A Comparison of 30-yr Climatic Temperature Normals for the Southeastern United States

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Thirty-year climatic normals are an integral part of climate and climate assessment, but they are typically not used to address issues of climatic change. For 104 stations within the southeastern United States, I analyze spatial parameters of the two most recent 30-yr temperature normals (1961–1990, 1971–2000) to illustrate the utility of 30-yr normals for an assessment of climatic change. My comparison of the two normal periods shows that the Southeast as a whole has experienced a small (0.10°C) but significant increase in average temperature. However, of the seven physiographic provinces examined, only the lower Coastal Plain has experienced a significant increase in temperature. My analysis of urban versus rural sites produced mixed results on the potential impacts of urbanization and the associated heat island effects on the observed changes in temperature. While some long-term analyses of the thermal climate of the Southeast have shown the region to be cooling, my results suggest that the thermal climate of the southeastern United States since 1961 is stable or slightly warming.

KEY WORDS: climatic normals, temperature, southeastern U.S., climate change

INTRODUCTION

Thirty-year normals have been a mainstay in climatology since the U.S. Weather Bureau adopted them during the 1950s in response to World Meteorological Organization guidelines (Lamb and Changnon 1981). The 30-yr climatic normals are updated each decade to reflect the most recent period of record (e.g., current normals are calculated using data from 1971–2000) (NCDC 2004a). In turn, moving averages associated with these periodic updates can impact analyses and perceptions of climate through interpretations of the deviations from normal. For example, deviations from normal are a standard element of the monthly NOAA publication "Climatological Data" (NOAA 2003) for each state and they are incorporated into forecasts provided by many media outlets to help place the current day's weather into historical perspective. Most studies use, at minimum, annual data to address questions related to changing climatic conditions (e.g., Karl et al. [1996] use various annual indices, Knappenberger, Michaels, and Davis [2001] use daily data). While 30-yr normals are useful both for instructive purposes (e.g., maps showing regional conditions) and for practical purposes (e.g., they are often incorporated into load forecasting models used by the electric power generation industry [Meentemeyer and Soulé 1989; Meentemeyer, Soulé, and Bland 1990]), they are generally not used to directly test changing climatic conditions. The purpose of this study is to show how 30-yr climatic normals can be used to assess changes in climate within the thermal regime of the southeastern United States. I use the two most recent 30-yr normal periods (1961–1990, 1971–2000) to: (1) determine if thermal conditions have remained stable through time, (2) examine the spatial pattern of any observed changes, and (3) assess the possible role that site selection (i.e., urban versus less urban/rural) plays in the determination of significant changes in climate.

The southeastern United States is somewhat anomalous in climate change research as most analyses show this area did not warm significantly during the twentieth century (e.g., Karl et al. 1996; Greenland 2001; NCDC 2004b). For example, while linear trends showed as much as 3°C of warming for much of the United States, temperatures in the Southeast largely exhibited cooling trends of 1–2°C for the period 1900–1994 (Karl et al. 1996). Over a shorter time period (1948–1994), Saxena and Yu (1998) also found downward trending temperatures in the Southeast. Analyzing temperature data from a small sample of sites ($n = 5$) across the Southeast, Greenland (2001) found no long-term (i.e., 1900–1997) trends in temperature, but rather a non-monotonic pattern with warming until mid-century, followed by cooling to about 1975 and then warming through 1999. Knappenberger, Michaels, and Davis (2001) also found changing trends through time in the Southeast, with warming from 1910 to 1939, cooling from 1940 to 1969, and then a mixed pattern from 1970 to 1997, with warming during the coldest and warmest days of the year, but cooling during periods of intermediate temperatures. Easterling (2002, 1331) analyzed various measures of cooling and found no significant "changes in either the number of frost days or changes in the front-free season" over the period 1948–1999 in the Southeast. Recent analyses by the National Climatic Data Center (NCDC) (NCDC 2004b) show a warming trend over the 1961–2000 period, but a cooling trend over the full period of record (1895–2003). Thus, while there appears to be a consensus that warming has not occurred in the southeastern United States over the last century, over shorter periods the results are mixed and inconclusive.

