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AIR TEMPERATURE VARIABILITY IN ILLINOIS BASED ON WEATHER STATION RECORDS AND THE NORTH AMERICAN REGIONAL REANALYSIS FROM 1979 TO 2006

Running head: TEMPERATURE VARIABILITY IN ILLINOIS

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Abstract: Spatial and temporal near-surface air temperature variabilities and trends were analyzed for 30 locations in Illinois based on annual data derived from station records and the North American Regional Reanalysis (NARR) dataset from 1979 to 2006. A high correlation was found between the two datasets regarding interannual variability at most locations. Temperatures were generally higher at urban stations than non-urban stations while non-urban NARR data points showed higher temperatures than urban data points. The differences in medians were not statistically significant in either dataset. Significant positive temperature trends were found in the majority of the weather stations and in all NARR data points, with generally stronger trends with the NARR data. Observed trends from the station records were generally stronger in metropolitan areas and weaker for non-urban areas while the reanalysis data did not show a remarkable difference between urban and non-urban trends. [Key words: temperature, Illinois, weather station, North American Regional Reanalysis.]

INTRODUCTION

Anthropogenic reasons for climate change on a local scale is – beside changes resulting from greenhouse gas emissions – often the consequence of large modifications of land surfaces that often occur through urban development (Kalnay and Cai, 2003; Jin et al., 2005). The urban heat island (UHI) is the most well known impact of urbanization on the local climate. UHI is typically described by a variety of methods each of which has a limitation for identifying urban effects unequivocally (Arnfield, 2003). A comparison within clusters of urban and rural stations across the conterminous United States found that there are no statistically significant differences between urban and rural temperatures when biases caused by differences in elevation, latitude, time of observation, instruments, and siting practice are removed (Peterson, 2003). The primary signal of UHI from the same dataset in the conterminous United States was found to come from relatively high population sites, and the detection of the signal depended on urban/rural classification metadata (Peterson and Owen, 2005). However, for an unknown reason, major metropolitan cities such as New York, Chicago, and Atlanta were not included in the studies.

The impact of land modification, such as urbanization or deforestation, can be evaluated by the "observation minus reanalysis" (OMR) approach proposed by Kalnay and Cai (2003). Because the surface observations reflect all the sources of climate forcing while the reanalysis data only contain atmospheric forcings (Kalnay et al., 2006), the difference between observations and reanalysis is deemed largely due to land modification. The OMR approach is useful for avoiding problems due to the biases in weather stations data pointed out by Peterson (2003). For example, it was found that the surface temperature has been warming faster in surface observations than in the NCEP-NCAR 50-year reanalysis data (Kistler et al., 2001) in the conterminous United States between 1950 and 1999, which is largely due to urbanization and agriculture (Kalnay and Cai, 2003). The OMR approach has been adopted to separate the effect of surface forcings from atmospheric forcings for a few large domains so far (Kalnay and Cai, 2003; Zhou et al., 2004; Kalnay et al., 2006; Nuñez et al., 2008; Fall et al., 2010). Most of the case studies used global reanalysis datasets with coarse spatial resolutions (up to 2.5° latitude/longitude) except one (Fall et al., 2010) that used a fine-resolution regional reanalysis dataset, North American Regional Reanalysis (Mesinger et al., 2006).

The literature cited provided a rationale for this study that there is a need to study near surface air temperatures at local or regional scales using a fine-resolution reanalysis dataset. The objective of this study is to examine the near surface air temperature averages and trends in urban and rural settings in the Midwestern United States, in particular across the State of Illinois since the 1970s. In our study, we analyzed and compared data from weather stations and the North American Regional Reanalysis (NARR). Annual temperatures from weather stations show a positive trend between 1971 and 2002 across Illinois (Angel, 2004), but intra-regional variations are less well known and its robustness needs to be compared to a reanalysis-based assessment. Our approach is based on the principle of the OMR approach and will allow for the evaluation of the fine-resolution regional reanalysis dataset in terms of its usefulness for the detection of UHI-affected temperature trends in the region. An approach comparing decadal temperature trends between weather stations and reanalysis data with a focus on urban-rural differences is quite rare in the literature.

REGION AND DATA

This study is regionally focused on northern and central Illinois (Figure 1) in the Midwestern United States. The largest urban area is in the northeastern corner, with Chicago at its center. Other urban areas are scattered across the state and are fairly small in size compared to the greater Chicago area. Due to the adjacency to Lake Michigan, the temperature of the greater Chicago area is modulated by the lake.

Other than scattered urban areas, the predominant land cover in the study region is cropland (Figure 2), according to the land cover data obtained from the National Center for Earth Resources Observation and Science. The land cover data have a 1-km spatial resolution. Five land cover categories were chosen to determine the settings of the weather stations and data grid points. Because the urban areas shown in Figure 1 actually contain a non-negligible amount of non-urban land covers such as cropland or forest, it was necessary and beneficial to utilize readily available land cover data.

The temperature data were obtained from two sources: weather stations and the fine-resolution regional reanalysis dataset, North American Regional Reanalysis (NARR). NARR is a "long term, dynamically consistent, high-resolution, high-frequency, atmospheric and land surface hydrological dataset" (Mesinger et al., 2006 p. 343). Reanalysis climatic data are produced from state-of-the-art data assimilation systems, where different datasets (rawinsondes, aircraft, satellites, surface, etc.) are combined with computer models in a unified and consistent manner (Mesinger et al., 2006; Choi, 2008). It incorporates a land surface model that uses data such as vegetation type, snow albedo, soil temperature, and soil type (Mesinger et al., 2006). Datasets were added or improved upon for NARR, such as precipitation, sea surface temperature, and radiances, compared to the NCEP-NCAR global reanalysis (Kistler et al., 2001), resulting in the more realistic hydrological cycle (Mesinger et al., 2006). The NARR data are available since 1979 at a spatial resolution of 32 km, a temporal resolution of three hours and a vertical resolution of 45 layers. The annual mean weather station air temperatures were obtained from Illinois State Climatologist Office for 30 stations across the State of Illinois for the period 1979-2006 (Table 1 and Figure 1). The time period was selected as such to avoid missing records and allow for a comparison with the reanalysis data. The NARR 3-hour temperature was obtained from the National Oceanic and Atmospheric Administration. Twenty-nine grid points (thick cross marks in Figure 1) were selected according to their proximity to the weather stations. One grid-point was omitted due to its proximity to two weather stations (No. 8 Peru and No. 9 Ottawa). The stations listed in Table 1 were sorted and numbered by descending latitude.

Based on their setting derived from the land cover data (Figure 2), the 30 weather stations were classified into three categories, urban, urban-edge, and non-urban. A station was classified as "urban," when the location of the weather station is located within an urban pixel surrounded by other urban pixels. If a weather station is within an urban pixel neighboring non-urban pixels, it was classified as "urban-edge." Stations within cropland or forested areas were classified as "non-urban" stations. Most of the urban stations are located within the northern part of the study area with only a few in the southern part of the study region.

Due to the relatively low spatial resolution of the NARR data grid points it is not meaningful to classify their location in the same way as the weather stations. Alternatively we chose three data points within the greater Chicago area and defined them as "urban" data points. All others were classified as "non-urban" data points. Even though there are a few more NARR data points falling within urban areas shown in Figure 1, we decided to focus on the data points in a large urban area that has extensive urban land cover. The three points fall within not only the urban area (Figure 1) but also urban land cover (Figure 2).

