Arctic Sea Ice Thickness Distribution: Modeling and Observations

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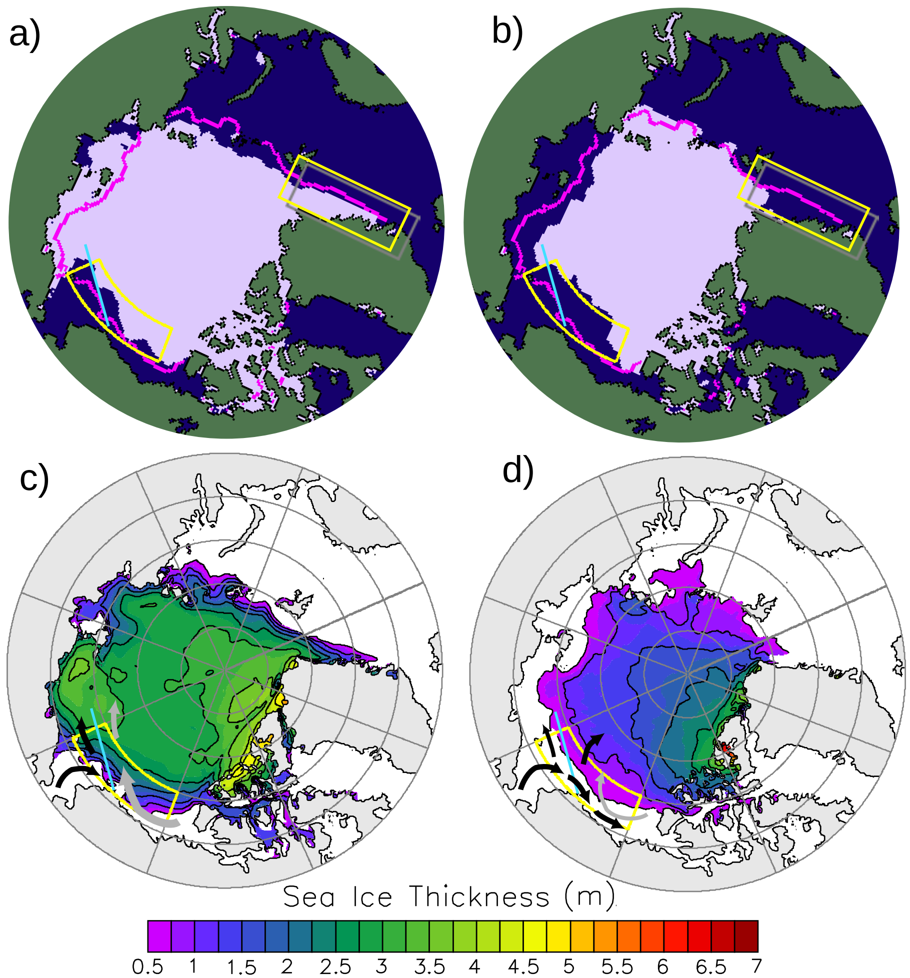
Observed Arctic sea ice extent (a,b) and modeled sea ice thickness (c,d) during September 1979 (a,c) and 2002 (b,c)

09/79 **09/02**

SSM/I – 2D

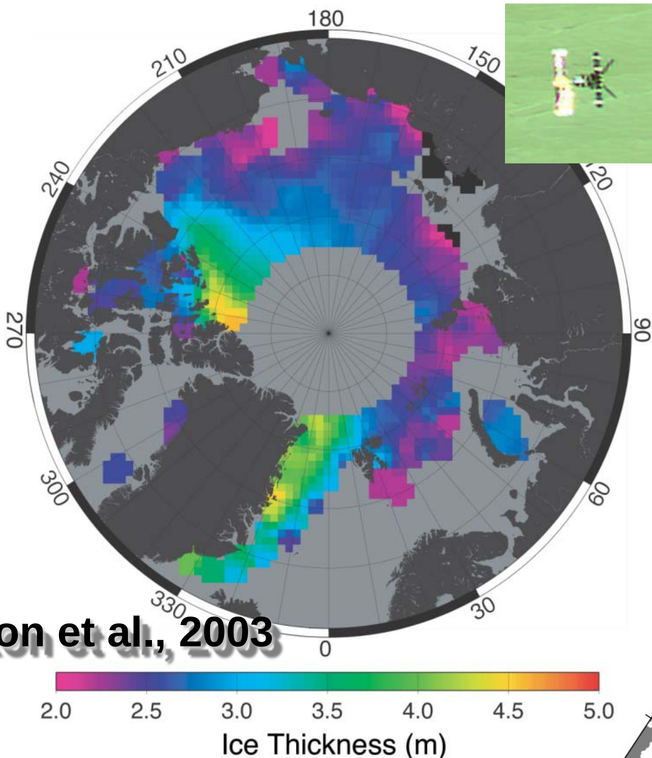
MODEL - 3D



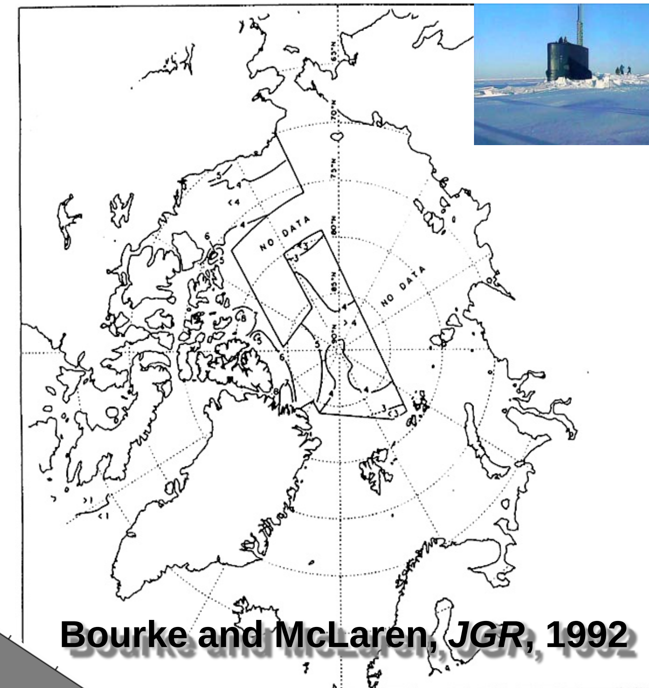
Significant decrease in observed sea ice extent (17-20%; top) and in modeled ice thickness (up to 1.5-2.0 m or ~35%; bottom) in the 2000s.

Note that largest changes are downstream of Pacific / Atlantic water inflow into the Arctic Ocean.
(Maslowski et al., 2007)

