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Twentieth Century Temperature Trends in Colorado's San Juan Mountains

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Abstract

We examine trends in surface air temperature for the San Juan Mountain region in southwestern Colorado from 1895 to 2005. Observations from both National Weather Service (NWS) and Snow Telemetry (SNOTEL) sites are analyzed. Results show a net warming of 1 °C between 1895 and 2005. Most of this warming occurred between 1990 and 2005, when the region experienced rapid and secular increases in temperature. Between 1950 and 1985, there was a cooling trend in the region during which there were significant decreases in the maximum temperature (T_{max}) and almost no trend in the minimum temperature (T_{min}). This cooling trend appears to be, in part, associated with increases in atmospheric aerosols. Between 1990 and 2005, the large increases in temperature anomalies are strongly correlated at the NWS and SNOTEL sites. Annual increases in T_{max} and T_{min} are similar between 1990 and 2005; however, they generally show greater increases during summer and winter, respectively. Spatially, there are similar increases in T_{max} and T_{min} except in the central mountain region, where the increases in T_{min} are larger and started earlier.

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Introduction

Observations in the high altitude regions of the planet during the latter half of the 20th century have suggested that they have been relatively more sensitive to climate change (Beniston et al., 1997; Giorgi et al., 1997; Beniston, 2003; Liu and Chen, 2000, Diaz and Eischeid, 2007). These regions have generally warmed at a greater rate than the global average, with greater increases in daily minimum temperatures than daily maximum temperatures (Beniston et al., 1997; Diaz and Bradley, 1997; Rangwala et al., 2009a). This pattern is also evident in some climate model simulations under greenhouse-warming scenarios (Chen et al., 2003; Rangwala et al., 2009b; Liu et al., 2009). Studies have suggested that increasing influences of snow/ice albedo feedback mechanisms during spring and summer (Giorgi et al., 1997; Chen et al., 2003; Rangwala et al., 2009b), and radiative influences of changes in cloud cover (Duan and Wu, 2006) and atmospheric specific humidity during cold seasons (Ruckstuhl et al., 2007; Rangwala et al., 2009a, 2009b) are important in high elevation regions. Pepin et al. (2005) found that surface temperatures at the majority of high elevation stations across the globe are increasing faster than the free air temperature at the same elevation. However, there is less discrepancy between surface and free air temperatures at mountain summits relative to mountain valleys where most of the observation stations are located.

This study investigates temperature trends in the San Juan Mountain (SJM) region in southwestern Colorado during the 20th century. The SJM region is an east-west-oriented belt of the Rocky Mountain range between 37 and 38.5°N, 105.5 and 109°W (Fig. 1). Hydrologically, this region contributes significantly to the annual flow in major streams and rivers in the southwest, such as the Colorado and Rio Grande. Climate change in the form of increased warming and changes in precipitation will have important consequences on the pattern of streamflow and hence its effect on humans and ecosystems (Dettinger and Cayan, 1995; Arnell, 2003; Nijssen et al., 2001). Recent studies have shown that the mountain region of the interior southwestern United States has warmed at one of the highest rates in the contiguous U.S.A. in the early years of the 21st century (Redmond, 2007; Diaz and Eischeid, 2007; Saunders et al., 2008). These warming trends are accompanied by drying trends in the associated river basins (Saunders et al., 2008) and modifications of climate type at higher elevations (Diaz and Eischeid, 2007).

This study was motivated by a recommendation of the San Juan Mountain Climate Initiative program of the Mountain Studies Institute (www.mountainstudies.org) in Colorado that a comprehensive analysis of the instrumental records was needed to better understand temperature trends in the region. In this paper, we examine annual and seasonal trends in the mean, maximum, and minimum temperatures between 1895 and 2005. We also examine monthly trends in temperatures between 1990 and 2005. A description of the region and the methodology are provided in the next section. In the following sections we analyze observed surface air temperatures in the region between 1895 and 2005, discuss the trends between 1990 and 2005 in greater detail, and provide a concluding discussion.

Methodology

The study area lies between 37 and 38.5°N, 105.5 and 109°W and consists primarily of the 12 counties listed in the caption of Figure 1. A few observation stations on the southern fringes of Montrose and Gunnison counties are also included. There is a comprehensive digitized record of climate observations from the 25 National Weather Service (NWS) stations in the study region from 1950 to 2005 (Table A1 in the Appendix). However, there are only six stations that inform us about the climatic trend in the early half of the 20th century. Owing to large inhomogeneities and physical inconsistencies in the maximum and minimum temperature trends prior to 1950, we incorporated homogenized observations available

