Next-Generation Ecosystem Experiments (NGEE Arctic) – Panel Review (August 4, 2011)

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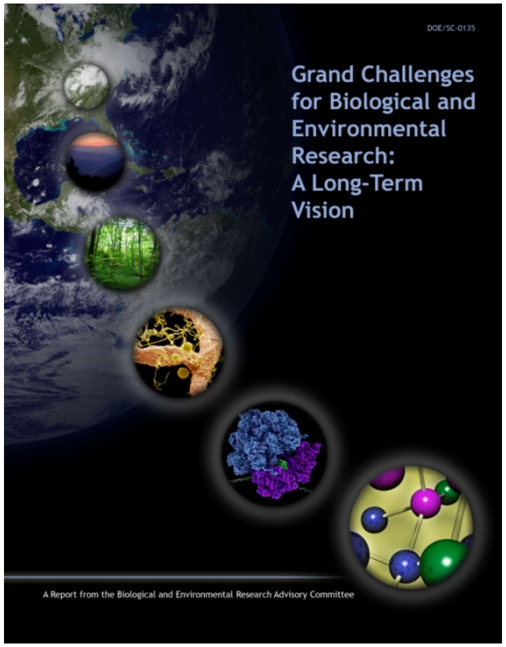
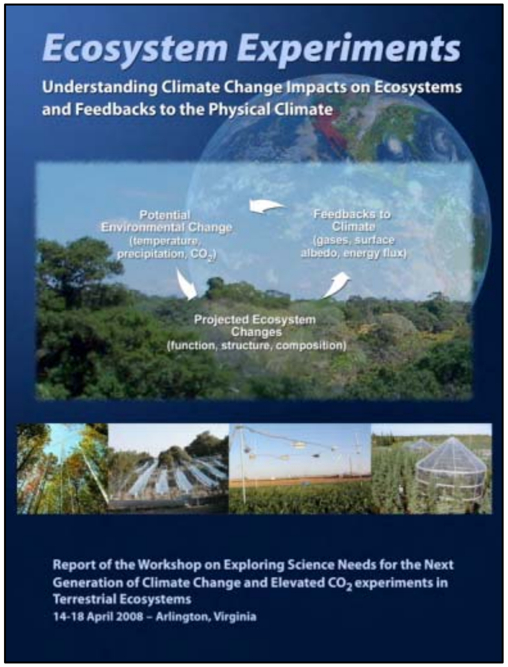
NGEE Arctic

Goal: Deliver scientific data that improves our understanding of the structure and function of terrestrial ecosystems in response to climate change; and that when represented in models lead to improved prediction of carbon cycle processes and net energy balance on Earth's climate.

- Integration across scales from subcellular to Earth system, drawing on plant and microbial biology, biogeochemistry, subsurface science, hydrology, terrestrial ecology, and modeling.
- Leverage insights from theory, observations, experiments, and process models.
- Interdisciplinary research that engages national laboratories and strategic university partners.
- Focuses on ecosystems that are globally important, sensitive, and poorly represented in climate models.





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 four components that determine whether the Arctic is, or in the future will become, a negative or positive feedback to climate:

Water – Complexity due to hydrology and surface and subsurface interactions

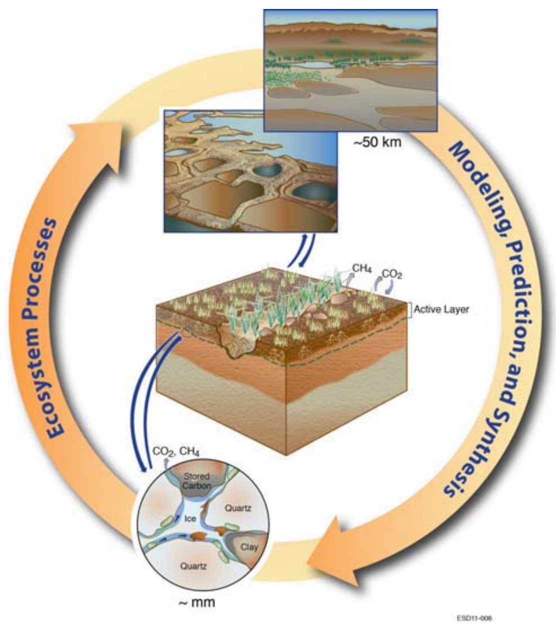
Nitrogen – Driver of large-scale changes in vegetation

Carbon – Microbial transformation of SOM to CO_2 and CH

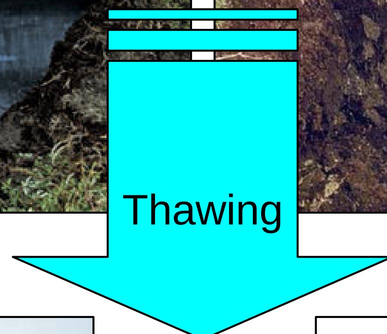
Energy – Permafrost dynamics and shrub expansion

Modeling – Integrate and extrapolate

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



Surface-subsurface interactions and the consequences for landscape evolution.



Thermokarst

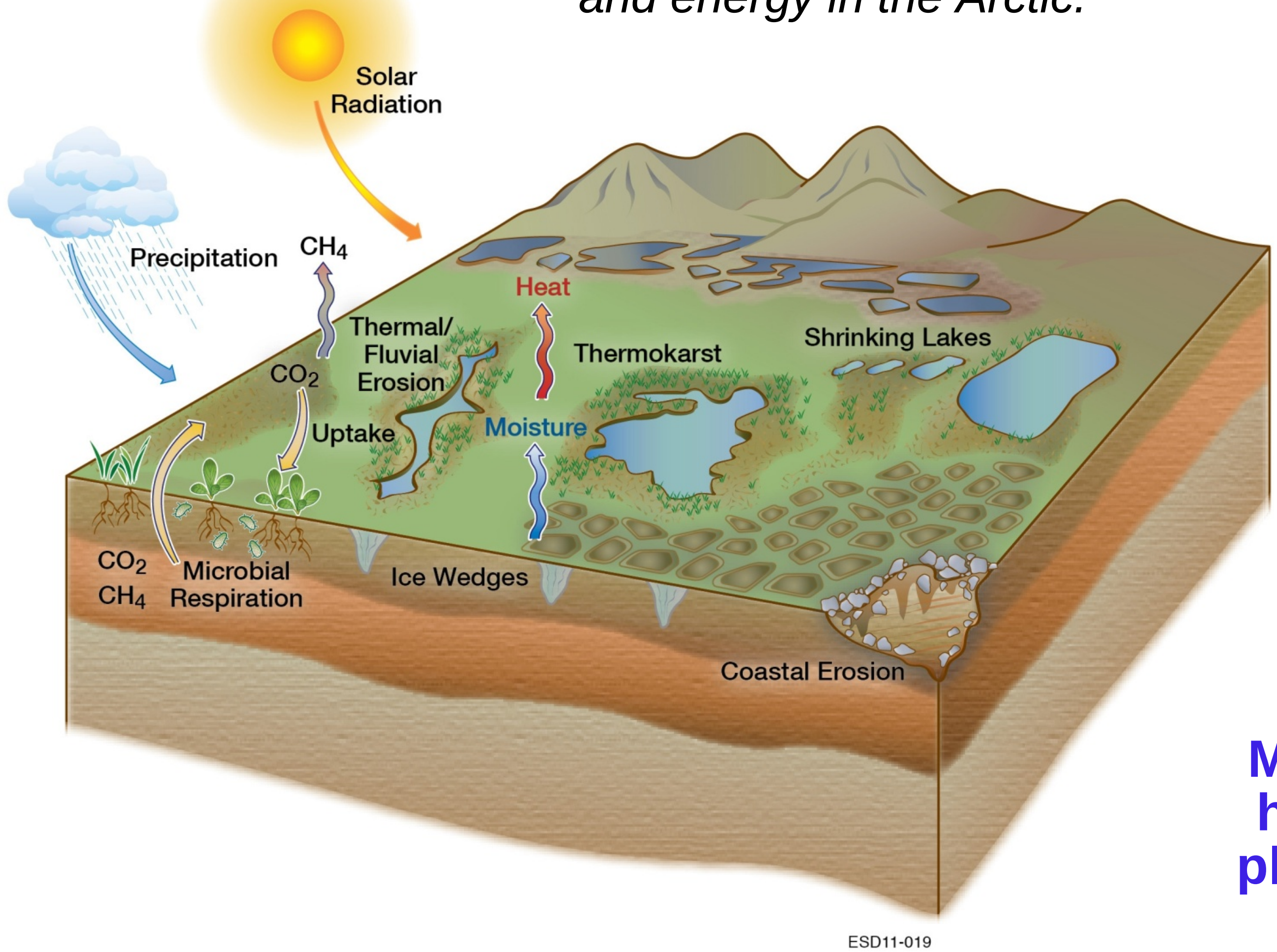
Thermal erosion

Transition from low-centered to high-centered polygons

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

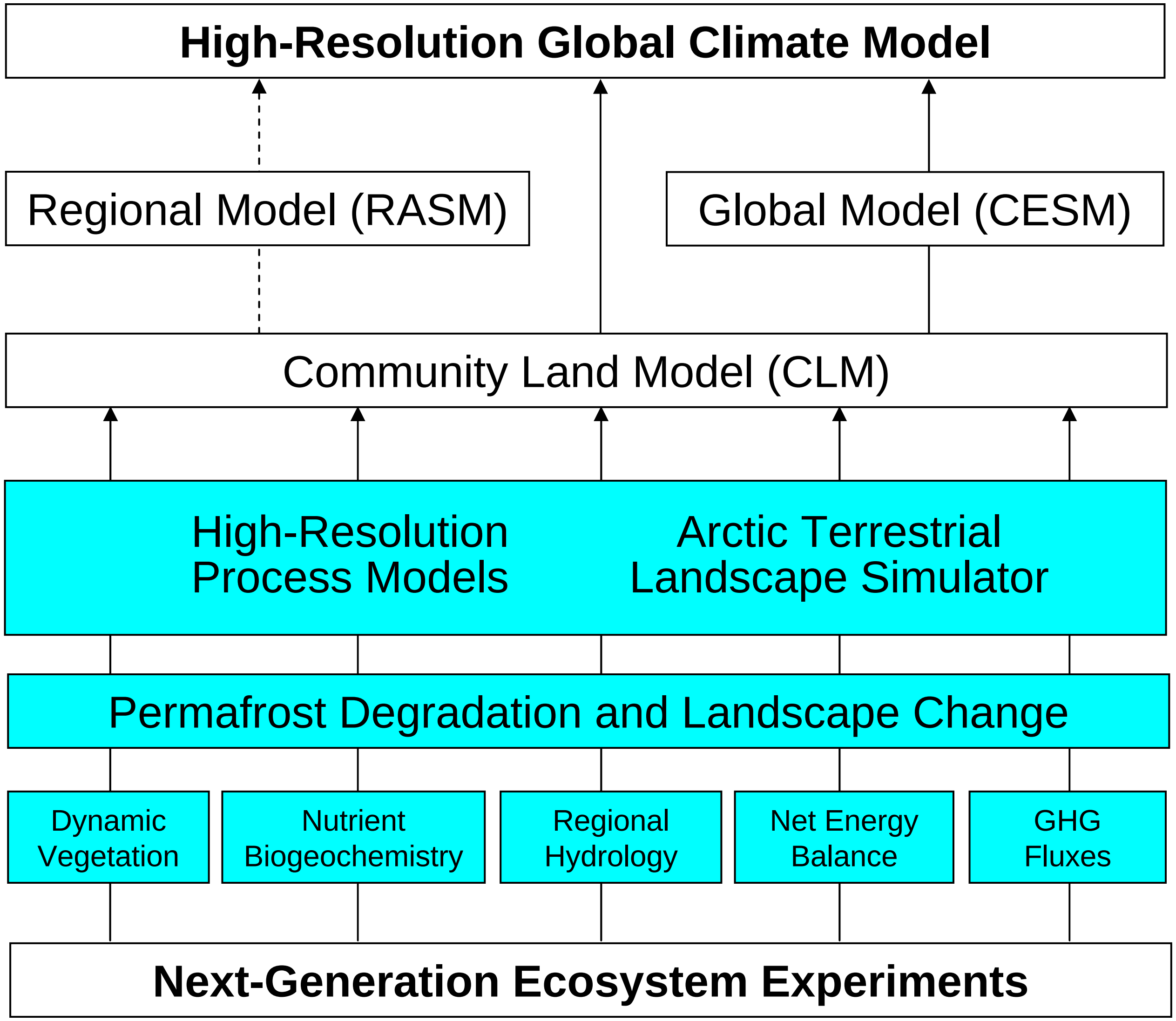
Landscapes in transition

...integrates water, nitrogen, carbon, and energy in the Arctic.

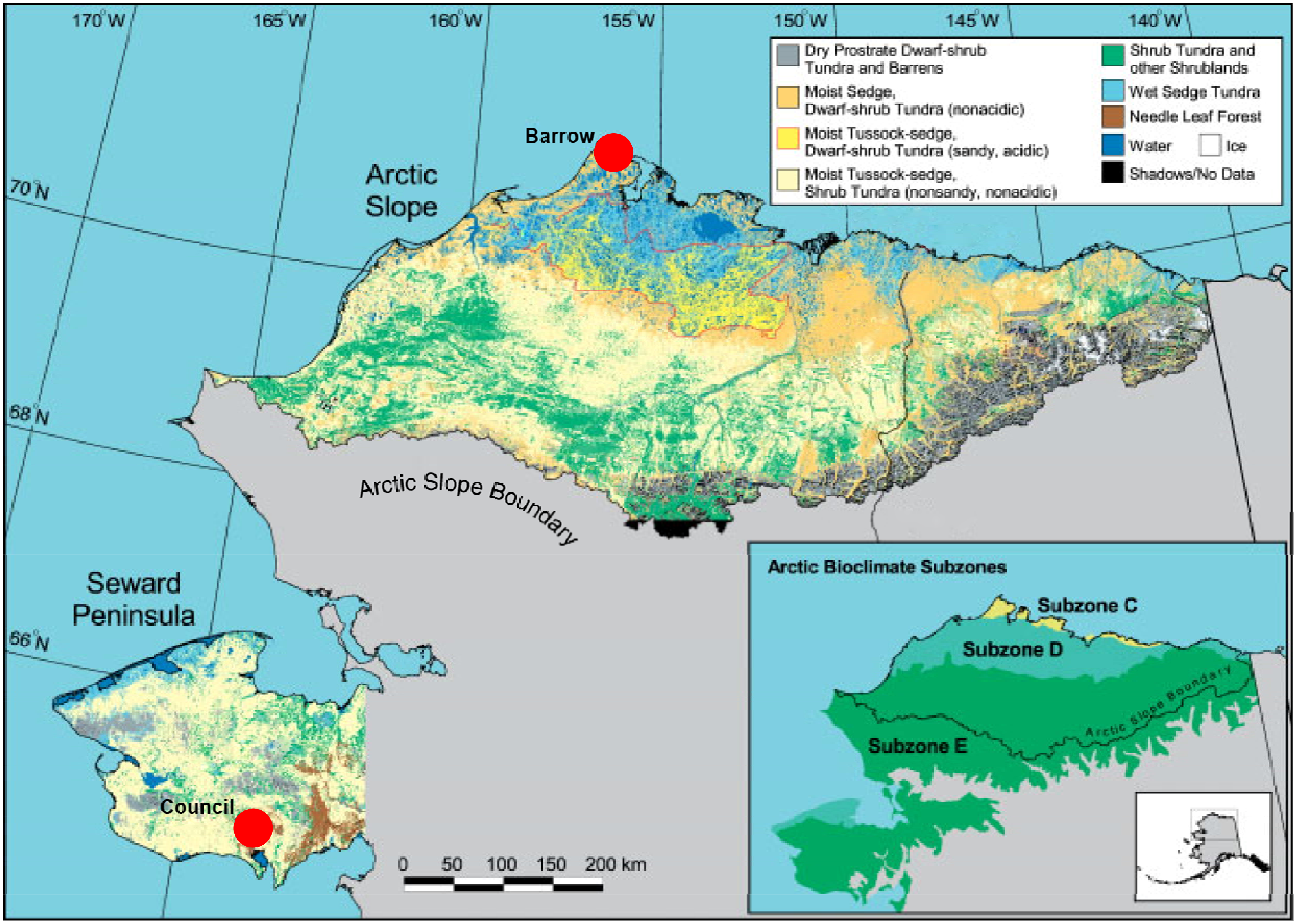


Must understand mechanisms that underlie the processes that control carbon and energy transfer in the biosphere.

