Toward Hierarchical Modeling of the Arctic System

Wieslaw Maslowski and Andrew Roberts

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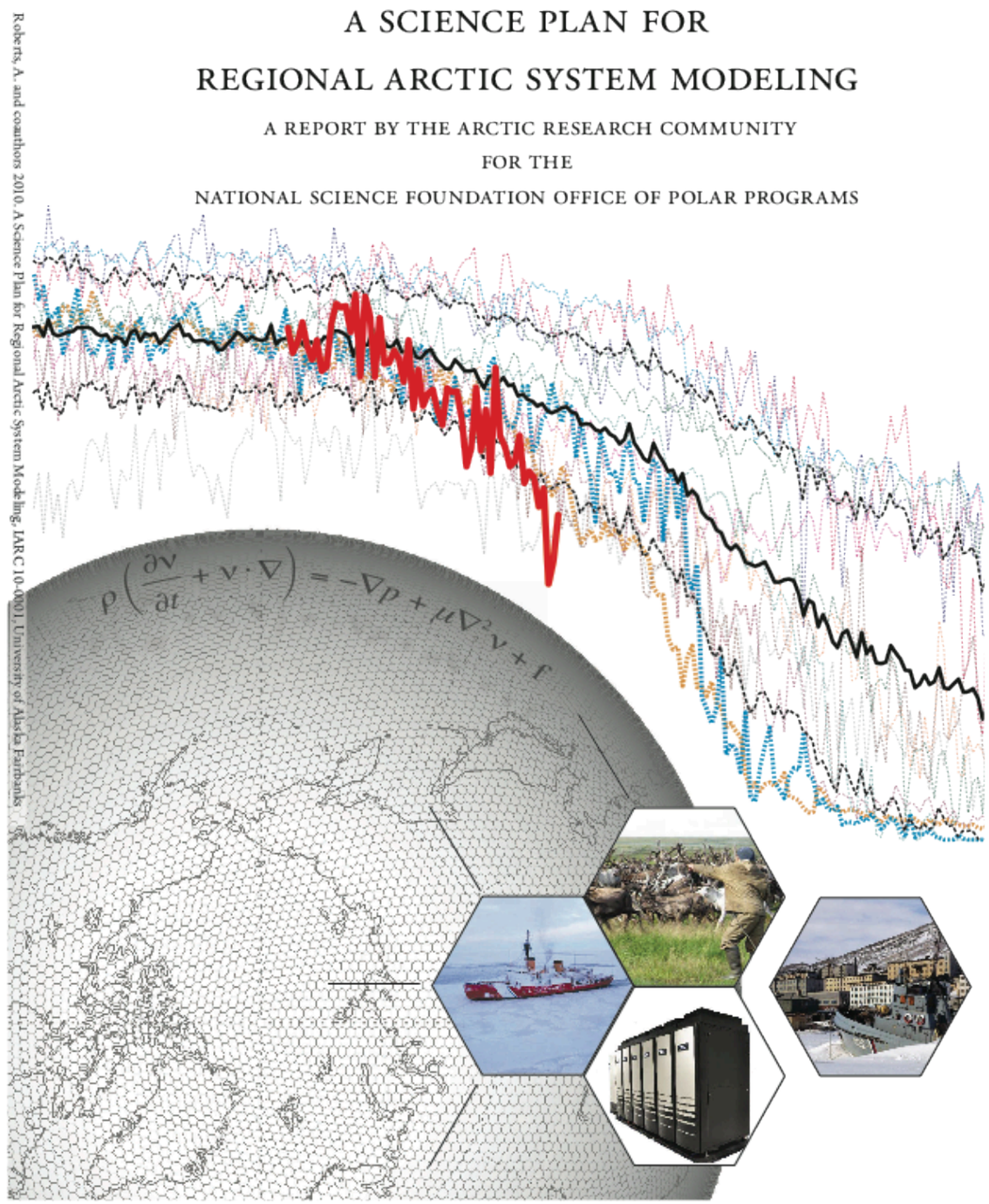
co-authors of "A science plan for regional Arctic System Modeling" for the National Science Foundation, 2010.

Adding regional system models to the mix



Roberts, A. and coauthors 2010

Outcomes from a three workshops 2007-2009 addressing two initial questions:

Is there scope for regional models to address:

- A shortfall in tools for downscaling (upscaling) from (to) global climate models for in situ arctic observations and civil operations?

- The large spread in multi-model ensembles and a divergence in climate projections from observations?

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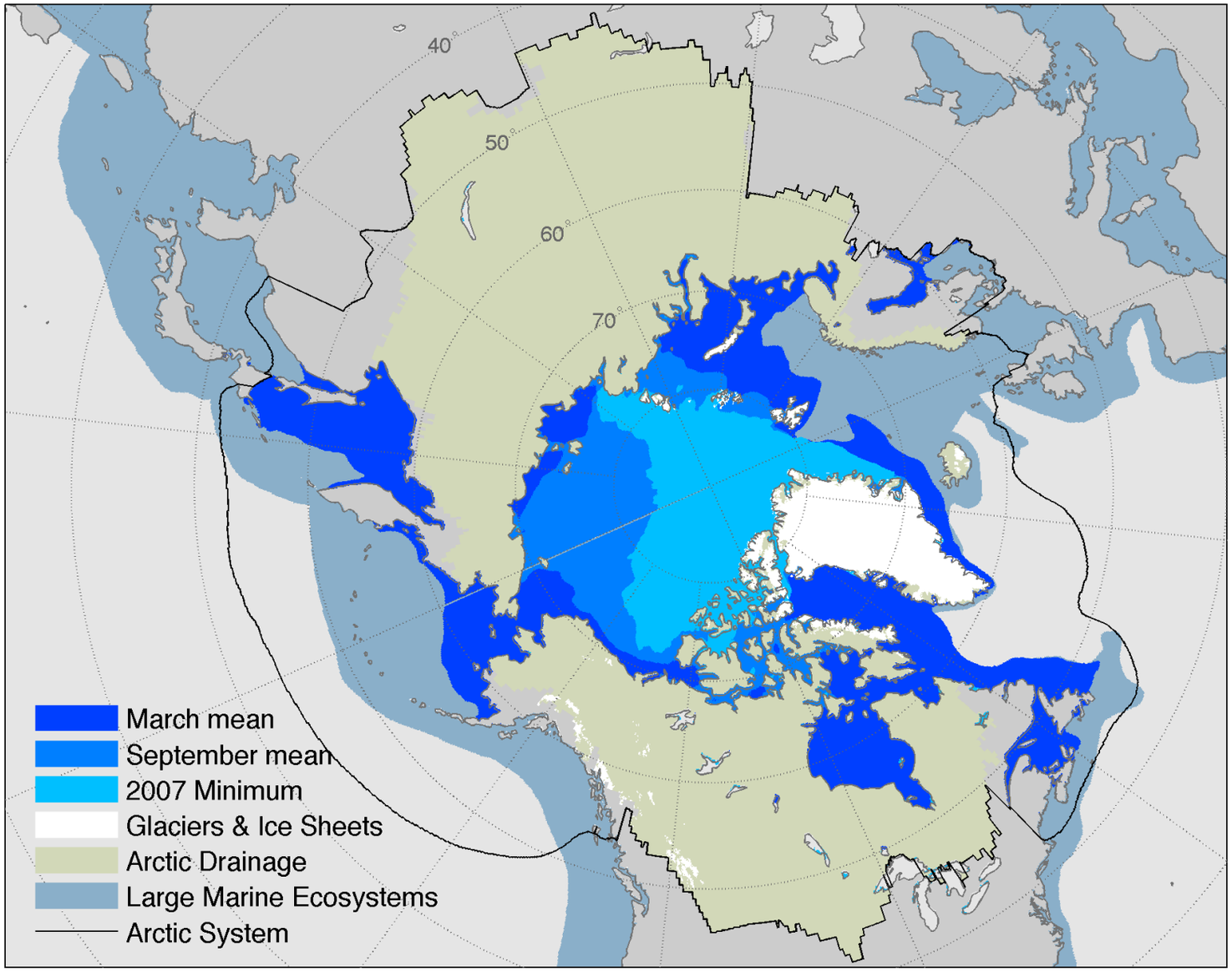
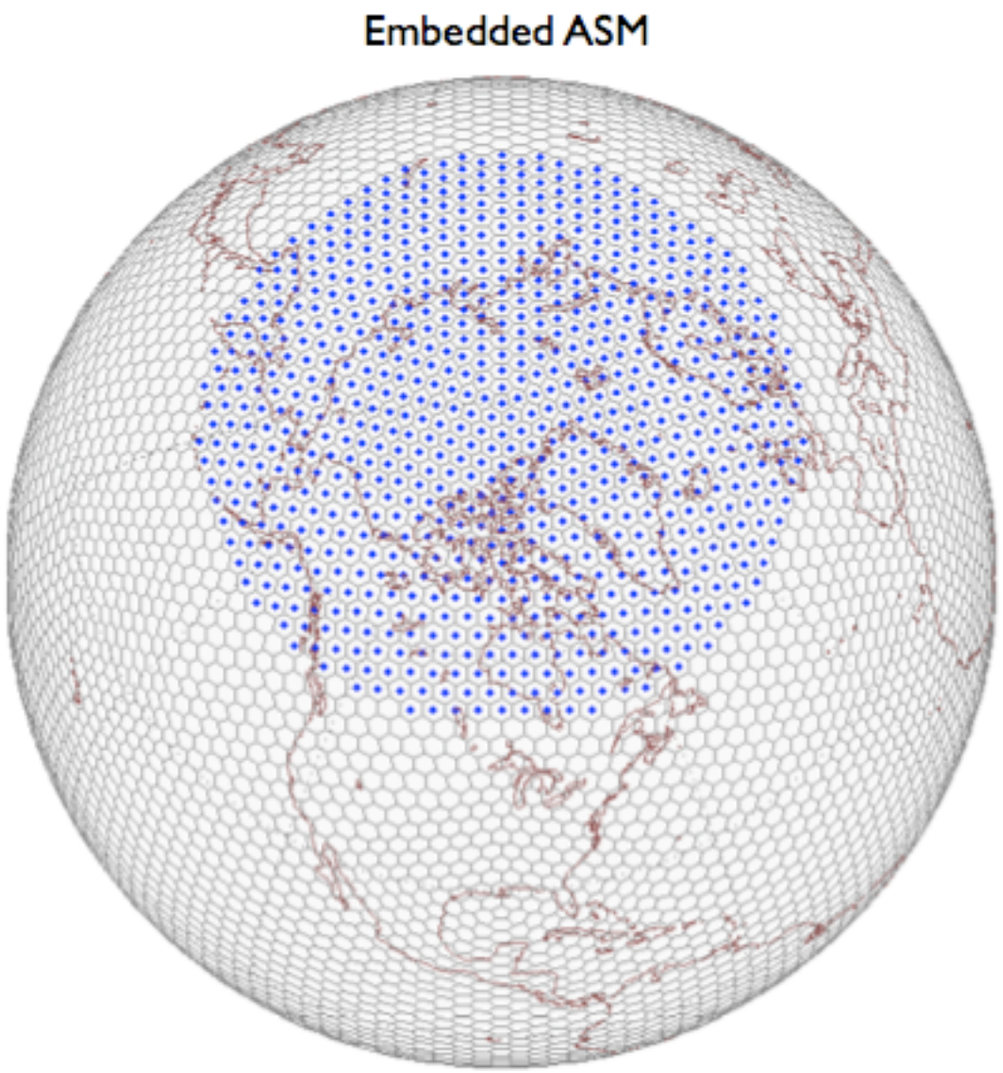
What is the Arctic System?



