Analysis of adjustments to the United States Historical Climatology Network (USHCN) temperature database

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Received 30 January 2002; revised 10 April 2002; accepted 14 April 2002; published 21 May 2002.

[1] The United States Historical Climatology Network (USHCN) temperature database is commonly used in regional climate analyses. However, the raw temperature records in the USHCN are adjusted substantially to account for a variety of potential contaminants to the dataset. We compare the USHCN data with several surface and upper-air datasets and show that the effects of the various USHCN adjustments produce a significantly more positive, and likely spurious, trend in the USHCN data. *INDEX TERMS:* 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3399 Meteorology and Atmospheric Dynamics: General or miscellaneous; 1610 Global Change: Atmosphere (0315, 0325)

1. Introduction

[2] Numerical climate models continue to simulate past surface warming and predict future significant warming on the regional and global scales given the ongoing buildup of greenhouse gases [*Houghton et al.*, 2001]. In an attempt to evaluate the primary output of these models, climate scientists have spent considerable effort assembling and evaluating temperature time series from stations throughout the world. Considered one of the best of its type, the United States Historical Climatology Network (USHCN) dataset consists of temperature records from 1,221 stations spanning most of the 20th century [*Karl et al.*, 1990]. An important feature of the USHCN is an extensive metadata file aiding in adjustments to the temperature data associated with station moves, instrument changes, microclimatic changes near the station, urbanization, and/or time of observation biases. As a result, there are many versions of the USHCN ranging from the raw temperature time series to more widely-used datasets that have been extensively adjusted for multiple potential contaminants to the record.

[3] Considerable debate surrounds the many adjustments that can produce highly statistically significant changes to the underlying trends in the USHCN dataset. Many station records that once showed cooling over the 20th century may be adjusted into time series that show warming over the same time period. All scientists agree that the raw records are in need of some adjustment, but the adjustments applied to the temperature data may result in bias errors that are greater than any errors in the raw time series. In this investigation, we examine trends between various USHCN datasets and compare the trends with those from other temperature databases available for the United States. The goal is to determine if the adjustments made to the raw data are producing trends in temperatures that are consistent (or not consistent) with other datasets available for the conterminous United States.

2. United States Temperature Datasets

[4] We use the following six United States temperature datasets in this investigation:

1. The first dataset includes the raw, unadjusted, temperature data used to construct the USHCN time series (referred to as RAW) from 1,221 stations across the conterminous United States [*Karl et al.*, 1990]. We converted all monthly values into anomalies based on the 1961–1990 normal period and annualized the record for each station and year. If any of the 12 monthly anomalies was missing, the annual temperature anomaly was considered missing. This resulted in 8,829 missing annual temperature values in the RAW dataset over the period 1930–2000 representing 10 percent of all data. The annual anomalies were then areally-averaged to generate the annual temperature anomalies for the conterminous United States. In addition to simply averaging the annual anomalies across all stations, we interpolated the station data to a grid and then averaged the values across the grid system. We found that gridding the data had virtually no effect on the end results. Our use of annual, as opposed to monthly, time series simplifies the analyses and allows direct comparisons with other similar recent studies [e.g., *Hansen et al.*, 2001].
2. The second dataset, referred to as the FILNET series, contains the temperature time series that has been adjusted for time of observation biasing [*Karl et al.*, 1986], changes to the new Maximum/Minimum Temperature System (MMTS) equipment [*Quayle et al.*, 1991], station history, including other instrument adjustments [*Karl and Williams*, 1987], and an interpolation scheme for estimating missing data from nearby highly correlated station records. Despite the attempt to eliminate missing data, there remained 1,191 missing annual temperature anomalies representing only one percent of the total dataset. We followed the procedures described above to generate the FILNET annual temperature anomalies for the study area over the 1930–2000 time period.
3. The urban-adjusted time series, referred to as URB-ADJ, is essentially the FILNET dataset with a regression-based adjustment to account for urbanization near the station [*Karl et al.*, 1988]. All procedures described above were used to generate the annual anomalies for the United States for the URB-ADJ dataset.
4. The Intergovernmental Panel on Climate Change (IPCC) utilizes a temperature dataset originally developed by *Jones* [1994] comprised of station records interpolated to 5° latitude by 5° longitude grid cells. The original station records are extensively checked for homogeneity and representativeness with every effort made to identify and eliminate errant values. The monthly station observations are expressed as deviations (anomalies) from a reference period defined as 1961 to 1990 and then interpolated into the 5° latitude by 5° longitude grid-boxes. A total of 24 grid cells largely cover the conterminous United States and the record includes sea-surface temperatures for the coastal cells. There are no missing data over the 1930–2000 time period.
5. We assembled the satellite-based time series of lower-tropospheric monthly temperature anomalies (the "MSU2LT" series) available from 1979–2000. This dataset is based on measurements of microwave emissions from molecular oxygen in the lower eight kilometers of the atmosphere made by polar orbiting satellites [*Christy et al.*, 2000]. Microwaves are able to penetrate the atmosphere with little attenuation, and the amount of energy received by the microwave sounding units (MSU) onboard the satellites is directly proportional to the temperature in the lower

