

On air-ice-ocean interactions under warming Arctic climate



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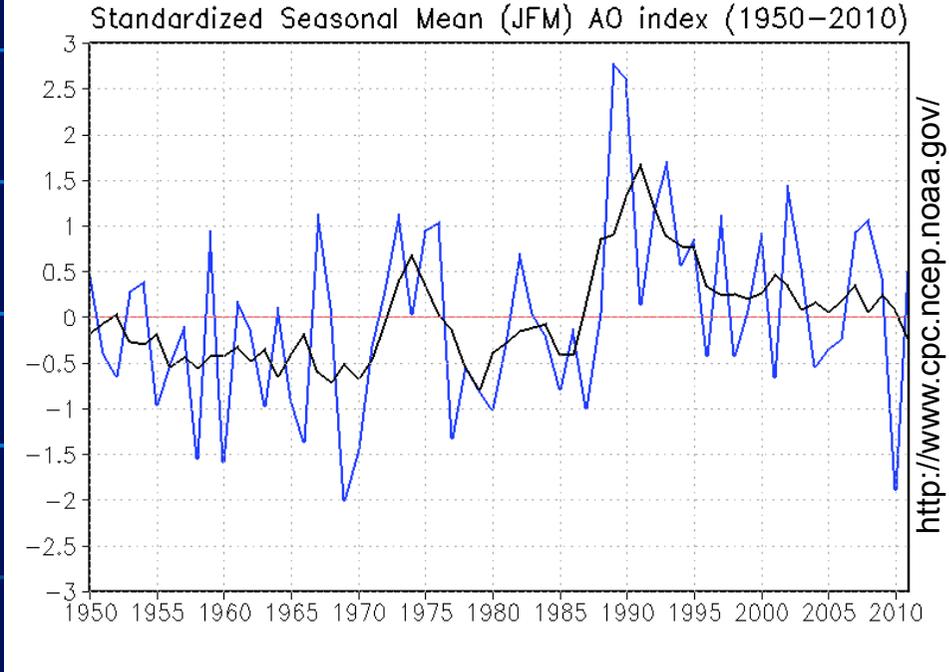
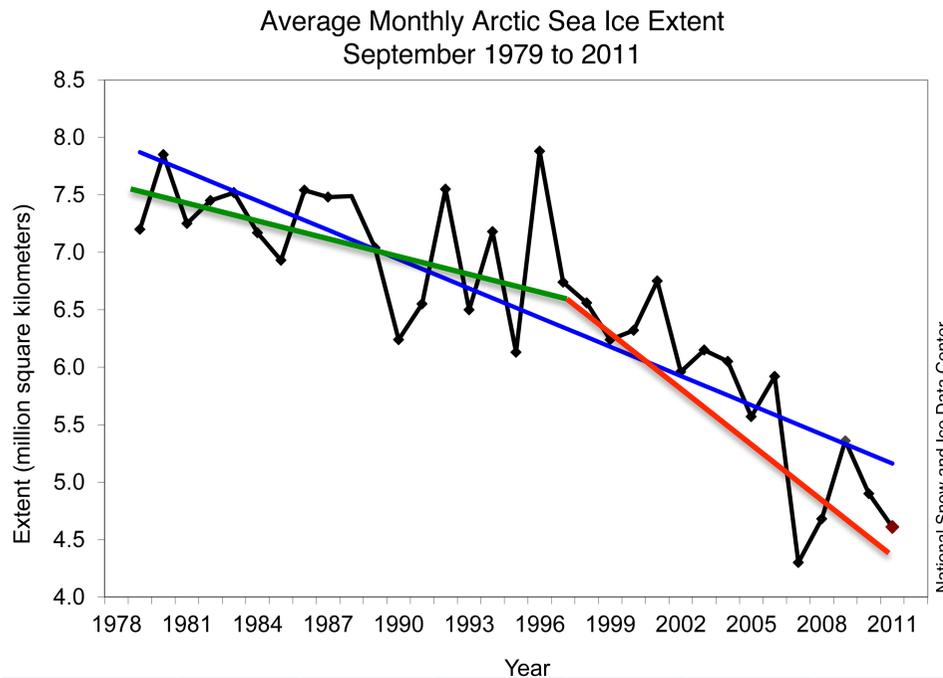


WCRP OSC, Denver, CO, 24 – 28 October, 2011

What is the source of Arctic sea ice 'memory'?

Accelerating trend September sea-ice extent:

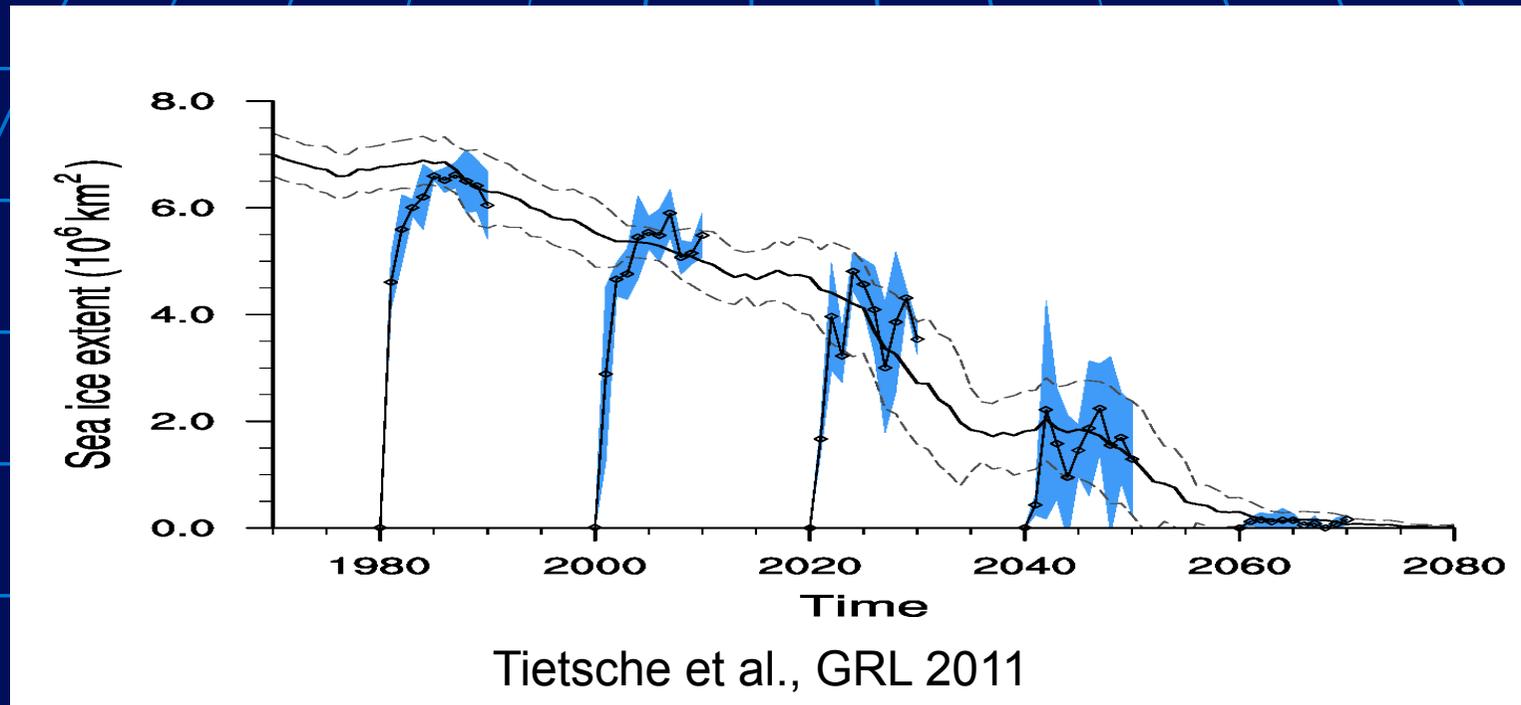
- 6.5% per decade - 1979-2001
- 8.6% per decade - 1979-2005
- 10.2% per decade - 1979-2007
- 12.0% per decade - 1979-2011