Roberts, A. and coauthors 2010



-The concurrent use of global and regional models, preferably in a "structured hierarchy" or using an "embedded system model" will help quantify uncertainty.

-This is not an arms race (resolution race) race between global and regional modeling groups.

- To make this possible, multiple regional models with a different lineage are essential.

Roberts, A. and coauthors 2010

How can coupled regional system models be used to understand uncertainty, complexity and change?

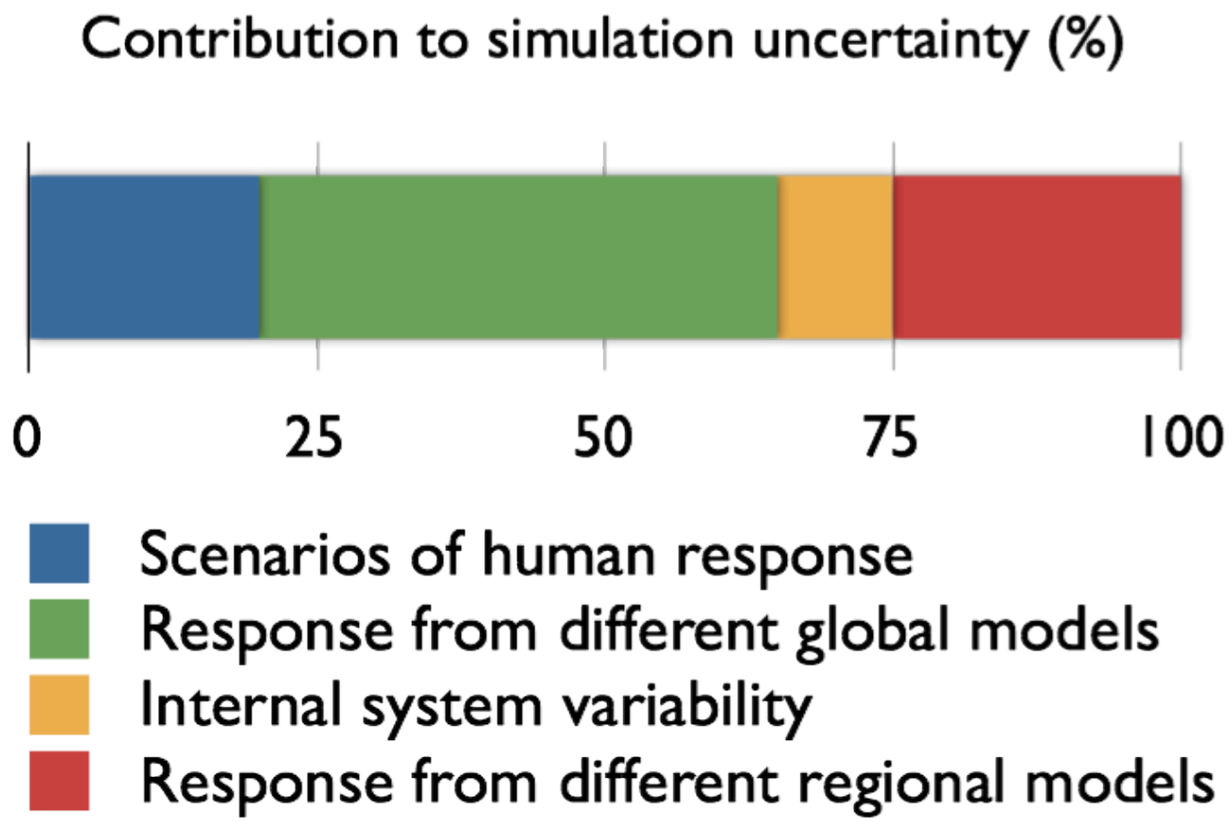
1. By resolving unresolved or under represented processes in individual system components.

2. By addressing inadequacies along coupling channels between different system components

3. Through a hierarchical modeling approach using both regional and global models to help quantify uncertainty.

Roberts, A. and coauthors 2010

Use of multi-model ensembles to quantify uncertainty with regional models

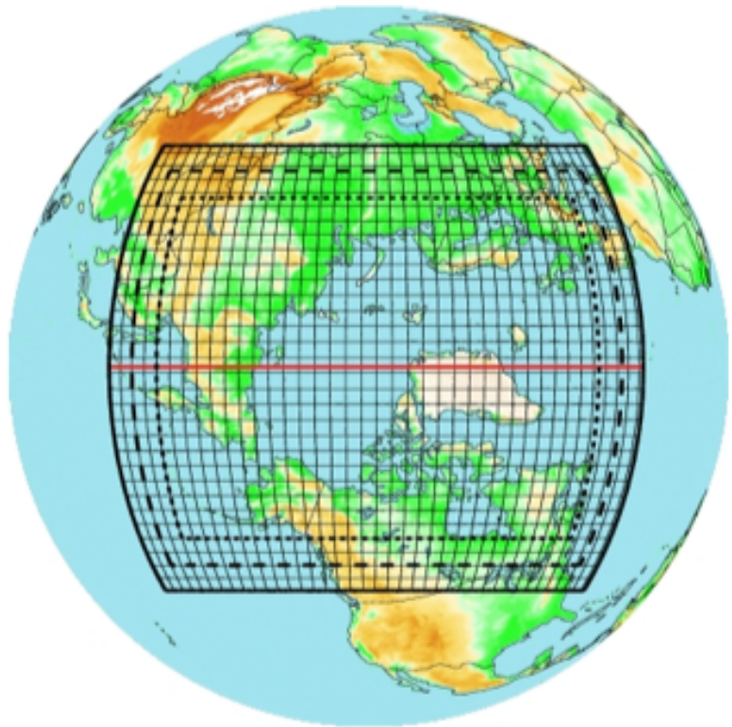


[Example adapted from PRUDENCE e.g. Giorgi et al. (2008)]

Roberts, A. and coauthors 2010

Building regional multi-model ensembles: Current models

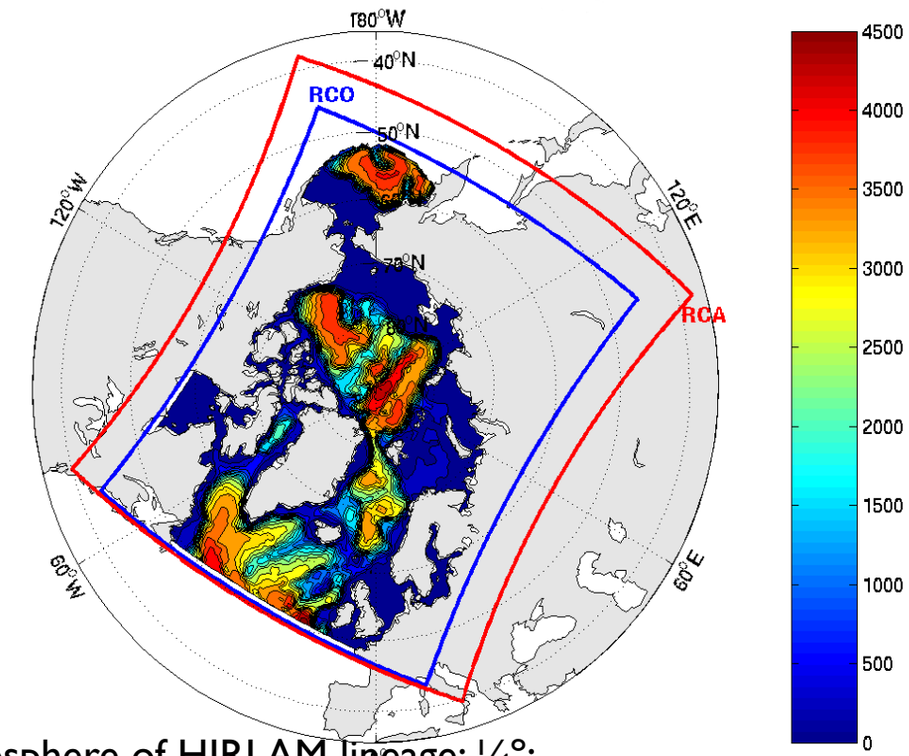
Canadian RCM: LAM (UQAM + Environment Canada)



