NGEE Arctic

Next-Generation Ecosystem Experiments in the Arctic

An Overview of ModEx Science Question 3: Shrub-Snow-Permafrost Interactions

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RESEARCH FOUNDATIONS OF PHASE 4 MODEX SCIENCE QUESTIONS (MEQ3)

Observations, experiments, and synthesis activities carried out in Phase 1-3 informed the development of multiple fine-scale, physics-based and statistical machine learning models. We used airborne LiDAR remote-sensing tools to capture detailed information required for testing, validating, and improving ELM's precipitation patterning at subgrid scales. Finally, ecosystem-type approaches were developed to scale snow properties for ELM improvement.

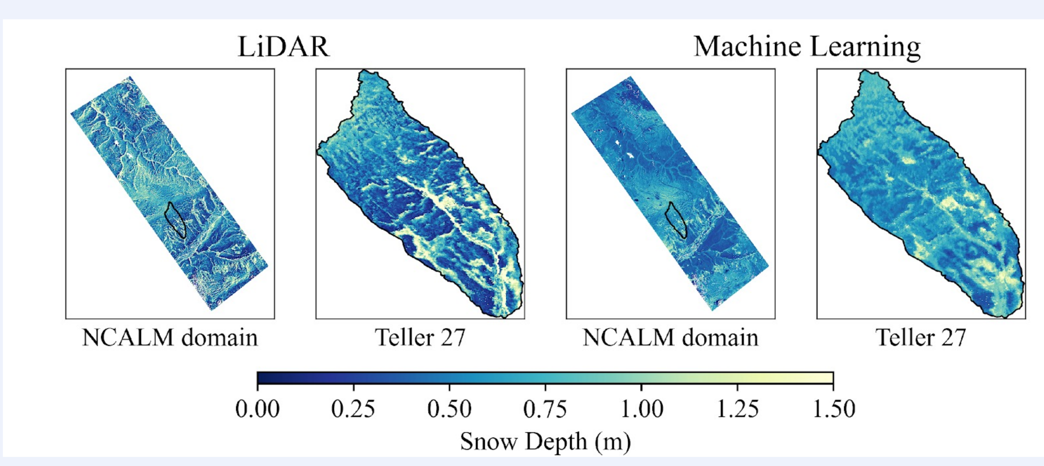

Figure 1. Peak snow depth (m) in April 2022 LiDAR imagery (left) collected by the National Center for Airborne Laser Mapping (NCALM) across a broad region that encompassed the Teller 27 study site (black outline in first image and second image) and predicted from ML models (right) for the entire region collected by NCALM and for the Teller 27 study site watershed only.
Bennett et al., 2022; Bennett et al. in prep 2025

Integrated Modeling (IMs)

IM3: Improved representation of the interactions among snowpack, terrain, and vegetation distributions

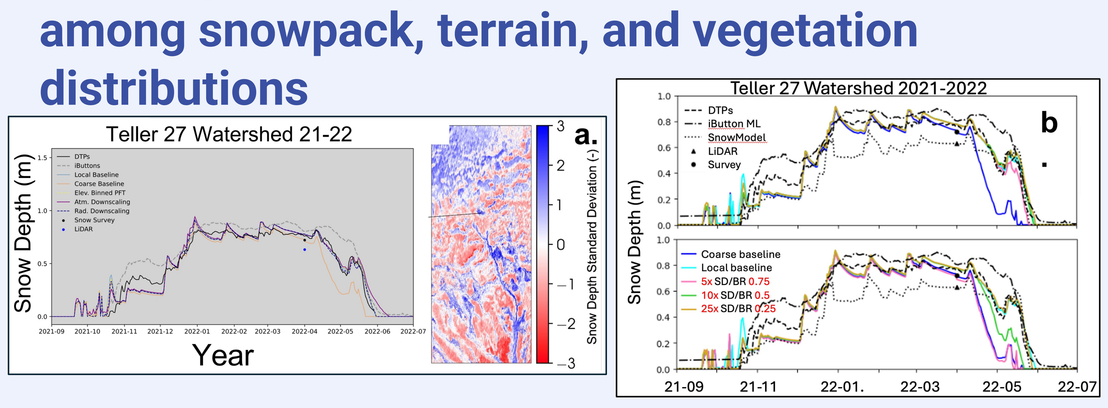

Figure 2. a. Modeled and observed snow depth data with improved topounit downscaling variations for the Teller 27 study site (left). Standard deviations of peak snow depth were derived from ML and used to correct SnowModel predictions (right). **b.** Model simulations for IM3 include the improvements against the baseline coarse ELM and the fine-scale ELM with vegetation improvements, including for stocking density.
Bennett et al., 2022; Bachand et al. 2025, Crumley et al. 2024

IM4: Expanded and improved representation of arctic tundra plant functional types and their physiology