No clear long-term forcing in the atmospheric record

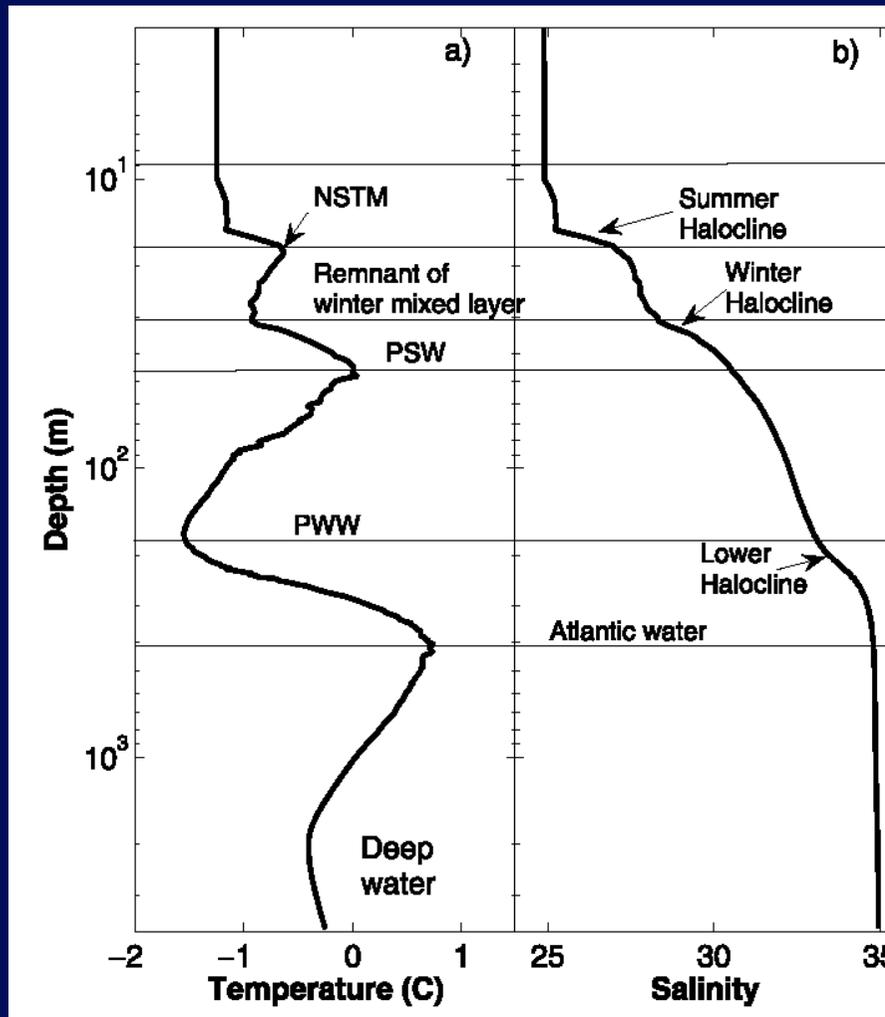
(e.g. Deser and Tang, 2008)

GCM simulation of sea ice memory?

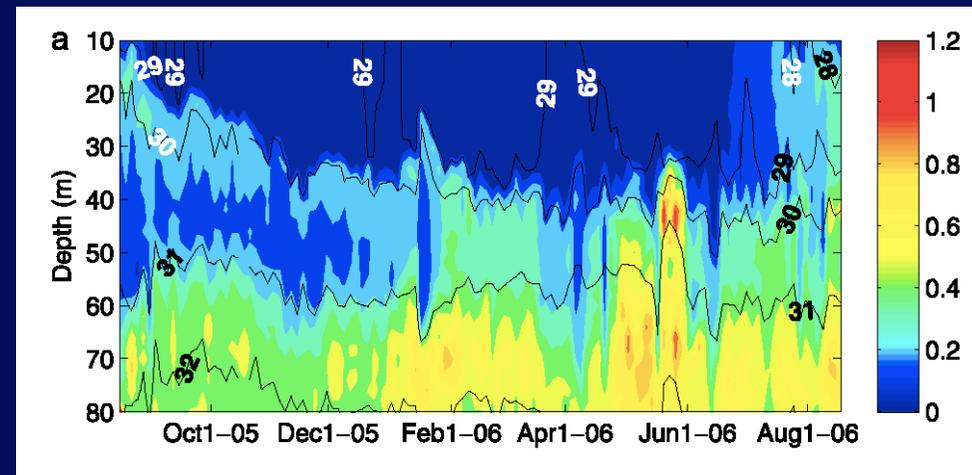
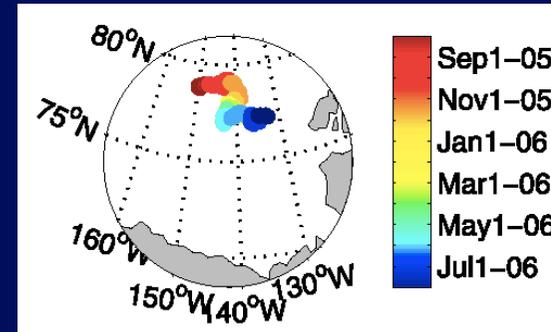


- 'Arctic summer sea-ice extent returns to the original, unperturbed extent typically within two years'however
- removal of sea ice without 'adjusting' the state of the ocean and atmosphere to reflect the ice-free climate regime is an 'ill-posed' experiment
- e.g. oceanic heat content under a decreasing sea ice cover is expected to increase significantly (Jackson et al., JGR-Oceans, 2010 & 2011)
- Oceanic heat in reality is removed only from the ocean mixed layer (10-40m) but not from the subsurface ocean

