An intercomparison of trends in surface air temperature analyses at the global, hemispheric, and grid-box scale

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[1] The IPCC Third Assessment Report noted that three major temperature analyses exhibited different warming rates over global land areas since 1976. This paper attempts to explain these trend discrepancies by quantifying the sensitivity of global, hemispheric, and grid-box trends to both the spatial averaging technique and the underlying station network. The Global Historical Climatology Network (GHCN) analysis and the Climatic Research Unit (CRU) analysis have comparable trends when the same approach is used to compute the global time series, and since the mid-1970s the rate of warming in both is as much as a third greater than in the Goddard Institute for Space Studies (GISS) analysis. On the hemispheric scale, GHCN and CRU have similar trends regardless of the gridding approach, whereas GISS again has less warming in recent decades (particularly in the Southern Hemisphere). GHCN and CRU also exhibit reasonable agreement at the grid-box level during the period 1976–2003. **Citation:** Vose, R. S., D. Wuertz, T. C. Peterson, and P. D. Jones (2005), An intercomparison of trends in surface air temperature analyses at the global, hemispheric, and grid-box scale, *Geophys. Res. Lett.*, *32*, L18718, doi:10.1029/2005GL023502.

1. Introduction

[2] *Intergovernmental Panel on Climate Change* (*IPCC*) [2001] reviewed several analyses of instrumental temperature records in its assessment of global land-surface air temperature variations during the 20th century. While based on somewhat different station networks and gridding techniques, all of the analyses documented virtually the same amount of warming from 1901–2000 ($\sim$0.060°C dec^{-1}). However, they also exhibited different rates of warming for the past few decades. In particular, the Global Historical Climatology Network (GHCN) analysis [*Peterson and Vose*, 1997] contained a "distinctly larger increase" in temperature than did the Climatic Research Unit (CRU) analysis [*Jones*, 1994], which in turn indicated "slightly more warming" than did the Goddard Institute for Space Studies (GISS) analysis [*Hansen et al.*, 2001]. Given recent revisions to the CRU analysis [*Jones and Moberg*, 2003], this paper reexamines these differential rates of warming at the annual time scale. In brief, the investigation quantifies the sensitivity of global, hemispheric, and grid-box trends to both the spatial averaging technique and the underlying station network. The study focuses on the growing trend discrepancy between GHCN and CRU since 1976 (which *IPCC* [2001] used as the start of the most recent warming period), but trends from 1900–2003 are also considered. For comparative purposes, global and hemispheric trends in the GISS analysis are also briefly discussed.

2. Global Trends

[3] *Wigley et al.* [1997] noted that it is not possible to determine a priori the best method for computing a global temperature time series, and as a result the analyses in *IPCC* [2001] were based on different techniques. For instance, the GHCN series was the area-weighted average of all grid boxes on global land areas. In contrast, the CRU series was an average of the two hemispheric time series. The latter approach gives more weight to the relatively small land area in the Southern Hemisphere, which warmed at a lesser rate than the Northern Hemisphere since about the mid-1980s. *IPCC* [2001] speculated that this methodological difference might explain the larger rate of increase in GHCN relative to CRU in recent decades, but no quantitative estimates were provided to support this supposition.

[4] The examination described here attempts to verify this hypothesis and, more generally, to isolate the source of the trend differences at the global scale. In essence, the investigation entails an intercomparison of land surface temperature trends derived from three gridded analyses over two time periods (1976–2003 and 1900–2003). The first analysis is the 7230-station GHCN dataset gridded using the first difference method [*Peterson et al.*, 1998]; the second is the 4167-station CRU dataset gridded using the climate anomaly method (i.e., CRUTEM2) [*Jones and Moberg*, 2003]; and the third is the 6000-station GISS subset of the GHCN dataset gridded using the reference station method [*Hansen et al.*, 2001]. Details of the three gridding techniques are given in the above papers. Two global time series are examined in each case; the first series is the area-weighted average of all grid boxes over global land areas whereas the second is the mean of the Northern and Southern Hemisphere time series (each of which is an area-weighted average of the grid boxes within the given hemisphere).

[5] Figure 1 depicts the least-squares trend in each global time series for the period 1976–2003. Both GHCN and CRU indicate more warming when "grid-box averaging" (as opposed to "hemisphere averaging") is used to compute

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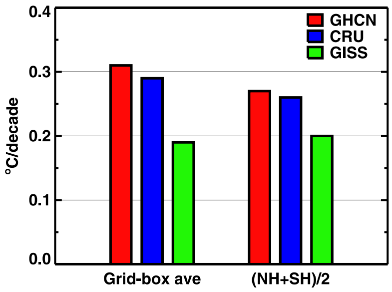

Figure 1. The least-squares trend in various global time series for the period 1976–2003.