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

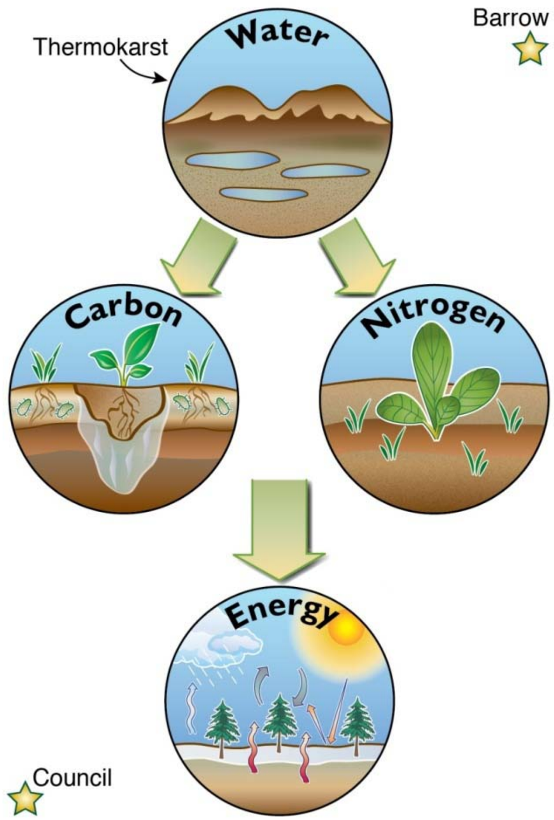

High-Resolution Global Climate Model
Regional Model (RASM)
Global Model (CESM)
Community Land Model (CLM)
High-Resolution Process Models
Arctic Terrestrial Landscape Simulator
Permafrost Degradation and Landscape Change
Dynamic Vegetation
Nutrient Biogeochemistry
Regional Hydrology
Net Energy Balance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

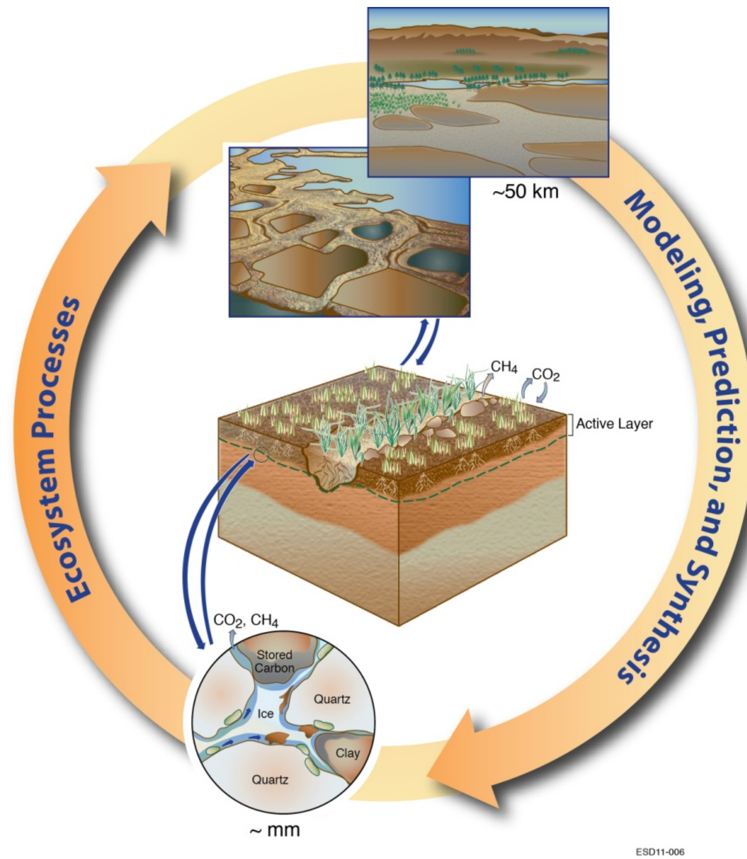
NGEE Arctic – Phase 1 Site Selection



Phase 1 Scientific Challenges

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





Water: Influence of permafrost degradation on hydrology
Nitrogen: Response of tundra plant community to changing resource availability
Carbon: Soil organic matter biodegradation mechanisms under varied environmental conditions
Energy: Impact of permafrost degradation on energy balance and climate forcing

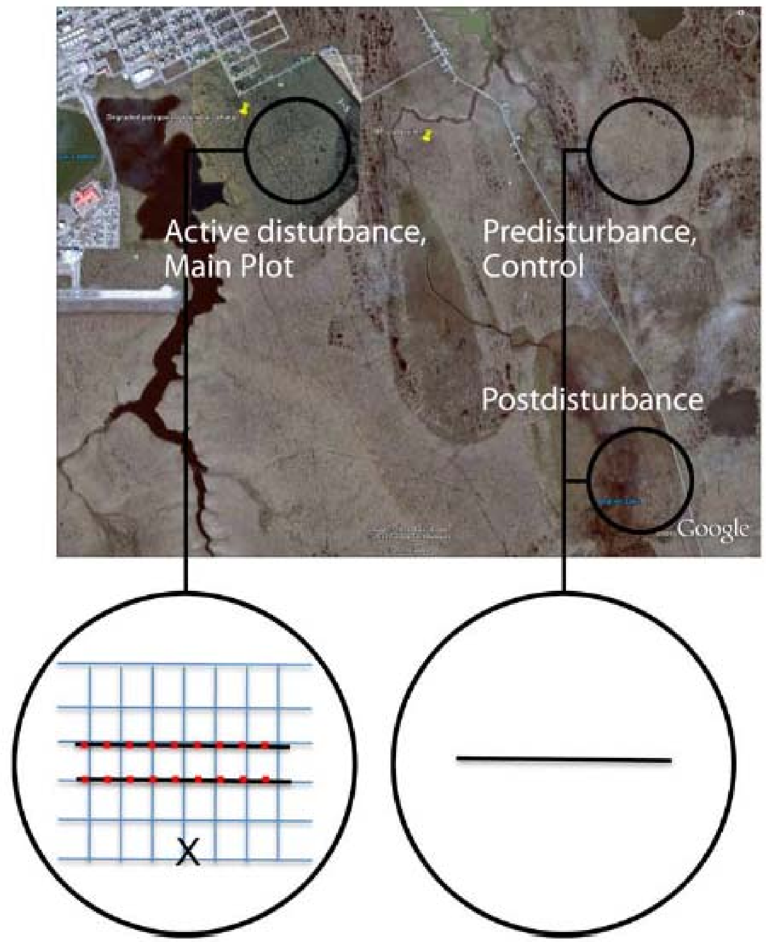
Field Strategy

Three plots will be chosen at both Barrow and Council Sites

Plots large enough to comprise set of similar thermokarst features

Plots chosen to **represent different states of permafrost degradation**

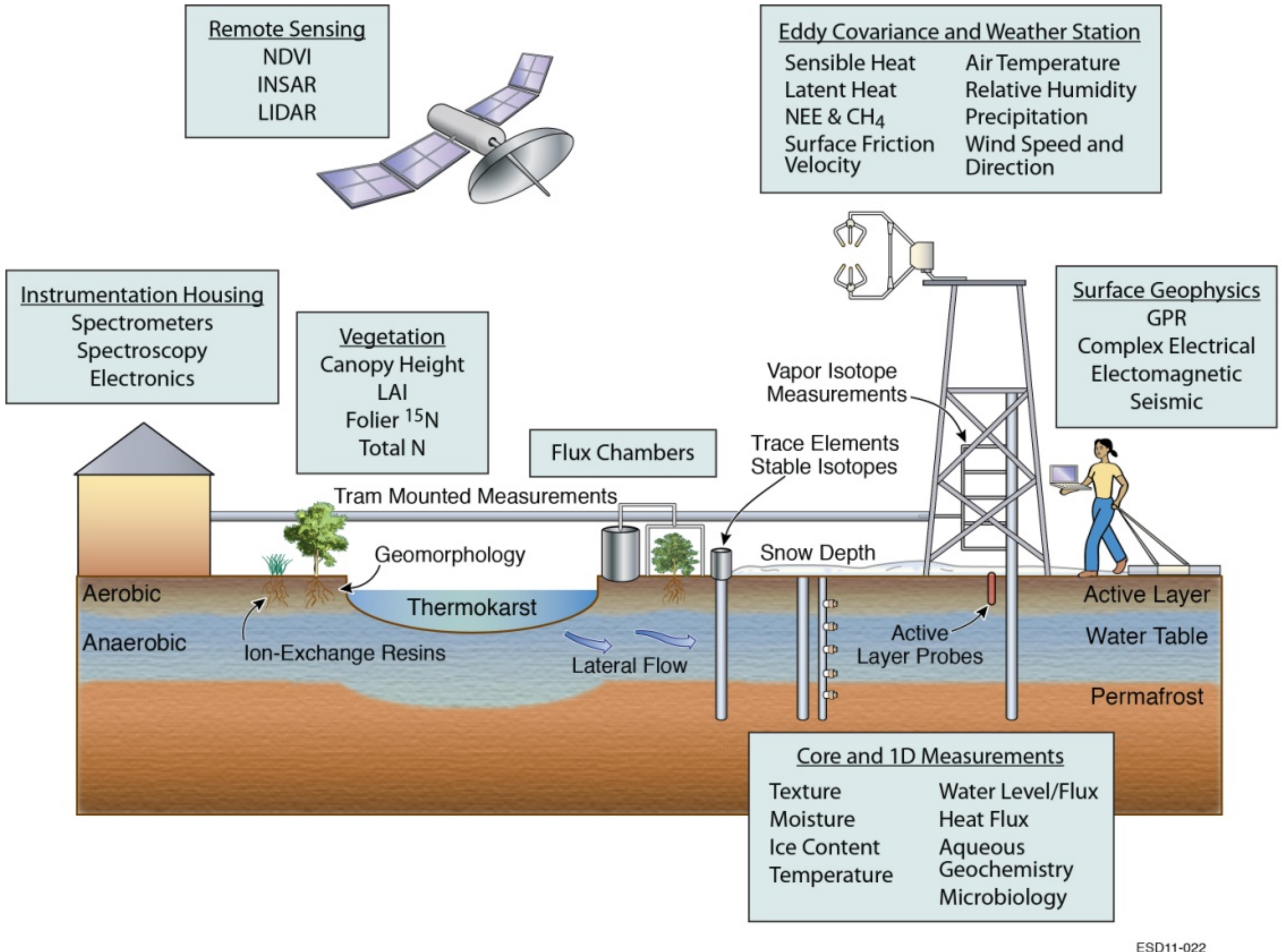
- Pre-disturbance
- Active disturbance
- Post or late disturbance



Eddy flux, met station, cores, coupled in situ continuous measurements of hydrology, nitrogen cycle and carbon cycle, genomics to geophysics, surveys

Met station, periodic surveys of hydrology, vegetation, soil properties (e.g., active layer) biogeochemistry

NGEE Site Characterization



1. **Choose Optimal Location** for Intensive Plot Studies
2. Install and maintain select plot instrumentation to provide **foundational datasets** (eddy covariance, micrometeorology, well network, etc.)
3. Provide conduit to **database repository**

Water Challenge

(Lead: Cathy Wilson)

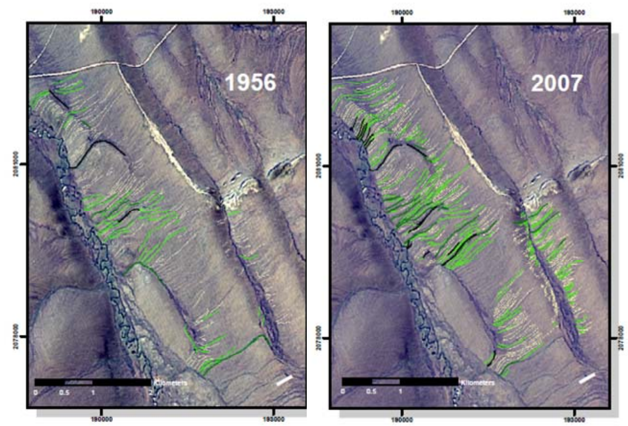
Overarching Goal: Identify and quantify **coupled hydrogeomorphic** processes occurring in an evolving Arctic system.

Rationale: Permafrost degradation is driving widespread hydrologic change and will have a cascading impact on the carbon cycle, vegetation response, and energy fluxes. Coupled hydrogeomorphic processes are not well understood or represented in models.

Konni Piel of AWI

Gradual transition from low to high centered polygons (years to decades)

Gradual formation of water tracks (near Toolik Lake)



Abrupt lake drainage (hours to days)

Objective W1: **Environmental Controls on Permafrost Degradation**

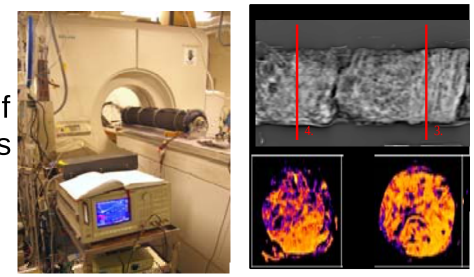
Quantify the environmental factors that **control the onset and rate of deformation**.

