The thermohaline circulation in the Los Alamos global ice-ocean model

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POP:

Bryan-Cox z-coordinate ocean model

hydrostatic, Boussinesq primitive equations for ocean temperature, salinity, momentum

implicit free surface

implicit barotropic fast gravity wave mode; else explicit 3D

KPP vertical mixing parameterization

adiabatic along-isopycnal mixing (Gent-McWilliams) OR biharmonic horiz mixing (on tracers)

biharmonic horizontal friction (on momentum)

CICE:

energy conserving thermodynamics

energy-based ridging and ice strength

elastic-viscous-plastic dynamics

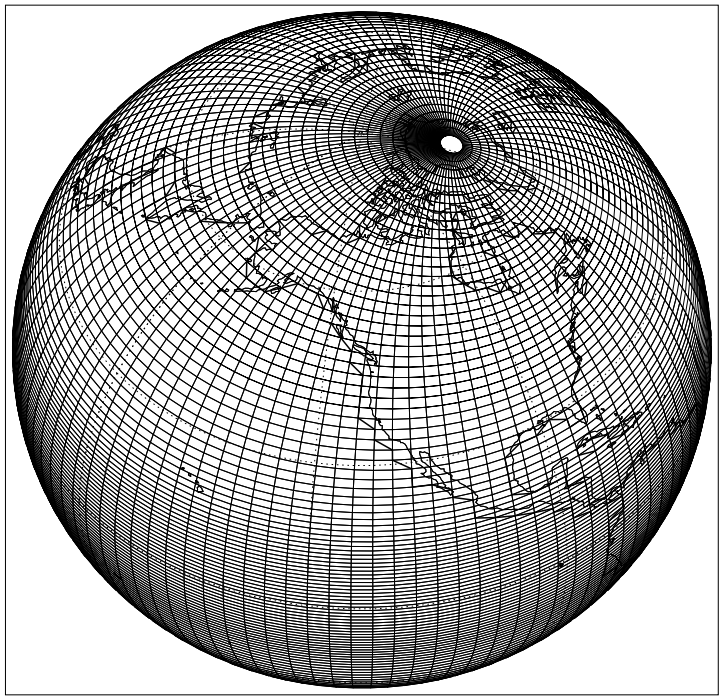
incremental remapping advection

5 thickness categories, 4 layers of ice + 1 layer of snow

variables/tracers (for each thickness category):

- ice area fraction
- ice/snow volume
- ice/snow energy in each vertical layer
- surface temperature

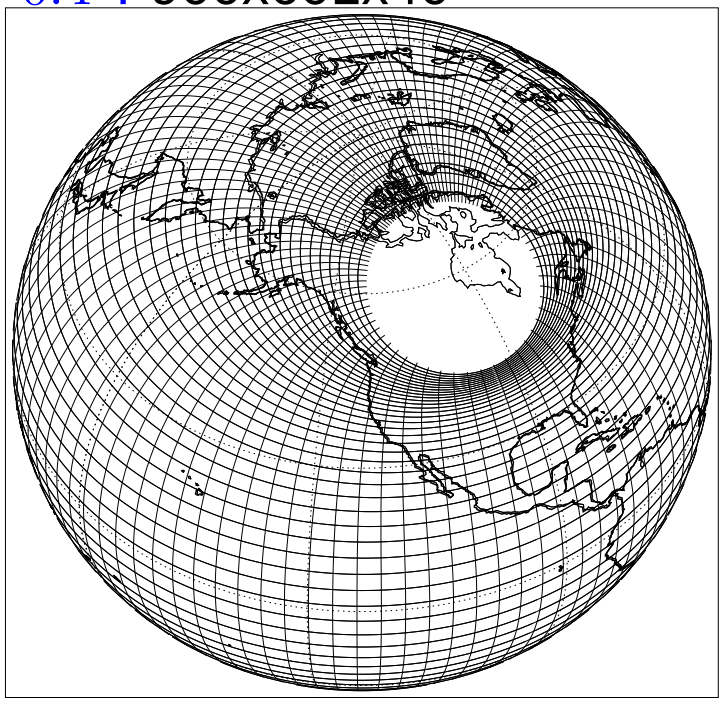
$3°$: 100x116x25



THC sensitivities:

horizontal mixing parameterization
restoring/timescales
T restoring too
atmo mixed layer
atmo bulk formulae
P-E balance
no ice-ocn freshwater/salinity feedback
heat flux formulation to ice
ice reference salinity

$0.4°$: 900x601x40



1 of every 100 mesh nodes shown

Forcing:

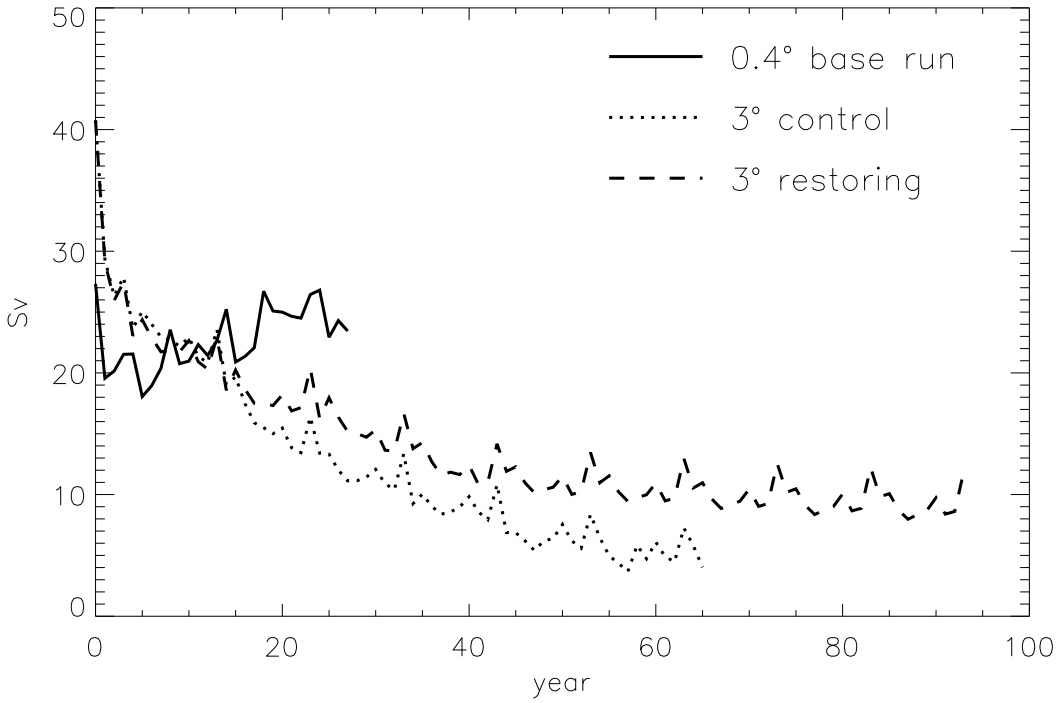
T62, 1979-1988 atmo

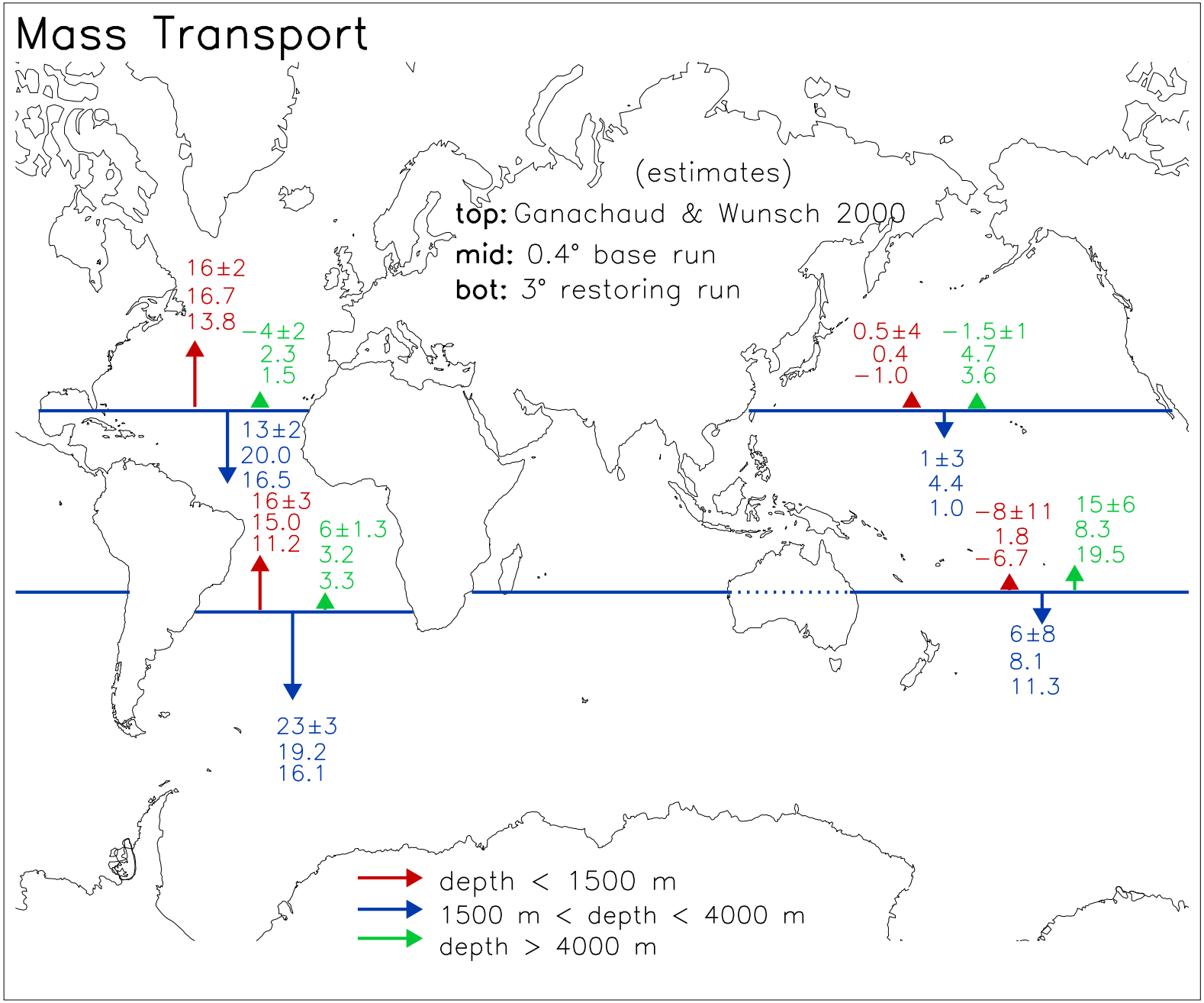
- NCEP T, Q, U, ρ
- ISCCP SW, cloud
- MSU-Xie-Arkin precip

