Next-Generation Ecosystem Experiments (NGEE Arctic)

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CES Modeling PI Meeting

September 22, 2011

U.S. DEPARTMENT OF ENERGY · Oak Ridge National Laboratory · Los Alamos National Laboratory · Berkeley Lab · Brookhaven National Laboratory · University of Alaska Fairbanks

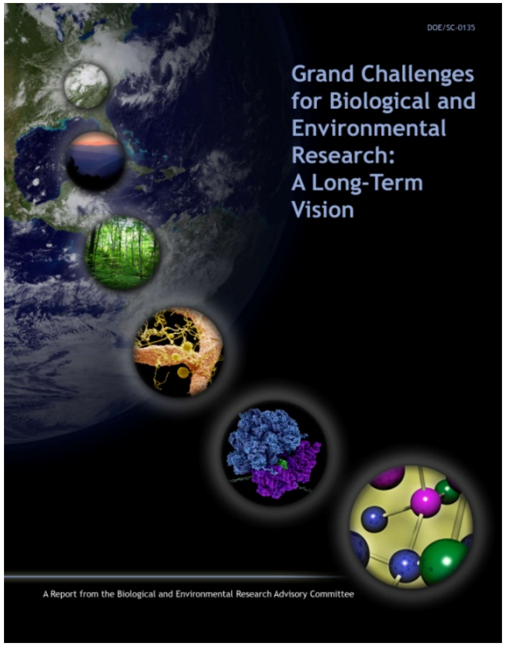
NGEE Arctic: Goals

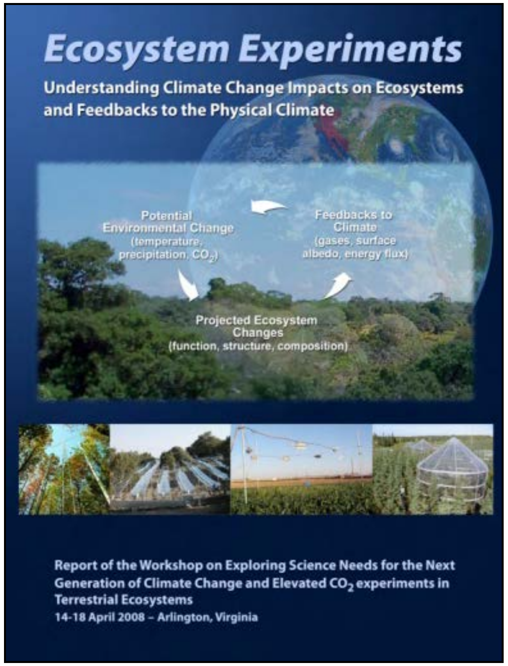
Deliver scientific data that improves our understanding of the structure and function of terrestrial ecosystems in response to climate change,

Incorporate into existing models for improved prediction of carbon cycle processes and net energy balance on Earth’s climate, and

Develop a process-rich land surface model in which the evolution of Arctic ecosystems in a changing climate can be modeled within a high-resolution Earth System Model.

- Integration across from subcellular to Earth system,
- Observations, experiments, and models,
- Interdisciplinary studies, and
- Focus on ecosystems that are globally important, sensitive, and poorly represented in climate models.





CESM Presentations and Posters:

- Changes in lake distribution for climate simulations – Subin (LBNL)
- Nitrogen limitation on vegetation dynamics – Xu (LANL)
- Methane biogeochemistry in CLM4 – Riley (LBNL)
- Arctic terrestrial methane emissions – Zhuang (Purdue)
- Shrub height and expansion on boreal climate – Bonfils (PNNL)
- Cold region hydrologic modeling – Bolton (UAF)
- Surface energy balance in Arctic ecosystems – Linn (LANL)
- Surface and groundwater in permafrost soils – Rowland (LANL)
- Permafrost and permafrost hydrology – Lawrence (NCAR)
- Improved process representation for the Arctic – Thornton (ORNL)
- Permafrost carbon and nitrogen dynamics – Koven (LBNL)
- Biogeochemical processes in high-latitudes – Jain (Univ. Illinois)


Barrow
Atqasuk
Ivotuk
Kotzebue
Seliwik
Kougarok
Nome
Council
Fairbanks
Anchorage
Image © 2011 TerraMetrics
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Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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64°15'53.29" N 150°12'07.00" W elev 860 ft
Eye alt 1266.59 mi
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Arctic is unique, sensitive to change, and already in transition…

- Ice-rich, permafrost-dominated system; highly complex,
- Tipping point defined by surface and subsurface physical, thermal, and hydrologic properties,
- Consequences are observed at landscape to regional scales, with implications for land-atmosphere interactions
- Carbon stored in permafrost is vulnerable to loss, but the timing, rate, and magnitude of CO_2 and CH_4 fluxes due to a deepening of the active layer are highly uncertain,
- Greening of the Arctic; mechanisms unidentified, and
- Feedbacks to climate are numerous, yet poorly understood with a critical need for improved representation in regional and global climate models.