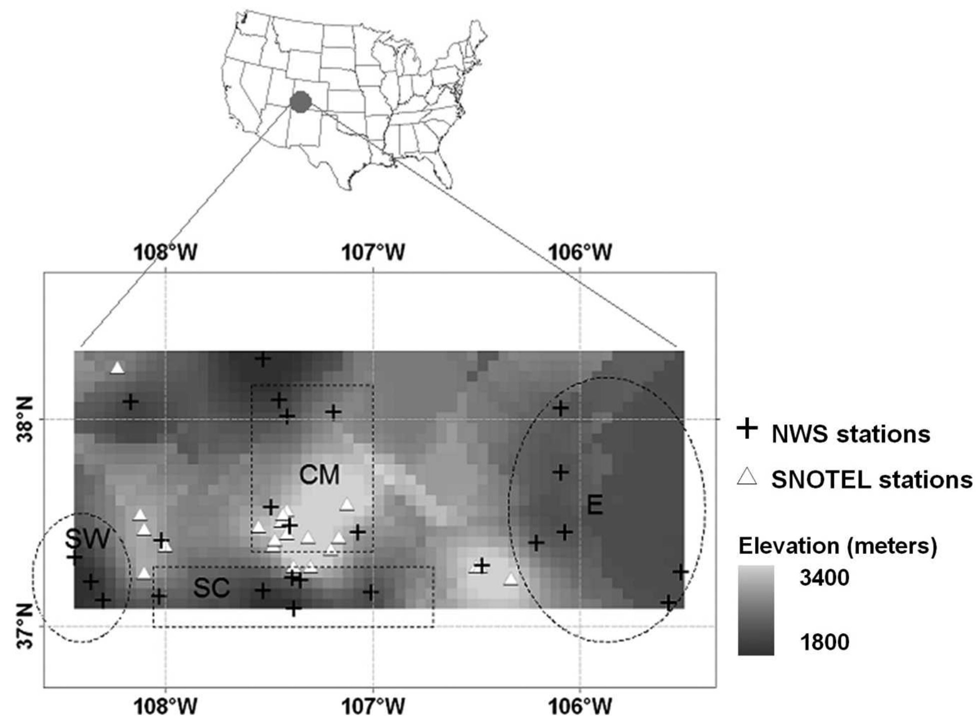

FIGURE 1. Spatial distribution of the National Weather Service and SNOTEL stations. Most of the observation stations are from these 12 counties: Archuleta, Conejos, Dolores, Hinsdale, La Plata, Mineral, Montezuma, Ouray, Rio Grande, Saguache, San Miguel, and San Juan. The NWS stations are grouped into the South West (SW), Central Mountains (CM), South Central (SC), and East (E) regions as shown by the enclosed curves.

from the United States Historical Climatology Network (U.S. HCN version 2) between 1895 and 2005. There were only six NWS stations in our study region for which the homogenized data were available for this entire period—Del Norte, Telluride, Manassa, Saguache, Montrose, and Hermit. We used these six stations to estimate temperature trends between 1895 and 1949. Since only two stations have observations prior to 1912, we suggest caution in the interpretation of our results prior to 1912.

All data are compiled as monthly averages. Missing monthly data (<5%) from NWS stations between 1950 and 2005 are estimated using a weighted average of values from neighboring stations. Between 1950 and 2005, our analysis includes a temporally variable number of stations. Because the changing distribution of stations with time could affect the calculated trends, we compared the time series using all 25 NWS stations with that using only the 16 stations for which we have a continuous record. Figures A1 and A2 in the Appendix show that there is no significant difference between the two time series and their trends, so we use all 25 NWS stations in our analysis. Long-term temperature trends are analyzed on annual and seasonal bases between 1895 and 2005. Trends in the daily maximum and minimum temperatures are also examined to provide insights into the relative importance of the physical mechanisms for surface warming. Linear regression on annual and seasonal temperatures is performed during recent decades, and results are presented for the 1990–2005 period. We have also used the $5^\circ \times 5^\circ$ gridded Global Historical Climatology Network (GHCN) land surface data set obtained from the National Climatic Data Center (NCDC) to compare SJM temperature trends with those in other geographical regions of the United States for the 1990–2005 period.

Since the mid-1980s, weather observations in our study region are also available from 23 Snow Telemetry (SNOTEL) sites managed by the National Resources Conservation Service (see Table A2 in the Appendix). The SNOTEL stations have been used primarily to measure snow water equivalent. Caution is suggested in the interpretation of SNOTEL temperatures because artificial trends could be created by changes in (a) the physical surroundings (e.g. vegetation) and distribution of snowpack, and (b) the instrumentation (Doesken and Schaefer, 1987; Julander et al., 2007). Replacement of temperature sensors at the SNOTEL sites in our study region occurred approximately during 1985, 1993, and 2004. Julander et al. (2007) suggested that inconsistent mounting of sensors at several sites in the SNOTEL network has occurred and it can affect the accuracy of the measurements. Julander et al. (2007) also found inconsistencies in the reporting time of observations during the 1970s, an issue that was minimized since the 1980s when better instruments were installed. This issue does not affect our analysis because the SNOTEL temperature records in our analysis begin in 1984. Pepin et al. (2005) found that, between 1982 and 1999, the most anomalous SNOTEL observations relative to NWS (GHCN) observations were in Oregon and Utah and not Colorado. For quality control, we examined the daily record for erroneous values and omitted them in calculating the monthly means. Moreover, in our analysis, we find strong correlations between the NWS and SNOTEL mean temperature anomalies, both annually and seasonally (Fig. 2), for the 1984–2005 period. Although this gives us additional confidence in the quality of the SNOTEL temperatures, we do not discount the possibility that differences between SNOTEL and NWS observations are caused by the non-uniformity in data collection in the SNOTEL network.

