Migrating Knowledge Across Scales through Coupled Modeling and Process Studies

Next-Generation Ecosystem Experiments (NGEE Arctic) Project

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- Permafrost contains ~1700 Pg carbon…
- Similar in size to fossil fuel reserves
- Situated in region that will experience maximum warming
Current Earth System Models represent complex climate-carbon and climate-ecosystem feedbacks.
How does warming influence the **physical** state of permafrost regions?

[Albedo and hydrology feedbacks]
How does warming influence the biogeochemical state of permafrost regions?

[Climate feedbacks through CO$_2$ and CH$_4$]

- Fossil Fuel Emissions
- Atm CO$_2$ (and CH$_4$)
- Ocean carbon
- Climate (T, P, q, rad)
- Land carbon
- Humans
- Land use / land cover change
How does atmospheric CO$_2$ influence the **physical** and **biogeochemical** state of permafrost regions?

[fertilization feedback]
Current climate model treatment of a permafrost tundra landscape...
Trying to achieve a sense of scale...

Polygonal tundra near Barrow, AK

Manhattan

Amazon Basin

Suburban Knoxville

Ohio cropland
A serious scaling problem:

All the quantities of interest for the large-scale climate-prediction problem…

(Moisture, temperature, freeze/thaw state, albedo, vegetation distribution and dynamics, biogeochemical processes)

… appear to be strongly controlled by microtopographic variations

(horizontal scales of centimeters to meters).
A possible solution to the scaling problem:

• Develop explicit process-resolving models at appropriate scales
  – Inform with observations and experimentation

• Add relevant process representation in the climate-scale model
  – Provide parameterization “hooks”

• Use fine-scale models to parameterize coarser-scale models
  – Evaluate with independent observations
Fine and intermediate scale models: explicit process representation
Climate-scale model: process representation through parameterized sub-grid heterogeneity

- Gridcells: approximately 10 km x 10 km
- Landunits: sub-grid basins
- Soil columns: groups of similar polygons
- Plant Functional Types: Multiple types on each column (competing)
Process knowledge migration through iterative scaling

Key:
- **MD** = Model Development
- **IP** = Initial Parameterization
- **Ex** = Execution
- **UP** = Up-scale Parameterization
- **DB** = Down-scale Boundary cond.
- **An** = Analysis
Characterizing the modeling domain

Polygon type delineation:
Chandana Gangodagamage, LANL
Characterizing the modeling domain

Intensive field measurements are translated to modeling domain characteristics

Surface weather observations drive multi-scale models

Soils data from Larry Hinzman and Anna Lilljedahl, UAF

Atmospheric data source: ARM
Soil temperature simulations over gridded domains (Site C, August)
Thermal-hydrology simulations over fine-scale domains

August: maximum active layer depth
December: active layer nearly frozen

Jitu Kumar, Nathan Collier: ORNL
Surface flow simulation

Ethan Coon, Marcus Berndt, Scott Painter (LANL LDRD-DR)
Fully coupled surface-subsurface thermal hydrology simulation
Parameterizing New PFTs for Arctic Tundra using intensive field observations

Field measurement (Vcmax) translated to model parameter (fraction of leaf nitrogen in Rubisco, flnr)

Vcmax with New PFTs at Barrow, AK

Vcmax parameterized via ‘flnr’

Ca rex aquatilis
Eriophorum angustifolia
Pe tasites frigidus
Sa lux pulchra
QL M
CL-CN
Be thy
Hybrid

(Alistair Rogers et al. 2013)

CLM-CN Vcmax at top canopy at 25oC for 7 Arctic PFTs and their ‘flnr’ parameters

Fengming Yuan, ORNL
Coupled vegetation and soil biogeochemistry modeling

A common modeling framework is being used for multi-scale simulation, reducing the loss of information in the up-scale migration of processes and parameterizations.
Example Data-Model Integration: Measuring and modeling CH₄ flux

Model development

CLM-Microbe Methane module

Field observations

NOAA GMD climate data, Auxiliary data

Model Application (CH₄ budget, concentration, methanogenesis, methanotrophy, environmental controls)

A Microbial Functional Group (MFG)-Based Methane Module

X. Xu, ORNL (modeling)
M. Torn, LBNL (observations)

Modeled CH4 flux in Barrow, AK
Next steps: Migrating NGEE-Arctic knowledge into global-scale models

• Observation-informed multi-scale modeling framework from NGEE-Arctic will be a core component of new land model development for next-generation, high-resolution Earth System Model
  – Nascent DOE project: Accelerated Climate Modeling for Energy
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