NGEE Arctic Project: A Model-Inspired Study of Climate Feedbacks in High-Latitude Ecosystems

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BERAC Presentation – February 21, 2013

NEXT-GENERATION ECOSYSTEM EXPERIMENTS
NGEE Arctic

2nd Annual All-Hands Meeting
December 1, 2012

U.S. DEPARTMENT OF ENERGY | Office of Science

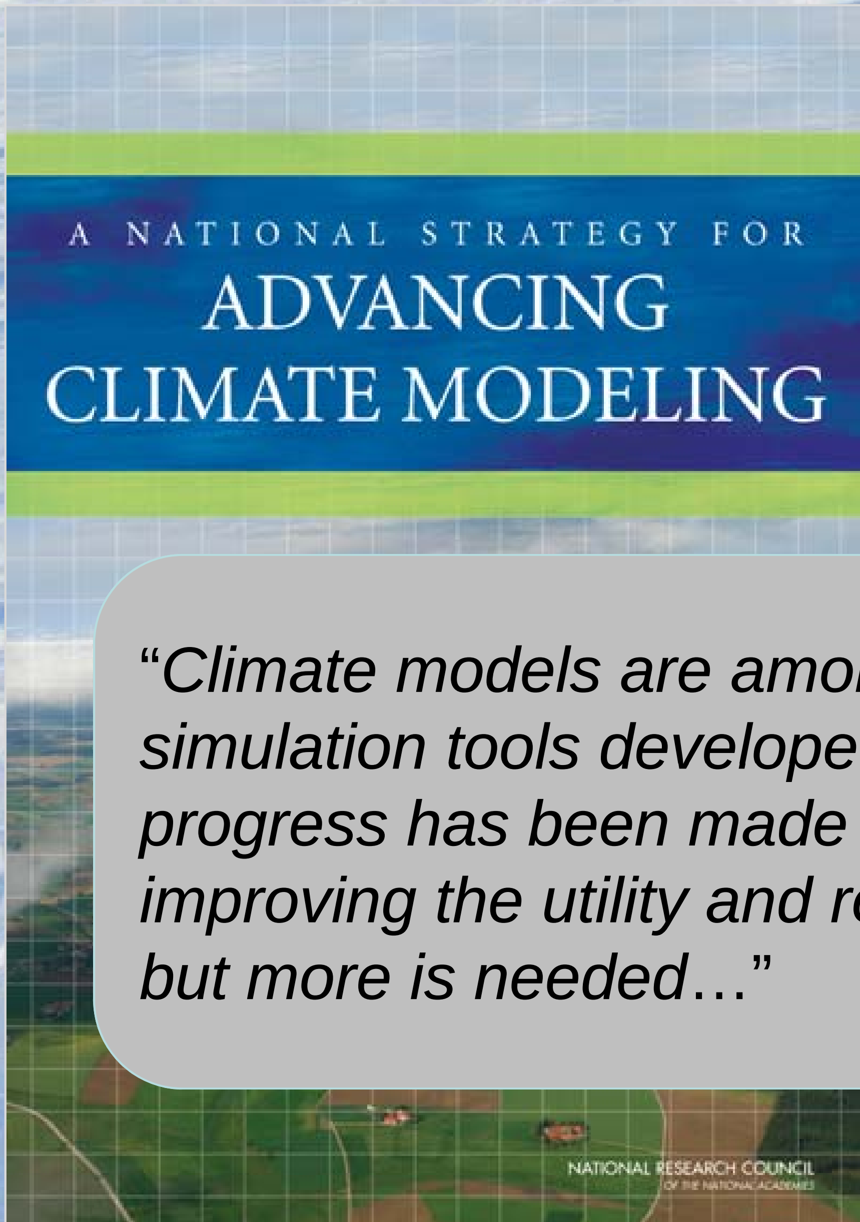
Goal:

Deliver 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.

...been — Community engagement, team development, and discussions of scientific plans with others.

...are — Completion of FY12 field activities, assessment of progress, evaluation of deliverables, FY13 planning, and preparation for collaborations.

...going — Systems understanding of Arctic tundra landscapes, an ability to model field-scale dynamics, and a translation of that knowledge to Earth System Models for improved climate prediction.



September 2012

- Ocean
- Atmosphere
- Land

"*Climate models are among the most sophisticated simulation tools developed by mankind. Enormous progress has been made in the past several decades in improving the utility and robustness of climate models, but more is needed*…"

Arctic Climate
Impact Assessment
Arctic Climate Impact Assessment
ACIA
UNEP
Policy
Implications
of Warming
Permafrost
U.S. DEPARTMENT OF ENERGY
Office of Science
BIOLOGICAL AND ENVIRONMENTAL RESEARCH
Climate and Environmental Sciences Division
STRATEGIC PLAN
USGS
science for a changing world
The United States National Climate Asses
Alaska Technical Regional Report
Circular 1379
U.S. Department of the Interior
U.S. Geological Survey
OUR CHANGIN
THE U.S. GLOBAL CHAN

Arctic Ecosystems and Climate Feedbacks

Land area in the Arctic is estimated at 29 x 10^6 km^2

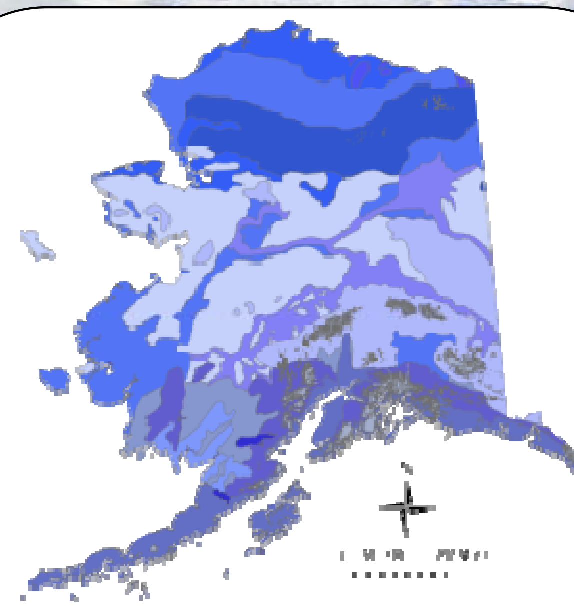
Permafrost occupies approximately 19 x 10^6 km^2

Permafrost soils contain about 1700 Pg C

7 to 90% of permafrost could be lost by 2100

Active layer thickness could increase by 30 to 300 cm by 2100

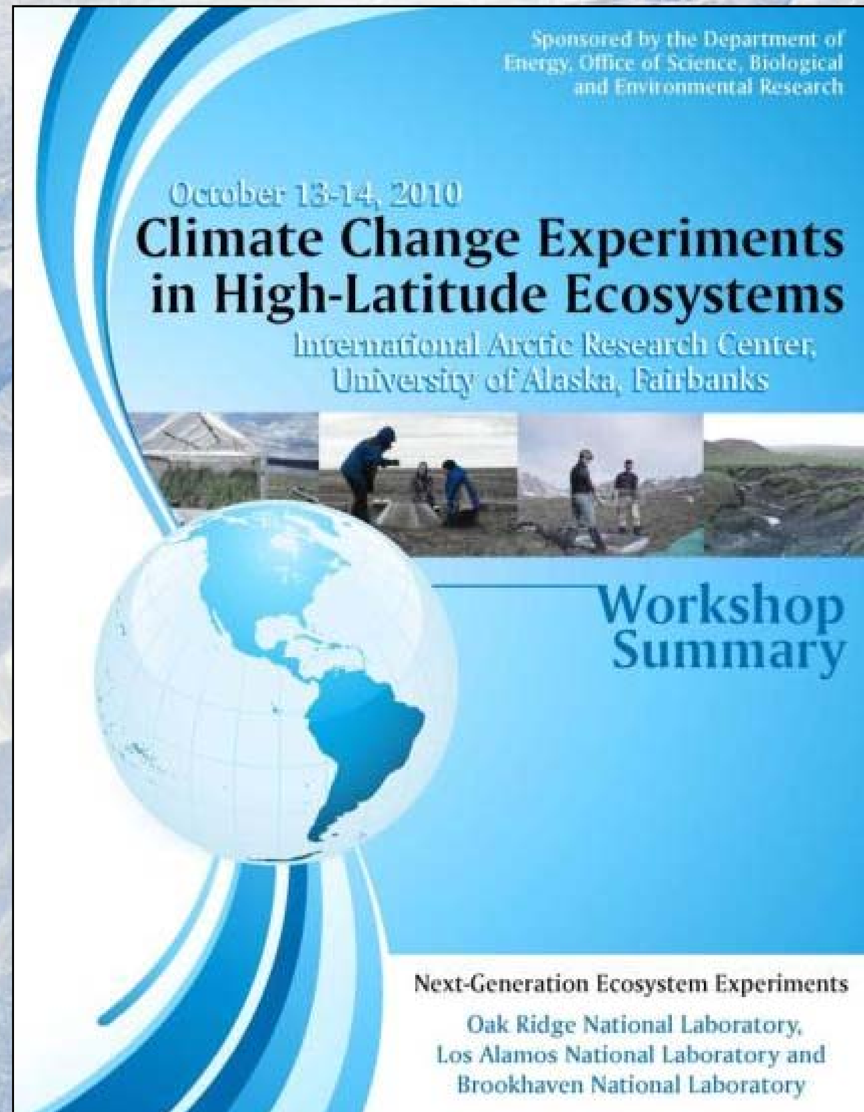
Microbial decomposition of this vulnerable C could represent a significant positive feedback to climate warming



Model-based projections of permafrost vulnerability and potential C loss associated with climate warming.

Reference	Time Frame (Years)	Vulnerable (Pg C)	Loss (Pg C)
Harden et al. (2012)	*2050 to 2100*	*147 – 436*	
Koven et al. (2011)	2100		62
Schaefer et al. (2011)	2100 2200		104 190
MacDougall et al. (2012)	2100 2300		68 – 508
Schneider von Deimling et al. (2012)	2100 2200 2300		16 – 63 34 – 302 43 – 380

Community Workshop - 2010

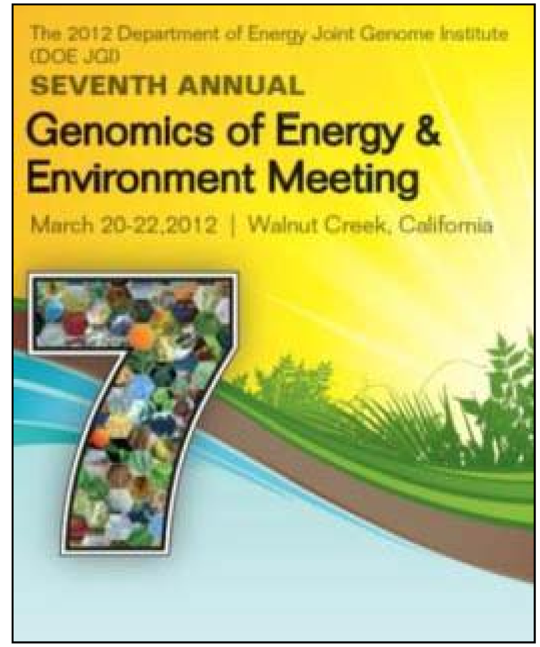


…identify the greatest uncertainties in current-generation ecosystem or climate models, and elaborate on what processes, impacts, or responses they would most like to see in predictive models.

http://ngee-arctic.ornl.gov/content/workshop-reports

Community Input

Presentations: Genomic Science Program; Subsurface Biogeochemistry Research; Earth System Modeling; Terrestrial Ecosystem Science; Joint Genome Institute



Omics in the Arctic

Discussions and Lab Visits: ANL, BNL, LANL, LBNL, ORNL, PNNL (EMSL), JGI

BER Town Halls: AGU (2011 and 2012); ESA (2012)

“Learn More” Session: AGU (2011)

Agency Interactions: NASA, NOAA, DOE, NSF

Logistical Support: BASC, UMIAQ, CH2M HILL Polar Services (CPS)

Village Discussions: Seward Peninsula and North Slope

Overarching Science Question:

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

Geophysics: Develop approaches to effectively use geophysical data for site characterization, process understanding, and model input.

Hydrology and Geomorphology: Acquire knowledge that relates to the thermal and hydrologic responses of tundra to permafrost degradation.

Biogeochemistry: Develop a quantitative understanding of SOM decomposition in permafrost as needed to improve predictions of CO_2 and CH_4 feedbacks.

Vegetation Dynamics: Quantify response of tundra to changing resource availability and evaluate GHG and energy feedbacks to climate.

Integrated Model-Data Evaluation: Quantify climate forcing across a range of spatial scales and document improvement in model prediction.

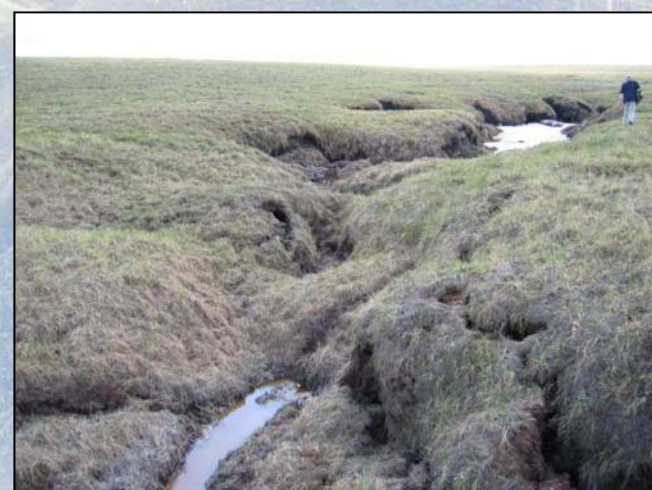
Multi-Scale Modeling: Facilitate prediction of ecosystem-climate feedbacks across fine, intermediate, and grid cell scales.

