Integration of observations, experimentation, and modeling across scales: Next-generation land models for coupled Earth system prediction

Peter Thornton

Section Head, Earth Systems Science Section, Environmental Sciences Division

Deputy Director, Climate Change Science Institute

Oak Ridge National Laboratory

Overview

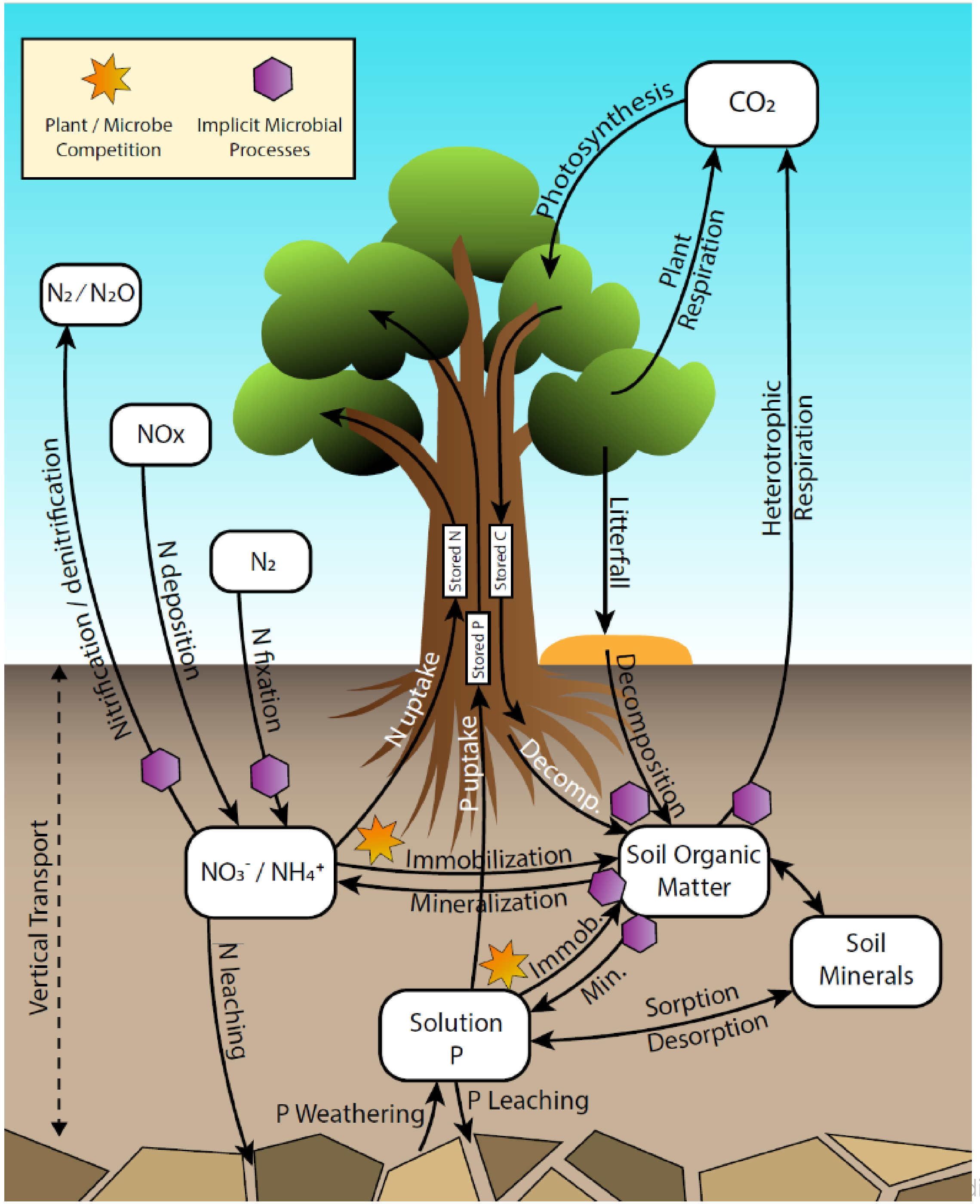
- Frontiers of land model development for ESMs: Experience from DOE's Energy Exascale Earth System Model (E3SM)
- New predictive capability for Arctic tundra systems: NGEE Arctic
- New predictive capability for coastal systems: COMPASS

Land model development for E3SM

- Representing processes and sub-grid heterogeneity
- Pushing the limits of grid resolution: challenges for computing and data
- Pushing the limits of process representation

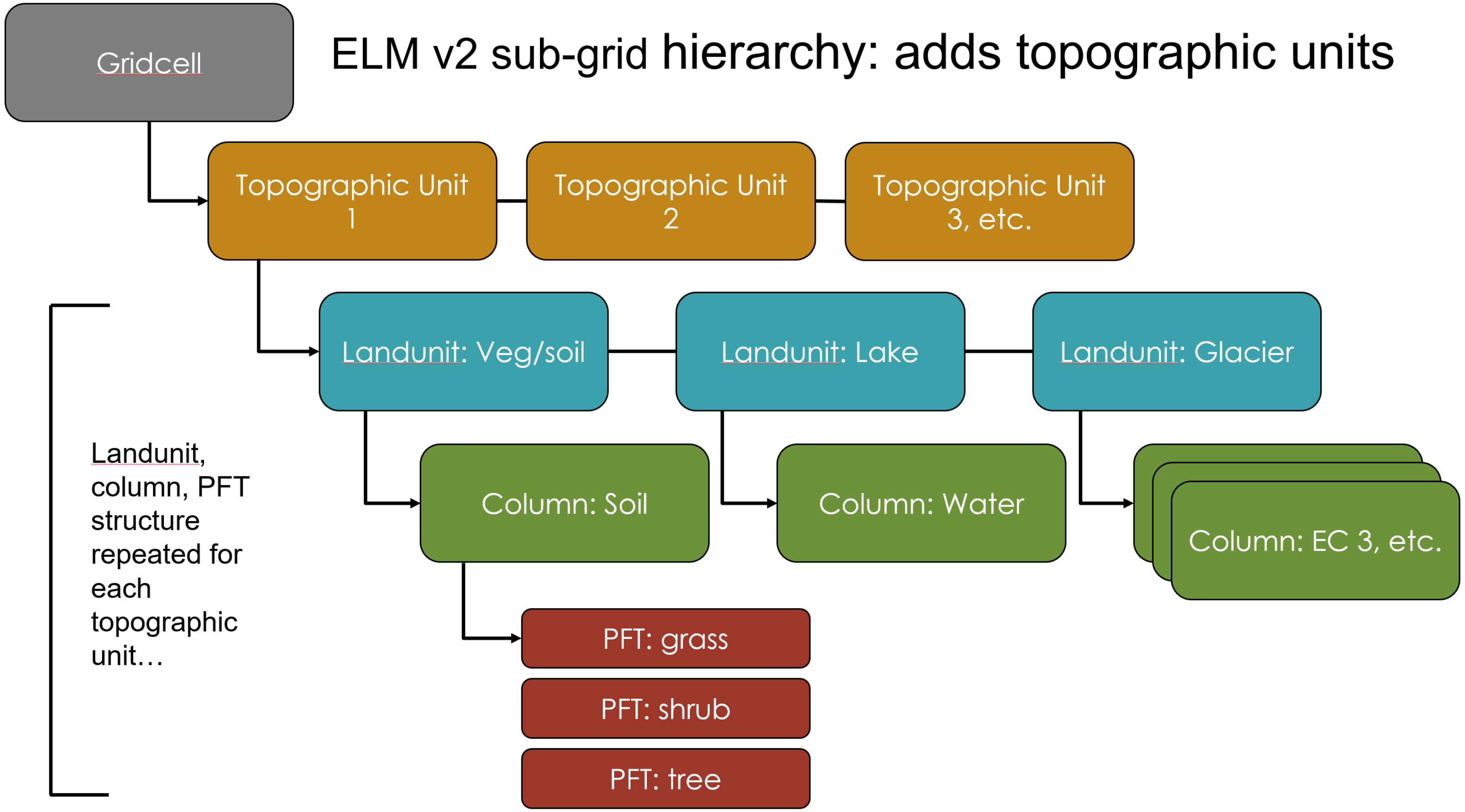
Process Representation in E3SM Land Model (ELM)

- Prognostic:
  - Energy
  - Water
  - Carbon
  - Nitrogen
  - Phosphorus
  - Vegetation structure
  - Soil biogeochemistry

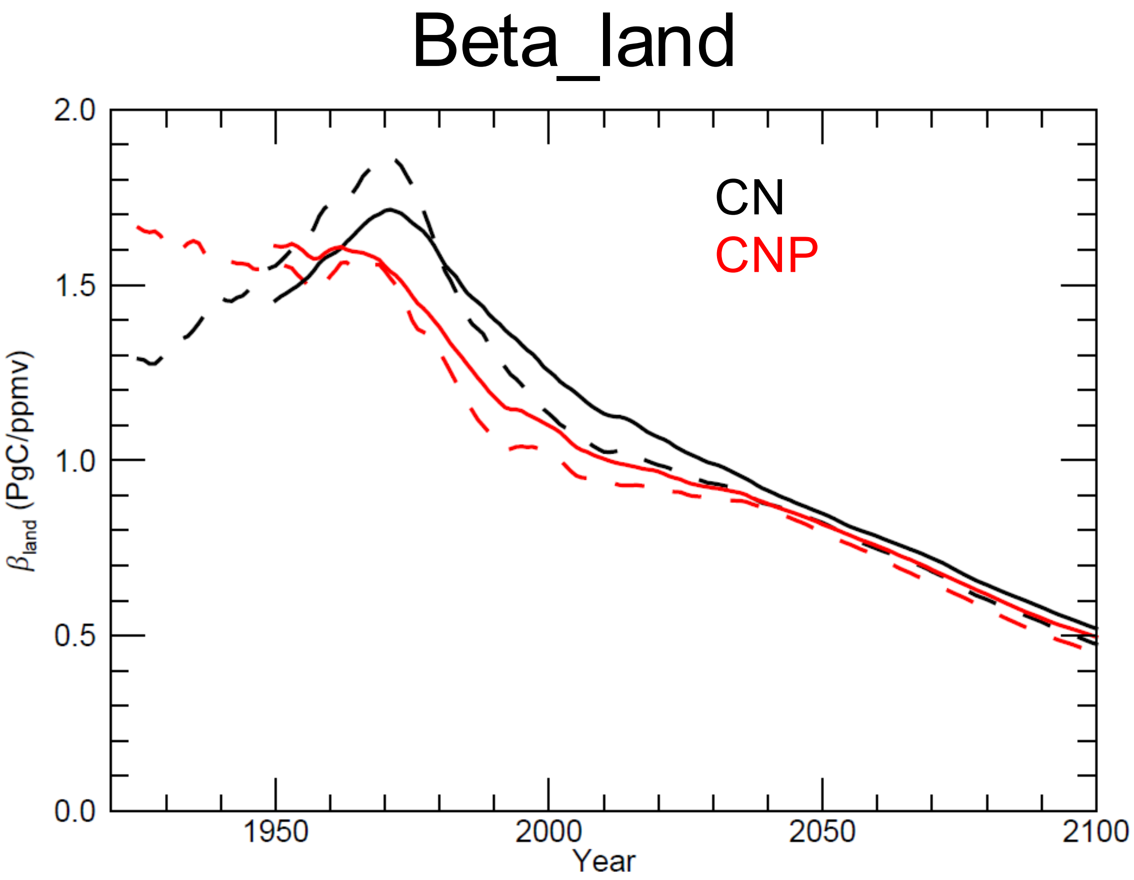


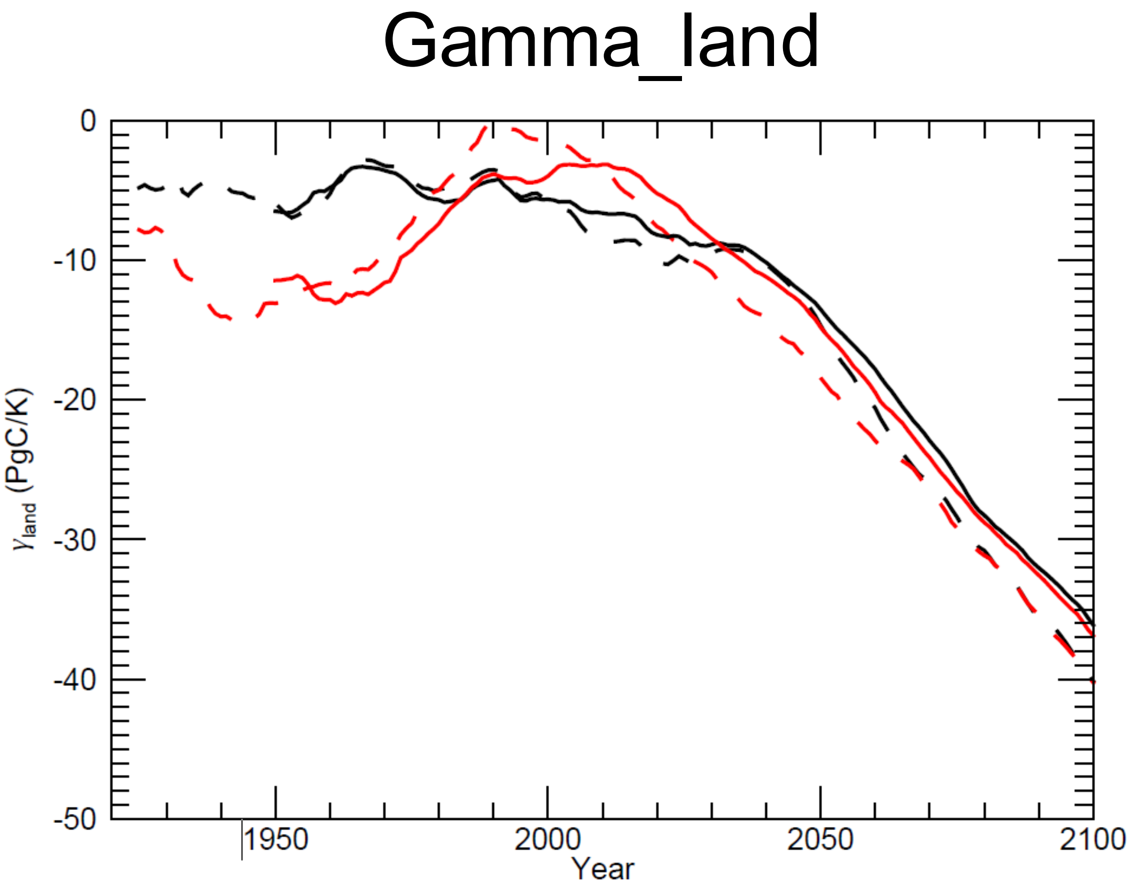
Subgrid representation in E3SM

- Use subgrid architecture of the E3SM Land Model (ELM) to capture ecosystem heterogeneity
- Use multi-scale modeling to define and parameterize the ELM subgrid configuration