DATA AND METHODS

I obtained temperature measurements directly from the Southeast Regional Climate Center's (SERCC) website (SERCC 2004) for 104 stations across six states. These data are from the NCDC's data set "CLIM81: Climatography of the U.S." (NCDC 2004a). I obtained two measurements directly, the 1961–1990 and the 1971–2000 Annual Temperature Normals. The 30-yr temperature normals have been subjected to extensive quality control by the NCDC (NCDC 2004a), including adjustments for missing data and other "inhomogeneities" (NCDC 2004b, 2), although not all adjustments were made to cooperative weather station records for the 1961–1990 normals. Despite the adjustments, a close examination of the station metadata revealed that many stations with 30-yr temperature normals contained large amounts of missing data and/or had been physically moved. In order to minimize potential biases, I employed stringent site-selection criteria. For a site to be included in this study it had to: (1) have recorded temperature continuously from 1961–2000, (2) have no more than one month of missing data during the 1961–2000 period, and (3) have moved no more than 25 m vertically and no more than 5 min (latitude or longitude) horizontally. In selecting stations I gave no consideration to potential urbanization effects. Any station that met my criteria was selected. All data were reported in degrees Fahrenheit and converted to degrees Celsius.

I created all maps using the geographic information system (GIS) ArcMap 8.3 (ESRI 2004). For the 30-yr normal maps (e.g., the 1971–2000 mean temperature), I interpolated raster layers using the Inverse Distance Weighted method. The raster layers for each variable were reclassified using equal intervals based on the range and converted to polygons for a shaded isoline map. I created a graduated cylinder map using natural breaks to show the difference in temperature between the current and prior 30-yr normal periods (i.e., 1971–2000 minus 1961–1990 normals).

I used the non-parametric Wilcoxon Matched Pairs test (McGrew and Monroe 2000) with a null hypothesis of no significant difference in average temperatures between the 30-yr normal periods and a .05 level of significance. I did this by physiographic province and for all sites combined. I used the physiographic province boundaries delimited by Miller and Robinson (1995). I also tabulated the percentage of stations recording an increase in temperature for the compared periods.

The potential effects of urbanization on atmospheric temperatures (i.e., urban heat islands) have long been known (e.g., Oke 1973), with some suggesting dramatic influences on the climatic record due to urbanization (e.g., Kalnay and Cai 2003). I examined the potential effects of urbanization on temperature change several ways. I identified all stations that were within 15 km of any city with a 2000 population of greater than 100,000 and: (1) compared the change in 30-yr normal temperatures of these stations to those with populations under 100,000 using a Mann Whitney test (McGrew and Monroe 2000); (2) compared the 30-yr normal periods for the greater than 100,000 and less than 100,000 population subsets using a Wilcoxon Matched Pairs test (McGrew and Monroe 2000); and (3) tabulated the percentage of stations recording an increase in temperature for the compared periods. I also matched each study site with population data (1999) from the county it resides in and then used simple correlation to assess the strength of the relationship between population and the change in mean temperature between 30-yr normal periods. The population data are from the U.S. Census Bureau and were accessed through ArcMap 8.3 files (ESRI 2004).

RESULTS AND DISCUSSION

There is high degree of spatial covariance across the six state study region, with a simple correlation of .992 ($p < .000$, $n = 104$) between the two 30-yr normal periods. Thus, only the most recent 30-yr period is shown (Fig. 1). The spatial pattern matches climatic expectations (Soulé 1998), with the coldest temperatures in the Appalachian Mountains of North Carolina and Virginia, and the warmest temperatures in south Florida.

