The Response of the Terrestrial Biosphere and the Global Mean $\delta^{18}O$ Value of Atmospheric CO_2 to Humidity Changes

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The atmospheric concentration of $CO^{18}O$ is largely influenced by the terrestrial biosphere through respiration and photosynthetic leaf fluxes. Both the gross CO_2 exchange and the isotopic composition of leaf and soil water influence the isotopic leaf and soil fluxes that affect the composition of ^{18}O in CO_2 (denoted hereafter as $\delta^{18}O=(R/R_{Standard}-1) \times 1000$, where R is the mole ratio of heavy to light isotopes). Craig and Gordon (1965) showed under the approximation of steady state conditions and constant leaf water volume, the leaf water isotope ratio of $H_2{}^{18}O/H_2{}^{16}O$ at the evaporation site is related to humidity such that it is most enriched in the heavy oxygen isotope at low humidity and is most depleted at 100% relative humidity. Soil water is also able to become enriched when the evaporation rate is high, which again is related to the relative humidity of the atmospheric surface layer. Because of this, the $\delta^{18}O$ value of CO_2 may be a sensitive indicator of the global hydrologic cycle. Using model simulations, we investigate how changes in relative humidity can affect the isotopic state of the terrestrial water pools and atmospheric CO_2.

The isotopic version of the NCAR Land Surface model (ISOLSM, Bonan, 1996; Riley et al., 2002) was used to simulate the isotopic state of the leaf and soil water pools and CO_2 fluxes. Conserving both water and energy, ISOLSM simulates the water and carbon exchanges, and uses kinetic and equilibrium fractionation to account for ^{18}O. The model is forced with meteorological data from the NCEP reanalysis, and the $\delta^{18}O$ value of precipitation and water vapor are prescribed from the MU-GCM monthly climatology (Noone and Simmonds, 2002). To simulate the $\delta^{18}O$ value of CO_2, the monthly mean balanced surface CO_2 fluxes from ISOLSM are inputted into the NCAR Community Atmosphere Model (CAM). The ocean fluxes are prescribed monthly means calculated from pCO_2 differences between the ocean and the marine atmosphere (Takahashi et al., 1997). All CO_2 fluxes and surface $CO^{18}O$ fluxes are prescribed monthly means. However $CO^{18}O$ fluxes from the atmosphere to the surface are dependent on the ratio of $CO^{18}O/ CO_2$, such that a global equilibrium of $\delta^{18}O$ in CO_2 is reached. To examine how relative humidity changes affect both the isotopic composition of the terrestrial water pools and atmospheric CO_2, two experiments were performed that reduced the prescribed relative humidity to 90% and 80% of its original value. For these two experiments, the $\delta^{18}O$ of water vapor is fixed and not allowed to adjust dynamically with the leaf water.

The results of these two experiments suggest that there is a strong dependence of relative humidity on the isotopic composition of the leaf and soil water, omitting latitudes without vegetation (Figure 1). When the relative humidity is reduced to 80% of its original value the zonal mean of the soil water becomes more enriched by about 0.0%-3.0%. The zonal mean of the leaf water becomes even more enriched (2.0-7.0%), due to the enriched soil water, decreased humidity, and enrichment occurring in the leaf itself.

When relative humidity is reduced to 90% and 80% of its original value, the $\delta^{18}O$ value of CO_2 becomes enriched globally by 1.3‰ and 3.0‰, respectively. Noting that observations show typical variability in the range of 1-2‰, these results suggest that small changes in global relative humidity could have a substantial impact on the $\delta^{18}O$ value of CO_2. Specifically, a global deviation of 0.5‰ (as seen in observations) would require a humidity change in the most productive regions of only 3% based on model results. This largely confirms that the $\delta^{18}O$ value of CO_2 provides an integrated metric of the global hydrologic cycle.

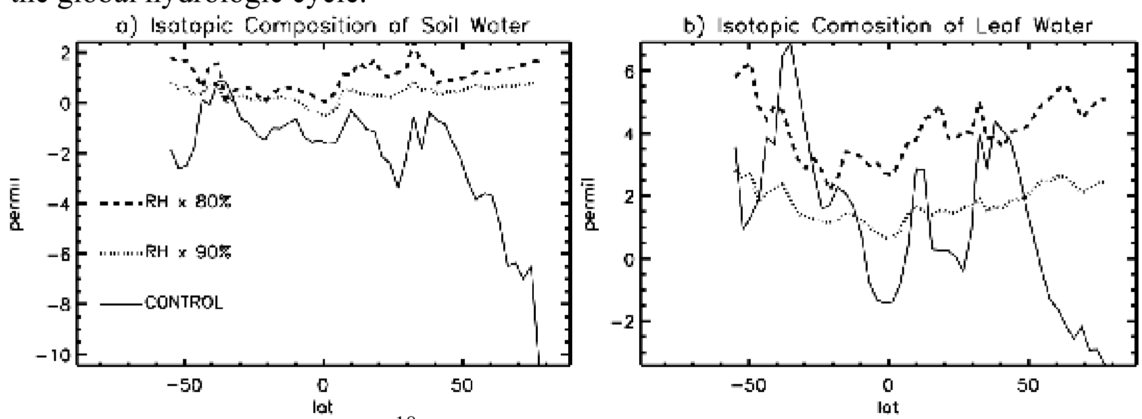

Figure 1. Zonal mean $\delta^{18}O$ of photosynthesis-weighted soil (a) and leaf (b) water for the control simulation (solid line). The experiments that reduce the relative humidity to 90% (dotted line) and 80% (dashed line) of its original value are plotted as experiment minus control.

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