Evaluation of Oceanic and Sea Ice Arctic – Subarctic Exchanges in CCSM3, CCSM4, RASM and other models

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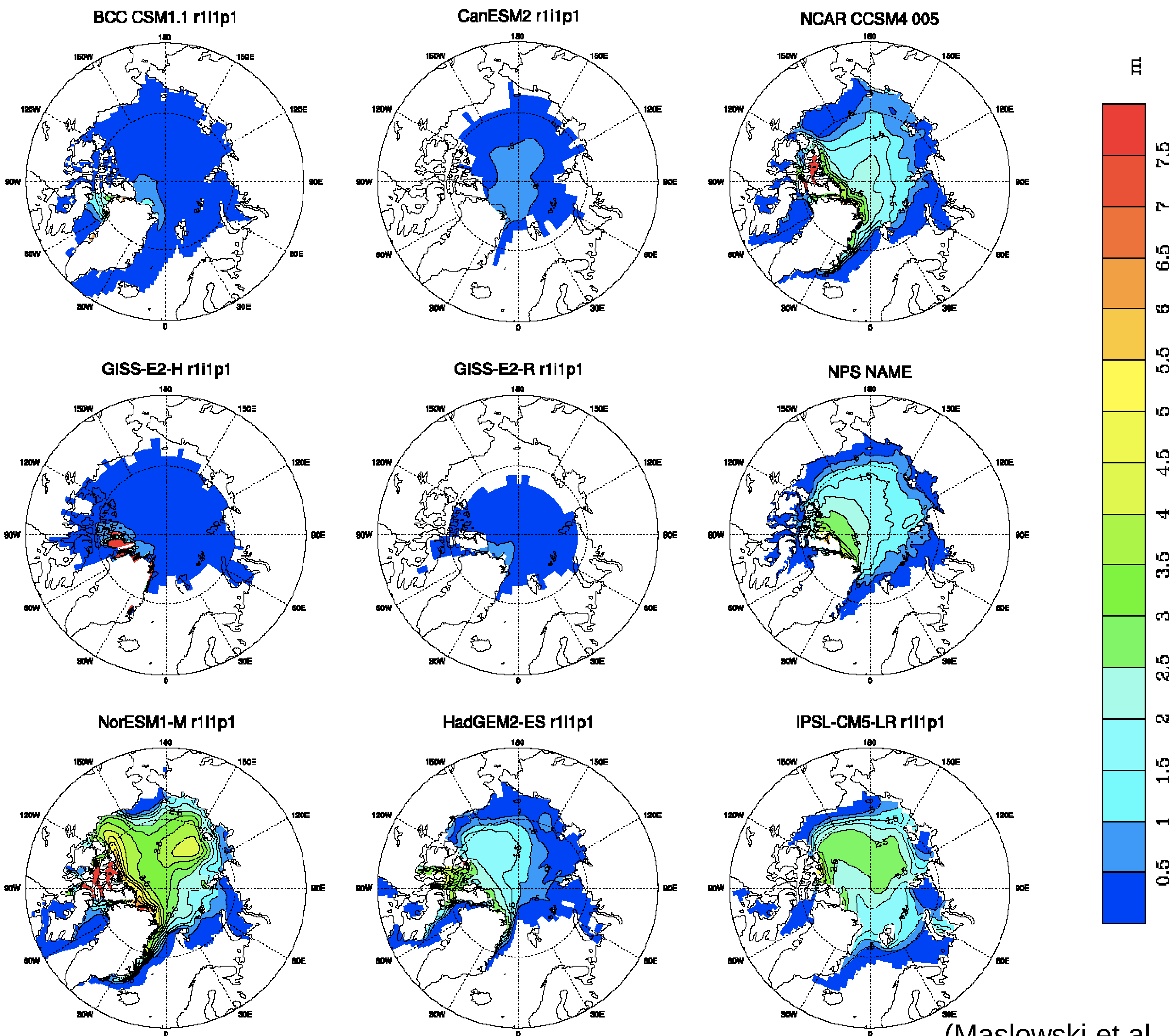
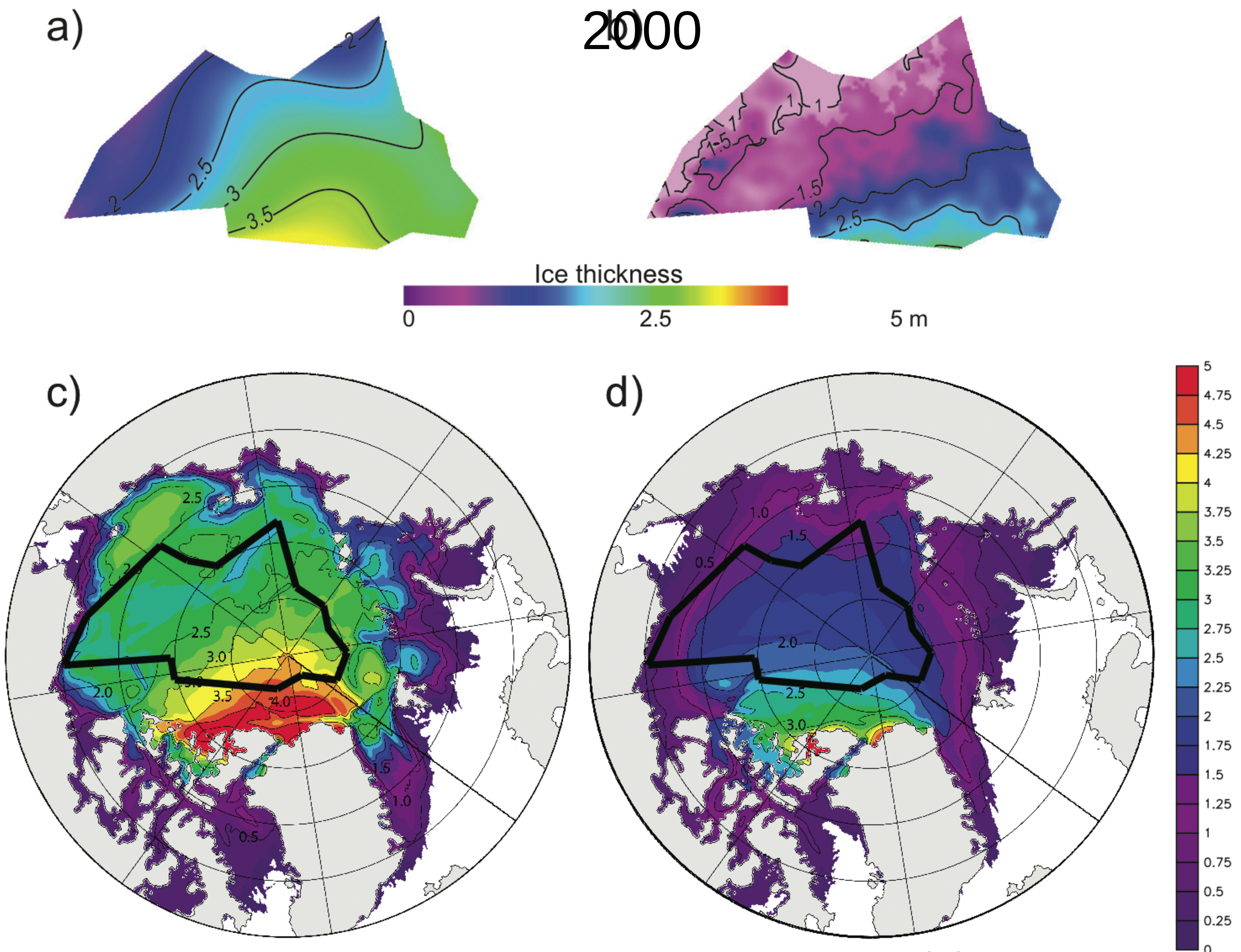
September mean sea ice thickness (m) averaged over 2000–2004 from CMIP5 and NAME models.



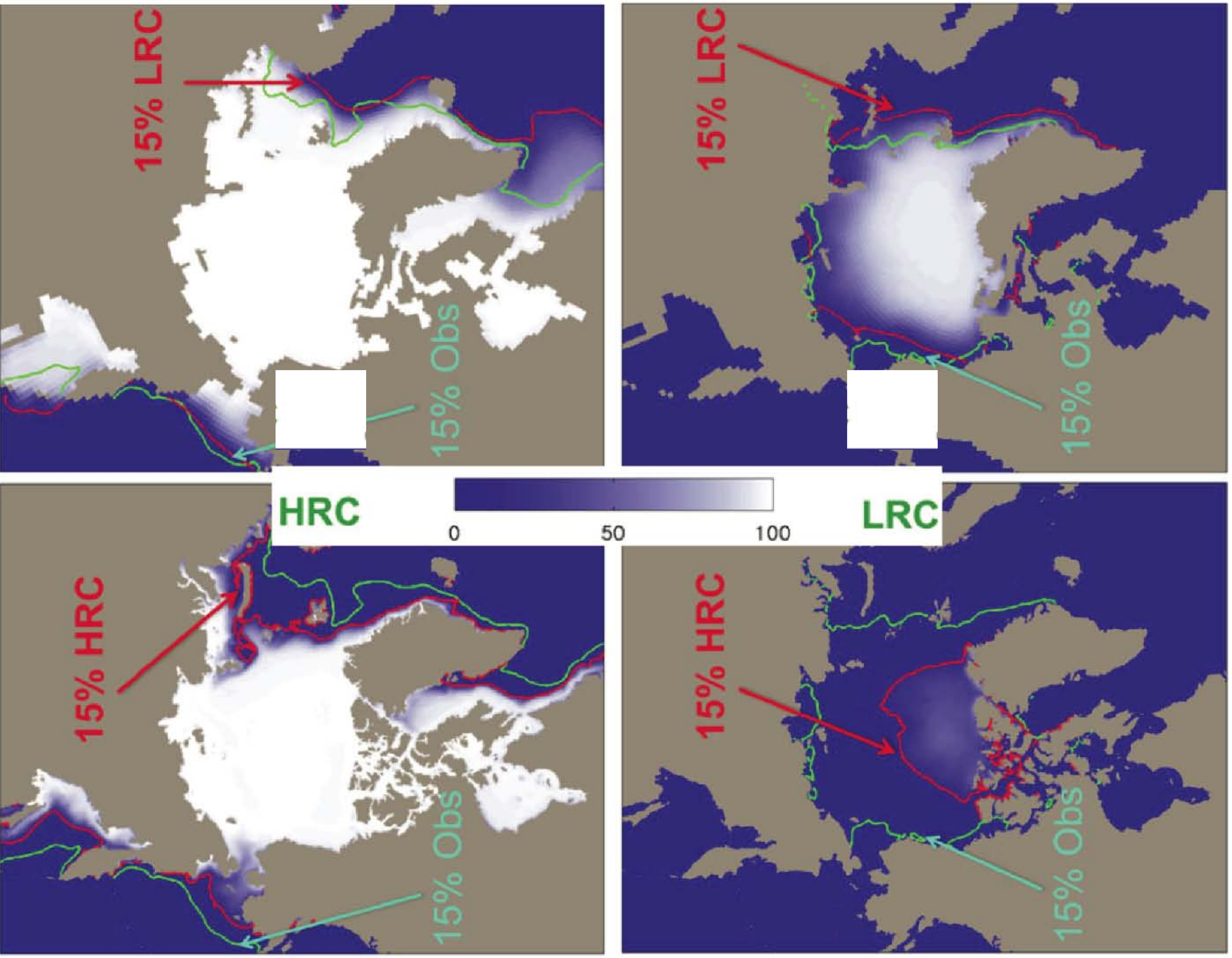
(Maslowski et al., 2012)

Comparison of the change in Arctic sea ice thickness before and after 2000



(a) October through December 1988 from submarine observations, (b) October through November 2003–2008 from ICESat observa- tions (as in Kwok & Rothrock 2009), and NAME model output from (c) October through November 1988 and (d) October through November 2004.

