Quantifying the role of topographical and edaphic complexity on coupled energy, water, and carbon cycles in forested, montane ecosystems

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Spatial heterogeneity in the physical structure of the critical zone (CZ) strongly influences both energy and water availability, affecting how water and carbon cycles are coupled in topographically complex terrestrial ecosystems. Predicting how climate change will affect both the structure and the ability of these systems to sequester carbon and provide fresh water requires quantifying how carbon storage has developed under historical climate and a spatially-explicit, mechanistic understanding of how changes in precipitation and temperature will affect these stores in the future. To address this knowledge gap, we utilize spatially explicit observations of landscape structure from Airborne Laser Swath Mapping (ALSM), isotopic and chemical tracers of carbon and water cycling, distributed observations of gaseous and dissolved carbon fluxes, and coupled biogeophysical models in seasonally snow-covered, forested ecosystems across elevation and latitudinal gradients in climate the Rocky Mountains.

ALSM mapping of vegetation at 1m2 resolution indicate that spatial patterns in biomass carbon varied strongly with topographic metrics of water availability. Within these landscape-mediated patterns in carbon sequestration driven by microclimate and hydrological redistribution of snowmelt, tree ring basal increment values indicate that growth of major tree species respond positively to both interannual and spatial patterns in water availability and negatively to increased temperature. Foliar Î´13C values further indicate the species response to climate varies with lodgepole pine showing increased water use efficiency in dry year while ponderosa pine does not.

Carbon efflux from these ecosystems was dominated by soil respiration, with relatively small fluvial export in dissolved forms occurring when local water table intersects surficial soils. Instantaneous soil CO_2 fluxes varied significantly across sites and seasons with higher fluxes associated with soil carbon availability, clay content, and shaded slopes, Multiple linear regression analysis across sites and seasons suggests that the response of respiration to a changing will be strongly constrained by spatial and temporal patterns in surface soil moisture.

These results suggest that understanding how catchment ecosystems redistribute water provides powerful insight into the sensitivity and response of carbon cycling to changes in climate. Specifically, decreases in snowmelt-driven recharge may limit topographically driven patterns in plant available water and carbon uptake, while increasing precipitation in the summer is likely to increase surface moisture, promoting respiration and mineralizing stored carbon sources