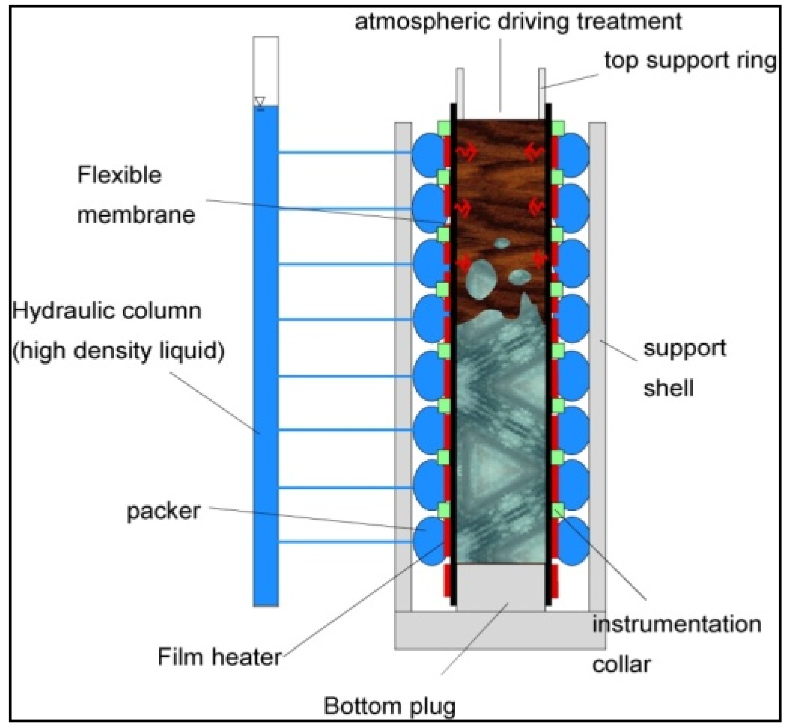
APPROACH: Controlled **freeze-thaw column** experiments (W1)

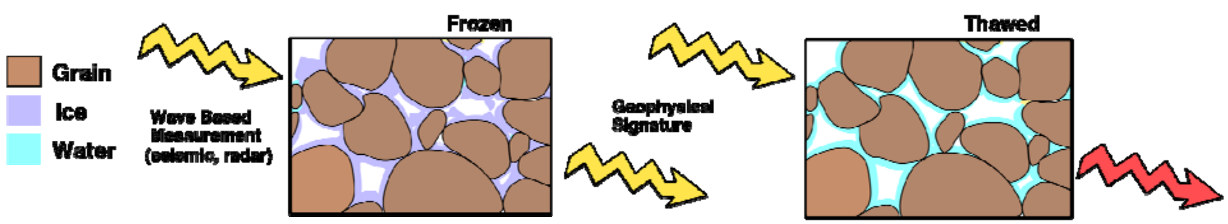
EXPECTED ACCOMPLISHMENTS:

- **Constitutive relationships for Arctic soils** needed to predict deformation as function of environmental parameters.
- Develop diagnostic geophysical signatures of permafrost dynamics

CT scan of Arctic cores

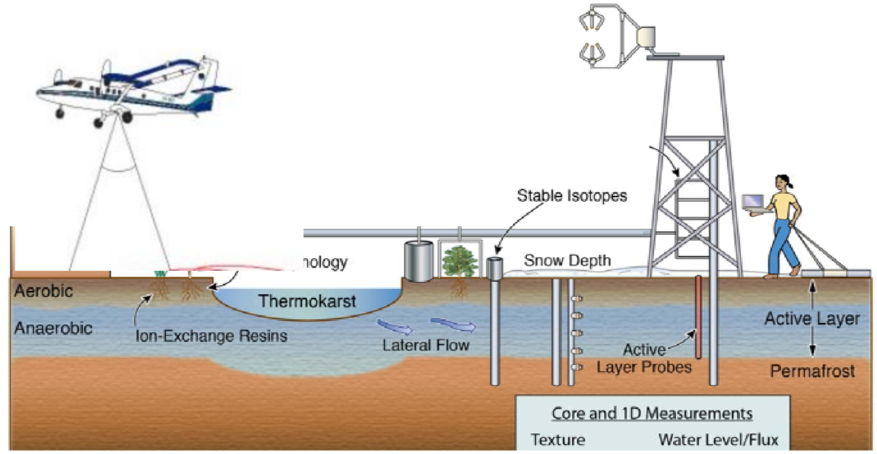






Objective W2: **How does permafrost degradation impact hydrological states, stocks, fluxes and pathways?**

Characterization across permafrost gradients of **hydrological parameters and pathways**

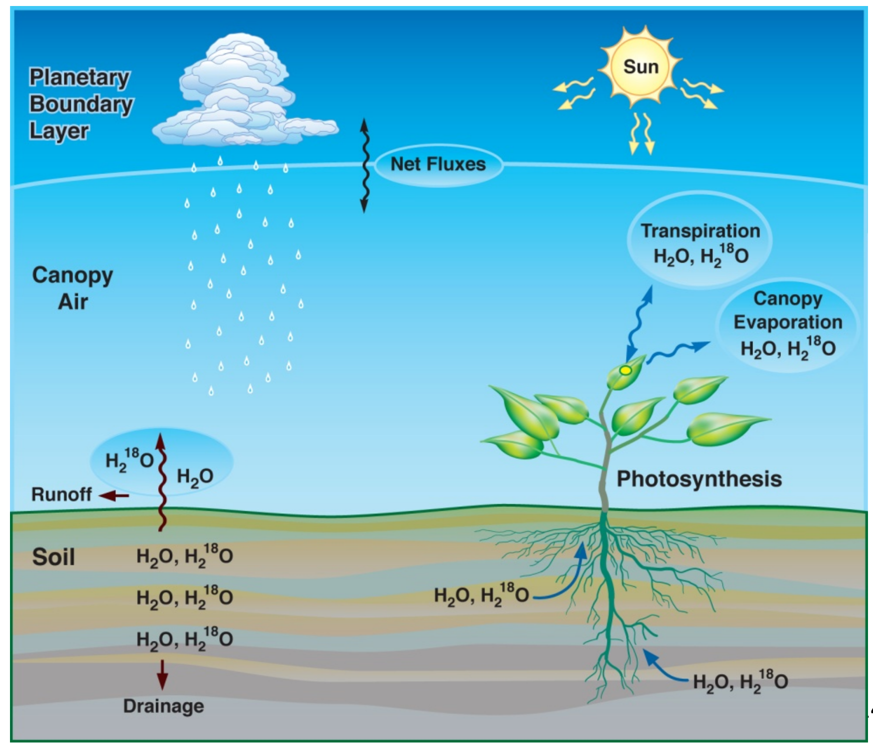


APPROACH:

- Runoff, water levels, soil moisture, ALT, soil texture, microtopography, geophysics, thermal states, **oxygen and hydrogen isotope measurements** (W2, W3)

EXPECTED ACCOMPLISHMENTS:

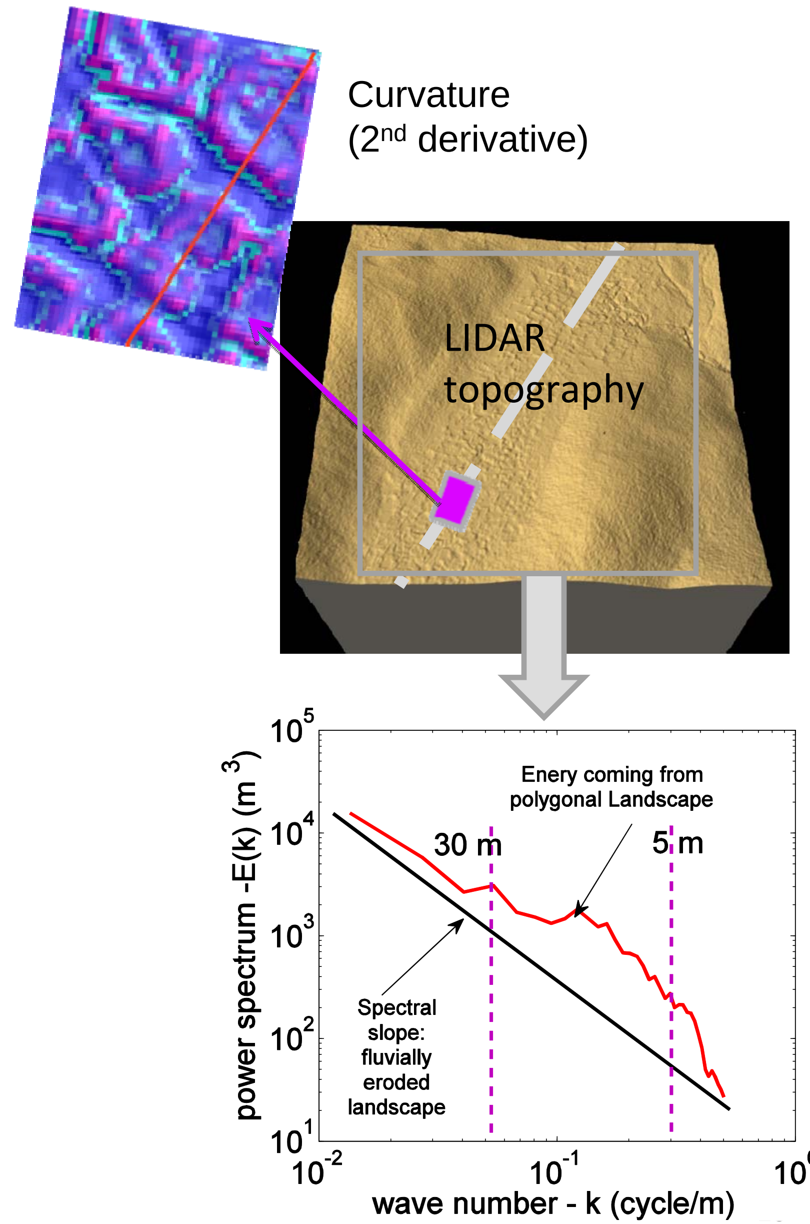
- Quantification of water isotope signatures of Arctic water cycle components.
- Use of isotopes to quantify the age and source of water and **lateral vs. vertical partitioning.**



Objective W3: **Can we quantify and predict landscape response to climate change?**

APPROACH:

- Automated techniques to **extract and quantify permafrost degradation features** from remote sensing data; (W5, W7);
- Thermo-hydro-geomechanical **code development** (W4)



EXPECTED ACCOMPLISHMENTS:

- Establish **new metrics** to classify degree of landscape degradation
- Initialization of **thermo-hydro-geomechanical model**
  - *A necessary step toward a Process-Resolving Arctic Simulator*

Nitrogen Challenge

(Lead: Rich Norby)

Rationale

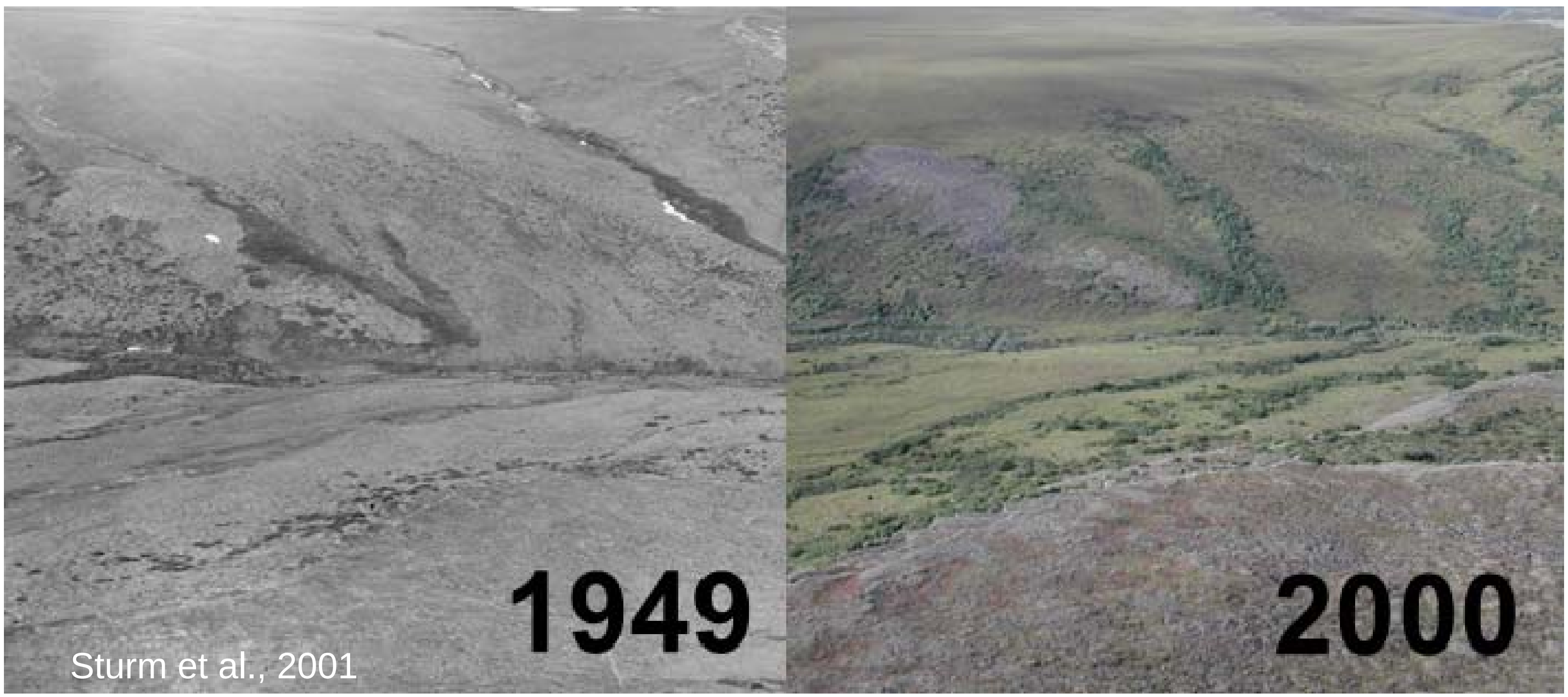
•Plant communities in the warming Arctic are changing