METHODS

Annual mean temperatures from 1979 to 2006 were calculated for all weather stations and grid points. Based on these data we calculated arithmetic means, standard deviation, and variance for each station. Given that linear trends are based on the assumption of approximate normal distributions we applied the Kolmogorov-Smirnov test for normal distribution to all datasets. Temporal trends in the datasets were analyzed with the linear regression model and the subsequent *t*-test to evaluate the significance of the slope coefficient. We also calculated correlation coefficients (*r*) to analyze the correlation between weather stations and NARR-derived records. The same NARR grid point was used for stations 8 and 9 to calculate correlation coefficients.

In addition, we applied the Mann-Kendall trend test (Mann, 1945; Kendall, 1975). The non-parametric, rank-based test is recommended by World Meteorological Organization for general use for test of randomness against trend (Mitchell et al., 1966) and does not assume any distribution form for the data, which makes it powerful and popular for testing trends in hydrometeorological time series (Zhang et al., 2005; Toreti et al., 2009; e.g. Zhang et al., 2009). The procedure described by Manly (2009 p .192) was followed, which is summarized as follows: For a series x_n, the test statistic S is the sum of the signs of the differences between any two observations,

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} \mathrm{sign}(x_i - x_j)$$

where sign(z) is –1 when z is negative, 0 when z is zero and 1 when z is positive. When a series of values is in a random order, the expected value of S is zero and the variance VS is given as follows:

$$VS = n(n-1)(2n+5)/18$$

whether S is significantly different from zero can be tested using Z statistic, which is given as follows:

$$\text{if } S > 0, \quad Z = \frac{S-1}{\sqrt{VS}}$$

$$\text{else } \ Z = \frac{S+1}{\sqrt{VS}}$$

Z follows the standard normal distribution, and a positive Z value indicates a positive trend and a negative one indicates a negative trend in a two-sided test for trend. The Z values were converted to probabilities of observing larger absolute Z values.

The results were also aggregated for each station type (urban, urban-edge and non-urban). Due to the range of latitude across the stations and the uneven latitudinal distribution of the urban stations, it was necessary to remove the effect of latitude on the temperature record. To remove the effect of latitude, the adjustment factor of – 0.9 ˚C per degree of latitude developed by Peterson (2003) was applied to the annual mean temperatures. The means and variability statistics were subsequently calculated for the aggregated station or data point types.

RESULTS

The results of the statistical analysis of the weather station records can be seen in Table 2. The average annual temperatures for the period from 1979 to 2006 in the region vary between 9.6 (Station 13 Princeville, located at one of the highest elevations) and 12.2 °C (Station 28 Charleston). Given that the stations are sorted by decreasing latitude, we observe generally increasing arithmetic means in the list. At a first glance we also notice that the stations in urban settings are generally characterized by slightly higher average air temperatures when compared to stations at similar latitudes in non-urban settings. The highest annual temperatures at most stations occurred in 1998, which was characterized by a strong El Niño event. At some stations we find maximum annual temperatures in 1986, 1987, or 2006, which were also El Niño years. This is not surprising because it is well known that teleconnections typically result in relatively high temperatures in the Great Lakes region in El Niño years. The distribution of years with minimum annual temperatures is more variable across the region. Frequently occurring years are 1979, 1989, and 1996, with the latter two being characterized by La Niña events.

The results of the Kolmogorov-Smirnov show that the data of all time series are approximately normally distributed. It is therefore meaningful to interpret the results of linear trend tests. The linear trend tests reveal to decadal trends that vary from -0.35 (Station 23, Rushville) to 0.7 °C (Station 4, Joliet Brandon). It is noteworthy, that nine of the 30 stations show decadal trends in excess of 0.5 °C and seven of these nine stations were classified as urban stations. The linear trend at 13 of the 30 stations was found insignificant by the *t*-test. Only one station in an urban setting shows insignificant trends (Station 22 Danville), all others are located in non-urban or urban-edge areas. The slightly negative trends that were observed at three stations are all insignificant according to the *t*-test. Angel (2004) found 0.3 °C per decade during 1971-2002, which is smaller than 0.35 °C per decade found in this study. The decadal trend from the NARR data is even higher at 0.6 °C, which is in agreement with Fall et al. (2010).

The results of the Mann-Kendal trend test are presented in Figure 3 and generally confirm the findings of the linear trend tests. All negative trends are insignificant at the 95% confidence level and all the urban stations are characterized by positive trends, even at the 95% confidence level. The Mann-Kendall test results for the NARR data are characterized by significantly positive trends at all data points (not shown).

The comparison of annual mean air temperatures from station records and NARR grid-point data reveals variable levels of correlation between the datasets. Figure 4 provides one example of a location with highly correlated data (Station 1 Chicago O’Hare) and one example with less well-correlated data (Station 29 White Hall). The interannual variability of mean air temperatures in Chicago was well emulated by the NARR data; the correlation coefficient is in excess of 0.9, peaks and troughs in both datasets correspond in terms of their occurrence and magnitude. The overall trends in both datasets consequently similar in both stations, even though certain differences can be observed. The comparison of the datasets at Station 29 (White Hall) reveals that the occurrence of peaks and troughs is relatively synchronous, however, their magnitudes remarkably differ between the datasets. During the first years, the station data show considerably higher values than the NARR data. However, after a large dip from 1984 to 1985, the station temperatures consistently stay below the NARR temperatures. The location of the station did not change during the period, and no other information is available to explain the consistently lower temperature. It is therefore evident that the trend based on the NARR data will be clearly more pronounced than the trend based on the station data.

Figure 5 illustrates decadal trends at all stations based on both datasets as well as the correlation coefficients. Negative trends or decadal trends below 0.3 °C are not depicted because they are statistically insignificant according to the *t*-test. It is clearly noticeable, that the datasets for most locations are highly correlated. Almost half of the locations are characterized by correlation coefficients above 0.9, and only six of the 30 locations feature correlation coefficients below 0.7. In terms of decadal trends we observe differences below 0.05 °C at four locations (1,5,6 and 11). Differences between 0.05 and 0.1 °C can be seen at locations 3, 12, 18 and 30; differences between 0.1 and 0.2 °C are noted for locations 7, 14 and 20; differences between 0.2 and 0.3 °C are noted for locations 2, 4, 13, 24, 26 and 28. The other locations show even larger differences in the trends; most of them are classified as non-urban and show very weak positive or even negative trends in the station data, which are not always easily explainable. Like location 29, locations 8, 19, and 27 feature lower station temperatures than the NARR temperatures in the later part of the period. The only known change to the stations is that Station 19 lowered its elevation by 4 meters according to the station history. At location 23 we observe a relatively good correlation before the year 2000. Afterwards the station temperatures fall below the NARR temperatures considerably, which is in contradiction to the NARR data as well as to all other observed temperatures in the vicinity. The station temperature in 2004 is particularly suspicious because it is 7.1 °C while the NARR temperature is 12.1 °C.

