Challenges of and opportunities for Arctic climate and sea ice projections

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and
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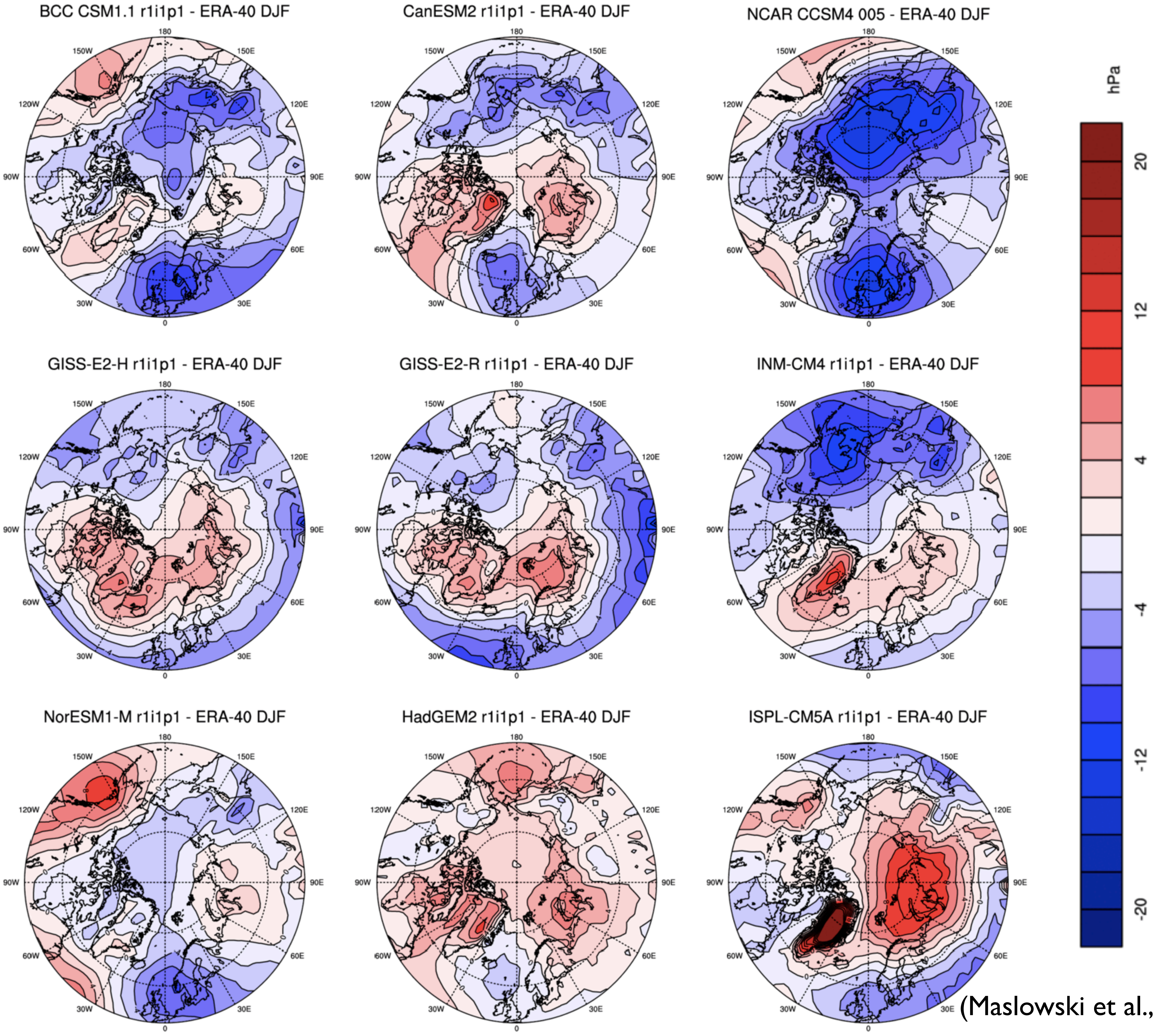
Differences in winter mean sea-level pressure averaged from 1979 to 2002 for nine CMIP5 global climate models versus ERA-40



BCC CSM1.1 r1i1p1 - ERA-40 DJF

CanESM2 r1i1p1 - ERA-40 DJF

NCAR CCSM4 005 - ERA-40 DJF

GISS-E2-H r1i1p1 - ERA-40 DJF

GISS-E2-R r1i1p1 - ERA-40 DJF

INM-CM4 r1i1p1 - ERA-40 DJF

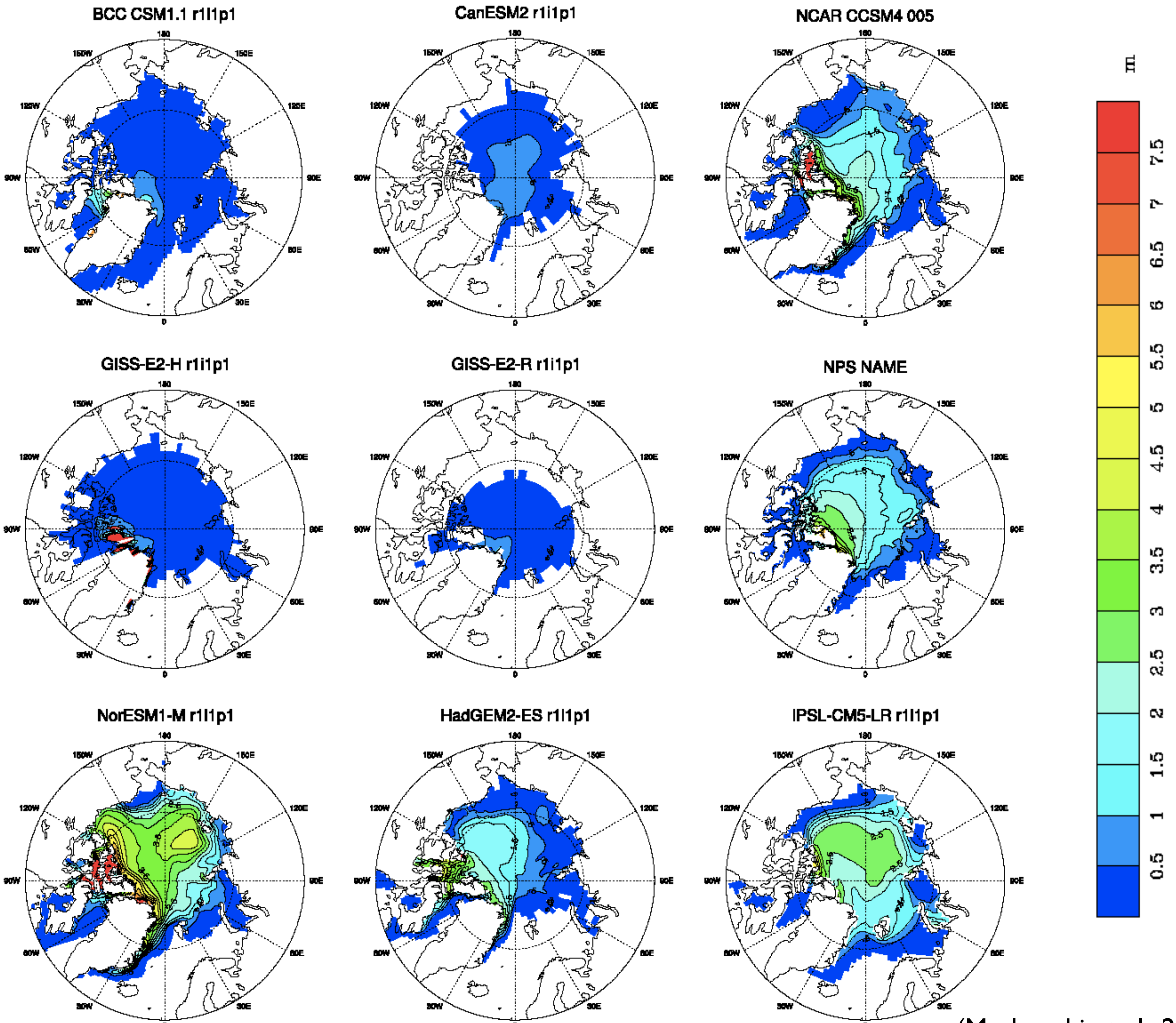
NorESM1-M r1i1p1 - ERA-40 DJF

HadGEM2 r1i1p1 - ERA-40 DJF

ISPL-CM5A r1i1p1 - ERA-40 DJF

(Maslowski et al., 2012)

September mean sea ice thickness (m) averaged over 2000–2004 from CMIP5 and NAME models.