Atmosphere of Global Environmental Multiscale (GEM) lineage Rossby Centre; and Ocean Model: both at 1/2° 59 levels

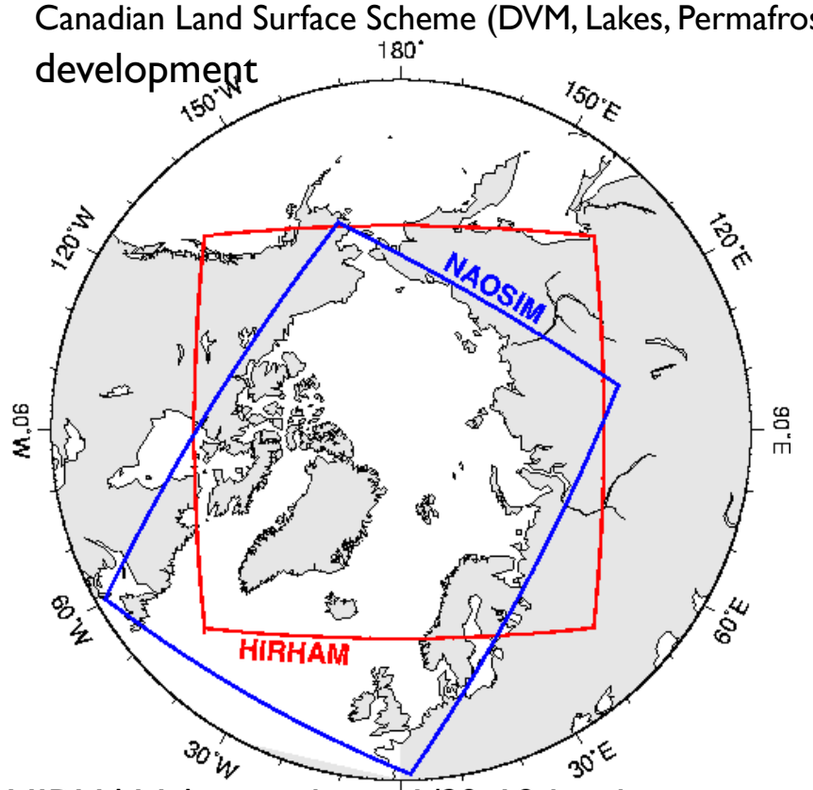
Canadian Land Surface Scheme (DVM, Lakes, Permafrost) under development

Sweden SMHI: Rossby Centre Atmosphere Ocean Model



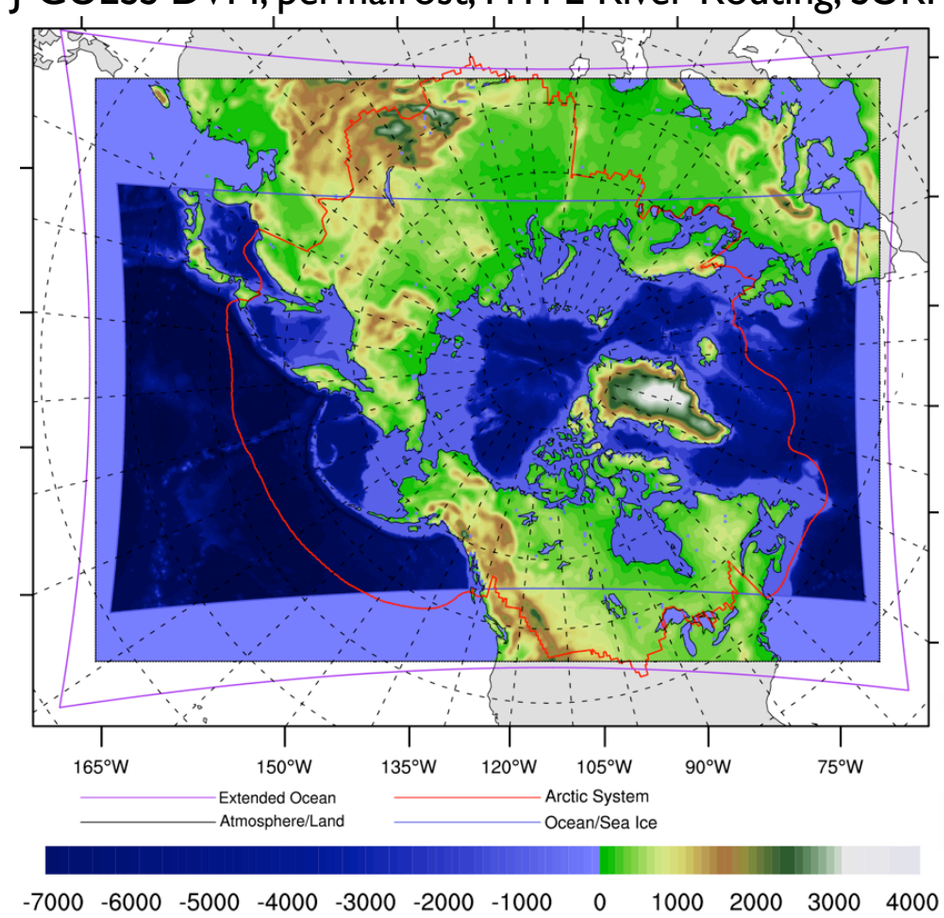
Atmosphere of HIRLAM lineage: ¼°;
Rossby Centre Ocean Model: ¼°
LPJ-GUESS DVM, permafrost, HYPE River Routing, SURFEX soil

Germany AWI: HIRHAM/NAOSIM

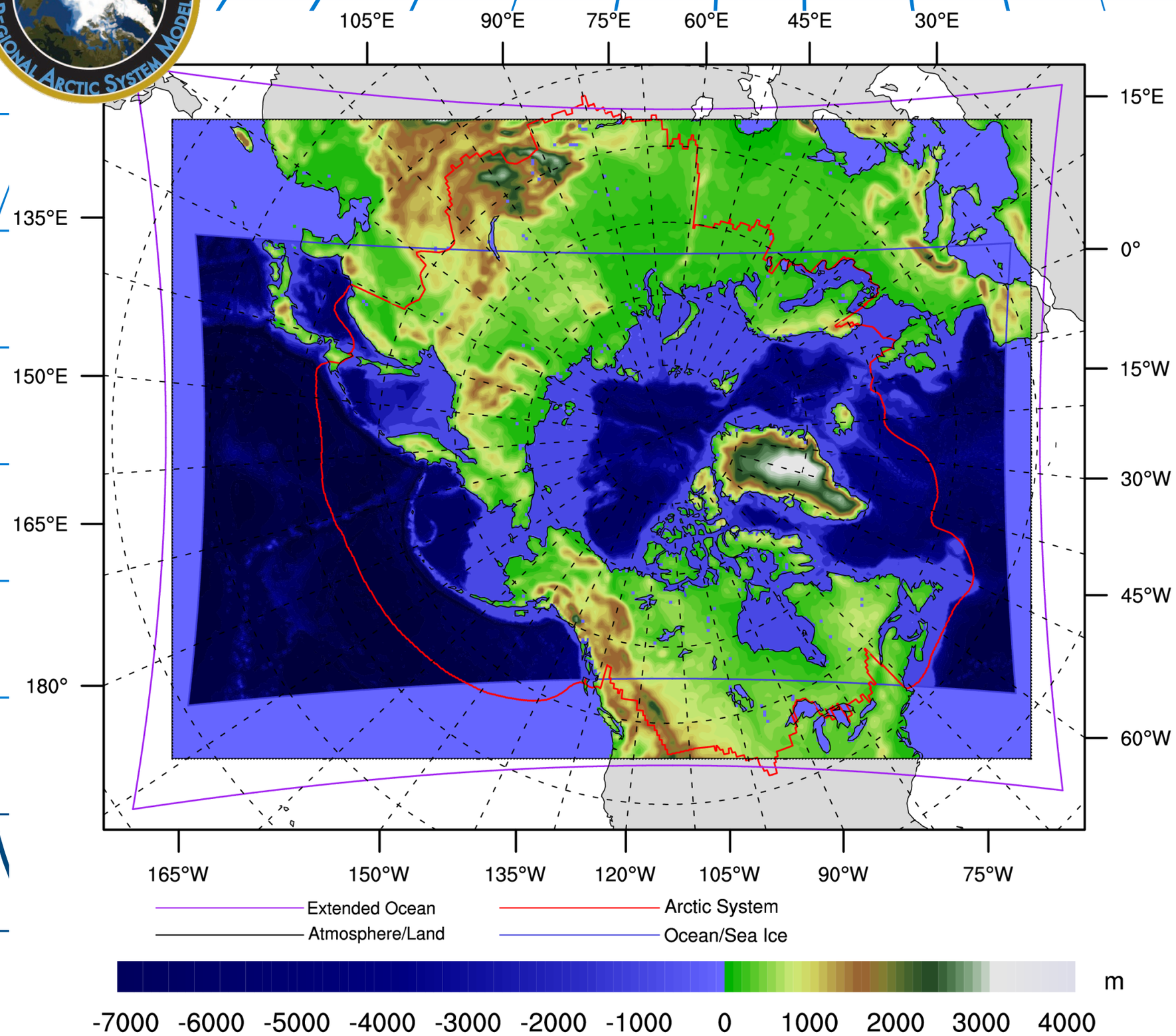


HIRHAM Atmosphere: 1/2°, 19 levels
NOASIM Ocean: 1/4° 30 levels
NCAR CLM under development

