On Modeling the Oceanic Heat Fluxes from the North Pacific / Atlantic into the Arctic Ocean

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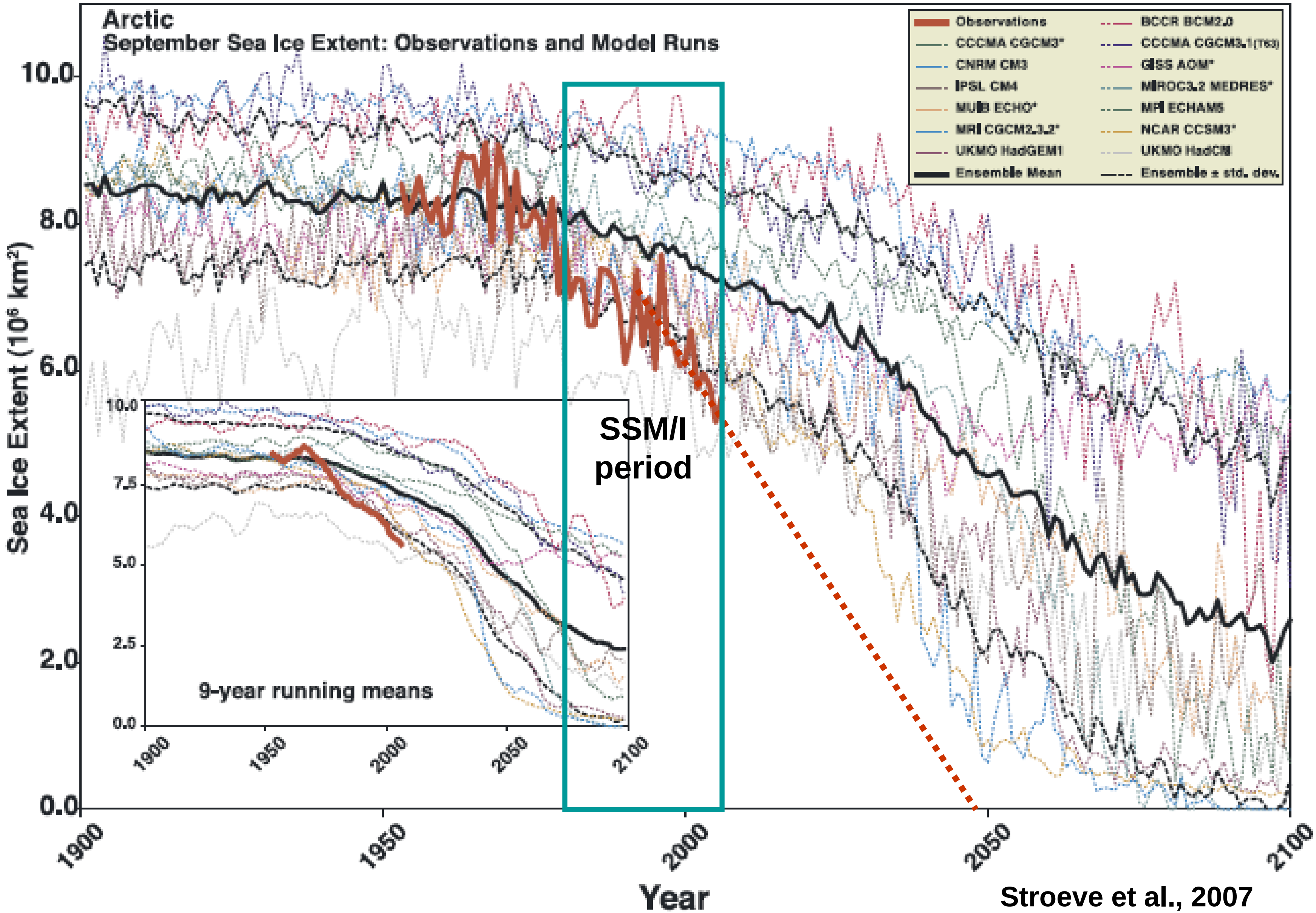
NCAR CCSM PCWG Meeting, Boulder, CO, 16-17 January 2008

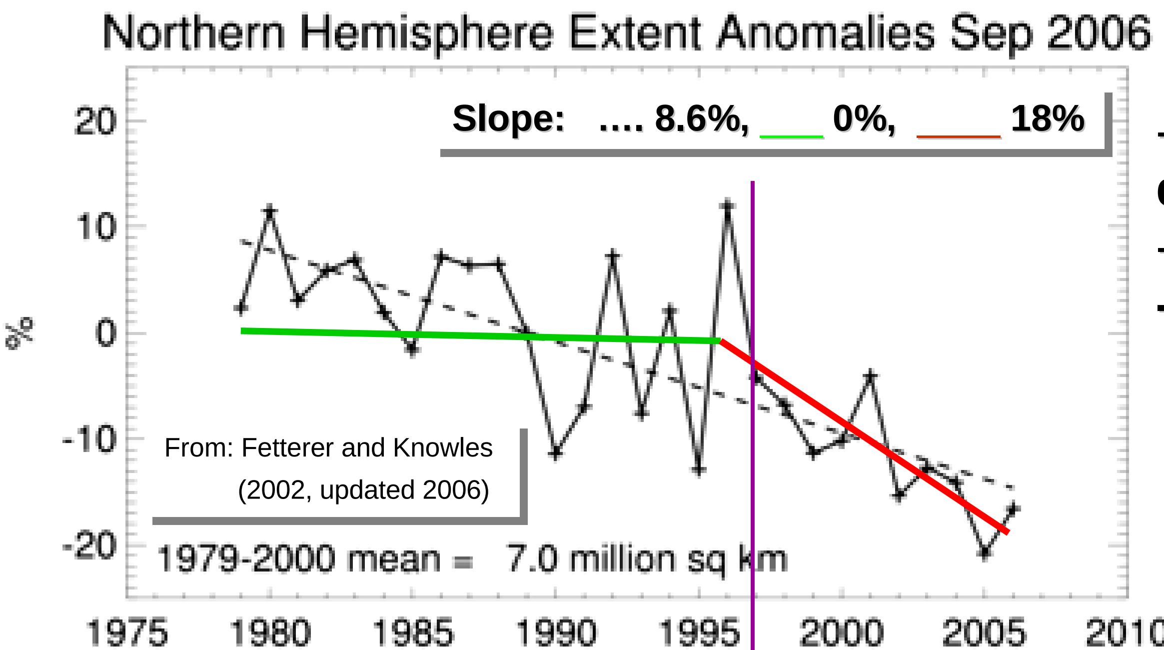
Faster than forecasts?

IPCC AR4 simulations of Arctic ice extent decline are too conservative!



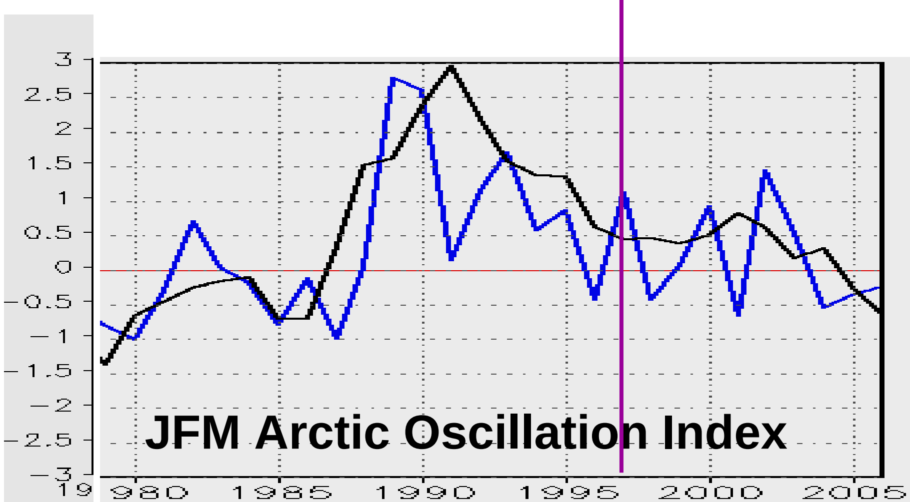
Stroeve et al., 2007

Do we really know the rate of Arctic Sea Ice Melt?



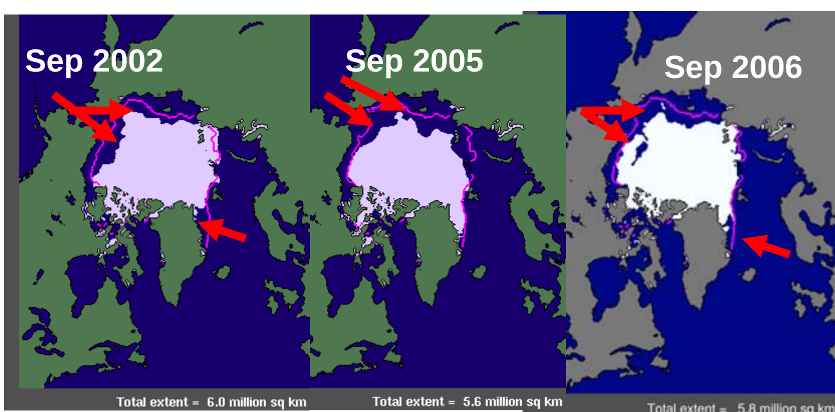
-at what rate: 8% or 18% per decade - SSM/I data too short?
-how about thickness / volume?
-what are the causes?

Most reductions downstream of oceanic heat advection



Low/no correlation since 1997!

Consequences: ecosystem,
shipping,
natural resource development,
defense



Combined (winds, radiative flux, advected heat) atmospheric forcing of minimum sea ice extent (at lags of 0, 10, 25, 50, and 80 days) explain 40-60% of variance. So what drives the rest of variance?

(Francis et al., GRL 2005)

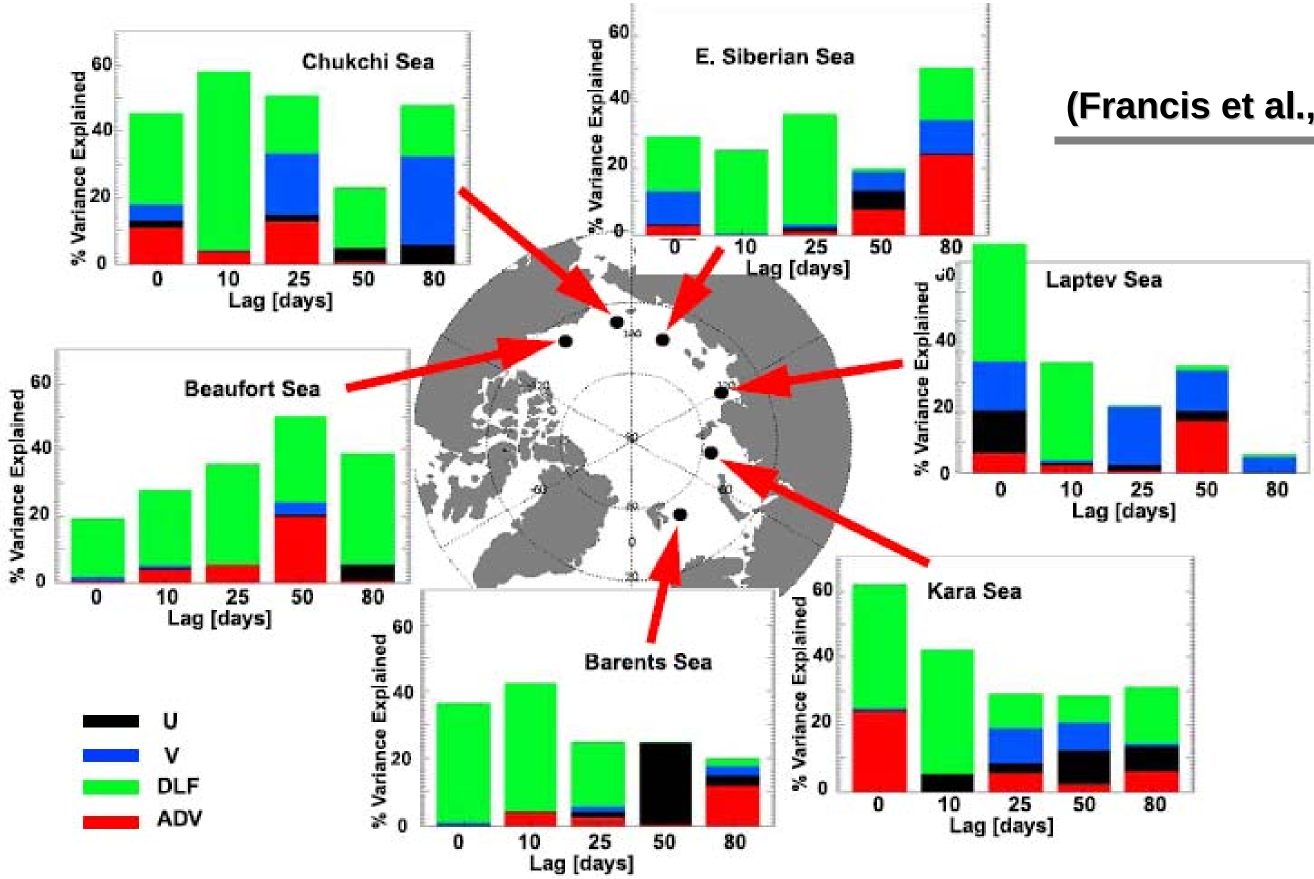


Figure 3. Percentages of variance (y-axis) in anomalies of sea ice maximum retreat explained by anomalies in zonal wind (U, black), meridional wind (V, blue), downwelling longwave flux (DLF, green), and the convergence of advected sensible heat (ADV, red) in each peripheral sea of the Arctic Ocean. The bars represent explained variance at lags of 0, 10, 25, 50, and 80 days, where the ice edge anomaly lags the forcing anomaly. Black dots mark locations in Table 1.

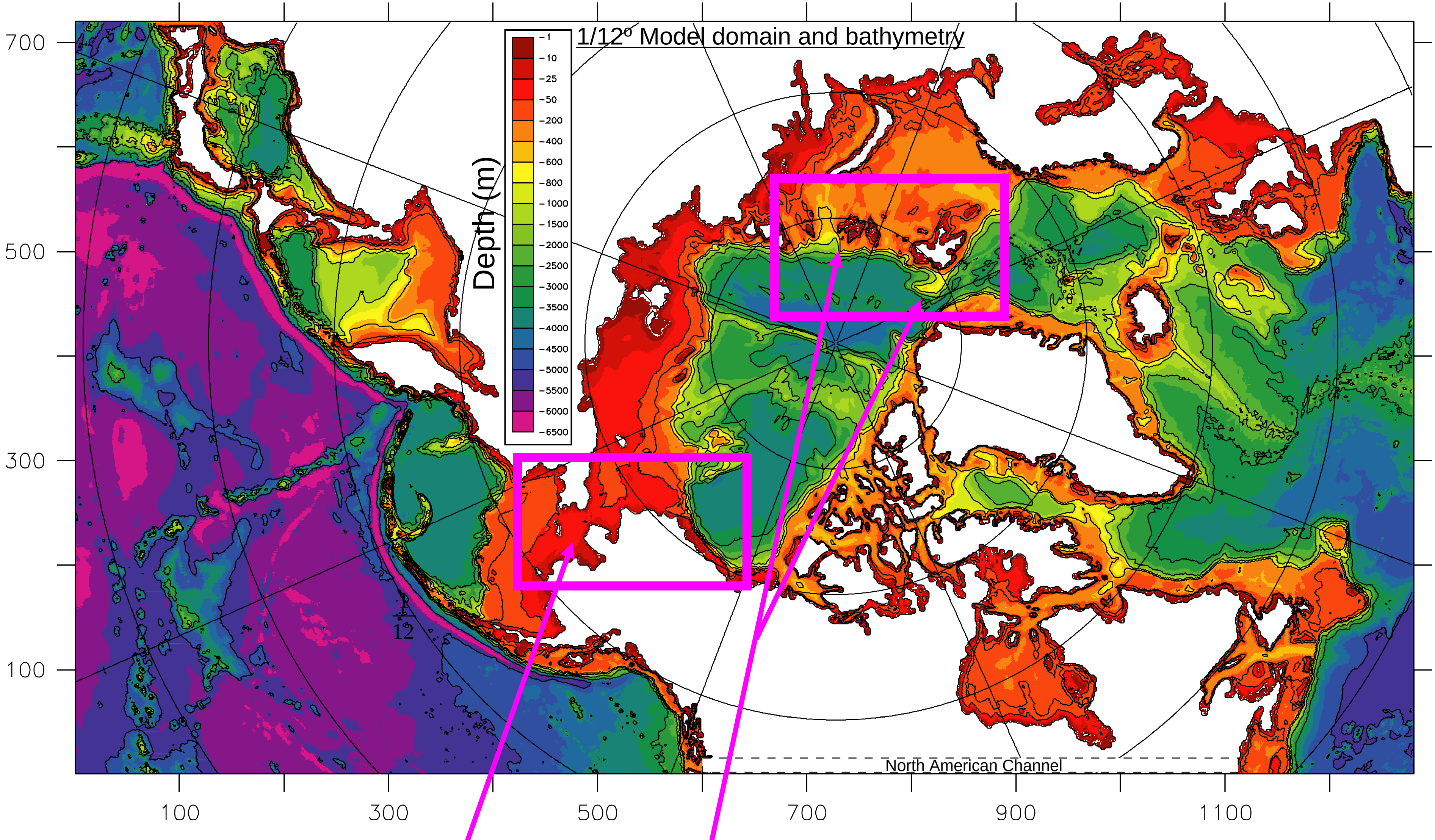
1/12^{o} (9-km) Coupled Ice-Ocean Model

1. **Ocean Model = LANL/POP, Sea Ice Model = ‘Hibler 1979’-type**
2. **New improved bathymetry**
3. **New hydrographic climatology (PHC)**
4. **Freshwater sources from runoff but no P-E fluxes**
5. **Numerical tracers for Pacific Water, Atlantic Water, and river runoff**
6. **Completed integrations:**
   - 48-year spinup with ECMWF reanalysis
   - ensemble of four 1979-2004 integrations using realistic ECMWF fields with variable surface T&S restoring (to account for P-E buoyancy flux)

7. More information at: www.oc.nps.navy.mil/NAME/name.html

Computer resources:

Arctic Region Supercomputing Center

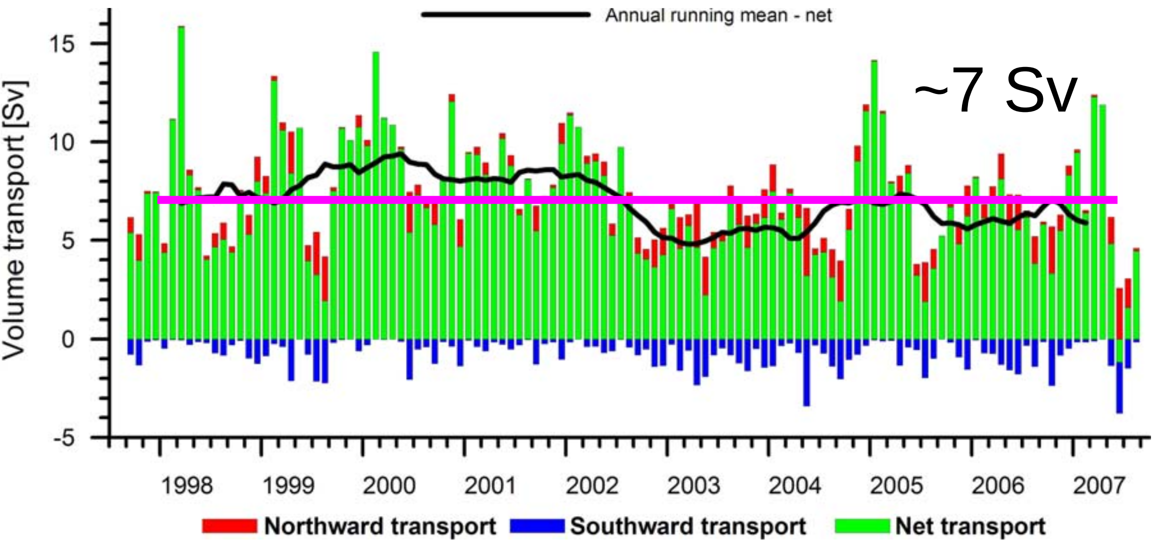


Gateways/Margins of Pacific Water and Atlantic Water Inflow into the Arctic Ocean