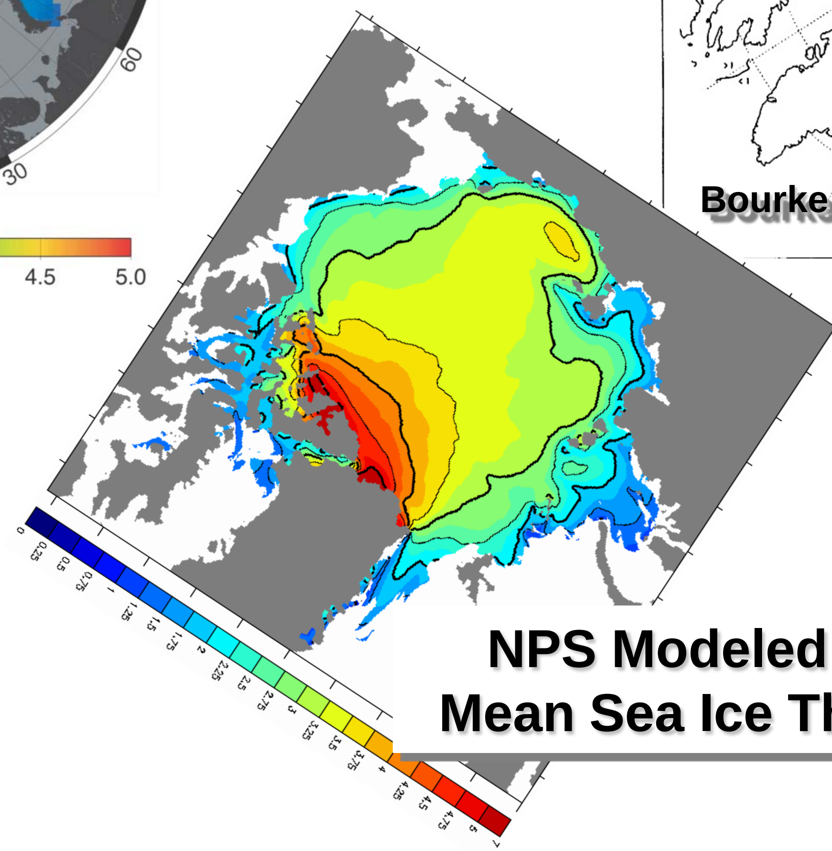
Arctic Mean Winter Sea Ice Thickness



Laxon et al., 2003

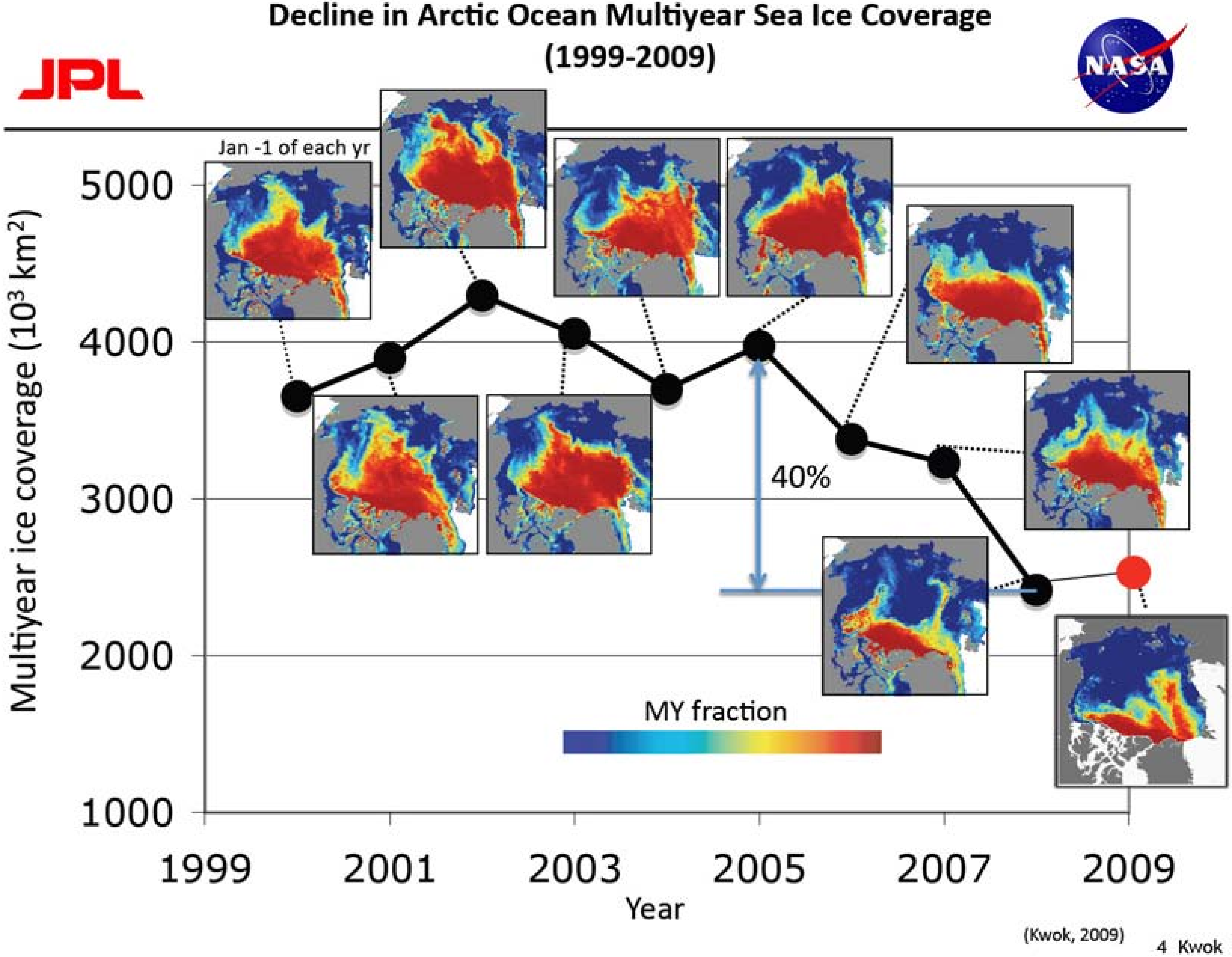


Bourke and McLaren, *JGR*, 1992

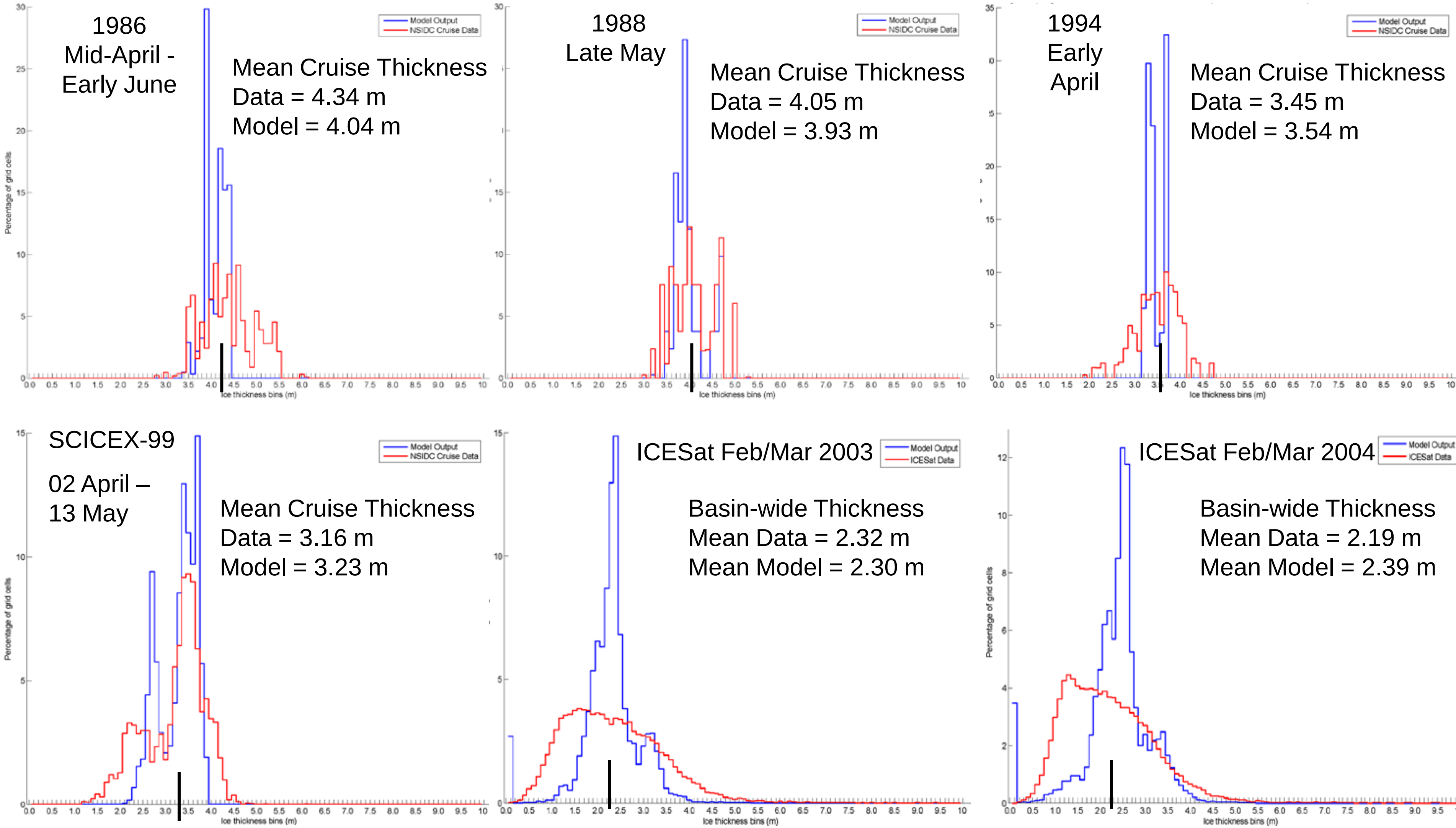


NPS Modeled 1979-1993
Mean Sea Ice Thickness (m)

Observed MY Ice Fraction



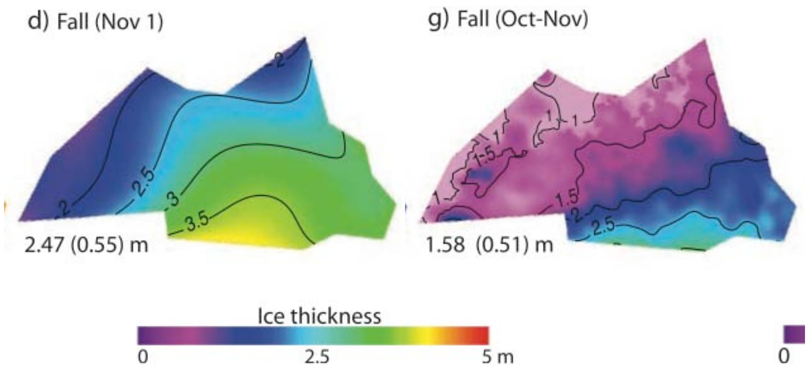
Winter PDFs of submarine (McNamara, 2006, Whelan, 2007) and ICESat (from J. Zwally) ice thickness and corresponding model monthly means



