Geophysical Research Abstracts
Vol. 17, EGU2015-4024, 2015
EGU General Assembly 2015

Arctic ecosystem functional zones: identification and quantification using an above and below ground monitoring strategy

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Although accurate prediction of ecosystem feedbacks to climate requires characterization of the properties that influence terrestrial carbon cycling, performing such characterization is challenging due to the disparity of scales involved. This is particularly true in vulnerable Arctic ecosystems, where microbial activities leading to the production of greenhouse gasses are a function of small-scale hydrological, geochemical, and thermal conditions influenced by geomorphology and seasonal dynamics. As part of the DOE Next-Generation Ecosystem Experiment (NGEE-Arctic), we are advancing two approaches to improve the characterization of complex Arctic ecosystems, with an initial application to an ice-wedge polygon dominated tundra site near Barrow, AK, USA.

The first advance focuses on developing a new strategy to jointly monitor above- and below- ground properties critical for carbon cycling in the tundra. The strategy includes co-characterization of properties within the three critical ecosystem compartments: land surface (vegetation, water inundation, snow thickness, and geomorphology); active layer (peat thickness, soil moisture, soil texture, hydraulic conductivity, soil temperature, and geochemistry); and permafrost (mineral soil and ice content, nature, and distribution). Using a nested sampling strategy, a wide range of measurements have been collected at the study site over the past three years, including: above-ground imagery (LiDAR, visible, near infrared, NDVI) from various platforms, surface geophysical datasets (electrical, electromagnetic, ground penetrating radar, seismic), and point measurements (such as CO_2 and methane fluxes, soil properties, microbial community composition). A subset of the coincident datasets is autonomously collected daily. Laboratory experiments and new inversion approaches are used to improve interpretation of the field geophysical datasets in terms of ecosystem properties. The new strategy has significantly advanced our ability to characterize and monitor ecosystem functioning - within and across permafrost, active layer and land-surface compartments and as a function of geomorphology and seasonal dynamics (thaw, growing season, freeze-up, and winter seasons).

The second construct uses statistical approaches with the rich datasets to identify Arctic functional zones. Functional zones are regions in the landscape that have unique assemblages of above- and below-ground properties relevant to ecosystem functioning. Results demonstrate the strong co-variation of above and below ground properties in this Arctic ecosystem, particularly highlighting the critical influence of soil moisture on vegetation dynamics and redox-based active-layer biogeochemistry important for carbon cycling. The results also indicate that polygon types (low centered, high centered) have more power to explain the variations in properties than polygon features (trough, rim, center). This finding allows delineation of functional zones through grouping contiguous, similar types of polygons using remote sensing and surface geophysical datasets. Applied to the tundra NGEE study site, the functional zone approach permitted aggregation of critical properties associated with $\sim$1350 polygons and their individual features, which vary over centimeter-to-meter length scales, into a few functional zones having suites of co-varying properties that were tractably defined over $\sim$hundred meter length scales.

The developed above-and-below ground monitoring strategy and functional zone approach are proving to be extremely valuable for gaining new insights about a complex Arctic ecosystem and for characterizing the system properties at high resolution and yet with spatial extents relevant for informing models focused on simulating ecosystem-climate feedbacks.