Comment on "Contributions of Anthropogenic and Natural Forcing to Recent Tropopause Height Changes"

Comment on "Contributions of Anthropogenic and Natural Forcing to Recent Tropopause Height Changes"

Santer *et al.* (*1*) concluded that an observed increase in tropopause height from 1979 to 1999 resulted, in part, from tropospheric warming due to increased greenhouse gases. They further showed that the largest increases in tropopause height occurred towards the poles, particularly in the Southern Hemisphere, and asserted that this spatial pattern is significant.

Tropospheric warming can be characterized by an increase in the distance between upper-tropospheric pressure surfaces and a near-surface pressure level. This distance can be directly interpreted as the mean layer temperature, with warming of the 1000–300 hPa layer resulting in a larger vertical separation between the two pressure surfaces (*2*). The globally averaged 300 hPa surface, and other pressure surfaces, would also elevate if the global mean troposphere warmed. We agree with Santer *et al.* (*1*) that the use of quantities such as tropopause height, which represent an integral description of the atmosphere, may provide effective metrics to diagnose complex changes in atmospheric structure. For this reason, we conclude that pressure altitude and the thickness-derived temperature between pressure surfaces, such as the 300 hPa heights and the thickness temperature between the 1000–300 hPa pressure surfaces, provide effective alternative assessments of layer-averaged tropospheric temperatures.

Interannual variability in the NCAR/NCEP (*3*, *4*) reanalysis of the 1000–300 hPa thickness temperature and the 300 hPa heights over 1979–1999, using the same data as (*1*), are shown in Fig. 1, A and B. Trends are 0.032°C/decade (*P* = 0.65) in the layer-averaged temperature and 0.53 m/decade (*P* = 0.84) in the 300 hPa height change. Globally-averaged tropospheric temperature trends are statistically indistinguishable from zero. Thus, the elevation of the globally averaged tropopause reported in (*1*) cannot be attributed to any detectable tropospheric warming over this time period.

Santer *et al.* (*1*) concluded that spatial patterns of tropospheric warming are significant. The NCAR/NCEP reanalysis of the 1000–300 hPa average temperature trends over 1979–1999 and their zonal average are shown in Fig. 1, C and D. Santer *et al.* (*1*) found the largest increase in tropopause height in the high southern latitudes. This increase is clearly dominated by stratospheric changes [including atmospheric dynamics (*5*)], as there is broad tropospheric cooling in the Antarctic regions. Additionally, Fig. 1C shows little statistical significance (90 and 95% levels are shaded). Therefore, in general, regional trends are statistically indistinguishable from zero and a tropospheric effect on tropopause height cannot be inferred.

Christy *et al.* (*6*) and Santer *et al.* (*7*) reported on a spurious lower stratospheric cooling in the NCAR/NCEP reanalysis data beginning in 1997. This coding might affect measures of tropospheric thickness temperature and height. This concern is unfounded