•Nitrogen availability is a key parameter driving that change

•Special considerations for nitrogen cycling in Arctic environment

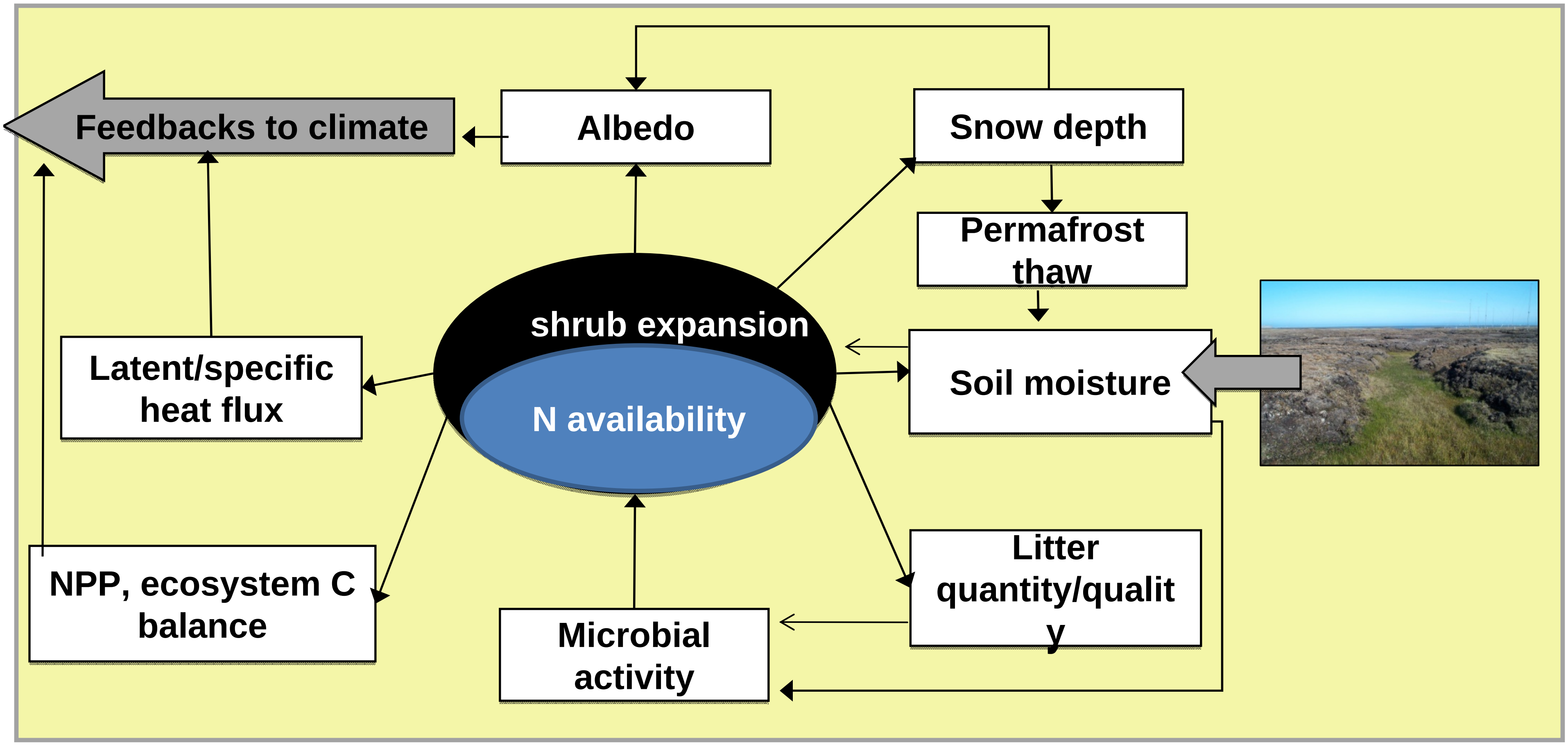
•Thermokarst gradients will alter soil moisture and nutrient availability, creating habitat differentiation

•Lack of mechanistic process understanding and simulation capability leads to high uncertainty



Sturm et al., 2001

Goal: Identify the mechanisms that drive **structural and functional responses** of the tundra plant community to a **changing resource availability** to **enable predictions** of the consequences of those responses to climate change

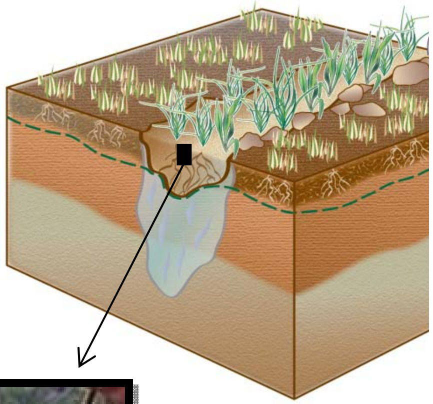


Nitrogen Objective and Approach

Quantify N cycling and its impact on plant community dynamics through working across scales

Lab Scale Tasks

Using Samples Extracted across Permafrost Gradient



APPROACH:

- Quantify potential **N cycling rates** using ^{15}N method in relation to geomorphology, active layer soil C content, and plant community composition (N1)
- Controlled experiments on the influence of **plant detritus** input on amino acid and inorganic N pool sizes (N2)

EXPECTED ACCOMPLISHMENTS:

- Identify **environmental controls on N transformations** of Arctic soils

N cycling via ^{15}N pool dilution

Plot Scale Tasks

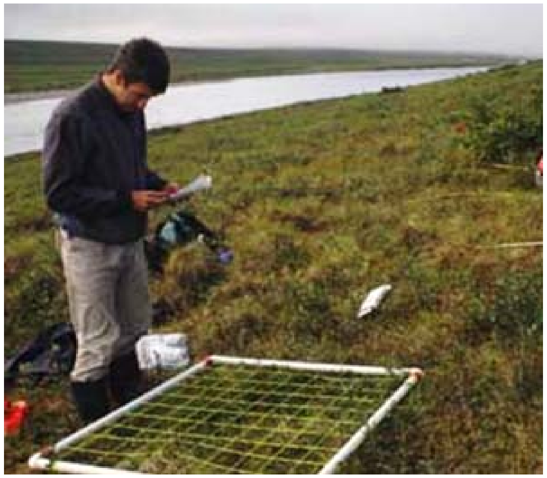
Sampling Across Permafrost Gradients

APPROACH:

- Characterize plant communities (N3)
- Seasonal patterns of nitrogen availability using buried ion-exchange resins (N4)
- Nitrogen acquisition strategies and utilization (N5, N6)
- Spectral characterization of leaves (N7)

EXPECTED ACCOMPLISHMENTS:

- Understanding of how soil moisture and N availability impact **structure and function of plant community**.
- **Plant functional types** related to N uptake/assimilation and plant performance that can inform ArcVeg.



Plant Community structure (number, type, biomass, rooting distribution, etc)

Measurements of foliar N and reflectance characteristics of vascular and non-vascular plants

Landscape Scale Tasks

Extrapolate leaf and canopy N along Barrow-Council transect

APPROACH:

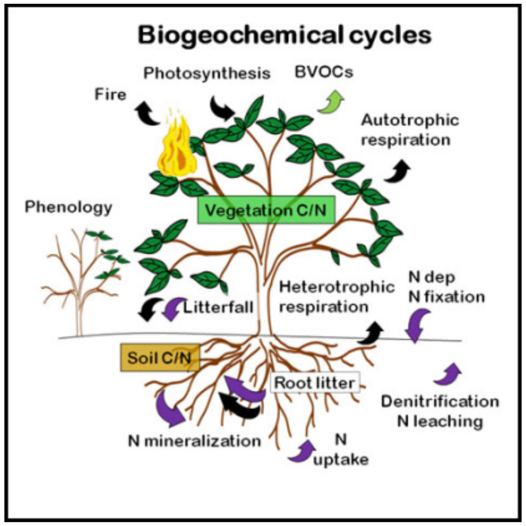
- Use knowledge of mechanisms and remote sensing to **estimate N and GPP along transect;** compare to geomorphology and tower-based measurements (N9,N10);
- **Simulate interplay between N availability and plant growth** (N10)

EXPECTED ACCOMPLISHMENTS:

- Methodology for **landscape-scale assessment of N**
- Assessment of impact of **N availability on vegetation dynamics** at landscape scale

Aircraft imaging spectroscopy for N concentration + NDVI for LAI to estimate fine-scale GPP

Interplay between N availability and plant growth and consequences: ArcVeg and CLM



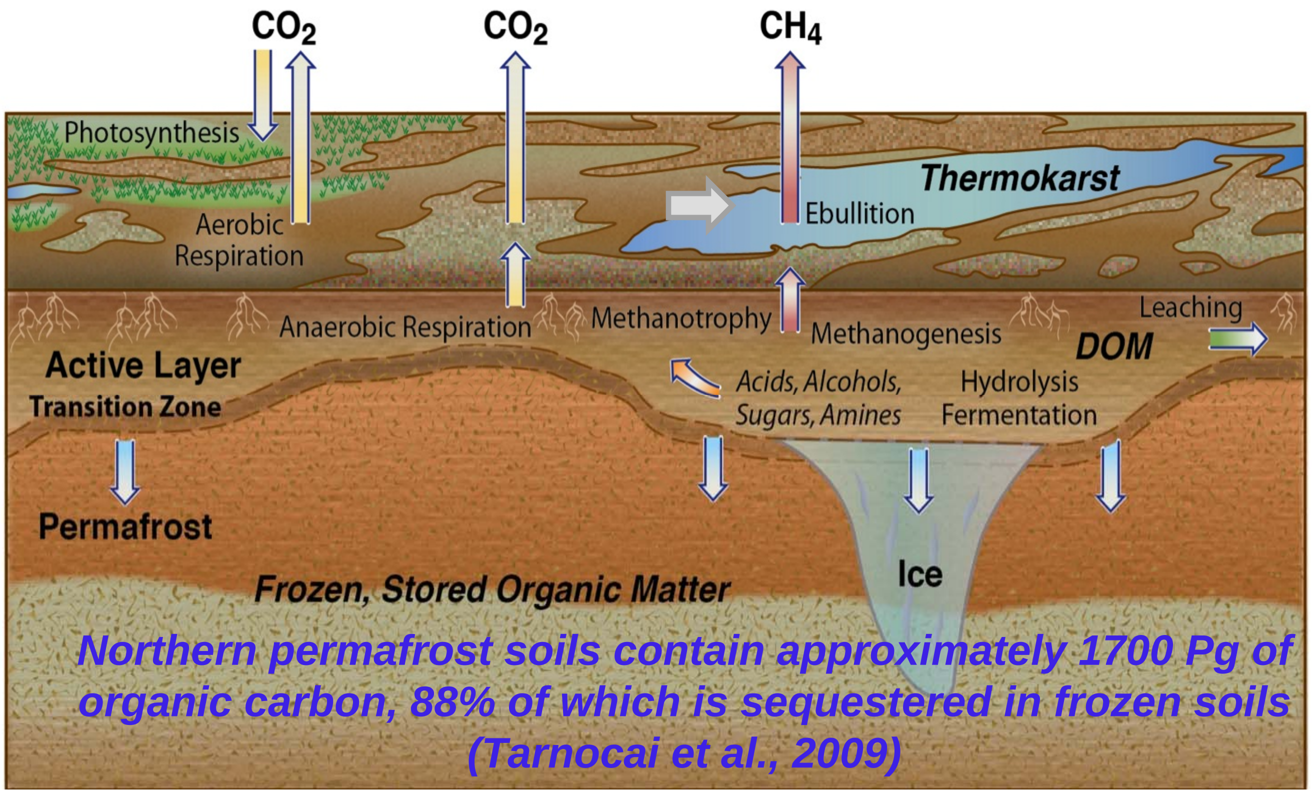
Carbon Challenge

(Lead: David Graham)

Rationale: Permafrost thawing will expose buried carbon, making it susceptible to biodegradation and potentially causing the terrestrial ecosystem to transition from a GHG sink to a source

Microbial decomposition occurs within a deepening active layer;

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



Northern permafrost soils contain approximately 1700 Pg of organic carbon, 88% of which is sequestered in frozen soils (Tarnocai et al., 2009)

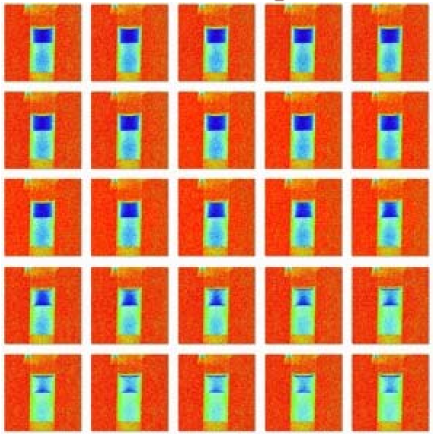
Goal:

Quantify organic matter biodegradation rates, mechanisms, and key controls under various environmental conditions

Objective C1: **Control of water content, water phase and temperature on organic matter degradation?**

How do **liquid water films** and **freeze-thaw processes** influence microbial activity and GHG production?

Neutron imaging: ionic species distribution in a freezing sediment column

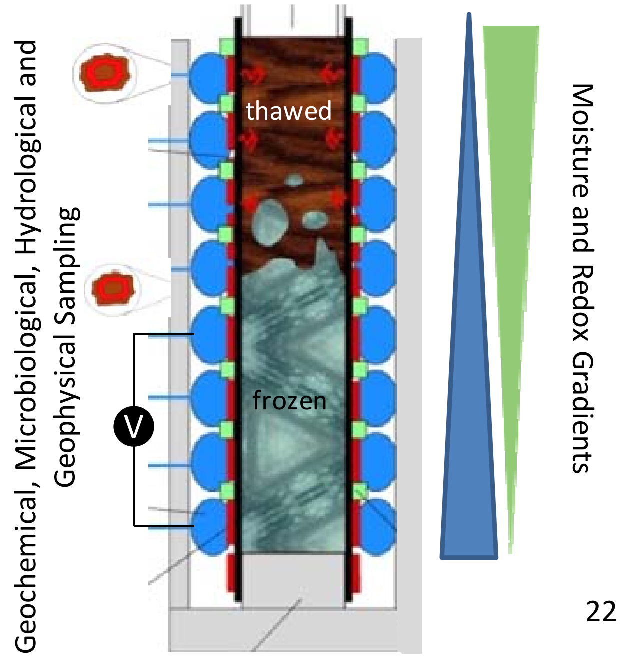


APPROACH:

- Pore Imaging (Neutron imaging, synchrotron microtomography - C1)
- **Freeze-thaw column** experiments (C2)

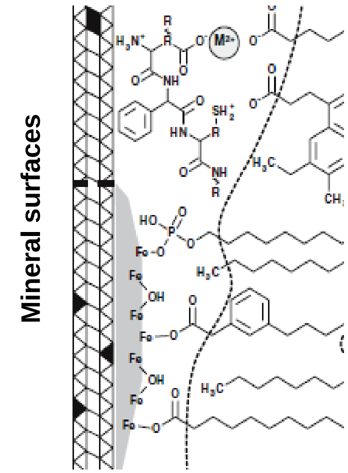
EXPECTED ACCOMPLISHMENTS:

- Quantify interactions between **temperature, phase, water content, and aqueous geochemistry** impact microbial activity and GHG production.
  - ➢ Vertical variability
  - ➢ Iteration with **reactive transport modeling** and CLM



Objective C2: **How do soil carbon structure and interactions affect degradation of soil organic matter?**

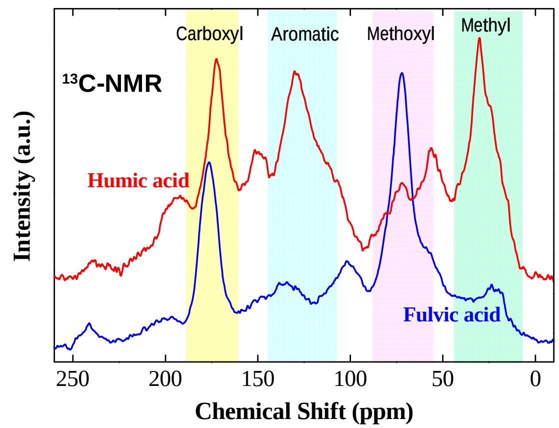
What is the relative influence of **organic carbon chemistry** and **soil C–mineral associations** on soil organic carbon recalcitrance?