(Maslowski et al., 2012)



Mean 1979-1999 sea ice concentration in March (left) and September (right) from CCSM3.5: LRC-top and HRC-bottom. The model 15% contour is shown in red and observed (Comiso 1999) in green.

(Kirtman et al. 2012)

"A primary reason for the lack of sea ice in the Atlantic sector and central Arctic in HRC06 compared to LRC is the relatively higher ocean heat transport into the Nordic Seas and Arctic in HRC06. Interestingly, transport of the mean temperature by the mean currents is the key difference, rather than by eddies"

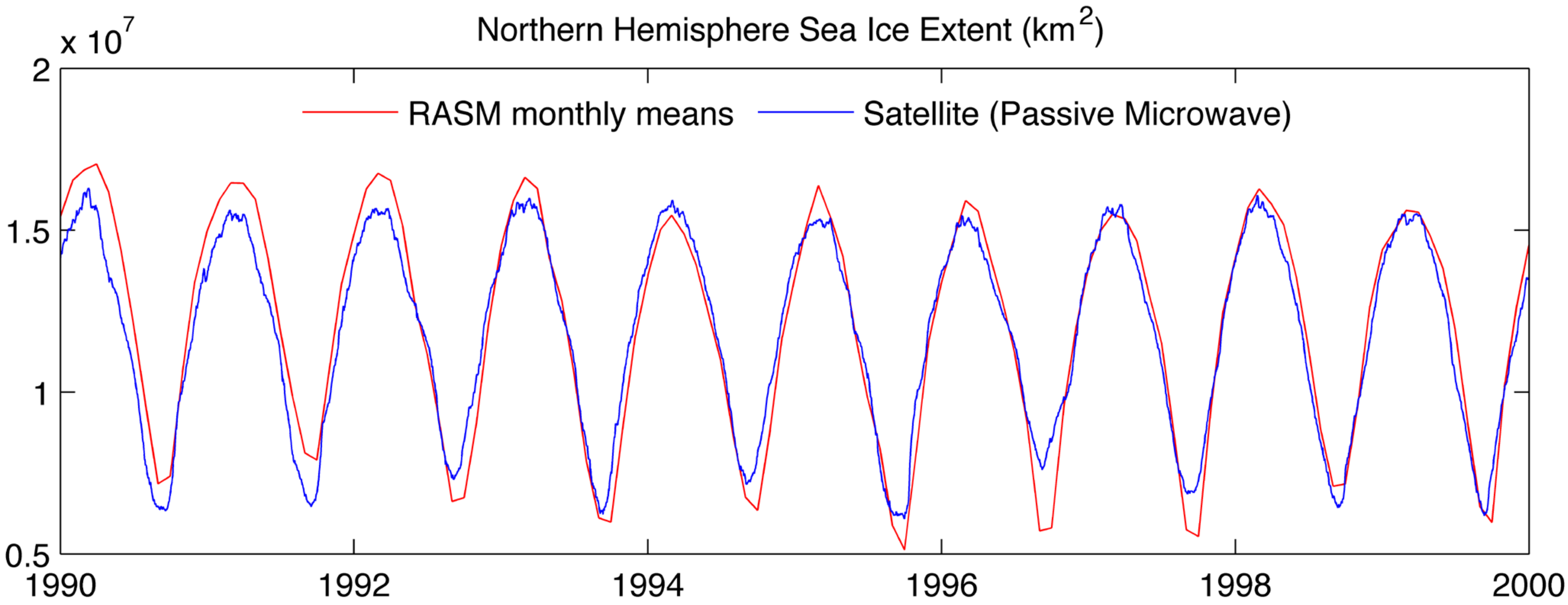
RASM components and resolution

- **Atmosphere - Polar WRF** (gridcell ≤50km) -
- **Land Hydrology – VIC** (same as WRF) |
- **Ocean - LANL/POP** (gridcell ≤10km) |-> RACM
- **Sea Ice - LANL/CICE** (same as POP) |
- **Flux Coupler – NCAR CPL7** -

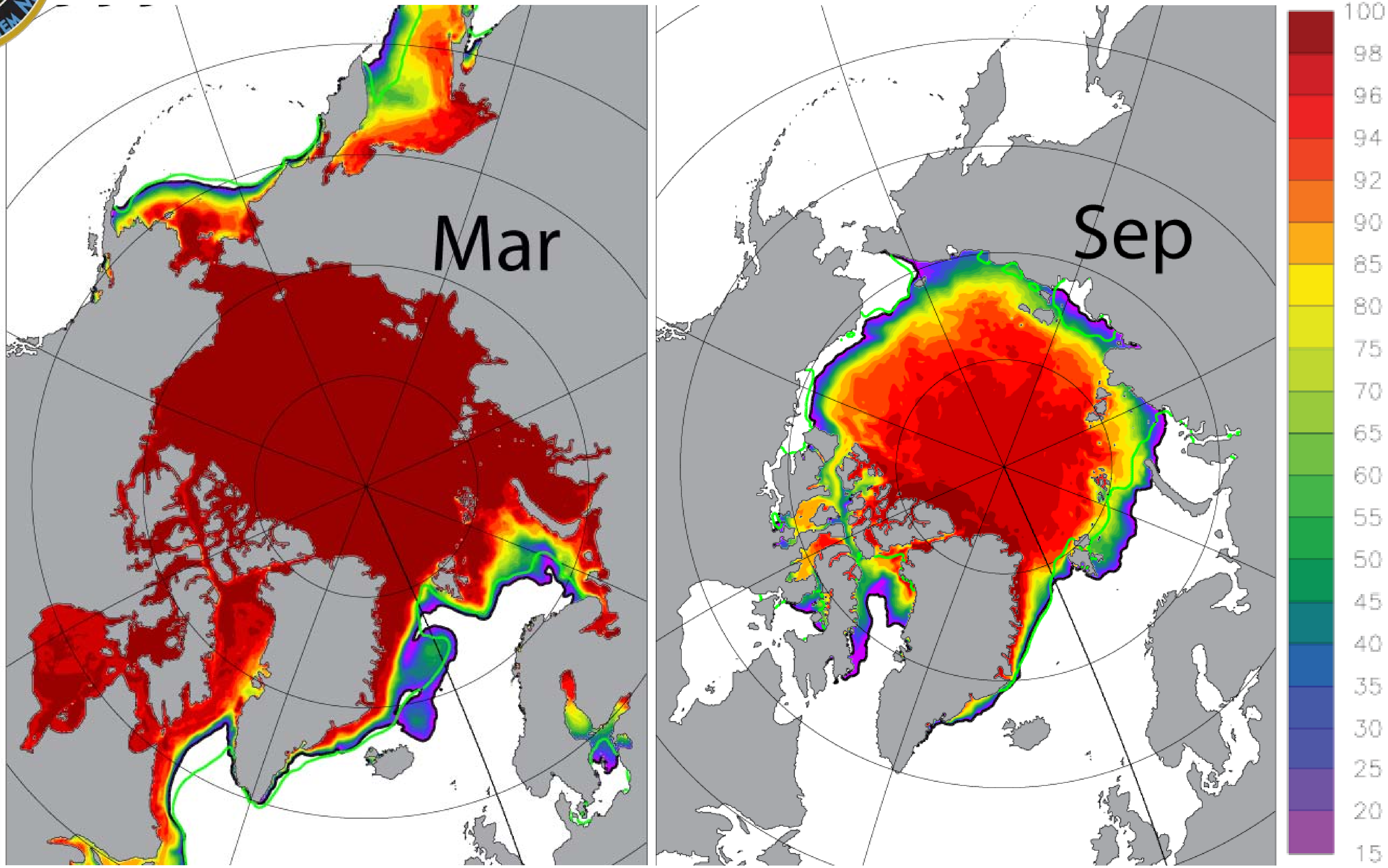
+

- **Dynamic Vegetation – VIC(4.1.1) + CLM(4.0)** (same as WRF)
- **Dynamic Ice Sheet – Glimmer-CISM plus** (gridcell ≤5km)
  - Basal sliding due to meltwater penetration to the bed
  - Ocean thermal forcing of ice sheets and tidewater glaciers
- **Glacier and Ice Caps (GIC)**
  - A new parameterization for evolving area and volume of GIC in VIC

Northern hemisphere sea ice area simulated by RASM, compared to estimates from SSM/I.

