Investigating the Role of Biogeochemical and Biophysical Processes in the NHL Using an Efficient Scalable Earth System

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Collaborators

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Objectives

- Using the coupled ISAM-CESM framework to evaluate key interactions amongst Earth's climate and terrestrial processes in the Northern High Latitude regions (NHL).
  - ISAM is a land surface model (equivalent to NCAR's land surface model CLM)
- Applying a novel load-balancing mechanisms to the ISAM to achieve dynamic and improved modeling scalability.

Studying the key interactions amongst Earth's climate and terrestrial processes in the Northern High Latitude (NHL) regions

Background and Issues

- Studying the vulnerability of permafrost Carbon using models require new process knowledge
  - Particularly the processes that affect
    - thawing permafrost
    - wetland drying
    - fires/land use change
- Key Areas of Progress Needed:
  - Improvements of
    - large-scale permafrost models
    - coupled large-scale permafrost-carbon models
    - coupled large-scale permafrost-carbon cycle – climate models

Missing Gaps in Modeling Studies

- *Driving Data Sets (Initial Conditions):* What new data sets can be developed to drive models or to specify model initial conditions?
  - soil carbon maps, wetland maps, ground ice maps, etc.
- *Model Evaluation:* What new data sets can be developed to better evaluate models ?
  - soil carbon maps, active layer dynamics, etc.

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Community level efforts are needed

Next Generation Ecosystem Experiment (NGEE)

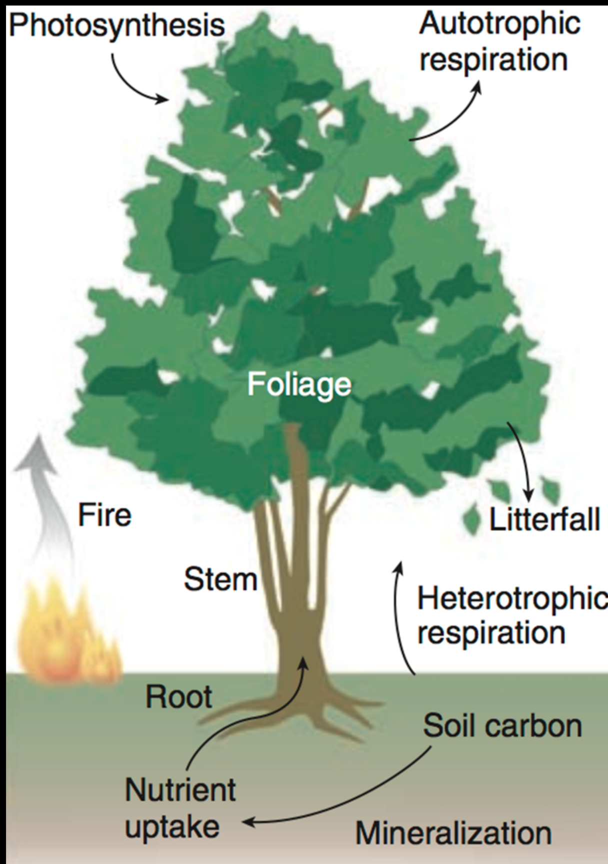
Vulnerability of Permafrost Carbon Research Coordination Network (*RCN*)

Carbon-Land Model Intercomparison Project (C-LAMP)

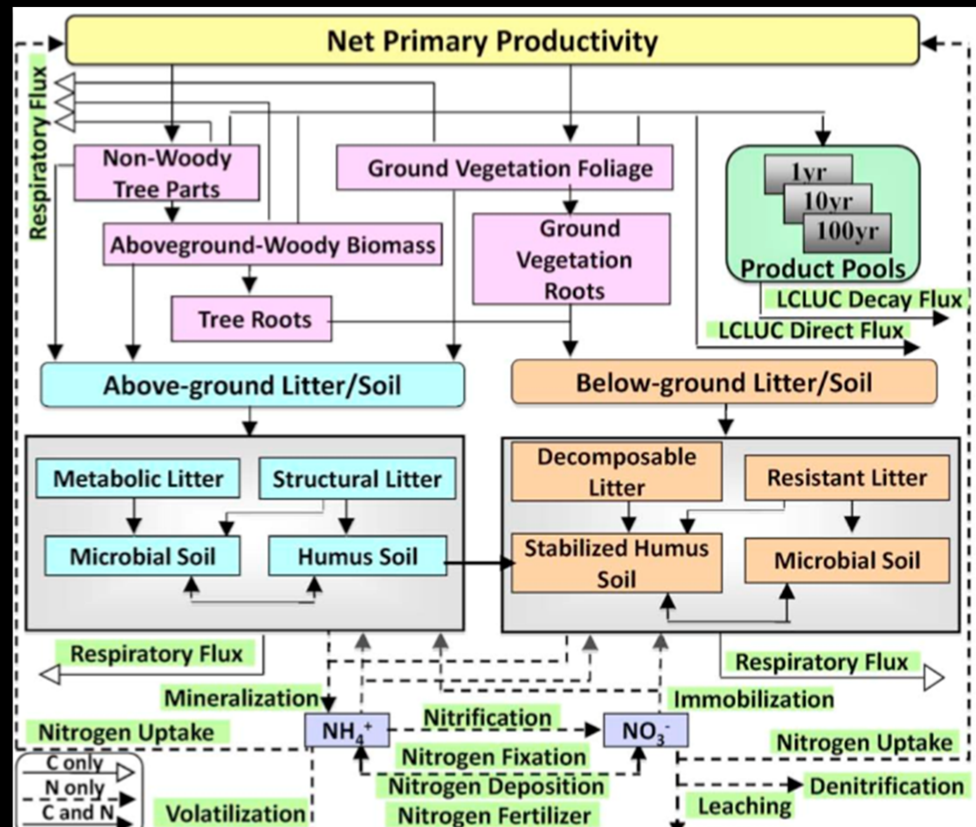
Missing Gaps in Modeling Studies (cont.)

- *Formulations/parameters:* How should models represent relationships between outputs and driving variables as well as the parameters in those relationships
  - Biogeochemistry: C-N interactions, decomp relationships, rate-limiting parameters of decomp, temperature sensitivity parameters, etc.
  - Biogeophysics: Snow hydrological (wind compaction, depth hoar formation) and energy processes etc.

ISAM Land-Surface Model



Carbon and Nitrogen Cycling

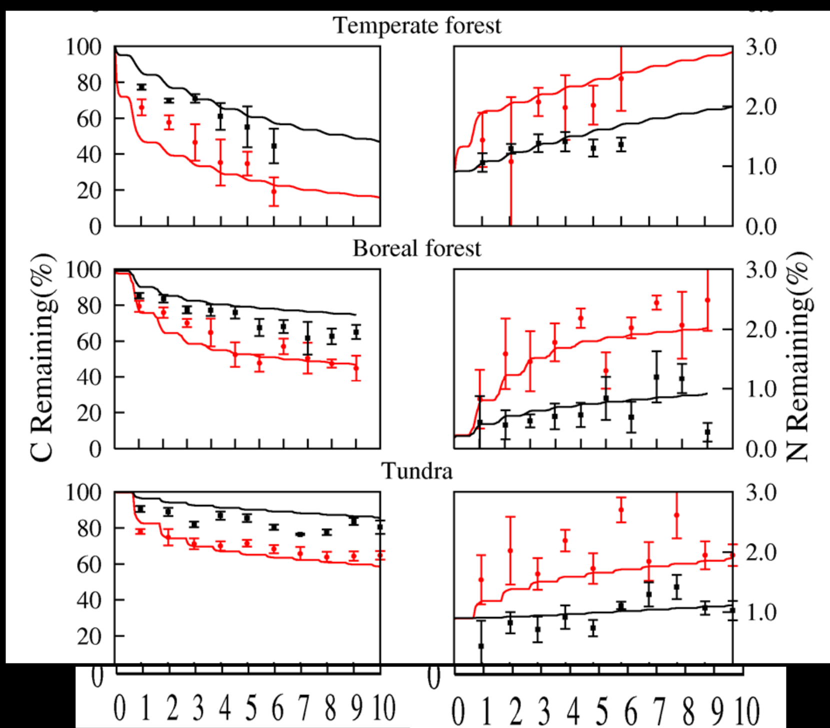


Jain and Yang (2005, GBC)
Jain et al. (2005, GRL)
Jain et al. (2006, JGR)
Jain et al. (2009, GBC)
Yang et al (2009, GBC)
Yang et al.(2010, Biogeoscience)

