A Scaling Framework Connecting Models with Process Knowledge for NGEE Arctic

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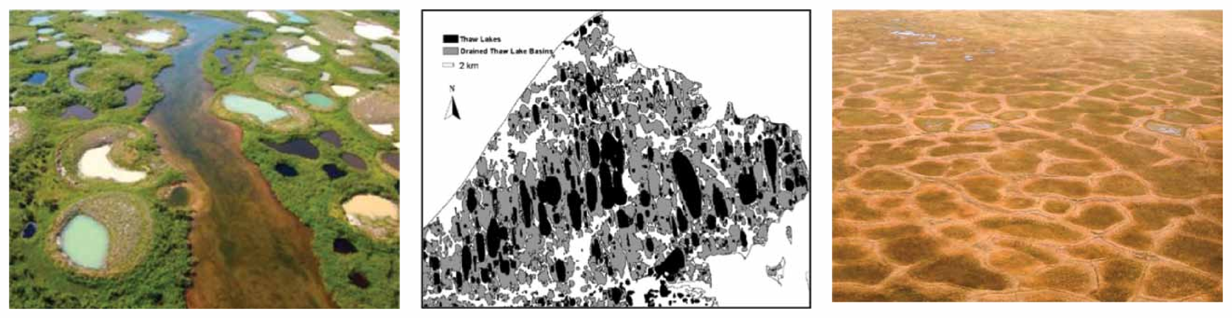
Introduction

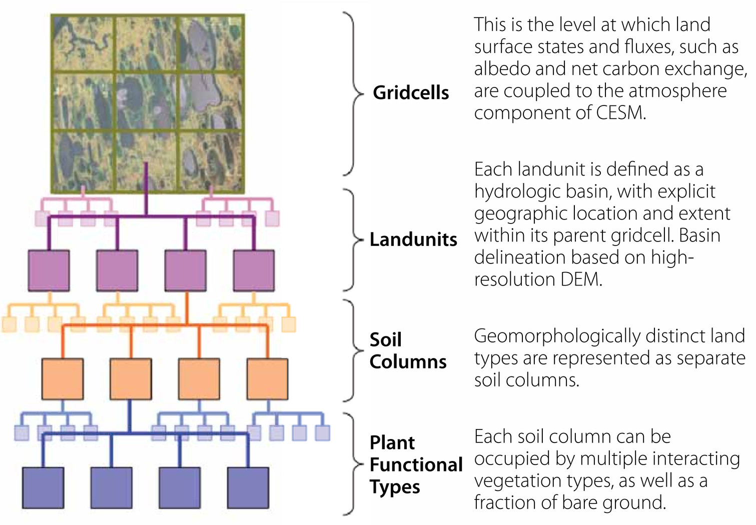
An important challenge for Earth System Models is to properly represent the land surface. This can be problematic, yet failure to identify and appropriately account for complexities at the landscape scale can compromise climate predictions. The Next-Generation Ecosystem Experiments (NGEE Arctic) project will address this challenge for sensitive and rapidly changing ecosystems of the Arctic tundra through a combination of direct observation and process-resolving simulation in this vast and remote landscape.

A Scaling Framework Based on Geomorphological Units

A distinguishing characteristic of the Arctic tundra, especially the coastal plains of the North Slope, is the existence of recognizable and quantifiable landscape units which are repeated over large domains, and occur at multiple spatial scales. Previous efforts using remote-imagery have identified active thaw lakes, and drained thaw lake basins, and ice-rich polygonal ground as three common landscape units that occur over large parts of the Arctic tundra.

