Reply to comment by David E. Parker et al. on "Unresolved issues with the assessment of multidecadal global land surface temperature trends"

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1. Introduction

[1] *Pielke et al.* [2007a] identified a variety of problems affecting the accuracy or appropriate level of confidence of the global historical land surface temperature data set, as applied to estimates of global temperature trends, and called for several measures to be taken to improve this network for this purpose. *Parker et al.* [2009], while acknowledging the importance of making improvements to the network and its data, take issue with two particular aspects of our analysis. We are grateful for the opportunity to engage in further discussion regarding these important issues.

2. Degree of Independence of Land Surface Global Surface Temperature Analyses

[2] Lack of independence and incomplete coverage are two important shortcomings of estimates of global and regional temperature trends. Lack of independence has two related meanings: the extent to which different estimates of temperature trends rely on the same underlying data, and the extent to which homogenization has conflated data from an individual station with data from surrounding stations. This lack of independence, when quantitatively assessed, will increase the uncertainty of estimates of temperature trends. Incomplete coverage particularly affects estimates of regional trends in undersampled areas, with an impact on global and hemispheric trend estimates as well.

[3] *Parker et al.* [2009] claim that effectively independent analyses of land surface global temperature trends have already been carried out. These previous analyses either involve subsampling of data from more comprehensive analyses or are independently performed comprehensive analyses. They also conduct their own new subsampling analysis. As discussed by *Pielke et al.* [2007a, 2007b], however, the raw data from which all of these analyses are drawn are not independent. The typical procedures to "homogenize" climate data may involve any of several steps, as summarized from *Pielke et al.* [2002]: (1) a hand-checked quality assurance of data outliers from the original records; (2) an adjustment for time-of-observation biases [*Karl et al.* 1986]; (3) an adjustment based on known instrumentation changes, such as correcting for the introduction of the maximum-minimum temperature system (MMTS) using the bias value given by *Quayle et al.* [1991]; (4) an adjustment based on station moves, for example, using the procedure described by *Karl and Williams* [1987]; and (5) an adjustment for urban effects, such as described by *Karl et al.* [1988]. Recent papers to evaluate the urban temperature bias include those by *Gallo et al.* [1999] and *Owen et al.* [1998a, 1998b]. The first three steps are essential, and we agree they are needed in order to standardize the data sets. However, explicit treatment of the statistical uncertainty associated with the second and third steps (e.g., in terms of the standard deviation associated with the regression adjustment) has only recently been included in the development of grid point analyses [*Brohan et al.*, 2006].

[4] Even more significant, however, are step 4 and (in those analyses where it is used) step 5. Adjustment for station moves results in an interdependency among nearby stations, as each adjustment compels a trend segment from

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one station to agree with a weighted average of trend segments from neighboring stations. The *Peterson et al.* [1999] subsampling study cited by *Parker et al.* [2009] suffered from this interdependency, while *Parker* [2006] used no adjustments whatsoever, suggesting that its trend agreement with more comprehensively analyzed data sets may be fortuitous.

[5] The additional subsampling study undertaken by *Parker et al.* [2009], contrary to what they state, also suffers from this interdependency. According to *Brohan et al.* [2006], approximately 18% of the stations underwent adjustments that were archived and quantified at the Climatic Research Unit (CRU), but "for most stations only a single series is archived, so any adjustments that might have been made. . .are unknown." Thus the number of adjusted stations may be much greater than 18%, illustrating the need for better worldwide documentation of quality control and adjustment procedures for both current and historical climate data. Adjustments involving data from neighboring stations, even if they have a near-zero effect on large-scale temperature averages, increase interdependency.

[6] There have been, unfortunately, relatively few attempts to look at the effects of including large numbers of truly independent stations (supersampling) in a region beyond the set used in the global analyses. Two of these, by *Christy* [2002] (North Alabama) and *Christy et al.* [2006] (California), clearly show that when many new independently adjusted stations are examined, resulting trends can be quite different compared to the few base sites in the global analyses. For California and North Alabama, the resulting trend differences between the supersampled regional data and the sparse global data are on the order of 0.10°C/decade. These supersample analyses clearly undercut the assertion by *Parker et al.* [2009] that the subsampling adequately demonstrates consistency in trends.