The statistical comparison of climatic temperature normals for the two 30-yr periods by physiographic province shows that only the lower Coastal Plain has experienced a significant change in tempera-

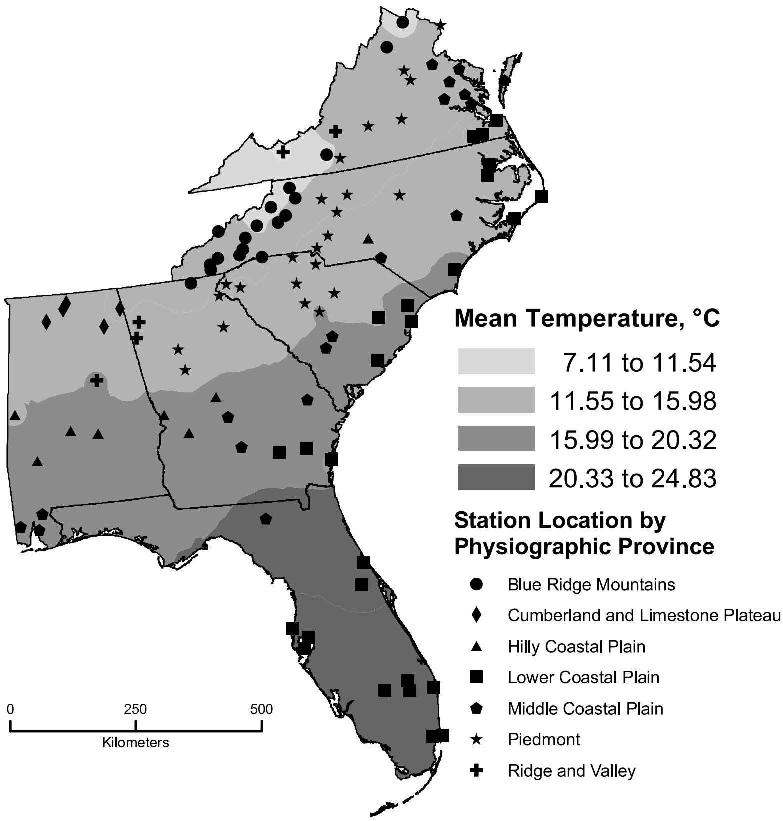

Figure 1. Mean annual temperature (°C) based on the 30-yr normal period 1971–2000. The locations of reporting stations used in this study are depicted with symbols matching them to physiographic regions identified by Miller and Robinson (1995).

ture (Table 1). While the majority of stations within each physiographic province have registered increases in temperature and the change is statistically significant for all sites combined (n = 104), the average increase was only 0.1° C.

For the 30-yr mean comparisons (Fig. 2, Table 1), there is some degree of spatial continuity in the observed patterns of cooling and warming. For example, all of the Coastal Plain stations in North Carolina register warmer temperatures in the most recent 30-yr period, and all Florida stations except Miami Beach (temperature decrease of 0.06°C) had increases. Conversely, spatial continuity is absent throughout much of the Piedmont and Blue Ridge Mountains, where adjacent stations often show opposite trends. Except for the Cumberland and Limestone Plateau physiographic province, the general spatial pattern shows fewer stations with warming as distance increases from the coast (Table 1).

The mean change in temperature (i.e., 1971–2000 minus 1961–1990 normals)

Table 1. Comparison of 30-yr Normals by Physiographic Province and for all Sites Combined.

	30-yr Normals				
Physiographic Province	Number of Stations	1961–1990 Mean (°C)	1971–2000 Mean (°C)	p-value[a]	Percentage of Stations with Higher Mean Temperature[b]
Blue Ridge Mountains	18	12.27	12.23	.760	55.6
Cumberland & Limestone Plateau	5	15.08	15.26	.074	80.0
Hilly Coastal Plain	8	17.61	17.66	.528	62.5
Lower Coastal Plain	26	19.53	19.82	.000	84.6
Middle Coastal Plain	18	16.67	16.78	.107	72.2
Piedmont	24	15.07	15.13	.415	58.3
Ridge and Valley	5	14.07	14.06	.715	60.0
All Sites	104	16.13	16.23	.002	68.3