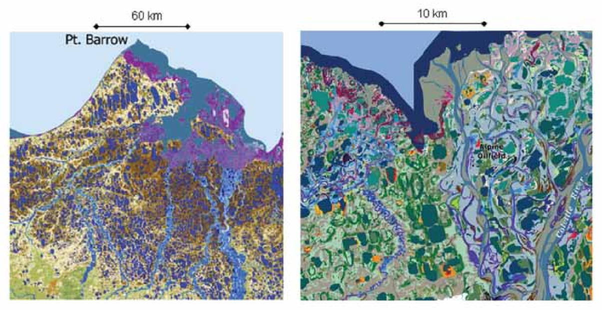


Implementation of CLM Subgrid Hierarchy

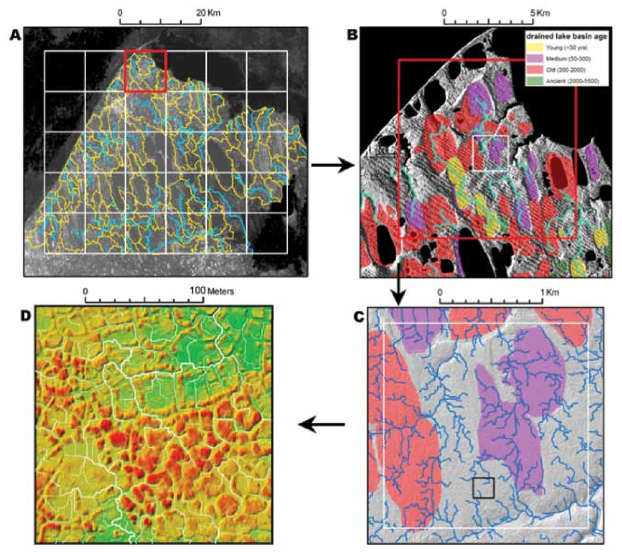


Assumptions of simple linear scaling that are used to represent subgrid heterogeneity in current state-of-the-art Earth System Models do not appear to be valid for Arctic tundra landscapes. These landscapes are characterized by organized variability in physical state and hydrologic dynamics across several orders of magnitude in spatial scale. The fundamental challenge for NGEE Arctic modeling is to relate new process knowledge gained at fine and intermediate spatial scales to states and fluxes relevant for integration in global-scale climate system models. Our approach will engage a nested hierarchy of models at fine, intermediate, and climate scales, connecting process studies to models and models to each other in a quantitative up-scaling and down-scaling framework.

Mapping of Geomorphological Units on Arctic Coastal Plain



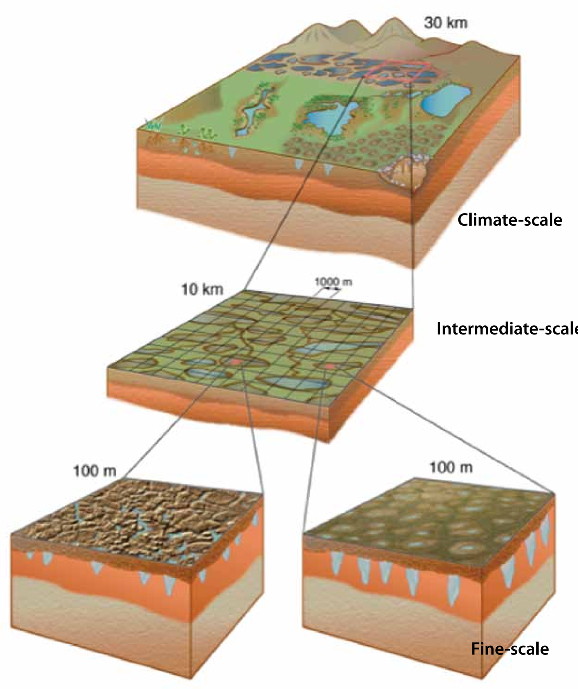
High-resolution elevation data from LIDAR instruments and multi-spectral remote sensing imagery will be used to characterize the tundra landscape within our modeling domains. As a major departure from previous climate modeling efforts, we will retain explicit sub-grid information regarding the location and topology of hydrologic basins, represented in the CLM4 hierarchy as landunits. Geomorphologically distinct subsets of these hydrologic basins will be identified and classified, populating the soil column level of the CLM4 subgrid. These soil columns will represent fractional areas of land types such as ice wedge polygon rim and trough, or recently drained thaw lake basins.