Main uncertainties of importance to global climate

1. Northward heat transport from the N. Atlantic/Pacific to Arctic Ocean *
2. Arctic sea ice thickness and volume *
3. Freshwater export from the Arctic to North Atlantic

'AWI' VOLUME TRANSPORT IN WSC

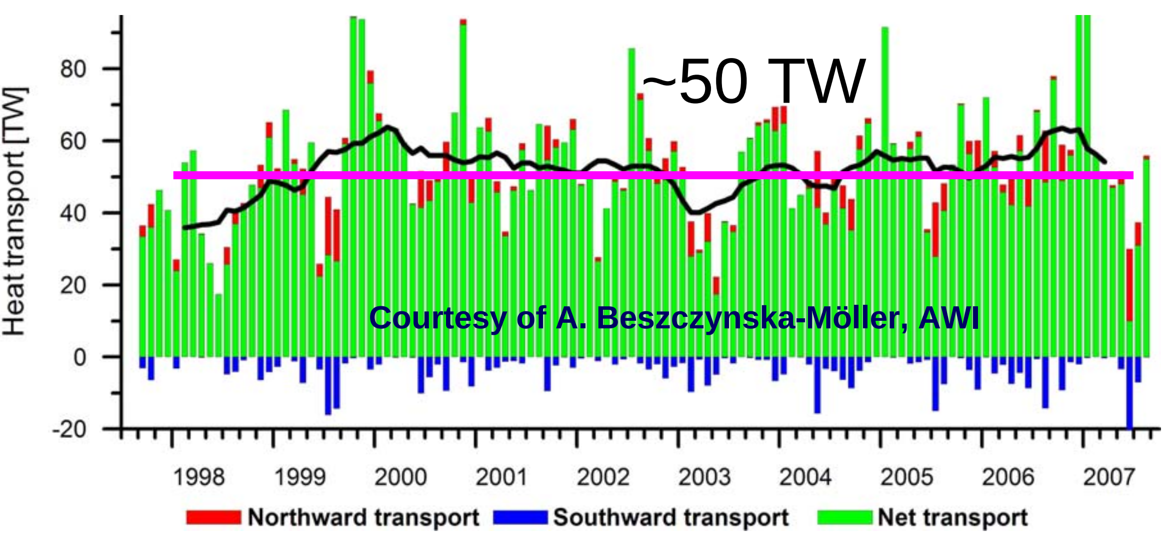


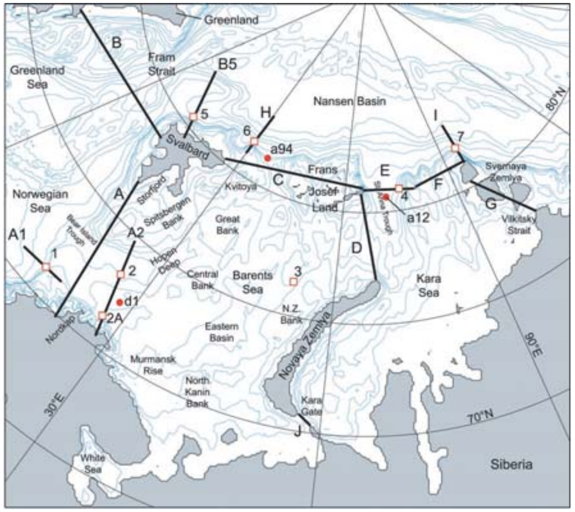
'NPS' VOLUME and HEAT TRANSPORTS (Maslowski et al., JGR, 2004)

	Volume Flux			Heat Flux		
	Net	In	Out	Net	In	Out
Fram Strait	-2.34	6.4	-8.73	10	47	-37
BSO	3.27	5.07	-1.8	78.4	106	-27.6
FJL-NZ	2.56	3.16	-0.6	2.15	2.58	-0.43

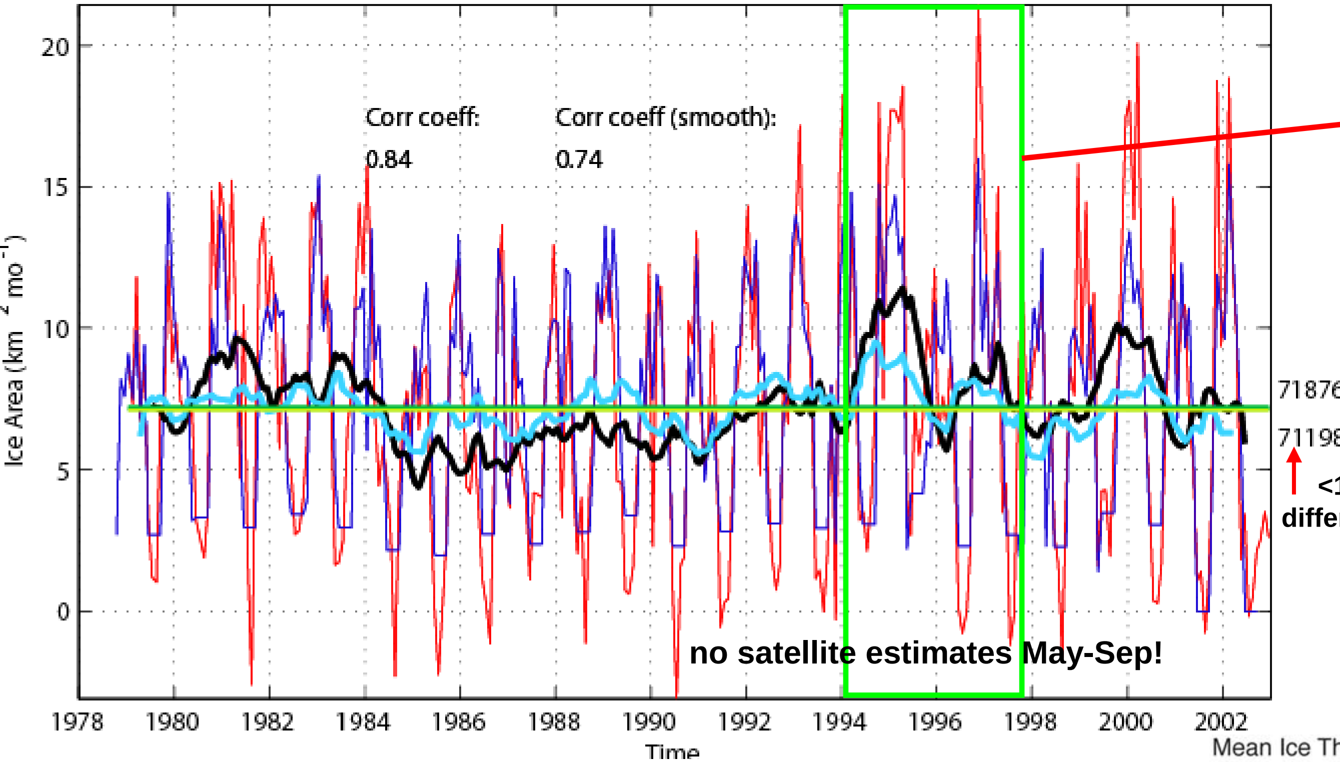
(Tref=-0.1C)

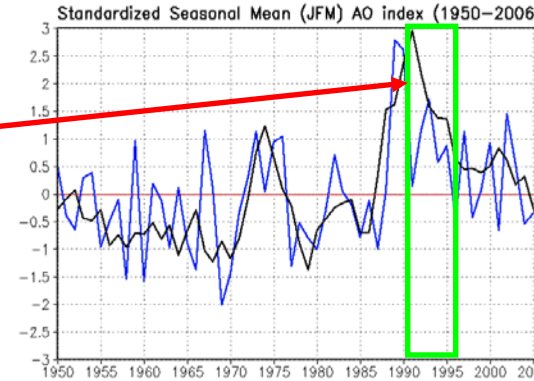
"AWI TEMPERATURE TRANSPORT" IN WSC





Comparison of area fluxes through Fram Strait (wind-driven)

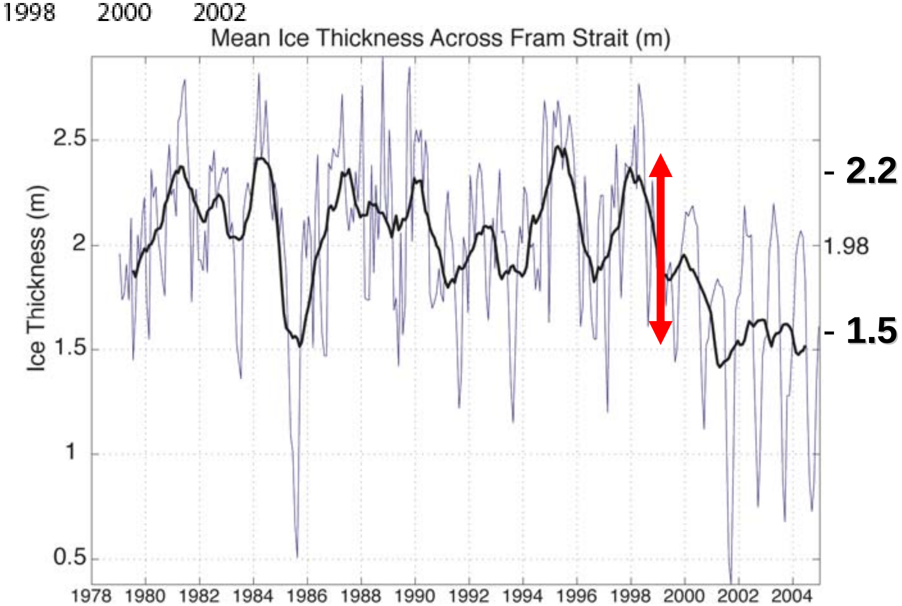




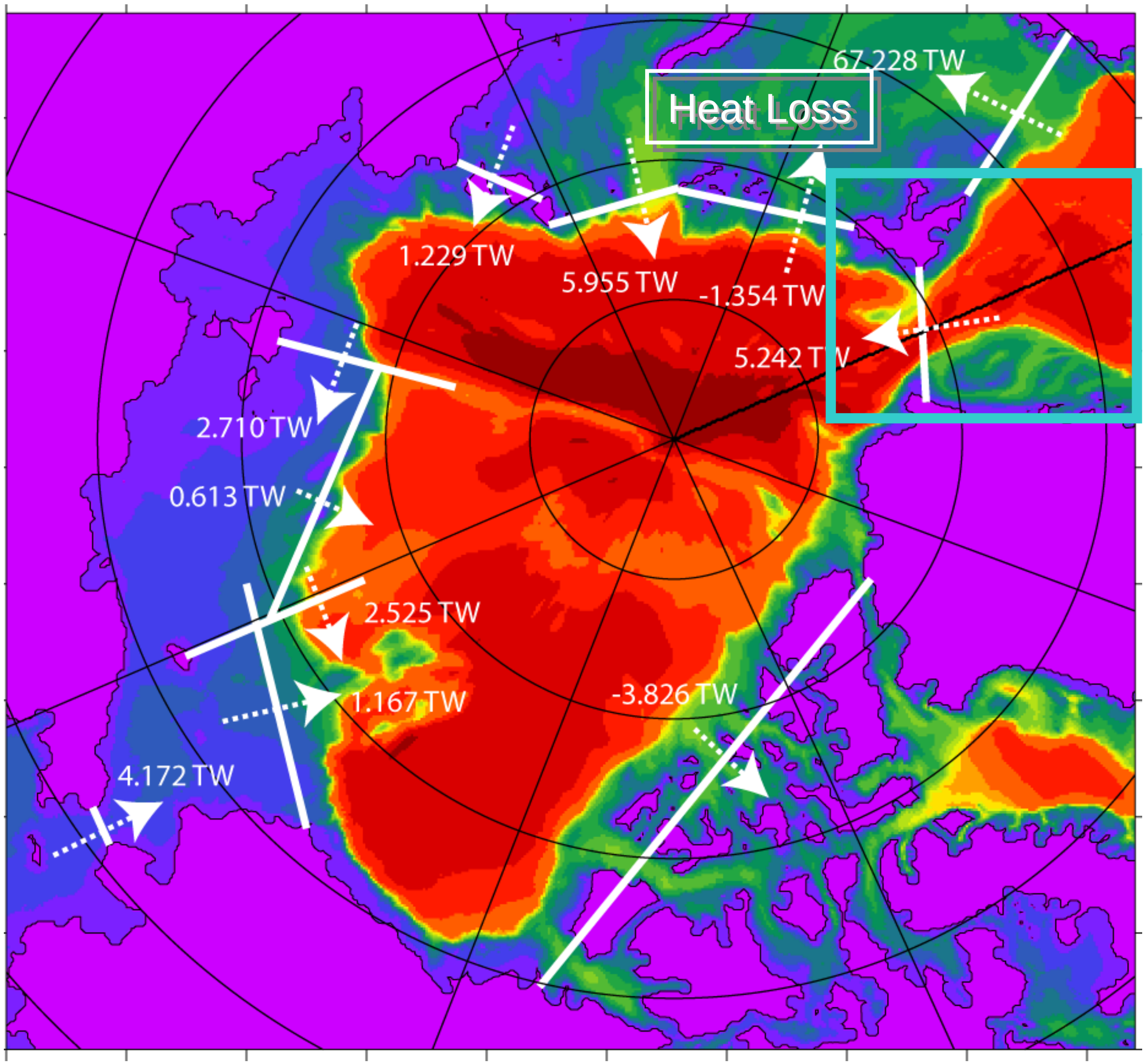
Mean area flux [km²/mo]
Estimates from:
- satellite (Kwok et al., 2003 blue/cyan/yellow)
- model (red/black/green)

High export of thick sea ice from the Artic Ocean in the mid-1990s:

- **mean thickness of sea ice across Fram Strait decreased by ~70 cm (or ~1/3)**
- **less multi-year ice in the Arctic Ocean**
- **warming more pronounced on thinner ice**
- **thinner ice less stable to perturbations**



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



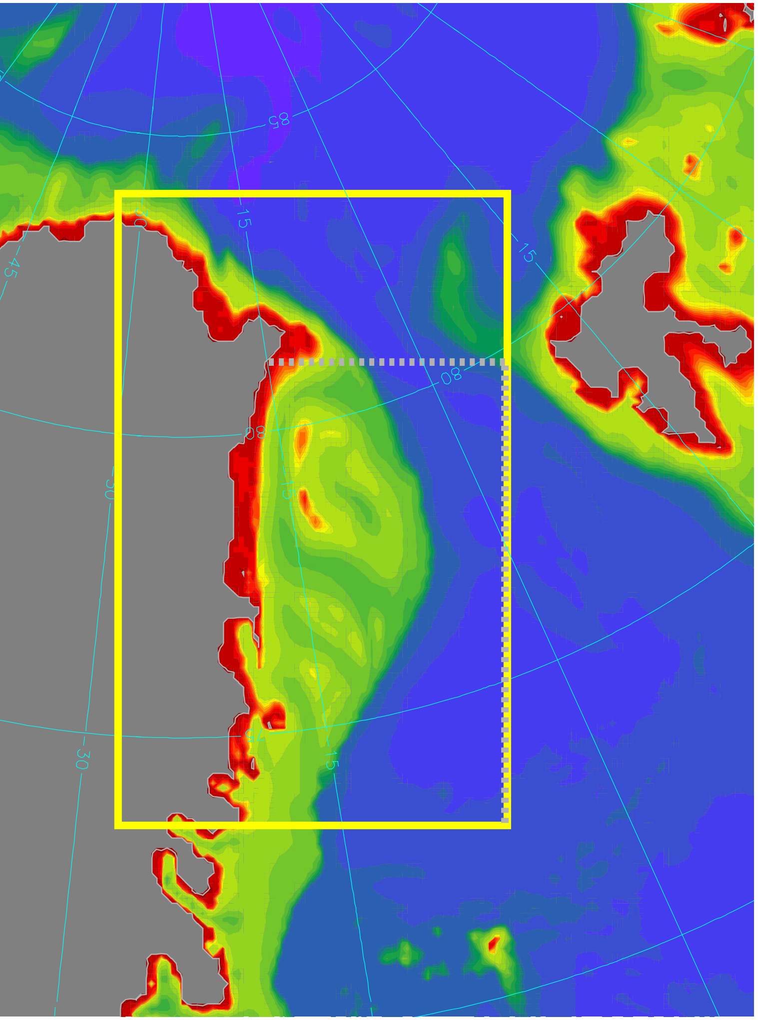
Modeling Challenges: Inflow of Pacific / Atlantic Water into the Arctic Ocean

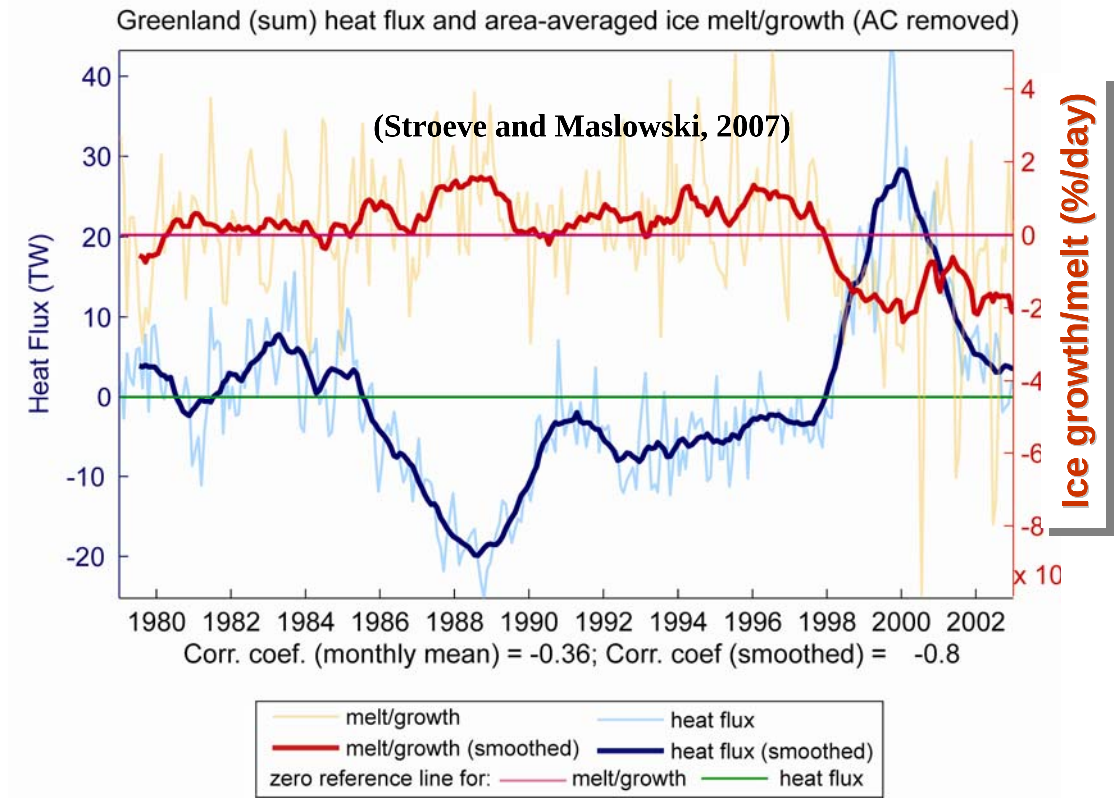
- Pacific Water entering via narrow (~60mi) Bering Strait
- outflow through Fram Strait vs. Atlantic Water inflow (FSBW)
- Atlantic (BSBW) and Pacific Water each losses majority of heat to the atmosphere before entering Arctic Basin

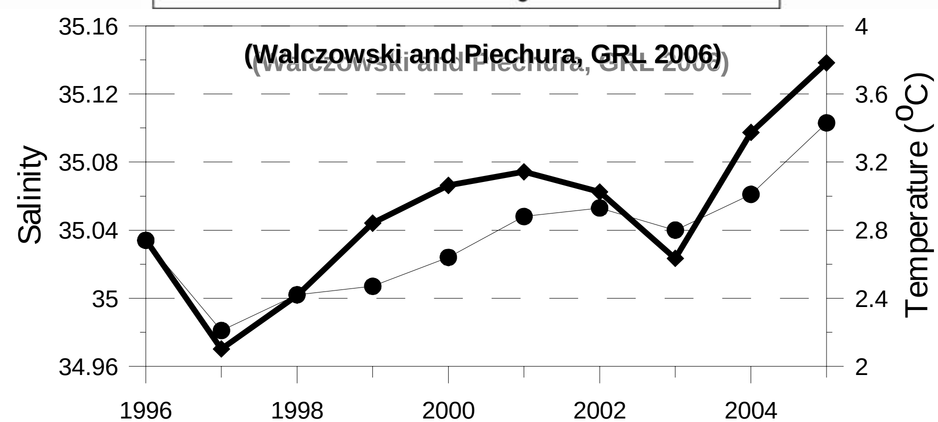
Arctic ocean-ice-atm feedbacks – not fully represented in climate models