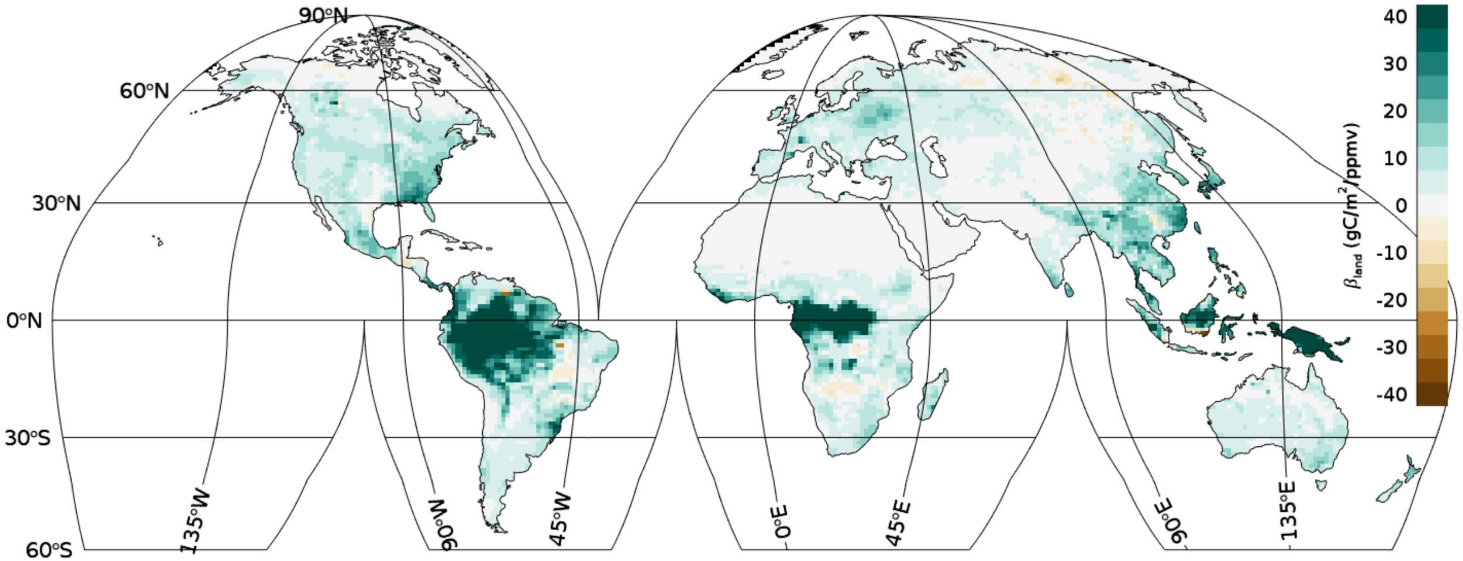
Primary feedback comparisons



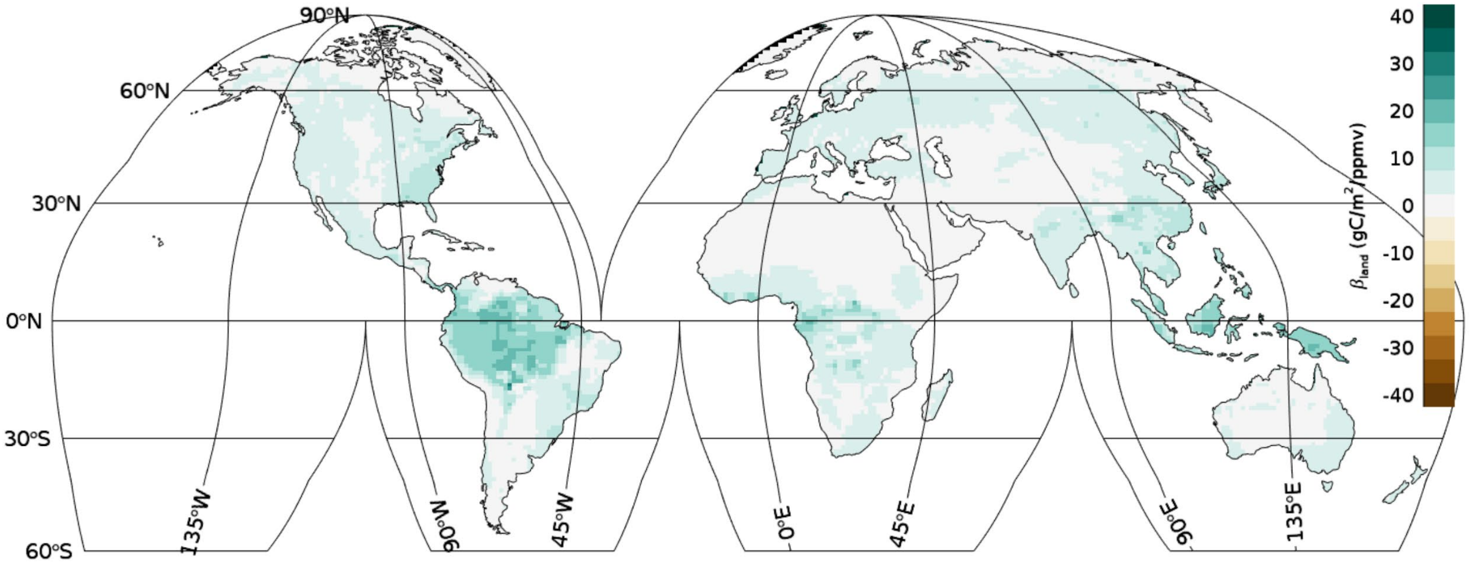


OAK RIDGE National Laboratory

CNP

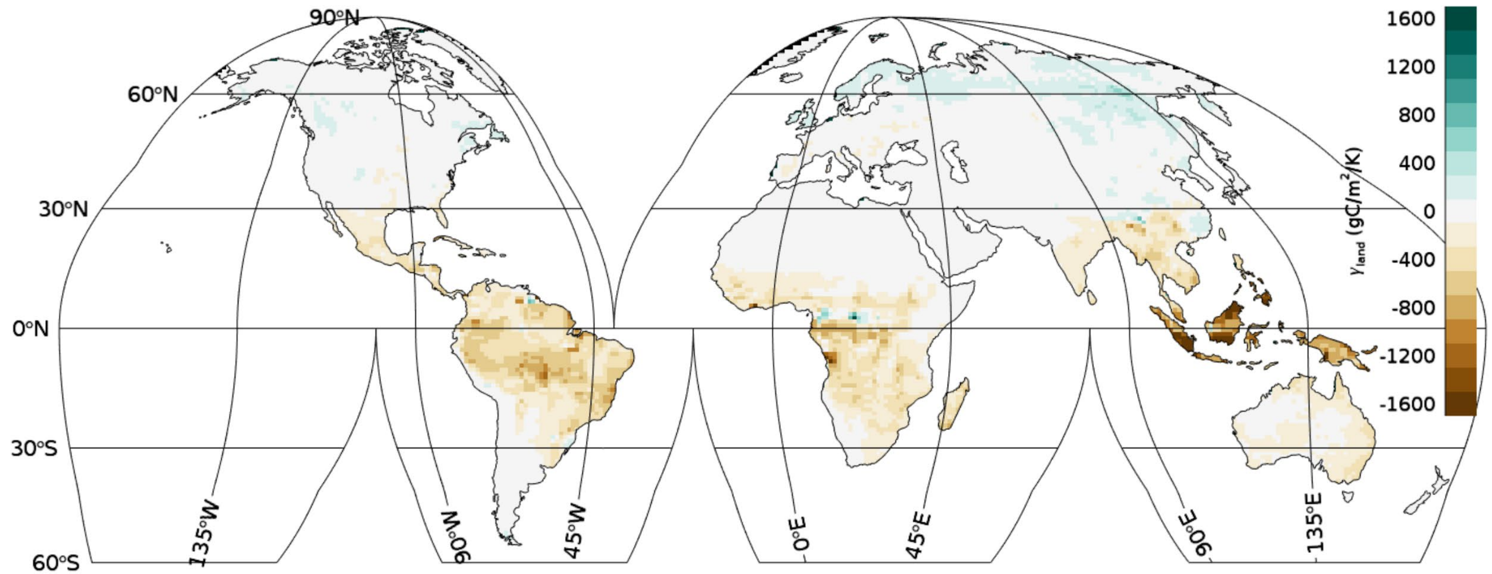


Beta$_{land}$ assessed at 2015

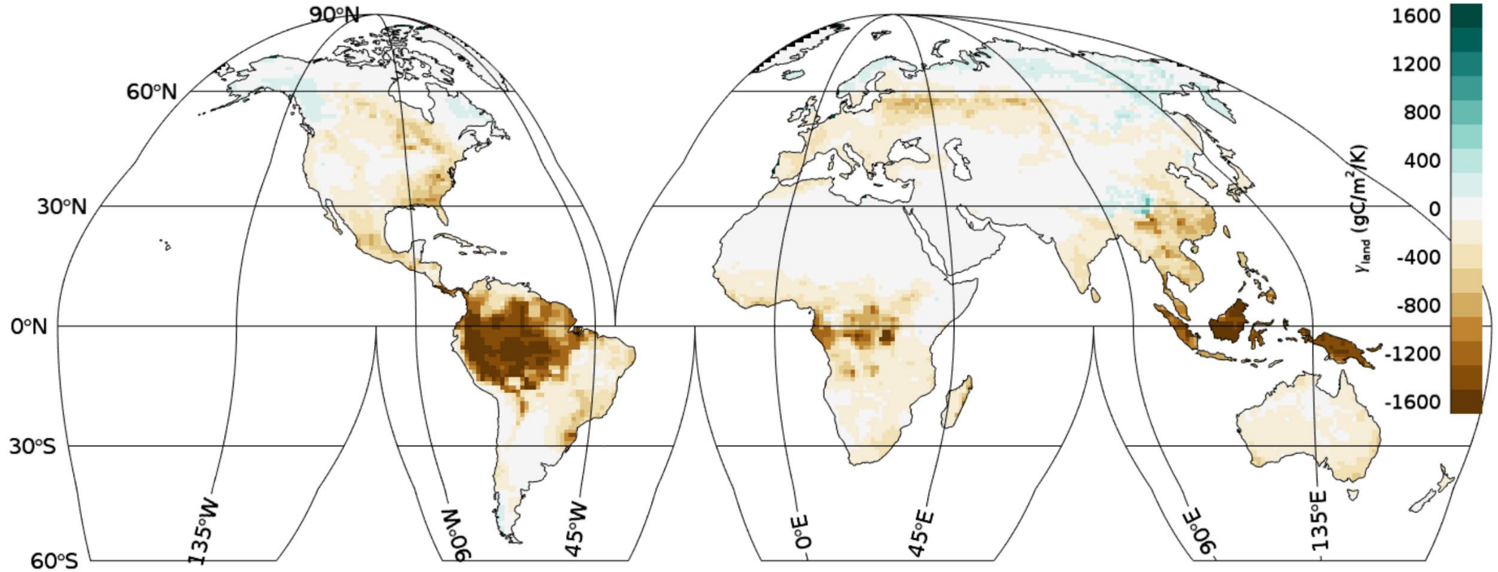


Beta$_{land}$ assessed at 2100

CNP

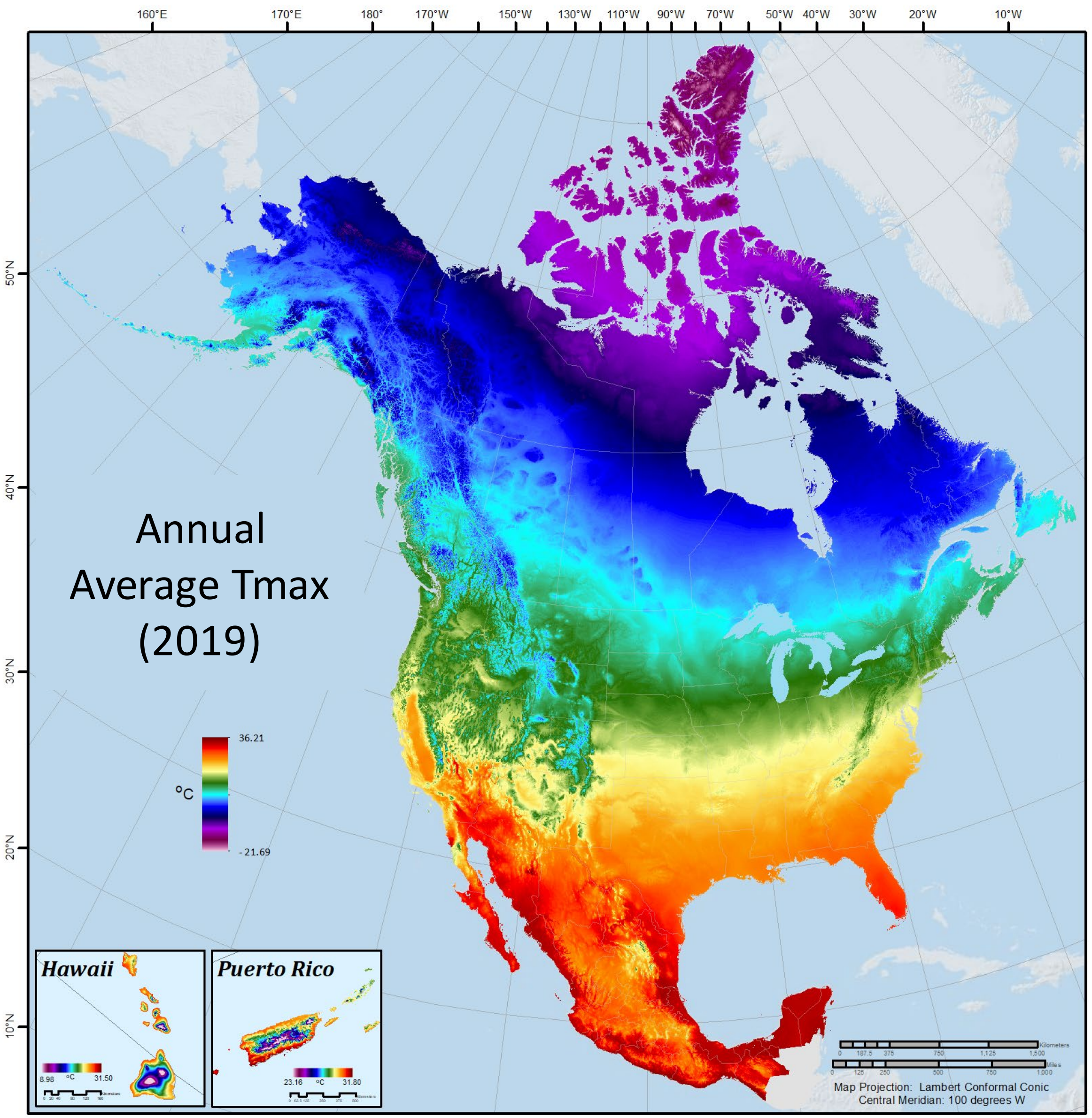


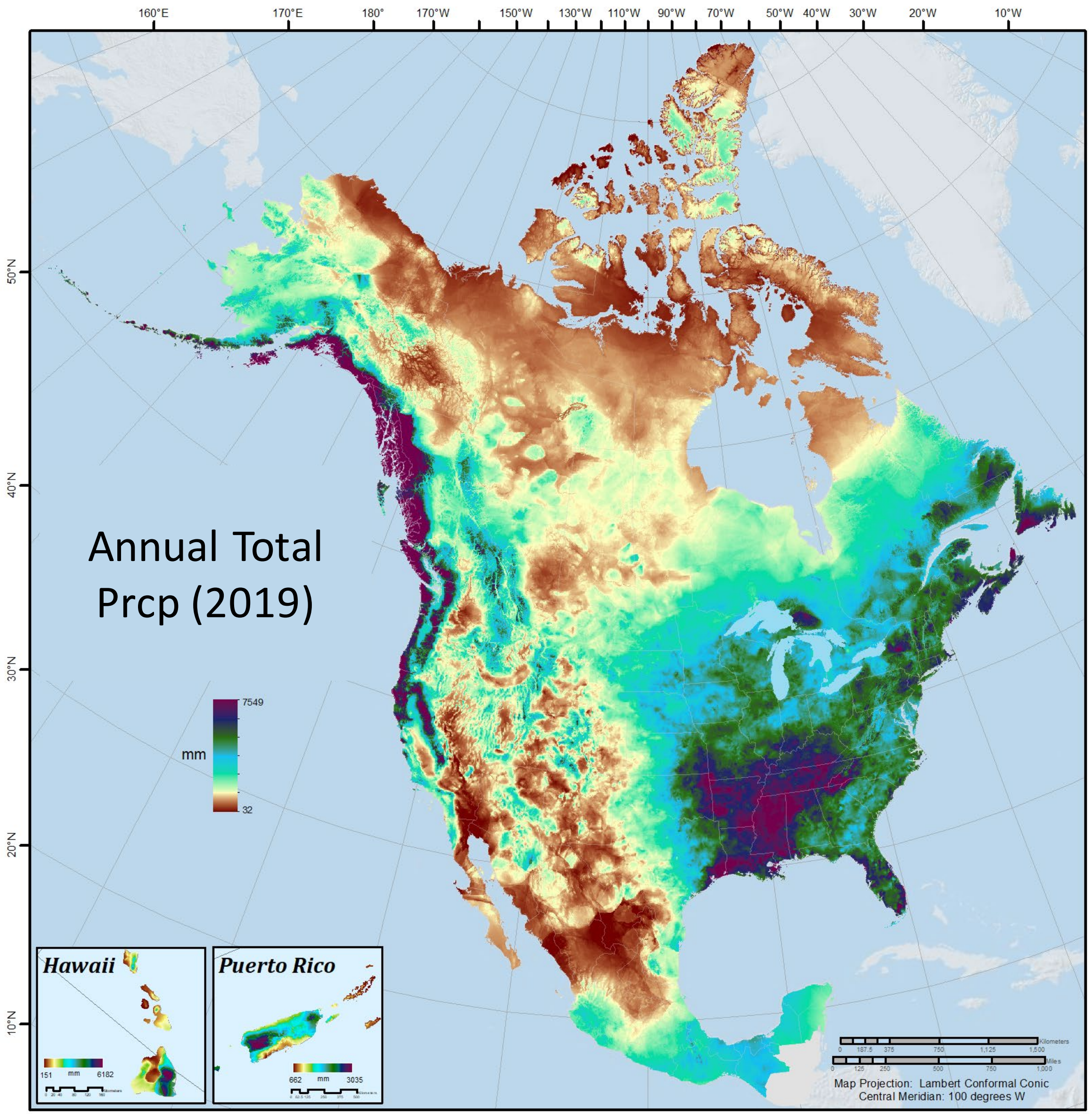
Gamma$_{land}$ assessed at 2015

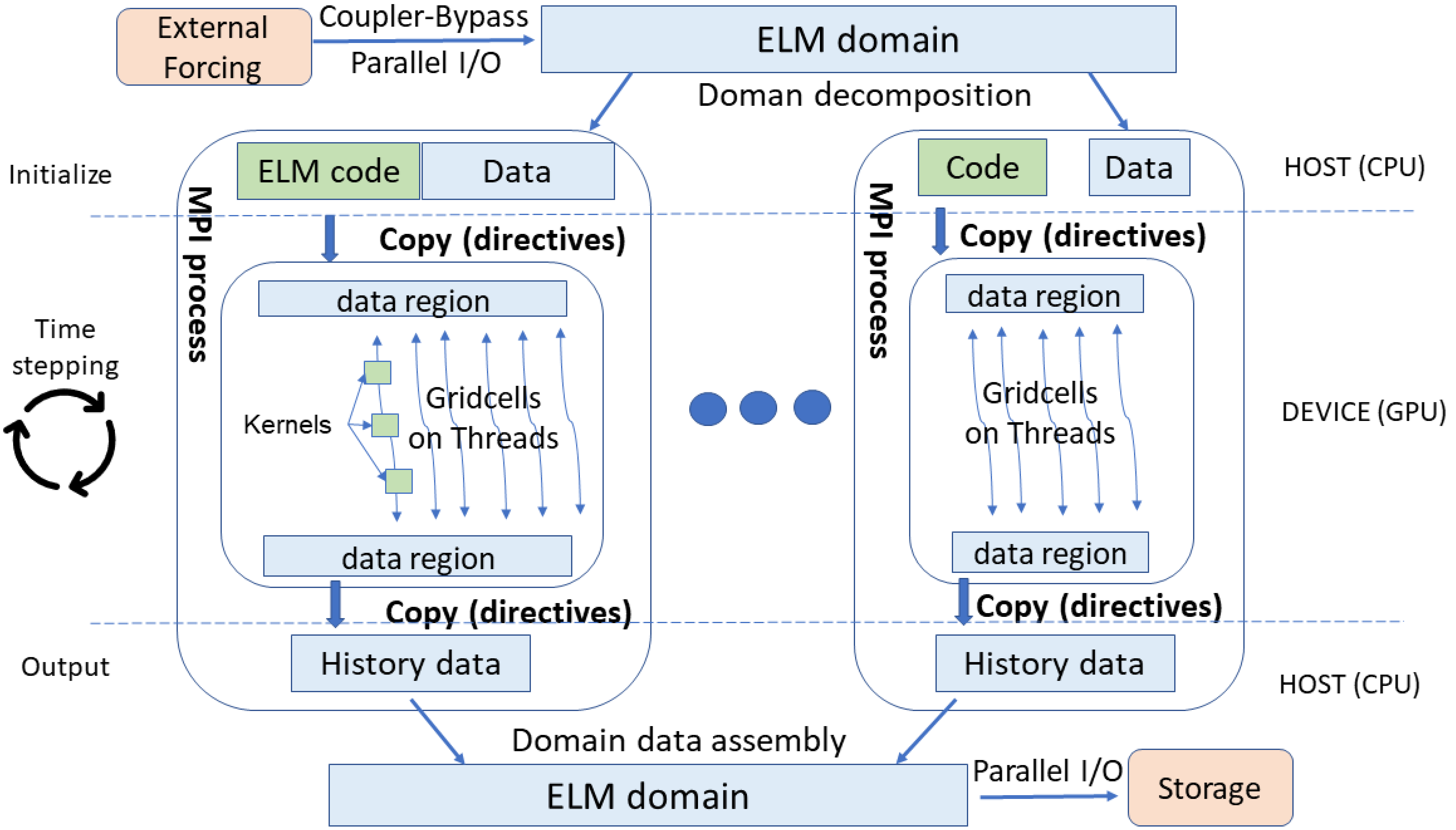


Gamma$_{land}$ assessed at 2100

Bridging scales: High resolution (1 km) simulation

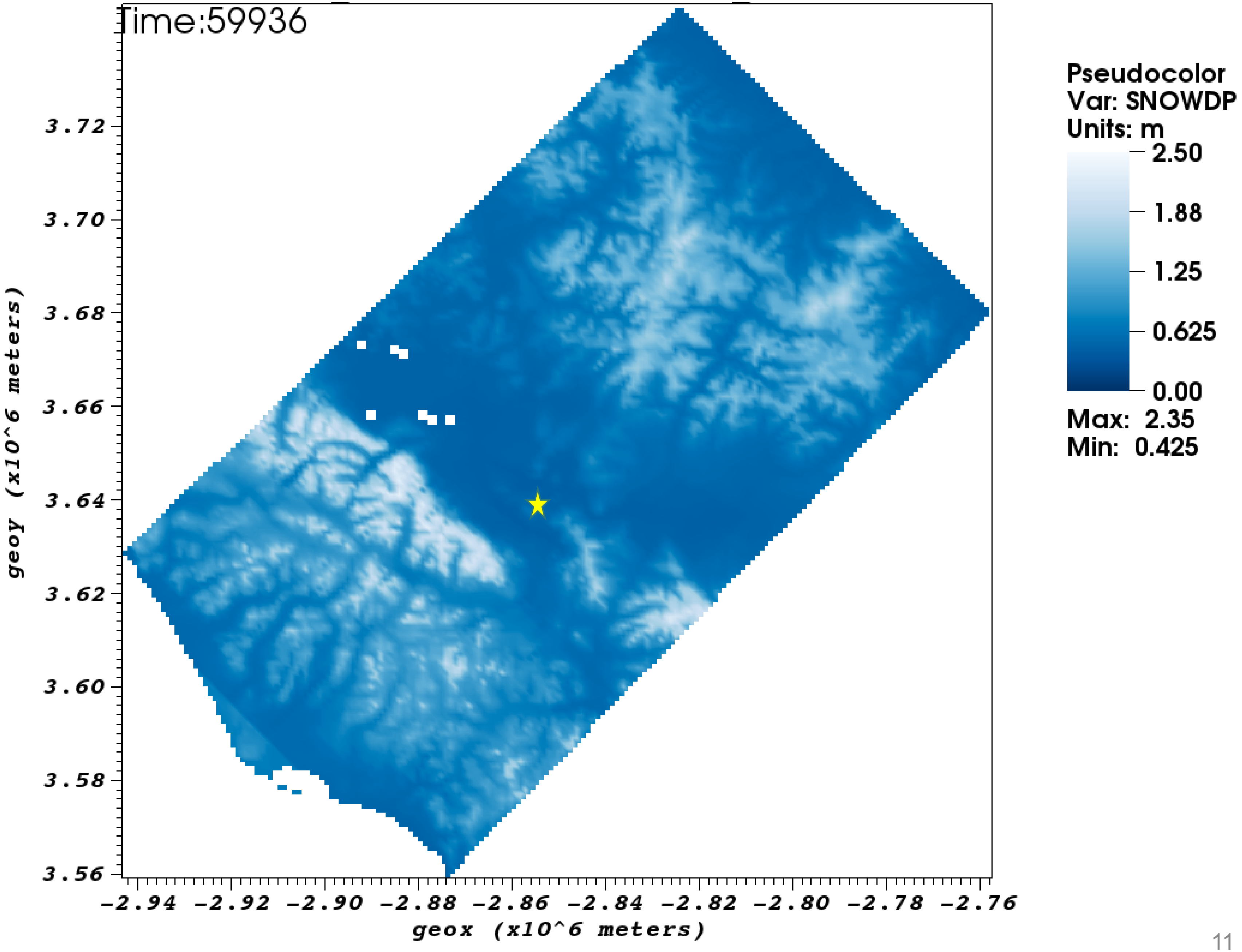


