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Analysis of Temperature Variability over Desert and Urban Areas of Northern China

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Abstract

Although many studies carried out have shown evidence of regional temperature variability along with global climate changes, it is important to compare the trends over different regions considering urbanization and levels of development. The study investigated temperature variability over urban and desert areas of Northern China using Mann-Kendall trend test, ranking temperatures and regression analysis for the data from 20 stations. The results show decreasing diurnal temperature range (DTR) over both deserts and cities in spring but decreasing (increasing) for cities (deserts) in summer (cities: -0.140°C/decade and deserts: 0.068°C/decade). The DTR over cities is decreasing faster in spring over deserts (cities: -0.307°C/decade, desert: 0.023°C/decade). The maximum temperature over desert areas is increasing at a higher rate (annual: 0.510°C/decade, spring: 0.540°C/decade and summer: 0.550°C/decade) than over cities (annual: 0.325°C/decade, spring: 0.252°C/decade and summer: 0.389°C/decade). The high temperature days and high temperature extremes for both areas are increasing while the frost days and low temperature extremes for both areas are decreasing. The spring minimum temperatures are also increasing over both areas and increasing at a higher rate over deserts (0.536°C/decade) than over cities (0.529°C/decade).

Keywords: Climate response; Mann-kendall trend test; Urban and desert areas of China

Introduction

The air temperature is one of the key parameters used in classification of climatological zones, for instance: temperate, humid, desert and semi-desert [1]. The variation of daily temperature is controlled mainly by incoming solar energy and outgoing long-wave surface radiation [2]. The air temperate does not vary in isolation and one of the cases is explained by Bryan et al. [3] of high temperatures and high pollution concentrations being associated with strength of high pressure systems and sunny (with fast photolysis rates) conditions.

Over a large area and over a long time, the temperatures can be averaged and thus assisting to describe the climate of area in terms of hotness/coldness. While weather elements vary from day to day or even place to place [4], climate too exhibits variability inter or intra season as well as inter or intra annual.

The changes in climate may manifest as changes in the mean state or in variability of their cycles [3]. Boko [5] illustrates these changes graphically as (Figures 1-3).

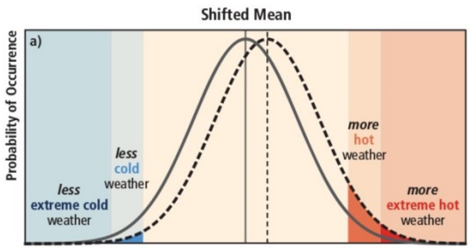

Figure 1: Shift in mean temperature.

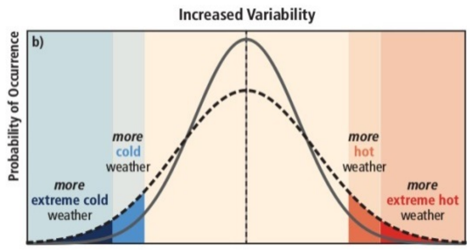

Figure 2: Change in temperature variability.

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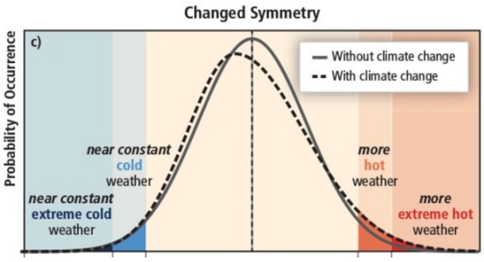

Figure 3: Change in symmetry distribution of temperature.

Climate change and variability has remained a research problem over the years. The previous studies demonstrated changes in precipitation, temperature, and other climatic parameters as well as vegetation cover [6] and these changes have been linked to economic development and urbanization [7]. Additionally, climate extremes have increased both in frequency and magnitude [8] but other areas have seen notable decline [9].

One of the indicators of climate change is changes in temperature and according to Roy et al. [10]; local temperature change is influenced by urbanization. A change in average temperature, can affect the amount of cloudiness as well as the type and amount of precipitation that Occurs [11] and is attributed to changes in radiative forcing [8,12,13] such as changes in landscape leading to changes in surface reflectivity to solar radiation; surface moisture variability; modification of vegetation cover as well as anthropogenic heat release which combine and cause temperature rise.