Water column structure – western Arctic

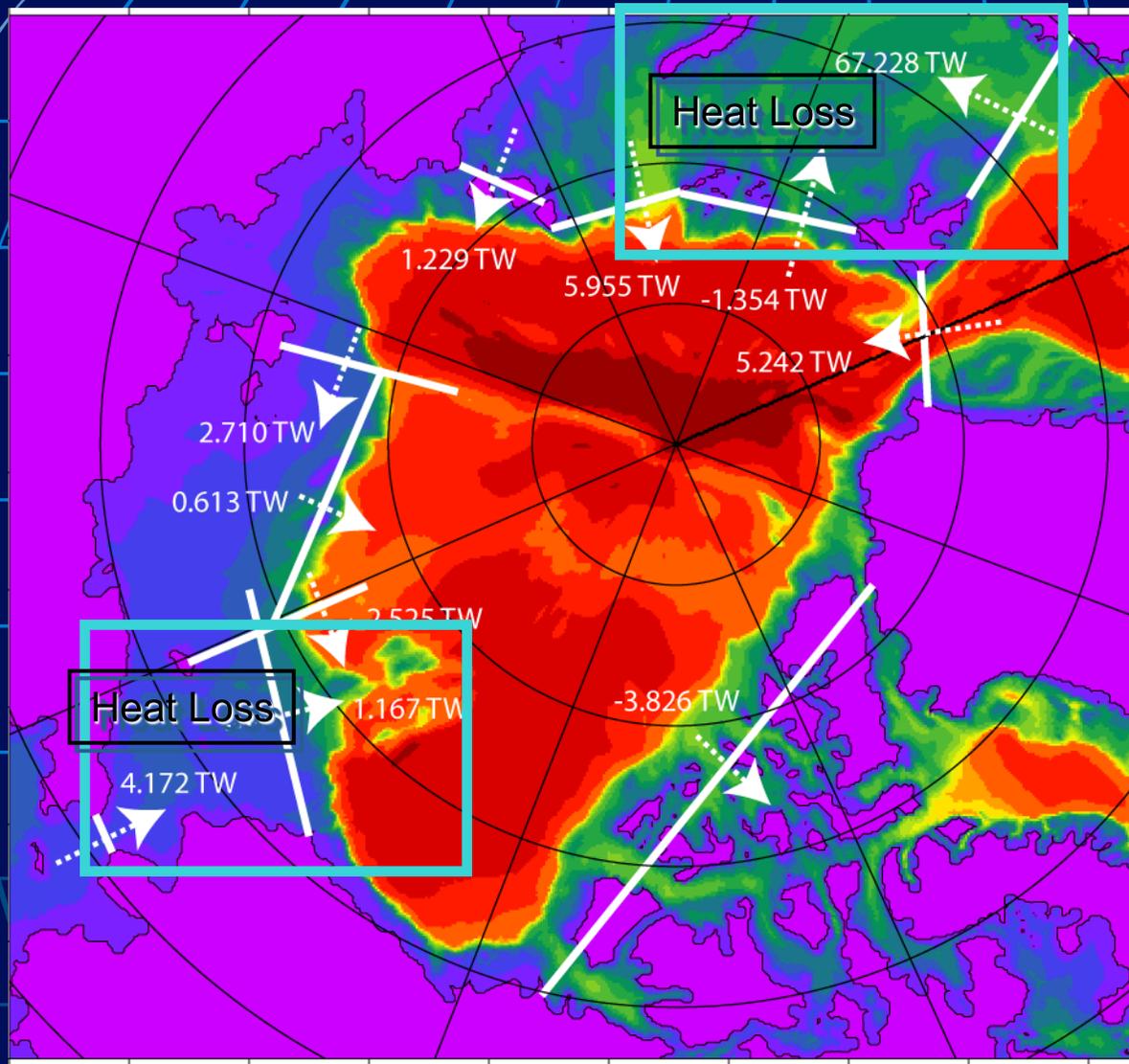


(Jackson et al., JGR-O, 2010)



- Warm water (NSTM, PSW) is present below the mixed layer in the western Arctic Ocean throughout the year
- Fall/winter cooling and sea ice formation does not remove all the heat from the upper ocean

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

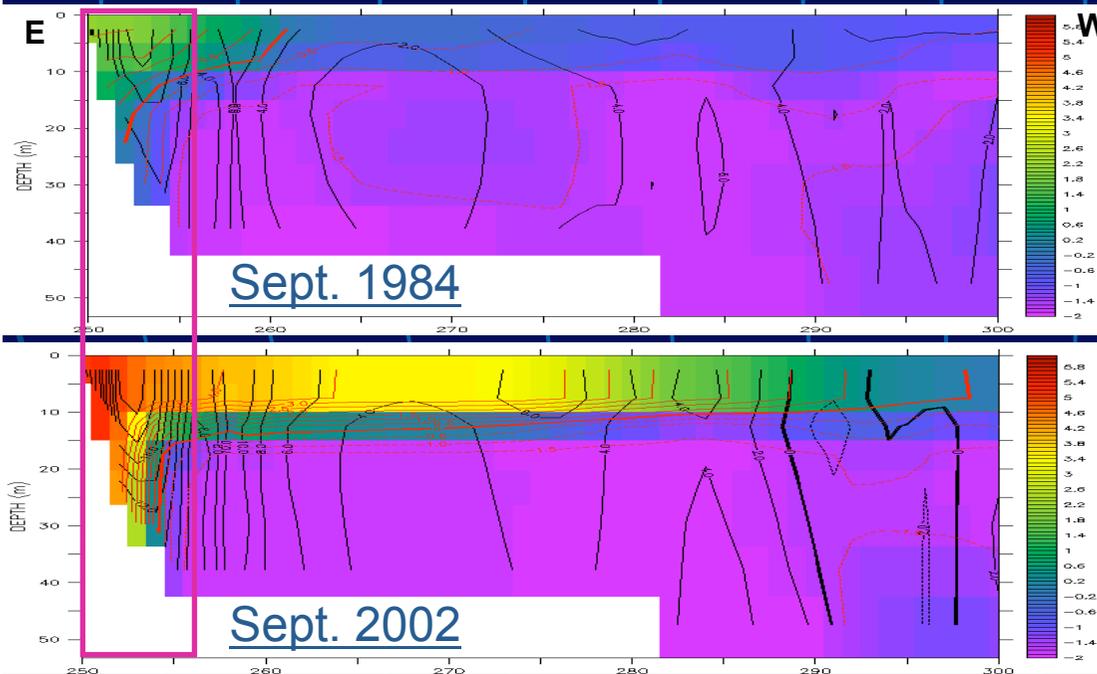
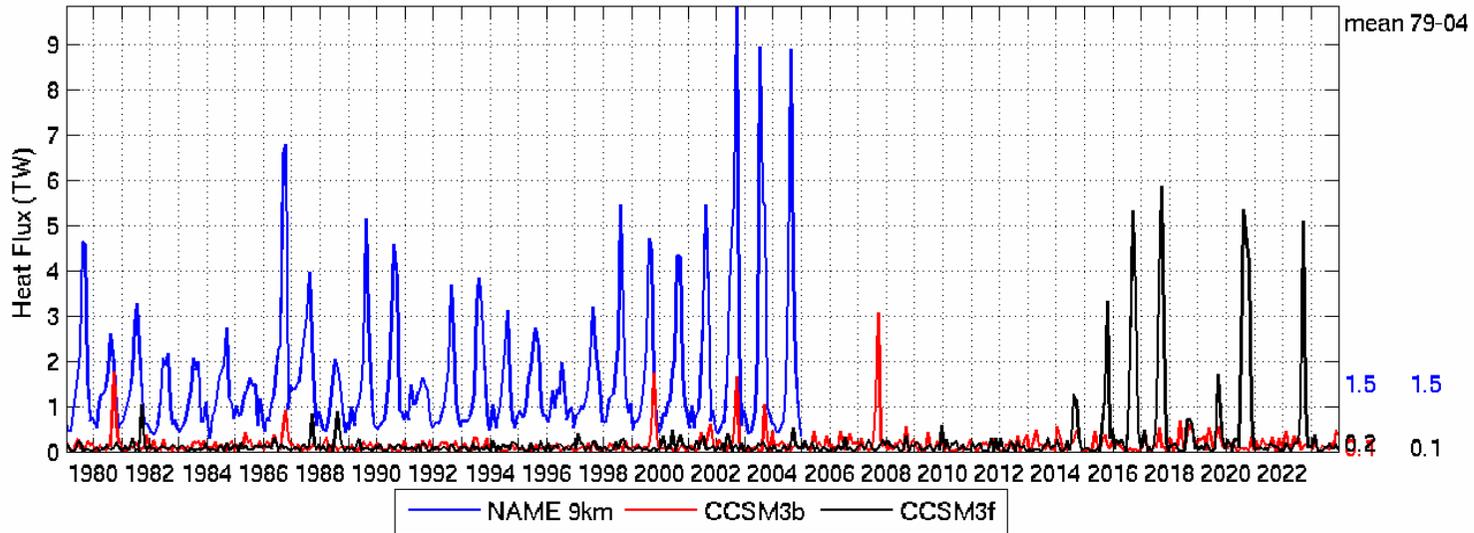
**Arctic ocean-ice-atm
feedbacks** – need more
realistic representation in
climate models

