

1 AIR TEMPERATURE VARIABILITY IN ILLINOIS BASED ON WEATHER STATION
2 RECORDS AND THE NORTH AMERICAN REGIONAL REANALYSIS FROM 1979 TO
3 2006

4 Running head: TEMPERATURE VARIABILITY IN ILLINOIS

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20 This publication is available at Taylor & Francis via <http://dx.doi.org/10.2747/0272-3646.32.4.338>

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

33 INTRODUCTION

34 Anthropogenic reasons for climate change on a local scale is – beside changes resulting from
35 greenhouse gas emissions – often the consequence of large modifications of land surfaces that
36 often occur through urban development (Kalnay and Cai, 2003; Jin et al., 2005). The urban heat
37 island (UHI) is the most well known impact of urbanization on the local climate. UHI is typically
38 described by a variety of methods each of which has a limitation for identifying urban effects
39 unequivocally (Arnfield, 2003). A comparison within clusters of urban and rural stations across
40 the conterminous United States found that there are no statistically significant differences
41 between urban and rural temperatures when biases caused by differences in elevation, latitude,
42 time of observation, instruments, and siting practice are removed (Peterson, 2003). The primary

43 signal of UHI from the same dataset in the conterminous United States was found to come from
44 relatively high population sites, and the detection of the signal depended on urban/rural
45 classification metadata (Peterson and Owen, 2005). However, for an unknown reason, major
46 metropolitan cities such as New York, Chicago, and Atlanta were not included in the studies.

47 The impact of land modification, such as urbanization or deforestation, can be evaluated
48 by the “observation minus reanalysis” (OMR) approach proposed by Kalnay and Cai (2003).
49 Because the surface observations reflect all the sources of climate forcing while the reanalysis
50 data only contain atmospheric forcings (Kalnay et al., 2006), the difference between observations
51 and reanalysis is deemed largely due to land modification. The OMR approach is useful for
52 avoiding problems due to the biases in weather stations data pointed out by Peterson (2003). For
53 example, it was found that the surface temperature has been warming faster in surface
54 observations than in the NCEP-NCAR 50-year reanalysis data (Kistler et al., 2001) in the
55 conterminous United States between 1950 and 1999, which is largely due to urbanization and
56 agriculture (Kalnay and Cai, 2003). The OMR approach has been adopted to separate the effect
57 of surface forcings from atmospheric forcings for a few large domains so far (Kalnay and Cai,
58 2003; Zhou et al., 2004; Kalnay et al., 2006; Nuñez et al., 2008; Fall et al., 2010). Most of the
59 case studies used global reanalysis datasets with coarse spatial resolutions (up to 2.5°
60 latitude/longitude) except one (Fall et al., 2010) that used a fine-resolution regional reanalysis
61 dataset, North American Regional Reanalysis (Mesinger et al., 2006).

62 The literature cited provided a rationale for this study that there is a need to study near
63 surface air temperatures at local or regional scales using a fine-resolution reanalysis dataset. The
64 objective of this study is to examine the near surface air temperature averages and trends in
65 urban and rural settings in the Midwestern United States, in particular across the State of Illinois

66 since the 1970s. In our study, we analyzed and compared data from weather stations and the
67 North American Regional Reanalysis (NARR). Annual temperatures from weather stations show
68 a positive trend between 1971 and 2002 across Illinois (Angel, 2004), but intra-regional
69 variations are less well known and its robustness needs to be compared to a reanalysis-based
70 assessment. Our approach is based on the principle of the OMR approach and will allow for the
71 evaluation of the fine-resolution regional reanalysis dataset in terms of its usefulness for the
72 detection of UHI-affected temperature trends in the region. An approach comparing decadal
73 temperature trends between weather stations and reanalysis data with a focus on urban-rural
74 differences is quite rare in the literature.

75 REGION AND DATA

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

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

88 The temperature data were obtained from two sources: weather stations and the fine-
89 resolution regional reanalysis dataset, North American Regional Reanalysis (NARR). NARR is a
90 “long term, dynamically consistent, high-resolution, high-frequency, atmospheric and land
91 surface hydrological dataset” (Mesinger et al., 2006 p. 343). Reanalysis climatic data are
92 produced from state-of-the-art data assimilation systems, where different datasets (rawinsondes,
93 aircraft, satellites, surface, etc.) are combined with computer models in a unified and consistent
94 manner (Mesinger et al., 2006; Choi, 2008). It incorporates a land surface model that uses data
95 such as vegetation type, snow albedo, soil temperature, and soil type (Mesinger et al., 2006).
96 Datasets were added or improved upon for NARR, such as precipitation, sea surface temperature,
97 and radiances, compared to the NCEP-NCAR global reanalysis (Kistler et al., 2001), resulting in
98 the more realistic hydrological cycle (Mesinger et al., 2006). The NARR data are available since
99 1979 at a spatial resolution of 32 km, a temporal resolution of three hours and a vertical
100 resolution of 45 layers. The annual mean weather station air temperatures were obtained from
101 Illinois State Climatologist Office for 30 stations across the State of Illinois for the period 1979-
102 2006 (Table 1 and Figure 1). The time period was selected as such to avoid missing records and
103 allow for a comparison with the reanalysis data. The NARR 3-hour temperature was obtained
104 from the National Oceanic and Atmospheric Administration. Twenty-nine grid points (thick
105 cross marks in Figure 1) were selected according to their proximity to the weather stations. One
106 grid-point was omitted due to its proximity to two weather stations (No. 8 Peru and No. 9
107 Ottawa). The stations listed in Table 1 were sorted and numbered by descending latitude.