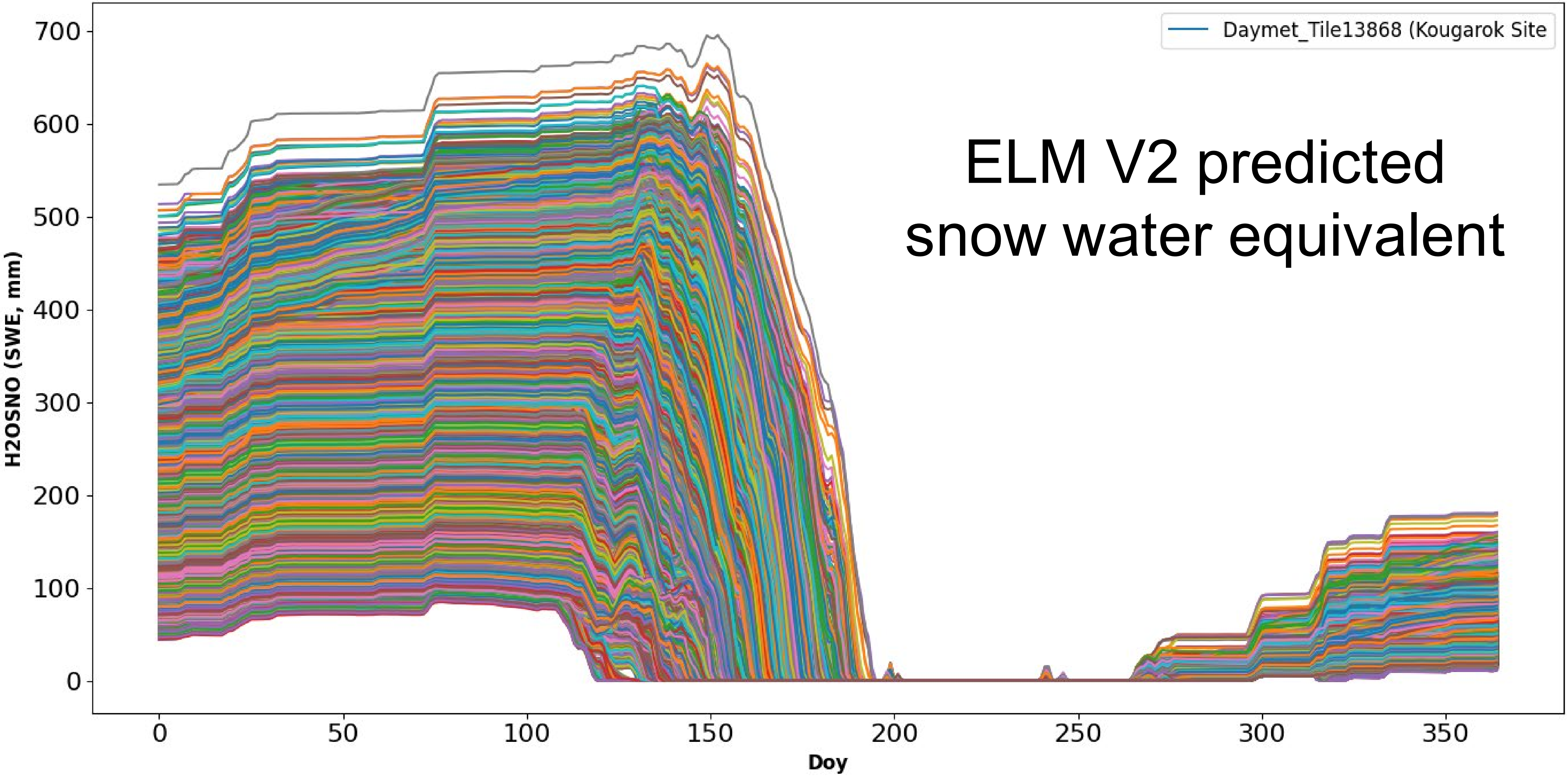



External Forcing
Coupler-Bypass
Parallel I/O
ELM domain
Doman decomposition
Initialize
ELM code
Data
Code
Data
HOST (CPU)
MPI process
Copy (directives)
data region
Time stepping
Kernels
Gridcells on Threads
DEVICE (GPU)
data region
Copy (directives)
Output
History data
HOST (CPU)
Domain data assembly
ELM domain
Parallel I/O
Storage

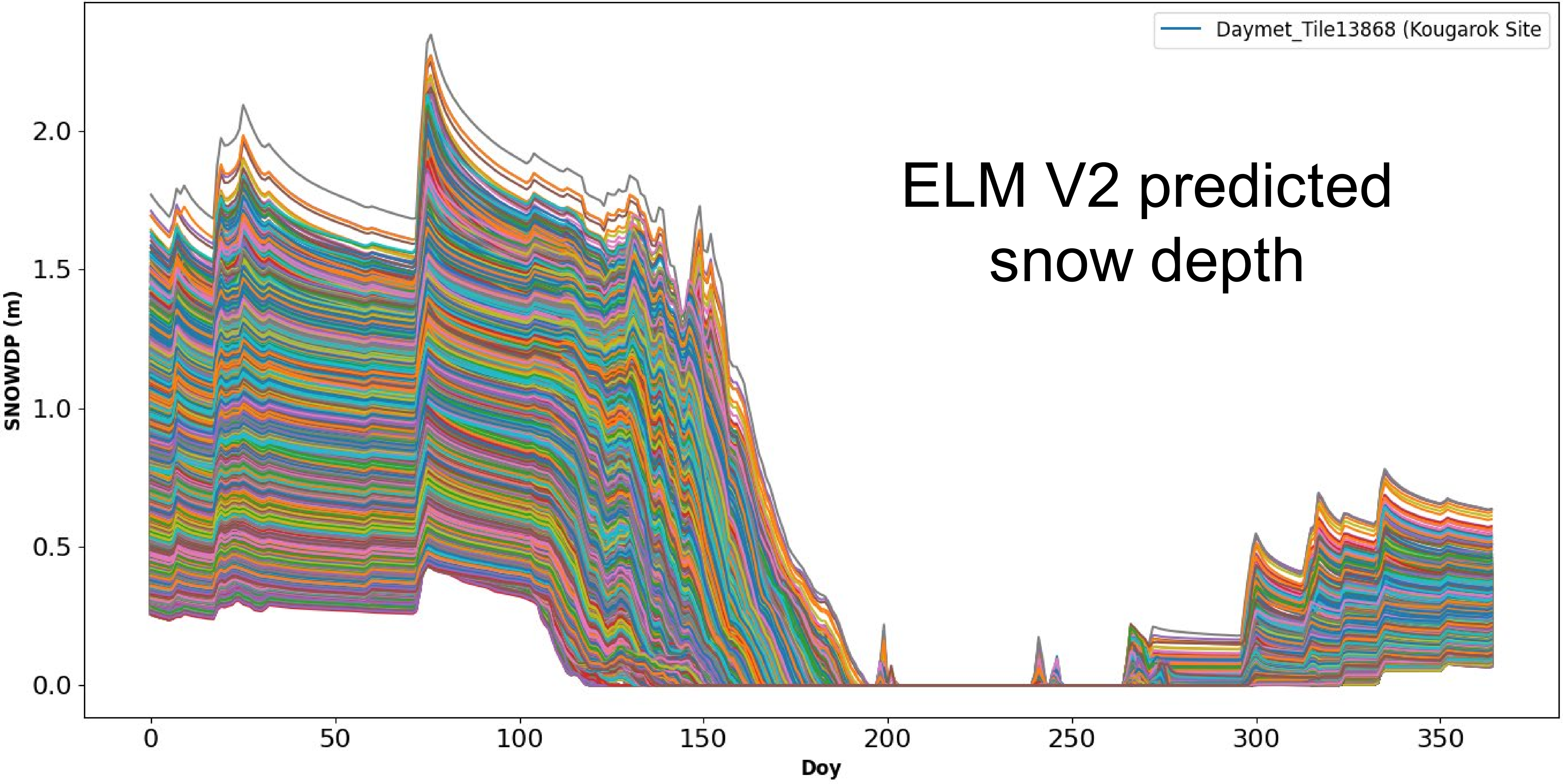
ELM V2 predicted snow depth

We expect to use the sub-grid topographic units available in ELM V2 to represent variation in snow fractions.