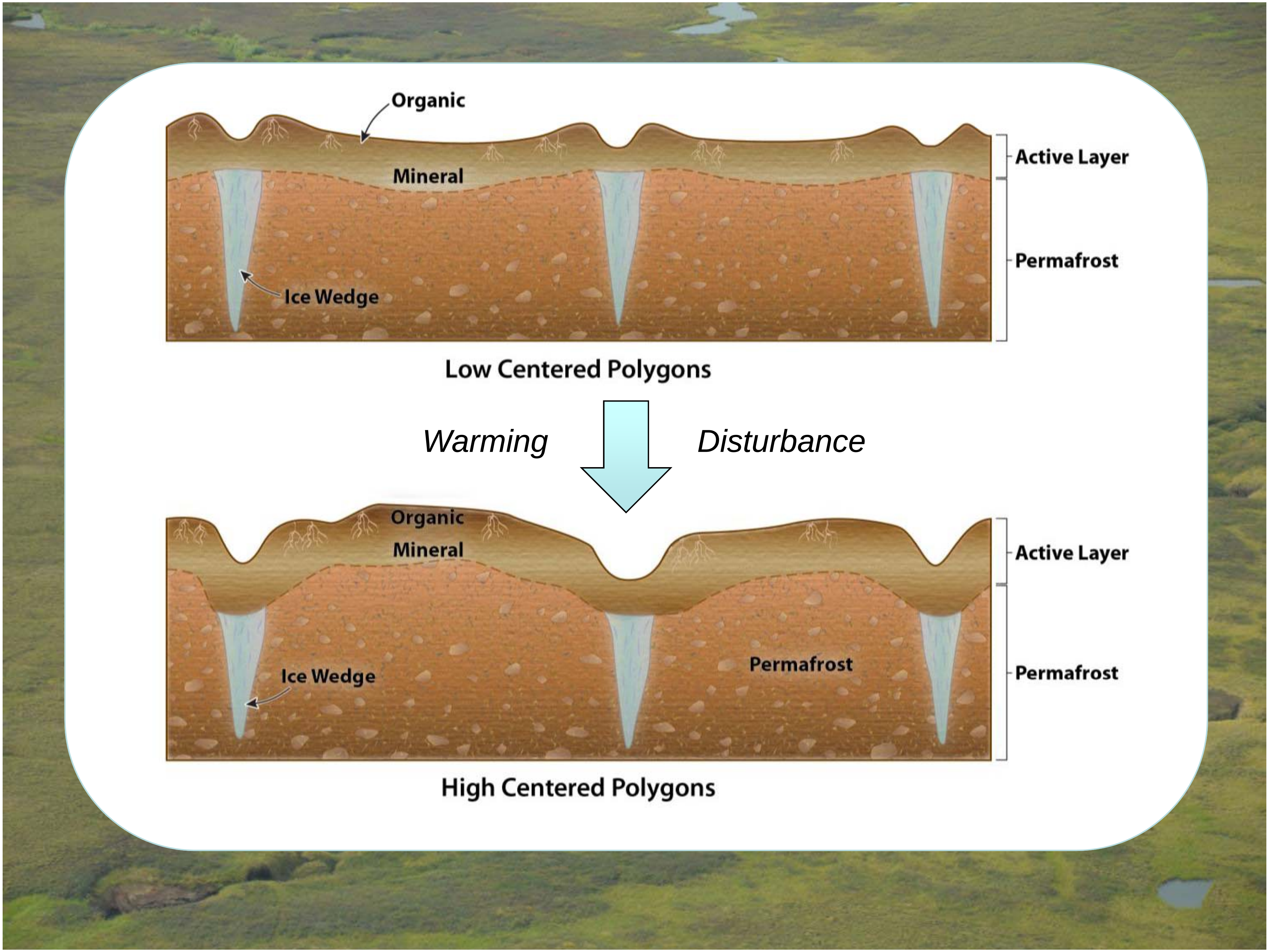
Surface-subsurface interactions and the consequences for landscape evolution.

Thawing

Thermokarst

Thermal erosion

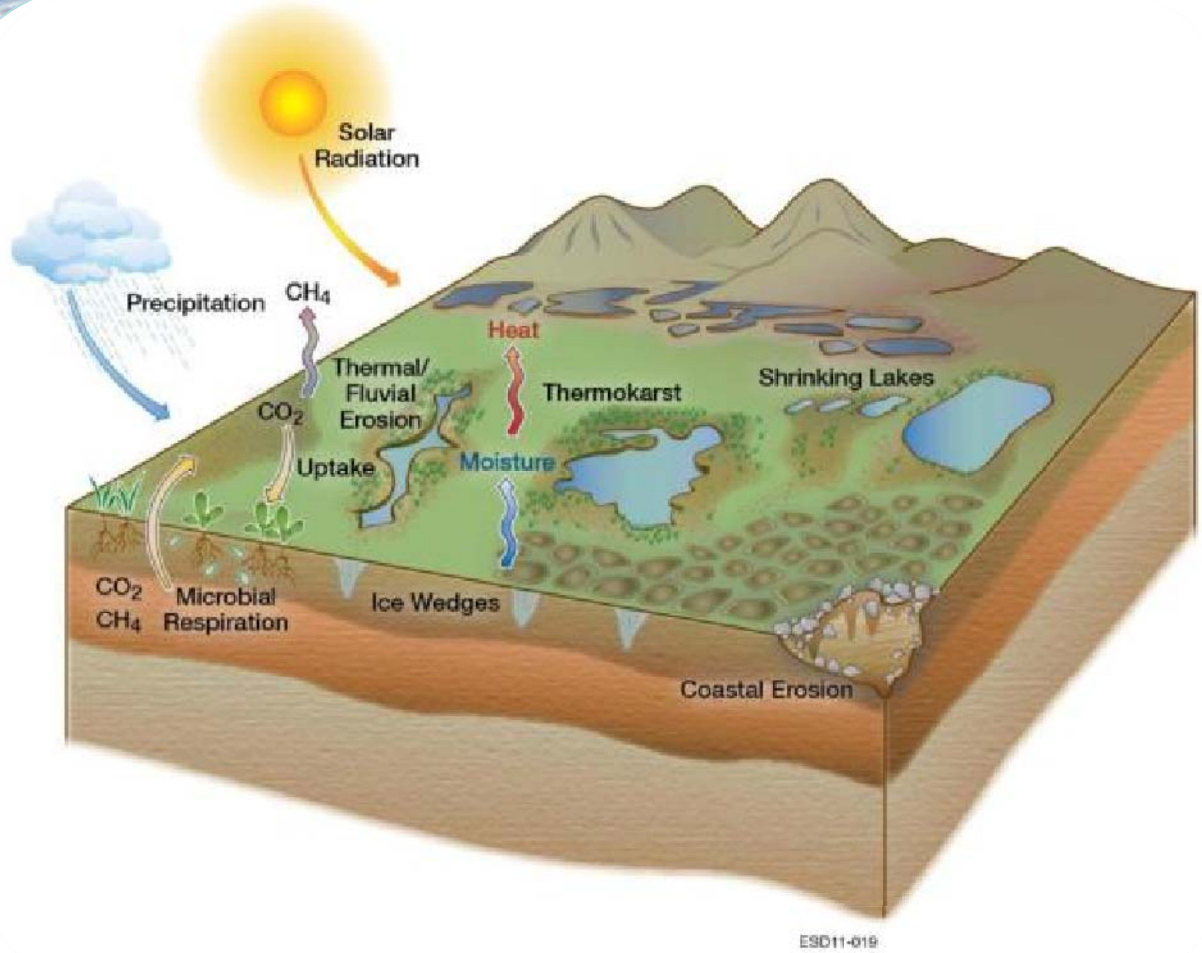




Organic
Mineral
Ice Wedge
Active Layer
Permafrost
Low Centered Polygons
Warming
Disturbance
Organic
Mineral
Ice Wedge
Permafrost
Active Layer
Permafrost
High Centered Polygons

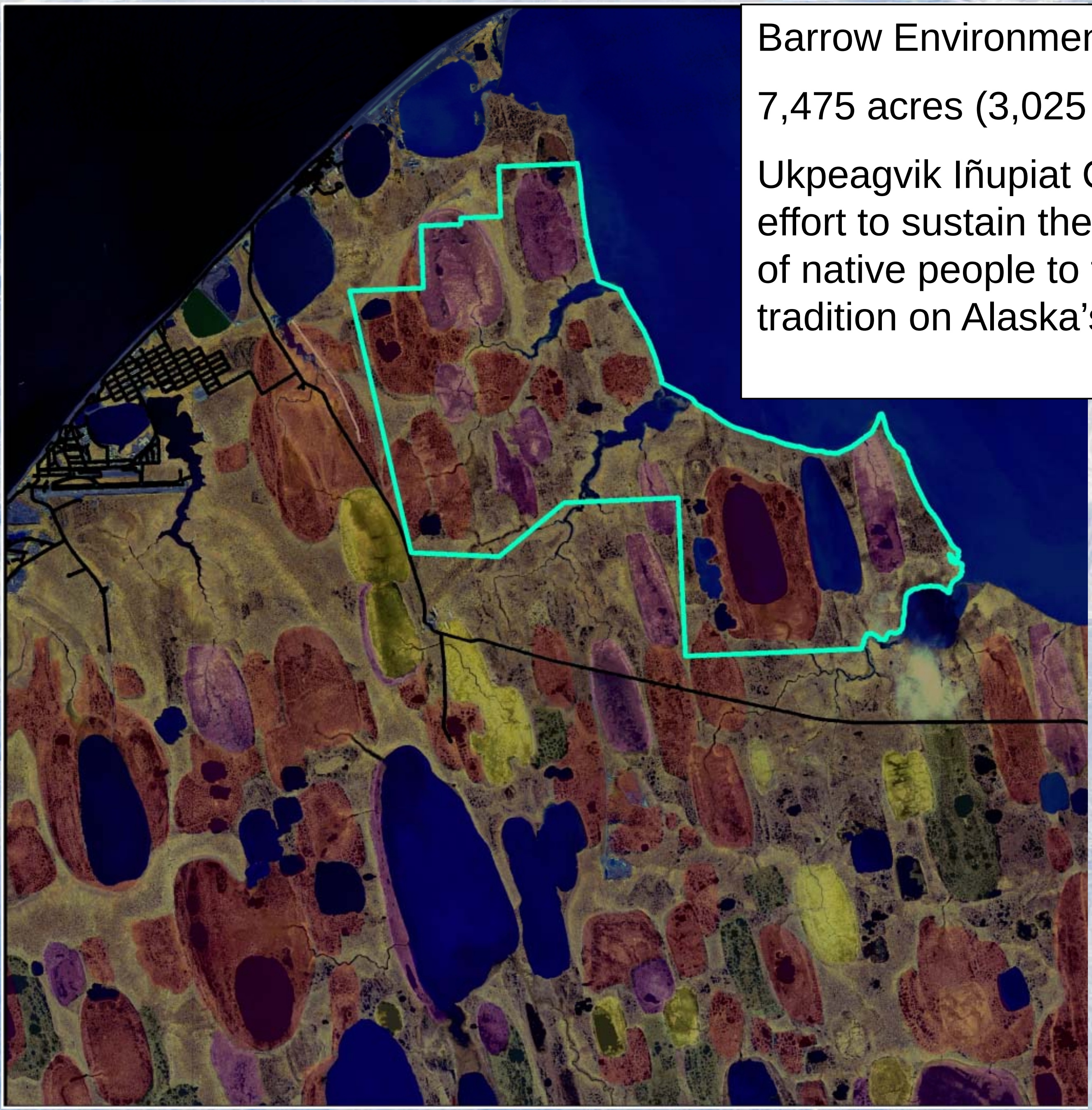
Landscapes in transition

...integrates hydrology, vegetation dynamics, soil processes, and energy transfer 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.



Barrow Environmental Observatory (BEO)

7,475 acres (3,025 ha)

Ukpeagvik Iñupiat Corporation (UIC) in an effort to sustain the long-term commitment of native people to the scientific research tradition on Alaska's North Slope.

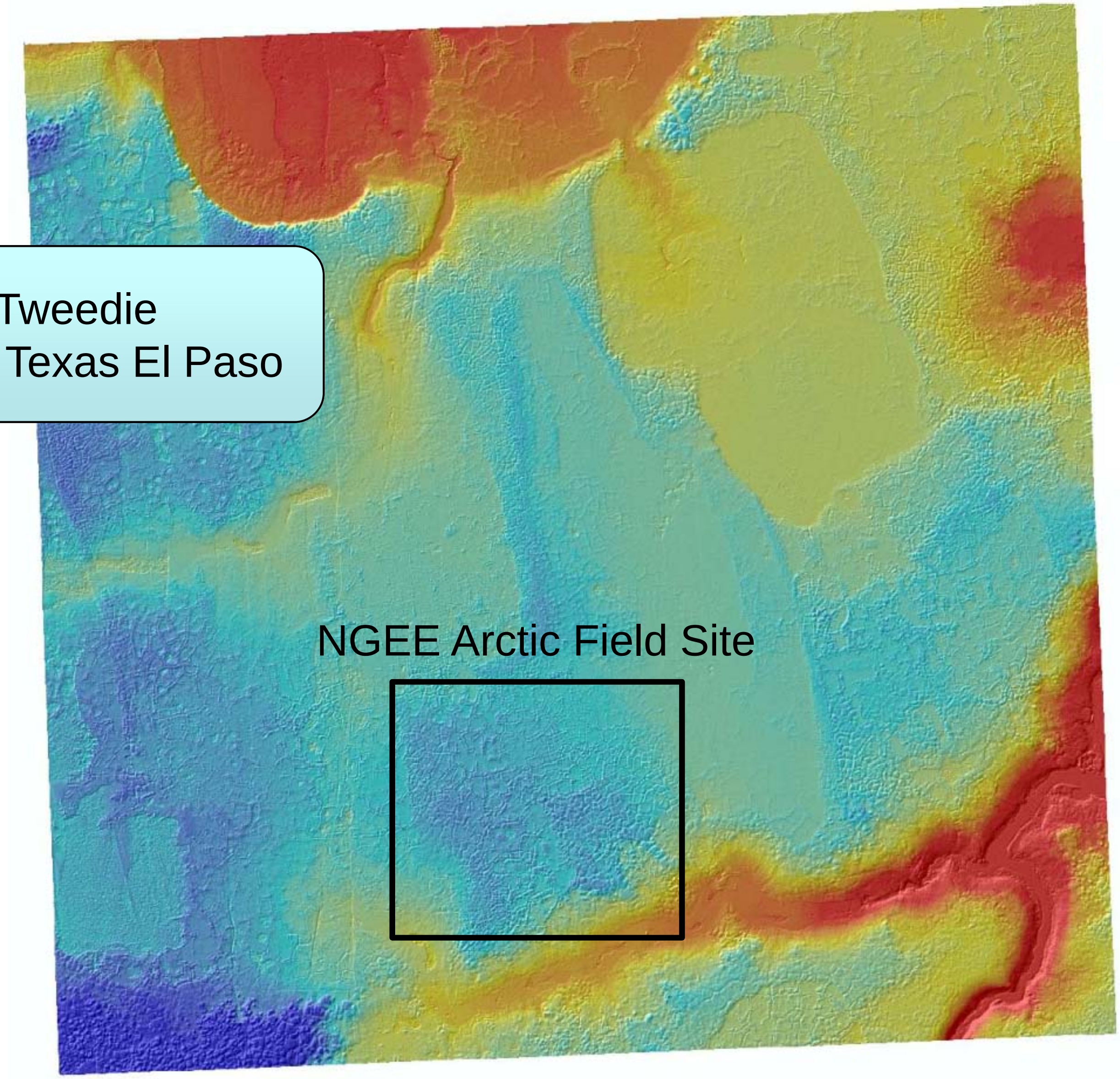
Landscape coverage of geomorphological features on the Arctic Coastal Plain