108 Based on their setting derived from the land cover data (Figure 2), the 30 weather stations
109 were classified into three categories, urban, urban-edge, and non-urban. A station was classified
110 as “urban,” when the location of the weather station is located within an urban pixel surrounded

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

$$140 \quad S = \sum_{i=2}^n \sum_{j=1}^{i-1} \text{sign}(x_i - x_j)$$

141 where $\text{sign}(z)$ is -1 when z is negative, 0 when z is zero and 1 when z is positive. When a series
142 of values is in a random order, the expected value of S is zero and the variance VS is given as
143 follows:

$$144 \quad VS = n(n-1)(2n+5)/18$$

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

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

147

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

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

173 trend tests. The linear trend tests reveal to decadal trends that vary from -0.35 (Station 23,
174 Rushville) to 0.7 °C (Station 4, Joliet Brandon). It is noteworthy, that nine of the 30 stations
175 show decadal trends in excess of 0.5 °C and seven of these nine stations were classified as urban
176 stations. The linear trend at 13 of the 30 stations was found insignificant by the *t*-test. Only one
177 station in an urban setting shows insignificant trends (Station 22 Danville), all others are located
178 in non-urban or urban-edge areas. The slightly negative trends that were observed at three
179 stations are all insignificant according to the *t*-test. Angel (2004) found 0.3 °C per decade during
180 1971-2002, which is smaller than 0.35 °C per decade found in this study. The decadal trend from
181 the NARR data is even higher at 0.6 °C, which is in agreement with Fall et al. (2010).

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

187 The comparison of annual mean air temperatures from station records and NARR grid-
188 point data reveals variable levels of correlation between the datasets. Figure 4 provides one
189 example of a location with highly correlated data (Station 1 Chicago O'Hare) and one example
190 with less well-correlated data (Station 29 White Hall). The interannual variability of mean air
191 temperatures in Chicago was well emulated by the NARR data; the correlation coefficient is in
192 excess of 0.9, peaks and troughs in both datasets correspond in terms of their occurrence and
193 magnitude. The overall trends in both datasets consequently similar in both stations, even though
194 certain differences can be observed. The comparison of the datasets at Station 29 (White Hall)
195 reveals that the occurrence of peaks and troughs is relatively synchronous, however, their

196 magnitudes remarkably differ between the datasets. During the first years, the station data show
197 considerably higher values than the NARR data. However, after a large dip from 1984 to 1985,
198 the station temperatures consistently stay below the NARR temperatures. The location of the
199 station did not change during the period, and no other information is available to explain the
200 consistently lower temperature. It is therefore evident that the trend based on the NARR data will
201 be clearly more pronounced than the trend based on the station data.

202 Figure 5 illustrates decadal trends at all stations based on both datasets as well as the
203 correlation coefficients. Negative trends or decadal trends below 0.3 °C are not depicted because
204 they are statistically insignificant according to the *t*-test. It is clearly noticeable, that the datasets
205 for most locations are highly correlated. Almost half of the locations are characterized by
206 correlation coefficients above 0.9, and only six of the 30 locations feature correlation coefficients
207 below 0.7. In terms of decadal trends we observe differences below 0.05 °C at four locations
208 (1,5,6 and 11). Differences between 0.05 and 0.1 °C can be seen at locations 3, 12, 18 and 30;
209 differences between 0.1 and 0.2 °C are noted for locations 7, 14 and 20; differences between 0.2
210 and 0.3 °C are noted for locations 2, 4, 13, 24, 26 and 28. The other locations show even larger
211 differences in the trends; most of them are classified as non-urban and show very weak positive
212 or even negative trends in the station data, which are not always easily explainable. Like location
213 29, locations 8, 19, and 27 feature lower station temperatures than the NARR temperatures in the
214 later part of the period. The only known change to the stations is that Station 19 lowered its
215 elevation by 4 meters according to the station history. At location 23 we observe a relatively
216 good correlation before the year 2000. Afterwards the station temperatures fall below the NARR
217 temperatures considerably, which is in contradiction to the NARR data as well as to all other

218 observed temperatures in the vicinity. The station temperature in 2004 is particularly suspicious
219 because it is 7.1 °C while the NARR temperature is 12.1 °C.

