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Incorporating an enzymatic model of effects of temperature, moisture, and substrate supply on soil respiration into an ecosystem model for two forests of northeastern USA

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Soils represent the largest terrestrial carbon (C) pool, and microbial decomposition of soil organic matter (SOM) to carbon dioxide, also called heterotrophic respiration (Rh), is an important component of the global C cycle. Temperature sensitivity of Rh is often represented with a simple Q10 function in ecosystem models and earth system models (ESMs), sometimes accompanied by an empirical soil moisture modifier. More explicit representation of the effects of soil moisture, substrate supply, and their interactions with temperature has been proposed to disentangle the confounding factors of apparent temperature sensitivity of SOM decomposition and improve performance of ecosystem models and ESMs. The objective of this work was to incorporate into an ecosystem model a more mechanistic, but still parsimonious, model of environmental factors controlling Rh.
The Dual Arrhenius and Michaelis-Menten (DAMM) model simulates Rh using Michaelis-Menten, Arrhenius, and diffusion functions. Soil moisture affects Rh and its apparent temperature sensitivity in DAMM by regulating the diffusion of oxygen and soluble carbon substrates to the enzymatic reaction site. However, in its current configuration, DAMM depends on assumptions or inputs from other models regarding soil C inputs. Here we merged the DAMM soil flux model with a parsimonious ecosystem flux model, FöBAAR (Forest Biomass, Assimilation, Allocation and Respiration) by replacing FöBAAR's algorithms for Rh with those of DAMM. Classical root trenching experiments provided data to partition soil CO_2 efflux into Rh (trenched plot) and root respiration (untrenched minus trenched plots). We used three years of high-frequency soil flux data from automated soil chambers (trenched and untrenched plots) and landscape-scale ecosystem fluxes from eddy covariance towers from two mid-latitude forests (Harvard Forest, MA and Howland Forest, ME) of northeastern USA to develop and validate the merged model and to quantify the uncertainties in a multiple constraints approach.
The optimized DAMM-FöBAAR model better captured the seasonal dynamics of Rh compared to the FöBAAR-only model for the Harvard Forest, as indicated by lower cost functions (model-data mismatch). However, DAMM-FöBAAR showed less improvement over FöBAAR-only for the boreal transition forest at Howland. The frequency of droughts is lower at Howland, due to a shallow water table, resulting in only brief water limitation affecting Rh in some years. At both sites, the declining trend of soil respiration during drought episodes was captured by the DAMM-FöBAAR model, but not the FöBAAR-only model, which simulates Rh using only a Q10 type function. Greater confidence in model prediction resulting from the inclusion of mechanistic simulation of moisture limitation on substrate availability, an emergent property of DAMM, depends on site conditions, climate, and the temporal scale of interest. While the DAMM functions require a few more parameters than a simple Q10 function, we have demonstrated that they can be included in an ecosystem model and reduce the cost function. Moreover, the mechanistic structure of the soil moisture effects using DAMM functions should be more generalizable than other commonly used empirical functions.