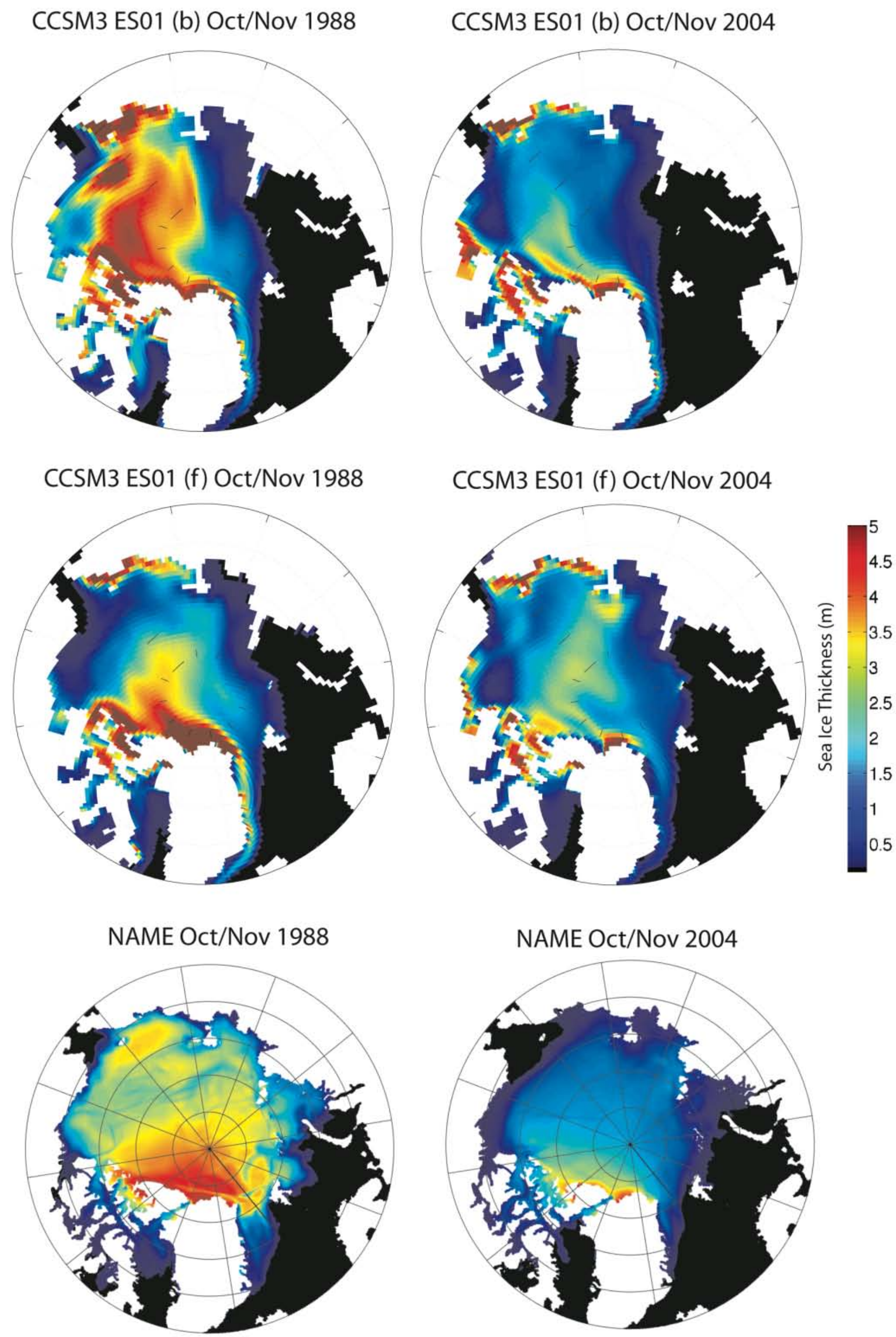
Modeled reduction of sea ice thickness is well supported by limited data and it is most pronounced since the late 1990s (~ 9cm/yr during 1997-2004). Limited observations suggest accelerated decline of ice thickness through present

(Hass et al., 2008, Giles et al., 2008)

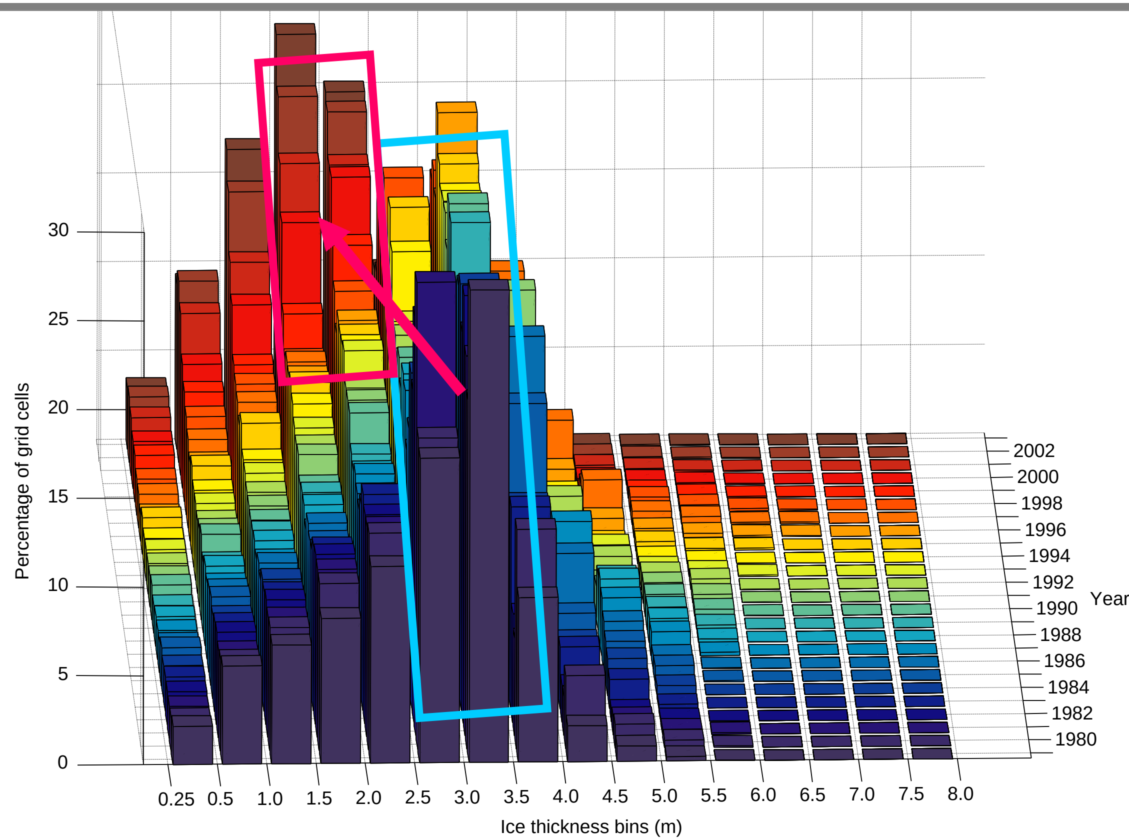
Comparison of Fall sea ice thickness: 1988 – 2000s



Observed from submarines (1988) and ICESat (2000s)



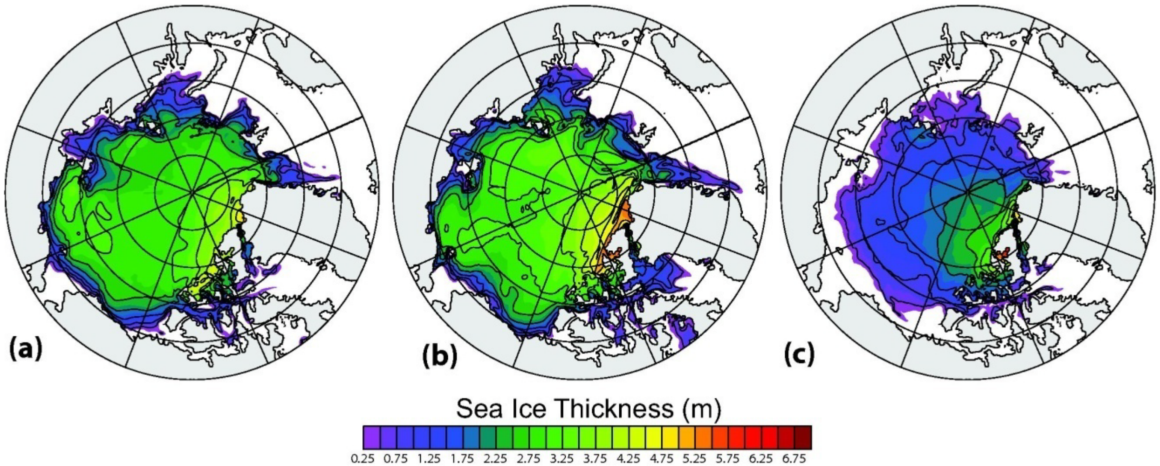
Probability Distribution Function of Model Mean 1979-2003 Annual Sea Ice Thickness (% of cells per bin)



Shift in maximum from 2.5-3.5 m in the 1980s to mid-1990s to 1.5-2.5 in the 2000s

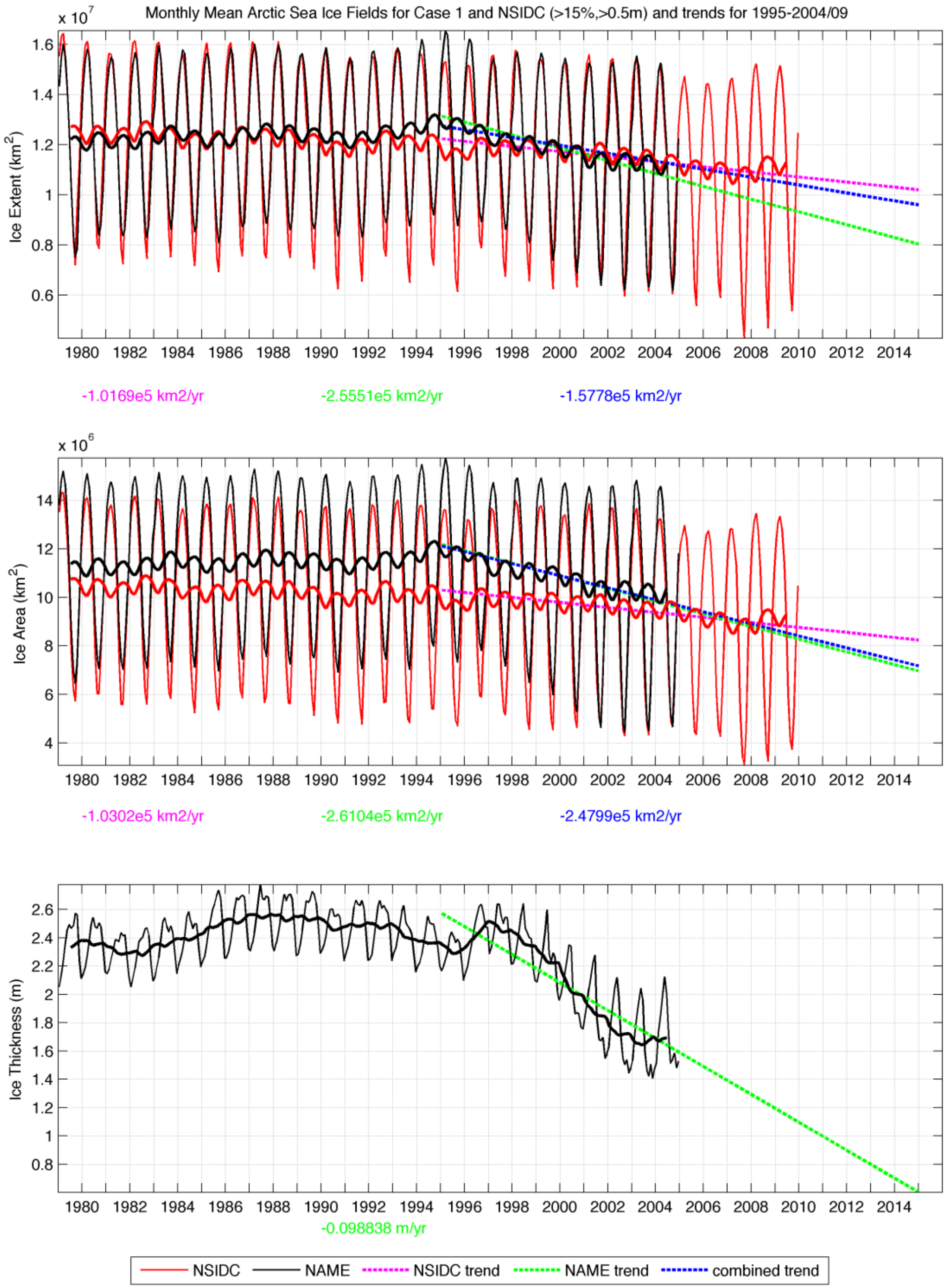
Result: ~33% reduction of ice thickness!