220 The result in Figure 5 provides an interesting comparison to those from Kalnay et al.
221 (2006). They found mixed trends of mean temperatures in Illinois from observations and
222 dominantly cooling trend from the NCEP/NCAR reanalysis. The results from observations are
223 similar to this study but those from the reanalysis are opposite. The dominantly warming trend in
224 Illinois from NARR can partially attributed to the NARR's incorporation of additional
225 observation data and much finer resolution than the NCEP/NCAR reanalysis. But NARR shows
226 much stronger trends which are beyond our explanation. Kalnay et al. (2006) also compared the
227 trends of OMR between Baltimore (urban) and Owings Ferry Landing (rural) weather stations in
228 Maryland, and found that Baltimore showed a stronger increasing trend of mean temperatures in
229 observation than reanalysis while Owings Ferry Landing showed little trend difference. Stations
230 2, 3 and 4 in the Chicago area showed stronger trends than NARR in this study, but NARR
231 showed stronger trends than most central and southern stations.

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

239 Figure 7 is the box plot that shows annual mean temperatures from the stations sorted by
240 descending latitude. Each column along the horizontal axis represents a station and shows the

241 variation throughout the data period. The upper panel, showing the original data without latitude
242 adjustment, reveals - with some exceptions - an increasing trend of temperature with decreasing
243 latitude. After applying the latitudinal correction factor (lower panel), the increasing temperature
244 trend with descending latitude is removed. Some urban stations (such as 2, 3, 4, 11 and 12) show
245 higher medians than their immediate neighbors, and urban stations 2 and 3 stand out among
246 many other non-urban stations. A few other urban stations (1, 6, and 22) also show above-
247 average temperatures. On the other hand, there are many non-urban stations with higher average
248 temperatures than some urban and urban-edge stations.

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

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

264 other stations. On the other hand, urban NARR data points show smaller median and variability
265 of annual mean temperatures at the urban locations.

266 DISCUSSION AND CONCLUSIONS

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

273 The urban weather stations revealed higher median temperature and larger variability
274 than the urban-edge and non-urban stations, even though the difference in medians was not
275 found to be significant. Peterson (2003) found no significant urban-rural differences in mean
276 temperatures across the United States after various adjustment but found larger variabilities in
277 urban stations. Our finding is similar to Peterson's, but a main difference is that Peterson
278 compared urban and rural stations for each metropolitan area while we compared between station
279 types aggregated across the state. A detailed investigation of the Chicago metropolitan area,
280 which was not included in Peterson's study, could have provided a different picture but was
281 simply beyond the scope of the present study. Ackerman (1985) investigated the Chicago heat
282 island with temperature records for 1950-1970 from Midway Airport and Argonne National
283 Laboratory, which was deemed rural at the time of measurement and is located about 13 km
284 southeast of Station 2 Wheaton. Temperatures were higher at Midway Airport most of the time
285 by an average of 1.9 °C, even though Argonne National Laboratory was about 23 km southwest

286 of Midway Airport, meaning lower in latitude and further from Lake Michigan. The finding is in
287 line with ours, because Station 2 Wheaton is now considered urban and its mean temperature is
288 lower than Station 3 Midway by only 0.2 °C. Station 2 Wheaton could be classified as rural in
289 the 1960s and the temperature margin could be larger.

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

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

305 Our study reveals that stronger trends in metropolitan areas are visible in the station
306 records but not in the NARR records where trends were significant regardless of location,
307 especially in southern locations. Based on our findings we conclude that temperature trends from
308 the NARR data are weaker for metropolitan and stronger for non-urban areas in comparison with

309 station records. The trends were all significant in the NARR data. Considering that the trends in
310 NARR are quite different from the NCEP/NCAR reanalysis found in Kalnay et al. (2006), we
311 speculate that it has something to do with the way NARR assimilated observation data but do not
312 have a definitive answer at this moment. These findings for Illinois need to be tested for other
313 regions and metropolitan areas and – in case that they will be confirmed by other studies – they
314 will be of utmost relevance for regional temperature trend studies.

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

325

326 *Acknowledgements:* The authors sincerely appreciate the comments from the anonymous
327 reviewers and Hyejin Yoon. They significantly improved the manuscript.

328

Table 1. Weather stations selected for the study

Reference Number	Station Name	Latitude (dd)	Longitude (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