The increase in temperature has impacts such as: increased incidence and severity of heat-waves, droughts [13,14]; shrinking of glaciers ice caps, mountain glaciers, and permafrost regions of the world [15] and can affect growing practices such as sowing dates and cultivars [16]. The global temperatures are estimated to have increased by 0.5-0.6°C over the last century [9,13] and are estimated to increase by 0.3-0.7°C by 2035 [17].

Due to differential rates of development and urbanization as well as differences in land surface characteristics, we can expect different trends of temperature over deserts and cities. This is because, the economic development of a region is directly correlated with urbanization [18,19] and urbanization affects surface greenness and leads to changes in surface albedo [12]. Thus these changes affect receipt of solar radiation on the earth and influence air temperature. Additionally urbanization and industrialization have led to increase in greenhouse gases (GHGs) which has also influenced temperature [20]. In recent years, China has experienced massive industrial growth and economic development as well as increased urbanization [21]. The growth of cities introduces the need for constant monitoring of weather and climate over different regions of China.

Although temperature trends have been studied in many regions of the world [17], studies considering differential responses of temperature over desert and cities are limited. We compare the temperature variability including their extremes over cities and desert areas of Northern China for the period 1981-2010. The study areas are presented in Figure 4; section 2 describes the data sources, section 3 presents the study methods, section 4 presents results and discussion while section 5 gives summary and conclusion.

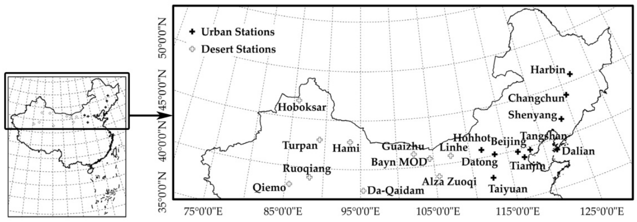

Figure 4: Map of China showing study region.

Data

The daily maximum and minimum temperature data is obtained from the School of Atmospheric Science of Nanjing University of Information Science and Technology (NUIST). This data is regularly updated and quality controlled to take care of the on-going research in the university. The data is then organized into temporal scales (annual, spring and summer). The diurnal temperature range (DTR) is computed from eqn. (1) as the difference between daily maximum temperature (T_{max}) and daily minimum temperature (T_{min}) and is also organized in terms of annual and seasonal temporal scales.

$$DTR = T_{max} - T_{min} \qquad (1)$$

The high temperature days are computed according to Thomas et al. [13] as days that have T_{max} exceeding 32.0°C and the number of days with extreme high temperature is those that exceed 90th percentile of daily observed T_{max}. Our study used a higher threshold of 35.0°C for high temperature days and the number of days with extreme high temperatures as those with T_{max} over the 95th percentile. The extreme low temperature as those days with T_{min} below the 5th percentiles of daily T_{min} and the frost days as the days with T_{min} below 0°C.

Methods

In order to study the trends of temperature over regions of different climatology, the relative deficit and or surplus (anomalies) of temperature $\hat{T}$ are used and calculated using the eqn (2).

$$\hat{T} = \frac{T_i - \overline{T}}{\overline{T}} \qquad (2)$$

Ti is temperature in question and $\overline{T}$ is respective long-term mean temperature over the study period. The $\overline{T}$ of a temperature data set, {T1, T2, · · ·, Tn} is computed using eqn (3):

$$\overline{T} = \frac{1}{n}\sum_{i=1}^{n} T_i \qquad (3)$$

The Mann-Kendal trend test

The Mann-Kendall (MK) trend test is used to analyze the trends of: T_{max}, T_{min} and DTR. The MK is recommended by Qiang et al. [22] because it is (1) a rank-based nonparametric test, able to test trends without requiring normality or linearity; (2) less sensitive to outliers and (3) recommended by the World Meteorological Organization. Additionally Jagannathan and Parthasarathy [23] have identified the MK test as powerful for testing trends that are linear or non-linear. For a time ordered temperature data-set, we define MK trend test statistic, S (eqn. 4):

$$s = \sum_{i=1}^{n-1} \sum_{j+i=1}^{n} \operatorname{sgn}\left(T_j - T_i\right) \quad (4)$$

where $\operatorname{sgn}(T_j - T_i)$ is:

$$\operatorname{sgn}\left(T_j - T_i\right) = \begin{cases} +1: if T_j - T_i > 0 \\ 0: if T_j - T_i = 0 \\ -1: if T_j - T_i < 0 \end{cases} \quad (5)$$