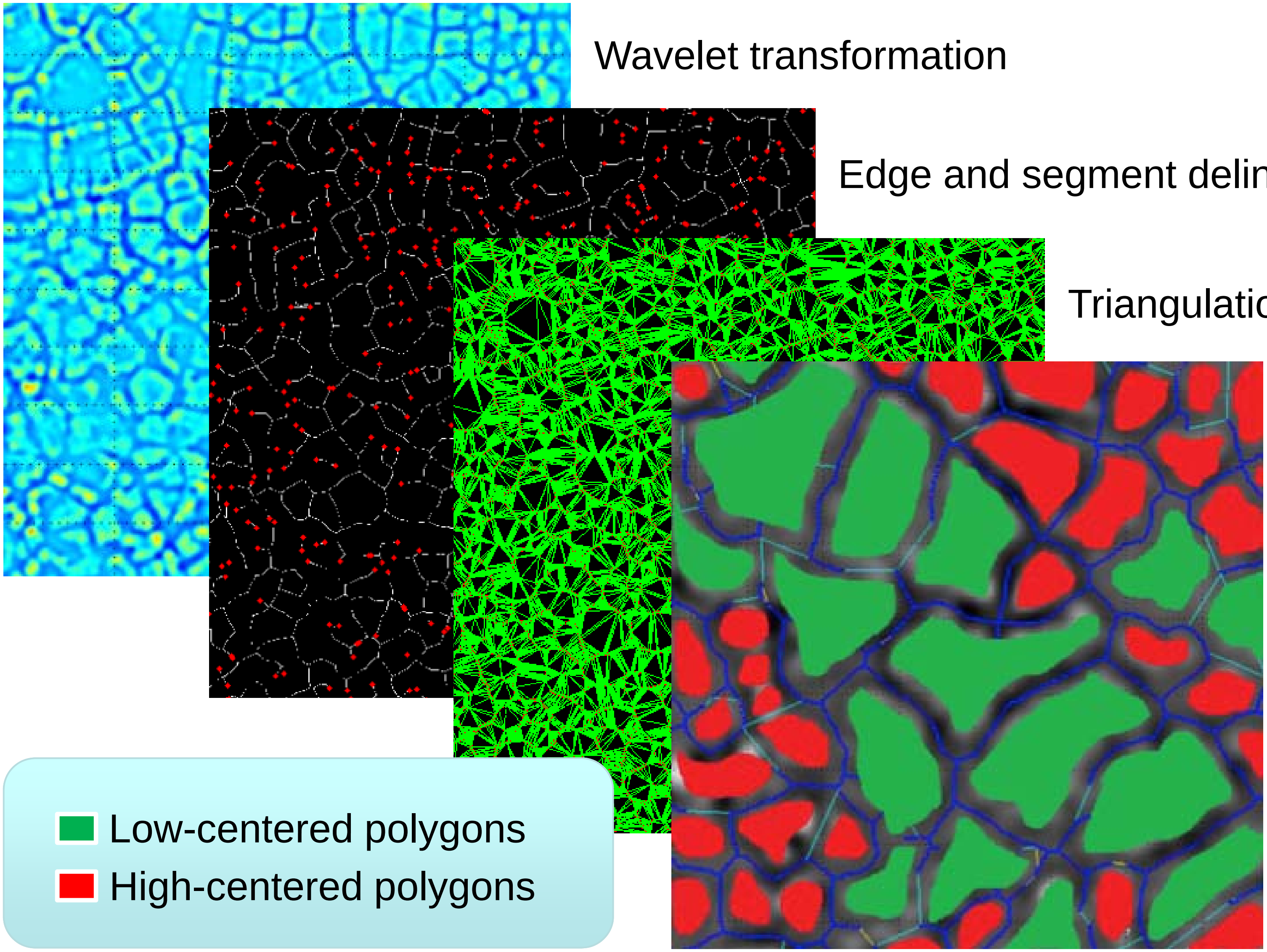
Feature	Age (years)	Surface area (km^2)	Surface area (%)
Drained thaw lake basins			
Young	0-50	57	3.2
Medium	50-300	141	7.8
Old	300-2000	443	24.6
Ancient	>5000	97	5.4
Thaw lakes		395	21.9
Interstitial (e.g. polygons)		669	37.1
Low-centered		?	?
High-centered		?	?
		Total area 1,802	

Zulueta et al. (2011)

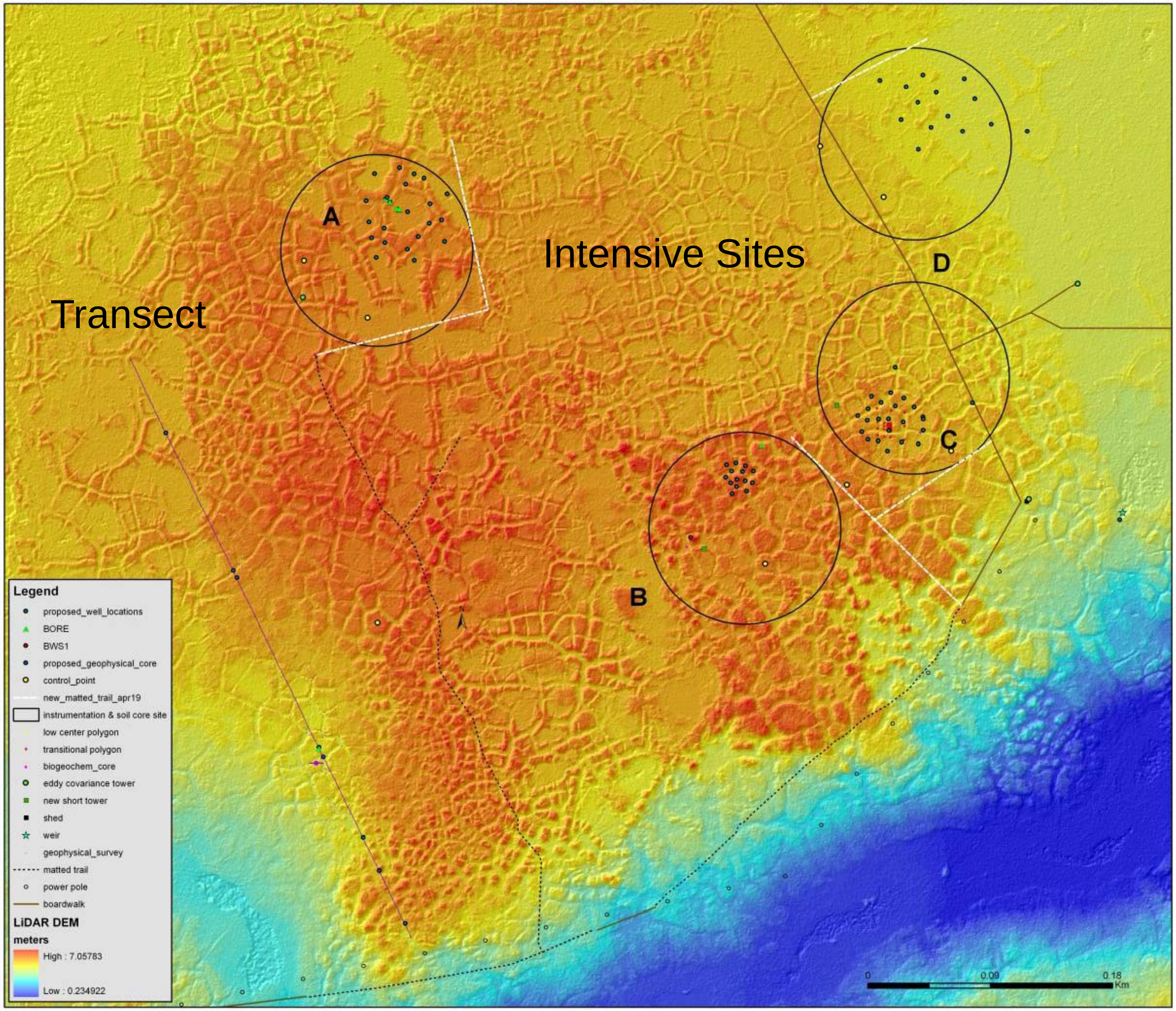
LiDAR – Light Detection and Ranging

Craig Tweedie
University of Texas El Paso





Gangodagamage C., J.C. Rowland, C. Wilson, A.N. Skurikhin, S.P. Brumby, G. Altmann, A. Liljedahl, C. Tweedie, and S.D. Wullschleger. 2013. Spatial and spectral characterization and mapping ice-wedge polygons using high resolution LiDAR data: a metric to quantify the degradation level of Arctic polygonal ground. Journal of Geophysical Research (in review).

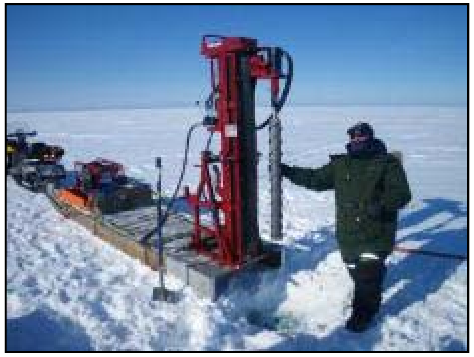

Transect
Intensive Sites
A
B
C
D
Legend
proposed_well_locations
BORE
BWS1
proposed_geophysical_core
control_point
new_matted_trail_apr19
instrumentation & soil core site
low center polygon
transitional polygon
biogeochem_core
eddy covariance tower
new short tower
shed
weir
geophysical_survey
matted trail
power pole
boardwalk
LiDAR DEM
meters
High : 7.05783
Low : 0.234922
0
0.09
0.18
Km


A4


C2


B3

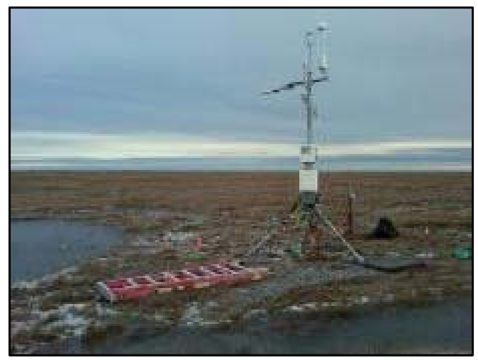

D1






Nanuq




Early Results

Publications (18)
Abstracts and Presentations (56)
Conferences and Workshops Attended (13)
Story Lines and Press Releases (7)

Emails Sent and Received (16,575)

Geophysics: Subsurface Characterization

Environmental controls on subsurface properties and processes are critical for predictive understanding of Arctic terrestrial systems.

Controls are highly heterogeneous and are difficult to characterize accurately over large regions.

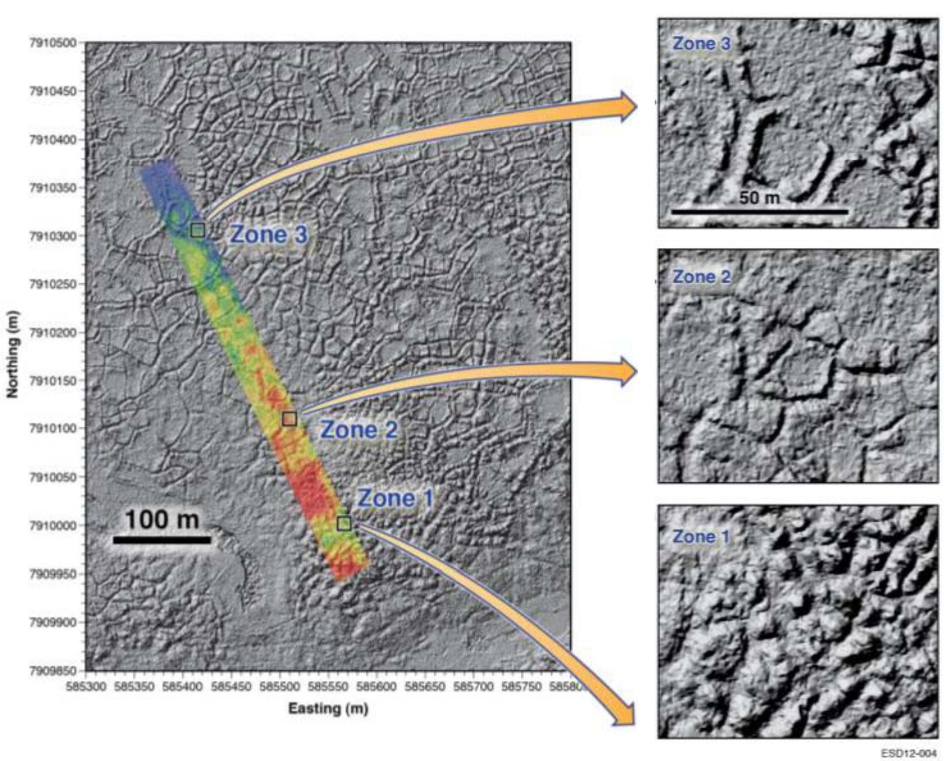
Develop approaches to use geophysical data with point measurements for characterization, process understanding and model input.

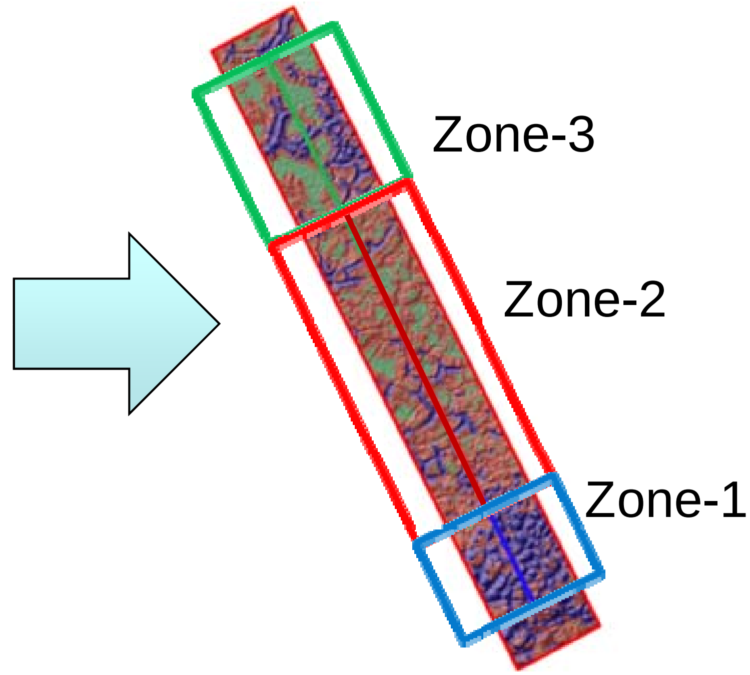
Baptiste Dafflon (LBNL)

September 2011

Susan Hubbard (LBNL)

Cluster Analysis Reveals Consistent Geomorphic and Subsurface Zonation



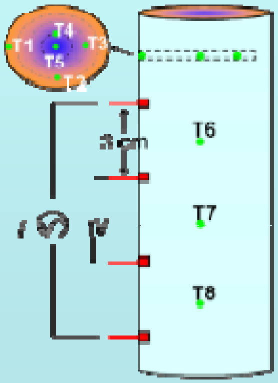


Illustrates new approach for quantifying co-variance of land and subsurface processes in high resolution and in a minimally invasive manner.

Hubbard S.S., C. Gangodagamage, B. Dafflon, H. Wainwright, J. Peterson, A. Gusmeroli, C. Ulrich, Y. Wu, C. Wilson, J. Rowland, C. Tweedie and S.D Wullschleger. 2013. Quantifying and relating subsurface and land-surface variability in permafrost environments using surface geophysical and LiDAR datasets. Hydrogeology Journal (in press).