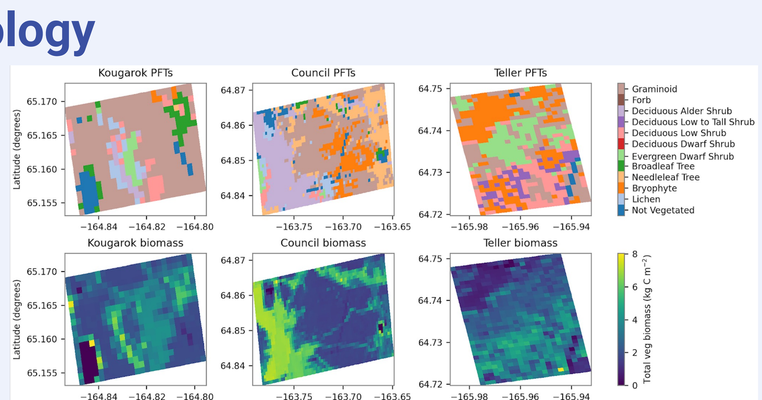

Figure 3. Simulated vegetation growth on the Seward Peninsula, AK. Vegetation biomass was simulated using the new spatially explicit ELM model configuration (bottom row). The simulation inputs include spatial distributions of tundra PFTs (top row, showing the most common PFT in each grid cell), for study sites on the Seward Peninsula, AK.
Sulman et al., 2021, Konduri et al., 2022, Breen et al. 2020

MEQ3: SNOW, VEGETATION, PERMAFROST INTERACTIONS

Hypothesis Statement

"Shrub-snow interactions will lead to increased spatial variability in energy, water, and carbon fluxes in areas with increasing shrub dominance and canopy height, with the net effect being accelerated permafrost thaw across the landscape."

Task 3.1: Synthesis to Inform Models

We aim to collect and interrogate multi-scale, multi-temporal data on snow, vegetation, and permafrost interactions across Model Evaluation Sites, regions, and the pan-Arctic to develop a pragmatic understanding of snow-vegetation impacts on subsurface hydrothermal properties and permafrost dynamics.

Task 3.2: Site-Level Model Evaluation

Our final site selection for MEQ3 includes the Toolik Research Site, Trail Valley Creek, and the Abisko Scientific Research Station.

