Variations in the relative humidity budget from the NCAR/NCEP Reanalysis from 1979-2004

Derek Brown and David Noone

Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado at Boulder (email: derek.brown@colorado.edu)

Relative humidity (RH) of an air parcel varies by changing the amount of moisture within the parcel or by changing the saturation vapor pressure. Dynamic processes in the atmosphere can bring about changes in temperature and moisture and thus RH, and warrants the use of RH as a useful diagnostic. The water vapor feedback is central to understanding climate change since constant relative humidity in model simulations of global warming indicate positive water vapor feedback on temperature, while increases in RH can lead to a net negative feedback via cloud effects (e.g., Held and Soden, 2000). Indeed, Lindzen (1990) found that diminished cirrus clouds resulting from convective detrainment with increasing temperature produced less greenhouse heating associated with clouds and that the strength of this negative feedback is at least equal to the positive feedback associated with greenhouse warming due to water vapor. Hall and Manabe (1999) point to the relationship between water vapor and temperature as key in understanding the future of greenhouse-gas induced hydrologic cycle intensification. A more precise understanding of the relationship between moisture and temperature is needed before the role of RH in climate models and on global precipitation anomalies during global climate shifts is appreciated.

RH can be approximated by the ratio of specific humidity to the saturation specific humidity, as $H = e / e_s \approx q / q_s$. Using the Clausius-Clapeyron equation at constant pressure, one can show

$$d \ln H = d \ln q - \left(\frac{L}{R_v T} \right) d \ln T \; . \qquad (1)$$

Peixoto and Oort (1996) showed that on constant pressure surfaces, temperature changes are 20 times more effective at changing RH values than are changes in moisture. However, since moisture is more variable than temperature, both moisture and temperature become important in changing RH values. The humidity, wind and temperature fields from the NCEP reanalysis were used to decompose the time mean budgets for relative humidity into contributions from condensation, advection (both eddy and zonal mean components), adiabatic work, and diabatic heating as they appear in the budget equations for both specific humidity and temperature that appear in equation (1).

Figure 1 shows the variability of dominant terms in the RH budget over the northern midlatitudes. RH changes brought about by zonal mean divergence and adiabatic work correlate with the ENSO events, while latent heating effects to RH remain fairly constant over time. Moisture induced RH changes in the northern midlatitudes vary with zonal mean and eddy moisture divergence, as well as with condensation (or evaporation). Additionally, RH changes by eddy moisture divergence appear to govern RH changes associated with condensation. For the northern subtropical region, **Figure 2** shows the zonal mean heat divergence, heating by adiabatic work and latent heat release to be central to producing interannual variability in RH. For moisture variability, the zonal mean circulation counters RH changes induced by condensation.

The different terms important for the two regions' RH budgets are indicative of the trends in circulation patterns. For instance, in 1998, a strong El Nino event caused the northern midlatitudes to have increased heat and moisture convergence by the zonal mean resulting in RH fluctuations. In the northern subtropics, the convergence of cool, dry air during this same year, combined with the additional effect of increased latent heating, drove decreases in RH values. As such, because variations in moisture and temperature are associated with the global atmospheric circulation, RH values give a diagnostic view of first order hydrologic balance as well as insight into the atmospheric circulation.