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

Heat flux onto the Greenland shelf versus mean ice melt anomalies over the shelf



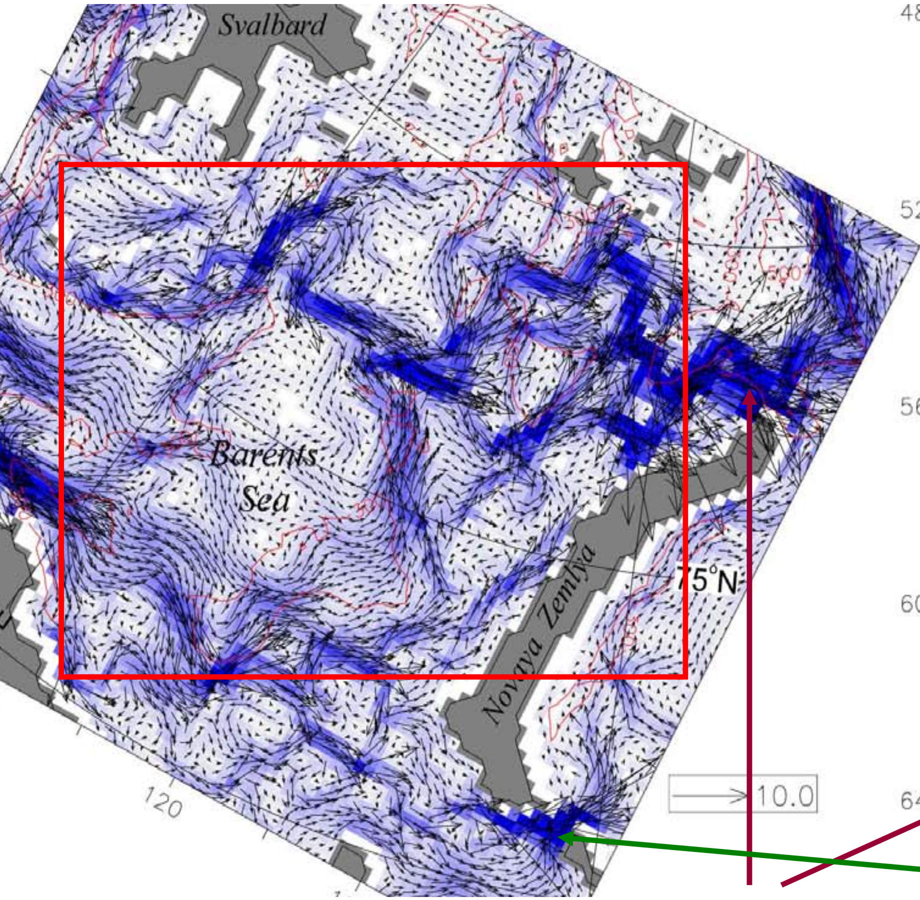




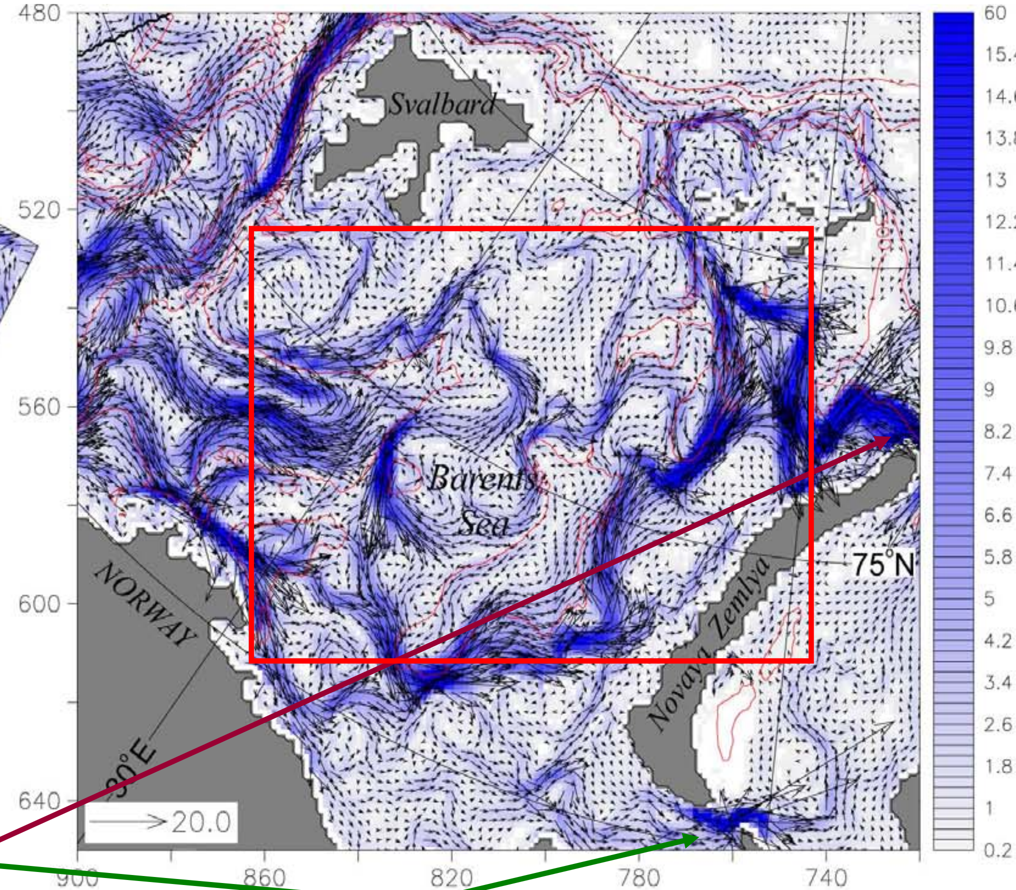
Correlation coefficient (thick lines) is -0.80, i.e. ~64% of Greenland ice extent variability can be explained by oceanic heat advection onto the shelf

BATHYMETRY/RESOLUTION IMPACTS

18-km Model
0-225 m (levels 1-7), every vector

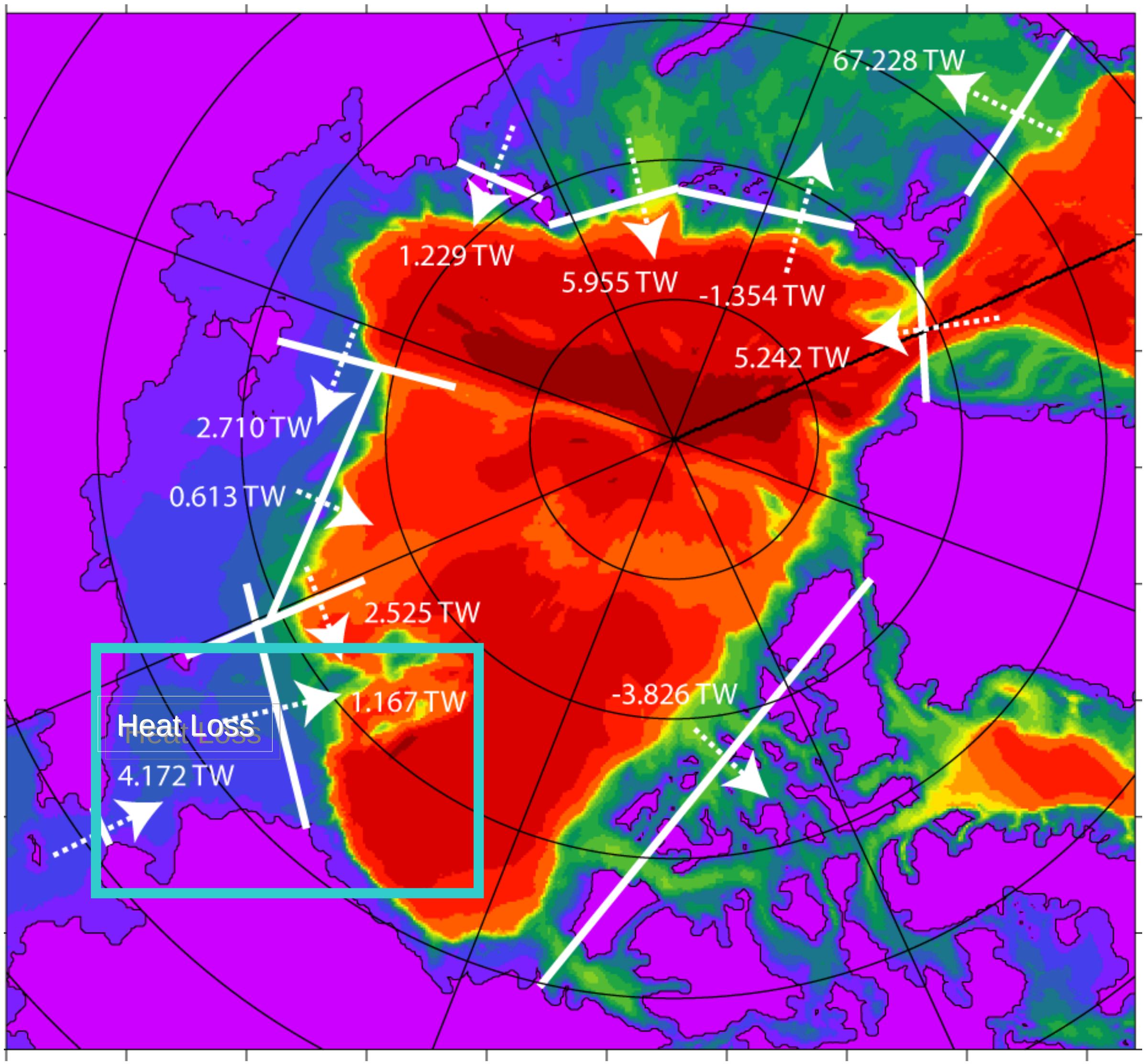


9-km Model
0-223 m (levels 1-15), every 2nd vector



- Barents Sea outflows (north of Novaya Zemlya and through Kara Gate) look similar but:
- Mean paths significantly different due to representation of bathymetry (I.e. resolution)
- Velocity magnitudes differences
- 9-km model circulation shown to match observed well (Maslowski et al., 2004)
- Implications for location of fronts, water mass transformations, heat and salt balances

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



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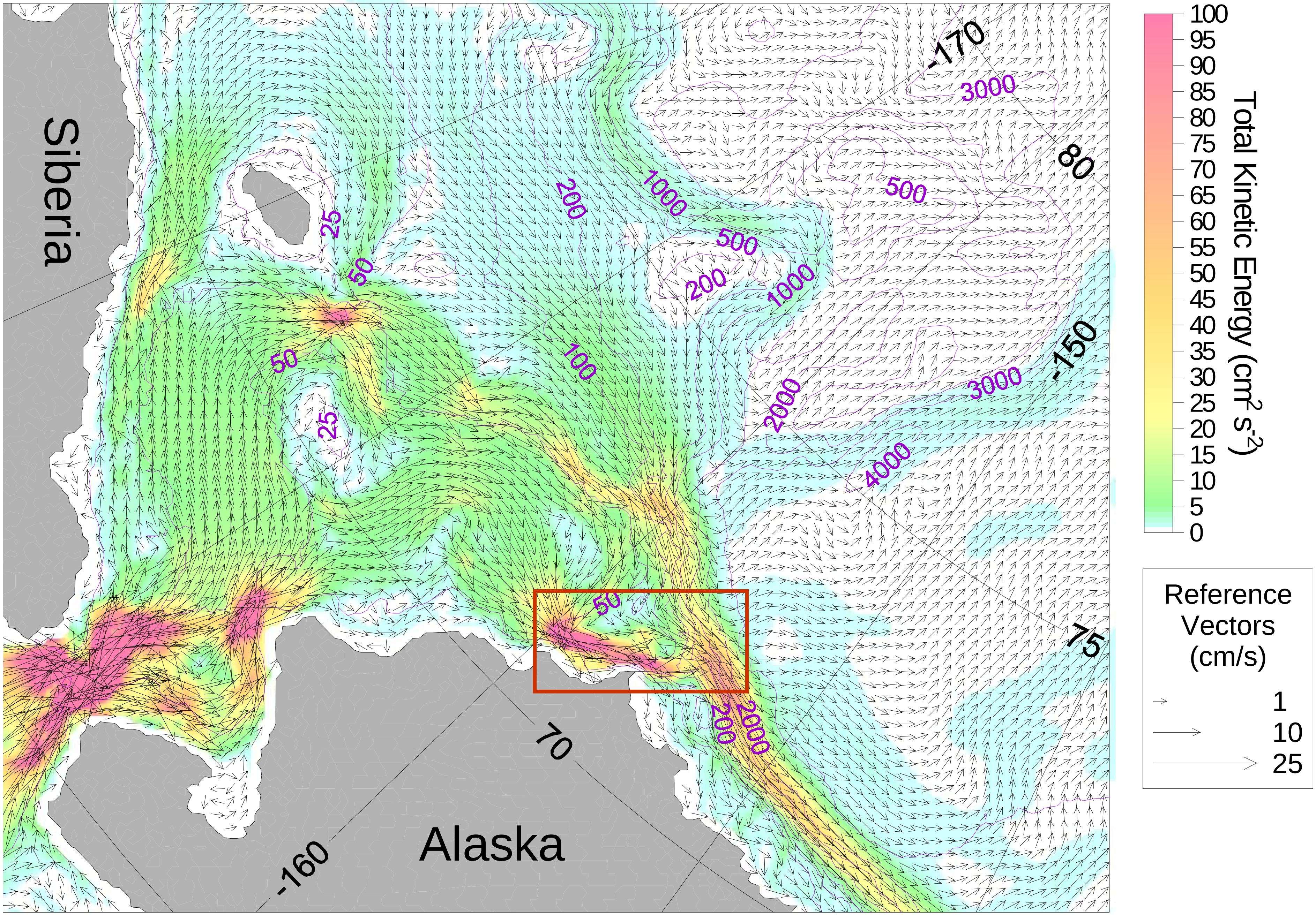
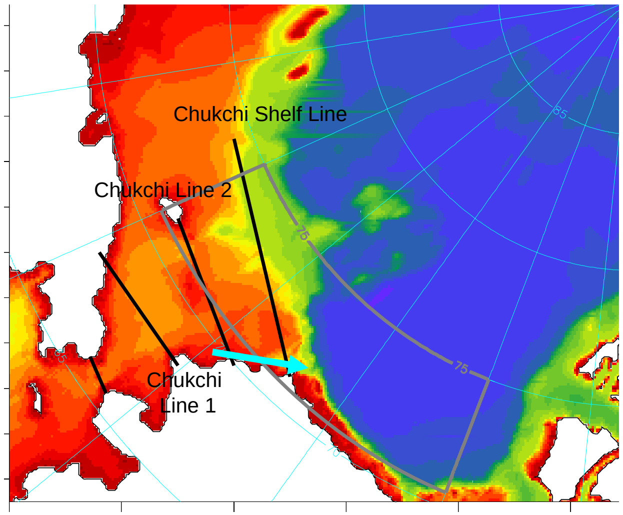
Arctic ocean-ice-atm feedbacks – not fully represented in climate models

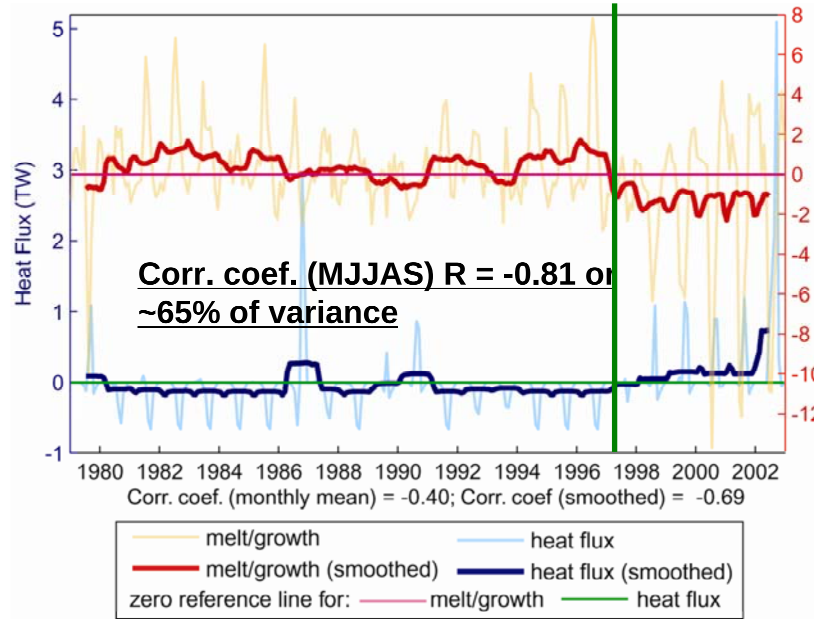
High resolution is one of the top requirements for advanced modeling of Arctic climate

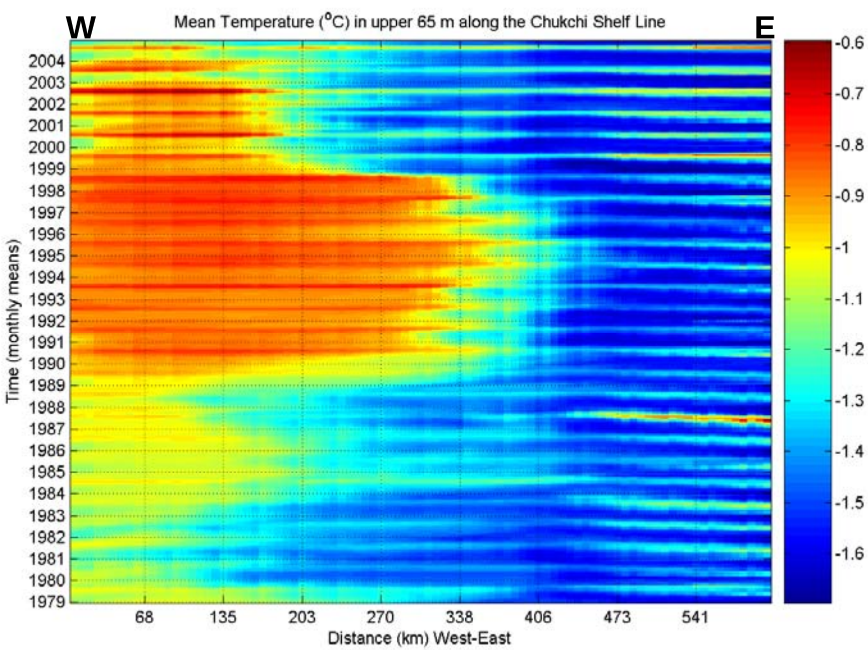
23-yr mean (1979-2001) 0-50 m mean velocity & TKE

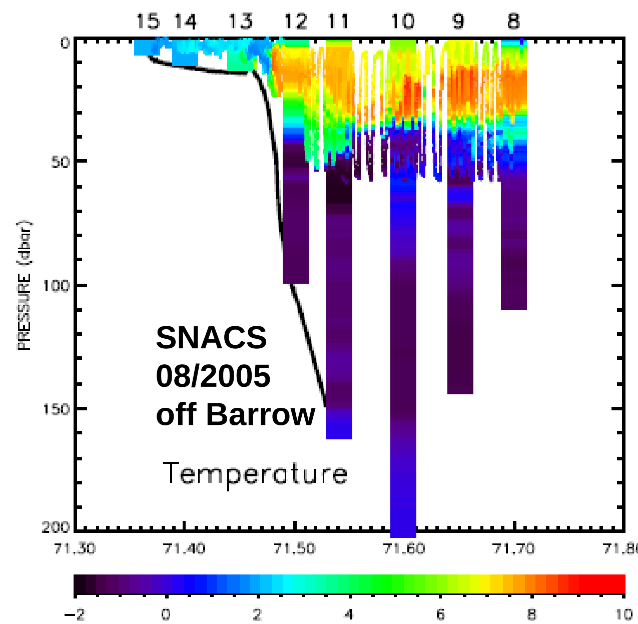


Increased northward heat flux off the Chukchi Shelf coincides with the sea ice retreat in the late 1990s and 2000s