US: RASM



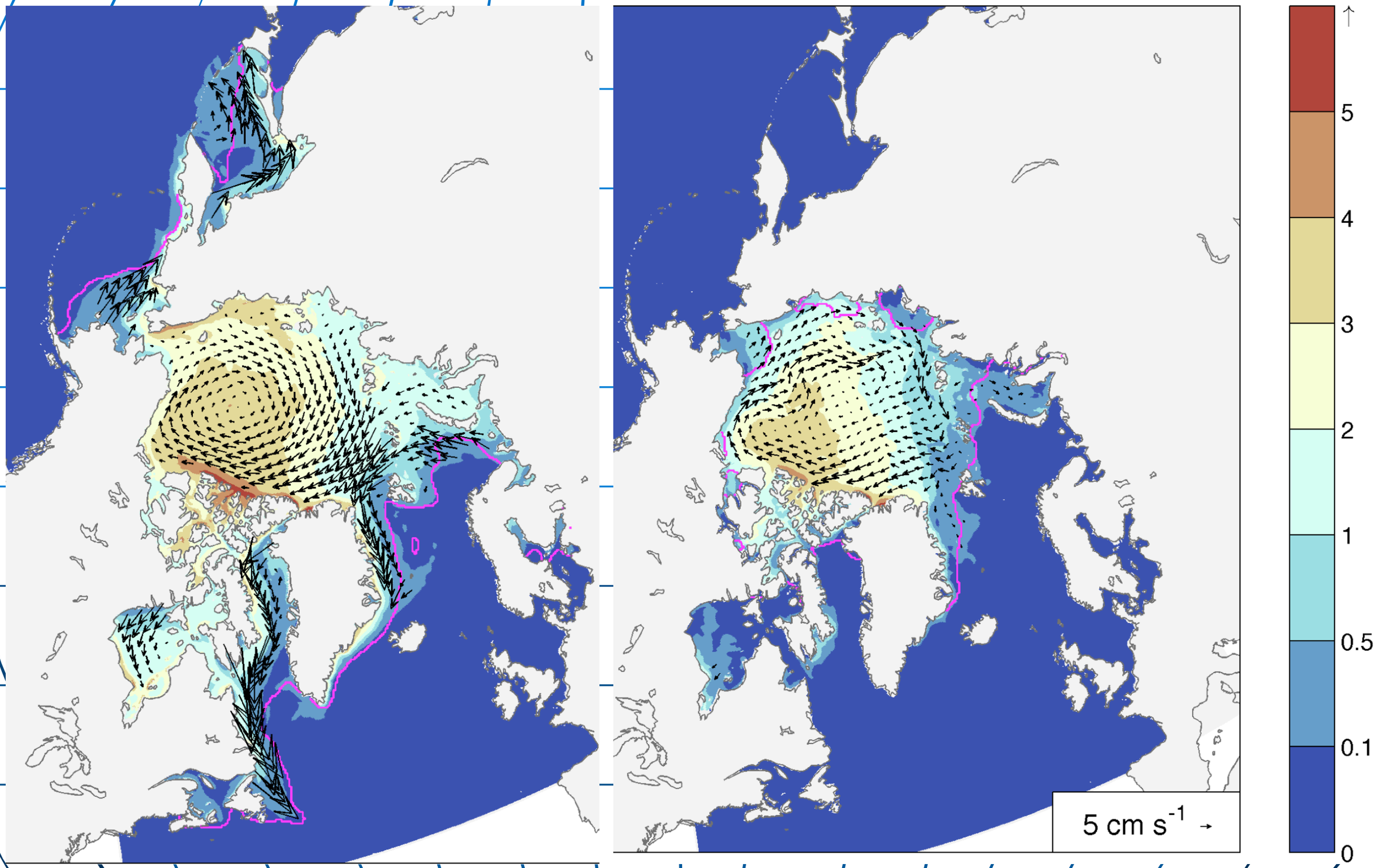
RASM Domains for Coupling and Topography



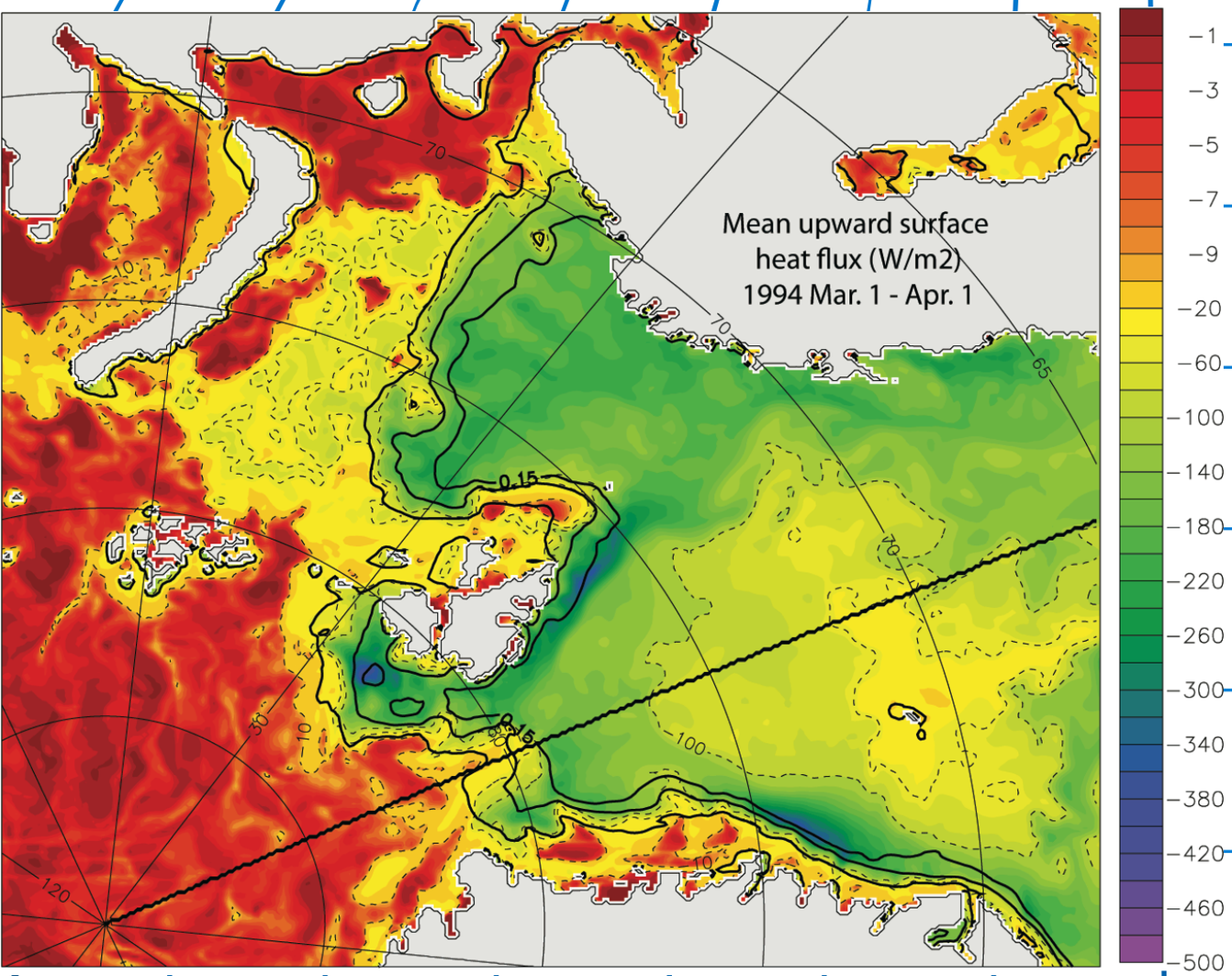
Pan-Arctic region to include:
- all sea ice covered ocean in the northern hemisphere
- Arctic river drainage
- critical inter-ocean exchange and transport
- large-scale atmospheric weather patterns (AO, NAO, PDO)

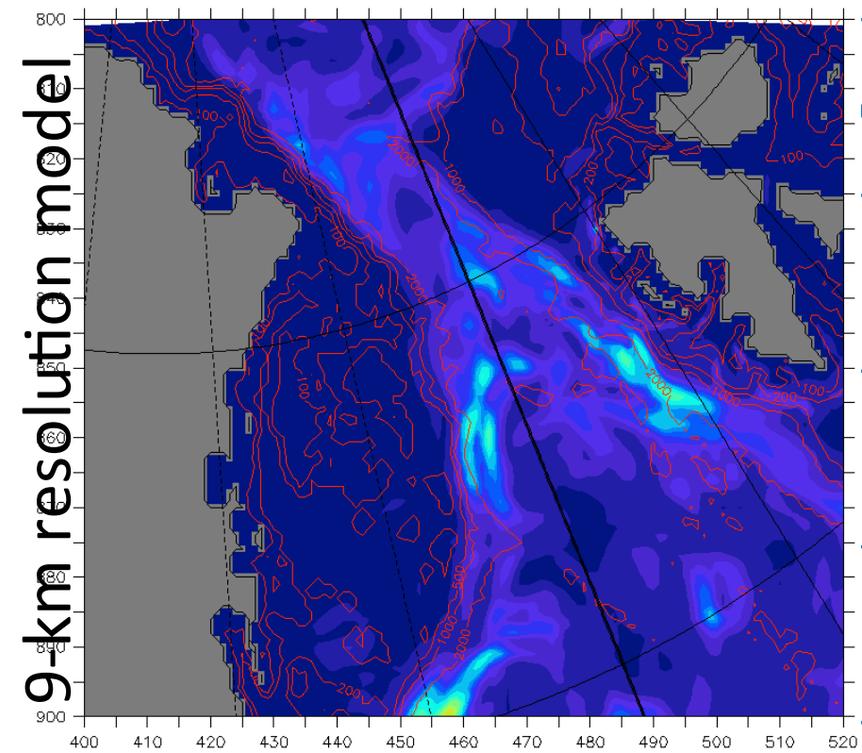
RASM pan-Arctic model domain. WRF and VIC model domains include the entire colored region. POP and CICE domains are bound by the inner blue rectangle. Shading indicates model topobathymetry.