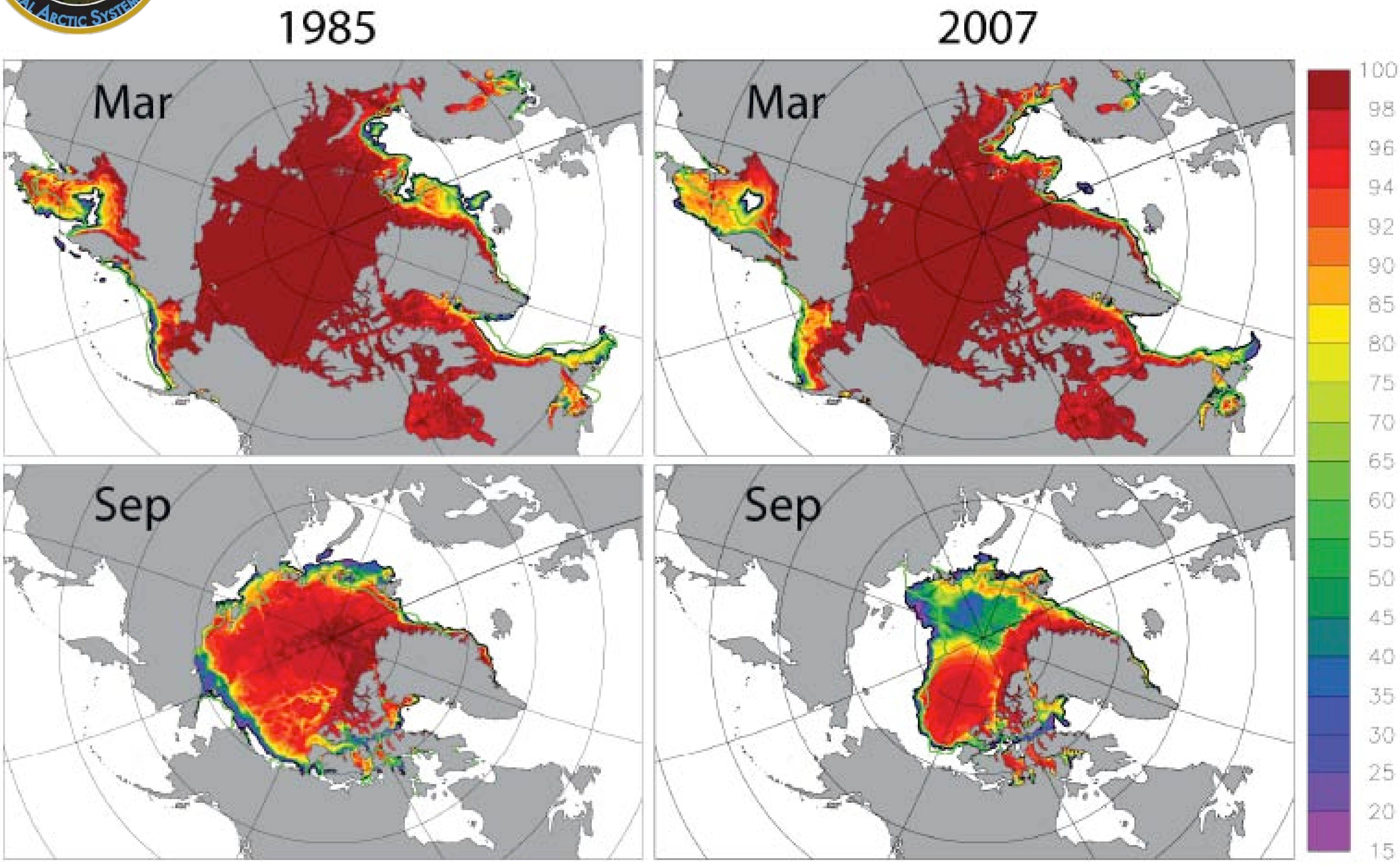


RASM forced with CORE2 vs SSM/I

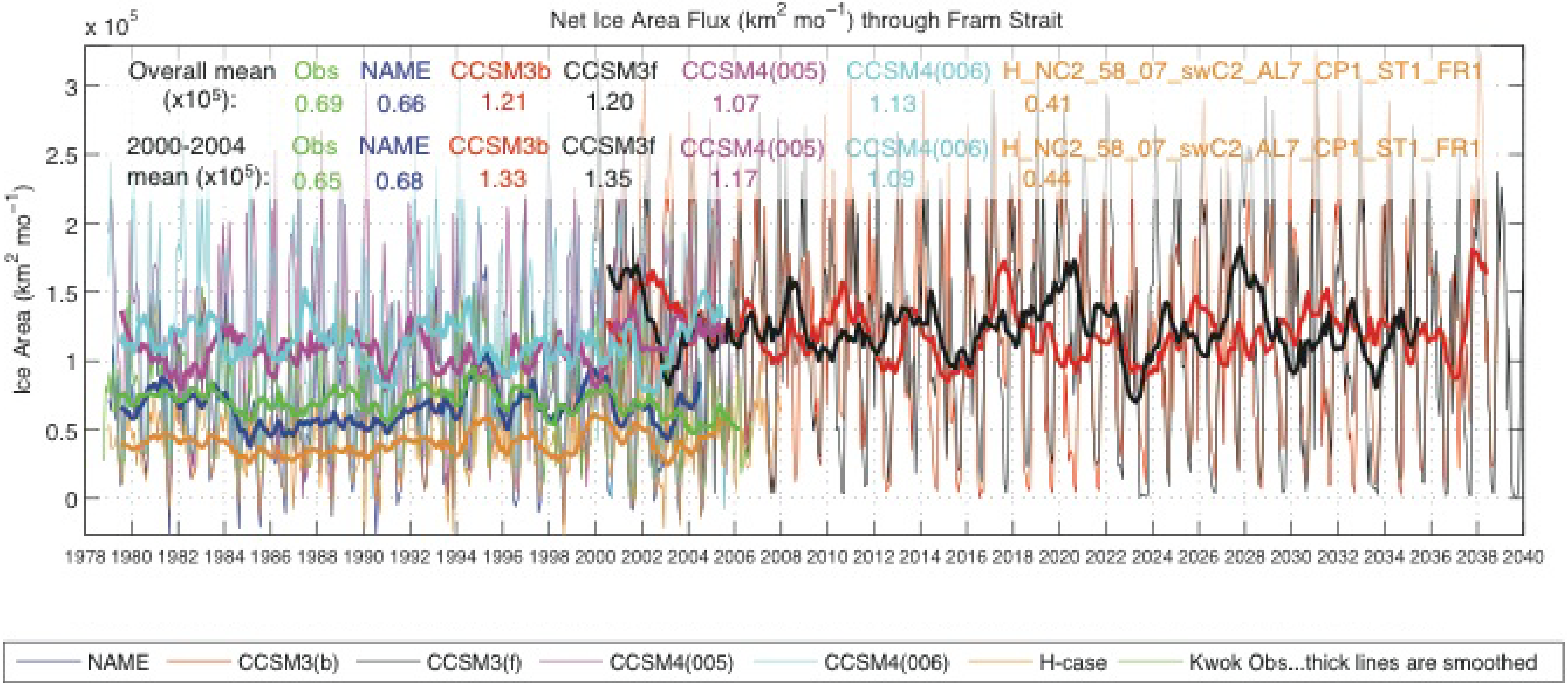


Mean 1979-1999 sea ice concentration. The observed mean mean 15% concentration contour is shown in green (Comiso 1999). The model shading 15% is end of shading.

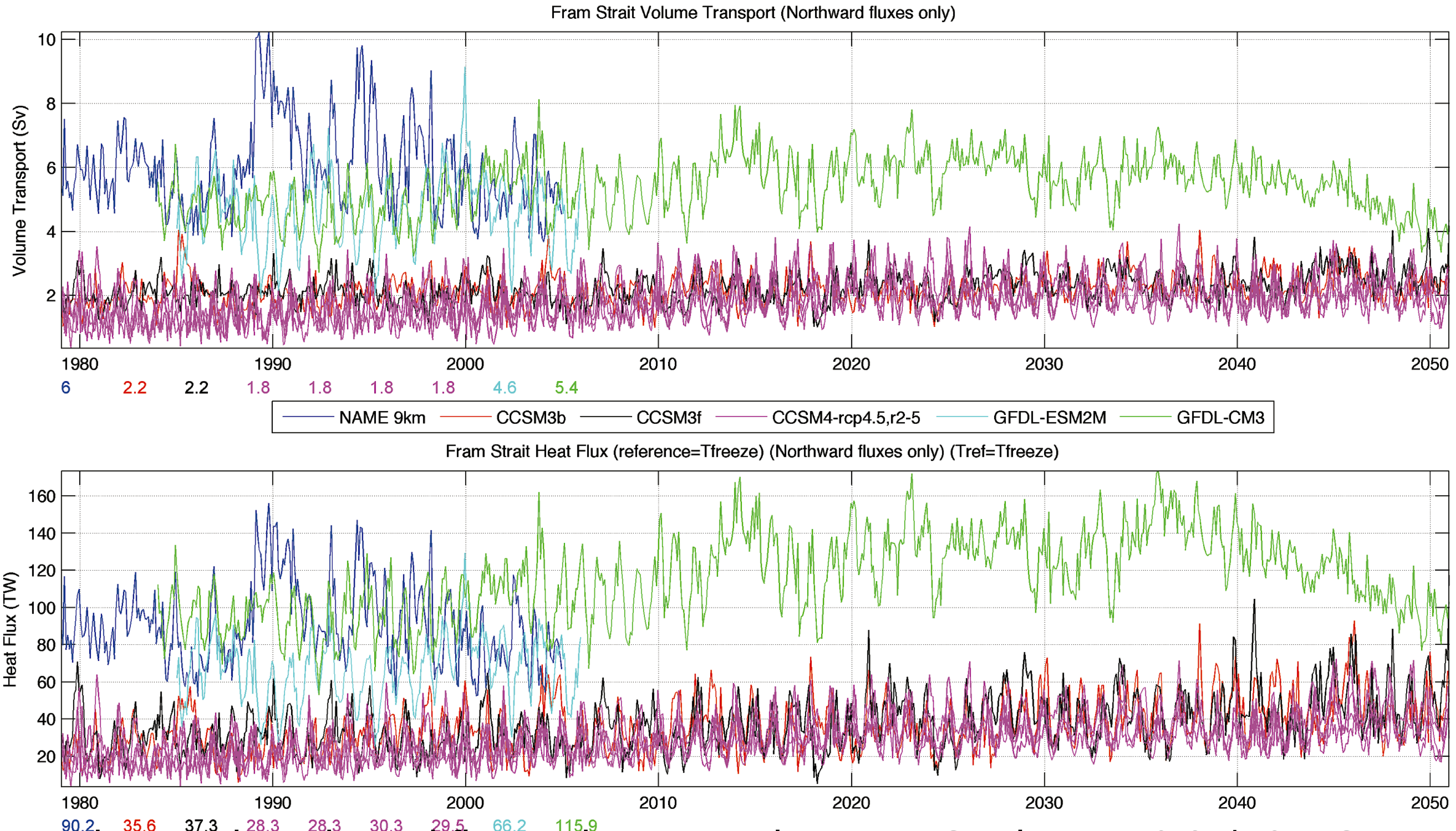
RASM forced with CORE2 vs SSM/I



Monthly mean time series of Fram Strait net ice area fluxes from multiple models and observations.

