Global rural temperature trends

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Abstract. Using rural/urban land surface classifications derived from maps and satellite observed nighttime surface lights, global mean land surface air temperature time series were created using data from all weather observing stations in a global temperature data base and from rural stations only. The global rural temperature time series and trends are very similar to those derived from the full data set. Therefore, the well-known global temperature time series from in situ stations is not significantly impacted by urban warming.

Introduction

Time series of global mean temperatures clearly indicate that the observed temperature has warmed since the late Nineteenth Century (Nicholls et al., 1996). While considerable work has gone into assuring the fidelity of the data that contribute to globally averaged time series, one question that continues to surface is: Has urbanization around weather observing stations contaminated the time series (e.g., Michaels, 1998; Singer, 1997)? The urban heat island effect is a well-documented phenomenon (Oke, 1986). As fields and forests give way to asphalt and buildings in the area surrounding an observing station, the measured temperature will rise in part due to increased heat retention and decreased evapotranspiration. In order to examine this problem, we derived global mean land surface air temperature time series from all stations and a similar time series produced from rural stations only.

Data

The land surface data set used was the Global Historical Climatology Network (GHCN; Peterson and Vose, 1998) mean temperature data set. Most of the 7,280 station time series in this data set have been homogeneity adjusted to account for artificial discontinuities in their record, though some stations that either have no nearby neighbors or have a short (less than 20 years) period of record were not homogeneity adjusted (Peterson et al., 1998a).

Rural/urban metadata

Two techniques were used to assess the rural/urban nature of each of the stations. In the first one, each station in GHCN was located on Operational Navigation Charts (ONC, Peterson and Vose, 1998). Created by the U.S. Department of Defense but made available through NOAA, these 1:1,000,000 scale charts are used by pilots worldwide. ONC have elevation contours, outlines of urban areas, locations of airports and towns, and for most of the world, a simple vegetation classification. The populations of the towns located on the ONC were determined by cross-referencing with a variety of atlases. To be classified as rural, a station could not be associated with a town larger than 10,000 people.

The second methodology is based primarily on Defense Meteorological Satellite Program Operational Linescan System (hereafter, simply night lights) data (Elvidge et al., 1997) which were supplied by NOAA's Geophysical Data Center. This methodology (Owen et al., 1998) included two steps. First, each 1-km grid cell was individually classified as rural, suburban, or urban based on a 1994-95 night lights data set and gridded ONC data. The grid cells defined as urban in the ONC data were included in a global 1 km land cover data set (Loveland and Belward, 1997). A 1-km grid cell designated as urban by the ONC data was designated urban no matter what the night lights data indicated. This use of ONC data was designed to partially overcome the limitation of the night lights data in regions where cultural, political, or economic factors would limit the display of light at night. Each observation station was then classified as rural, suburban, or urban based on local (3 by 3 km) and regional (21 by 21 km) samples of the individual 1-km grid cells that surrounded the station. This methodology is designed to assure that a station must be predominantly rural at the local and regional scales to be classified as rural.

Both methods have drawbacks. The map approach uses urbanization and population data that are often a decade or more out of date, although this factor was subjectively taken into account during the creation of the map based rural/urban metadata. The night lights approach is adversely impacted by significant differences in how outdoor electric lighting is used around the world. Furthermore, neither approach can assess the land use/land cover characteristics within the nearest 100 meters of the station which can impact measured temperatures (Gallo et al., 1996).

Of the 7,280 stations currently in the GHCN temperature data base, the map approach classified 3,912 stations as rural while the night lights approach designated 2,712 rural. Using only the 2,290 stations that were classified as rural by both sources of metadata takes advantage of the best features of both approaches. Figure 1 shows the station locations while Figure 2 depicts how the number of stations and spatial coverage, as measured by the area of 5°x5° grid boxes with data, change with time.