The result in Figure 5 provides an interesting comparison to those from Kalnay et al. (2006). They found mixed trends of mean temperatures in Illinois from observations and dominantly cooling trend from the NCEP/NCAR reanalysis. The results from observations are similar to this study but those from the reanalysis are opposite. The dominantly warming trend in Illinois from NARR can partially attributed to the NARR's incorporation of additional observation data and much finer resolution than the NCEP/NCAR reanalysis. But NARR shows much stronger trends which are beyond our explanation. Kalnay et al. (2006) also compared the trends of OMR between Baltimore (urban) and Owings Ferry Landing (rural) weather stations in Maryland, and found that Baltimore showed a stronger increasing trend of mean temperatures in observation than reanalysis while Owings Ferry Landing showed little trend difference. Stations 2, 3 and 4 in the Chicago area showed stronger trends than NARR in this study, but NARR showed stronger trends than most central and southern stations.

NARR time series at urban and urban-edge locations, particularly in the northern section (locations 1-4, 6-7), are characterized by lower interannual variability as expressed by standard deviation than the station data series (Figure 6). For most other stations we find lower standard deviations in the station records with exception of stations 13, 23 (the station with the spurious stations records) and 30 (an urban-edge location). Standard deviations in the NARR data tend to be larger in southern locations than in northern locations, while those in the station data tend to be lower in southern locations.

Figure 7 is the box plot that shows annual mean temperatures from the stations sorted by descending latitude. Each column along the horizontal axis represents a station and shows the variation throughout the data period. The upper panel, showing the original data without latitude adjustment, reveals - with some exceptions - an increasing trend of temperature with decreasing latitude. After applying the latitudinal correction factor (lower panel), the increasing temperature trend with descending latitude is removed. Some urban stations (such as 2, 3, 4, 11 and 12) show higher medians than their immediate neighbors, and urban stations 2 and 3 stand out among many other non-urban stations. A few other urban stations (1, 6, and 22) also show above-average temperatures. On the other hand, there are many non-urban stations with higher average temperatures than some urban and urban-edge stations.

Figure 8 shows annual mean temperatures from the 29 NARR points sorted by descending latitude. The upper panel displays the data without latitude adjustment and shows an even more consistent increasing trend with decreasing latitude in comparison to the station data. The ranges of data are also much more consistent than the station data. When the data are latitude-adjusted, no data point apparently stands out, as seen in the lower panel. Even the data points located in the greater Chicago area (points 1, 2 and 3) do not reveal any noticeable difference in comparison to other data points. In fact, we actually observed lower medians and smaller ranges compared to many other data points.

For each category of the weather stations, the mean annual temperatures of each year were averaged across the weather stations, and the same approach was taken for the NARR data. Figure 9 shows latitude-adjusted annual mean temperatures for different weather station (Panel A) or NARR data points categories (Panel B). The median of annual mean temperatures from urban stations is larger than those from urban-edge or non-urban stations, even though the difference is not statistically significant ($\alpha = 0.05$). The urban stations also show noticeably larger magnitudes of the first and third quartiles (bottom and top of the box) and ranges than other stations. On the other hand, urban NARR data points show smaller median and variability of annual mean temperatures at the urban locations.

DISCUSSION AND CONCLUSIONS

We investigated the variabilities and trends of annual mean near surface air temperatures at 30 locations across Illinois using weather stations data and the regional reanalysis model, North American Regional Reanalysis. We calculated descriptive statistics, applied the Kolmogorov-Smirnov test for normal distribution, tested for trend using the Mann-Kendall test, and compared aggregated temperatures between urban and non-urban locations. The study provides several new insights into temperature variability and trends in Illinois.

The urban weather stations revealed higher median temperature and larger variability than the urban-edge and non-urban stations, even though the difference in medians was not found to be significant. Peterson (2003) found no significant urban-rural differences in mean temperatures across the United States after various adjustment but found larger variabilities in urban stations. Our finding is similar to Peterson's, but a main difference is that Peterson compared urban and rural stations for each metropolitan area while we compared between station types aggregated across the state. A detailed investigation of the Chicago metropolitan area, which was not included in Peterson's study, could have provided a different picture but was simply beyond the scope of the present study. Ackerman (1985) investigated the Chicago heat island with temperature records for 1950-1970 from Midway Airport and Argonne National Laboratory, which was deemed rural at the time of measurement and is located about 13 km southeast of Station 2 Wheaton. Temperatures were higher at Midway Airport most of the time by an average of 1.9 °C, even though Argonne National Laboratory was about 23 km southwest of Midway Airport, meaning lower in latitude and further from Lake Michigan. The finding is in line with ours, because Station 2 Wheaton is now considered urban and its mean temperature is lower than Station 3 Midway by only 0.2 °C. Station 2 Wheaton could be classified as rural in the 1960s and the temperature margin could be larger.

On the other hand, this difference between urban and non-urban locations was not reproduced in the NARR data. The NARR non-urban data points showed a higher median of annual mean temperatures than urban data points but it was not statistically significant. It is obvious at least across Illinois that the NARR data have smaller sensitivity to local forcings than the station data and do not reveal the urban modification of regional climate in this region. The reason for this finding is most likely related to the fact that surface temperature observations are not included in compiling the NARR data. A comparison of NARR temperatures between urban and non-urban locations across a region has not been performed in previous studies.

We observed relatively high correlations between the time series of both datasets. Consequently, interannual variabilities at each location generally correlate well between the datasets. Despite the different sensitivity to local and surface forcings between weather stations and NARR, both datasets generally well agreed in temporal variability. A few stations with particularly weak correlation were all non-urban; they had stagnant or decreasing temperature trends while corresponding NARR data points showed constantly increasing temperatures, resulting in low correlation coefficients.

Our study reveals that stronger trends in metropolitan areas are visible in the station records but not in the NARR records where trends were significant regardless of location, especially in southern locations. Based on our findings we conclude that temperature trends from the NARR data are weaker for metropolitan and stronger for non-urban areas in comparison with station records. The trends were all significant in the NARR data. Considering that the trends in NARR are quite different from the NCEP/NCAR reanalysis found in Kalnay et al. (2006), we speculate that it has something to do with the way NARR assimilated observation data but do not have a definitive answer at this moment. These findings for Illinois need to be tested for other regions and metropolitan areas and – in case that they will be confirmed by other studies – they will be of utmost relevance for regional temperature trend studies.

A couple of limitations of the study have to be mentioned. First, the latitude-adjustment for the aggregated data that followed the approach by Peterson (2003) is certainly a very generalized and limited measure for comparing locations. Given that our study region does not show major differences in elevation it appeared to work relatively well in eliminating the latitude-factor from the datasets, however, it would certainly need to be revised and adjusted regionally to deliver more robust results. Second, the current study was based on annual averages only. A higher temporal resolution based on seasonal or monthly data or maximum and minimum temperatures would reveal a more differentiated picture of spatial and temporal variabilities but it was beyond the scope of the present study. Third, we assumed that the land cover surrounding the weather stations did not change during the data period.