(Maslowski et al., 2012)

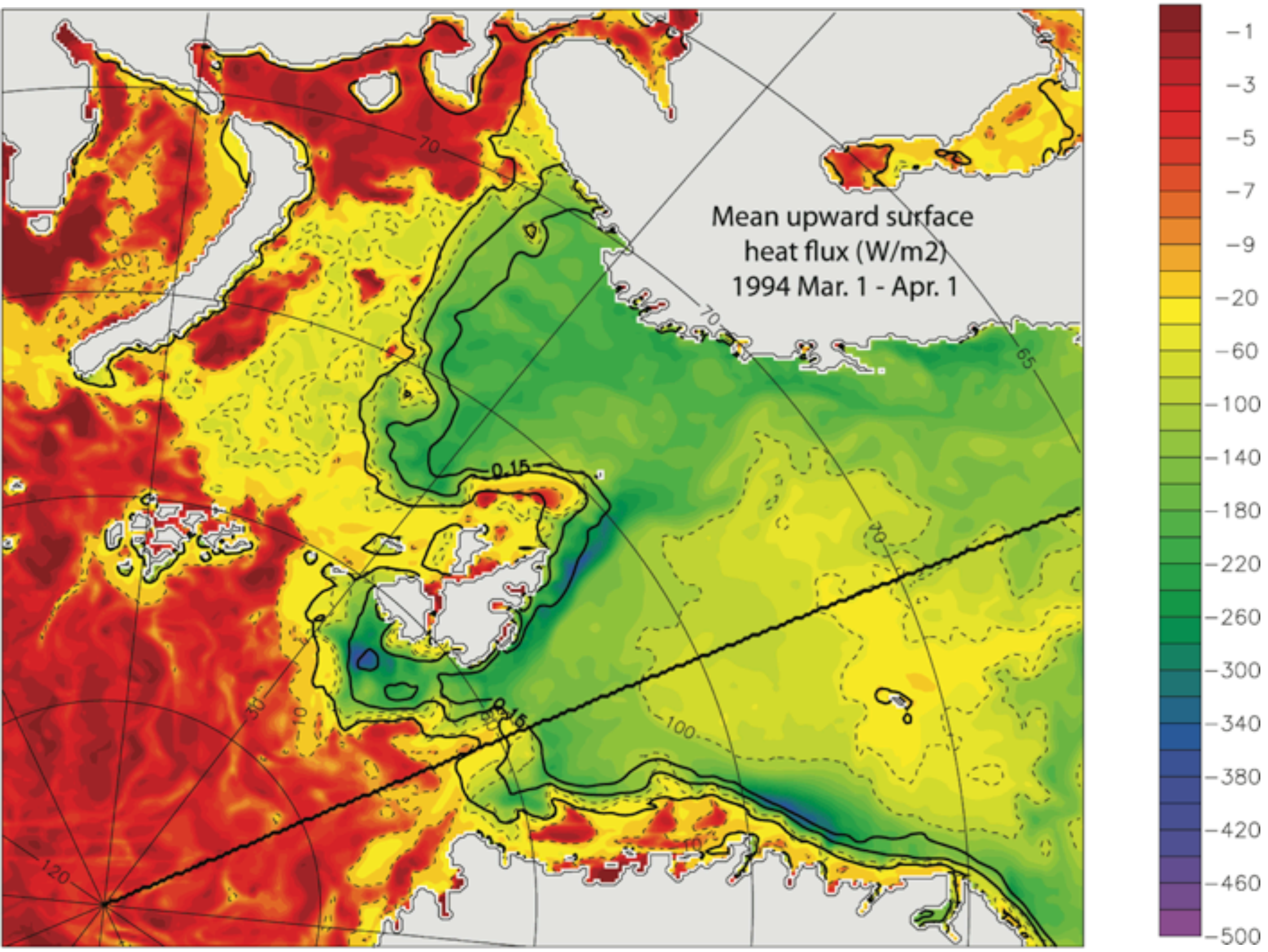
MODEL LIMITATIONS AND BIASES CONTRIBUTING TO UNCERTAINTY

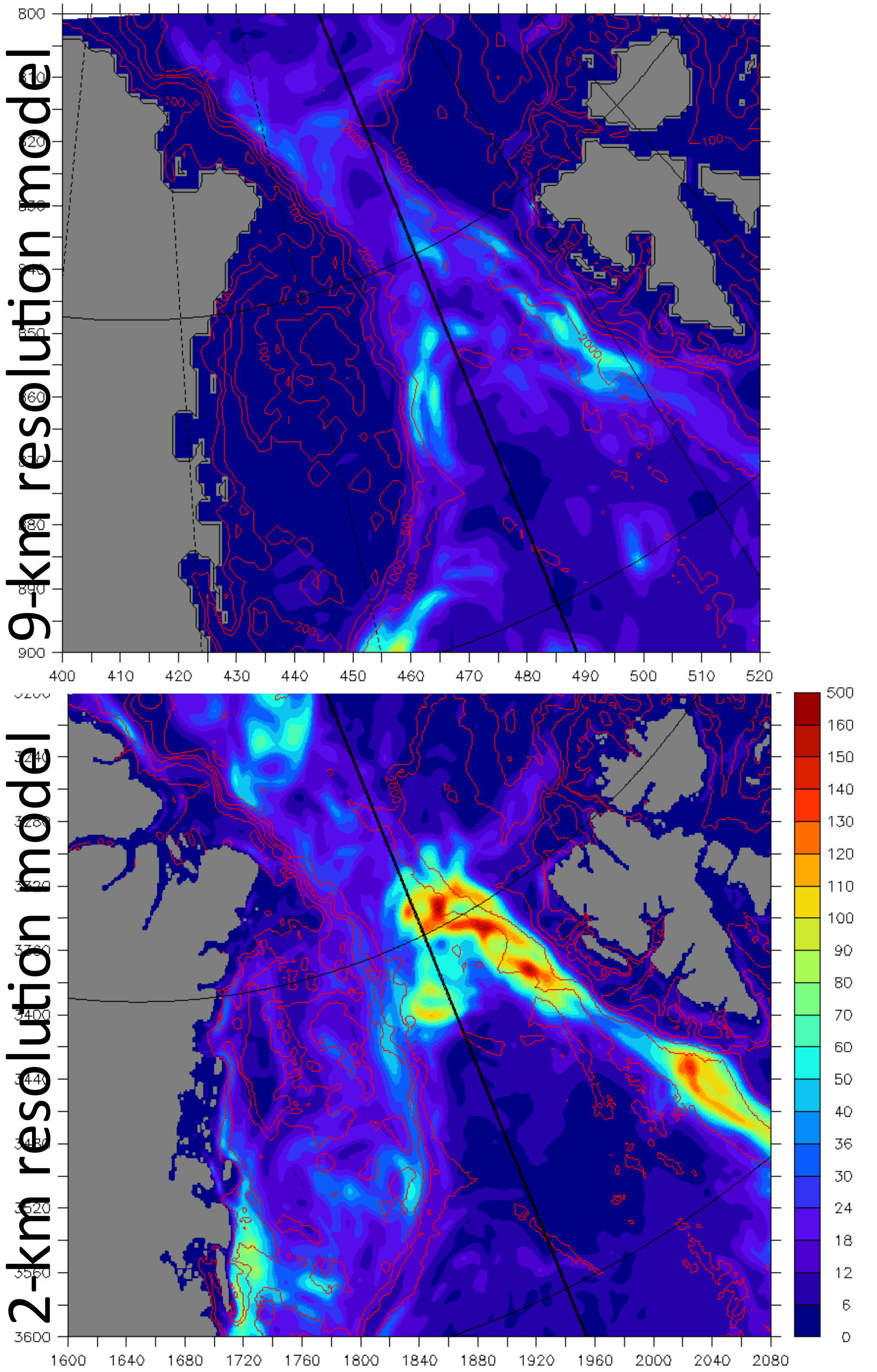
There are many **arctic physical processes and feedbacks** not, or poorly, represented in state-of-the-art ESMs, including:

- sea ice thickness distribution, deformation and export, fast ice, snow cover, melt ponds and surface albedo, permafrost,
- oceanic eddies, tides, surface/bottom mixed layer, buoyancy-driven coastal and boundary currents, fronts, cold halocline, upper ocean heat content, dense water plumes and convection,
- atmospheric modes of circulation, clouds, aerosols, fronts,
- ice-sheets/ocean, fjord-shelf-basin, wave-ice and air–sea-ice interactions and coupling.

Realistic representation of such processes/feedbacks should reduce uncertainty and improve prediction!