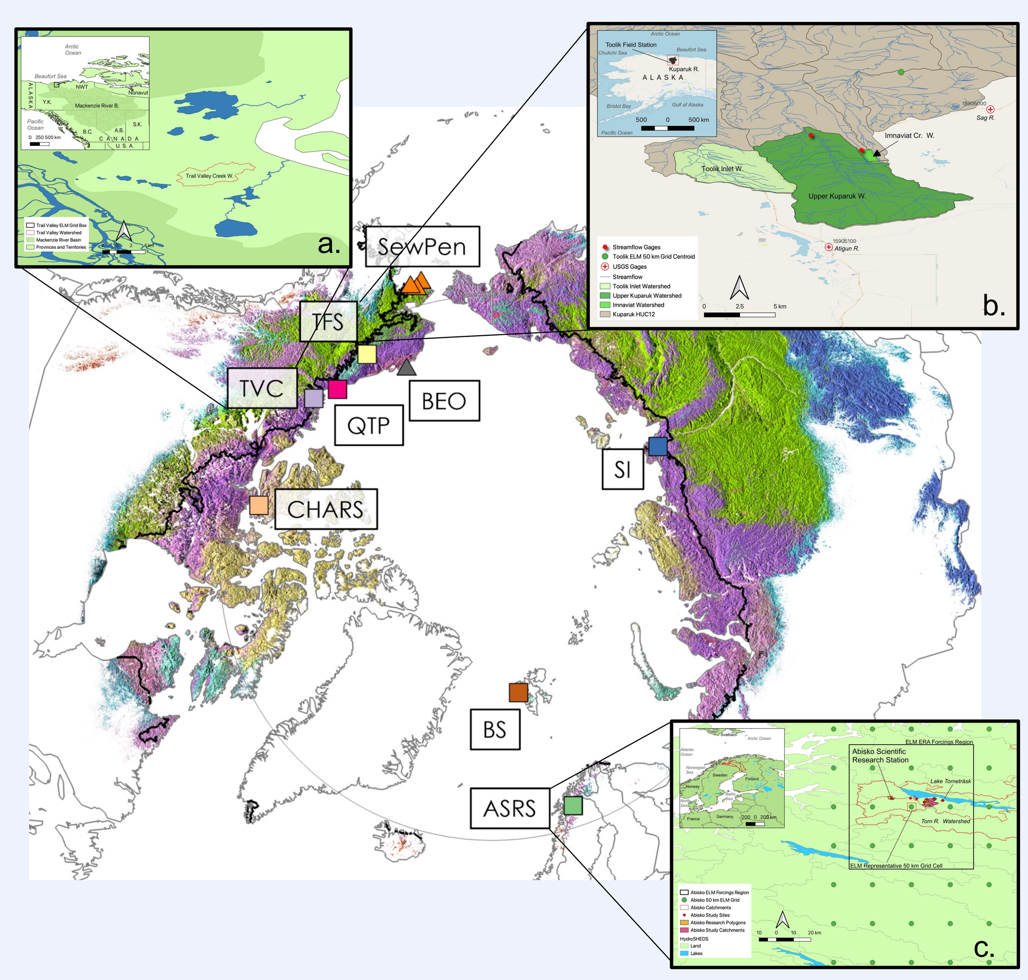

Figure 5. MEQ3's final site selection includes Trail Valley Creek Arctic Research Station (a., TVC), Toolik Field Station (b., TFS), Abisko Research Station (c., ASRS), and. We will also look at Svalbard and Samoylov Island as alternate sites.

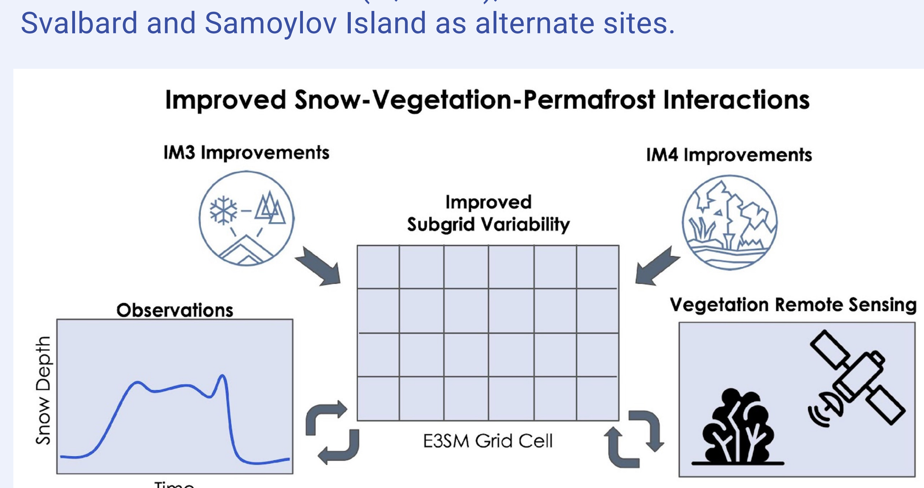

Figure 6. Conceptual diagram of improved snow-vegetation-permafrost interactions, merging IM3 and IM4 model improvements and then testing them against our synthesis data from each of our selected field sites.

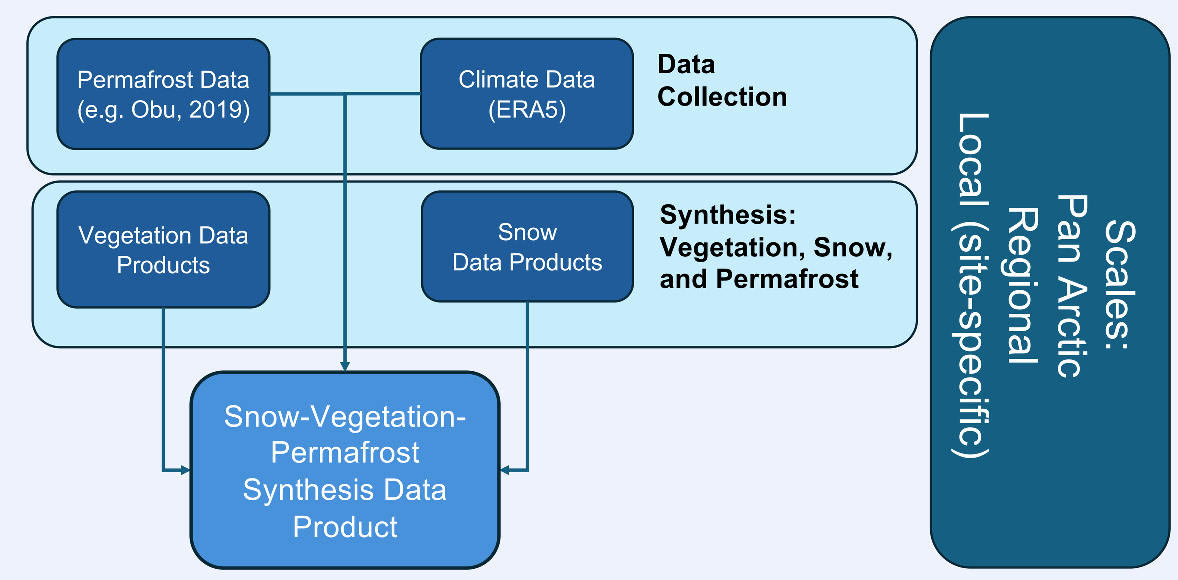

Figure 7. Workflow for data collection, synthesis, and eventual output of our snow-vegetation-permafrost synthesis data product. This product will allow us to both interrogate surface-subsurface interactions, spatial and temporal changes, and consider to what extent snow and vegetation affect seasonal and spatial variations in surface and subsurface hydrothermal properties. We will also consider what scale is appropriate to best capture relevant snow-vegetation-permafrost interactions.