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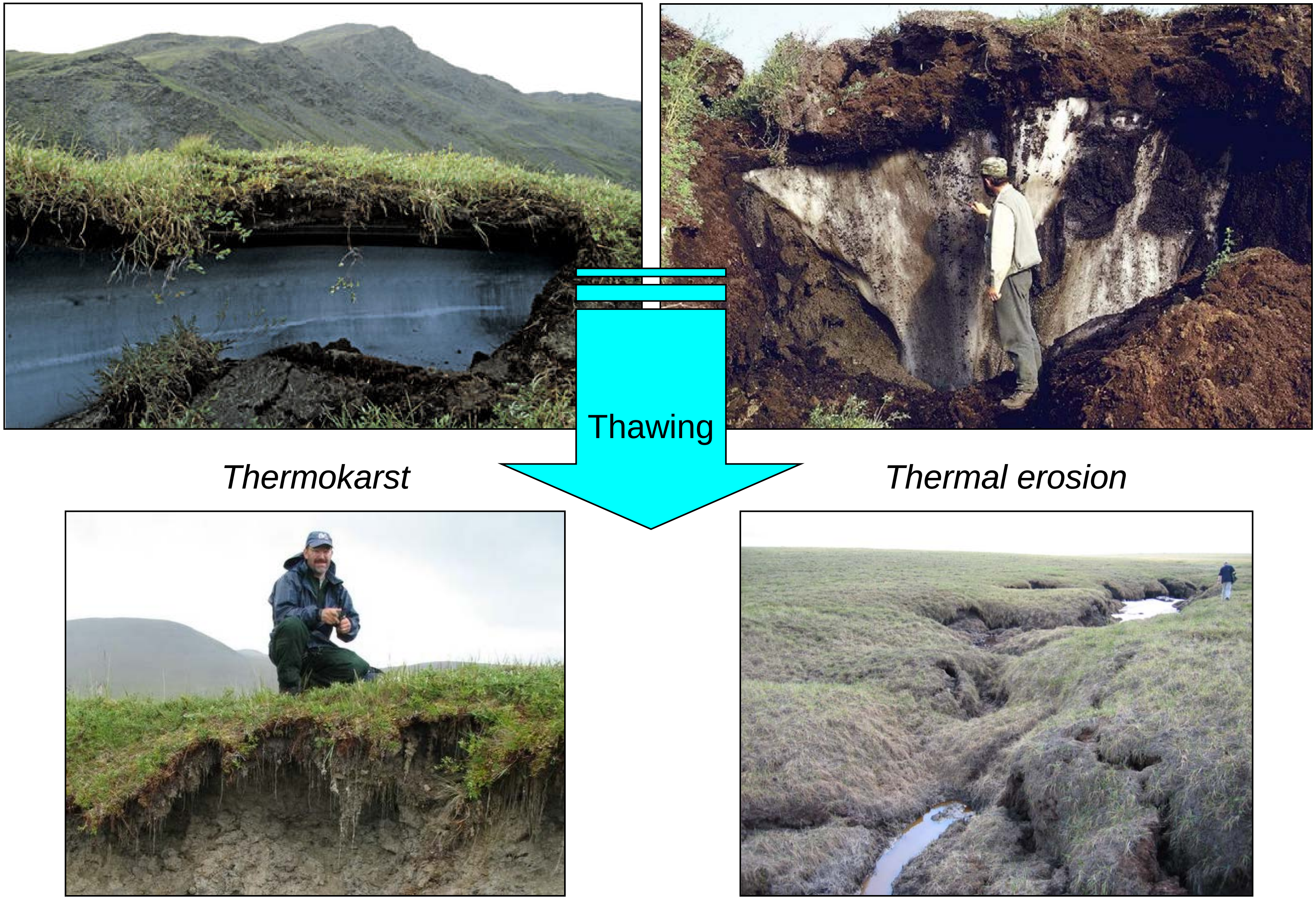
Surface-subsurface interactions and the consequences for landscape evolution.