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

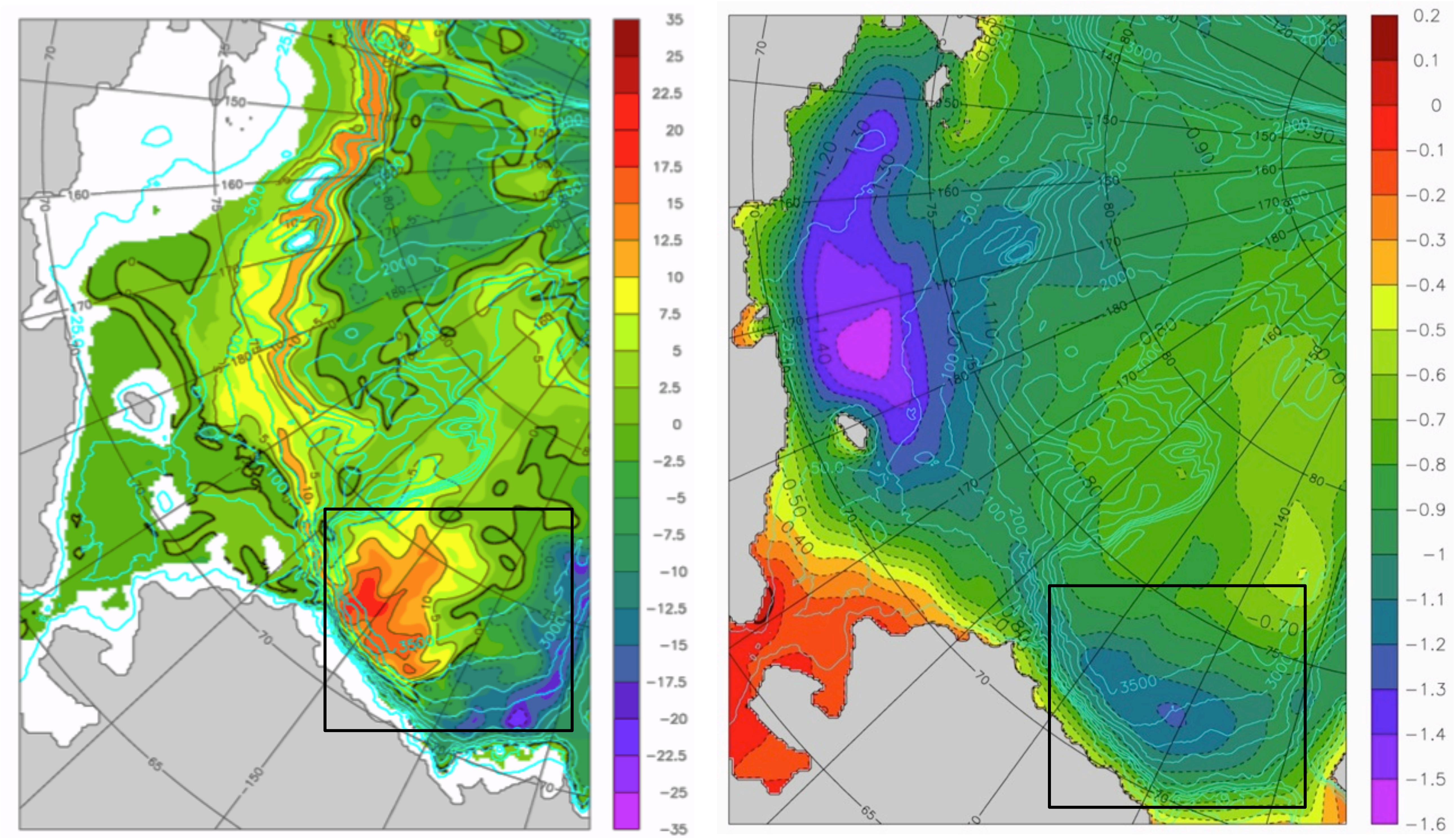




(Maslowski et al., 2012)	obs	NAME	CCSM3
Fram Strait Vol Heat Flux (N)	6.8 Sv 36 TW	6.9 Sv 45 TW	2.0 Sv 17 TW
FJL – NZ Vol. Heat Flux (net)	NA Near zero	2.6 Sv 2.2 TW	4.35 Sv 31 TW

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

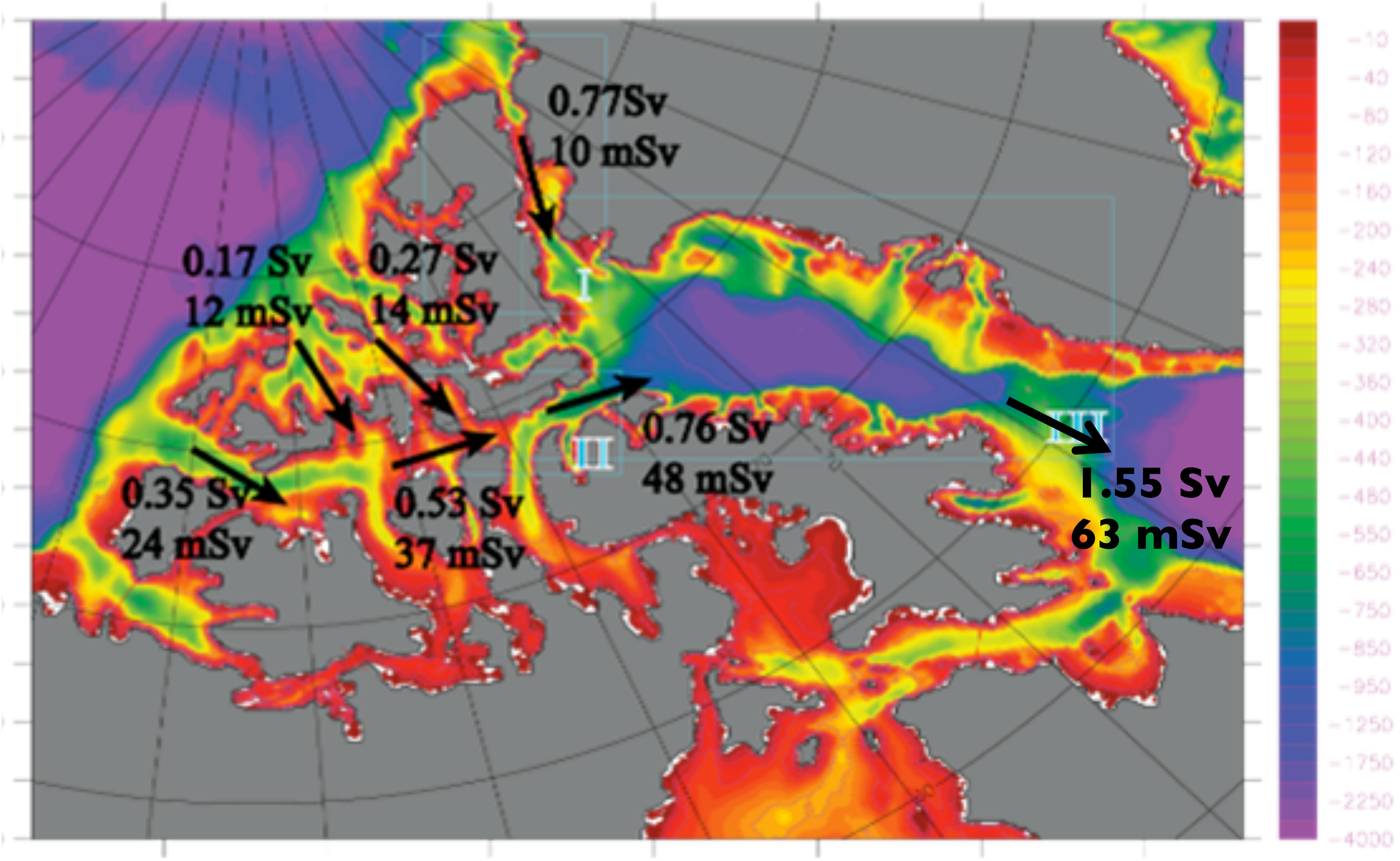
Modeled changes in (a) heat content (TJ) at depth 33-120 m and (b) sea ice thickness (m) between the mean of 1979-1998 and the mean of 1999-2004.



Increasing heat content due to local insulation, advection of warm water from shelves, anticyclonic eddies, slope upwelling or advection

(Maslowski et al, 2014)

Arctic – North Atlantic Communication



The total volume flux through the Canadian Arctic Archipelago should match the net volume flux through Davis Strait.

(McGeehan and Maslowski 2012)

EKE comparison in the Labrador Sea

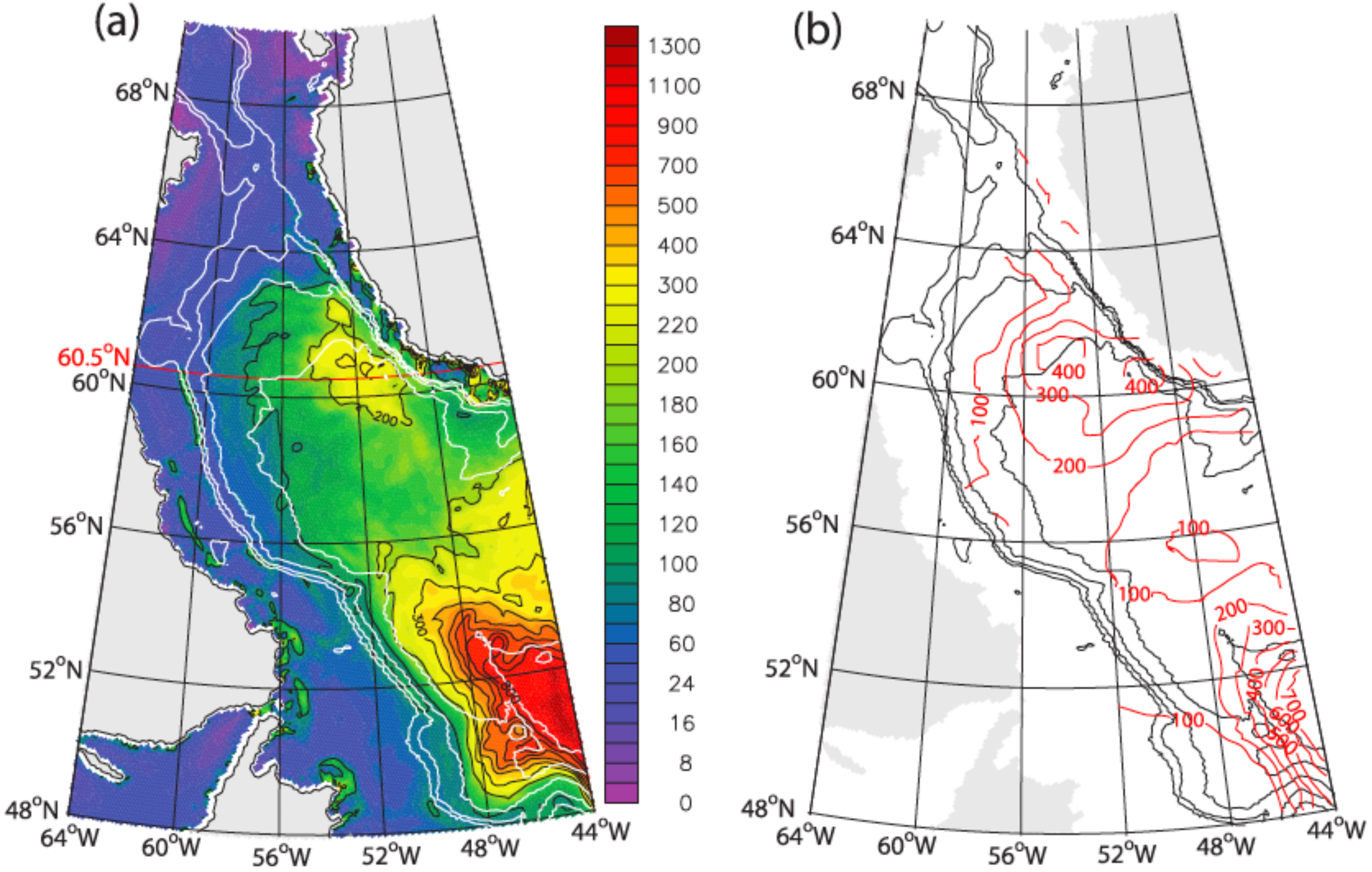


Plate 3. Horizontal distribution of eddy kinetic energy (cm^2/s^2) in the Labrador Sea. (a) 1993–1997 annual mean, 0–5 m (model level 1) calculated from daily model output. EKE contours 100, 200, 300, 400, 500, 600, 700, and 800 cm^2/s^2 in black. (b) Eddy kinetic energy deduced from surface drifter data released in North Atlantic Ocean and Labrador Sea in during 1993–1997. (After Figure 7 from *Cuny et al.* [2002].)

