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Measuring and modeling CO_2 and H_2O fluxes in complex terrain

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Measuring and modeling CO_2 and H_2O fluxes in complex terrain

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The feedbacks between the water and the carbon cycles are of critical importance to global carbon balances. Forests and forest soils in northern latitudes are important carbon pools because of their potential as sinks for atmospheric carbon. However there are significant unknowns related to the effects of hydrologic variability, mountainous terrain, and landscape heterogeneity in controlling soil carbon dioxide (CO_2) efflux. Mountainous terrain imposes large spatial heterogeneity in the biophysical controls of soil CO_2 production and efflux, including soil temperature, soil water content, vegetation, substrate, and soil physical properties. Further complications are introduced by the superimposed temporal heterogeneity (i.e., the asynchronous response of each variable to changes in environmental conditions). As a result, extrapolating from single- or multiple-point measurements to larger areas requires understanding of the emerging patterns controlled by the underlying spatiotemporal nature of biophysical drivers.

At the Tenderfoot Creek Experimental Forest (TCEF) in central Montana, two factors that we use to our advantage in the understanding of watershed-scale soil CO_2 efflux are 1) the temporal seasonality imposed by snowmelt and 2) the spatial redistribution of soil water imposed by topography. Snowmelt controls the timing of the most dramatic increase in water content in the soil, while landscape morphology redistributes that moisture down slope to lower areas of the landscape. Our site selection (62 soil respiration plots) targeted those areas of the landscape that offered natural biophysical gradients (Figure 1). Two eddy covariance systems were installed over the canopy of the two most important systems: a riparian meadow and a lodgepole pine forest (Figure 2). Additionally, we investigate surface water – groundwater interactions and subsurface flowpaths between different landscape positions and the stream using an array of 80+ groundwater wells and piezometers (~1-2 m depth). Our coupled water-carbon approach is based on the concept of topographic similarity [*Beven and Kirkby*, 1979], which hydrologists and biogeochemists have used to transfer process and response understanding to topographically and thus hydrologically and biogeochemically similar areas [e.g., *Creed et al.,* 1996*; Boyer et al.*, 1997; *McGlynn and McDonnell*, 2003]. This idea is conceptually intuitive because 1) many biogeochemical processes are mediated by temperature, water content, radiation, and energy balance, variables that often vary predictably with topographic position; and 2) this form of heterogeneity also depends on other abiotic factors (e.g., slope, soil type, upslope accumulated area), which can be considered static over relevant times scales [*Moorcroft*, 2006]. As such, topographic similarity can help scale soil CO_2 efflux rates from single- or multiple-point measurements to watershed scales or larger areas. Determining the minimum set of watershed measurements or variables needed to characterize soil CO_2 efflux both spatially and temporally is not trivial. However, terrain analysis techniques can help link spatial watershed patterns with biogeochemical processes, aid in transfer and interpolation, and indicate where additional field observations are needed. New process knowledge gained from such observations can help characterize the landscape, discretely or continuously, as an arrangement of response characteristics and thresholds.

Current work at the TCEF based on multiple-point measurements has demonstrated that the spatial variability of soil CO_2 efflux across the 62 sites is higher than previously thought (Figure 3). Riveros-Iregui et al.

cont. on page 13

Photo: Riparian meadow

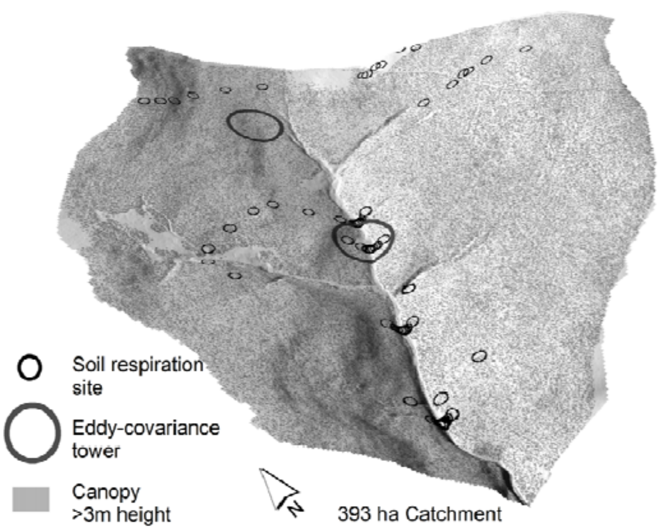

Figure 1: Tenderfoot Creek Experimental Forest (TCEF) in the Little Belt Mountains of Central Montana. Soil respiration is measured at 62 sites distributed across the catchment.