Methodology

Two global land surface mean temperature time series were produced. One used data from all GHCN stations and the other used only the 2,290 stations classified as rural by both metadata sources. These time series were created using the usual National Climatic Data Center methodology: A first difference time series (the interannual change in temperature; $FD_1 = T_{yr\,2} - T_{yr\,1}$) was created for each station (Peterson et al., 1998b). An FD value for

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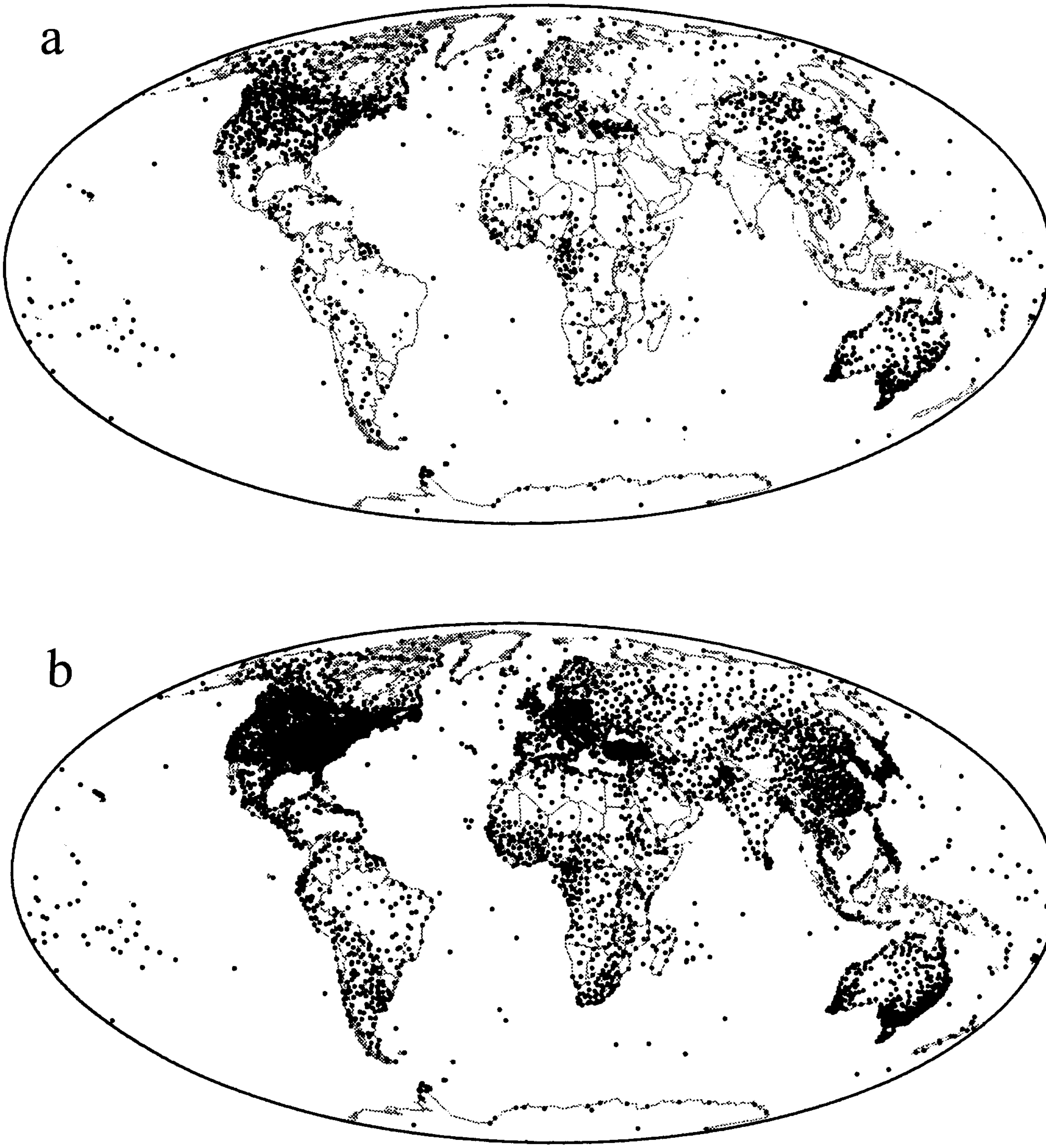