[7] *Parker et al.*'s [2009] comparison of comprehensive global temperature analyses is also misleading. We note that "reduced" trends are not necessarily less correct, especially since *Hansen et al.* [2001] obtain their "reduced" trend by attempting to estimate temperatures over a broader area of the globe than did the other global analyses. Contrary to what *Parker et al.* [2009] imply, *Vose et al.* [2005] did not consider the global temperature analysis of K. M. Lugina et al. (Monthly surface air temperature time series area averaged over the 30-degree latitudinal belts of the globe, 1881–2005, in Trends: A Compendium of Data on Global Change, 2006, an online report available at http://cdiac.ornl.gov/trends/temp/lugina/lugina.html) (hereinafter Lugina et al. online report, 2006) at all. *Trenberth et al.* [2007] do argue in passing that the trend of the Lugina et al. online report (2006), is biased low because of optimal interpolation, but this argument is unpersuasive: optimal interpolation would reduce the amplitude of regional anomalies compared to the global mean anomaly, but global mean trends would remain unaffected.

[8] *Parker et al.* [2009] agree with us that incomplete coverage is a serious issue for parts of the globe that are undersampled. Such areas are not limited to polar regions, however; *Pielke et al.* [2000, 2002] found that even in eastern Colorado there were substantial statistically significant differences in long-term trends over distances of tens of kilometers in average maximum and minimum temperatures, extreme temperatures, and growing season length, including the sign of those trends. Multiple climate records are needed for reliable assessment of trends even at the local scale.

[9] Thus, we disagree that "these criticisms" (referring to the lack of independence of trend estimates) have been refuted by past analyses or even the new analysis of *Parker et al.* [2009].

3. Influence of Land Use/Land Cover (LULC) on Surface Temperature Trends

[10] *Parker et al.* [2009] agree with us that the strong correlations between LULC change and alterations in near-surface air temperature trends, as presented by *Pielke et al.* [2007a] and *Hale et al.* [2006], do not establish a causative relationship, and neither study asserted such a causative relationship. Isolating the effects of LULC change from other climatic forcings is a challenging proposition [see *Hale et al.* 2008].

[11] *Parker et al.* [2009] provide an interesting analysis of sea surface temperature (SST) trends for periods corresponding to the pre- and post- LULC change periods presented by *Hale et al.* [2006]. They found an average pre-change-period trend of -0.20°C dec^{-1} and an average post-change-period trend of 0.58°C dec^{-1}. They then imply that these trends are indicative of near-surface air temperature trends that have occurred in the absence of nearby LULC change, and they further state that these trends are similar to the trends presented by *Hale et al.* [2006].

[12] Mechanisms of surface temperature change are not the same over land as over water, however, and in this case, neither are the magnitudes of the trend changes. The post-change minimum temperature trend found by *Hale et al.* [2006] (1.35°C dec^{-1}) was more than double the post-change trend found by *Parker et al.* [2009] (0.58°C dec^{-1}), and the post-change maximum temperature trend found by *Hale et al.* [2006] (2.13°C dec^{-1}) was nearly 4 times the SST trend value. Thus at best, *Parker et al.* [2009] can argue on the basis of their analysis that something less than half of the post-change trend may have been caused by "externally-imposed large-scale warming." This leaves the bulk of the change to have been caused by other factors, for example, LULC effects [*Kabat et al.*, 2004], regional variations that also happened to coincide with the LULC changes [*National Research Council*, 2005], and differences in climate responses over land and sea [*Compo and Sardeshmukh*, 2009].