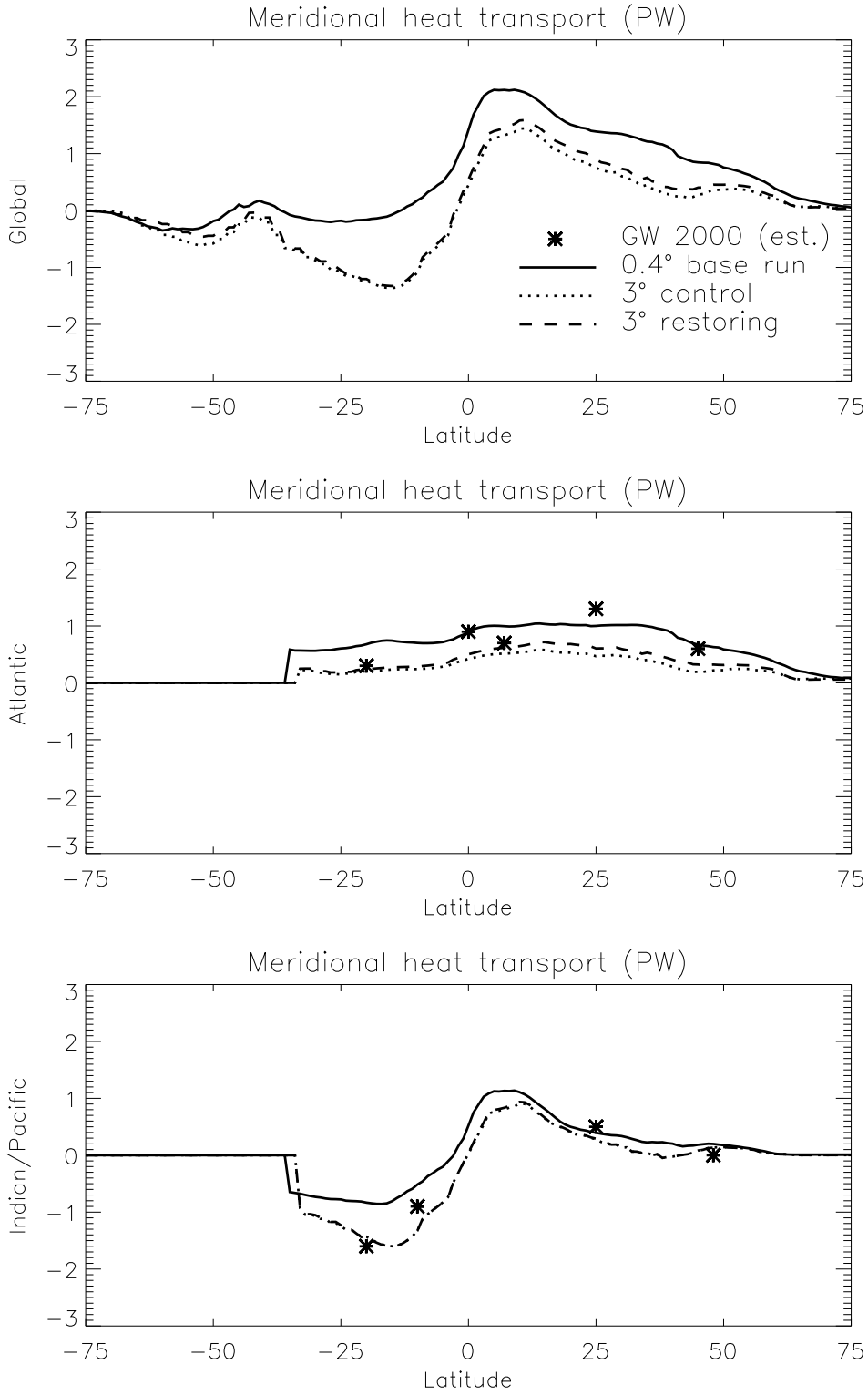
monthly river runoff

Resolution/ Simulation Name	Horizontal mixing	Surface salinity restoring	Length (years)
3° **control**	GM	none	67
3° restoring	GM	180-day	110
0.4° **base run**	biharmonic	none	28

Maximum North Atlantic MOC, Sv

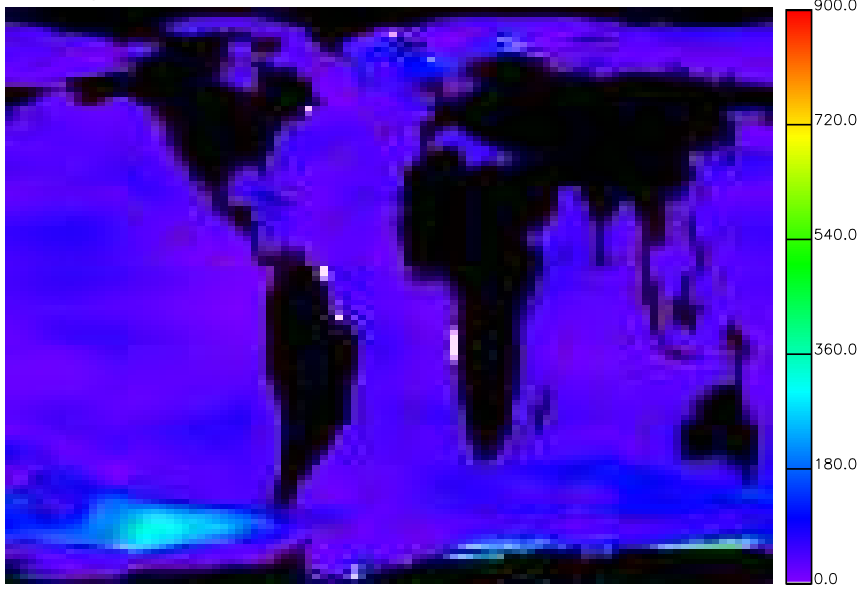



Mass Transport
(estimates)
top: Ganachaud & Wunsch 2000
mid: 0.4° base run
bot: 3° restoring run
16±2
16.7
13.8
−4±2
2.3
1.5
13±2
20.0
16.5
16±3
15.0
11.2
6±1.3
3.2
3.3
23±3
19.2
16.1
0.5±4
0.4
−1.0
−1.5±1
4.7
3.6
1±3
4.4
1.0
−8±11
1.8
−6.7
15±6
8.3
19.5
6±8
8.1
11.3
depth < 1500 m
1500 m < depth < 4000 m
depth > 4000 m

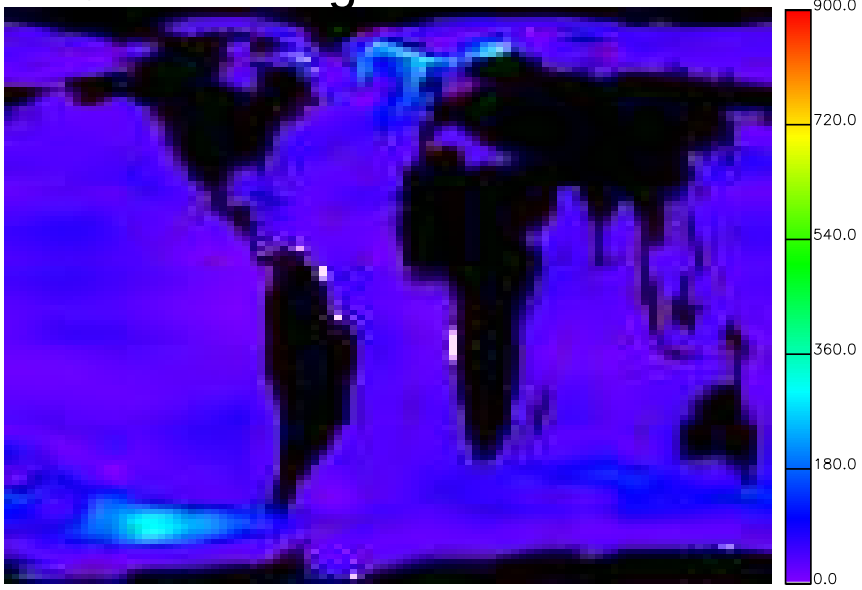

Meridional heat transport (PW)
Global
Latitude
GW 2000 (est.)
0.4° base run
3° control
3° restoring
Meridional heat transport (PW)
Atlantic
Latitude
Meridional heat transport (PW)
Indian/Pacific
Latitude

