Next-Generation Ecosystem Experiments (NGEE-Arctic)

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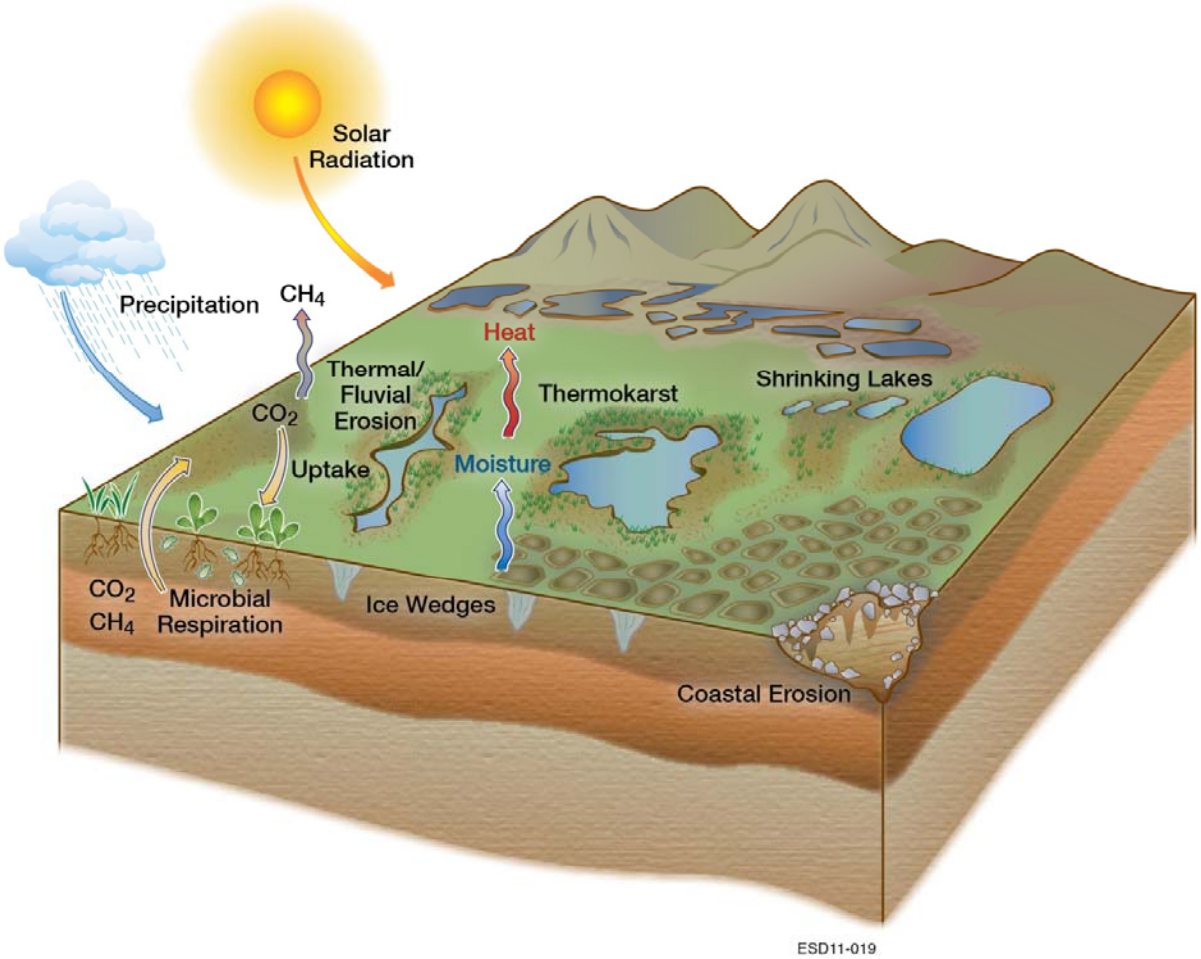
Vulnerable Arctic Landscapes in Transition

•***Changes in Arctic processes will be significant drivers*** *to ecosystem-climate feedbacks at the global scale*

•*The presence of* ***permafrost, ground ice, and abundant soil organic carbon*** *complicates prediction of ecosystem -climate feedbacks.*

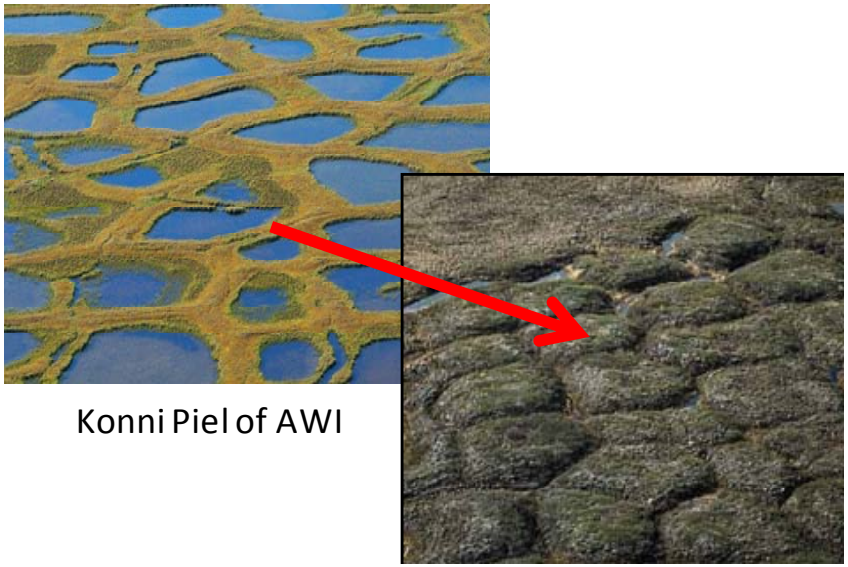


Must understand mechanisms that that control carbon and energy transfer in the biosphere.

