Validation Analysis of the 0.72° HYCOM/CICE 4.0 2003-2006 run

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Arctic Study at COAPS FSU

Participant in the International partnership program funded by NSF:

Arctic Ocean Model Intercomparison Project (AOMIP).

AOMIP Goals:

(1) Validate and improve Arctic Ocean models in coordinated fashion

- identify the most consistent errors across models

- propose solutions

- select the most reliable and consistent Arctic Ocean / Sea Ice models

(2) Investigate processes using observations and model results

- How to avoid restoring and flux correction?

- Formation of the Arctic Ocean halocline

- Parameterization of stress-driven and convection-driven mixing

(3) Climate change

- 50-year experiment under "observed" forcing and 100-year experiment under reconstructed forcing

AOMIP Models

Institution	AWI	GSFC	UW	NPS	UMASS / WHOI	FSU (ARCc0.72 / ARCc0.08)
Ocean Model	MOM	POM	MOM	MOM	FVCOM	HYCOM
Ice Coupled	Yes	Yes	Yes	Yes	Yes	Yes
Vertical Levels	Z levels	sigma	30 Z levels	30 Z levels	40 s-layers	32 hybrid
Resolution	>20 km		~22 km	~18 km	1 km shelf ~15 km deep	~30 km / ~3 km
Min Depth			15 m	45 m	5 m	50 m / 10 m

HYCOM/CICE 4.0 Overview

- Developed at NRL coupled HYCOM/CICE application
  - ESMF-based HYCOM provided by NRL-SSC
  - ESMF-based CICE 4.0 provided by LANL
  - All coupling by NRL-SSC

- HYCOM/CICE at NRL
  - Initially for Arctic-only domain and a Bering Sea domain for testing data assimilation
  - Soon for fully global domain

Los Alamos Sea Ice Model (CICE 4.0)

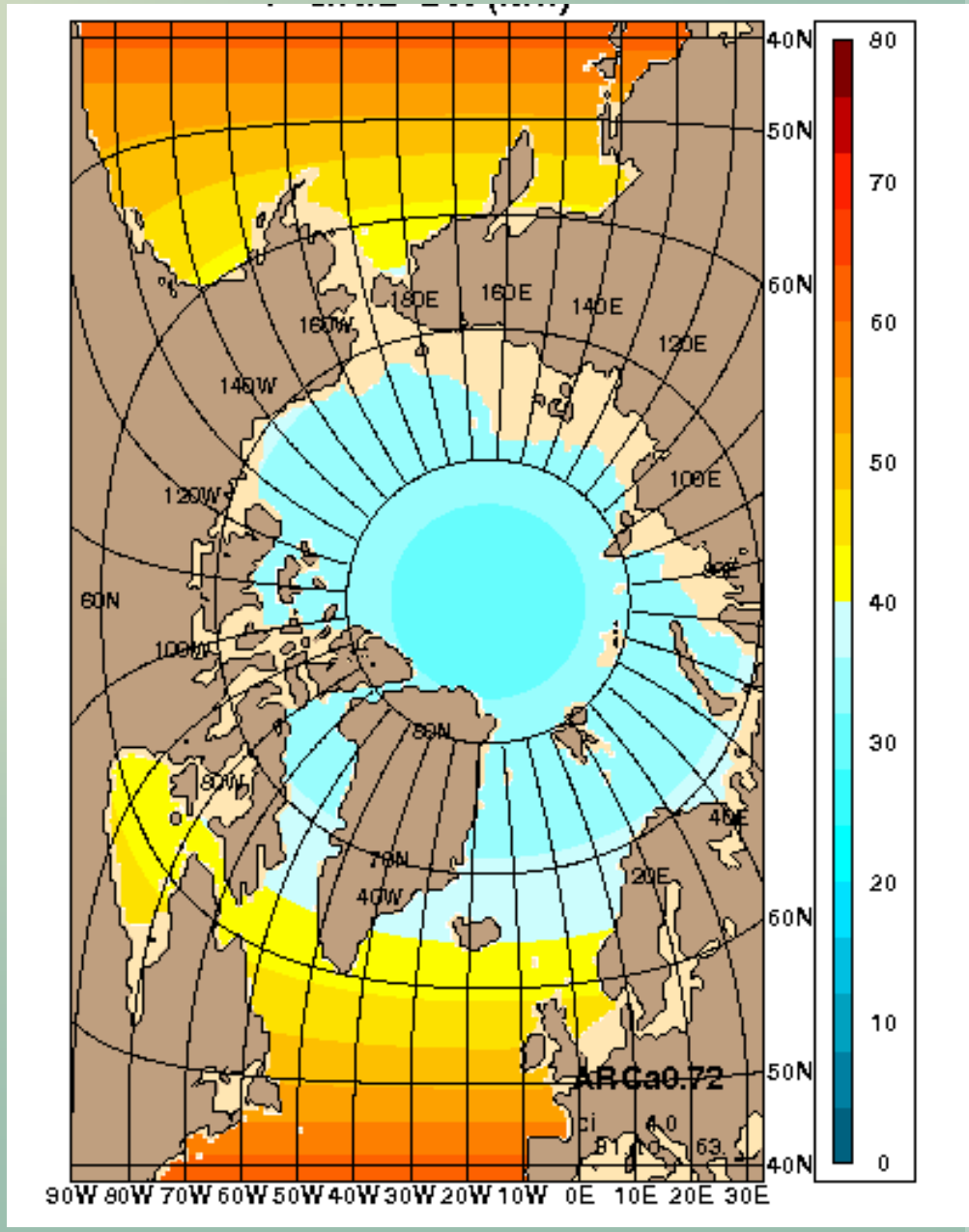
- State of the art sea-ice model
  - Multi-category ice thickness
  - Energy conserving thermodynamics
  - Energy-based ridging scheme
  - Elastic-viscous-plastic (EVP) ice dynamics

- Open Source ice model
  - http://climate.lanl.gov/Models/CICE

HYCOM/CICE ARCc 0.72°

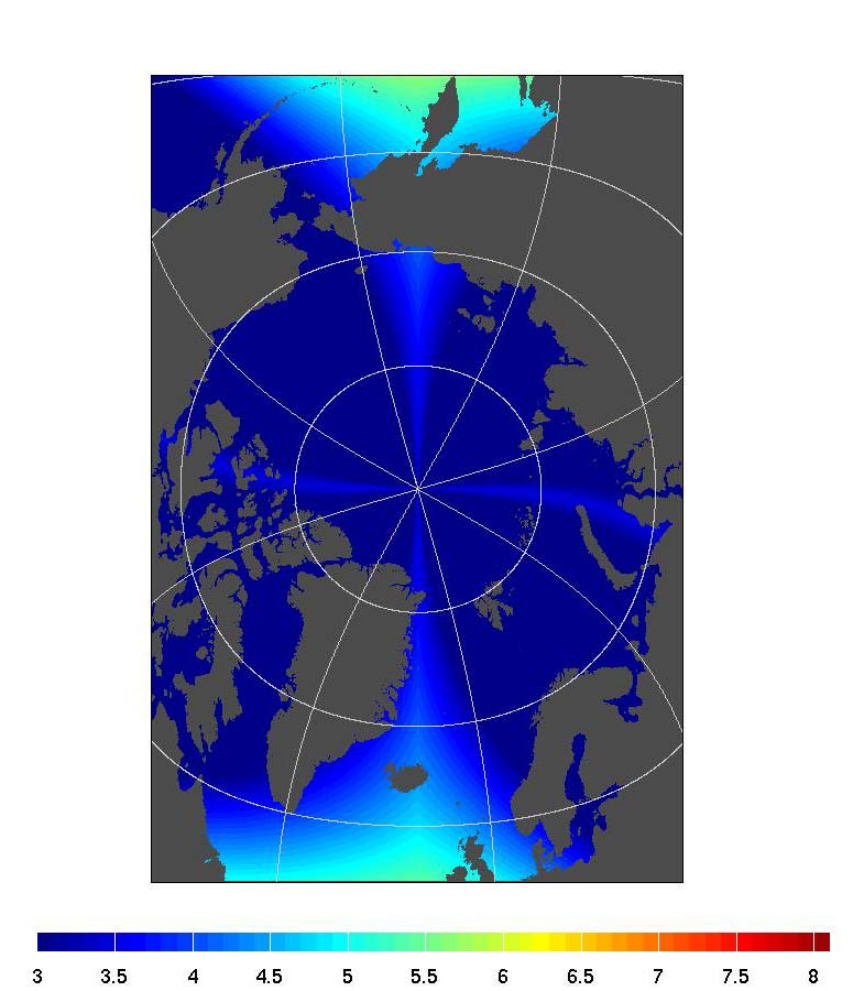
- Run for 2003-2006
- Arctic-only grid is a sub-region of the tripole grid
  - Bottom in the Atlantic, top in the Pacific
- Atlantic and Pacific boundaries
  - Closed (no-ice) in CICE
  - Closed but with relaxation to climatology in HYCOM
- The model coastline is at the 50 m isobath (closing the Bering Strait)
- 3 hourly NOGAPS 0.5° atmospheric forcing fields

0.72° Arctic P-grid DX (km)



HYCOM/CICE ARCc0.08

0.08° Arctic grid resolution (km)



Run for 2005-2008

The model coastline is at the 10 m isobath (Bering Strait open).

3 hourly NOGAPS 0.5 degree atmospheric forcing fields

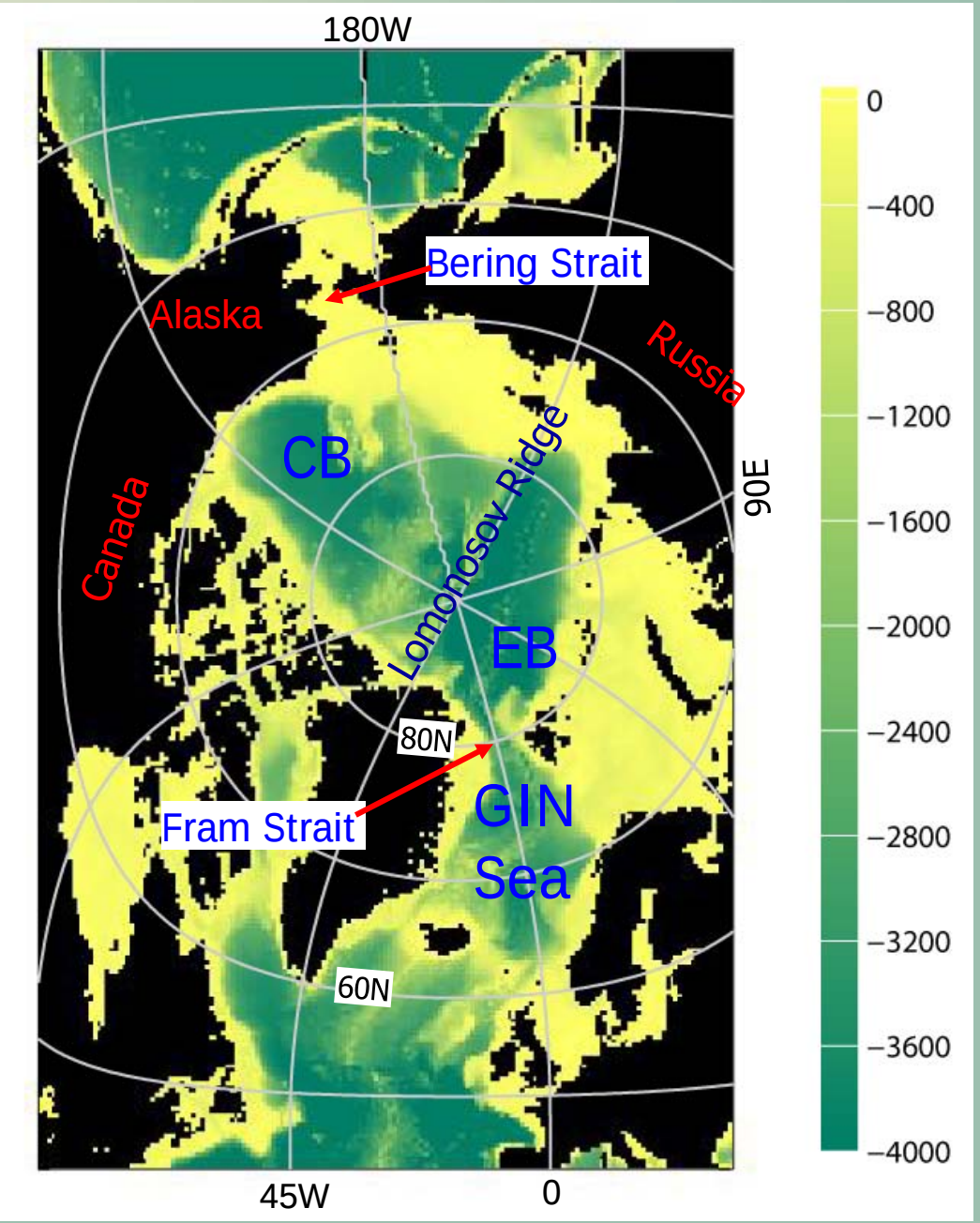
OBs are forced by the 1/12° global HYCOM

Ocean model is initialized from 1/12° non-assimilative global HYCOM

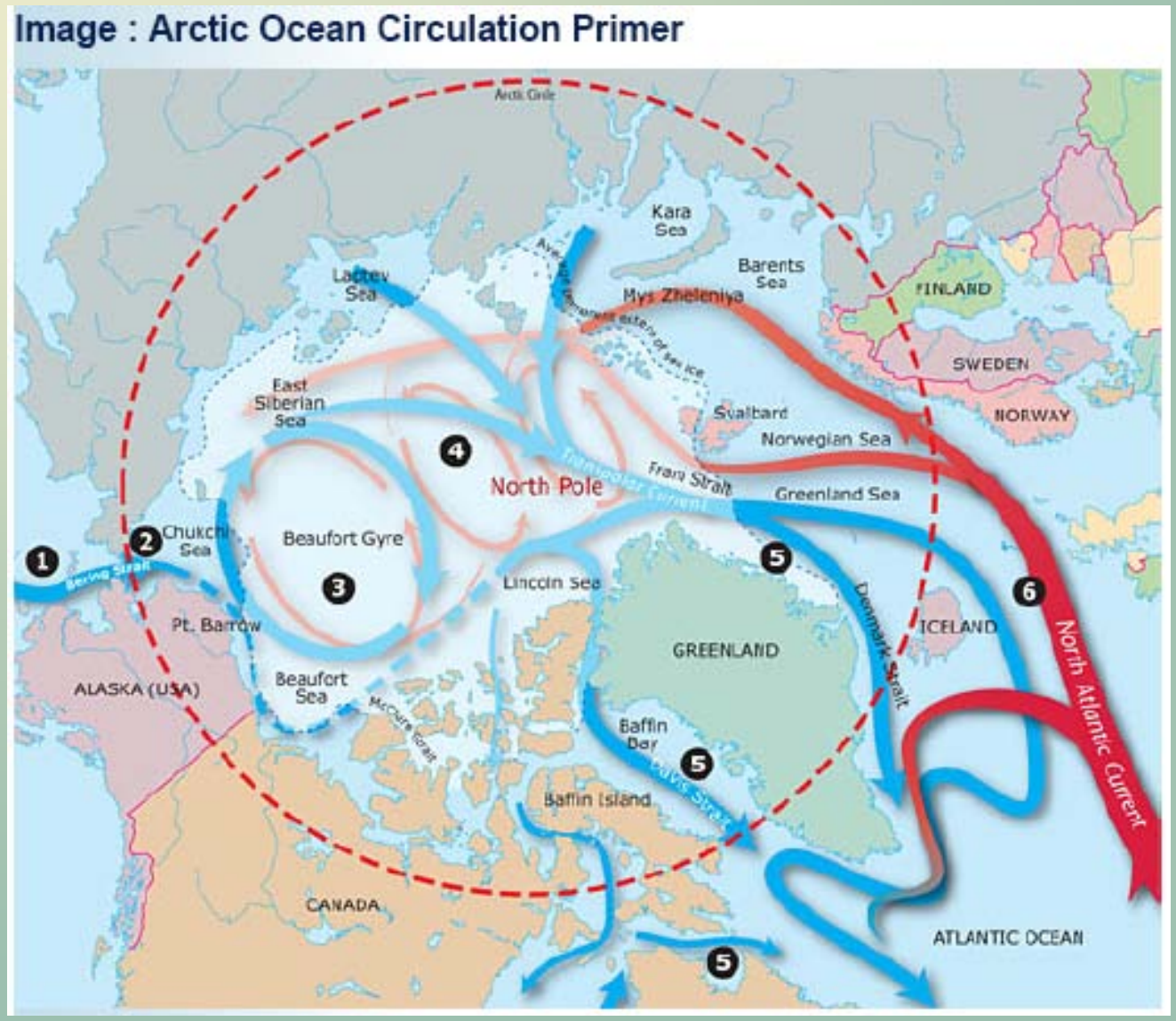
Background: Arctic Ocean

Arctic Ocean Bathymetry

(NGDC ETOPO-2)