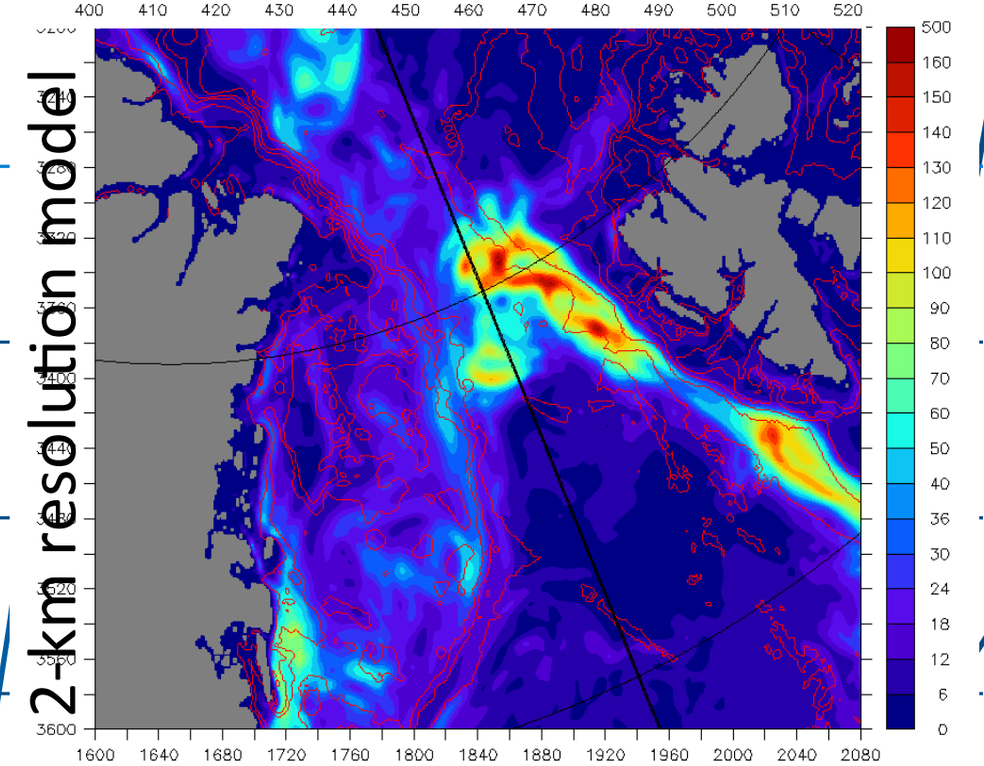
RASM mean (1990-1997) March sea ice thickness and drift



RASM monthly mean upward sfc heat flux – 3/93 and mean EKE (cm^2/s^2; 0-223 m) – Fram Strait



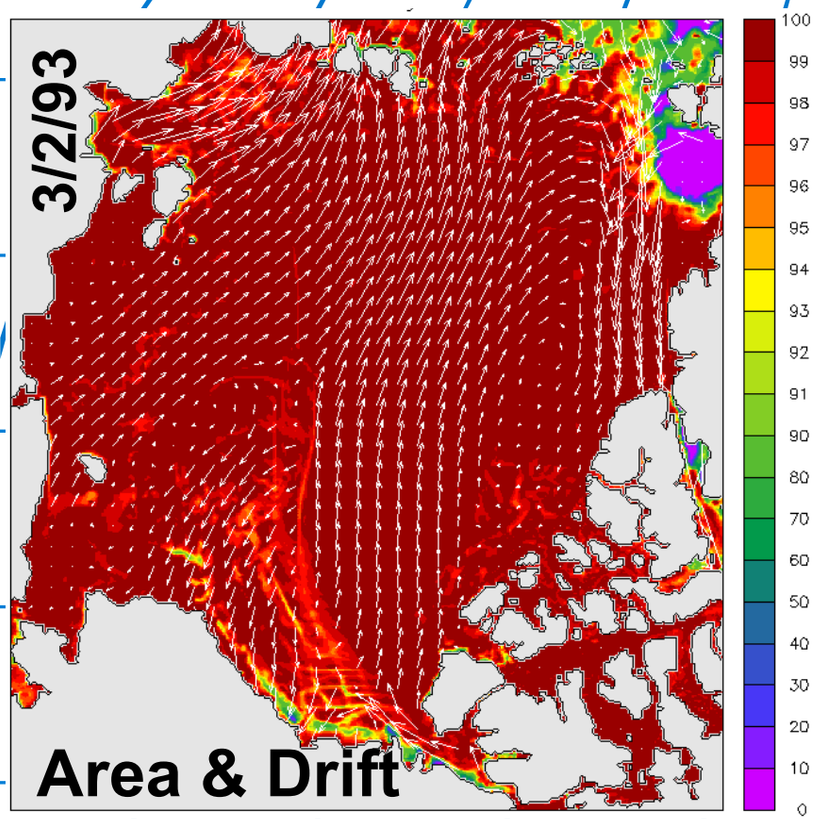


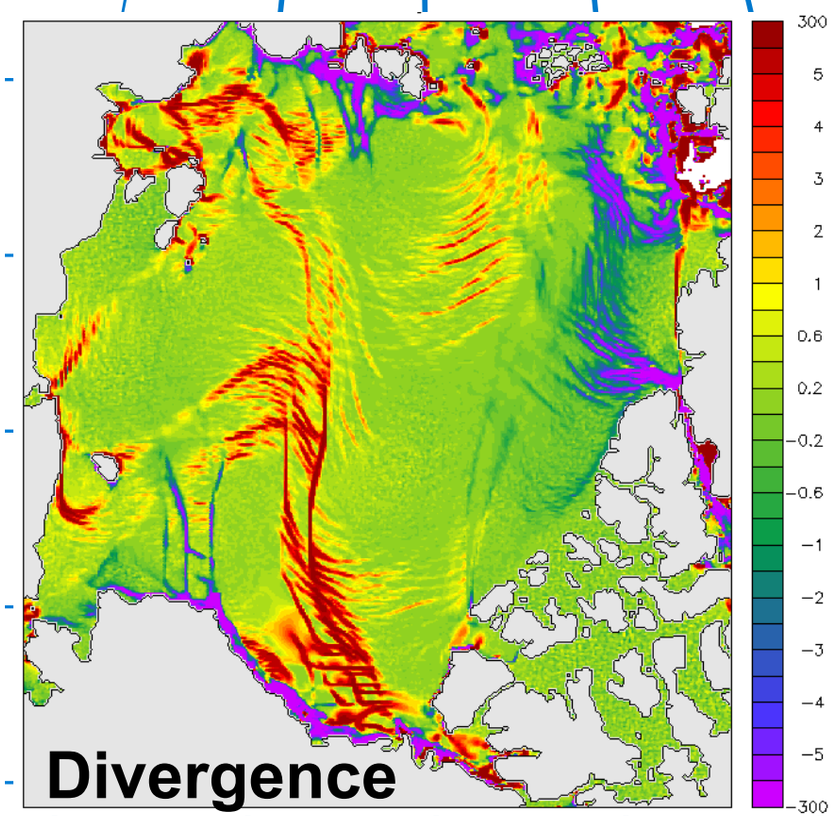


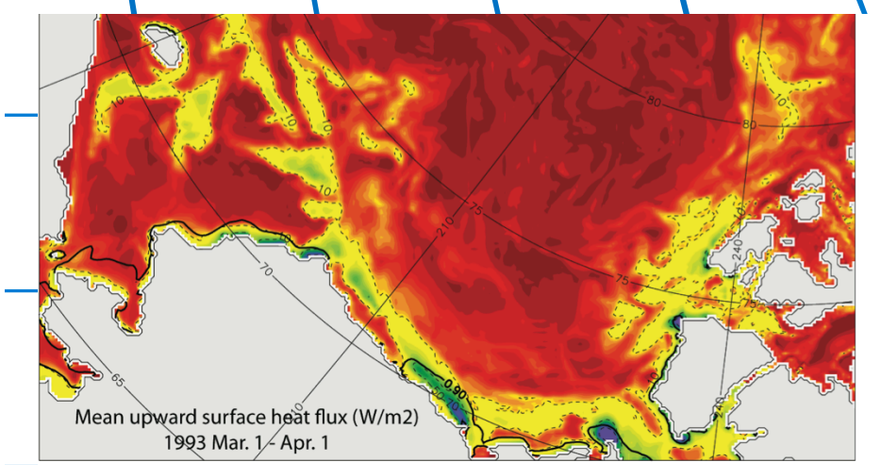
Fram Strait Vol Heat Flux (N)	6.8 Sv 36 TW	6.9 Sv 45 TW	2.0 Sv 17 TW
FJL – NZ Vol. Heat Flux (net)	NA Near zero	2.6 Sv 2.2 TW	4.35 Sv 31 TW