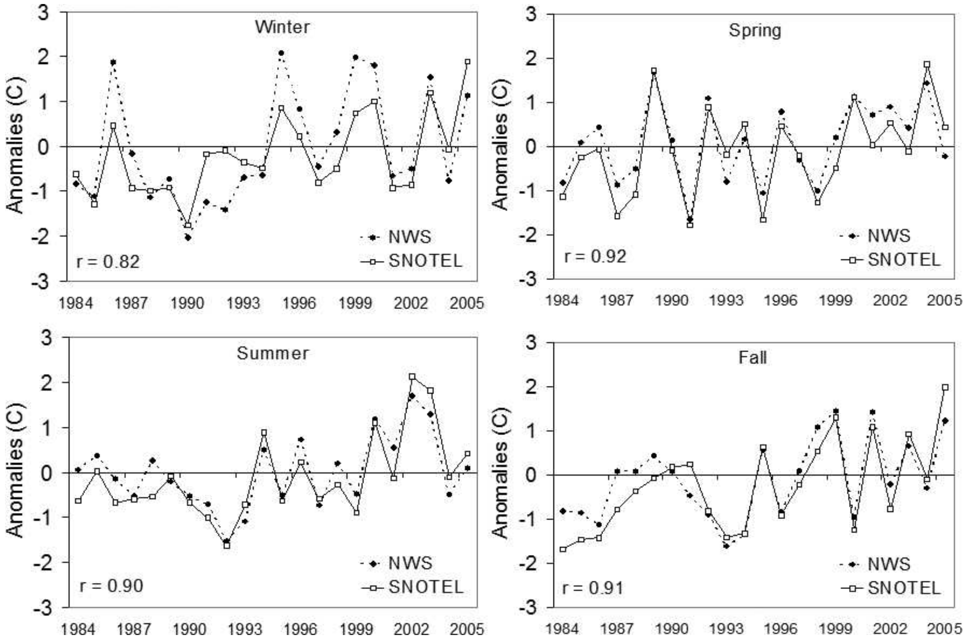

FIGURE 2. Comparison of seasonal temperature anomalies (°C) between NWS (7 stations) and SNOTEL (13 stations) stations which are located within 37–37.5°N and 107–107.5°W. "*r*" gives the correlation coefficient value.

Temperature Trends in the 20th Century

In this section, we examine time series of mean (T_{mean}), maximum (T_{max}), and minimum (T_{min}) temperatures during the 20th century. Figure 3 shows the annual mean surface air temperature in the SJM region during the 20th century. In general, it shows a cooler period between 1910 and 1930, which is followed by warming between 1935 and 1955, cooling of about 1 °C between 1955 and 1975, and a rapid warming of about 1 °C from 1995 to 2005. Overall, the mean annual surface air temperature in the region has increased by a little more than 1 °C between 1895 and 2005. However, this increase does not appear to result from a gradual long-term warming trend in the T_{mean} anomalies but rather because of a large secular increase in T_{mean} that occurs after 1995. Temperature trends from the SNOTEL sites in the region also suggest a 1 °C increase in surface air temperature between 1984 and 2005, most of which occurs between 1995 and 2005. There is a strong correlation ($r = 0.90$) between the T_{mean} anomalies at the SNOTEL and NWS sites.

To better understand the long-term changes in T_{mean}, we next examined changes in T_{max} and T_{min}. Figure 4a shows the trends in T_{max} between 1895 and 2005, which are similar to the trends in T_{mean} ($r = 0.90$). There is a decreasing trend in T_{max} from the 1950s until 1990 and a rapidly increasing trend between 1995 and 2005. The latter is strongly correlated at both the NWS and SNOTEL sites. The T_{min} anomalies in Figure 4b show a gradual long-term warming trend between 1920 and 1995 followed by a rapid warming of 1 °C between 1995 and 2005, which also corresponds to the increases observed at the SNOTEL sites.

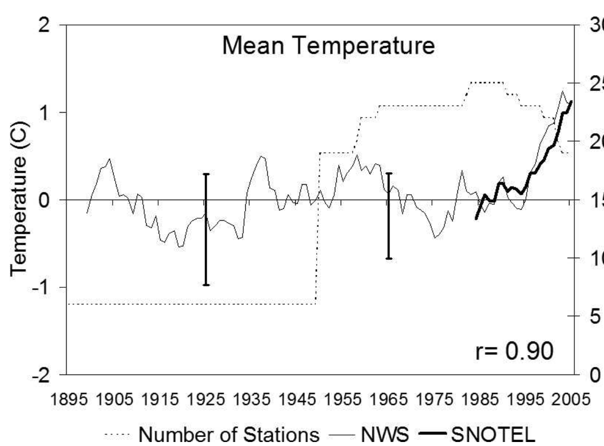

FIGURE 3. Anomalies in mean annual surface air temperature (°C) in the San Juan Mountains region between 1895 and 2005 relative to the 1960–1990 period. The light and bold curves show five-year moving average trends in temperature at the NWS and SNOTEL sites, respectively. The dashed curve shows the number of NWS stations. The number of SNOTEL stations stays constant between 1984 and 2005. The error bars describe the mean standard deviation (2 σ) in NWS temperatures for the 1895–1949 (left) and 1950–2005 (right) periods. "*r*" describes the correlation between the NWS and SNOTEL temperatures between 1984 and 2005.

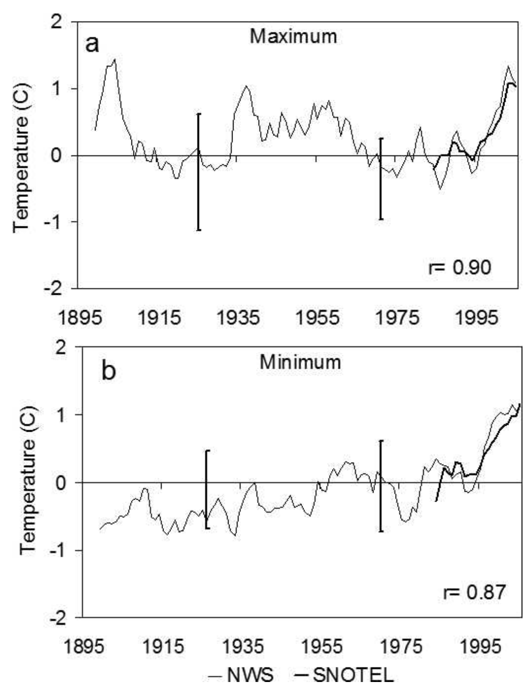

FIGURE 4. Same as Figure 3 but for the annual (a) maximum and (b) minimum temperature.

