Trend analysis on temperature and precipitation over North China Plain for past five decades

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Abstract. The trend of change in temperature and precipitation in North China Plain over past few decades was examined using the non-parametric Mann-Kendall test in this paper. For the temperature part, a significant positive trend in annual temperature (0.03 °C/year) and a non-significant negative trend in annual precipitation (-0.67 mm/year) are found over the North China Plain (NCP) from 1960 to 2009. Furthermore, the winter temperature change and summer precipitation are found to be the most important factors for annual temperature and precipitation change. The winter temperature increases 0.04 °C per year. As for the summer precipitation, it increases by 11% to the south of the Yellow River, over the NCP, and decreases by 20% to the north from 2000-2009 compared to 1990-1999. The reveal of the changing pattern in precipitation is a good start for us to further understand the main driving force of these changes and make a forecast on that.

1. Introduction
Anthropogenic climate change is arguably the most pressing environmental emergency of our time. Among the most important aspects of observed climate change are multi decadal trends in temperature and precipitation. Globally land precipitation has increased by about 2% since the beginning of the 20th century, but the increase is not spatially uniform [1]. As climate change continues to affect the global atmospheric circulation and water circulation mode, the temperature and precipitation exhibited different trends at regional and local level correspondingly. As for the relationship between temperature and precipitation trends, both positive and negative correlations exist in different regions [2].

The North China Plain (NCP, Figure 1) is one of the most important agricultural regions in Asia and produces up to 50% of the cereal consumed in China each year [3]. It is the largest alluvial plain, draining into the Yellow River, of eastern Asia and has a population of more than 0.3 billion. Due to the severe problem of water shortage in the NCP, groundwater has been overexploited causing all manner of environmental hazards, such as sea water intrusion [4] and land subsidence [5]. Furthermore, extreme precipitation occurs from time to time [6], such as the rainstorm on the 21st of July, 2012, which led to at least 79 people killed and an economic loss of 1.8 billion dollars [7].
There are numerous studies on observed climate change over the NCP. Ren et al [8] analyzed the climate change from 1951 to 2001 over China and concluded that the annual mean temperature has increased by 1.1 °C, with various increases in most parts of the country; the annual precipitation increases a little but the trend is not statistically significant. It is also found that, while temperature increases, unlike in most other regions, precipitation decreases over the NCP. This was confirmed by Fu et al [9]. Fu et al studied the temperature and precipitation changes over the NCP with particular focus on the decadal climate trend and future scenarios in this region. Such variations of temperature and precipitation require a detailed and evidence based trend analysis.

In this study we will examine the trend of temperature and precipitation based on the observed data over the NCP from 1960 to 2009 and try to figure out in what pattern these changes have occurred.

2. Data sources and methods

2.1. Data sources
Annual, monthly and daily temperature and precipitation data for the period 1960 to 2009 from 16 stations are used to characterize the inter-decadal temperature and precipitation trends over the NCP (Figure 1). All the stations selected for the study have been maintained following the standard of the National Meteorological Administration of China (NMAC). The strict data quality control has been done before they are released. The data can be downloaded from http://www.cma.gov.cn/2011qxfw/2011qsjgx/. These selected stations could be used to represent the interdecadal trends of regional climate over the NCP [9][10].

2.2. Methods
We first used the annual mean temperature and precipitation from all 16 stations as the representative value of the entire region. Then we calculated the seasonal average in spring (March to May), summer (June to August), autumn (September to November) and winter (December to February). Furthermore, the annual and seasonal temperature and precipitation at each station are analyzed to reveal the spatial distribution of temperature and precipitation trends. The trend for all the time series of temperature and precipitation is revealed by the non-parametric Mann-Kendall test [11][12]. The rate (slope) of temperature and precipitation changes is estimated by the Sen’s non-parametric trend estimator [13].
We also examined the role of the temperature change in each individual season in the annual trend, in order to find out if certain seasons play a greater role than others. Li et al [14] presented a method to quantify the relative importance of specific seasons in terms of their proportional contribution to the annual trend:

\[ I_s = \frac{T_{s,i} - \bar{T}_{s,\text{reference period}}}{\sum (T_{s,i} - \bar{T}_{\text{reference period}})} \cdot 100 \]  

(1)

where \( I_s \) is the importance index for season \( s \) (spring, summer, autumn and winter); the reference period denotes the period before the occurrence of significant trend; \( T_{s,i} \) is the seasonal temperature of year \( i \) after the reference period; \( \bar{T}_{s,\text{reference period}} \) and \( \bar{T}_{\text{reference period}} \) are the average seasonal and annual temperature during the reference period, respectively.

