The Next Generation Ecosystem Experiments- Arctic

PI: Stan Wullschleger ORNL, Larry Hinzman UAF, David Graham ORNL, Susan Hubbard LBNL, Liyuan Liang ORNL, Richard Norby ORNL, Bill Riley LBNL, Alistair Rogers BNL, Joel Rowland LANL, Peter Thornton ORNL, Margaret Torn LBNL, Cathy Wilson LANL

NGEE science question and goal

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?

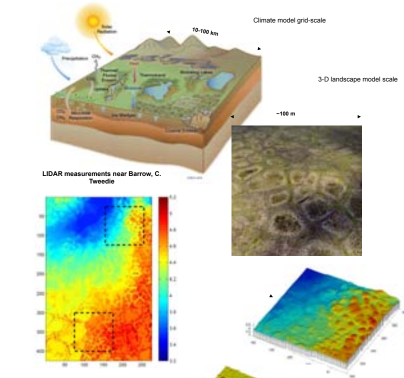
Goal: the development of a process-rich high resolution ecosystem model, extending from bedrock to the top of the vegetative canopy, in which the evolution of the terrestrial Arctic in a changing climate can be predicted with high certainty at the scale of an Earth System Model grid cell.

Photos by:E. Schuur, K. Peil, L. Hinzman, T. Jorgenson

3-D process-resolving Arctic tundra landscape simulator

Process requirements

- Subsurface
  - Permafrost
    - thermal conditions
  - Differential ice concentrations
    - ice wedges, sheets, thermokarst
  - Active layer
    - thermal hydrology, 3-phase, one or two component
  - Biogeochemistry
    - dynamic organic matter quantity and quality with depth
    - microbial dynamics and plant-microbe interactions
    - CO_2, CH_4, and N species responsive to temperature, moisture, O_2, pH.
- Surface
  - Deformable topography
  - Surface flow and dynamic flow paths
  - Snowpack dynamics
  - Vegetation dynamics
    - plant-microbe interaction and plant N uptake
    - dynamic allocation in response to changing environment and N availability
    - representation of realistic Arctic plant functional types and community dynamics
    - plant interactions with surface energy balance (albedo, insulation effect)
- Near-surface atmosphere
  - Canopy interactions with surface wind, humidity, temperature, and radiation balance
  - Influence of microtopography on near-surface weather



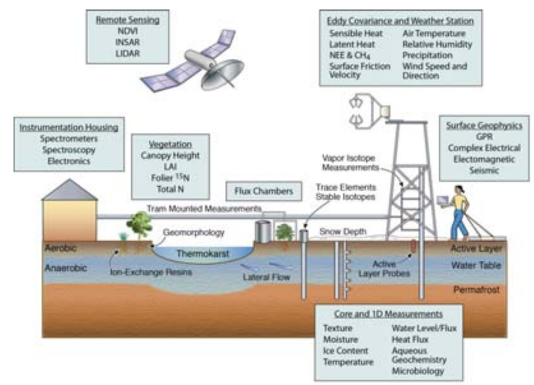
Spatial characteristics:
Domain: approx. 10Km x10Km
Resolution: ~10 cm (horiz), variable cm+ (vert)
Temporal characteristics:
Domain: decades to century
Resolution: sub-hourly

NGEE Arctic Phase 1 Approach (roadmap)

- Year 1
  - Site Selection
  - Guided by modeling process requirements, commence NGEE measurement campaigns
    - Early focus on measurements needed to initialize/parameterize 3-D landscape model at selected sites
  - Using existing observations, and new NGEE observations, evaluate and refine relevant algorithms from subset of existing models
  - Expand process and computational requirements to detailed architectural design for 3-D landscape model
  - Evaluate SciDAC PFLOTRAN and ASCEM AMANZI frameworks against design requirements, quantify and compare suitability as 3-D landscape modeling framework.
- Year 2
  - Continued NGEE measurement campaigns, expansion of process studies
    - Increased focus on integrative observations to be used for model evaluation, and remote sensing observations to inform up-scaling approaches.
  - Implementation of coupled subsurface/surface/near-surface 3-D landscape model
    - Integration of best-performing methods and algorithms from existing models
  - Test implementation of scaling approaches to inform global/regional scale models
- Year 3
  - Continued NGEE measurement campaigns, expansion of process studies
  - Initial execution of 3-D landscape model, and begin evaluation against integrative observations
  - Application of scaling approaches to inform global/regional model, comparison against default global model implementation - assess prediction improvements.
  - Assessment of new measurement requirements emerging from modeling activity, and new modeling requirements emerging from process studies.