for three reasons. First, as can be seen from Fig. 1, A and B, ignoring data after 1996, linear trends in globally averaged 1000–300 hPa thickness temperature and 300 hPa over 1979 to 1996 were not significant [–0.045°C/decade (*P* = 0.55) and –2.59 m/decade (*P* = 0.33) for 1000–300 hPa thickness temperature and 300 hPa height, respectively]. This indicates that the warming described by Santer *et al.* (*1*) resulted from data at the end of the time series and is not the result of a general linear warming trend. The map of thickness temperature spatial trends and their zonal average over 1979–1996 (Fig. 2) shows that warming in the Northern Hemisphere is statistically significant only in several small isolated regions, and does not support a conclusion of general warming of the Northern Hemisphere troposphere— or the latitudinal characteristics reported in (*1*). Second, because the NCAR/NCEP reanalysis data are tuned by radiosonde data, long-term trends are dependent on the evolution of the radiosonde data over time (*6*). This connection with observations prevents any model drift in tropospheric heating over time. Third, temperature profiles are integrated upwards (*8*), so any bias in the stratosphere would not have a direct effect on the computation of
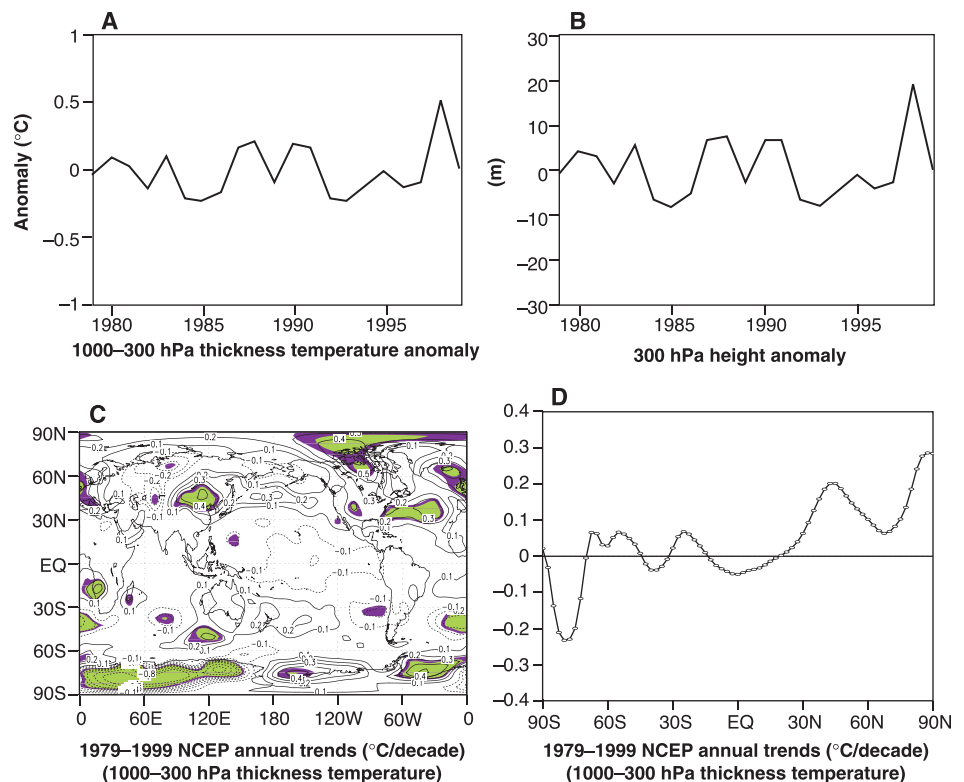

Fig. 1. Interannual variability in the NCAR/NCEP reanalysis of the 1000–300 hPa thickness temperature (**A**) and the 300 hPa heights (**B**) over 1979–1999 using the same data as in (*1*). Bottom panels show the NCAR/NCEP reanalysis map of 1000–300 hPa thickness temperature spatial trends (**C**) and their zonal average (**D**) over 1979–1999.
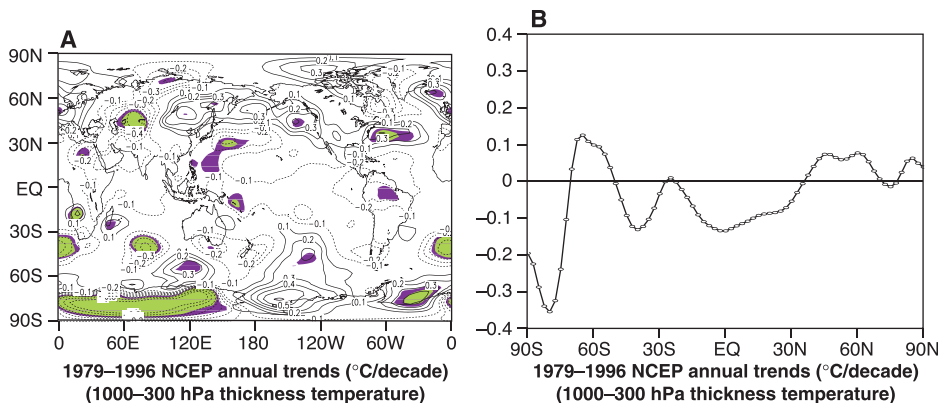
Fig. 2. NCAR/NCEP reanalysis map of 1000–300 hPa thickness temperature spatial trends (**A**) and their zonal average (**B**) over 1979–1996.