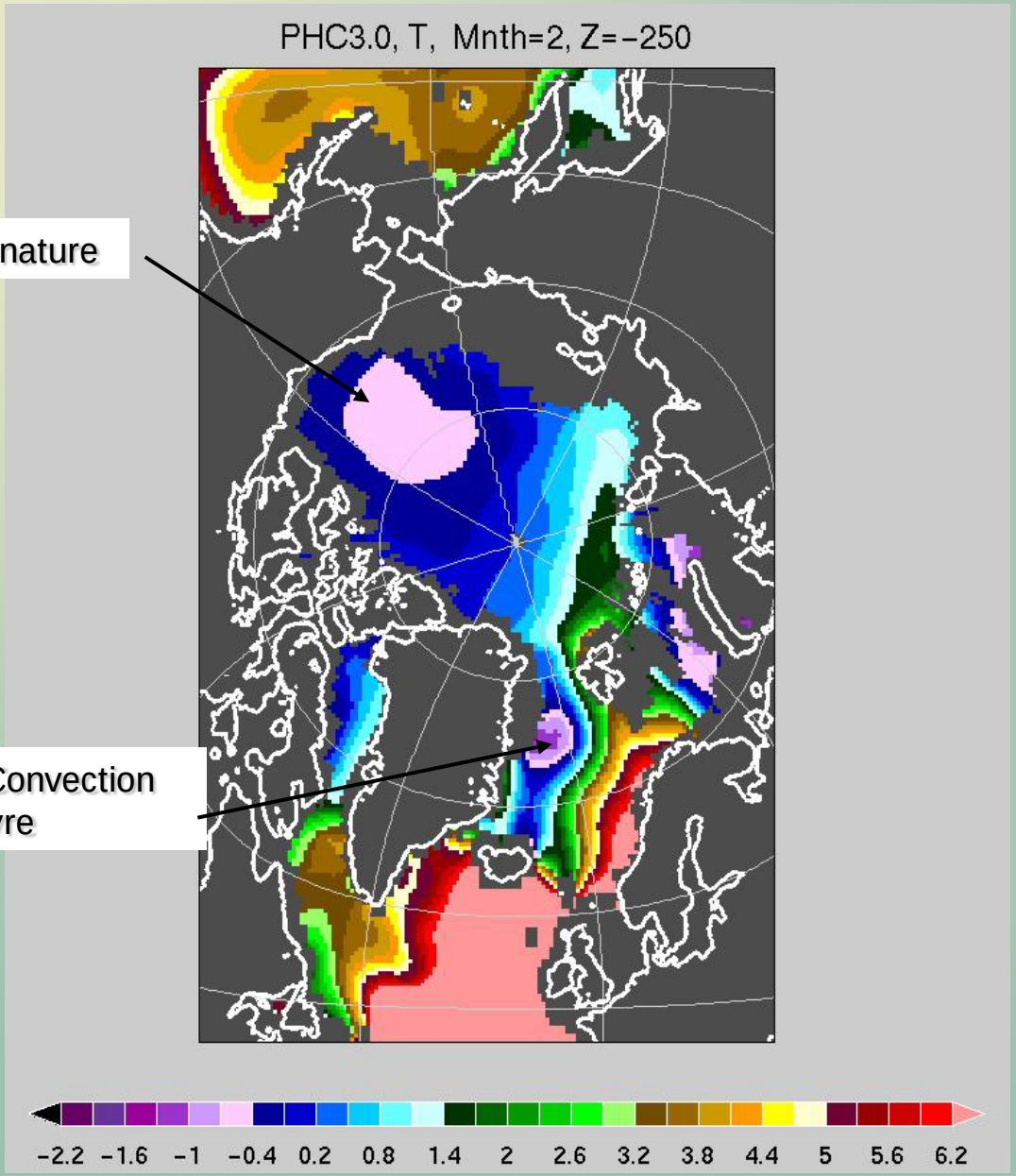


Arctic Ocean Circulation



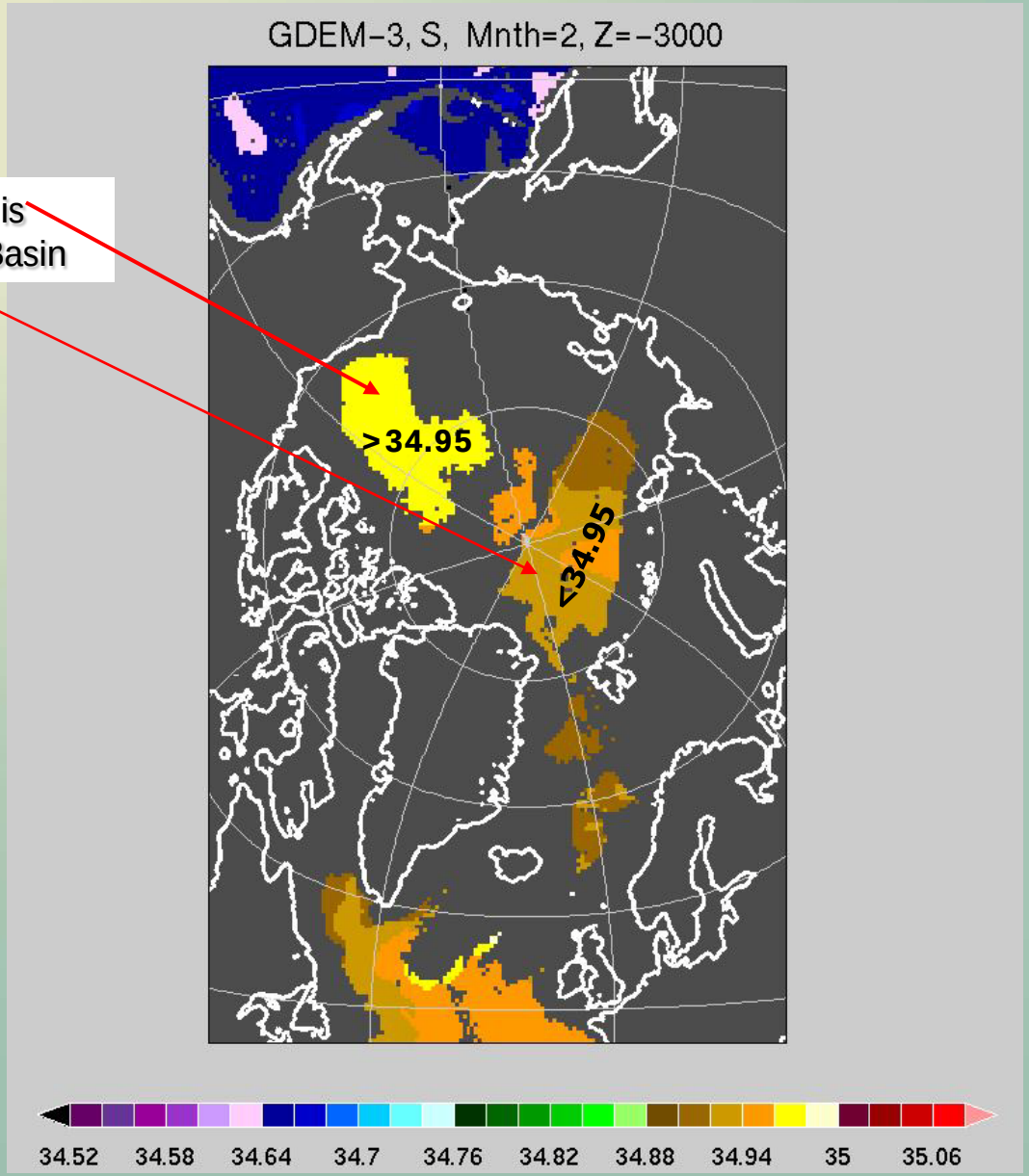
WHOI: www.whoi.edu

Temperature, February 250 m, PHC 3.0



GDEM3, Salinity at 3000 m

The deep Canadian Basin is saltier than the Eurasian Basin

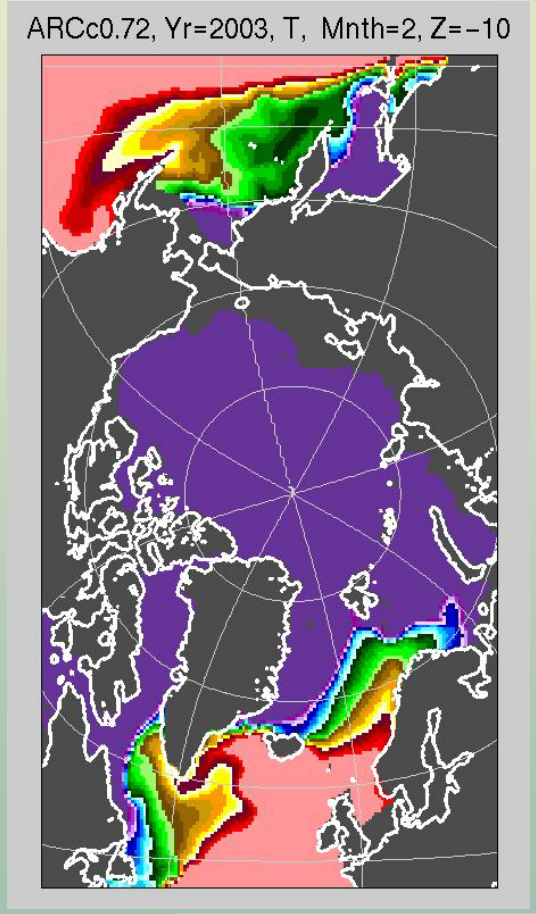


Analysis of ARCc 0.72°
2003-2006 Run

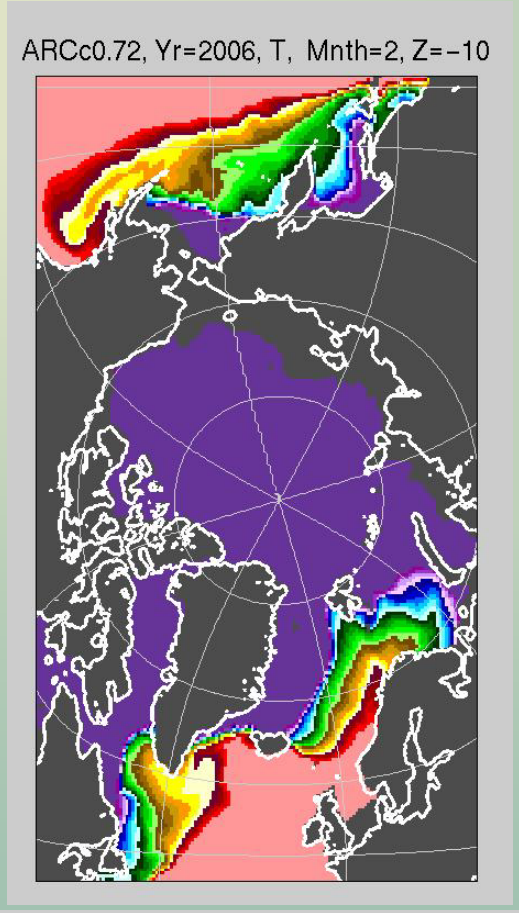
Near-Surface Temperature, February

HYCOM/CICE ARCc 0.72° grid

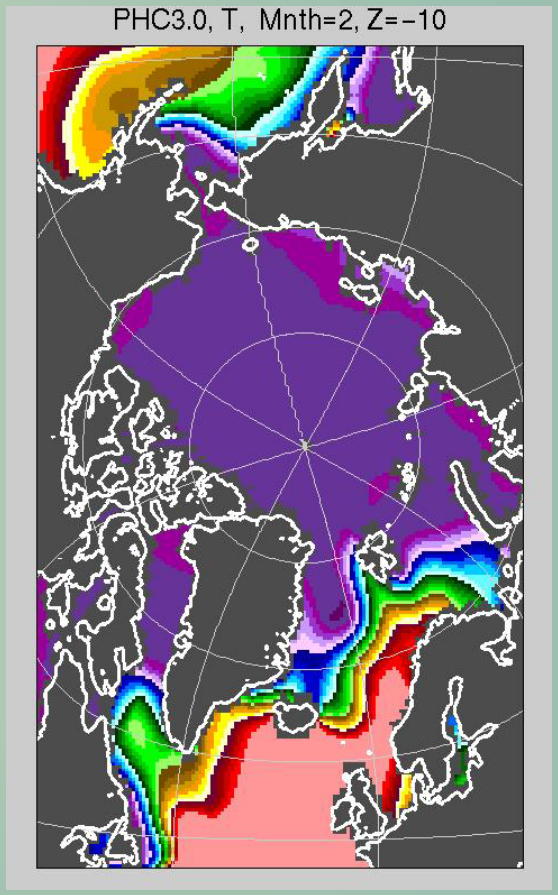
2003

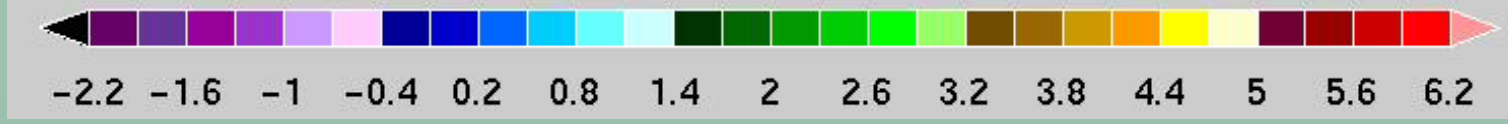


2006



PHC 3.0

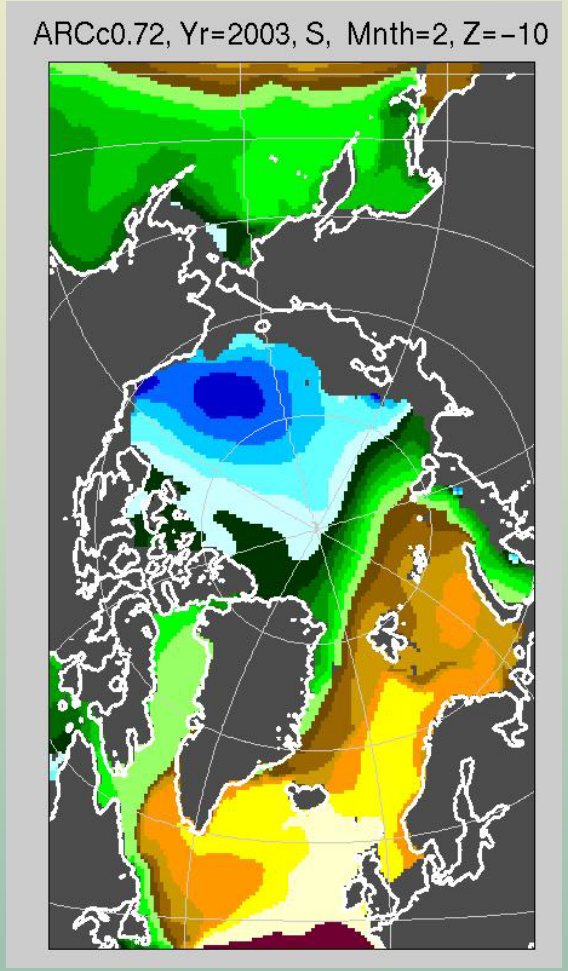




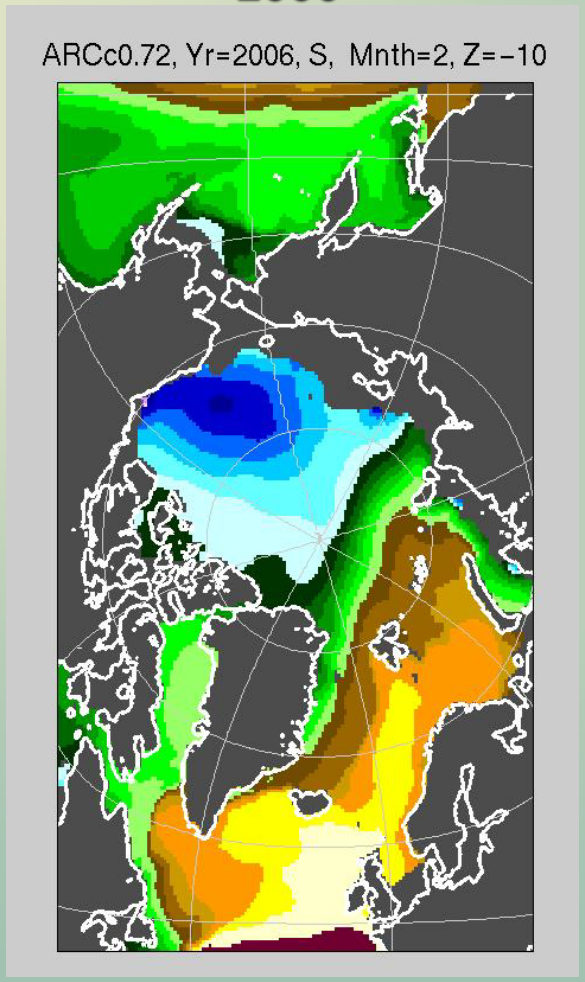
Near-Surface Salinity, February

HYCOM/CICE ARCc 0.72° grid

2003



2006



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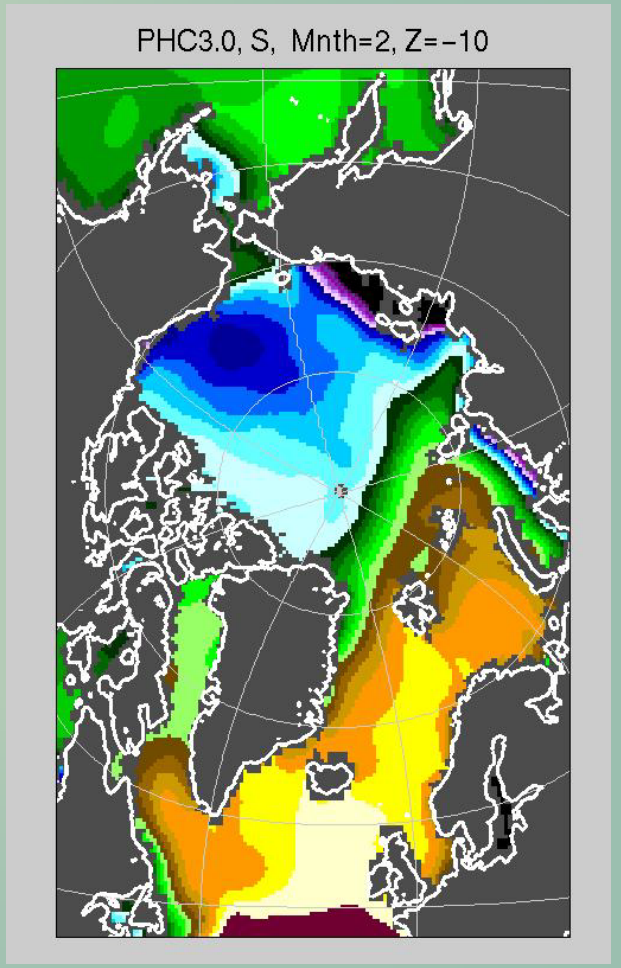
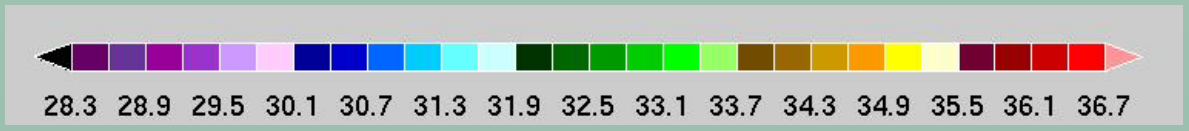
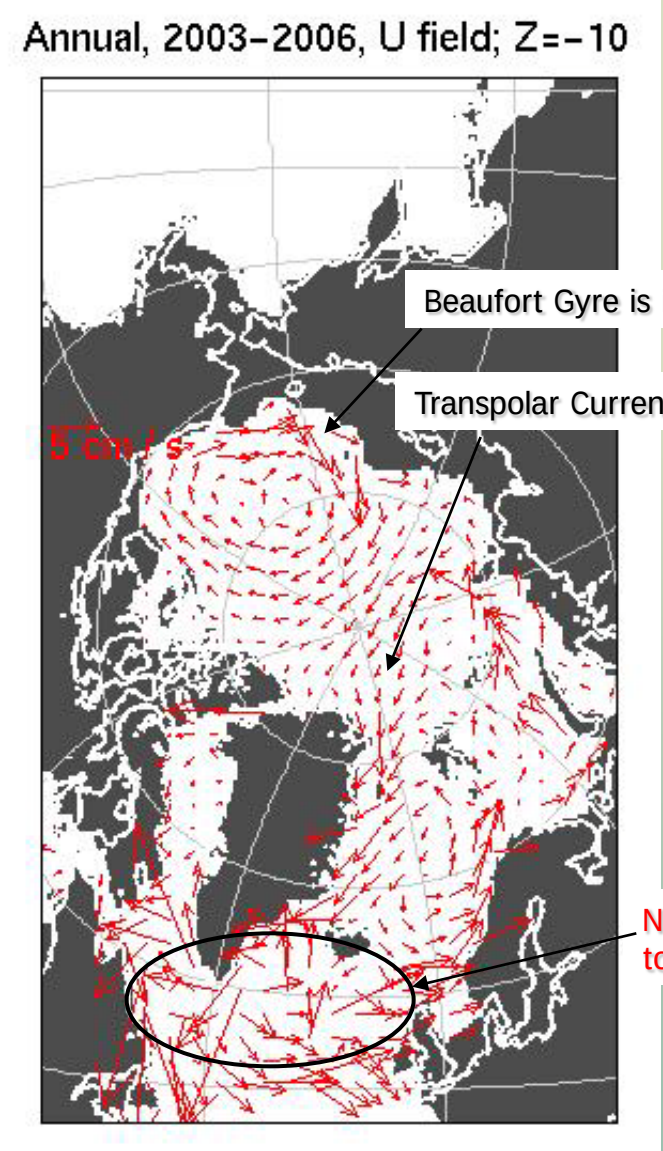


