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# Long-term meteorological trends in the Naiman County of northern China

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**Abstract.** The annual trends of six meteorological variables (precipitation, evaporation, relative humidity, sunshine hours, and wind-speed and air temperature) were analyzed by wavelet analyses and mutation analyses of Mann-Kendall method based on daily average data observed from Naiman National automatic meteorological station from 1970 to 2014. Results indicated: (1) The ranges of annual mean precipitation, evaporation, relative humidity, daily sunshine hours, wind-speed and air temperature were 213~567 mm, 1408~2192 mm, 46%~58%, 7~9 h, 2.7~3.8 m/s and 5.8~8.6°C,respectively. (2) Air temperature and daily sunshine hours had increased by 0.29°C /10a and 0.11h/10a ($P<0.01$) respectively over 45 years (1970~2014); (3) Wavelet analysis indicated that wind-speed had a long cycle (26 years); the cycle for daily sunshine hours was somewhat shorter (18 years); evaporation had no obviously cycle; and the other three variables had both shorter and longer cycles. (4) Mutation analysis determined six meteorological parameters that differed from each other, e.g., evaporation had a mutation from low to high occurred in 2001; relative humidity had a mutation from high to low occurred in 2000; daily sunshine hours had a mutation from low to high occurred in 1993.

## 1. Introduction

Long-term trends in meteorological variables are some of the most important issues of the present time. The analysis of long-term trends is essential for the assessment of the impacts of climate variability and change in a given area [1]. Climate change research developed rapidly over the last century from 1 article in 1907 to 862 articles in 2009. Moreover, China, from 8 to 22 articles during 1992–1998, showed great interest in climate change research, quickly catching up with developed countries in 2009, with 377 articles which ranked among the top 6 in the world [2].

Naiman County (42°55′ N, 120°42′ E, 360 m a.s.l.) is located in the eastern part of Inner Mongolia, China, which is one of four well-known sandy areas in northern China, and are generally thought to originate from sand and dust storms that occur frequently in the arid and semi-arid regions of northern China [3,4]. Temperature, precipitation and other are major factor of climate change. Analysis their changes and characteristics are important for region's environmental and ecological. Many studies are analyzed individual elements of change, rarely multi-factor analysis. The method based on non-parametric is first application in this region. The objective of this study was to provide a brief overview of annual climate in Naiman County, by means of trend, wavelet and mutation analyses on six meteorological parameters: air temperature, precipitation, evaporation, sunshine hours, relative humidity and wind-speed on data collected continuously during 1970 to 2014 from the Naiman National automatic meteorological station.

## 2. Materials and methods

### *2.1 Study area description*

Naiman County has a temperate, continental, semi-arid monsoonal climate. Annual precipitation is 366 mm. Mean annual potential pan-evaporation is approximately 1935 mm. The mean annual temperature is 6.4 ℃. The topography is characterized by dunes and inter-dune lowlands [5].

### *2.2 Data*

All data were extracted from the Naiman National automatic meteorological station. The data was collected continuously from 1970 to 2014 and the analysis was applied to daily data sets for the following six parameters: (1) annual precipitation (mm); (2) annual evaporation (mm); (3) annual mean relative humidity (%); (4) annual mean daily sunshine hours (h); (5) annual mean wind-speed (m/s); and (6) annual mean air temperature ( ℃). The annual data of each meteorological parameter was the average of monthly date, which was obtained by averaged daily date.

### *2.3 Methods*

The trend analysis of each meteorological variable (precipitation, evaporation, relative humidity, sunshine hours, wind-speed and air temperature) changed with year was regressed by the linear equation: $y= at + b$, where: $y$ denotes meteorological variable, $t$ denotes year; A=a*10 was the trend rate of variable. The positive (negative) A represents linear increasing (decreasing) of the variable in the statistical time [6]. Trends of significance test chose F-test method.

Period and mutation features of the six variables were analyzed by wavelet and mutation analyses using the non-parametric Mann-Kendall (M-K) Method [7,8]in Origin 8.0 software.

