu	58259	0.62

As shown in Figure 1, from the annual mean temperature and annual mean minimum temperature data in 1990-2004 in the station 54339, there is a significant difference in annual mean temperature, annual mean minimum temperature and general time series from 2002.

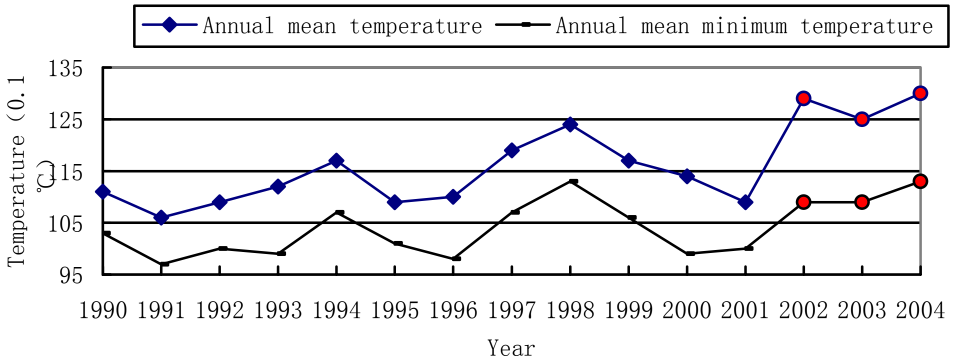


Figure 1: annual mean temperature and annual mean minimum temperature in station 54339 in 1990-2004

2.3 Homogeneous Test of Monthly Mean Temperature

The monthly mean temperature in 1996-2005 in 658 stations of China has been tested. Both the calculations in reference [16] and in this paper show that in the test of maximum likelihood ratio the maximum of T value time series often appears in the two ends of one record. Because the mean value is estimated to appear at the beginning or the end of the time series based on relatively fewer observations, we calculate the situation when the maximum in T-value time series exceeds the critical value and the two ends of time series are not taken. On the significance level of 0.05, there are 24 automatic stations whose interrupting time basically matches the time when automatic stations started functioning (i.e. the time occurs in the same year), and there are 32 stations, occupying 45.5% of all 123 stations with interruptions, whose interruptions are caused by station relocation. Namely 45.5% stations have interruptions in time series due to the station relocation or the start of automatic stations. Further test confirms that 7 stations among the 24 automatic stations were relocated around the year of 2002, so it can be assumed that the interruption is caused by relocation of stations. The interruption of the rest 17 stations is caused by the use of automatic stations, and the 17 stations take up 4.2% of all the 405 automatic stations till 2004.

Table 3: interruptions in automatic stations in the homogeneous test of monthly mean temperature

Year	Station
2001	58015 （02、relocation）
2002	57259（02） 57355（02、relocation） 58027（02、relocation）58251（02）
2003	53959（04、relocation） 56033（04） 57806（04、relocation）
2004	52323 53663 54436 54606 54662 54715 54871（relocation） 56125 56167 56768（relocation） 57127 57206 57245 57554 57606 57669

Note: the number in the brackets is the starting year of automatic stations; stations with interruptions in 2004 are all the automatic stations starting from 2004

The difference between the interrupting time and the time when automatic stations started is calculated (with the unit of month).

Table 4: the difference between the interrupting time and the time when automatic stations starting

(months) Time Differece	-12~-9	-8~-6	-5~-3	-2~2	3~5	6~8	9~12
Num. of Stations	0	1	0	3	4	5	4
Percentage	0%	5.9%	0%	17.6%	23.5%	29.4%	23.5%

From Table 4, it can be seen that 41.1% stations have the difference between the interrupting time and the time when automatic stations started within 5 months, which means nearly half stations have the interrupting time different from the time of automatic stations functioning in 5 months, and most interruptions occur after the use of automatic stations.

The above calculation shows that the interruption of monthly temperature time series is associated with the observation of automatic stations. The AWS-observed record has a certain influence on the homogeneity of monthly mean temperature time series.

In Figure 2 and 3, (a), (b), (c), (d) are respectively the monthly mean temperature anomaly time series, q series, z series, and t series of the latest 5-year data (from Jan. of 2001 to June of 2005) in the tested series of station 56033 and station 57127. From the figures, it can be seen that the tested mean value changes basically conform to the time of automatic stations starting functioning. For example, the station 56033 has used the formal record from automatic observation since 2004, and in the May of 2003, there occurs a significant change in data (exceeding the critical value of 9.23 on the significance level of 0.05, and taking the maximum). The station 57127 started automatic station observation in 2004, and the interruption of time series appeared in July of 2004.