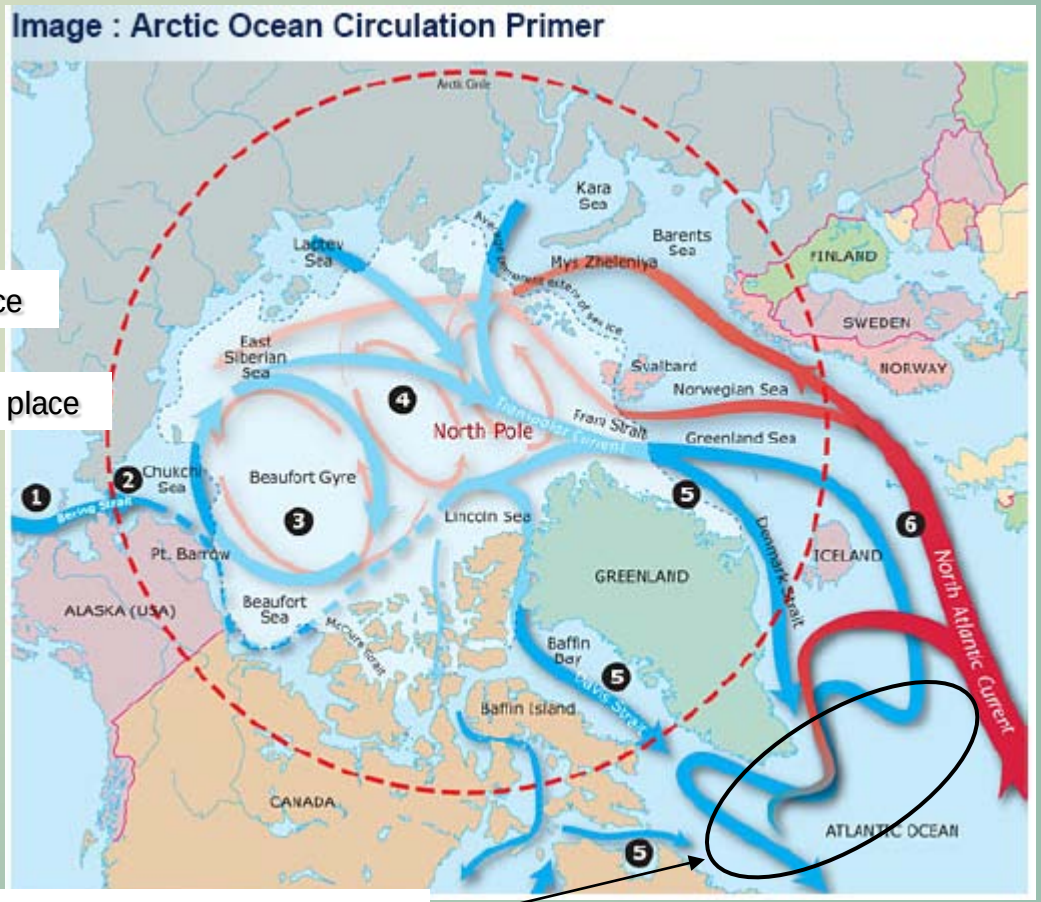


Annual Mean Near-Surface Velocity Field



Beaufort Gyre is in place

Transpolar Current is in place



North Atlantic Gyre does not seem to be reproduced in the model

WHOI: www.whoi.edu

250 m Fields

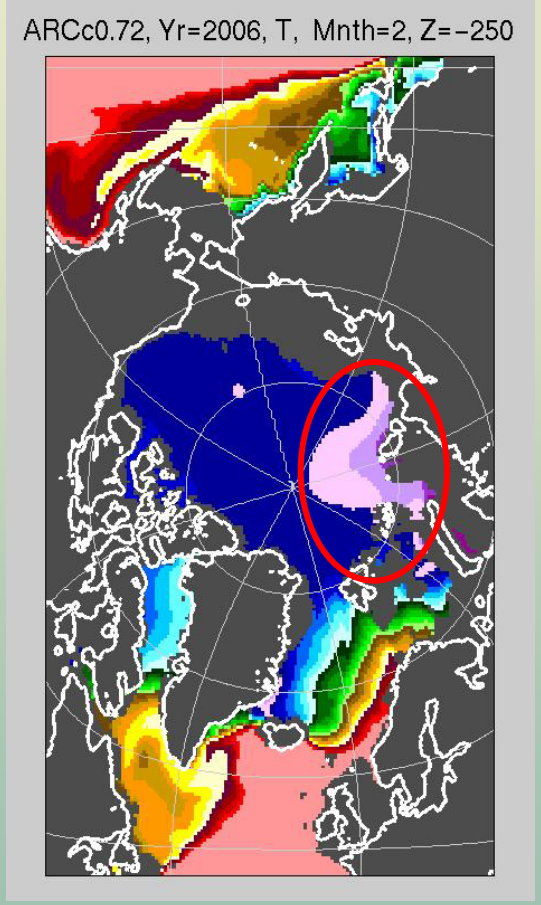
from

HYCOM/CICE ARCc 0.72°

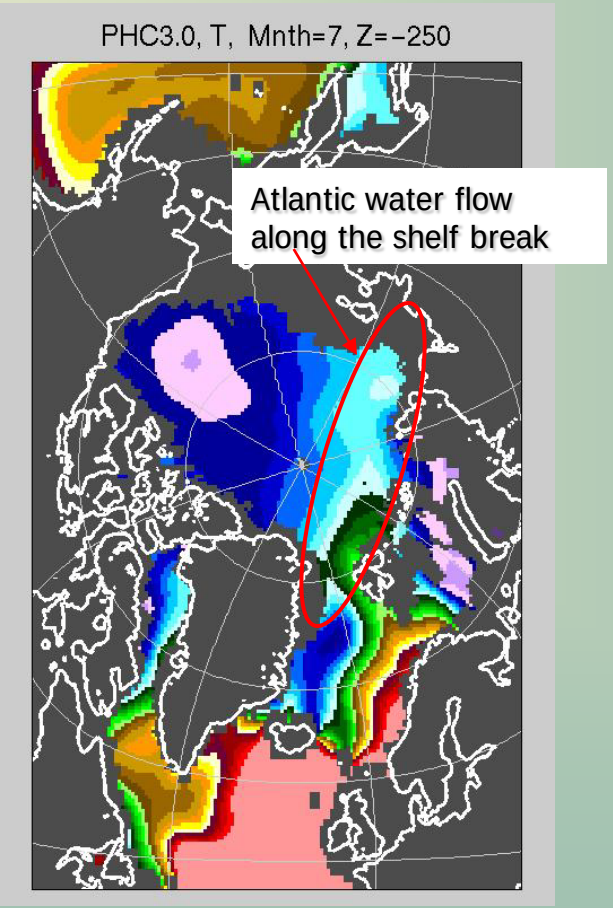
HYCOM/CICE ARCc 0.08°

Temperature 250 m, February

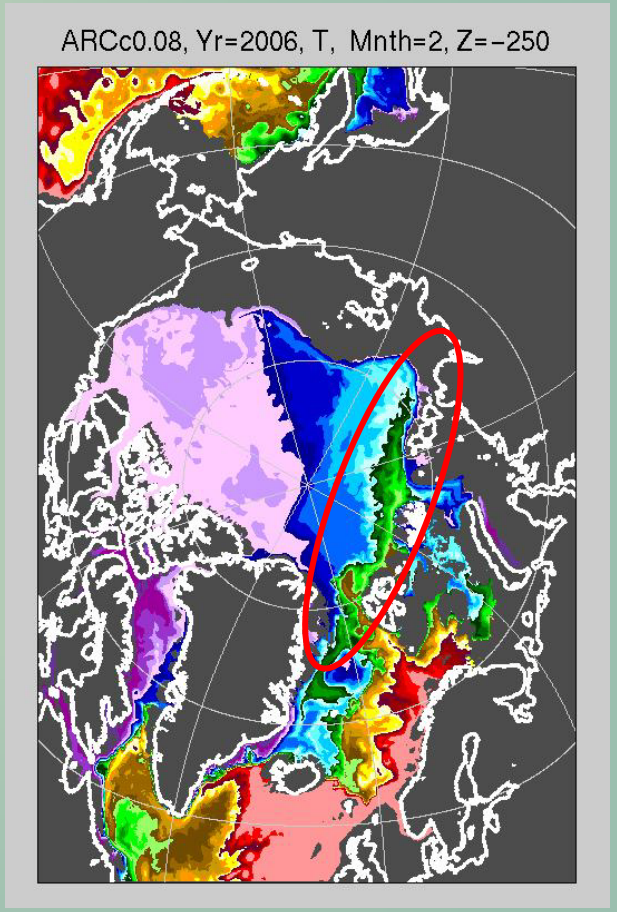
ARCc 0.72° grid 2006

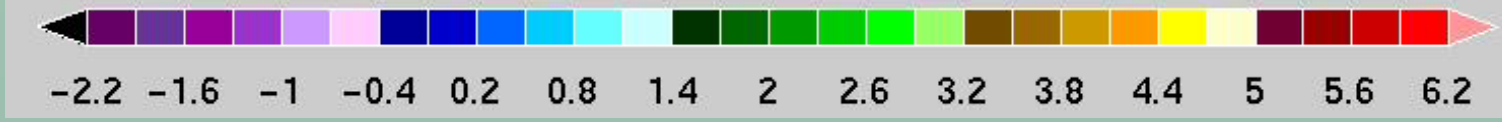


PHC 3.0



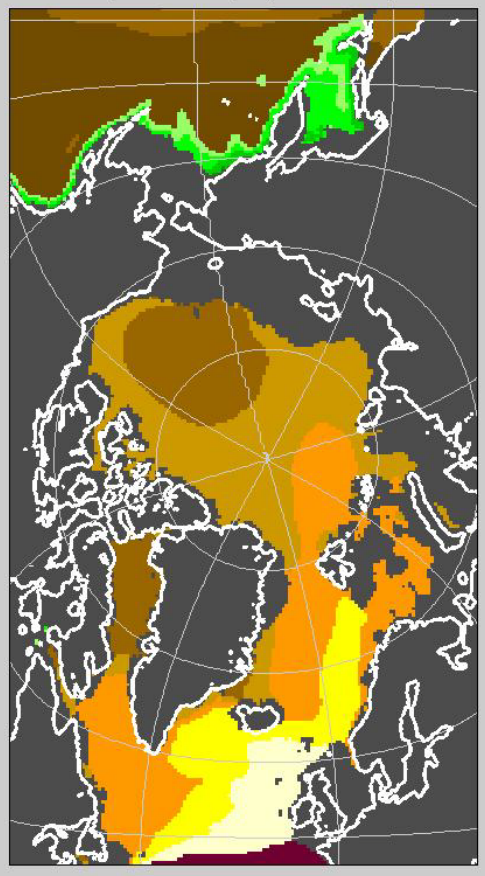
ARCc 0.08° grid 2006



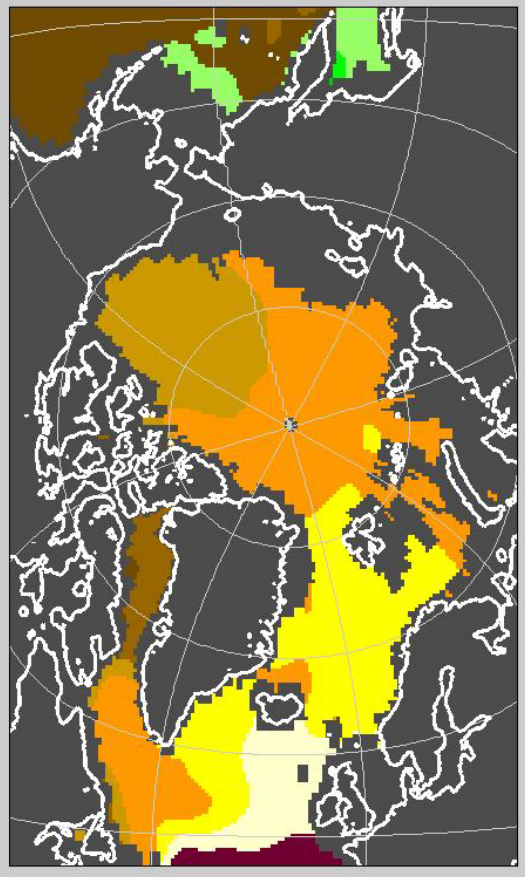


Salinity 250 m, February

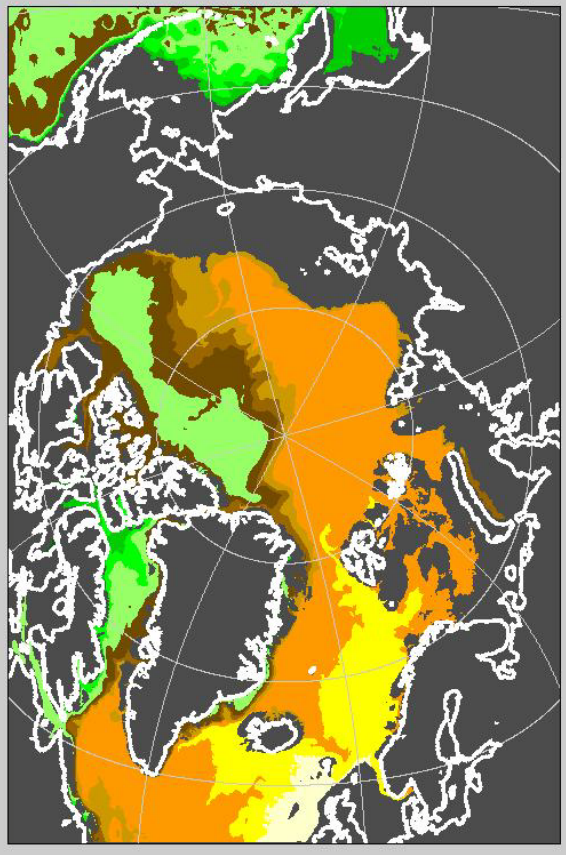
ARCc 0.72° grid 2006

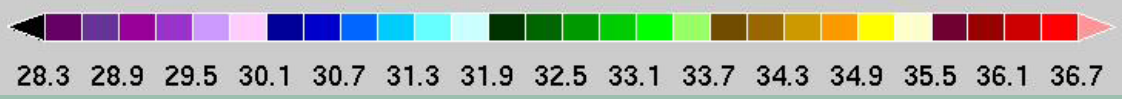


PHC 3.0



ARCc 0.08° grid 2006



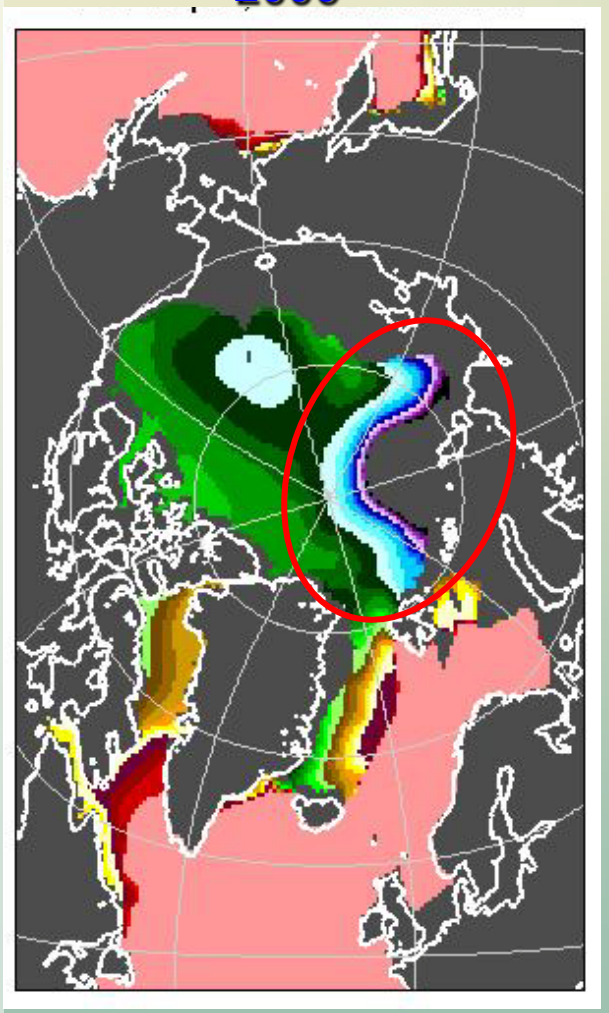


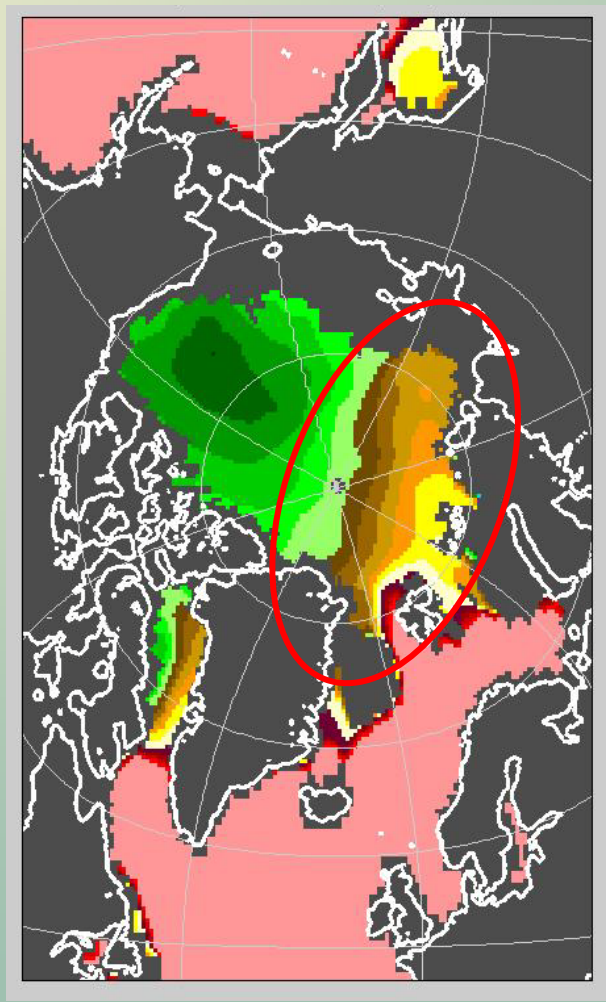
Depth of the Upper Atlantic Water (Depth of 0° Surface)

