Using Observed Carbon Residence Times to Improve Simulation of Total CO_2 and $^{13}CO_2$ Land Carbon Fluxes

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Land sequesters up to half of emitted carbon but land carbon cycle responses to climate variability remain uncertain and difficult to predict. Present-day land carbon cycle models include a variety of ecosystem processes linking moisture and climate to carbon pool dynamics and land biosphere-atmosphere exchanges. In this study, we explore these processes using the Simple Biosphere Model version 4.2 (SiB4). SiB4 simulates photosynthetic uptake of atmospheric CO_2 considering constraints imposed by radiation, soil water availability and atmospheric CO_2 concentrations. Carbon is then transferred to live “pools” (leaves and wood); as the live pools die and decay, carbon is transferred to dead pools, mainly litter and soil carbon. Respiration of CO_2 back to the atmosphere is associated with all these transfers: autotrophic respiration from live pools and heterotrophic from dead pools. Additionally, in previous work, we added to SiB4 the capability to track not just total C through the pools but also carbon-13 in CO_2 (^{13}C), whose photosynthetic uptake is separately simulated. The residence time of carbon in ecosystems is a fundamental aspect of ecosystem behavior and linked to an ecosystem’s capacity to act as a carbon sink. Studies comparing modeled and observed carbon residence times show that ecosystem models tend to underestimate biosphere residence times, and this is also true of SiB4. To address this bias, we developed a range of empirical tuning factors for both heterotrophic and autotrophic respiration, based on observationally-constrained residence times for a wide range of global ecosystems.

Applying these tuning factors to SiB4 creates a version of the model with much better correspondence to both observed residence times as well as vegetation and soil C biomass. We then explore interannual and seasonal variability in the carbon cycle using simulated and observed ^{13}C:^{12}C ratios (denoted as d^{13}C). While atmospheric CO_2 observations trace NEE, d^{13}C traces plant responses to water stress (e.g., droughts) during photosynthesis. However, a significant impediment to using atmospheric d^{13}C measurements in this way originates from our lack of knowledge of terrestrial “isotopic disequilibrium flux”. This is the land-to-atmosphere $^{13}CO_2$ flux that derives from the long-term decrease in atmospheric d^{13}C because of increasing fossil fuel emissions which are depleted in ^{13}C. The disequilibrium emanates from the fact that atmospheric CO_2 taken up in the past is re-emitted via respiration by which time atmospheric d^{13}C has changed substantially. As such, it is tied to the age of biosphere pools from which carbon is released. In most representations of the atmospheric d^{13}C budget, terrestrial disequilibrium is not large enough to explain the observed atmospheric d^{13}C trend. Improving simulation of residence times in terrestrial biosphere models also improves estimates of terrestrial isotopic disequilibrium resulting in closer agreement with the atmospheric C13 growth rate. Finally, we use the International Land Model Benchmarking (ILAMB) tool to demonstrate that this improved version of SiB4 shows better agreement with observed carbon cycle variables compared to CMIP6 models (Figure 1).

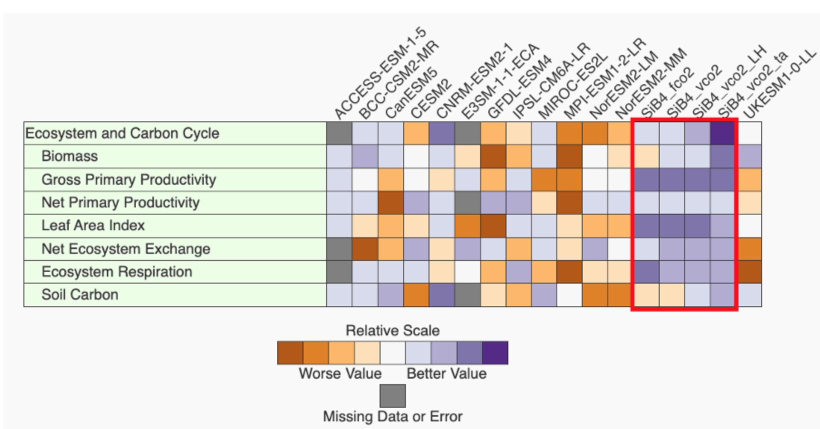

Figure 1. SiB4 model iterations (highlighted in red box) show better agreement with observed carbon cycle datasets for 2000-2014 compared to other CMIP6 models. Our optimally tuned version (SiB4_vco2_ta) shows the overall best agreement with observations, with the most improvements in agreement for vegetation biomass and soil carbon compared to other SiB4 iterations. This figure is produced using ILAMB tools for benchmarking land models.