## 3 Results

### *3.1 Statistical analysis*

The 45-year means of the six meteorological variables were: annual mean precipitation -344 mm, evaporation -1810 mm, relative humidity -53%, daily sunshine hours -8 h, wind-speed - 3 m/s and air

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temperature -7 ℃ (Table 1). The coefficient of variation (CVs) for precipitation was the largest (27%), followed by evaporation (11%) and air temperature (10%); the other three variables had small CVs (<10%). On the whole, variation was moderate (10% < CVs < 100%) for precipitation, evaporation and air temperature, and lower (CVs ≤10%) for relative humidity, daily sunshine hours and wind-speed. The skewness was negative for evaporation and air temperature, and positive for the other four variables. This indicated that evaporation and air temperature were left deviated and had mainly large values, while the other four variables were right deviated and the majority of the values were small. The kurtosis of precipitation and relative humidity were positive, but negative for the other four variables. Precipitation and relative humidity had a peak in their distribution, and the values were concentrated over a limited range, while the other four variables had flat distributions and were spread over a much larger range.

**Table 1.** Statistical characteristic of six meteorological variables.

| Variables | Min. | Max. | Mean | SD | CVs(%) | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| Precipitation (mm) | 213.10 | 567.10 | 343.88 | 91.68 | 27 | 0.88 | 0.07 |
| Evaporation (mm) | 1408.00 | 2192.00 | 1810.20 | 199.12 | 11 | -0.24 | -0.66 |
| Relative humidity (%) | 45.94 | 58.01 | 52.57 | 2.47 | 5 | 0.17 | 0.51 |
| Daily sunshine hours (h) | 7.33 | 9.10 | 8.14 | 0.42 | 5 | 0.23 | -0.66 |
| Wind-speed (m/s) | 2.70 | 3.75 | 3.24 | 0.25 | 8 | 0.35 | -0.54 |
| Air temperature ( ℃) | 5.75 | 8.62 | 7.11 | 0.71 | 10 | -0.07 | -0.98 |

### *3.2 Trend analysis*

The time series of the six meteorological variables are presented (Fig.1). From the linear trends of the six variables over 45 years (1970-2014), the relative humidity and wind-speed had downward trends ($R^2$>0.1) in recent 45 years, and with trend rate 0.62%/10a and 0.06 (m/s)/10a ($P$<0.01), respectively. While trends for the other four variables were upward, and the air temperature increased most obviously (with highest $R^2$ (0.29)), and the trend rate was 0.29 ℃ /10a ($P$<0.01), followed by daily sunshine hours (with $R^2$=0.11 and trend rate 0.11h/10a ($P$<0.01)). The upward trends of precipitation and evaporation was weak ($R^2$ <0.02), and with trend rate 1.02 mm/10a and 20.96 mm/10a (($P$>0.05)), respectively.

For convenience, let (a), (b), (c), (d), (e) and (f) denote precipitation, evaporation, relative humidity, daily sunshine hours, wind-speed and air temperature, respectively behind.