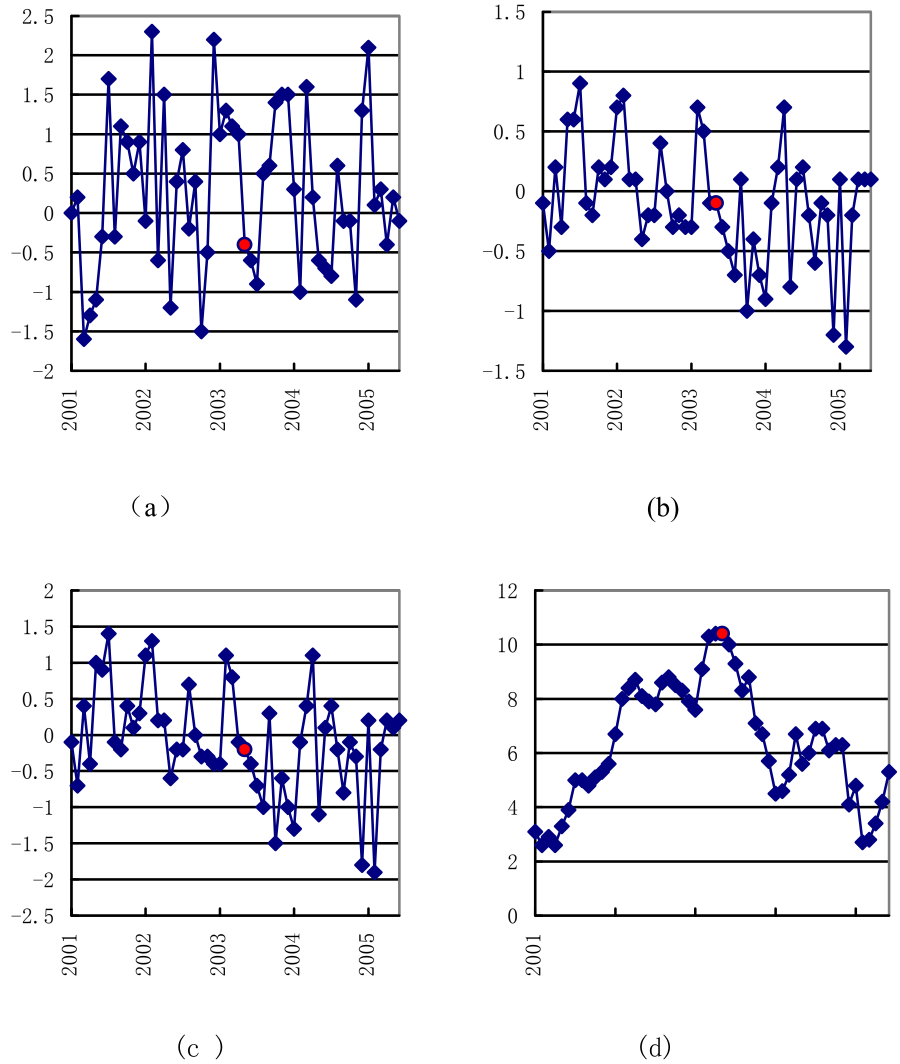


Figure 2: the monthly mean temperature anomaly time series, q series, z series, and t series of the latest 5-year data of the station 56033