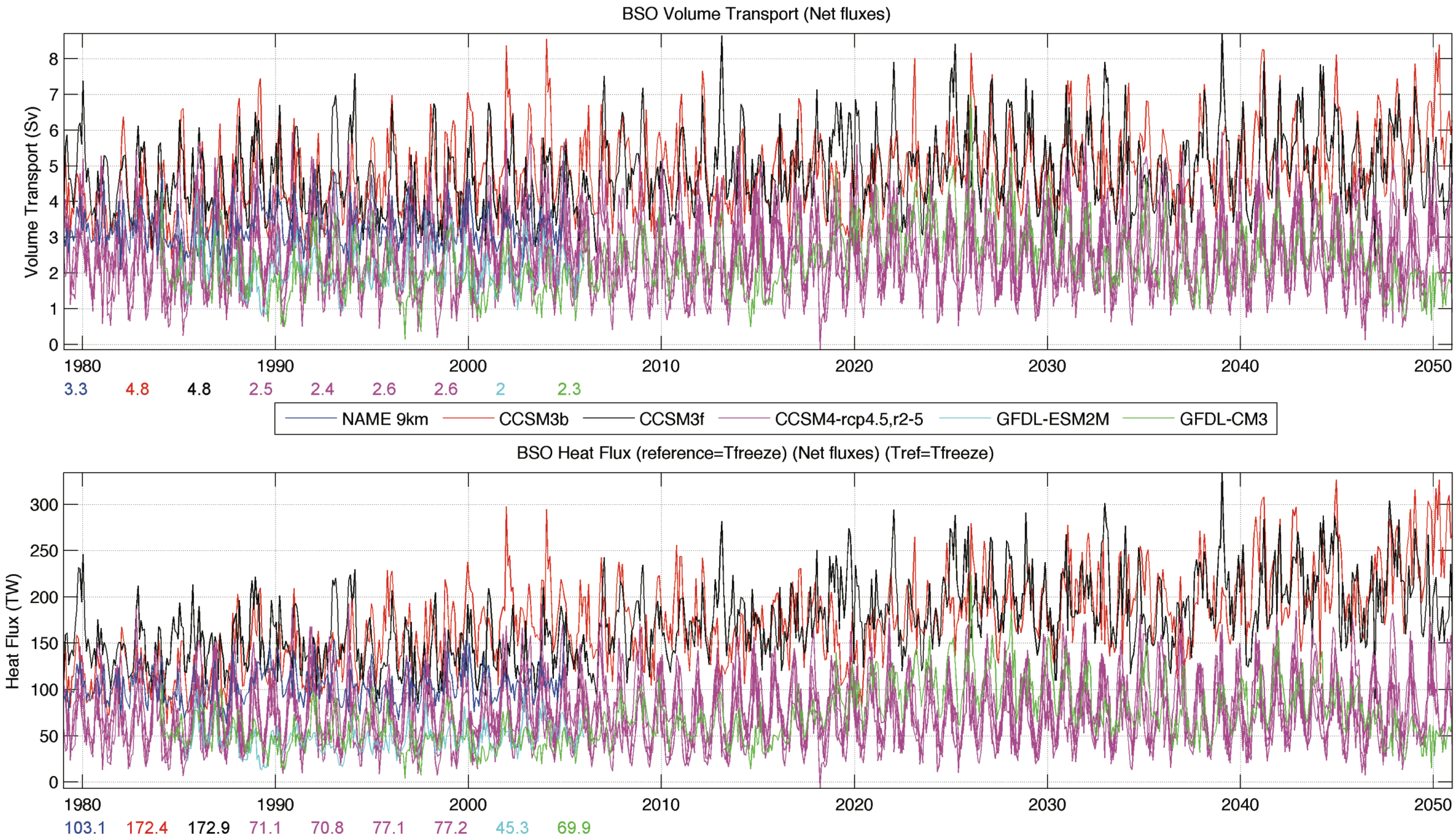


Monthly mean time series of volume and heat: Fram Strait northward only

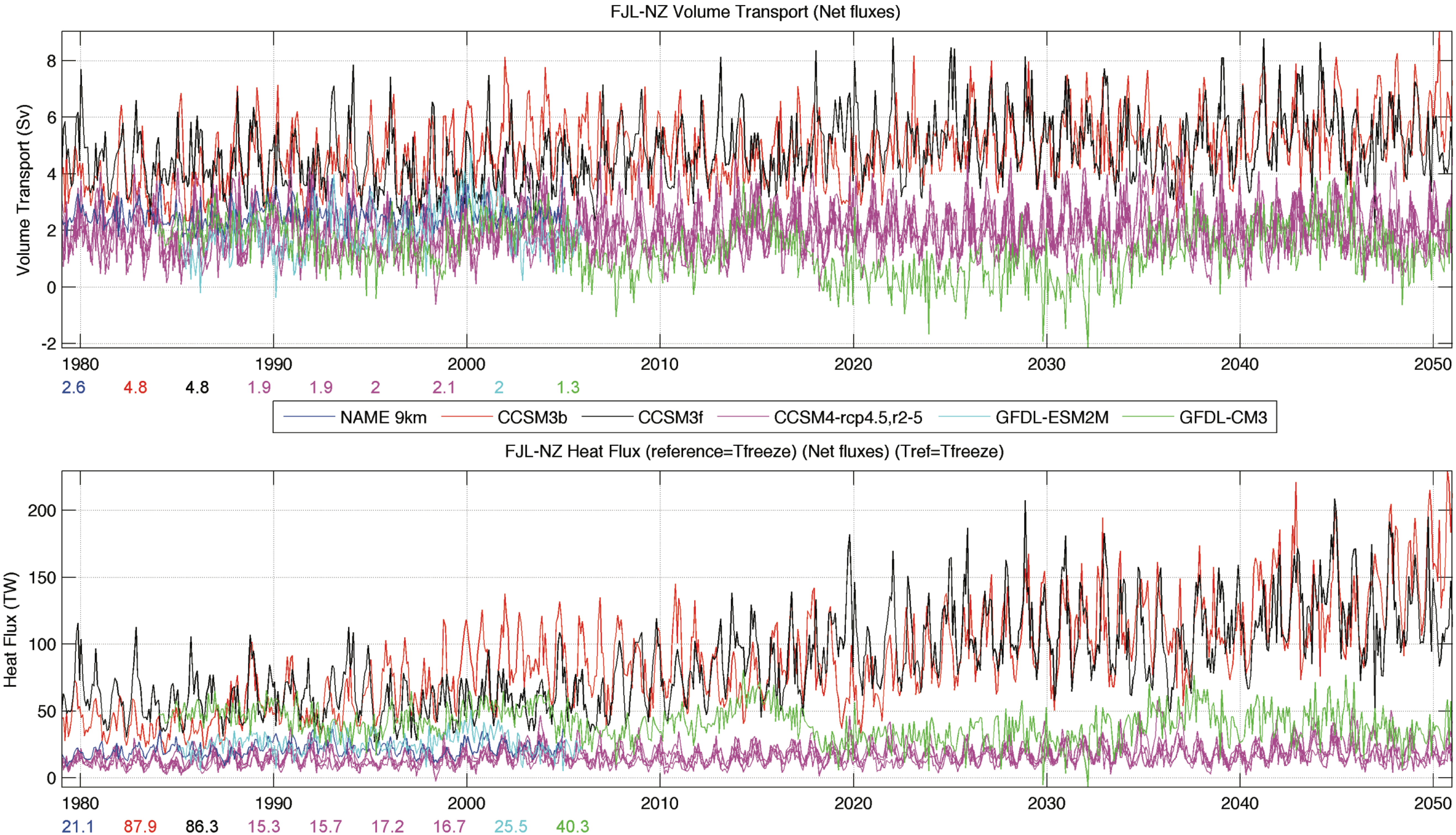


Observed northward flux estimates at the Fram Strait are ~6.8 ± 0.5 Sv (Beszczynska-Möller et al. 2011).

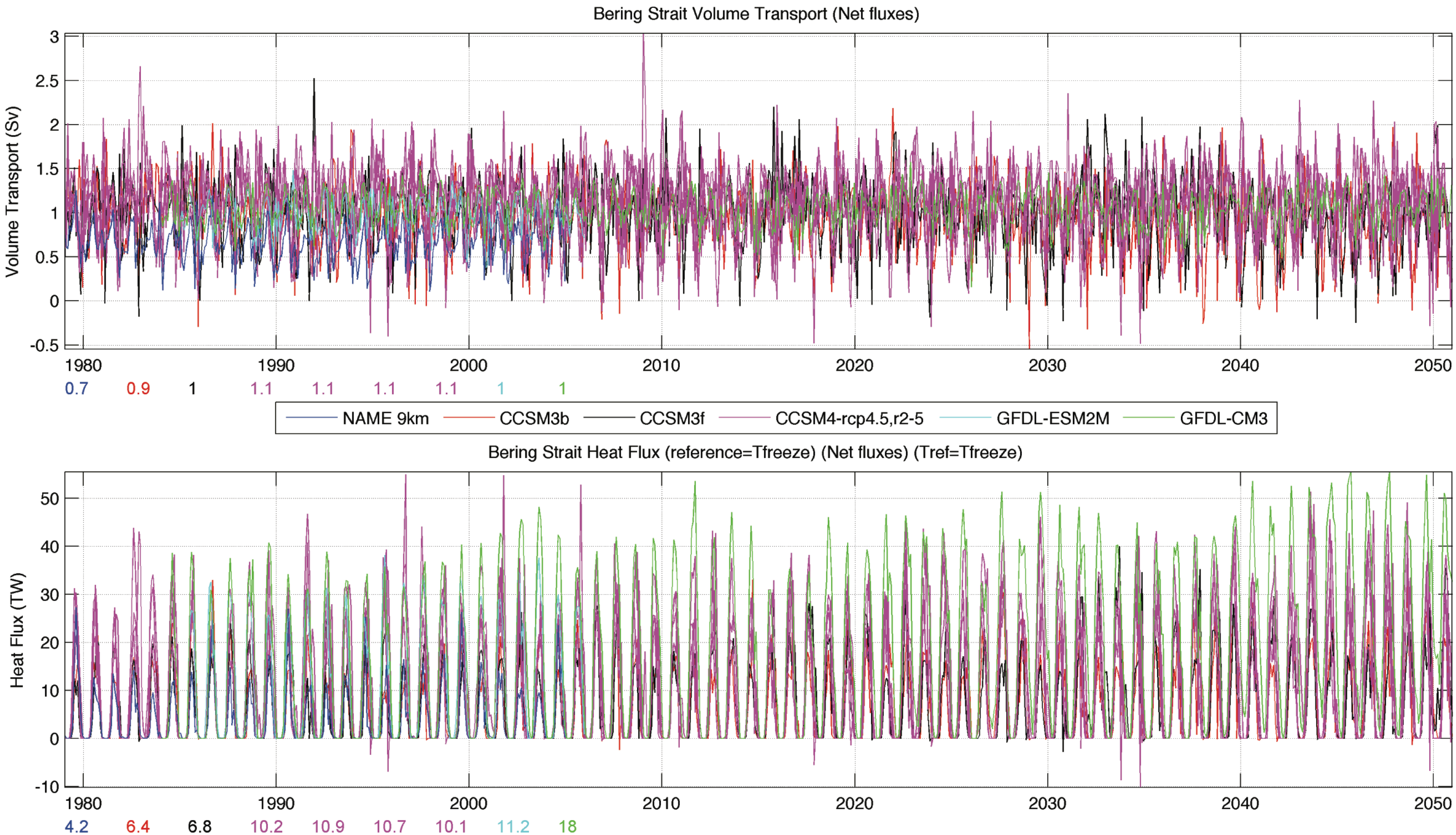
Monthly mean time series of volume and heat transport: Barents Sea Opening (BSO) - net



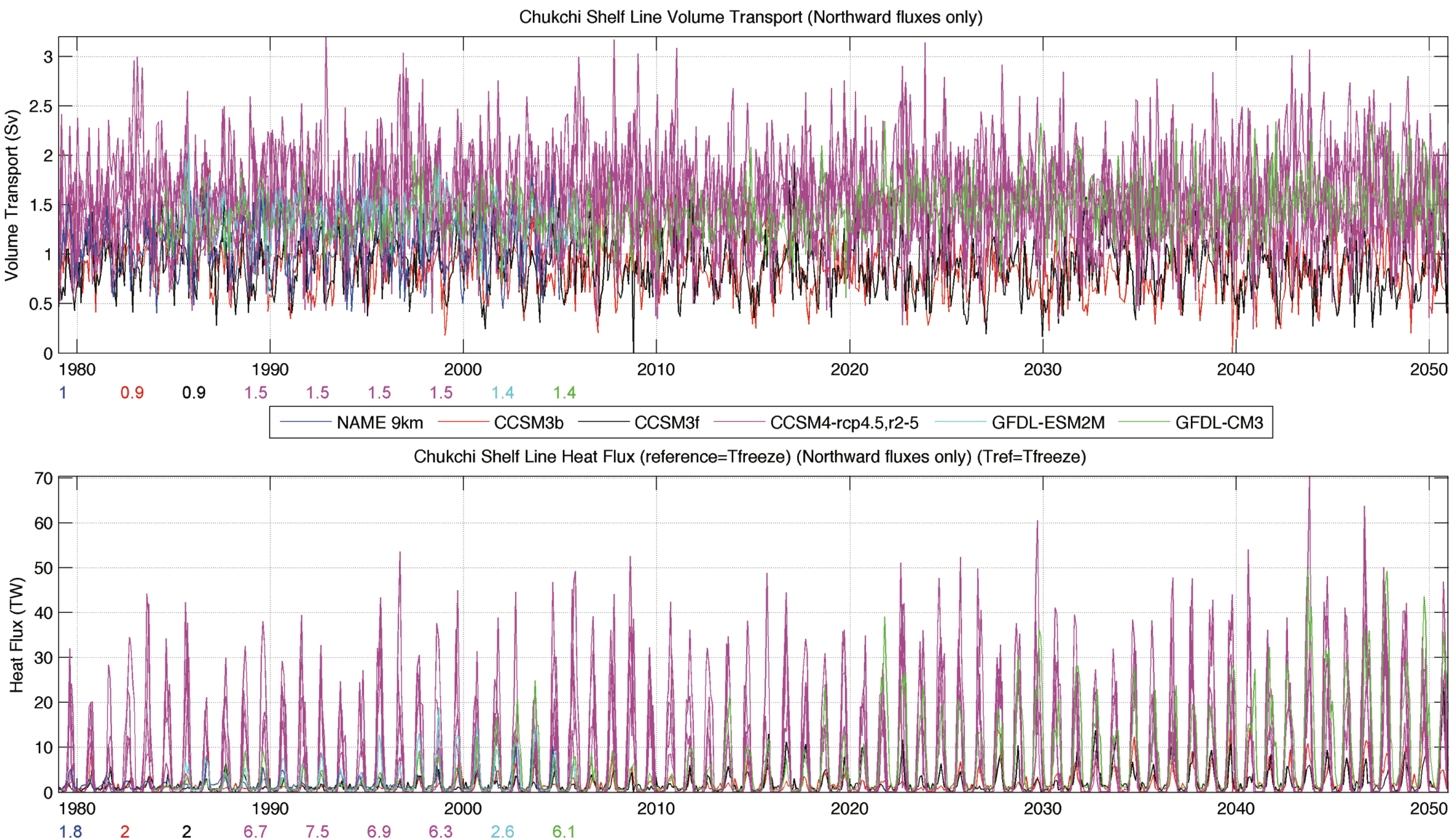
Monthly mean time series of volume and heat transport: Franz Josef Land – Novaya Zemlya net