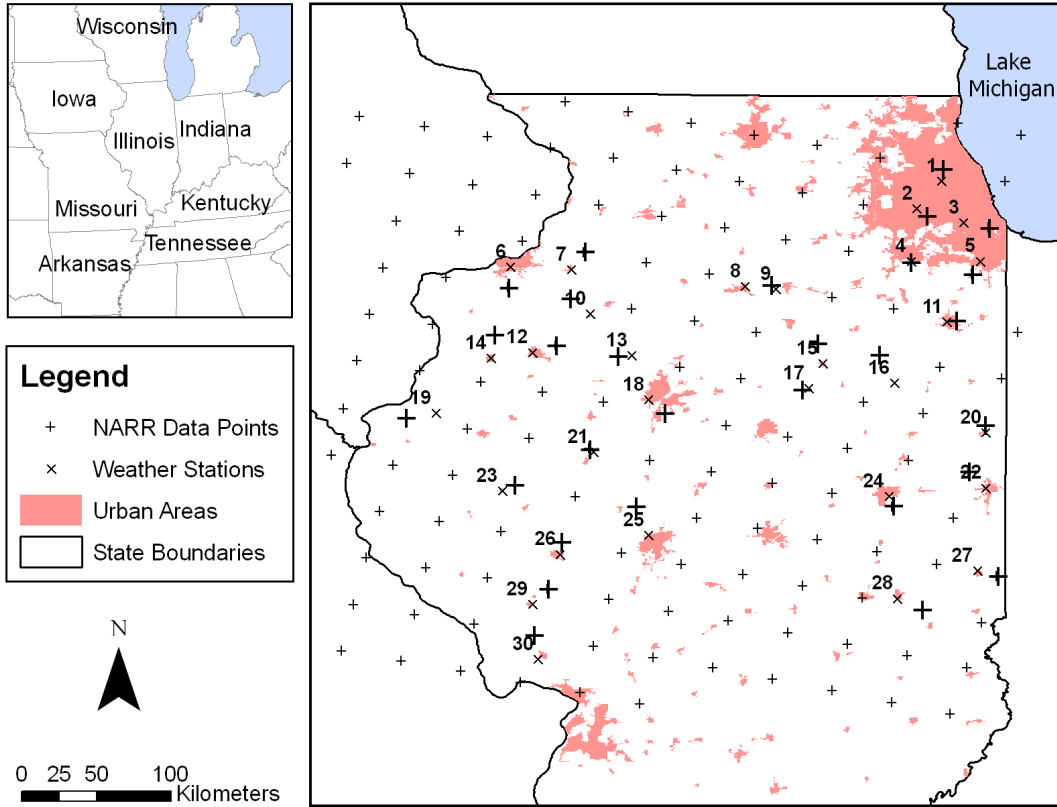
330 Table 2. Results of the statistical analyses of the weather stations time series. The shading of the stations number
 331 column indicates station types (black: urban, grey: urban-edge, white: non-urban). The shaded fields in the last
 332 column indicate that the observed trends were significant at the 95% confidence level (coefficient of the t-test for
 333 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

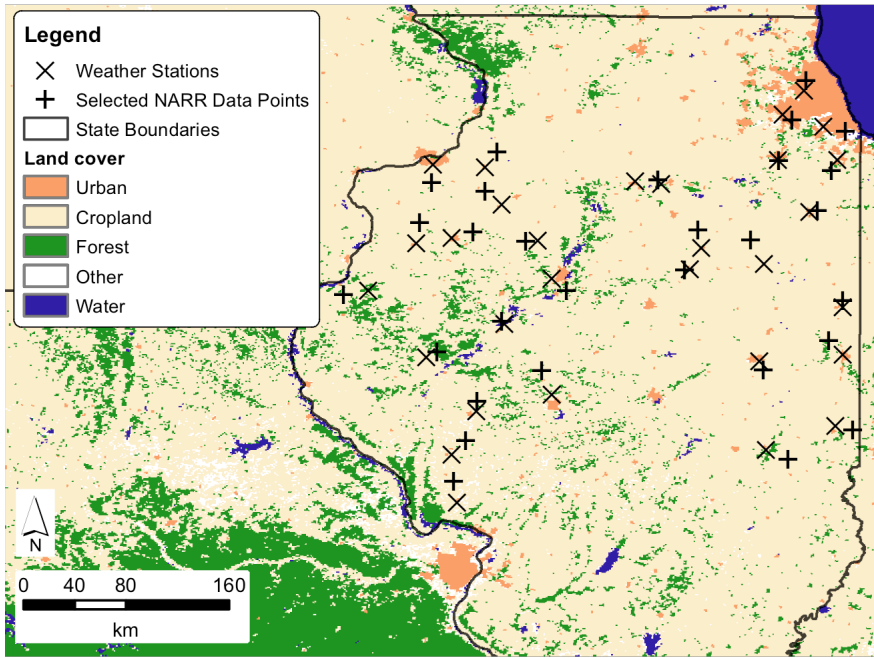
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337 Figure 1. Study area: North American Regional Reanalysis data points, weather stations, state boundaries and urban
 338 areas designated by the United States Census Bureau. Large cross marks represent the data points selected for this
 339 study.