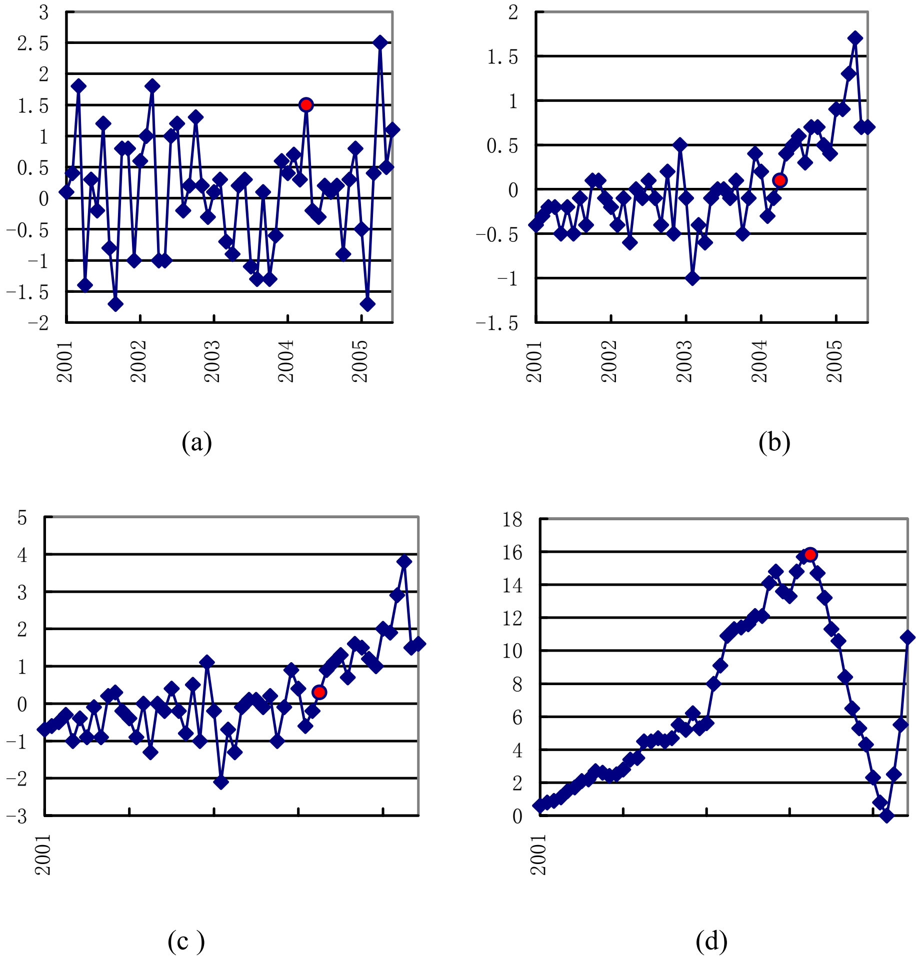


Figure 3: the monthly mean temperature anomaly time series, q series, z series, and t series of the latest 5-year data of the station 57127

2.4 Homogenous Test of Monthly Mean Minimum Temperature

The test of monthly mean minimum temperature is made by the same method mentioned above. It turns out that 210 stations have interrupting point. Find reasons for each interrupting point. 64 stations, occupying 30.5% of all stations with interruptions, have found causes, among which 41 stations, taking up 19.5% of all 210 stations, have the record of station relocation around the interrupting time. 23 stations started the function of automatic stations within one year around the interrupting month. And 3 stations among the 23 stations have the record of station relocation, so the rest 20 stations account for 4.9% of all the 405 automatic stations till 2004. Namely it has been tested out that 4.9% of automatic stations have interrupting point in monthly mean minimum temperature and inhomogeneity appears in the time series.

Table 5: interruptions of automatic stations in the homogeneous test of monthly mean minimum temperature

Year	Station
2001	
2002	58015（02、relocation） 58362（02）
2003	53959（04 relocation） 54579（04） 56033（04）56571（04）57036（04） 57127（04） 57206（04） 58326 （02）
2004	52323 53663 53738 54436 54715 56125 56374 56444 56768(relocation) 56954 57606 57608 57669

(note: the number in the brackets is the year when automatic stations started, and relocation means the relocation around the year of 2002)

3. Testing Result of Monthly Mean Temperature Changing Trend

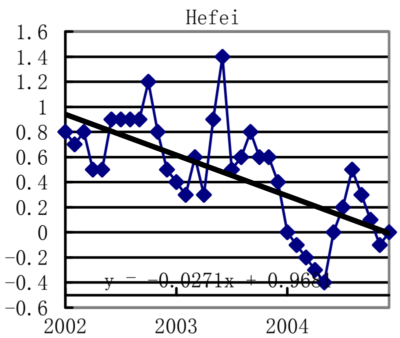
43 stations which have been automatic weather stations since 2002 have been tested. The result is shown in Table 6.