for non-tied values of T_i, the variance $\delta^2(S)$ of the distribution of S is computed using:

$$\delta^2(s) = \frac{n(n-1)(2n+5)}{18} \quad (6)$$

for tied values of T_i, the variance is given by:

$$\delta^2(s) = \frac{n(n-1)(2n+5) - \sum t_i(i)(i-1)(2i+5)}{18} \quad (7)$$

t_i is number of ties of extent i. The MK test statistic is then given by the standard Gaussian value, M K_z defined as:

$$MK_Z = \begin{cases} \frac{s-1}{\delta(s)}: if S > 0 \\ 0: if S = 0 \\ \frac{s+1}{\delta(s)}: if S < 0 \end{cases} \quad (8)$$

The computation of temperature extremes

We use Jenkinson [24] formula (eqn. 9) for computing extreme temperatures. This formula is discussed by Chris and Anderson [25] in comparison with other formula for studying extremes and is recommended for the study of climate extremes [25,26]. According to the Jenkinson formula, the probability, p that a random value is less than or equal to the rank of that value, T_i is given by:

$$p = \frac{m - 0.31}{n + 0.38} \quad (9)$$

where m is the position of the value and n is the number of values in the data set. The T_i for example summer season which has 92 days, is arranged in ascending order: {T1, T2, · · ·, T91, T92}. The T_i representing the 95th percentile is linearly interpolated between the 88th ranked value (giving: p=94.9%) and 89th ranked value (p=96.0%). The 95th percentile is thus interpolated.

We considered high temperature days, frost days, high temperature extremes and low temperature extremes. The high temperature days are the days with T_{max} greater than 35.0°C, frost days are the days with T_{min} below 0°C, high temperature extreme days are the number of days with T_{max} over the 95th percentiles of daily T_{max}, while low temperature extreme days are the days with T_{min} below the 5th percentiles of daily T_{min}. The number of days with extreme high temperature and extreme low temperature are obtained using the Jenkinson formula (eqn. 9).

Regression method

We use regression to obtain the decadal (10 year) rate of changes of temperature, described as under. Given an n time-ordered temperature dataset: $\{T_1, T_2, \cdots, T_{n-1}, T_n\}$, ordered in time, t the linear regression equation is given as:

$$T_i = \alpha t_i + \in \quad (10)$$

where

i=1, 2, · · ·, n

α is the rate of change, is the error and the decadal rate of change of temperature (α_{10}) is computed as:

$$\alpha_{10} = \frac{T_{i+10} - T_i}{10} \quad (11)$$

Results and Discussion

Annual temperature trends

The annual temperature trends over deserts (Table 1) and over cities (Table 2) are obtained using MK_z at 99% confidence level. Over deserts, we find an increasing trend for both T_{max} (MK_z=0.431) and T_{min} (MK_z=0.407) and a decreasing trend for DTR (MK_z=-0.091). The annual DTR shows high variability (Figure 5). It peaked during the period 1990-2000 and declining over the period 2001-2010. This variability probably explains the weak decreasing trend in Table 1. The annual trends of DTR for individual stations were in the range of: -0.35°C/decade to -0.04°C/decade. The T_{max} has been increasing since 1985 (Figure 6) in the range of 0.36-0.70°C/decade and on average at 0.51°C/decade. The T_{min} shows a high variable increasing trend (Figure 7) in the range of 0.06-0.8°C/decade and on average at 0.52°C/decade. This rate is slightly greater than that of T_{max}. We thus argue that T_{min} increase faster than T_{max} which could be accounting for the rate of decrease of DTR over deserts in (Table 1).

Station	T_{max}	T_{min}	DTR
Alza Zuoqi	0.370	0.527	-0.457
Bayn MOD	0.448	0.037	0.269
Da-Qaidam	0.591	0.497	-0.067
Guaizhu	0.301	0.467	-0.223
Hami	0.444	0.144	0.301
Hoboksar	0.264	0.385	-0.269
Linhe	0.315	0.480	-0.545
Qiemo	0.522	0.406	0.278
Ruoqiang	0.545	0.531	0.177
Turpan	0.508	0.596	-0.375
Average	0.431	0.407	-0.091

Table 1: Annual temperature variation for desert areas.