Cluster Analysis Reveals Consistent Geomorphic and Subsurface Zonation

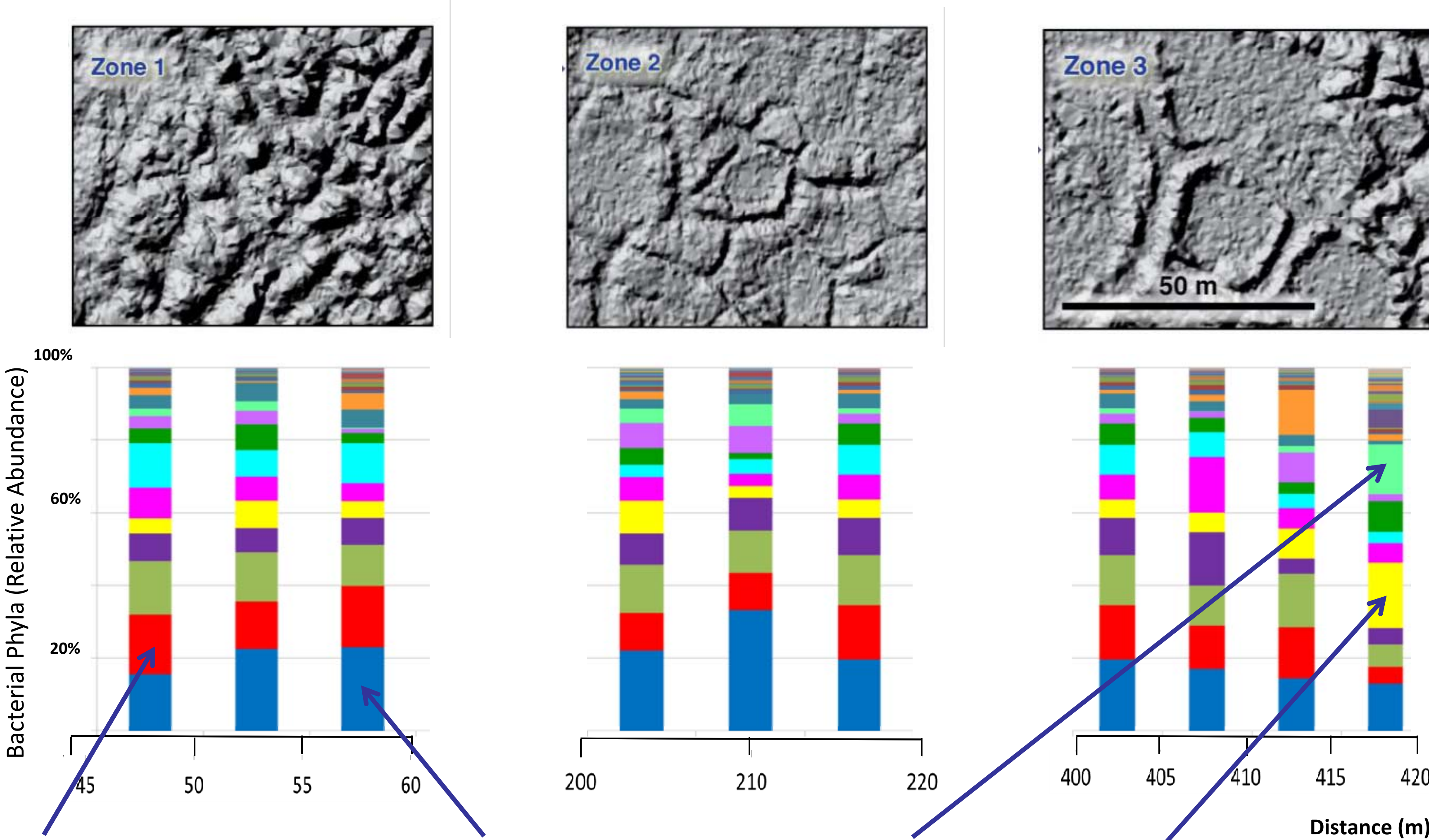
Analysis of point measurements documented that each zone had unique distribution of hydro-thermal-geochemical properties.



…exploring the potential of the complex resistivity signals for monitoring spatiotemporal variation in freeze-thaw transitions over field-relevant scales.

Wu Y., S.S. Hubbard, C. Ulrich, and S.D. Wullschleger. 2013. Remote monitoring of freeze-thaw transitions in Arctic soils using the complex resistivity method. Vadose Zone Journal (in press).

Spatial Variability of Bacterial Composition



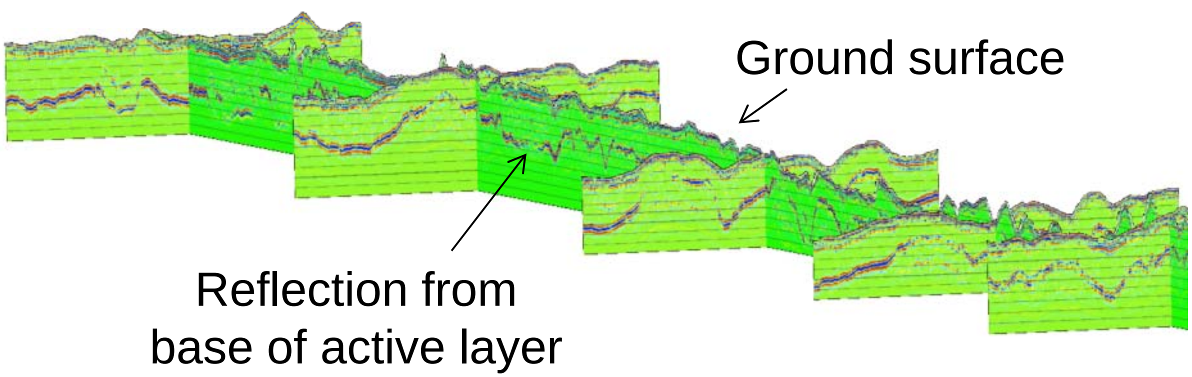
Alphaproteobacteria and Actinobacteria abundant in high-centered polygon

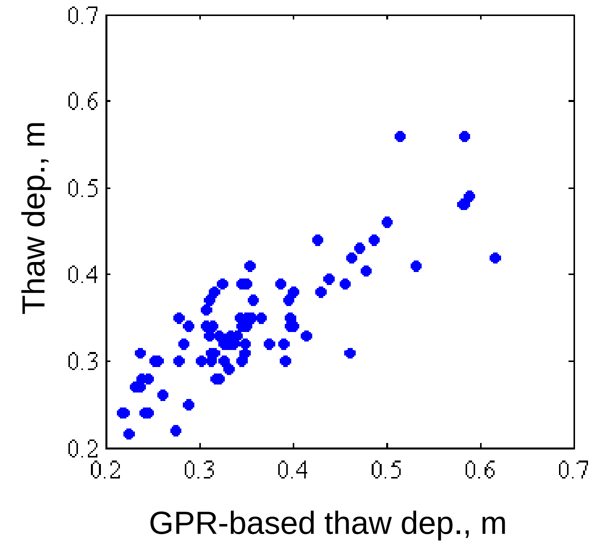
Chloroflexi and Bacteroidetes more abundant in low-centered polygon

Janet Jansson et al. (LBNL)

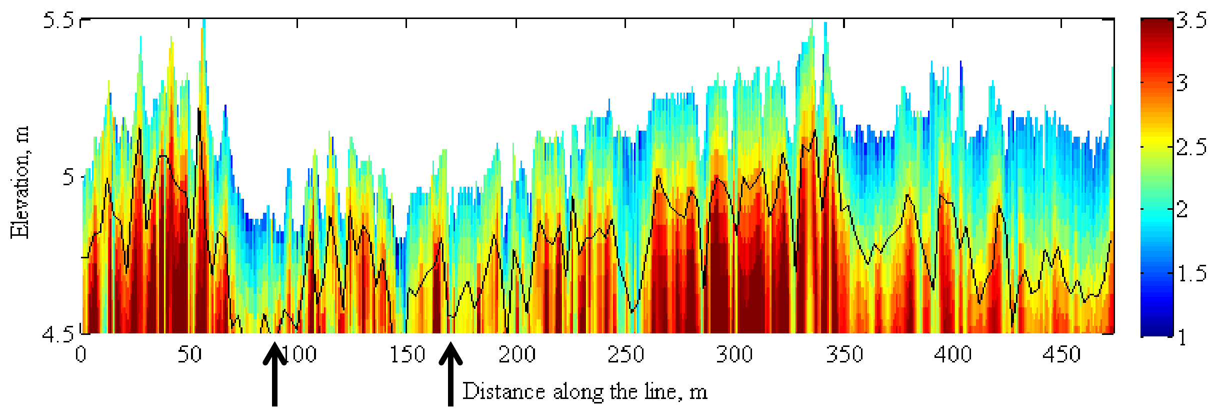
ALT and Soil Moisture Estimated Using Geophysical Data

GPR Travel Time → Thaw Depth

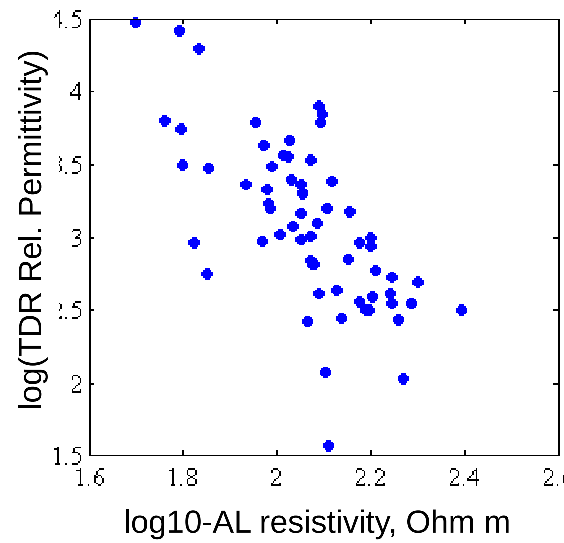




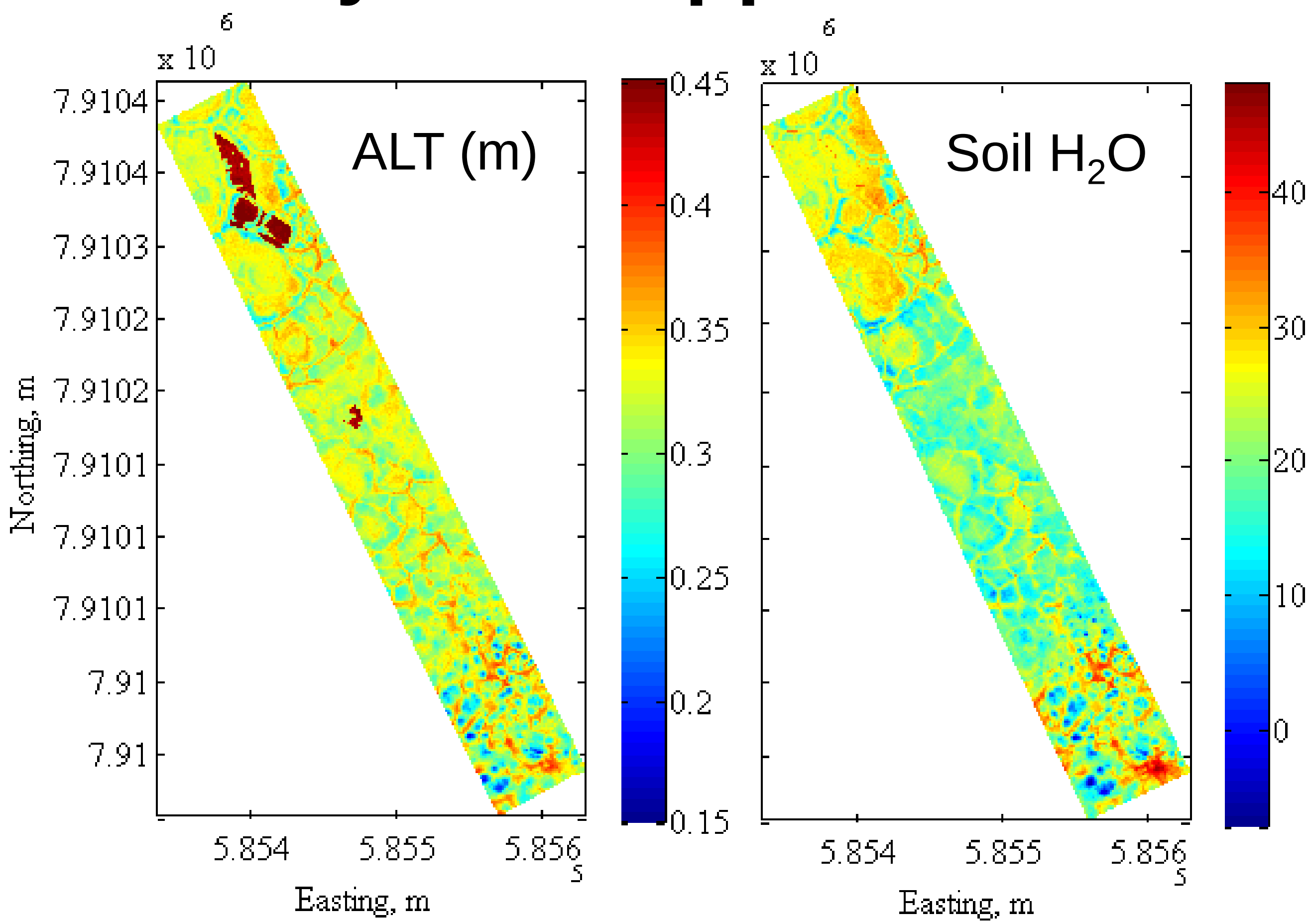
2D ERT Resistivity → Soil Moisture



Lower active layer resistivity at troughs = higher soil moisture

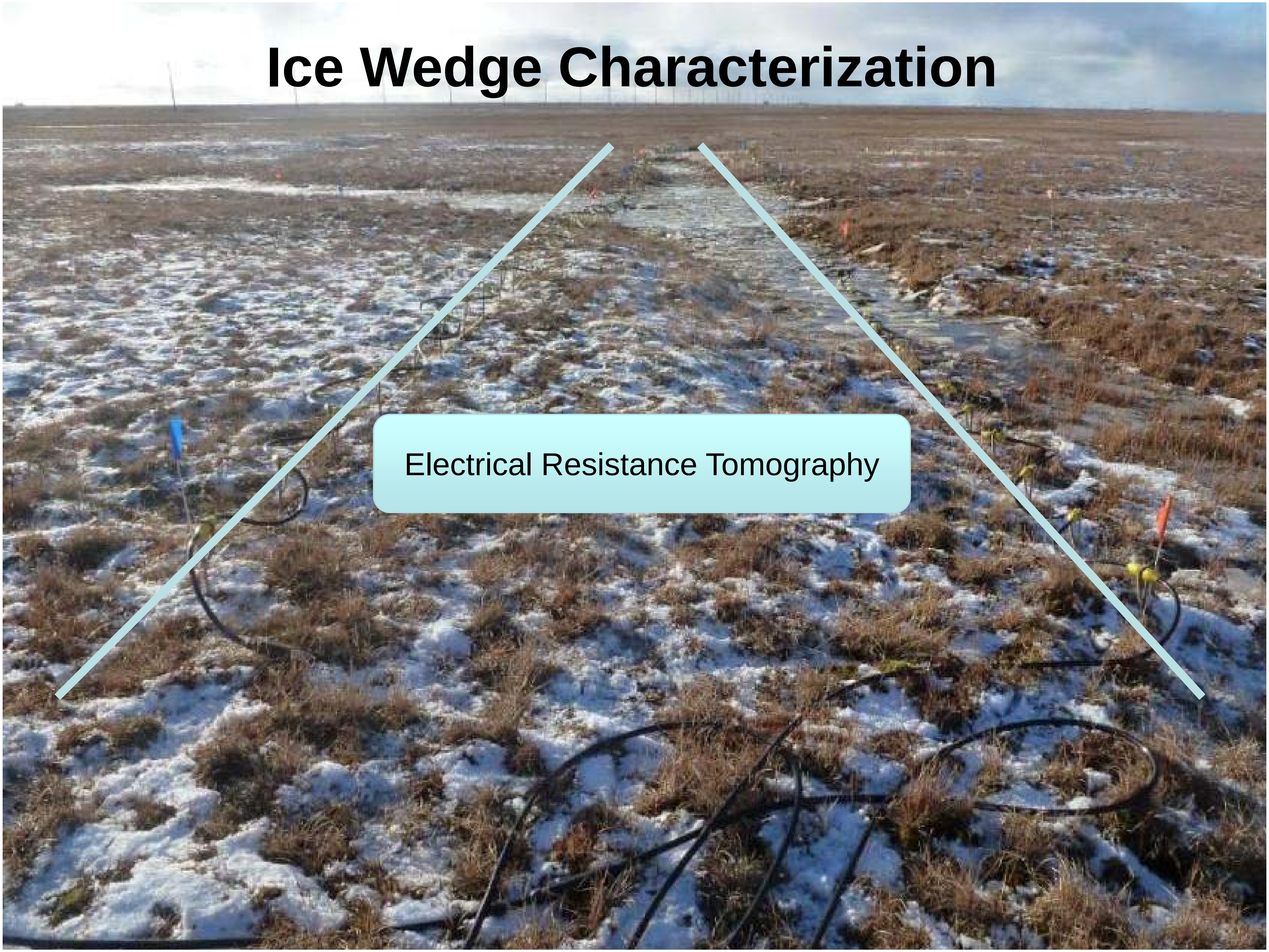


ALT and Soil Moisture Estimated Using Bayesian Approaches



Wainwright, H., S. S. Hubbard, C. Gangodagamage, J. C. Rowland, A. Liljedahl, A. Gusmeroli, B. Dafflon, C. Ulrich, Y. Wu, C. Wilson, C. Tweedie, and S.D. Wullschleger. 2013. High resolution characterization of heterogeneous Arctic tundra subsurface properties using a multiscale Bayesian fusion approach with geophysical datasets. Journal TBD (to be submitted).