However, this method is only valid when all seasonal trends are positive or negative, which is not in common. Therefore, we modified the method by eliminating the season which has a trend of different sign. The portion is calculated as:

\[ I_s = \frac{T_{s,i} - \bar{T}_{s,\text{reference period}}}{\sum (T_{s,i} - \bar{T}_{s,\text{reference period}})} \cdot 100 \]  

(2)

where season \( s \) denotes the seasons with trend of the same sign. It should be noted that season \( s \) in Equation (2) is different to the \( s \) in Equation (1), when the seasonal trends are different. For example, if summer temperature has a negative trend and that of the other seasons has a positive one, \( s \) in Equation (2) only denotes the seasons without summer, while \( s \) in Equation (1) denotes four seasons. Meanwhile, the \( \bar{T}_{\text{reference period}} \) in the denominator is replaced by \( \bar{T}_{s,\text{reference period}} \) in Equation (2), because the annual average could not be used in this context. In this paper, the reference period is specified as 1960 -1970, because a significant increasing trend is detected since 1970s [8][9][15] (Figure 2).

3. Results and discussion

3.1. Temporal trend

The Mann-Kendall results show that annual temperature has a significant positive trend of 0.03°C per year from 1960 to 2009 (Figure 2-a). During the same period, annual precipitation has a negative trend of -0.67 mm per year, but it is not statistically significant. Given that temperature and precipitation may change in different ways in different seasons, we further examined the trends of seasonal temperature and precipitation over the NCP. We found that temperature in winter, spring and autumn has a significant increasing trend with the slope of 0.04°C, 0.04°C and 0.02°C per year, while temperature in summer and precipitation in all the seasons have no significant trends (Figure 2-b and Figure 2-c).

The importance of seasonal temperature change in the annual trend is calculated after eliminating the summer season, during which no significant trend is found. The importance index for spring, autumn and winter is 32%, 20% and 48%, respectively. The results imply that winter temperature change is the most important factor for the annual temperature trend. Therefore, it is more meaningful to examine what is causing the increase of winter temperature rather than annual temperature.

During the period from 1960 to 2009, summer precipitation contributed 60% of annual precipitation over the NCP. In addition, precipitation extremes mainly occurred in summer which caused flood and drought events in the region [16]. Hence, we focus on the long-term variations of
summer precipitation instead of annual precipitation. Consequently, the trend of winter temperature and summer precipitation will be discussed in detail in what follows.

Figure 2. Temporal trends of annual (a), summer (b) and winter (c) temperature and precipitation in the North China Plain from 1960 to 2009.

3.2. Spatial distribution
The spatial distribution of temperature and precipitation trends for summer, winter and the entire year are illustrated in Figure 3. For the temperature, winter and annual average at all the stations have significant increasing trends except for the winter average at Zhumadian station (Figure 3-a1 and 3-c1). For precipitation, summer and annual values at most of the stations have a similar trend, although they are not significant (Figure 3-a2 and 3-b2). These results further confirm the importance of winter temperature and summer precipitation in the annual trends of temperature and precipitation.

In addition, we find that north of the Yellow River over the NCP, summer temperatures at all stations have a positive trend. The northernmost stations generally have a significant positive trend. Summer precipitation at the stations north of the Yellow River has a negative trend, even if most of
them are not significant. But south of the Yellow River, the summer precipitation at most of the stations has a positive trend, albeit not significant.

![Annual mean temperature vs. Annual precipitation](image1)

**Figure 3.** Annual (a), summer (b) and winter (c) temperature and precipitation trend of each station in the North China Plain from 1960 to 2009. The regular and inverted triangles indicate the increase and decrease trend, respectively; the red and black colors for the triangles are statistical significant and insignificant, respectively.

4. **Conclusions**

Observations of annual mean temperatures show a positive and statistically significant trend of 0.03 °C/year over the NCP from 1960 to 2009. By contrast, observations of annual mean precipitation show a negative, but not statistically significant, trend of -0.67 mm/year over the same period and region. Temperature in spring, autumn and winter all exhibit a positive trend of 0.04, 0.02 and 0.04 °C/year, respectively, while there is no significant trend for temperature in summer or for precipitation in any season.

**Acknowledgement**

This study is supported by National Key Research and Development Project(2018YFC0406505).
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