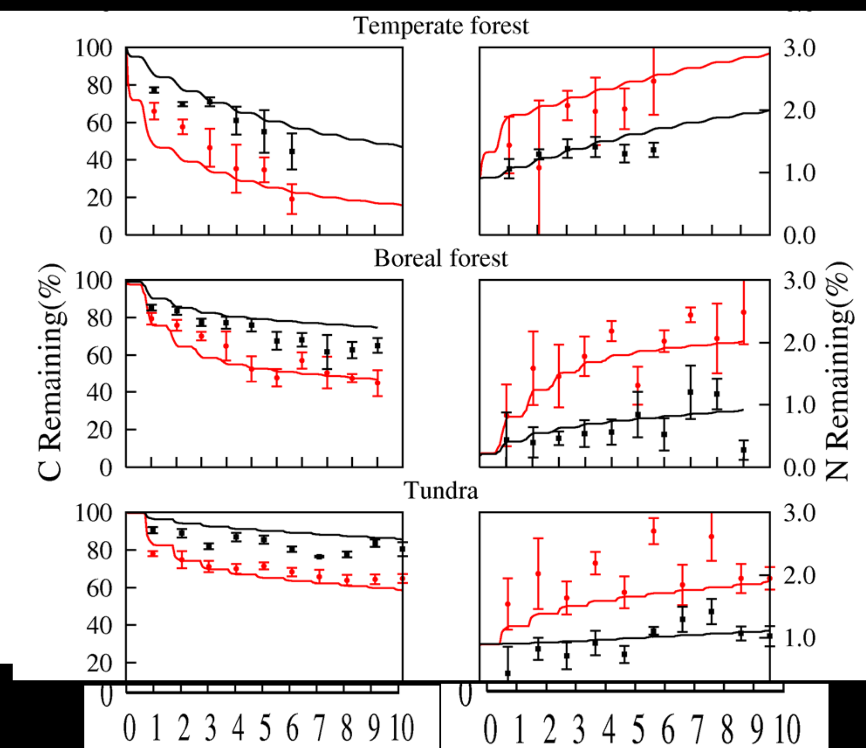
Calculate fluxes of carbon, nitrogen, energy, water, and the dynamical processes that alter these fluxes

- 18 Biome types
- 0.5 x 0.5 degree resolution
- 30 minutes temporal scale
- Season-to-interannual variability (penology)

Evaluation of N-C cycle - Below and Above Ground N and C Masses



Leaf Litter Decay

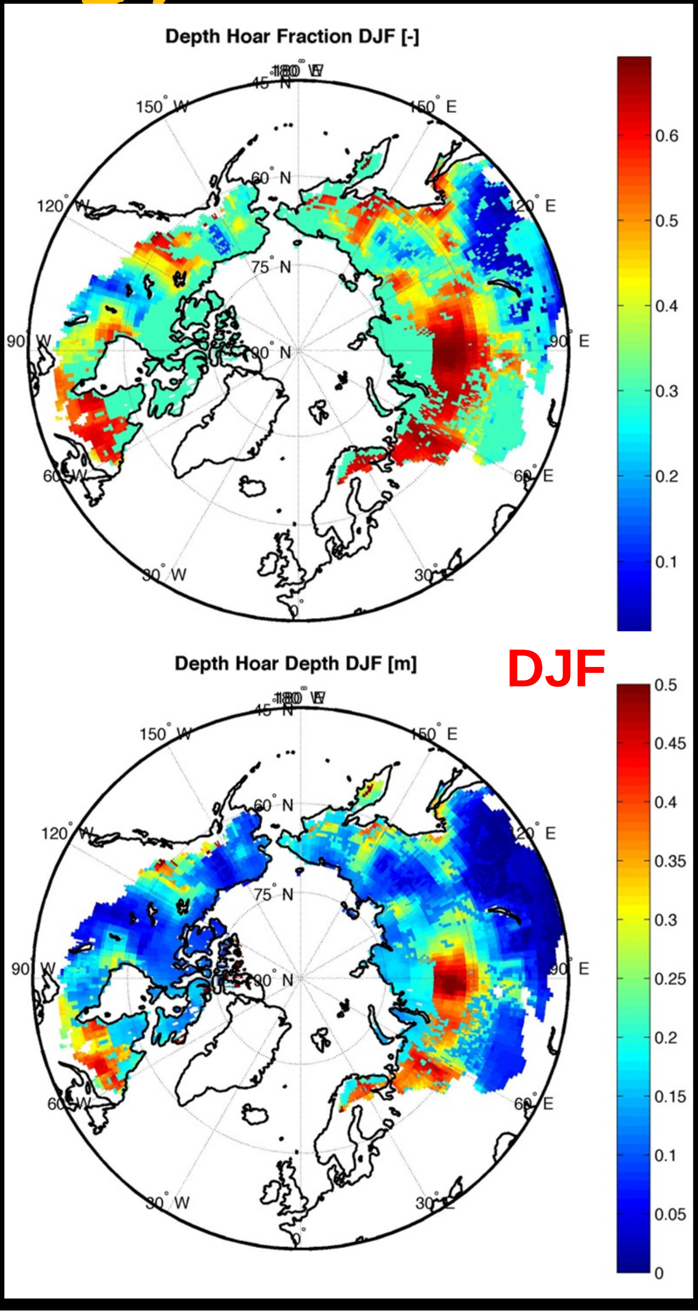


Root Litter Decay

Yang et al. (2009, GBC)

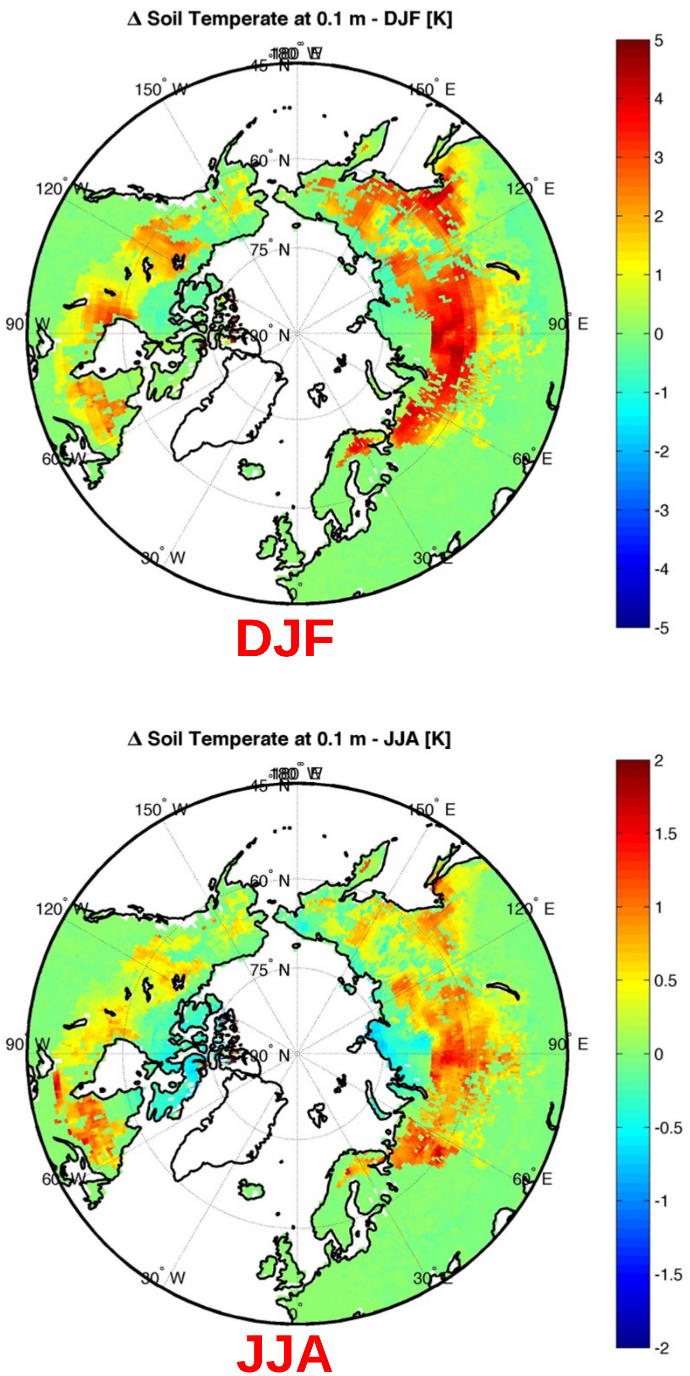
Snow Hydrology

- Soil crystals (or Depth Hoar, DH)
  - formation depends on snow cover type (Stern et al., 1995)
  - has low thermal conductivity
- Implementation of DH fraction and depth in ISAM