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Table 1. Weather stations selected for the study

Reference Number	Station Name	Latitude (dd)	Longtitude (dd)	Elevation (meters a.s.l.)	Land cover	Classification
1	Chicago O'Hare (Intl AP)	41.983	-87.917	200.6	urban	urban
2	Wheaton (SE)	41.817	-88.067	207.3	urban	urban
3	Chicago Midway (AP 3 SW)	41.733	-87.783	189.0	urban	urban
4	Joliet Brandon (RD DAM)	41.5	-88.1	165.5	urban	urban
5	Park Forest	41.5	-87.683	216.4	cropland	non-urban
6	Moline Quad City (AP)	41.467	-90.517	180.4	urban	urban
7	Geneseo	41.45	-90.15	194.8	urban-edge	urban-edge
8	Peru	41.35	-89.1	189.0	cropland	non-urban
9	Ottawa (5 SW)	41.333	-88.917	160.0	cropland	non-urban
10	Galva	41.1833	-90.033	246.9	cropland	non-urban
11	Kankakee Metro (WASTWTR)	41.133	-87.883	195.1	urban	urban
12	Galesburg	40.95	-90.383	235.0	urban	urban
13	Princeville	40.933	-89.783	224.0	cropland	non-urban
14	Monmouth	40.917	-90.633	227.1	cropland	non-urban
15	Pontiac	40.883	-88.633	198.1	urban-edge	urban-edge
16	Piper City	40.767	-88.2	204.2	cropland	non-urban
17	Chenoa	40.733	-88.717	216.4	cropland	non-urban
18	Peoria (GTR Peoria AP)	40.667	-89.683	198.7	cropland	non-urban
19	La Harpe	40.583	-90.967	213.4	forest	non-urban
20	Hoopeston (1 NE)	40.467	-87.65	216.4	cropland	non-urban
21	Havana (4 NNE)	40.35	-90.017	140.2	cropland	non-urban
22	Danville	40.133	-87.65	170.1	urban	urban
23	Rushville	40.117	-90.567	201.2	cropland	non-urban
24	Urbana	40.083	-88.233	226.5	cropland	non-urban
25	Springfield Capital (AP)	39.85	-89.683	178.6	cropland	non-urban
26	Jacksonville (2 E)	39.733	-90.217	185.9	cropland	non-urban
27	Paris Wtr Wks	39.633	-87.7	207.3	cropland	non-urban
28	Charleston	39.467	-88.183	207.3	cropland	non-urban
29	White Hall (1 E)	39.433	-90.383	176.8	cropland	non-urban
30	Jerseyville (2 SW)	39.1	-90.35	192.0	urban-edge	urban-edge

Table 2. Results of the statistical analyses of the weather stations time series. The shading of the stations number column indicates station types (black: urban, grey: urban-edge, white: non-urban). The shaded fields in the last column indicate that the observed trends were significant at the 95% confidence level (coefficient of the t-test for linear trends > 2.055).

No	Arith-metic Mean	Standard Deviation	Maximal Value	Minimal Value	Median	Kolmogorov-Smirnov test for Normal Distribution	Trend /10 years	*T*-test for linear trend coefficient
1	9.85	0.89	12.0(1998)	8.4(1985)	9.9	D=0.140(p=0.645)	0.52	2.821
2	10.68	1.05	12.7(1998)	8.4(1979)	10.5	D=0.147(p=0.584)	0.71	3.399
3	10.88	0.90	12.8(1998)	9.0(1979)	10.8	D=0.093(p=0.967)	0.58	3.161
4	10.06	1.00	12.2(1998)	8.1(1989)	10	D=0.117(p=0.835)	0.74	3.903
5	9.92	0.83	12.0(1998)	8.1(1979)	9.8	D=0.113(p=0.869)	0.59	3.672
6	10.34	0.86	11.9(1998)	8.6(1979)	10.3	D=0.080(p=0.994)	0.54	3.067
7	10.37	0.80	12.0(1998)	8.9(1996)	10.3	D=0.104(p=0.920)	0.50	3.064
8	10.19	0.84	11.7(1998)	8.1(1997)	10.3	D=0.098(p=0.949)	-0.14	-0.712
9	10.69	0.87	12.4(1998)	9.0(1996)	10.9	D=0.126(p=0.763)	0.17	0.817
10	9.92	0.84	11.8(1998)	8.4(1979,1994)	9.9	D=0.083(p=0.990)	0.24	1.243
11	10.33	0.88	12.2(1998)	8.6(1979)	10.2	D=0.107(p=0.904)	0.62	3.592
12	10.51	0.93	12.3(2006)	8.9(1979)	10.5	D=0.081(p=0.993)	0.57	2.97
13	9.64	1.12	11.8(1998)	7.5(1996)	9.8	D=0.092(p=0.973)	0.58	2.387
14	10.96	0.81	12.5(1987)	9.5(1985,1996)	11	D=0.089(p=0.980)	0.37	2.046
15	10.48	0.86	12.2(1998)	8.9(1989)	10.3	D=0.092(p=0.971)	0.26	1.316
16	10.50	0.74	12.3(1998)	9.2(1996)	10.5	D=0.108(p=0.898)	0.17	0.99
17	10.91	0.85	12.6(1998)	8.6(1989)	10.8	D=0.077(p=0.996)	0.40	2.16
18	10.93	0.84	12.6(1998)	8.9(1979)	11	D=0.076(p=0.997)	0.50	2.893
19	10.60	0.85	12.1(1986)	9.1(1996)	10.5	D=0.076(p=0.997)	0.08	0.398
20	11.16	0.82	13.3(1998)	9.7(1979)	11	D=0.103(p=0.926)	0.42	2.407
21	11.09	0.81	12.4(2006)	9.7(1979)	11	D=0.091(p=0.975)	0.13	0.68
22	11.60	0.75	13.1(1998)	10.3(1996)	11.4	D=0.110(p=0.886)	0.33	1.998
23	11.06	1.11	12.8(1998)	7.1(2004)	11.1	D=0.134(p=0.700)	-0.35	-1.387
24	11.11	0.75	12.8(1998)	9.8(1979,1996)	11	D=0.116(p=0.844)	0.39	2.438
25	11.70	0.73	13.0(1998)	10.4(1996)	11.7	D=0.114(p=0.861)	0.27	1.638

26	11.08	0.82	12.6(1998)	9.4(1979)	11	D=0.081(p=0.993)	0.41	2.27
27	11.71	0.84	13.3(1987)	10.1(1996)	11.7	D=0.081(p=0.993)	-0.02	-0.107
28	12.22	0.71	13.8(1998)	10.9(1979)	12.1	D=0.120(p=0.814)	0.38	2.529
29	11.67	0.72	12.9(1998)	10.2(1989)	11.7	D=0.107(p=0.903)	0.04	0.217
30	11.88	1.02	13.3(1998)	8.3(1979)	11.8	D= 0.123 (p=0.788)	0.59	2.764