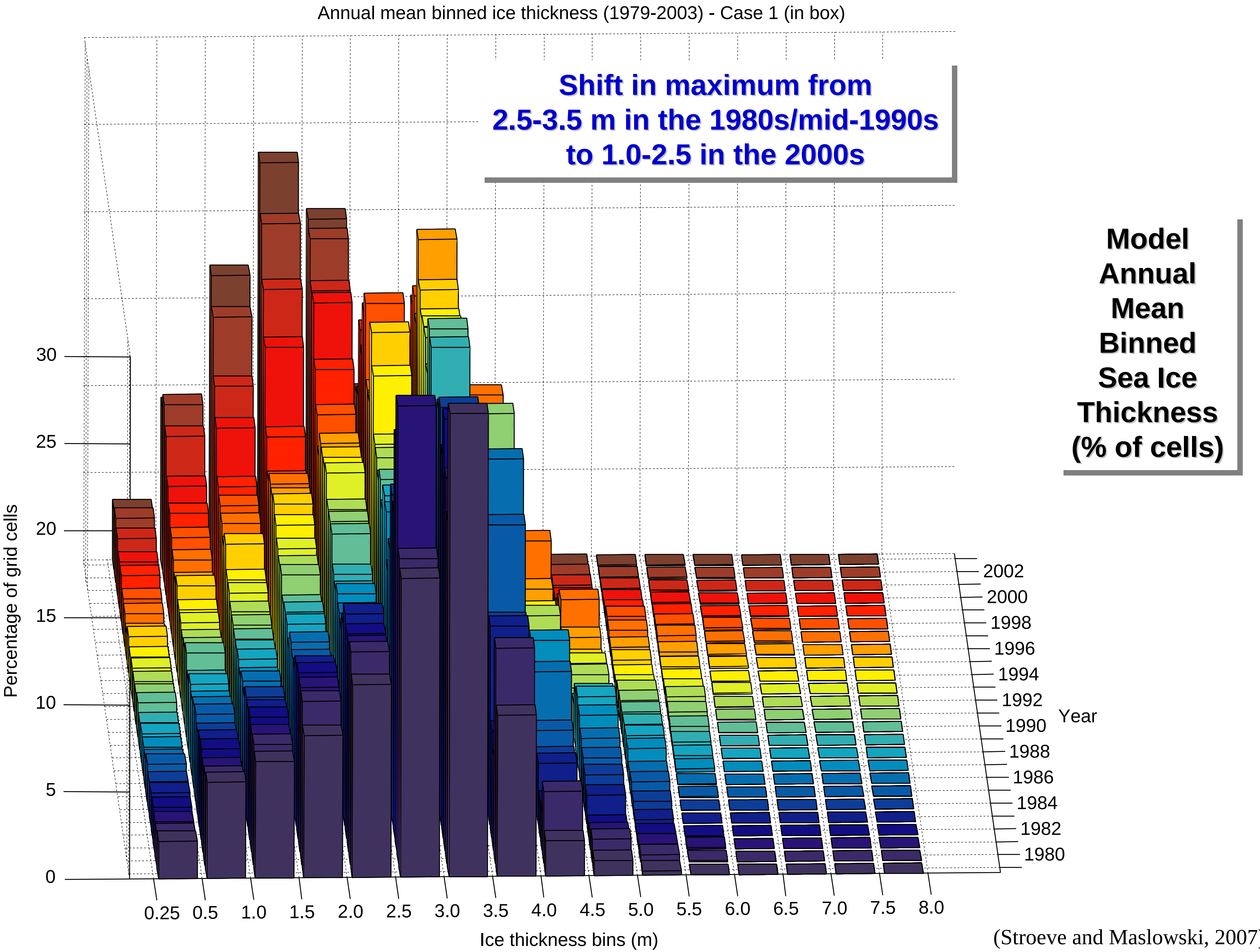






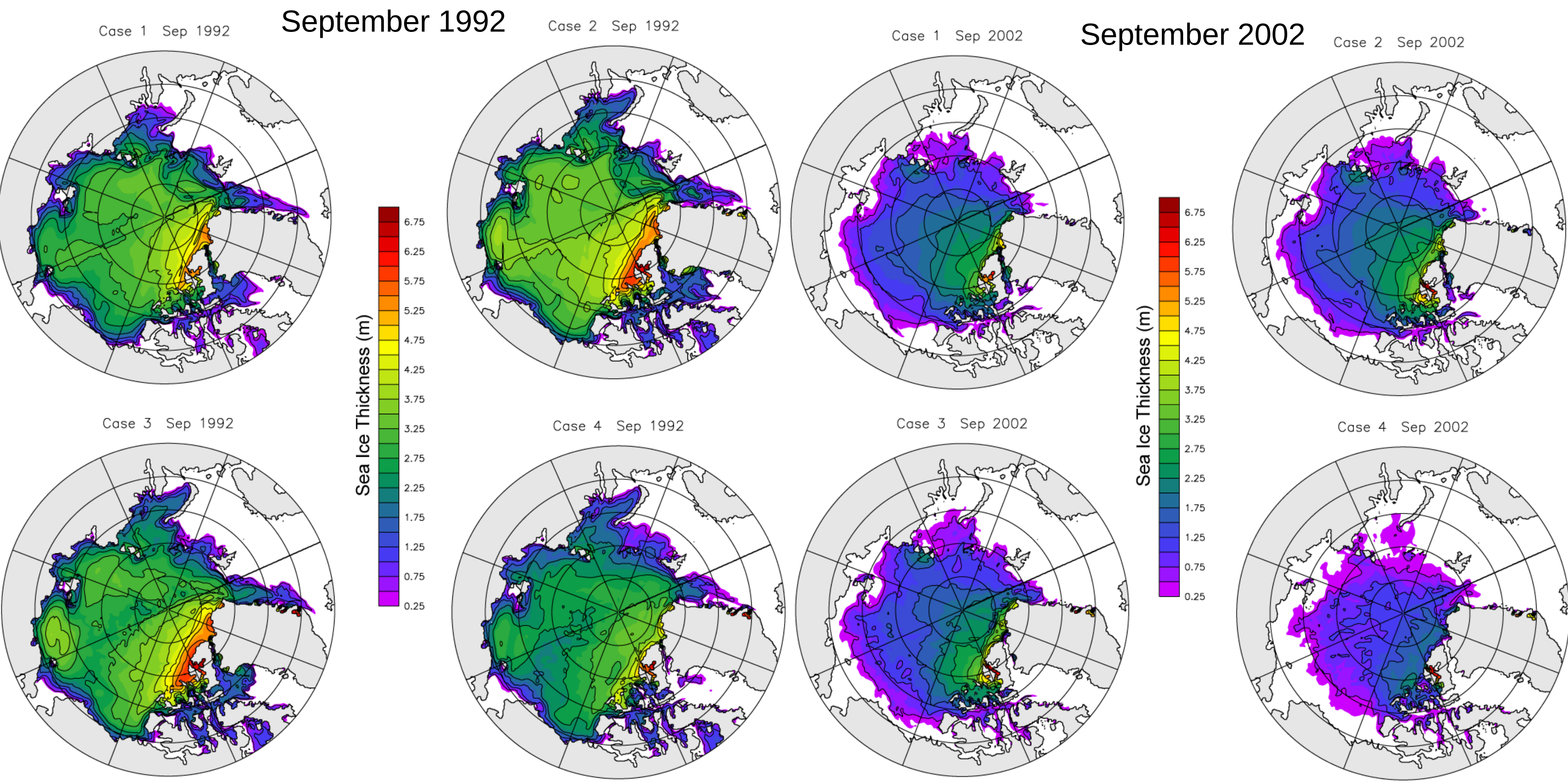


Heat Flux via Alaska Coastal Current accounts for ~67% of the Total Heat Flux across Chukchi Shelf Line



(Stroeve and Maslowski, 2007)

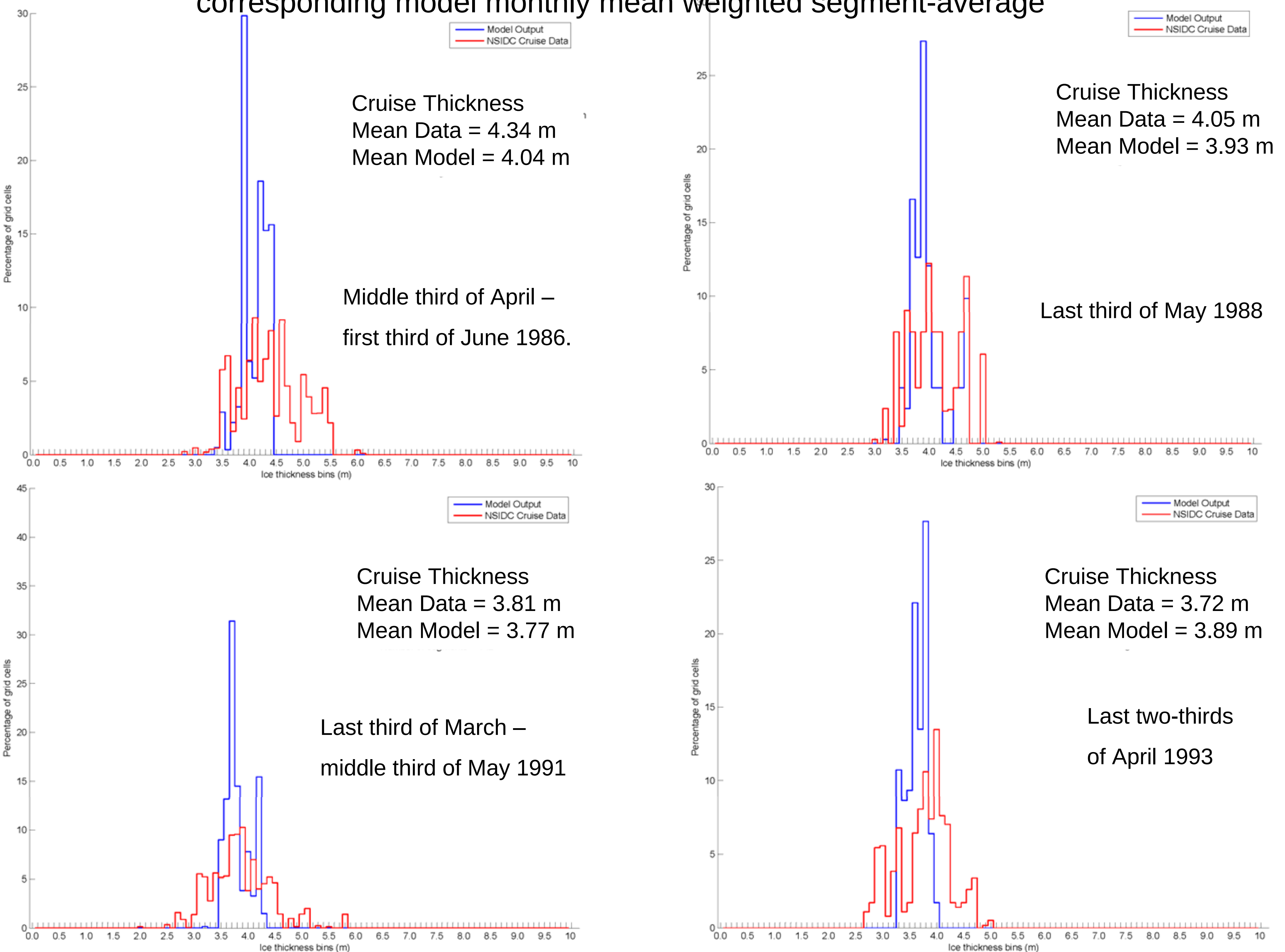
Modeled Arctic ensemble sea ice thickness distribution in September 2002



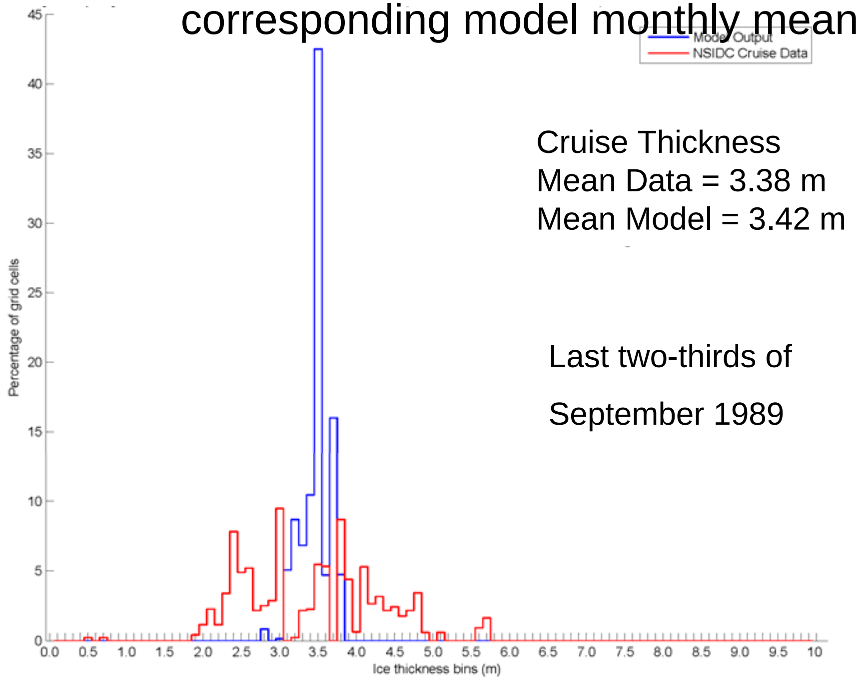
Sea ice thickness reduction in the range of 1.0-1.5 m in a decade between 1990s and 2000s

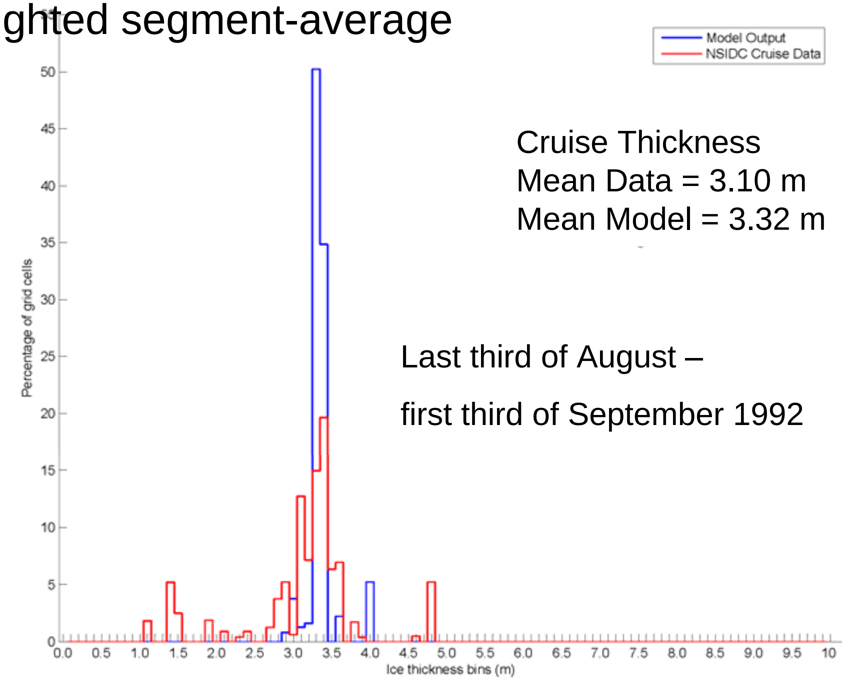
(Maslowski et al., 2007)

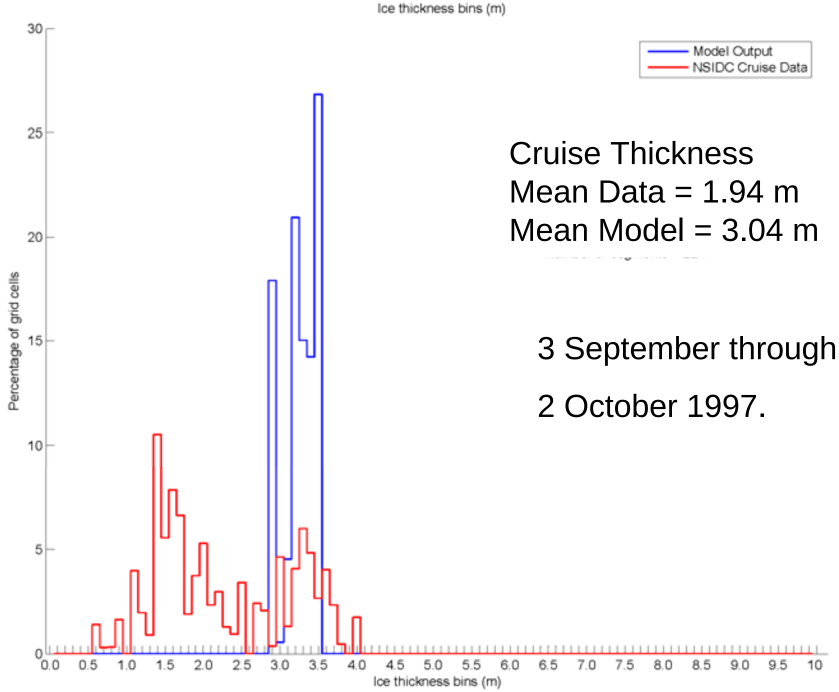
Winter PDFs of cruise segment-weighted average ice thickness and corresponding model monthly mean weighted segment-average

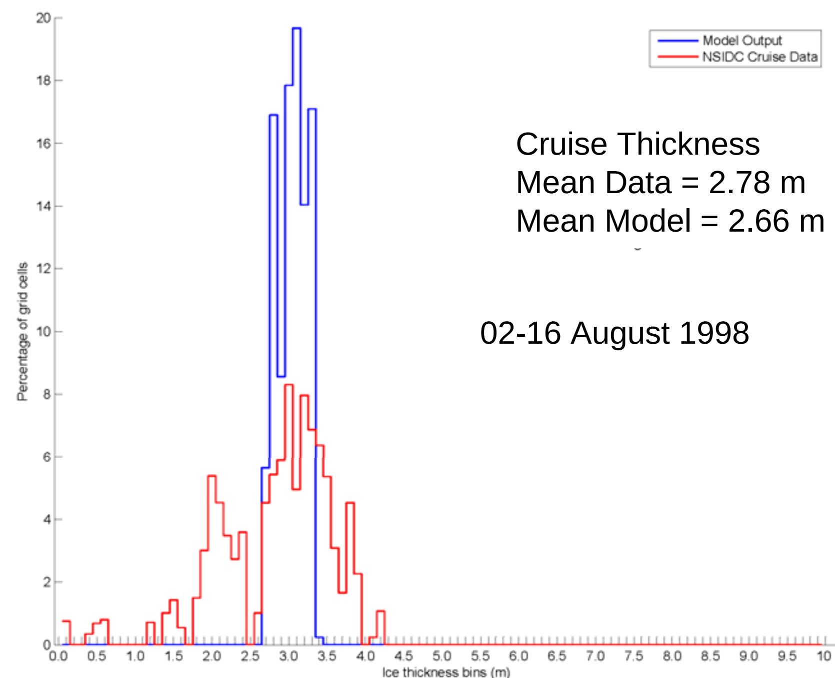


Summer PDFs of cruise segment-weighted average ice thickness and corresponding model monthly mean weighted segment-average