(Maslowski et al., 2008)

1983 annual mean velocity at 0-183 m in the Labrador Sea

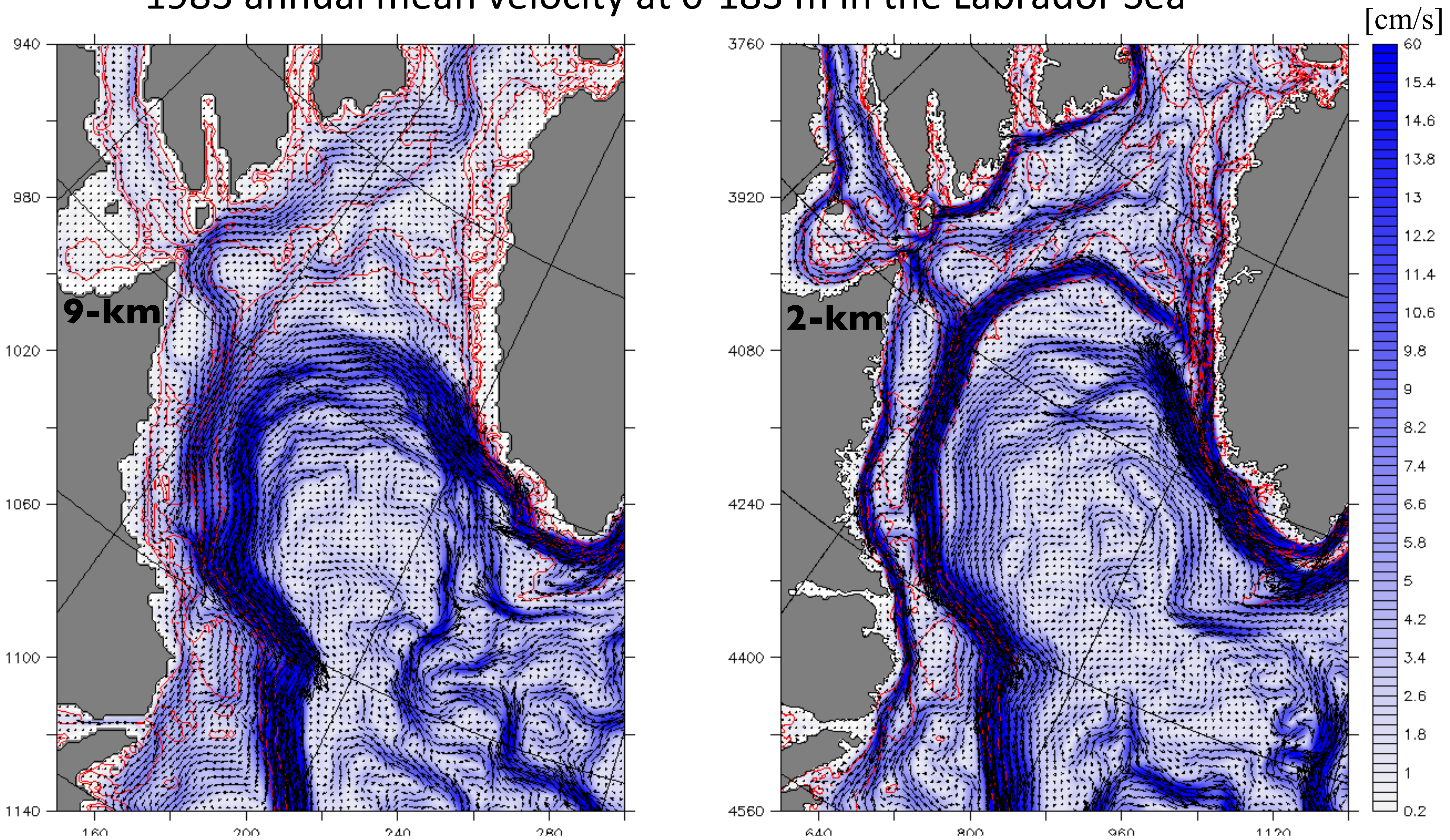


Table 2. Eddy Kinetic Energy (cm/s) Statistics for the 0- to 45-m Regional

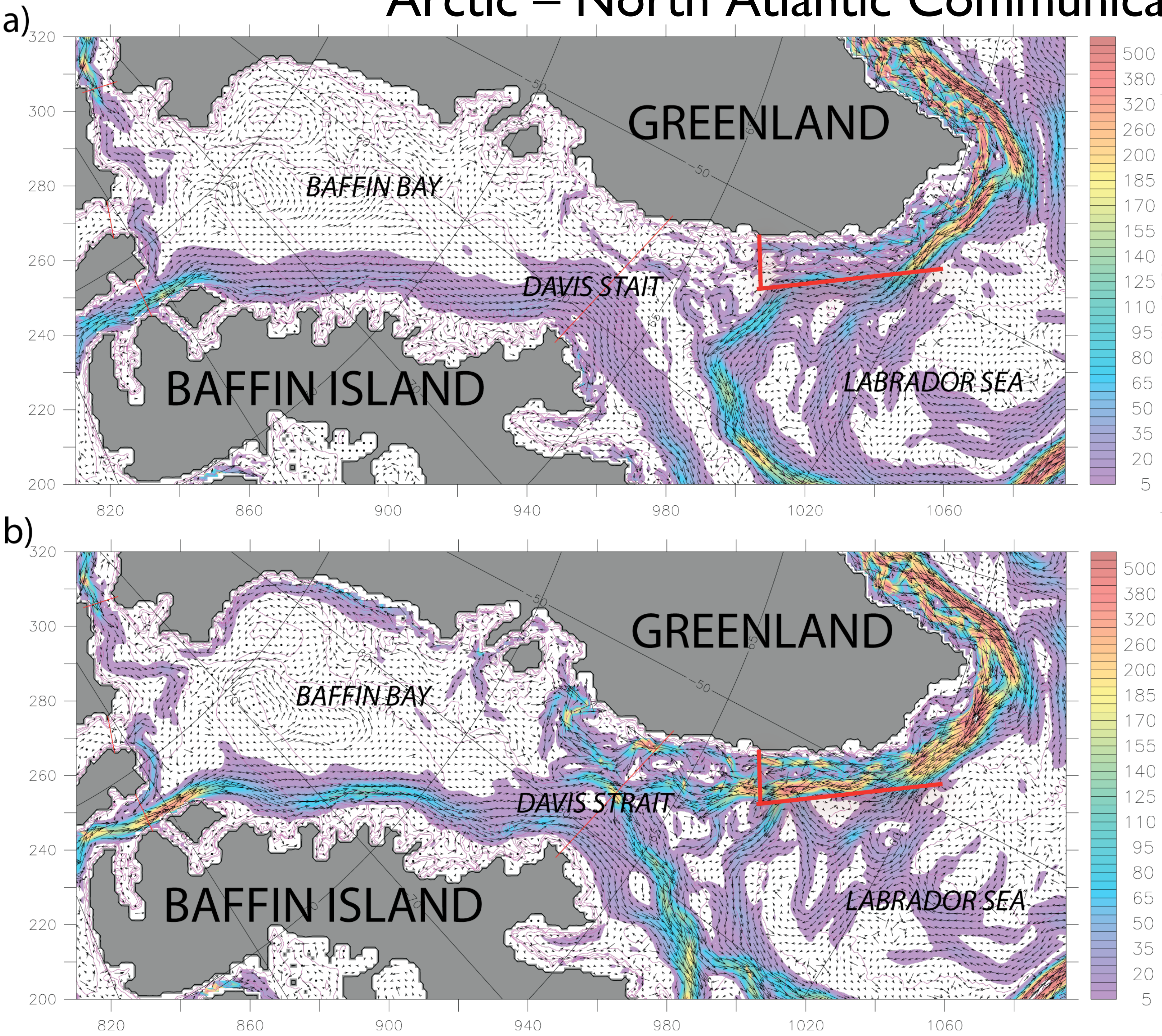
Model	Labrador Sea EKE		
	Maximum	Mean	Std Dev
PCAP58	132.50	4.90	9.20
PIPS	3998.00	70.40	203.70

