Title: Soil Respiration Modeling and Prediction Variabilities Across Scales

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Project Abstract: Soil respiration is a major component of the global carbon cycle, and it is regulated by a multitude of biotic and abiotic factors and their interactions. Predictive models rely on both empirical data and the underlying theory to provide robust predictions, yet model simplifications are often necessary due to data and parameterization limitations. This is particularly true for modeling soil moisture-respiration relationship, given that the control water exerts on soil respiration remains challenging to capture at various scales. Here we took both bottom-up and top-down models and evaluated the scale-dependence of model simplifications. In the microscale diffusion-based bottom-up model, we derived a generalizable analytical solution of diffusion-limited nonlinear microbial uptake kinetics, in which microbial metabolic rates were governed by both physical and biological drivers via substrate diffusion and effective microbial-substrate binding. This mechanistic model accounting for soil texture-dependent microscale (~10 to 200 μm) heterogeneity accurately captured observed variations of soil moisture-respiration relationships in laboratory incubations. However, when evaluated with field observations, this mechanistic model did not show significant advantage over simplified polynomial functions. This result indicates control factors, such as soil topography, vegetation etc. that operates at field-to-site scales could be more important in explaining field based observations. In the top-down modeling, we evaluated the relationships between soil respiration and soil water content (SWC) or precipitation with a monthly global soil respiration database (MGRsD). Relationships between soil respiration and monthly soil water content or precipitation vary widely across the 507 sites encompassing a wide variety of environmental conditions. The correlation between soil respiration and SWC or precipitation drastically decreased when data from different sites were aggregated at larger scales (i.e., climate region), further supporting site-specific parametrization of soil moisture-respiration relationships. These two studies with distinct modeling approaches both identify the importance of scale aggregation in soil respiration modeling and simplification. There remains a profound gap between mechanistic models targeting soil microscale heterogeneity and data driven models focusing on regional and global patterns. Developing site-specific understanding of soil functionality that integrates the spectrum of abiotic and biotic processes is an important next step for increasing scale-awareness of current modeling practice and identifying data needs to illuminate the complexity of soil functionality across scales.