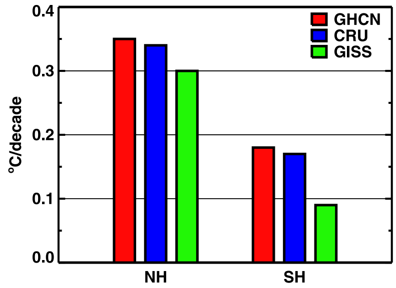

Figure 3. The least-squares trend in various "standard" hemispheric time series for the period 1976–2003.

the global time series, suggesting that the IPCC supposition is correct. Notably, the grid-box average trend for GHCN only differs by 0.024°C dec^{-1} from its CRU counterpart, and the two respective hemisphere average trends differ from one another by only 0.010°C dec^{-1}. In other words, GHCN and CRU depict comparable rates of warming when the approach used to compute the global time series is the same. Relatively speaking, both GISS time series (i.e., the grid box average series and the hemisphere average series) exhibit about a third less warming than GHCN and CRU. As noted by IPCC, this is likely a consequence of the GISS gridding method, which provides estimates for empty land and ocean grid boxes when at least one station falls within a 1200 km radius of an unsampled box. This is common in the South Pacific Ocean and Antarctica, and because both regions warmed less than most land areas since the mid-1970s, the two GISS series have smaller trends. Stated differently, GHCN and CRU have larger trends because the gridding techniques used in those analyses do not provide estimates for unsampled grid boxes, which are more prevalent in the Southern Hemisphere.

[6] All of the global time series are in good agreement for the period 1900–2003. For example, the grid-box average trends for GHCN, CRU, and GISS are 0.074°C dec^{-1}, 0.077°C dec^{-1}, and 0.063°C dec^{-1}, respectively, while the hemisphere average trends are 0.071°C dec^{-1}, 0.076°C dec^{-1}, and 0.064°C dec^{-1}, respectively. In short, for any given analysis the two methods for computing the global time series produce the same long-term trend. The similarity in long-term warming rates between GHCN, CRU, and GISS also suggests that global-scale trend estimates are not extremely sensitive to differences in the underlying station network or the gridding technique (although the smaller trend in GISS again can likely be attributed to that analysis containing estimates for unsampled grid boxes in the Southern Hemisphere). As depicted by Figure 2, the year-to-year differences between

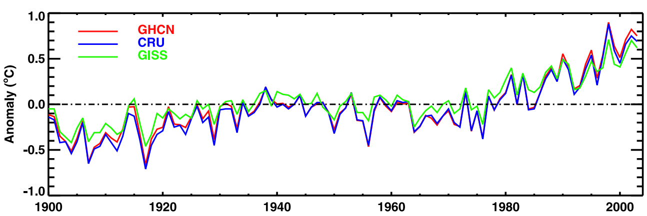

Figure 2. Plot of global anomalies through time for the period 1900–2003.

the analyses are also quite small, with GHCN and CRU being virtually indistinguishable. (Note that GISS appears slightly warmer for much of the record in part because of its gridding technique and in part because it uses a base period of 1951–80, which was slightly cooler than the 1961–90 base period used by the other analyses.)

3. Hemispheric Trends

[7] This section evaluates the relative impact of the station network and the gridding approach on time series of the Northern and Southern Hemispheres. For comparative purposes, trends are examined in two sets of gridded analyses. The first set consists of the three "standard" analyses used in the previous section. The second set includes the standard analyses for GHCN and CRU as well as two "supplemental" gridded analyses for those datasets.

[8] Figure 3 depicts the least-squares trend in each standard hemispheric time series for the period 1976–2003. In general, all of the series indicate that the Northern Hemisphere warmed at least twice as fast as the Southern Hemisphere during this period. There is little trend difference between GHCN and CRU in either hemisphere (less than 0.011°C dec^{-1} in each case). In other words, GHCN and CRU depict comparable rates of warming even though they employ different gridding techniques and have different underlying station networks (7280 stations in GHCN versus 4167 in CRU). In contrast, GISS has a distinctly smaller trend than GHCN and CRU in both hemispheres. The difference is particularly large in the Southern Hemisphere, which again is consistent with the fact that the GISS gridding approach gives greater weight to areas that warmed less during this period (i.e., the South Pacific Ocean and Antarctica).