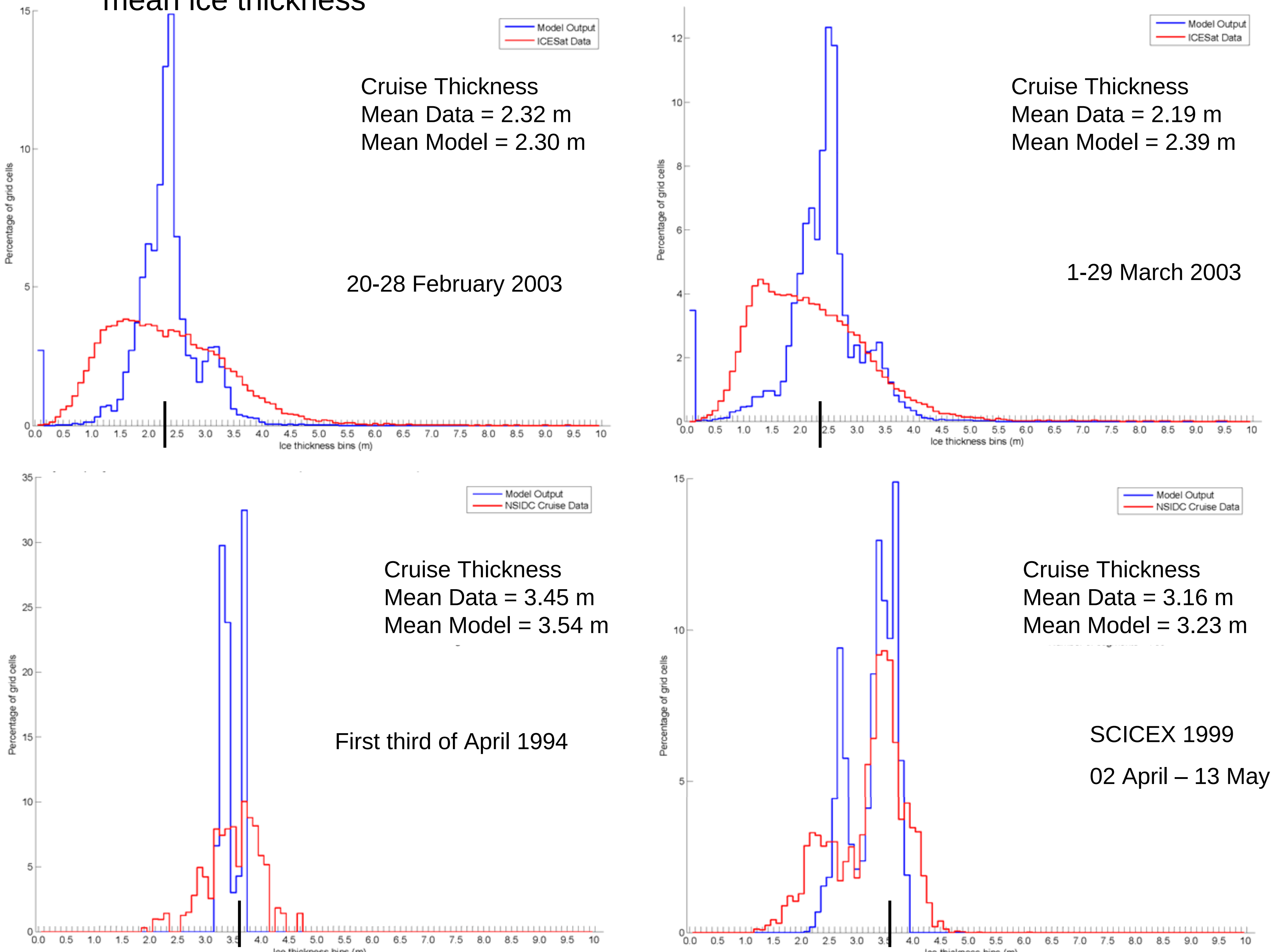




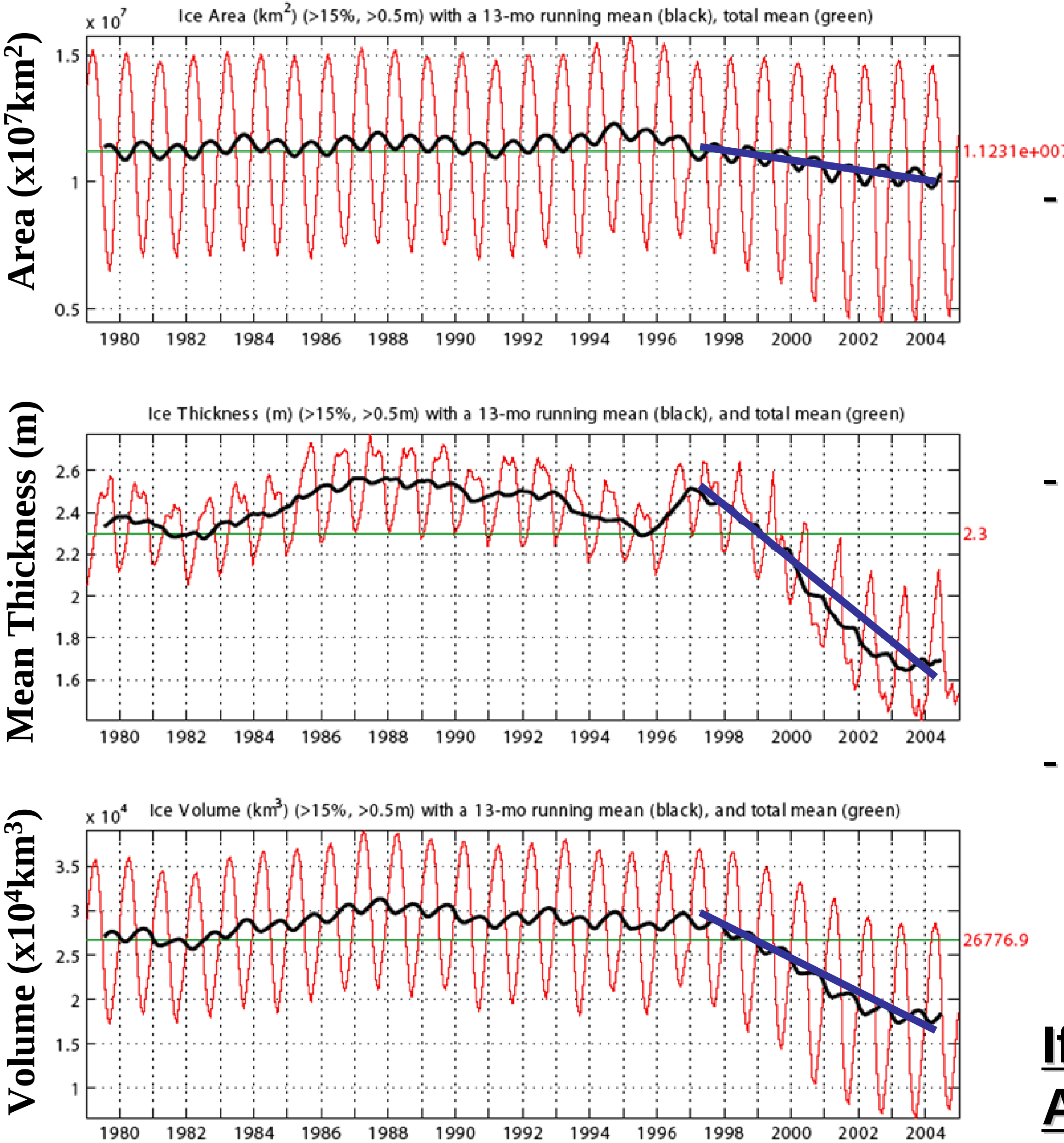




PDFs of ice thickness estimated from ICESat (top) / submarines (bottom) and model monthly mean ice thickness



79-04 time series of Ice Volume, Area, Mean Thickness

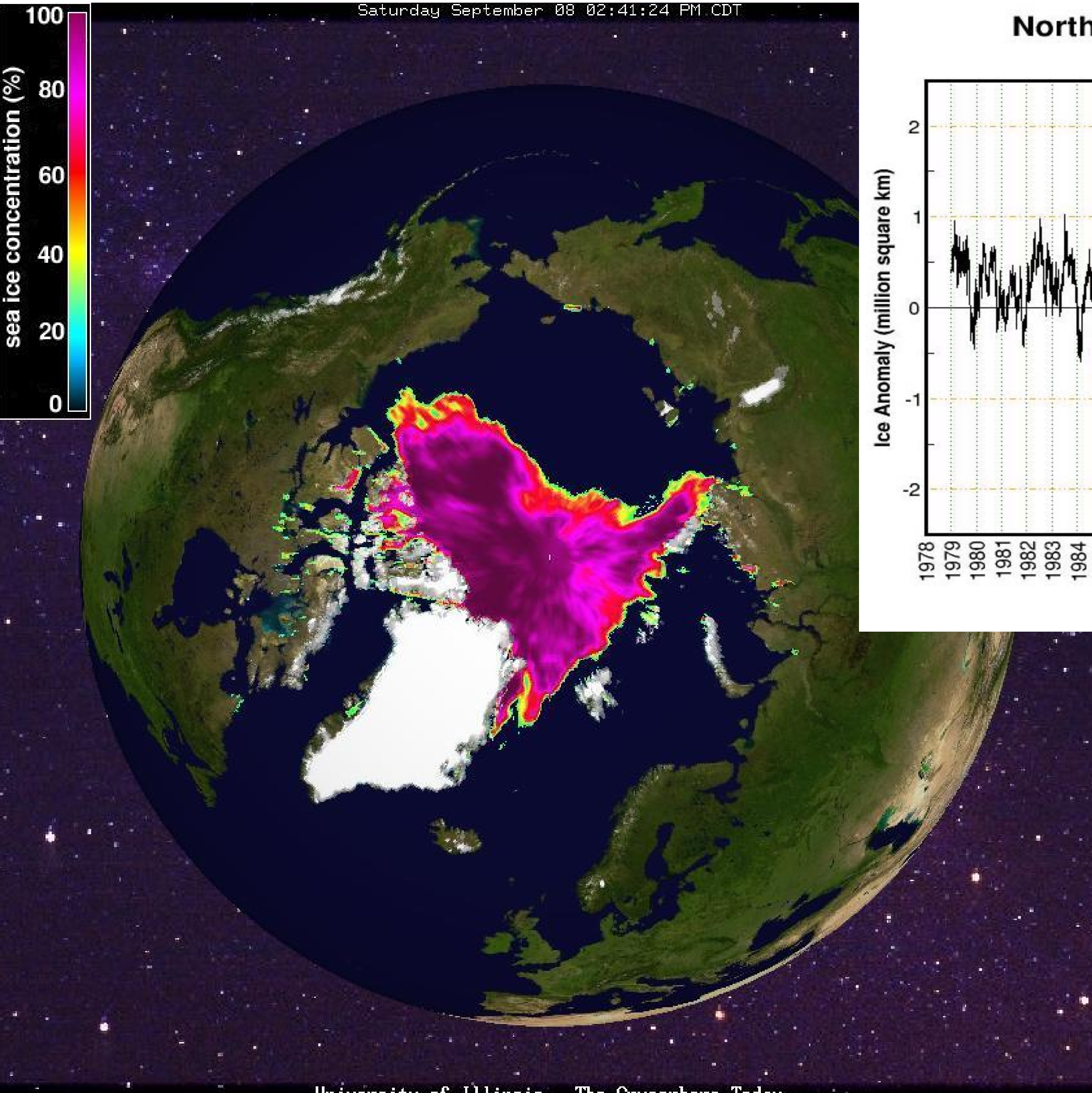


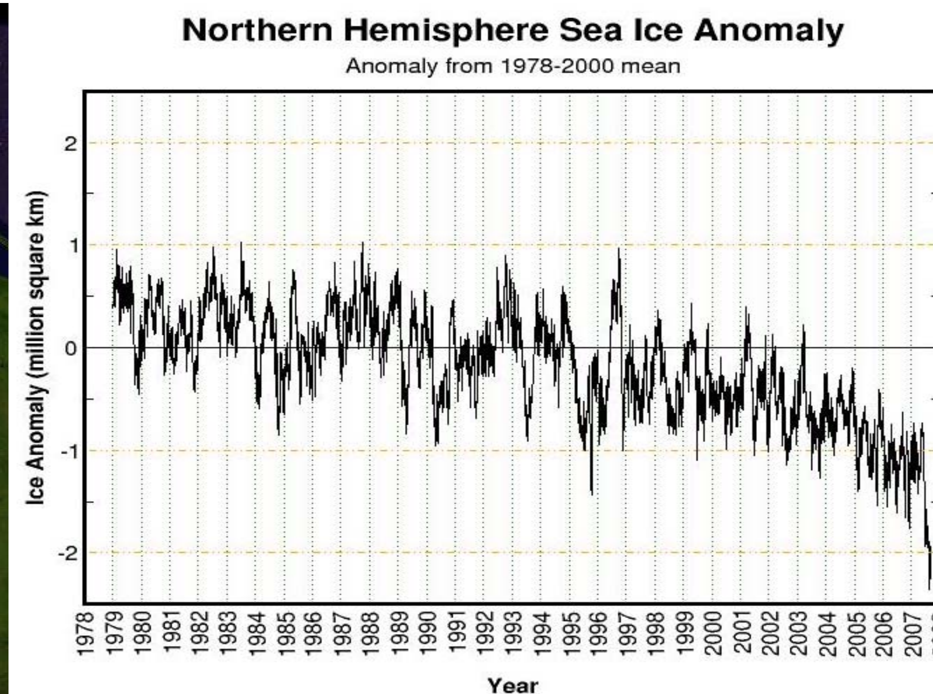
Between 1997-2004:

- **annual mean sea ice concentration has decreased by ~17%**
- **mean ice thickness has decreased by ~0.9 m or ~36%**
- **ice volume decreased by 40%, which is ~2.5x the rate of ice area decrease**

<u>If this trend persists the Arctic Ocean will become ice-free by ~2013!</u>

Sea Ice Concentration – Sep 8 2007





New historic concentration minimum of 3.98 Mln km^2 reached on Aug 9, 2007, 1 month ahead of the 2005 minimum of 4.01 Mln km^2.

It reached:

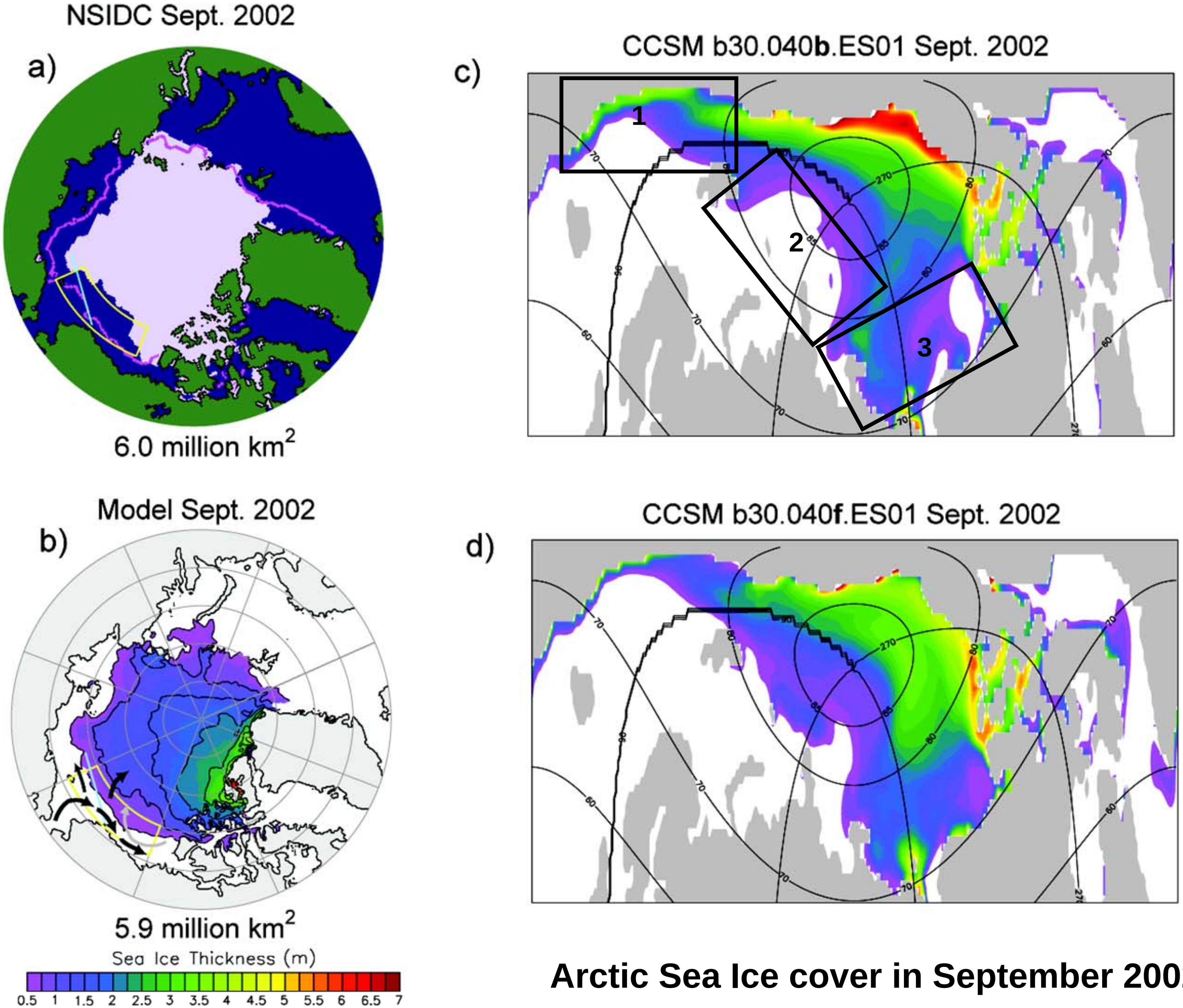
- **2.99 Mln km^2 Aug 28 ’07**
- 3.06 Mln km^2 Sep 6 ’07

Conclusions #1

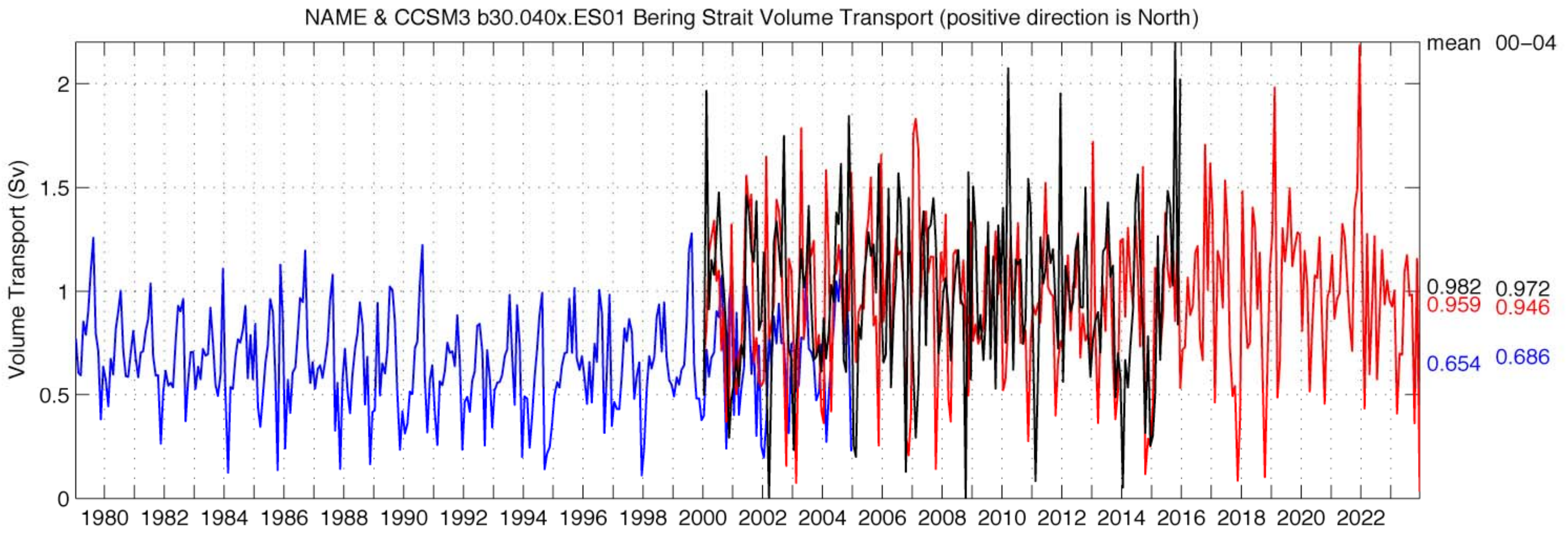
1. Decrease of sea ice thickness and volume possibly greater than sea ice extent – but observations are needed for verification
2. Anomalous export of sea ice through Fram Strait during the mid-1990s a precursor of sea ice decline
3. Oceanic heat advection has contributed significant forcing (>60%) to sea ice melt during the last decade (1997-2006)

   … which helps explain the lack of correlation with AO/NAO/PDO
4. Decline of sea ice cover and increased SSTs must affect the Arctic atmosphere and possibly Greenland Ice Sheet reduction