Must also understand how those processes play out in a changing landscape.

Landscape Evolution Accelerated by Permafrost Thaw

Thaw Lake drainage
(100s-1000s of meters; days to years)



Konni Piel of AWI

Polygonal ground transitions
(1-10s of meters; years to decades)

Landscape dynamics will influence water distribution, having a cascading affect on plant dynamics and soil biogeochemistry.
Coupled hydrological-biological-geochemical processes are not well understood or represented in models!

NGEE Science Question and Goal

SCIENCE QUESTION:

How does **permafrost thaw and degradation**, and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community dynamics, **affect feedbacks to the climate system**?

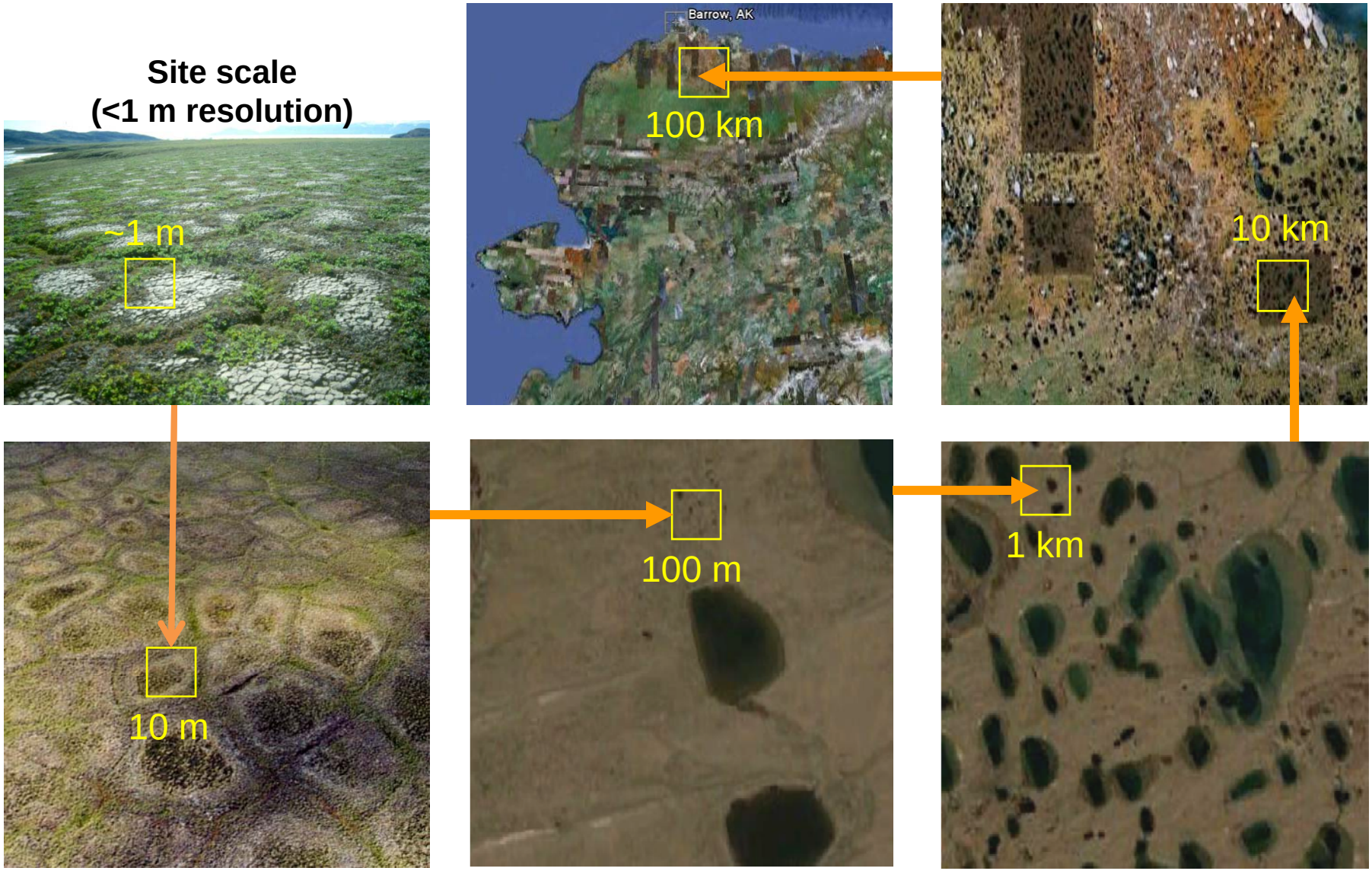
OVERARCHING GOAL:

Development of a **process-rich ecosystem model**, extending from bedrock to the top of the vegetative canopy, in which the evolution of Arctic ecosystems in a changing climate can be modeled at the **scale of a high resolution Earth System Model grid cell.**

