Watershed Functional Zonation: Advancing Bedrock-to-Canopy Characterization across Watersheds

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Project Abstract:
Predictive understanding of watershed function and dynamics is often hindered by the heterogeneous and multiscale fabric of watersheds. In particular, ecohydrology and biogeochemical cycling involves complex hydrological-biogeochemical interactions occurring from bedrock-to-canopy, including geology, plants, microorganisms, organic matter, minerals and weathering products, dissolved solutes, and migrating fluids. Quantifying such interactions across heterogeneous watersheds is critical for estimating and predicting integrated hydrological and biogeochemical responses, such as carbon and nutrient exports, water resources and quality, as a function of both climate change and system disturbance. The Watershed Function SFA seeks to develop novel characterization methodologies to quantify complex watershed systems across scales, using advanced remote sensing, inversion, and machine learning approaches. We explore a variety of machine learning techniques – unsupervised learning, such as hierarchical and Bayesian clustering, and supervised learning, such as random forest – to gain a quantitative understanding of watershed organization and functionality. We hypothesize that (1) the co- evolution of terrestrial systems generates co-variability among subsurface/surface spatial features (e.g. topographic, plant, snow and geological metrics), (2) we can reduce the parameter dimensionality by exploiting such co-variability, and (3) we can identify several representative landscapes – so-called watershed functional zones – that capture distinct characteristics of those co-varied properties and associated watershed functions. We demonstrate our approach using airborne electromagnetic data, LiDAR-derived snow metrics, and hyperspectral data collected over the East River Watershed. Results show that unsupervised learning has the ability to resolve surface/subsurface co-variability, such as bedrock fracturing and plant species composition over the watershed, identifying several key zones that capture watershed-scale heterogeneity. Supervised clustering results indicate that elevation, aspect and geology are key controls on both drought sensitivity and nitrogen export, with the consequence being an ability to map watershed "functional" zonation and potentially prediction of annual nitrogen export in unmeasured sub-catchments given unique spatial features and peak snow water equivalent.

By characterizing spatiotemporal (i.e., four-dimensional) variability of critical properties over the watershed, we aim to develop the new 4D Digital Watershed concept for model parameterization and validation of hydrological and biogeochemical simulations. In addition, we plan to use both model and data-driven approaches to co-design our characterization and monitoring network.