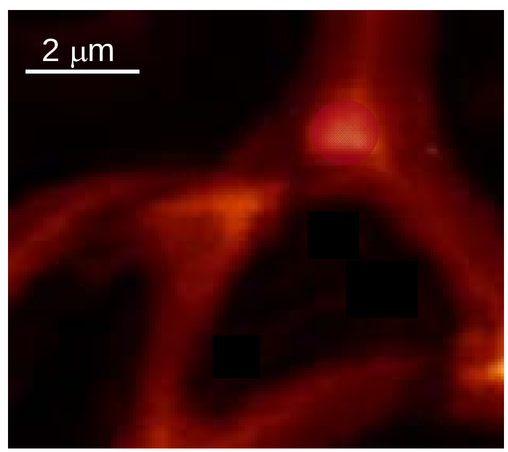
Kleber et al. Biogeochem. 2007

APPROACH:

- **Monitor changes in organic structure using spectroscopy** (NMR, fluorescence, FTIR) analysis of organic matter during warming (C6);
- **Measure how organic C is bound to minerals** (using Micro-Raman and FTIR) (C8)



NMR spectroscopic analyses for investigating C structures and signatures



Micro-Raman imaging: C on mineral surfaces

EXPECTED ACCOMPLISHMENTS:

- Identify **relative control** of chemical and mineralogical interactions on C availability and turnover rate.

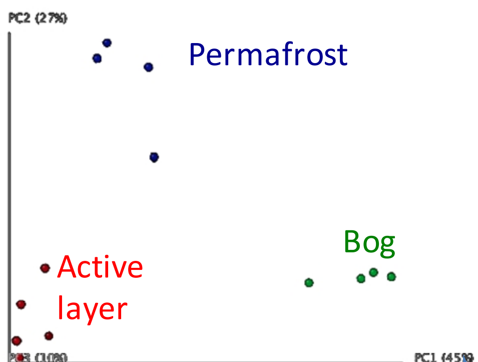
How do **changes in microbial community** structure and function affect degradation (Task C7)?

Approach & Expected Accomplishment:

- Initiation of Molecular Analysis Pipeline for Permafrost Microbiomes
- Development of molecular profiles of changes in microbial communities and enzymatic activities due to permafrost thawing

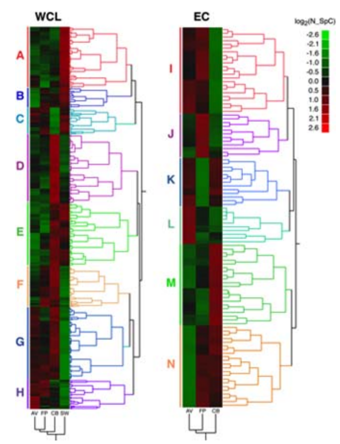
Pipeline for Molecular Analysis of Permafrost Microbiomes

C7

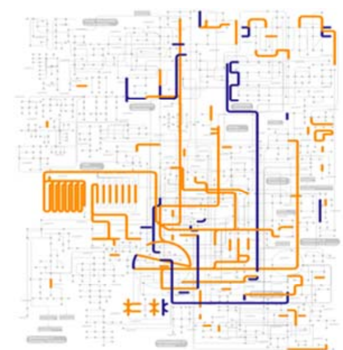


Phylotyping

Draft genomes of novel uncultivated microbes



Metaproteomics & Metatranscriptomics

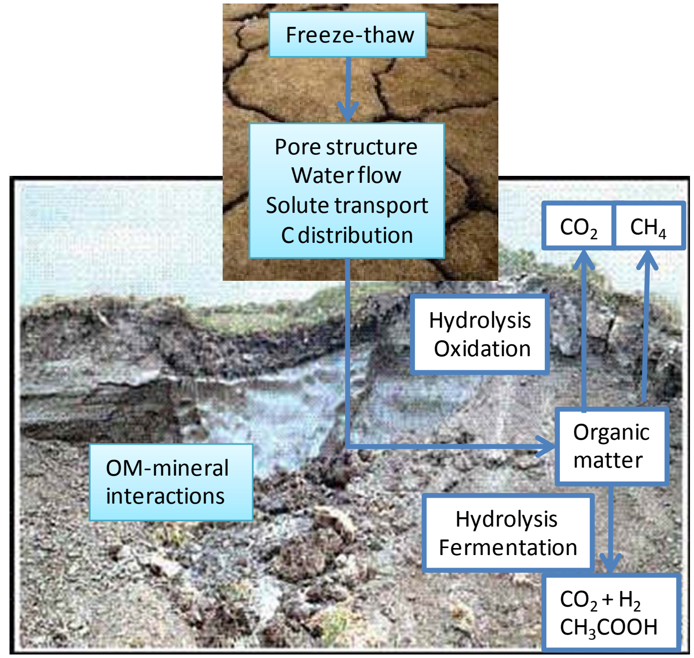


Metabolomics & Reaction Networks

Variability of Biodegradation Mechanisms & GHG Production

Sampling Across Permafrost Gradients

- How does **subsurface variability** affect biodegradation mechanisms and rates?
- What is the **residence time** of organic material in permafrost soils?



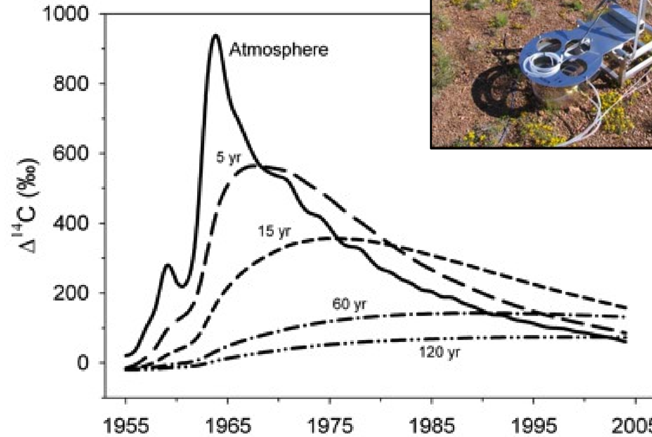
Approach:

- Characterize **spatial variability of** (hydro)**geochemistry,** including OM, DO, ORP, pH, ionic composition, geophysics (C3)
- **GHG sampling** using soil gas tubes, chamber, and eddy covariance (C4)
- Radiocarbon and ^{13}C **isotopic analysis** (C4)

CH_4 and CO_2 fluxes

Expected Accomplishments

- Insights into how **permafrost degradation** affects biodegradation mechanisms
- GHG integration across scales
- Isotope assessment of the **depth of CO_2 and CH_4** production and carbon source



Soil carbon residence time using ^{14}C (Torn, 2009)

Energy Challenge

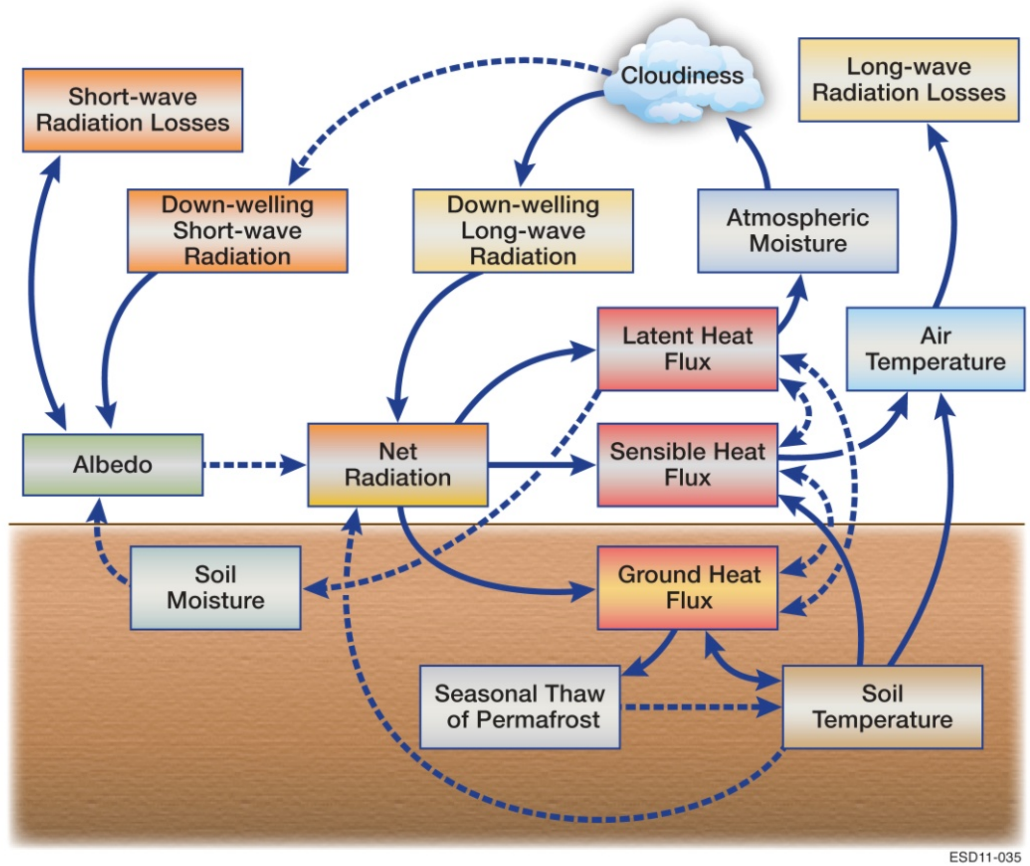
(Lead: Margaret Torn)

Science Goal: Quantify the impact of permafrost degradation on ecosystem albedo, energy partitioning, and total climate forcing (from changes in albedo and greenhouse gas fluxes).

Rationale:

- Potential for very large changes in albedo and energy fluxes in Arctic;
- Change in energy partitioning below ground will affect water and carbon;
- Lacking is a predictive understanding of important energy and climate forcing processes, including the *rate* of change also *how much* change occurs.

First study at high latitudes to use coupled data-model integration to explore both **energy and GHG feedbacks** and **surface and subsurface** energy phenomena at **multiple spatial and temporal** scales.



Drawn from Eugster et al. 2000

How does permafrost degradation alter energy balance at different scales?

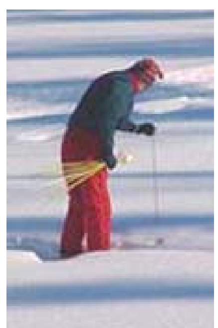
Objective E1: Quantify **albedo and energy partitioning** across permafrost degradation gradients and **scales**.

– Shrubs, soil moisture, surface water (incl. thermokarst lakes), snow cover

APPROACH: Multi-scale suite of field and remote sensing observations coupled with fine scale modeling. Tasks: E1, E2, E5.

EXPECTED ACCOMPLISHMENTS: Estimated spatial and temporal variations in energy terms

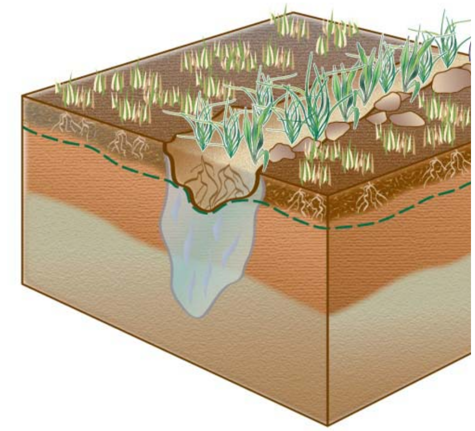
- Snow depth
- Ground heat fluxes
- Soil Moisture
- Radiometers -Albedo
- Eddy Covariance Tower - Latent and Sensible heat
- Remote Sensing



Will shrub establishment limit the rate of albedo change?

Objective E2a: Assess the role of vegetation change on energy feedback across our transects.

- Relative contribution of **emergence** vs. **new shrub establishment** on energy feedbacks



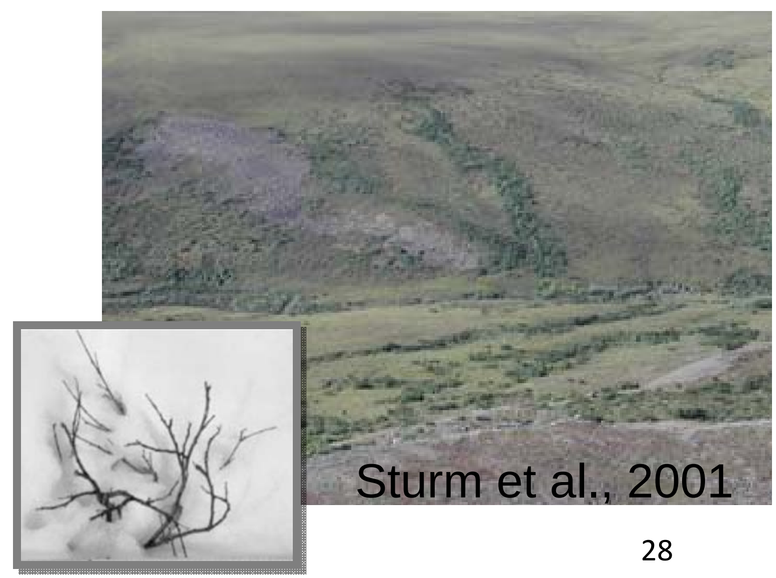
APPROACH:

- Measure spectral and biophysical properties of vegetation. Survey species and shrub densities.
- Translate in situ and remote sensing results to reflectance parameters for Arctic plant functional types (PFT)

  Tasks: E3, E4, E5, N3, M1

EXPECTED ACCOMPLISHMENTS:

- Assess the relative impact of vegetation-mediated changes on energy balance
- Reflectance parameters for Arctic-specific PFT for input into CLM