Complex, hierarchical system

Typical GCM / ESM scales (1°x1°) ≈ 100km

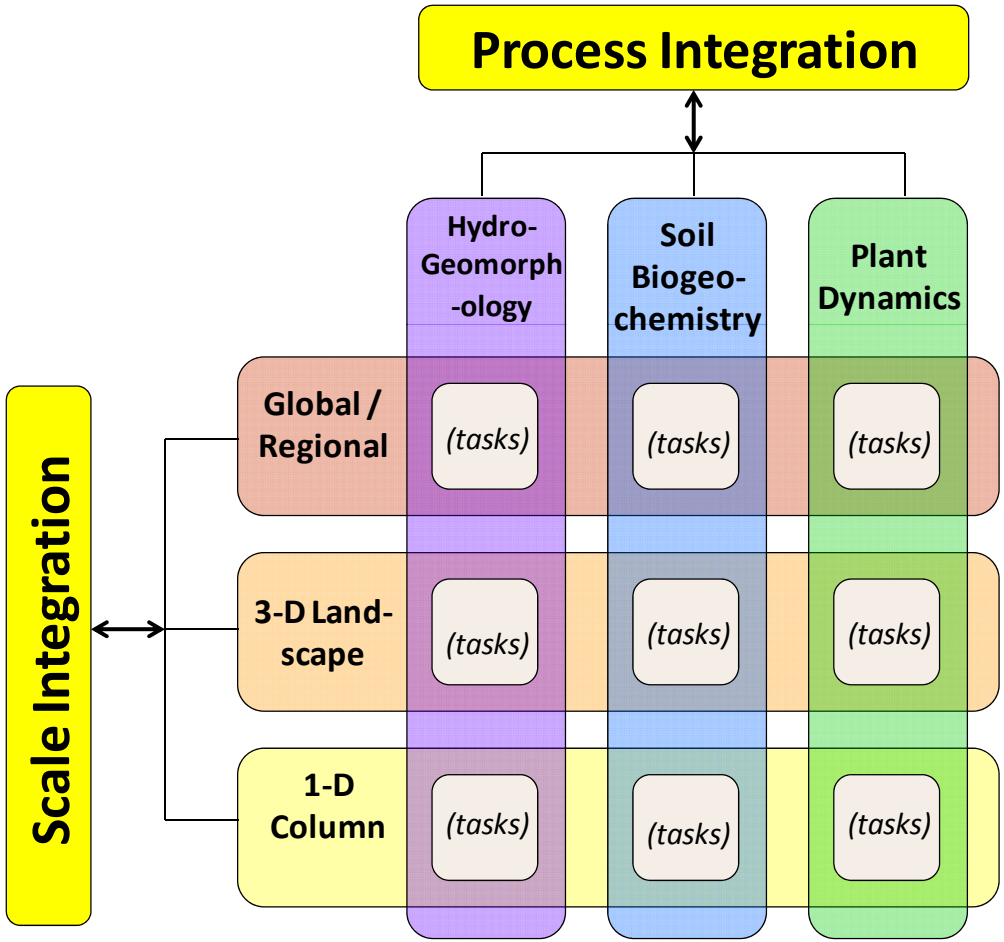
Site scale (<1 m resolution)

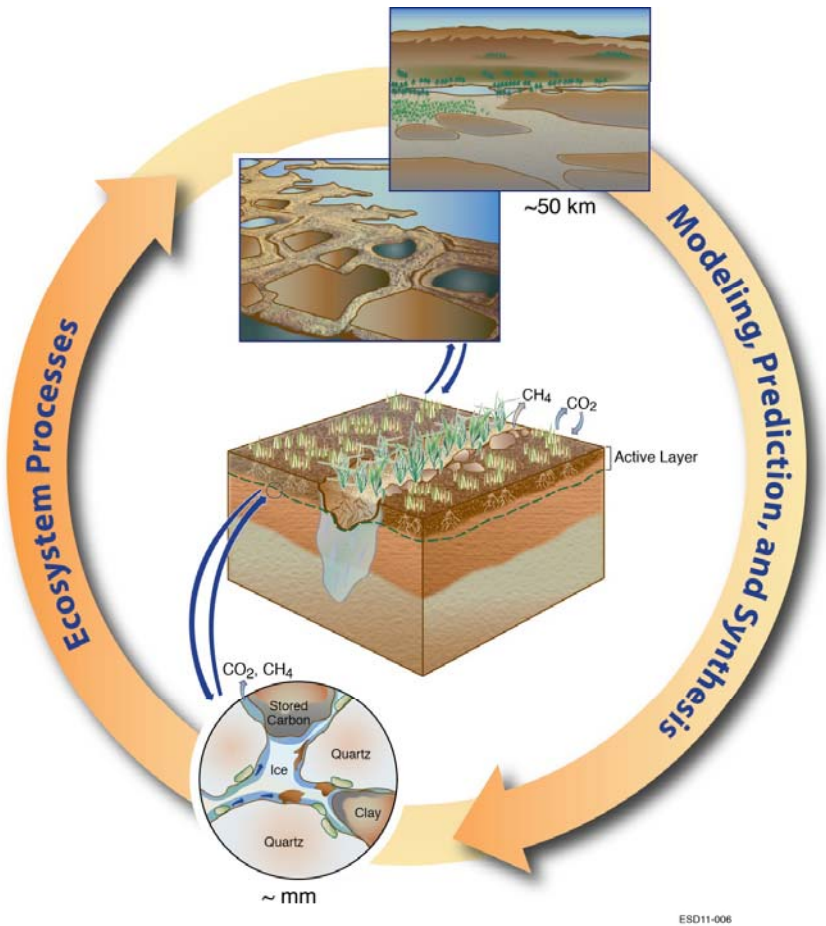


Landscape scales (100 m to 10 km)