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atmosphere. Though the MSU measures the temperature of the deep layer of the atmosphere (surface to 8 km) rather than the near-surface air, strong mixing over mid-latitude continental regions acts to create vertical consistency between the surface and the troposphere as shown by high correlations and trend agreement over the United States and Europe [*Houghton et al.*, 2001]. The monthly data are available for 151 2.5° latitude by 2.5° longitude grid cells that cover the conterminous United States. We generated annual anomalies for each cell (there are no missing values), and then averaged the cells to generate the annual temperature anomalies for the United States.

6. Radiosonde (balloon-based) measurements are made throughout the United States daily at 0Z and 12Z. After considerable screening of the extensive dataset, we identified 50 stations with nearly continuous records (less than 3 percent missing data) over the same 1979–2000 period for which satellite-based MSU records are available. Though changes in radiosonde stations occur and may impact the surface temperature measurement, these changes are less numerous than found in the traditional surface network. We used only the surface reading taken the moment the balloon is launched; this typically occurs near 1.5 m above the surface which is near the shelter heights used in the USHCN dataset. For each radiosonde launch site, we determined the annual temperature and then converted the data into anomalies. We averaged all anomalies per year to generate the annual temperature anomalies for the conterminous United States (referred to as the SONDE record).

3. 1930–2000 Analyses

[5] The IPCC, RAW, FILNET, and URB-ADJ time series are shown in Figure 1, and they show a high intercorrelation averaging 0.96 and ranging from 0.95 to 1.00 (between FILNET and URB-ADJ). These records all show a general cooling from 1930 to 1970 and a warming from 1970 to 2000. Interpolating these data to a uniform grid across the United States and then averaging the data produces only trivial effects on these time series.

[6] The RAW dataset reveals a linear cooling of 0.05°C dec^{-1} that is statistically significant at the 0.05 level of confidence. The IPCC dataset shows a cooling of 0.02°C dec^{-1} that is not statistically significant. The URB-ADJ record has a highly insignificant warming of 0.003°C dec^{-1} and the FILNET dataset has an insignificant warming of 0.01°C dec^{-1}. We used a variety of trend-identification techniques and found essentially no difference from the results of the least-squares simple regression procedure. Recognizing that cooling occurred until about 1970 followed by warming, we repeated the linear regression analysis for the period 1970–2000. During those three decades, the RAW dataset warms by 0.18°C dec^{-1} (not significant at the 0.05 level of confidence), while the IPCC, URB-ADJ, and FILNET time series warm significantly at rates of 0.21, 0.26, and 0.26°C dec^{-1}, respectively. Even at this time scale, the various adjustments produce significantly significant warming to the RAW dataset.

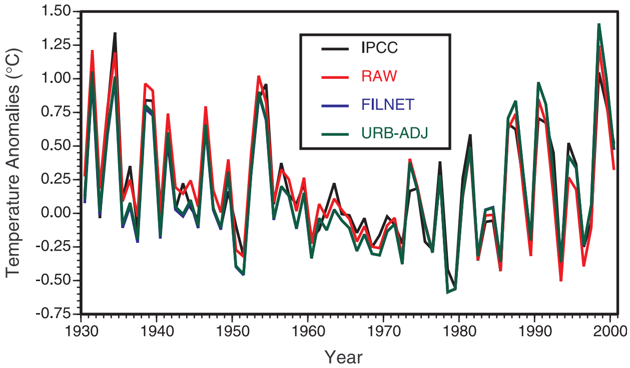

Figure 1. Plot of United States annual temperature anomalies (°C) over the period 1930–2000 for the IPCC, RAW, FILNET, and URB-ADJ datasets.