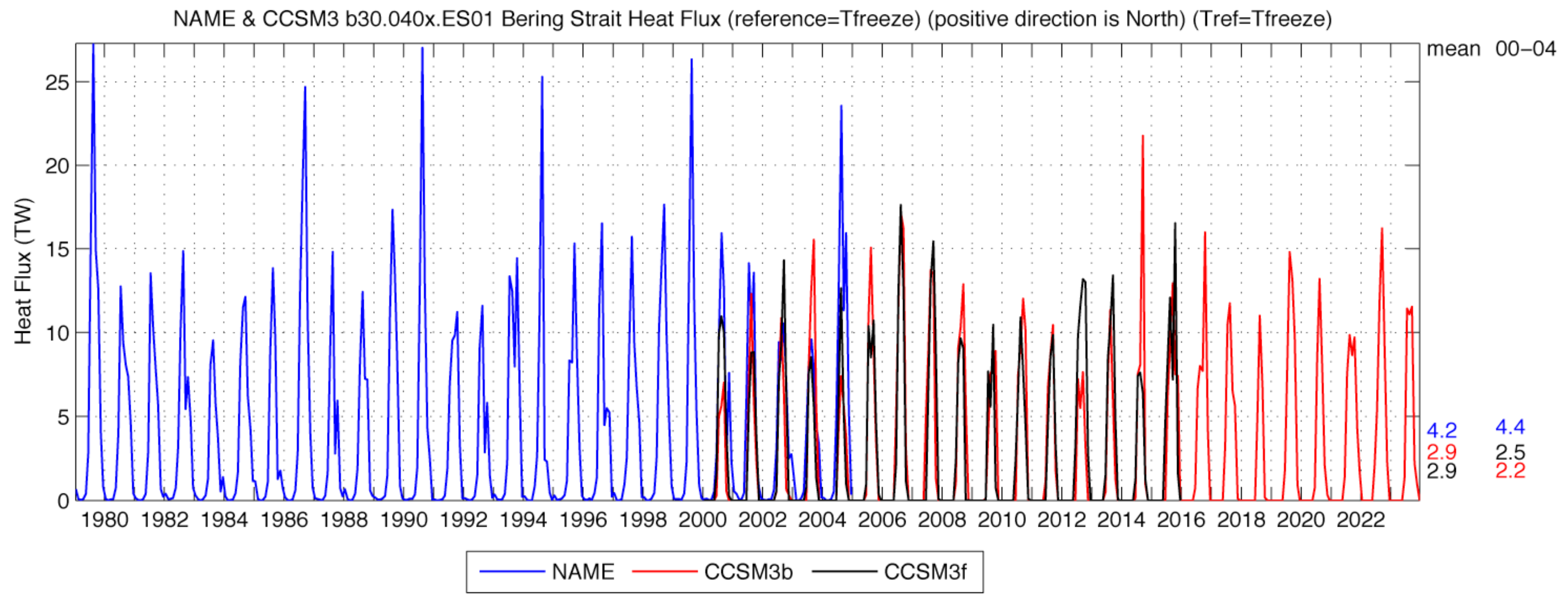
   … but those feedback processes have not been so far fully accounted in climate models
5. A regional <u>high-resolution</u> Arctic Climate System Model can address these deficiencies and improve predictive skill of climate models.
6. <u>Dedicated</u> computer resources are needed and critical to advance the science of Arctic climate change

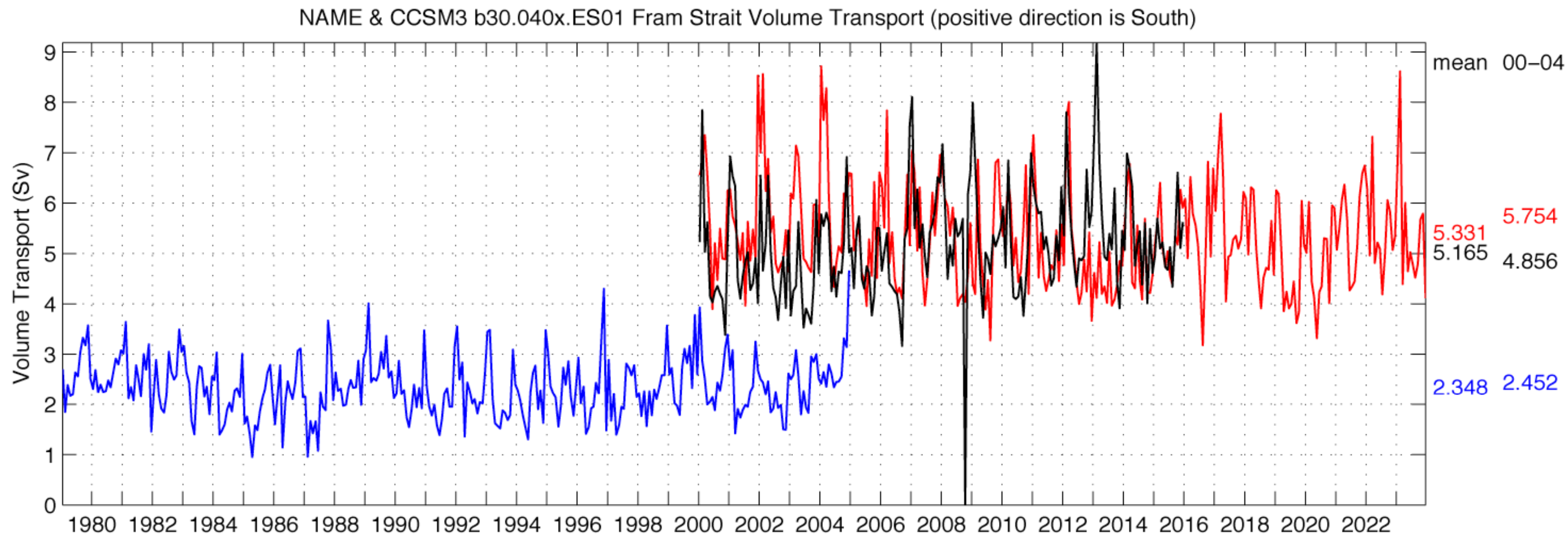


Arctic Sea Ice cover in September 2002



Net Bering Strait Fluxes: CCSM (case b&f) and NPS model





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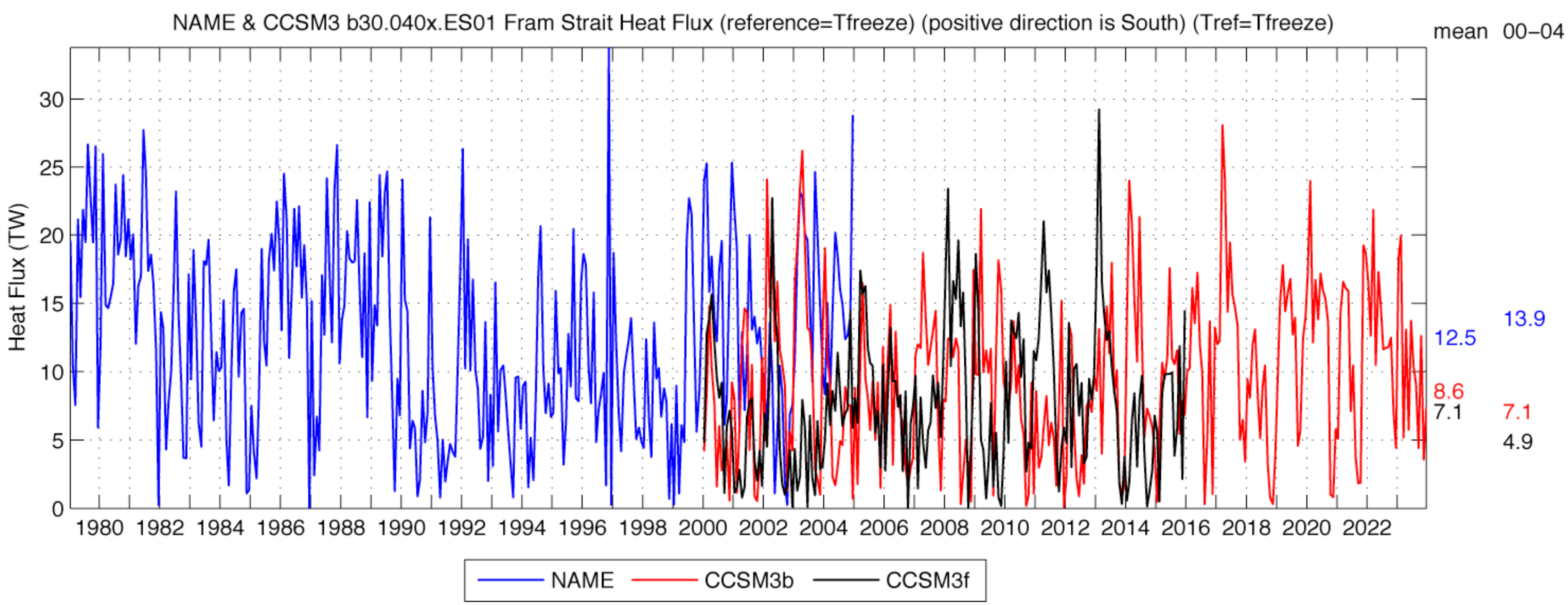
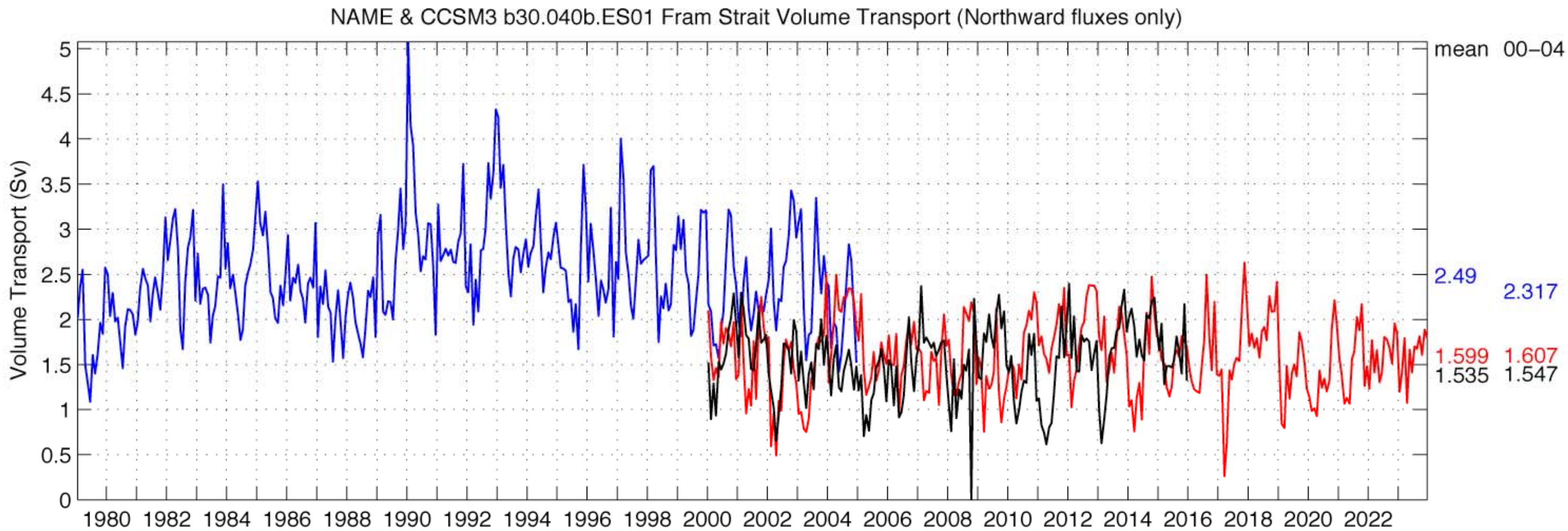
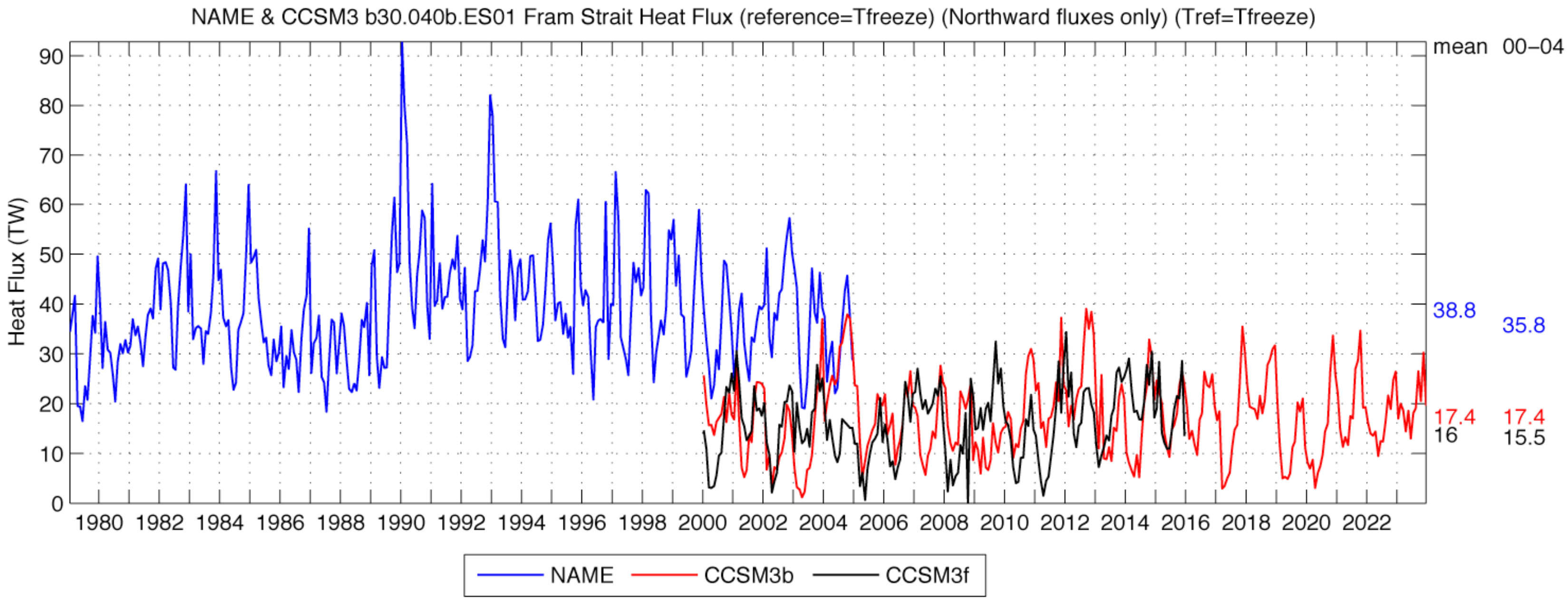
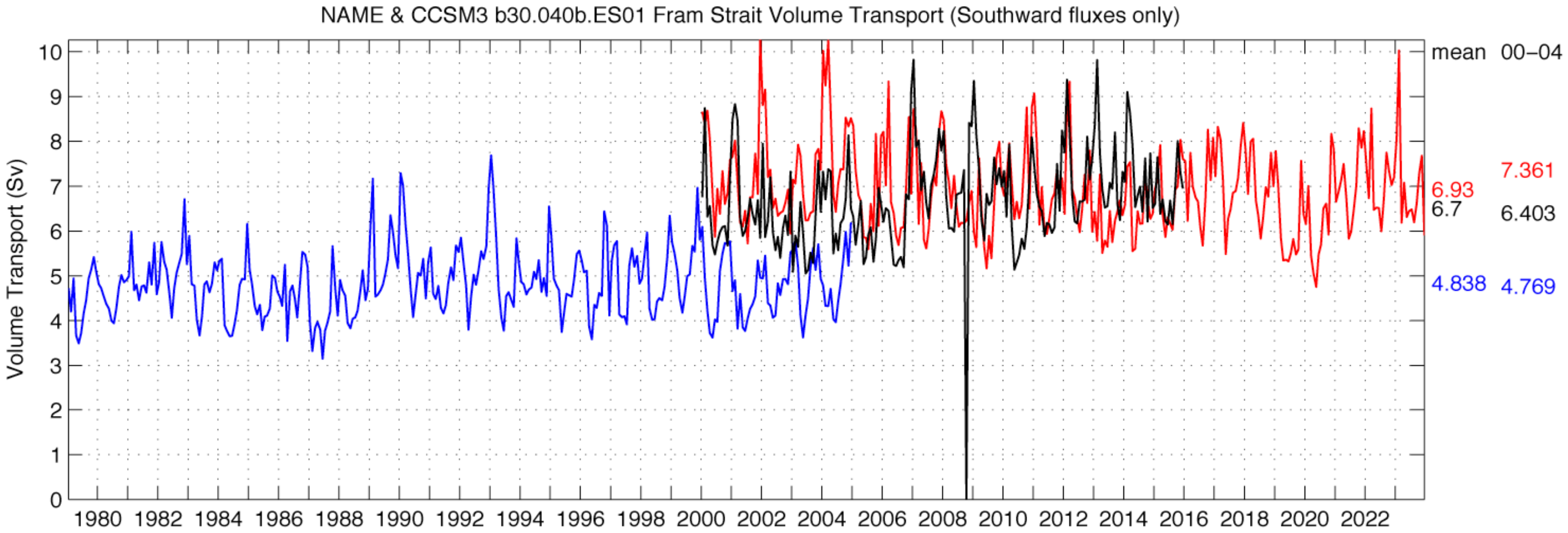


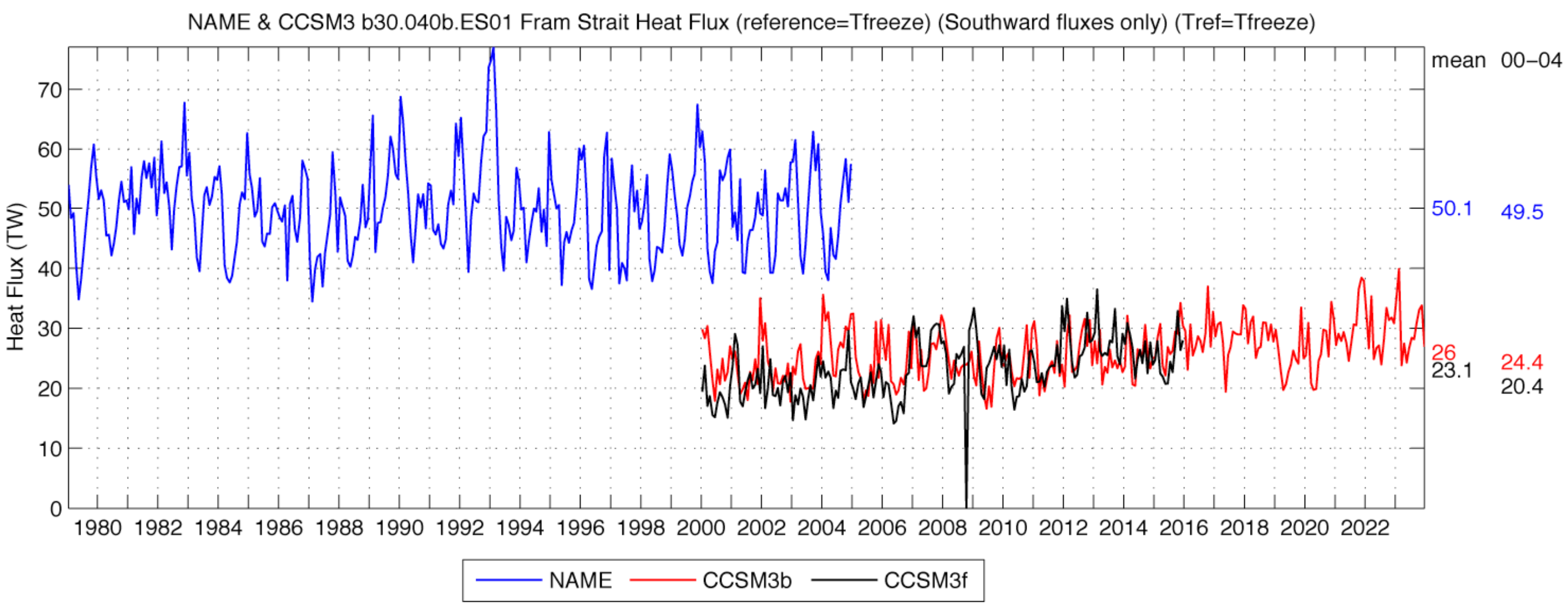


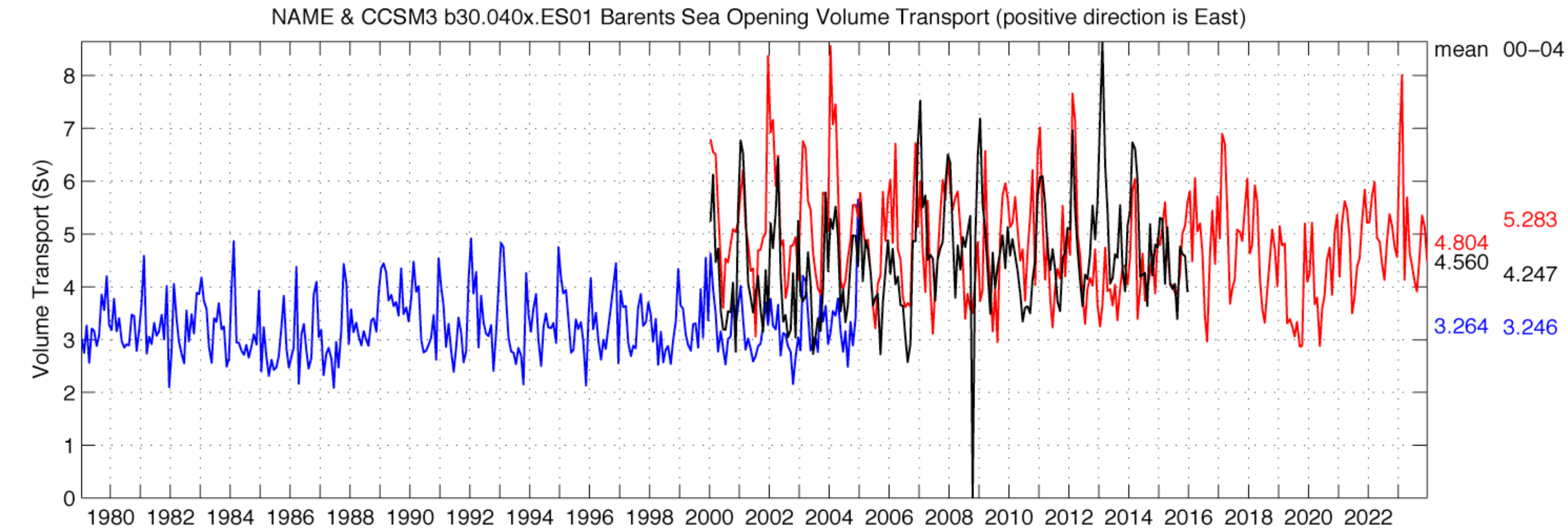
Fram Strait Fluxes North: CCSM (case b&f) and NPS model