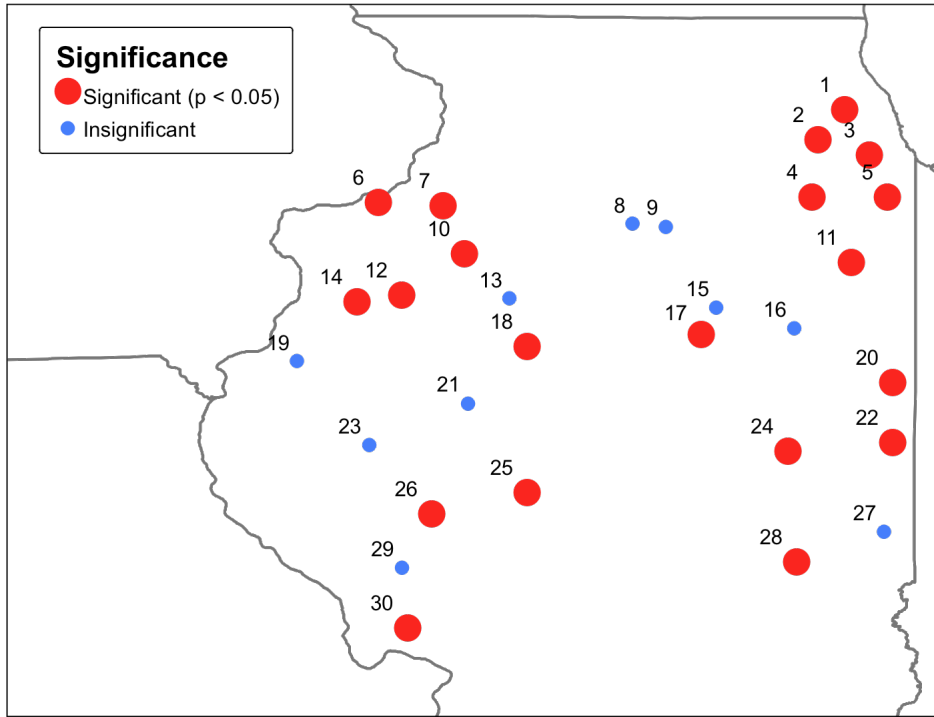


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341 Figure 2. Land cover of the study area

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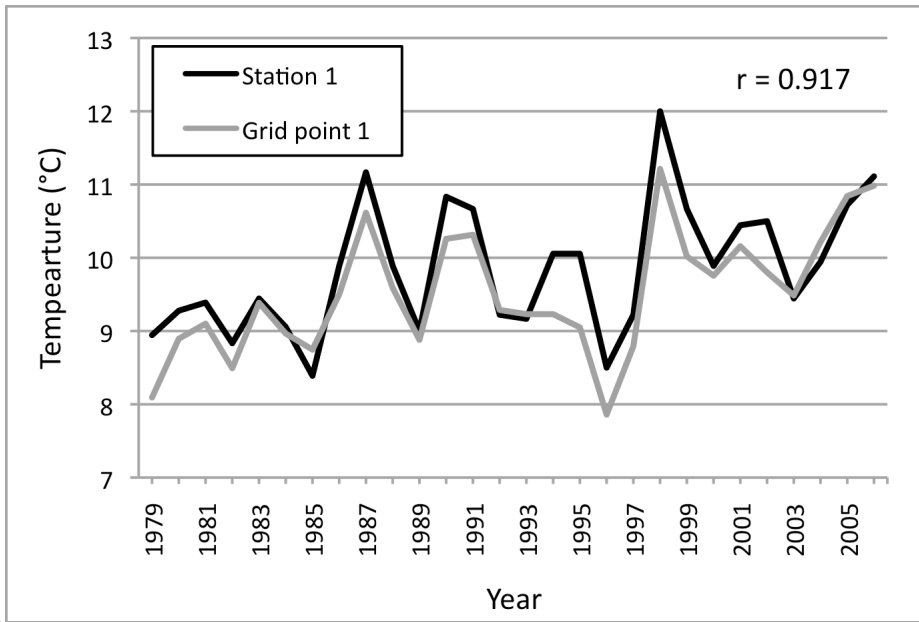


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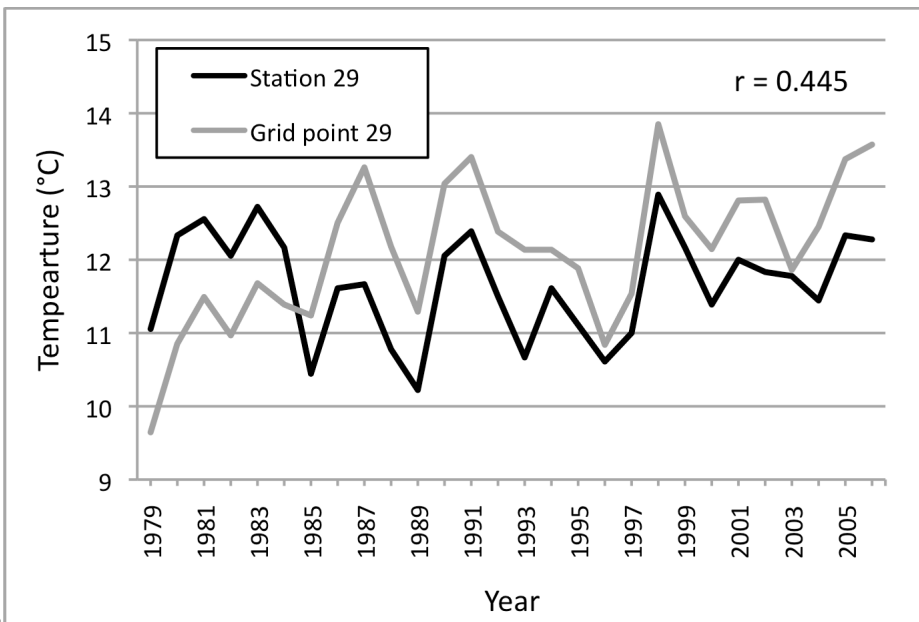
345 Figure 3. Significance of Z scores from the Mann-Kendall test for trend for the stations data at the 95% confidence
346 level