Barman et al. (2010)

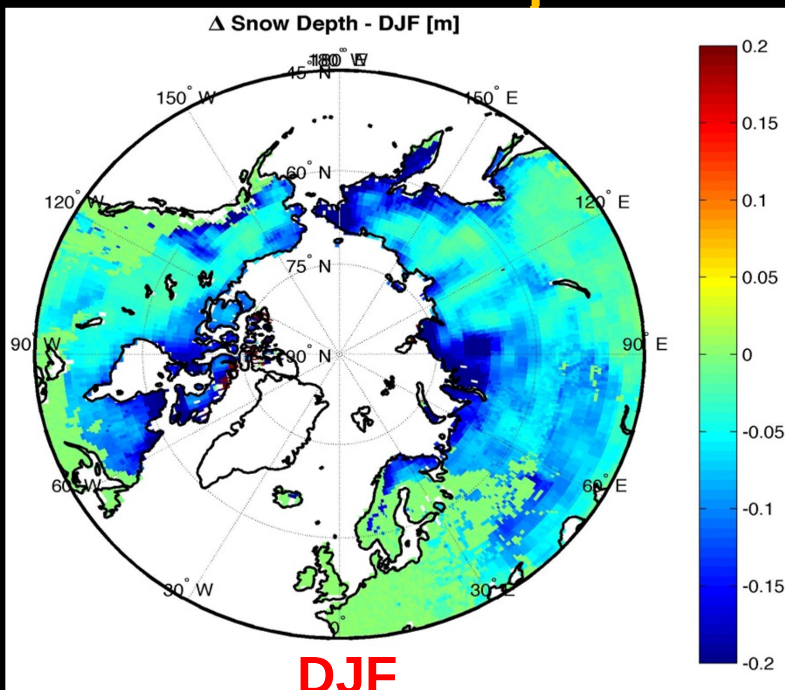
Depth Hoar Effect of Soil Temperature



Barman et al. (2010)

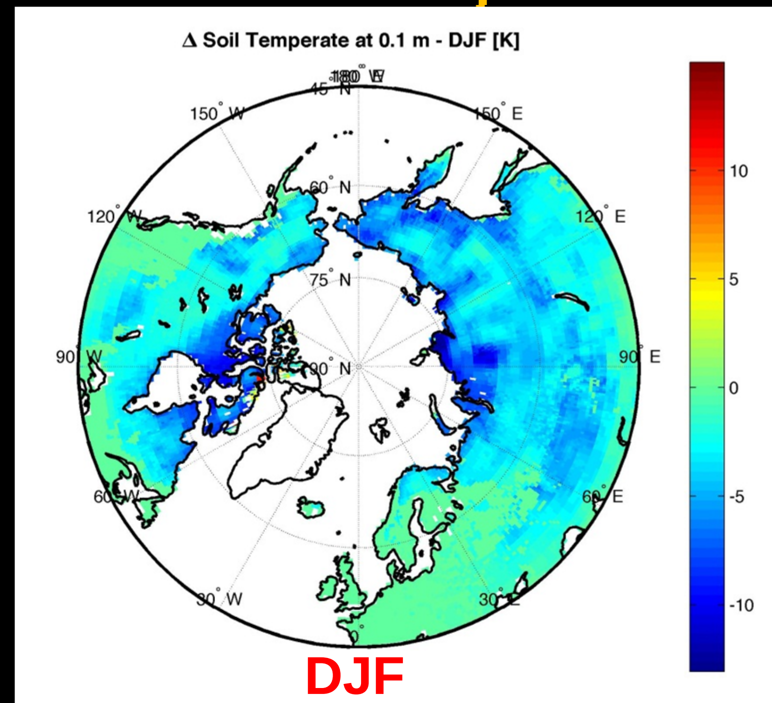
ISAM Estimated Wind Compaction Effect

on Snow Depth



Significant decrease of Snow Depth in Tundra snow class

on Soil Temperature

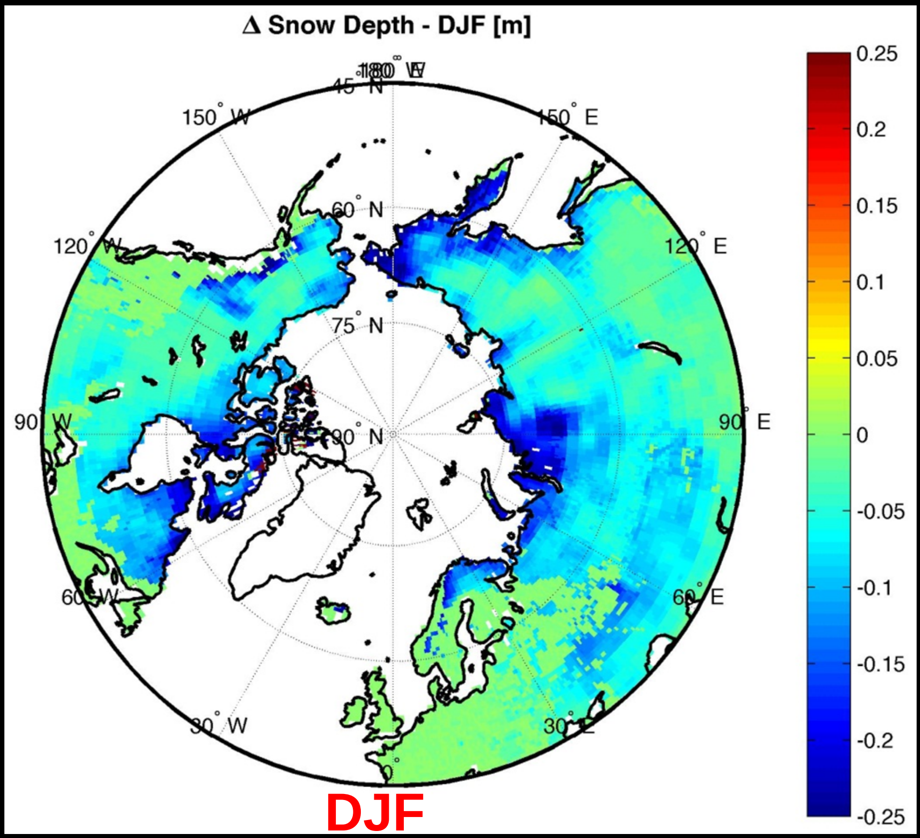


Cooler Soil Temperatures due to more efficient heat flow out of the soil in Winter.

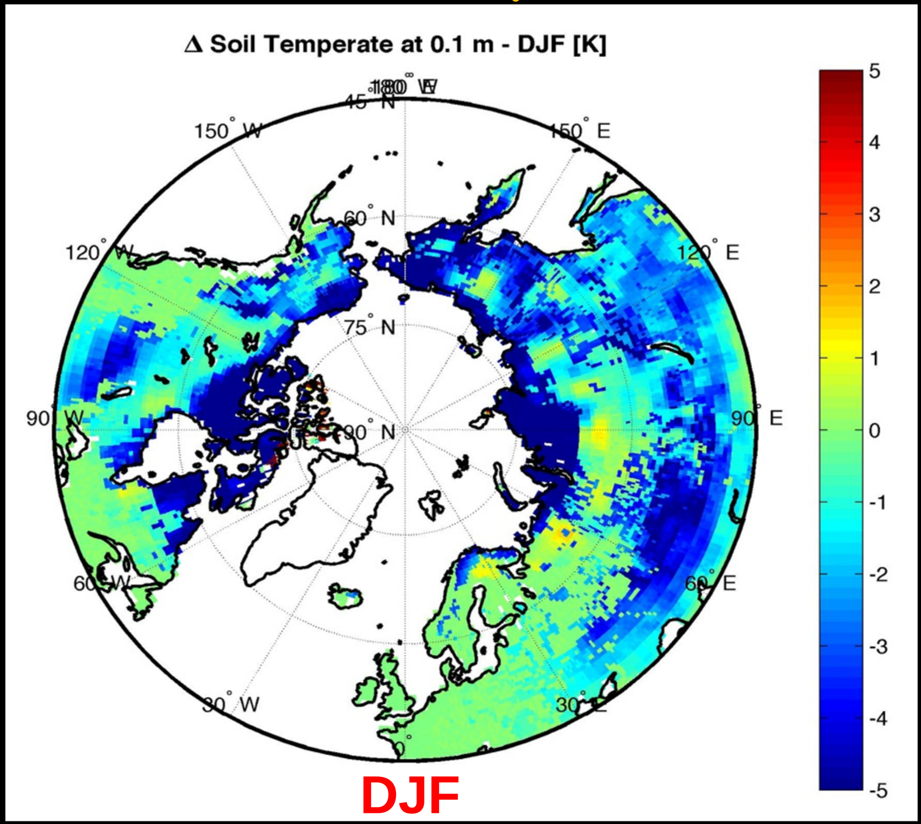
Barman et al. (2010)