Ice Wedge Characterization



Ice Wedge Characterization

Baptiste Dafflon
(LBNL)

Vegetation Dynamics:

Most Earth System Models (ESMs) use the Farquhar et al. (1980) approach to estimate Gross Primary Production (GPP).

Rubisco Carboxylation

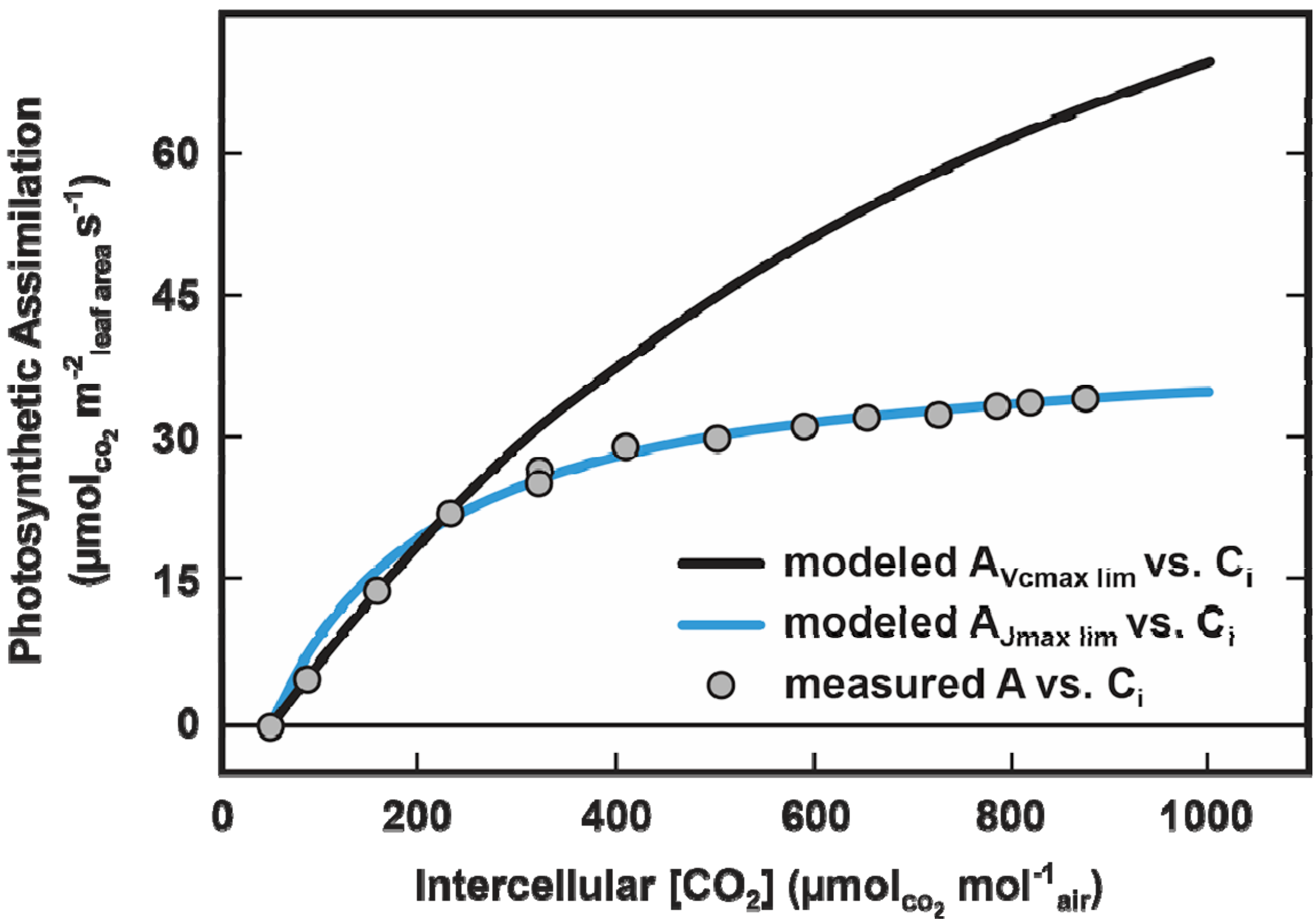
$$w_c = \frac{V_{\mathrm{c,max}} C_{\mathrm{i}}}{C_{\mathrm{i}} + K_{\mathrm{c}}(1 + O/K_{\mathrm{o}})}$$

RuBP Regeneration

$$w_{\mathrm{j}} = \frac{J C_{\mathrm{i}}}{4.5 C_{\mathrm{i}} + 10.5 \Gamma^{*}}$$

Triose-Phosphate Utilization

$$w_{\mathrm{p}} = \frac{3 V_{\mathrm{tpu}}}{\left(1 - \frac{\Gamma *}{C_{\mathrm{i}}}\right)}$$


Photosynthetic Assimilation (μmol_{CO_2} $m^{-2}_{leaf\ area}$ s^{-1})
0
15
30
45
60
0
200
400
600
800
1000
Intercellular [CO_2] (μmol_{CO_2} mol^{-1}_{air})
modeled $A_{Vcmax\ lim}$ vs. C_i
modeled $A_{Jmax\ lim}$ vs. C_i
measured A vs. C_i

Vegetation Dynamics: Continued

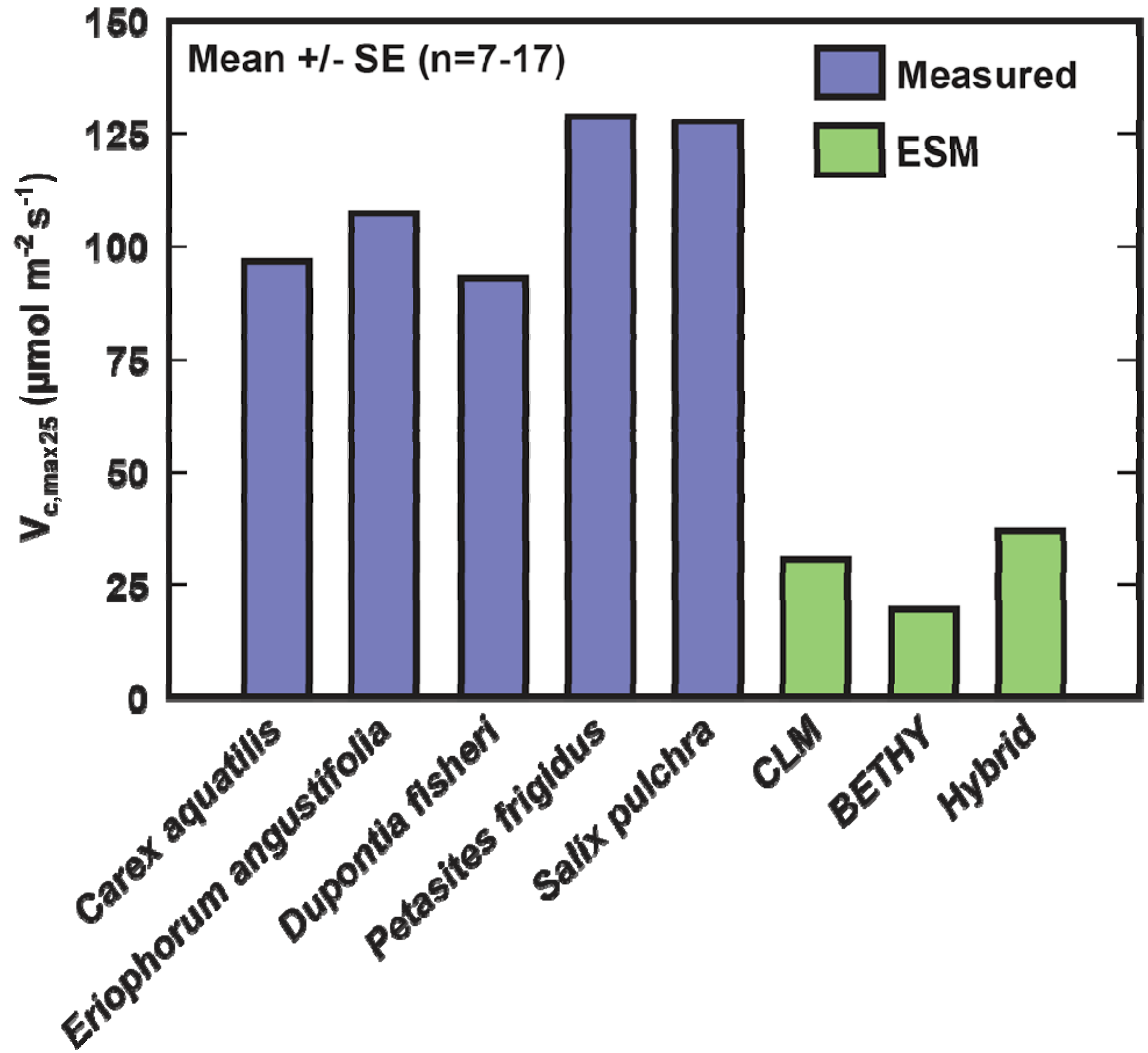
Synthesis efforts to derive estimates of $V_{c,max}$ for Arctic plant species have historically not contained enough data to generate parameters for the Farquhar et al. model of photosynthesis…

Wullschleger SD. 1993. Biochemical limitations to carbon assimilations in C3 plants – A retrospective analysis of the A/Ci curves from 109 species. Journal of Experimental Botany 44: 907-920.

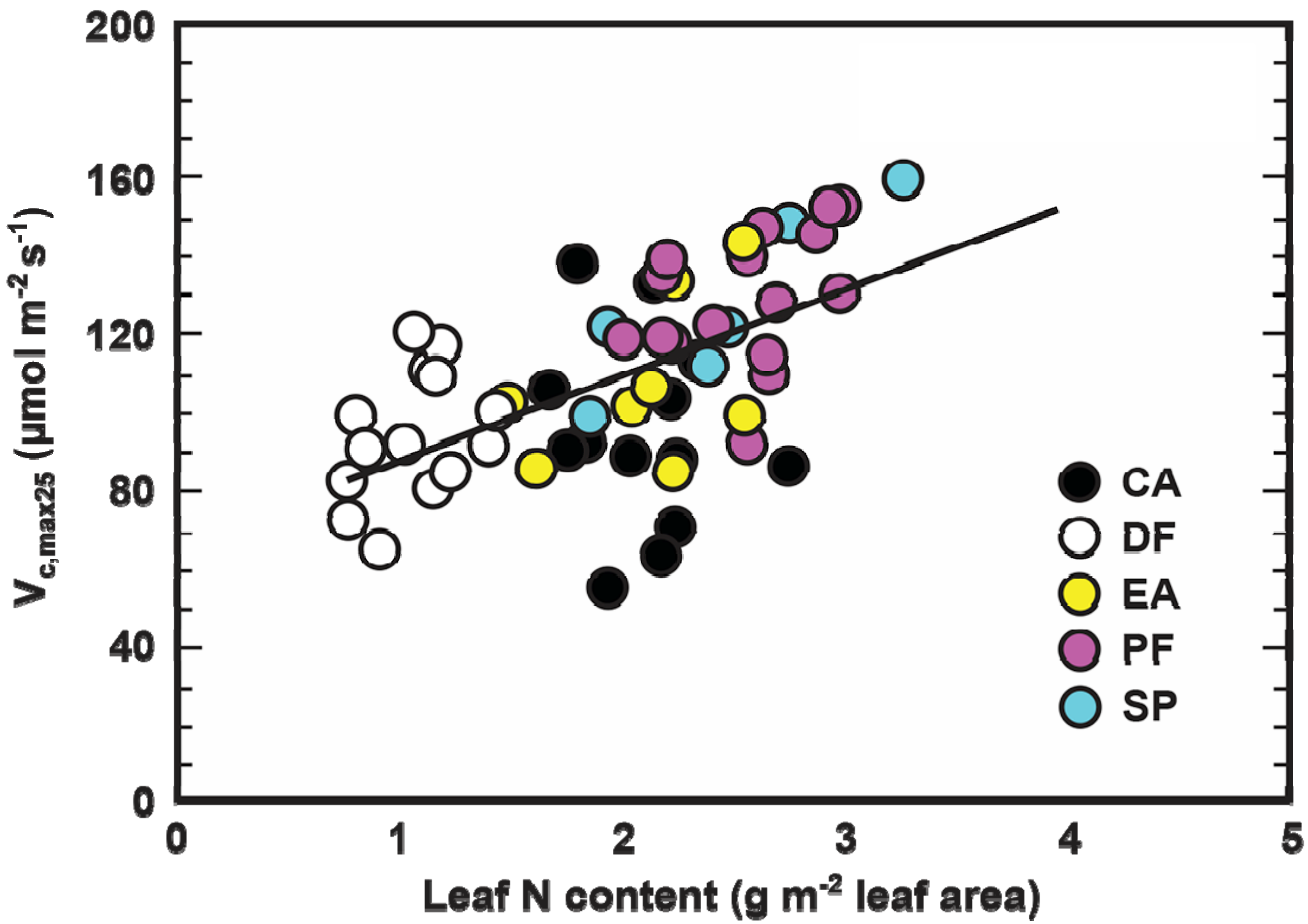
Kattge J, W. Knorr, T. Raddatz and C. Wirth. 2009. Quantifying photosynthetic capacity and its relationship to leaf nitrogen for global-scale terrestrial biosphere models. Global Change Biology 15: 976-991.

