Constraining Carbon Exchange Processes over North America by Joint Assimilation of Atmospheric CO_2 and $\delta^{13}C$

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Given the complex feedbacks that exist between the terrestrial biosphere and climate, the future of the terrestrial carbon sink remains uncertain in a world where droughts may be more extreme and more frequent. The ratio of carbon-13 (^{13}C)/carbon-12 (^{12}C) in atmospheric carbon dioxide (CO_2) (reported as delta carbon-13 [$\delta^{13}C$] in ‰ relative to the Vienna Pee Dee Belemnite [VPDB] reference ratio), which we measure, provides insight into climate-carbon coupling. Photosynthesis imposes distinctive isotopic fractionation (also known as discrimination depicted as Δ) patterns upon atmospheric $\delta^{13}C$. Variations of $\delta^{13}C$ in the atmosphere reflect spatially coherent changes in stomatal and mesophyll conductance, and in the relative contributions from C3 (e.g. forests) and C4 (e.g. maize) plant growth. However, these biogeochemical interactions are often poorly represented in climate land surface models. In an effort to diagnose and improve such models, we have developed an inverse model capable of assimilating $\delta^{13}C$ and CO_2 data. So far, $\delta^{13}C$ in inversion experiments was mainly used to distinguish the global land carbon sink from the ocean carbon sink. Now we take this one step further by estimating the magnitude of Δ during photosynthesis. This could help us better understand the biogeochemical interactions between the atmosphere and vegetation, and help us to improve parameterizations of carbon exchange in land surface models. Starting with synthetic datasets of CO_2 and $\delta^{13}C$ of North America, we present and discuss the performance of different inversion techniques. One complicating aspect is the nonlinearity of the $\delta^{13}C$ budget as net carbon exchange (NEE) and Δ are multiplicative terms. Our findings confirm we can only retrieve meaningful signals in isotopic Δ if the total CO_2 budget is correctly estimated. We find noticeable improvements of the inverted NEE and Δ primarily over the aggregated boreal and temperate forests, and cultivated land of the U.S. Potential atmospheric transport errors may leave $\delta^{13}C$ and estimates of Δ unaffected as biases are cancelled out in the isotope ratio carbon-13 dioxide ($^{13}CO_2$)/carbon-12 dioxide ($^{12}CO_2$) (example shown in figure below). Real data inversions furthermore reveal potential problems in land surface models, such as oversimplified description of biological processes (e.g. stomatal and mesophyll conductance) and land use.

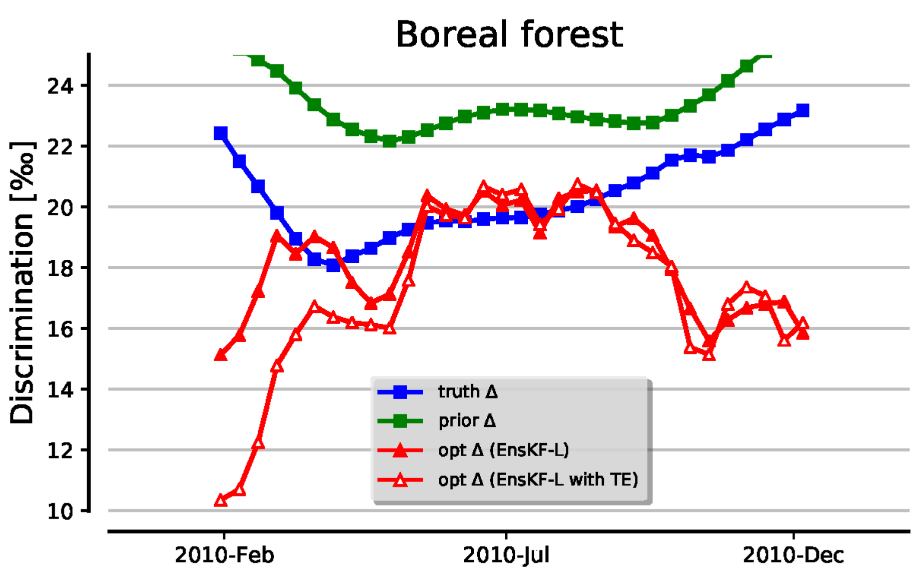

Figure 1. Synthetic data experiment showing aggregated 10-day mean Δ estimates (red) for boreal forest along with prior (green) and true (blue) Δ estimates. During summer, we are able to recover the true discrimination. The estimates with the open red symbols come from an inversion with an intentionally created atmospheric transport error (TE). These transport errors produced different CO_2 and $^{13}CO_2$ mole fractions over North America, but left $\delta^{13}C$ ratios and Δ unaffected as biases cancel out when we take ratio of $^{13}CO_2/^{12}CO_2$.