Observation, measurement, and process study requirements in support of NGEE Arctic modeling

- Global/regional scale (Alaskan tundra region up to pan-Arctic)
  - Physical and biological characterization with remote sensing and inventory methods
    - Lake vs. non-lake, plant functional type distributions, landform distributions
  - Integrative measurements for model evaluation
    - Albedo and radiative surface temperature
  - Assessment of "representativeness" of different sites
- Landscape scale (multiple 100m x 100m sites)
  - Detailed physical and biological site characterization
    - LIDAR mapping of elevation, sub-meter horizontal resolution
    - Geophysical survey of subsurface states (ground penetrating radar, complex electrical, and electromagnetic methods). Hydraulic gradients, thermal gradients.
    - Vegetation community mapping
  - Integrative measurements for model evaluation
    - Eddy covariance measurements of energy, water, and carbon exchange
    - Hydrologic outflow measurements on nested basins, and associated water chemistry
    - Snow cover
- Column scale (multiple plots within each landscape site)
  - Vertical characterization of physical and biological properties through core and bore hole sampling
    - Ice distribution, organic matter quantity and quality, mineral composition
  - Process studies for parameterization, new knowledge and understanding
    - Freeze/thaw, soil moisture, and water table dynamics
    - Subsurface biogeochemical and microbial dynamics: response to warming, changing moisture, changing soil chemistry
    - Vegetation response to growth environment and resource availability
    - Snowpack dynamics
  - Integrative measurements for model evaluation
    - Soil surface fluxes of CO_2 and CH_4
    - Canopy N concentration



Our approach is one that closely integrates models and observations to improve climate prediction, and one that will allow us to determine whether the Arctic is, or in the future will become, a negative or positive feedback to climate.

Integrated model-data activities:

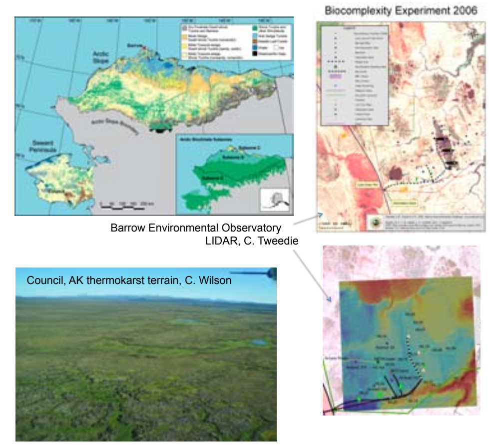
Hydrology and geomorphology – Develop a predictive understanding of thermal, hydrologic, and mechanical controls on permafrost degradation and its impact on topography and inundation dynamics in a changing climate.

Biogeochemistry – Develop a quantitative description of SOM decomposition rates in permafrost soils to improve predictions of greenhouse gas feedbacks.

Plant dynamics – Quantify nitrogen and soil water controls on plant production, competition, and incorporate into new representations of plant functional types.

Energy – Quantify albedo and energy partitioning in Arctic ecosystems, with a goal of describing energy transfer in models of highly-coupled systems.

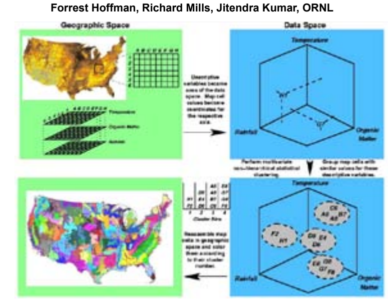
Barrow and Council as two end members
Multivariate geographic clustering, NEON approach



Barrow Environmental Observatory
LIDAR, C. Tweedie

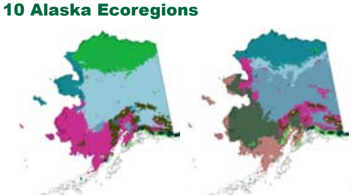
Council, AK thermokarst terrain, C. Wilson

Forrest Hoffman, Richard Mills, Jitendra Kumar, ORNL



- For a preliminary analysis, we used climate-only data from http://www.snap.uaf.edu/
- 2 decadal averages were clustered: 2000–2009 and 2090–2099 using 8 data layers from the A1B five-model composite
  - Air temperature
  - Precipitation
  - Length of Growing Season (Mean and Standard Deviation)
  - Day of Freeze (Mean and Standard Deviation)
  - Day of Thaw (Mean and Standard Deviation)

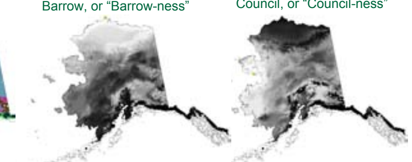
10 Alaska Ecoregions



(2000-2009) **(2090-2099)**

Present representation of Barrow, or "Barrow-ness"

Present representation of Council, or "Council-ness"



Light-colored regions are well represented and dark-colored regions are poorly represented by the sampling location marked with a yellow circle.