Station	T_{max}	T_{min}	DTR
Beijing	0.260	0.545	-0.384
Changchun	0.269	0.416	-0.320
Dalian	0.228	0.370	-0.315

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Datong	0.402	0.554	-0.292
Harbin	0.260	0.582	-0.683
Hohhot	0.384	0.577	-0.503
Shenyang	0.140	-0.145	0.214
Taiyuan	0.407	0.697	-0.393
Tangshan	0.343	0.485	-0.398
Tianjin	0.214	0.016	0.145
Average	0.291	0.410	-0.293

Table 2: Annual temperature variation for cities.

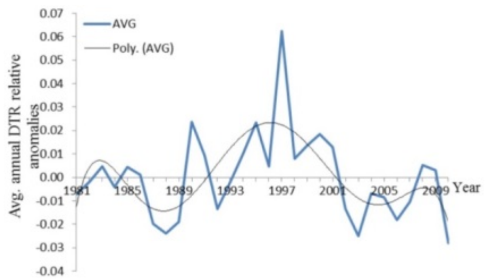

Figure 5: Annual DTR anomalies for selected desert areas.

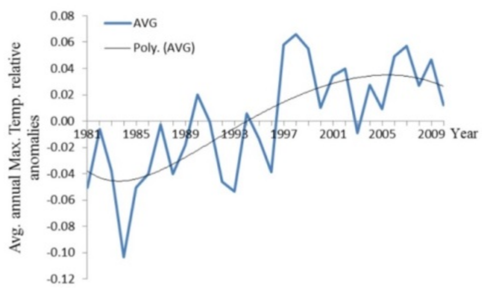

Figure 6: Annual maximum temperature anomalies for selected desert areas.

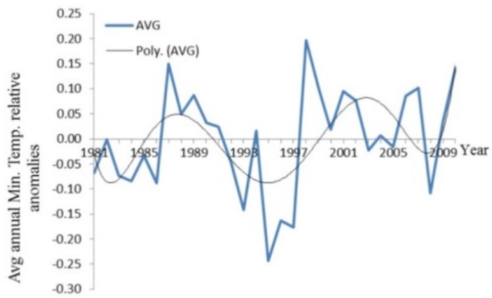

Figure 7: Annual minimum temperature anomalies for selected desert areas.

Over cities, we find both T_{max} and T_{min} increasing annually with exception of Shenyang and a decreasing DTR (MK_z=-0.293). The annual DTR for cities decrease sharply (Figure 8) in the range of -0.659 to -0.146°C/decade and on average -0.238°C/decade. The T_{max} is increasing (Figure 9) in the range of 0.11 to 0.501°C/decade and an average of 0.325°C/decade.

The T_{min} (Figure 10) does not present plausible results but we can infer that T_{min} was decreasing slightly over the period 1995-2010. With exception of Shenyang, the annual T_{min} trends for individual stations were increasing in the range of 0.022 to 1.015°C/decade and an average of 0.566°C/decade. Thus the annual rate of increase of T_{min} is greater than that of T_{max} over cities.

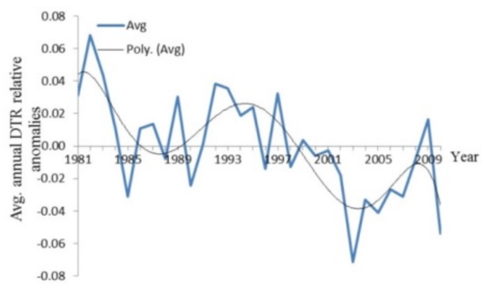

Figure 8: Annual DTR anomalies for selected cities.

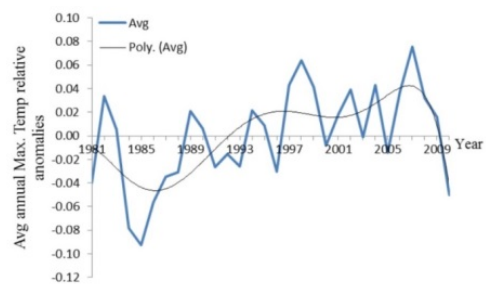

Figure 9: Annual maximum temperature anomalies for selected cities.

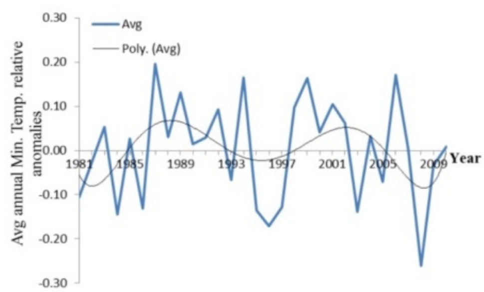

Figure 10: Annual minimum temperature anomalies for selected cities.