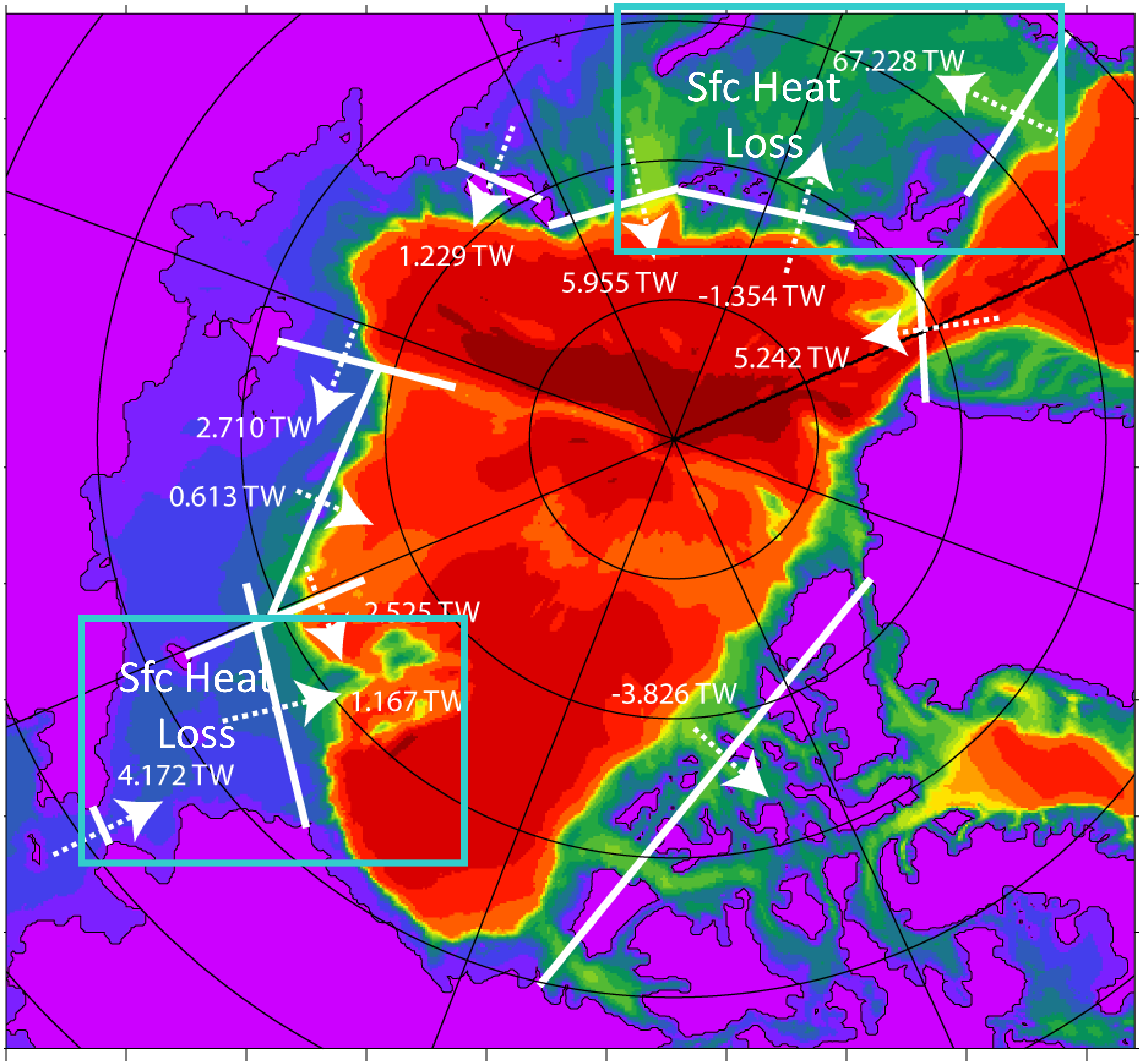
Monthly mean time series of volume and heat transport: Bering Strait net



Monthly mean time series of volume and heat transport: Chukchi Shelf Line northward only



1979-2004 Mean Oceanic Heat Convergence: 0-120 m; $T_{ref} = T_{freezing}$



Modeling Challenges: Inflow of Pacific / Atlantic Water into the Arctic Ocean

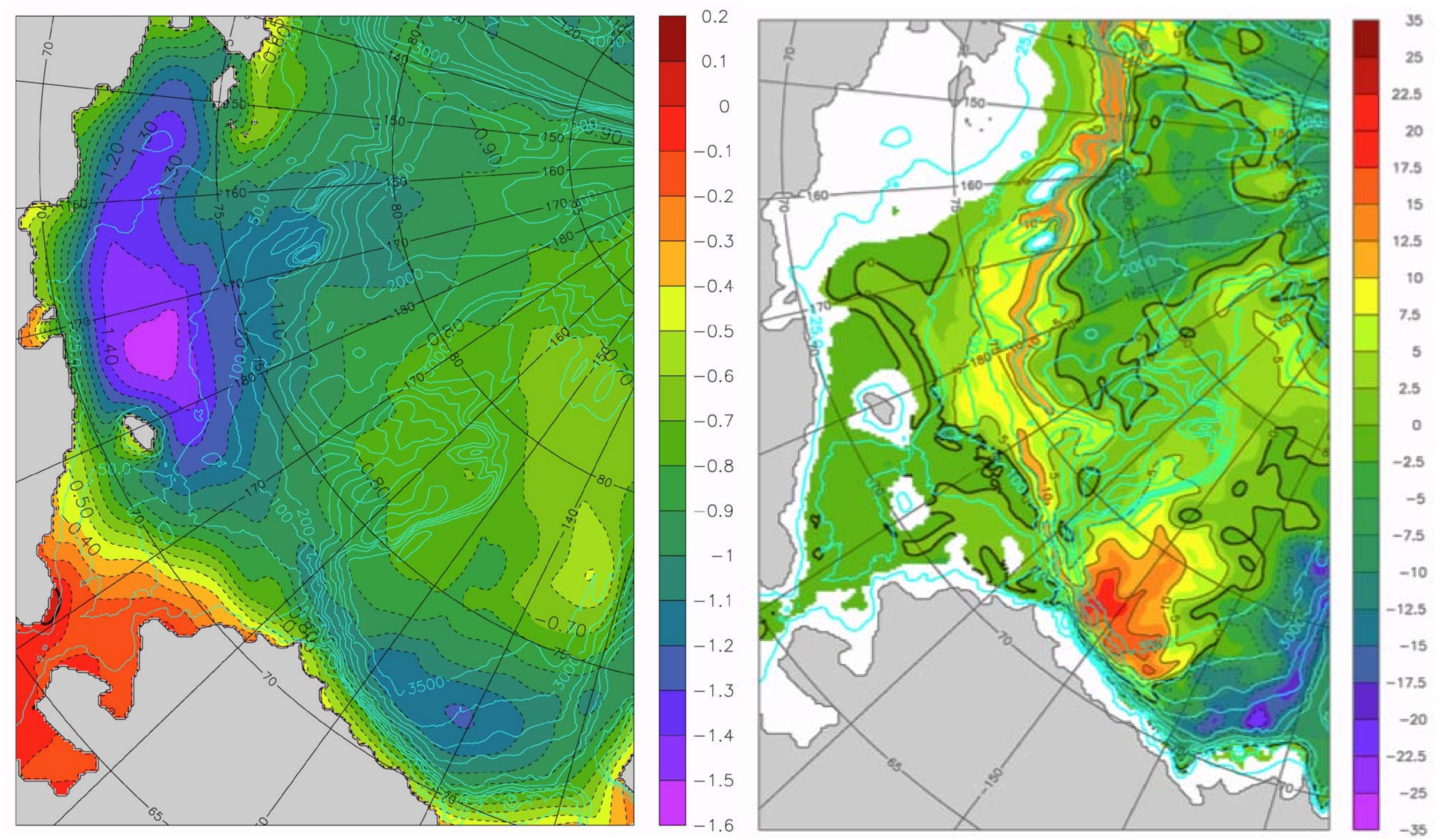
- Pacific Water entering via narrow (~60mi) Bering Strait
- inflow through Fram Strait (FSBW)
- Atlantic (BSBW) and Pacific Water each losses majority of heat to the atmosphere before entering Arctic Basin

Arctic ocean-ice-atm feedbacks – need more realistic representation in climate models

gh resolution is one of the top requirements for advanced modeling of Arctic climate

(Maslowski et al., 2013; Maslowski et al., 2008, Clement et al., 2005, 2011, 2013)

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.