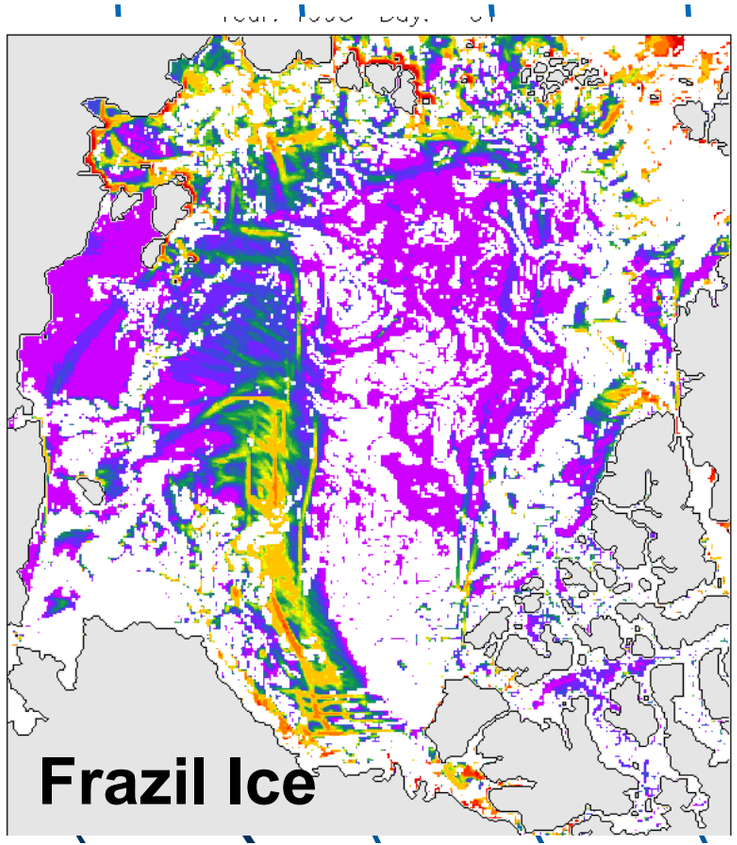
- Surface monthly-mean heat fluxes in excess of 350 W/m^2 along the marginal ice zone

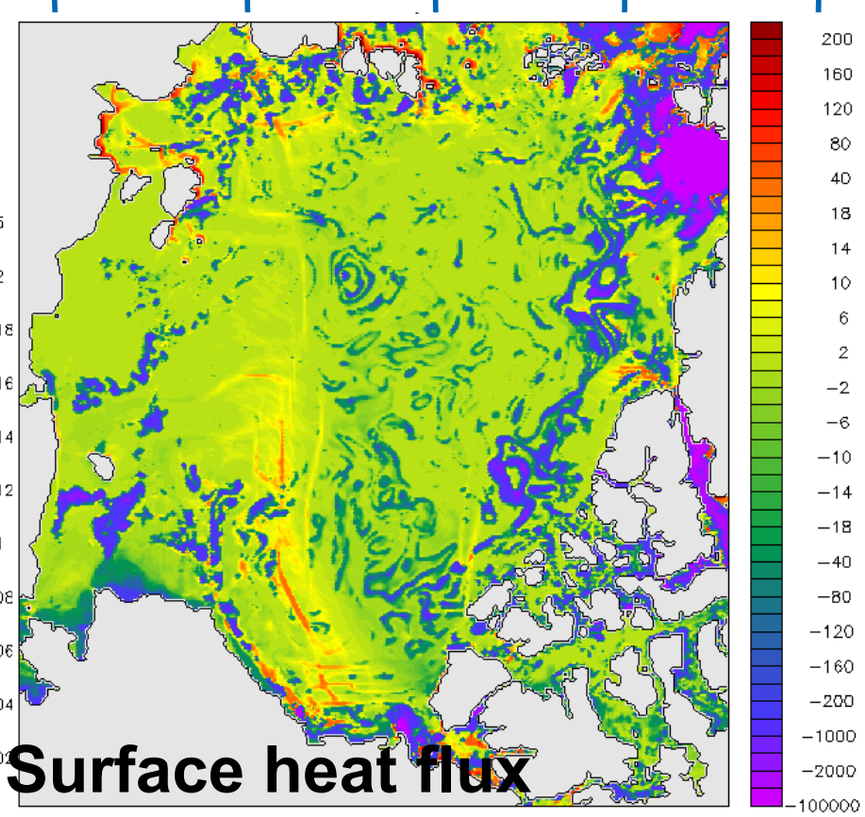
RACM sea ice drift, deformations, effect on thickness distribution and air-sea fluxes