(Stroeve and Maslowski, 2007)

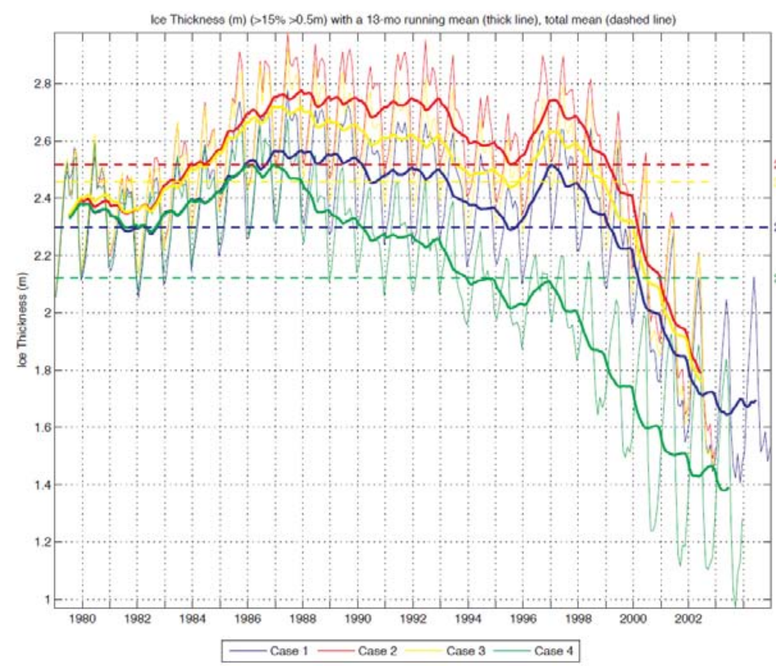


Modeled Arctic sea ice thickness distribution [in m] in September a) 1982, b) 1992, c) 2002 The color scale is the same for all panels to emphasize dramatic reduction of ice thickness in the 2000s. (Maslowski et al., 2007)

Monthly mean sea ice extent, area, and thickness from NPS model



Recent decline of Arctic sea ice cover is more rapid when ice thickness is considered



Sea ice thickness with varying surface ocean restoring

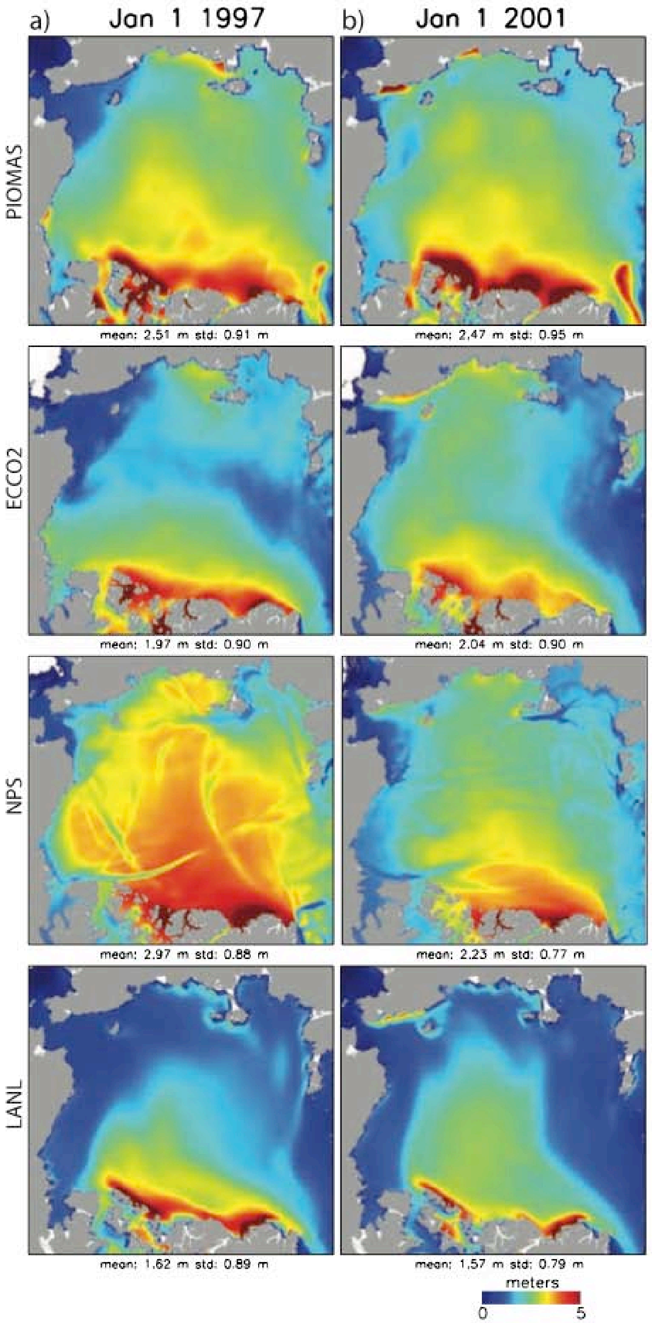
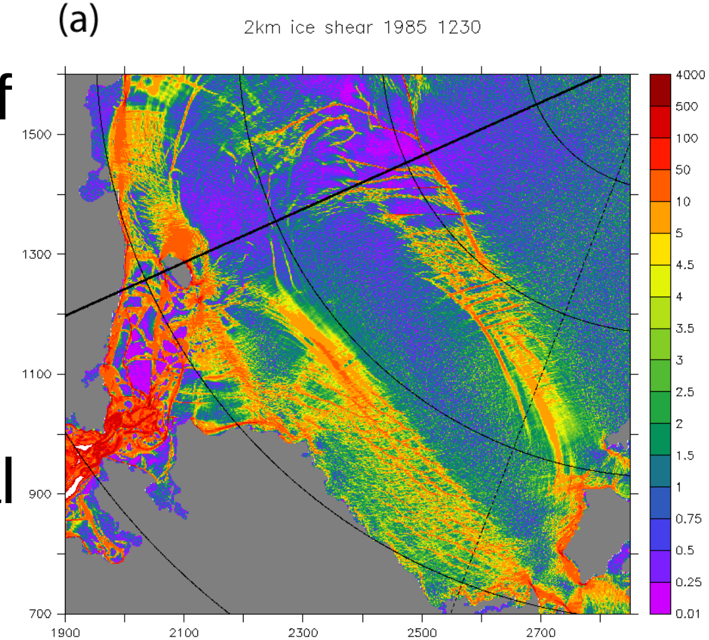


Figure 1. Simulated thickness fields. (a) 1 January 1997 and (b) 1 January 2001. (Kwok et al., 2008)

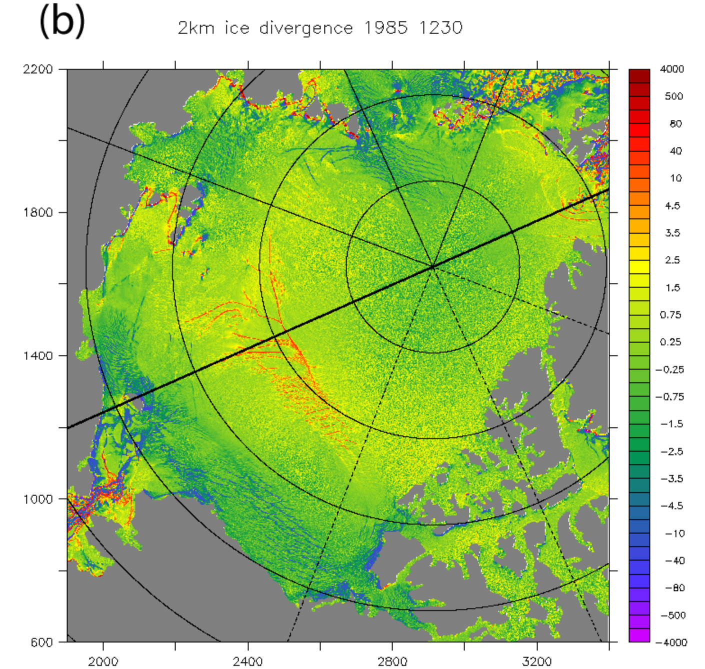
Shear (a) and divergence (b) NPS 2-km ice-ocean model

The importance of representation of ice deformations in climate models to simulating ice production, spatial distribution and temporal change