ISAM Estimated Combined Effect (Wind Compaction & Depth Hoar)

on Snow Depth



on Soil Temperature



Net significant cooling in the Tundra snow class; Net warming in the Taiga snow class

Barman et al. (2010)

Permafrost Extent & Active Layer Depth

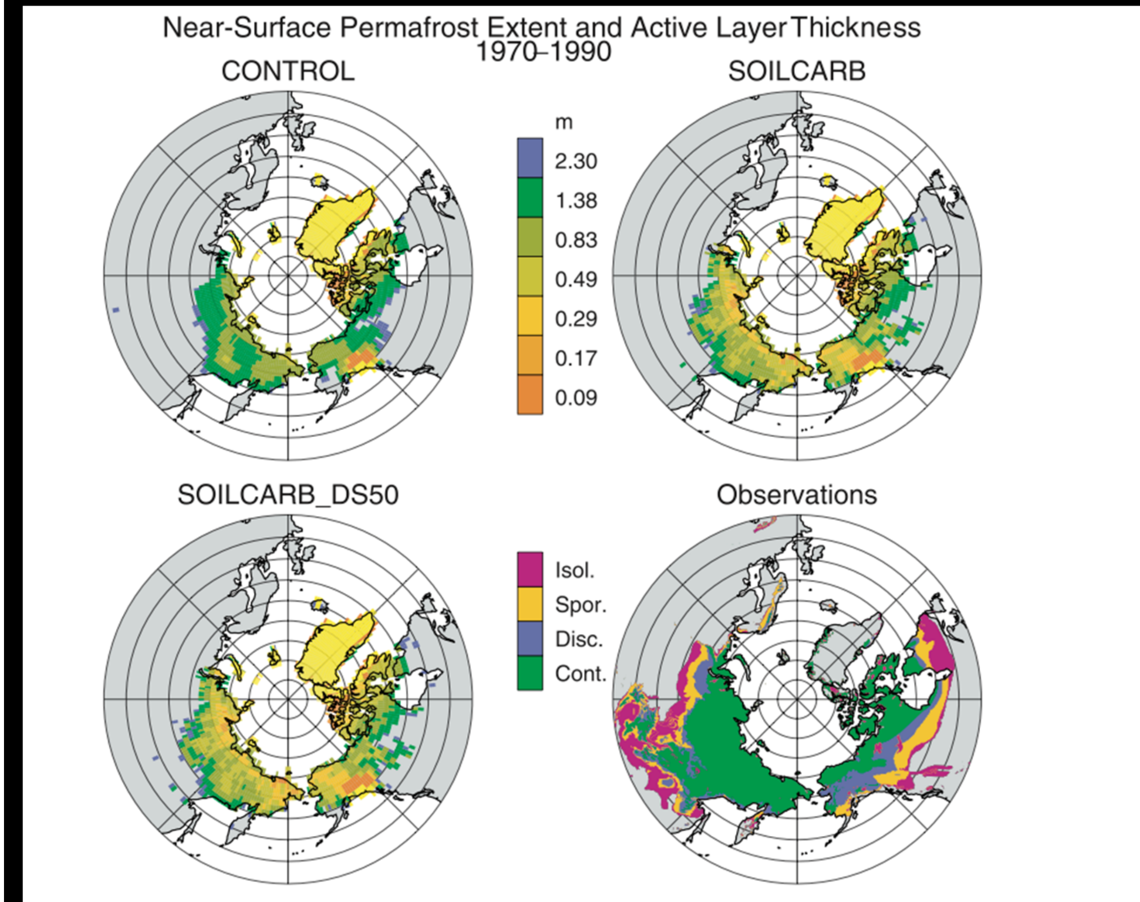
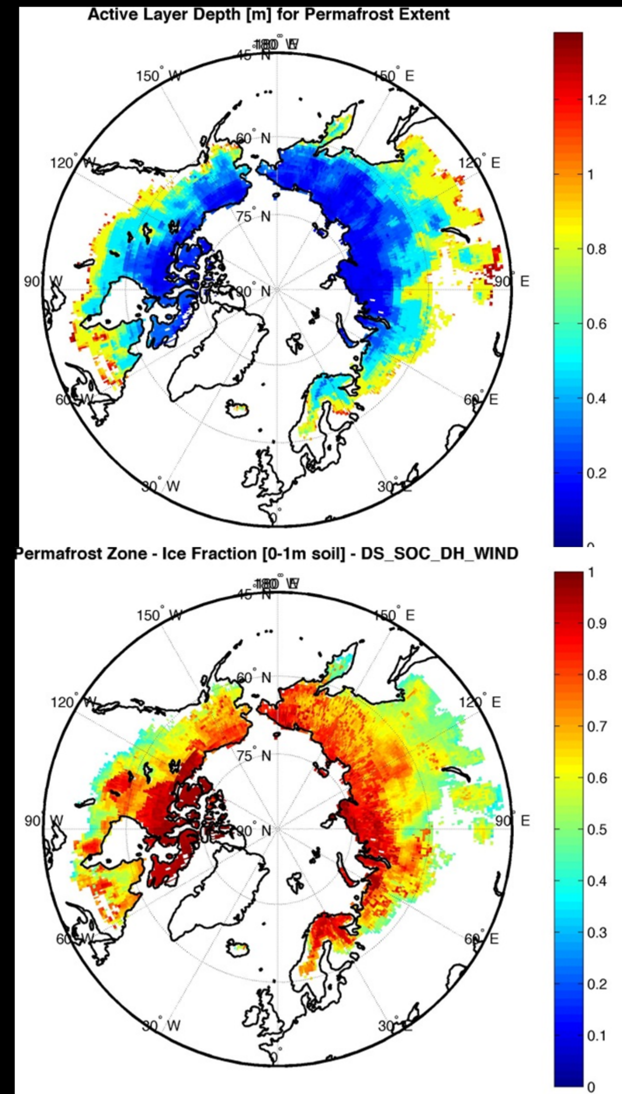


Figure 3. Modeled near-surface permafrost extent and ALT for off-line experiments CONTROL, SOILCARB, and SOILCARB_DS50 averaged over the period 1970–1990. Yellow denotes area where the dominant land unit in the CLM surface data set is glacier. Also shown are observed estimates of permafrost extent (continuous, discontinuous, sporadic, and isolated).