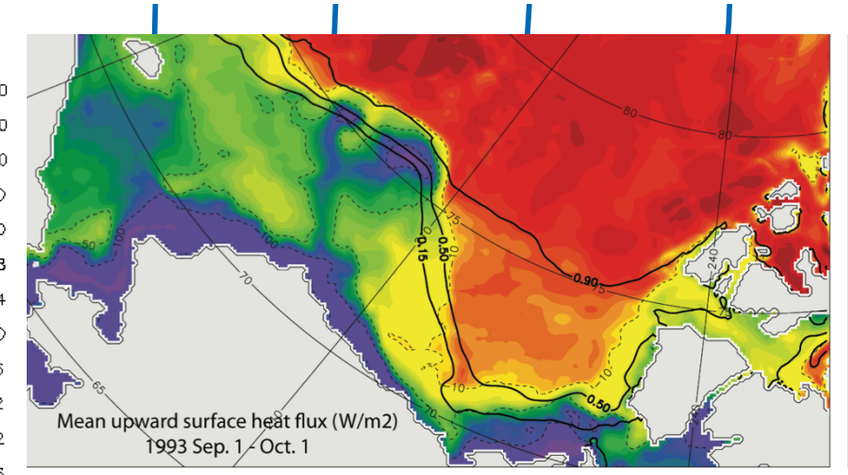






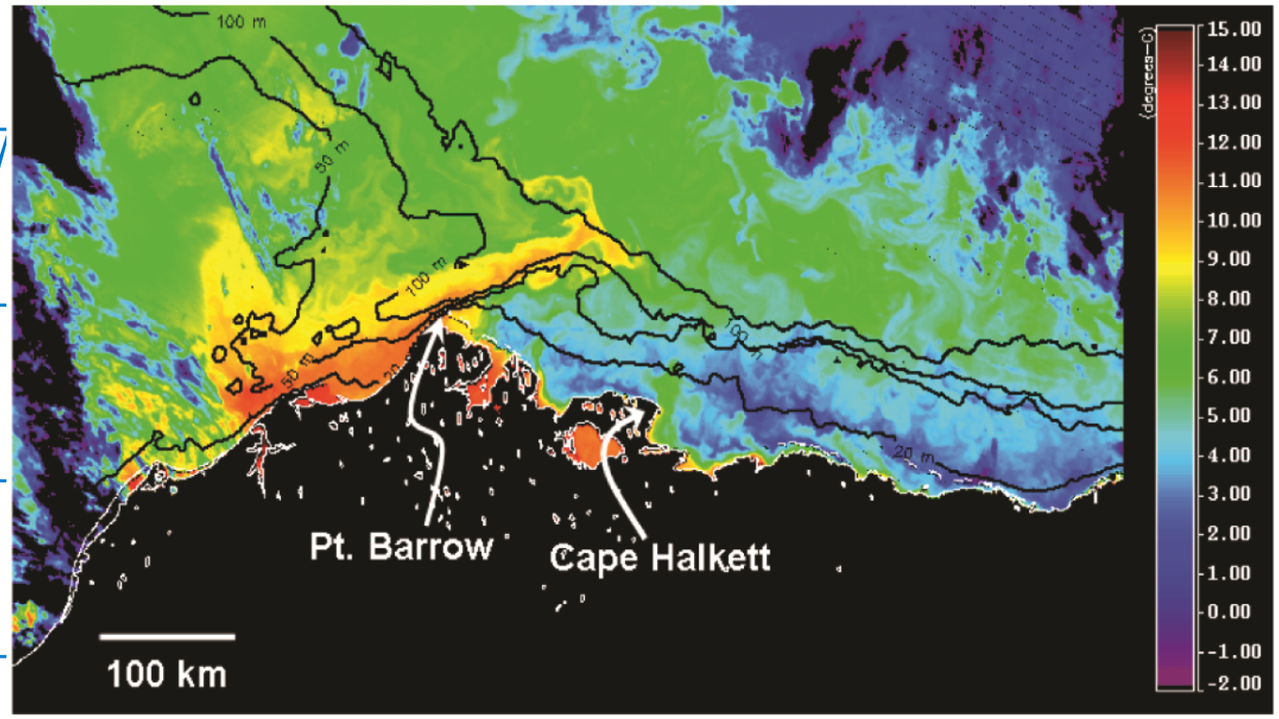


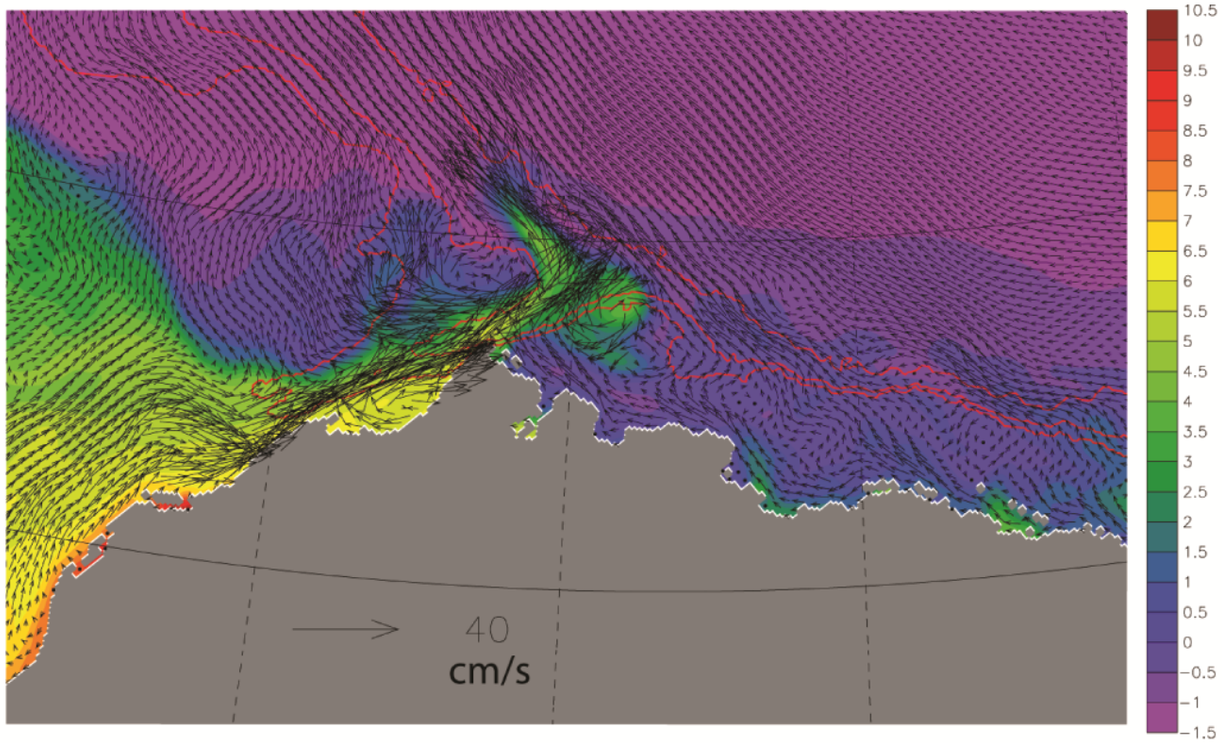




Ice-albedo & ocean circulation

MODIS sea surface temperatures for 10 August 2007, 2335 UT. Vector-averaged winds for the 24-hour period preceding the image acquisition were from the east-southeast at 4.1 m s^{-1}. Okkonen et al., 2009.





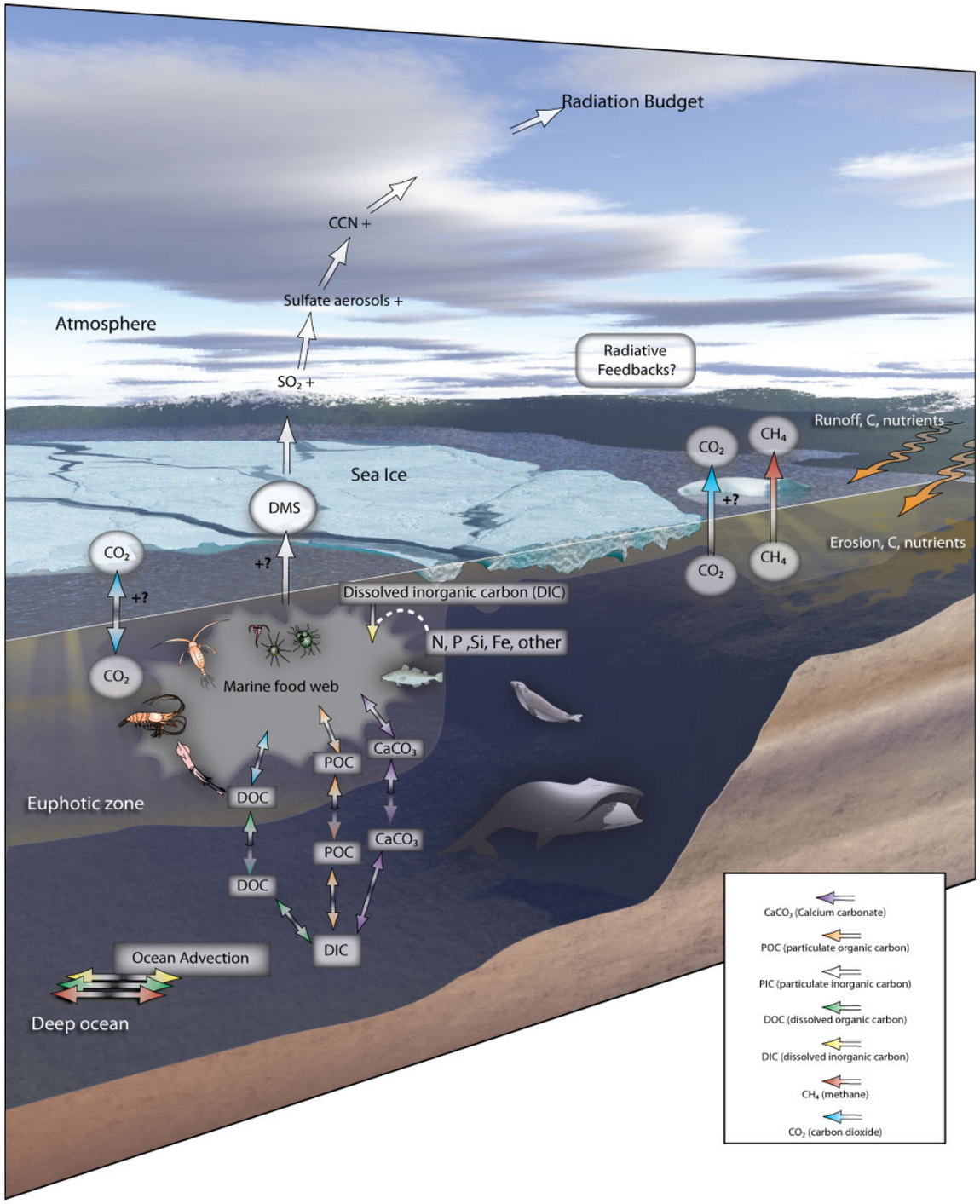
MODIS SST – 08/10/2007, 2335UT

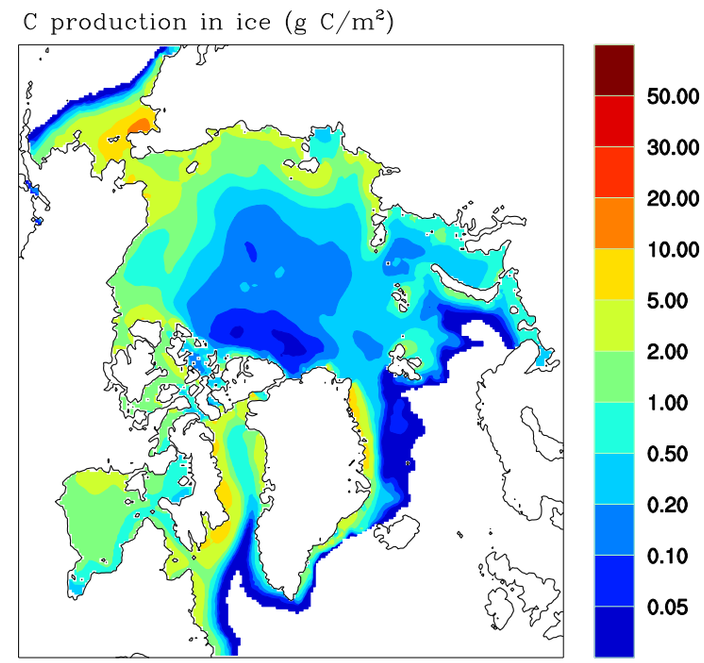
Modeled SST and Velocity – 08/15/1988

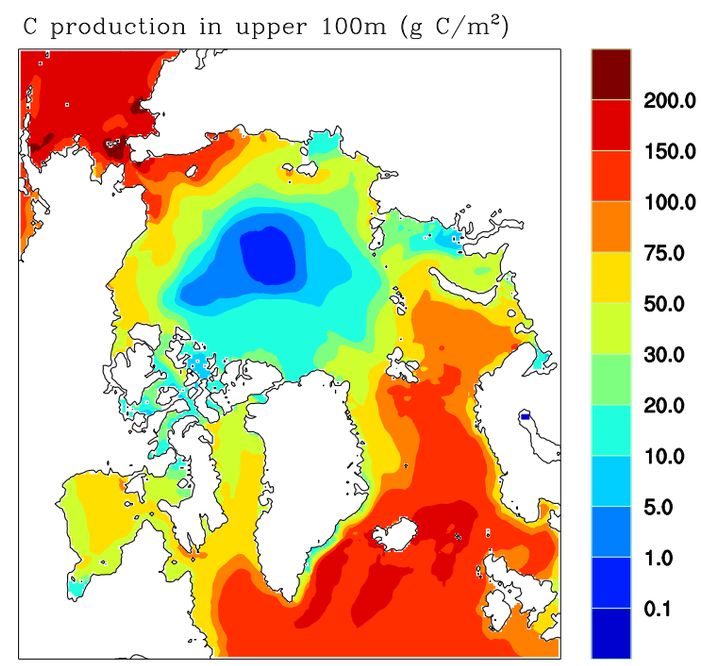
- Surface warming due to ice-albedo effect up to 7°C (local warming / limited flow)
- ACC carries water up to 13°C and it extends below the surface (strong advection)
- At resolution of ~2 km models can capture details of ocean circulation, eddy generation and heat distribution