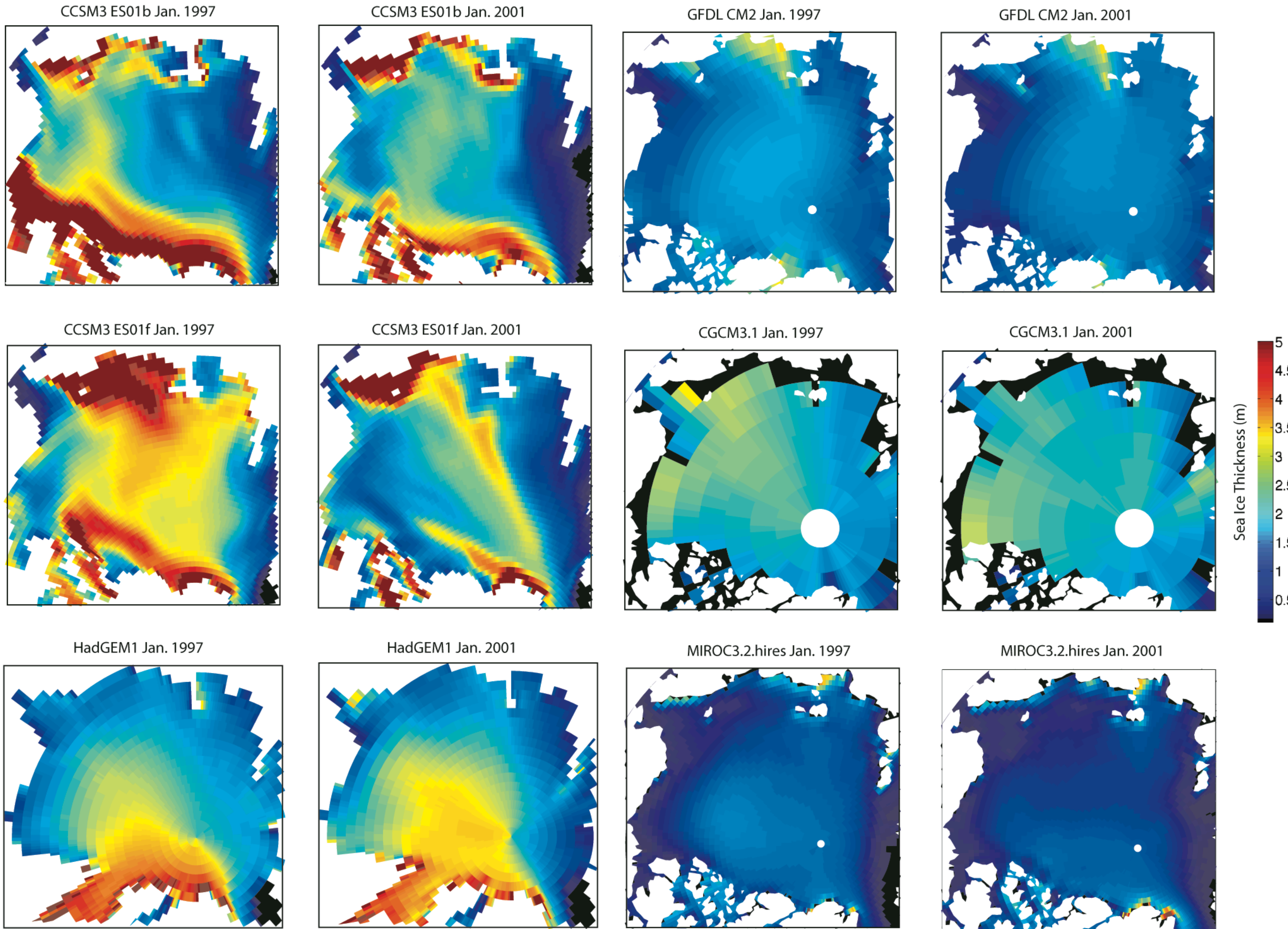
(a)



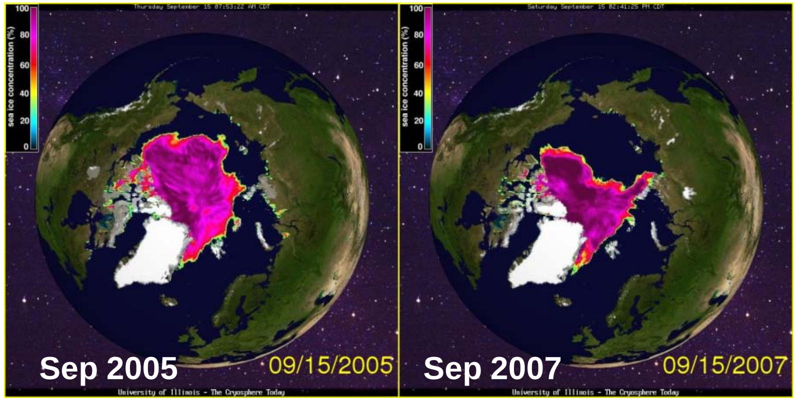
(b)



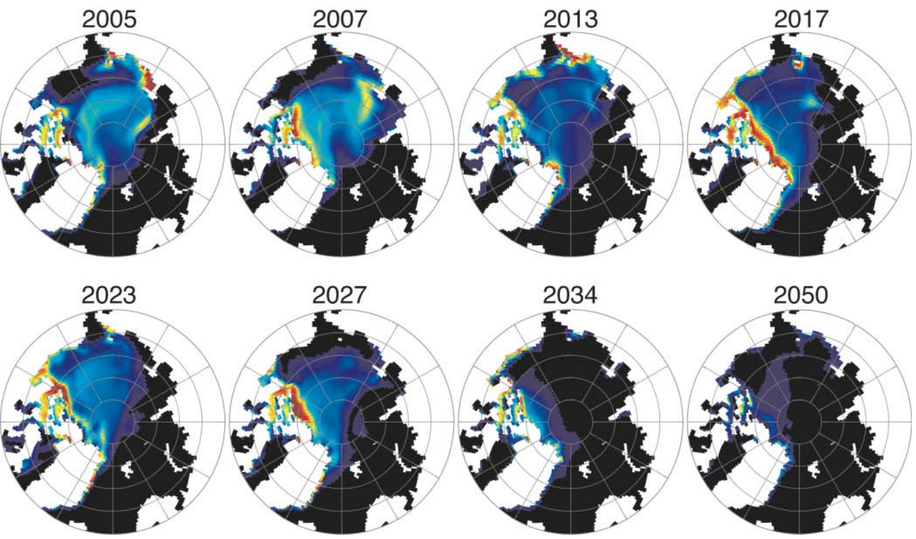
1997-2001 Arctic ice thickness change in IPCC-AR4 models

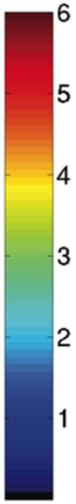


Selected model predictions of September sea ice cover/thickness in the Arctic Ocean through 2050