[13] When one looks at specific regions where land-use change is clearly defined the effects are quite evident. For example, *Christy et al.* [2006] showed substantial differences in long-term temperature trends in California depending on whether the stations were in areas subjected to large land-use change (the Central Valley) or in more pristine areas (the Sierras). A similar type of response was reported by *Lobell and Bonfils* [2008] when they compared temperatures from irrigated and nonirrigated sites in California. In addition, *Mahmood et al.* [2004, 2006, also Observed data-based evidence of impacts of irrigation on 20th century temperature in the Ogallala aquifer region, submitted to

Climate Change, 2008] found considerable differences in temperature trends between irrigated and nonirrigated locations in the Ogallala aquifer region, particularly when maximum and minimum temperature trends were examined separately.

[14] *Parker et al.* [2009] further claim that "for *Hale et al.* [2006] to have demonstrated LULC effects, their calculated trends should have spanned the LULC changes, not followed them." This is a misinterpretation of the methodologies and results of *Hale et al.* [2006]. A persistent change in temperature trend (not just the underlying prechange and postchange averages) may follow LULC changes, as has been demonstrated by not only *Hale et al.* [2006], but other works cited above and by *Pielke et al.* [2007a]. Such a LULC-induced change in temperature trend is more readily apparent without examining the immediate period of LULC change, since the LULC change may have short-term effects of little climatic consequence that could result in spurious calculated trend changes.

[15] *Parker et al.* [2009] also take issue with the *Hale et al.* [2008] analyses utilizing potentially inhomogeneous NCEP-NCAR Reanalysis (NNR) data. Interestingly, the *Simmons et al.* [2004] paper, cited by *Parker et al.* [2009] as indicative of inhomogeneities rendering NNR comparisons seriously flawed, found only five instances of suspect NNR data over North America. None of these data were located in the United States, and thus did not influence the *Hale et al.* [2008] analyses. Further analyses as in the work by *Hale et al.* [2008] with ERA-40 data in addition to NNR data, as suggested by *Parker et al.* [2009], might provide for interesting comparisons. Such analyses, however, are complicated by the fact that ERA-40 data indirectly assimilate near-surface air temperature and soil moisture, and thus include some degree of LULC effects. As a result, it is not surprising that ERA40 trends are closer to observations than NNR [*Simmons et al.*, 2004; *Lim et al.*, 2005, 2008]. The inclusion of near-surface variables renders the ERA-40 comparison with in situ data less meaningful from the perspective of isolating potential LULC effects from other climatological forcings compared to the NNR data (that does not include these near-surface variables).

4. Conclusions

[16] We welcome a critical examination and further analysis of each of the arguments and findings of *Pielke et al.* [2007a]. Indeed, we are continuing this further assessment [e.g., see *Lin et al.*, 2007]. However, the analyses performed by *Parker et al.* [2009] do little to improve confidence in the global surface temperature record. In particular, we reaffirm the statement of *Pielke et al.* [2007a] that nearby changes in LULC may be influencing the temperature trends observed at surface climate observing stations. We further continue to emphasize the lack of data independence in the global surface temperature analyses (including that of *Parker et al.* [2009]). We do agree with *Parker et al.* [2009] that data sparseness makes temperature trend estimates less robust over many parts of the globe, and join their call for improved data collection, metadata, and data rescue.

References

Brohan, P., J. J. Kennedy, I. Harris, S. F. B. Tett, and P. D. Jones (2006), Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850, *J. Geophys. Res.*, *111*, D12106, doi:10.1029/2005JD006548.

Christy, J. R. (2002), When was the hottest summer? A state climatologist struggles for an answer, *Bull. Am. Meteorol. Soc.*, *83*, 723–734, doi:10.1175/1520-0477(2002)083<0723:WWTHS>2.3.CO;2.

Christy, J. R., W. B. Norris, K. Redmond, and K. P. Gallo (2006), Methodology and results of calculating central California surface temperature trends: Evidence of human-induced climate change?, *J. Clim.*, *19*, 548–563, doi:10.1175/JCLI3627.1.

Compo, G. P., and P. D. Sardeshmukh (2009), Oceanic influences on recent continental warming, *Clim. Dyn.*, *32*, 333–342, doi:10.1007/s00382-008-0448-9.