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cont. from page 12

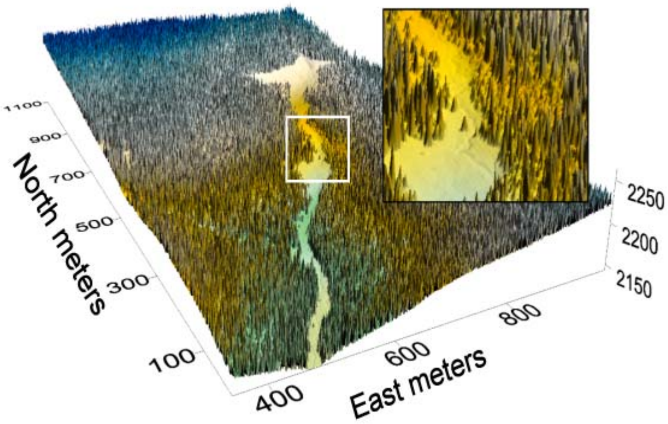

Figure 2: LIDAR-derived image of vegetation cover at the TCEF.

[in press] demonstrated that more persistent, high soil water content was the major control on the spatial difference of soil CO_2 efflux and nighttime ecosystem respiration between riparian-hillslope sites especially after snowmelt or rainfall. Pacific et al. [2008] analyzed soil CO_2 efflux measurements across riparian-hillslopes transitions based on soil gas wells and discrete chamber measurements. Their results show that soil CO_2 efflux rates differ, both in magnitude and timing, across riparian-hillslope transitions. While early in the growing season soil CO_2 efflux is higher in hillslopes than in riparian areas, later in the season soil CO_2 efflux from riparian areas becomes higher than in hillslopes. Our preliminary results demonstrate how landscape discretization and the concept of topographic similarity can help extend understanding and measurements of soil CO_2 efflux based on benchmark measurements to larger areas of the landscape. There remain great challenges in dealing with complex topography, especially transferring knowledge acquired at point/plot scales to larger spatial scales, and reconciling C fluxes measured at different levels of the ecosystem. However, based on initial results of coupled water-carbon studies in the subalpine forests of the TCEF, we recommend implementation and further investigation of the concept of "organized heterogeneity" as a responsible agent in the emergent patterns of these fluxes from the plot to the watershed to regional scales.

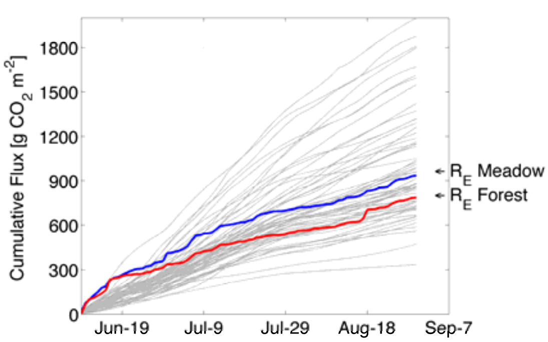

Figure 3: Comparison of cumulative CO_2 fluxes for the 2006 growing season at 62 sites (gray lines) and ecosystem respiration (R_E) measured with the EC technique over a riparian meadow (blue line) and the lodgepole pine forest (red line). Range of soil respiration varies by us much as ~600% across the catchment. Terrain analysis as well as process understanding of the organized heterogeneity are critical in up-scaling plot measurements of soil respiration to spatial scales comparable to towers.

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