The NGEE Arctic project is beginning to provide field-relevant estimates of photosynthetic biochemistry, as well as insights into how parameters vary with temperature, water, and nitrogen, and how that variation should be represented in models.

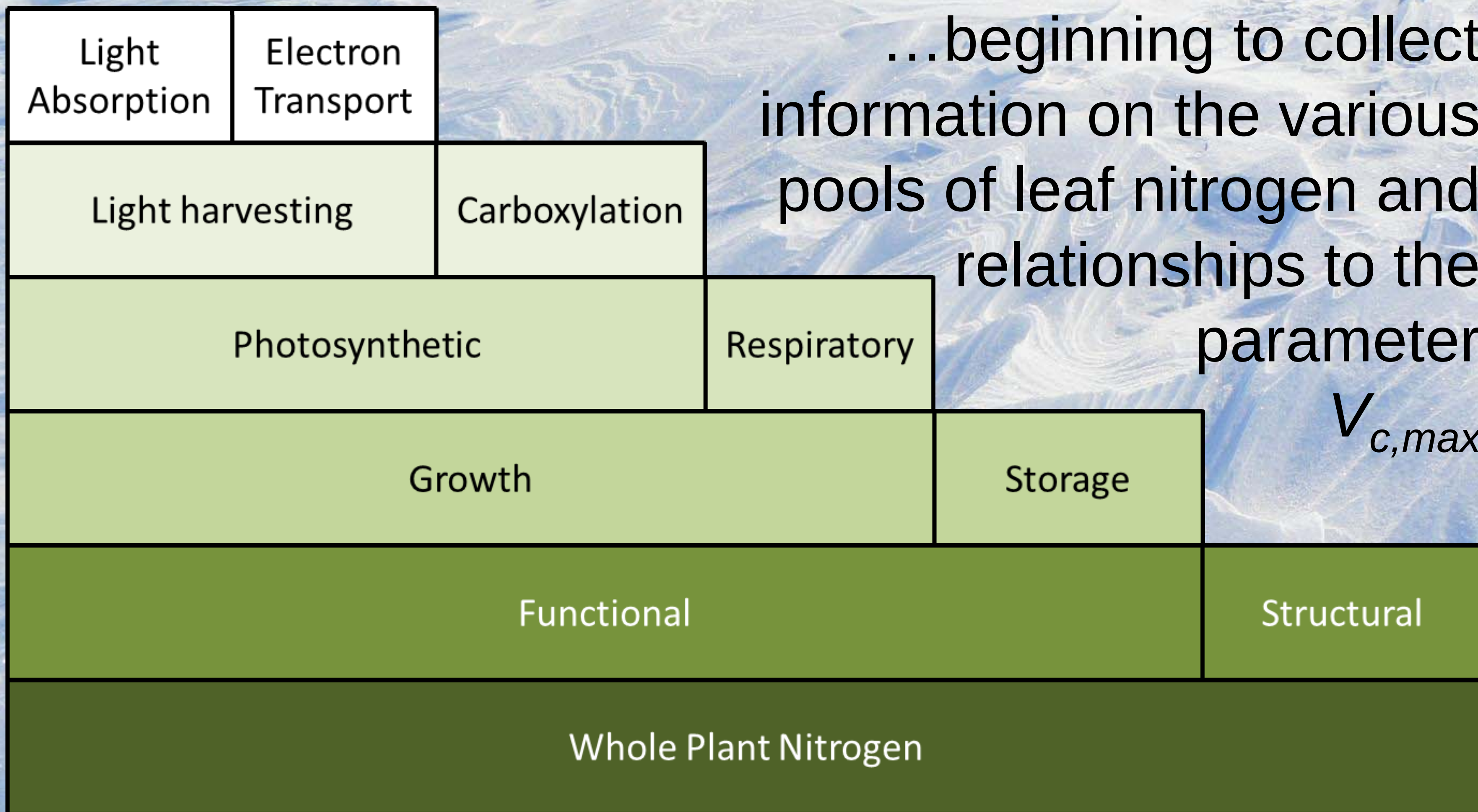
Plant physiologist Alistair Rogers (BNL) demonstrates operation of LiCOR photosynthesis system to modeler Peter Thornton (ORNL) outside Barrow, Alaska.



Rogers A. 2013. The use and misuse of Vc,max in Earth System Models. Photosynthesis Research (in press).


200
160
120
80
40
0
0
1
2
3
4
5
Vc,max25 (µmol m-2 s-1)
Leaf N content (g m-2 leaf area)
CA
DF
EA
PF
SP

Dynamic Nitrogen Allocation Model

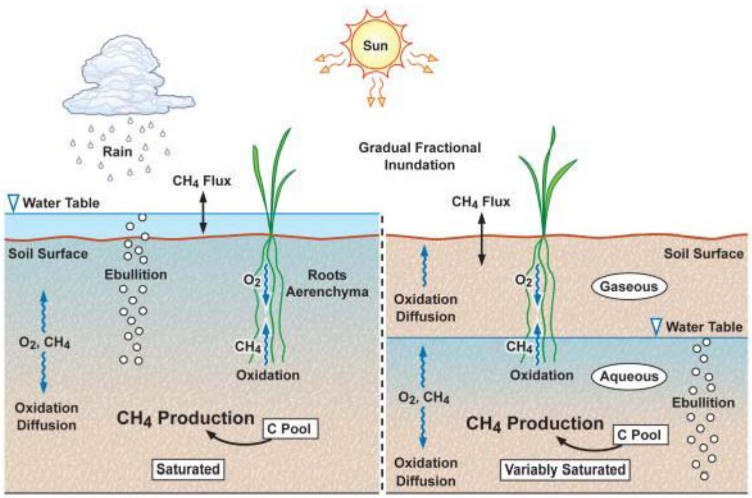


…beginning to collect information on the various pools of leaf nitrogen and relationships to the parameter $V_{c,max}$

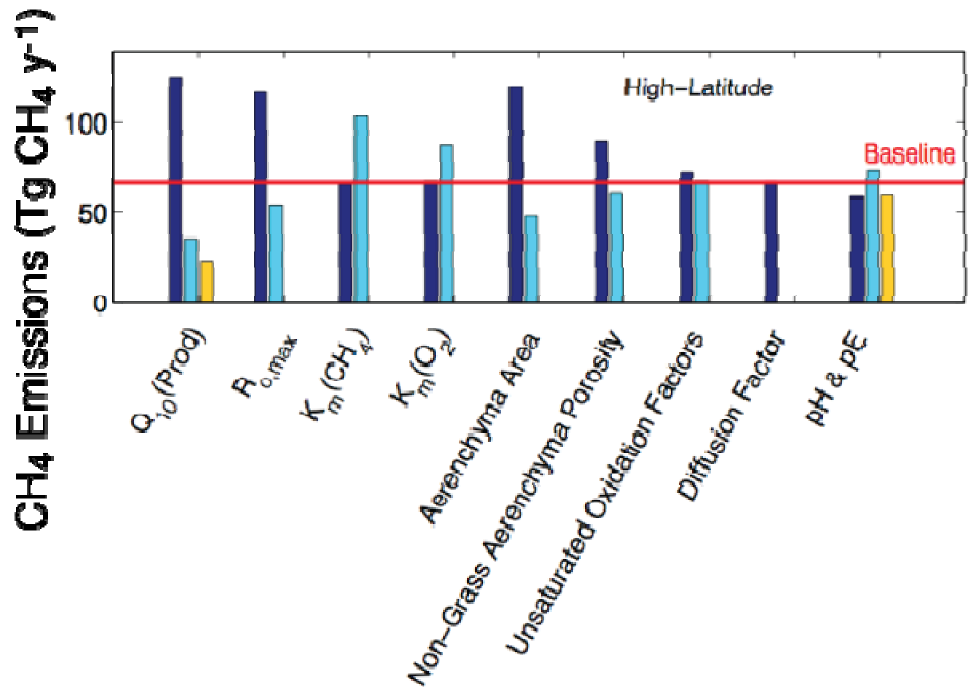
Xu C., R. Fisher, S.D. Wullschleger, C.J. Wilson, M. Cai and N.G. McDowell. 2012. Toward a mechanistic modeling of nitrogen limitation on vegetation dynamics. PLoSONE e37914.

Biogeochemistry:

What are the controls on methane production?



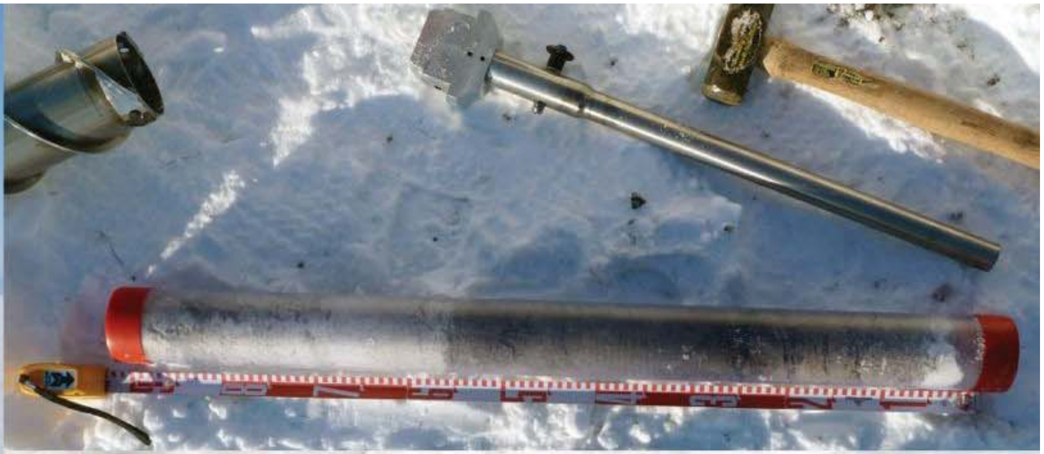
CLM4Me

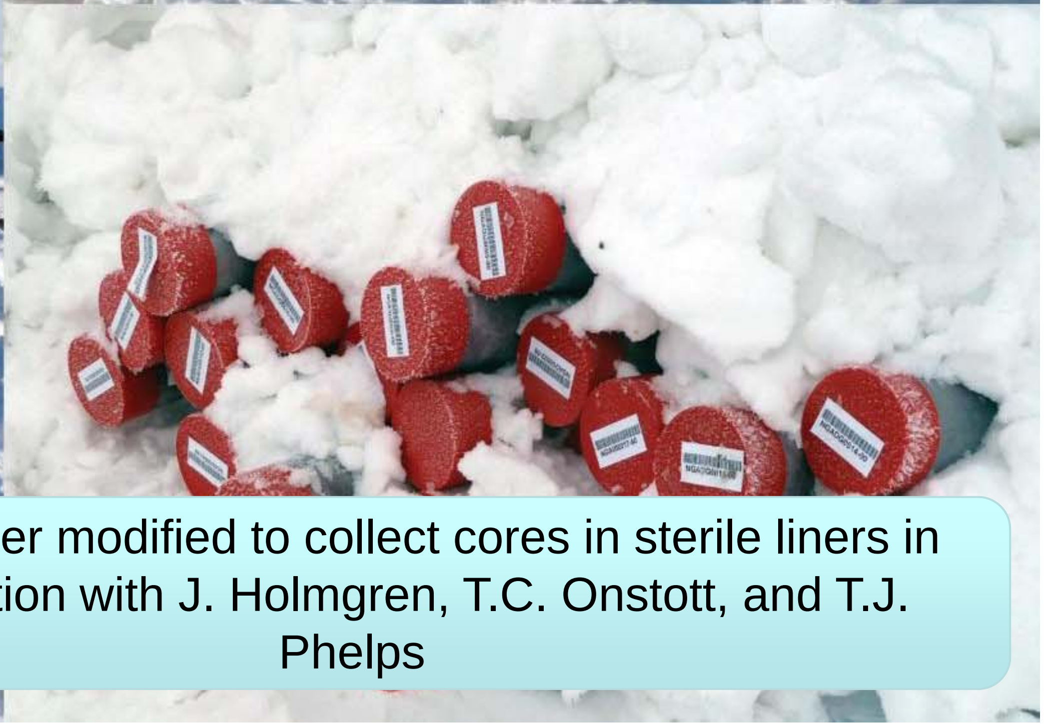


Methane emission models are highly sensitive to differences in temperature and oxygen response factors. Extrapolating parameters measured in temperate soils introduces significant uncertainty in predictions.

Riley, W. J., Z. M. Subin, D. M. Lawrence, S. C. Swenson, M. S. Torn, L. Meng, N. M. Mahowald, and P. Hess. 2011. Barriers to predicting changes in global terrestrial methane fluxes: analyses using a methane biogeochemistry model integrated in CESM. Biogeosciences 8:1925-1953.

27 permafrost cores drilled from Barrow polygonal tundra

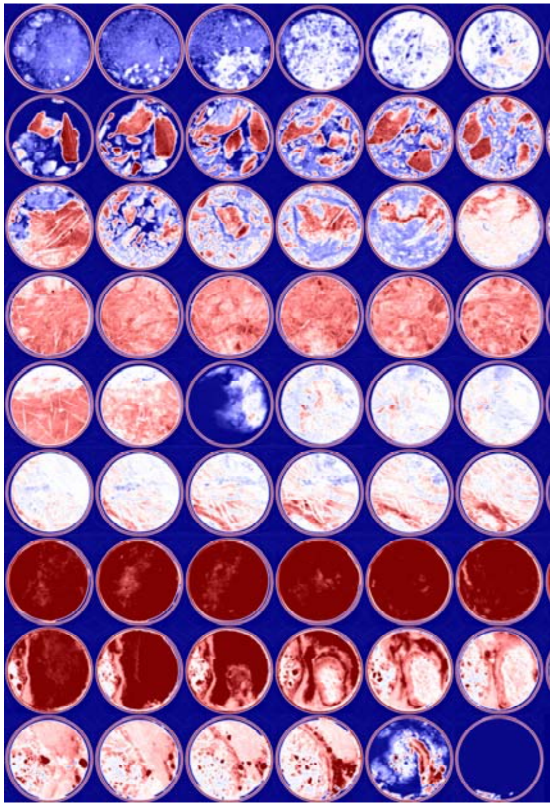




SIPRE auger modified to collect cores in sterile liners in collaboration with J. Holmgren, T.C. Onstott, and T.J. Phelps

Frozen cores analyzed using x-ray computer tomography (CT scans)

Tim Kneafsey (LBNL)



