Multi-scale modeling of hydrologic and biogeochemical processes in Arctic ecosystems

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Permafrost dominated Arctic soils contains vast stock of frozen organic carbon. As warming climate accelerates the thaw of the permafrost, increasing amounts of organic matter is exposed to respiration leading to the release of carbon into the atmosphere in the form of CO\textsubscript{2} and CH\textsubscript{4}.

Terrestrial Arctic ecosystems are sensitive to climate change and disturbance through interactions of complex ecosystem processes and feedbacks. Understanding of hydrologic, thermal, biogeochemical and vegetation dynamics processes is crucial in understanding this sensitive ecosystem. This requires processes--level understanding through observations and process--based modeling of the system to simulate the ecosystem behaviour under predicted climate change scenarios.

The Department of Energy's Next Generation Ecosystem Experiments (NGEE--Arctic) project is working to develop process rich representation of Arctic ecosystems in global Earth System Models (ESM). We are developing a multi-scale modeling framework to investigate ecosystem processes at plot to regional to global scale.

Fine scale microtopography in tundra ecosystem exerts important control on local scale hydrology, below ground biogeochemistry and microbial dynamics, vegetation dynamics and surface energy budgets. The multi—scale modeling framework consists of high resolution process based model (PFLOTRAN) that captures these microtopography in three—phase thermal hydrology models for permafrost freeze--thaw dynamics. Parameterized with field based observations the model was successfully applied to understand the control of polygonal ground microtopography (center/ridge/trough) for different landscapes (high-centered/low-centered/transitional polygons). High resolution simulations help constrain the intermediate resolution models which uses geomorphologic features as its building blocks for regional scale simulations.

The reactive transport module developed within PFLOTRAN consists of a complete CLM-CN biogeochemical reaction framework and inorganic N cycle including nitrification, denitrification and transport (leaching). The model also allows for the usage of alternative biogeochemical models (eg. CENTURY), and microbial--enzyme reactions.

High resolution PFLOTRAN has been tightly coupled to Community Land Model (CLM) to improve the representation of hydrology and biogeochemistry in global scale ESMs. Preliminary results from fully coupled thermal--hydrologic--biogeochemical and terrestrial ecosystem processes using CLM--PFLOTRAN are promising to better resolve hydrology, below ground biogeochemistry and vegetation productivity. The multi--scale framework of nested plot to regional to global scale models will also allows for systematic model--data integration of field/laboratory observations.