An observational constraint on stomatal function in forests: evaluating coupled carbon and water vapor exchange with carbon isotopes in the Community Land Model (CLM 4.5)

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Land surface models are useful tools to quantify contemporary and future climate impact on terrestrial carbon cycle processes, provided they can be appropriately constrained and tested with observations. Stable carbon isotopes of CO_2 offer the potential to improve model representation of the coupled carbon and water cycles because they are strongly influenced by stomatal function. Recently a representation of stable carbon isotope discrimination was incorporated into the Community Land Model component of the Community Earth System Model. Here, we tested the model's capability to simulate whole-forest isotope discrimination in a subalpine conifer forest at Niwot Ridge, Colorado, USA. We implemented a V_{cmax} seasonally-varying model formulation that optimized net CO_2 carbon exchange, latent heat exchange and biomass relative to observations. The model accurately simulated observed $\delta^{13}C$ of needle and stem tissue, but underestimated the $\delta^{13}C$ of bulk soil carbon by 1-2 ‰. The model overestimated the (2006-2012) average Δ_{canopy} relative to prior data-based estimates by 5-6 ‰. The amplitude of the average seasonal cycle of Δ_{canopy} (i.e. higher in spring/fall as compared to summer) was correctly modeled but only with an alternative formulation for nitrogen limitation. The model attributed most of the seasonal variation in discrimination to the net assimilation rate (A_n), whereas inter-annual variation in Δ_{canopy} during the summer months was driven by stomatal response to vapor pressure deficit. Soil moisture did not influence modeled Δ_{canopy}. Model results indicated that there has been an increase in both photosynthetic discrimination and water use efficiency (WUE, 10%) since 1850 as a result of CO_2 fertilization, under constant climate conditions. This increasing trend in discrimination is counter to established relationships between discrimination and WUE. The isotope observations used here to constrain CLM suggest 1) the parameterization for stomatal conductance was too large and should be reduced via stomatal slope adjustments and 2) the default approach to representing nutrient limitation was not capable of reproducing observed trends in discrimination. These findings demonstrate that isotope observations can bring important information related to stomata function driven by environmental stress from VPD and nitrogen limitation.