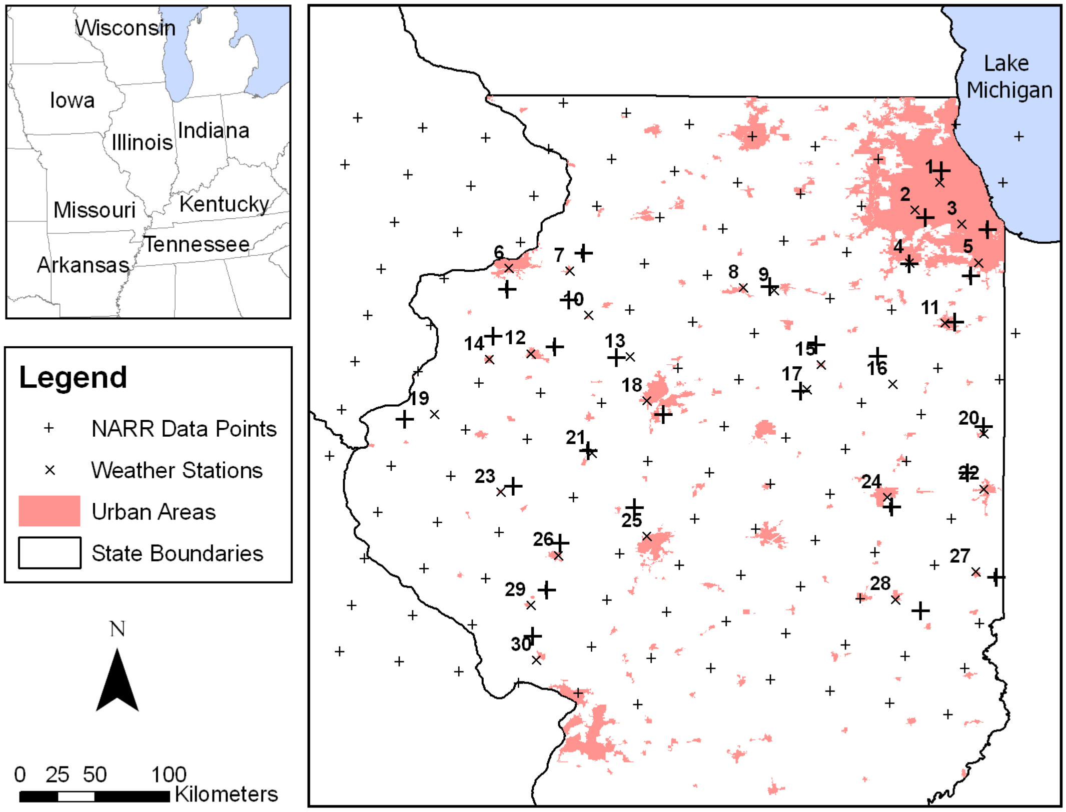


Figure 1. Study area: North American Regional Reanalysis data points, weather stations, state boundaries and urban areas designated by the United States Census Bureau. Large cross marks represent the data points selected for this study.

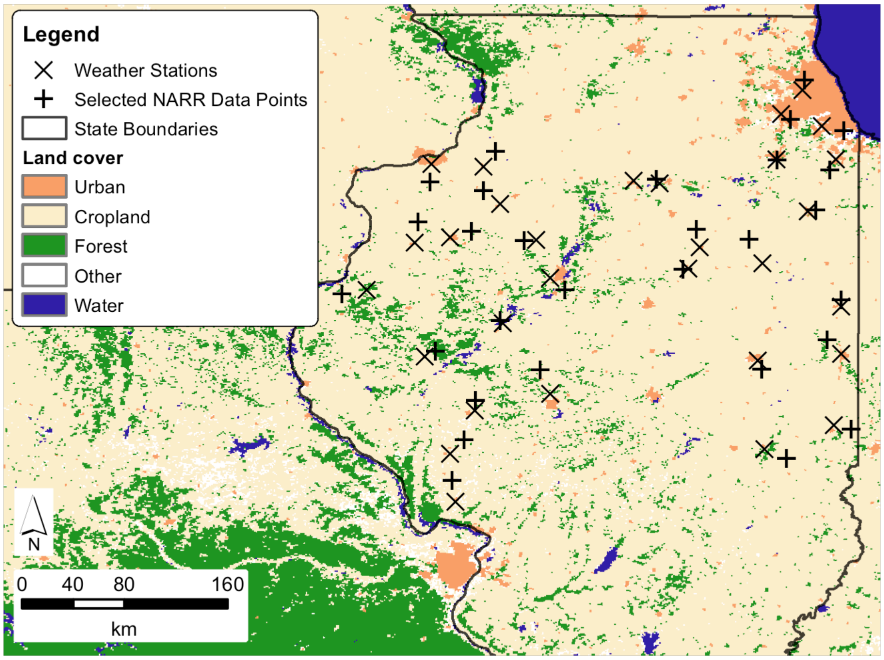


Figure 2. Land cover of the study area

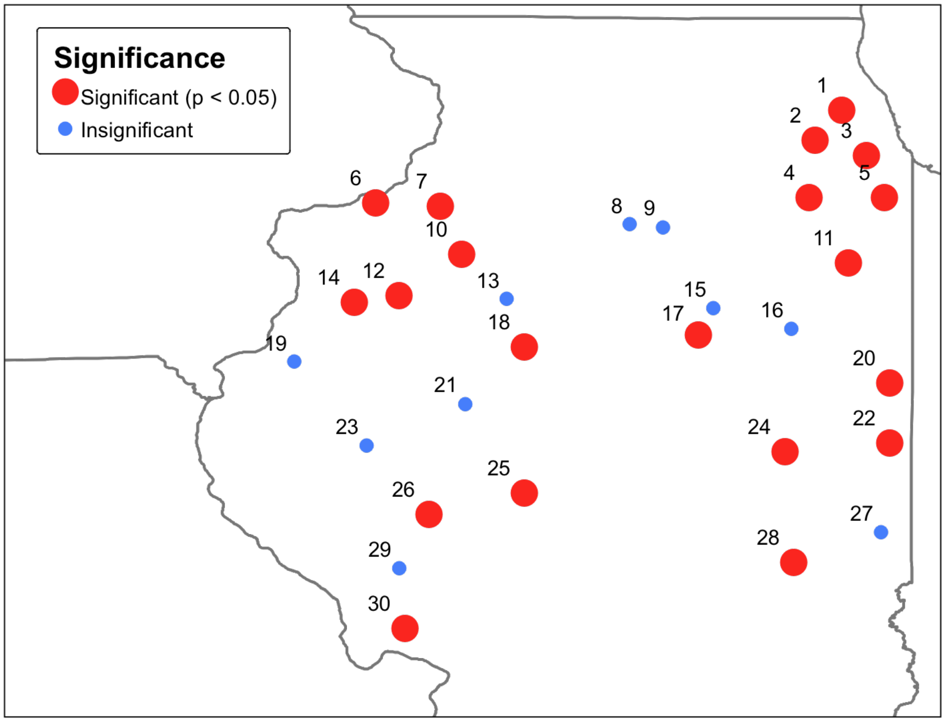
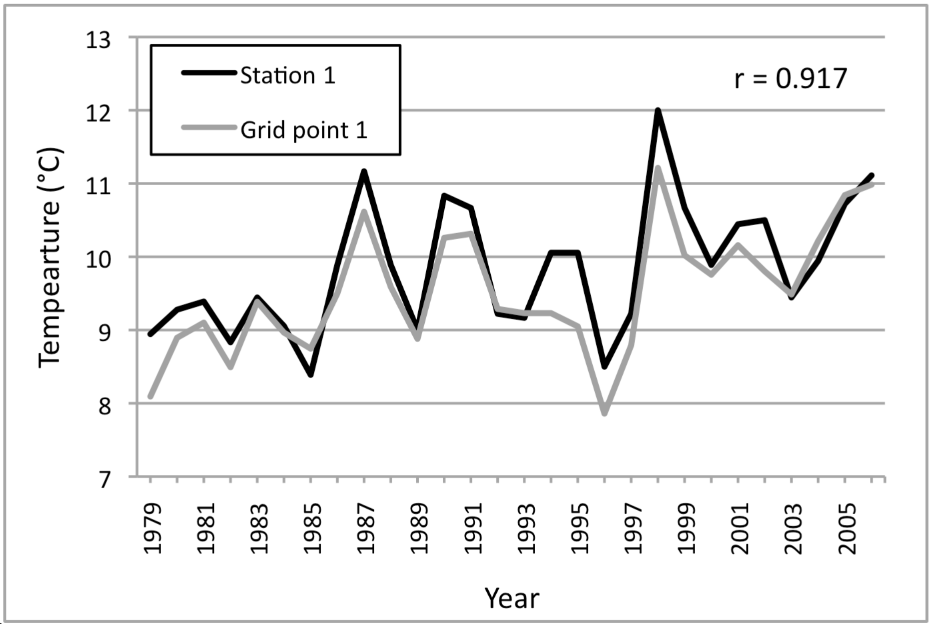
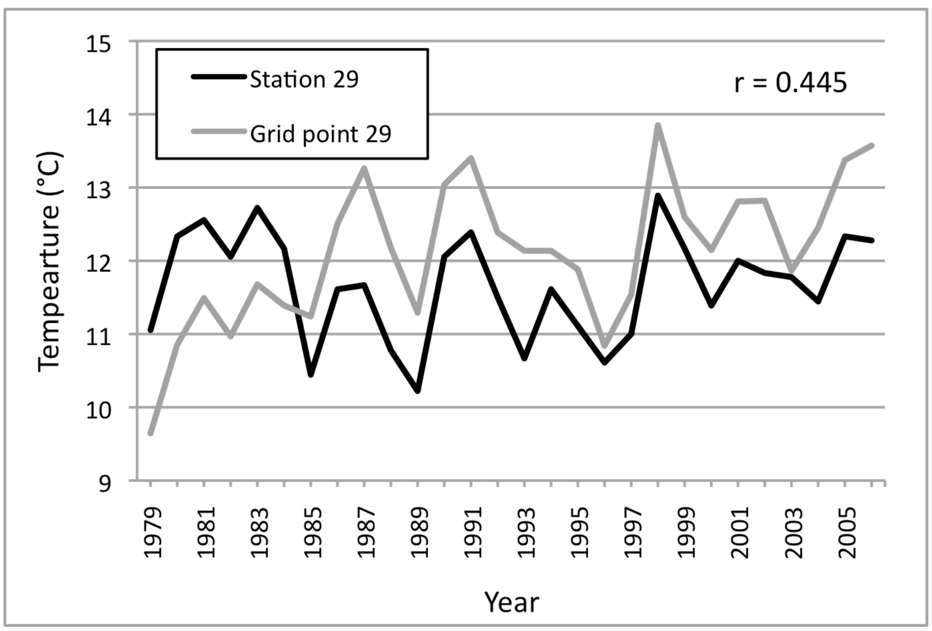


