EARTH Interactions

A Comparison of Local and Regional Trends in Surface and Lower-Tropospheric Temperatures in Western North Carolina

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ABSTRACT: Temperature time series for stations in western North Carolina are used to evaluate the potential for an urban signal in the local temperature trend, and to compare a homogeneous temperature record from a mountain-top station to two versions of the lower-tropospheric, satellite-derived temperatures from the Microwave Sounding Unit (MSU). Results regarding the urban signal are in agreement with the conclusion from previous investigations that after a location is urbanized, the local temperature trend is consistent with trends derived from surrounding, more rural stations. With respect to the mountain top and lower-tropospheric temperature comparison, the magnitudes of the two MSU-derived trends for the western North Carolina area are closer to the average annual minimum temperature trend than to the annual average maximum temperature trend.

KEYWORDS: Temperature trends; Urbanization; MSU

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1. Introduction

The globally averaged annual surface temperature time series since 1900 (e.g., Folland et al. 2001; Levinson et al. 2004) appears to be characterized by three distinct periods with differing temporal trends. During the early part of the record a positive trend occurs through the early 1940s, which is followed by a period of little change or possibly a slight negative trend. Since the late 1970s, however, the observed trend in global surface air temperature is approximately 0.2°C decade^{-1} (Karl et al. 2000). Temperature changes appear to be larger in daily minimum temperature (nighttime lows), rather than the daily maximum temperature (daytime highs) for most parts of the world (Karl et al. 1993; Easterling et al. 1997). However, globally averaged temperature trends for the troposphere since 1979 appear to be much less than what has been observed at the surface (Christy et al. 2000).

In part because of the discrepancy between the calculated lower-tropospheric and surface temperature trends, questions regarding the nature of observed warming at the surface continue to be raised. These questions include the impact of land-use/land-cover changes, including urbanization on in situ temperature records, and how much these land-use/land-cover changes impact the observed trend in global or regional averages calculated from individual station temperature records (e.g., Kalnay and Cai 2003; Vose et al. 2004). These questions are compounded at the local level, when the site characteristics of individual stations are considered. For example, Christy and Norris (Christy and Norris 2004) examined stations in central California that were grouped according to whether they were in the irrigated valley, foothills, or mountains of the Sierra Nevada. They found no trend in either maximum or minimum temperatures from stations in the mountains, slight negative trends for maximum temperature at both foothill and valley sites, but significant positive trends in the valley minimum temperatures. They hypothesized that local irrigation increases have differentially impacted valley minimum temperatures through local changes in the energy balance caused by increases in water vapor from the evaporation of irrigation water.

In an attempt to quantify the magnitude of urban warming contamination in local and regional averages, Peterson (Peterson 2003) and Peterson and Owen (Peterson and Owen 2005) concluded that U.S. stations classified as urban circa 1990 showed little annual mean differences from locations classified as rural after adjustments were made for differences in elevation, instrumentation, and latitude. Parker (Parker 2004) stratified days according to wind speed and compared temperature trends for windy and calm days and found little difference between calculated trends. These results are consistent with Boehm (Boehm 1998) who found evidence to suggest that once a location becomes urbanized it yields trends that are consistent with nearby rural sites. Here we examine temperature time series compiled using observations from a group of stations located in western North Carolina, comprised of a mountain-top site, a station located in a moderately urbanized environment, and other more rural sites. In situ temperature trends during the period, plus trends from Microwave Sounding Unit (MSU) lower-tropospheric temperature data for the same region from the University of Alabama in Huntsville (UAH; Christy et al. 2000) version 5.2 (newly reprocessed and released), and the new Remote Sensing Systems lower-troposphere dataset (RSS;

Mears and Wentz 2005) are calculated. Two questions related to differences between surface and lower-tropospheric temperature trends are examined. First, are trends from a station that is urbanized the entire period consistent with surrounding, more rural sites? Second, how do the trends for the high-elevation site compare to MSU lower-troposphere data for the same area?