Figure 1. GHCN station locations. (a) Rural GHCN stations. (b) All GHCN stations.

each 5° x 5° grid box for each year was created by taking the mean of all the FD values from homogeneity adjusted time series within that grid box. If homogeneity adjusted data in a grid box were not available, data from time series that were not homogeneity adjusted were used. Grid box FD values were area-averaged into a global FD time series. This global FD time series was then cumulatively summed to produce a temperature time series. As a final step, the temperature time series was adjusted so the mean value from 1880-1997 was zero to allow the resultant time series to be presented as anomalies to its long-term mean.

Results

The two annual global temperature time series from 1880 to 1998 are shown in Figure 3a. A linear regression performed on both time series reveals that the global temperature trend measured at only the rural stations is warming at 0.70°C/100 years and the full data set analyses at 0.65°C/100 years. Both linear trends were significant at the 0.0005 level though the differences between the two were not significant. To look closer at the time period when the rural coverage was greatest, Figure 3b shows the two time series for

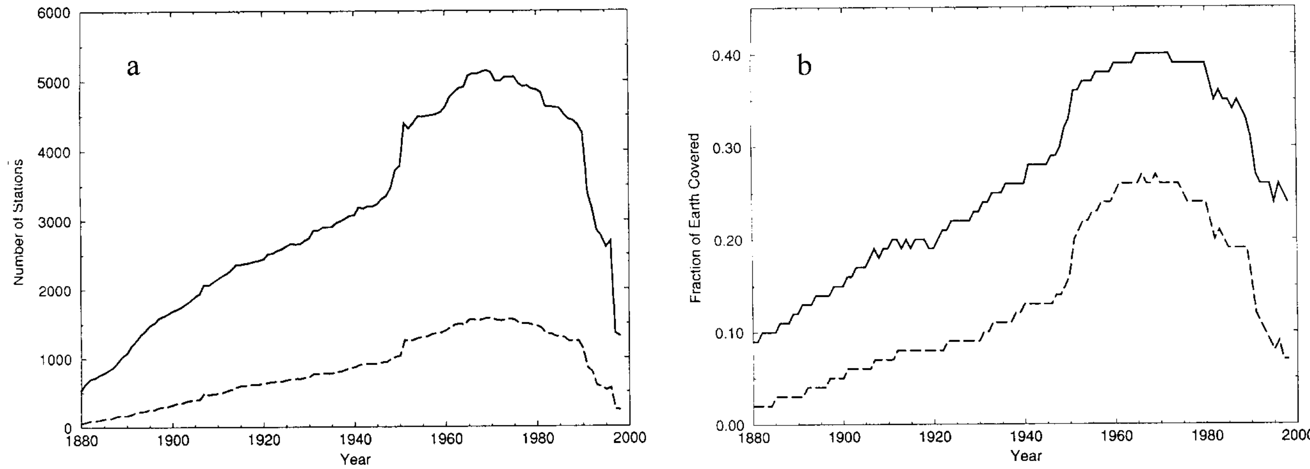

Figure 2. (a) The number of stations used in the analyses versus time. (b) The fraction of the Earth (land and sea) covered by the 5°x5° grid boxes with data used in the analyses versus time. Solid line from the full GHCN data set. Dashed line from rural stations only.

the period 1951-1989. This time period was selected based on the number of rural grid boxes exceeding two-thirds of the maximum value and represents a minimum spatial coverage of approximately 20% of the earth's surface (land and sea). Again the two time series are in close agreement with the full data set time series having a linear regression of 0.92°C/100 years and rural having 0.80°C/100 years. For this shorter time period, both trends were significant at the 0.0025 level and again the differences between the two were not significant. Examination of Figure 3 reveals that the interannual and interdecadal variability of the two time series is also similar.