NGEE Organization & Approach

Model driven approach that recognizes the complex, hierarchical nature of the Arctic System





Iterative and multi-scale experiments, observations and simulations

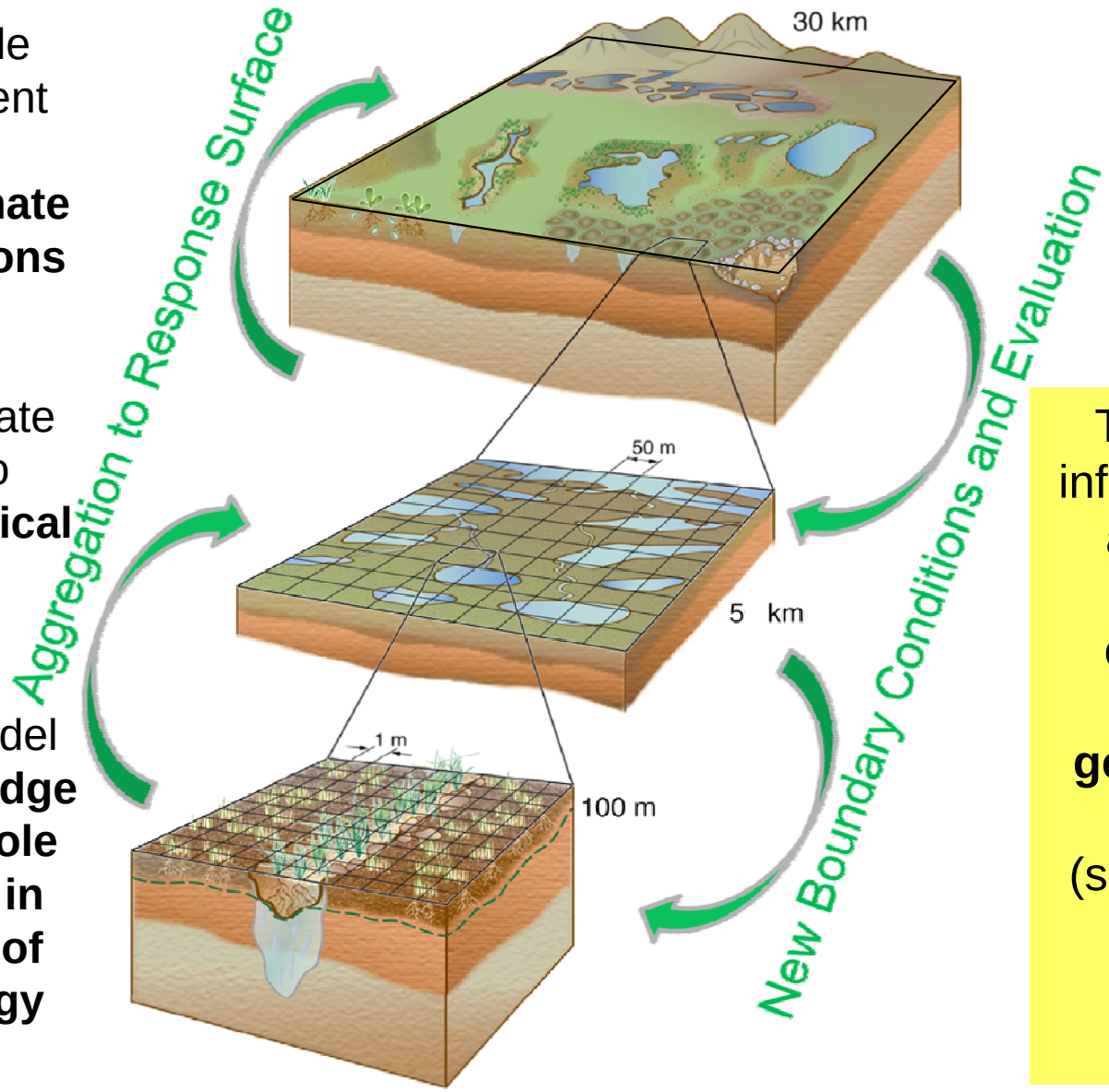
Hierarchical NGEE Simulation Framework

Cross-scale iterative solutions
required to honor energy, mass and momentum conservation

1D Climate scale model to represent arctic tundra processes in **climate change predictions**

2D/3D Intermediate Scale model to resolve **hydrological connectivity**

3D fine scale model to **resolve ice wedge dynamics and role of thermokarst in reorganization of mass and energy fluxes**



Transfer of information up and down scales organized around **geomorphic units** (such as thaw lakes and polygonal ground)