Average Mixed Layer Depth

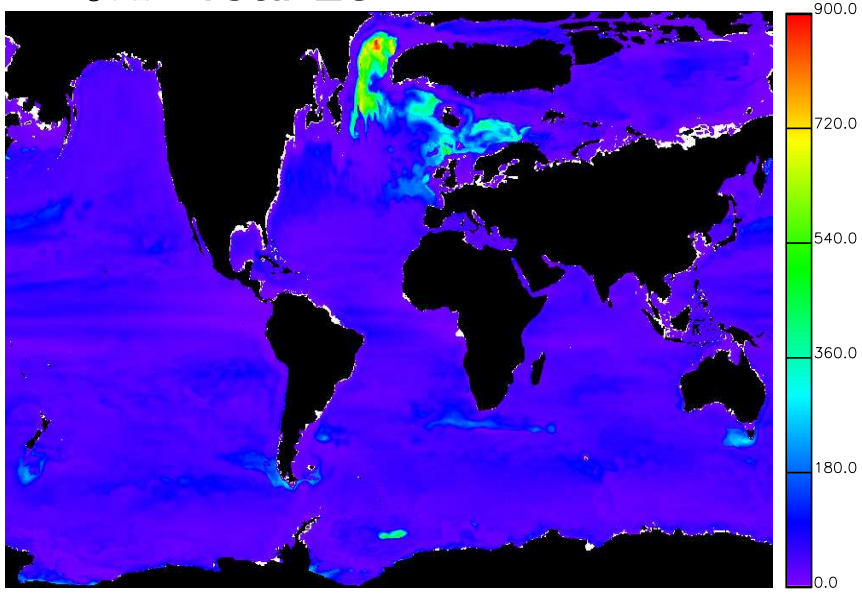
$3°$ control Year 25



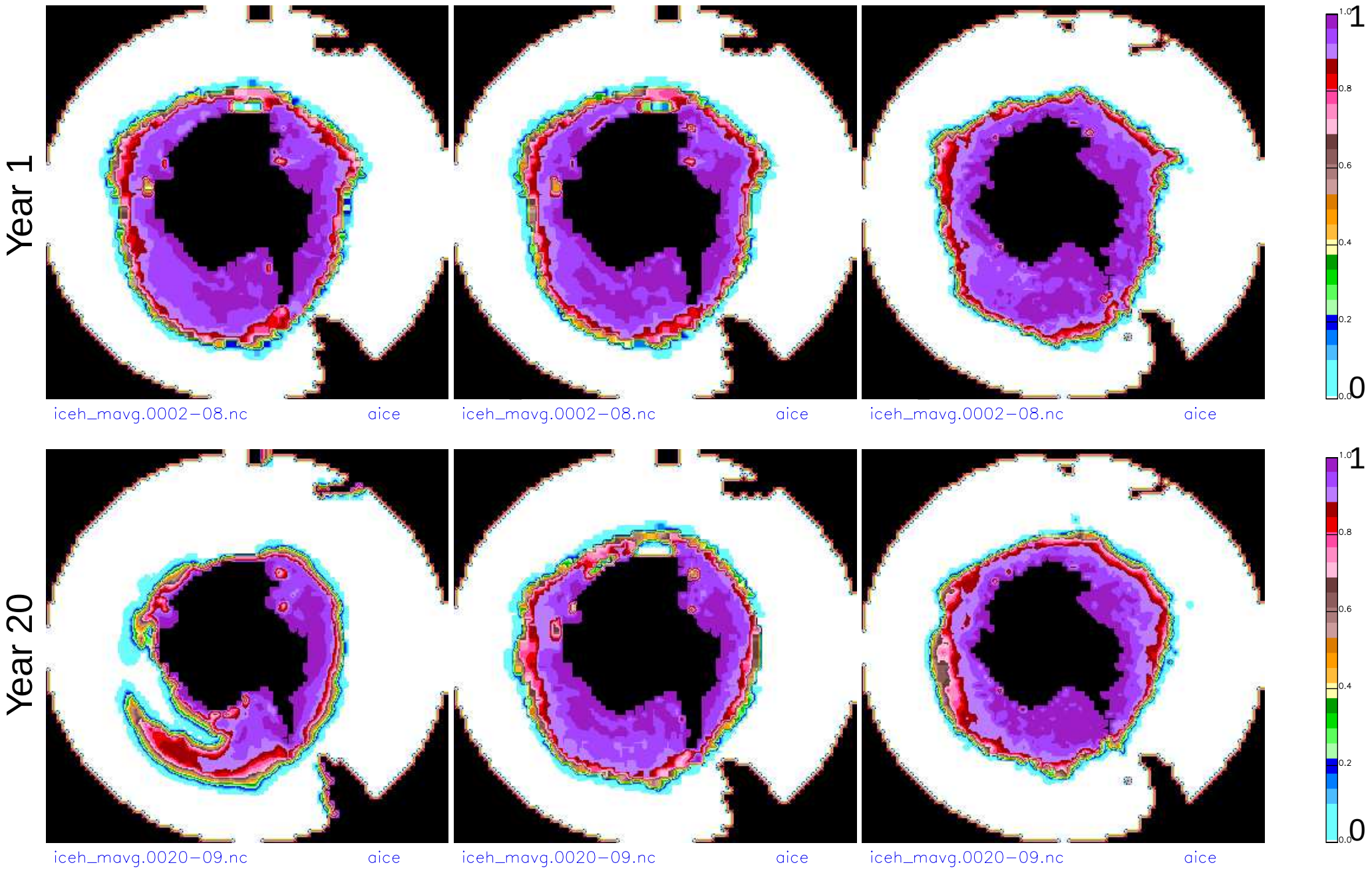
$3°$ restoring Year 25



$0.4°$ Year 25

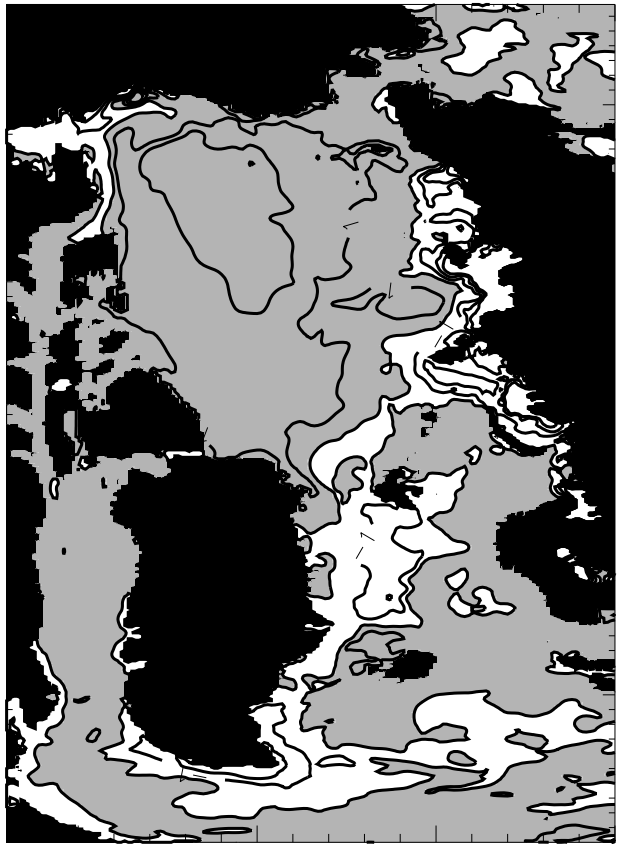


Ice Area Fraction



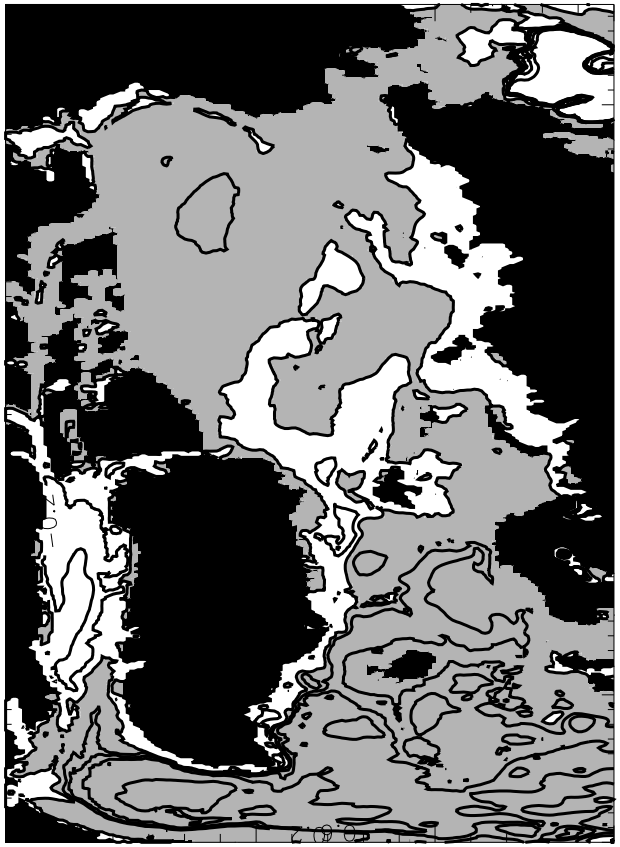
Salinity Change Year 25 - Year 1