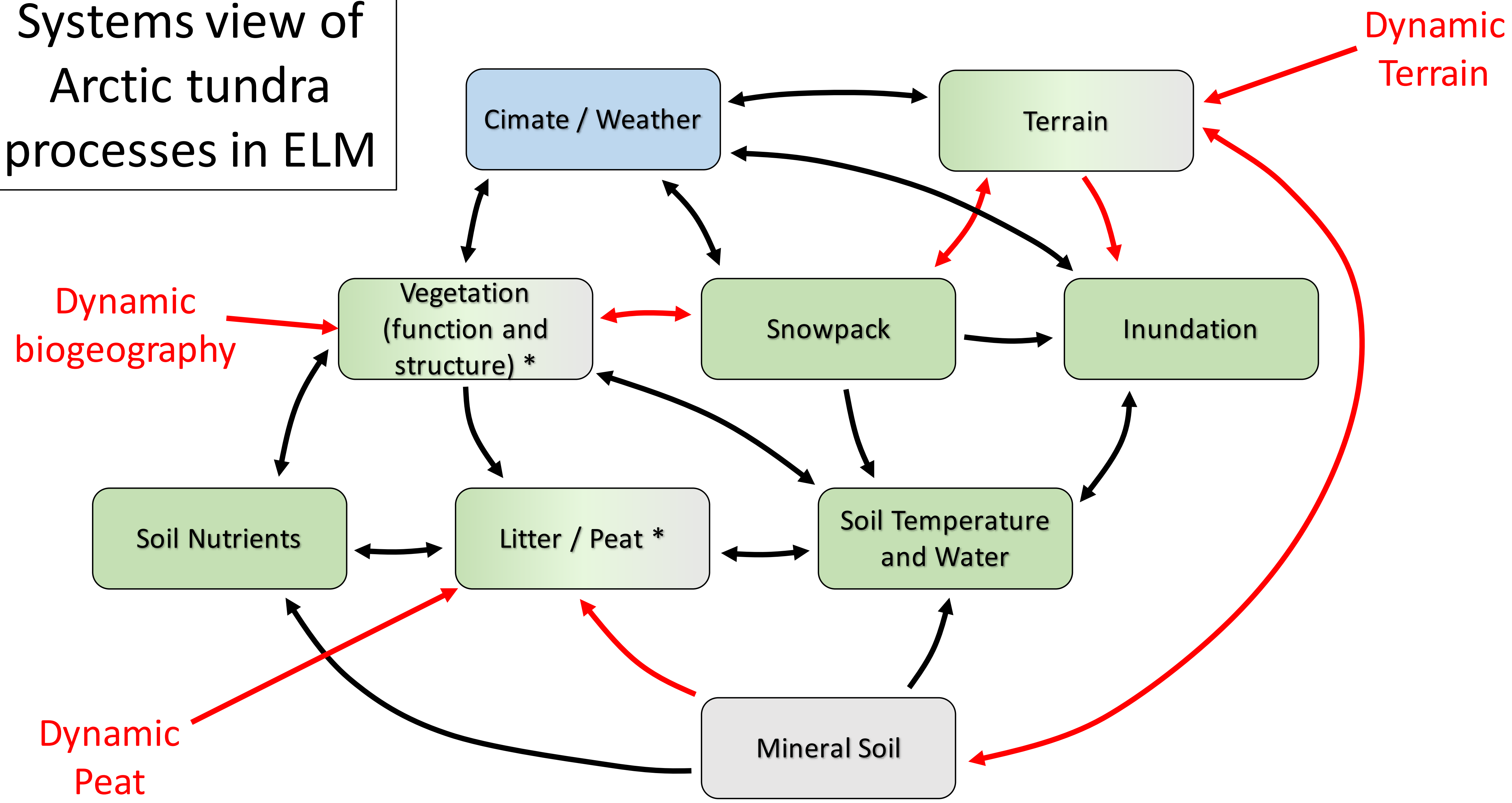


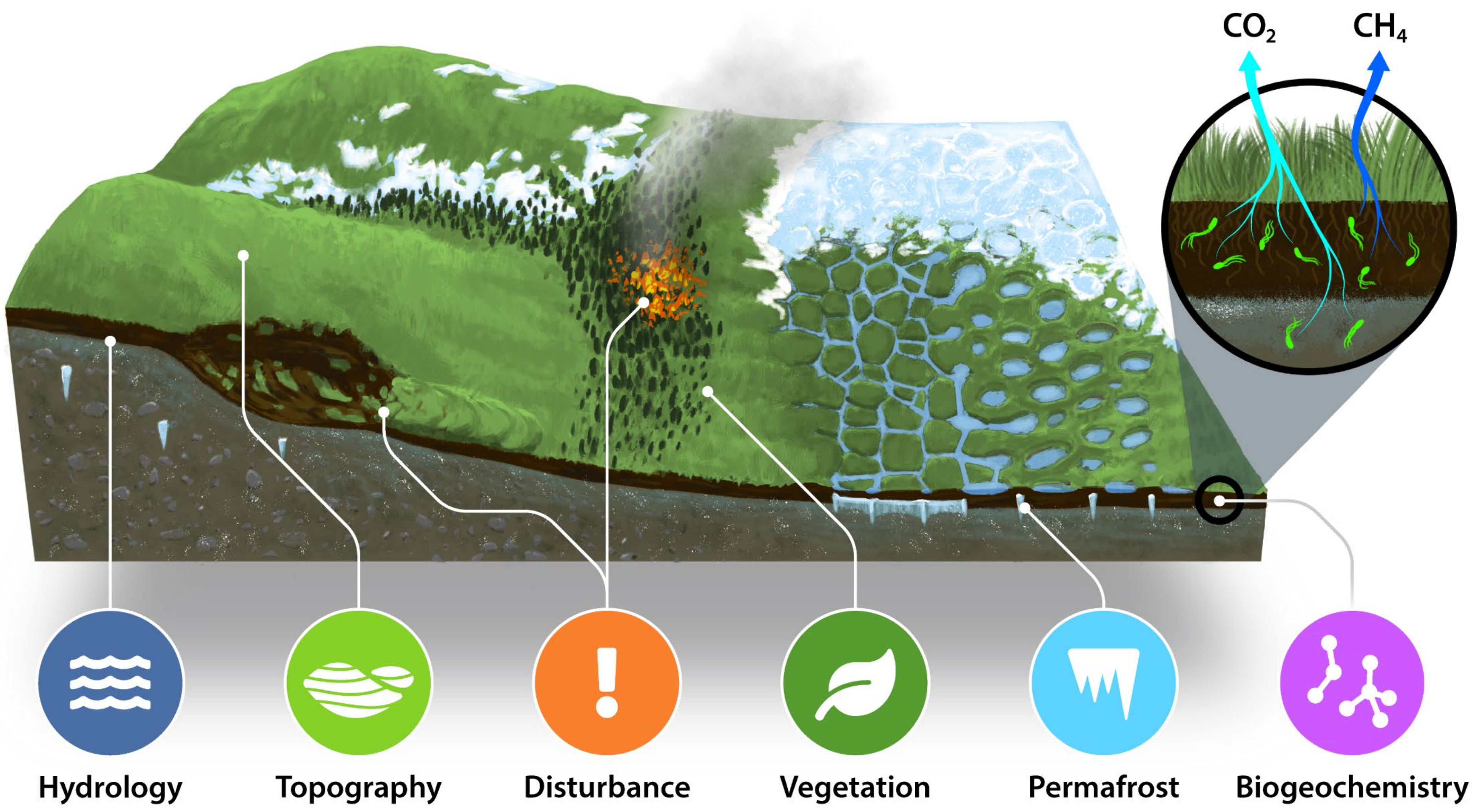
ELM V2 predicted snow water equivalent



ELM V2 predicted snow depth

Systems view of Arctic tundra processes in ELM





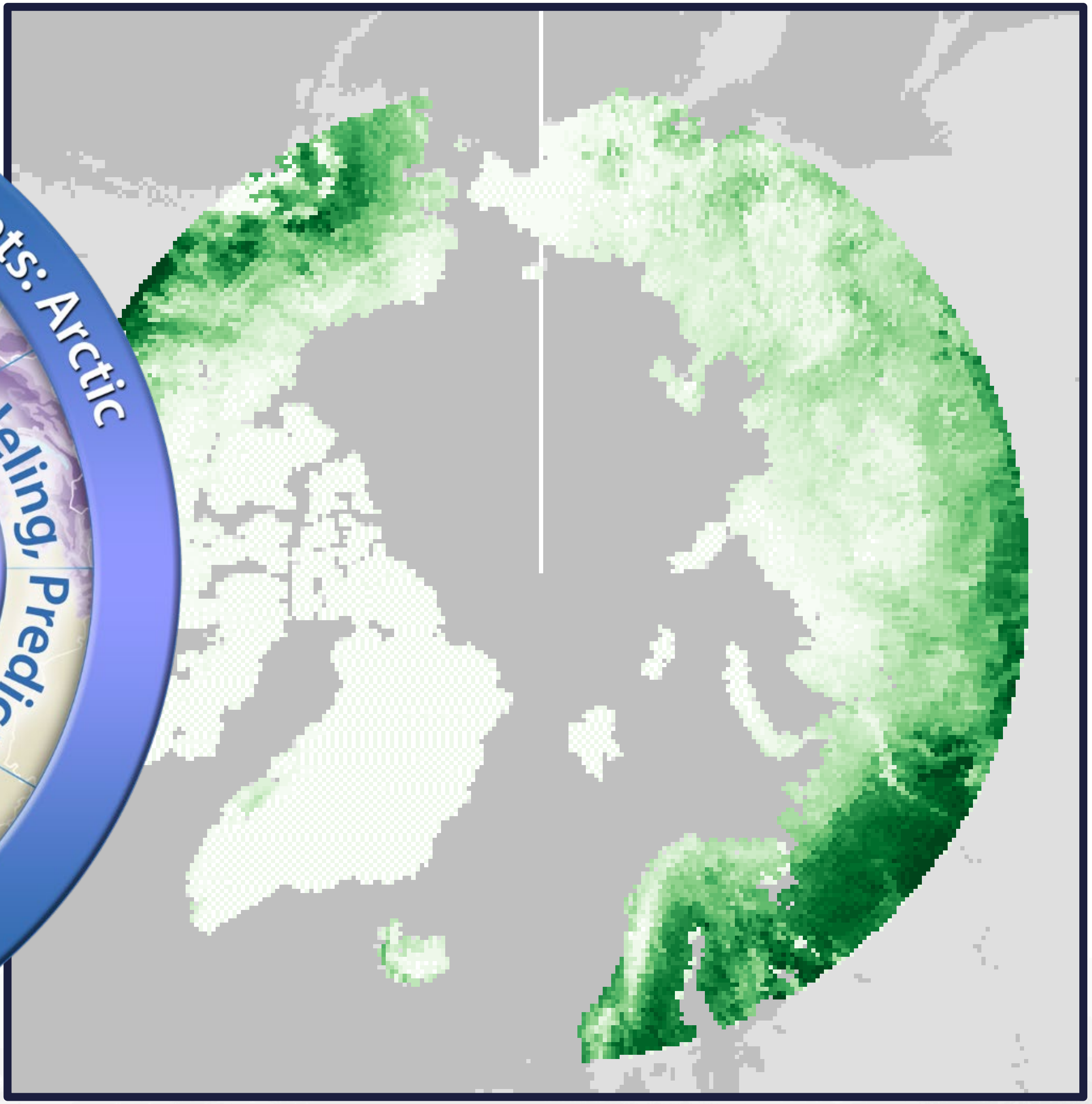
Patterned after V. Leshyk illustration, Schuur and Mack, 2018