Figure 3. Significance of *Z* scores from the Mann-Kendall test for trend for the stations data at the 95% confidence level



A



B

Figure 4. Comparison of station records and NARR grid point data at Chicago O'Hare (Station 1) and White Hall (Station 29)

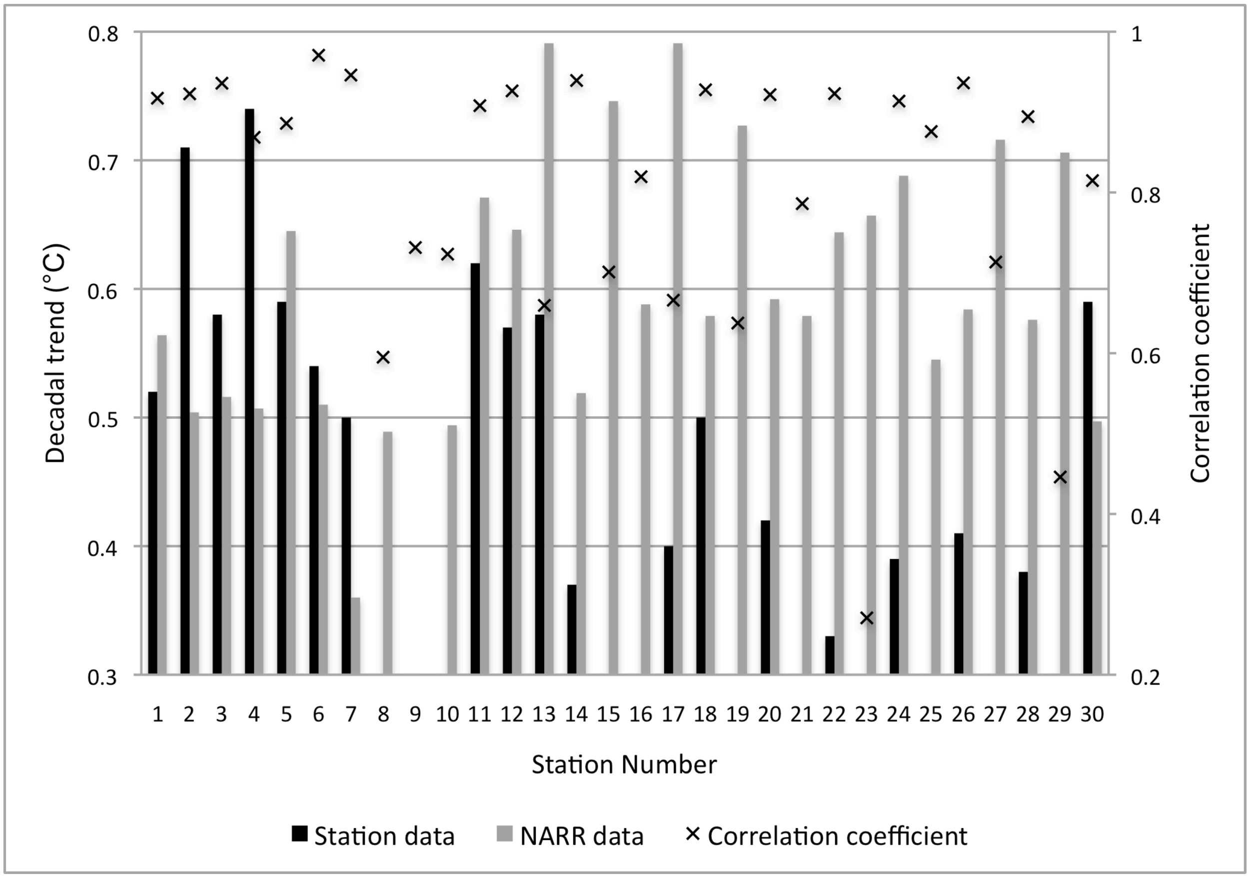


Figure 5. Decadal temperature trends (columns; left vertical axis) at all measuring stations and grid points and correlation coefficients (cross marks; right vertical axis) between the datasets at each location