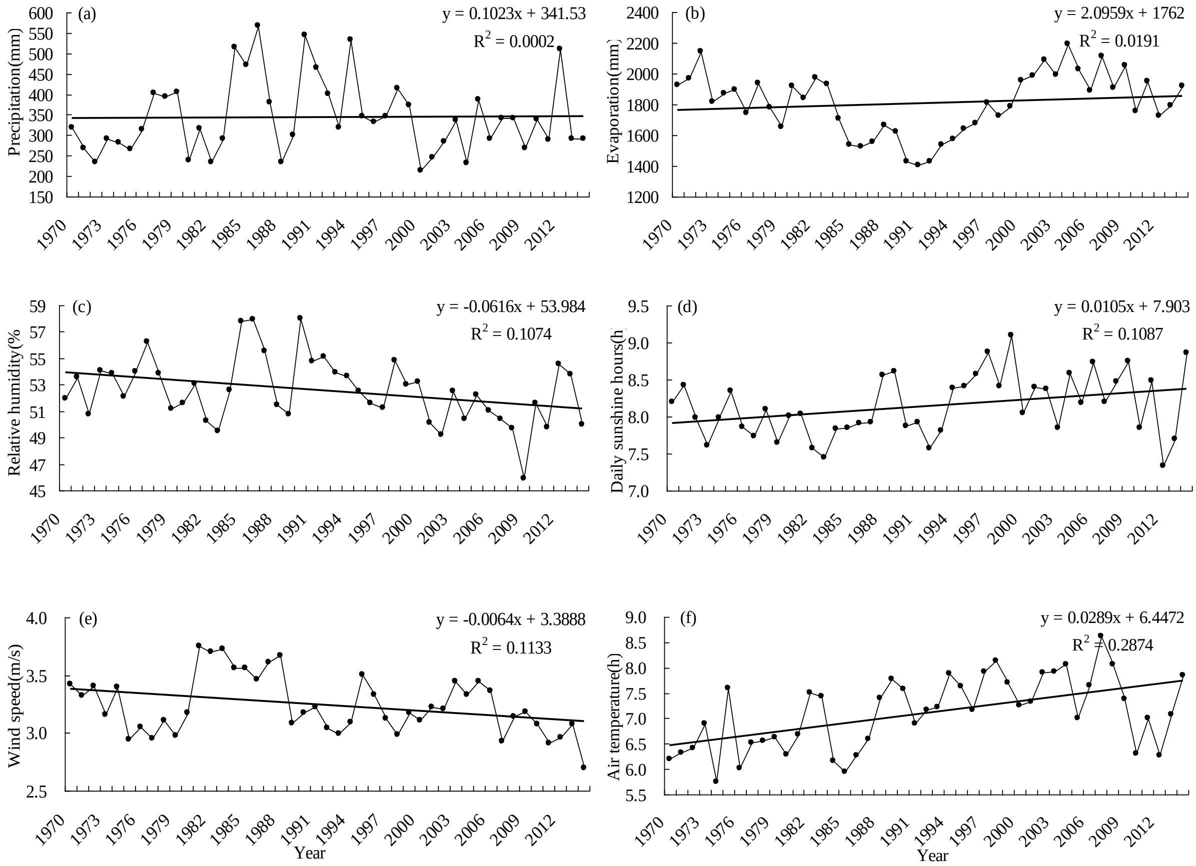


**Figure1.** Time series and trend analysis of six meteorological variables.

The trend of increased air temperature was consistent with trends reported for global temperatures [2, 9]. Increasing air temperature, number of daily sunshine hours and evaporation exacerbate drought, and thus exacerbate the deterioration of ecological environment of Naiman County [10].