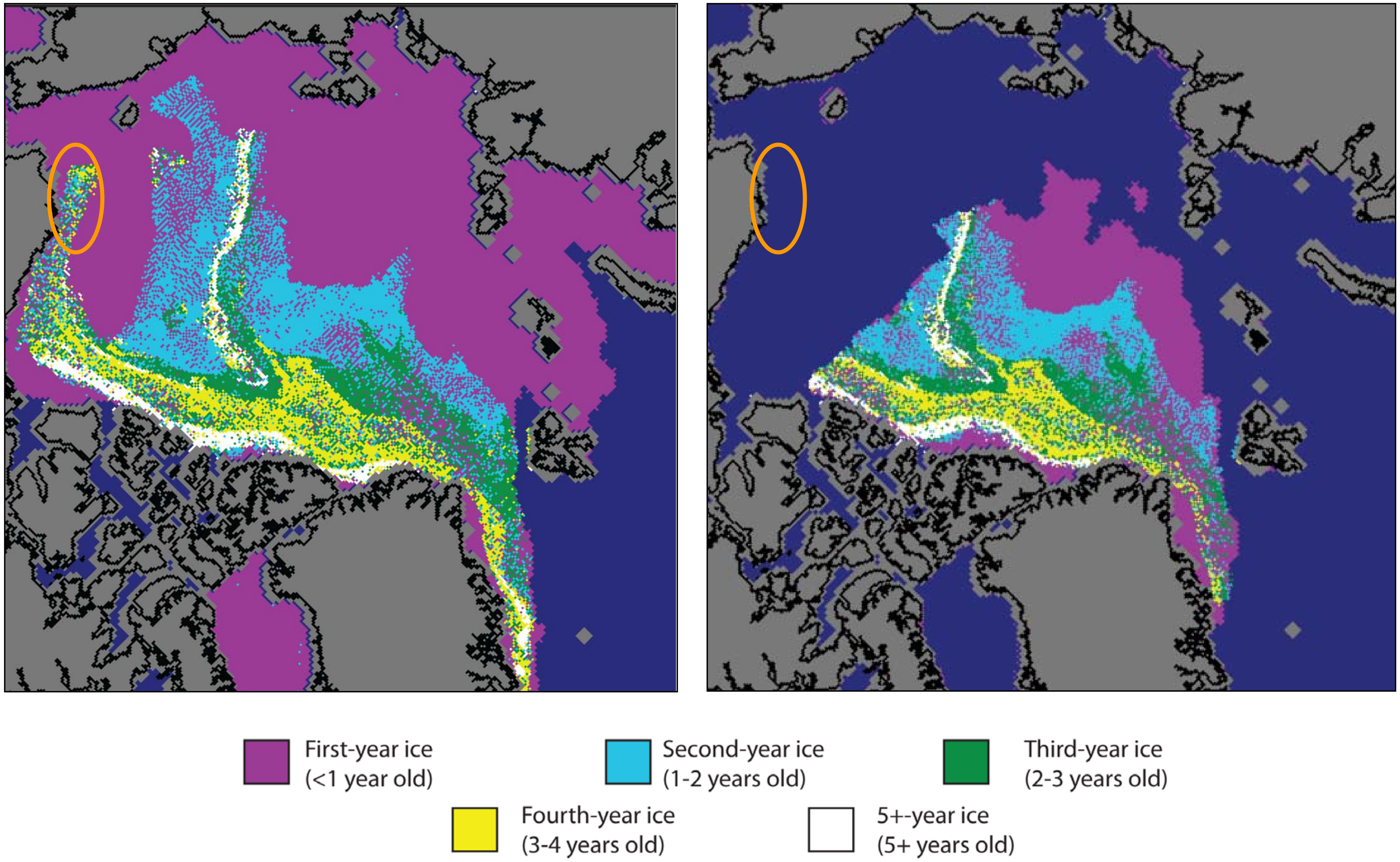


Increasing heat content due to local insulation, advection of warm water from shelves, anticyclonic eddies, slope upwelling or advection

(Maslowski et al, 2013)

Melt of old ice during summer 2012

March 2012 September 2012



Conclusions

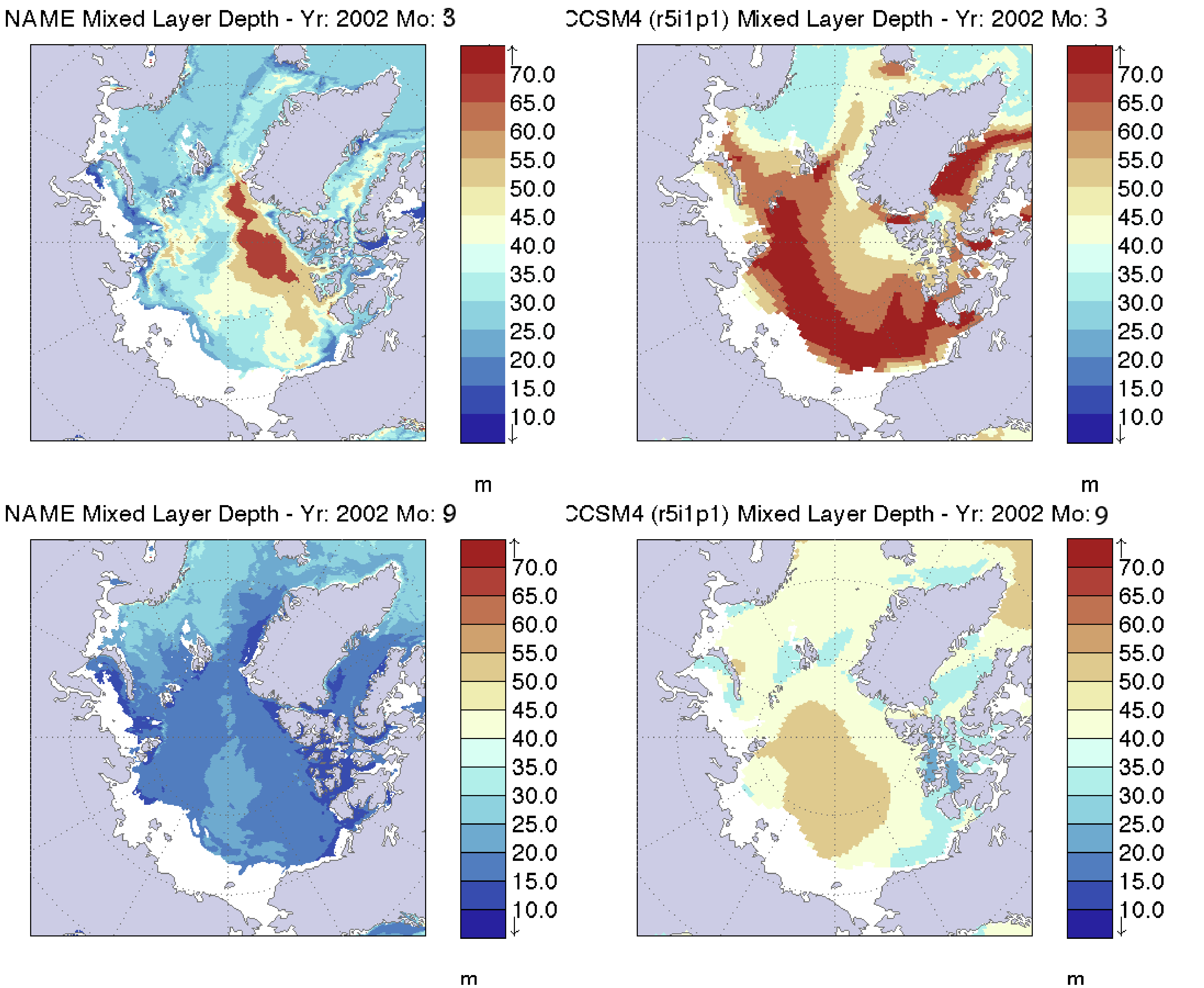
1. CMIP5 climate models are less conservative wrt sea ice but the spread has increased relative to CMIP3

2. Air-sea interactions and feedbacks under diminishing ice cover must be realistically represented in climate models to improve prediction of Arctic climate change

3. Some processes controlling these interactions involve: ice edge and marginal ice zone, sea ice thickness, area and export, surface mixed layer, upper ocean heat content, coastal and boundary currents and mesoscale eddies

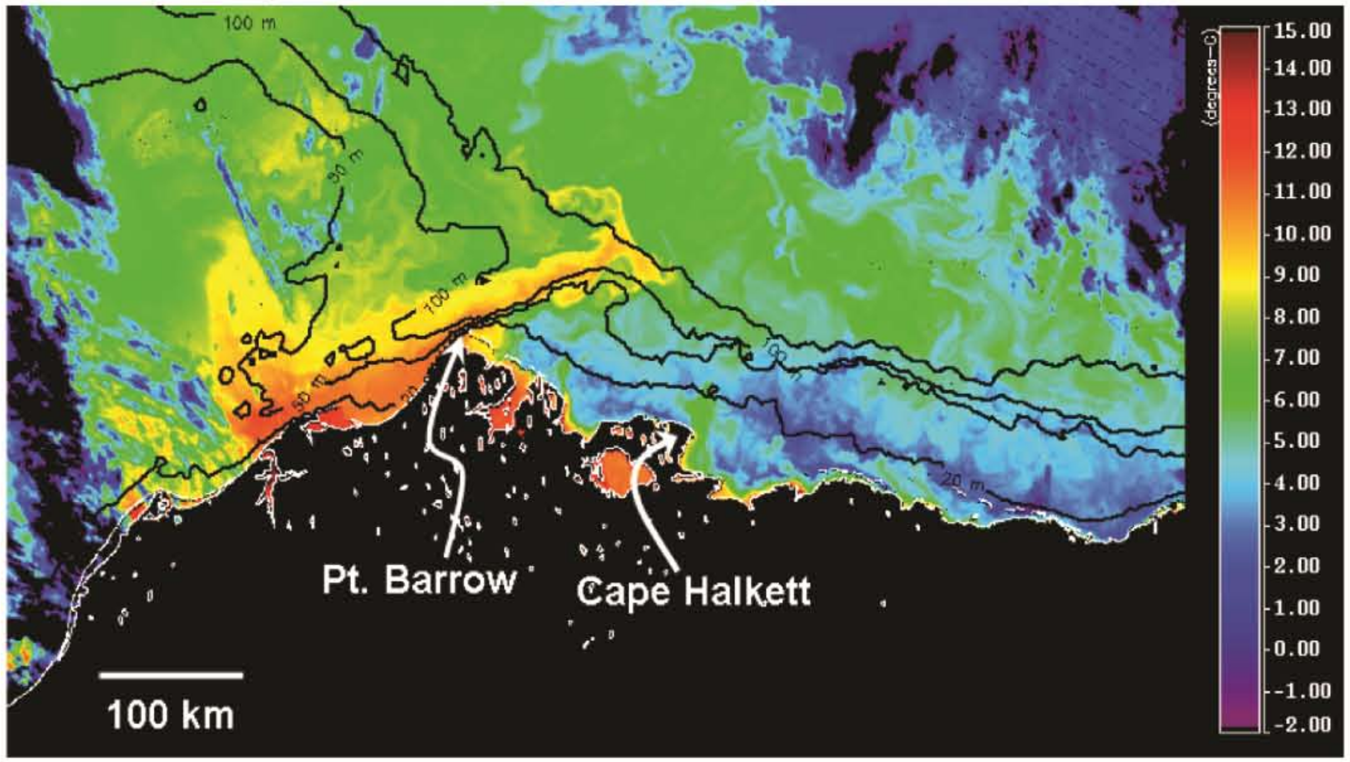
4. High-resolution regional Arctic System models can help better understand the role of ocean forcing of sea ice variability and feedbacks to the atmosphere