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Spring temperature trends

The spring temperature trends over deserts (Table 3) and over cities (Table 4) are obtained using MK_z at 99% confidence level.

Station	T_{max}	T_{min}	DTR
Alza Zuoqi	0.274	0.416	-0.218
Bayn MOD	0.329	0.195	0.149
Da-Qaidam	0.467	0.301	0.122
Guaizhu	0.191	0.375	-0.260
Hami	0.255	0.269	0.113
Hoboksar	0.149	0.324	-0.209
Linhe	0.195	0.499	-0.370
Qiemo	0.411	0.425	0.297
Ruoqiang	0.343	0.508	0.090
Turpan	0.177	0.425	-0.209
Average	0.279	0.374	-0.050

Table 3: Spring temperature variation for desert areas.

Station	T_{max}	T_{min}	DTR
Beijing	0.154	0.338	-0.195
Changchun	0.113	0.264	-0.278
Dalian	0.214	0.320	-0.175
Datong	0.186	0.377	-0.195
Harbin	-0.002	0.324	-0.511
Hohhot	0.246	0.457	-0.297
Shenyang	0.117	-0.039	0.039
Taiyuan	0.315	0.476	-0.228
Tangshan	0.163	0.384	-0.338
Tianjin	0.195	0.149	0.090
Average	0.170	0.410	-0.293

Table 4: Spring temperature variation for cities.

Over deserts, we find both spring T_{max} and T_{min} increasing. The DTR over five stations is increasing while the rest are decreasing. On average, DTR is decreasing (MK_z=-0.050) and it increased over the period 1990-2010 (Figure 11). Both T_{max} (Figure 12) and T_{min} (Figure 13) are increasing at MK_z=0.279 and MK_z=0.374 respectively and increased over the period 1987-2007. The differential increases in trends of T_{max} and T_{min}, can in part explain the moderate increase of DTR over the same period. The rate of decrease of DTR of individual stations is in the range of -0.547 to -0.18°C/decade except for the stations that presented an increasing DTR trend.

In general, the rate of decrease of DTR over 1981-2010 is -0.023°C/decade (negative sign is maintained to emphasize the decrease and differentiate it from increasing trend, where increase is shown with a positive sign). The spring T_{max} is in general increasing in the range of 0.3-0.8°C/decade and on average at 0.54°C/decade. The spring T_{min}, (Figure 13) is increasing too in range of 0.23-0.85°C/decade with an average of 0.56°C/decade.

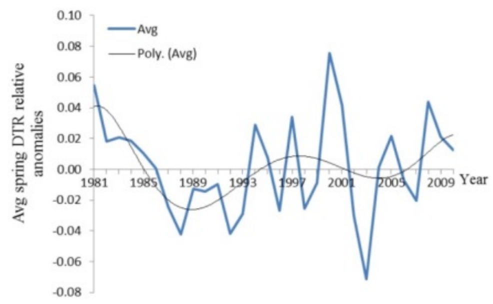

Figure 11: Spring DTR anomalies for selected desert areas.

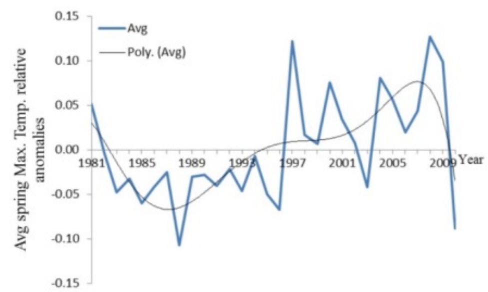

Figure 12: Spring maximum temperature anomalies for selected desert areas.

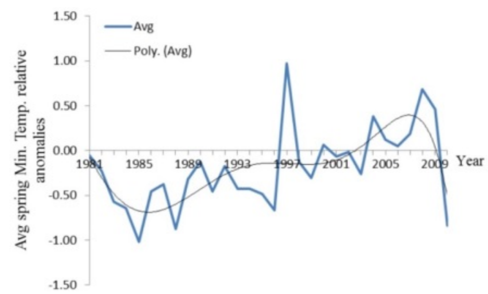

Figure 13: Spring minimum temperature anomalies for desert areas.