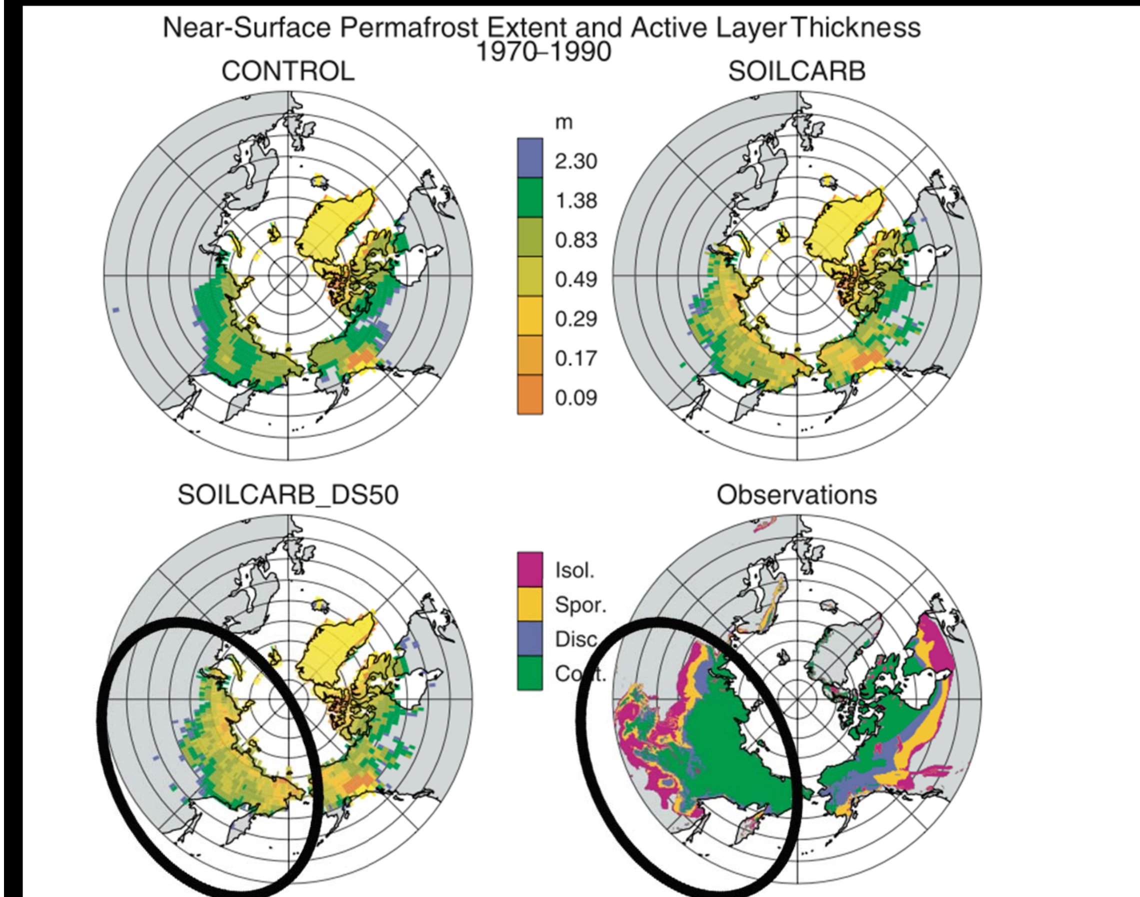
Source: Lawrence et al., 2008, JGR



ISAM Estimates

Barman et al. (2010)

Permafrost Extent & Active Layer Depth



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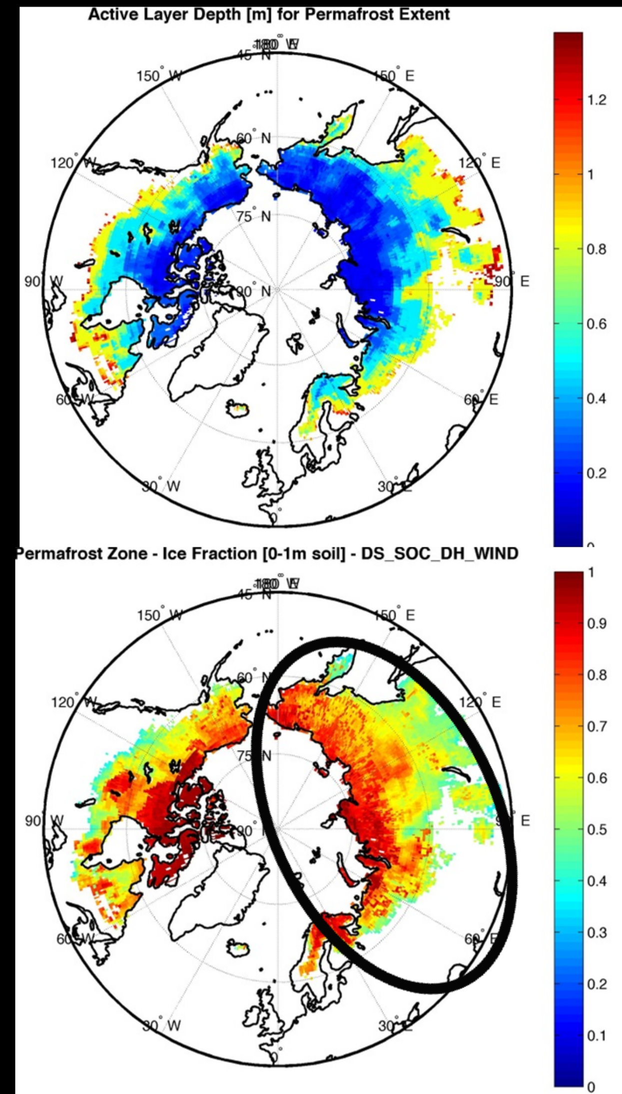
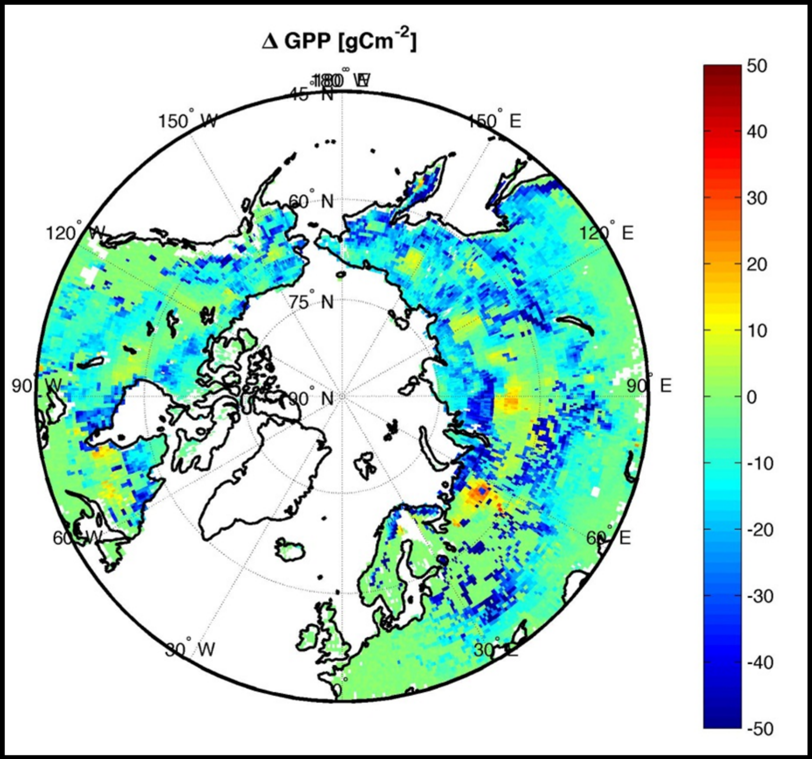
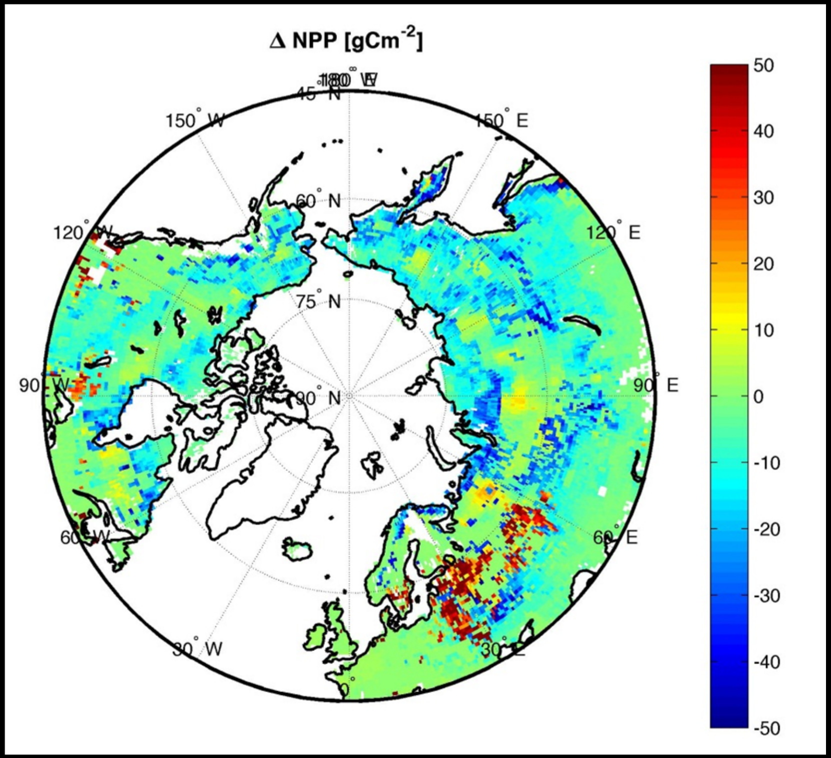