Surface



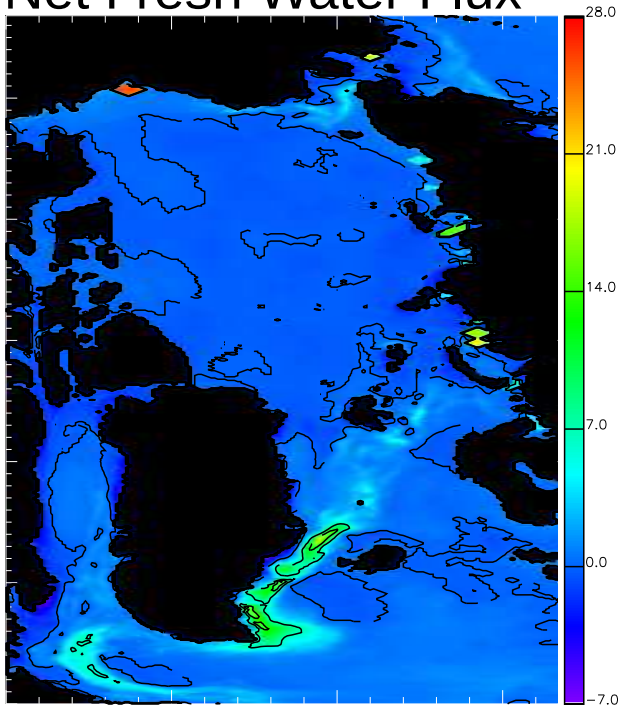
Contour interval: 1 psu

Full depth



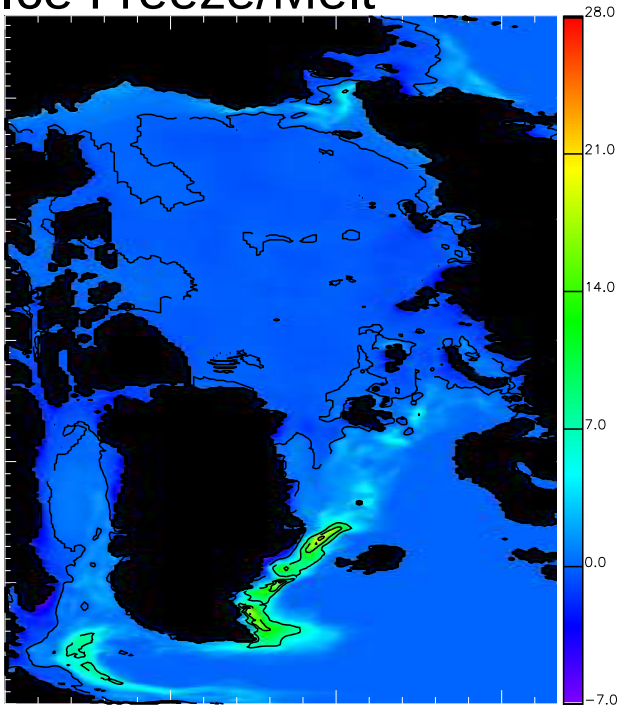
Contour interval: 0.1 psu

Net Fresh Water Flux



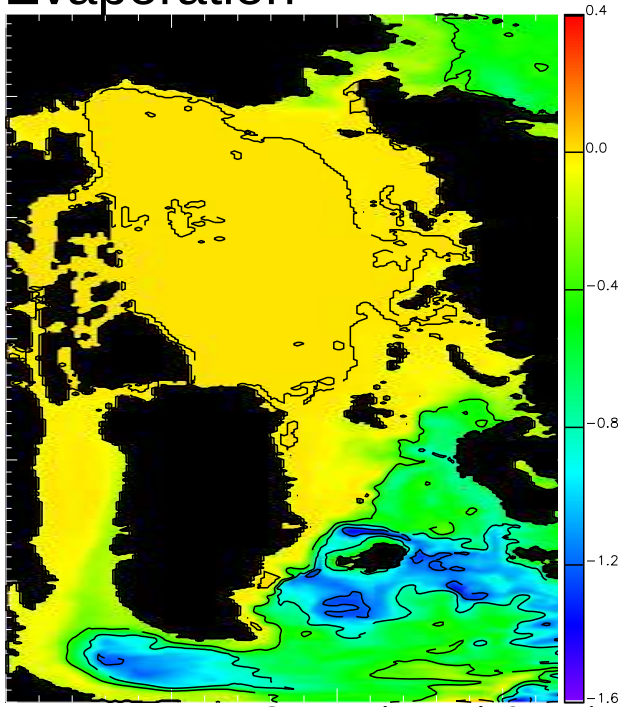
Contour interval: 7 m/yr

Ice Freeze/Melt



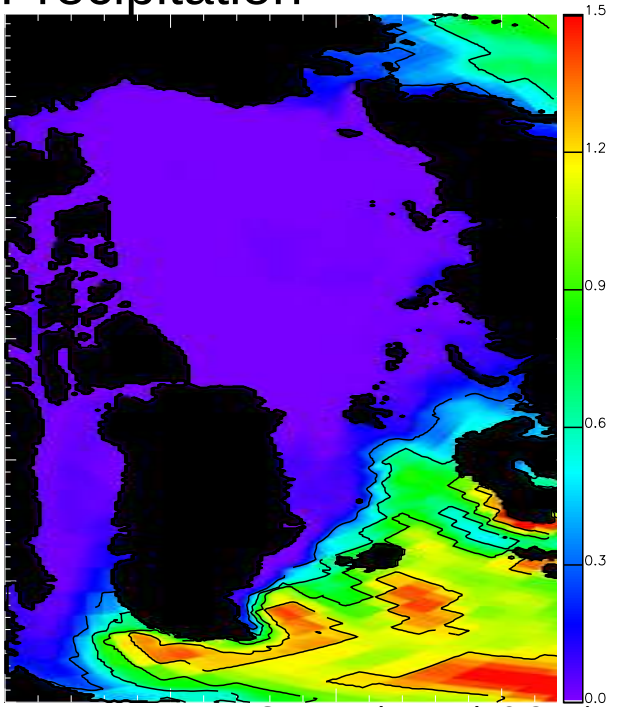