Next-Generation Ecosystem Experiments: Arctic

Ecosystem Processes

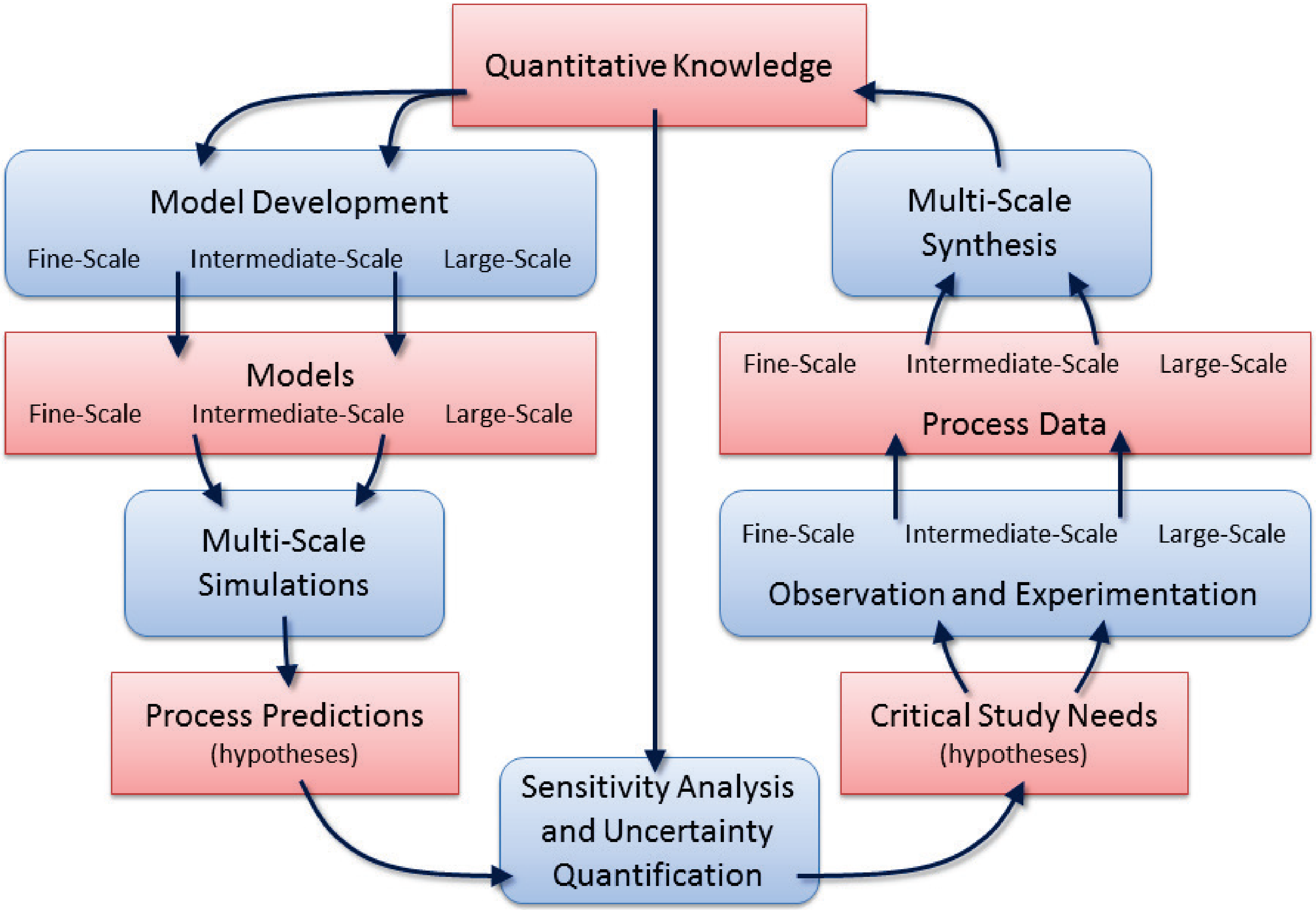
Modeling, Prediction

Systems Understanding

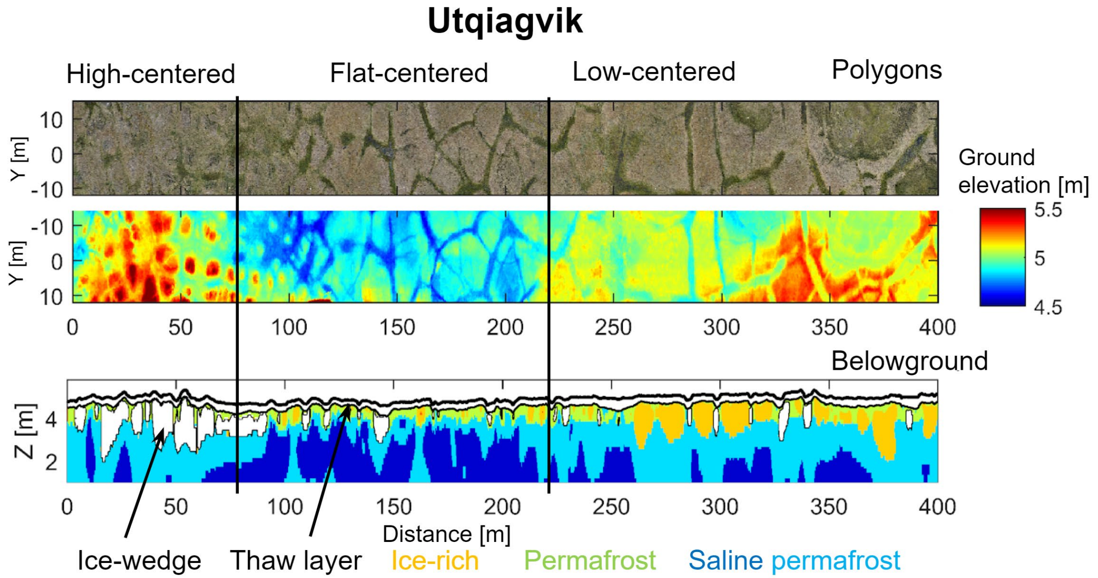


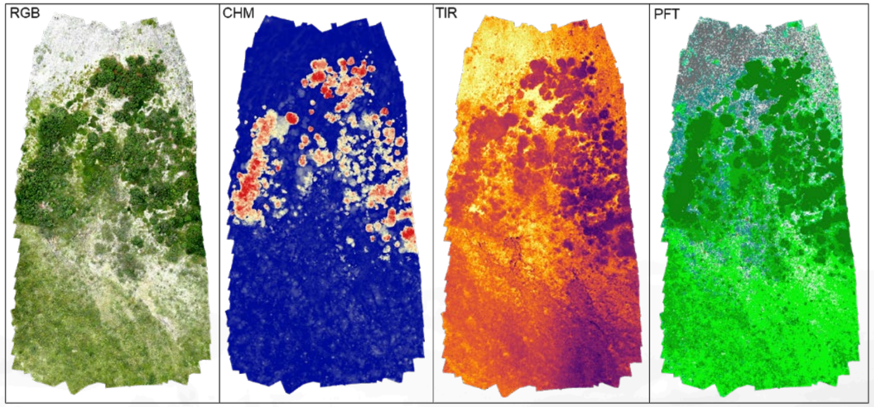
NGEE-Arctic Integrated Modeling Objectives: targeting E3SM/ELM

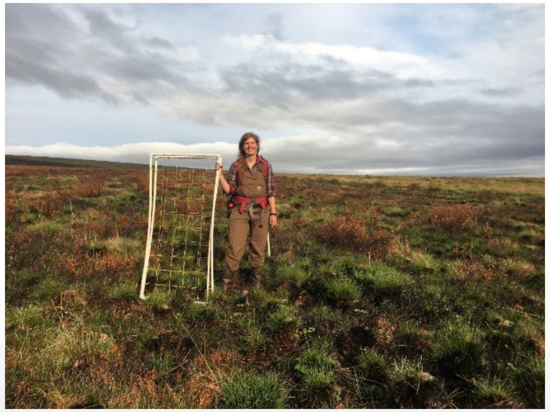
- Prioritize modeling requirements
- Develop framework for pan-Arctic modeling
- Evaluate new modeling capabilities
- Apply to science questions



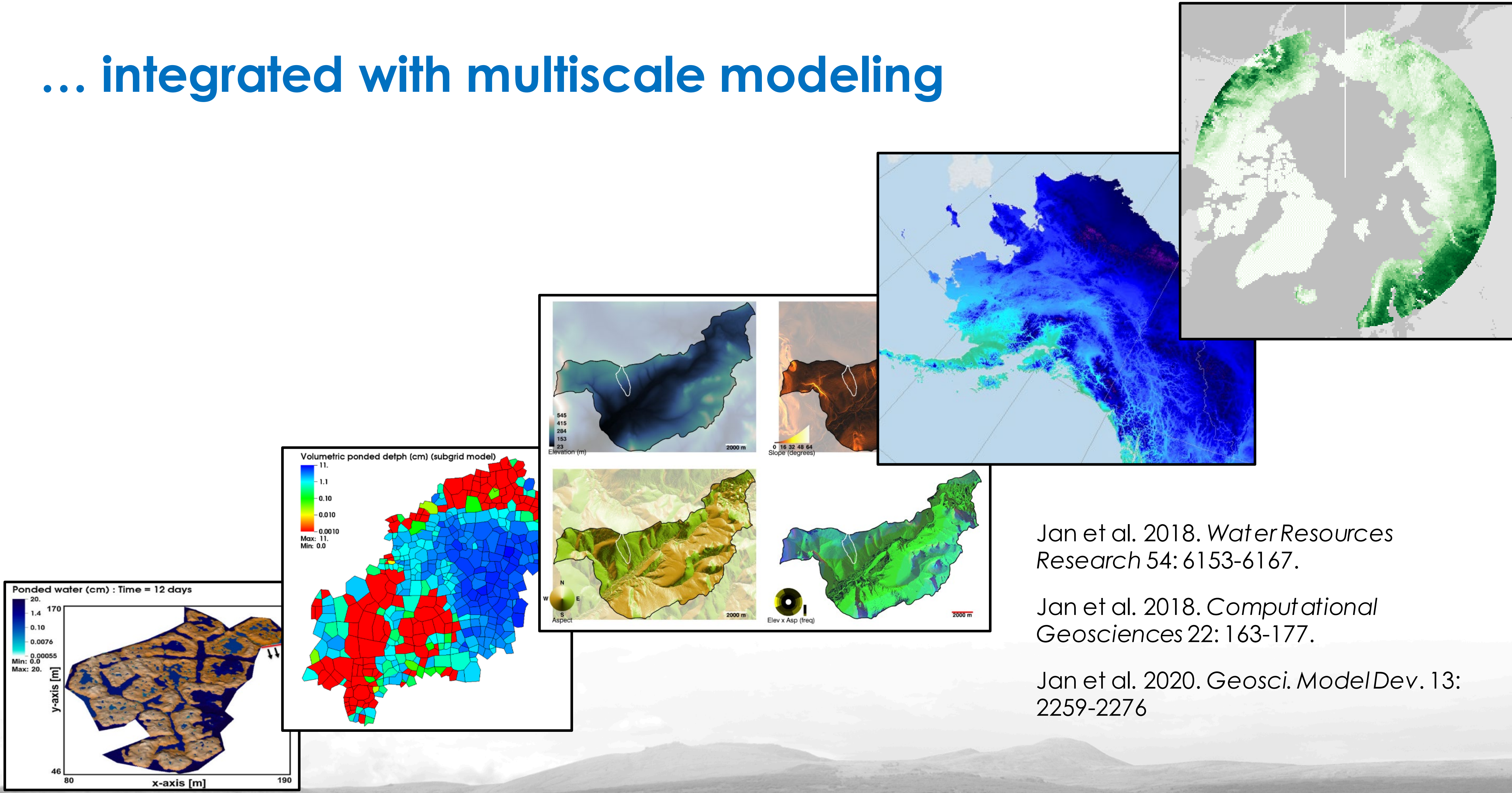
Question-based observation and experimentation…







… integrated with multiscale modeling



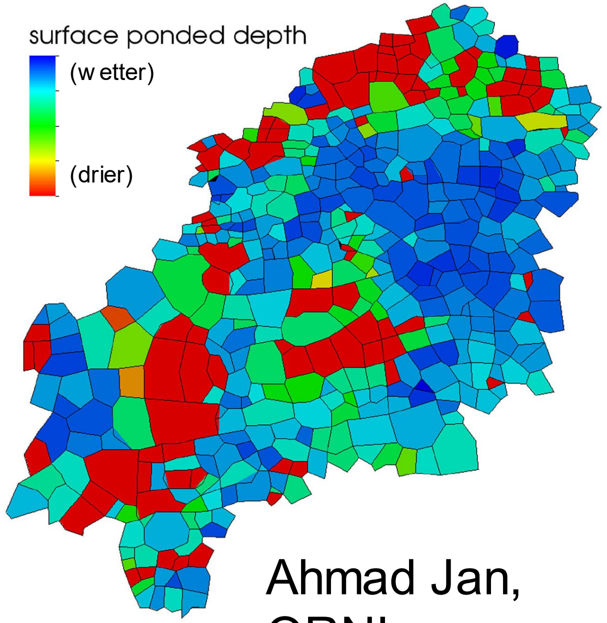
Jan et al. 2018. *Water Resources Research* 54: 6153-6167.

Jan et al. 2018. *Computational Geosciences* 22: 163-177.