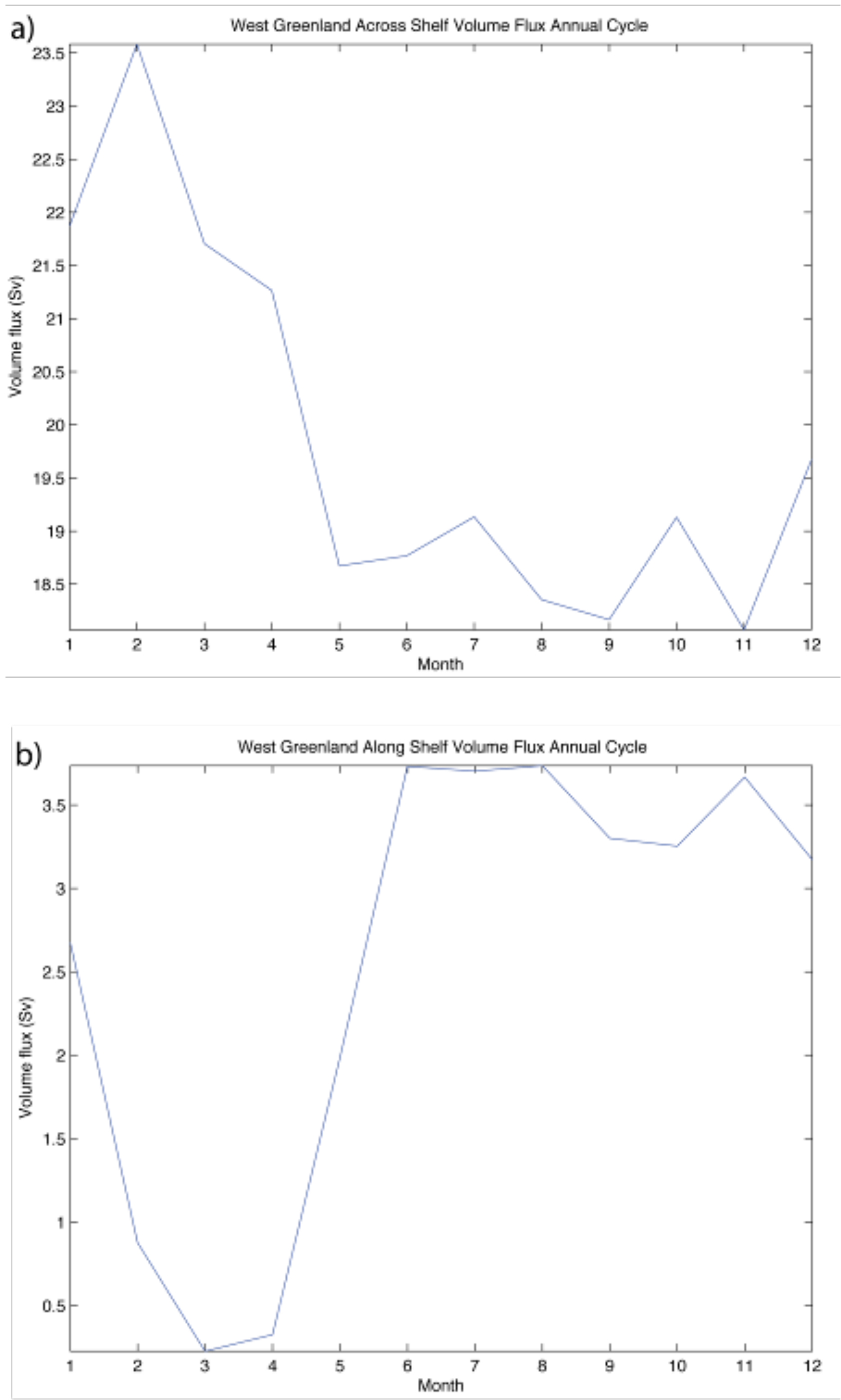
At 2-km resolution:

- main recirculation further north
- better defined Labrador Current
- well-resolved coastal currents

(Maslowski et al., 2008b)

Arctic – North Atlantic Communication





The exchange through the Canadian Arctic Archipelago is in part controlled by eddies generation along the West Greenland Current.

(McGeehan and Maslowski 2012)

How can coupled regional system models help understand uncertainty & improve prediction?

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

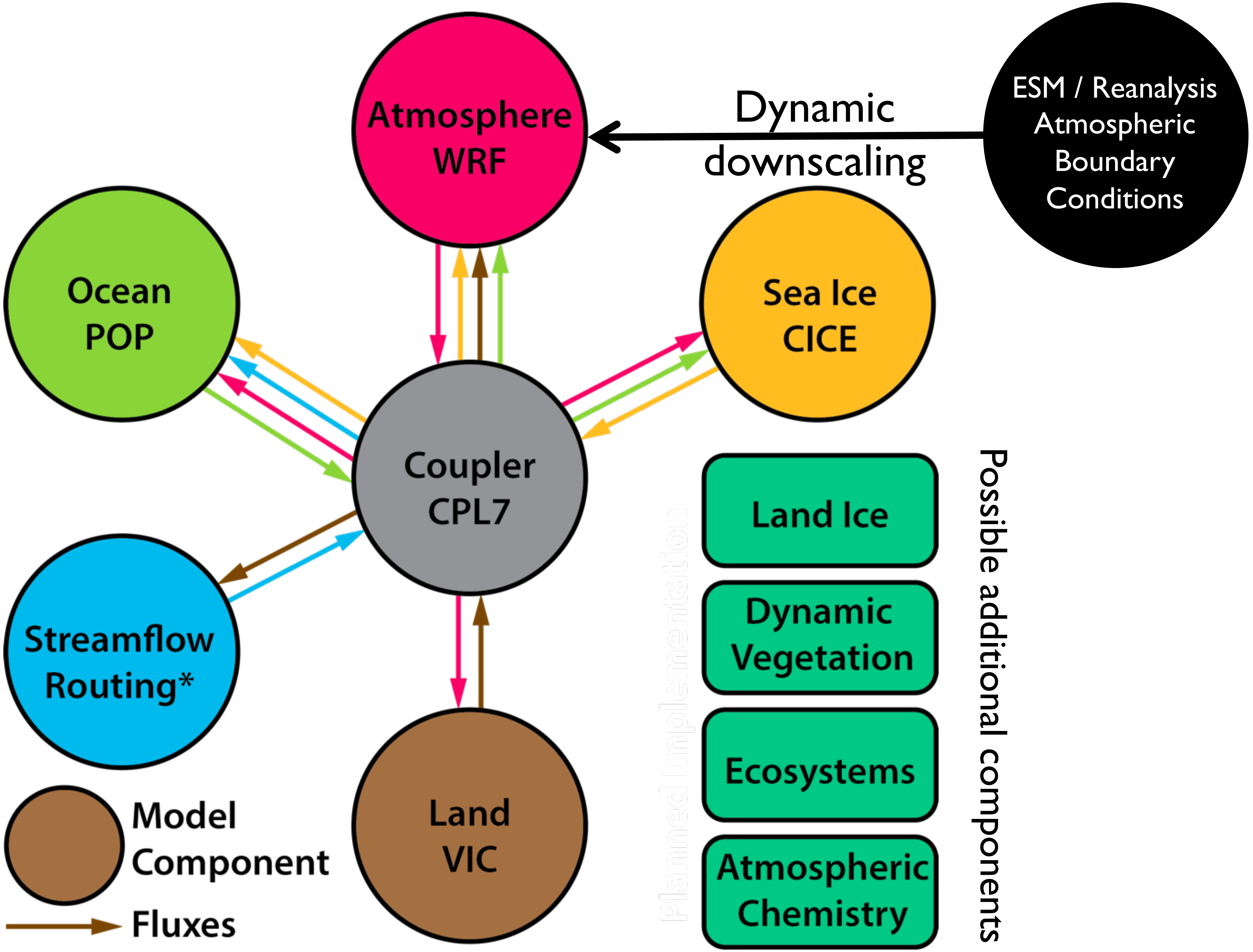
2. By addressing inadequacies along **coupling** channels between different system components