Gallo, K. P., T. W. Owen, D. R. Easterling, and P. F. Jamason (1999), Temperature trends of the U.S. historical climatology network based on satellite-designated land use/land cover, *J. Clim.*, *12*, 1344–1348, doi:10.1175/1520-0442(1999)012<1344:TTOTUS>2.0.CO;2.

Hale, R. C., K. P. Gallo, T. W. Owen, and T. R. Loveland (2006), Land use/land cover change effects on temperature trends at U.S. Climate Normals stations, *Geophys. Res. Lett.*, *33*, L11703, doi:10.1029/2006GL026358.

Hale, R. C., K. P. Gallo, and T. R. Loveland (2008), Influences of specific land use/land cover conversions on climatological normals of near-surface temperature, *J. Geophys. Res.*, *113*, D14113, doi:10.1029/2007JD009548.

Hansen, J. E., R. Ruedy, M. Sato, M. Imhoff, W. Lawrence, D. Easterling, T. Peterson, and T. Karl (2001), A closer look at United States and global surface temperature change, *J. Geophys. Res.*, *106*, 23,947–23,963, doi:10.1029/2001JD000354.

Kabat, P., M. Claussen, P. A. Dirmeyer, J. H. C. Gash, L. Bravo de Guenni, M. Meybeck, R. A. Pielke Sr., C. J. Vörösmarty, R. W. A. Hutjes, and S. Lötkemeier (Eds.) (2004), *Vegetation, Water, Humans and the Climate: A New Perspective on an Interactive System*, 566 pp., Springer, Berlin.

Karl, T. R., and C. N. Williams Jr. (1987), An approach to adjusting climatological time series for discontinuous inhomogeneities, *J. Clim. Appl. Meteorol.*, *26*, 1744–1763, doi:10.1175/1520-0450(1987)026<1744:AATACT>2.0.CO;2.

Karl, T. R., C. N. Williams Jr., P. J. Young, and W. M. Wendland (1986), A model to estimate the time of observation bias associated with monthly mean maximum, minimum and mean temperatures for the United States, *J. Clim. Appl. Meteorol.*, *25*, 145–160, doi:10.1175/1520-0450(1986)025<0145:AMTETT>2.0.CO;2.

Karl, T. R., H. F. Diaz, and G. Kukla (1988), Urbanization: Its detection and effect in the United States climate record, *J. Clim.*, *1*, 1099–1123, doi:10.1175/1520-0442(1988)001<1099:UIDAEI>2.0.CO;2.

Lim, Y.-K., M. Cai, E. Kalnay, and L. Zhou (2005), Observational evidence of sensitivity of surface climate changes to land types and urbanization, *Geophys. Res. Lett.*, *32*, L22712, doi:10.1029/2005GL024267.

Lim, Y., M. Cai, E. Kalnay, and L. Zhou (2008), Impact of vegetation types on surface temperature change, *J. Appl. Meteorol. Climatol.*, *47*, 411–424, doi:10.1175/2007JAMC1494.1.

Lin, X., R. A. Pielke Sr., K. G. Hubbard, K. C. Crawford, M. A. Shafer, and T. Matsui (2007), An examination of 1997–2007 surface layer temperature trends at two heights in Oklahoma, *Geophys. Res. Lett.*, *34*, L24705, doi:10.1029/2007GL031652.

Lobell, D. B., and C. Bonfils (2008), The effect of irrigation on regional temperatures: A spatial and temporal analysis of trends in California, 1934–2002, *J. Clim.*, *21*, 2063–2071, doi:10.1175/2007JCLI1755.1.

Mahmood, R., K. G. Hubbard, and C. Carlson (2004), Modification of growing-season surface temperature records in the Northern Great Plains due to land use transformation: Verification of modeling results and implications for global climate change, *Int. J. Climatol.*, *24*, 311–327, doi:10.1002/joc.992.

Mahmood, R., S. A. Foster, T. Keeling, K. G. Hubbard, C. Carlson, and R. Leeper (2006), Impacts of irrigation on 20th-century temperatures in the Northern Great Plains, *Global Planet. Change*, *54*, 1–18, doi:10.1016/j.gloplacha.2005.10.004.