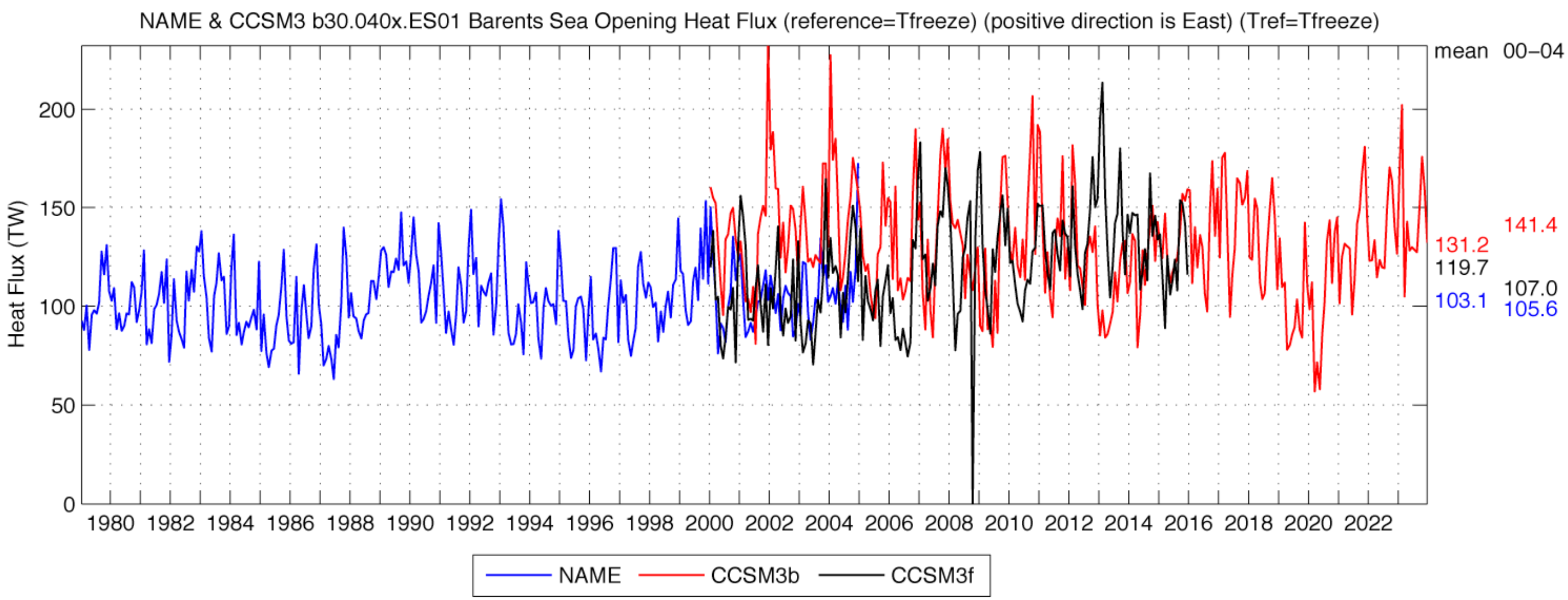


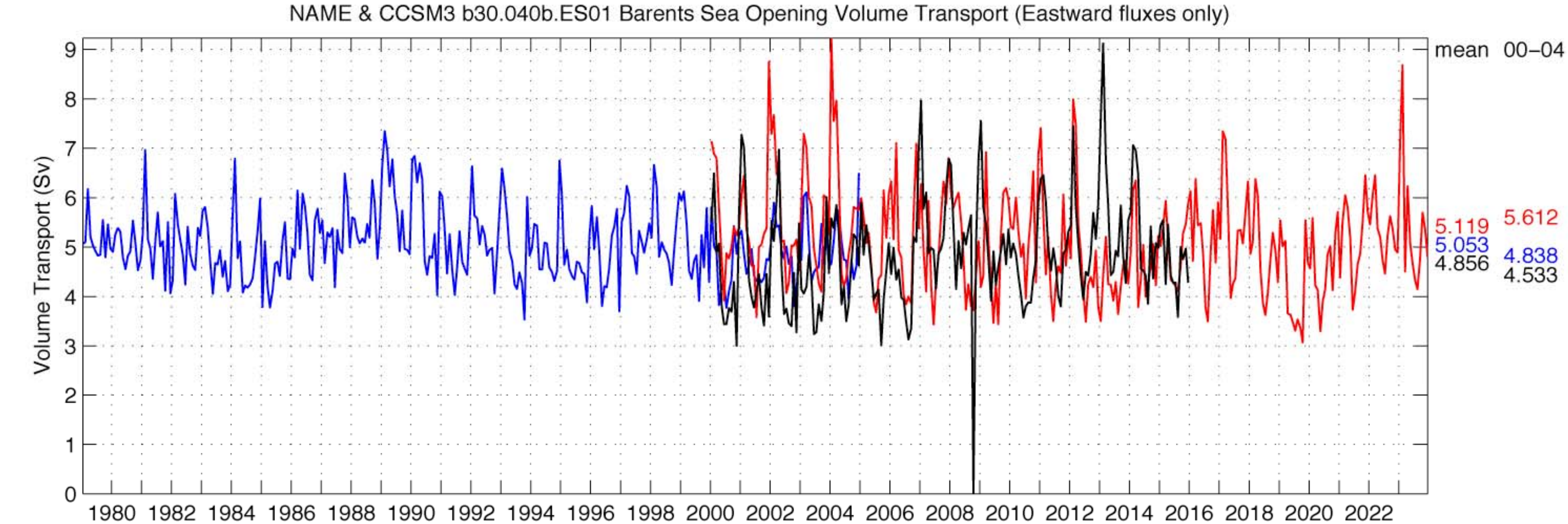
Fram Strait Fluxes South: CCSM (case b&f) and NPS model



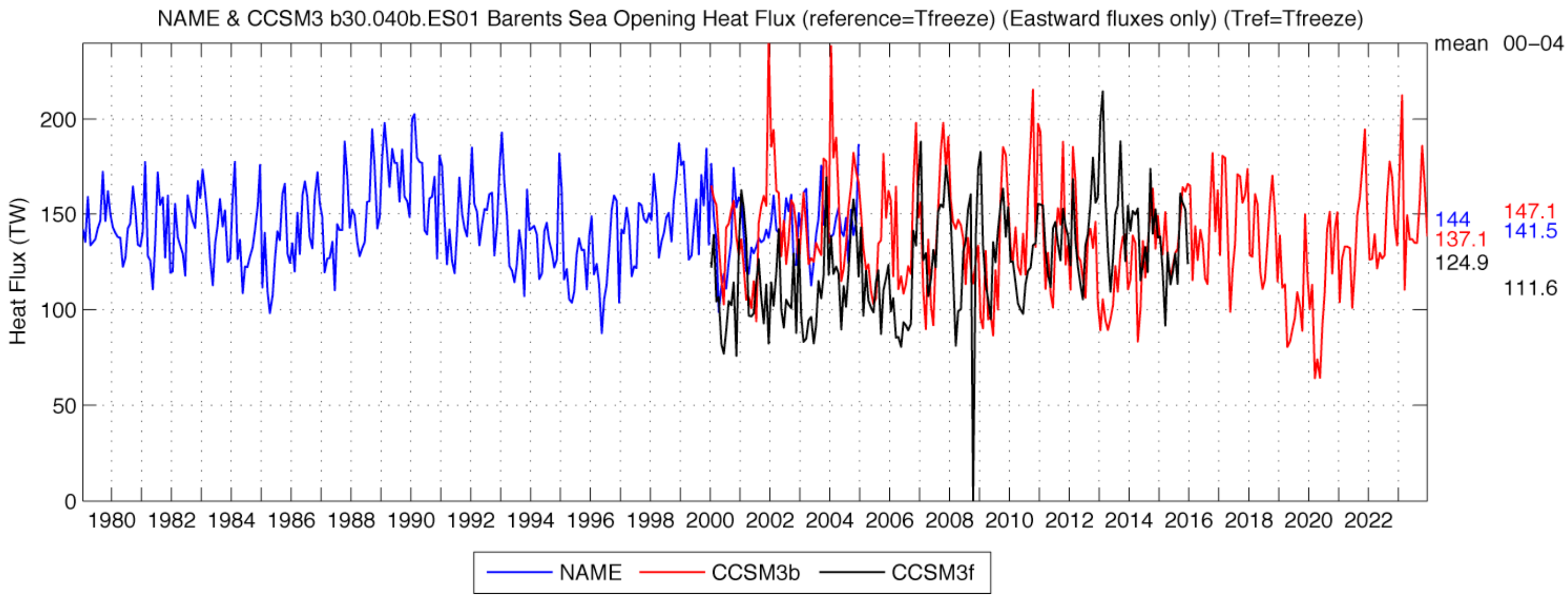


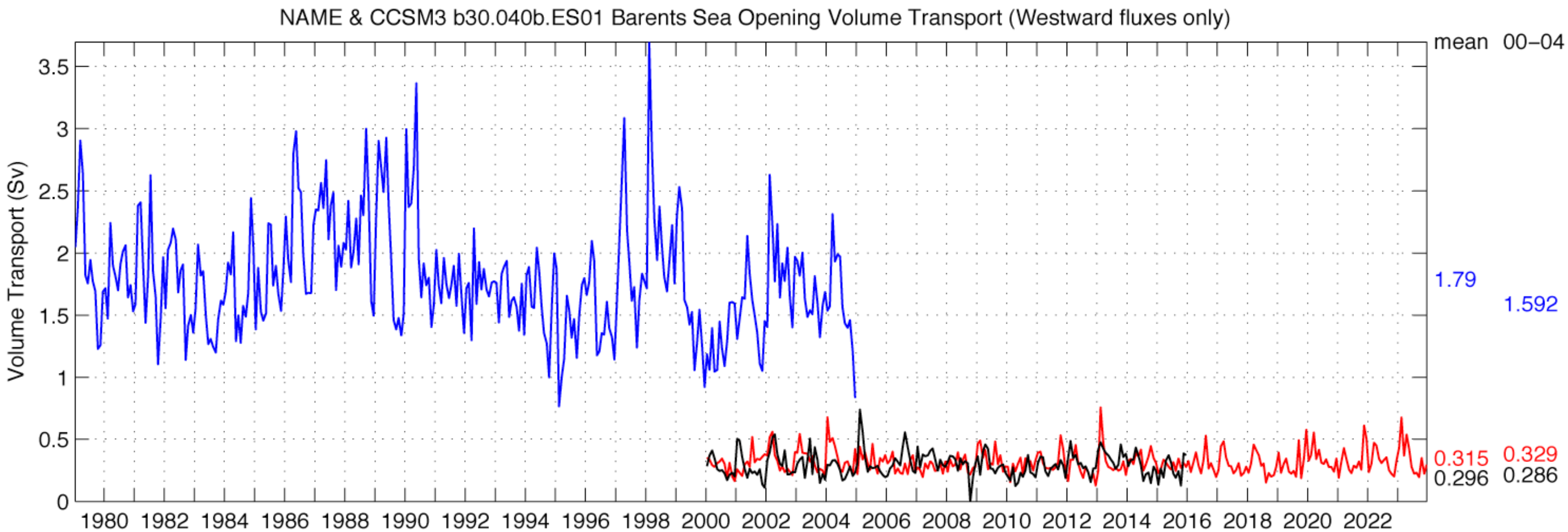
Net BSO Fluxes: CCSM (case b&f) and NPS model



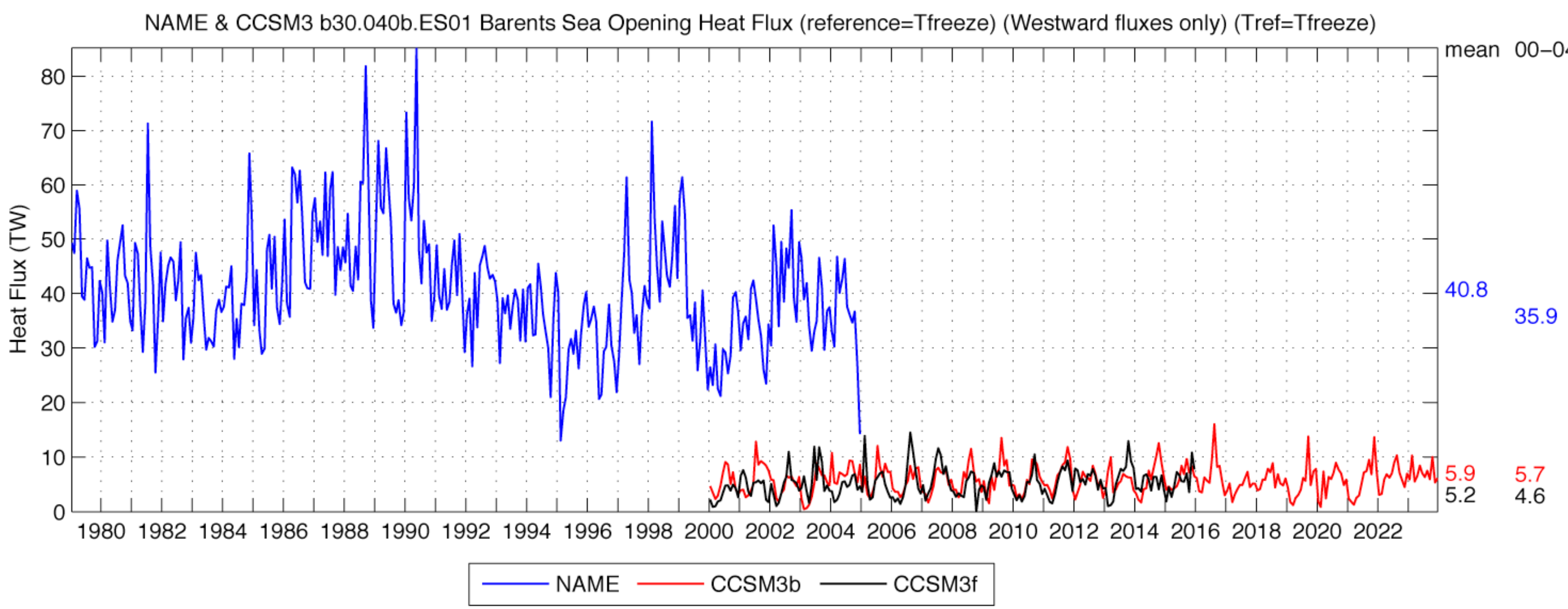


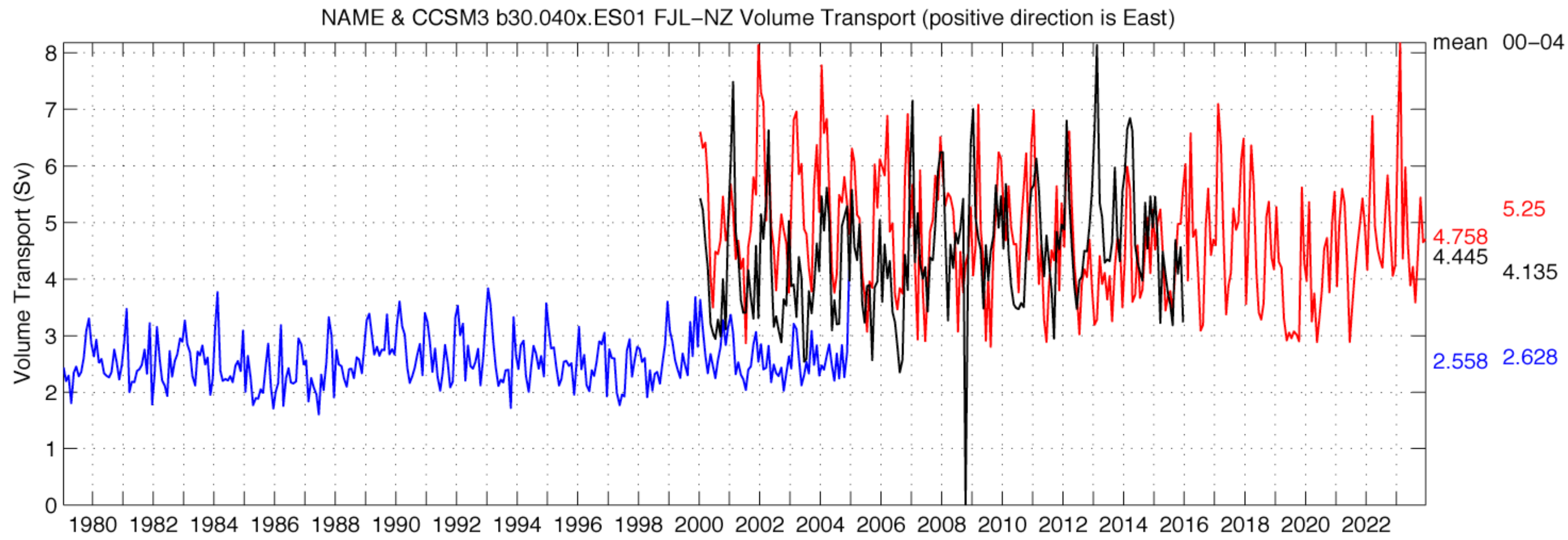
BSO Fluxes East: CCSM (case b&f) and NPS model