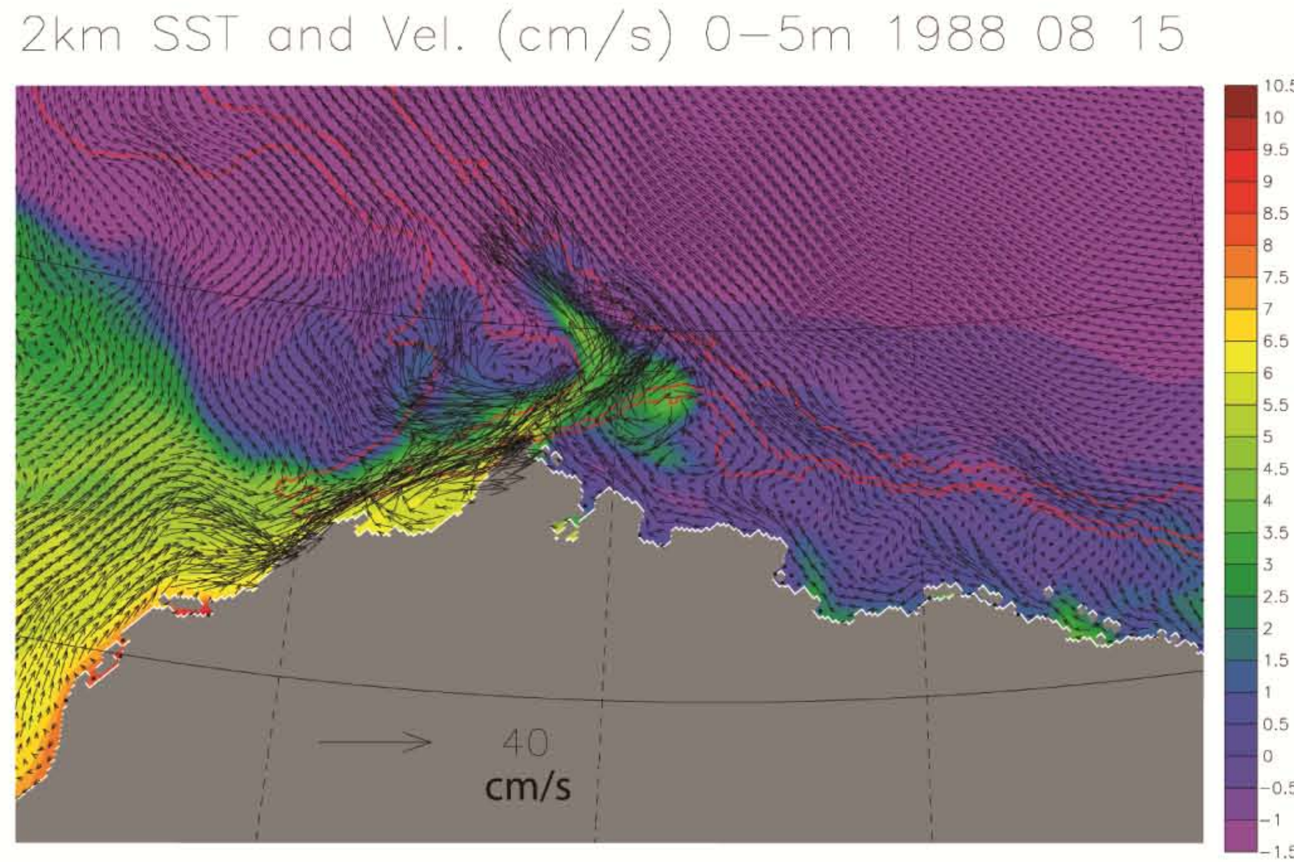
Arctic surface mixed layer depth



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

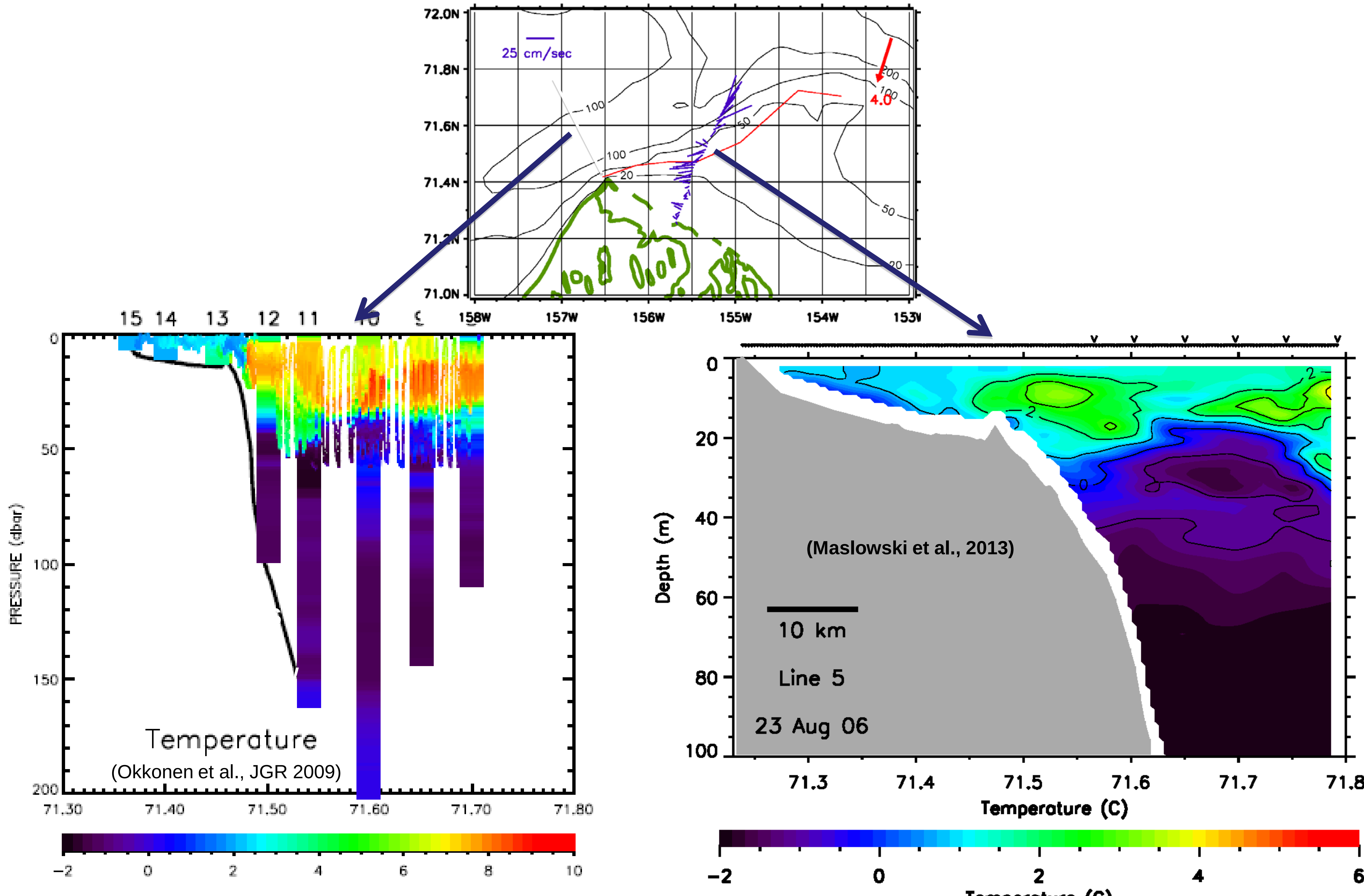
Modeled SST and Velocity – 08/15/1988

- Surface warming due to ice-albedo effect up to 7^{o}C (local warming / limited flow)

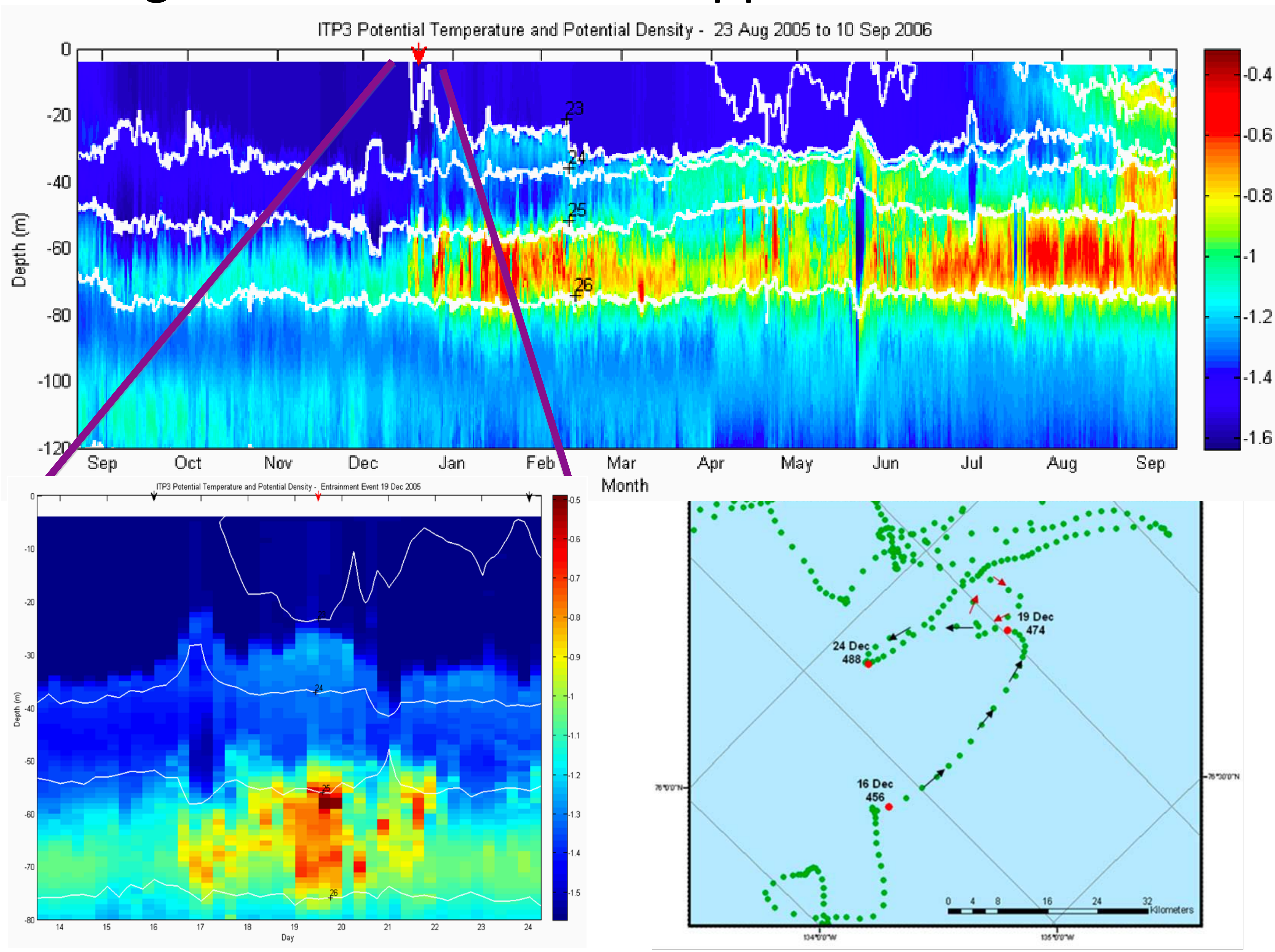
- ACC carries water up to 13^{o}C and it extends below the surface (strong advection)

- At resolution of ~2 km models can capture details of ocean circulation, eddy generation and heat distribution