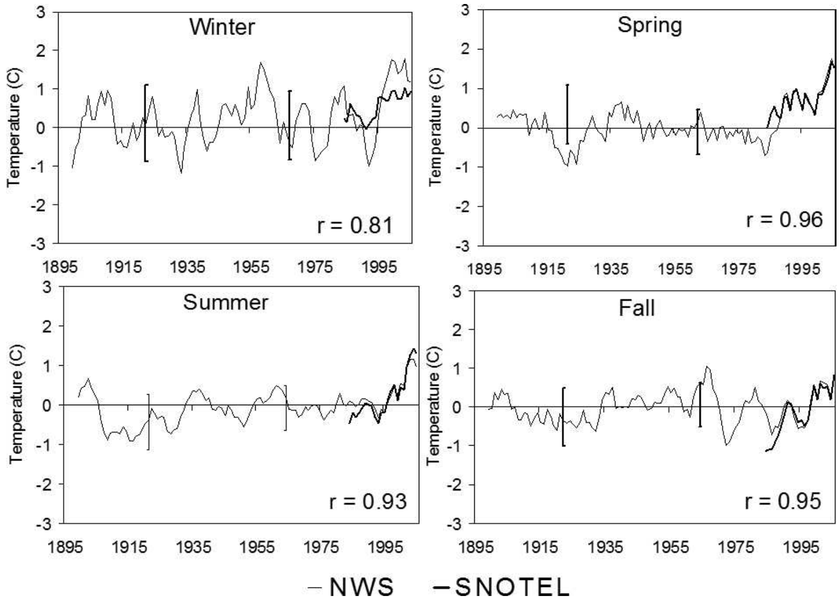

FIGURE 5. Same as Figure 3 but for T_{mean} during each season.

However, unlike SNOTEL temperatures, the NWS temperatures show a large increase in T_{min} (1 °C) within a period of less than 5 years, starting in 1995, followed by near constant temperatures until 2005. There is an overall weak correlation between T_{max} and T_{min} on an annual basis. The decreasing trend in T_{max} (−0.17 °C/decade) between 1950 and 1990 is stronger than the increasing trend in T_{min} (0.02 °C/decade) and is responsible for the decrease in T_{mean} during this period. After 1990, both T_{min} and T_{max} are increasing rapidly and contribute to the increase in T_{mean}.

The large positive anomalies in T_{mean} prior to 1912 are caused by questionably large T_{max} anomalies. For the same time period, T_{min} has negative anomalies. We view the data for this period as suspect because we are unaware of any specific physical mechanisms which could explain the large inconsistency between T_{max} and T_{min} anomalies. We caution the reader in the interpretation of our analysis during this early part of the record.

We next examine seasonal temperature trends in Figures 5 and 6 to determine whether there are significant seasonal differences in temperature trends. Unlike other seasons, there is large interannual and interdecadal variability in mean winter temperature anomalies. This large variability might result, in part, from variations in winter precipitation, and therefore snow cover, influenced by synoptic-scale Pacific influences from the El Niño Southern Oscillation (e.g. Dettinger et al., 1998), the Pacific Decadal Oscillation (e.g. Latif and Barnett, 1994) and the Pacific Quasi-decadal Oscillation (Wang et al., 2009). In spring, large warming trends have occurred during the 1920–1935 and 1980–2005 periods. Summer also experienced greater warming trends during these periods; however, they are lower in magnitude.

Relative to the long-term mean for the 20th century, the warming during spring and summer between 1995 and 2005 is unprecedented, and it is primarily responsible for the sudden and rapid warming observed in the SJM region in recent decades. Large positive anomalies in temperatures are also observed during winter between 1990 and 2005; however, such anomalies appear to have occurred in the past, too. Relatively smaller increases in temperature have occurred during fall.

Similar to the annual trends, T_{min} also shows a gradual warming trend during the 20th century in all seasons (Fig. 6). There is no long-term warming trend for T_{max} during any season. In fact, during fall, there appears to be a slight cooling trend in T_{max} in the latter half of the 20th century. Furthermore, during fall

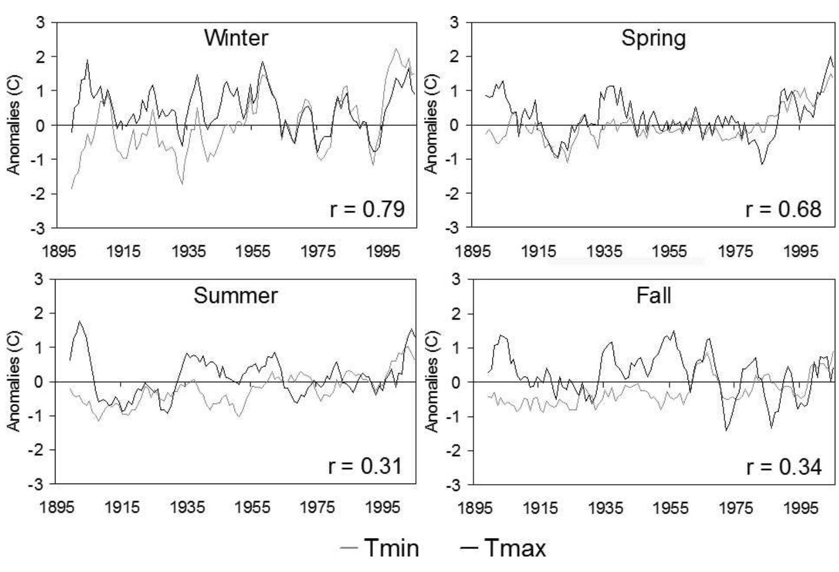

FIGURE 6. Seasonal trends in the T_{min} (light curve) and T_{max} (dark curve) temperatures (°C) between 1895 and 2005 at the NWS stations in the SJM region. All curves are five-year running means. The "*r*" values show correlation between the two curves.