ISAM Estimates

Barman et al. (2010)

Effect on Biogeochemistry – Change in Annual GPP, NPP





Model results suggest temperature driven response in annual GPP & NPP

Barman et al. (2010)

ISAM CURRENT EFFORTS:
Coupling of Land Model with Climate

CESM Model
- Atmosphere
- Ocean
- Sea-ice
- Other components

↕ CLM

↕ ISAM Land
- Biogeochemistry
- Permafrost
- Biogeophysics

Objectives:
- Compare the performance of CESM-ISAM with the CESM-CLM and to identify areas of major disagreements, and
- Gain a better understanding of the impact of alternative representations of ISAM formulations in climate feedbacks.

Collaborators:
- Mariana Vertenstein (NCAR)
- Forrest Hoffman (ORNL)
- Robert Jacob (ANL)

Research Plan - Short Term Goals

- Evaluate the performance of ISAM-CESM modeling framework
  - Use the Carbon-Land Model intercomparison Project (C-LAMP) as a diagnostic framework to compare results with data and other models.
- Perform coupled ISAM-CESM modeling experiments to evaluate key climate-carbon interactions and feedbacks
  - Study the magnitude and dynamics of the permafrost and terrestrial carbon cycle feedback.

Research Plan – Long Term Goals

- Couple the permafrost models to models of ecosystem structure and function to study:
  - vertical distribution of soil temperature and C & N with time.
  - landscape-level effects of thaw:
    - Surface Subsidence (thermokarst)
    - Cryoturbation
    - Wetland expansion/contraction
  - the effects of disturbance (like fire) on ecosystem structure.

Applying novel load-balancing mechanisms to the ISAM to achieve dynamic and improved modeling scalability

Background:
Current Imbalance in ISAM

<u>Biogeophysics</u>

Component:

MPI, P=64,

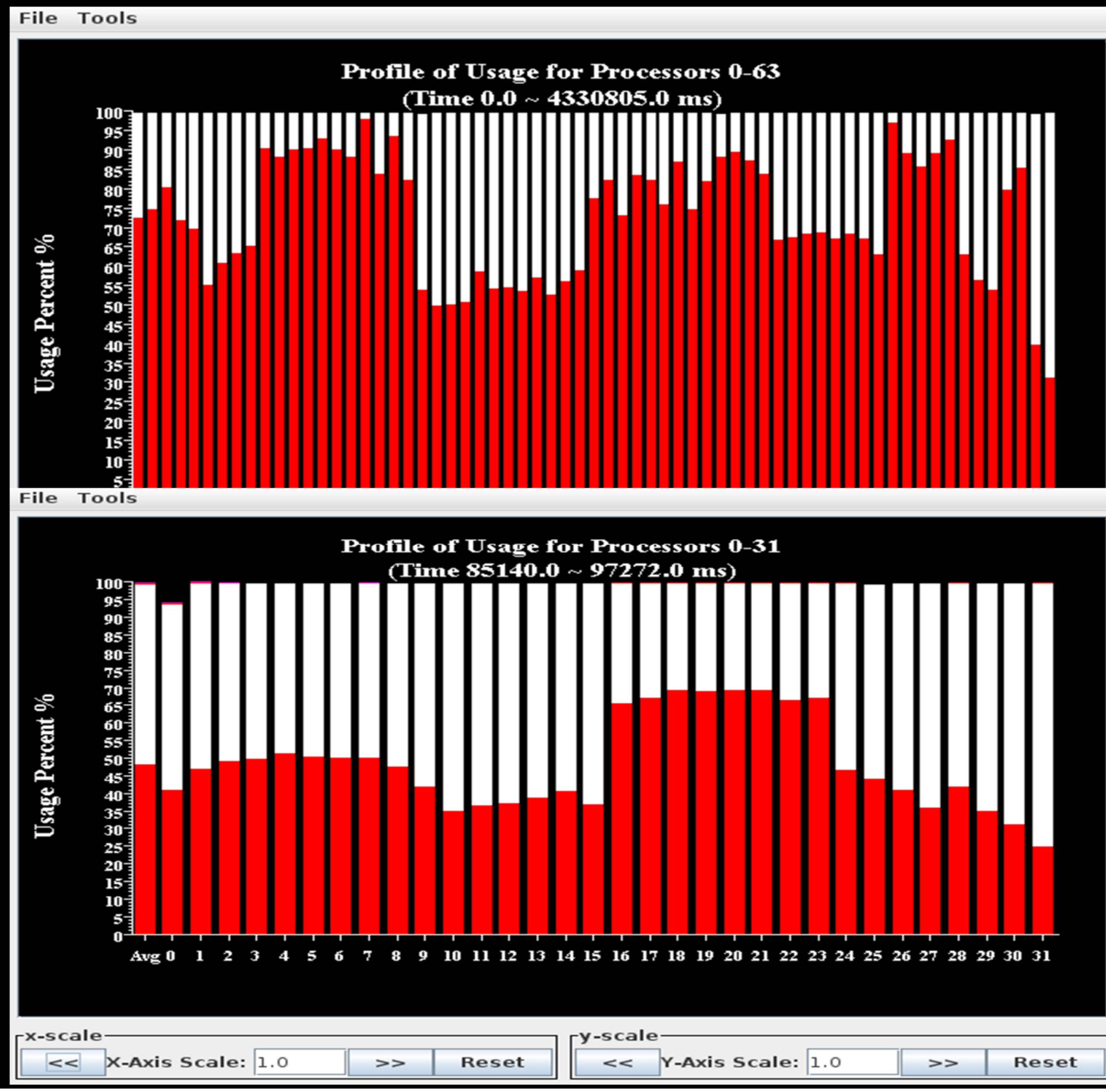
10-year simulation

<u>Biogeochemistry</u>

Component:

MPI, P=32,

4-year simulation



Near and Long Term Project Goals

- Near Term Goals
  - Use advanced load balancing algorithms using Charm++/Adaptive-MPI (AMPI) systems -to balance the load of ISAM when running standalone
    - AMPI employs migratable objects, enabling dynamic load balancing and enhanced scalability
- Long Term Goals
  - Use AMPI to balance the load of coupled ISAM+CESM
    - This may require development of new load balancers, tuned to CESM's characteristics