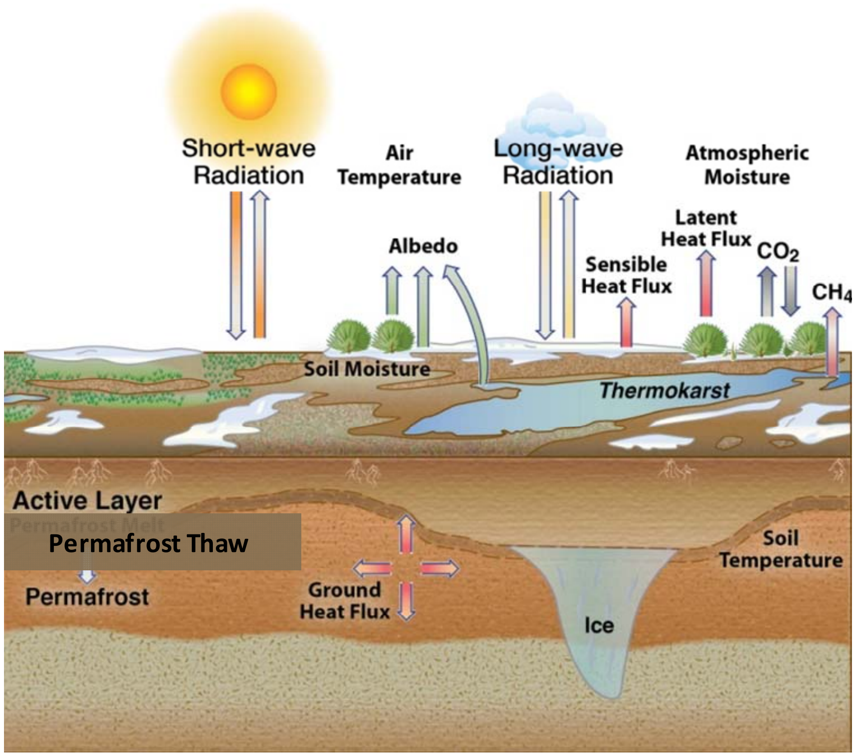


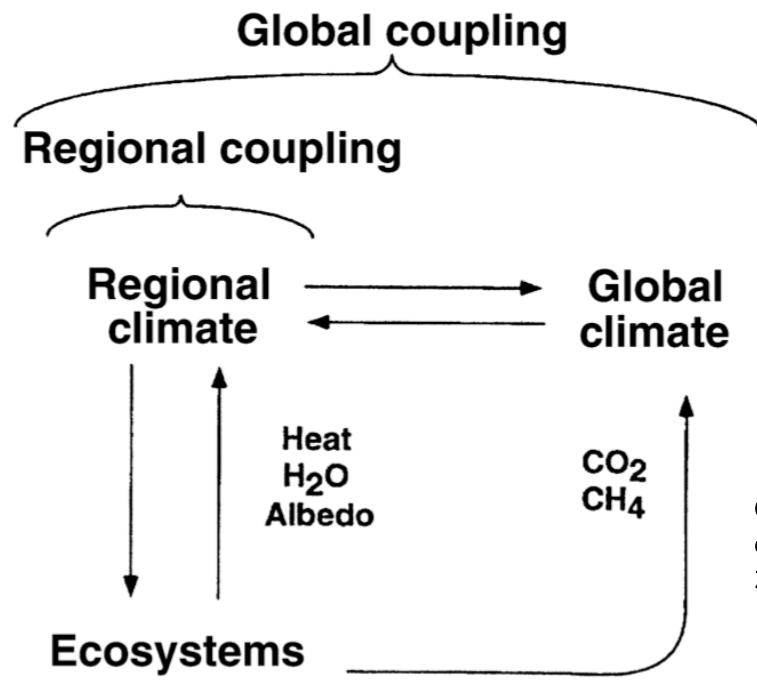
Sturm et al., 2001

Arctic climate-ecosystem feedbacks:
How big, how, and how fast?

Objective E2b: Estimate **total ecosystem climate forcing** associated with permafrost degradation and compare the contributions of **energy** vs. **greenhouse gas fluxes** over time

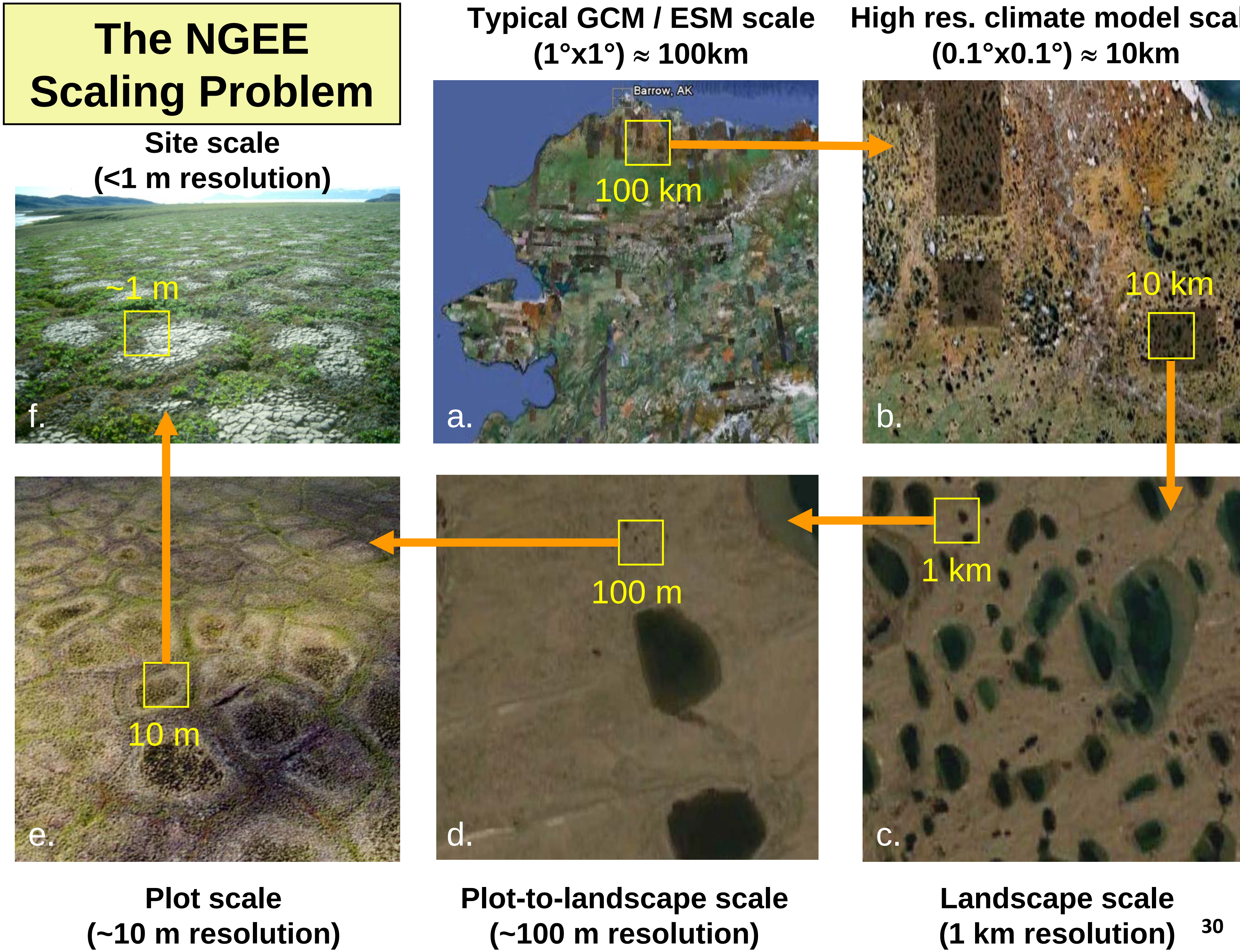
APPROACH: Use comprehensive and multi-scale NGEE observations of climate forcing and data/model integration for future predictions. (W,N,C findings and E6, E7, E8)



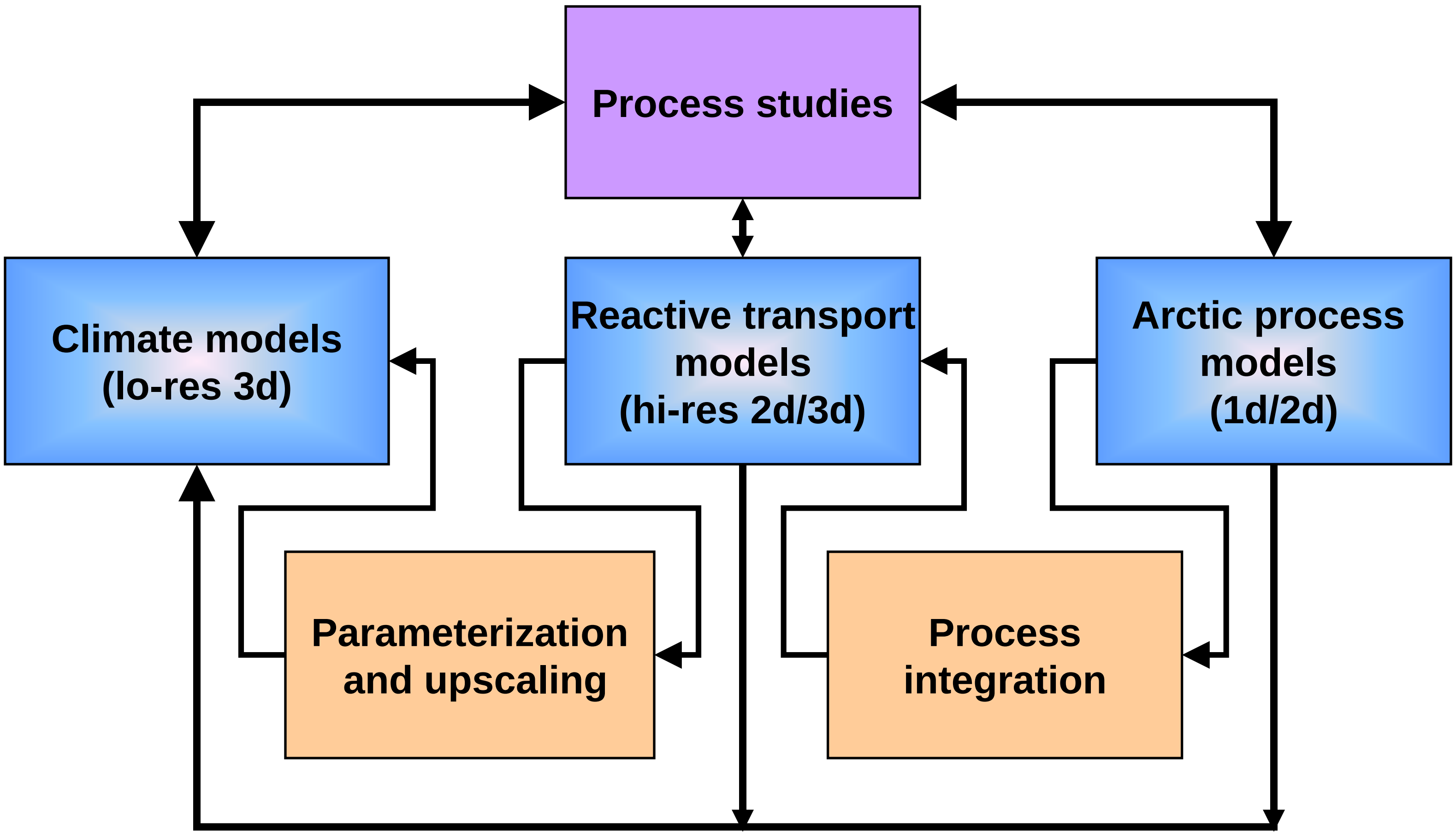


Chapin et al. 2000

The NGEE Scaling Problem



NGEE modeling: knowledge synthesis, integration, and scaling



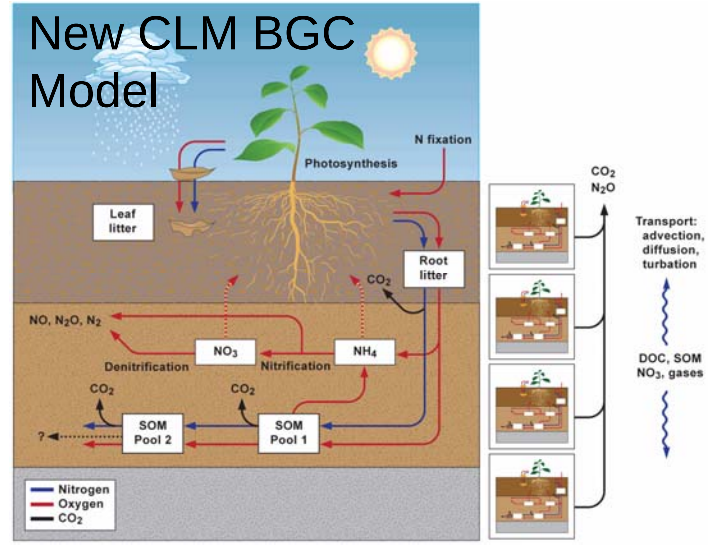
Phase 1 NGEE Modeling Approach

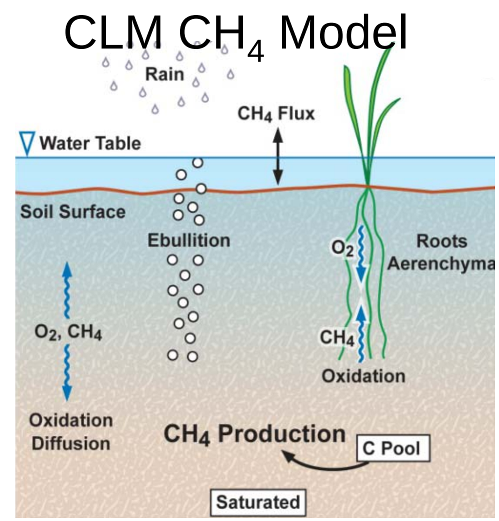
- Objective 1: Evaluate the skill of existing models
  - Exercise three classes of models across multiple spatial scales
  - Use NGEE observations to test, constrain, and improve model structures and parameterizations

- Objective 2: Establish foundation for process-resolving Arctic Land Simulator
  - Explore scaling approaches
  - Design a framework that integrates best capabilities of existing models and fills existing gaps in processes and scales.