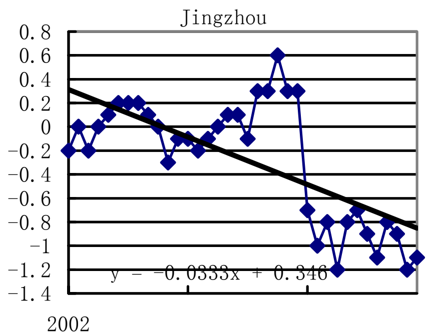
Table 6: testing result of monthly mean temperature changing trend in 2002-2004（℃）

Station	Trend	2000's contrast value	2001's contrast value	Reason
58259	0.01	-0.23	-0.00	
57476(Jingzhou)	-0.03	0.05	0.00	relocation in 2004
58436(Ningguo)	-0.03	-0.07	-0.09	
58236	0.02	-0.10	-0.04	
54342	-0.01	0.32	0.20	
57461	0.01	0.02	0.02	
57259	-0.02	-0.07	0.09	
58321(Hefei)	-0.03	-0.03	-0.07	relocation in 2004
58311	0.01	0.02	0.00	
58138	-0.01	0.02	0.17	

As shown in Table 4, while testing the values of 36 months in successive 3 years of 2002-2004, there are 10 stations have the changing trend. Among the 10 stations, the greatest trend (absolute value) is 0.03℃/month, equivalent to about 0.3℃/year. There are altogether 3 stations, which are station 57476 (Jingzhou, Hubei province), station 58436 (Ningguo, Anhui province) and station 58321 (Hefei, Anhui province). However, from record, it is found that the stations of Jingzhou and Hefei were relocated in 2004 (respectively 4000 meters and 1100 meters away from the original station), and the rest stations have no great change in station location and environment. From Figure 3, it also can be seen that there is a significant incontinuity in the annual time series of station Jingzhou and station Hefei in the year of 2004. The changing trend of 0.3℃/year exceeds the order of magnitude of climate changing trend, so only station Ningguo of Anhui province in the 3 stations with greatest changing trend has the changing trend of time series which is caused not by the change of climate or the station environment, but probably by the drift of instrument. In the test, only 1 station is possibly influenced by instrument drift, occupying 2.3% of 43 tested stations, which is very low. Since the time series are short, further test is still required.

From Figure 4, it can be seen that the 3 stations have a significant difference with the mean temperature of each month of the reference station in the trend of contrast values.





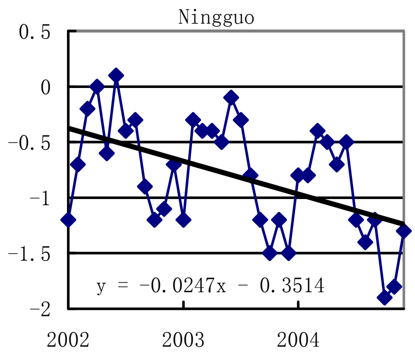


Figure 4: the contrast value of the three stations and the reference station in monthly mean temperature in 2002-2004

4. Conclusion

1) From the above analysis, after statistical test, it is necessary to further analyze the reasons for interruptions, to verify the real situation of stations to determine the interruptions caused by station relocation or the change of automatic station. It is very essential for the analysis on the real reason of data change and on the influence of automatic station observation on temperature data.
2) The change of automatic station instruments has a certain influence on the homogeneity of annual mean temperature and annual mean minimum temperature. On the significance level of 0.05, for annual mean temperature, 5 stations have interruptions with obvious causes, occupying 11.1% of all the 45 automatic stations. For the mean minimum temperature, the test shows that on the significance level of 0.05, 15.6% of all the automatic stations starting from 2002 have interruptions in 2002, which means the change of automatic station instruments has a certain influence on the annual mean minimum temperature.
3) The change of automatic station instruments has a certain influence on the homogeneity of monthly mean temperature and monthly mean minimum temperature. Due to the automatic station, respectively 4.2% and 4.9% of all tested automatic stations (405) have interrupting points in their time series.
4) 2.3% of AWS-observed data have the trend in time series possibly caused by instrument drift, which is very low. In the tested 36 months, there is no obvious drift in the instrument of the 43 automatic stations starting from 2002.
5) The analysis and the test are based on data which are still very short and cover not many stations, especially the first group of automatic weather stations from 2002 have good technical support, so the tested result in this paper may not represent the general situation in China. With the longer observational time series and more automatic weather stations, further analyses will be made. In our country, with the change of ground temperature observation system, the influence on data should be our great concern and study focus.

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