[9] Two supplemental gridded analyses were developed to verify the trend consistency in the standard GHCN and CRU analyses. Specifically, the GHCN dataset was gridded with the climate anomaly method generally used with CRU, and the CRU dataset was gridded with the first difference method generally used with GHCN. Because the first difference method can utilize a time series of any length, the first difference grids were derived from all stations in each dataset (7280 in GHCN and 5070 in CRU). In contrast, the climate anomaly method requires averages for each station during a fixed base period, and consequently the climate anomaly grids were derived from a subset of each dataset consisting of mostly long-term stations (5985 in GHCN and 4167 in CRU). For consistency with *Jones and*

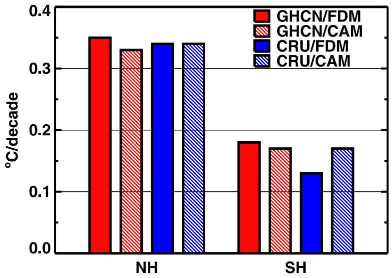

Figure 4. The least-squares trend in "standard" and "supplemental" hemispheric time series for the period 1976–2003.

Moberg [2003], the base period used here was 1961–90. A long-term mean was computed for each station that had at least 20 years of data in this base period as well as a minimum of four years in each decade (4711 in GHCN and 3348 in CRU). For the remaining stations (1274 in GHCN and 819 in CRU), 30-year normals were obtained from *Jones and Moberg* [2003].

[10] Figure 4 depicts the least-squares trend in each standard and supplemental time series for GHCN and CRU during the period 1976–2003. In general, there is little difference in trends in the Northern Hemisphere (i.e., the GHCN first difference series, the GHCN climate anomaly series, the CRU first difference series, and the CRU climate anomaly series all have trends within 0.023°C dec^{-1} of one another). There is also little difference in trends in the Southern Hemisphere – except for the CRU first difference series, which is at least 0.032°C dec^{-1} lower than the other analyses. This is likely an artifact of the first difference approach, which is somewhat more sensitive than the climate anomaly method to station networks (such as those in the Southern Hemisphere) that are not particularly dense and that contain modest amounts of missing data [*Free et al.*, 2004; J. Lawrimore, personal communication, 2005].

[11] Trend discrepancies in all of the gridded analyses (standard and supplemental) are comparatively minor for the period 1900–2003. For instance, all of the Northern Hemisphere series have a trend between 0.068 and 0.080°C dec^{-1}, and all the Southern Hemisphere series have trends between 0.043 and 0.070°C dec^{-1}. In short, differences in the underlying station network and the gridding approach have a relatively small impact on long-term temperature trends at the hemispheric scale.

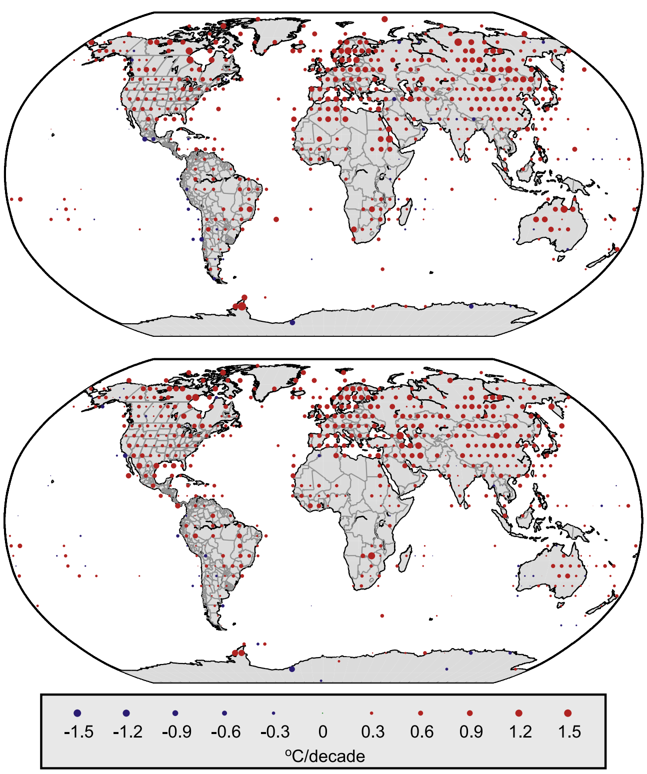

Figure 5. Map of least-squares trends in 5° by 5° grid boxes for the period 1976–2003 for GHCN (top panel) and CRU (bottom panel).