3. By exploring space-dependent **sensitivities** in the parameter space

4. Through a **hierarchical modeling** approach using both regional and global models

Maslowski et al. 2012

RASM wiring diagram



ESM / Reanalysis Atmospheric Boundary Conditions

Dynamic downscaling

Atmosphere WRF

Ocean POP

Sea Ice CICE

Coupler CPL7

Streamflow Routing*

Land VIC

Model Component

Fluxes

Planned Implementation

Land Ice

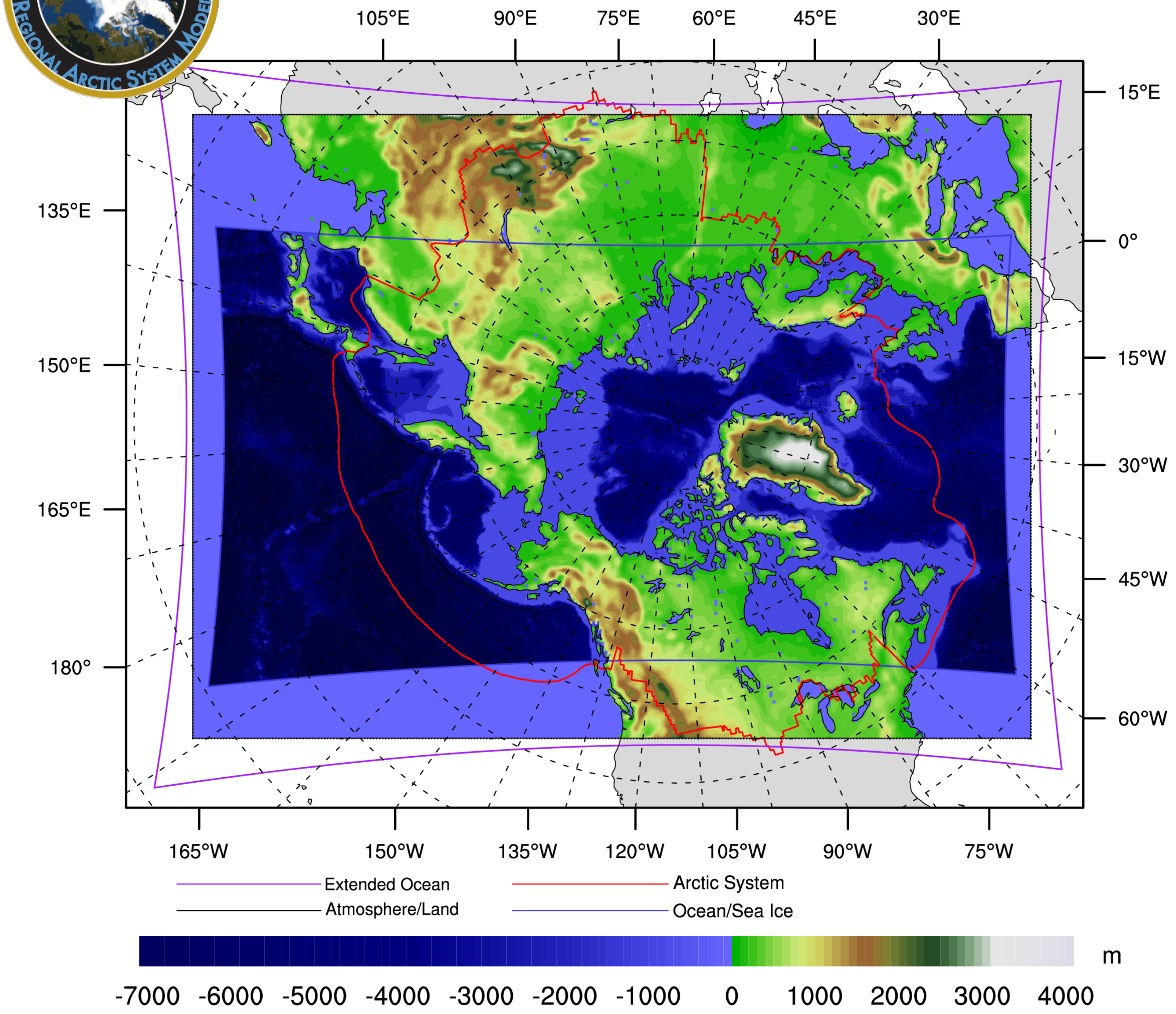
Dynamic Vegetation

Ecosystems

Atmospheric Chemistry

Possible additional components

RASM Domains for Coupling and Topography



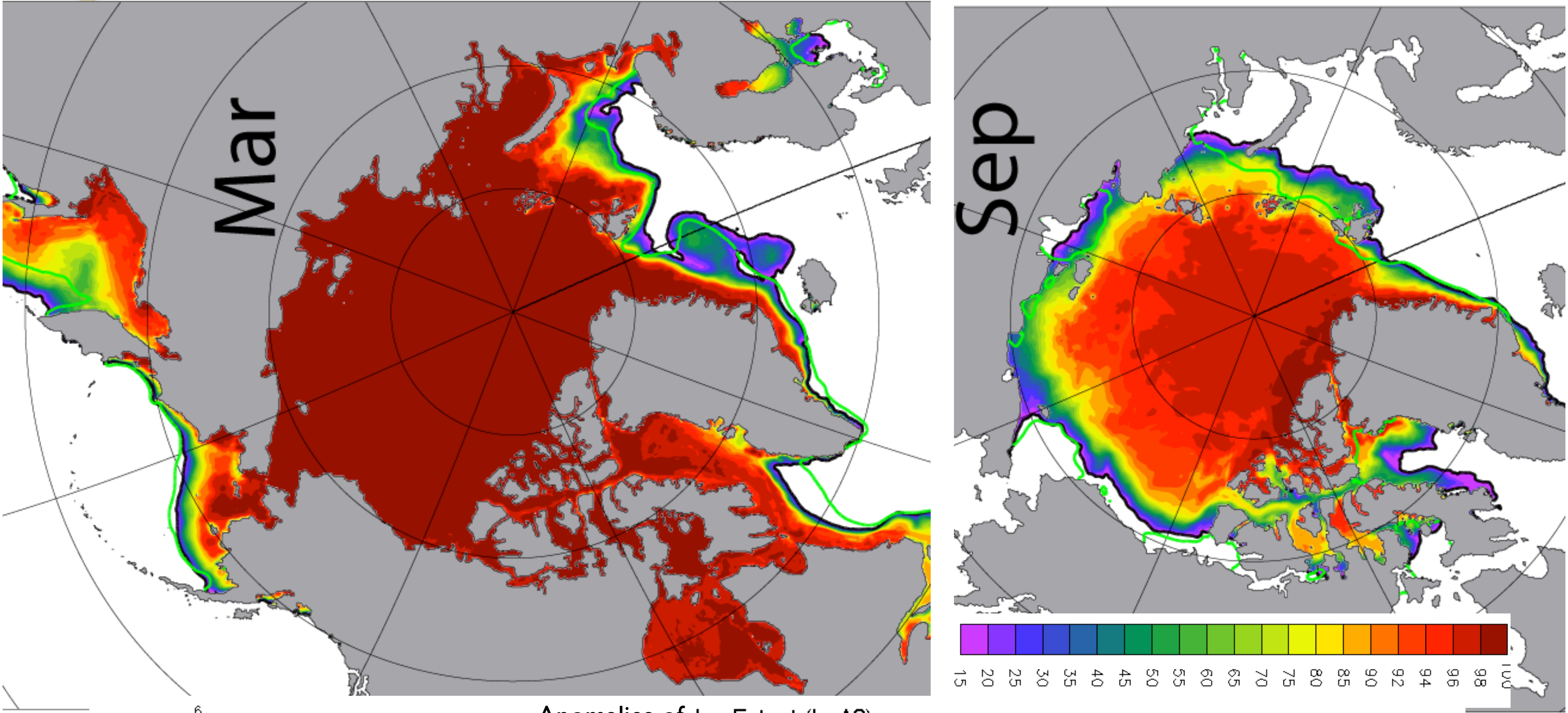
The Arctic System domain (red line) after Roberts et al. (2010).

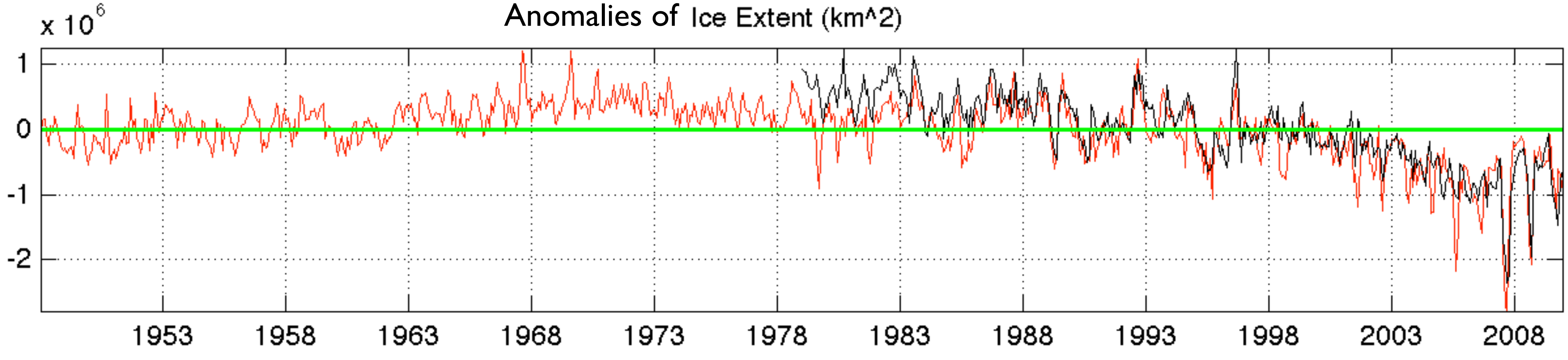
Pan-Arctic region to include:

- all sea ice covered ocean in the NH
- Arctic river drainage
- critical inter-ocean exchange and transport
- large-scale atmospheric weather patterns (AO, NAO, PDO)
- WRF and VIC model domains cover the entire colored region
- POP and CICE domains cover the inner colored region

RASM-H sea ice analyses with observations

RASM 1979-1999 mean sea ice concentration and sea ice extent (black) vs SSM/I extent (green)




Anomalies of Ice Extent (km^2)

Summary

Regional Arctic and global climate predictive models need:

- Resolve critical processes (e.g. eddies, coastal currents, sea ice deformation, melt ponds) and feedbacks (air-ice-sea interaction)
- Represent Arctic - North Atlantic exchanges (via Fram Strait and Canadian Arctic Archipelago)
- Validation Data (e.g. eddy kinetic energy, mixed layer depth, upper ocean (0-150m) hydrography, air-sea fluxes)
- Process studies (e.g. subsurface heat content and entrainment into the surface mixed layer, seasonal pycnocline, marginal ice zone (MIZ), air-sea fluxes, ice-wave interaction)

RASM - a tool to:

(i) Resolve / understand processes and feedbacks,
(ii) Reduce uncertainty and
(iii) Improve prediction