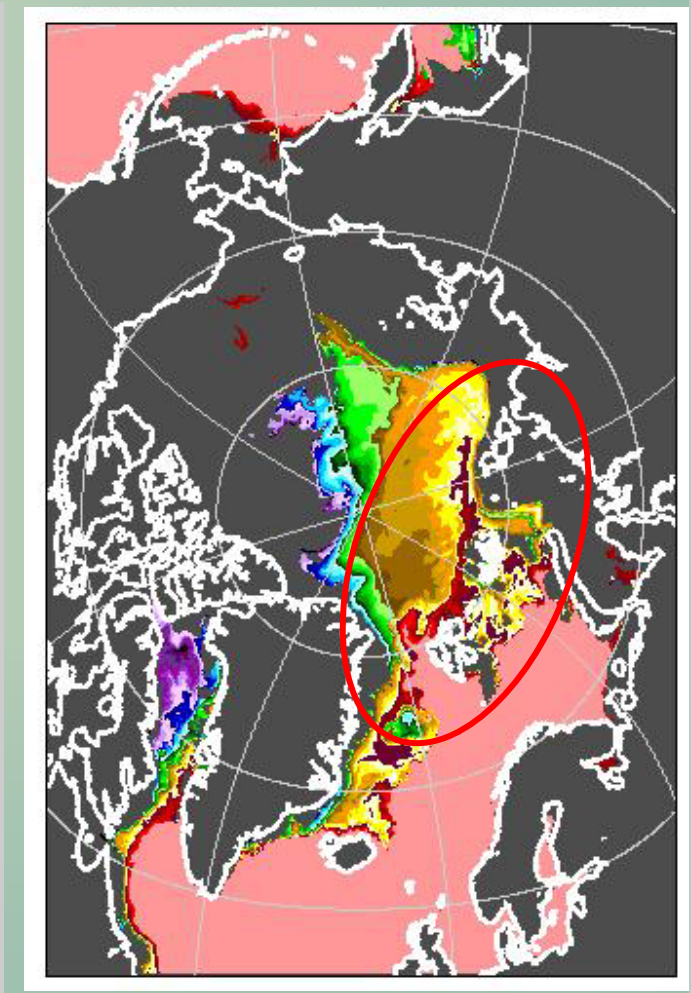
ARCc 0.72° grid
2006

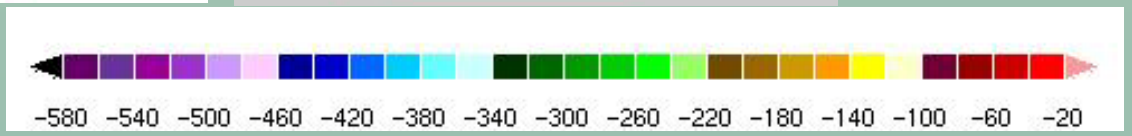
PHC 3.0

ARCc 0.08° grid
2006



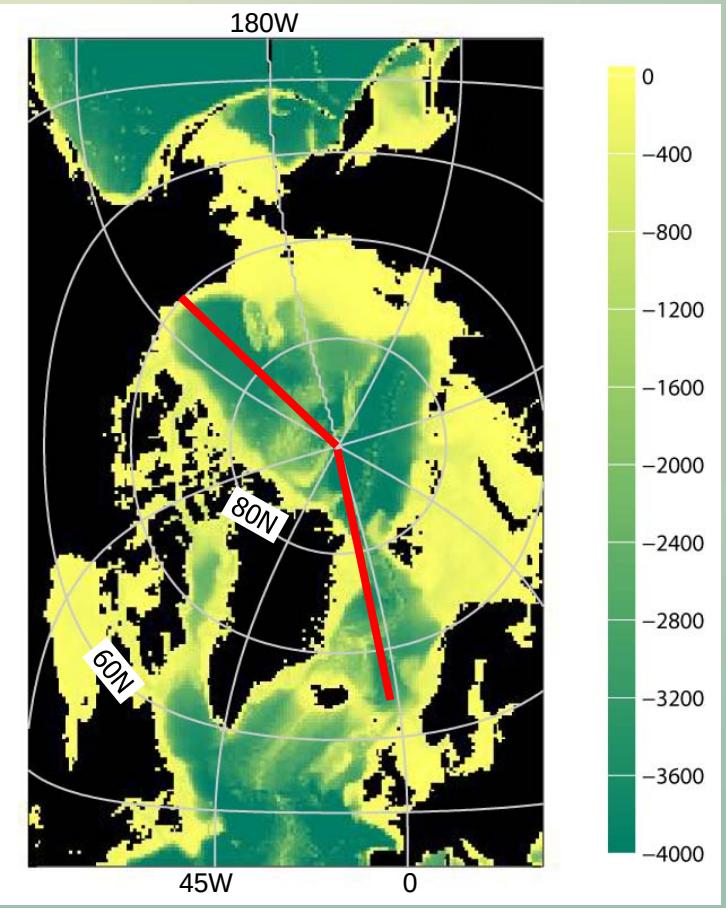




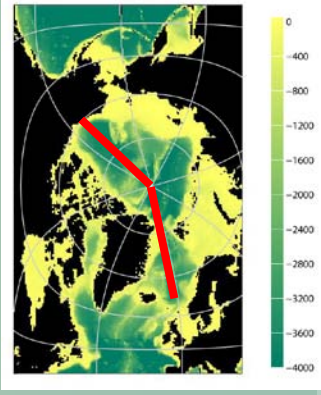


Arctic Ocean – Greenland – Norwegian Seas cross-section

HYCOM/CICE ARCc 0.72°

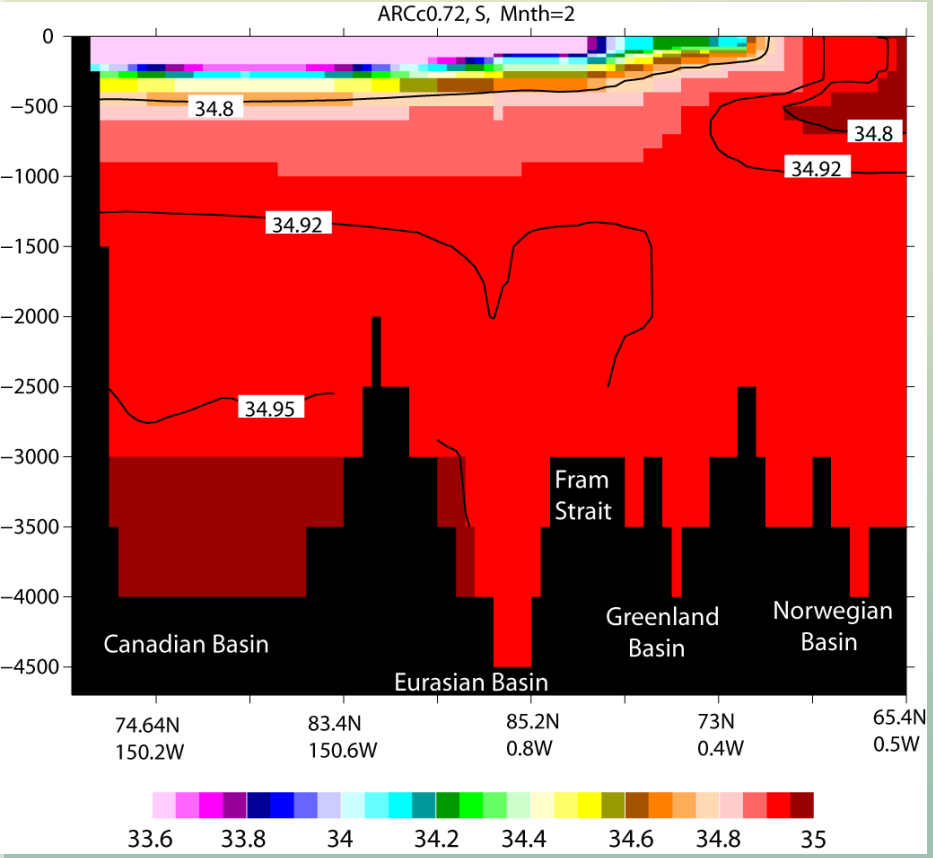


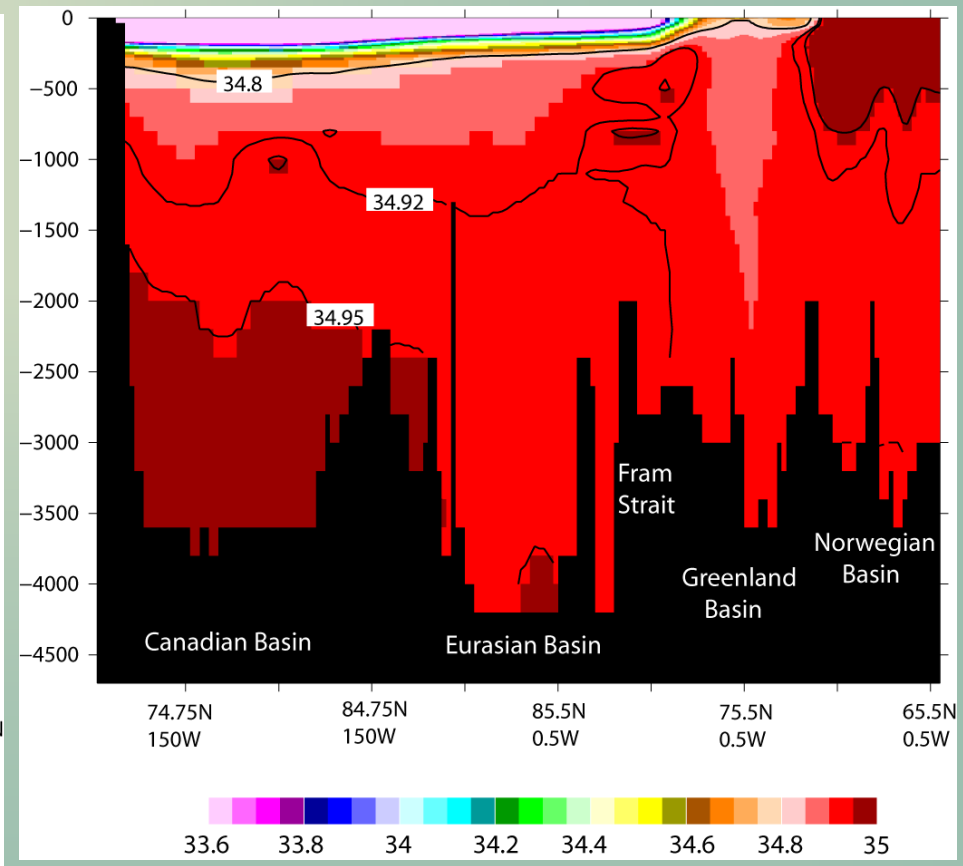
Salinity, February



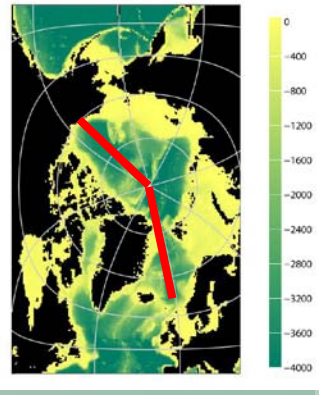
HYCOM/CICE ARCc 0.72°

GDEM 3



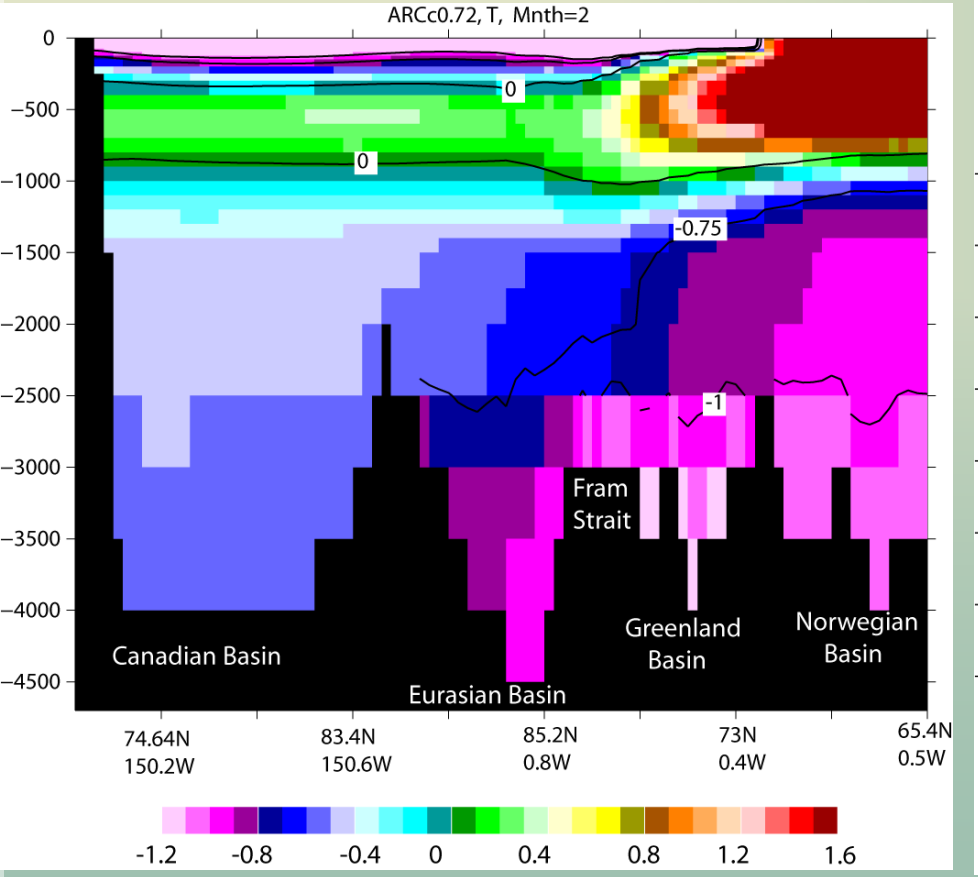


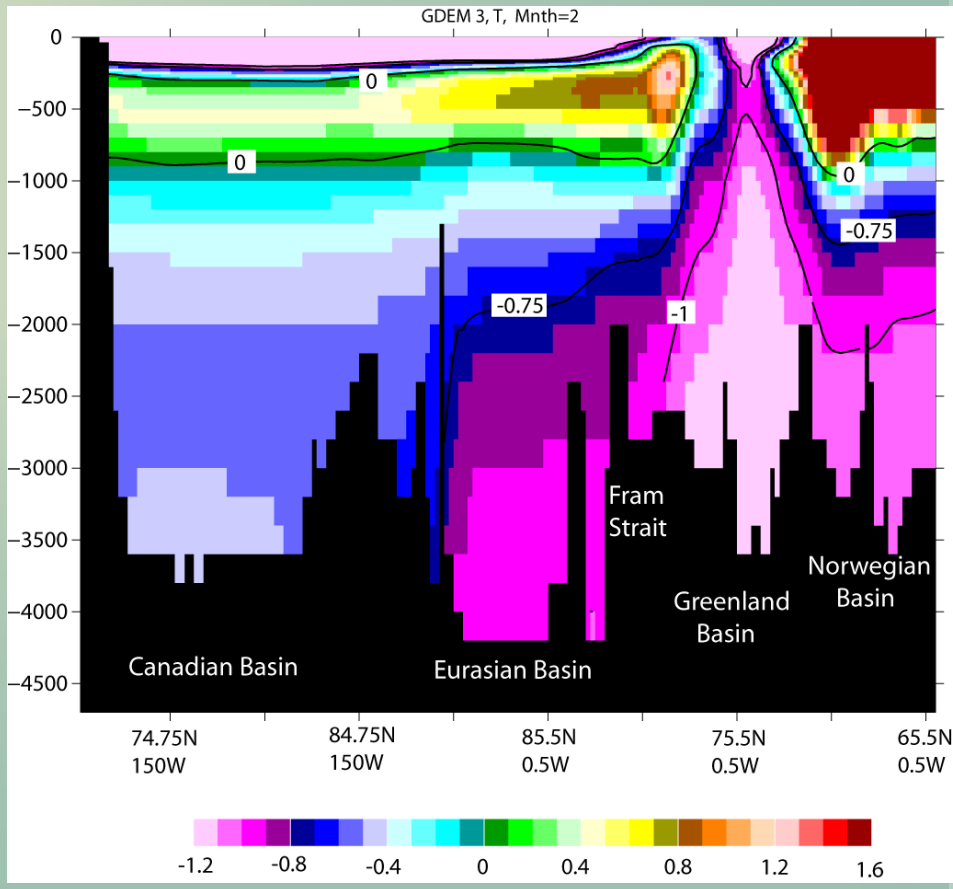
Temperature, February



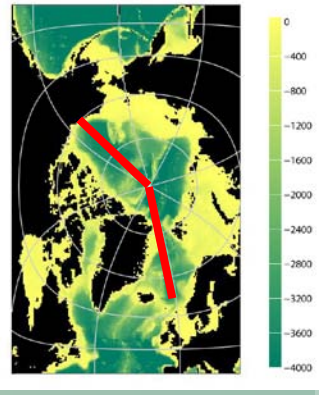
HYCOM/CICE ARCc 0.72°

GDEM 3



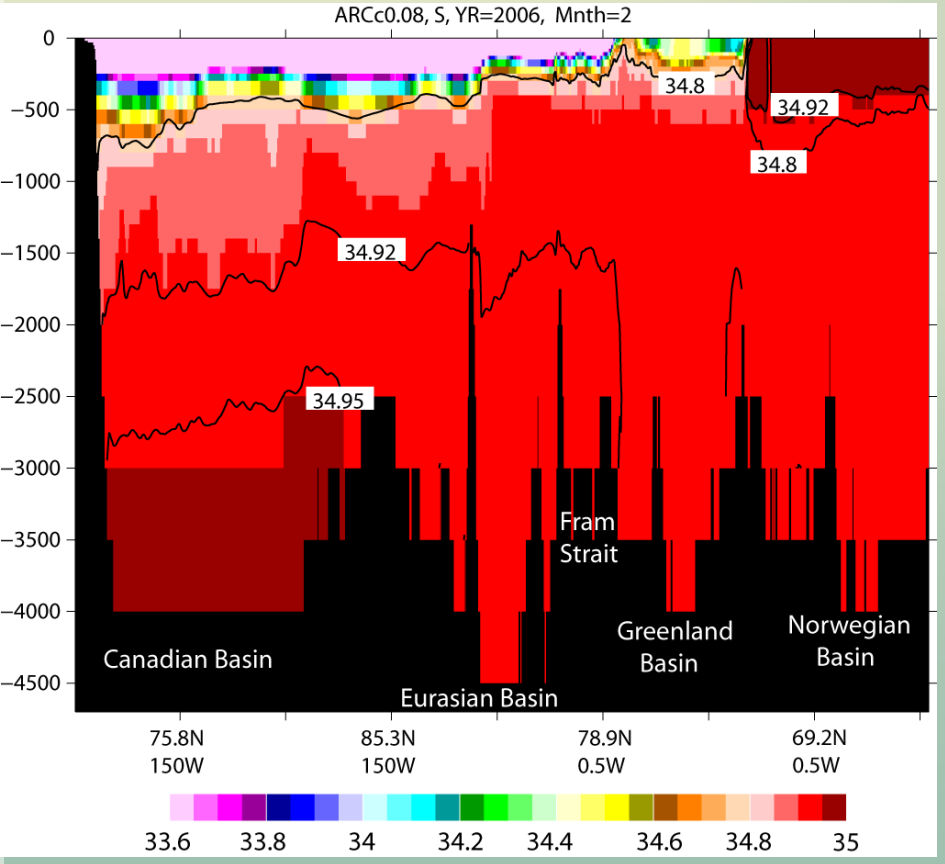


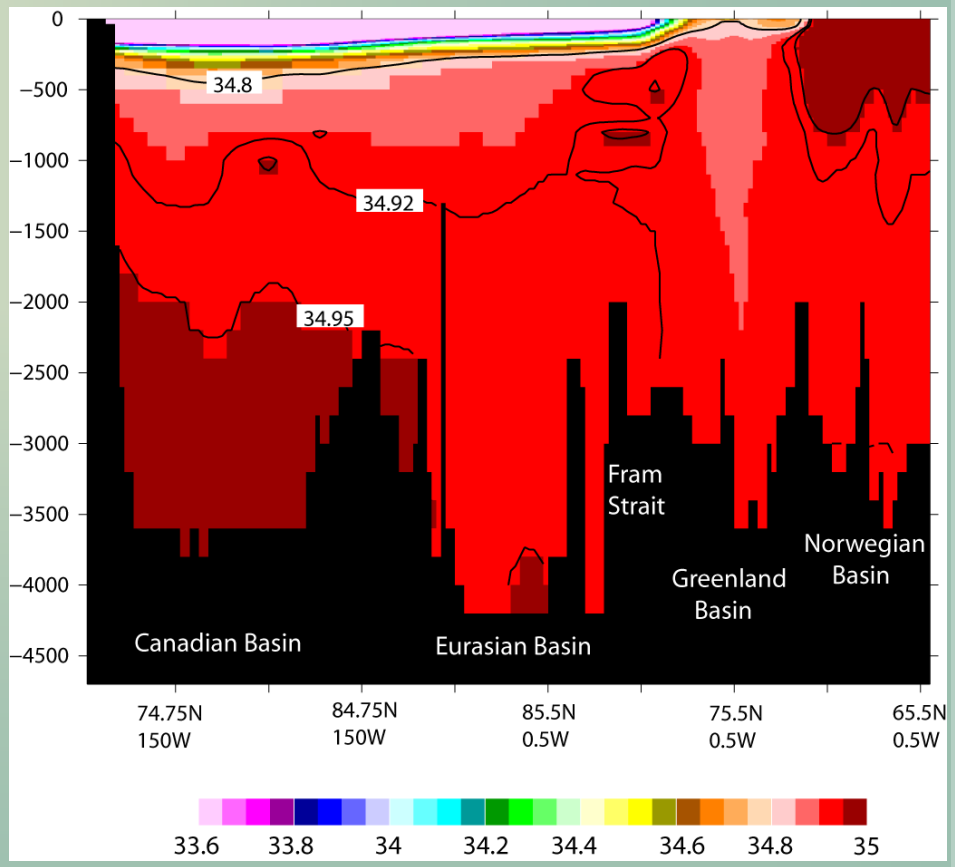
Salinity, February



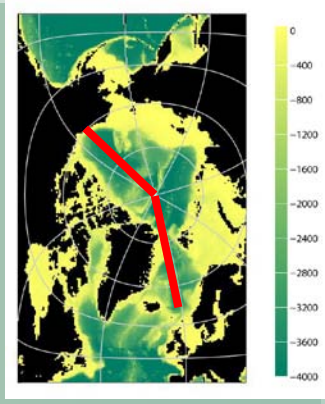
