Modeling Interannual Variability of $\delta^{18}O$ of Atmospheric CO_2 and its Dependence on Humidity and Isotope Hydrology

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Measurements of the abundance of $CO^{18}O$ in the atmosphere (denoted hereafter as $\delta^{18}O=(R/R_{Standard}-1) \times 1000$, where R is the mole ratio of heavy to light isotopes) at the NOAA/ESRL baseline observatories have shown a gradual downward trend during a period from the early 1990s until the late 1990s. This downward trend is then followed by a recovery period, and then another decline up to present day (solid line in Figure 1). It is believed that fluxes from the terrestrial biosphere largely influence changes in $\delta^{18}O$-CO_2, with photosynthetic fluxes enriching the atmosphere in $CO^{18}O$ and respiratory fluxes depleting it. However the interannual changes could also be a consequence of changes in the isotopic composition of the fluxes. The fluxes from the leaves and the soils take on the isotopic composition of the terrestrial water pools with which CO_2 interacts. There are a number of factors that affect the isotopic composition of both soil and leaf water, including the isotope input from precipitation and water vapor. A steady state model based on the Craig-Gordon (1986) method would suggest that the water pools are largely influenced by relative humidity. While an increase in humidity would increase stomatal conductance and in turn increase biospheric productivity, it also will cause leaves to take in more of the isotopically light water vapor, causing the leaf water to become less enriched with the heavy ^{18}O isotope. Thus, isotope modeling provides a critical test of the humidity estimate in the reanalysis datasets and in climate models.

To model the interannual variability of $\delta^{18}O$-CO_2, we use an isotopic version of the NCAR Land Surface Model (ISOLSM, Bonan, 1996; Riley et al., 2002) to simulate the isotopic composition of the water pools as well as the terrestrial CO_2 fluxes. ISOLSM is forced with meteorological data produced by Dai (2006) for the years 1979-2004, and the $\delta^{18}O$ values of precipitation and water vapor are prescribed from the MU-GCM monthly climatology (Noone and Simmonds, 2002). Fluxes from the oceans, biomass burning, and fossil fuel burning are taken from various datasets, with no interannual variability. All of these fluxes are then put into the NCAR Community Atmosphere Model (CAM) to model $\delta^{18}O$-CO_2 and its interannual variability. In additional to an unperturbed control simulation, two perturbations are conducted. To examine the affects of humidity changes, the model is forced with artificially imposed relative humidity variations in the form of sine wave with an anomaly of ±5% about the long term mean. Another simulation is conducted with artificially imposed variations in the $\delta^{18}O$ value of precipitation of water vapor; again in the form of a sine wave and with a ±1‰ amplitude.

Figure 1 shows these results for the gridcell close to Mauna Loa, along with the observed annual means. Results from the control simulation show very small changes relative to the observations, and the overall shape of interannual variations do not match up with the Mauna Loa observations. These results could suggest that there are very small, and unrealistic, interannual humidity variations in the reanalysis dataset that is used to force ISOLSM. However, the simulations with artificially imposed anomalies in humidity and isotope hydrology, show large interannual variations. In fact, the imposed variations were more than enough to explain the changes seen in the observations. Results from the control simulation would indicate that there is not enough year-to-year change in relative humidity to cause large $\delta^{18}O$-CO_2 variations. However, humidity records at several stations in Southeast Asia show an upward trend during the 1990s, which is consistent with the observed trend in the $\delta^{18}O$ value of atmospheric CO_2. These station observations suggest that the reanalysis does not capture the true humidity variations that were observed during this period. Similarly, interannual changes in $\delta^{18}O$ of precipitation at Bangkok and Darwin also match up well with $\delta^{18}O$-CO_2 observations. So since $\delta^{18}O$-CO_2 is sensitive to even relatively modest variations in humidity, these results show that the reanalysis data has unrealistically low variability in near-surface relative humidity.

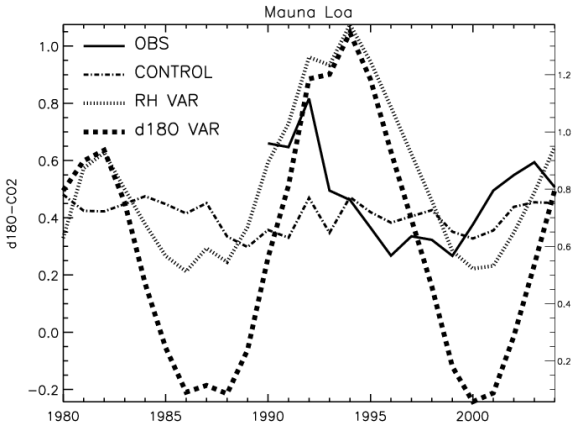

Figure 1. Annual mean of $\delta^{18}O$-CO_2 observed at Mauna Loa (solid line), and for the control simulation (dash-dot), humidity anomaly simulation (hashed line), and isotope hydrology anomaly run (dashed)

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