Examples of inadequacies along coupling channels

Biogeochemical coupling





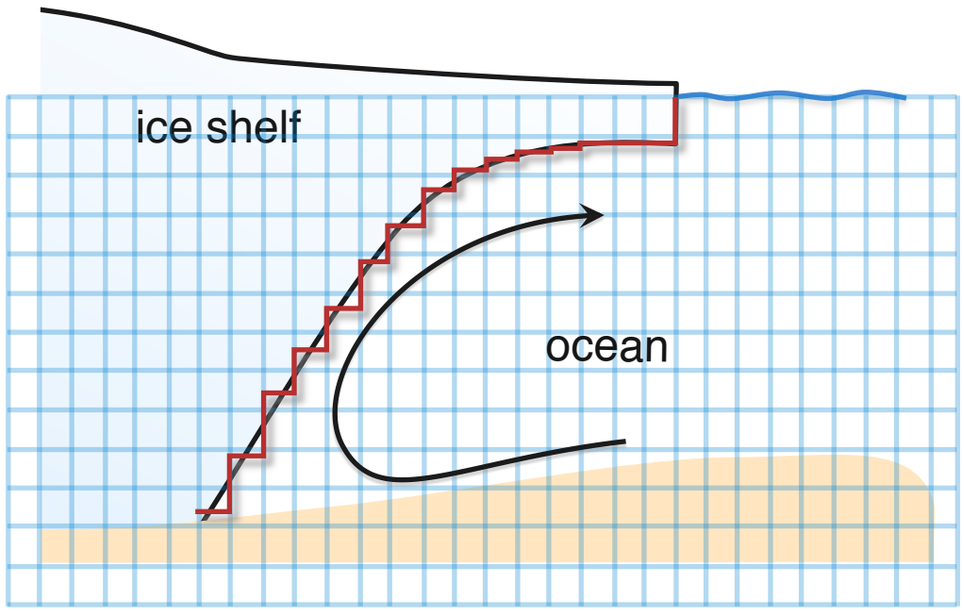


POP/CICE Chl-a 1998-2007

Jin, Deal, Elliott et al

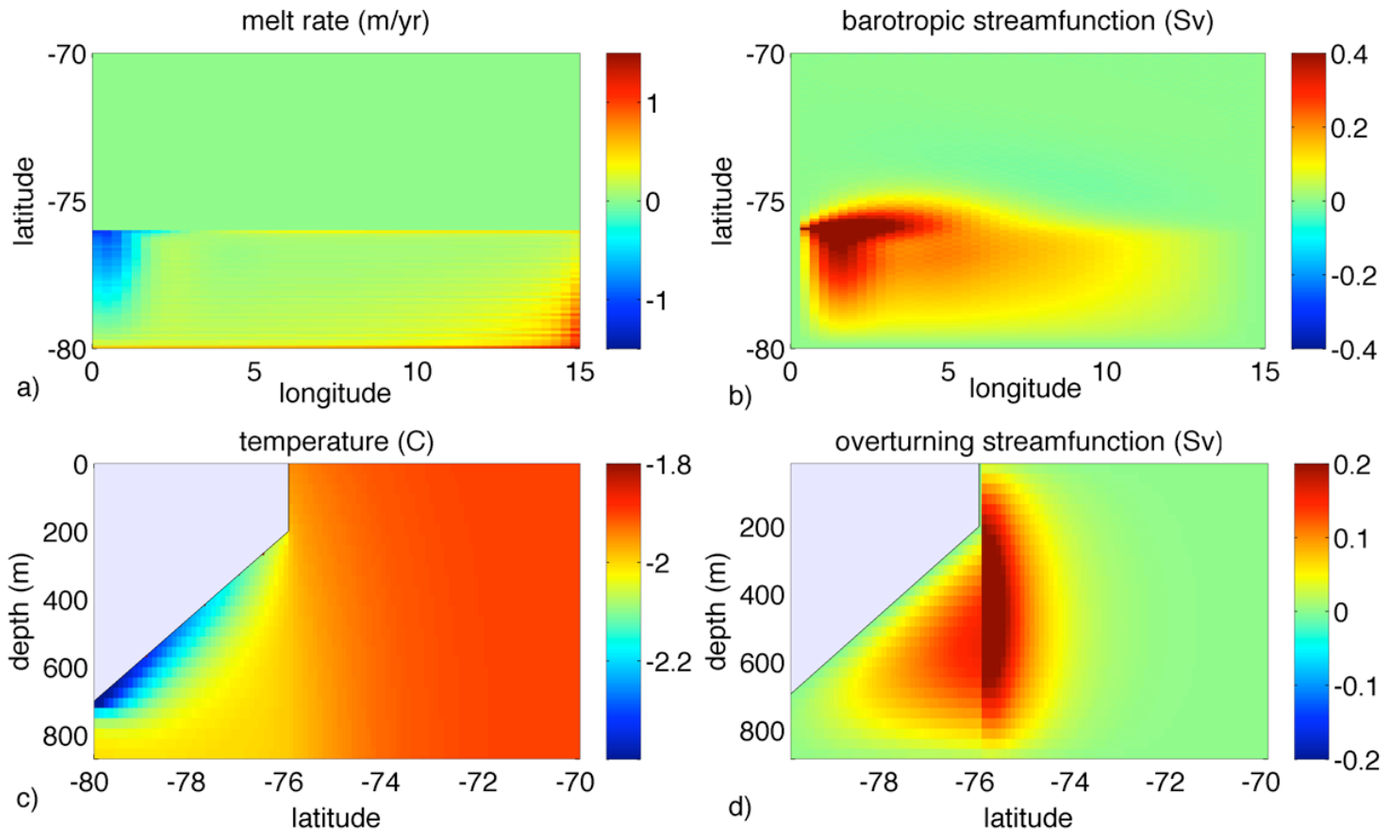
POP2X with Ice-shelf Cavities

- Modified version of POP ocean model: POP2X includes ocean cavities under ice shelves
- Ice boundary represented by "partial top cells" (Losch 2008)
- Like "partial bottom cells" for bathymetry in POP and others



An idealized test for comparison:

- Ice Shelf-Ocean Model Intercom-parison Project (ISOMIP; Hunter 2006)
- 30 year spin-up to steady state, shown on the right
- Our results show melt rates and streamfunctions that compare well with other models



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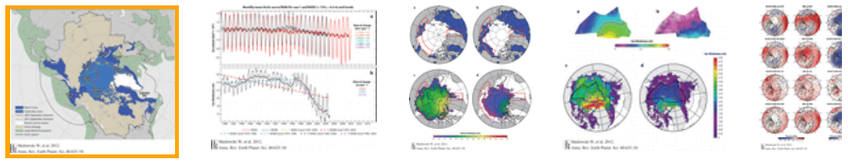

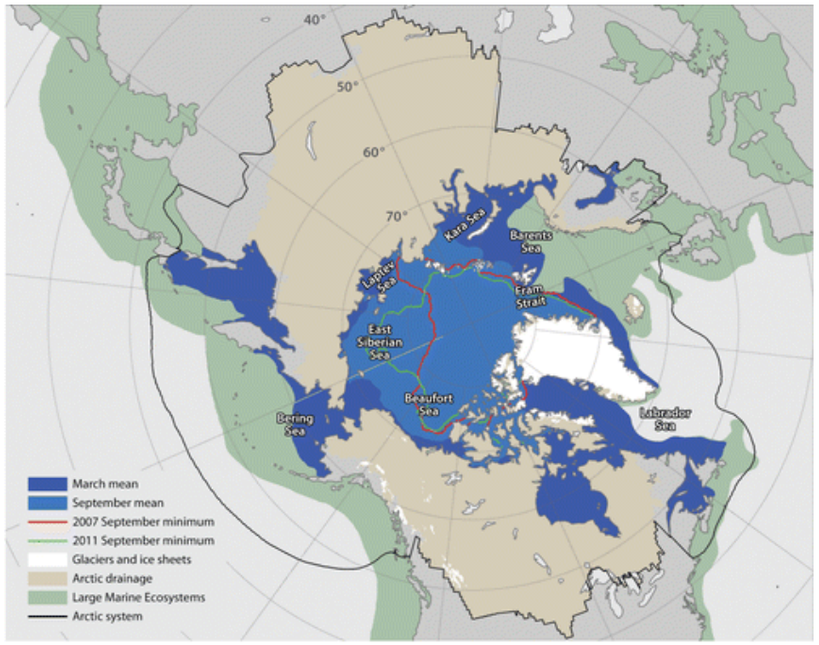

Maslowski W, et al. 2012.
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ABSTRACT

Arctic sea ice is a key indicator of the state of global climate because of both its sensitivity to warming and its role in amplifying climate change. Accelerated melting of the perennial sea ice cover has occurred since the late 1990s, which is important to the pan-Arctic region, through effects on atmospheric and oceanic circulations, the Greenland ice sheet, snow cover, permafrost, and vegetation. Such changes could have significant ramifications for global sea level, the ocean thermohaline circulation, native coastal communities, and commercial activities, as well as effects on the global surface energy and moisture budgets, atmospheric and oceanic circulations, and geosphere-biosphere feedbacks. However, a system-level understanding of critical Arctic processes and feedbacks is still lacking. To better understand the past and present states and estimate future trajectories of Arctic sea ice and climate, we argue that it is critical to advance hierarchical regional climate modeling and coordinate it with the design of an integrated Arctic observing system to constrain models.