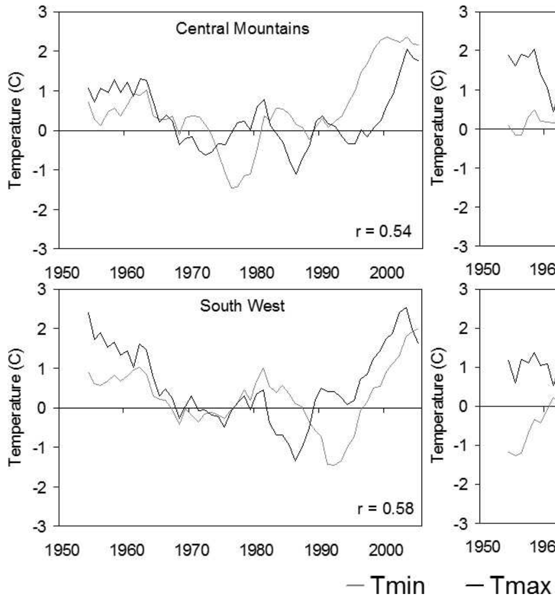

FIGURE 7. Anomalies of T_{min} (light curve) and T_{max} (dark curve) temperatures (°C) in the four regions identified in Figure 1 between 1950 and 2005. All curves are five-year running means. The "*r*" values show correlation between the two curves.

and summer, there is much lower correlation between T_{max} and T_{min} as compared to winter and spring. Between 1990 and 2005, T_{max} increases more than T_{min} during summer and spring, whereas T_{min} shows greater increases during winter. Fall has much lower increases in both T_{max} and T_{min} relative to other seasons.

To understand the spatial patterns among the temperature trends in the SJM region, we examined four sub-regions and refer to them as Southwest, Central Mountains, South Central, and East (see Fig. 1). Figure 7 shows decreases in T_{max} in each of these regions between 1950 and 1990. During this period there are greater decreases in T_{max} than T_{min}, and the decreases in T_{max} occur over a longer period. The largest decreases in T_{max} occur in the Southwest (−0.6 °C/decade) and the East (−0.5 °C/decade) sub-regions, although the Southwest region shows the most continuous decrease in T_{max}. The 1990–2005 period is marked by large and secular increases in T_{min} and T_{max} in all four sub-regions. Increases in T_{min} lead T_{max}, except in the Southwest. In the Central Mountains, Figure 7 shows rapid increases in T_{min} starting in the early 1990s, while the increases in T_{max} start in the late 1990s.

Table 1 shows trends in annual T_{mean}, T_{max} and T_{min} for different time periods. These trends and their significance are estimated using the Theil-Sen slope estimator and Mann-Kendall test, respectively, as described in Helsel et al. (2006). All trends are significant except the 75-year (1931–2005) and 50-year (1956–2005) trend for T_{max}.

TABLE 1

Trends (°C/decade) in T_{mean}, T_{max}, and T_{min} calculated using Theil-Sen non-parametric slope estimator for the 1931–2005 (75 years), 1956–2005 (50 years), 1976–2005 (30 years), and 1990–2005 periods for the SJM region. Superscript letters denote the significance level estimated from the Mann-Kendall test (N: not significant; A: $p < 0.001$; B: $p < 0.01$; C: $p < 0.05$).

Time Period	T_{mean}	T_{max}	T_{min}
1931–2005 (NWS)	0.08^C	-0.02^N	0.17^A
1956–2005 (NWS)	0.16^C	0.11^N	0.20^B
1976–2005 (NWS)	0.45^A	0.44^C	0.51^B
1990–2005 (NWS)	1.03^B	1.15^B	0.87^C
1990–2005 (SNOTEL)	1.00^A	0.94^A	1.04^C

Temperature Trends between 1990 and 2005

We examine the temperature trends between 1990 and 2005 in greater detail because the SJM region experiences a sharp and continuous increase in surface temperature during this period. These temperature increases are observed at both the NWS and SNOTEL sites. The mean temperature at both the NWS and SNOTEL sites increased by about 1 °C/decade (Fig. 8). The increases in T_{max} and T_{min} are also similar at the NWS and SNOTEL sites. The rapid warming between 1990 and 2005 also occurs during each season. However, the winter and summer warming trends differ between the NWS and SNOTEL sites. Prominent temperature increases at NWS sites occur during winter (1.5 °C/decade), while at SNOTEL sites they occur during summer (1.5 °C/decade). The SNOTEL sites (average elevation = 3200 m) are about 760 m higher than the NWS sites (average elevation = 2130 m), and they experience the bulk of snowmelt later in the year than the NWS sites. For example, there is likely to be negligible snow cover at the elevations associated with NWS stations (<3050 m) in early summer, whereas there is still substantial snow cover at the elevation associated with SNOTEL sites (>3050 m). Therefore, temperature changes driven by the

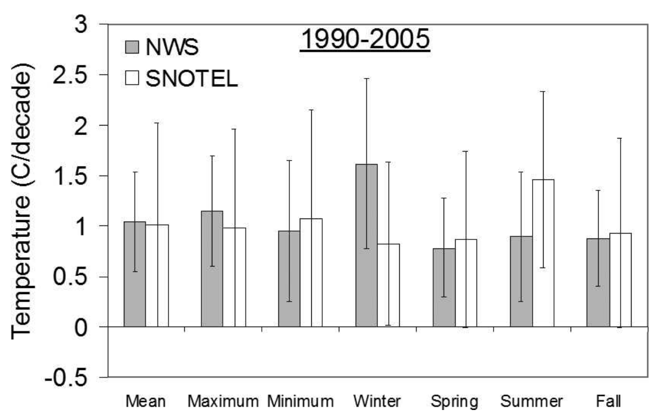

FIGURE 8. Linear regression in annual (mean, maximum, and minimum) and seasonal (winter, spring, summer, and fall) surface air temperatures (°C/decade) during the 1990–2005 period in the San Juan Mountain region from both the NWS and SNOTEL observations. Error bars show one standard deviation.