Over cities, we find an increasing trend of both spring T_{max} and T_{min} with exception of Harbin whose T_{max} is decreasing and Shenyang's T_{min}. The DTR is decreasing (MK_z=-0.209) with the exception of Shenyang (Figure 14) in the range of -0.829 to -0.157°C/decade and on average at -0.307°C/decade.

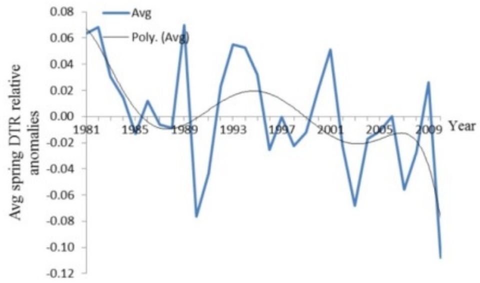

Figure 14: Spring DTR anomalies for selected cities.

The spring T_{max} (Figure 15) is increasing with an average MK_z of 0.170 and in the range of 0.052 to 0.533°C/decade and overall rate of 0.252°C/decade. The spring T_{min} (Figure 16) is increasing as well with exception of Shenyang in the range of 0.137 to 0.928°C/decade and overall increasing at 0.560°C/decade.

The rate at which spring T_{min} is increasing (0.560°C/decade) is greater than the rate of spring T_{max} (0.252°C/decade) which probably explains the decreasing trend of spring DTR (-0.307°C/decade).

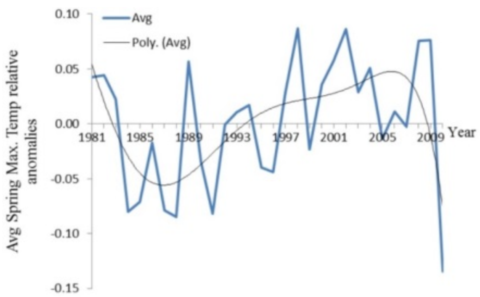

Figure 15: Spring maximum temperature anomalies for selected cities.

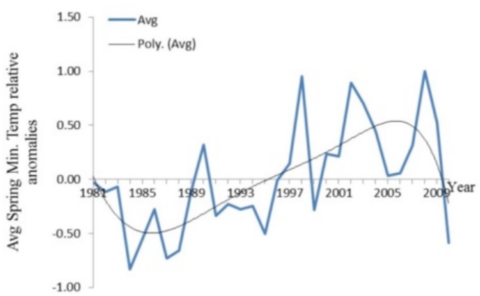

Figure 16: Spring minimum temperature anomalies for selected cities.

Summer temperature trends

The summer temperature trends over deserts (Table 5) and over cities (Table 6) are obtained using MK_z at 99% confidence level.

Station	T_{max}	T_{min}	DTR
Alza Zuoqi	0.287	0.444	-0.301
Bayn MOD	0.343	0.292	0.278
Da-Qaidam	0.439	0.513	-0.232
Guaizhu	0.434	0.410	0.062
Hami	0.485	0.195	0.315
Hoboksar	0.324	0.434	-0.090
Linhe	0.278	0.526	-0.315
Qiemo	0.494	0.343	0.159
Ruoqiang	0.522	0.462	-0.039
Turpan	0.499	0.333	0.163
Average	0.411	0.395	-2.8×10^{-18}

Table 5: Summer temperature variation for desert areas.

Station	T_{max}	T_{min}	DTR
Beijing	0.228	0.494	-0.255
Changchun	0.287	0.352	-0.136
Dalian	0.085	0.186	-0.145
Datong	0.352	0.526	-0.011
Harbin	0.267	0.494	-0.287
Hohhot	0.324	0.536	-0.067
Shenyang	0.071	-0.057	0.182
Taiyuan	0.379	0.568	-0.140
Tangshan	0.237	0.384	-0.329
Tianjin	0.154	0.186	0.094
Average	0.238	0.367	-0.109

Table 6: Summer temperature variation for cities.

Over deserts, the summer T_{max} and T_{min} are increasing with DTR for five stations increasing while the rest decreasing. We find a moderate decreasing trend for summer DTR over the deserts (Figure 17) in the range of 0.026 to 0.382°C/decade. The summer T_{max} is increasing (Figure 18) as well in the range of 0.369 to 0.723°C/decade and on average 0.55°C/decade. The summer T_{min} is also increasing sharply over the period 1985-2010 in the range of 0.28 to 0.94°C/decade and on average 0.536°C/decade (Figure 19).