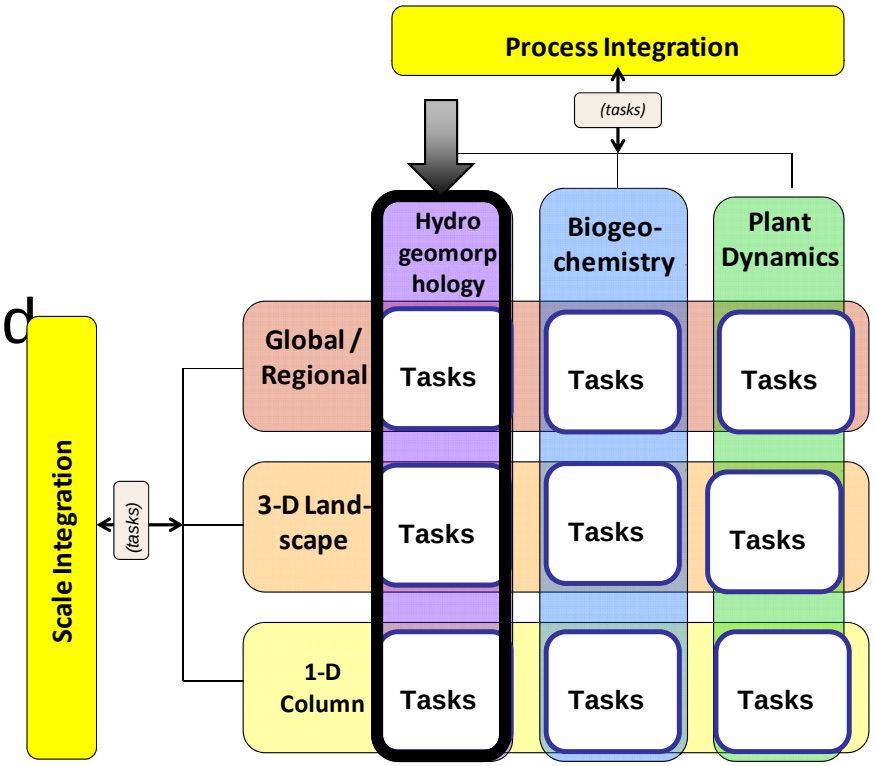
Hydrogeomorphology Challenge

GOAL: Develop predictive understanding of permafrost dynamics and its impact on water distribution and movement in a warming climate

OBJECTIVES.

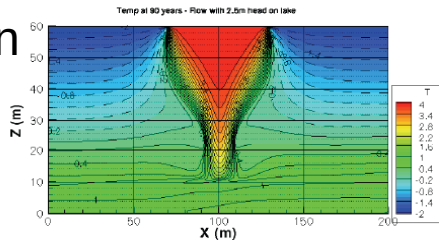
Quantify:

1. Controls on permafrost and active layer dynamics
2. Initiation and evolution of ground subsidence and thermokarst.
3. Impacts of thermokarst and topographic evolution on water and heat fluxes and redistribution

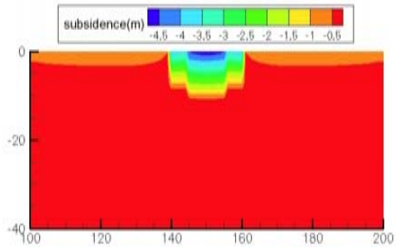


Example Task: Develop and Parameterize
Thermo-Hydrogeological-Mechanical Model (THM)

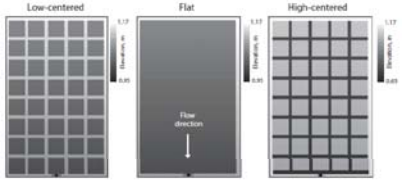
Permafrost degradation impact on hydrology (ARCHY)



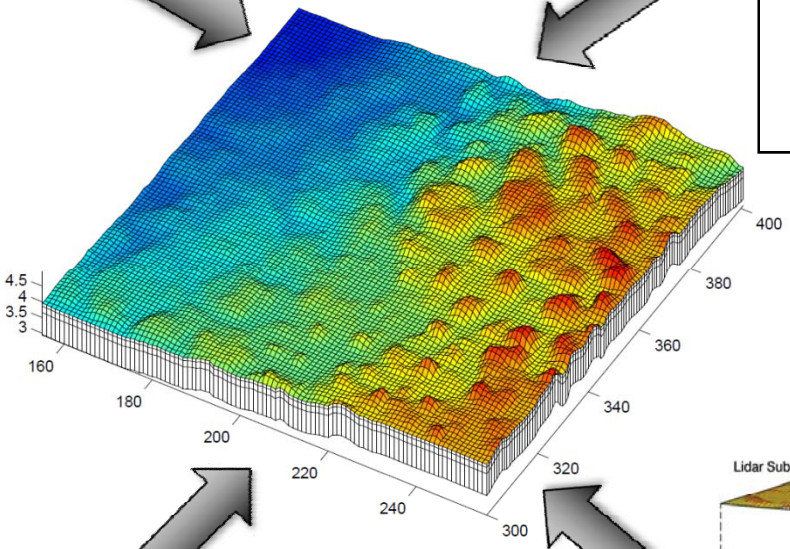
Permafrost degradation impact on micro-topography (FEHM)



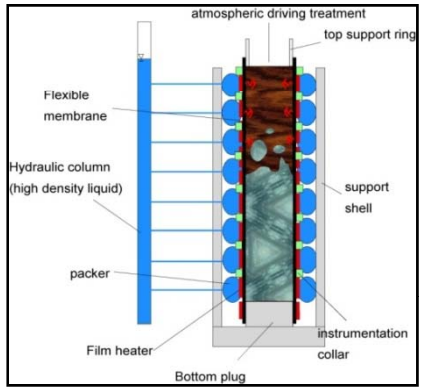
Micro-topography impacts on surface routing (WaSIM-ETH)