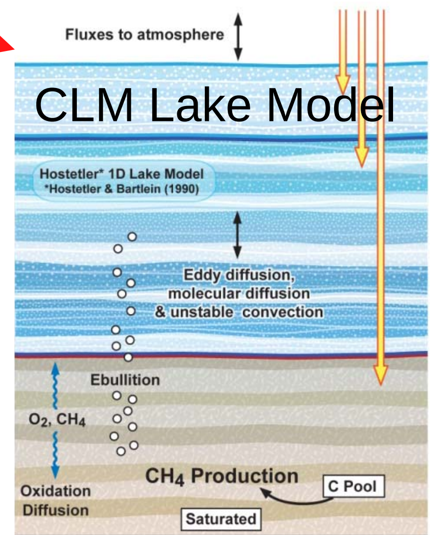
Existing Modeling Tools

- **Climate-scale models**: CLM
  - **Capabilities**
    - Water and energy balance, freeze/thaw dynamics
    - Perched water table
    - Coupled carbon and nutrients
    - Vertical BGC & transport
    - Cryoturbation
    - New modules for lakes and CH_4
  - **Shortcomings**
    - Poor representation of Arctic vegetation
    - Hydrology not related to local elevation
    - Poor representation of soil chemistry
    - Geomorphic response not represented





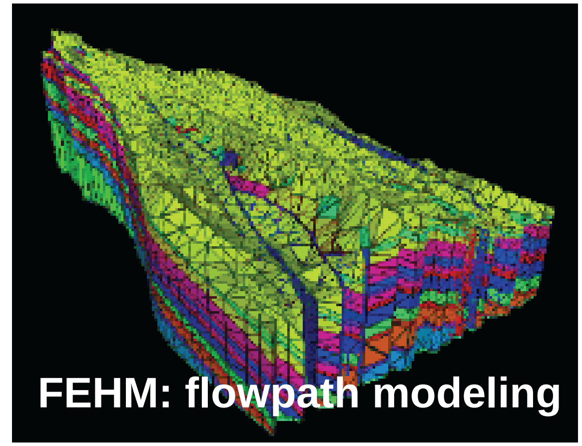
Riley et al. 2011



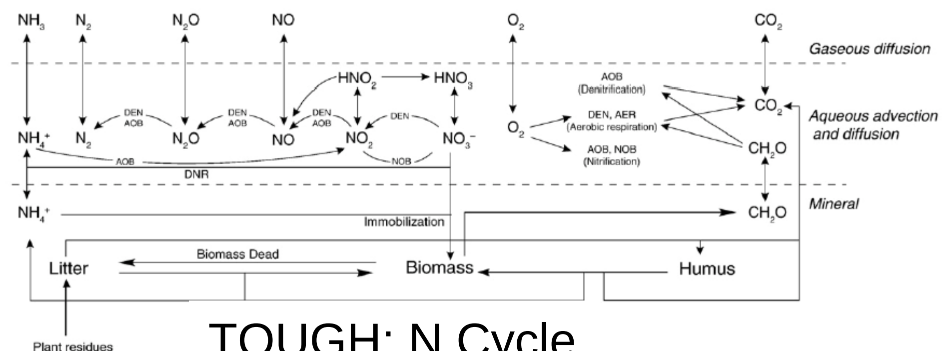
Subin et al. 2011

Existing Modeling Tools (cont'd)

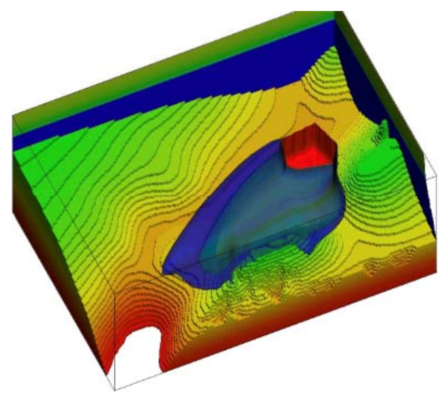
- **Reactive transport models:** ARCHY, TOUGH, FEHM, PFLOTRAN
  - **Capabilities**
    - 3D multi-phase, multi-species mass and energy transport
    - Support for adaptive mesh
    - Previous applications in permafrost
    - Successful examples of coupling
  - **Shortcomings**
    - Mass wasting and surface deformation poorly captured
    - No treatment of cryoturbation
    - Not explicitly coupled to surface hydrologic network



FEHM: flowpath modeling



TOUGH: N Cycle



PFLOTRAN: Subsurface Simulations

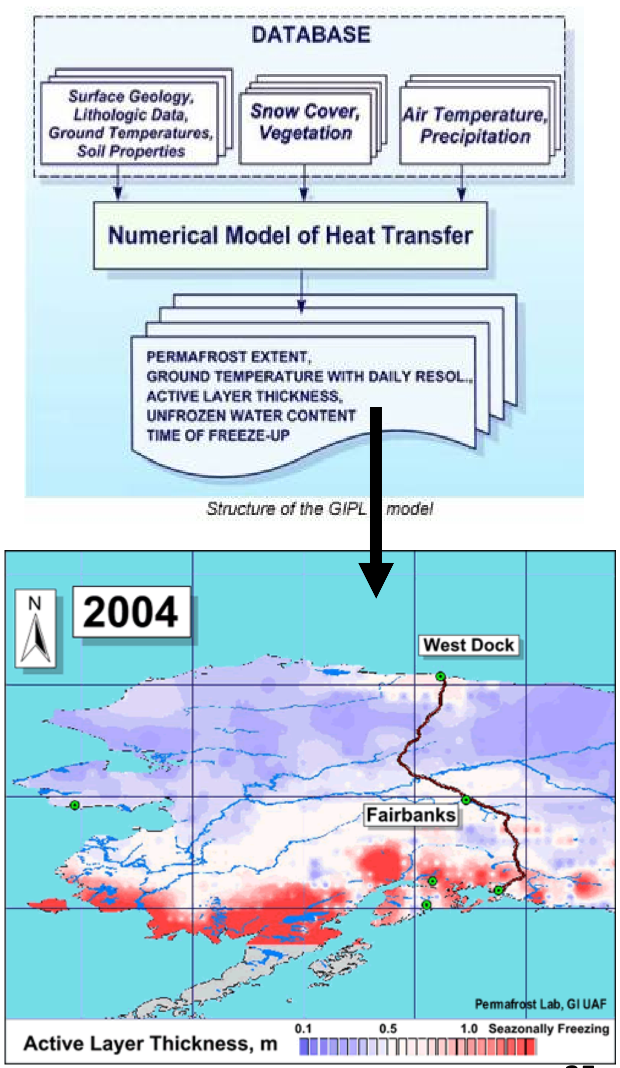
Existing Modeling Tools (cont'd)

- **Arctic process models**:

  Arc-Veg, GIPL-2.0, TopoFlow

  – **Capabilities**
    - Designed for Arctic systems
    - Cryoturbation and frost heave, and influence on vegetation dynamics
    - Freeze/thaw dynamics
    - Overland flow and surface routing

  – **Shortcomings**
    - Not designed for climate model coupling
    - Simplified belowground BGC
    - No reactive transport capability

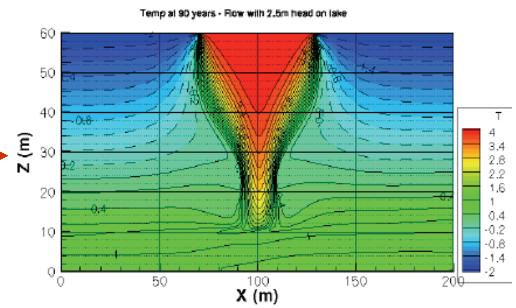


Modeling tasks by challenge area (selected)

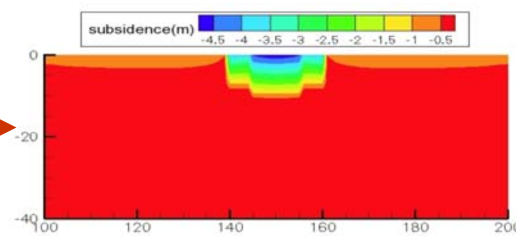
- **Water:**
  - Landscape-scale prediction of hydrologic response to permafrost degradation
- **Nitrogen:**
  - Plot-scale prediction of plant distribution in relation to thermokarst features
- **Carbon:**
  - Core-pore scale prediction of microbial dynamics, soil chemistry, and residence times as a function of depth in warming permafrost
- **Energy:**
  - Landscape-scale prediction of surface energy balance as influenced by geomorphic and vegetation features

Landscape-scale prediction of hydrologic response to permafrost degradation

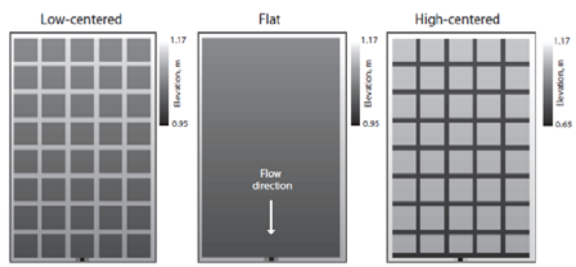
Permafrost degradation impact on near-surface and subsurface flowpaths (ARCHY)



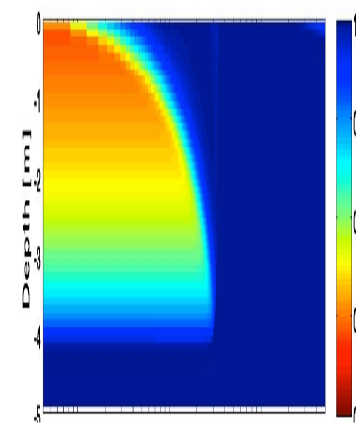
Permafrost degradation impact on microtopography (FEHM)



Microtopography impacts on surface routing (WaSIM-ETH)



Integration in a single framework, and connection to climate scale (PFLOTRAN and CLM)



Soil saturation: variation with depth and time (G. Bisht)

Plot-scale interactions among N availability, plant growth, and vegetation structure

Vegetation observations

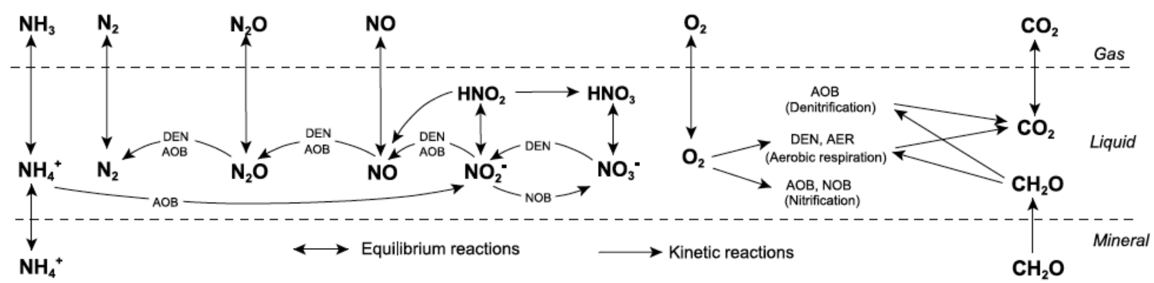
Canopy N
Functional traits
N use
Phenology

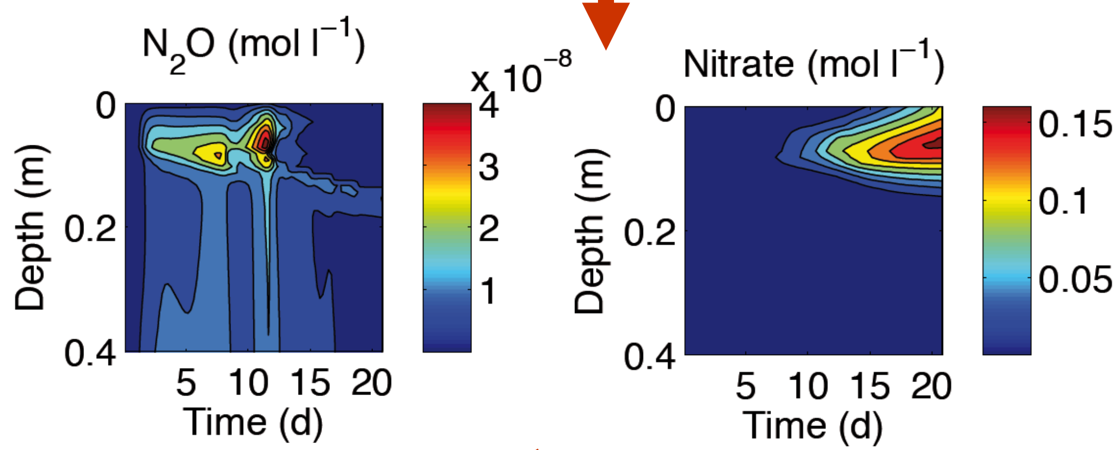
Vegetation dynamics models

Arc-Veg

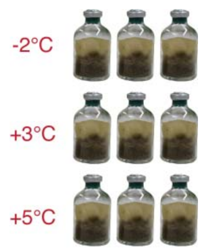
ARCHY-ED

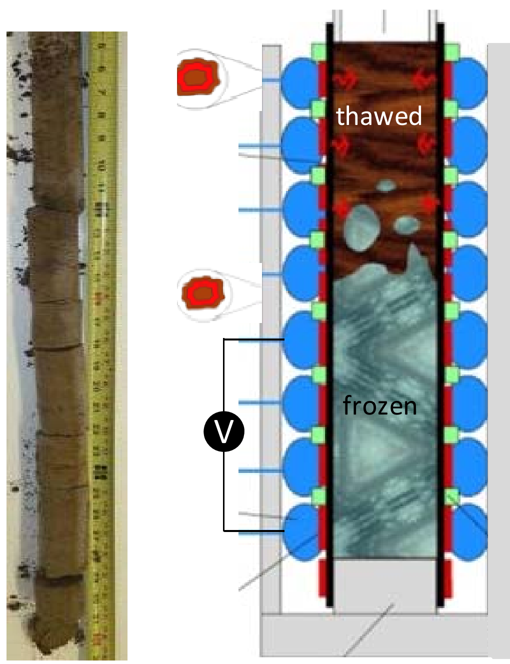
TOUGHREACT

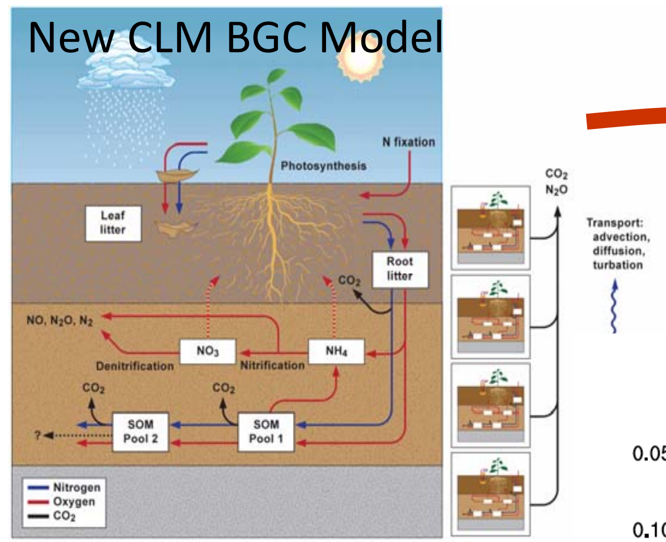


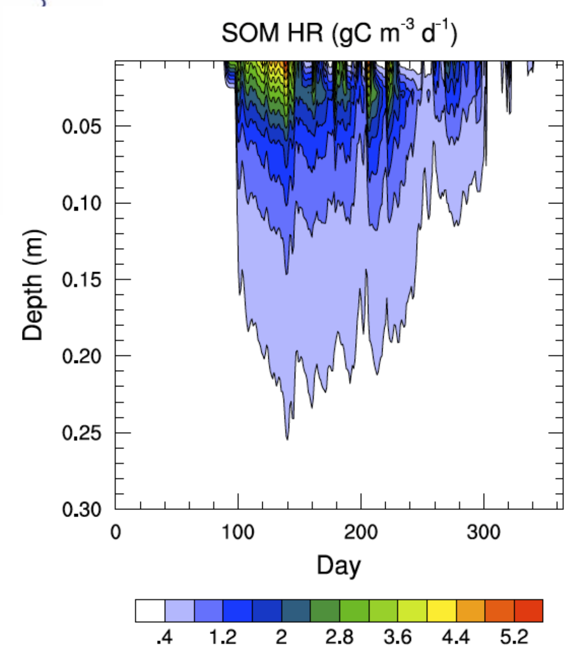


Core-scale, depth-dependent prediction of CO_2 and CH_4 emissions from thawed organic matter.