[a] p-value for a Wilcoxon Matched Pairs test with a null hypothesis of no significant difference between the 1971–2000 and 1961–1990 30-yr normal periods.
[b] percentage of stations with a higher mean temperature in the most recent 30-yr normal period.

for the 22 stations within 15 km of a city with a 2000 population greater than 100,000 (Fig. 3) was 0.18°C, and for the remaining 82 stations it was 0.09°C. The Mann Whitney test for this comparison reveals there is no significant difference between the two groups ($p = .652$). Both subgroups had significant differences in mean temperature between the two 30-yr normal periods ($p = .005$ for the greater than 100,000 population sites, $p = .031$ for the less than 100,000 population sites), with 77.3% of the greater than 100,000 population subgroup stations and 65.8% of the less than 100,000 population stations recording higher temperatures in the 1971–2000 normal period relative to the 1961–1990 period. The Pearson r-value for the comparison between county population and the mean change in temperature was .14 ($p = .16$). With double the relative change in temperature between the two 30-yr normal periods, stations near large urban areas are warming at a faster rate relative to less urban and rural stations. However, both the urban and less urban subgroups have experienced significant increases in temperature, and these changes are not significantly different (at $\alpha = .05$) between the two groups. Further, the county-scale comparison of population change and temperature change shows only a weak relationship between the two measures.

CONCLUSION

Although 30-yr climatic normals have been a mainstay of climatic record keeping since the 1950s, their direct usage in

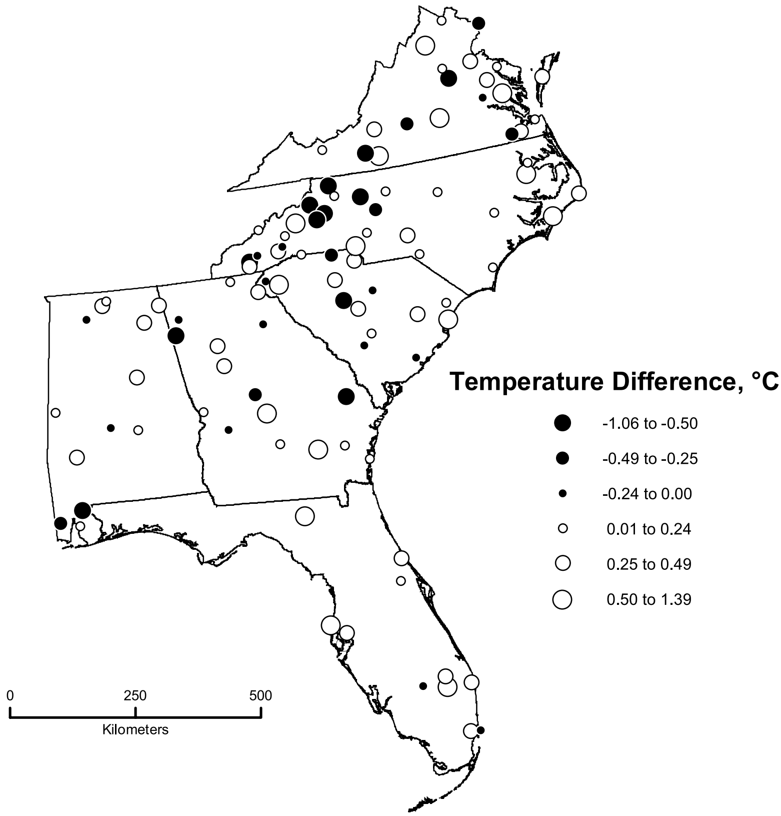

Figure 2. Temperature difference (°C) between the 1971–2000 normal period and the 1961–1990 normal period (1971–2000 minus 1961–1990).

