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

Pielke and Chase (*1*) contend that the troposphere has not warmed since 1979, and that tropospheric warming cannot contribute to observed increases in tropopause height (*2*). They base this contention on the absence of tropospheric warming in thickness data and geopotential heights obtained from the National Center for Environmental Prediction (NCEP) reanalysis, which is a synthesis of in situ observations and numerical weather forecasts (*3*). The crux of their argument is that NCEP reliably portrays the global-scale tropospheric temperature changes that have occurred in the real world. The validity of this argument rests heavily on the credibility of three scientific claims made in (*1*).

Before examining these claims, it is important to note that we do not dispute the Pielke and Chase finding of no recent tropospheric warming in NCEP. We reported a similar result previously (*2, 4*). Their analysis of the NCEP 300 hPa geopotential height and 1000–300 hPa thickness data provides equivalent information to that obtained in our earlier study of synthetic Microwave Sounding Unit (MSU) temperatures in NCEP (*4*). However, we strongly differ from Pielke and Chase in our assessment of the reliability of NCEP-based atmospheric temperature trends.

The first claim made by Pielke and Chase (*1*) is that tropospheric temperature trends in NCEP are primarily due to the assimilated radiosonde data ("long-term trends are dependent on the evolution of the radiosonde data over time"). This is incorrect. In addition to radiosonde information, the NCEP reanalysis incorporates observations from satellite sounders, aircraft, surface marine data, land surface synoptic data, and satellite-derived winds (*3*). In the three-dimensional variational assimilation scheme (3D-VAR) employed by NCEP, each type of observation can affect atmospheric temperatures.

NCEP uses satellite-based temperature retrievals from the National Environmental Satellite Data and Information Service (NESDIS). These retrievals commence in November 1978 and are assimilated over all ocean areas, and above 100 hPa over land areas with poor radiosonde coverage (*3*). Given the sparse distribution of radiosondes over most oceans, the NESDIS retrievals are the primary observational input to the NCEP reanalysis over much of the globe (at least during the satellite era). Radiosondes are therefore unlikely to be the main driver of NCEP's recent trends in global-scale tropospheric temperature.

Furthermore, there are significant uncertainties in the radiosonde data assimilated by NCEP. While these data are quality-controlled prior to assimilation (*3*), the control process does not explicitly adjust for effects of changes in radiosonde sensors and monitoring procedures. Accounting for such inhomogeneities can have considerable impact on radiosonde-based estimates of global-scale tropospheric temperature trends (*5*). Uncertainties in the assimilated radiosonde data must therefore propagate into the tropospheric temperatures estimated from NCEP or any other reanalysis. 3D-VAR systems do not completely remove this problem.

The second claim made in (*1*) relates to the assimilated NESDIS temperature retrievals. Pielke and Chase maintain that known biases in these retrievals (*6*) are confined to the stratosphere and do not adversely affect NCEP's tropospheric temperatures. This is also incorrect. Regionally, the NESDIS retrievals have large biases in the temperature and static stability of the troposphere (*7*). These biases are related to such factors as poor vertical resolution of the satellite radiances, airmass type, and the use of climatological-mean "first guess" temperature profiles for retrievals (*7, 8*). Intersatellite radiance biases, changes in cloud-clearing algorithms (*9*), and changes in the retrieval algorithms themselves (*7*) also introduce spurious temporal variability in the retrievals (*10*, *11*).

The third claim in (*1*) is that NCEP's trends in lower tropospheric temperature (LTT) are supported by an independent data set: MSU LTTs processed by the University of Alabama, Huntsville (UAH) (*12*). This is not the case. Although both groups employ different procedures to estimate LTT changes, the NESDIS temperature retrievals assimilated by NCEP rely partly on the same raw MSU radiances used by UAH. Given this similarity in primary data sources, trend agreement does not necessarily constitute independent validation of either NCEP or UAH; LTT changes in both data sets may be incorrect (*10*).

The same concerns apply to the Pielke and Chase assertion that radiosondes and UAH data provide independent estimates of LTT trends. UAH use radiosonde information in the process of merging MSU data from overlapping satellites (*12, 13*). This strategy can affect the claimed independence of MSU/radiosonde trend comparisons. Furthermore, such comparisons typically focus on the relatively small geographical areas where reliable radiosonde information is available and cannot be used to validate global-scale LTT changes estimated by UAH.

In summary, Pielke and Chase have focused on NCEP data, in which the troposphere cools over the satellite era. It is likely that some or all of this cooling is spurious and arises from biases in the temperature retrievals assimilated by NCEP (*10*). They ignore data sets showing recent tropospheric warming that conflicts with their claims. Examples include the ERA-15 reanalysis (*14*) and a new satellite-based temperature data set relying on the same raw MSU radiances processed by UAH (*15*). Tropospheric warming in ERA-15 contributed to our positive identification of a model "fingerprint" of anthropogenic and natural effects in ERA-15 tropopause height data (*2, 16*).

Our report (*2*) acknowledged uncertainties in the relative contributions of tropospheric and stratospheric temperature changes to recent tropopause height increases. Our detection results are robust to these uncertainties. In spite of NCEP's tropospheric cooling, there is strong evidence from other data sets that the troposphere has warmed, and that this warming contributes to recent tropopause height increases.

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References and Notes

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10. The NESDIS retrievals use radiances from multiple instruments: MSU, the Stratospheric Sounding Unit (SSU), and the High Resolution Infrared Radiation Sounder (HIRS). Clouds strongly affect the infrared radiances measured by HIRS, but have less impact on the microwave radiances measured by MSU. Retrievals for cloudy and partly cloudy conditions are therefore dominated by MSU-derived radiances. Temporal changes in the cloud identification algorithms used in the NESDIS retrievals may have impacted retrieval homogeneity by inducing systematic changes in the "mix" of MSU and HIRS radiances. Systematic changes in the retrievals also occurred in the late 1990s, during the transition from MSU to the Advanced MSU (AMSU) (*11*). The AMSU was not subject to significant cloud contamination and essentially replaced the HIRS (except for HIRS channel 12). Problems with the NESDIS retrievals are also illustrated by the fact that their assimilation into the numerical weather forecast model of the European Centre for Medium-Range Weather Forecasts (ECMWF) adversely affected forecast quality (*6*). This was one of the factors motivating the decision by ECMWF to assimilate satellite radiances (rather than temperature retrievals) in the ERA-15 reanalysis (*14*).
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16. This raises the question of why the tropopause height fingerprint from the Parallel Climate Model (PCM) is identifiable in NCEP, despite the tropospheric cooling in this data set. We attempted to explain this result in (*2*). NCEP's excessive stratospheric cooling, which is largely induced by biases in the NESDIS temperature retrievals (*10*), yields too large an increase in tropopause height. This error in stratospheric temperatures propagates into the upper troposphere, and is partly responsible for NCEP's mean tropospheric cooling, which decreases tropopause height. As noted in (*2*), compensating errors in stratospheric and tropospheric temperature changes must therefore influence the tropopause height detection results that we obtain with NCEP. Error compensation alone, however, cannot explain the correspondence between the detailed spatial patterns of tropopause height change in PCM and NCEP. It is far more likely that common physical mechanisms explain such similarities. We partially removed the effects of compensating errors through the "global mean removed" detection analysis and still found highly significant pattern similarities between PCM and NCEP tropopause height changes. These similarities are unlikely to be fortuitous.
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