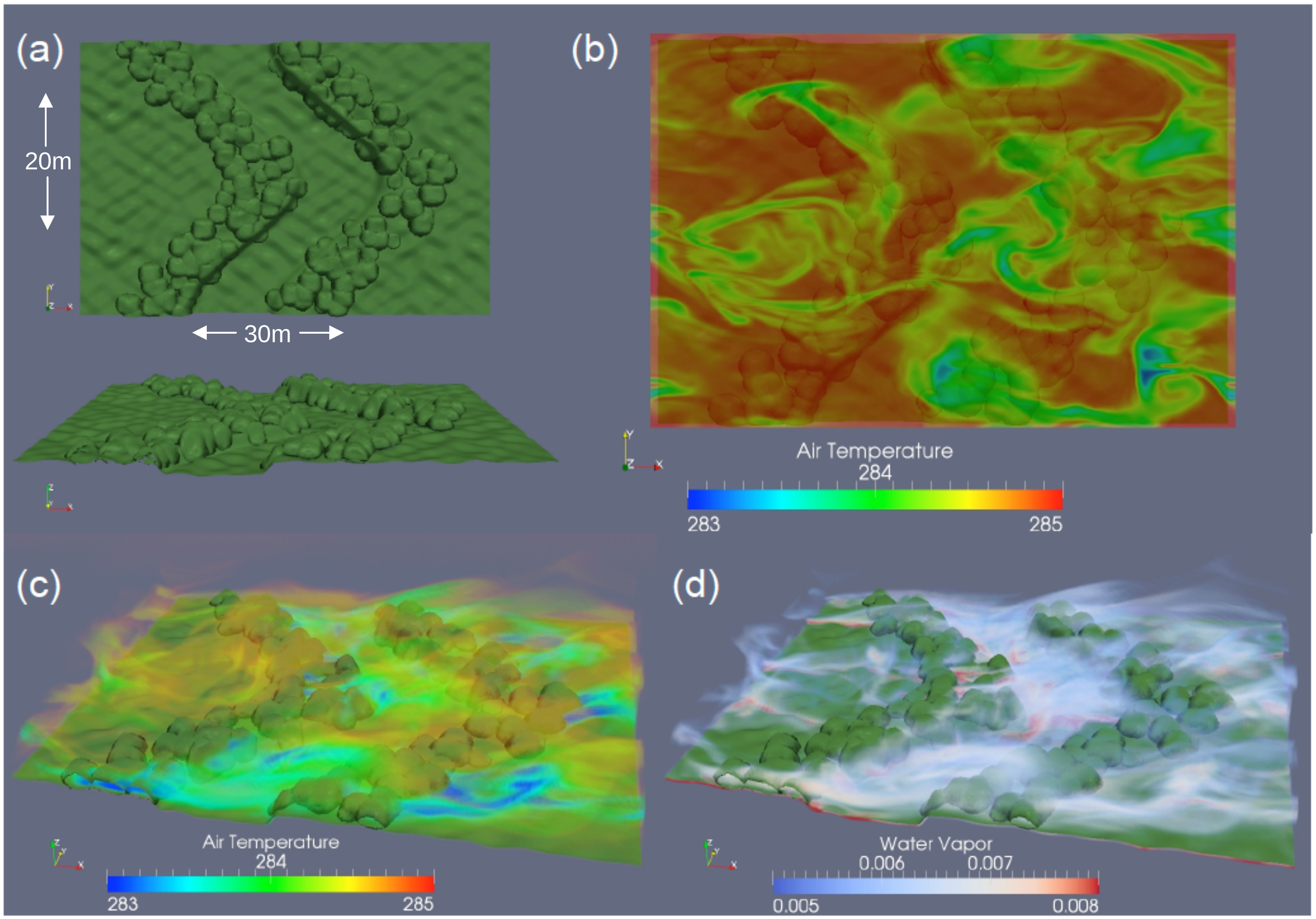




- Evaluate effects of depth and soil chemistry on decomposition

- Evaluate residence times and structure of trophic cascade

Landscape-scale prediction of surface energy balance as influenced by vegetation



HIGRAD simulation of heat and water vapor transport over wet thermokarst feature (1m deep x 5m wide)

(Cunningham, Linn, and Wilson, in prep.)

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Explore scaling approaches

1. Climate modeling grid scale:

- CLM simulations for 1°x1° gridcells at Barrow and Council
- Increasingly detailed parameterizations using remote-sensed and field observations, e.g.:
  - Remote sensing from Site Characterization task
  - Shallow lake and CH_4 models from LBL group.
  - Robust results from four Challenge areas at the end of Year 1

2. Scaling studies with high-resolution models

- Scaling organized by surface climate, vegetation water response, and drainage network topology.
- High dimensional model reduction techniques.

Modeling workshops leading to Phase 2 modeling architecture

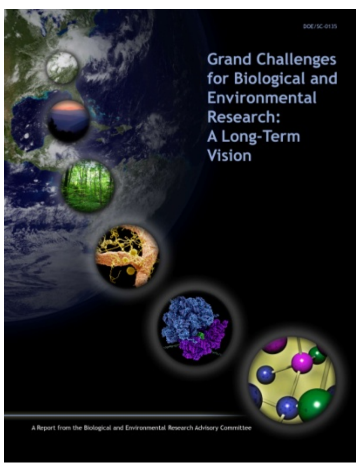
1. Define modeling protocols for Phase 1
2. Identify robust results from application of existing tools to existing datasets
3. Synthesize results from application of existing models to new NGEE datasets
4. Examine results of model scaling exercises
5. Initiate design of a coherent modeling framework for NGEE Phase 2

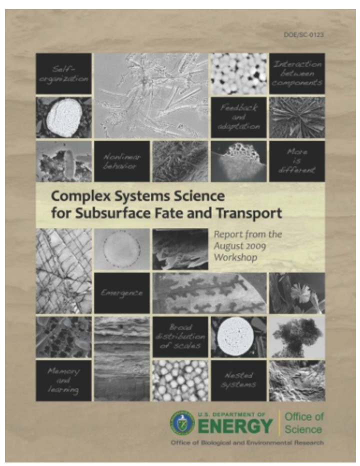
Motivation Behind NGEE Arctic

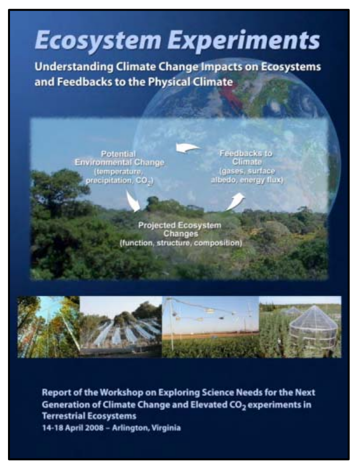
"Process Understanding, Predictive Capabilities"

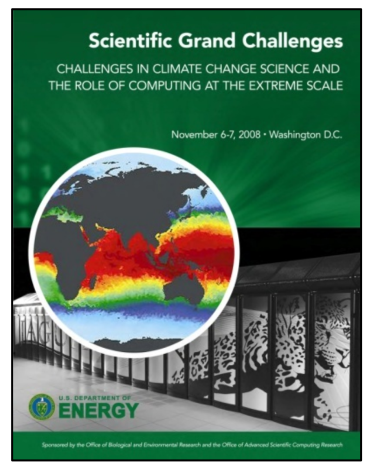
…a much more complete, process-based model representation of the Earth system will be needed to understand how the system operates and to provide information about how it might evolve [Grand Challenges for Biological and Environmental Research: A Long-Term Vision, 2010]

Incorporating and improving processes in global models, including physical components and dynamic vegetation, new biogeochemical components, and improvements in process representations are needed to reduce model uncertainties [Climate Research Roadmap Workshop, 2010]

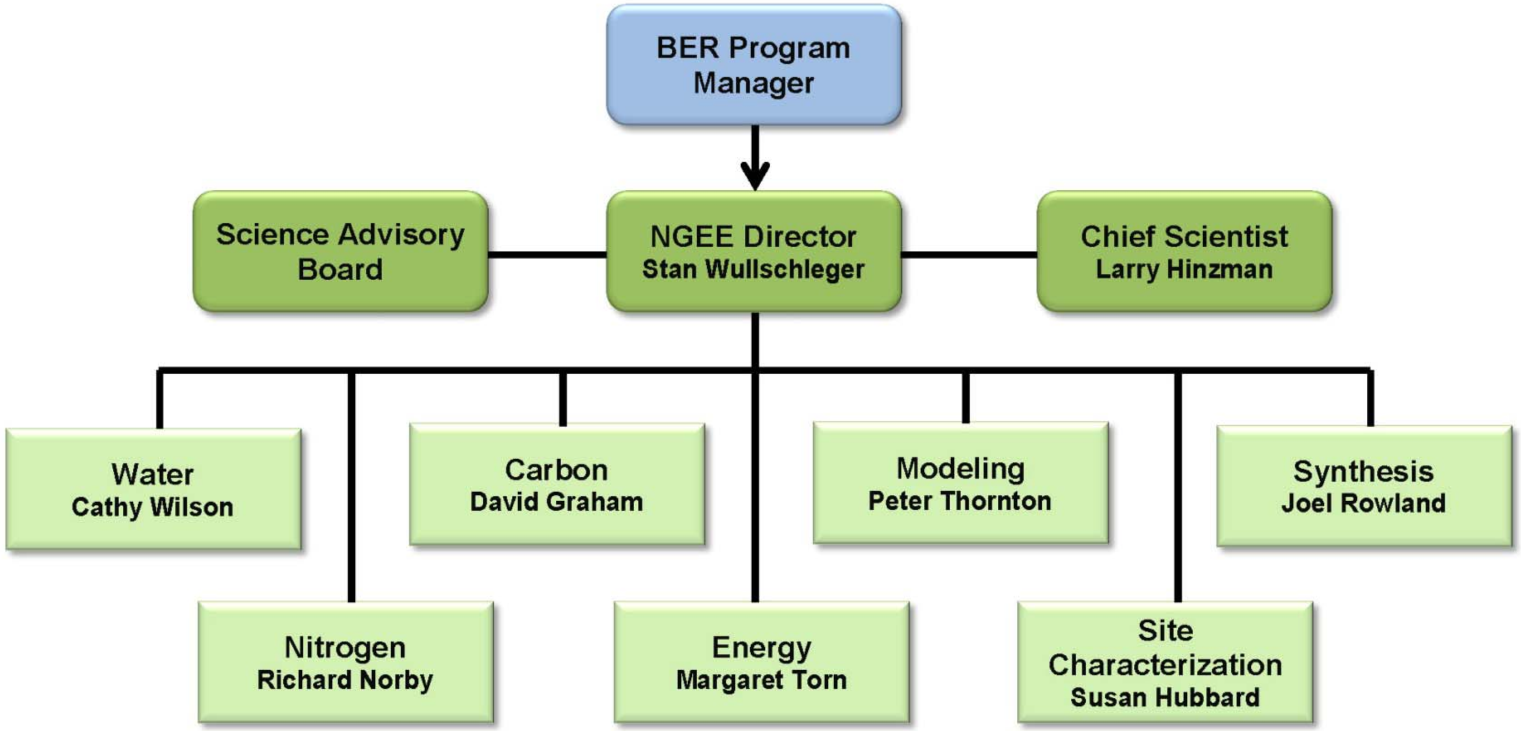








Organizational Structure



50+ other scientific and technical staff

Well-defined roles and responsibilities

Expectations and accountability

Other items critical to the success of NGEE

- Data management
- Performance metrics
  - Identify with BER desired Phase 1 outcomes
  - Tangible deliverables; measured against timeline
- Synthesis and analysis
- Communication plan
  - WebEx, ReadyTalk, and video
  - Team telecons and all-hands meetings
- Education
- Community outreach
- Partnerships
- Manipulative experiments

Deliverables (Phase 1)

Characterized sites at Barrow and Council, Alaska.

- Surface and subsurface surveys
- Instrumentation and methods development

Prioritized listing of properties and processes to be studied in Phase 2.

High-level architectural design for Arctic land simulator.

Description, design, and simulations of possible manipulative experiments for Phase 2.

Data management system for support of Phase 2 activities.

Expertise and Capabilities Across NGEE Team:

Ecology
- Micro-scale
  - Quantitative genetics
  - Proteomics, enzymology
  - Microbial ecology
  - Metabolomics and metagenomics
  - Plant and microbial biochemistry
- Macro-scale
  - *plant and ecosystem physiology*
  - carbon cycle science
  - *plant water relations*
  - *stable isotope ecology*

Hydrology
- *permafrost hydrology*
- hydrogeology

Geophysics
- *permafrost thermal dynamics*
- geomechanics
- environmental geophysics

Chemistry
- soil biogeochemistry
- surface geochemistry
- *isotope geochemistry*

Remote sensing and analysis

Meteorology and atmosphere
- biometeorology
- *micrometeorology*

Analysis and modeling
- regional climate
- land surface
- *permafrost hydrology*
- reactive transport
- biochemical networks
- lake and sediment
- earth system
- atmospheric tracer
- *statistics*

Logistics and management
- *Arctic remote logistics*
- electrical and mechanical engineering
- project management
- *field implementation*
- *telemetry and communications*
- data management and archival
- *data acquisition and electronics*

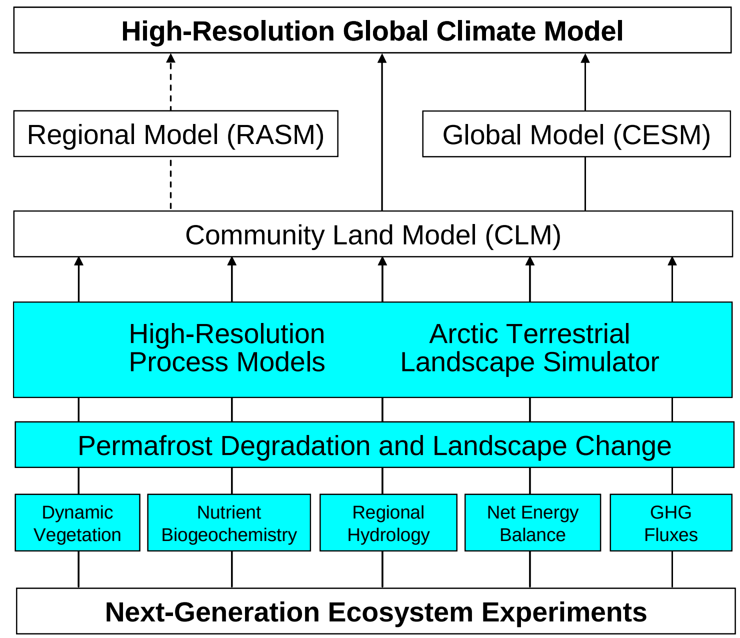
Organic spectroscopy

Neutron imaging

Synchotron sciences

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 reduce uncertainty and improve climate predictions at decadal to century scales.

Thank you