HYCOM/CICE ARCc 0.08°, 2006

GDEM 3



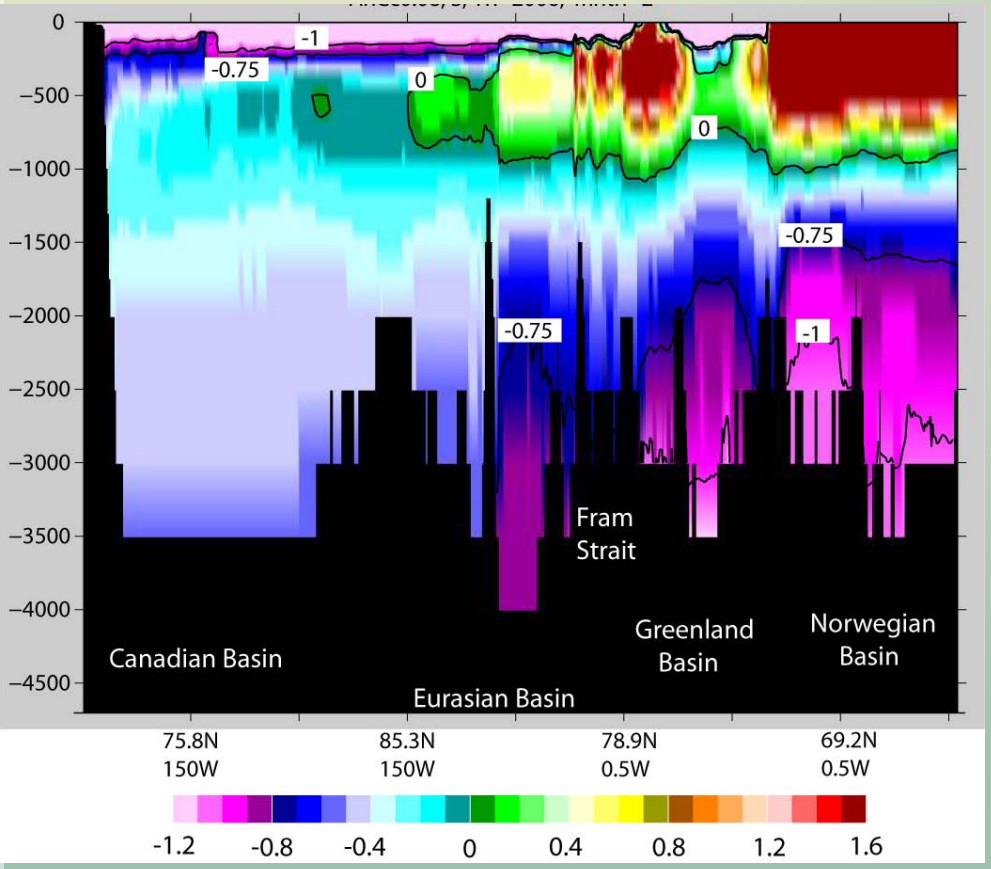


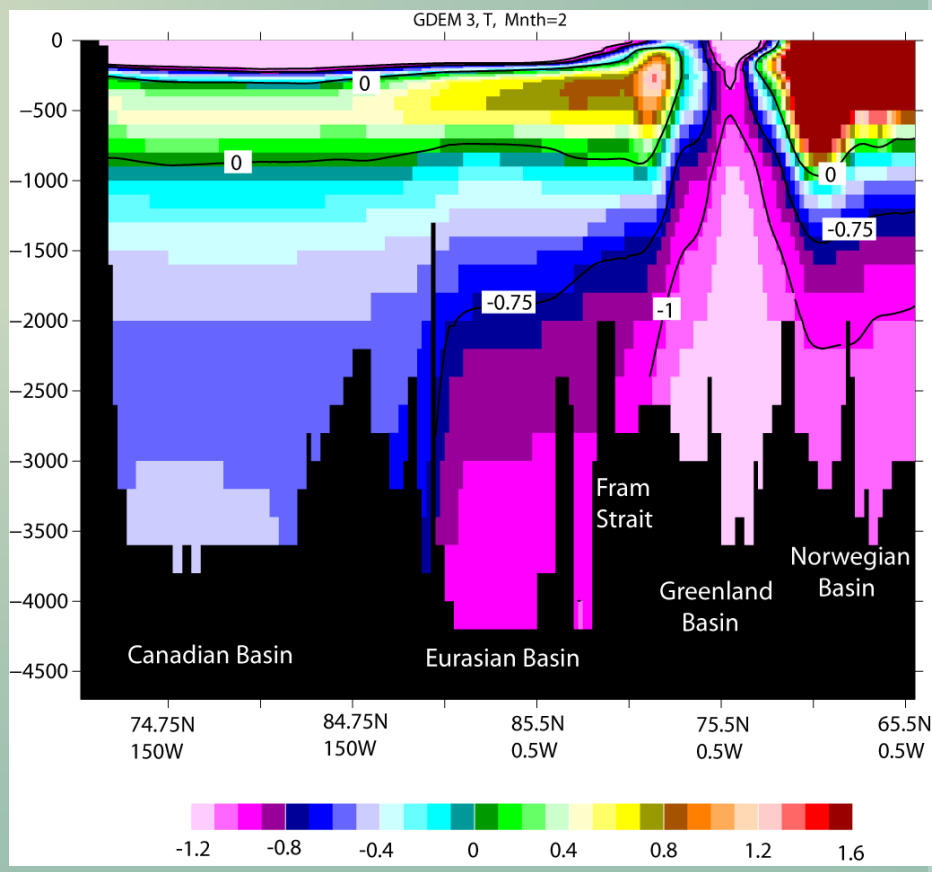
Temperature, February



HYCOM/CICE ARCc 0.08°, 2006

GDEM 3





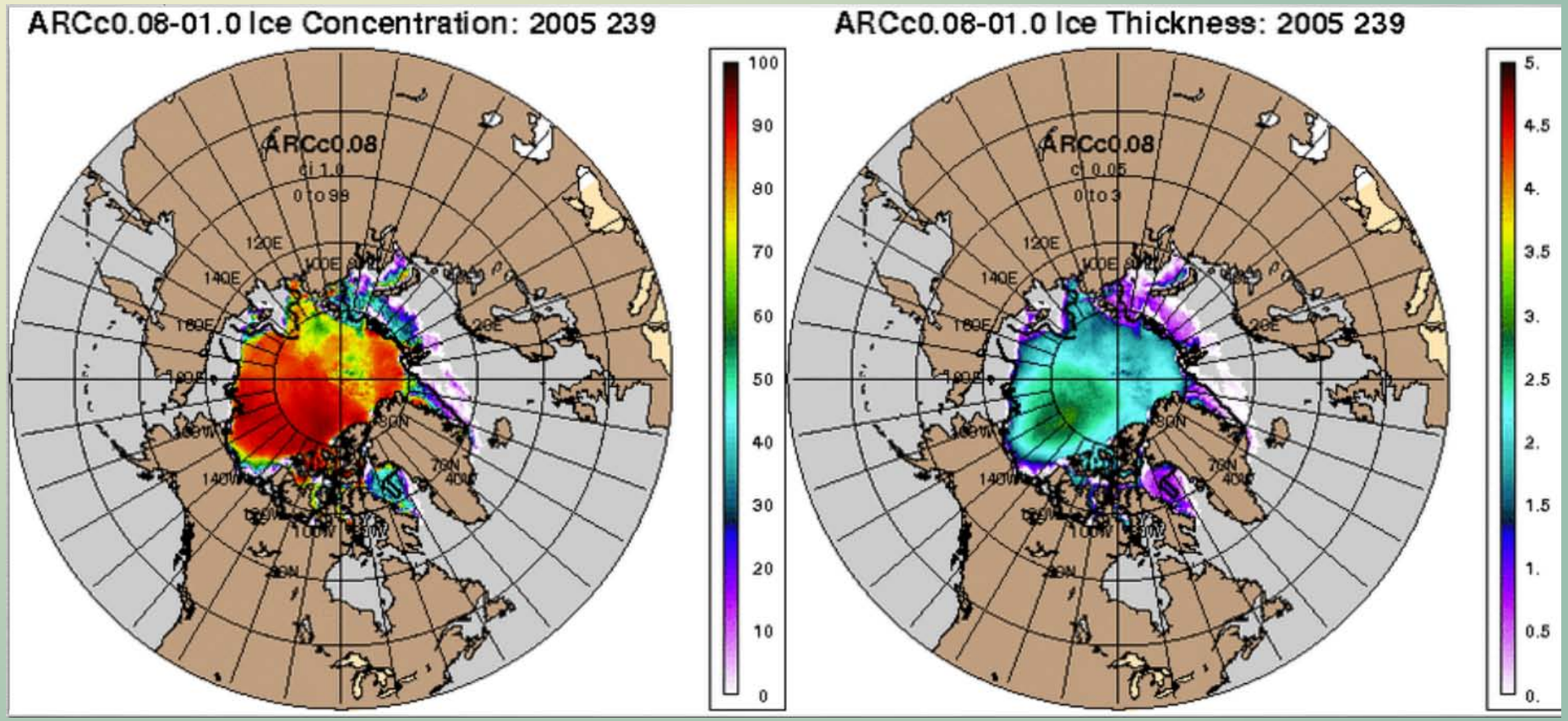
Summary

- **Coupled HYCOM/CICE 4.0 in place**
  - ARCc0.72: ran for 4 years (2003-2006) initialized using PHC 3.0 (ARCc0.72)
  - ARCc0.08: ran for 4 years (2005-2008) initialized using 1/12° Global HYCOM

- **Surface and deep water mass distribution modeled in ARCc 0.72° (and 0.08°) is similar to climatology**

- **In both ARCc 0.72° and 0.08°, the Atlantic layer in the Arctic Ocean is dislocated compared to observations:**
  - Atlantic layer is too deep in ARCc 0.72°
  - Atlantic water does not penetrate into the Canadian Basin in ARCc 0.08°