Task 3.3: Pan-Arctic Model Improvement

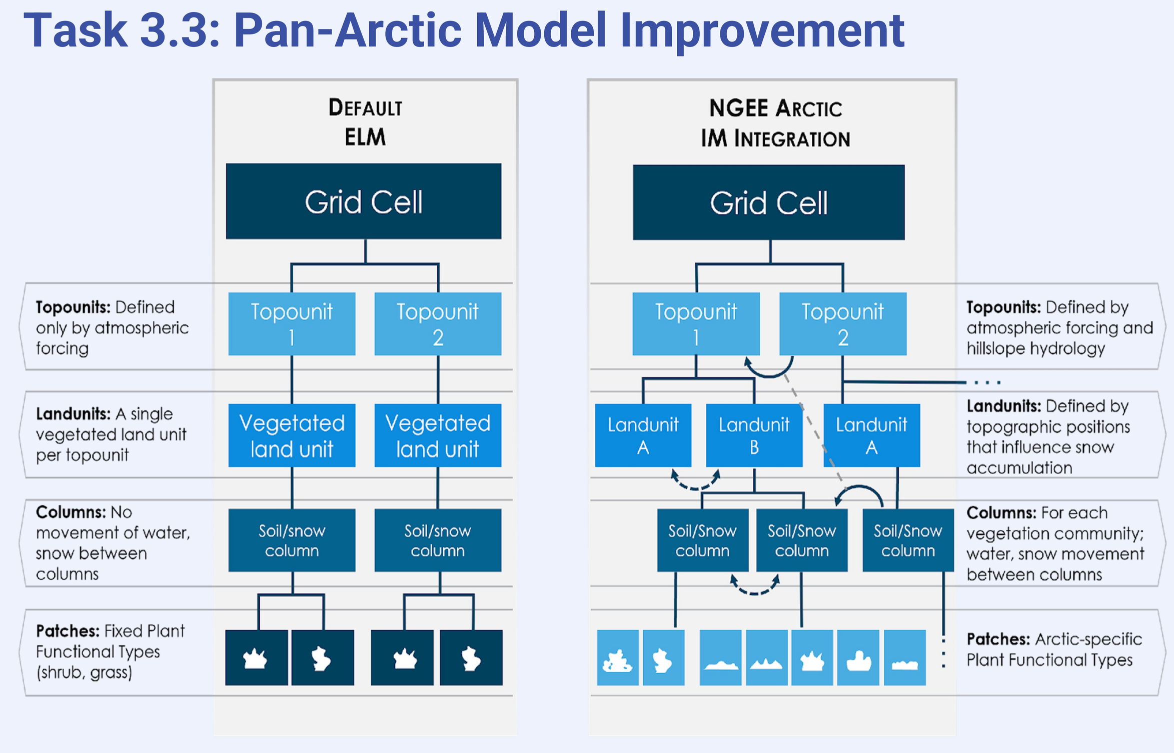

Figure 8. Terrain shape effects on snow distribution are represented with multiple landunits on each topounit (e.g. dashed arrow showing redistribution of snow between Landunit A and Landunit B on Topounit 1). Differences in the distribution of PFTs within recognizable vegetation communities are represented with multiple soil/snow columns on each landunit, each of which can have a different mixture of PFTs. Snowfall on a given landunit is redistributed based on relative differences in vegetation height (dashed line between two soil columns).

Task 3.4: Model Experiments

Our model experiments will consider a range of different scenarios and disturbances, as listed below:

- Fire disturbances
- Shrubification
- Rain-on-snow
- Long term earth system dynamics and weather extremes

References

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LA-UR-25-23434

Trail Valley Creek Research Station

TOOLIK FIELD STATION

ABISKO NATURVETENSKAPLIGA STATION ANS

POLAR POLAIRE

NGEE Arctic is supported by the Biological and Environmental Research Program in the Department of Energy's Office of Science. We thank our partners from the Native Communities in Alaska for allowing us to conduct our research on the traditional homelands of the Iñupiat, including UIC Science, Bering Straits, Council, Mary's Igloo, and Sitnasuak Native Corporations. NGEE Arctic is underscored by a culture of collaboration and open science.

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