2. Data

Mean annual minimum and mean annual maximum temperature time series from the six locations listed in Table 1 were used. It is rare that an observing station's time series of temperature can be considered truly homogeneous for any extended period. A truly homogeneous climatic time series has been defined by Conrad and Pollak (Conrad and Pollak 1962) as one where the variations and trends are the result of weather and climate only, whereas a relatively homogeneous time series is one where comparisons with surrounding stations indicate no detectable inhomogeneities. Based on our evaluation, a mountain-top station in the U.S. Cooperative Network near Asheville, North Carolina (Swannanoa 2 SSE, hereafter called Flat Top Mountain), appears to be truly homogeneous. This site has station history information and personal assurance by the observer, G. Goodge (coauthor here), that there have been no landscape or instrument changes, or missing data, that might impact the observed time series for the period 1977–2003. As can be seen in Figure 1, the only appreciable change was the growth of the small tree near the instrument shelter, which, since it was due north of the shelter, had no shading impact. We use the temperature record for a number of Cooperative observing stations in the region around Asheville for comparison with the temperature signal from Flat Top Mountain. Finally, we use the MSU lower-tropospheric (2LT) temperature values for the period 1979–2003 for comparison between the satellite-derived temperatures and surface air temperatures. The 2LT product was chosen since it represents the lower portion of the troposphere and should be most closely related to surface air temperatures, in particular the Flat Top Mountain site.

The urban influence on temperature trends is examined using a station (Downtown Asheville) that has been an urbanized rooftop station for the entire 1977–2003 period (Figure 2). The instruments were moved from one part of the roof to another for repair work during the late 1990s, but then moved back to the original position after the repairs were made. This resulted in discontinuities detected using

Table 1. Cooperative stations used. Data available from the National Climatic Data Center.

Coop No.	Name	Elev (m above sea level)
313106	Flat Top Mountain (Swannanoa 2 SSE)	1317
310301	Downtown Asheville	683
313976	Hendersonville 1 NE*	658
310724	Bent Creek	643
319147	Waynesville*	810
316805	Pisgah Forest	643

* U.S. Historical Climatology Network sites (Easterling et al. 1996).

Figure 1. View of Flap Top Mountain station looking west in (a) 1977 and (b) 2001. Instrument shelter is to the left (south) of the house over grass.

Figure 2. View of downtown Asheville station looking southeast.

the methodology described below, requiring adjustments to the data to make the time series relatively homogeneous.

Mean annual and mean monthly maximum and minimum temperature values for all stations were evaluated and adjusted for artificial change points based on results from two relative change point evaluations. In the first technique, a composite reference series was calculated using a correlation-weighted average of temperature values from stations surrounding the target site. The series of annual and monthly differences between the target series (e.g., mean maximum or mean minimum temperatures from Flat Top Mountain) and the composite reference were evaluated for abrupt changes using three separate change point test statistics. Unfortunately, the homogeneity of a reference series cannot be generally assumed since changes in the reference series components may transfer to the composite reference (Menne and Williams 2005). In the case of values from Flat Top Mountain, all abrupt shifts in the difference series were traced to apparent changes in observations from surrounding stations.

In the second approach, paired temperature series are tested for relative change points. In this case, there is no target or reference series. Rather, temperature series from the region are used to form all possible combinations of paired differences. Each difference series then is examined for abrupt change points and the station whose values are implicated by jumps in three or more difference series is attributed the change point. Evaluation of change points from the various paired difference series using observations from numerous stations in western North Carolina did not reveal any abrupt changes at the Flat Top Mountain target site.

3. Results and discussion

The trend analysis for Flat Top Mountain (Table 2) shows a clear warming signal for the period, with a trend in the annual maximum of 0.63°C decade^{-1} and in the annual minimum of 0.36°C decade^{-1}.

The two MSU 2LT time series for the grid box outlined by 35°–37.5°N, 82.5°–85°W has a trend in the annual temperature time series for 1979–2003 of 0.31°C decade^{-1} (UAH) and 0.34°C decade^{-1} (RSS). Given the 95% confidence limits, the two MSU trends are consistent with the trend in annual minimum temperature for Flat Top Mountain for the same period, and the annual maximum temperature for Downtown Asheville. However, although not truly statistically different (the confidence intervals do overlap), the MSU trends are much less than the observed trend for the annual maximum temperature at Flat Top Mountain.