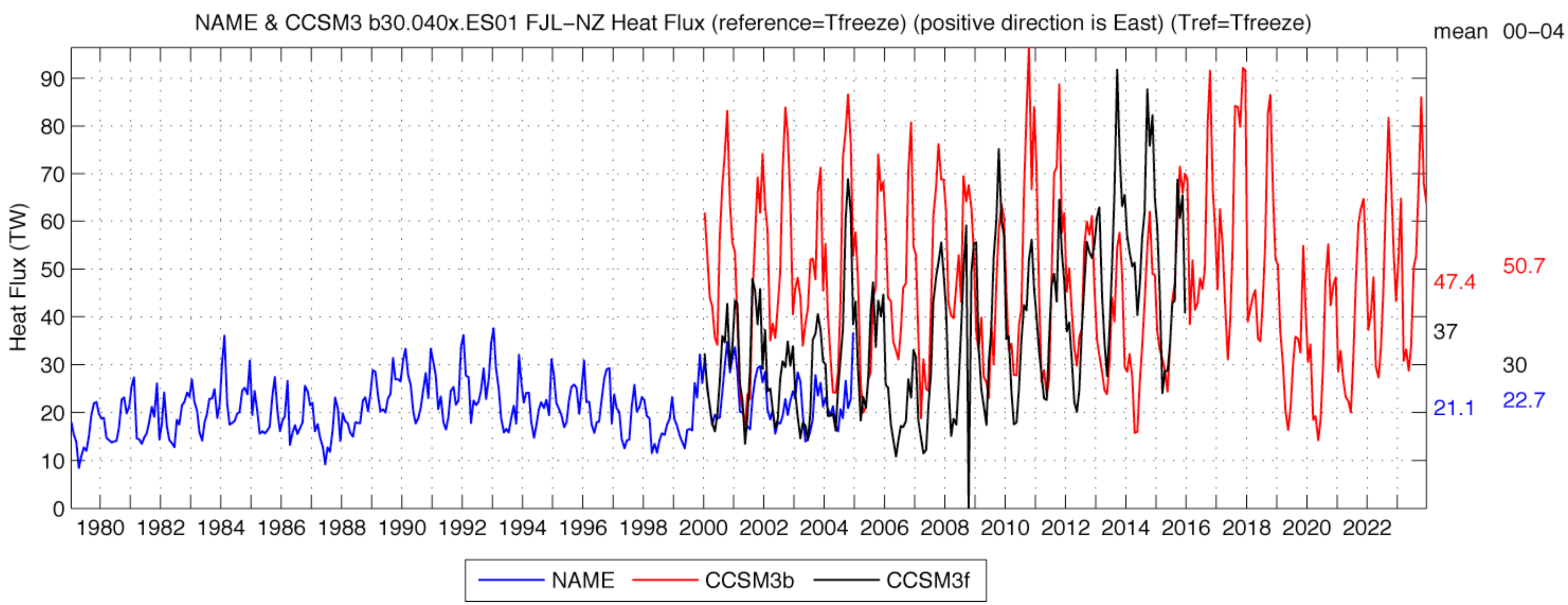


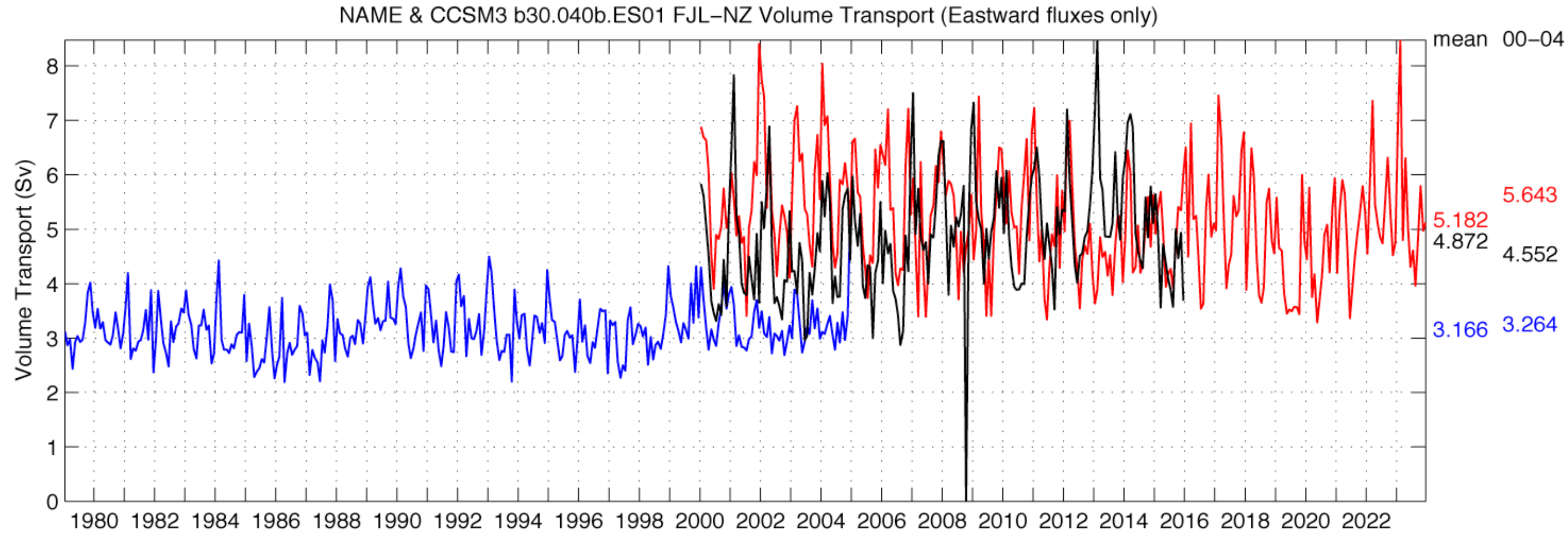
BSO Fluxes West: CCSM (case b&f) and NPS model



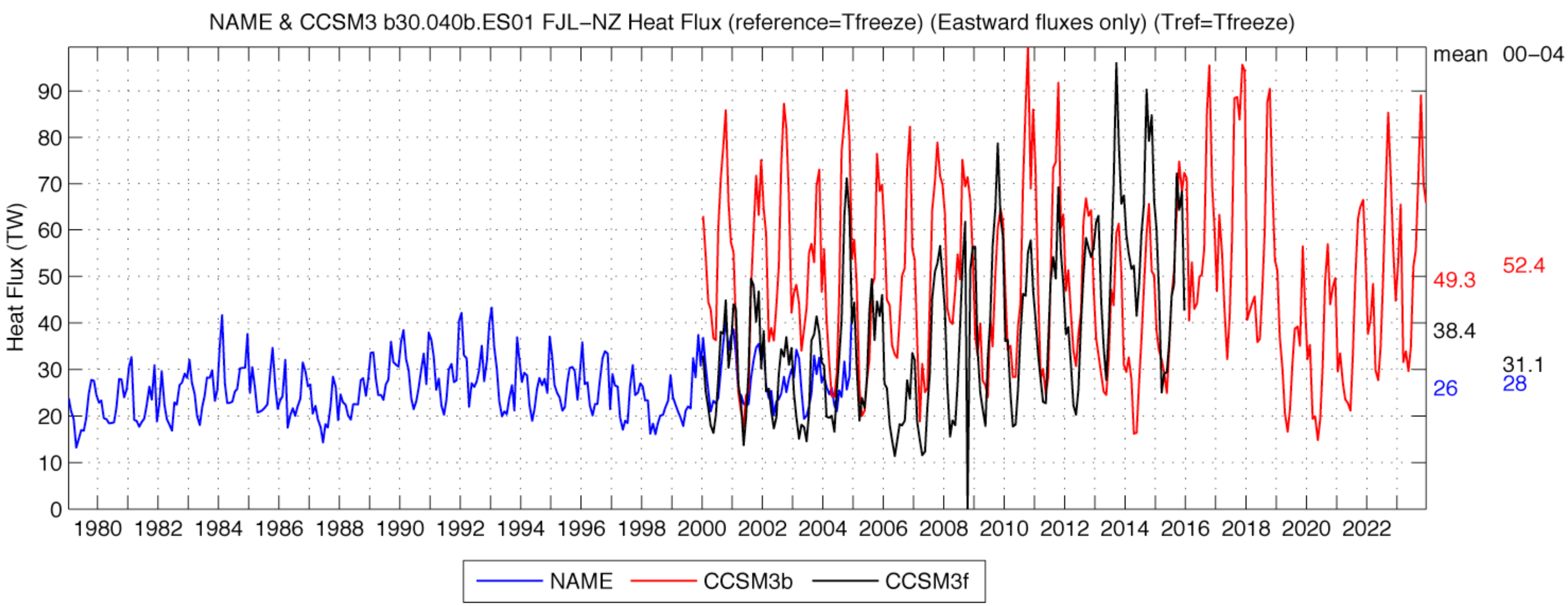


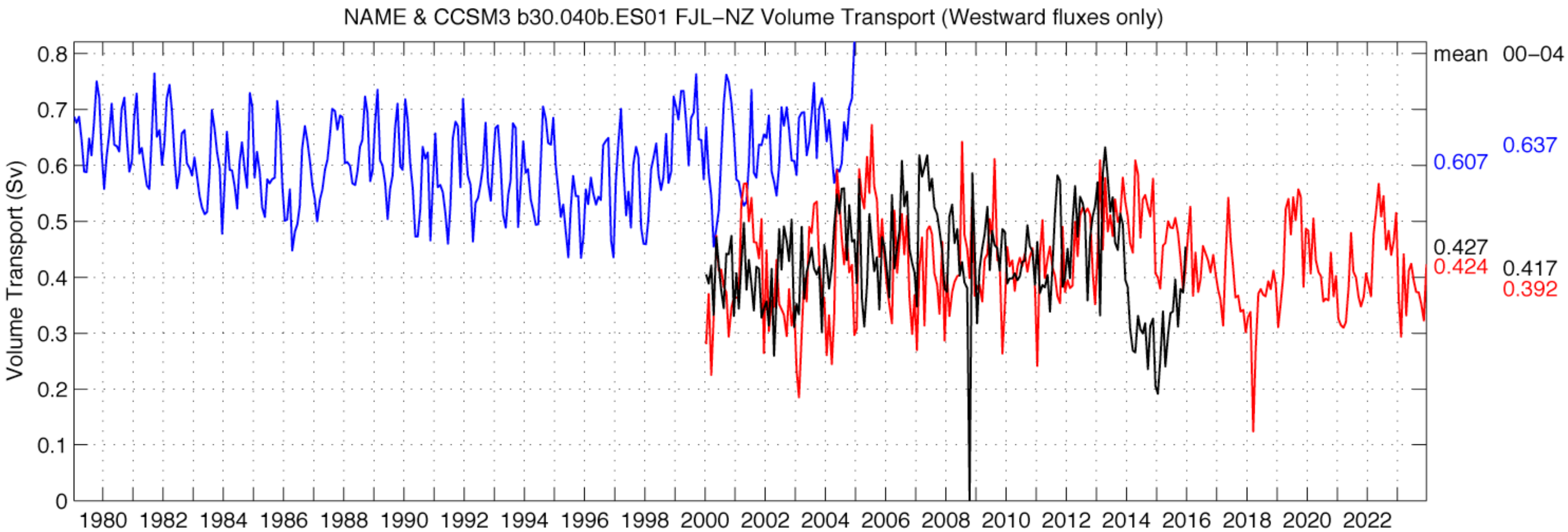
Net FJL-NZ Fluxes: CCSM (case b&f) and NPS model



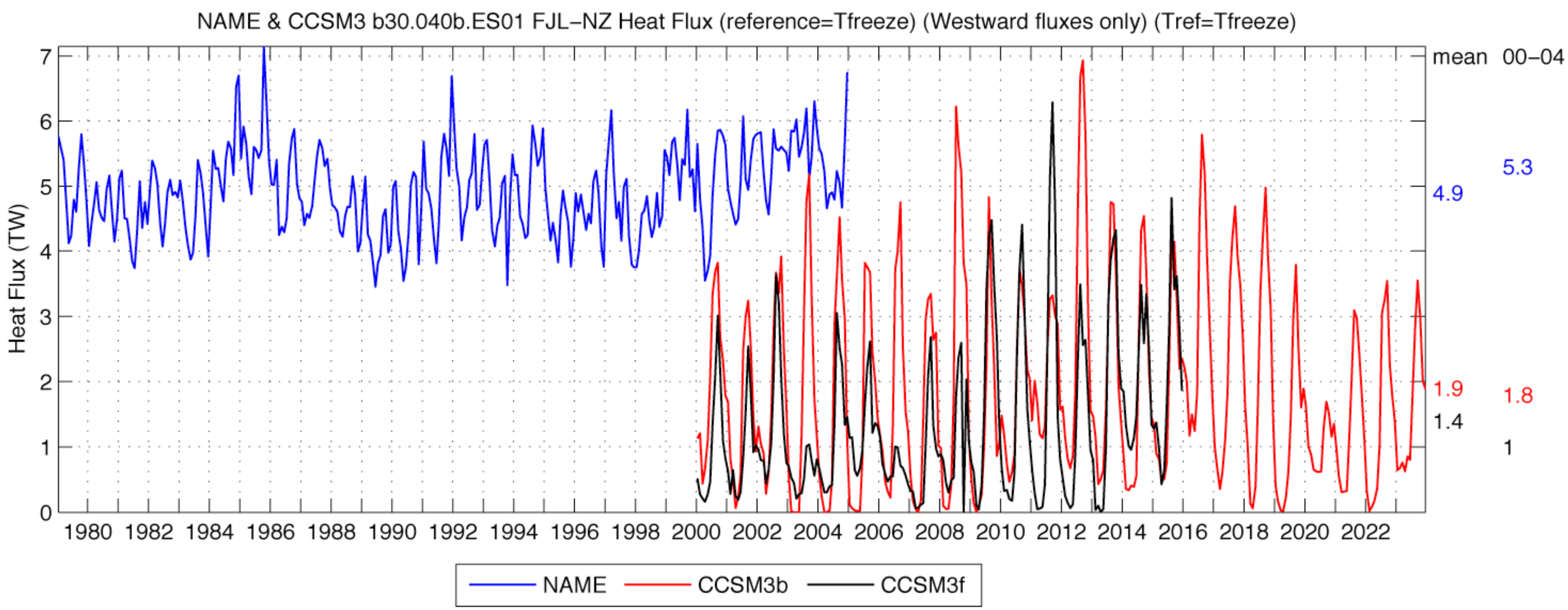


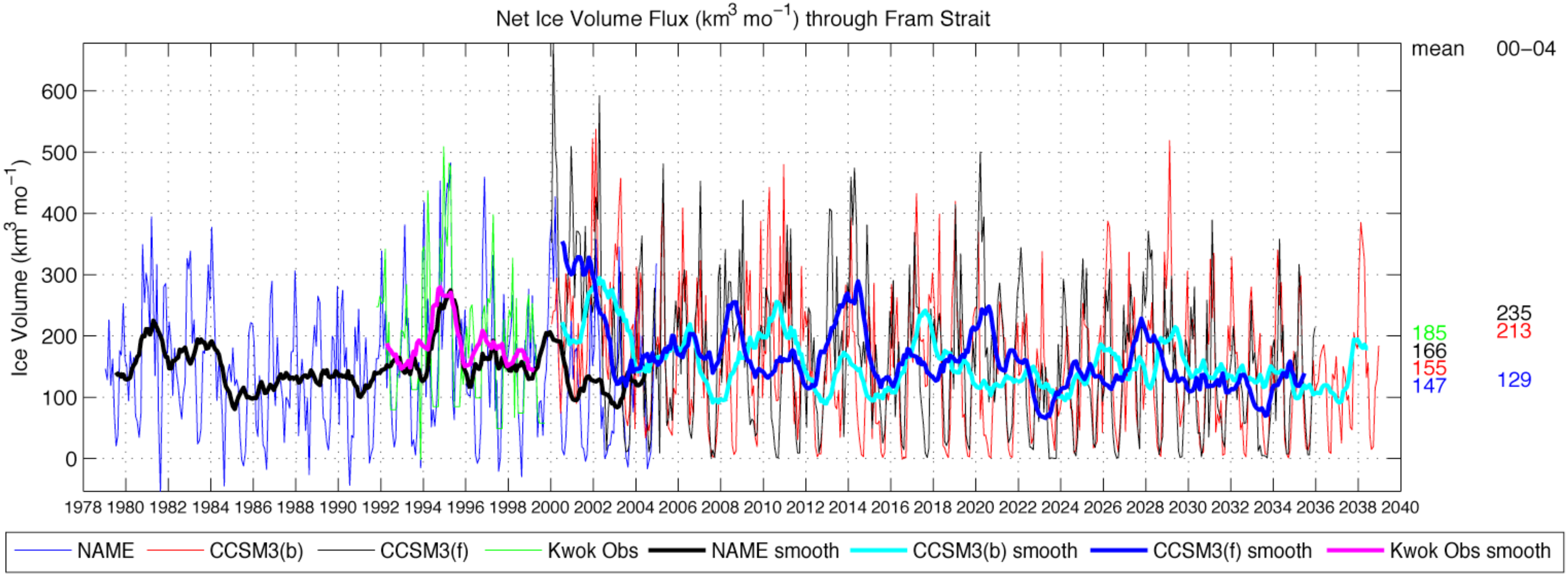
FJL-NZ Fluxes East: CCSM (case b&f) and NPS model

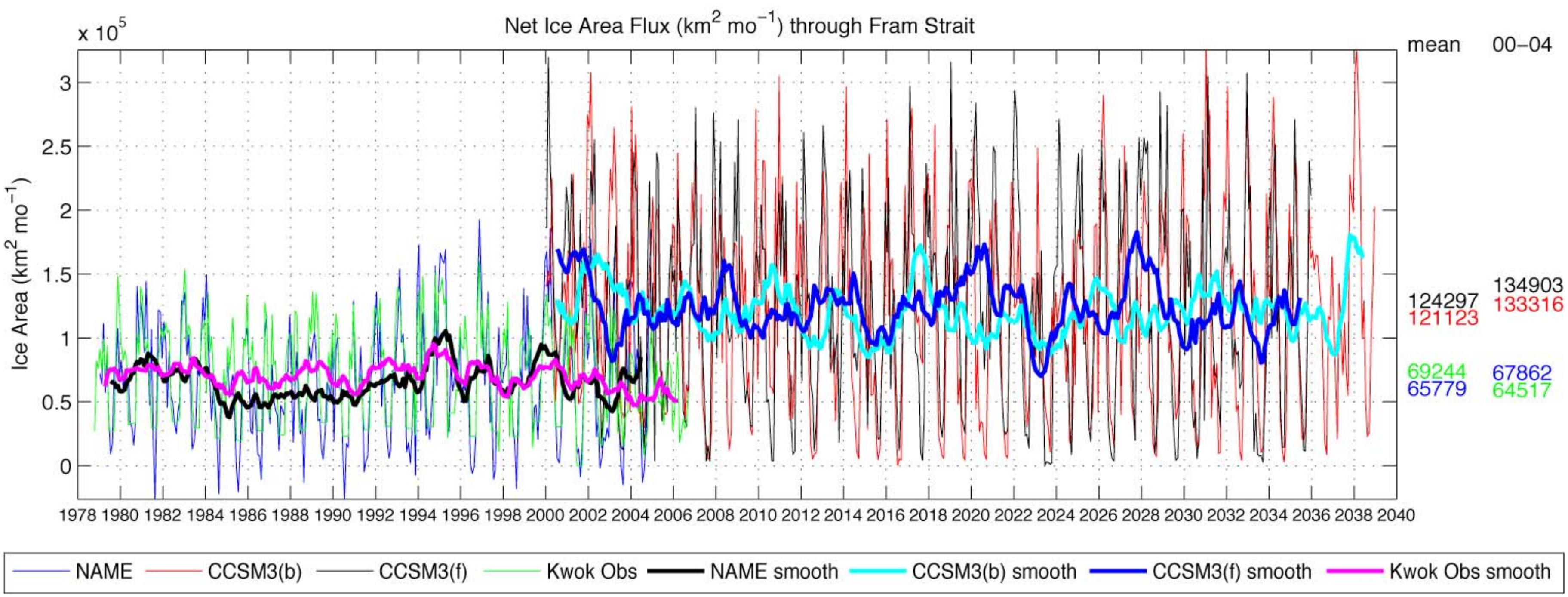




FJL-NZ Fluxes West: CCSM (case b&f) and NPS model




Net Ice Volume Flux (km^3 mo^{-1}) through Fram Strait
Ice Volume (km^3 mo^{-1})
mean
00–04
185
166
155
147
235
213
129
NAME
CCSM3(b)
CCSM3(f)
Kwok Obs
NAME smooth
CCSM3(b) smooth
CCSM3(f) smooth
Kwok Obs smooth


Net Ice Area Flux (km^2 mo^{-1}) through Fram Strait
x 10^5
Ice Area (km^2 mo^{-1})
mean
00–04
124297
121123
69244
65779
134903
133316
67862
64517
NAME
CCSM3(b)
CCSM3(f)
Kwok Obs
NAME smooth
CCSM3(b) smooth
CCSM3(f) smooth
Kwok Obs smooth

Conclusions #2

CCSM3 case b&f compared to NPS model and estimates from observations:

- **simulate too much volume and heat flux through the Barents Sea, which affects the sea ice cover and atmosphere in the eastern Arctic**
- **have too weak northward fluxes through Fram Strait, which allows too much ice in the Greenland Sea**
- **have too weak heat northward heat fluxes through Bering Strait, which may explain why there is too much ice in the western Arctic**