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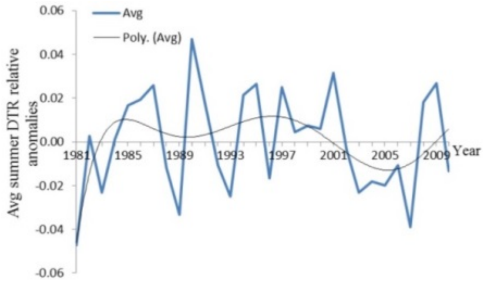

Figure 17: Summer DTR anomalies for selected desert areas.

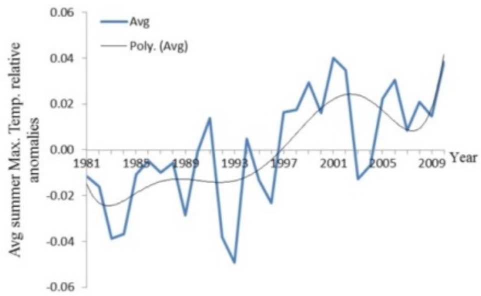

Figure 18: Summer maximum temperature anomalies for selected desert areas.

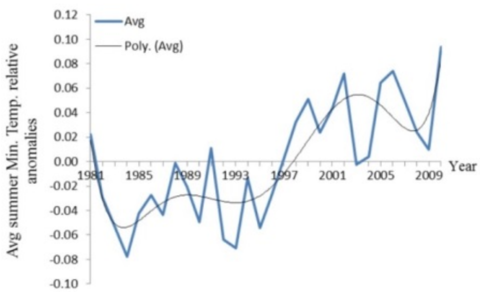

Figure 19: Summer minimum temperature anomalies for selected desert areas.

Over cities, we find increasing trends of summer T_{max} and T_{min} except Shenyang's T_{min} and decreasing trend of DTR (MK_z=-0.109) (Figure 20). The trend of summer DTR is in the range of -0.419 to -0.023°C/decade and on average decreasing at a rate of -0.140°C/decade. The summer T_{max} (Figure 21) is increasing over the period 1991-2010 in the range of 0.107 to 0.684°C/decade and in general, at a rate of 0.389°C/decade. From 1993, the summer T_{min} is also increasing (Figure 22) with exception of Shenyang in the range of 0.144 to 0.864°C/decade and in general increasing at 0.529°C/decade. Thus the rate of increase of T_{min} (0.529°C/decade) is greater than that of T_{max} (0.389°C/decade) explaining the decreasing trend of DTR.

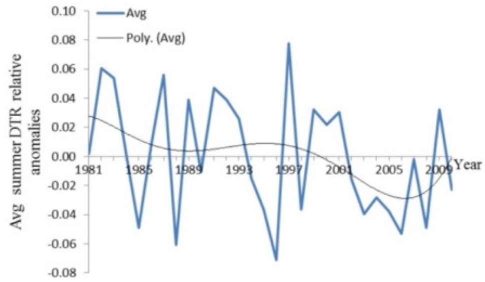

Figure 20: Summer DTR anomalies for selected cities.

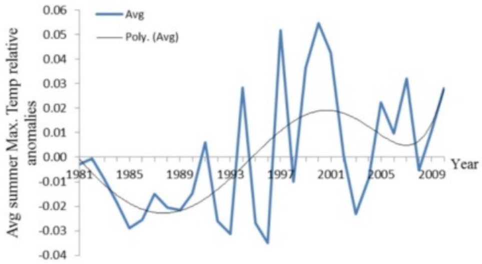

Figure 21: Summer maximum temperature anomalies for selected cities.

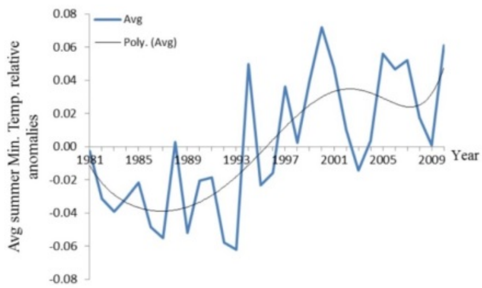

Figure 22: Summer minimum temperature anomalies for selected cities.

High temperature days and high temperature extremes

The Table 7 presents the trend of high temperature days and high temperature extreme days over desert areas during summer. The number of high temperature days, with exception of DaQaidam is increasing for all the stations (MK_z=0.151 to 0.492) as well as the days having high temperature extremes (MK_z=0.159 to 0.493). The highest temperature for Da-Qaidam was below 35°C and thus has the smallest rate of high temperature extremes.