TABLE 2

Comparison of temperature trends from linear regression between NWS and SNOTEL sites for the 1990–2005 period. Annually and for each season, the table describes which of these two sites has a statistically greater trend in the mean, maximum, and minimum temperature. Statistical significance is measured based on 1-tailed *t*-test (N: not significant; A: $p < 0.001$; B: $p < 0.01$; C: $p < 0.05$).

	Mean	Maximum	Minimum
Annual	N	N	N
Winter	NWS (A)	N	NWS (B)
Spring	SNOTEL (C)	N	SNOTEL (B)
Summer	SNOTEL (C)	SNOTEL (C)	SNOTEL (C)
Fall	N	N	N

snow-albedo feedback mechanism would be important during the earlier part of summer at higher elevations. Enhanced snow-albedo effects in mountain regions have been reported across the global scale (Pepin and Lundquist, 2008).

The rate of winter warming at the NWS sites is about twice that of the warming during spring, summer, and fall. However, there is a significant variability in the warming rate during winter. At the SNOTEL sites, the winter warming is about half that at the NWS sites. Table 2 provides a comparison of annual and seasonal temperature trends (mean, maximum, and minimum) between NWS and SNOTEL sites for the 1990–2005 period, and also indicates the differences that are statistically significant. The table shows that differences in temperature trends between NWS and SNOTEL sites are significant during winter, spring, and summer. T_{min} shows greater increases at NWS sites during winter and at SNOTEL sites during spring. However, this is not true for T_{max} during winter and spring. For summer, increases in both T_{max} and T_{min} are greater at the SNOTEL sites relative to the NWS sites.

Reviews of late 20th century climate change in different mountain regions around the world by Diaz and Bradley (1997) and Beniston et al. (1997) found that the annual increases in T_{min} were about two times higher than T_{max}. Rangwala et al. (2009a) obtained a similar result for the Tibetan Plateau. Our analysis in the SJM region was consistent with such greater rates of increase in T_{min} between 1950 and 1990, but we found equal increases in minimum and maximum temperatures at both the SNOTEL and NWS sites since 1990 (Fig. 8). Therefore, in the SJM region, there may be a greater influence of external climatic factors, which lead to the large increases in T_{max} between 1990 and 2005.

At the NWS sites, it appears that T_{max} has a greater influence on the mean warming trends during spring and summer. Therefore, warming during spring and summer might be associated more with factors that influence the surface insolation and its absorption. These factors include the influence of (a) changes in snow cover owing to changes in precipitation and melting processes during spring, and (b) changes in cloud cover and precipitation during summer. Our preliminary analysis of the precipitation record from the six HCN stations suggests significant negative correlation ($r < -0.6$) between T_{max} and precipitation during summer, spring, and fall for the 1950–1990 period. However, between 1990 and 2005, this negative correlation is only significant during summer. Decreases in precipitation between 1990 and 2005 indicate possible decreases in cloud cover and soil moisture, both of which will increase T_{max}.

At the SNOTEL sites, T_{min} seems to have a much greater influence on the mean warming trends during winter, while T_{max} has a greater influence during summer. The greater influence of T_{min} on the mean warming trend during winter at SNOTEL sites implies that these sites might have experienced increases in downward longwave fluxes owing to possible increases in cloud cover or specific humidity.

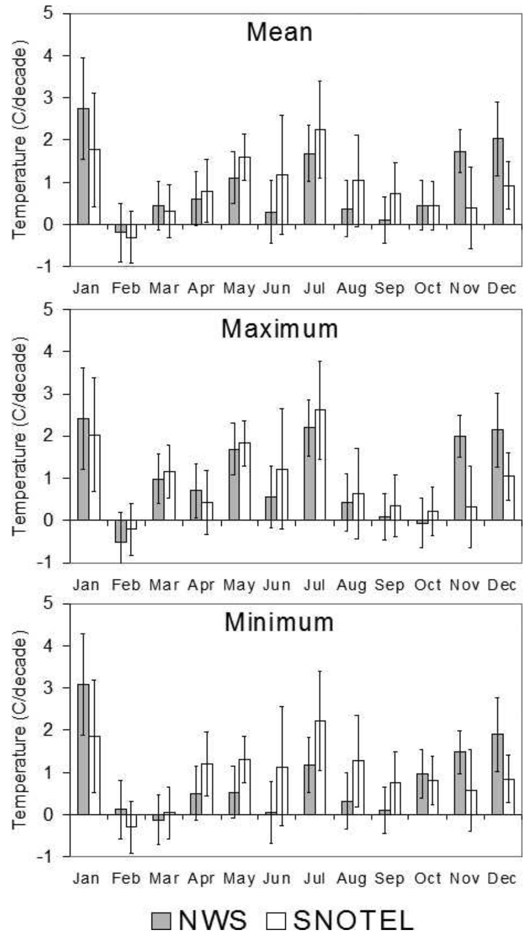

FIGURE 9. Linear regression for each month in daily mean, maximum and minimum temperatures (°C/decade) during the 1990–2005 period in the San Juan Mountains region from both the NWS and SNOTEL observations. Error bars show the standard deviations.