climate change research is limited by the moving average approach used, whereby the most recent averaging period contains data from two of the three decades used in the calculation of the prior normal. In this study I have demonstrated that climatic normals can be used as a vehicle to assess climatic change. In contrast to some analyses of long-term trends (i.e., 50–100 yr trends) of temperature in the Southeast which found cooling (e.g., Karl et al. 1996, Saxena and Yu 1998), my results suggest either a slight movement toward warming or no change. Urbanization and the associated heat island effects may be contributing to the observed warming, but my results on this are mixed. As both 30-yr normal periods share the decades of the 1970s and 1980s, the movement toward warmer conditions at the majority of stations may reflect recent (i.e., the 1990s) changes in the thermal climate of the Southeast. If the 2000s are as warm as the 1990s, the next 30-yr normals (i.e., 1981–

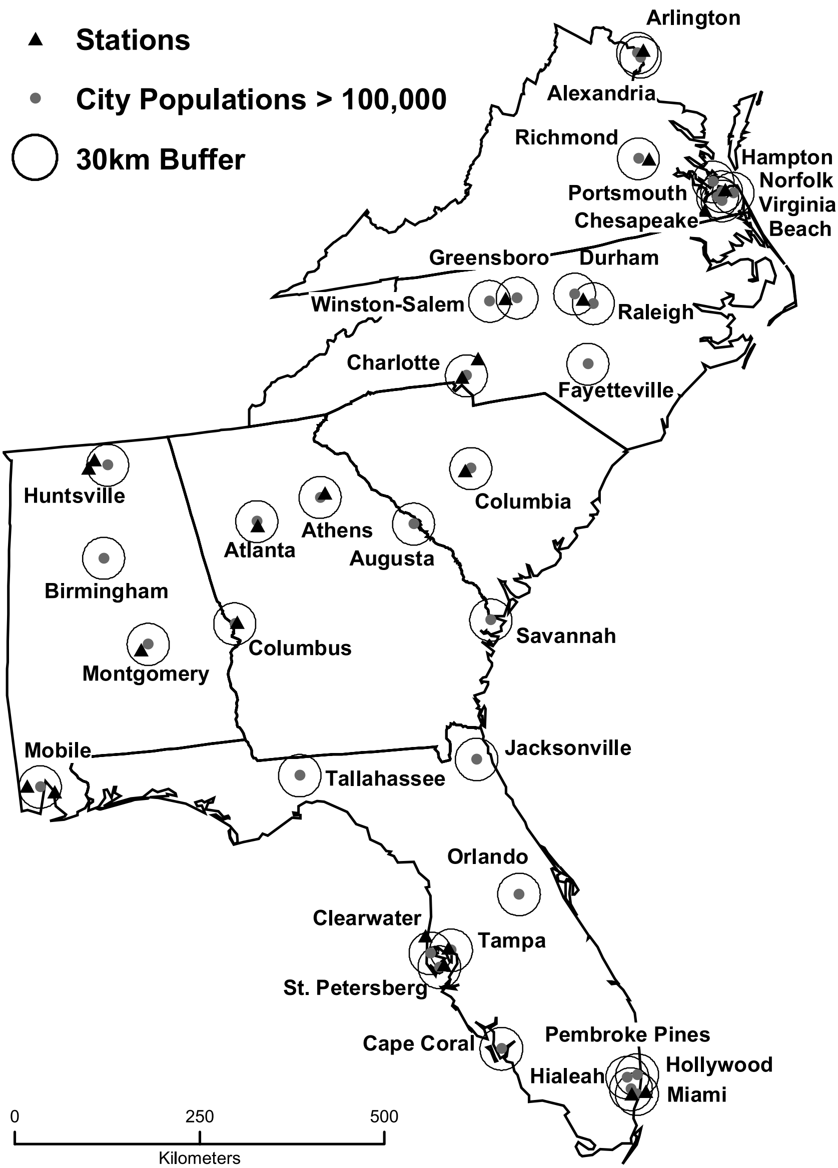

Figure 3. Cities with a 2000 population exceeding 100,000 and climatological stations falling within a 15 km radius of them.

2010) will be adjusted upward, and the long-term trends may begin to show that the southeastern United States are no longer an anomaly in the global patterns.

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