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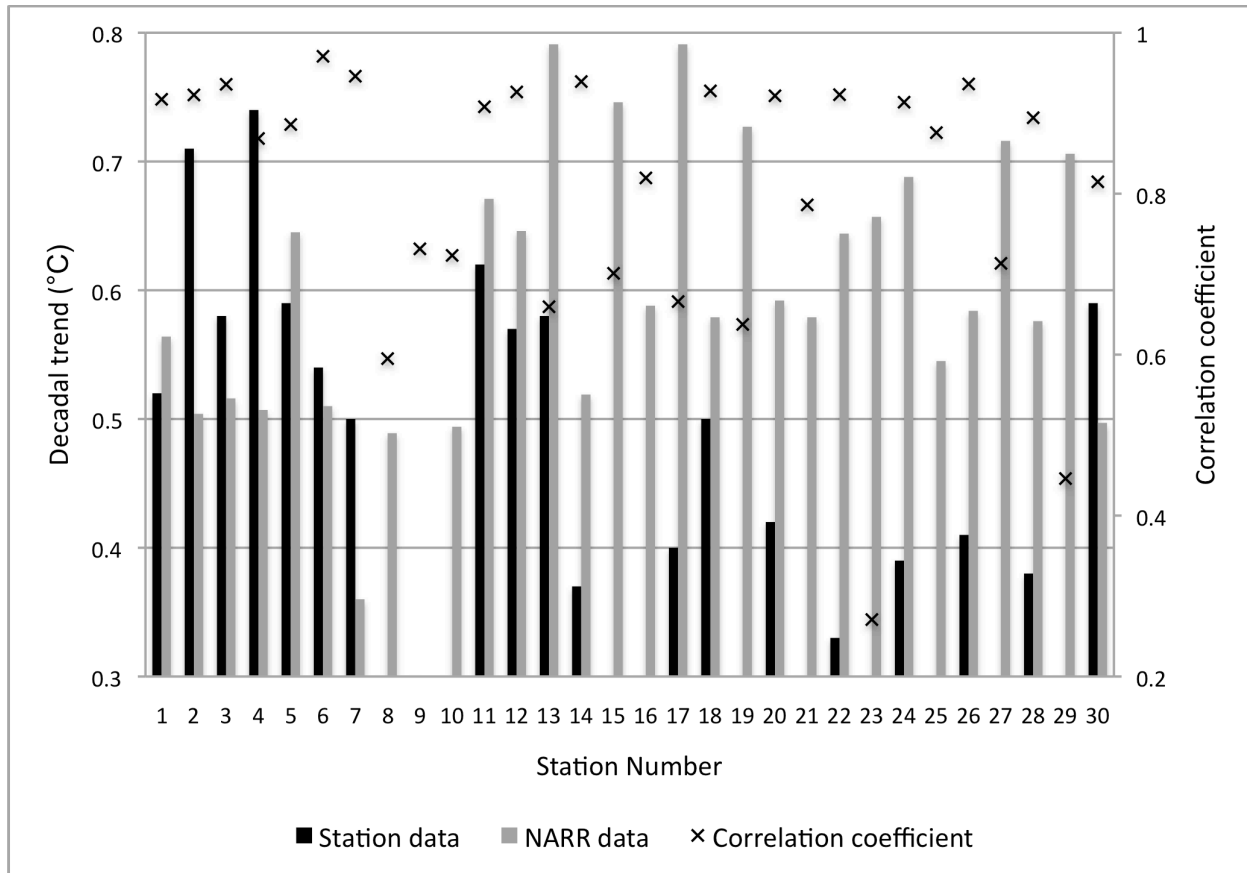
349 A