Conclusions:

This analysis clearly shows that the global land surface air temperature signal is robust and not adversely affected by urban warming. Similar trends and variability are observed in our full data set analysis as well as analysis of our most rural stations, despite the rural analysis having less than half the number of stations and two thirds or less of the spatial coverage. The small differences between the rural and full data set time series are more likely due to difference in climate variations of two regions observed rather than a rural/urban difference. This is not to say that urban warming does not exist, but rather that it is at most a small part of the observed global temperature signal. These results from a new global source of rural/urban metadata are in agreement with earlier research indicating that "urbanization influence in two of the most widely used hemispheric data sets is, at most, an order of magnitude less than the warming seen on a century timescale" (Jones et al., 1990) and that "urban effects on globally and hemispherically averaged time series are negligible" (Easterling et al., 1997).

Close examination of the global time series since 1990 reveals that the full data set has warmed more than the rural during recent years and this coincides with a decreasing percentage of the rural stations in the full data set. However, because we area-average the interannual change in temperature to obtain our anomalies rather than area-averaging station anomalies, this difference in trend

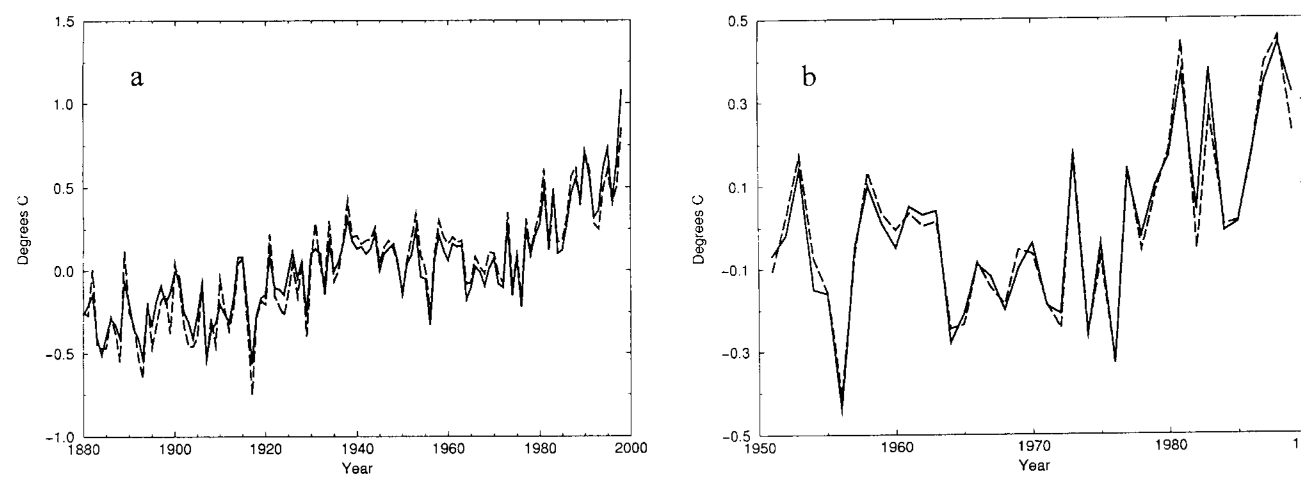

Figure 3. (a) Annual area-averaged mean global temperature anomalies (from 1880-1997 mean) from land stations. The value for 1998 based on January through September data only. (b) Annual averaged mean global temperature anomalies (from 1951-1989 mean) from land stations for the period 1951 to 1989 when there was the greatest rural coverage. Solid line from the full GHCN data set. Dashed line from rural stations only.

cannot be due to the effects of historical urbanization being revealed in the last few years although there may be a small effect of concurrent increasing urbanization during the 1990s. Because there are over twice as many grid boxes with data during the 1990s in the full data set than the rural subset, they are sampling considerably different regions. The reason rural station fraction of the Earth covered in 1998 was only 0.07, compared to 0.24 for the full data set, is because rural climate stations are not given a high priority in near real time international data exchange and are instead acquired years later. This, however, will be changing with the creation of the Global Climate Observing System Surface Network (Peterson et al., 1997).