Jan et al. 2020. *Geosci. Model Dev.* 13: 2259-2276

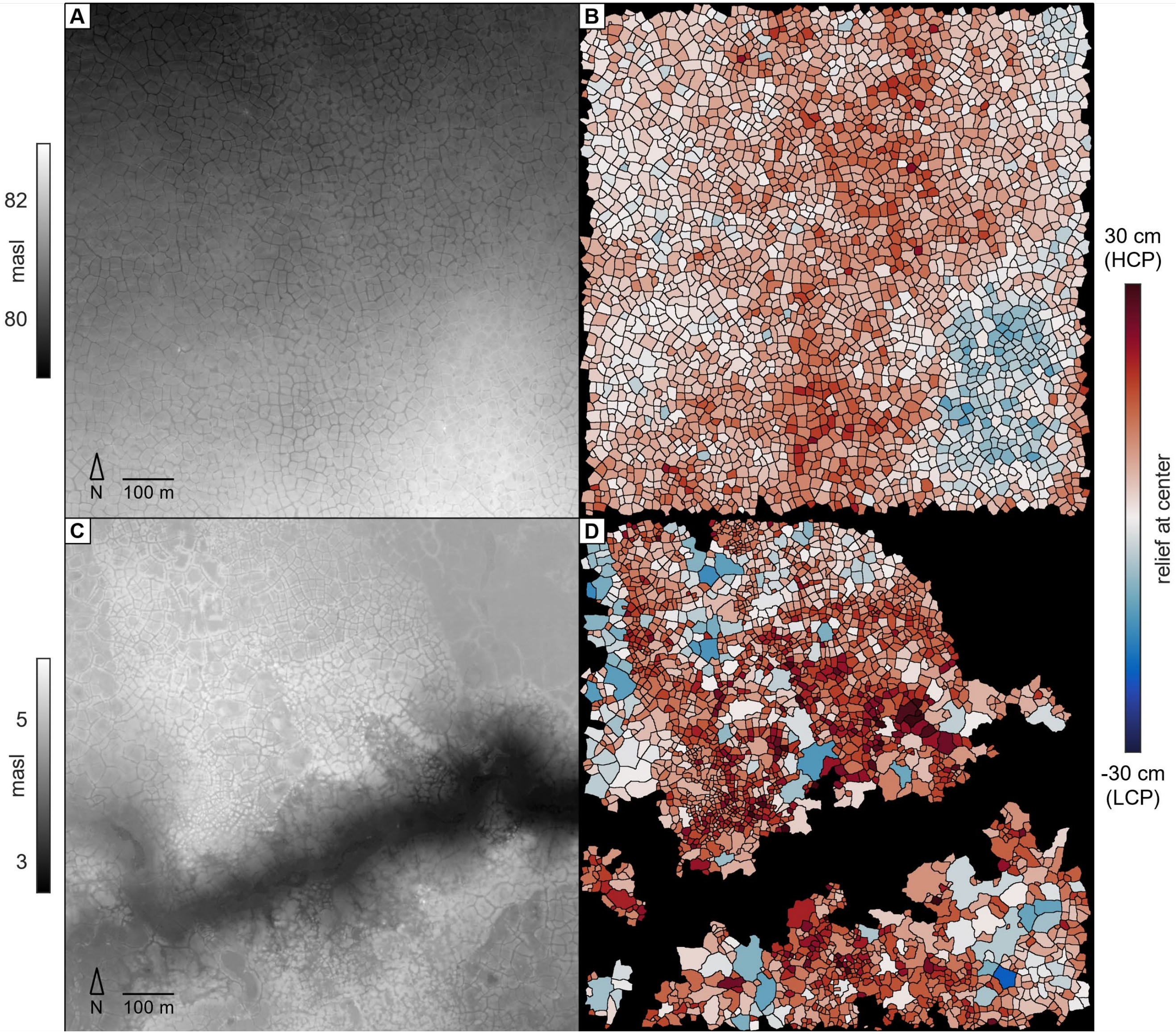
Improved Inundation Dynamics

https://eu-interact.org/field-sites/research-station-samoylov-island/

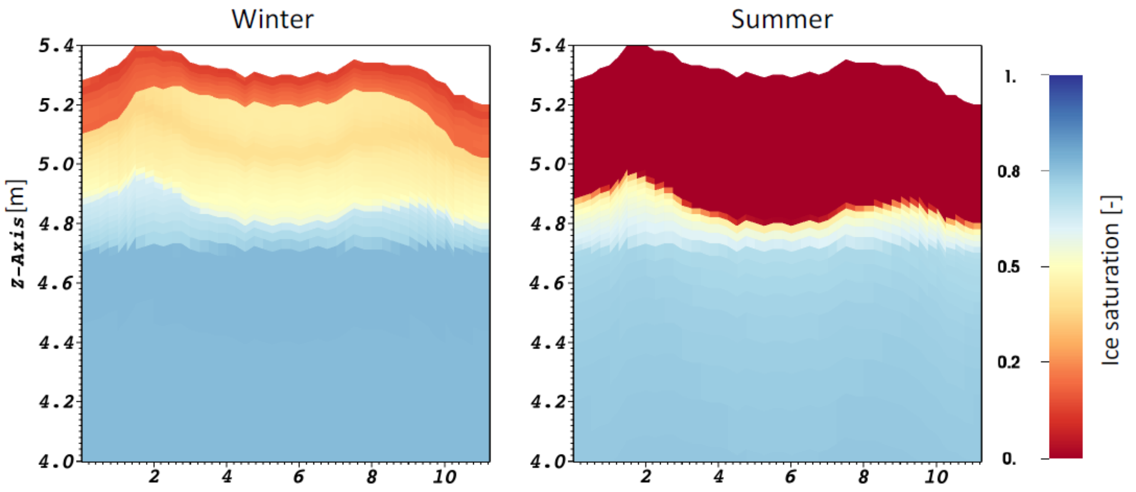


Ahmad Jan, ORNL

Improved Inundation Dynamics



Chuck Abolt, LANL



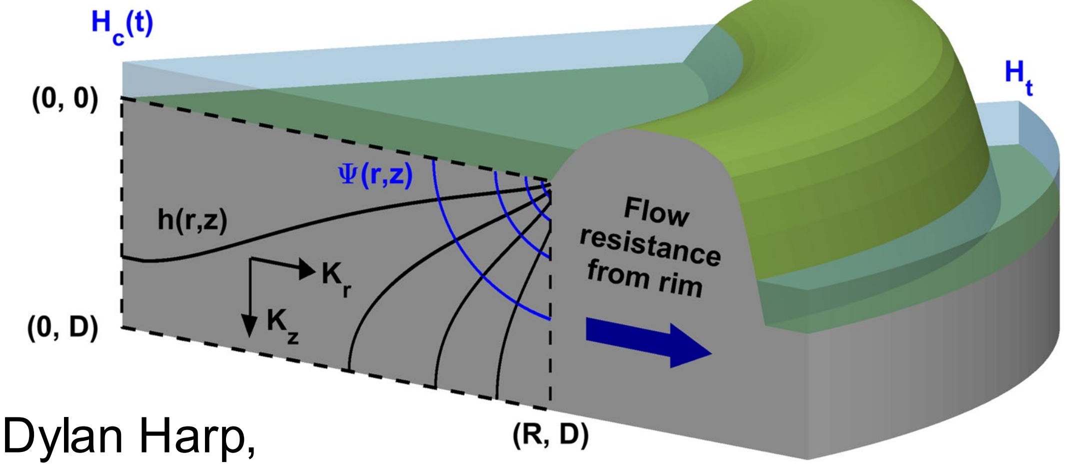
Elchin Jafarov, LANL

Head distribution:

$$h^*(r^*, z^*) = \sum_{n=1}^{\infty} B_n \frac{\cosh(\lambda_n(1 - z^*))}{\cosh(\lambda_n)} J_0(\lambda_n r^*)$$

Ponded depth:

$$H^*(t^*) = \frac{H(t) - h_w}{H_0 - h_w} = e^{-t^*} = e^{-\frac{t}{t_L}}$$

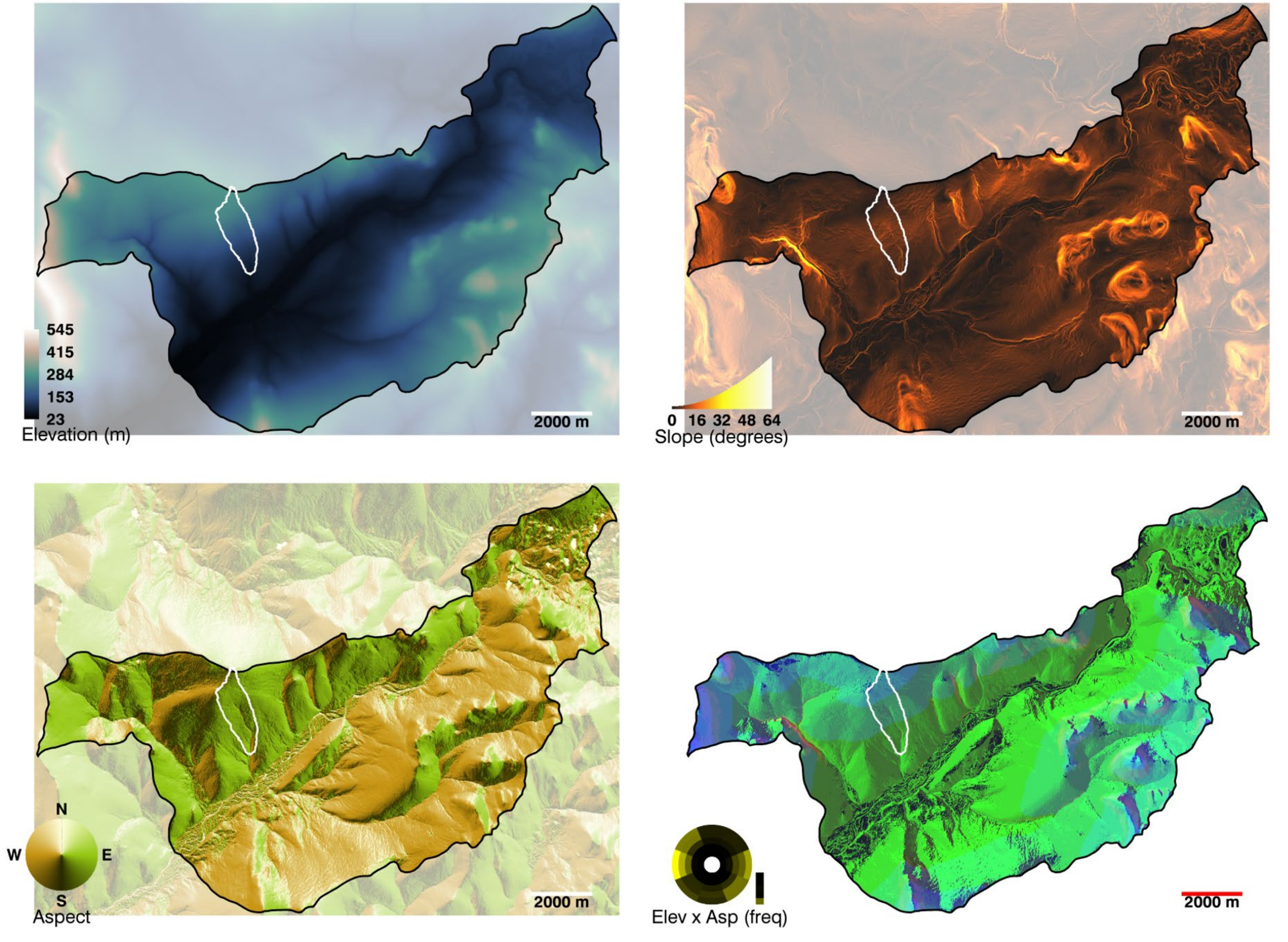


Dylan Harp, LANL

Improved Hillslope Hydrological Processes

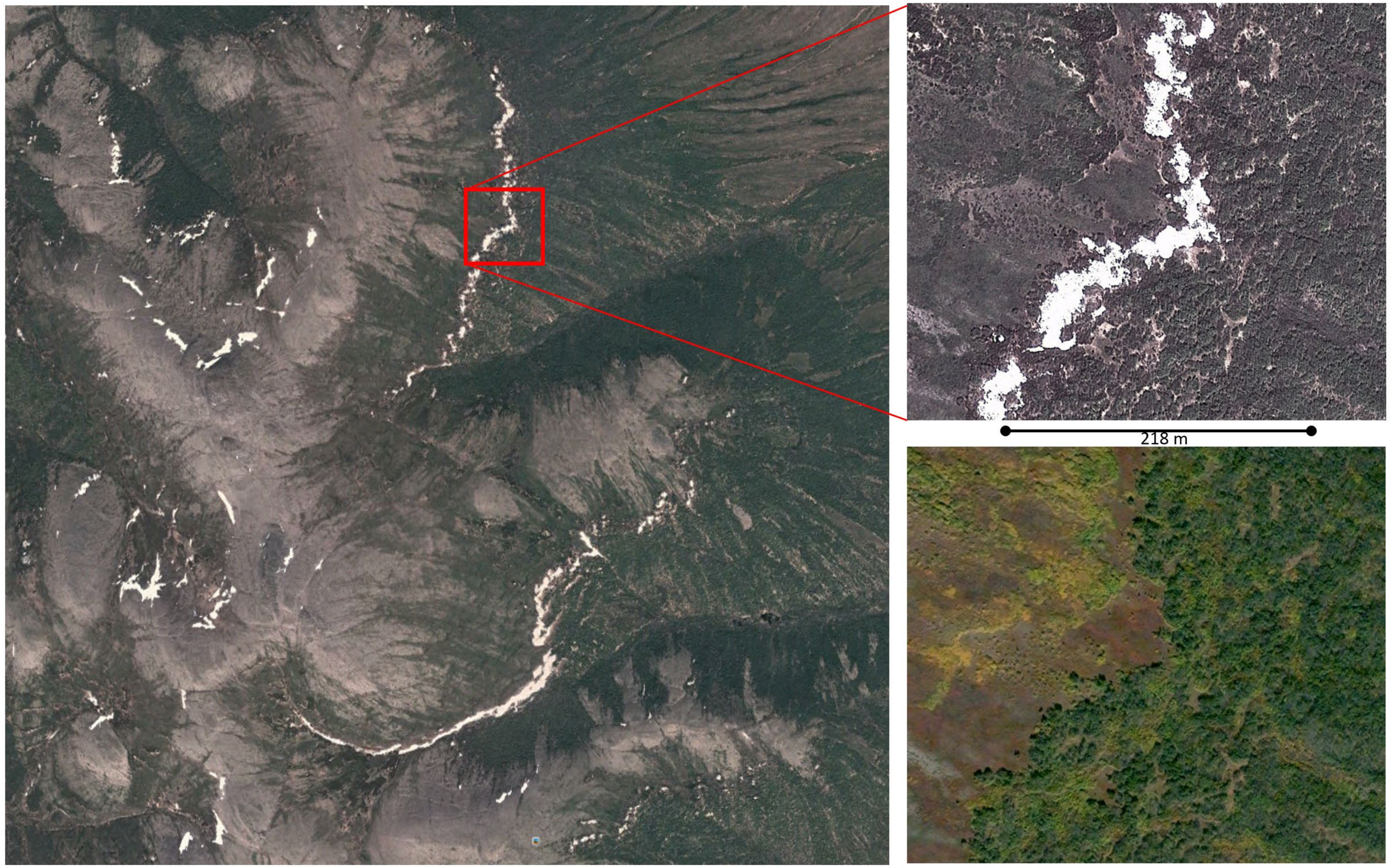
- Influence of soil and bedrock on thermal hydrology
- Influence of taliks on hillslope and watershed hydrology
- Use ELM subgrid representations

Example: HUC12 containing Teller watershed: 139.8 km^2

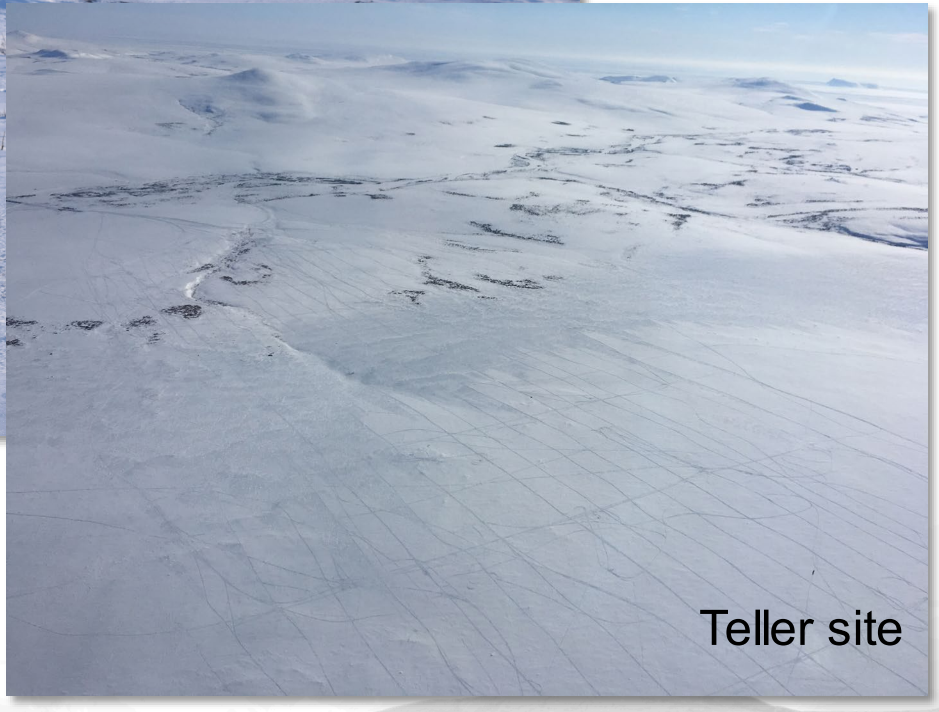


Improved Snow-Vegetation-Terrain Interaction

- Interactions of snow, wind, terrain, and vegetation
- Use ELM topounits to capture variance in snow
- Evaluated with NGEE snow surveys, vegetation surveys, remote sensing