350 B

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

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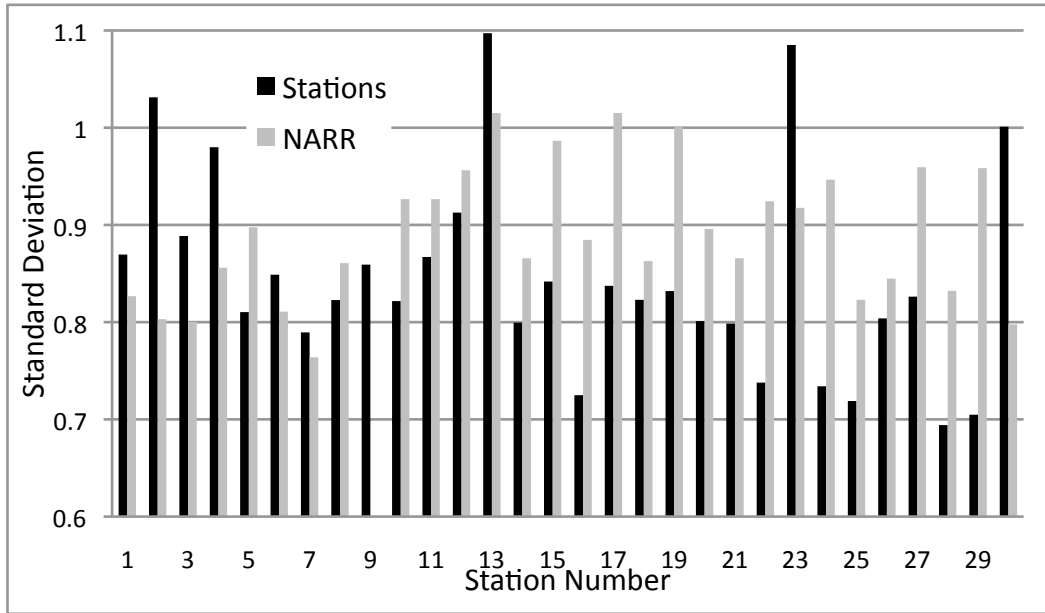
Figure 5. Decadal temperature trends (columns; left vertical axis) at all measuring stations and grid points and

356

correlation coefficients (cross marks; right vertical axis) between the datasets at each location

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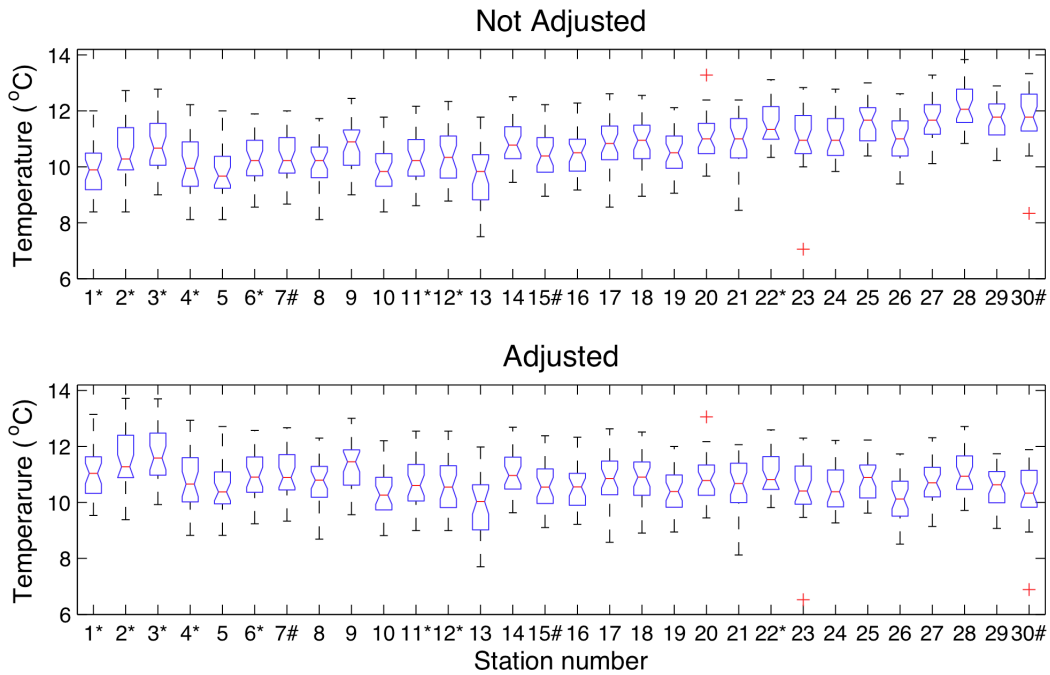
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360 Figure 6. Standard deviation in the time series of station and NARR datasets