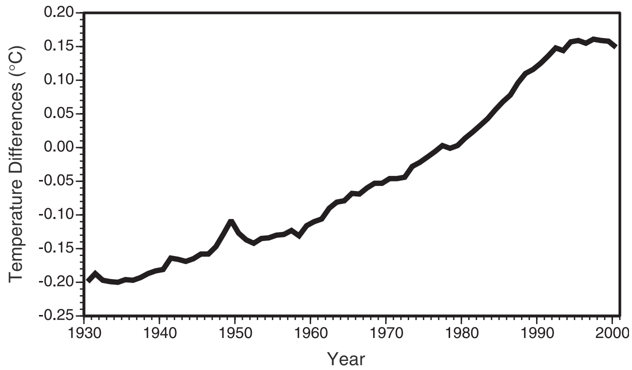

Figure 2. Annual difference (°C) between FILNET and RAW (FILNET-RAW) United States annual temperatures over the period 1930–2000.

[7] The annual difference between the RAW and FILNET record (Figure 2) shows a nearly monotonic, and highly statistically significant, increase of over 0.05°C dec^{-1}. Our analyses of this difference are in complete agreement with *Hansen et al.* [2001] and reveal that virtually all of this difference can be traced to the adjustment for the time of observation bias. *Hansen et al.* [2001] and *Karl et al.* [1986] note that there have been many changes in the time of observation across the cooperative network, with a general shift away from evening observations to morning observations. The general shift to the morning over the past century may be responsible for the nearly monotonic warming adjustment seen in Figure 2. In a separate effort, *Christy* [2002] found that for summer temperatures in northern Alabama, the correction for all contaminants was to reduce the trend in the raw data since 1930, rather than increasing it as determined by the USHCN adjustments in Figure 2. It is noteworthy that while the various time series are highly correlated, the adjustments to the RAW record result in a significant warming signal in the record that approximates the widely-publicized 0.50°C increase in global temperatures over the past century.

4. 1979–2000 Analyses

[8] The introduction of the MSU and SONDE records during the 1979–2000 period may shed light on the validity of the adjustments that appear to produce significant warming to the United States temperature record. As seen in Figure 3, all available time series show warming over the recent 22-year time period, and again, the intercorrelations are high averaging 0.95. The SONDE dataset shows the lowest amount of warming at 0.24°C dec^{-1} which is close to the trend for the RAW dataset of 0.25°C dec^{-1}. The IPCC record warmed by 0.28°C dec^{-1} while the MSU series also warmed by 0.28°C dec^{-1}. Despite the discrepancies in other locations [*Wallace et al.*, 2000], the IPCC and MSU records are in near-perfect agreement for the United States. Both the FILNET and URB-ADJ datasets show a warming of 0.33°C dec^{-1} during the 1979–2000 period. Even at this relatively short time scale, the difference between the RAW and FILNET trends is highly significant (0.0001 level of confidence), while no statistically significant difference appears between the RAW, MSU, SONDE, and IPCC records. Missing data during the 1979–2000 period are very small, and few changes in the network occurred during this period; therefore, there is little

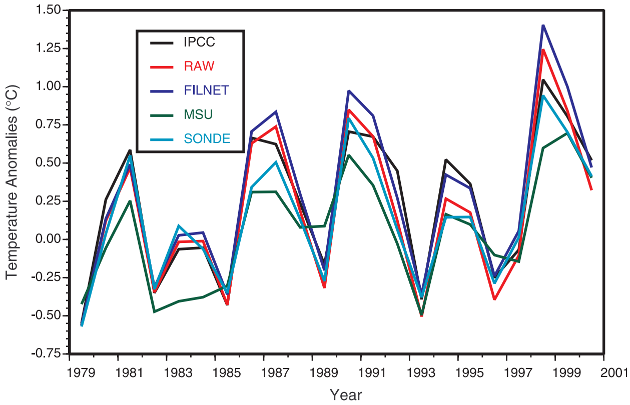

Figure 3. Plot of United States annual temperature anomalies (°C) over the period 1979–2000 for the IPCC, RAW, FILNET, MSU, and SONDE datasets.

chance that changes in the network induced some artificial trend in the data [*Robeson*, 1995].

5. Conclusion

[9] We certainly realize that the conterminous United States represents only 1.54 percent of the Earth's surface area, and analyses of that areal unit may have limited interpretations for any global temperature record. Nonetheless, we show clearly that adjustments made to the USHCN produce highly significant warming trends at various temporal scales. We find that the trends in the unadjusted temperature records are not different from the trends of the independent satellite-based lower-tropospheric temperature record or from the trend of the balloon-based near-surface measurements. Given that no substantial time of observation bias would be contained in either the satellite-based or balloon-based measurements, and given that the time of observation bias is the dominant adjustment in the USHCN database, our results strongly suggest that the present set of adjustments spuriously increase the long-term trend.

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