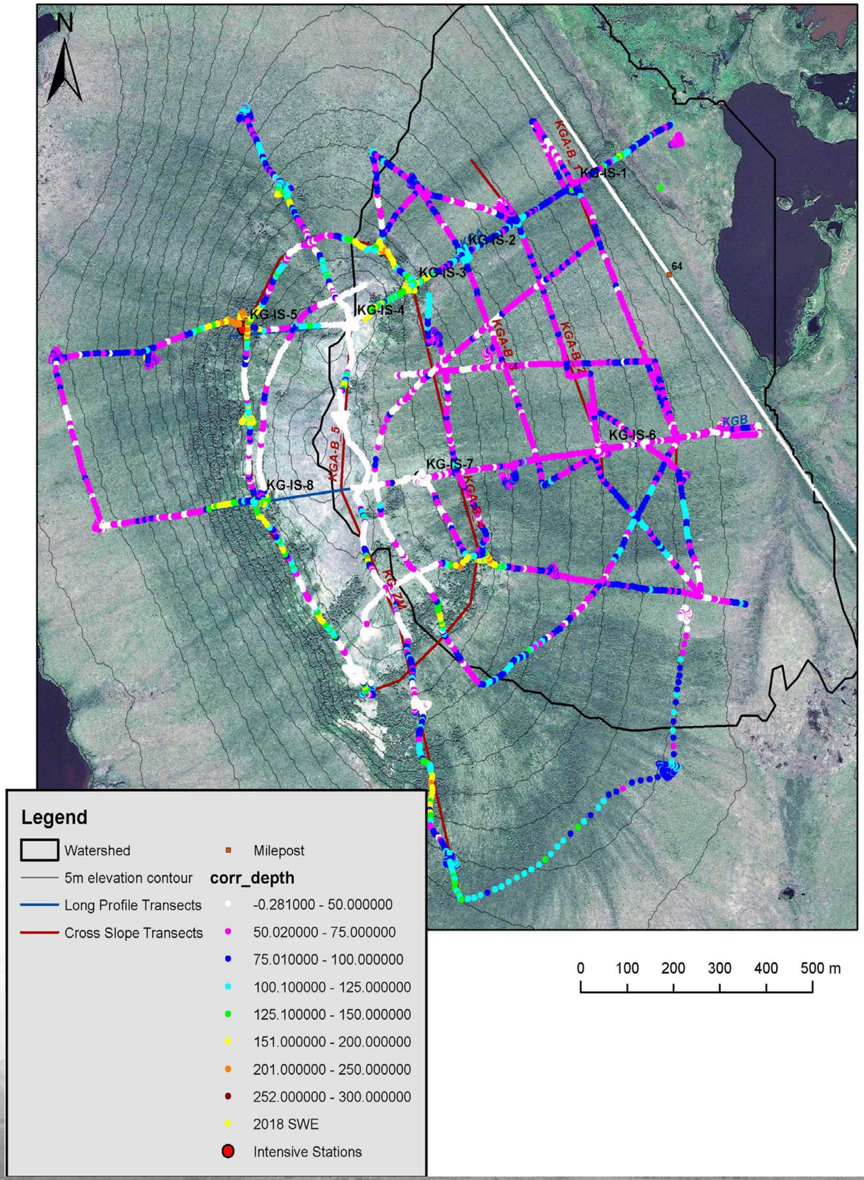


Improved Snow-Vegetation-Terrain Interaction



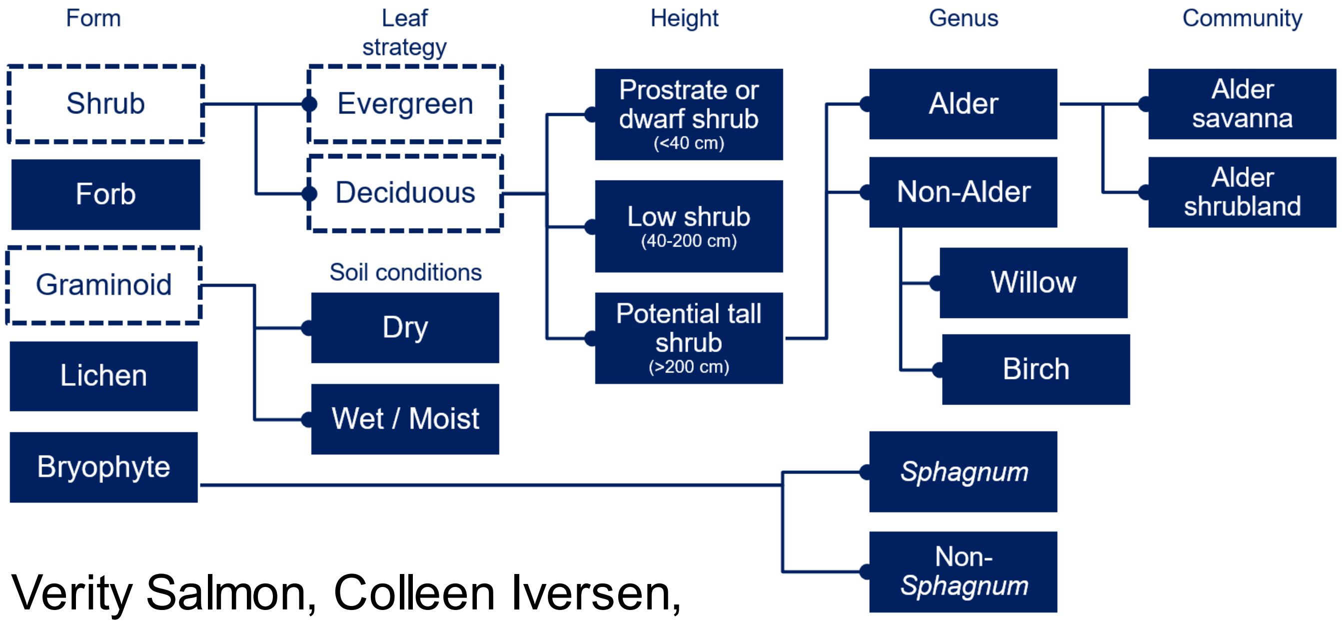
Snow survey lead:
Cathy Wilson, LANL

2018 Kougarok Snow Survey



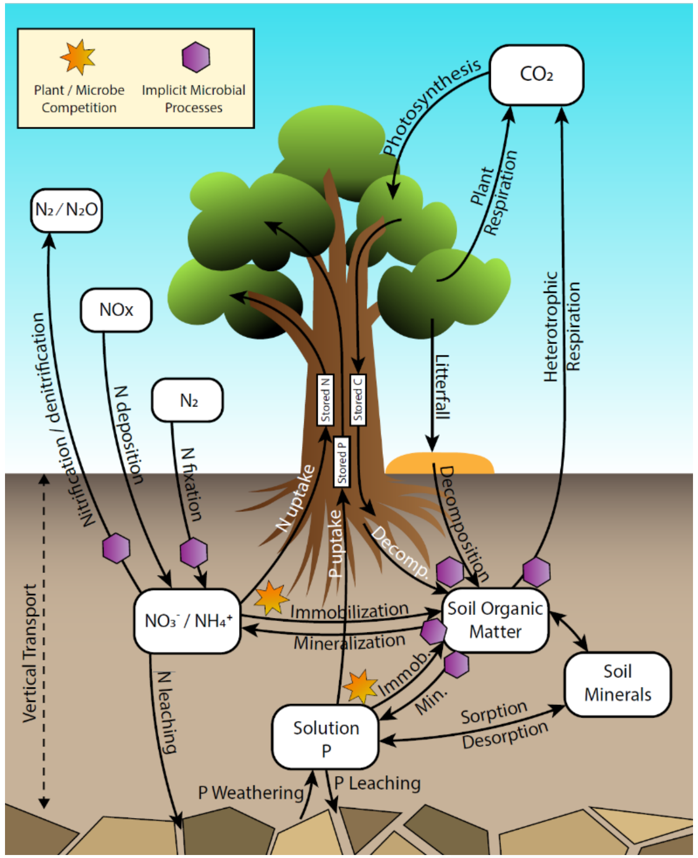
Improved Representation of Tundra Vegetation

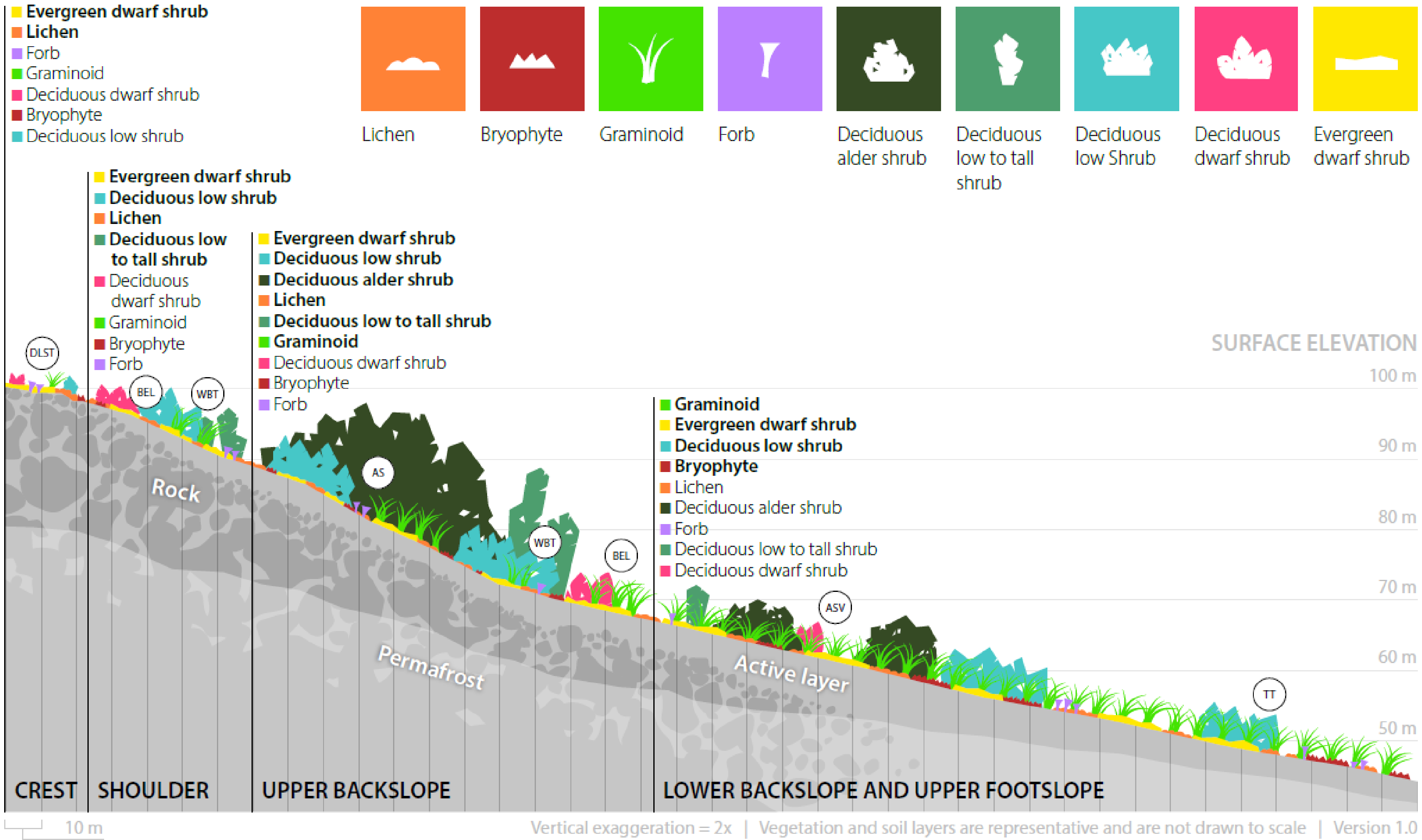
- Multiple new Arctic tundra PFTs, including alder
- Large-scale mapping with remote sensing data



Verity Salmon, Colleen Iversen, ORNL

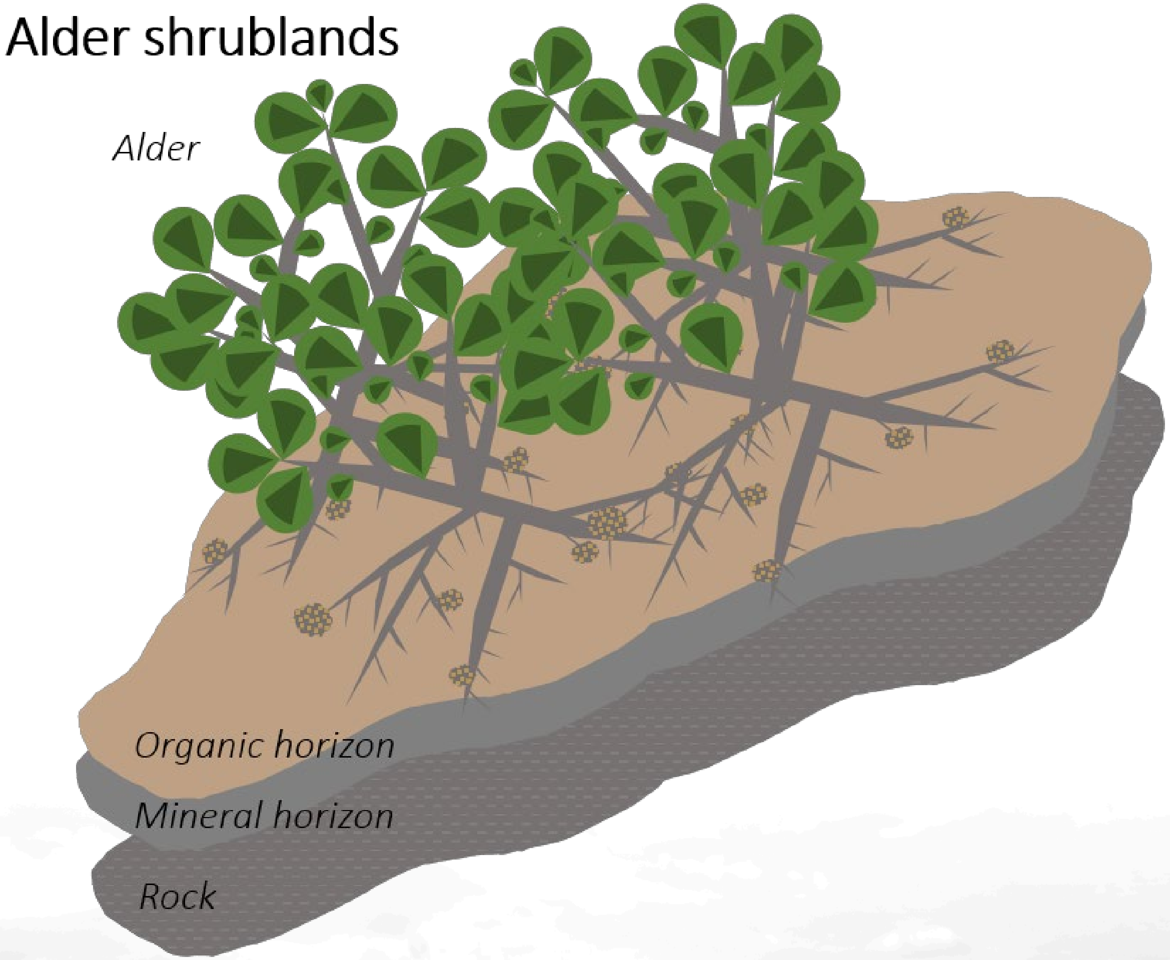
Site-level simulations testing new vegetation trait parameters for present-day and future climates (Model parameterization)