*3.3 Wavelet analysis*

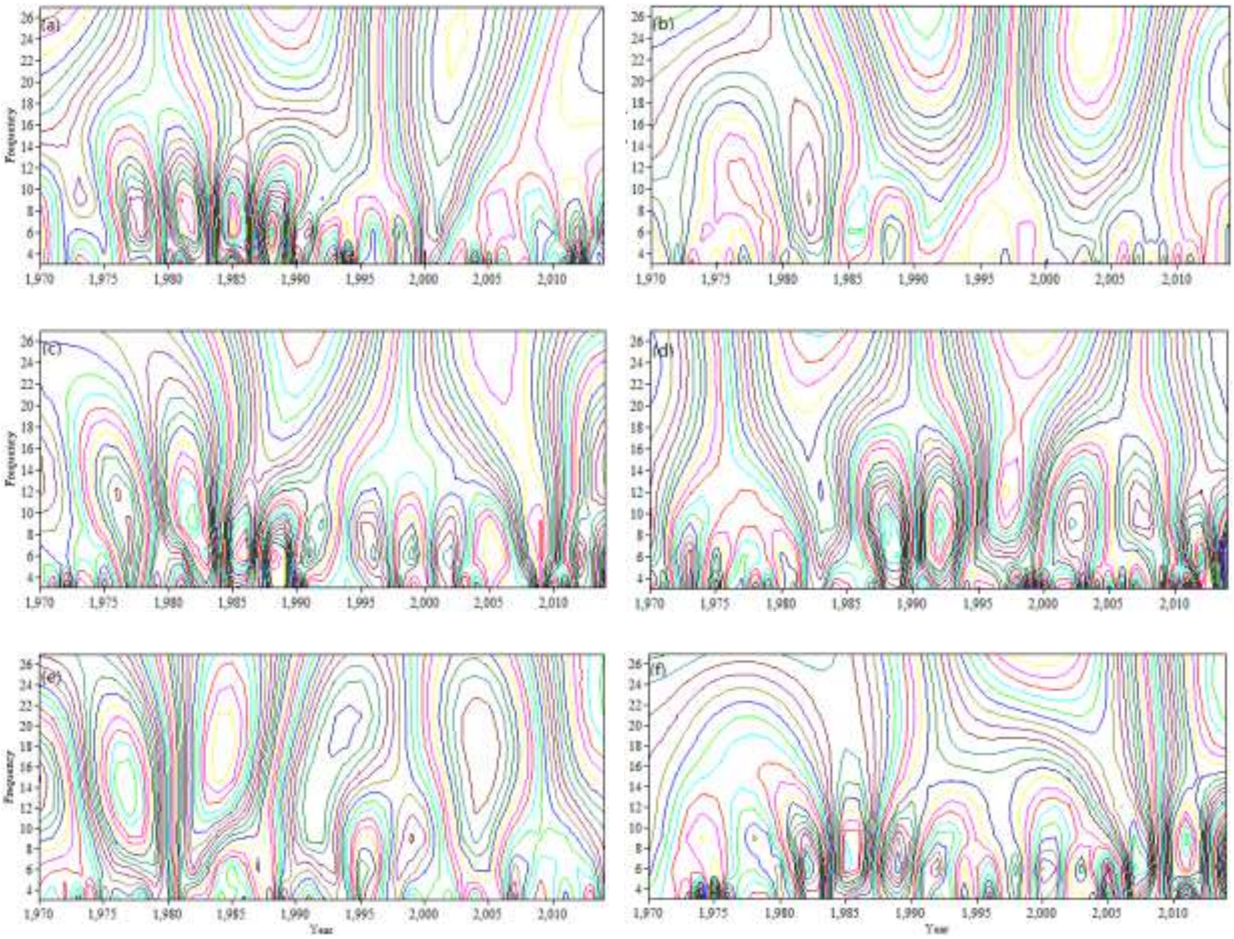


**Figure 2.** Wavelet analysis of six meteorological variables.

Wavelet analyses of the six meteorological variables suggest two characteristic cycles of annual precipitation, namely a 6-8 year short cycle (beginning after 1990) and a 16 year long cycle (from 1975 to 1990) (Figure 2a). This observation was consistent with the result of our previous study [11], and the period feature for annual precipitation was more obvious in 1975~1990. The period features of relative humidity were 13-year short cycles (beginning after 1985) and a 25-year long cycle (before 1985) (Figure 2c). Number of daily sunshine hours had an 18-year period feature (especially after 1985) (Figure 2d). The period features of wind-speed were 13-year short cycles and a 26-year long cycle (Figure 2e). Air temperature had 7-year short cycles and a 16-year long cycle at the same time (Figure 2f). There was no apparent period feature for evaporation (Figure 2b).On the whole, wind-speed had the longest cycle (26 years), followed by the number of daily sunshine hours (18 years), evaporation had no obviously period feature, and the other three variables had both short and long cycles.