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

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

Modeled Oceanic heat flux exiting the Chukchi Shelf

NAME (new) & CCSM3 b30.040b.ES01 Chukchi Shelf Line Heat Flux (reference=Tfreeze) (Northward fluxes only) (Tref=Tfreeze)

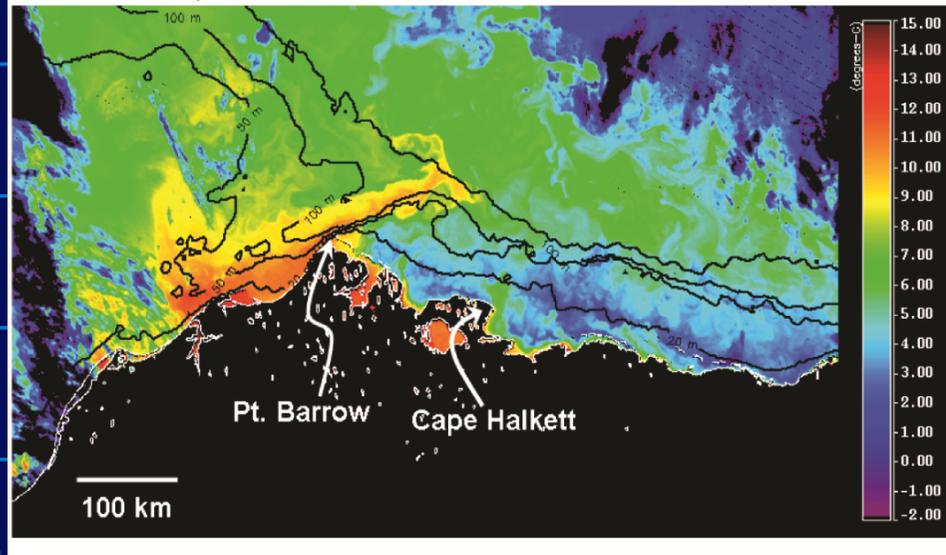


Impossible d'afficher l'image. Votre ordinateur manque peut-être de mémoire pour ouvrir l'image ou l'image est endommagée. Redémarrez l'ordinateur, puis ouvrez à nouveau le fichier. Si le x rouge est toujours affiché, vous devrez peut-être supprimer l'image avant de la réinsérer.

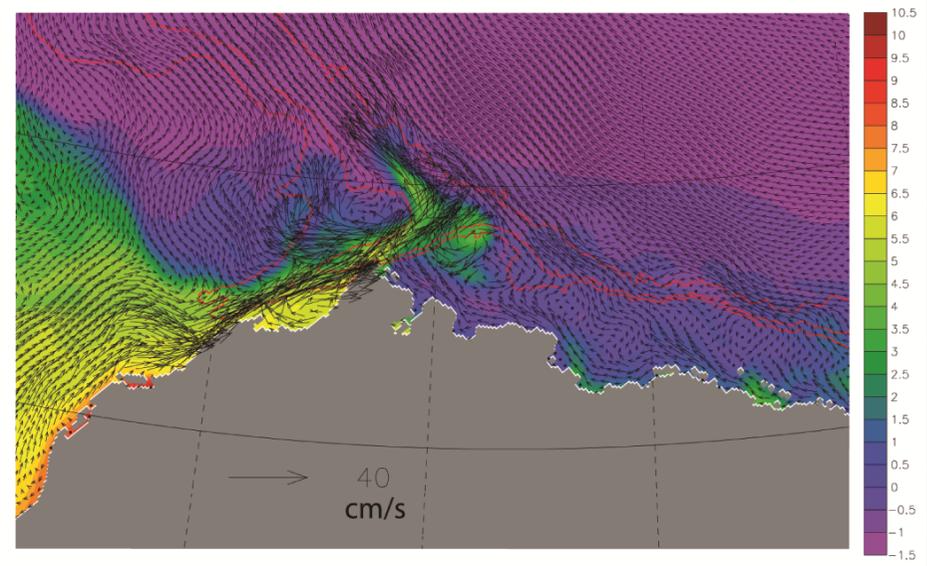
Heat Flux via Alaska Coastal Current accounts for ~67% of the Total Heat Flux across Chukchi Shelf Line

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.



2km SST and Vel. (cm/s) 0–5m 1988 08 15

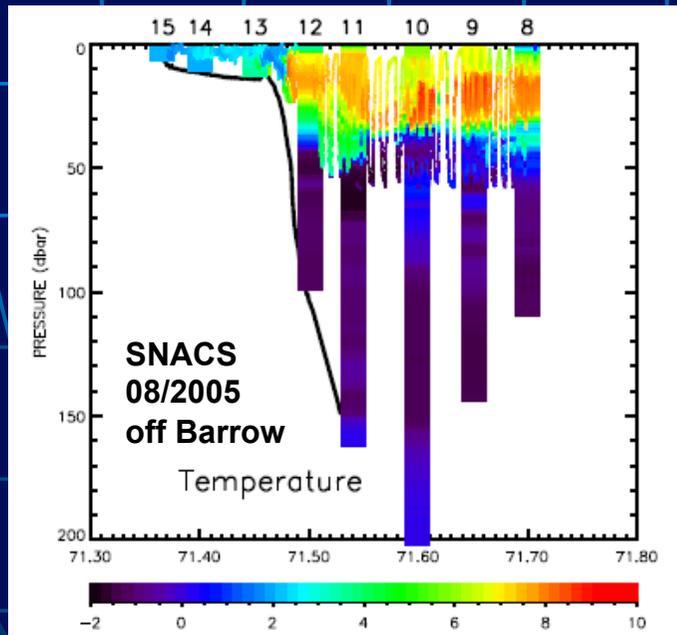
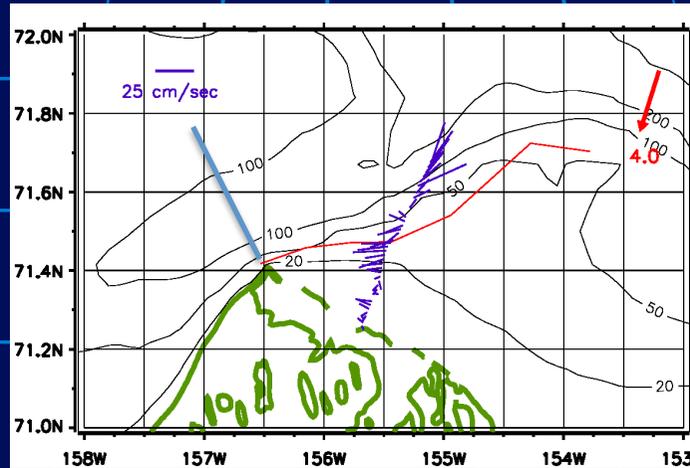


