High-dimensional characterization of forest mesophication effects on reactive nitrogen emissions by soil microorganisms

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In forests of the eastern United States, wildfire suppression policies have significantly changed the tree structure, soil composition, and moisture levels, a process known as "mesophication". “Mesic” forest soils have increased moisture content and nutrient availability. These mesophication-associated changes are expected to have a major impact on soil nitrogen (N) cycling by microorganisms. Microorganisms involved in N-cycling in forest soils are major sources of nitrogen oxides (NO_x= NO + NO_2) and nitrous acid (HONO) to the atmosphere. These gases are both air pollutants and greenhouse gas precursors. However, we do not know the specific microbial populations and genetic systems responsible for these emissions, making it challenging to predict their contributions to global atmospheric change. Additionally, the specific populations of microorganisms that produce these gases likely vary across ecosystems. Thus, forest ecosystems at different stages of mesophication provide a unique opportunity to study how different environmental factors like soil moisture and nutrient content influence microbial production of NO_x/HONO. This research team will use a novel approach to investigate the microbial origins of these emissions across forests of varying mesophication stages.

This new research is driven by several hypotheses: (1) Soil moisture and N are the primary drivers of microbial emissions of NO_x/HONO in forest ecosystems. Both variables will increase alongside the degree of forest mesophication. (2) In mesic (*i.e.,* moist) forest soils, higher N levels from more easily decomposed leaf litter and increased water runoff from trees contribute to greater NO_x/HONO emissions. (3) The high moisture levels in these soil conditions create small oxygen-deprived zones where anaerobic microorganisms become the main source of NO_x/HONO emissions. (4) Emissions from these microbial processes have a significant impact on regional air quality and atmospheric chemistry across the eastern United States.

Key outcomes of the research include a detailed analysis of soil microbial communities across forests experiencing different levels of fire suppression and resulting mesophication. The study will describe how changes in these microbial populations are connected to the release of NO_x/HONO. Researchers will also determine how specific soil microbial processes, such as denitrification and nitrification, contribute to the production of these gases. Additionally, the team will create a computer model that incorporates isotope data to simulate how nitrogen cycles through the environment and estimate the natural emissions of NO_x/HONO from forest soils at various stages of mesophication. Using these results, they will run simulations to understand how changes in fire management and microbial populations affect atmospheric chemistry and, ultimately, the climate. These findings will be important for both climate modeling and forest management, especially as forests in the eastern U.S. become increasingly dominated by mesic, fire-suppressed conditions.

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Improving the physical realism of snow processes in E3SM

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Water stored as snow is an essential freshwater resource over extended regions of the world, feeding surface and groundwater systems, sustaining agriculture, energy production, and natural ecosystems. The presence of snow also impacts the land surface temperature and its reflectivity, leading to warming feedbacks between the land and the atmosphere. For these reasons, adequately capturing snow processes is an essential step required to advance the representation of land surfaces in the current generation of Earth System Models such as the Energy Exascale Earth System Model (E3SM).

Improving global snow predictions in these models is important for understanding multiple physical processes, ranging from surface and subsurface hydrology, to the warming rates in the arctic and in mountainous regions, to the interactions between land and atmosphere. Important practical applications of an improved representation of snow include planning resilient agriculture and energy production in a changing climate. To date, E3SM is still affected by biases in snow-dominated regions, and especially in mountainous regions such as the Tibetan Plateau and the Western United States.

Two main challenges in representing snow in E3SM are the relatively coarse resolution of land model simulations, and the simplified physics used to represent snow processes in the model. Objective of this project is to improve the representation of snowpack dynamics in the E3SM land model (ELM) by resolving key physical processes which are still absent: the effects of snow aging on the evolution of snow grain shape, and the variability of snow cover over mountainous terrain. The snow grain shape, linked to its specific surface area, affects how heat penetrates through the snowpack and thus contributes to determining its surface reflectivity to solar radiation (that is, its albedo).

The snow cover is a key quantity which also contributes to the land surface albedo, and is challenging to predict over complex terrain due to its spatial variability. Here we plan to improve the representation of snow cover over mountains in ELM by adopting a data-driven approach based on high-resolution terrain datasets. Together, these model improvements will be comprehensively evaluated by comparing model simulations with in-situ and remote sensing data. This analysis will evaluate how the model reproduces changes in snow cover, snow albedo, and snowmelt rates. We will then employ the updated version of ELM developed as part of this project to investigate the strength of surface albedo feedback, to quantify how the uncertainty in snow model parameters translates to uncertainty in snowpack predictions, and to assess the changing risk of snow drought for the continental United States

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