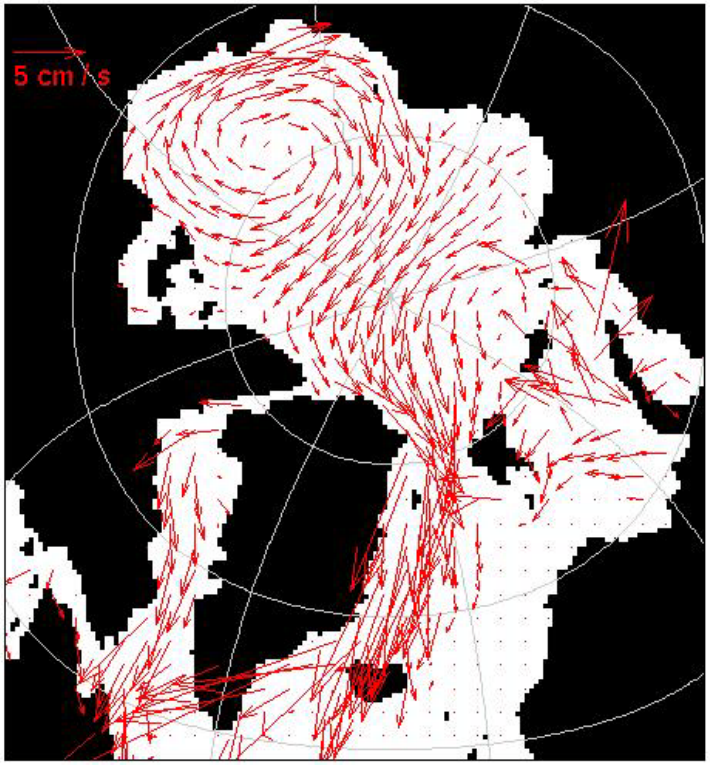
Sea Ice from ARCc 0.08°, 2005-2008

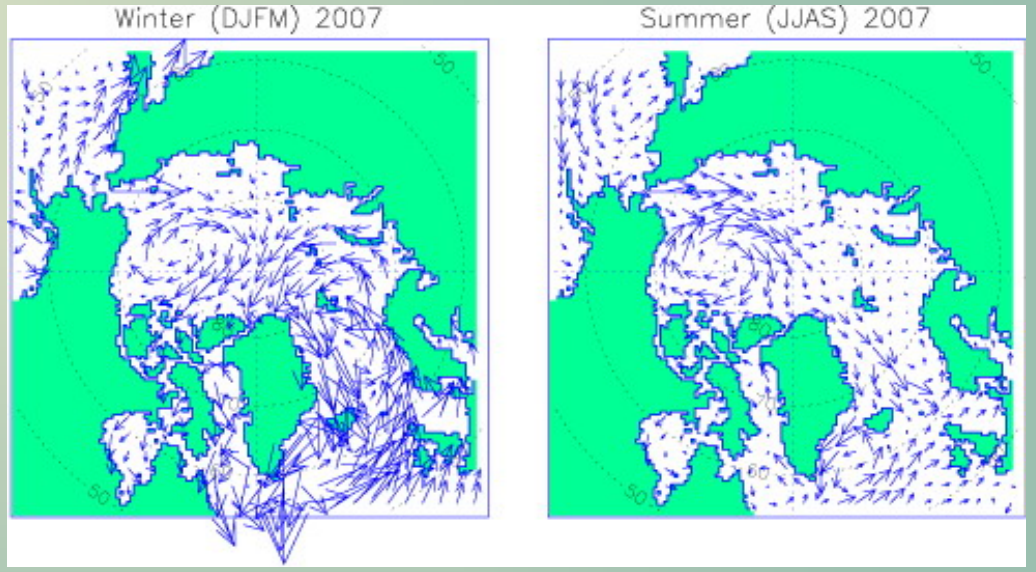


Sea Ice Simulation from HYCOM/CICE ARCc 0.72°

Sea Ice Drift Field

HYCOM/CICE ARCc0.72 grid, 2006

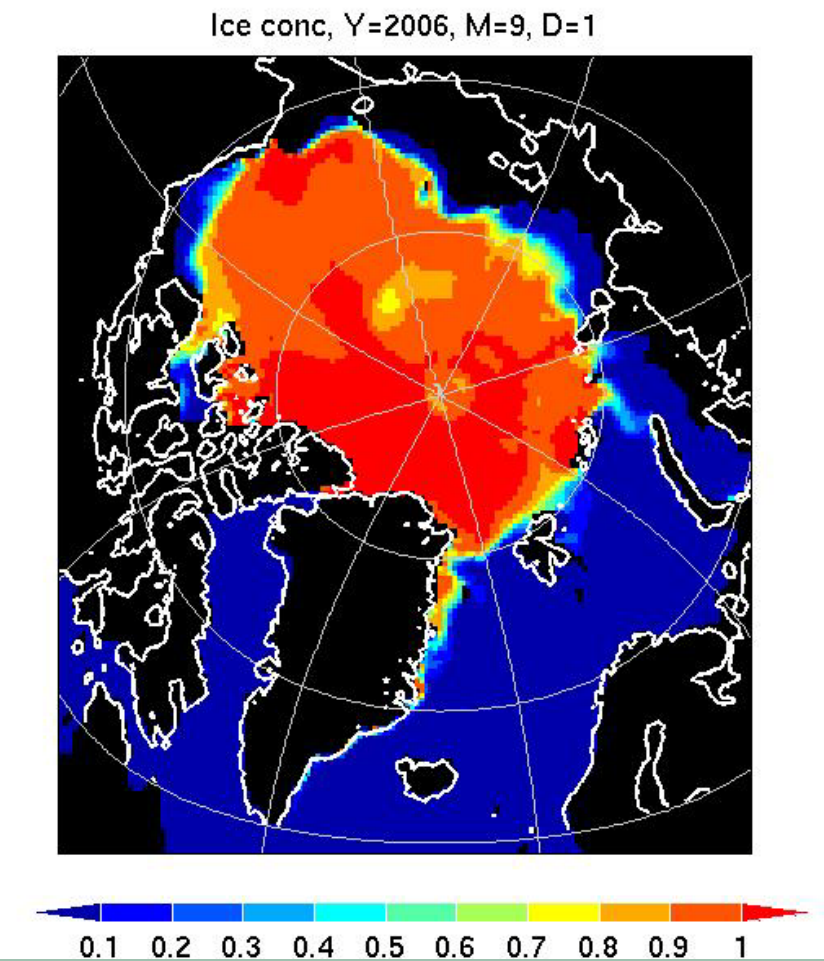


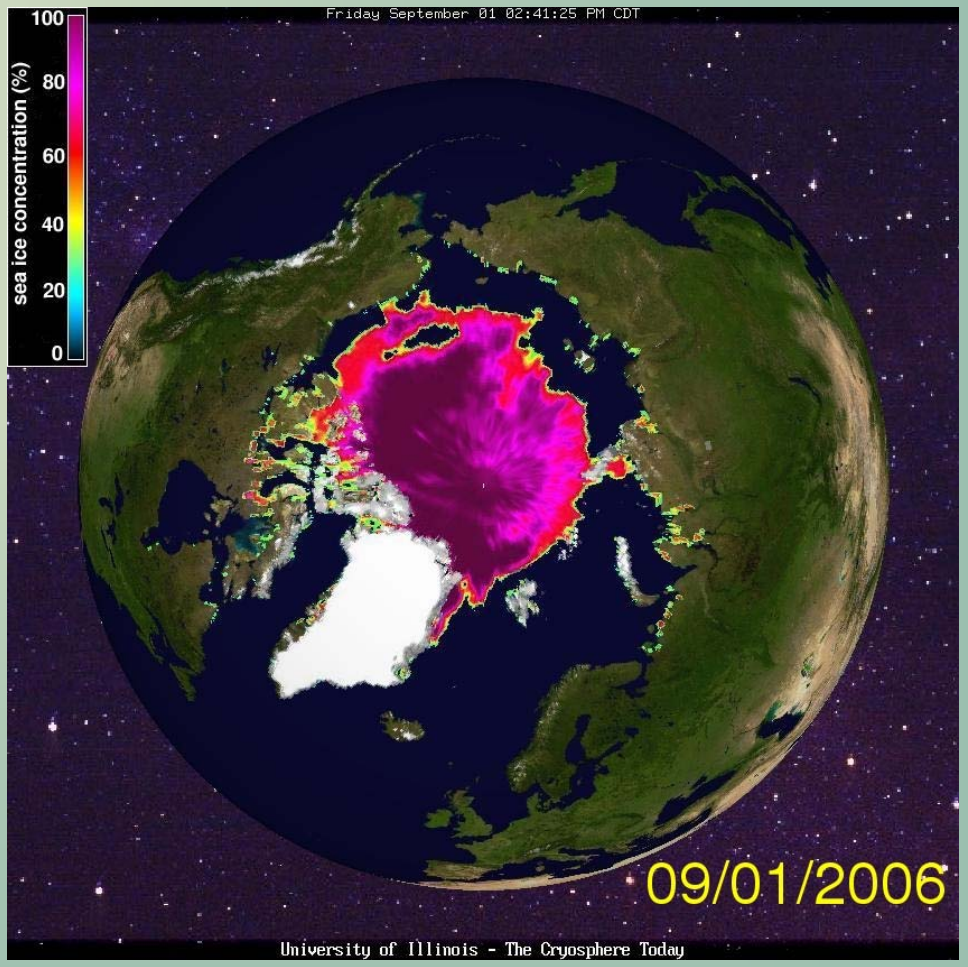


Proshutinsky et al., 2008

www.arctic.noaa.gov/reportcard/ocean.html

Sea Ice Concentration, ARCc 0.72°
September 1, 2006

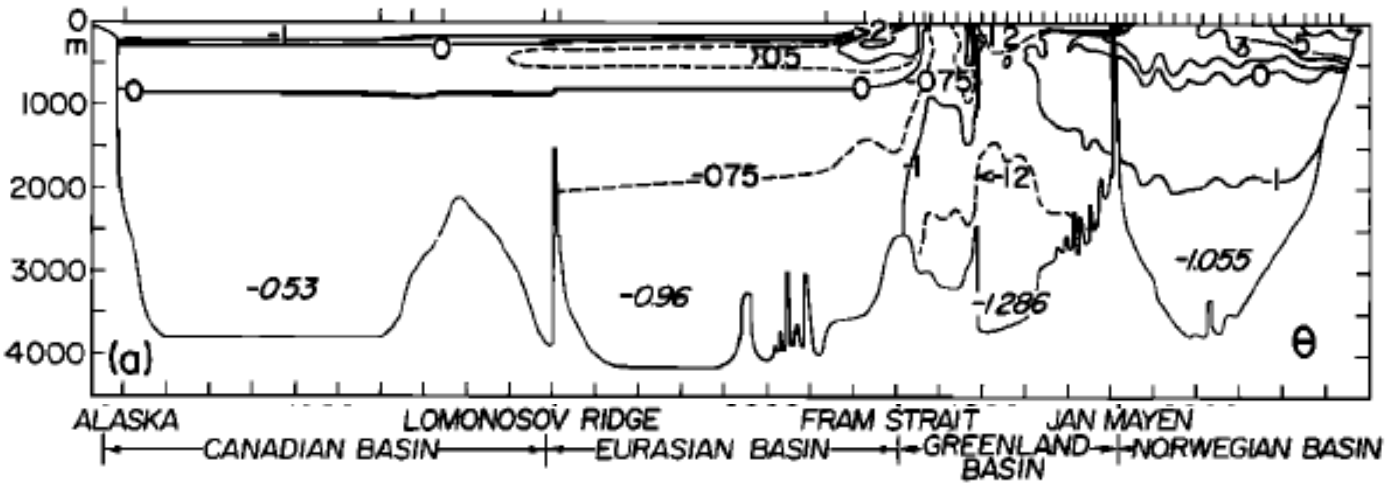




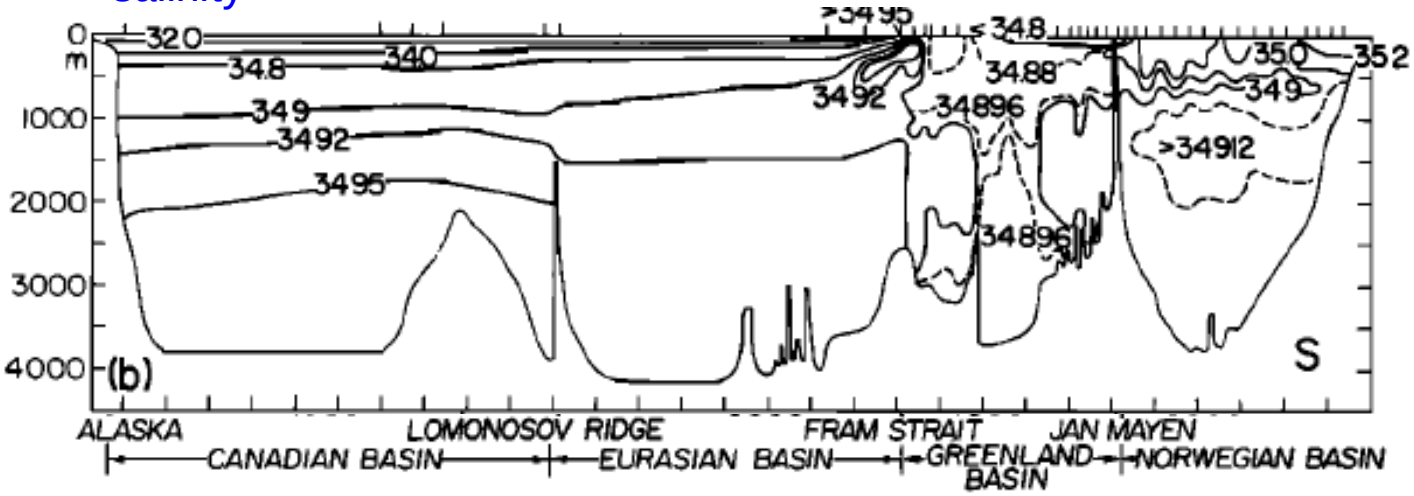
arctic.atmos.uiuc.edu/cryosphere

Distribution of potential T and S along the section

Potential Temperature



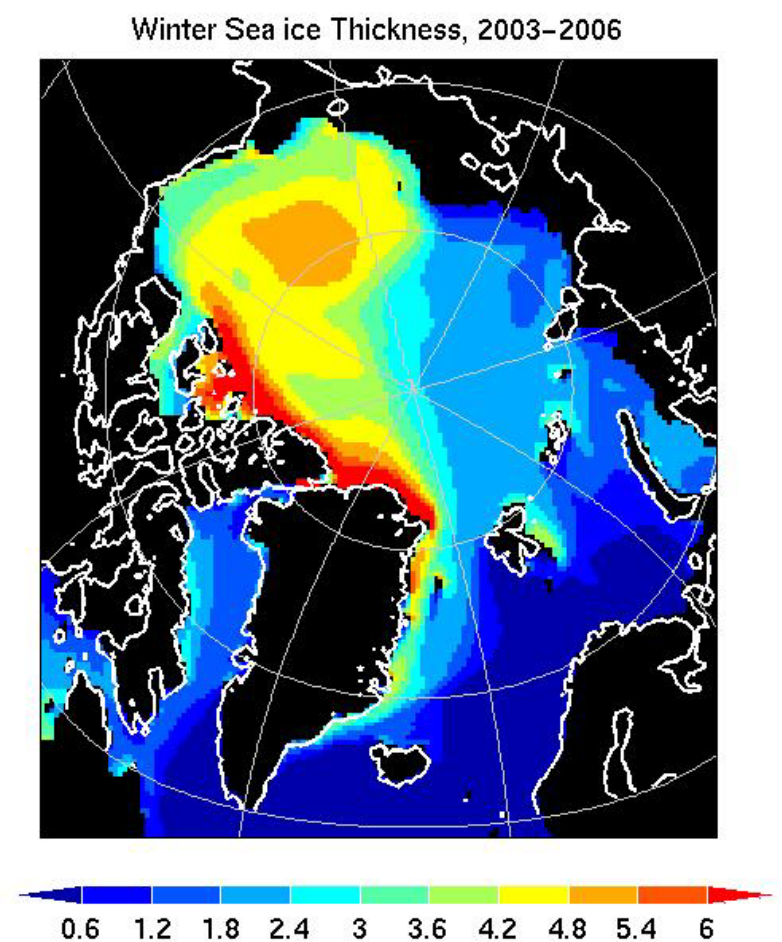
Salinity



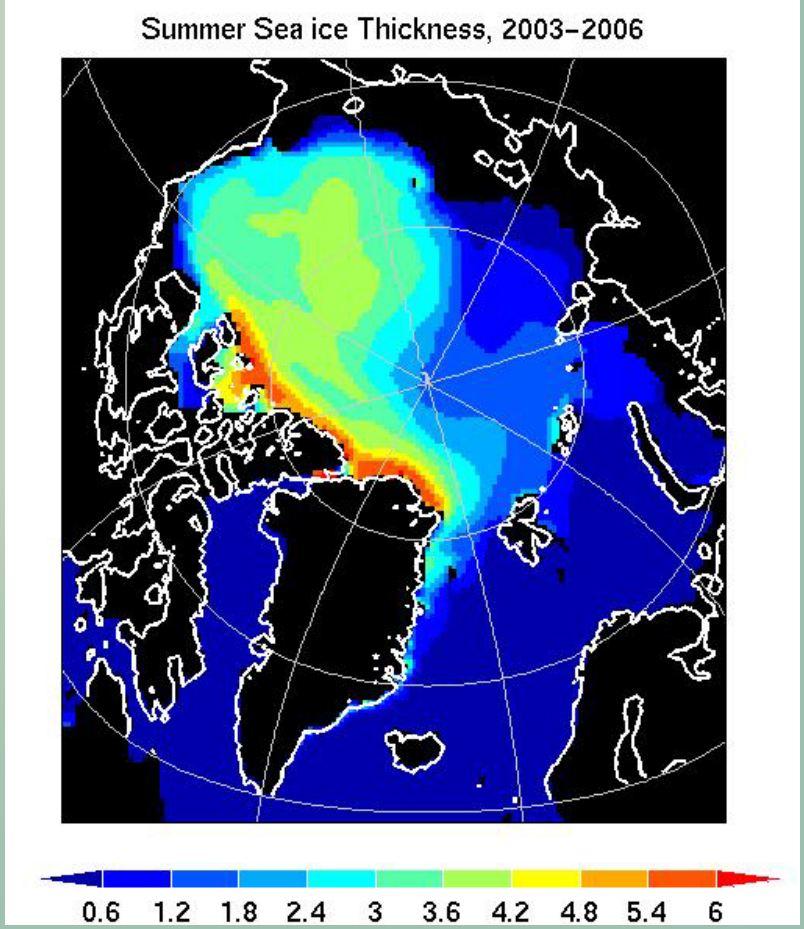
Aaagaard et al., *Thermohaline circulation in the Arctic Mediterranean Seas,* JGR, 1985

Seasonal Sea Ice Thickness (m)

Winter

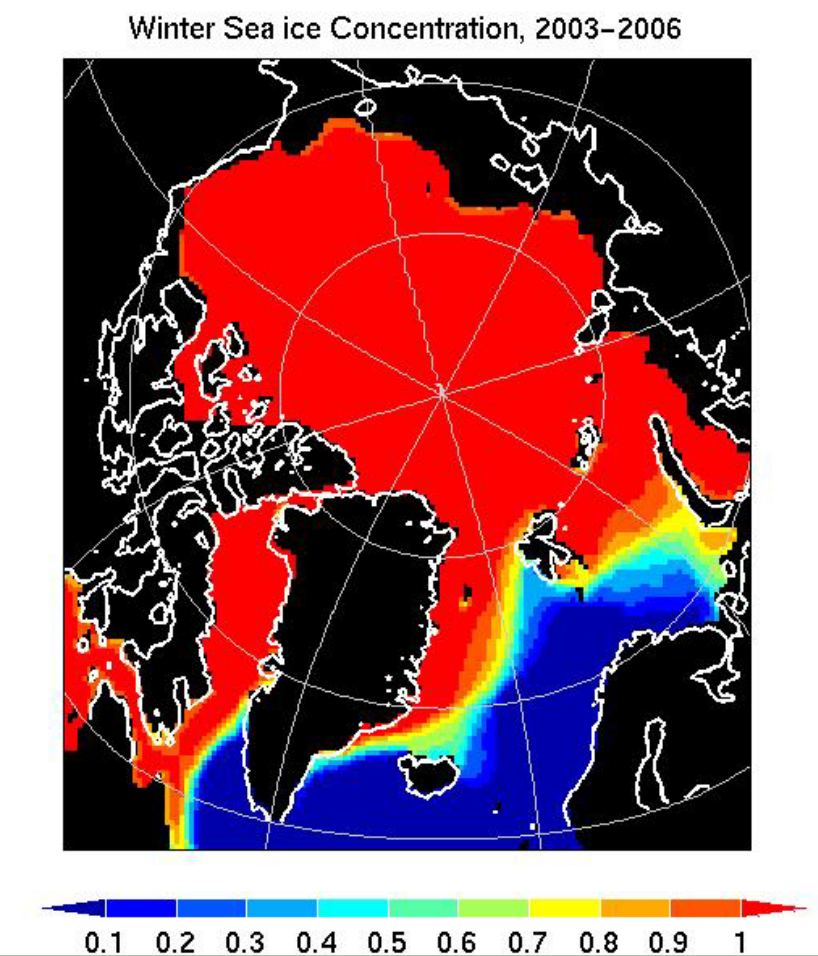


Summer

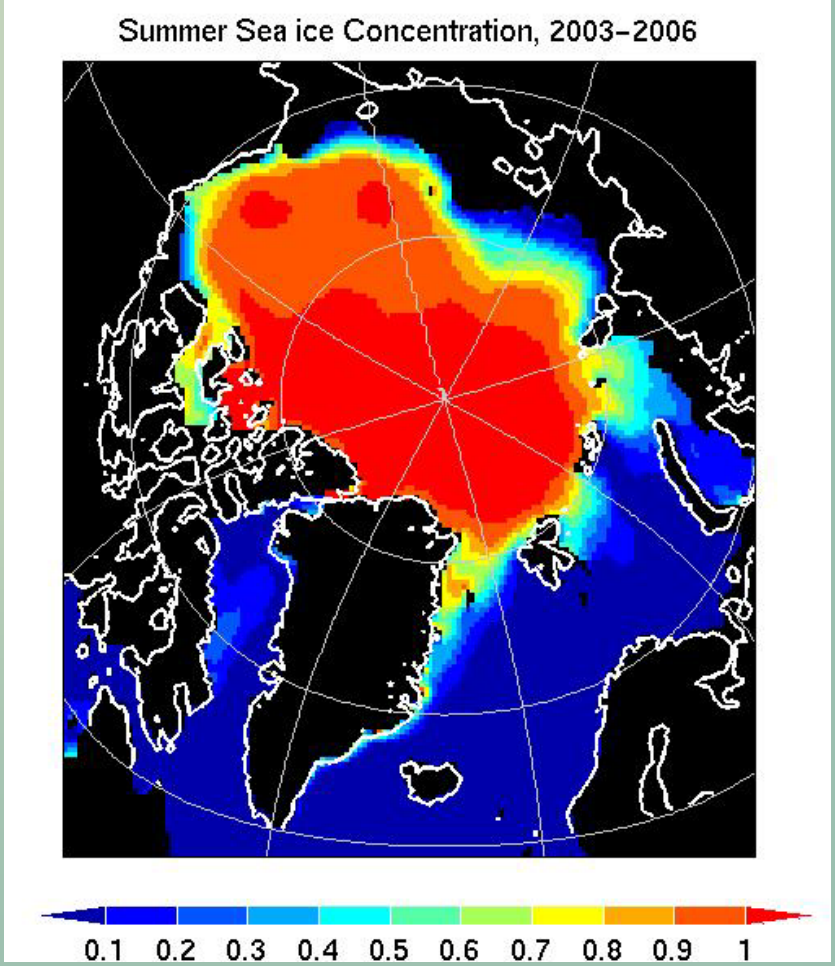


Seasonal Sea Ice Concentration (m)