National Research Council (2005), *Radiative Forcing of Climate Change: Expanding the Concept and Addressing Uncertainties*, 208 pp., Natl. Acad. Press, Washington, D. C.

Owen, T. W., T. N. Carlson, and R. R. Gillies (1998a), An assessment of satellite remotely sensed land cover parameters in quantitatively describing the climatic effect of urbanization, *Int. J. Remote Sens.*, *19*, 1663–1681, doi:10.1080/014311698215171.

Owen, T. W., K. P. Gallo, C. D. Elvidge, and K. E. Baugh (1998b), Using DMSP-OLS light frequency data to categorize urban environments associated with US climate observing stations, *Int. J. Remote Sens.*, *19*, 3451–3456, doi:10.1080/014311698214127.

Parker, D. E. (2006), A demonstration that large-scale warming is not urban, *J. Clim.*, *19*, 2882–2895, doi:10.1175/JCLI3730.1.

Parker, D. E., P. Jones, T. C. Peterson, and J. Kennedy (2009), Comment on "Unresolved issues with the assessment of multi-decadal global land surface temperature trends" by Roger A. Pielke Sr. et al., *J. Geophys. Res.*, *114*, D05104, doi:10.1029/2008JD010450.

Peterson, T. C., K. P. Gallo, J. Lawrimore, A. Huang, and D. A. McKittrick (1999), Global rural temperature trends, *Geophys. Res. Lett.*, *26*(3), 329–332, doi:10.1029/1998GL900322.

Pielke, R. A., Sr., T. Stohlgren, W. Parton, J. Moeny, N. Doesken, L. Schell, and K. Redmond (2000), Spatial representativeness of temperature measurements from a single site, *Bull. Am. Meteorol. Soc.*, *81*, 826–830, doi:10.1175/1520-0477(2000)081<0826:SPATIA>2.3.CO;2.

Pielke, R. A., Sr., T. Stohlgren, L. Schell, W. Parton, N. Doesken, K. Redmond, J. Moeny, T. McKee, and T. G. F. Kittel (2002), Problems in evaluating regional and local trends in temperature: An example from eastern Colorado, USA, *Int. J. Climatol.*, *22*, 421–434, doi:10.1002/joc.706.

Pielke, R. A., Sr., et al. (2007a), Unresolved issues with the assessment of multidecadal global land-surface temperature trends, *J. Geophys. Res.*, *112*, D24S08, doi:10.1029/2006JD008229.

Pielke, R. A., Sr., et al. (2007b), Documentation of uncertainties and biases associated with surface temperature measurement sites for climate change assessment, *Bull. Am. Meteorol. Soc.*, *88*(6), 913–928, doi:10.1175/BAMS-88-6-913.

Quayle, R. G., D. R. Easterling, T. R. Karl, and P. Y. Hughes (1991), Effects of recent thermometer changes in the Cooperative Station Network, *Bull. Am. Meteorol. Soc.*, *72*, 1718–1723, doi:10.1175/1520-0477(1991)072<1718:EORTCI>2.0.CO;2.

Simmons, A. J., P. D. Jones, V. da Costa Bechtold, A. C. M. Beljaars, P. W. Kållberg, S. Saarinen, S. M. Uppala, P. Viterbo, and N. Wedi (2004), Comparison of trends and low-frequency variability in CRU, ERA-40 and NCEP/NCAR analyses of surface air temperature, *J. Geophys. Res.*, *109*, D24115, doi:10.1029/2004JD005306.

Trenberth, K. E., et al. (2007), Observations: Surface and Atmospheric Climate Change, in *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon et al., chap. 3, pp. 235–336, Cambridge Univ. Press, Cambridge, U. K.

Vose, R. S., D. R. Easterling, and B. Gleason (2005), Maximum and minimum temperature trends for the globe: An update through 2004, *Geophys. Res. Lett.*, *32*, L23822, doi:10.1029/2005GL024379.

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