MODIS SST – 08/10/2007, 2335UT

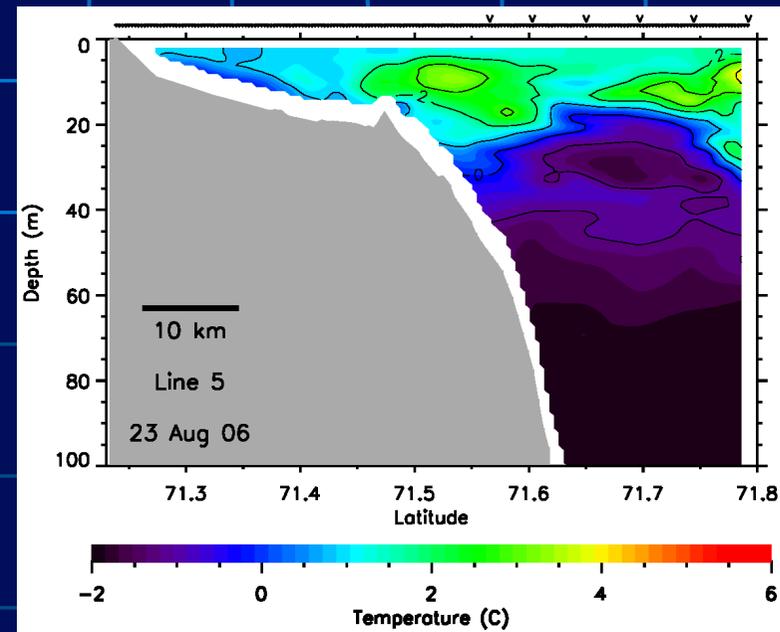
Modeled SST and Velocity – 08/15/1988

- 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 $\sim 2 \text{ km}$ models can capture details of ocean circulation, eddy generation and heat distribution

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

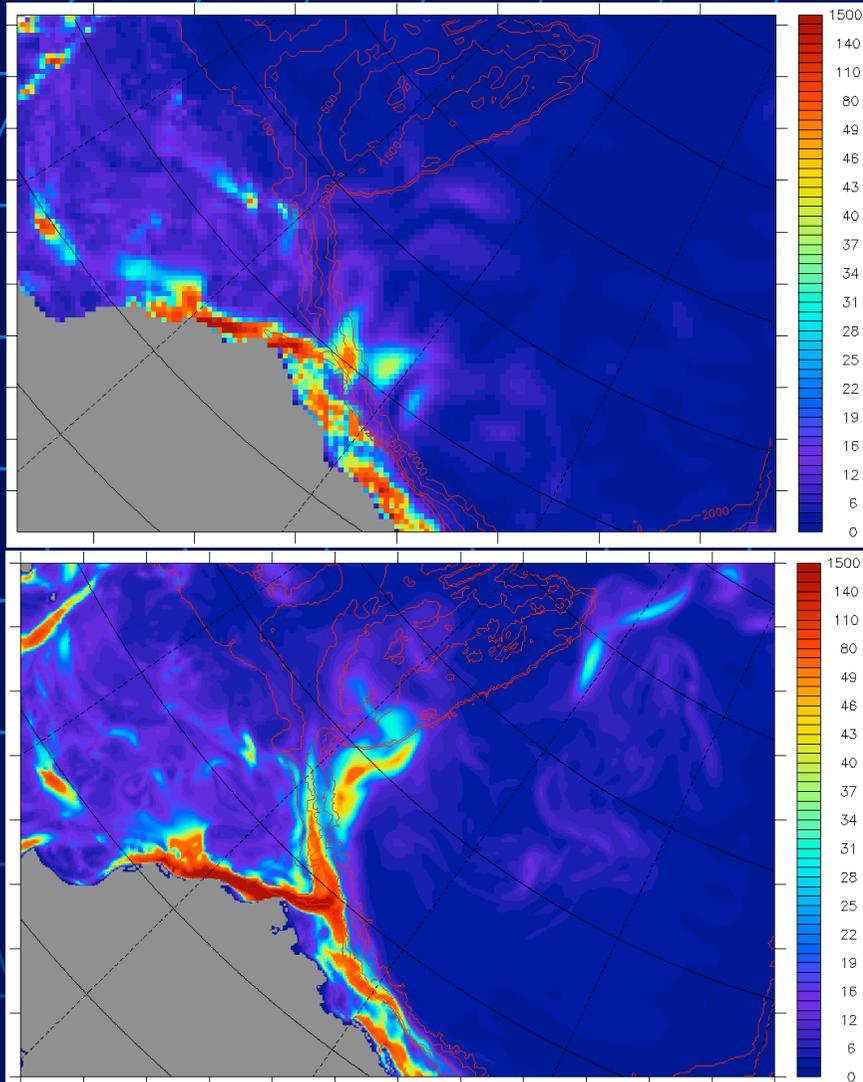


(Okkonen et al., JGR 2009)

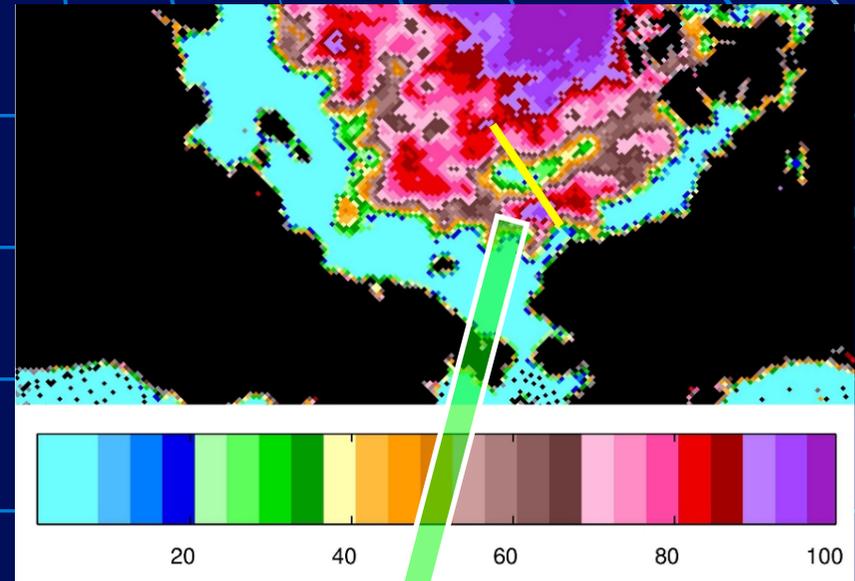


(courtesy of S. Okkonen)