Contour interval: 7 m/yr

Evaporation

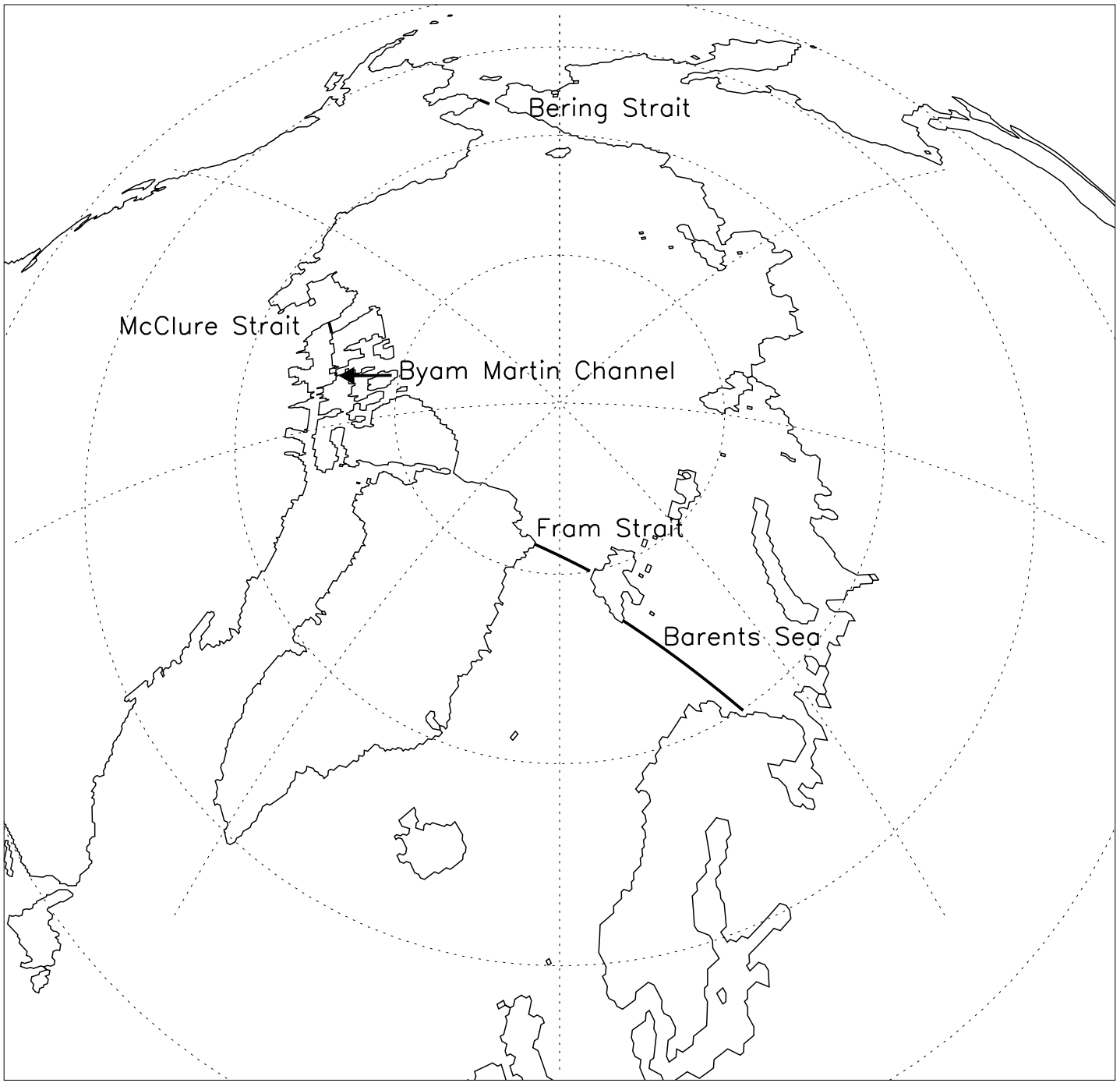


Contour interval: 0.4 m/yr

Precipitation



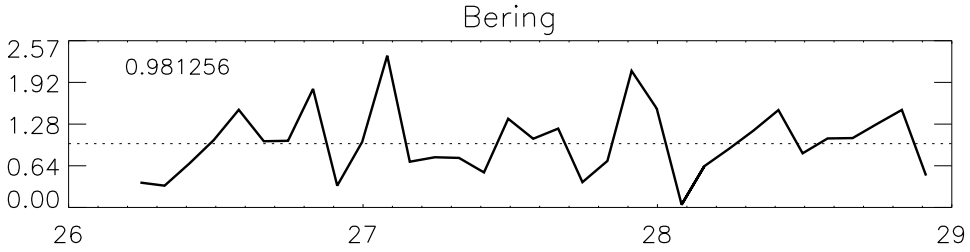
Contour interval: 0.3 m/yr


Bering Strait
McClure Strait
Byam Martin Channel
Fram Strait
Barents Sea

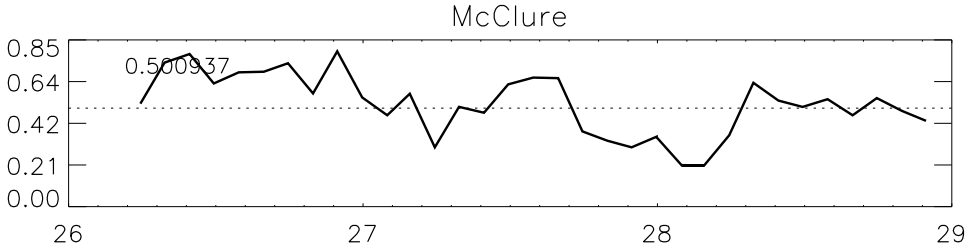
Arctic Ocean