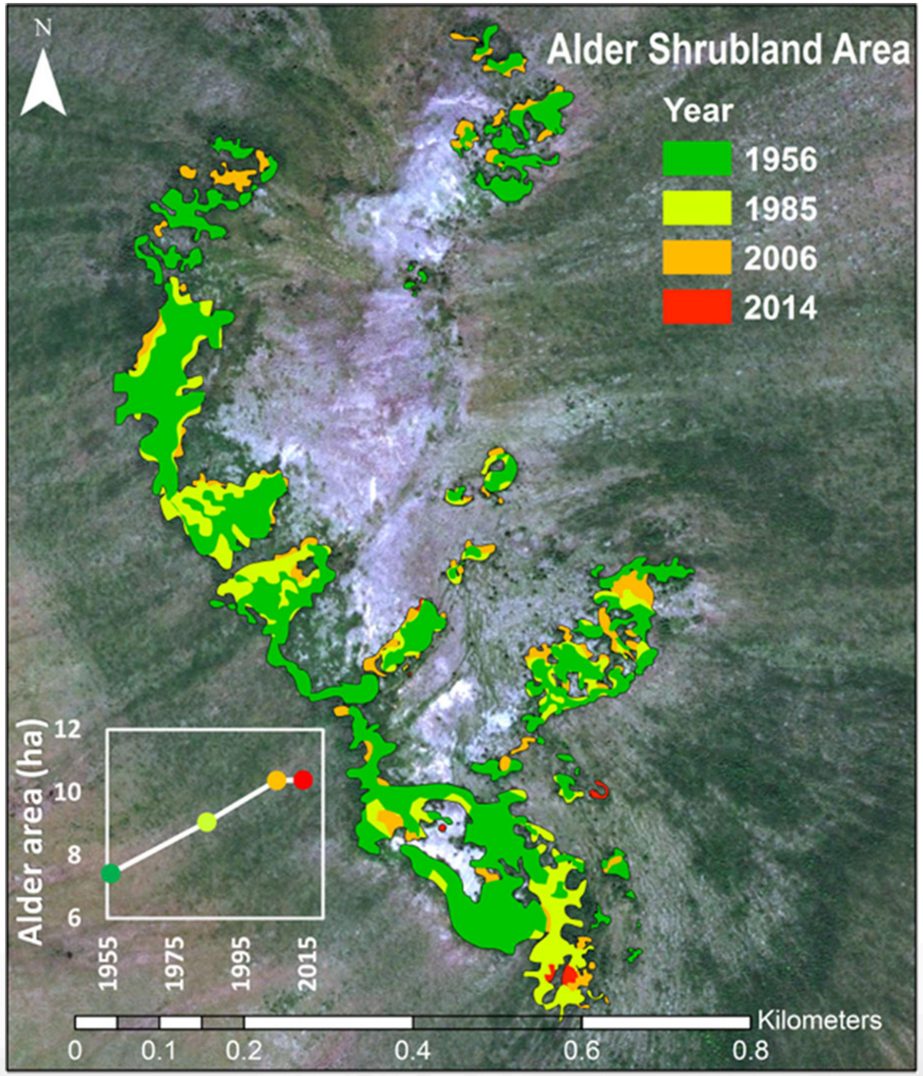




Sulman *et al*. 2021 (*JAMES*), and associated data sets

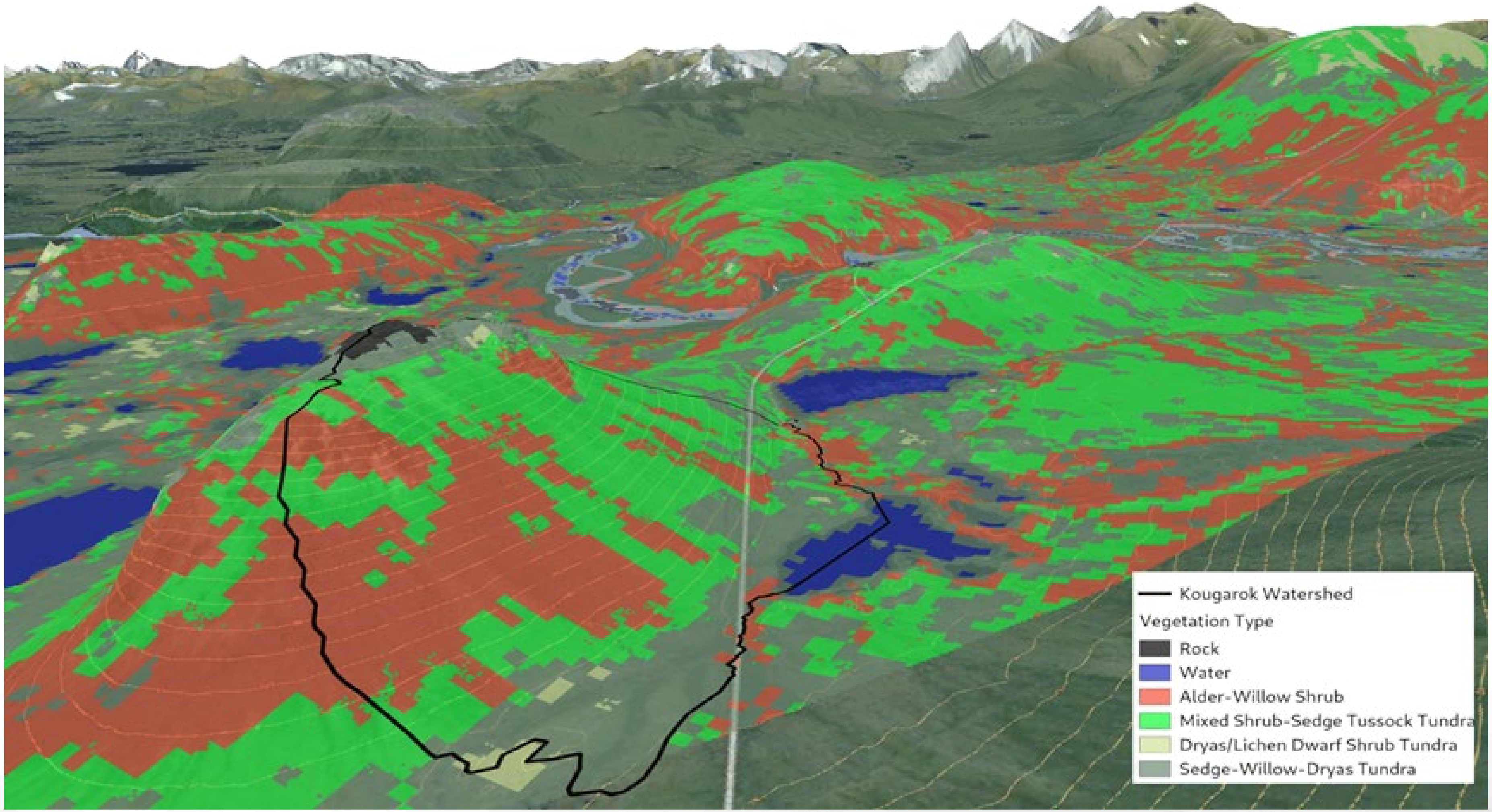
Characterize N-fixation rates and traits to inform new alder plant functional type in ELM (Observations)





Salmon *et al.* 2019 (*Frontiers in Plant Science*) and associated data sets

Maps of plant communities across the landscape (Scaling, ABoVE collaboration)



Langford *et al.* 2019 (*Remote Sensing*) and associated data sets

Integration of remote sensing observations, boots on the ground, experimentation in the field and in the lab, and multi-scale modeling allows us to tackle the most challenging Earth science problems.

Too Remote, Too Wild, and Too Cold: Helping Satellites See Arctic Greening With Boots on the Ground

Ellen Gray

October 6, 2021

ABoVE

Facebook | Twitter | Pinterest | Tumblr | Myspace | Blogger

Pixel walkers (left to right) Logan Berner, Patrick Burns, Ben Weissenbach, Julia Ditto, Madeline Zietlow, Russell Wong. Photo by Roman Dial.

by Roberto Molar Candanosa

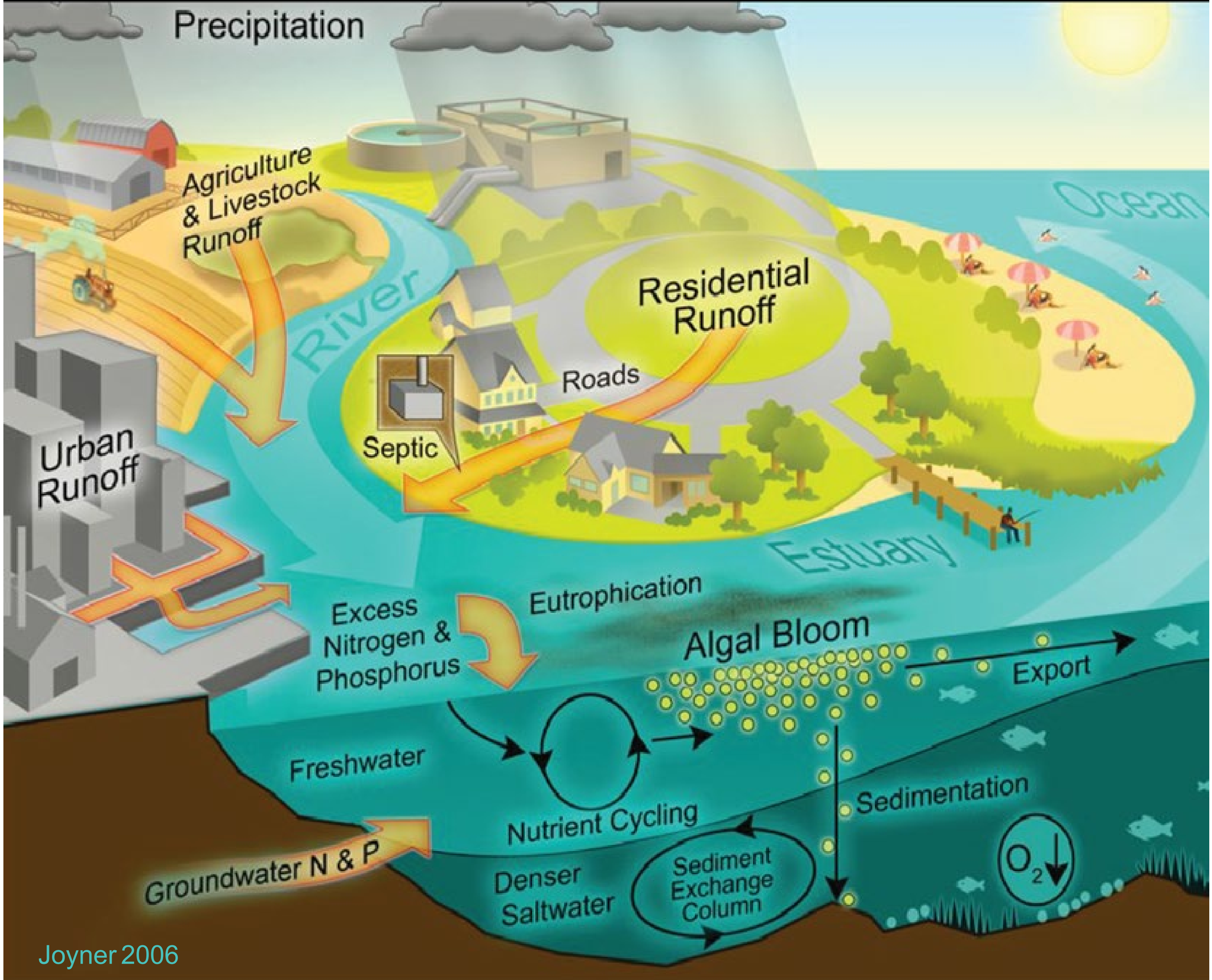
https://blogs.nasa.gov/earthexpeditions/2021/10/06/too-remote-too-wild-and-too-cold-helping-satellites-see-arctic-greening-with-boots-on-the-ground/

Representing coastal systems in an ESM: first steps with the COMPASS project

- Quantifying heterogeneity in the coastal zone
- Coastal land-water interfaces across salinity gradients
- Humans as a fundamental system component
- Next steps

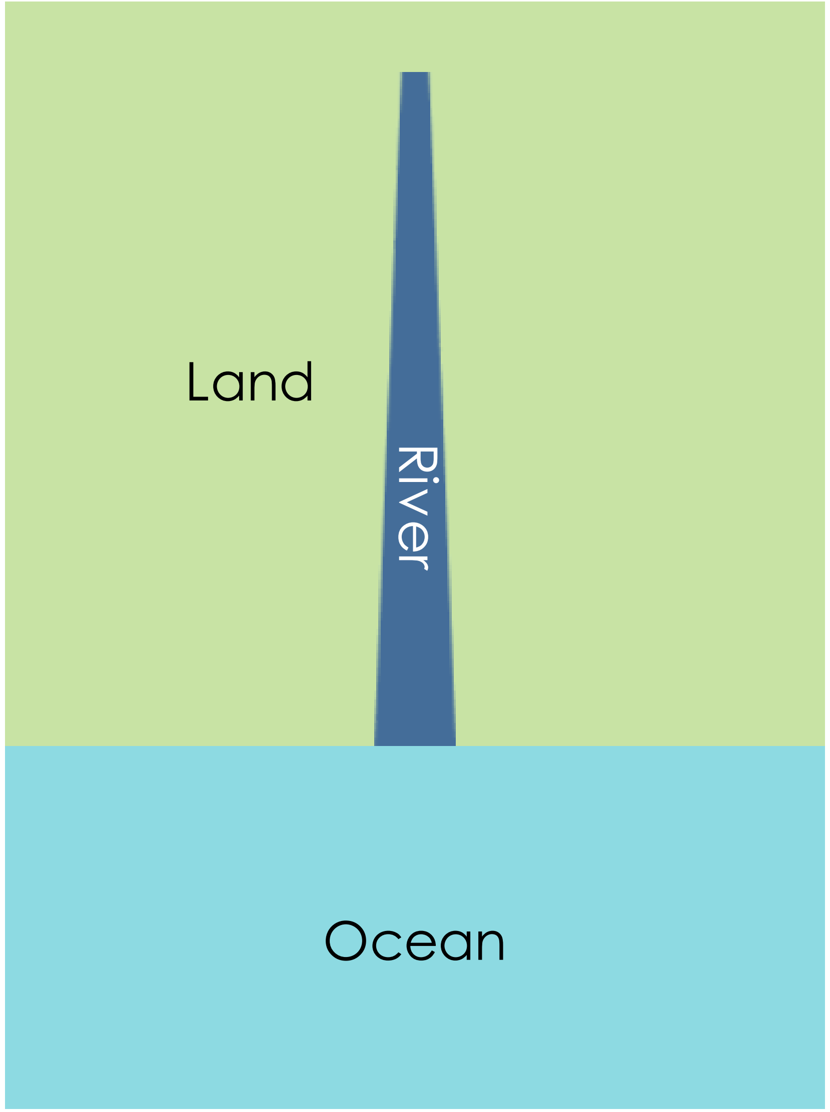
Vision:

Fully coupled Earth system prediction for air-land-water interfaces, including human systems

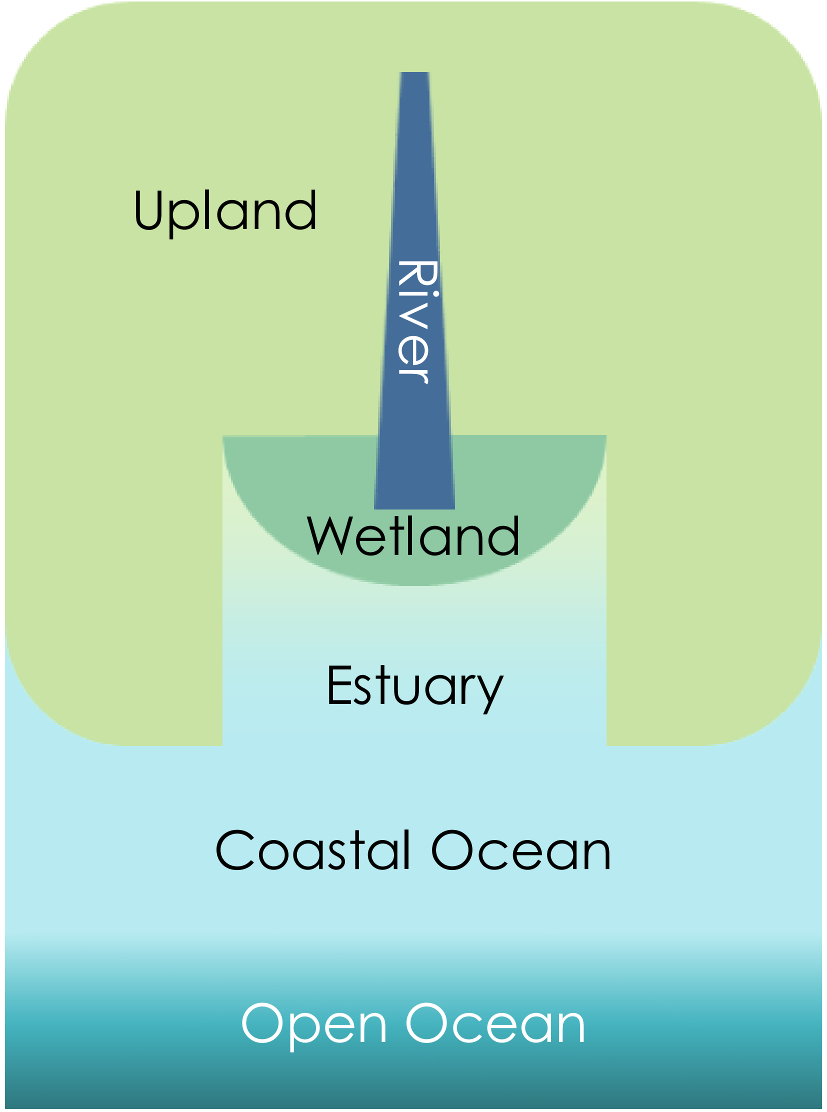


Joyner 2006

Current ESM



Coastal-TAI ESM



Rhode River

Choptank River

Great Lakes Region

Thank you