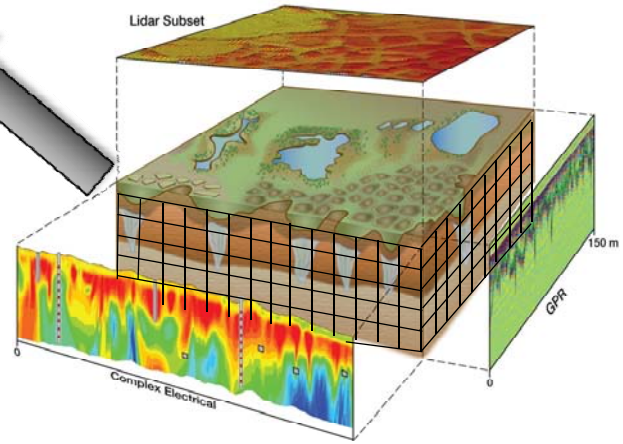
3D, multi-phase THM model



Constitutive relationships



Surface-subsurface data fusion & characterization

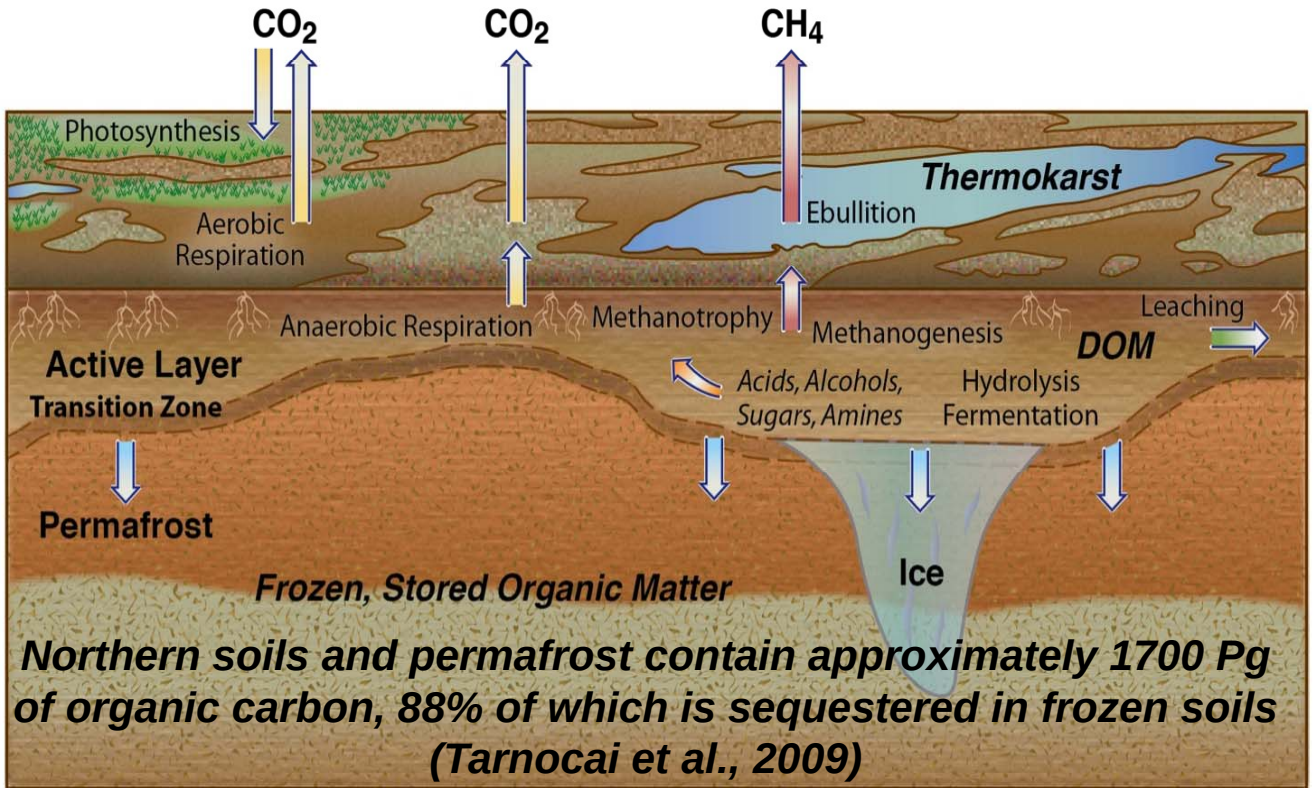


Soil Biogeochemistry Challenge

GOAL: Develop a quantitative model of organic matter decomposition rates in high latitude soils as needed to improve predictions of CO_2, CH_4 and N_2O greenhouse gas feedbacks on changing Arctic ecosystems

Microbial decomposition occurs within an expanding active layer.

There is a great **uncertainty about the decomposition processes, rates, and impact on GHGs.**



Soil Biogeochemistry Objectives and Example Task

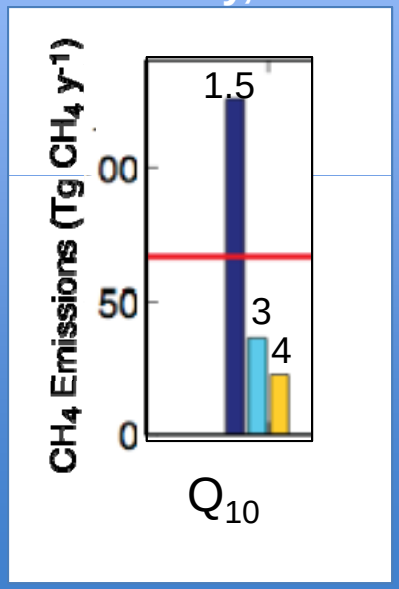
Quantify:

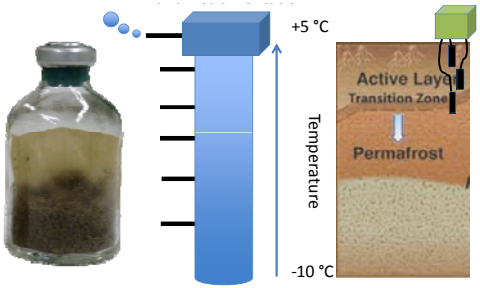
- Soil Freeze Effects on Decomposition and SOM Distribution
- SOM Turnover Times in Thawing Soils
- Temperature and Oxygen controls on GHG Flux
- Carbon-Nitrogen Interactions
- Carbon decomposition and GHG emissions from thaw lakes

$$\text{Production}(CH_4) = R_H\, f_{CH4}\, \boxed{f_T}\, f_{pH}\, f_{pE}\, S$$

Uses a Q_{10} respiration parameter that is based on 22°C

Riley, et al Biogeosciences, 2011



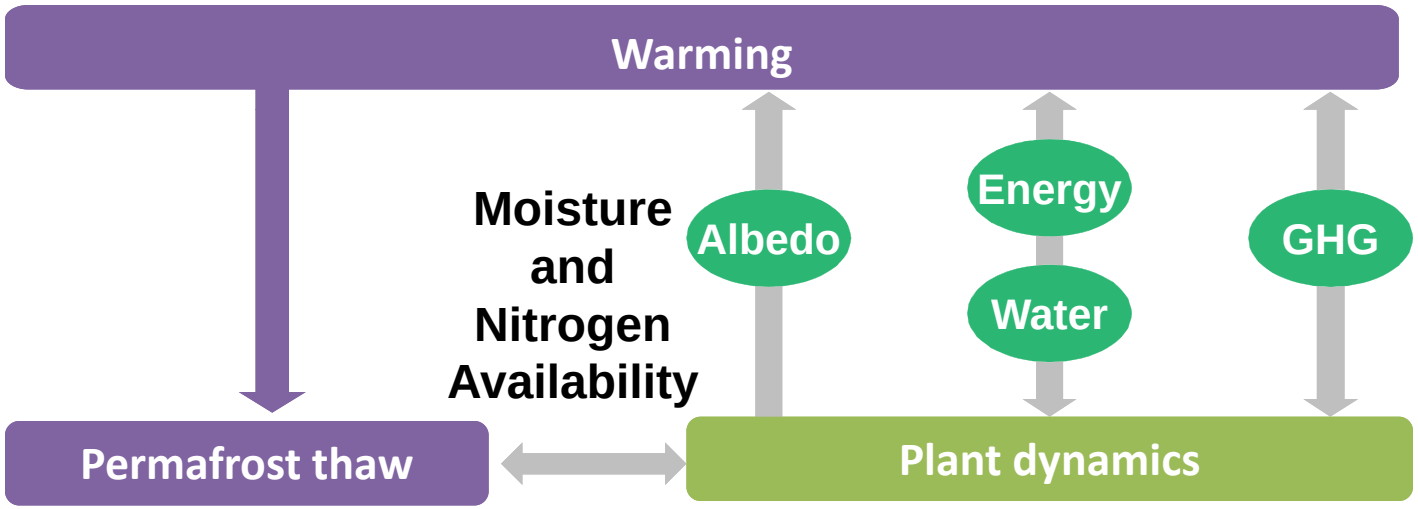


Incorporate revised temperature respiration response functions into models to reduce uncertainty

Plant Dynamics Challenge

GOAL

Quantify the mechanisms that drive **structural and functional responses of the tundra plant community** to **changing resource availability associated with permafrost thaw and degradation,** as needed to predict feedbacks to climate associated with vegetation dynamics.



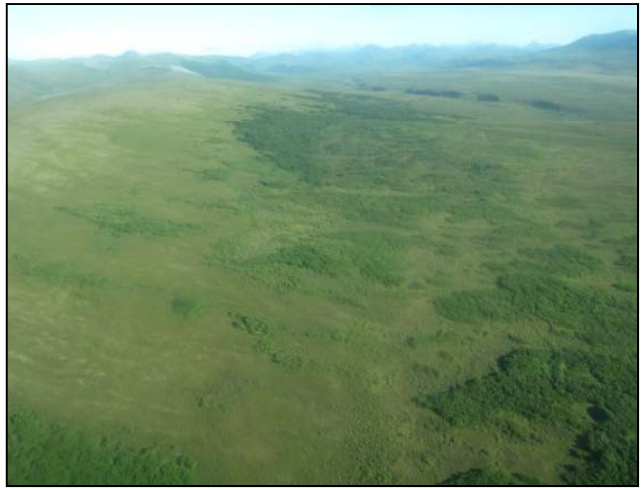
OBJECTIVES

1) **Improved Arctic Plant Functional Types (PFTs)**
2) Quantify plant community composition in relation to soil N availability
3) Improve landscape-scale estimates of C uptake

Example task: **Arctic Plant Functional Types**

- Develop improved representations of **plant functional types** that consider nitrogen and water acquisition strategies