1371 Campus Delivery
Colorado State University
Fort Collins, CO 80523, USA
E-mail: pielke@atmos.colostate.edu

Thomas N. Chase
Cooperative Institute for Research in
Environmental Sciences (CIRES) and
Department of Geography
Campus Box 216
University of Colorado
Boulder, CO 80309, USA

underlying tropospheric pressure-surface heights. Thus, the NCAR/NCEP reanalysis is a valuable tool for climate assessments (*9–12*).

Some have questioned the independence of the NCAR/NCEP reanalysis and the MSU lower tropospheric data (*13*). However, our previous intercomparisons were made specifically with the Christy *et al*. (*9*) MSU lower tropospheric data (which was adjusted and merged with the microwave data sets), and not the raw MSU satellite radiances used in the package that generates temperature retrievals for NCEP reanalyses. The Christy *et al*. data product was not used in the NCAR/NCEP reanalysis (*6*). Since the MSU lower tropospheric data and radiosonde data are independent sources, the long-term rate of change in the temperature fields that they diagnose are independent of each other. These data can therefore be compared to assess the accuracy of trend and variability in the reanalysis.

Observed changes in the magnitude of the 200 (or 300) hPa winds provide an additional integrative measure of changes in tropospheric thermal structure where the atmosphere itself does the integration. Using the thermal wind equation, the east-west wind velocity allows inference of the tropospheric-averaged, north-south horizontal temperature gradient (*14*). As shown in (*14*), there was no reduction in the equator-to-pole temperature gradient over 1979–1997 in either hemisphere, contrary to the indication in (*1*).

Finally, the climate system is much more complex than defined by tropospheric temperature and tropopause changes. Linear trend analysis is of limited significance (*15*). Changes in global heat storage provide a more appropriate metric to monitor global warming than temperature alone (*16*).

Roger A. Pielke Sr.
Department of Atmospheric Science

References and Notes

1. B. D. Santer *et al*., *Science* **301**, 479 (2003).
2. S. D. Gedzelman, *The Science and Wonders of the Atmosphere* (Wiley and Sons, New York, 1980), p. 535.
3. E. Kalnay *et al*., *Bull. Am. Meteorol. Soc.* **77**, 437 (1996).
4. NCAR is the National Center for Atmospheric Research; NCEP is the National Center for Environmental Prediction.
5. P. Haynes, J. Scinocca, M. Greenslade, *Geophys. Res. Lett.* **28**, 4179 (2001).
6. J. Christy, R. W. Spencer, W. B. Norris, W. D. Braswell, D. E. Parker, *J. Atmos. Ocean. Tech.* **20**, 613 (2003).
7. B. D. Santer *et al*., *J. Geophys. Res.* **108**, D1 (2003) (DOI 10.1029/2002JD002258).
8. E. Kalnay, personal communication.
9. J. R. Christy, R. W. Spencer, E. S. Lobl, *J. Clim.* **11**, 2016 (1998).
10. R. A. Pielke, J. Eastman, T. N. Chase, J. Knaff, T. G. F. Kittel, *J. Geophys. Res.* **103**, 16927 (1998).
11. R. A. Pielke, J. Eastman, T. N. Chase, J. Knaff, T. G. F. Kittel, *J. Geophys. Res.* **103**, 28909 (1998).
12. T. N. Chase, R. A. Pielke, J. A. Knaff, T. G. F. Kittel, J. L. Eastman, *Int. J. Climatol.* **20**, 503 (2000).
13. A. N. Basist, M. Chelliah, *Bull. Am. Meteorol. Soc.* **78**, 1431 (1997).
14. R. A. Pielke Sr., T. N. Chase, T. G. F. Kittel, J. Knaff, J. Eastman, *J. Geophys. Res.* **106**, D21, 27287 (2001).
15. J. Rial *et al*., *Clim. Change*, in press.
16. R. A. Pielke Sr., *Bull. Am. Meteorol. Soc.* **84**, 331 (2003).