WRF POP CICE CPL7 CISM VIC

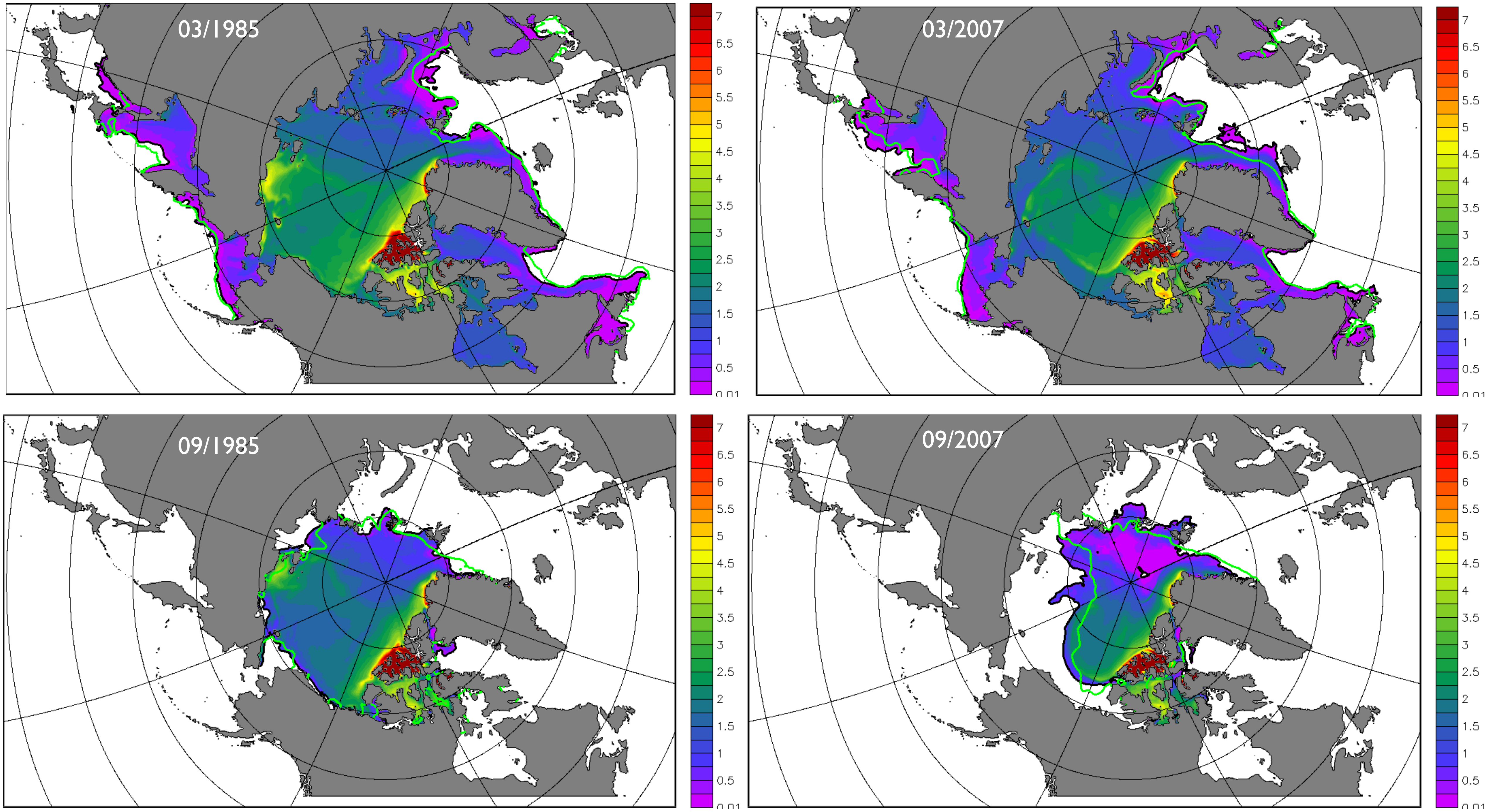
REGIONAL ARCTIC SYSTEM MODEL

Thank You!

Evaluation Metrics for Polar Models

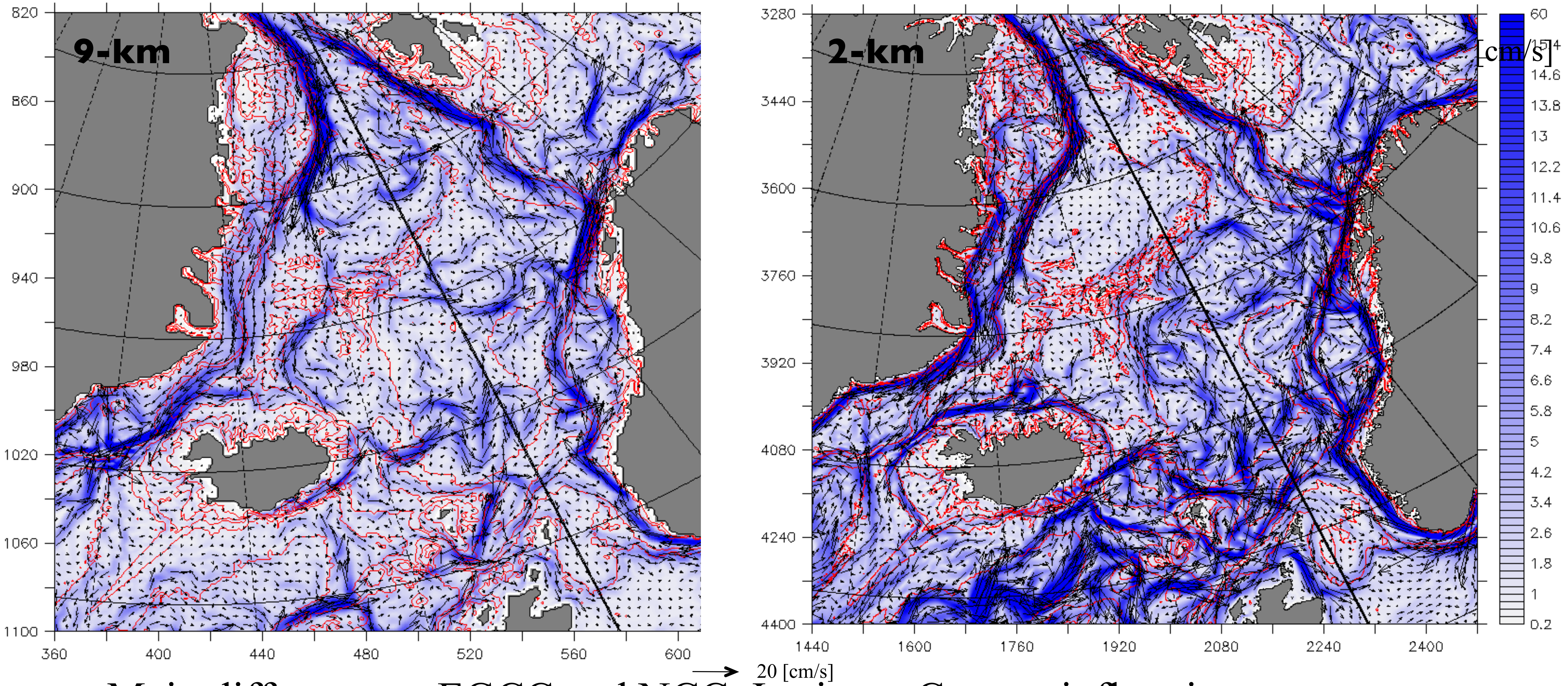
- Observations currently do not close surface energy budgets in the Arctic
- State variables may be “correct”, though different terms in the model energy budget have opposing errors
- By contrast, fully coupled polar models are strongly dependent upon variability and sensitivities deriving from feedbacks. (e.g. surface-cloud radiative feedbacks)
- There is a need for evaluation metrics that target constraining sign and magnitude of key feedbacks in the Arctic system
- This requires constraining energy terms rather than state variables.

G-case semi-optimized sea ice thickness distribution at 1/12° in March (top) and September (bottom) 1985 (left) / 2007 (right)



… after ~25 G-case tests

1983 Annual mean velocity at 0-223 m in the Nordic Seas



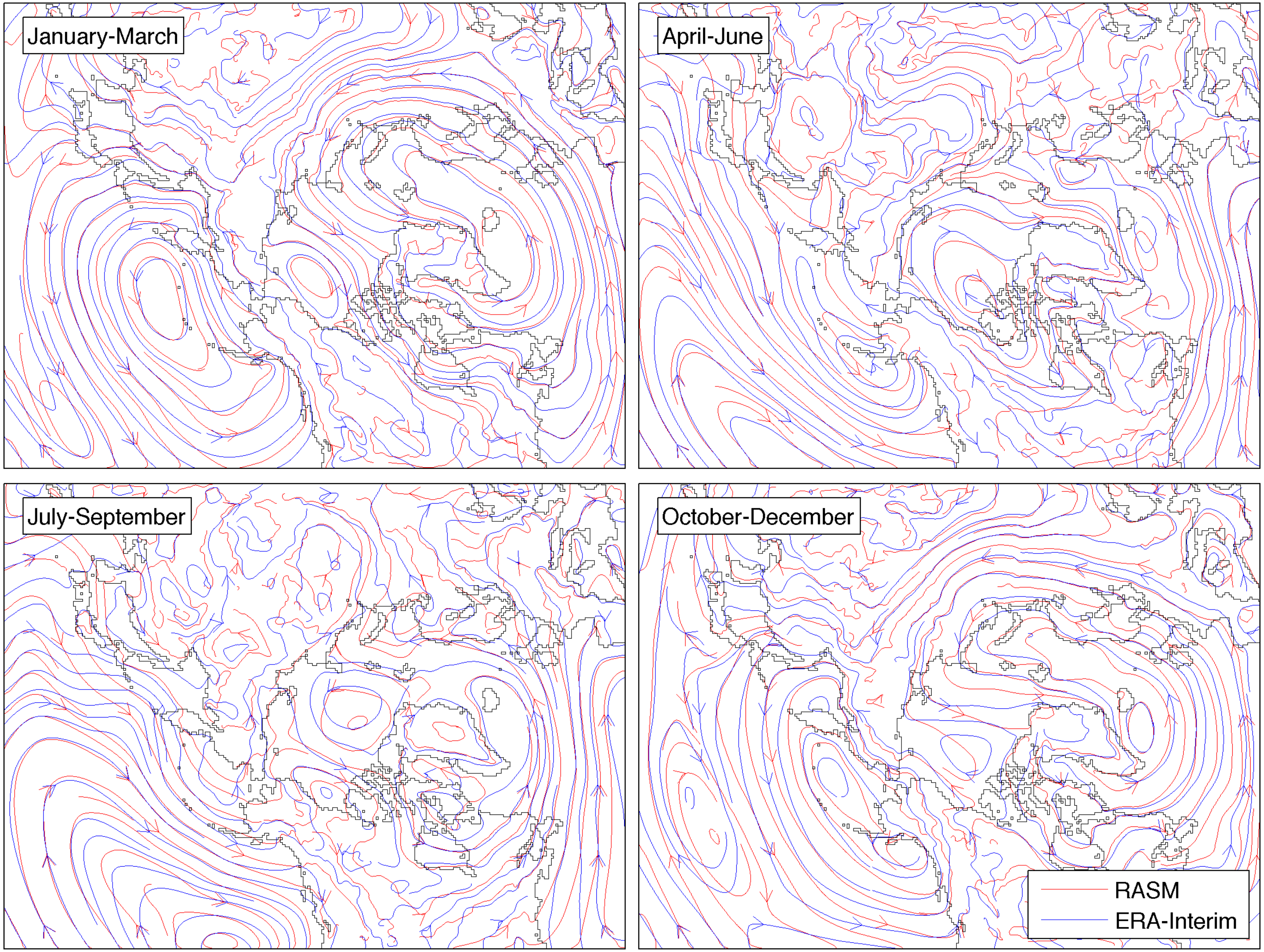
Main differences: EGCC and NCC; Irminger Current inflow into the Iceland Sea; better defined circulation across the Iceland-Scotland Ridge; western branch of Norwegian Atlantic Current

