LBNL TES SFA: Emergent responses of soil C dynamics to seasonal variability in nonlinear SOM-microbial models

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Soil organic matter (SOM) decomposition is regulated by biotic and abiotic processes. Interactions between these processes may dampen oscillatory responses to perturbations. Indeed, although biological oscillations have been observed in small-scale laboratory incubations, plot-scale behavior often exhibits a relatively stable response to disturbances in input rates and temperature. Recent studies have demonstrated the ability of microbial models to capture nonlinear feedbacks in SOM decomposition that linear Century-type models are unable to reproduce, such as soil priming in response to increased carbon input. However, these microbial models often exhibit strong oscillatory behavior that is deemed unrealistic. The inherently nonlinear dynamics of SOM decomposition have important implications for global climate-carbon and carbon-concentration feedbacks. It is therefore imperative to represent these dynamics in Earth System Models (ESMs) by introducing sub-models that accurately represent microbial and abiotic processes.

In this LBNL TES SFA modeling study we explore, both analytically and numerically, microbe-enabled model structures of varying levels of complexity. The most complex model combines microbial physiology, a non-linear mineral sorption isotherm, and enzyme dynamics. Based on detailed stability analysis of the nonlinear dynamics, we calculate the system modes as functions of model parameters. This dependence provides insight into the source of state oscillations. We find that feedback mechanisms that emerge from explicit representation of enzyme and mineral interactions, with parameter values in a prescribed range, are critical for both maintaining system stability and capturing realistic responses to disturbances. Furthermore, we explore the effect of forcing microbial models with periodic temperature and carbon inputs, and conclude that the frequency at which the system is resolved can greatly influence the dynamics. This observation has important implications for comparing model predictions to field studies and laboratory incubations. Corroborating and expanding upon the results of recent studies, we discuss the appropriate microbe-enabled model structure for inclusion in ESMs.