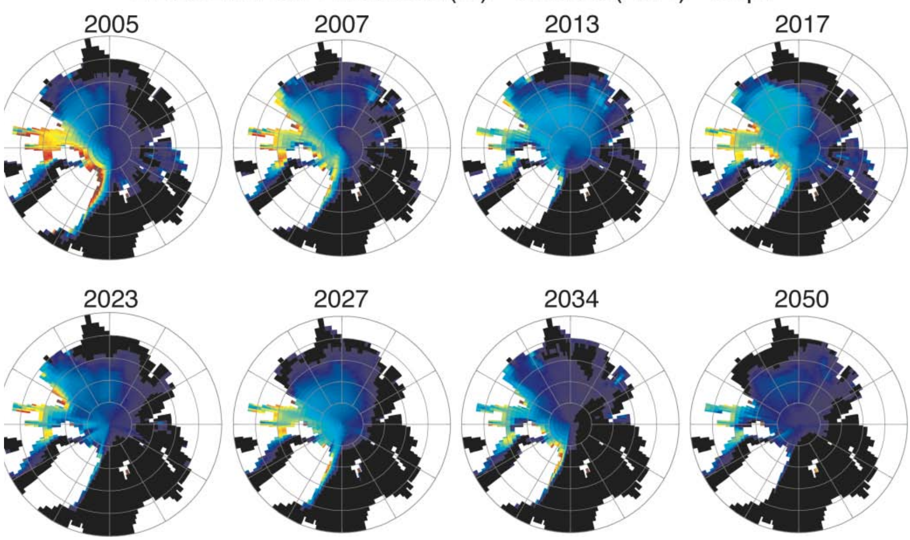


CCSM3





HadGEM1



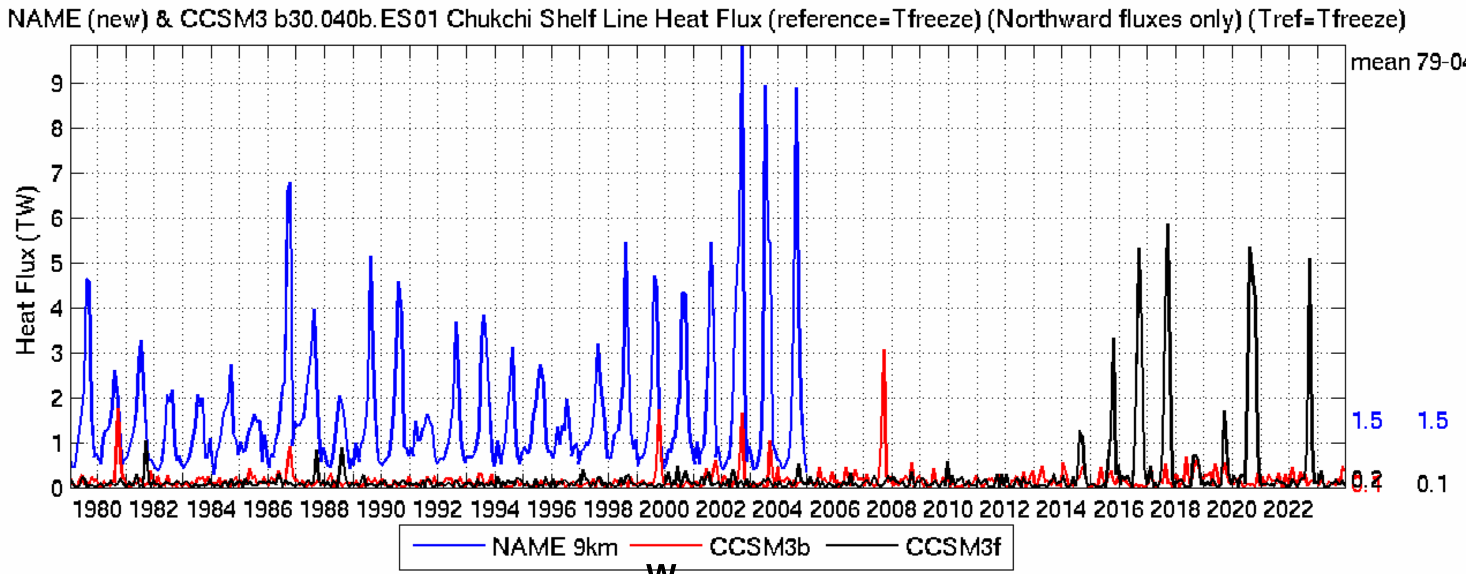
- Too much ice in the western Arctic and over Siberian shelves through 2007
- Too little ice in the eastern Arctic through 2007
- Possibly too thick ice

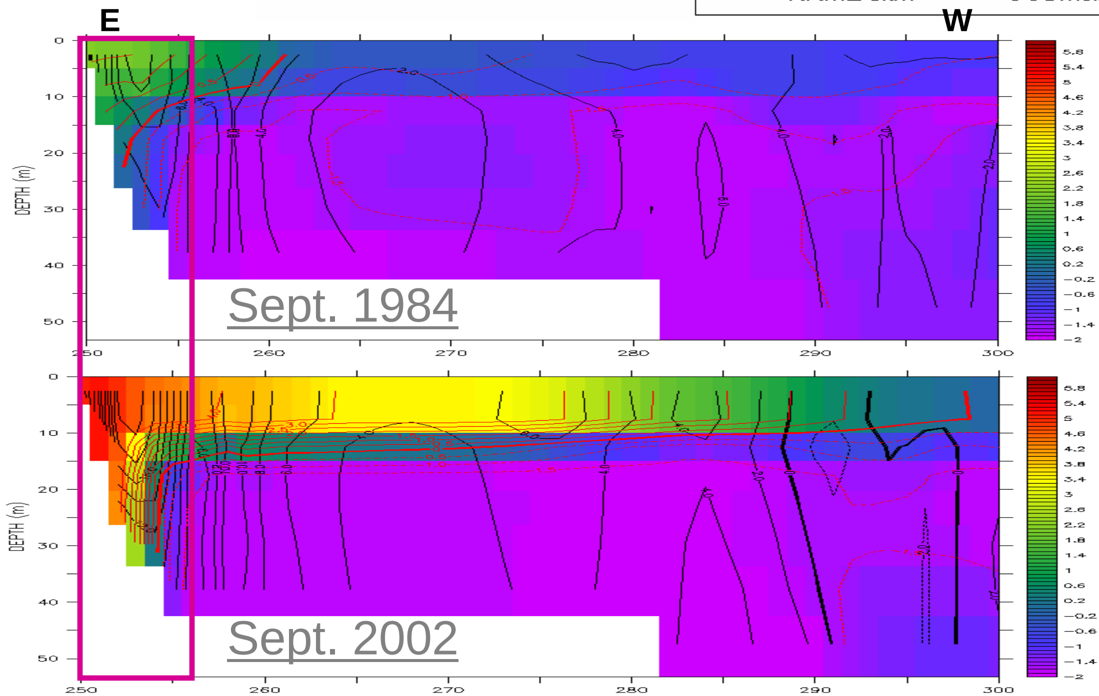
Forcing of Arctic sea ice melt

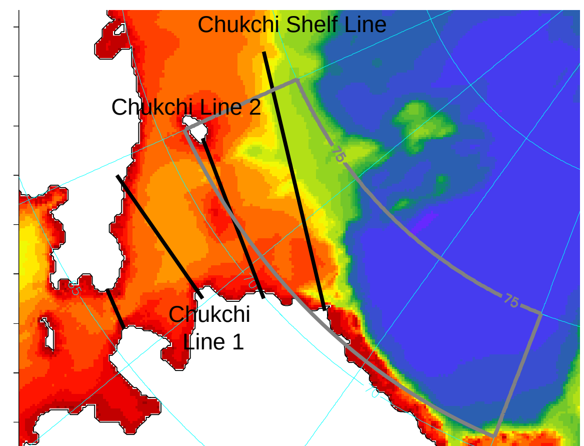
- "*Atmospheric circulation trends are weak over the record as a whole, suggesting that the long-term retreat of Arctic sea ice since 1979 in all seasons is due to factors other than wind-driven atmospheric thermal advection*." - Deser and Teng, J. Clim. 2008

- Oceanic Forcing can locally play critical role in melting sea ice via:
  - horizontal advection of warm Pacific / Atlantic water into/under the sea ice cover (e.g. Stroeve and Maslowski, 2007)
  - Locally induced (upwelling, topographically controlled flow, eddies) upward heat flux into the mixed layer (Maslowski and Clement Kinney, in revision, 2010)

Modeled Oceanic heat flux exiting the Chukchi Shelf

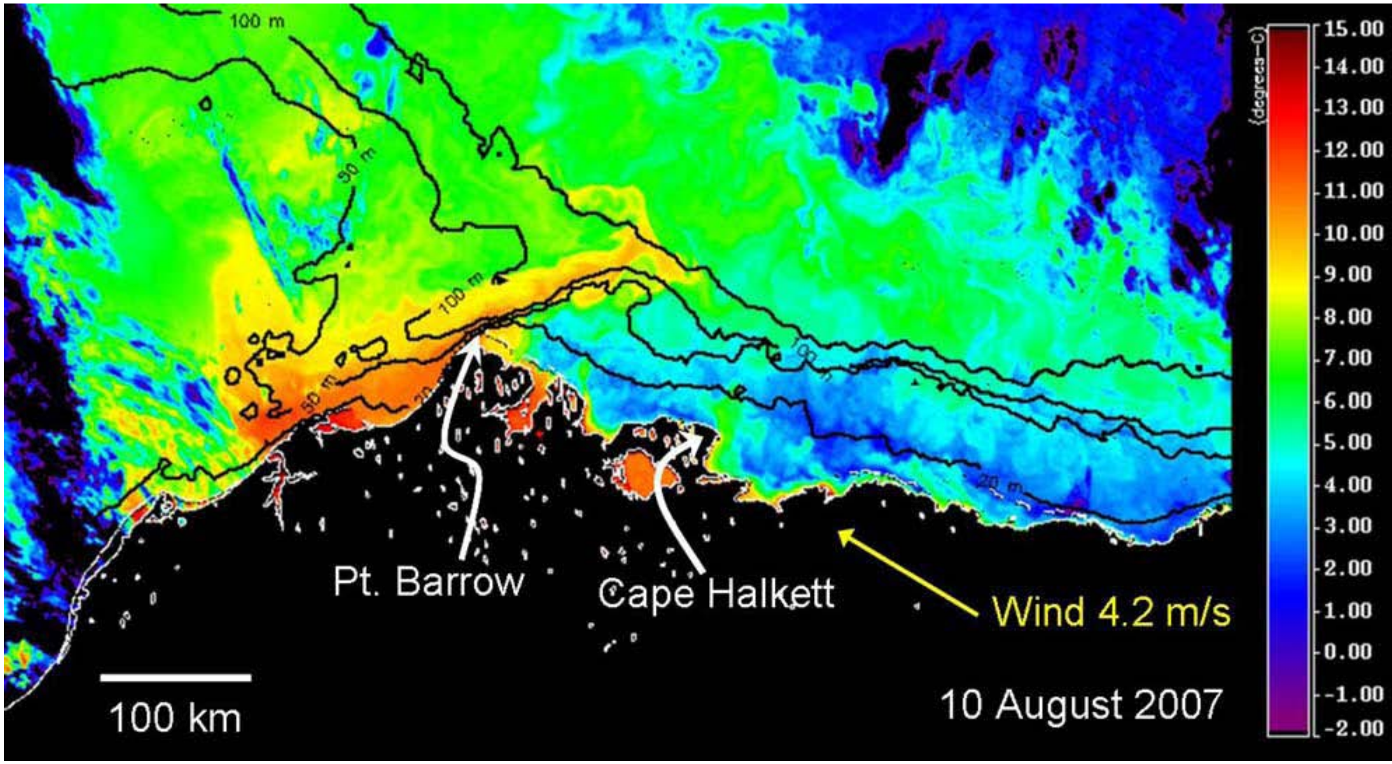


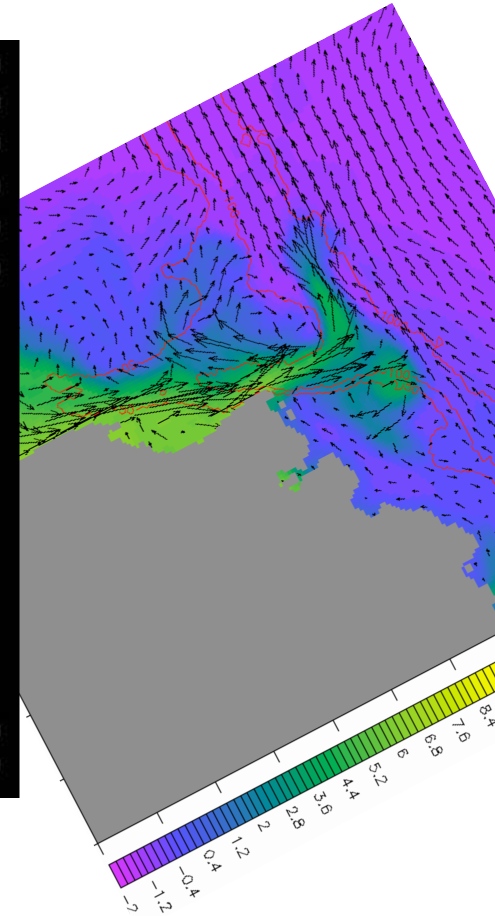




Heat Flux via Alaska Coastal Current accounts for ~67% of the Total Heat Flux across Chukchi Shelf Line