Table 2. Eddy Kinetic Energy (cm/s) Statistics for the 0- to 45-m Regional Snapshots Presented in Plates 4 and 5

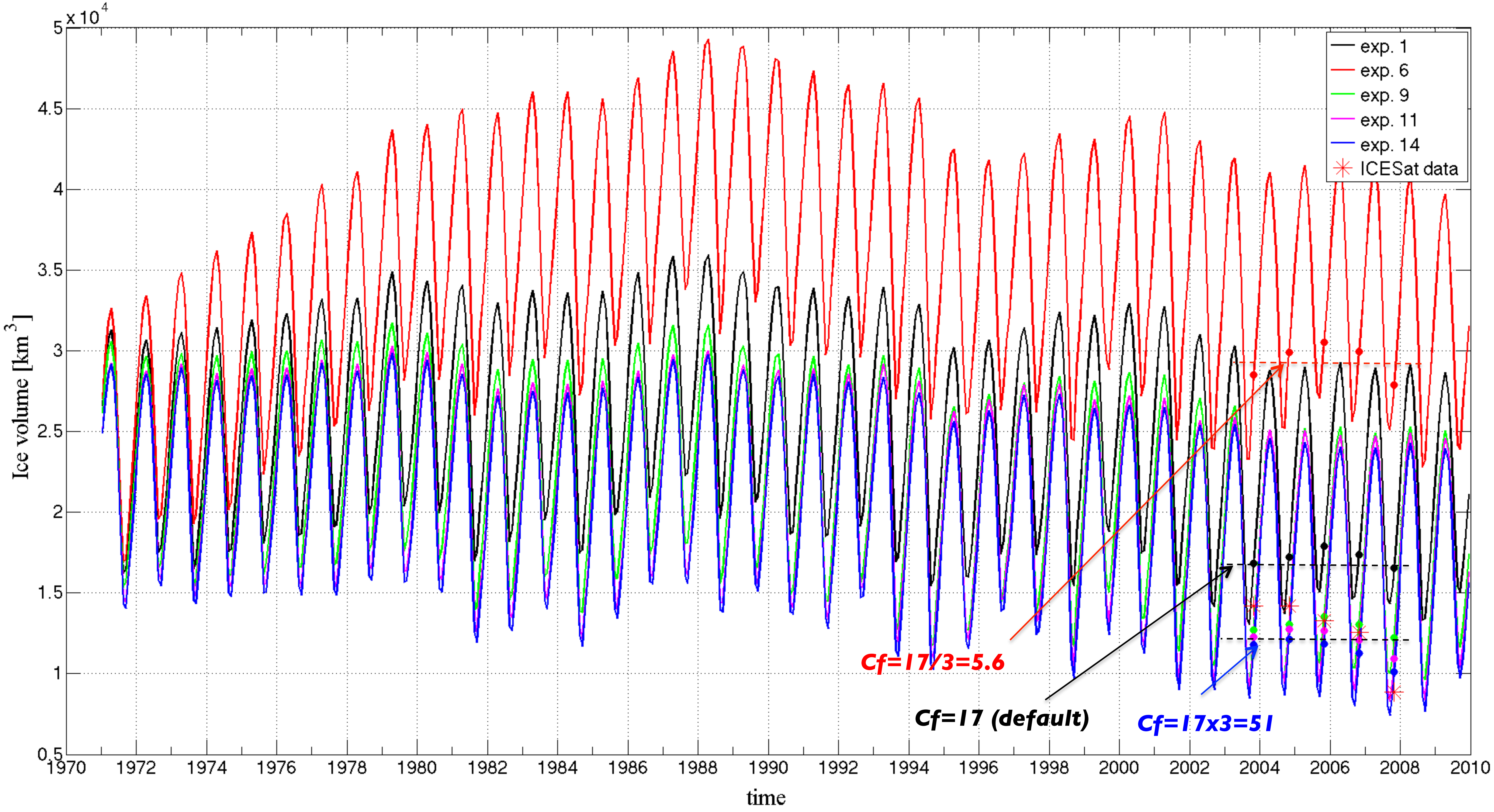
Model	Labrador Sea EKE			Nordic Seas EKE		
	Maximum	Mean	Std Dev	Maximum	Mean	Std Dev
PCAP58	132.50	4.90	9.20	269.40	4.70	13.30
PIPS	3998.00	70.40	203.70	4959.00	43.50	142.70

(Maslowski et al., 2008b)

Physically consistent sea ice assimilation



Time series of monthly mean sea ice volume. October-November means estimated from IceSat are shown with red asterisks with equivalent model values shown by color dots for comparison.



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Cf=17 (default)

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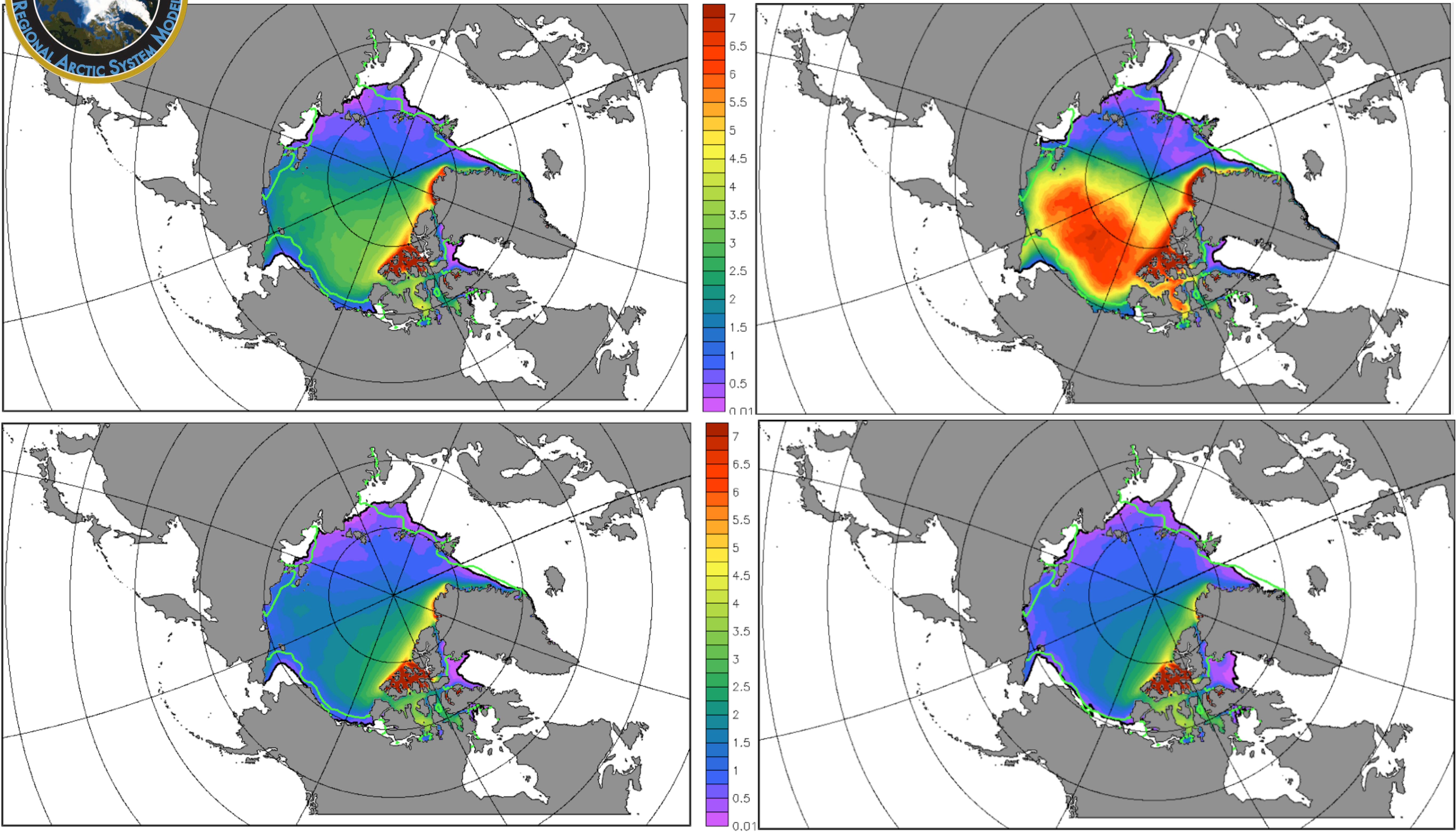
RASM G-compset forced with CORE2 vs SSM/I



1979-2009 mean September sea ice thickness distribution from 4 G-ensembles.
The green contour represent the 1979-2009 mean 15% ice extent from satellites.

(Osinski et al. in review)

Observed sea ice extent is not a sufficient model constraint!