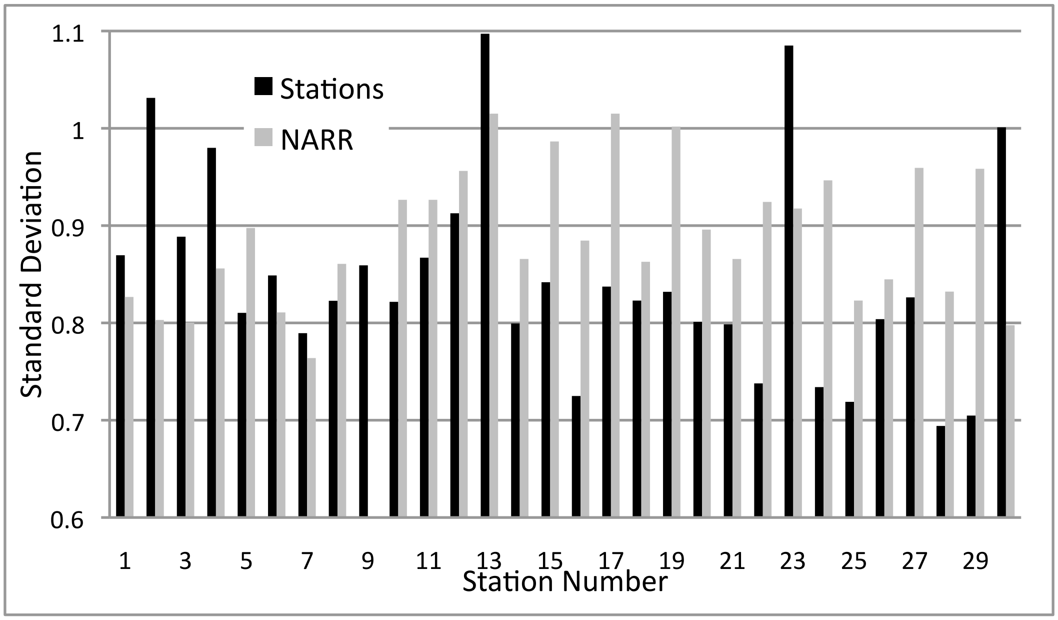


Figure 6. Standard deviation in the time series of station and NARR datasets

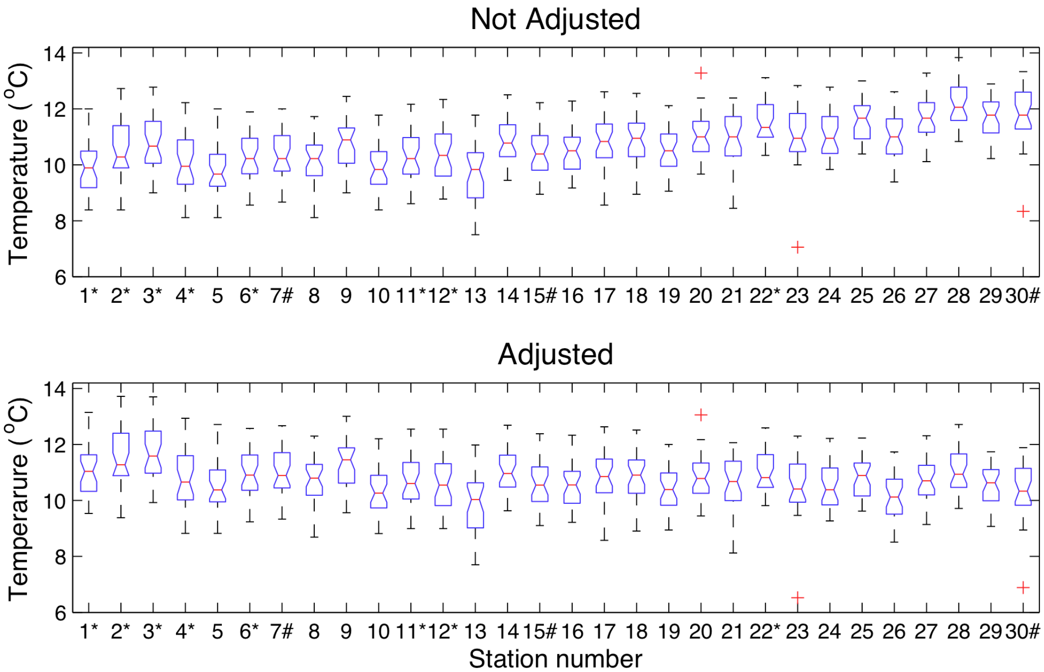


Figure 7. Box plots of annual mean temperatures from the weather stations. The upper plot shows the data without latitude adjustment, and the lower plot shows the data with latitude adjustment. Station numbers with an asterisk (*) indicate urban stations and those with a sharp (#) indicate urban-edge stations. Note: The boxes have lines at the lower quartile, median, and upper quartile values. Whiskers extend from each end of the box to the most extreme values within 1.5 times the interquartile range. Plus (+) signs denote outliers. Non-overlapping notch intervals indicate that the medians are significantly different at the 95% confidence level. The same note is applied to following box plots.

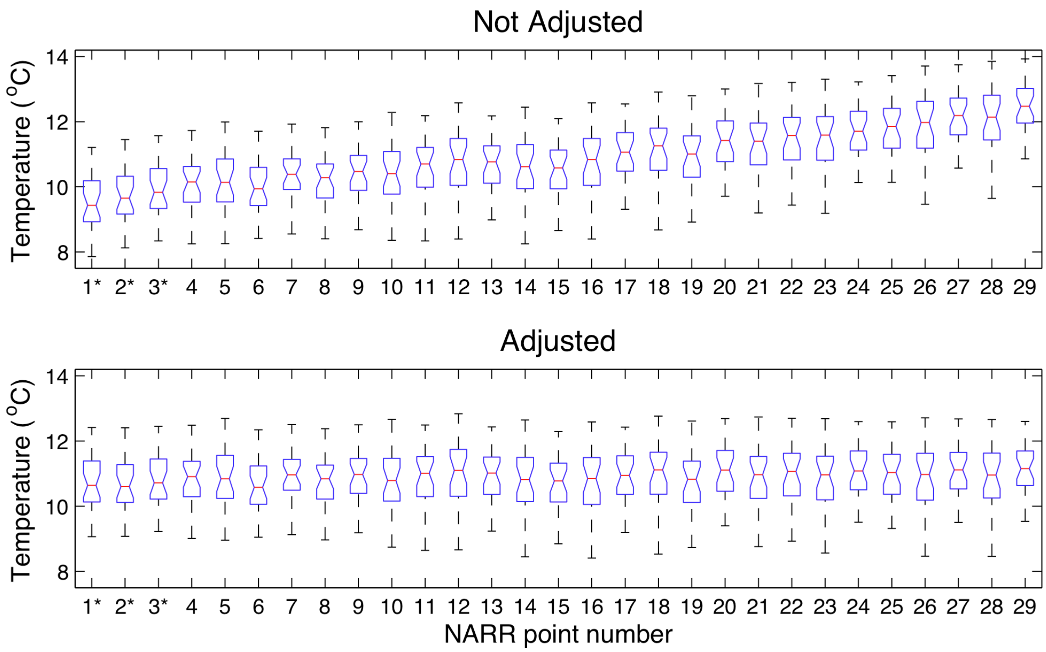
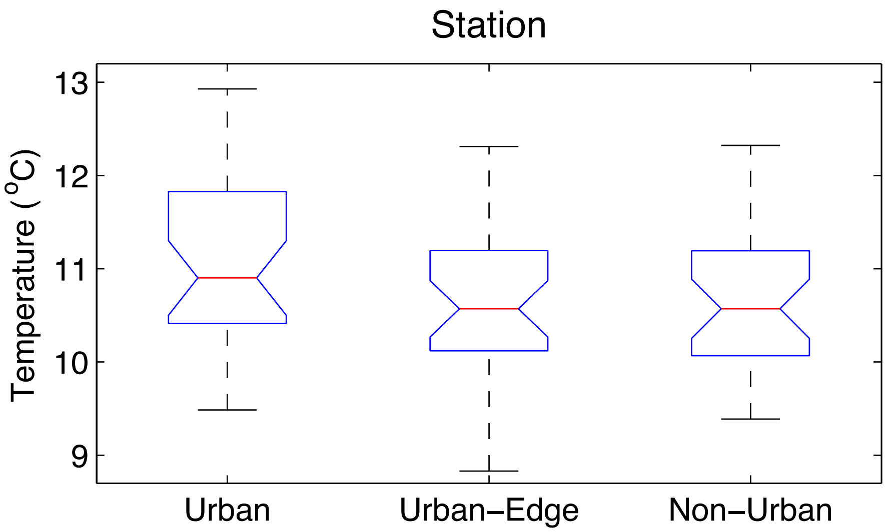
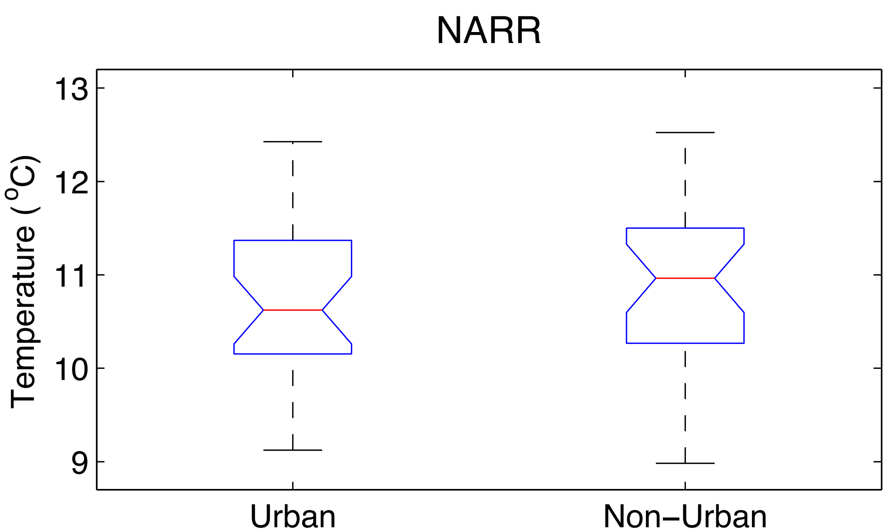