Oceanic fresh water transport, Sv

in



out



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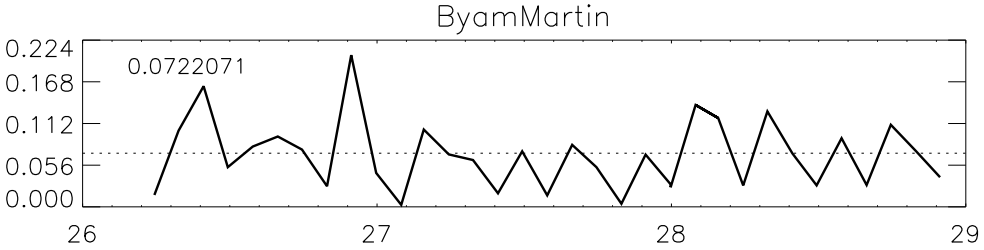

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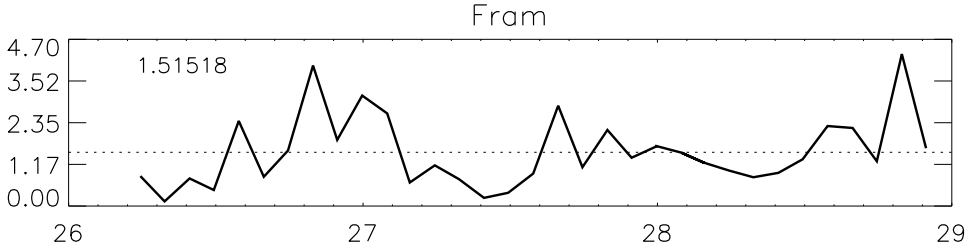
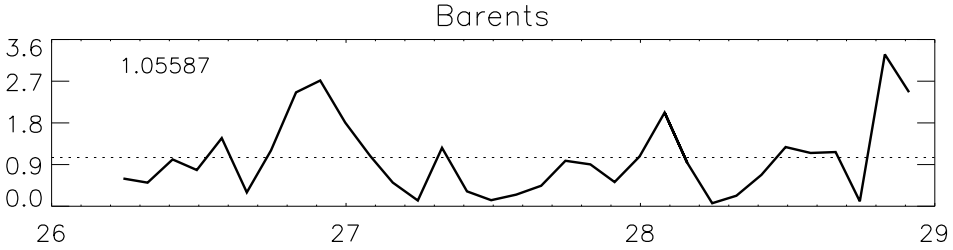
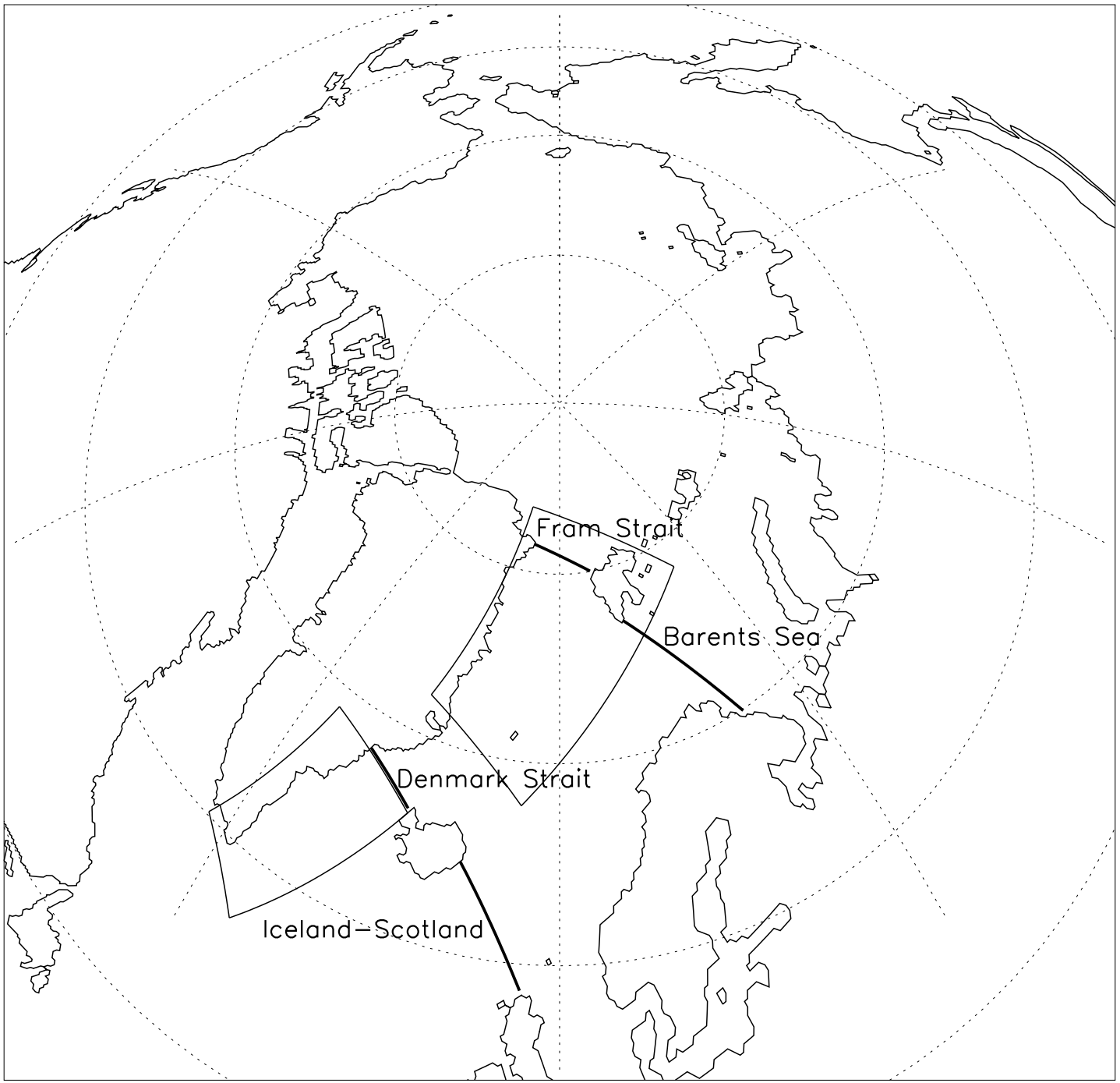