Our scaling approach will build on the hypothesis that the transfer of information across spatial scales can be organized around these discrete geomorphological units for which processes are represented explicitly at finer scales, with information passed to coarser scales through sub-grid parameterization of Earth System Models.

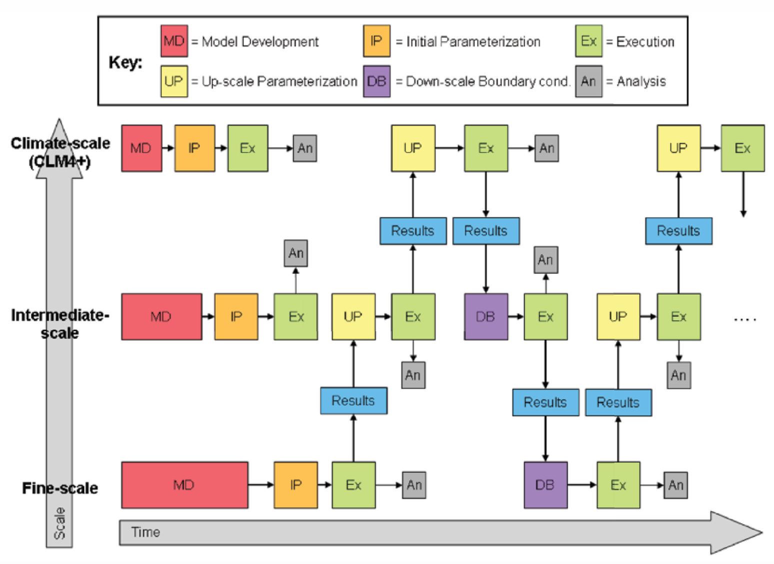
A Hierarchy of Models

Our scaling framework engages models at three spatial scales: the climate-grid scale, an intermediate scale, and a fine scale, with larger domain and coarser grid resolution for the climate-scale model, and smaller domains and finer grid resolution for the intermediate and fine-scale models.



Observations, experimental results, and new process understanding will be integrated with modeling components at scales appropriate to the measurements and mechanisms.

Multi-model Up-scaling and Down-scaling Framework



Our up-scaling and down-scaling approaches depend on carefully constructed modeling domains, with intermediate-scale domains nested within the climate-scale, and fine-scale domains nested within the intermediate scale. Models at these three scales are developed and executed independently, with thermal and hydrologic boundary conditions being passed as down-scale information, and empirical subgrid parameterizations used to capture the up-scale flow of process knowledge. Ground-based and remote sensing observations will be used to initialize the models at each scale, and independent observations will be used to evaluate model predictions at multiple scales. Process studies on hydrology, geomorphology, vegetation dynamics, and biogeochemistry will inform fine-scale and intermediate-scale model development and parameterization.

Representativeness

A promising method for characterization of representativeness at the climate modeling scale uses multiple environmental input data layers and a clustering algorithm to generate discrete landscape units with uniform variance distributions. The same approach is also able to provide a continuously varying metric describing the representativeness of a particular location in a broader spatial context.

Process Studies and Observations Linked to Scaling Framework

The scaling framework adopted for the NGEE Arctic project will allow us to begin immediately to integrate new process knowledge into a climate prediction-scale land model, while establishing a quantitative framework connecting this scale to more process-rich models implemented at finer spatial resolution and over smaller spatial domains.

Process studies and observations will inform models at each of three scales by providing new parameters and new algorithms for important, yet poorly represented components of Earth System Models.

A range of techniques will also be used to collect datasets that will be used in model initialization and evaluation. This will ensure that state variables are appropriately represented in models and that process knowledge gained at plot scales can be evaluated at larger landscape scales.

Conclusion

Our objective with this research program is to achieve a generalization of knowledge and understanding, gained through direct observation and fine-grained simulation of Arctic tundra ecosystems and the mechanisms that regulate their form and function. More specifically, this generalization of knowledge will take the form of improved representation of Arctic tundra states and dynamics in the land model component of a global coupled Earth system model.

Next-Generation Ecosystem Experiments (NGEE Arctic)

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