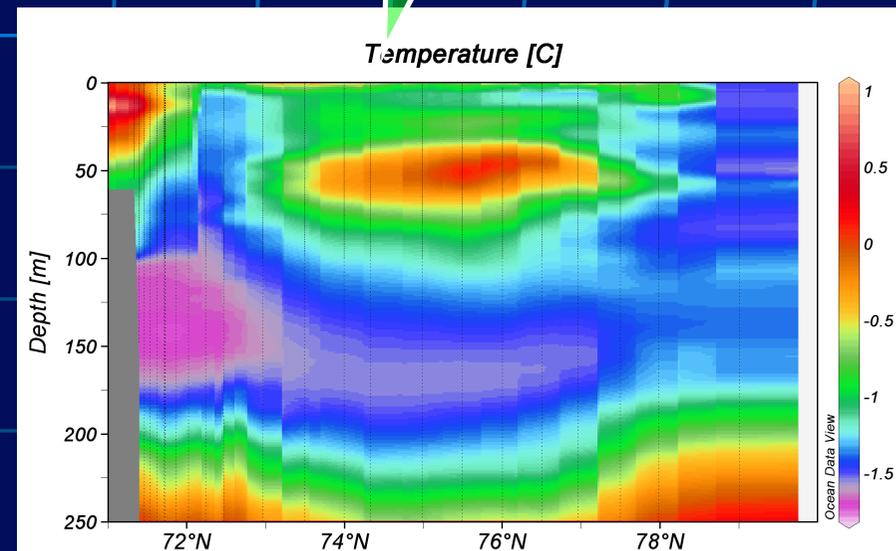
Eddy activities over the Northwind Ridge : Summer (JAS) mean EKE in the upper 110m from 1/12° (top) and 1/48° (bottom) model



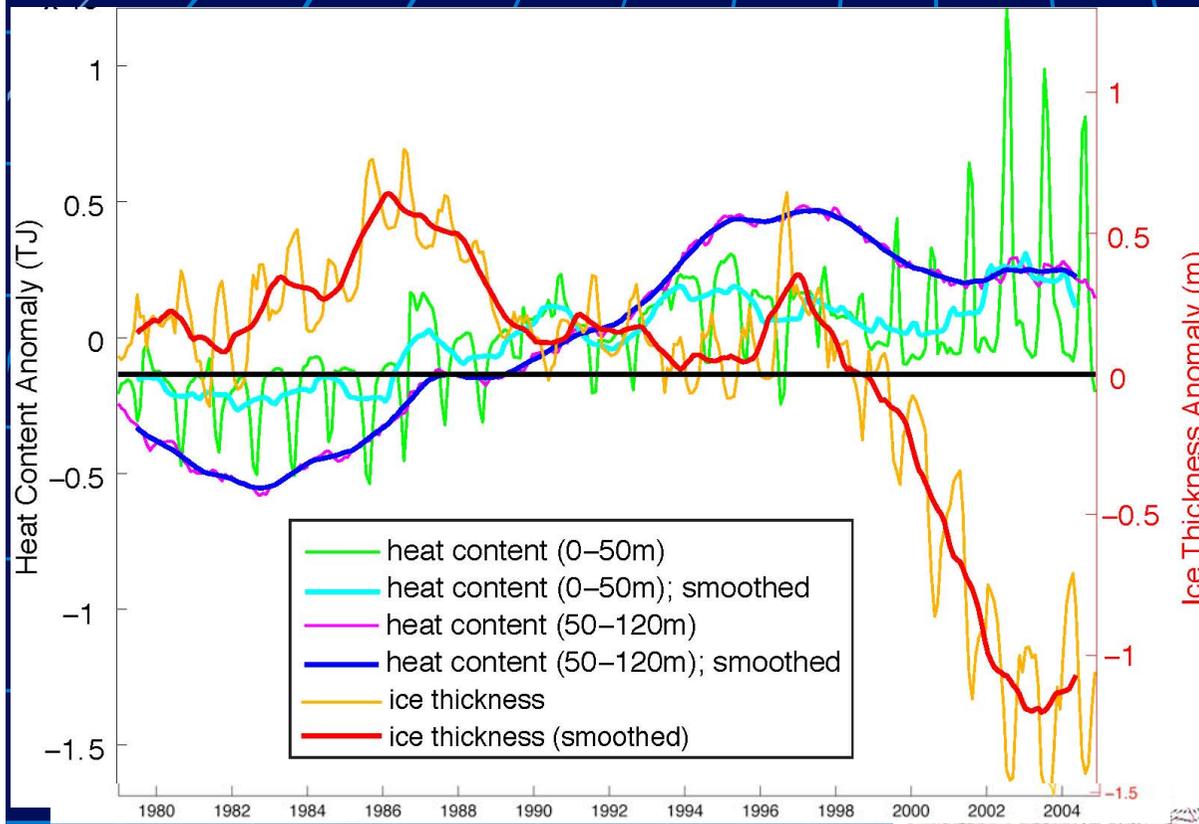
Emergence of open-ocean Polynya in the Arctic Ocean



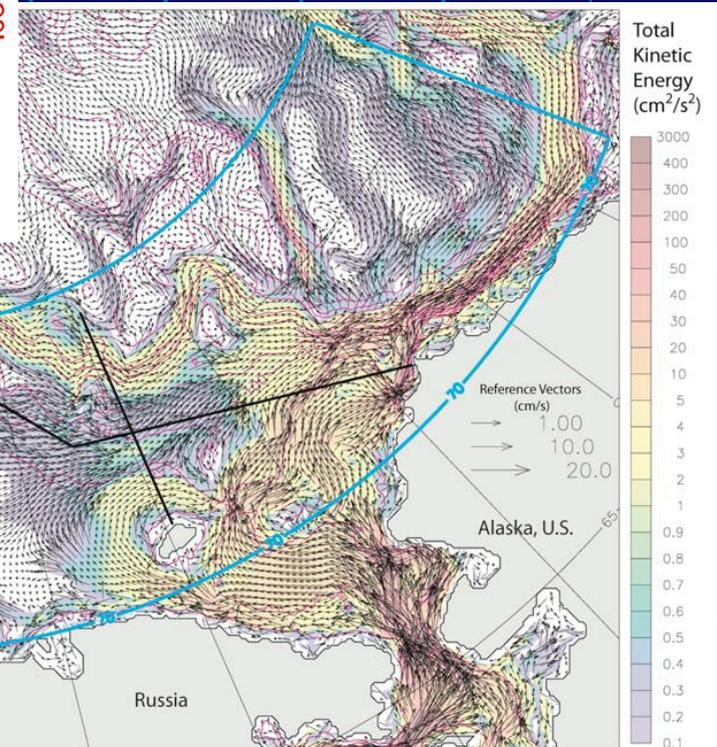
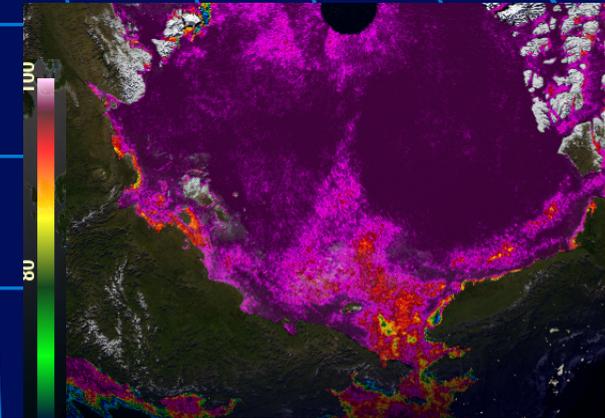
Vertical section of temperature along 150W (Yellow line in the sea ice concentration map (08/27), CCGS Louis S. St-Laurent JWACS2006) – courtesy of K. Shimada