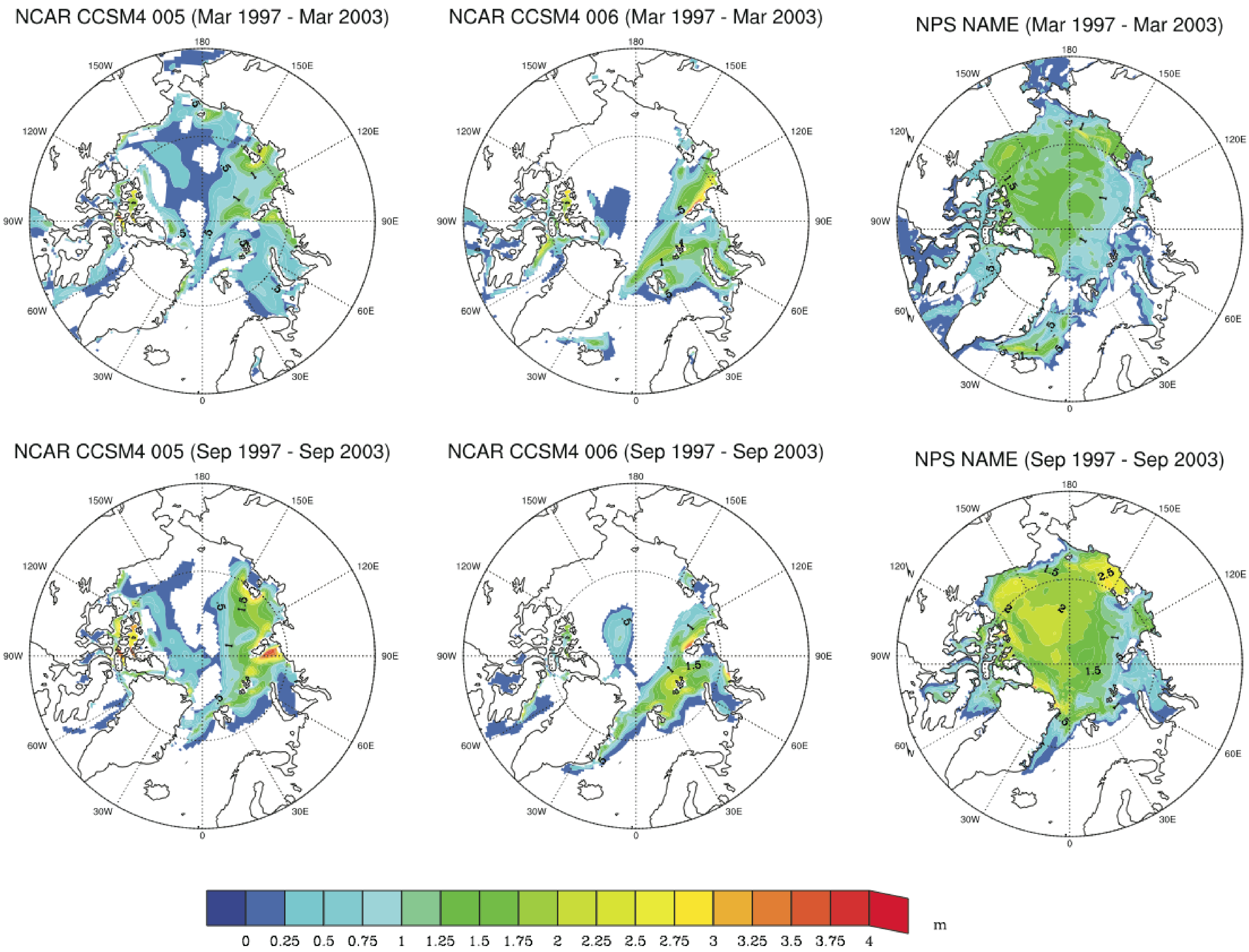
Oceanic advection and eddies transports heat (Pacific Summer Water) from the Chukchi Shelf towards and under the ice cover



Missing Heat Source - Arctic Upper Ocean Heat Content

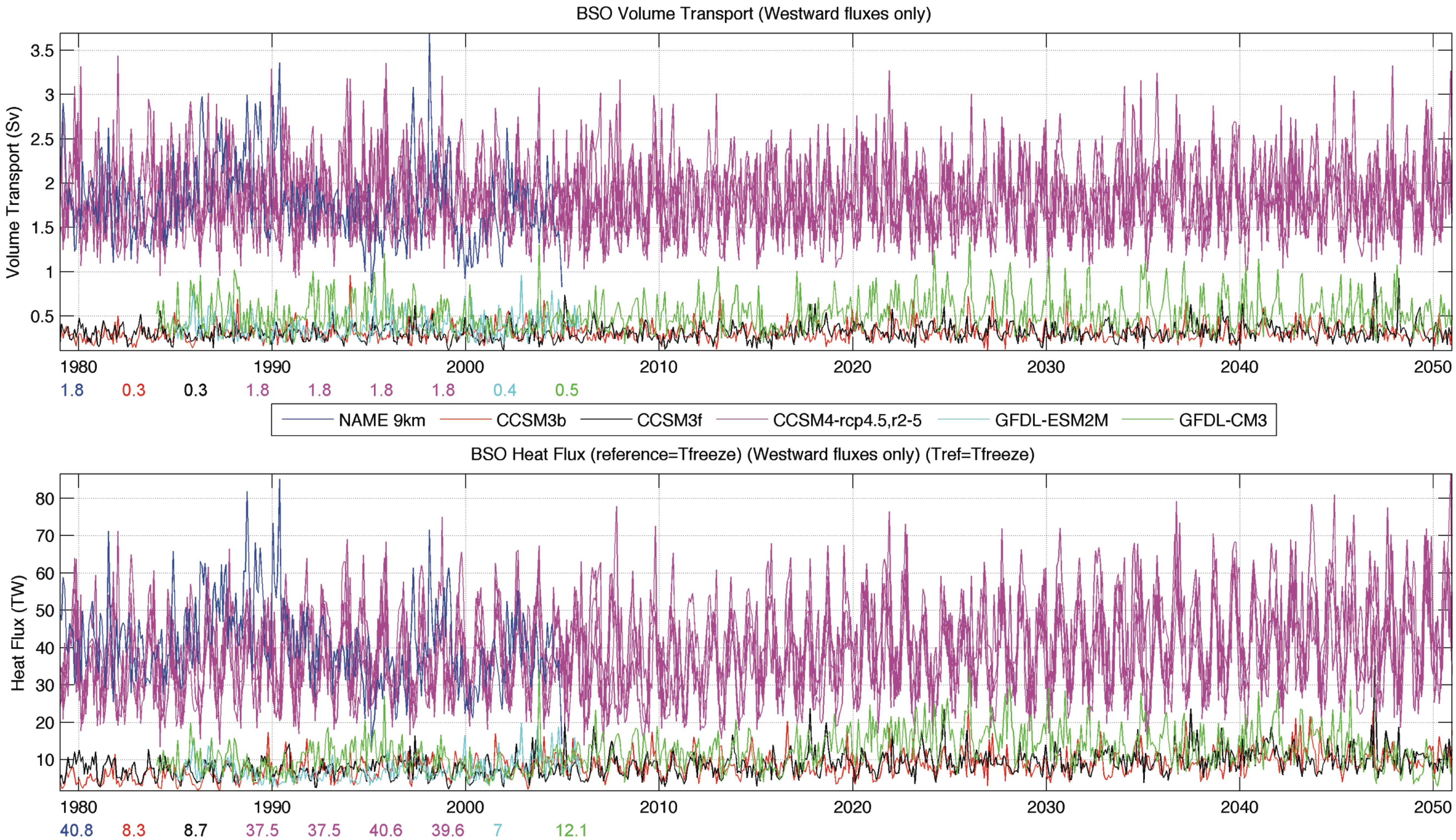


Oceanic heat in reality is removed only from the ocean mixed layer (10-40m) but not from the subsurface ocean (>40m)

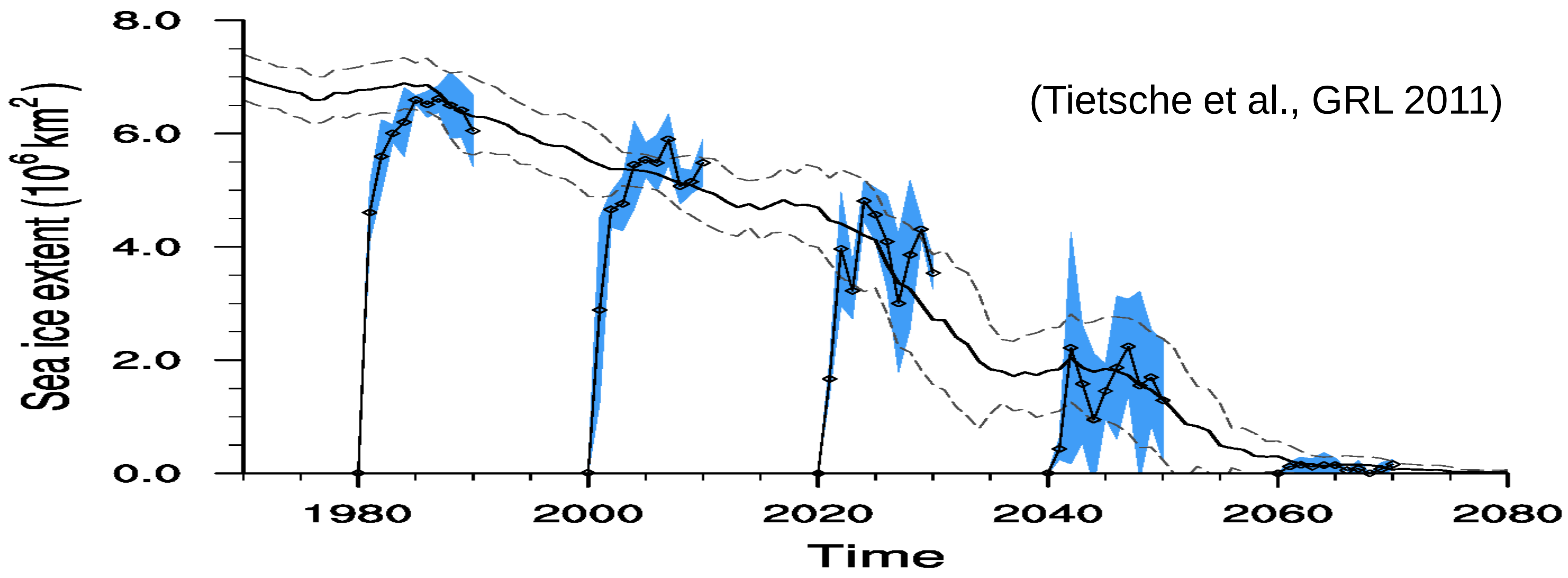


Sea ice thickness difference (m) between 1997 and 2003 during (top row) March and (lower row) September from (left column) CCSM4 b40.20th.005, (center column) CCSM4 b40.20th.006, and (right column) the NAME model.

Monthly mean time series of volume and heat transport: Barents Sea Opening (BSO) west



GCM sea ice simulation - missing heat source?



- 'Arctic summer sea-ice extent returns to the original, unperturbed extent typically within two years' due removal of all oceanic heat to atmosphere

…..however …

- oceanic heat content under a decreasing sea ice cover is expected to Increase significantly (Jackson et al., JGR-Oceans, 2010 & 2011)
- removal of sea ice without 'adjusting' the ocean/atmosphere state does not reflect the ice-free climate regime, i.e. it is an 'ill-posed' experiment