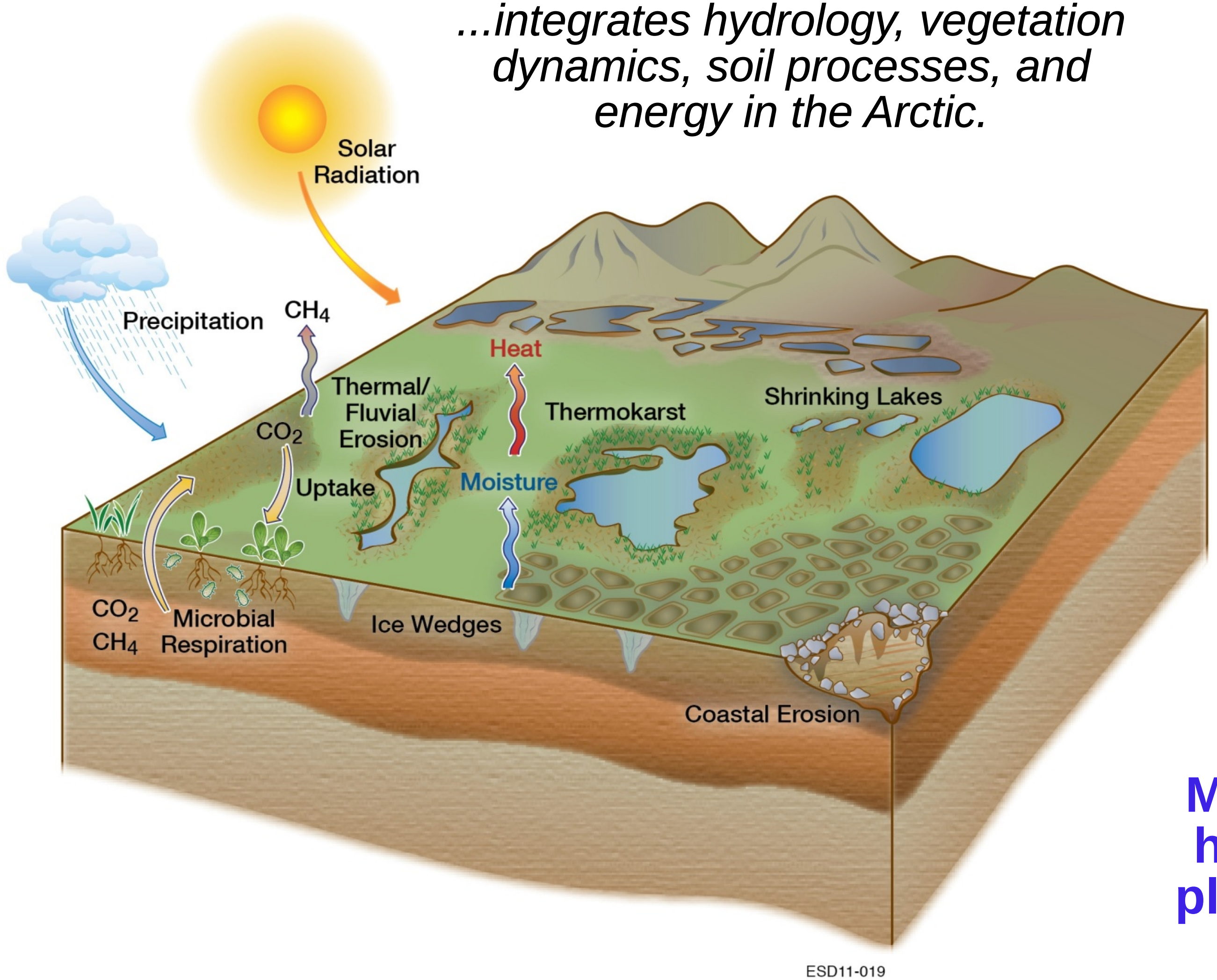


Transition from low-centered to high-centered polygons

Formation of channel networks, drainage, and drying of the landscape

Landscapes in transition

...integrates hydrology, vegetation dynamics, soil processes, and energy in the Arctic.



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

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

Overarching Science Question:

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

Our research tasks are organized around five components that determine whether the Arctic is, or in the future will become, a negative or positive feedback to climate:

Modeling – Integrate, iterate, and extrapolate

Hydrology – Complexity due to topography; surface and subsurface interactions

Vegetation Dynamics – Structural and functional contributions to carbon cycle processes and surface energy balance

Soil and Subsurface Processes – Microbial transformation of SOM to CO_2 and methane; geophysical interactions

Energy – Permafrost dynamics and shrub expansion

Multi-scale research activities are organized around these areas, and are designed to quantify the interactions between climate, permafrost degradation, hydrology, vegetation dynamics, net energy balance, and greenhouse gas fluxes.