Modeled Upper Ocean Heat Content and Ice Thickness Anomalies



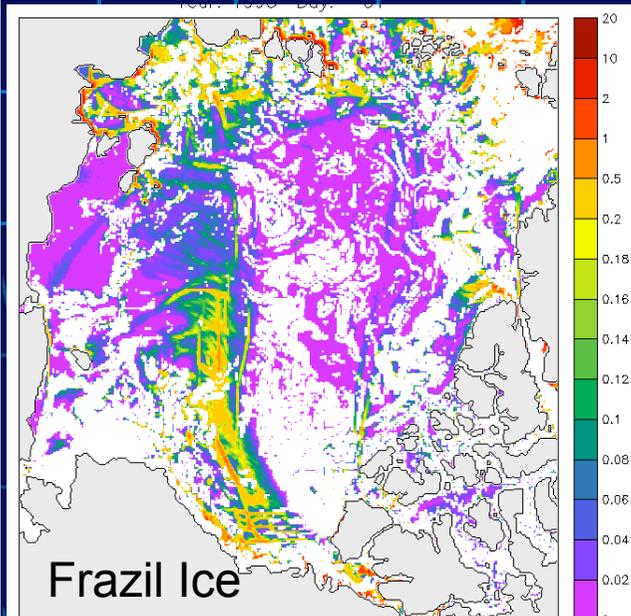
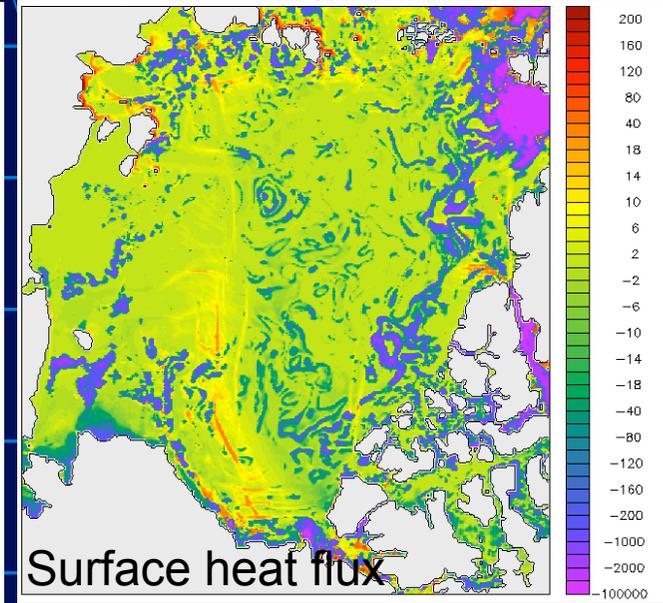
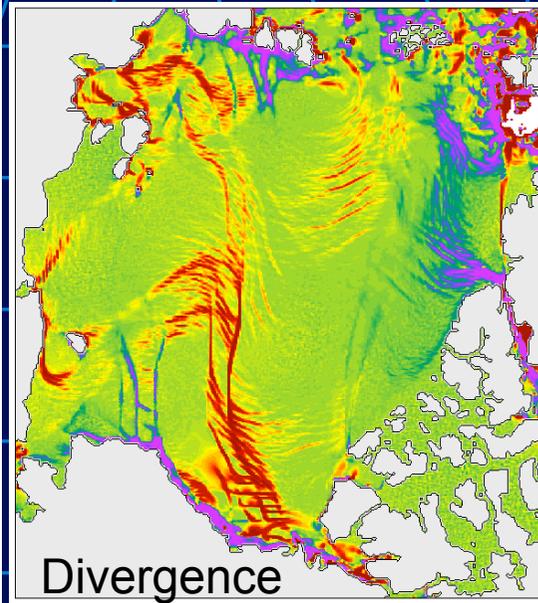
(Ice Removed)



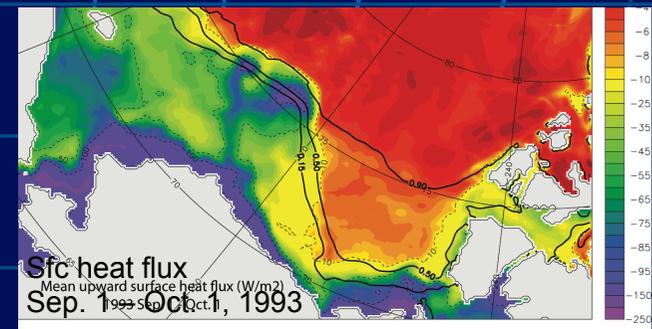
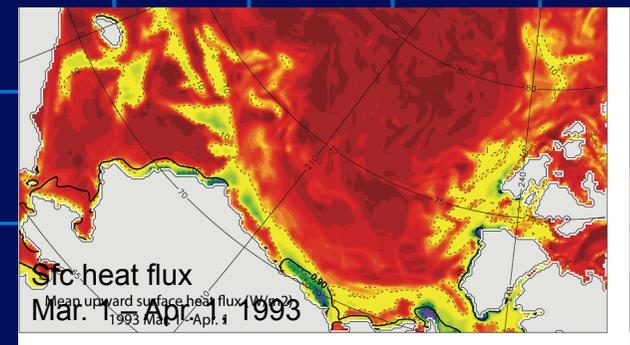
Heat content anomalies accumulated in the sub-surface ocean since mid-1990s can explain over 60% of sea ice thickness anomalies