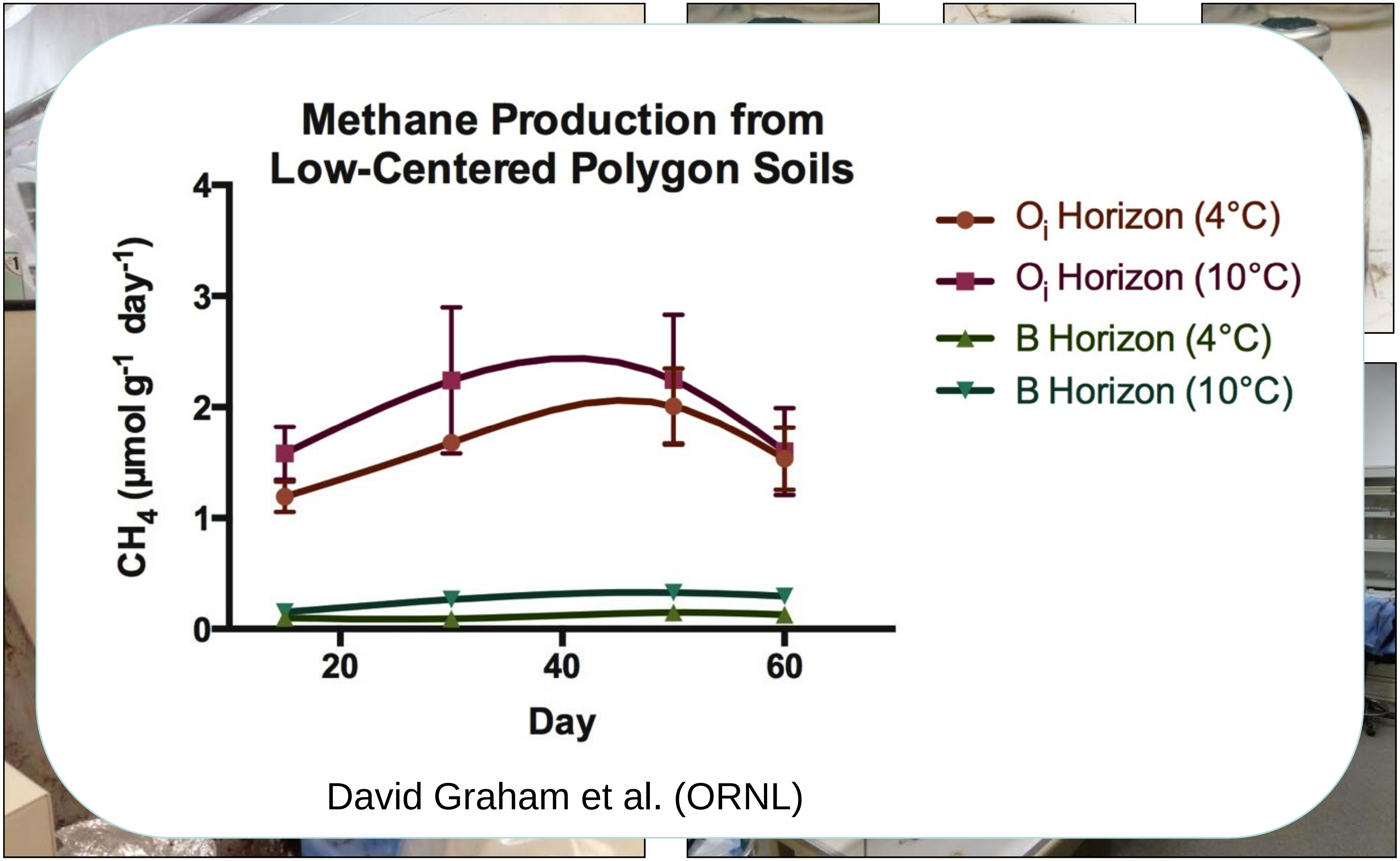
0 – 6 cm
7 – 12 cm
13 – 18 cm
19 – 24 cm
25 – 30 cm
31 – 36 cm
37 – 42 cm
43 – 48 cm
49 – 54 cm

Qualitative Legend
White: density close to 1 ~ ice
Red: higher density ~ mineral soil
Blue: low density ~ organic matter, voids

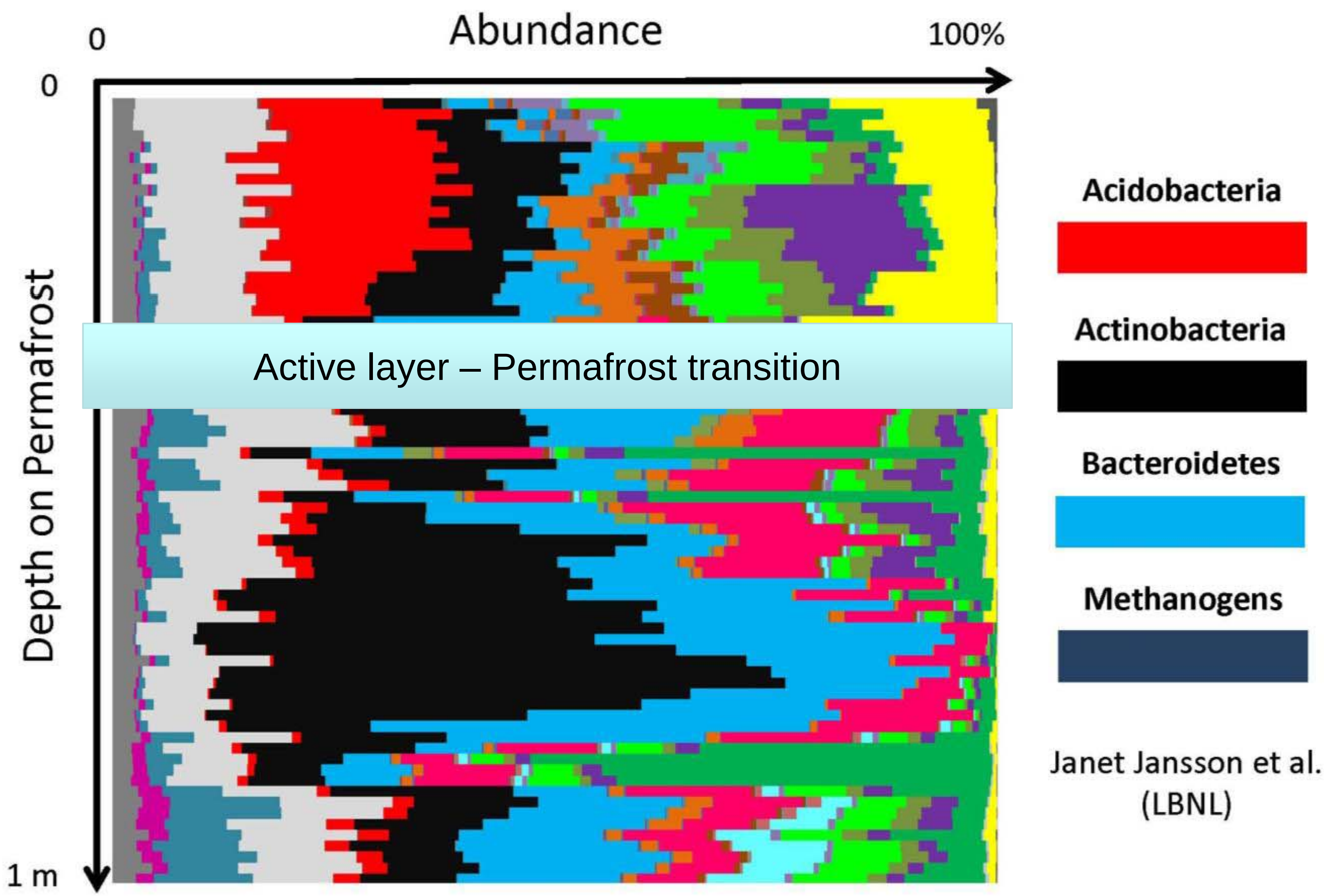
Frozen cores processed for anoxic incubations and SOM analysis

Beth Herndon and Taniya Roy-Chowdhury (ORNL)

Frozen cores processed for anoxic incubations and SOM analysis



David Graham et al. (ORNL)



Graham D.E., M.D. Wallenstein, T.A. Vishnivetskaya, M.P. Waldrop, T.J. Phelps, S.M. Pfiffner, T.C. Onstott, L.G. Whyte, D. Gilichinsky, D.A. Elias, R. Mackelprang, N.C. VerBerkmoes, R.L. Hettich, D. Wagner, S.D. Wullschleger and J.K. Jansson. 2012. Microbes in thawing permafrost: The unknown variable in the climate change equation. The ISME Journal 6: 709-712.

Collaborative analysis of microbial communities and SOM chemistry will improve models of decomposition

JGI CSP Proposal (PI: Jansson)
Metagenome and microbial isolate genome sequencing

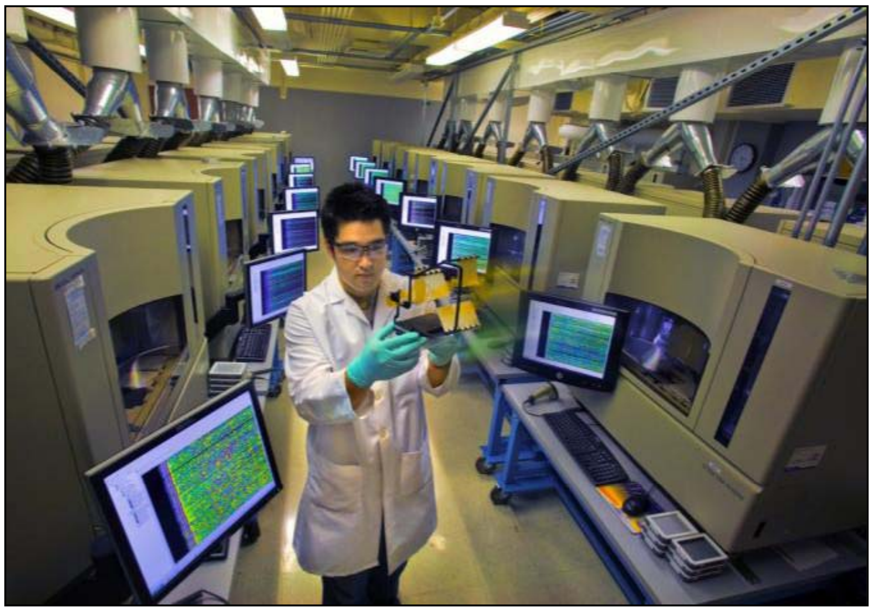


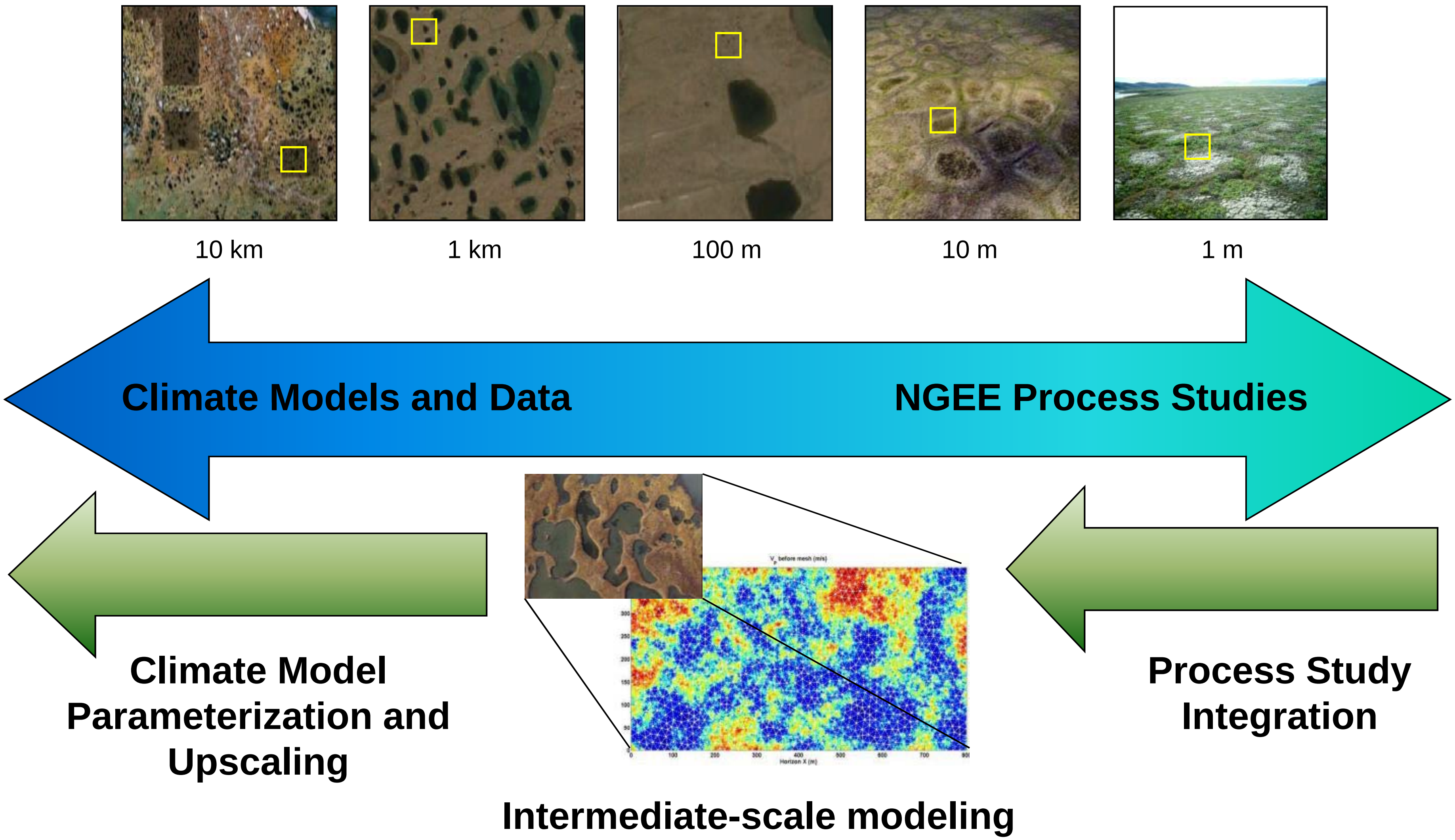
Photo courtesy Joint Genome Institute

EMSL User Proposal (PI: Gu)
Ultrahigh resolution spectroscopy of soil carbon chemistry