An area average was derived by arithmetically averaging the four remaining stations shown in Table 1 (i.e., excluding Flat Top Mountain and Downtown Asheville), and linear trends for the area average were calculated. Winter season temperatures have the largest positive trends, which are slightly larger (though not statistically different) for average minimum than for average maximum temperatures. For the winter season, the area average has the largest positive trend in both maximum and minimum temperatures, followed by Flat Top Mountain, while the Downtown Asheville station has the smallest trend. Spring maximum temperatures for Flat Top Mountain and the mean UAH and RSS MSU temperatures also have significant positive trends, as do the fall maximum temperatures for Flat Top Mountain.

Figure 3 shows time series plots for both annual maximum and minimum

Table 2. Trends in annual and 3-month seasonal maximum (max) and minimum temperature (min) in °C decade^{-1}, and 95% confidence intervals for two stations (Flat Top Mountain (Flat Top) and Downtown Ashville (AVL)), the area average of four stations, and the two versions of the Microwave Sounding Unit (mean only). DJF = Dec–Feb; MAM = Mar–May; JJA = Jun–Aug; SON = Sep–Nov.

Season	Flat Top	AVL	Area	UAH MSU	RSS MSU
DJF max	1.33* ± 0.63	0.83* ± 0.58	1.50* ± .09	0.52* ± 0.41	0.60* ± 0.43
DJF min	1.39* ± 0.68	1.06* ± 0.62	1.61* ± 1.19		
MAM max	0.54* ± 0.22	0.08	0.0	0.39** ± 0.38	0.54* ± 0.35
MAM min	0.05	0.0	0.2		
JJA max	0.2	0.0	0.0	0.15	0.05
JJA min	0.14	0.0	0.0		
SON max	0.45** ± 0.41	0.12	0.0	0.29	0.30
SON min	0.04	−0.3	−0.6		
Annual max	0.63* ± 0.27	0.30* ± 0.24	0.52* ± 0.25	0.31* ± 0.22	0.34* ± 0.21
Annual min	0.36* ± 0.23	0.14	0.17		

* Significant at the 5% level.
** Significant at the 10% level.

