A New Inverse Modeling Tool for Understanding Plant Drought Stress using Atmospheric 13C of CO2 Measurements

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Feedbacks related to exchanges of water and carbon between the atmosphere and the terrestrial biosphere are key uncertainties in our understanding of Earth's climate. Of particular importance for climate projections is the response of diverse biomes to moisture stress due to increasing vapor pressure deficit and changing precipitation regimes, as well as responses to increasing atmospheric CO_2. The ^{13}C:^{12}C ratio of CO_2 (denoted as $\delta^{13}C$) is a proxy for plant water stress, since most plants favor the assimilation of $^{12}CO_2$ during photosynthesis by about 2%, and this "discrimination" is reduced under periods of moisture stress. While discrimination has been observed at the leaf and ecosystem scales for decades, recent studies have shown that atmospheric $\delta^{13}C$ is sensitive to changes in plant response to water stress at regional to global scales. However, few studies have tried to formally assimilate $\delta^{13}C$ within the context of an atmospheric inverse model to constrain regional-scale plant water stress. Here, we first examine the fundamental requirements that allow $\delta^{13}C$ to constrain discrimination using a simple physical model that links observed changes in d^{13}C to net ecosystem exchange, discrimination, and atmospheric mixing. We then present a novel and rigorous regional data assimilation system and test it using synthetic measurements from a network of highly calibrated CO_2 and δ^{13}Catm measurements. The model simultaneously solves for net ecosystem exchange of CO_2 and discrimination fluxes that are optimally consistent with pseudo-measurements. We find that the model can resolve signals that are considerably smaller than the limits of the simple physical model. However, this improvement is contingent on the analytical uncertainty of measurements. We find that a dense network of highly calibrated measurements of δ^{13}Catm can constrain regional-scale linkages between carbon and water fluxes between terrestrial ecosystems and the atmosphere.

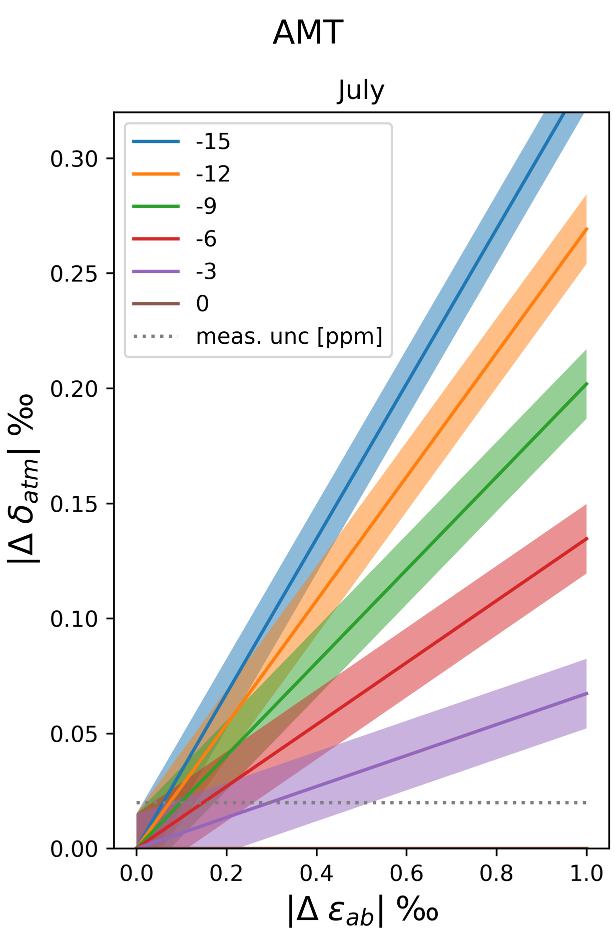

Figure 1. A simple physical model showing the sensitivity of atmopsheric $\delta^{13}C$ measurements to changing photosynthetic discrimination at a tall tower site in Maine. Here, different colors indicate different values of Net ecosytem exchange of CO_2 (NEE), and the shading represents variability in sensitivity to total surface flux (i.e., "footprints"). The model shows that the the sensitivity of atmopsheric $\delta^{13}C$ to photosynthetic discrimination is additionally contingent on the mgnitude of NEE. Finally the dotted horizontal line shows a typical value of analytical uncertainty for the measurements.