Winter

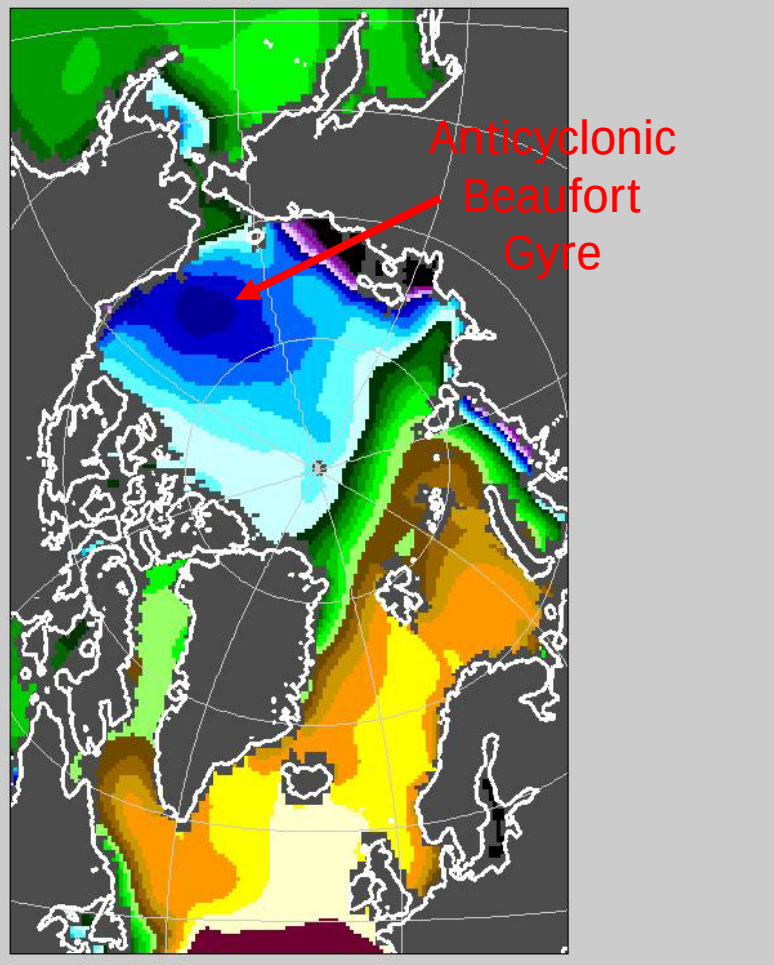


Summer

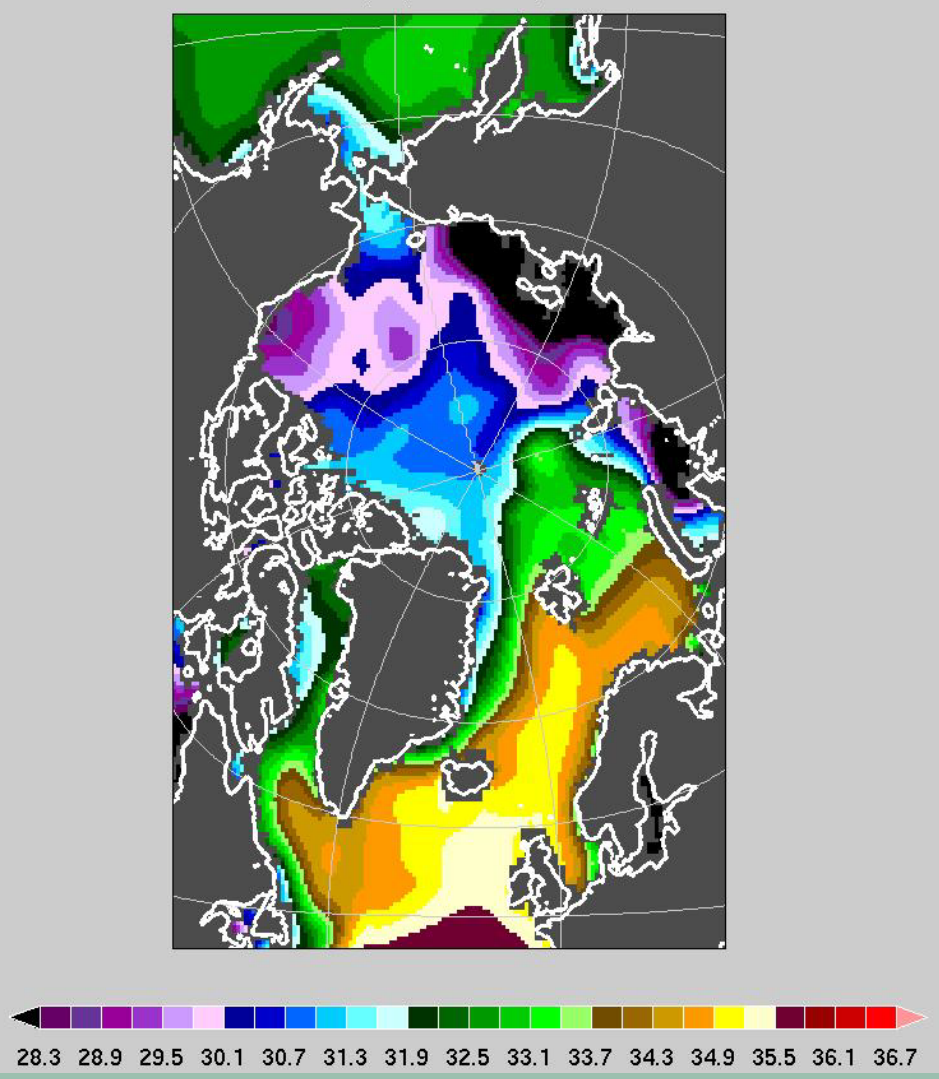


Salinity, 10 m, PHC 3.0

February



August



Seasonal Signal

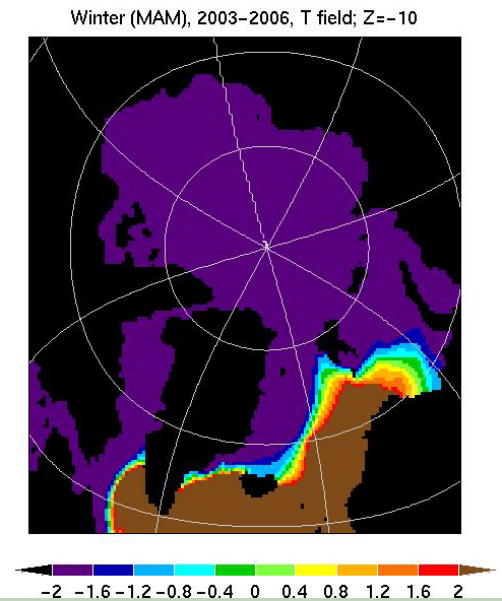
Simulated in

HYCOM/CICE ARCc 0.72°

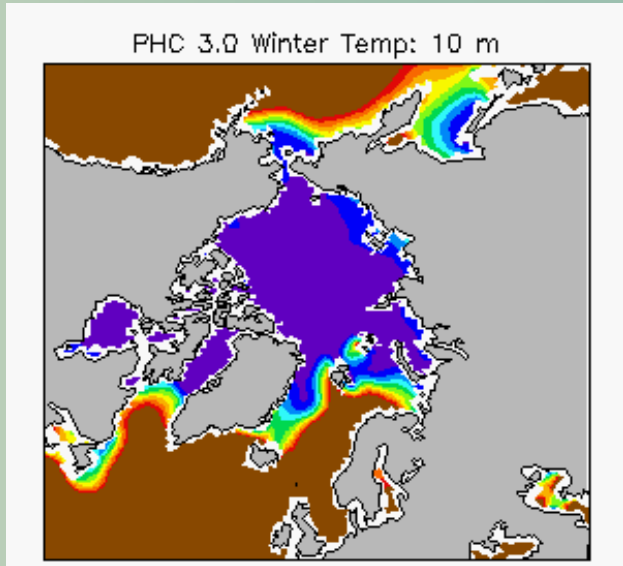
Seasonal Near-Surface Temperature

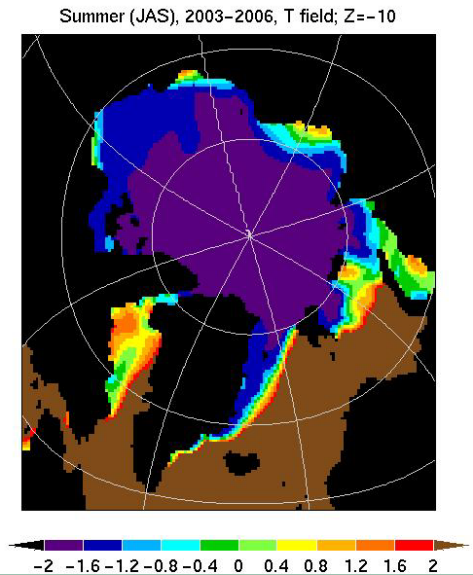
HYCOM/CICE ARCc0.72 grid, 2003-2006

PHC 3.0

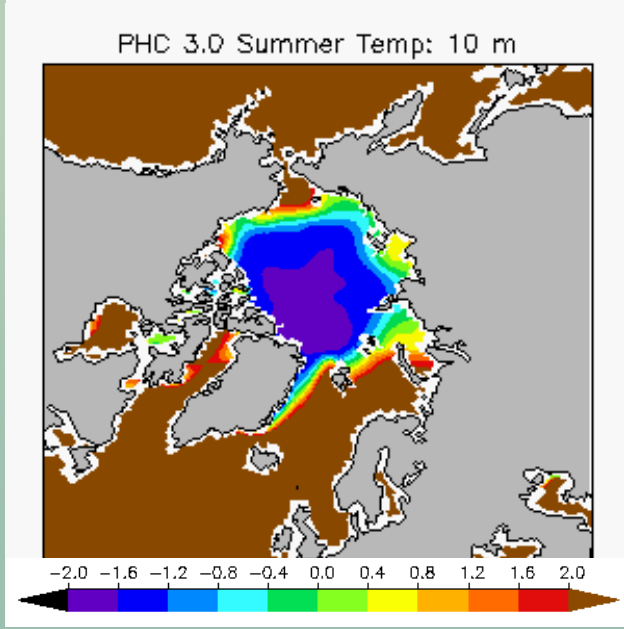


Winter





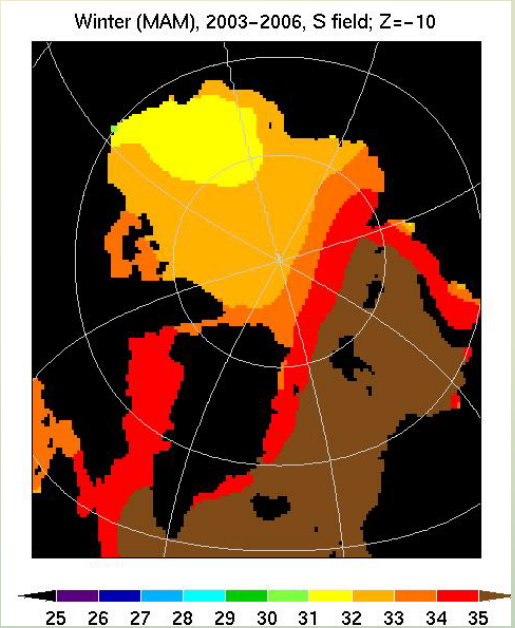
Summer



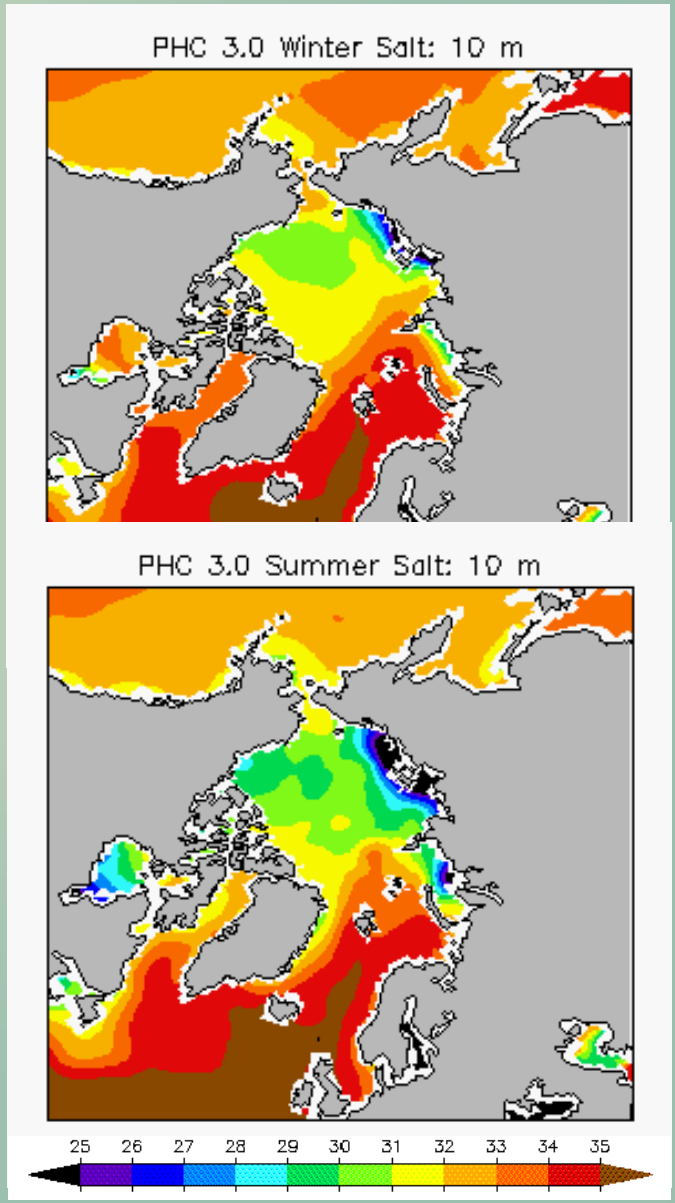
Seasonal Near-Surface Salinity

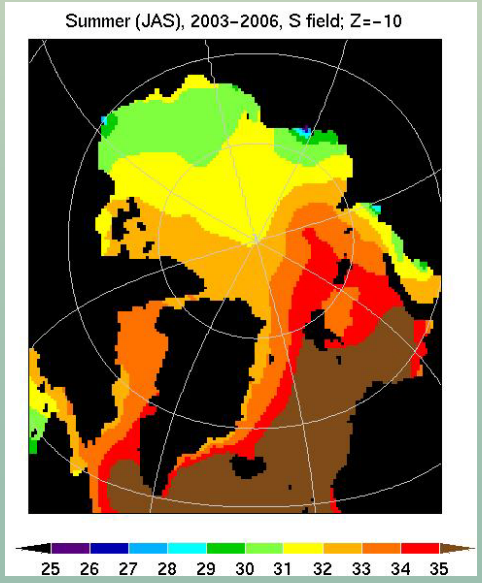
HYCOM/CICE ARCc0.72 grid, 2003-2006

PHC 3.0



Winter





Summer

COAPS Plans

1) Analysis of 0.72 and 0.08 model runs performed by NRL SSC
2) Test runs with ARCc0.72
3) Transition to ARCc0.08
4) AOMIP coordinated 50-year run of ARCc0.08

Two-way coupled HYCOM/CICE – exchanges fields every 3 hours

- HYCOM uses a 18 minute time step and exports:
  - SST
  - SSS
  - Surface currents

- CICE uses a 45 minute time step and exports:
  - Ice concentration
  - Ice-ocean stresses
  - Actual Freeze/Melt Heat/Salt/Mass Flux
  - Solar radiation at ice base

** Runs on three HPC systems: IBM p655+, SGI Origin 3900 and Cray XT3

Stand-alone vs Coupled

- Stand-alone
  - CICE has simple bulk ocean mixed layer
    - Relaxes to climatological SST and SSS
    - Calculates an ice-ocean stress, based on zero ocean currents
  - HYCOM treats sea-ice as an “energy bank”
    - No ice advection
    - No ice-ocean stress (wind stress applied directly to the ocean)

- Best possible coupling:
  - HYCOM’s ocean CICE’s sea-ice
  - Ice-Ocean Stress identical in HYCOM and CICE
  - Ice-Ocean Fluxes identical in HYCOM and CICE

- Actual 2-way coupling:
  - Ice-Ocean Stress identical in HYCOM and CICE
  - Similar, but not identical, Ice-Ocean Fluxes
    - CICE’s SST strongly relaxed to HYCOM SST
    - HYCOM’s sea-ice concentration strongly relaxed to CICE sea-ice concentration
  - Fields exchanged every 3 hours

Global Tripole Grid

- Arctic dipole patch on standard Mercator globe

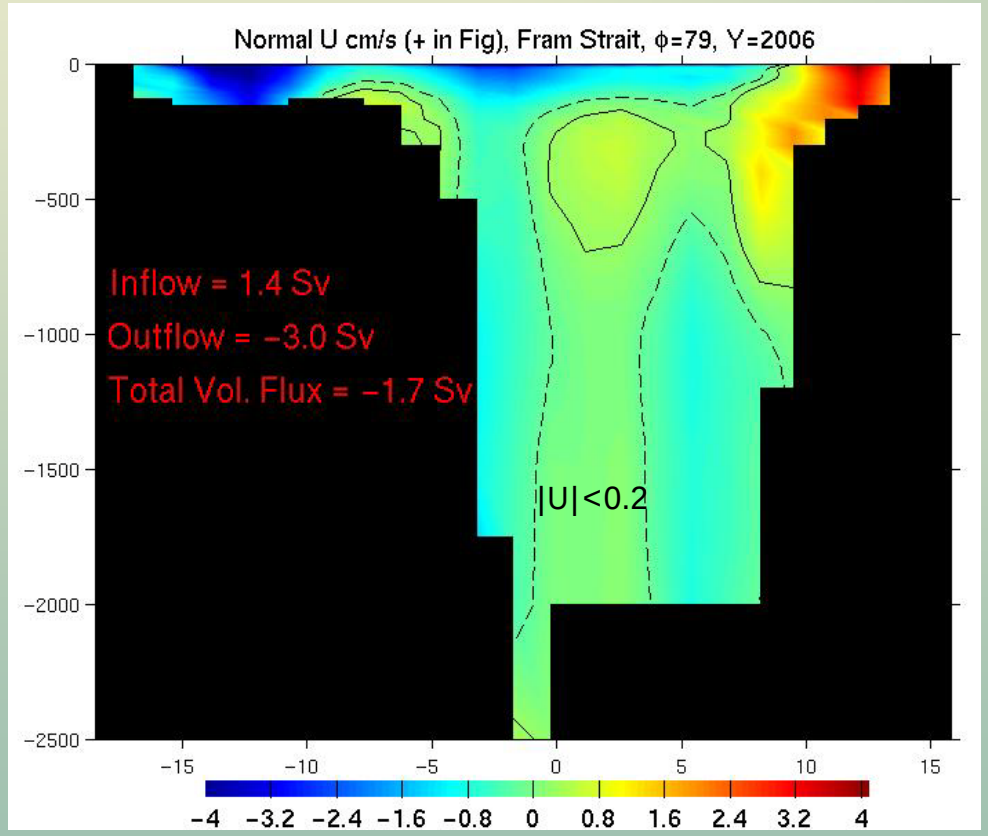
- This tripole grid has many good properties
  - Rectilinear grid south of the Arctic patch
  - Grid aligned with the equator
  - Same resolution in Arctic and Antarctic – if Arctic patch starts about 47N
  - relatively smooth transition across the patch boundary

- The "full" tripole grid contains all locations twice
  - Just as a "full" periodic domain contains all locations an infinite number of times

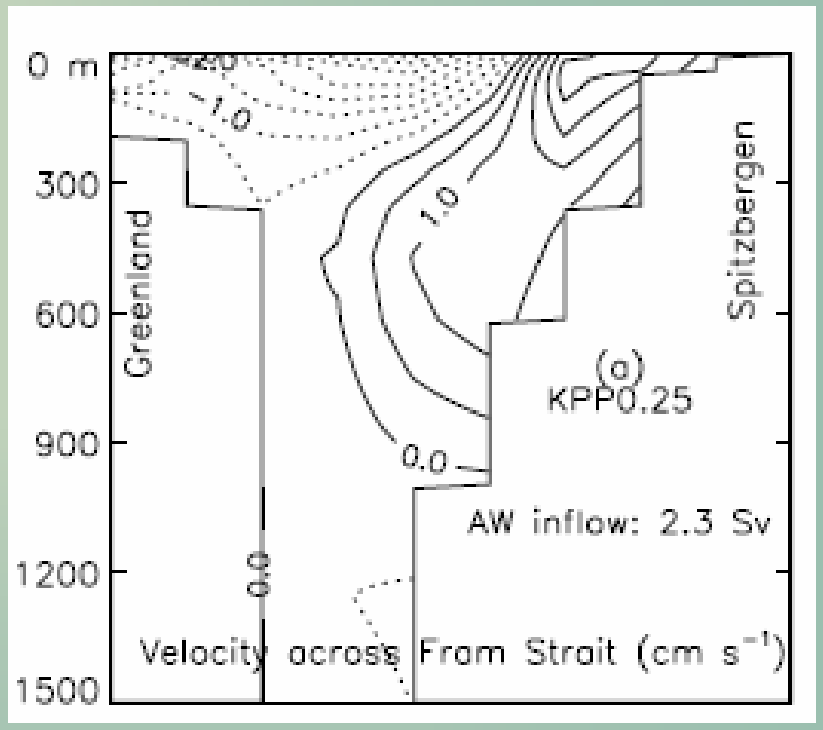
- Global: use the lower copy of each location
  - Logically rectangular arrays
  - Needs a special halo exchange on the top edge
    - -- Includes a sign change for v-velocity
    - -- Some points still included twice (both copies must be identical – consistency check)

Mean Horizontal Velocity Across Fram Strait

HYCOM/CICE ARCc0.72 grid, 2006



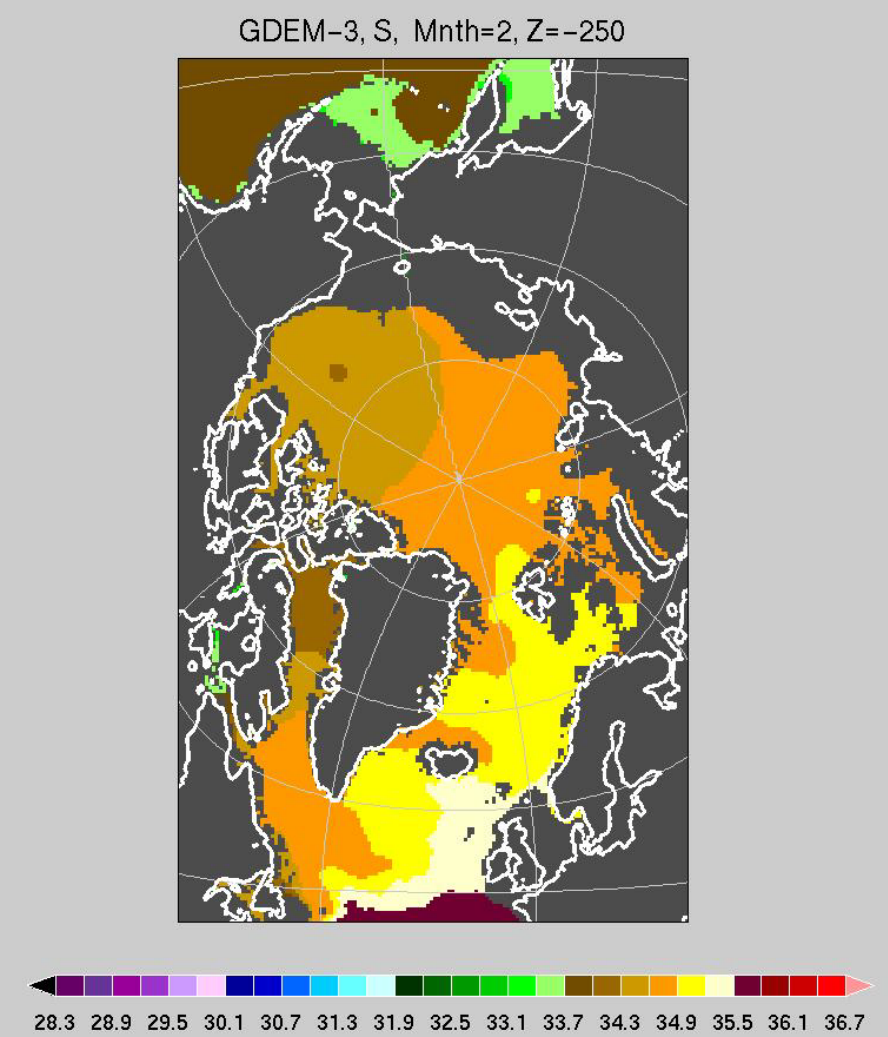
POP model, 1978



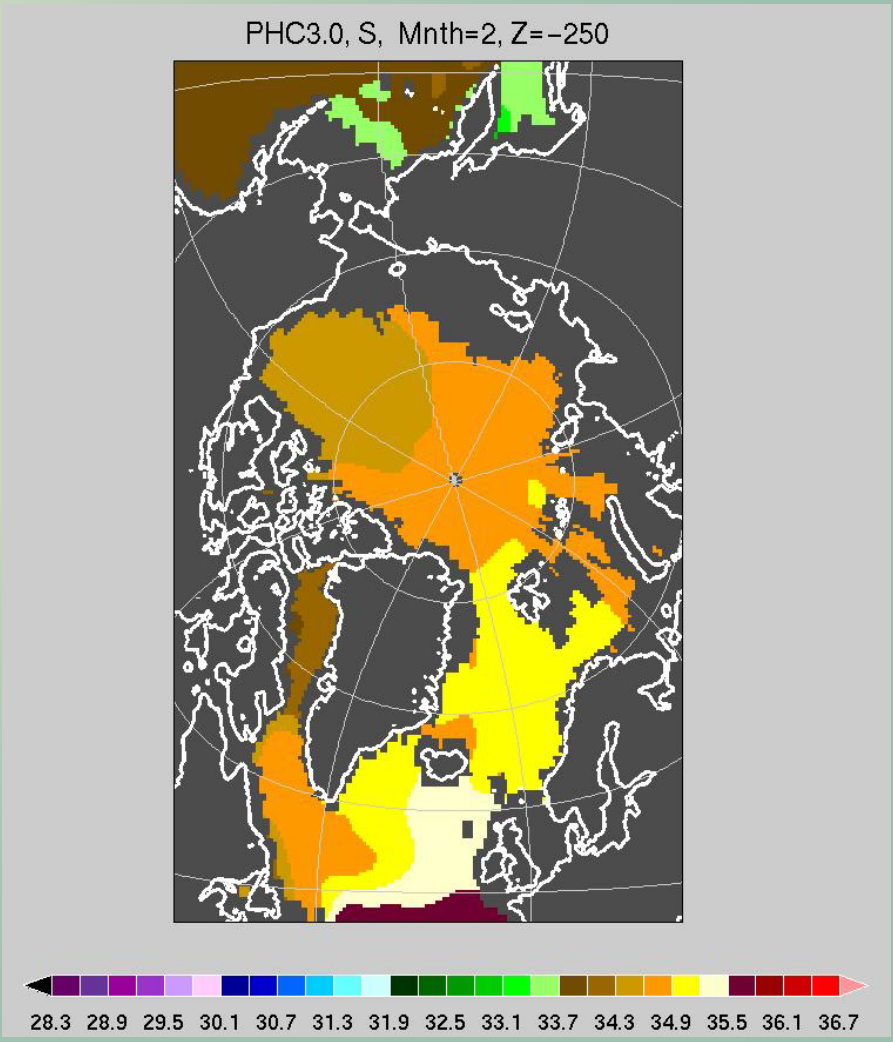
Zhang and Steele (*JGR,* 2007)