The End

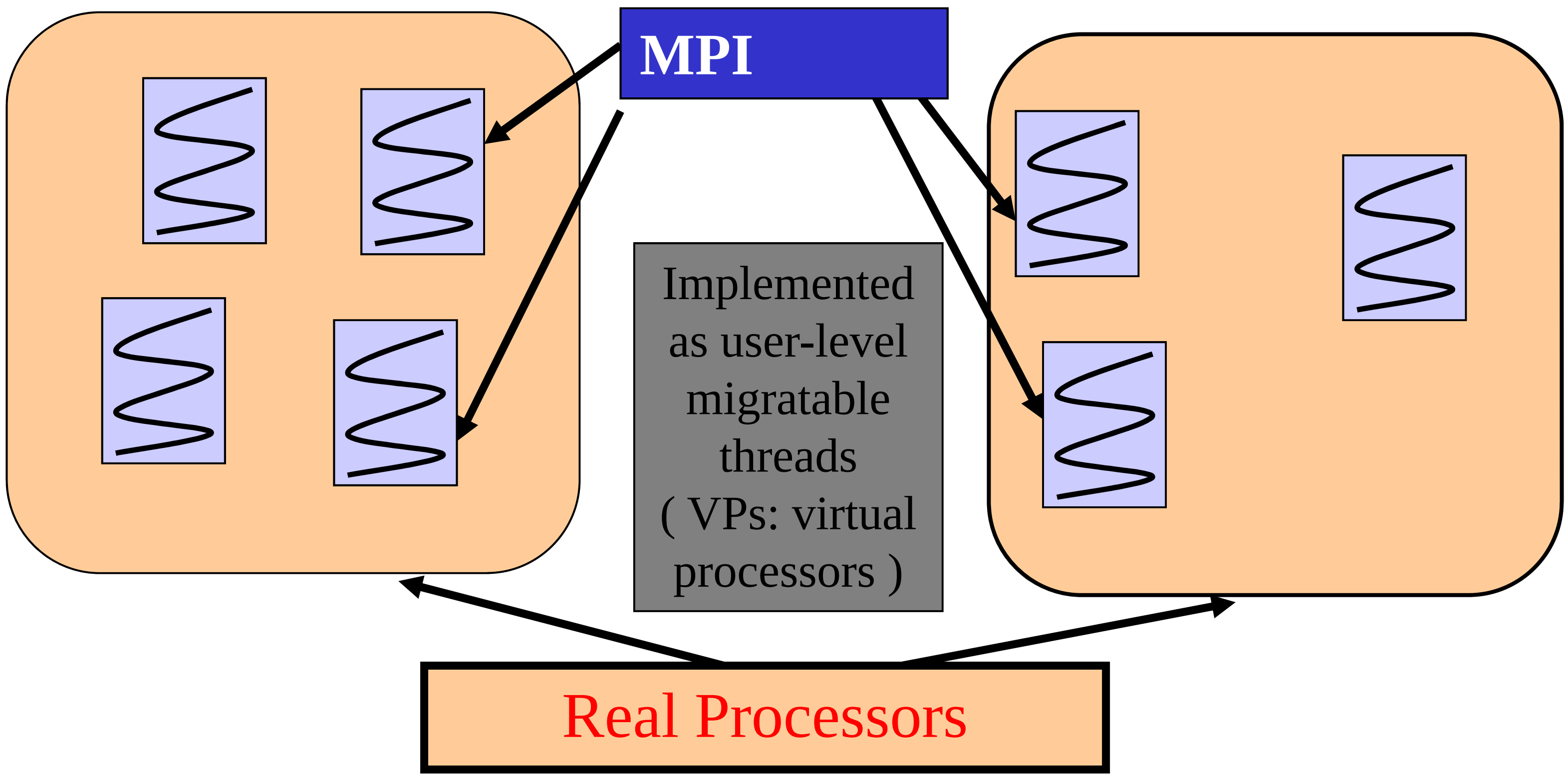
Extra Slides

AMPI: Motivation

- Challenges
  - New generation parallel applications are:
    - Dynamically varying: load shifting during execution
    - Adaptively refined
    - Composed of multi-physics modules
- Typical MPI Implementations:
  - Not naturally suitable for dynamic applications
  - Available processor set may not match algorithm
- Alternative: Adaptive MPI (AMPI)
  - MPI & Charm++ virtualization: VP ("Virtual Processors")

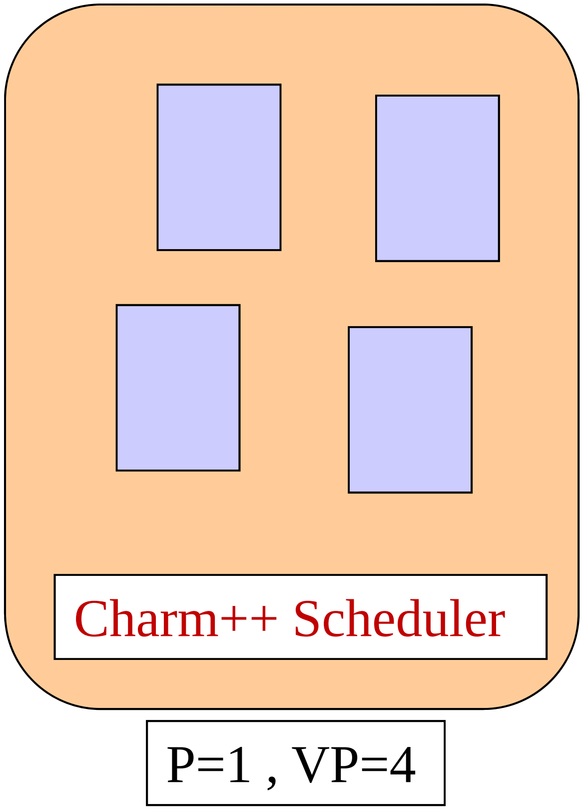
AMPI: Overview

- Virtualization: MPI ranks → Charm++ threads



AMPI: Overview (cont.)

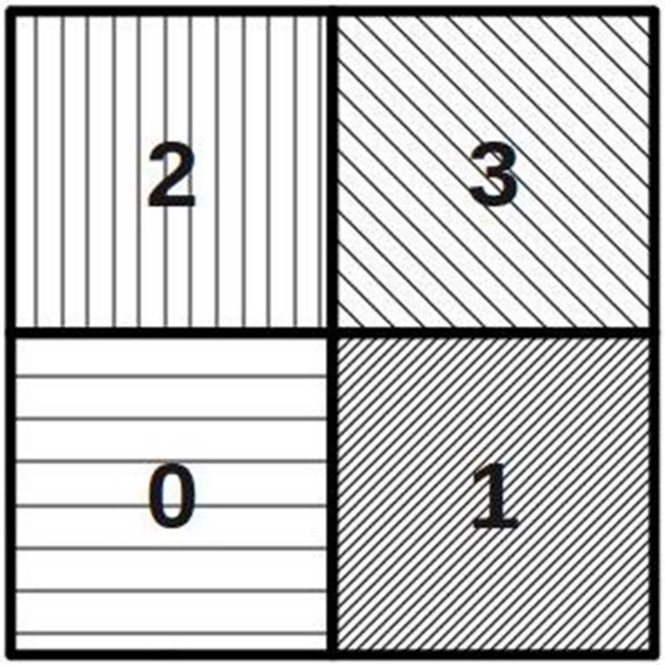
- AMPI Execution Model:
  - Multiple user-level threads per process
  - Typically, one process per physical processor
  - Charm++ Scheduler coordinates execution
  - Threads (VPs) can migrate across processors
  - Virtualization ratio: R = #VP / #P (over-decomposition)



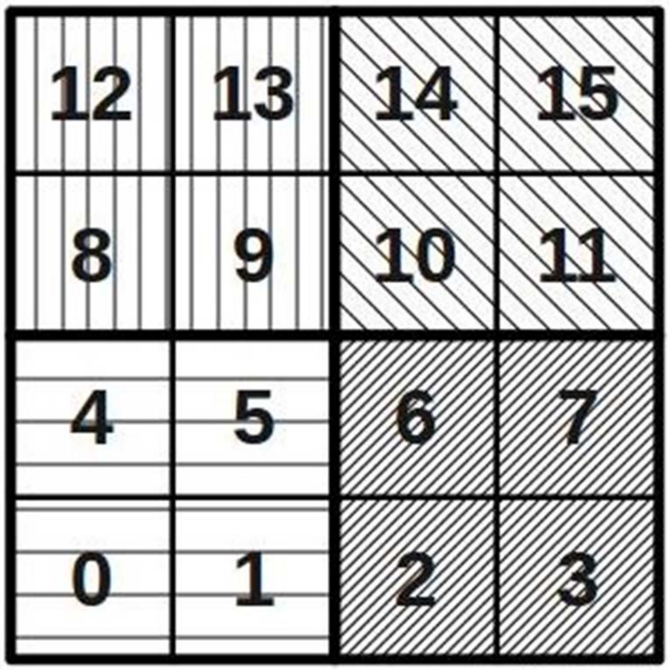
AMPI: Overview (cont.)