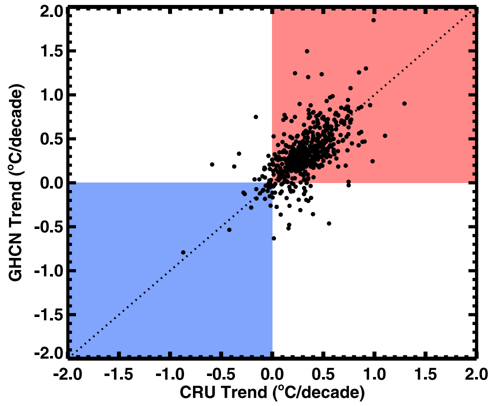

Figure 6. Scatter plot of least-squares trends in GHCN and CRU for collocated 5° by 5° grid boxes for the period 1976–2003.

4. Grid-Box Trends

[12] The various global and hemispheric time series used in this paper were derived by computing the area-weighted average of time series in 5° by 5° latitude/longitude grid boxes. To determine the similarity between GHCN and CRU at this spatial scale, least-squares trends were computed for each grid box in each analysis for the period 1976–2003. Because the standard gridded analyses produce comparable trends at the global and hemispheric scale, the trends discussed here were also derived from the standard gridded analyses (i.e., the GHCN dataset gridded with the first difference method, and the CRU dataset gridded with the climate anomaly approach).

[13] Figure 5 portrays the least-squares trend in each grid box in GHCN and CRU for the period 1976–2003. Although there are slight differences in spatial coverage (e.g., Canada and Australia), both analyses indicate that virtually all land areas warmed during this period. Both analyses also have similar spatial patterns in the rates of warming and cooling; for instance, northern Eurasia and northern North America have the largest positive trends in both cases while western Latin America and western Australia have the most cooling. A scatter plot of GHCN trends versus CRU trends (Figure 6) also attests to the similarity between the analyses at the grid-box level. For

example, if a grid box has a positive trend in the GHCN analysis, it generally also has a positive trend of about the same size in the CRU analysis. In addition, very few grid boxes have negative trends, but those that do typically have comparable magnitudes in both analyses.

[14] Despite the general agreement between the analyses, 9.4% of all grid-box trends differ by more than 0.100°C dec^{-1} in both magnitude and sign. Because a detailed assessment of all such discrepant trends is beyond the scope of this paper, two grid boxes with large trend differences are discussed here to illustrate the typical causes involved. The first box, centered near the southern tip of Baja California (22.5°N, 112.5°W), has a GHCN-CRU trend difference of −0.776°C dec^{-1}. While both analyses have only one station (La Paz) in that box, the GHCN record lacks data from 1986–1993, a gap that effectively detrends the series. The second problematic box, centered near southern California (32.5°N, 117.5°W), has a GHCN-CRU trend difference of 0.796°C dec^{-1}. Although both analyses contain more than 20 stations in that box, the CRU network abruptly falls to 7 stations starting in 1997, a decline that corresponds to a sudden cooling (and negative CRU trend). In short, these grid-box examples indicate that many large discrepancies likely result from differences in the number of stations as well as data completeness. Consequently, it is recommended that caution be exercised when using only one analysis to assess trends at the grid-box level.

5. Summary and Conclusions

[15] This paper examined the differential rates of global warming exhibited by three surface temperature analyses discussed in *IPCC* [2001]. In general, century-long trends at the global and hemispheric scale are largely immune to variations in the underlying station network and the gridding approach. For the period 1976–2003, the method for computing the global time series has a discernable impact on trends in GHCN and CRU; consistent with the IPCC hypothesis, grid-box averaging (as opposed to averaging the two hemispheres) results in slightly more warming. GHCN and CRU have comparable trends when the same approach is used to compute the global time series, and since the mid-1970s the rate of warming in both is as much as a third greater than in GISS. On the hemispheric scale, GHCN and CRU have nearly identical trends regardless of the gridding approach, whereas GISS again has less warming in recent decades (particularly in the Southern Hemisphere). GHCN and CRU also exhibit reasonable agreement at the grid-box level during the period 1976–2003. In short, the three surface temperature analyses depict similar rates of warming over long time scales, and discrepancies in recent decades are largely consistent with differences in methodology.

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