We next analyze linear trends in the mean, maximum, and minimum temperatures between 1990 and 2005 on a monthly basis. Figure 9 shows that January, July, and May experience the largest warming rates overall. The four months showing the largest warming rates at the NWS sites, in descending order, are January, December, November, and July; at the SNOTEL sites they are July, January, May, and June. Generally, we found that winter months have warmed at a higher rate at the NWS sites, while summer months warmed more at the SNOTEL sites. At the NWS sites, T_{min} shows much greater increases than T_{max} in January; this is reversed from May through July. Greater increases in T_{max} also occur at the SNOTEL sites during summer. Furthermore, there is a conspicuous cooling trend in February at both the SNOTEL and NWS sites.

Discussion

We have examined temperatures from 25 NWS and 23 SNOTEL stations in the SJM region. Our analysis suggests that the region has warmed by 1 °C between 1895 and 2005 and that almost all of this warming has occurred between 1990 and 2005. Prior to 1990, there is a long-term warming trend in T_{min} for each season but no discernable trend in T_{max}. The general

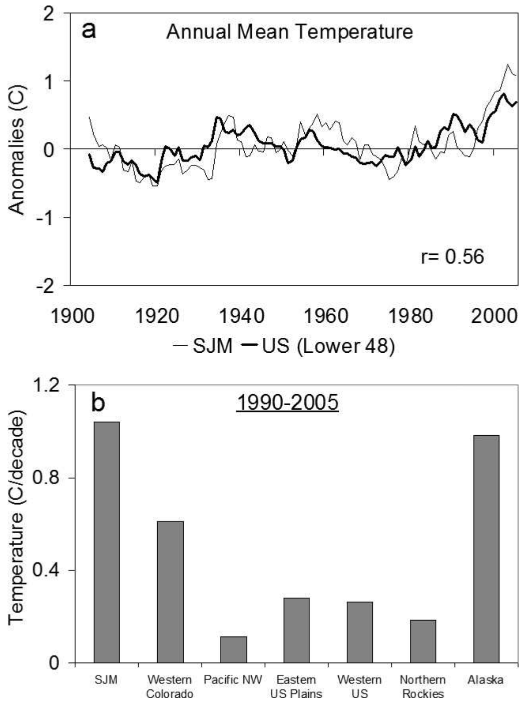

FIGURE 10. (a) Comparison of SJM (all NWS stations) and lower 48 United States' surface air temperature anomalies (°C). Curves are five-year running means. U.S. temperature anomalies are obtained from National Climatic Data Center (NCDC). (b) Temperature trends (°C/decade) for different geographic regions compared to the SJM region for the 1990–2005 period. Trends in regions other than SJM are estimated using the 5° × 5° gridded Global Historical Climatology Network land surface data set provided by NCDC.

pattern of warming in the SJM region during the 20th century is similar to the pattern observed at the global scale: (i) a gradual warming during the early half of the century, (ii) a mid-century cooling, and (iii) a relatively rapid warming in the latter part of the century. Figure 10a compares the 20th century trends in mean temperatures in the contiguous United States to the SJM region. The comparison shows that the mid-century cooling and the late century warming occurred later in the SJM region, although the recent warming occurred much more rapidly in the SJM region.

The SJM region experienced a cooling of about 1 °C between 1955 and 1975. In fact, between 1950 and 1990 there is a large decreasing trend in T_{max} (−0.17 °C/decade) and almost no trend in T_{min} (0.02 °C/decade), which indicates that the decreasing mean temperature during this period is primarily associated with the decrease in T_{max}. A possible explanation for these trends could be related to the "solar dimming" phenomenon during this period. One of the direct effects of particulate pollution in the atmosphere is to reduce incoming solar radiation at the surface, thereby causing a decrease in daytime heating of the surface and hence affecting T_{max} more than T_{min}. This effect is thought to be, in part, responsible for a global-scale cooling from 1940 to 1980, although it was mostly restricted to the northern hemisphere (Stanhill and Cohen, 2001; Wild et al., 2005). Estimates of atmospheric sulfate burden for the 20th century from Boucher and Pham (2002) indicate an increasing trend between 1960 and 1980 for our region. This period is also associated with the largest decrease in T_{max} in our analysis. Moreover, the increases in T_{max} anomaly around 1935 might be owing to reductions in atmospheric load of mineral dust from the western United States rangeland, such as the Colorado Plateau, driven by imposed restrictions on grazing (Neff et al., 2008)

Between 1990 and 2005, both T_{max} and T_{min} increased rapidly. The temperature anomalies are strongly correlated between the NWS and SNOTEL stations. The largest warming at the SNOTEL sites occurred during summer while it was largest during winter at the NWS sites. Spatially, there are similar increases in T_{max} and T_{min} except in the central mountain region, where increases in T_{min} started earlier and were greater. The rapid warming during this period is largely owing to large increases in T_{max} during spring and summer. These results suggest possible trends towards early snowmelt in spring and reduced soil moisture in summer in recent decades.

Figure 10b provides a comparison of the warming trend in the SJM region to other regions in the United States during the 1990–2005 period. It appears that the warming in western Colorado that includes the SJM region has been one of the highest in the contiguous United States during recent decades, which has also been suggested by Redmond (2007) and Saunders et al. (2008). The 1990–2005 warming in the SJM region is greater than the trend for western Colorado.