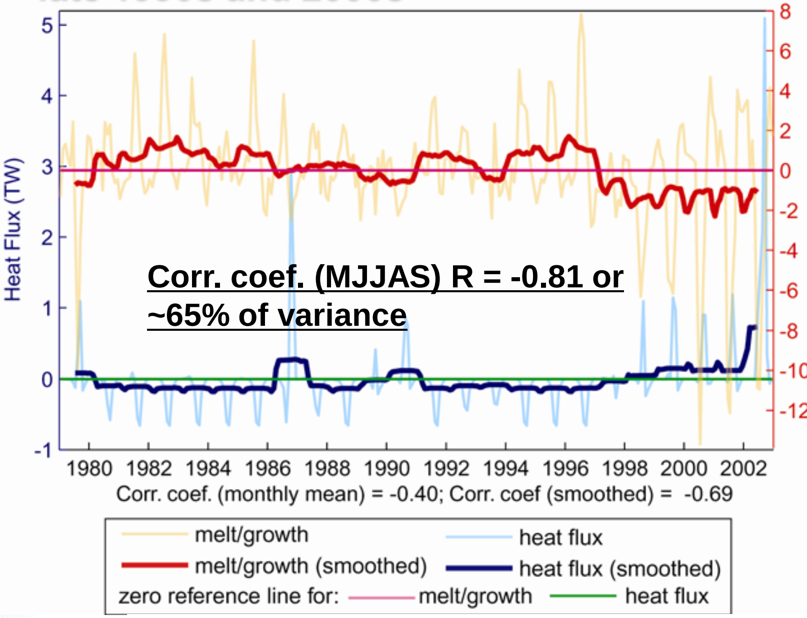
Warm water from the Chukchi Shelf is exported towards ice edge by oceanic currents

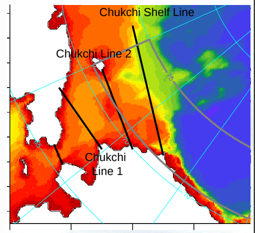


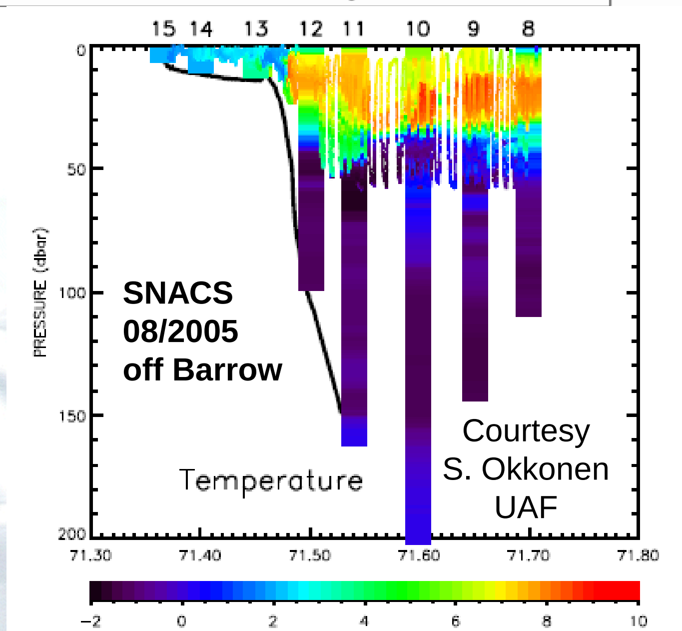


Moderate Resolution Imaging Spectroradiometer (MODIS) sea surface temperatures for 10 August 2007, 2335 UT. (Okkonen et al., JGR 2009) – left
SST (0-5m) and velocity snapshot from the NPS 2-km model spinup on 08/15 - right

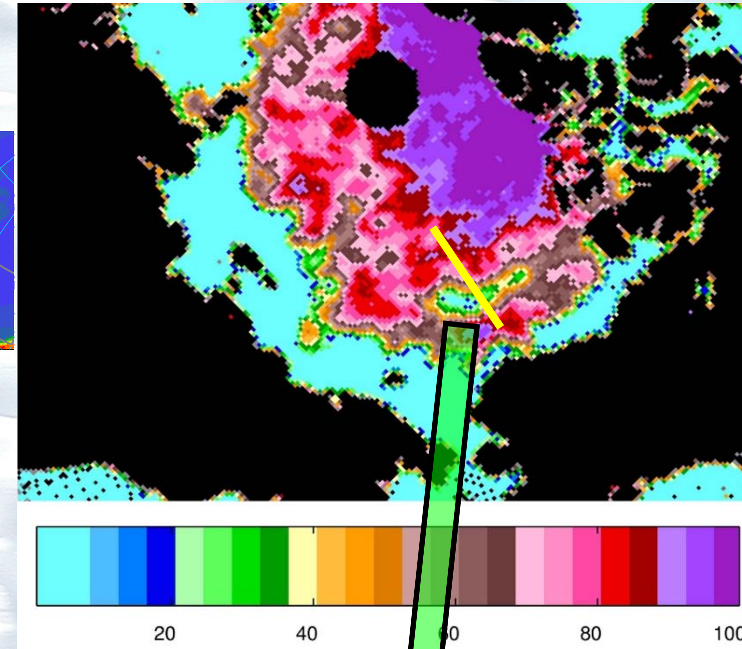
Increased northward heat flux off the Chukchi Shelf coincides with the sea ice retreat in the late 1990s and 2000s



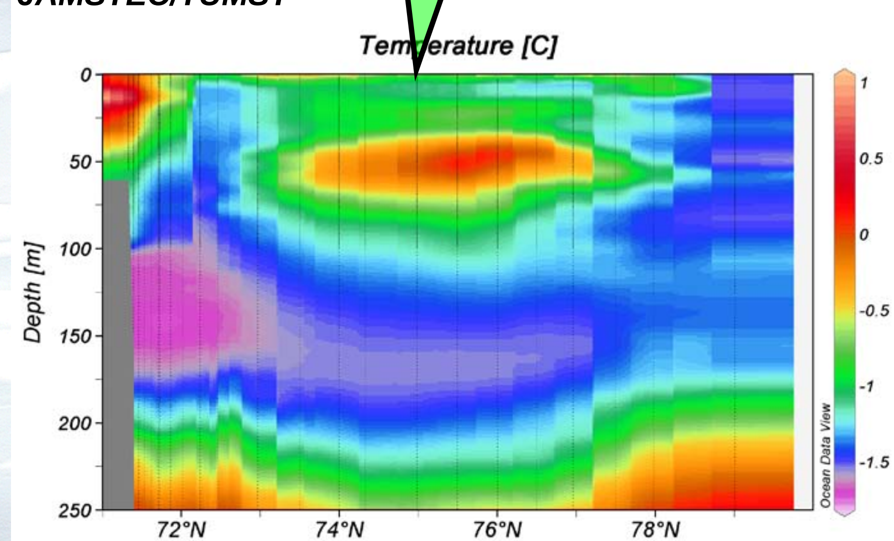




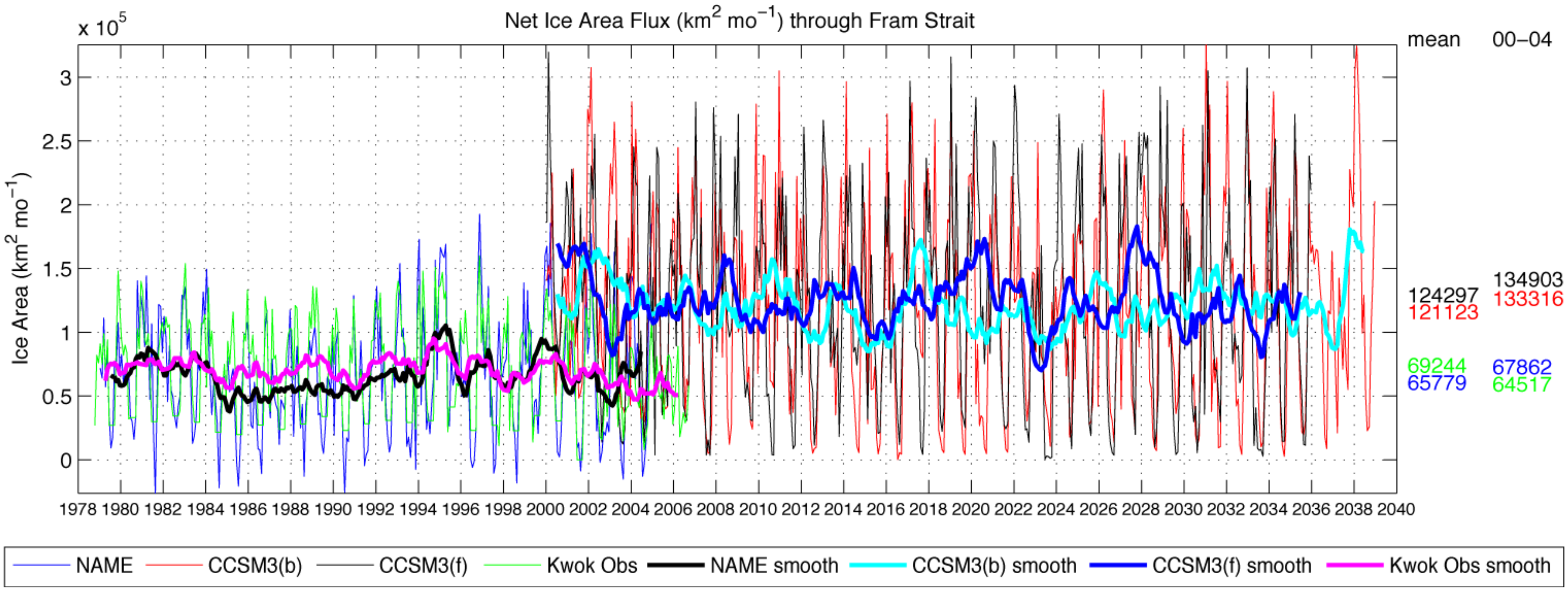
Emergence of open-ocean Polynya in the Arctic Ocean