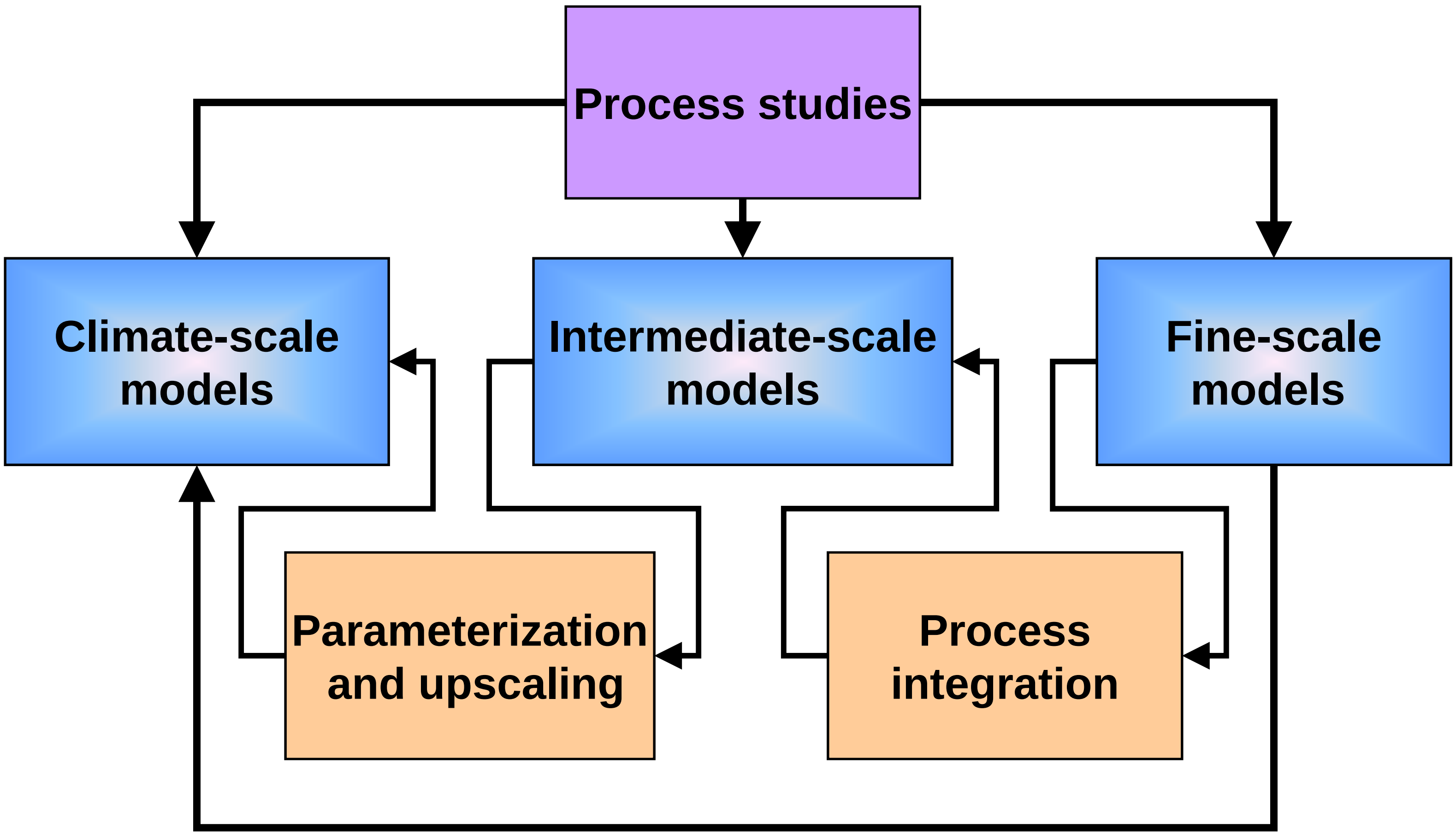
Photo courtesy Pacific Northwest National Laboratory

Multi-Scale Process Integration and Modeling Challenge

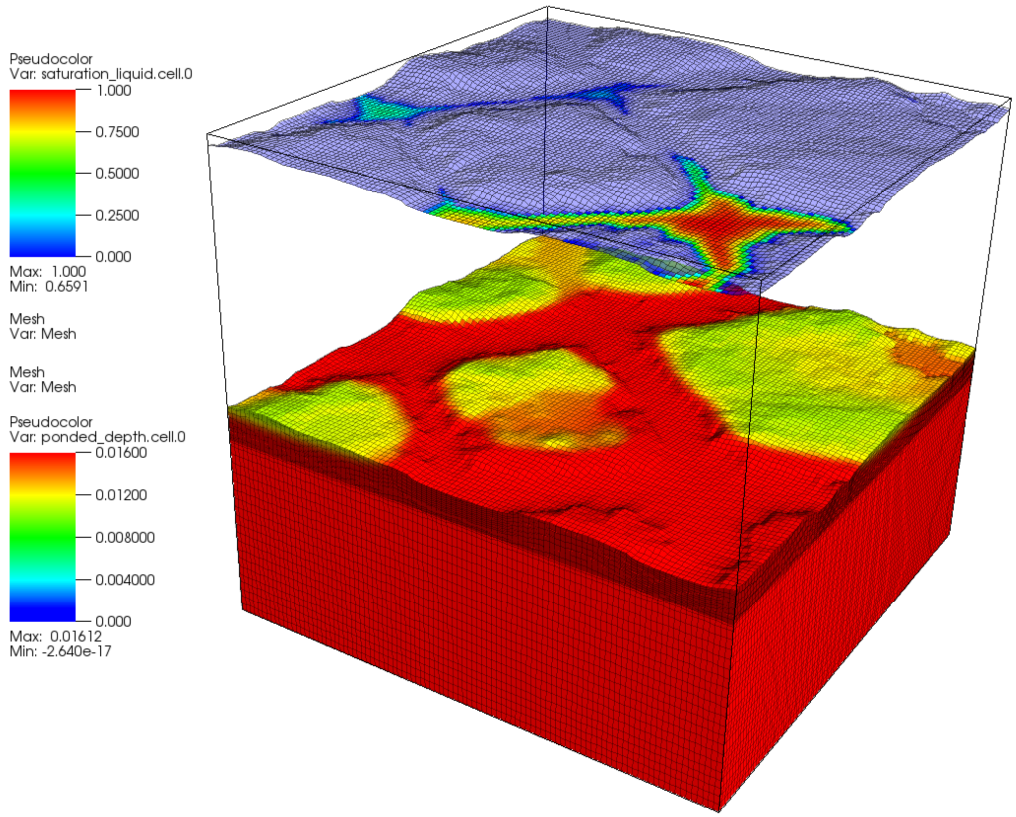
--- Migration of new process knowledge across 5 orders of magnitude ---



NGEE Arctic Modeling: Knowledge Synthesis and Integration



Arctic Terrestrial Simulator (ATS)



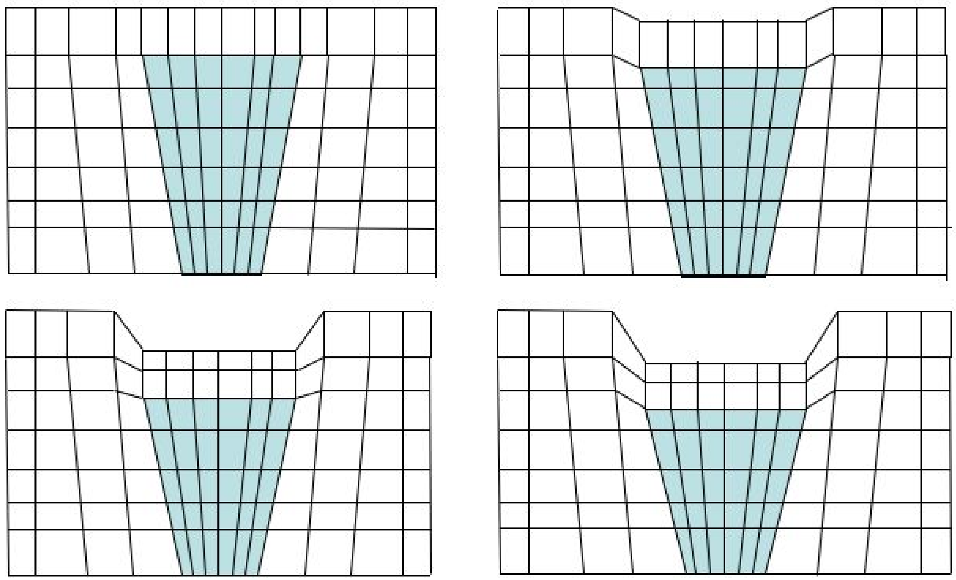
- *Single polygon domain* (25m x 25m) with surface topography from Barrow LiDAR data.
- *Multiple polygon domain* (100m x 100m) with surface topography from Barrow LiDAR data.

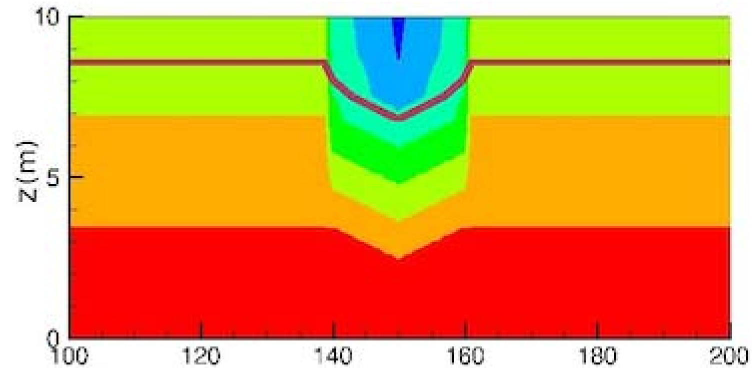
Lewis K., G. Zyvoloski, C. Wilson, B. Travis, and J. Rowland. 2012. Drainage subsidence associated with Arctic permafrost degradation. Journal of Geophysical 117: F04019

Painter S., J.D. Moulton, and C. Wilson. 2013. Modeling challenges for predicting hydrologic response to degrading permafrost, Hydrogeology Journal 21: 221-224.

Arctic Terrestrial Simulator (ATS)

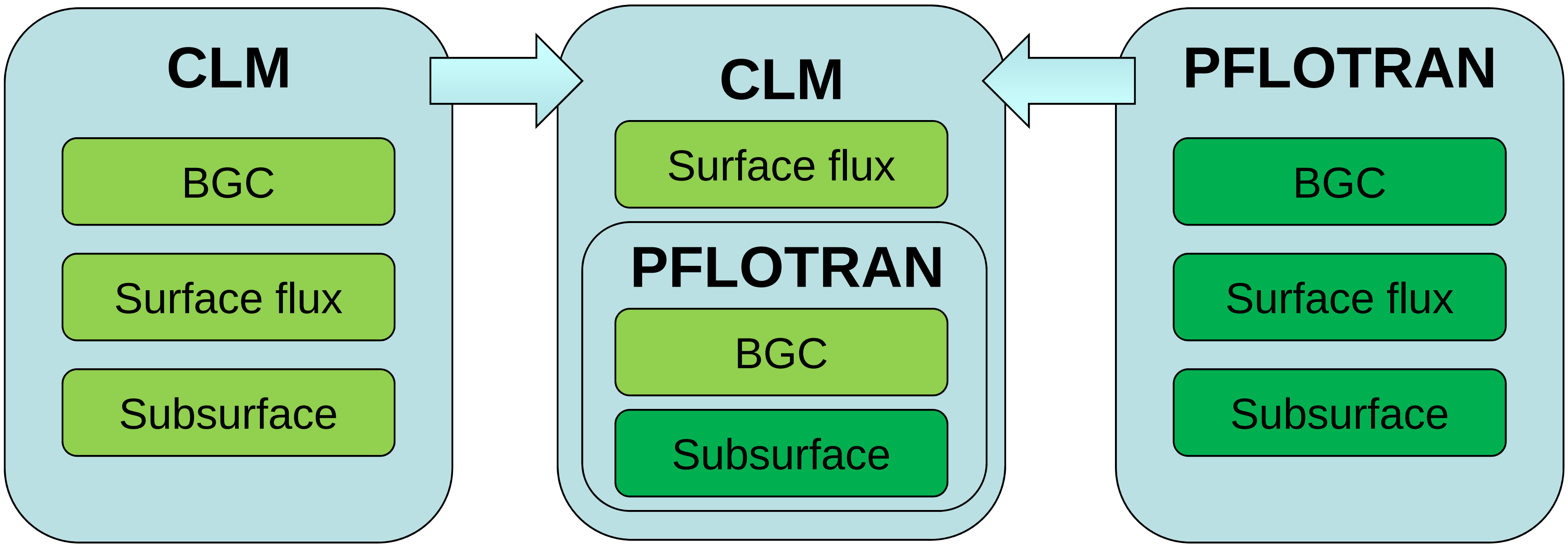
Subsidence





Left: Schematic showing four time snapshots of a cross section of a deforming grid. The time sequence advances left to right (a–b) then top to bottom (c–d). The blue cells represent ice, the clear cells soil. Note the deforming grid, which requires advanced discretization methods to maintain accuracy (Painter et al. 2012). Right: Subsidence field (Lewis et al. 2013).

CLM-PFLOTRAN coupling for NGEE Arctic



CLM's BGC algorithms are being implemented in PFLOTRAN.

CLM's subsurface routines are being replaced by PFLOTRAN.

CLM's surface flux algorithms and implementation are being retained.

Current prototype interface between CLM and PFLOTRAN is being refined.

This diagram illustrates how the interoperability of CLM and PFLOTRAN is being addressed. The Arctic Terrestrial Simulator (ATS) will assess a similar interoperability approach with CLM.

NGEE Arctic: Developing a process-rich land surface model for improved climate prediction

Field and Laboratory Studies

- New parameters and algorithms
  - Landscape evolution
  - Plant functional types
  - Permafrost
  - Root function
  - Biogeochemistry
  - Hydrology
- Initialization
  - Topography
  - Geophysical characterization
  - Plant distribution
  - Soil carbon stocks and distribution
- Evaluation
  - Eddy covariance estimates of flux
  - Water outflow
  - Energy exchange and albedo
- Discovery science

Model-Knowledge Integration

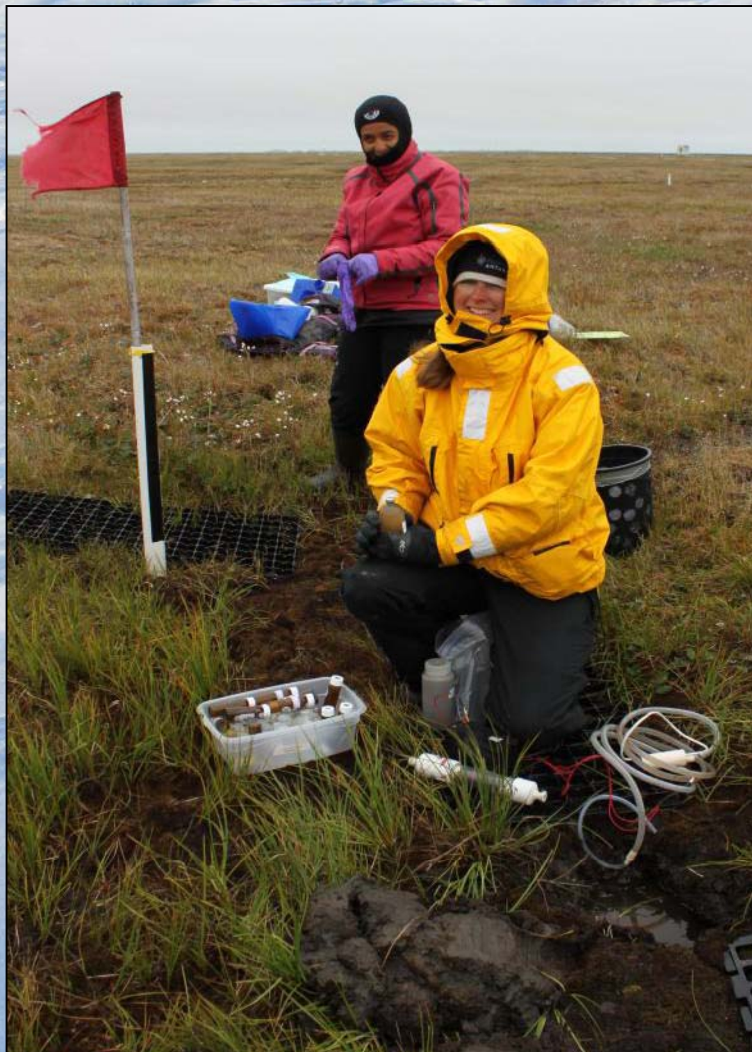
Climate Scale

"Down-scaling"

"Up-scaling"

Plot Scale

Collaborators Welcomed!



Adina Payton, UC Santa Cruz

Ken Williams (LBNL) and Derick Lovley (UMass)

Next-Generation Ecosystem Experiments: Arctic

Ecosystem Processes

Modeling, Prediction

Systems Understanding

http://ngee-arctic.ornl.gov/

http://www.flickr.com/photos/ngee-arctic/