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Trends in middle- and upper-level tropospheric humidity from NCEP reanalysis data

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Abstract The National Centers for Environmental Prediction (NCEP) reanalysis data on tropospheric humidity are examined for the period 1973 to 2007. It is accepted that radiosonde-derived humidity data must be treated with great caution, particularly at altitudes above the 500 hPa pressure level. With that caveat, the face-value 35-year trend in zonal-average annual-average specific humidity q is significantly negative at all altitudes above 850 hPa (roughly the top of the convective boundary layer) in the tropics and southern midlatitudes and at altitudes above 600 hPa in the northern midlatitudes. It is significantly positive below 850 hPa in all three zones, as might be expected in a mixed layer with rising temperatures over a moist surface. The results are qualitatively consistent with trends in NCEP atmospheric temperatures (which must also be treated with great caution) that show an increase in the stability of the convective boundary layer as the global temperature has risen over the period. The upper-level negative trends in q are inconsistent with climate-model calculations and are largely (but not completely) inconsistent with satellite data. Water vapor feedback in climate models is positive mainly because of their roughly constant relative humidity (i.e., increasing q) in the mid-to-upper troposphere as the planet warms. Negative trends in q as found in the NCEP data would imply that long-term water vapor feedback is negative—that it would reduce rather than amplify the response of the climate system to external forcing such as that from increasing atmospheric CO_2. In this context, it is important to establish what (if any) aspects of the observed trends survive detailed examination of the impact of past changes of radiosonde instrumentation and protocol within the various international networks.

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1 Introduction

Balloon-borne radiosonde measurements are the basis of the NCEP reanalysis atmospheric humidity data that are available for the entire globe at each of the standard pressure heights from 1,000 to 300 hPa. The data are continuous from 1948 to the present. However, radiosonde humidity measurements are notoriously unreliable and are usually dismissed out-of-hand as being unsuitable for detecting trends of water vapor in the upper troposphere (e.g., Soden et al. 2005). This is unfortunate, since the feedback response of water vapor at these upper levels is an important factor controlling the degree of global warming from increasing atmospheric CO_2.

Elliott and Gaffen (1991) examined problems of radiosonde humidity measurements for climate studies. They decided that data before 1973 are indeed unusable without adjustments to take account of instrumental changes and deficiencies. Since 1973, the instrumental changes have had less obvious impacts, but there are still problems with reporting practices—particularly the reporting of data from higher levels where both temperature and humidity are very low. They suggested that "data above 500 hPa, with the