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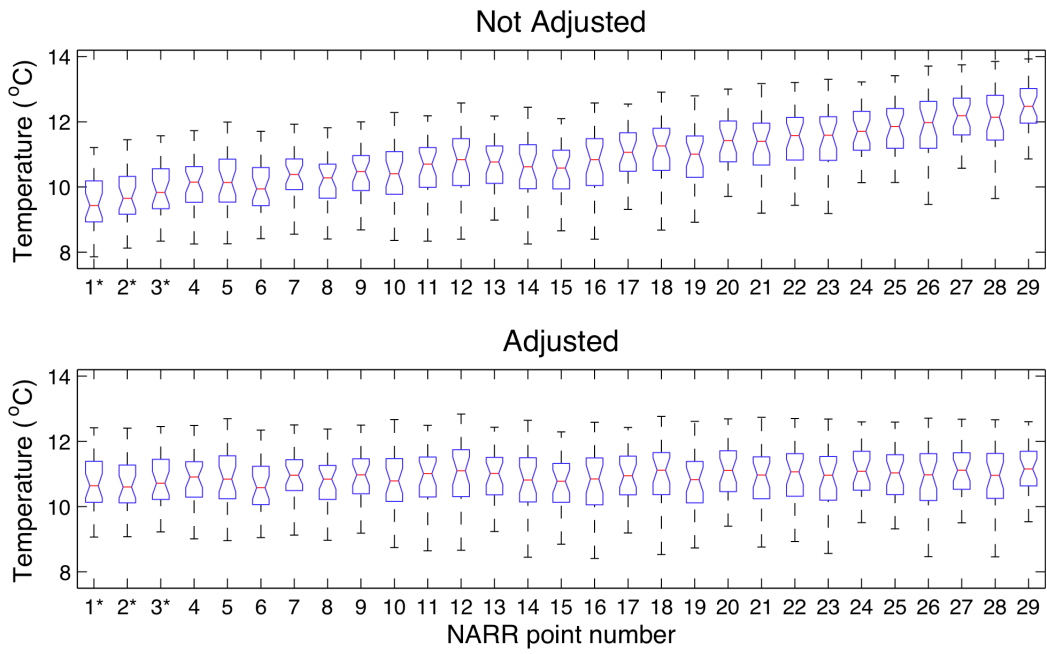


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363 Figure 7. Box plots of annual mean temperatures from the weather stations. The upper plot shows the data without
 364 latitude adjustment, and the lower plot shows the data with latitude adjustment. Station numbers with an asterisk (*)
 365 indicate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

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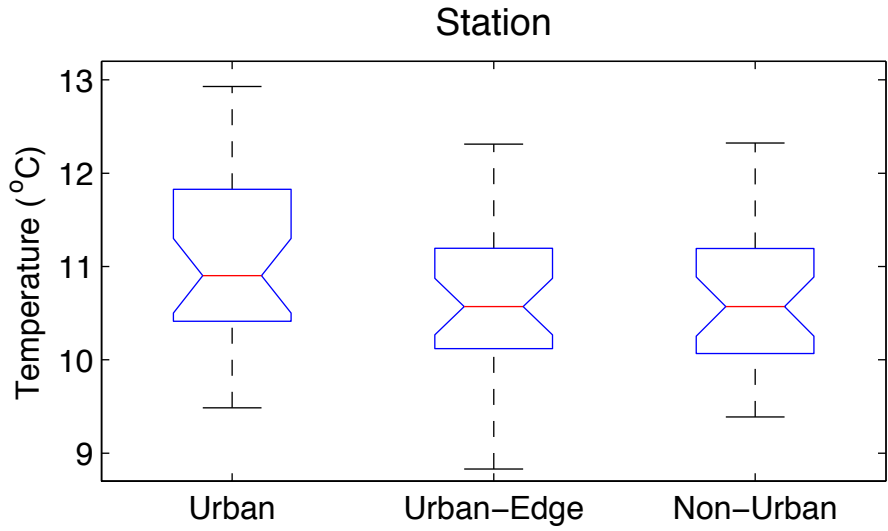
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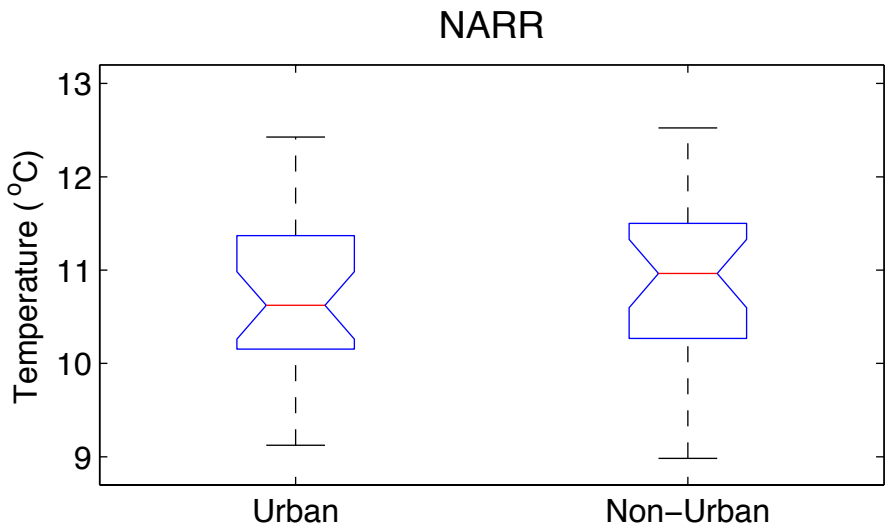
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373 Figure 8. Same as Figure 7 but for the NARR data. Urban data points are marked with asterisks.

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375 A



376 B

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

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