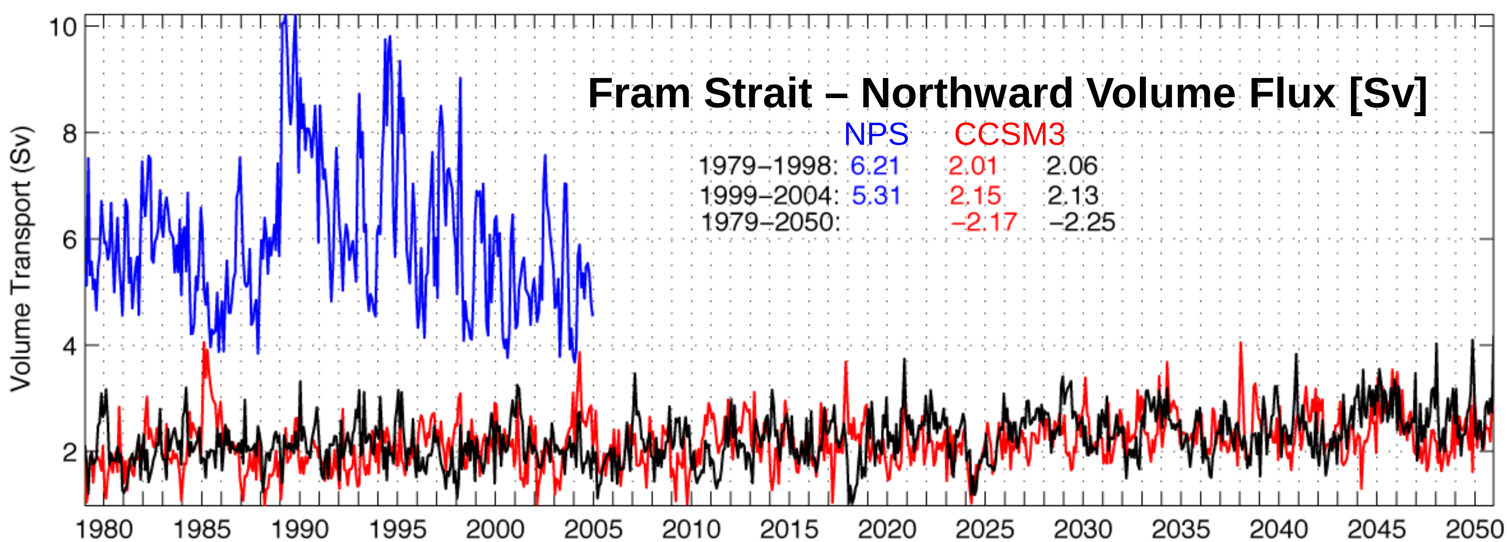


Vertical section of temperature along 150W (Yellow line in the sea ice concentration map (08/27), CCGS Louis S. St-Laurent JWACS2006) – courtesy of K. Shimada, JAMSTEC/TUMST



Comparison of areal sea ice export via Fram Strait





25-year mean volume transport (Sv) / heat trasnsport (TW)

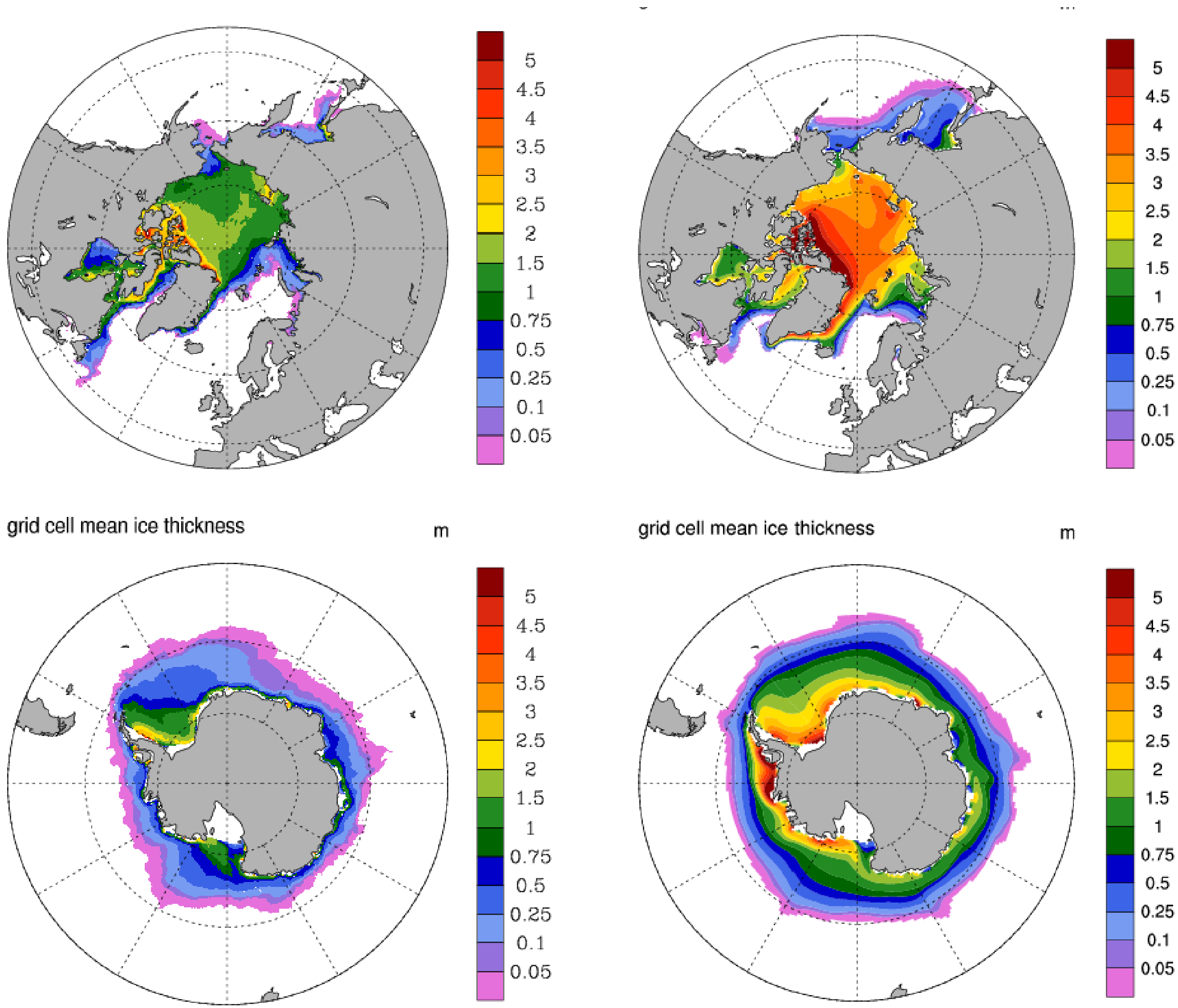
	CCSM(b)			NPS		
	In	Out	Net	In	Out	Net
Fram Strait	2.0/17	-6.9/ -23	-4.9/-6	6.0/45	-8.4/-36	-2.4/+9
Barents Sea Opening	4.8/115.	-0.3/-5	4.5/110	5.0/107	-1.8/-28	3.2/79
FJL-NZ	4.7/32	-0.35/-1	4.35/31	3.4/2.9	-0.8/-0.7	2.6/2.2

'NPS' TRANSPORTS (Maslowski et al., JGR, 2004)
Fram Strait 'in' obs estimates: 7.0 Sv / 50 TW - Courtesy of A. Beszczynska-Möller, AWI
FJL-NZ: near-zero heat transport (Gammelsrod et al., JMS submitted)

High resolution (0.1-deg) CCSM sea ice simulations

HIRES CCSM3.5 1 Deg CCSM4

AMJ Thickness



The (HIRES) Arctic could use some more ice (after C. Bitz – CCSM-OMWG 2009)

Conclusions

1. **Arctic sea ice thickness has declined faster than extent/area in the recent decades**
2. **CCSM3 is one of few GCMs simulating qualitatively similar changes but …**
   a) have too weak northward heat fluxes through Bering / Chukchi seas, which explains why they have too much ice in the western Arctic
   b) have too weak northward and recirculating fluxes at Fram Strait, which allow too much ice in the Greenland Sea
   c) simulate too much volume and heat flux through the Barents Sea

   …which possibly affect predictions of summer ice retreat

3. **Oceanic heat advection / storage has contributed significant forcing to the recent sea ice melt in the western Arctic**
4. **Ice-edge & shelf/slope upwelling, eddies and other mesoscale circulation features in the Canada Basin provide a mechanism for horizontal heat distribution throughout the basin and up into the mixed layer**
5. **Improved representation of sea ice conditions in ultra-high resolution models?**

"A linear increase in heat in the Arctic Ocean will result in a non-linear, and accelerating, loss of sea ice."

N. Untersteiner, 2006

Be prepared … for rapid ice melt