Area	High Temp. Days	High Temp. Extremes
Alza Zuoqi	0.250	0.493
Bayn MOD	0.338	0.440
Da-Qaidam	N/A	0.159

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Guaizhu	0.464	0.426
Hami	0.492	0.445
Hoboksar	0.151	0.308
Linhe	0.189	0.328
Qiemo	0.363	0.300
Ruoqiang	0.509	0.339
Turpan	0.386	0.353
Average	0.349	0.326

Table 7: Trend of high temperature days and high temperature extremes for desert areas.

The Table 8 shows the trend of high temperature days and high temperature extremes for selected cities. Like for the desert areas (Table 7), both the number of high temperature days is increasing for all the cities (MK_z=0.140 to 0.511) and the number of days with high temperature extremes (MK_z=0.105 to 0.442).

Area	High Temp. Days	High Temp. Extremes
Beijing	0.283	0.343
Changchun	0.314	0.138
Dalian	0.179	0.105
Datong	0.505	0.321
Harbin	0.269	0.307
Hohhot	0.289	0.303
Shenyang	0.14	0.02
Taiyuan	0.511	0.442
Tangshan	0.242	0.307
Tianjin	0.252	0.327
Average	0.298	0.261

Table 8: Trend of high temperature days and high temperature extremes for cities.

Frost days and low temperature extremes

The Table 9 shows the trend of frost days and days for low temperature extreme over spring for desert areas. We find both the frost days (MK_z=-0.414 to -0.128) and the number of days with extreme low temperatures (MK_z=-0.446 to -0.010) decreasing with a positive correlation of 0.614. This decreasing trend means that few and fewer days have minimum temperature below zero degrees Celsius (0°C). The Table 10 shows the trend of frost days and days for low temperature extreme over spring for cities.

Area	Frost Days	Low Temp. Extremes
Alza Zuoqi	-0.335	-0.209
Bayan MOD	-0.128	-0.01
Da-Qaidam	-0.355	-0.05
Guaizhu	-0.375	-0.222
Hami	-0.215	-0.107
Hoboksar	-0.379	-0.094
Linhe	-0.383	-0.446
Qiemo	-0.155	-0.054
Ruoqiang	-0.414	-0.242
Turpan	-0.339	-0.125
Average	0.308	0.156

Table 9: Trend of frost days and low temperature extremes for desert areas.

Area	Frost Days	Low Temp. Extremes
Beijing	-0.125	-0.304
Changchun	-0.133	-0.381
Dalian	-0.231	-0.148
Datong	-0.334	-0.311
Harbin	-0.272	-0.442
Hohhot	-0.324	-0.29
Shenyang	0.021	0.319
Taiyuan	-0.362	-0.389
Tangshan	-0.272	-0.184
Tianjin	-0.08	0.01
Average	-0.237	-0.308

Table 10: Trend of frost days and low temperature extremes for cities.

Like deserts, the cities show a decreasing trend of both frost days (MK_z=-0.362 to -0.080) and the number of days having extreme low temperature (MK_z=-0.442 to -0.148) with a positive correlation of 0.730. The decreasing trend means that few and fewer days have T_{min} below zero degrees Celsius (0°C.) and it also explains the increase of spring T_{min}. We find a greater decrease of frost days for desert greater than the rate for the cities which probably indicates that spring night are becoming warmer for deserts at a faster rate compared to cities.

Summary and Conclusion

In the present study, we investigated the variability of temperature over desert and cities of Northern China for the period 1981-2010. We found DTR decreasing for both desert and cities. It is evident that the DTR for cities is decreasing faster than the desert's. The T_{max} is increasing for both desert and cities and that T_{max} for the deserts is increasing faster than that for the cities. The T_{min} is increasing as well for both deserts and cities and the rate of increase of T_{min} for the desert greater than the one for cities.

We also find both the deserts and cities exhibiting an increasing trend of high temperature days and high temperature extremes. The rate of increase of high temperature extremes over deserts is slightly higher than the one over cities. In general, the summer T_{max} for all the areas show increasing trend. The frost days and low temperature extremes over both the deserts and cities are decreasing. The frost days over deserts decrease slightly higher than over cities and in general, the spring T_{min} for all the stations is increasing explaining the decreasing trend of the frost days and low temperature extremes.

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