Final Technical Report

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Title: Model-Data Fusion Approaches for Retrospective and Predictive Assessment of the Pan-Arctic Scale Permafrost Carbon Feedback to Global Climate

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Summary

Policy decisions regarding climate change mitigation and adaptation rely on having reliable projections of future climate change. Coupled climate-carbon models predict that the northern high latitudes will serve as a substantial land carbon sink during the 21stcentury, but these models lack many of the key processes governing high-latitude ecosystem processes. Arctic tundra and boreal forests are unique from other biomes particularly because of the presence of snow, ice and frozen ground, and it is important to understand the mechanisms that drive interconnected processes in these landscapes. Increasing our confidence in climate projections requires an integrated approach where existing, on-going and planned observational and experimental studies of high-latitude ecosystem processes are organized and analyzed in a framework designed to target improvements in understanding key ecosystem-climate feedbacks.

For this project we designed an approach to improve our scientific understanding of the permafrost carbon feedback through broad-scale assessment of the drivers and responses of the Arctic system carbon cycle using data-driven models of simple-to-intermediate complexity. The approach drew on a conceptual framework for integrating the key system components and their underlying data within a “book-keeping” framework for assessment of the key processes driving the permafrost carbon feedback. The framework used environmental proxy data sets examining recent-era geomorphologic land-form transitions and vegetation dynamics, through remotely-sensed data, to guide the extrapolation of site-based data on the key system components to larger regions. The research has made a valuable contribution to the first of its kind, data-driven quantitative assessment of the impact of permafrost thaw on pan-Arctic scale carbon cycle feedbacks to the global climate system. The results provided quantitative model-data benchmarking to constrain future projections of carbon cycle responses to a warming Arctic. These products contribute to the development of finer-scale, more complex representation of permafrost carbon processes in terrestrial biogeochemistry models, to operate within coupled Earth system modeling frameworks.

Objectives

The project aimed to synthesize available data collections related to the key system components from observational and experimental research networks into a pan-Arctic scale framework for identifying and understanding the key drivers, impacts and consequences of permafrost dynamics under a warming Arctic.

Results

The data synthesis, process modeling and scaling research conducted in this project contributed to highly impactful scientific understanding on the permafrost carbon feedback (Schuur et al., 2013; Schuur et al., 2015). The synthesis work focused on observational data sets describing soil carbon stocks, active layer dynamics, organic matter decomposition and the fate of fluxes as greenhouse gases (Koven et al., 2015). The scaling component of this project brought together geographical datasets to describe and analyze the circumarctic variability in permafrost dynamics and carbon cycling (Olefeldt et al., 2016). A key element of both the scaling and modeling advances made in this project is based on the spatio-temporal characterization an incorporation of information on disturbances, including wildfire in Arctic and Boreal regions (Chen et al., 2017; Jones et al., 2015). The scaling and synthesis work formed the basis of new understanding of the major components of the Arctic system carbon budget based on the analysis of multiple top-down and bottom-up constraints (McGuire et al., 2012).

This work has led to advances in simulation work using new modules of active layer dynamics and the associated impacts on carbon losses from permafrost regions, including an analysis of the main drivers and sensitivities (Hayes et al., 2014; Kicklighter et al., 2013). These results have contributed to model inter-comparison efforts (McGuire et al., 2016; Fisher et al., 2014) as well as further studies of regional-to-global scale controls and teleconnections between the Artic system carbon cycle and climate change (Li et al., 2018; Parmentier et al., 2015; Thomas et al., 2016; Xia et al. 2017). The research undertaken in this project has led to the current state of land surface models in projecting future climate-carbon feedbacks in the northern permafrost region (McGuire et al., 2018) and our understanding of the major uncertainties (Fisher et al., 2018). In addition to the permafrost carbon research, this work has added an important piece to more general carbon cycle studies and model inter-comparisons (Hayes et al., 2012; Hayes et al., 2018; Huntzinger et al., 2013; Huntzinger et al., 2017; King et al., 2012; King et al., 2015: Tian et al., 2014; Tian et al., 2015).

Significance

Several high-level collaboration and synergistic activities were borne from and facilitated by this project. The PI served leadership roles in the NSF Permafrost Carbon Network and the North American Carbon Program throughout the project. A significant portion of the work over the course of this project was dedicated to multi-institution, inter-agency coordination and research development through DOE's Next Generation Earth Experiment (NGEE-Arctic) and NASA's Arctic-Boreal Vulnerability Experiment (ABoVE).

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