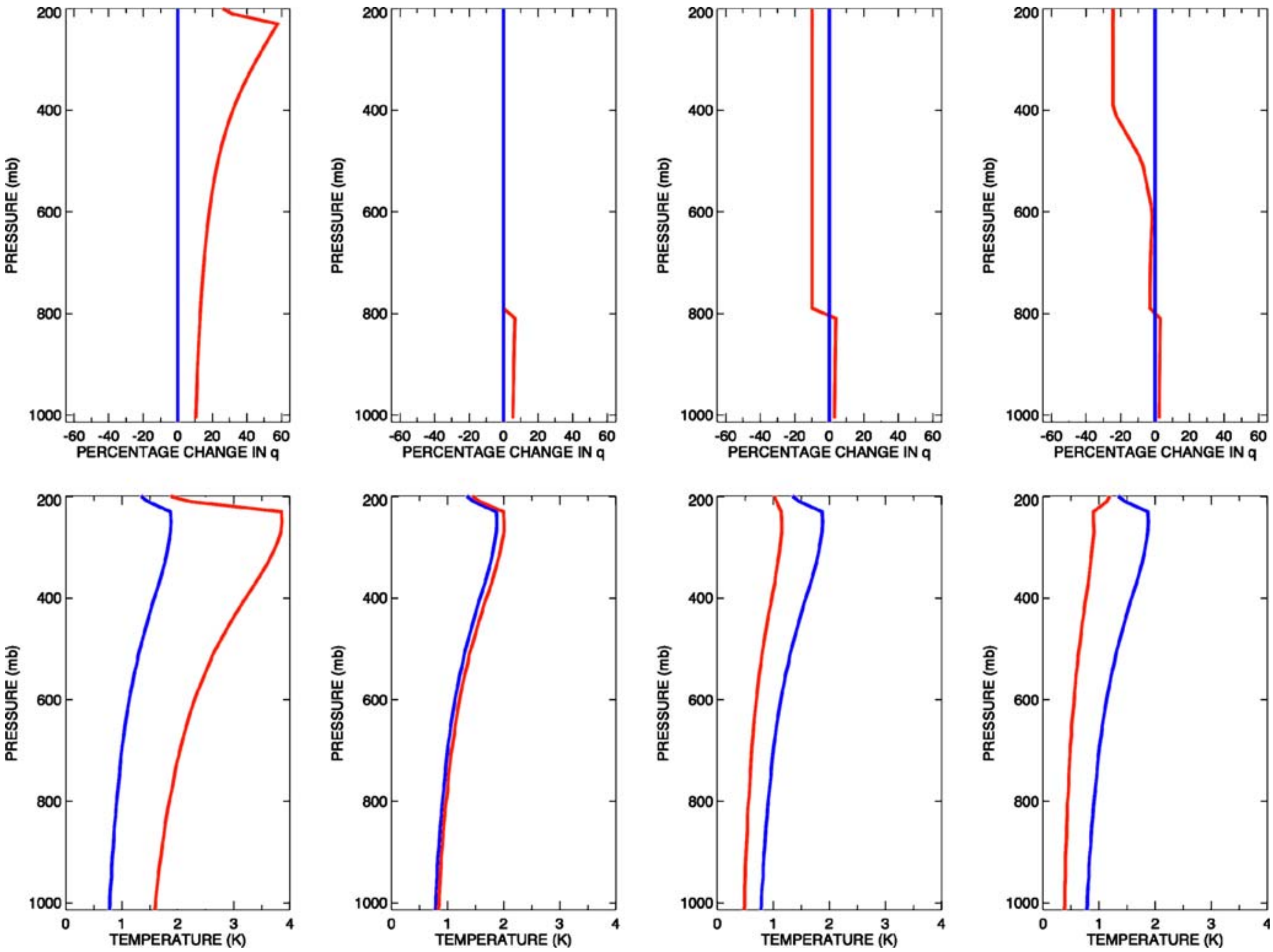

Fig. 10 The change in temperature from a doubling of CO_2 (*lower frames*) showing the effects of prescribed changes in the water vapor profile (*upper frames*) for a midlatitude summer standard atmosphere (McClatchey et al. 1972) without clouds and assuming a moist adiabatic lapse rate. Below the 800-hPa level, q is adjusted to keep the relative humidity fixed at the climatological value. Above the 800-hPa level, various changes in q are imposed: (from *left* to *right*) relative humidity fixed at the climatological value; no change; uniform decrease of 10%; and a profile based on the NCEP trends (see text). Each plot of temperature response shows the response with fixed humidity (*blue*) and with the prescribed change in humidity (*red*)

feedback in response to doubled CO_2. A decrease in mid-to-upper-level q produces negative feedback and a reduction of the CO_2-induced rise of surface and atmospheric temperature. Whatever the change in the upper levels, the overall water vapor in the total atmospheric column increases because changes in the large absolute values of q in the atmosphere below 800 hPa dominate the total. Put the other way around, increases in total column water vapor in response to global warming do not necessarily indicate positive water vapor feedback, since very small decreases of water vapor in the mid-to-upper troposphere can negate the effect of large increases in the boundary layer.

There have been discussions in the past (e.g., Lindzen 1990, Lindzen et al. 2001; Betts 1990; Spencer et al. 2007) about the theoretical possibility of a negative trend in upper-level humidity associated with global warming, and the issue has not been resolved. The many and various mechanisms governing vertical transport of water vapor in the atmosphere include a number of subgrid-scale processes. Moist convection and turbulent diffusion for instance are among the most highly parameterized of all the simulated processes within an atmospheric model and are very difficult to verify. In particular (in view of the discussion earlier with reference to Fig. 7), it is not necessarily true that verification of the short-term simulation of vertical water vapor transport is sufficient for studies on the longer time scales of climate change.

4 Conclusion

It is of course possible that the observed humidity trends from the NCEP data are simply the result of problems with the instrumentation and operation of the global radiosonde network from which the data are derived. The potential for such problems needs to be examined in detail in an effort rather similar to the effort now devoted to abstracting real surface temperature trends from the face-value data from individual stations of the international meteorological networks. As recommended by Elliot and Gaffen (1991) in their original study of the US radiosonde network, there needs to be a detailed examination of how radiosonde instrumentation, operating procedures, and recording practices of all nations have changed over the years and of how these changes may have impacted on the humidity data.

In the meantime, it is important that the trends of water vapor shown by the NCEP data for the middle and upper troposphere should not be "written off" simply on the basis that they are not supported by climate models—or indeed on the basis that they are not supported by the few relevant satellite measurements. There are still many problems associated with satellite retrieval of the humidity information pertaining to a particular level of the atmosphere—particularly in the upper troposphere. Basically, this is because an individual radiometric measurement is a complicated function not only of temperature and humidity (and perhaps of cloud cover because "cloud clearing" algorithms are not perfect), but is also a function of the vertical distribution of those variables over considerable depths of atmosphere. It is difficult to assign a trend in such measurements to an individual cause.

Since balloon data is the only alternative source of information on the past behavior of the middle and upper tropospheric humidity and since that behavior is the dominant control on water vapor feedback, it is important that as much information as possible be retrieved from within the "noise" of the potential errors.

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