Climate change in the SJM region has significant implications for water resources. McCabe and Wolock (2007) suggested that increased warming in the Colorado River basin that is not accompanied by increased precipitation will lead to more severe water supply shortages than in the past. The rapid warming trend since 1990 in the SJM region may be, in part, associated with regional circulation and precipitation changes. Further research is required to understand the causal mechanisms and to determine the relative contributions of natural variability and anthropogenic forcing to the recent rapid temperature increase. Analysis of changes in precipitation, snow cover, cloud cover, and specific humidity during this period will provide useful insights to help predict whether these recent warming trends will continue during the coming decades.

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Appendix

TABLE A1

NWS stations included for temperature observations. All stations were considered in calculating the trends.

#	Name	Elevation (m)	Duration
1	MESA VERDE NATIONAL PARK (055531)	2155	1950–2005
2	CORTEZ (051886)	1884	1950–2005
3	YELLOW JACKET 2 W (059275)	2191	1962–2002
4	RICO (057017)	2697	1959–2001
5	TELLURIDE (058204)	2673	1895–2005
6	NORWOOD (056012)	2140	1950–2005
7	RIDGWAY (057020)	2134	1982–2005
8	OURAY (056203)	2390	1950–2005
9	SILVERTON (057656)	2844	1950–2005
10	LEMON DAM (054934)	2466	1982–2005
11	VALLECITO DAM (058582)	2332	1950–2005
12	FORT LEWIS (053016)	2316	1950–2005
13	DURANGO (052432)	2012	1950–1990
14	IGNACIO 1N (054250)	1969	1950–1993
15	PAGOSA SPRING (056258)	2164	1950–2005
16	LAKE CITY (054734)	2707	1959–2005
17	HERMIT 7 ESE (053951)	2743	1895–2005
18	WOLF CREEK PASS 1 E (059181)	3243	1958–2001
19	DEL NORTE (052184)	2402	1895–2005
20	MANASSA (055322)	2350	1895–2005
21	ALAMOSA WSO AP (050130)	2298	1950–2005
22	MONTE VISTA (055706)	2335	1950–2005
23	CENTER 4 SSW (051458)	2338	1950–2005
24	SAGUACHE (057337)	2344	1895–2005
25	MONTROSE (055722)	1763	1895–2005

TABLE A2

SNOTEL stations included for temperature observations.

#	Name	Elevation (m)	Duration
1	BEARTOWN	3536	1984–2005
2	CASCADE	2707	1987–2005
3	CASCADE #2	2719	1991–2005
4	COLUMBINE PASS	2865	1987–2005
5	COLUMBUS BASIN	3287	1995–2005
6	EL DIENTE PEAK	3048	1987–2005
7	IDARADO	2987	1987–2005
8	LILY POND	3353	1984–2005
9	LIZARD HEAD PASS	3109	1986–2005
10	LONE CONE	2926	1987–2005
11	MANCOS	3048	1997–2005
12	MIDDLE CREEK	3429	1984–2005
13	MINERAL CREEK	3060	1987–2005
14	MOLAS LAKE	3200	1987–2005
15	RED MOUNTAIN PASS	3414	1986–2005
16	SCOTCH CREEK	2774	1987–2005
17	SLUMGULLION	3487	1984–2005
18	SPUD MOUNTAIN	3249	1987–2005
19	STUMP LAKES	3414	1987–2005
20	UPPER RIO GRANDE	2871	1987–2005
21	UPPER SAN JUAN	3109	1984–2005
22	VALLECITO	3316	1987–2005
23	WOLF CREEK SUMMIT	3353	1987–2005

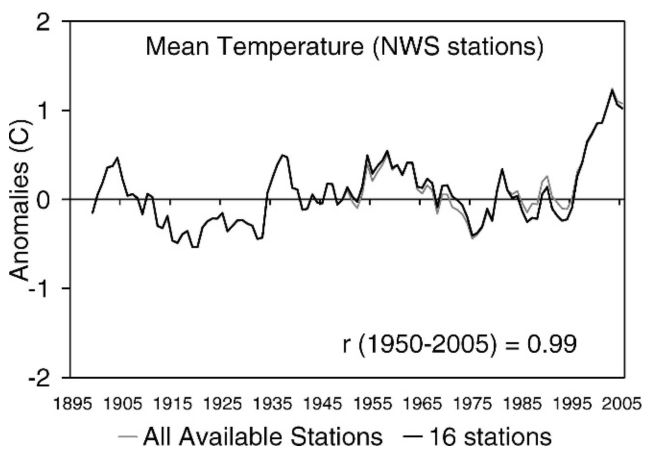

FIGURE A1. Comparison of time series of annual temperature anomalies using all 25 NWS stations with that using the 16 stations that have a continuous record for the 1950–2005 period.

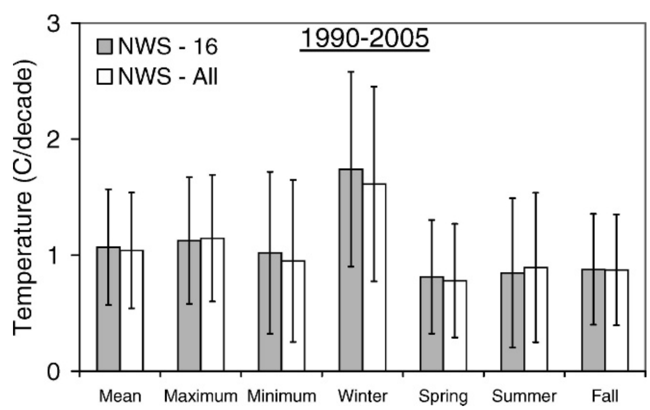

FIGURE A2. Comparison of linear regression of temperature anomalies using all 25 NWS stations with that using the 16 stations that have a continuous record for the 1950–2005 period.