Challenge Area: Modeling

Rationale: The Arctic is unique among terrestrial ecosystems given its complexity. Models must represent not only the important processes but also the evolution of the landscape that is associated with surface-subsurface interactions in a changing climate.

Question: What are the processes and properties that must be included in climate models; what spatial scale is required; how do we represent high-latitude ecosystems as coupled systems?

Task 1: Lessons learned from existing models; literature review and meta-analysis; exercise three classes of models across multiple spatial scales.

Task 2: Facilitate incorporation of new information into land surface models.

Task 3: Establish foundation for Arctic land simulator; explore scaling approaches; design a framework that integrates best capabilities of existing models and fills existing gaps in processes and scales.

Challenge Area: Hydrology

Rationale: Improving climate change prediction in high-latitude systems requires an accurate understanding of permafrost dynamics along with geomorphic processes that control hydrology and underpin ecosystem, soil biogeochemistry, and land-atmosphere interactions.

Question: Does permafrost degradation lead to a predictable progression of landscape change, characterized by thermokarst development, increased heterogeneity in soil moisture and surface water distribution, and eventual large-scale drying of the landscape?

Task 1: Assess mechanical properties of permafrost and freeze-thaw deformation of soils; lateral and vertical flux of water.

Task 2: Quantify active layer thickness and depth of water table; preferential flow paths; characterize lateral flow patterns.

Task 3: Characterize surface topography and watershed-scale hydrologic fluxes and stocks; conduct high-resolution surveys of surface micro-topography.

Challenge Area: Vegetation Dynamics

Rationale: Increasing dominance of shrubs over smaller statured tundra vegetation creates feedbacks to climate through changes in net energy balance and C fluxes; mechanisms uncertain.

Question: Does permafrost degradation and thermokarst formation promote increased availability of N within ecosystems, and if so, what is its role in driving plant competition, community composition, and transitions in the arctic landscape?

Task 1: Rates of microbial mineralization of organic compounds to ammonium and nitrate will be assessed; as will preferential uptake of N forms by plants.

Task 2: Plant community composition assessment along transects; nitrogen uptake and acquisition strategies determined; plant functional types for N developed for models (e.g., ArcVeg).

Task 3: Leaf- and canopy-scale N concentrations determined by optical properties obtained through aircraft imaging spectroscopy; optical signatures evaluated for regional-scale prediction of GPP; variation analyzed in relationship to landscape patterns.

Challenge Area: Soil and Subsurface Processes

Rationale: A predictive understanding of C transformation is needed, but does not yet exist given uncertainty in the biological and chemical reaction rates that are imposed by temperature and water.

Question 1: What is the primary variable that governs organic C degradation and the contribution of CO_2 or CH_4 to greenhouse gas emissions?

Question 2: Does organic C chemistry and geochemical interactions control microbial degradation in thawed permafrost?

Task 1: Water films around soil aggregates during freeze-thaw cycles using neutron imaging; methane oxidation associated with microbial community structure and enzyme activities.

Task 2: Soil water and redox potentials measured via lysimeters and groundwater wells; ^{14}C to determine age of organic C and advanced imaging to assess chemical structure.

Task 3: Conduct tower-based CO_2 and CH_4 flux determinations.