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References

Easterling, D.R., B. Horton, P.D. Jones, T.C. Peterson, T.R. Karl, D.E. Parker, M.J. Salinger, V. Razuvaëv, N. Plummer, P. Jamason, and C.K. Folland, Maximum and minimum temperature trends for the globe. *Science*, **277**, 364-367, 1997.

Elvidge, C.D., K.E. Baugh, E.A. Kihn, H.W. Kroehl and E.R. Davis, Mapping city lights with nighttime data from the DMSP Operational Linescan System. *Photogrammetric Engineering and Remote Sensing*, **63**, 727-734, 1997.

Gallo, K. P., D. R. Easterling, and T. C. Peterson, The influence of land use/land cover on climatological values of the diurnal temperature range. *J. Climate*, **9**, 2941-2944, 1996.

Jones, P.D., P.Ya. Groisman, M. Coughlan, N. Plummer, W-C. Wang and T.R. Karl, Assessment of urbanization effects in time series of surface air temperatures over land, *Nature*, **347**, 169-172, 1990.

Loveland, T.R. and A.S. Belward, The IGBP-DIS global 1 km land cover data set, DISCover: first results, *Intl. J. Remote Sensing*, **18**, 3289-3295, 1997.

Michaels, P.J., Summer in the city: Interpreting the urban bias. *World Climate Report*, **3**, 4-5, 1998.

Nicholls, N., G.V. Gruza, J. Jouzel, T.R. Karl, L.A. Ogallo, and D.E. Parker, Observed climate variability and change. *Climate Change 1995: The Science of Climate Change, Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*. J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell, editors. Cambridge University Press. 137-181, 1996.

Oke, T.R., ed., *Urban Climatology and its Applications with Special Regard to Tropical Areas*. WMO Technical Note No. 652, Geneva, Switzerland, 1986.

Owen, T.W., K.P. Gallo, C.D. Elvidge and K.E. Baugh, Using DMSP-OLS light frequency data to categorize urban environments associated with U.S. climate observing stations. *Intl. J. Remote Sensing*, **19**, 3451-3456, 1998.

Peterson, T.C., D.R. Easterling, T.R. Karl, P.Ya. Groisman, N. Nicholls, N. Plummer, S. Torok, I. Auer, R. Boehm, D. Gullett, L. Vincent, R. Heino, H. Tuomenvirta, O. Mestre, T. Szentimre, J. Salinger, E. Førland, I. Hanssen-Bauer, H. Alexandersson, P. Jones, D. Parker, Homogeneity adjustments of in situ atmospheric climate data: A review. *Intl. J. Climatol.*, **18**, 1493-1517, 1998a.

Peterson, T.C., T.R. Karl, P.F. Jamason, R. Knight, and D.R. Easterling, The first difference method: Maximizing station density for the calculation of long-term global temperature change. *J. Geophys. Res. – Atmos.*, **103**, 25,967-25,974, 1998b

Peterson, T.C. and R.S. Vose, An overview of the Global Historical Climatology Network temperature data base. *Bull. Amer. Meteorol. Soc.*, **78**, 2837-2849, 1997.

Peterson, Thomas, Harald Daan, and Philip Jones, Initial selection of a GCOS surface network, *Bull. Amer. Meteorol. Soc.*, **78**, 2145-2152, 1997.

Singer, F. S. *Hot Talk, Cold Science: Global Warming's Unfinished Debate*, The Independent Institute, Oakland, CA, 110 pp, 1997.

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