### *3.4 Mutation analysis*

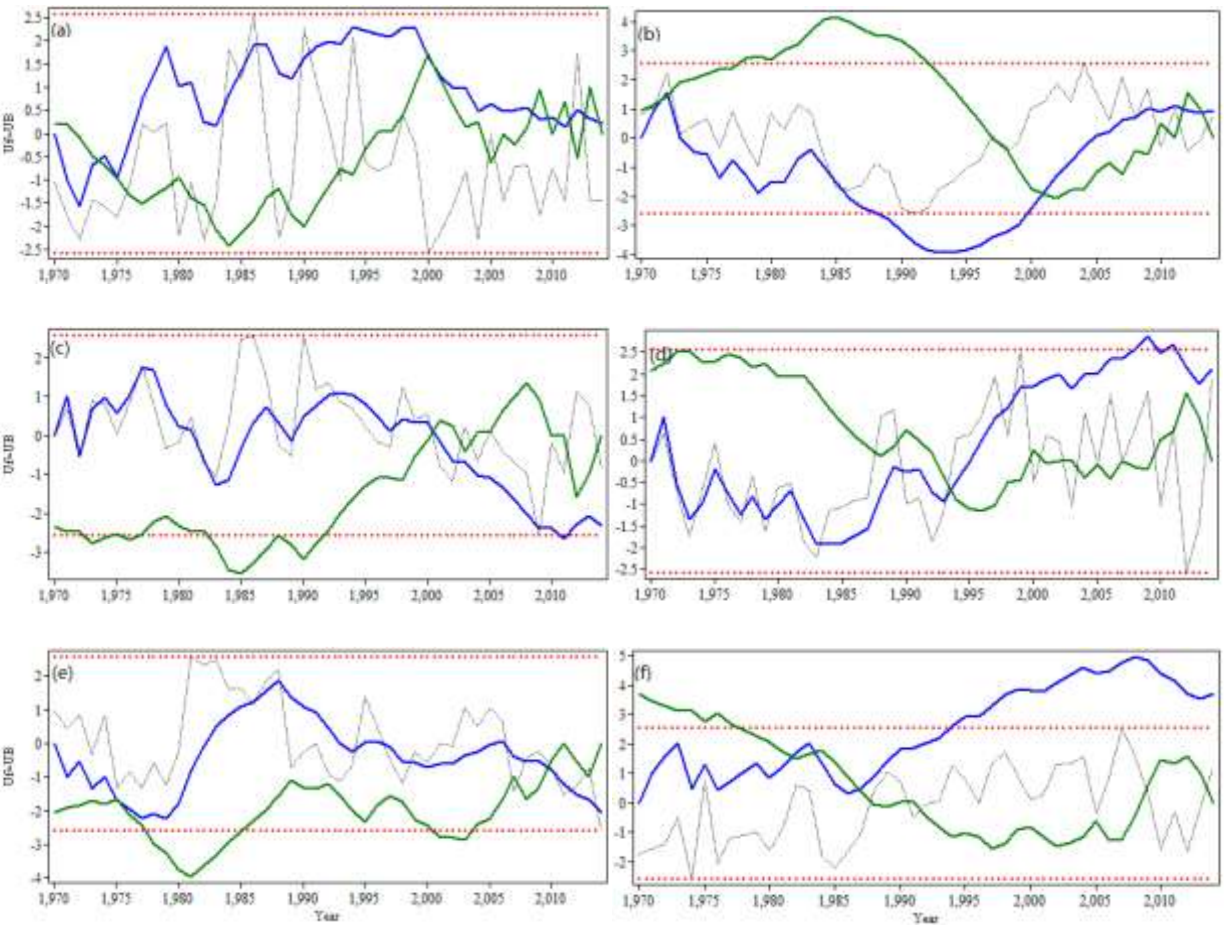

**Figure 3.** Mutation analysis of six meteorological variables.

In figure 3, the blue curve and green curve were the UF and UB curve, respectively. The gray curve represents the actual value measured. The cross point of UF and UB denotes the mutation point of the variable.