Figure 8. Same as Figure 7 but for the NARR data. Urban data points are marked with asterisks.



A



B

Figure 9. Latitude-adjusted annual mean temperatures for different weather station types (Panel A) and NARR data points (Panel B)

REFERENCES

Ackerman, B. (1985) Temporal March of the Chicago Heat Island. *Journal of Climate and Applied Meteorology,* Vol. 24, 547-54.

Angel, J. R. (2004) Temperature variability in Illinois: 1895-2002. *Transactions of the Illinois State Academy of Science,* Vol. 97, 103-16.

Arnfield, A. J. (2003) Two decades of urban climate research: A review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology,* Vol. 23, 1-26.

Choi, W. (2008) Climatic data, reanalysis. In *Encyclopedia of Global Warming and Climate Change.*, ed. S. G. Philander, 243-245SAGE Publications.

Fall, S., Niyogi, D., Gluhovsky, A., Pielke, R. A., Sr., Kalnay, E. and Rochon, G. (2010) Impacts of land use land cover on temperature trends over the continental United States: Assessment using the North American Regional Reanalysis. *International Journal of Climatology,* Vol. 30, 1980-93.

Jin, M. L., Dickinson, R. E. and Zhang, D. L. (2005) The footprint of urban areas on global climate as characterized by MODIS. *Journal of Climate,* Vol. 18, 1551-65.

Kalnay, E. and Cai, M. (2003) Impact of urbanization and land-use change on climate. *Nature,* Vol. 423, 528-31.

Kalnay, E., Cai, M., Li, H. and Tobin, J. (2006) Estimation of the impact of land-surface forcings on temperature trends in eastern United States. *Journal of Geophysical Research-Atmospheres,* Vol. 111, D06106, doi:10.1029/2005JD006555.

Kendall, M. G. (1975) *Rank Correlation Methods.* London, U.K.: Griffin.

Kistler, R., Kalnay, E., Collins, W., Saha, S., White, G., Woollen, J., Chelliah, M., Ebisuzaki, W., Kanamitsu, M., Kousky, V., van den Dool, H., Jenne, R. and Fiorino, M. (2001) The NCEP-NCAR 50-year reanalysis: Monthly means CD-ROM and documentation. *Bulletin of the American Meteorological Society,* Vol. 82, 247-67.

Manly, B. F. J. (2009) *Statistics for Environmental Science and Management.* Boca Raton: CRC Press.

Mann, H. B. (1945) Nonparametric tests against trend. *Econometrica,* Vol. 13, 245-59.

Mesinger, F., DiMego, G., Kalnay, E., Mitchell, K., Shafran, P. C., Ebisuzaki, W., Jović, D., Woollen, J., Rogers, E., Berbery, E. H., Ek, M. B., Fan, Y., Grumbine, R., Higgins, W., Li, H., Lin, Y., Manikin, G., Parrish, D. and Shi, W. (2006) North American Regional Reanalysis. *Bulletin of the American Meteorological Society,* Vol. 87, 343-60.

Mitchell, J. M., Dzerdzeevskii, B., Flohn, H., Hofmeyr, W. L., Lamb, H. H., Rao, K. N. and Wallén, C. C. 1966. *Climatic Change.* Geneva, Switzerland: World Meteorological Organization, Technical Note No. 79.

Nuñez, M. N., Ciapessoni, H. H., Rolla, A., Kalnay, E. and Cai, M. (2008) Impact of land use and precipitation changes on surface temperature trends in Argentina. *Journal of Geophysical Research-Atmospheres,* Vol. 113, D06111, doi:10.1029/2007JD008638.

Peterson, T. C. (2003) Assessment of urban versus rural in situ surface temperatures in the contiguous United States: No difference found. *Journal of Climate,* Vol. 16, 2941-59.

Peterson, T. C. and Owen, T. W. (2005) Urban heat island assessment: Metadata are important. *Journal of Climate,* Vol. 18, 2637-46.

Toreti, A., Fioravanti, G., Perconti, W. and Desiato, F. (2009) Annual and seasonal precipitation over Italy from 1961 to 2006. *International Journal of Climatology,* Vol. 29, 1976-87.

Zhang, Q., Xu, C. Y., Zhang, Z., Chen, Y. D. and Liu, C. L. (2009) Spatial and temporal variability of precipitation over China, 1951-2005. *Theoretical and Applied Climatology,* Vol. 95, 53-68.

Zhang, Q., Jiang, T., Gemmer, M. and Becker, S. (2005) Precipitation, temperature and runoff analysis from 1950 to 2002 in the Yangtze basin, China. *Hydrological Sciences–Journal-Des Sciences Hydrologiques,* Vol. 50, 65-80.

Zhou, L. M., Dickinson, R. E., Tian, Y. H., Fang, J. Y., Li, Q. X., Kaufmann, R. K., Tucker, C. J. and Myneni, R. B. (2004) Evidence for a significant urbanization effect on climate in China. *Proceedings of the National Academy of Sciences of the United States of America,* Vol. 101, 9540-4.