Salinity, February 250 m

GDEM3

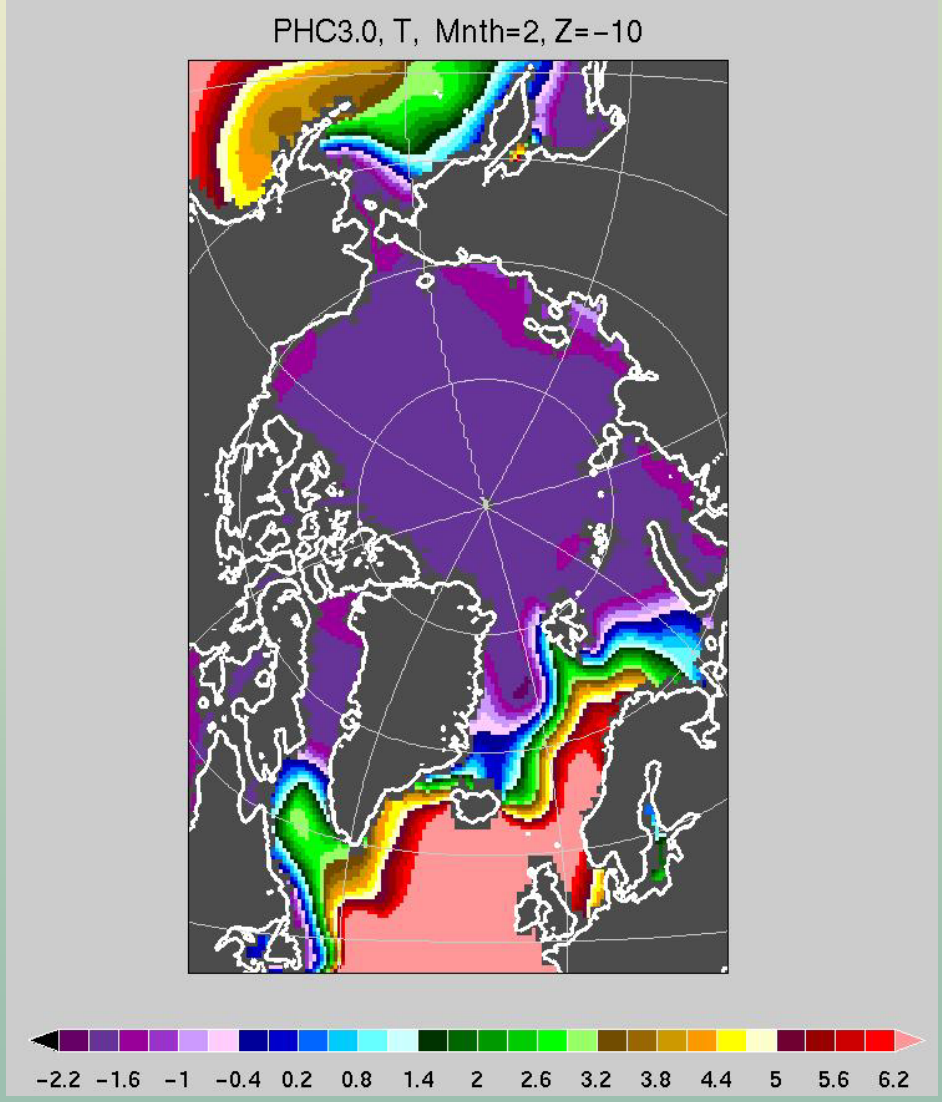


PHC 3.0

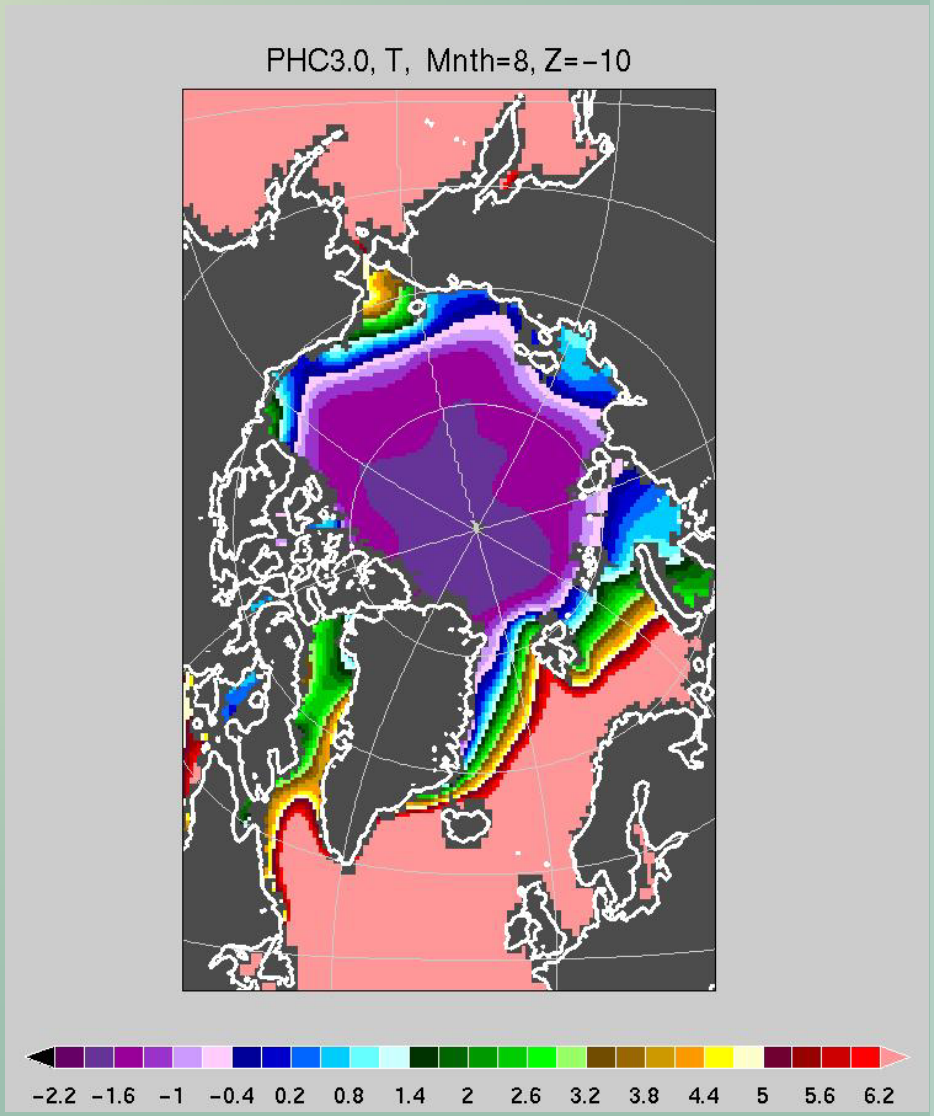


Temperature, 10 m, PHC 3.0

February



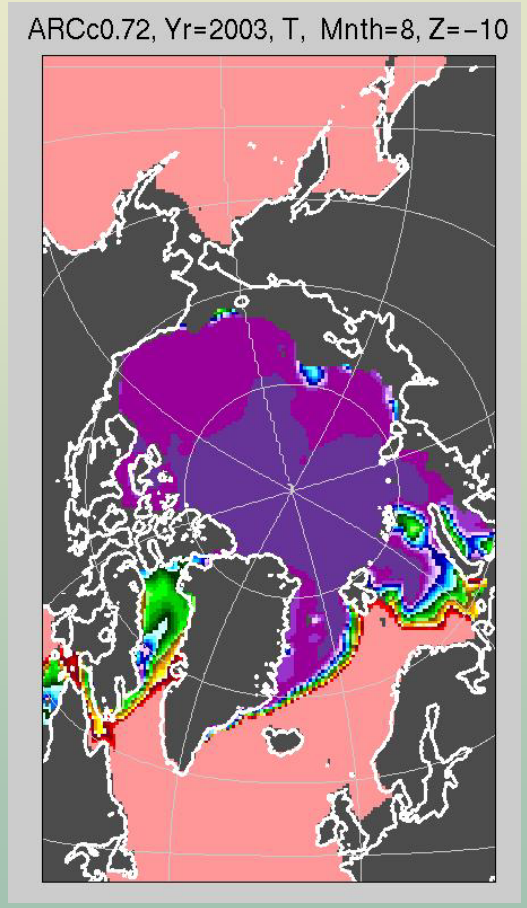
August



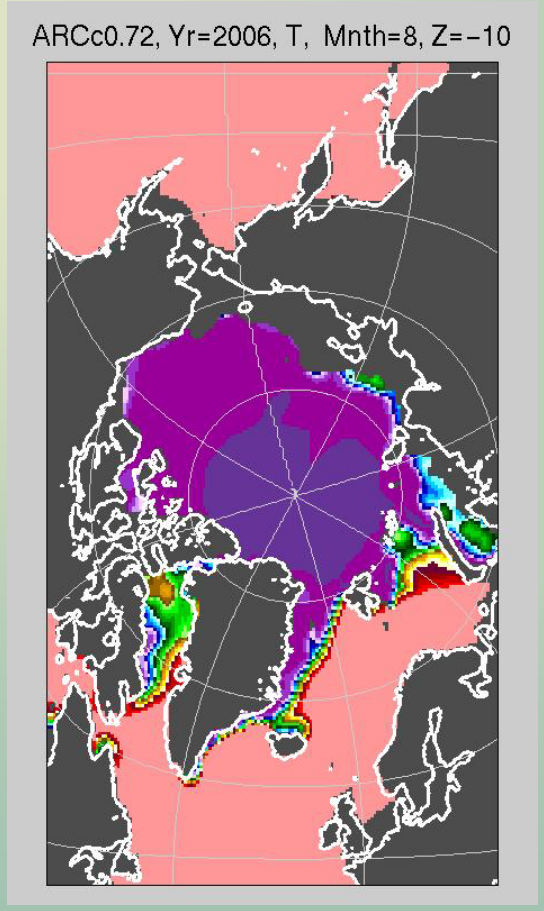
Near-Surface Temperature, August

HYCOM/CICE ARCc 0.72° grid

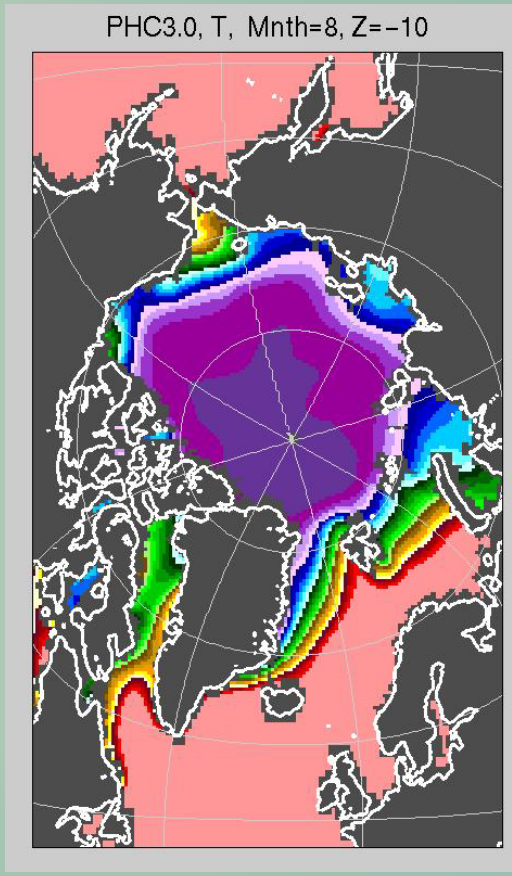
2003

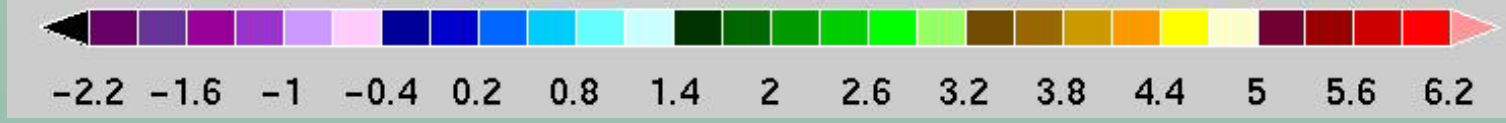


2006



PHC 3.0

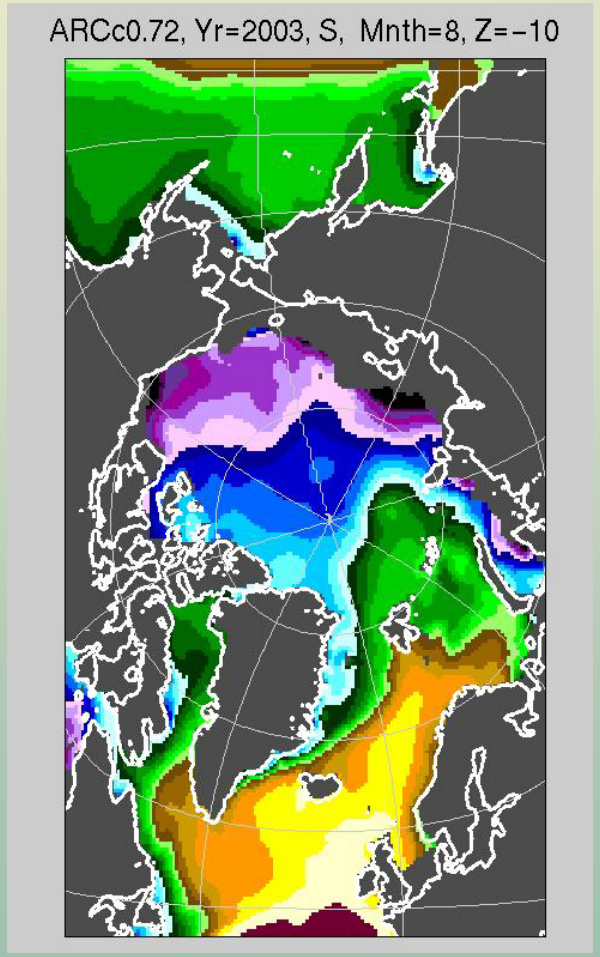




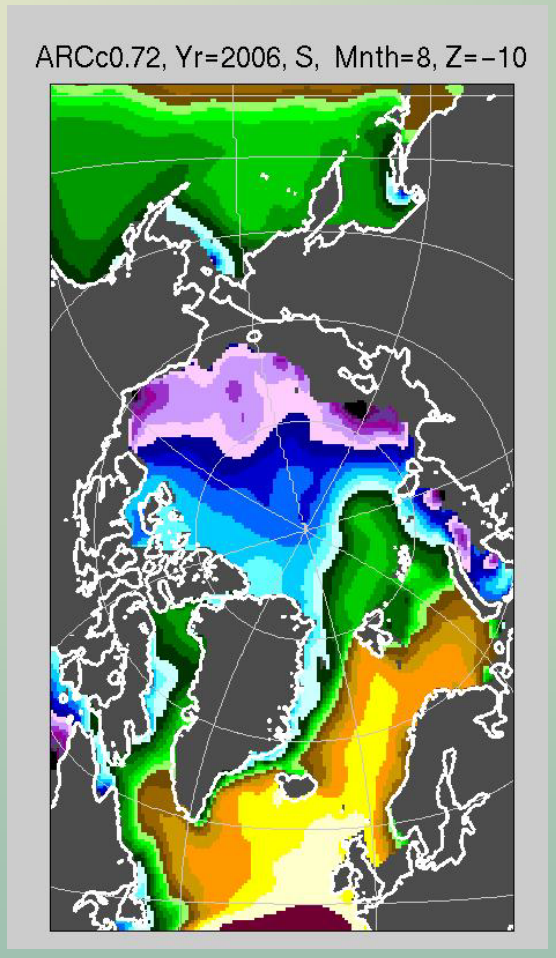
Near-Surface Salinity, August

HYCOM/CICE ARCc 0.72° grid

2003



2006



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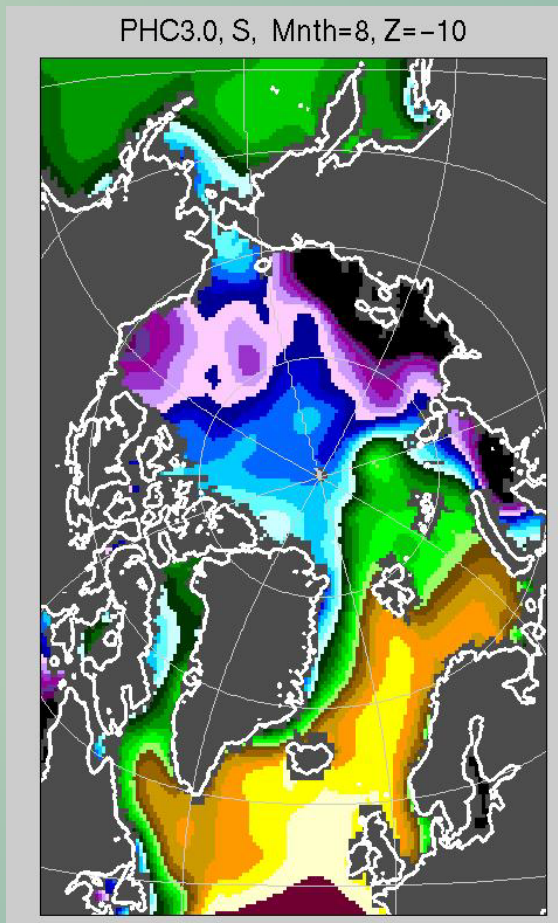
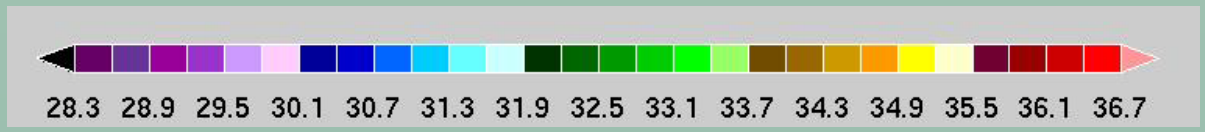
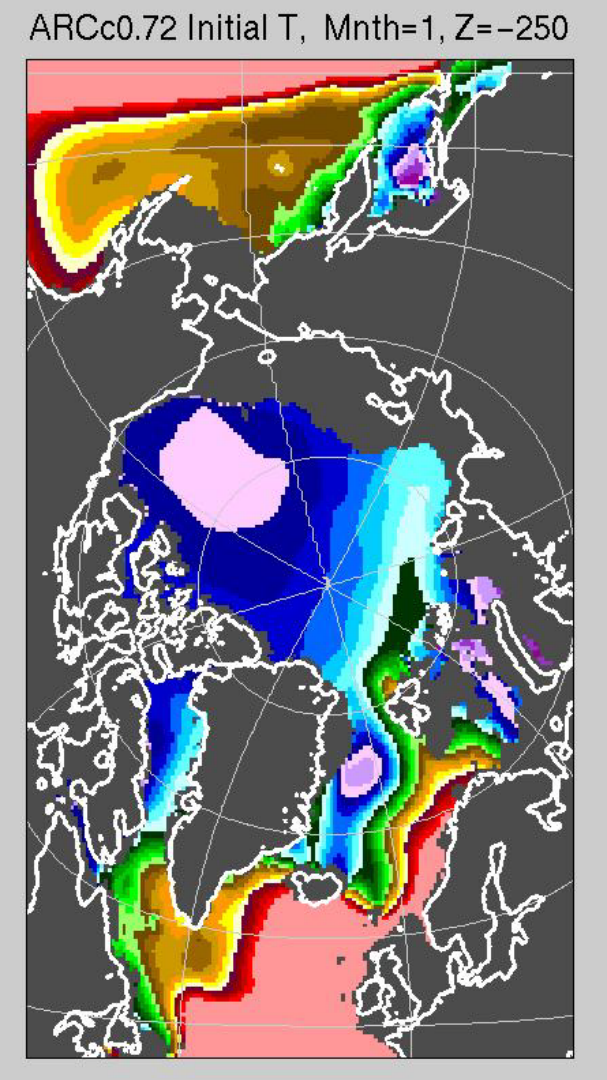




Initial Field: Temperature at 250 m, January

HYCOM/CICE ARCc 0.72 grid



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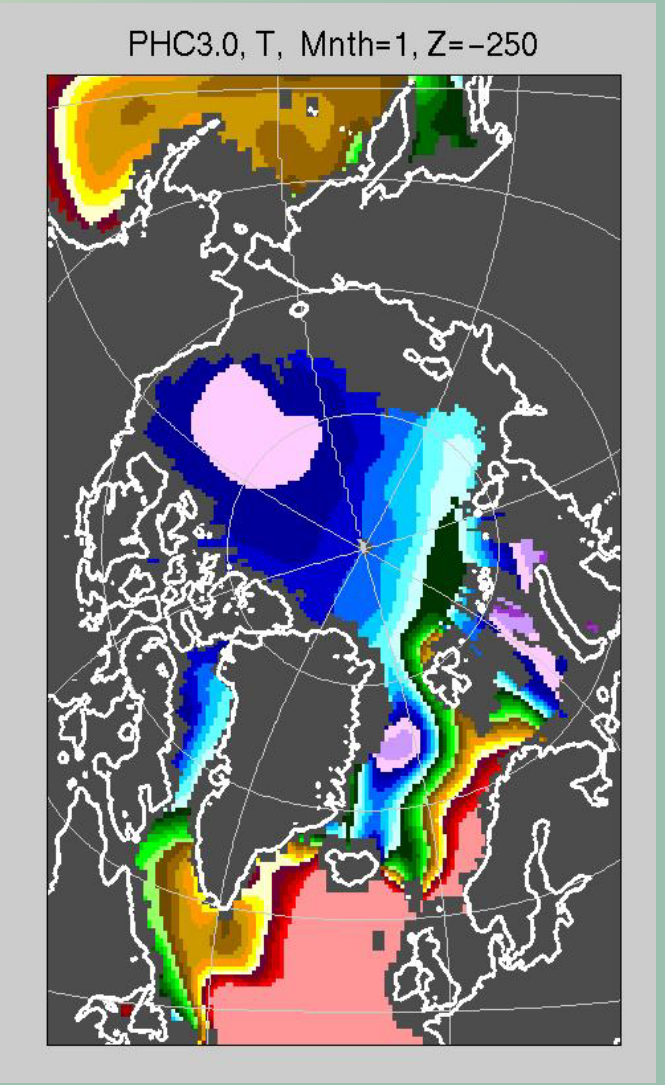
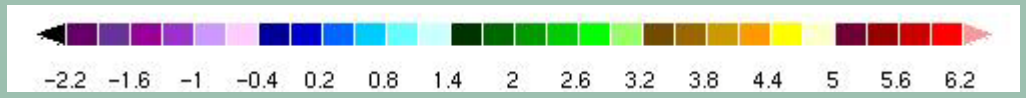
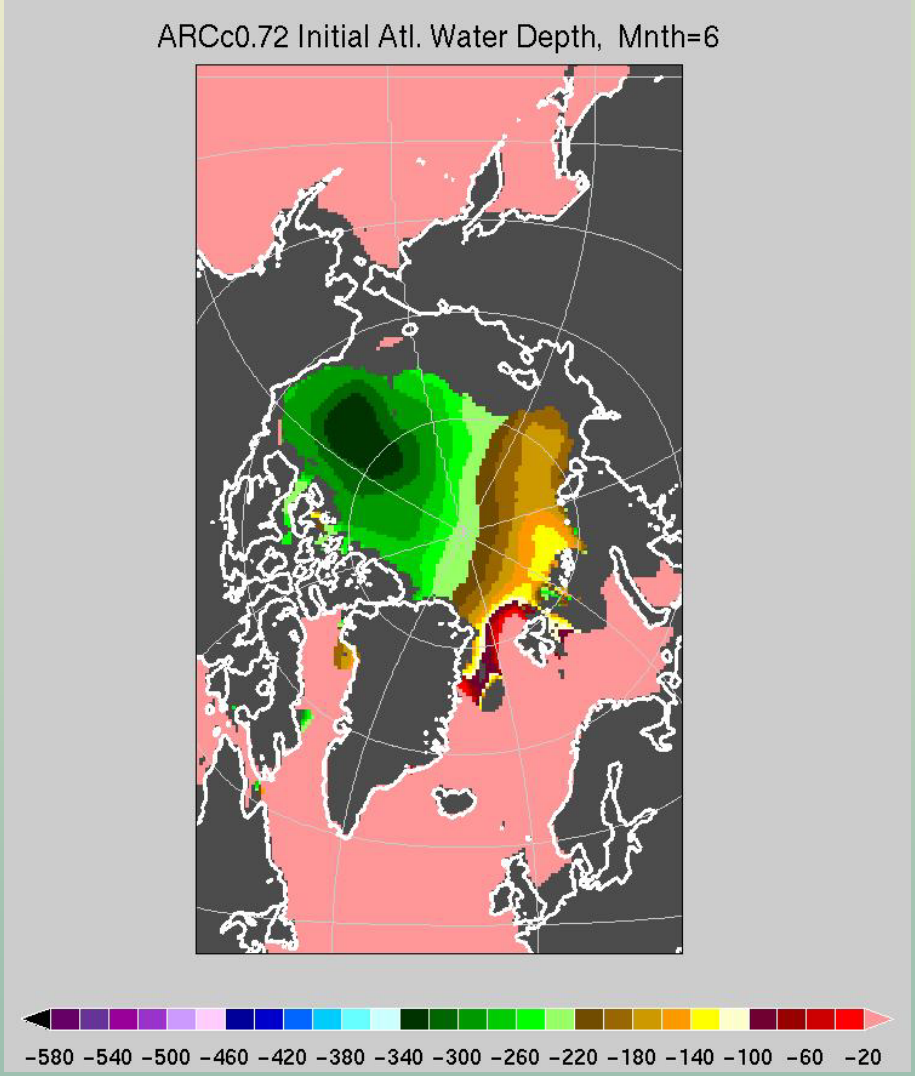




Initial Depth of the Upper Atlantic Water (Depth of 0° Surface)

Initial Field, ARCc 0.72, June



PHC 3.0, June