Challenge Area: Energy

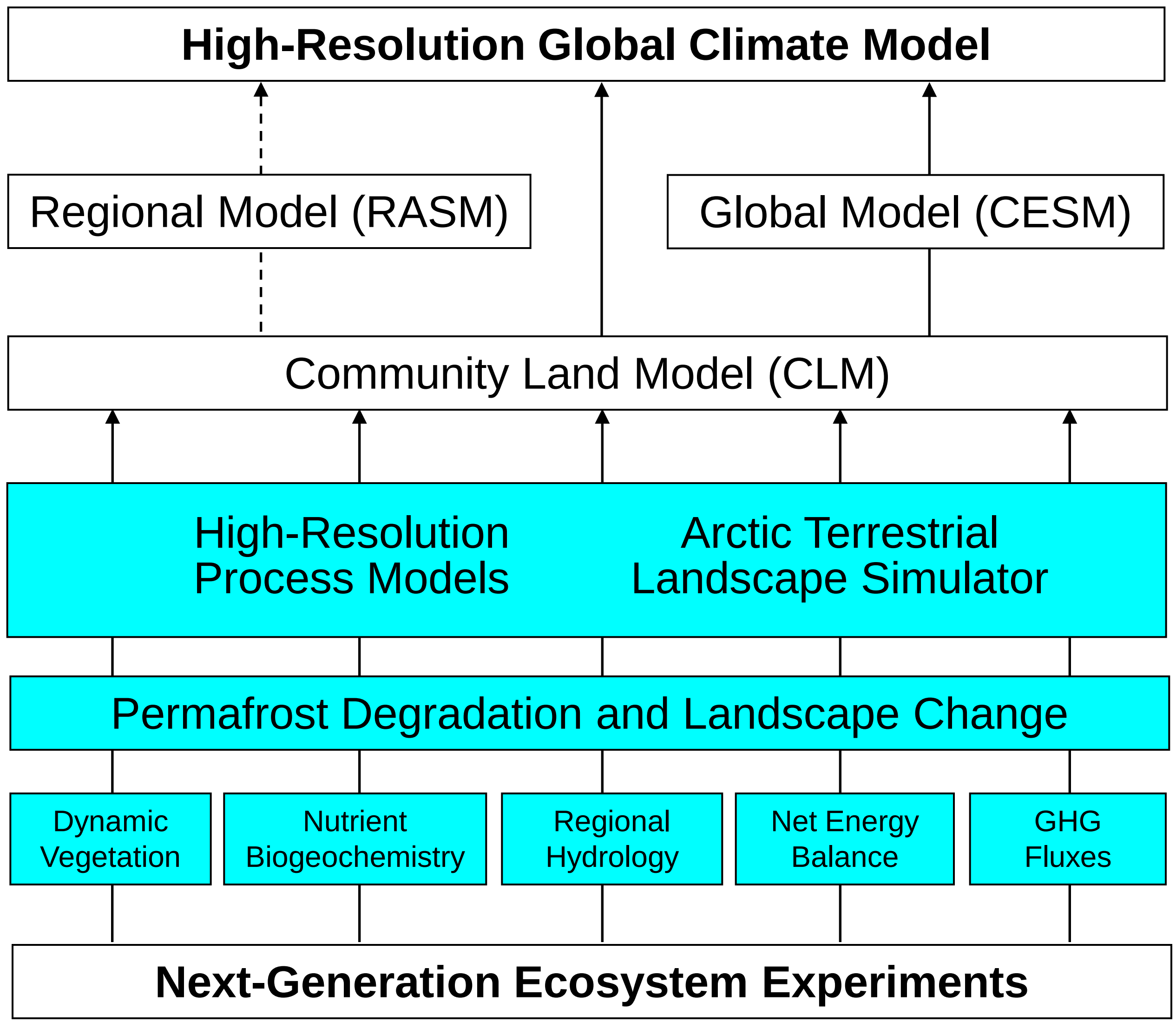
Rationale: Energy budgets are fundamental to climate feedbacks. Models must incorporate land-surface properties associated with changes in net energy balance due to vegetation dynamics and thawing permafrost.

Question: Will permafrost degradation result in a net positive feedback to the climate system through changes in albedo and energy exchange?

Task 1: Heat capacity and related thermal properties of permafrost; determination of ice fraction during freeze-thaw cycles; and multi-phase modeling in support of measurements.

Task 2: Measure components of land-atmosphere energy fluxes (e.g., latent heat flux, sensible heat flux, shortwave radiation); albedo in relation to vegetation surveys and snow cover dynamics.

Task 3: Remote-sensing approaches to reflectance characteristics, skin surface temperature, and heat capacities using MODIS-class sensors; Quickbird satellite and it successor Worldview; and leverage investments of the ARM Program at Barrow.


High-Resolution Global Climate Model
Regional Model (RASM)
Global Model (CESM)
Community Land Model (CLM)
High-Resolution Process Models
Arctic Terrestrial Landscape Simulator
Permafrost Degradation and Landscape Change
Dynamic Vegetation
Nutrient Biogeochemistry
Regional Hydrology
Net Energy Balance
GHG Fluxes
Next-Generation Ecosystem Experiments

Key Anticipated Outcomes from NGEE Arctic:

- Mechanistic understanding of important processes that drive changes in carbon cycle and net energy balance for ice-rich, permafrost-dominated ecosystems.
- New insights into surface and subsurface interactions that lead to changes in the physical landscape.
- An advanced high-resolution land surface model that uses process knowledge and concepts of landscape evolution to improve climate predictions at decadal to century scales.

http://ngee.ornl.gov