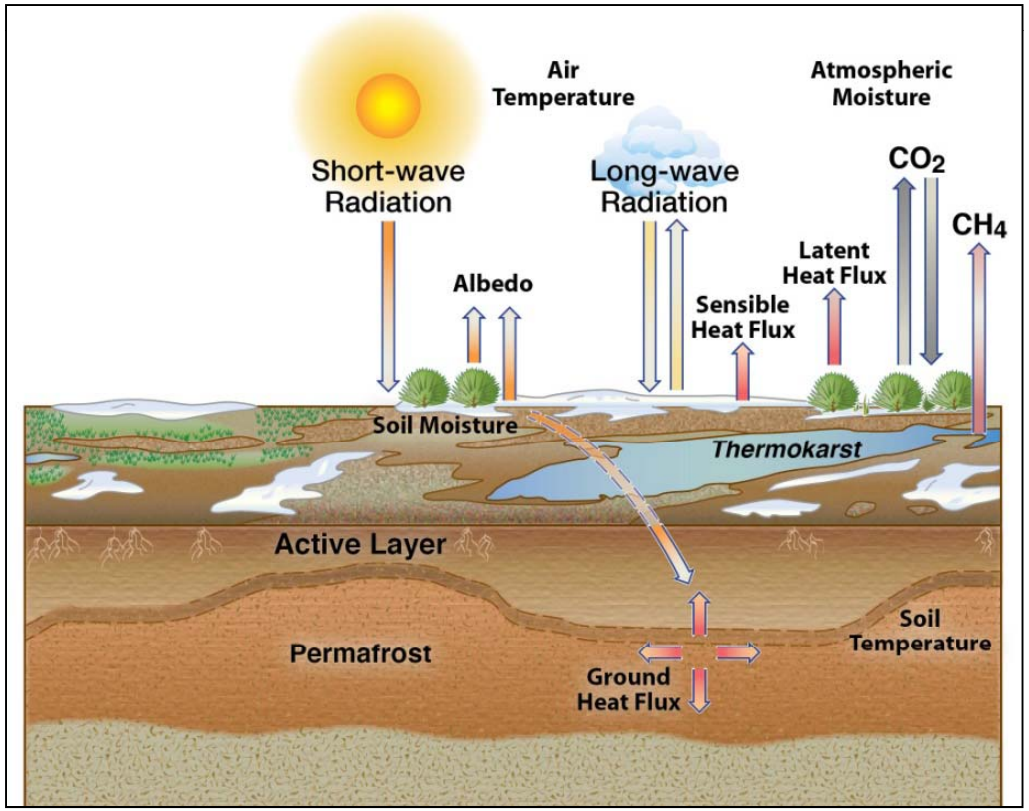
- Test **dynamic vegetation models with improved PFTs** against observed patterns across thermokarst gradients



Integration and Synthesis

How does **permafrost thaw and degradation**, and the associated changes in landscape evolution, hydrology, soil biogeochemical processes, and plant community dynamics, **affect feedbacks to the climate system**?

- Will CO_2 released from soil organic carbon decomposition be greater than CO_2 uptake by plants over time?
- How will changes in geomorphology affect the trajectory of methane emissions over time?
- What processes govern the rate at which arctic albedo changes?



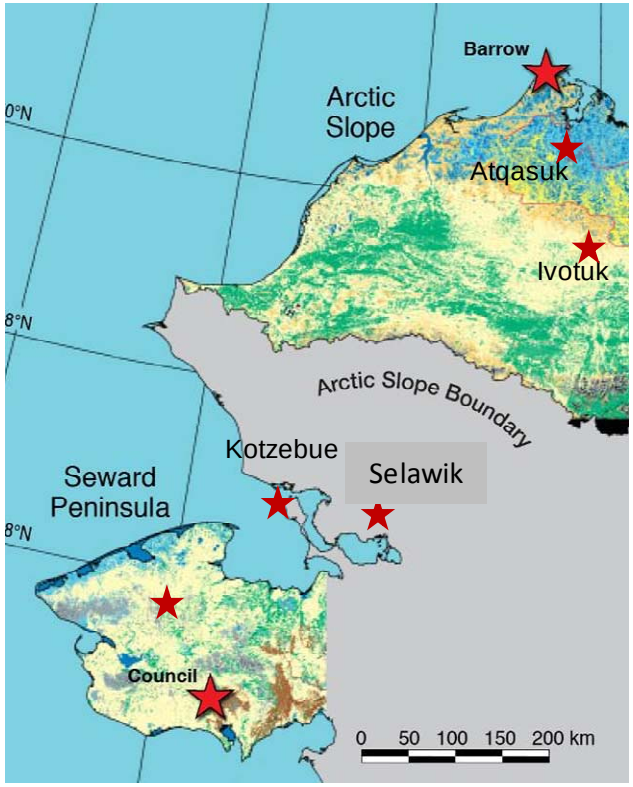
Why DOE & Community Resource

WHY DOE?

- **DOE Energy & Environment Mission**
- **Model-Driven Enterprise** that takes advantage of HPC capabilities
- **Long Term Research Facility** development/maintenance
- **Multi-disciplinary expertise** in ecology, soil biogeochemistry, hydrology, plant dynamics, geophysics and computational science

COMMUNITY RESOURCE:

- Well-instrumented and characterized **field sites**
- Extensive NGEE **database** and community **codes**
- Workshops



NGEE possible field sites, including Barrow and Council, AK

Thank You!

Department of Energy
Terrestrial Ecosystems Science

FOR MORE INFORMATION:
NGEE Townhall, TH 42A Thursday 12:30-1:30 &

Photo by Roy Kaltschmidt (LBNL)