The M-K curves of the six meteorological variables are presented (Figure 3). The mutations for the precipitation time series occurred in 1973 and 2008, and in addition, there was also a slight mutation at 2000. That was, precipitation had a mutations from high to low occurred in 2008, and had a mutations from low to high occurred in 1973 (Figure 3a). The mutations in the evaporation time series occurred in 1972, 2001, 2011 and 2013, so, evaporation had a mutations from high to low occurred in 1972 and 2011, and had a mutations from low to high occurred in 2001 (Figure 3b). Relative humidity had only one mutation point, at 2000, and it increased before 2000, and then decreased (Figure 3c). A single mutation for the number of daily sunshine hours occurred in 1993, and this variable decreased before 1993, but increased after 1993 (Figure 3d). Wind-speed had two mutation points: 1975 and 2009; Wind-speed had a mutations from low to high occurred in 1975, and had a mutations from high to low occurred in 2009. The mutations for the time series of air temperature was complex, it had three mutation points: 1981, 1983 and 1986. The air temperature had a mutation from low to high occurred in 1986 and had a mutation from high to low occurred in after 1981. In summary, the mutation points of the six meteorological variables differed from each other. After 2000, precipitation and relative humidity decreased, but evaporation, daily sunshine hours and air temperature increased, this provides further evidence of warming air temperatures in Naiman County.

**4. Discussion**

The annual mean air temperature of Naiman County for the period 1970-2014 was 7.11 ℃, and there was significant increase in air temperature, and air temperature of Naiman County increased by 0.29 ℃ /10a, which was consistent to the result of China for the period 1951–2004: the average annual mean Tmax and Tmin over China increased by 0.147 ℃ /10a and 0.283 ℃ /10a respectively [12]. The related research results also showed that there was obvious warming over the past century for many parts of the world, has been strongly associated with increases in air temperature [12-14], and the distributions of both daily maximum and minimum temperatures have significantly shifted towards higher values [15]. In fact, the climate on earth is changing rapidly, and the global surface temperature has increased by 0.2 ℃/10a over the last 30 years [16]. And the global average surface temperature of the Earth has increased by 0.6 ±0.2 ℃ since 1900 and it is likely that the rate and duration of the warming are greater than at any time in the past 1000 years [17]. But for Australia, it has warmed ~0.8 ℃ over the last century [18]. That was, there was a similar trend for climate system, but the rate of warming was differently among different areas.

The annual mean precipitation of Naiman County for the period 1970-2014 was 343.88 mm, and it has a weak upward trend, with trend rate 1.02 mm/10a. The research results of precipitation in Naiman County for the period 1961-2009 [19] and 1970-2010 [11] indicated that there was a decreased trend for annual precipitation. Because of different time-series of research data selected, the results of the analysis has a certain influence, the results vary. The trend of precipitation has showed a stable during this period during not pass the significance test. However, this trend is same as desertification in northern of China. On a continent-wide basis, the trend of precipitation is not statistically significant because of high interannual variability [18]. Because under the trend of warring for air temperature, there was a wide range of uncertainty in rainfall trends [18].

**5. Conclusions**

We have presented trend analyses of annual precipitation, evaporation, relative humidity, daily sunshine hours, wind-speed and air temperature of Naiman County in eastern Inner Mongolia, China, over the years 1970-2014. The main conclusions of the study are summarized as follows:

(1) The annual mean precipitation, evaporation, relative humidity, daily sunshine hours, wind-speed and air temperature were 344 mm, 1810 mm, 53%, 8h, 3 m/s and 7 ℃, respectively. Precipitation and relative humidity had a peak in their distribution range and values tended to be concentrated over a narrow range. Evaporation and air temperature were left deviated and the majority of the values were large, while for other variables the results were opposite (no peaks in the distribution and no concentration of values over the range).

(2) There is a general warming signal, with the air temperature increasing by 0.29 ℃/10a during 1970-2014, as did daily sunshine hours (0.11h/10a), evaporation (20.96 mm/10a) and precipitation

(1.02 mm/10a). Relative humidity and wind-speed decreased over the period, with trend rate were 0.6%/10a and 0.06 (m/s)/10a, respectively.

(3) The period features of the six meteorological variables were that wind-speed had a long cycle (26 years), as did daily sunshine hours (18 years), evaporation had no obvious period feature, and the other three variables had both short and long cycles.

(4) The mutation points of the six variables differed from each other. On the whole, after 2000, precipitation and relative humidity decreased, but evaporation, daily sunshine hours and air temperature increased.

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