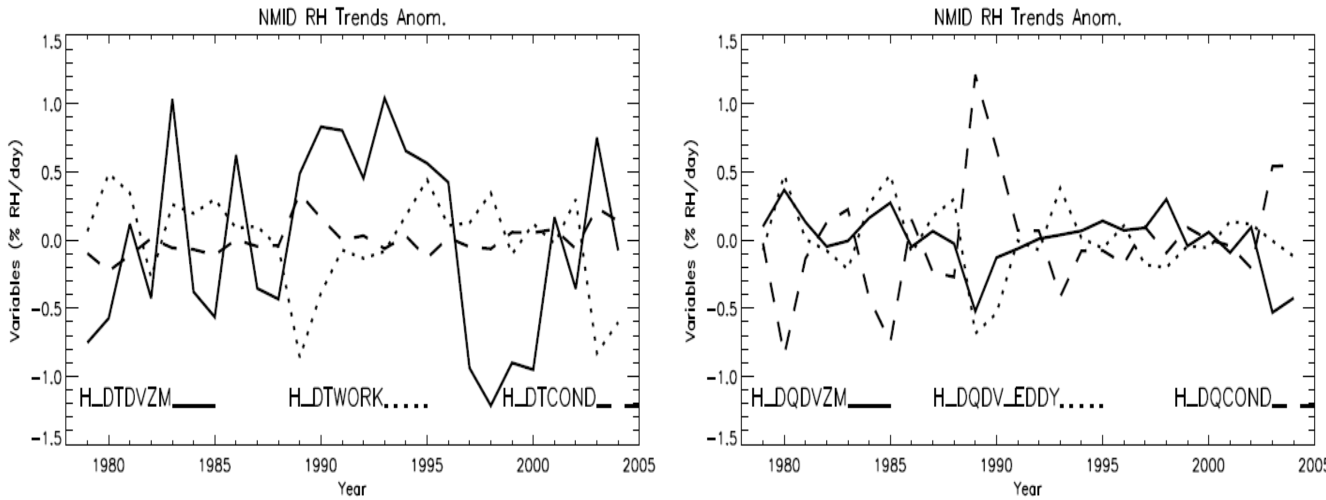

Figure 1: The dominant heating (left) and moisture (right) terms for the zonally averaged, mass weighted relative humidity budget over the northern midlatitudes (40-55N, 500-925hPa). Terms shown are changes in RH due to both meridional and vertical heat divergence by the zonal mean (H_DTDVZM), adiabatic compression or expansion (H_DTWORK), latent heating (H_DTCOND), to moisture divergence by the zonal mean (H_DQDVZM), moisture divergence by eddies (H_DQDV_EDDY) and net condensation (H_DQCOND).

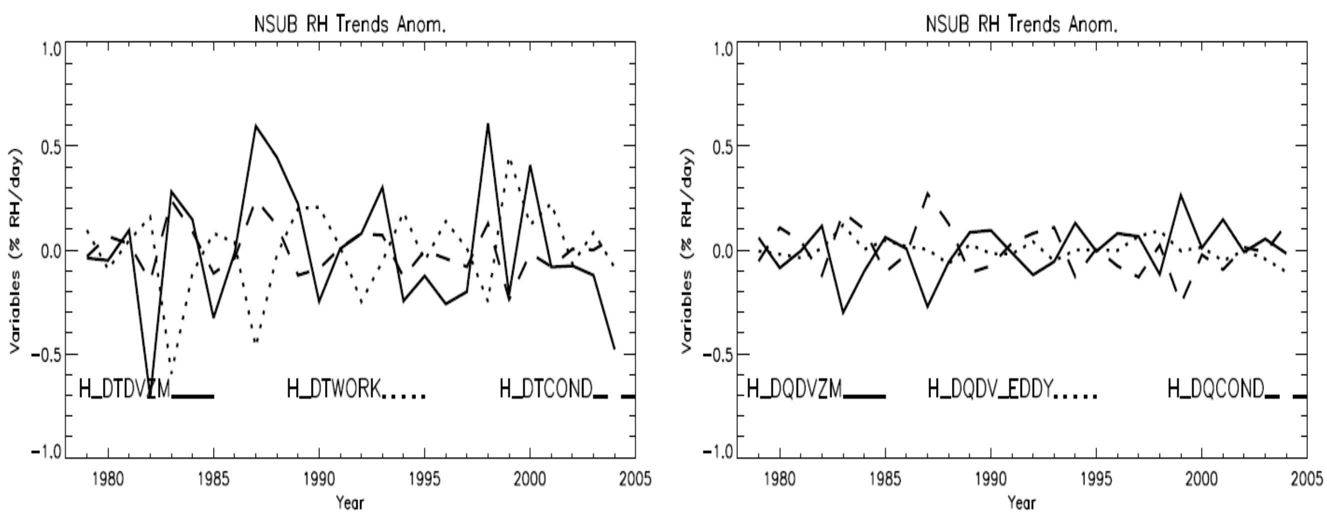

Figure 2: As in Figure 1 but for the northern subtropics (10-35N, 500-925hPa).

Hall A. and Manabe S. 1999: The Role of Water Vapor Feedback in Unperturbed Climate Variability and Global Warming. *Journal of Climate*, **12**, 2327-2346.

Lindzen R. 1990: Some coolness concerning global warming. *Bulletin of the American Meteorological Society*, **71**(3), 288-299.

Peixoto J. and Oort A. 1996: The Climatology of Relative Humidity in the Atmosphere. *Journal of Climate*, **9**, 3443-3463.

Held I. and Soden B. 2000: Water Vapor Feedback and Global Warming**.** *Annual Review of Energy in the Environment*, **25**, 441-475.