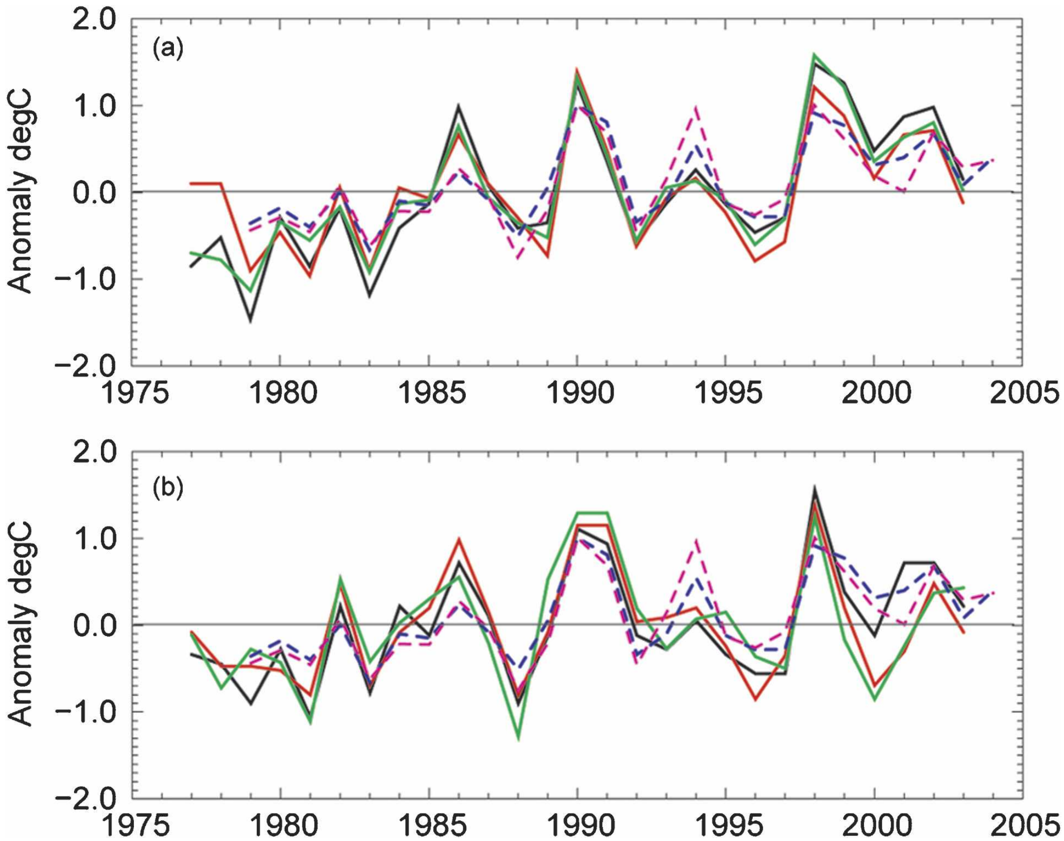

Figure 3. Annual (a) maximum temperature and (b) minimum temperature for Flat Top Mountain (black), Downtown Asheville (red), area average (green), UAH MSU (blue dashed), and RSS MSU (magenta dashed).

temperatures to match the results in Table 2. The two MSU time series are plotted on both graphs. If it is assumed that the temperature data for Flat Top Mountain are strongly related to the free atmosphere, since it is a highly exposed mountain-top site more than 1300 m above sea level and 600 m above the valley floor (Figure 1), then it is interesting to note that the trend for both the MSU datasets, with maximum weighting occurring around 740 hPa or about 2500 m above sea level, is only about half that of the maximum temperature trend.

In general, with station observations that are not as well ventilated as Flat Top Mountain, the expected best relationship would be between maximum temperature and the MSU, since the maximum temperature usually occurs in the mid- to late afternoon, while minimum temperatures usually occur in the early morning when the atmosphere is generally stable and stratified. Being a mountain-top station, Flat Top Mountain is typically well above the inversion layer, and usually is well ventilated even in the early morning hours. Indeed a correlation analysis using the detrended time series (Table 3) shows that both the annual MSU datasets have essentially the same correlation coefficient value for both annual maximum and annual minimum temperature at Flat Top Mountain, although the RSS data show

Table 3. Correlation between annual MSU for both UAH and RSS, and Flat Top, AVL, and the area average using detrended time series. The least squares linear trend was removed from all time series prior to correlation analysis. All values are significant at the 0.01 level.

	UAH/RSS
Flat Top annual max	0.85/0.76
Flat Top annual min	0.86/0.78
AVL annual max	0.87/0.79
AVL annual min	0.81/0.83
Area annual max	0.86/0.79
Area annual min	0.70/0.70

lower correlations than the UAH data. Also the annual minimum temperatures for AVL and the area average show lower correlations with the UAH time series than the maximum temperature. But the RSS data are more highly correlated with the AVL minimum than with the maximum temperature. Recent unpublished research (T. Peterson ????, personal communication) found that, globally, the UAH MSU trends are more closely related to maximum temperature trends than to minimum temperature trends probably, at least in part, because of both the mixing scenario described above and because the surface temperature variations at surface stations in western North Carolina are in agreement with the global temperature time series for the same period. Nevertheless, average minimum surface temperatures at the mountain-top station are more highly correlated with the UAH MSU-derived lower-tropospheric temperatures than the other surface stations (Table 3). However, for the RSS MSU the highest correlation is with the annual minimum temperature for AVL, and correlations with the Flat Top site are lower than for the UAH data. In general the RSS correlations are somewhat lower than for the UAH MSU data.

Addressing the second question, regarding trends in temperature at an urbanized station, also provided interesting results. The Downtown Asheville site has been urbanized the entire period, and the trends are less than the Flat Top Mountain site (though not statistically different at the 95% confidence level). However, they both show, as does the regional average, larger positive trends in annual maximum temperature than annual minimum temperature. Also, the trends for Downtown Asheville are slightly smaller than those for the regional average of the four other stations in Table 1, not including the Asheville or Flat Top Mountain sites. This is in agreement with previous results suggesting that once a station becomes urbanized, it gives consistent trends with surrounding, rural sites.

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