RACM ice drift, deformation, surface heat flux, ice production



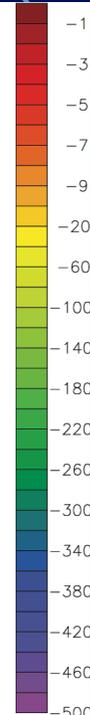
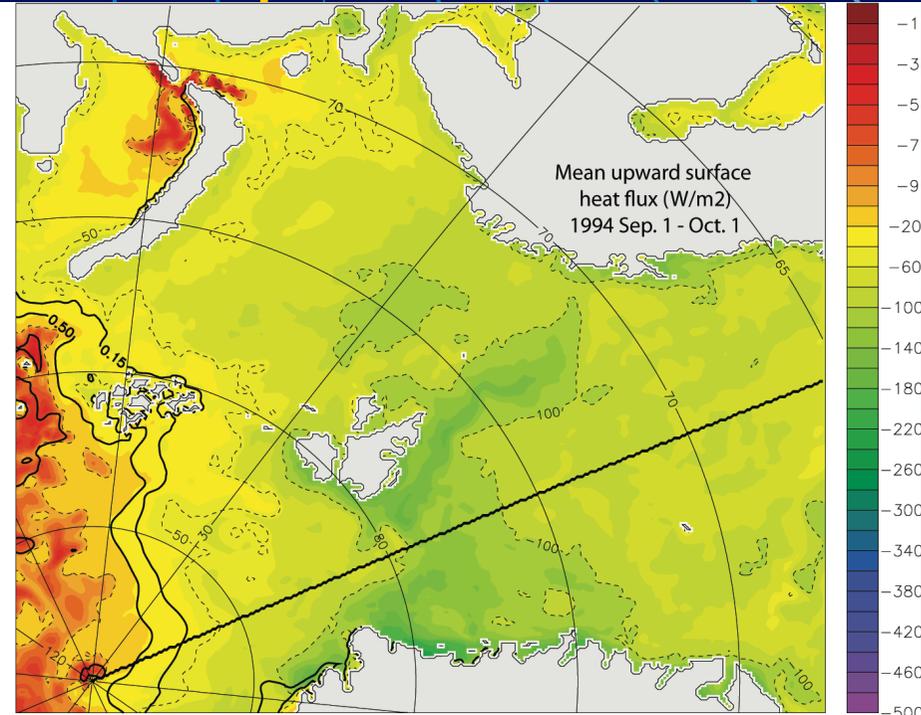
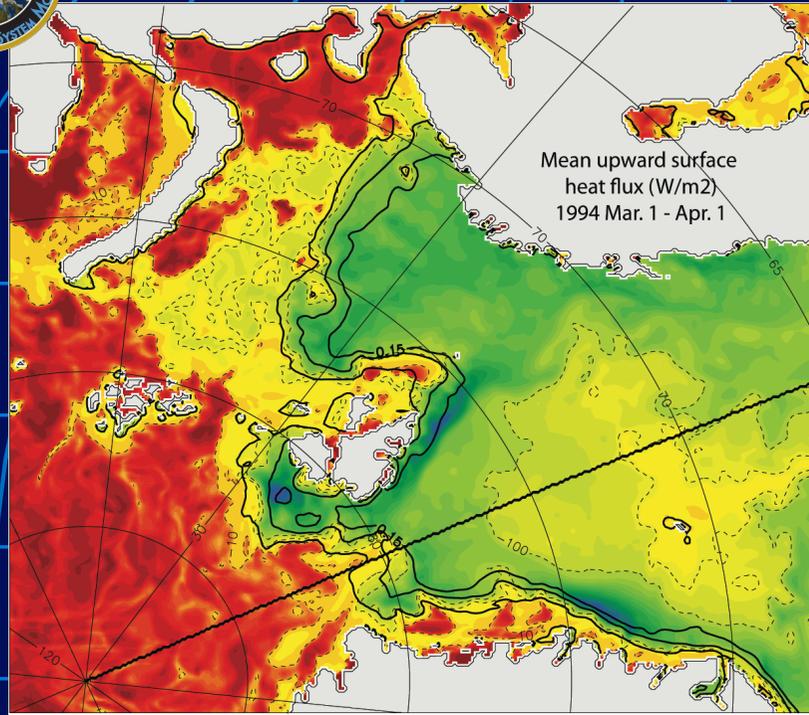
Small-scale sea-ice deformations contribute to surface heat flux and ice production, especially in winter



March 2, 1993, 0000Z



RACM Oceanic Heat Transport / Surface Flux



	Observations	NAME: POP/CICE	CCSM
Fram Strait (N-Inflow)	6.6 Sv / 50 TW	6.9 Sv / 45 TW	2.0 Sv / 17 TW
FJL – NZ (Net)	NA / Near zero	2.6 Sv / 2.2 TW	4.35 Sv / 31 TW

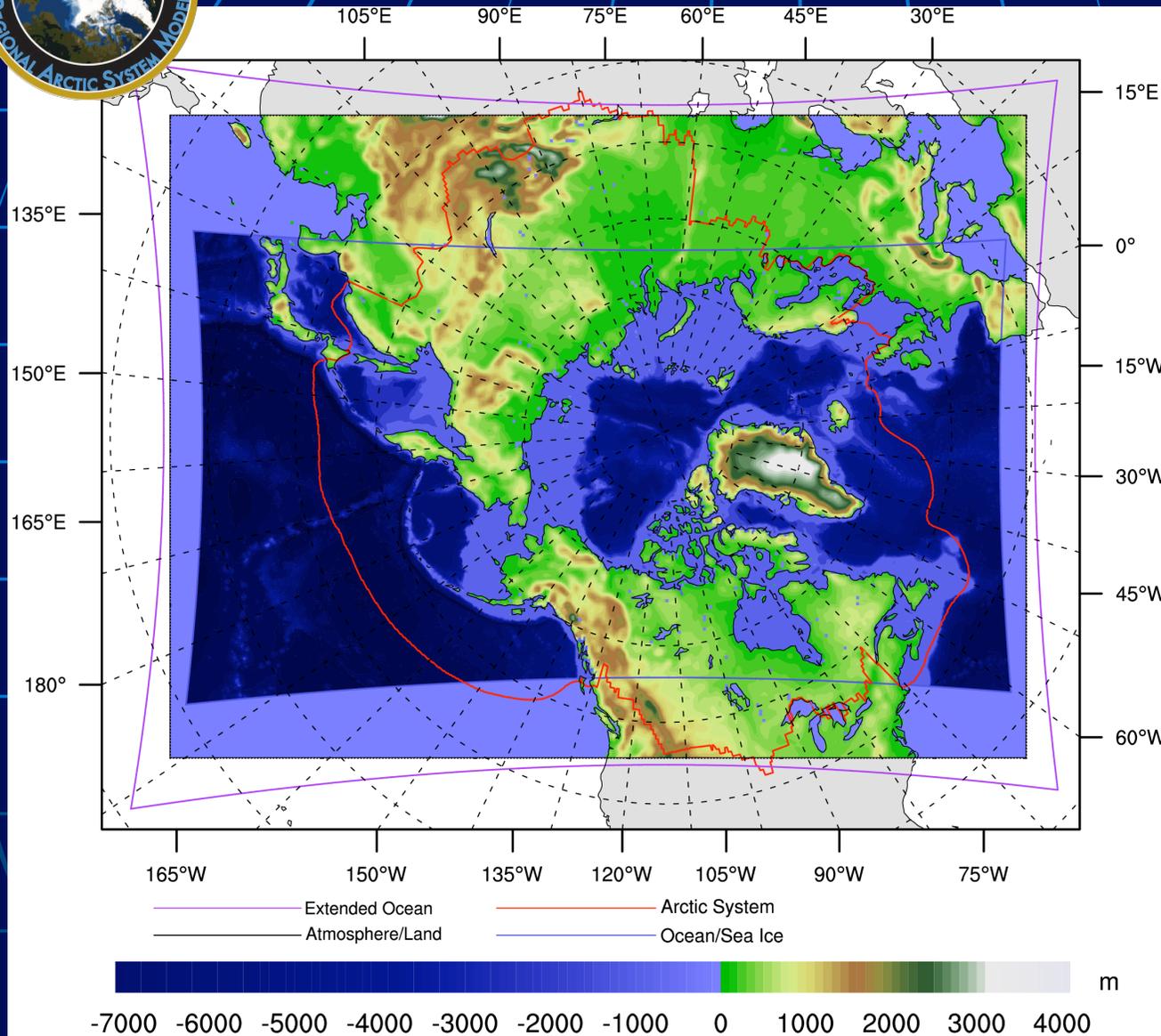
CCSM3 (IPCC-AR4 b&f) transports; NAME transports (Maslowski et al., JGR, 2004)
 Obs: Fram Strait - Courtesy of A. Beszczynska-Möller, AWI; FJL-NZ - Gammelsrod et al., 2008

Conclusions

- 1. Oceanic heat convergence have contributed critical forcing to sea ice melt in the western Arctic since the mid-1990s**
- 2. Eddy-resolving regional climate models of the Arctic Ocean are required to better understand the role of ocean forcing of sea ice variability**
- 3. Continuous observations of Arctic sea ice and ocean at both local/process and basin-wide scales needed for model validation, improvements and syntheses**
- 4. Air-sea interactions and feedbacks under diminishing ice cover must be represented in global climate models to improve their prediction of Arctic climate change**



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)

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

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.