- AMPI's Over-Decomposition in Practice

MPI: P=4, ranks=4

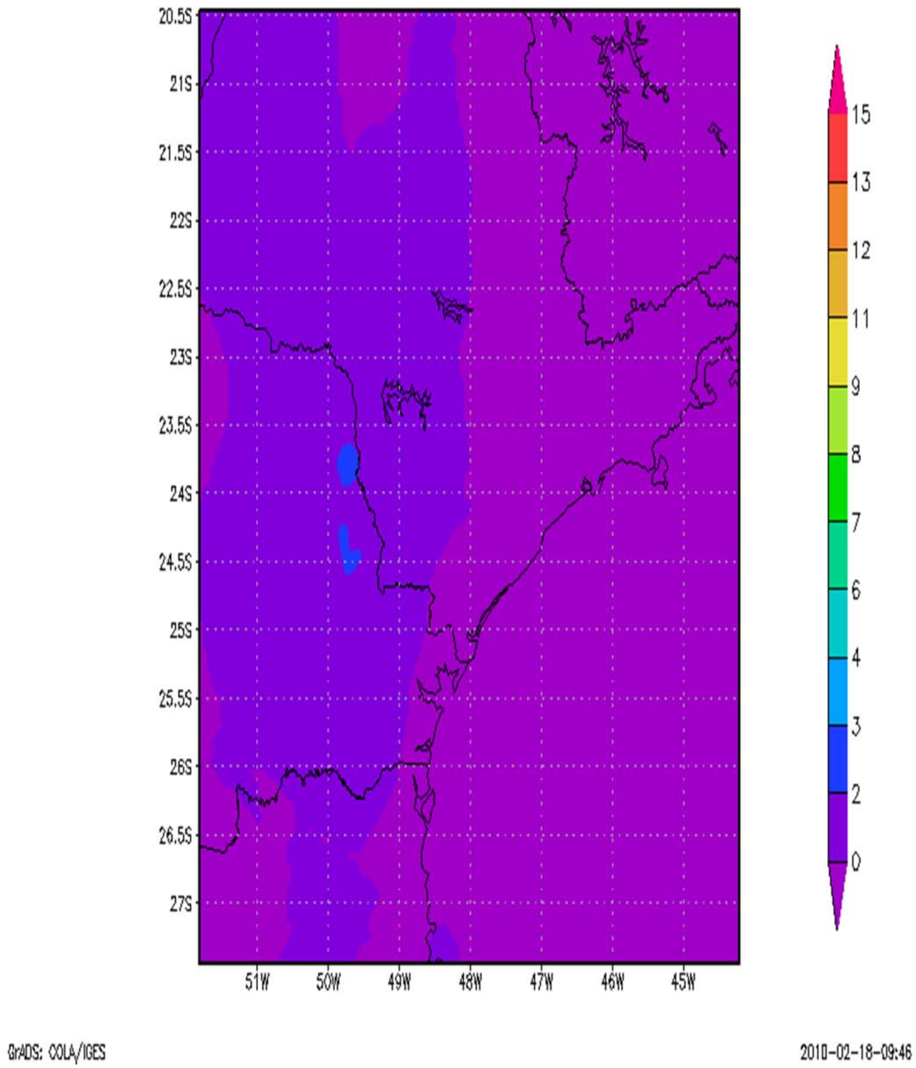


AMPI: P=4, VP=ranks=16

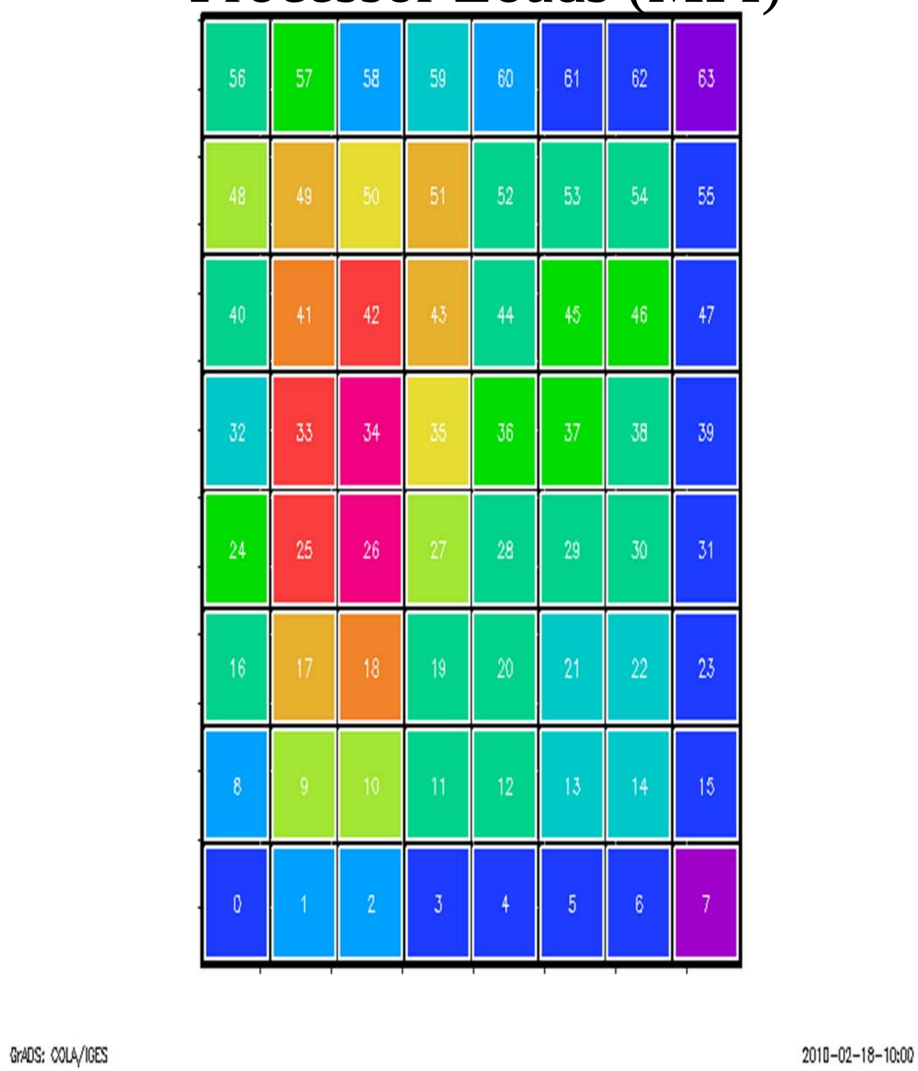


Load Imbalance Example

BRAMS Forecast

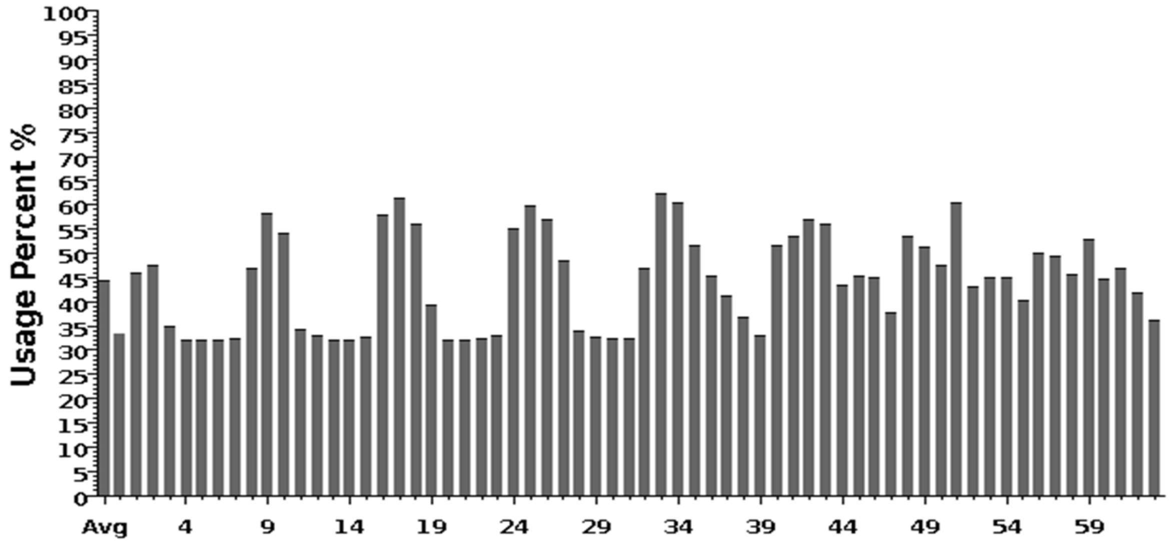


Processor Loads (MPI)



Processor Utilizations in BRAMS

Original (MPI)



After AMPI

Load Balancing