in

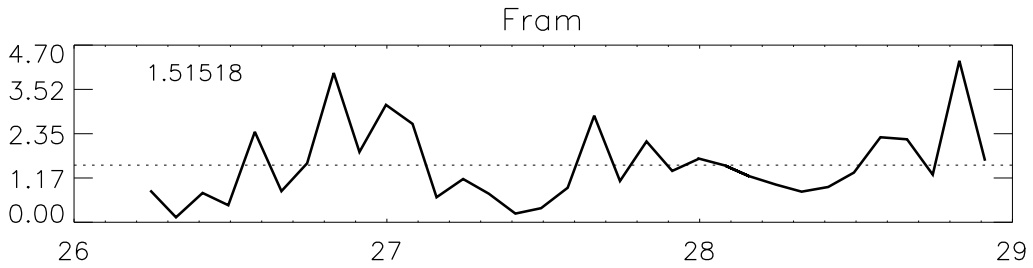



Fram Strait
Barents Sea
Denmark Strait
Iceland–Scotland

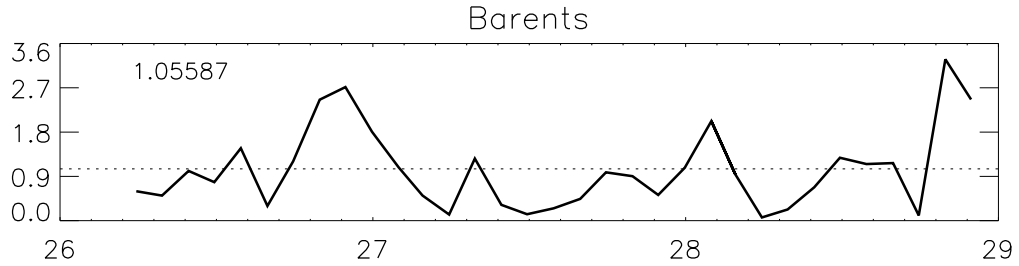
GIN Seas

Oceanic fresh water transport, Sv

in



out



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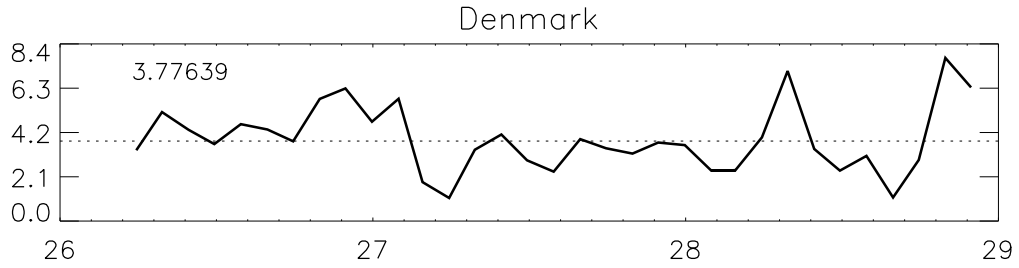

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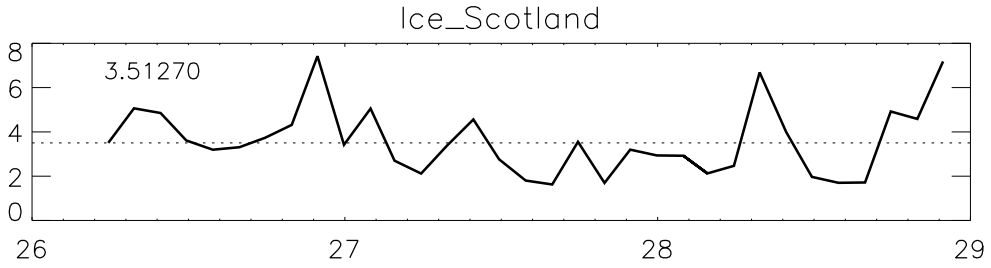
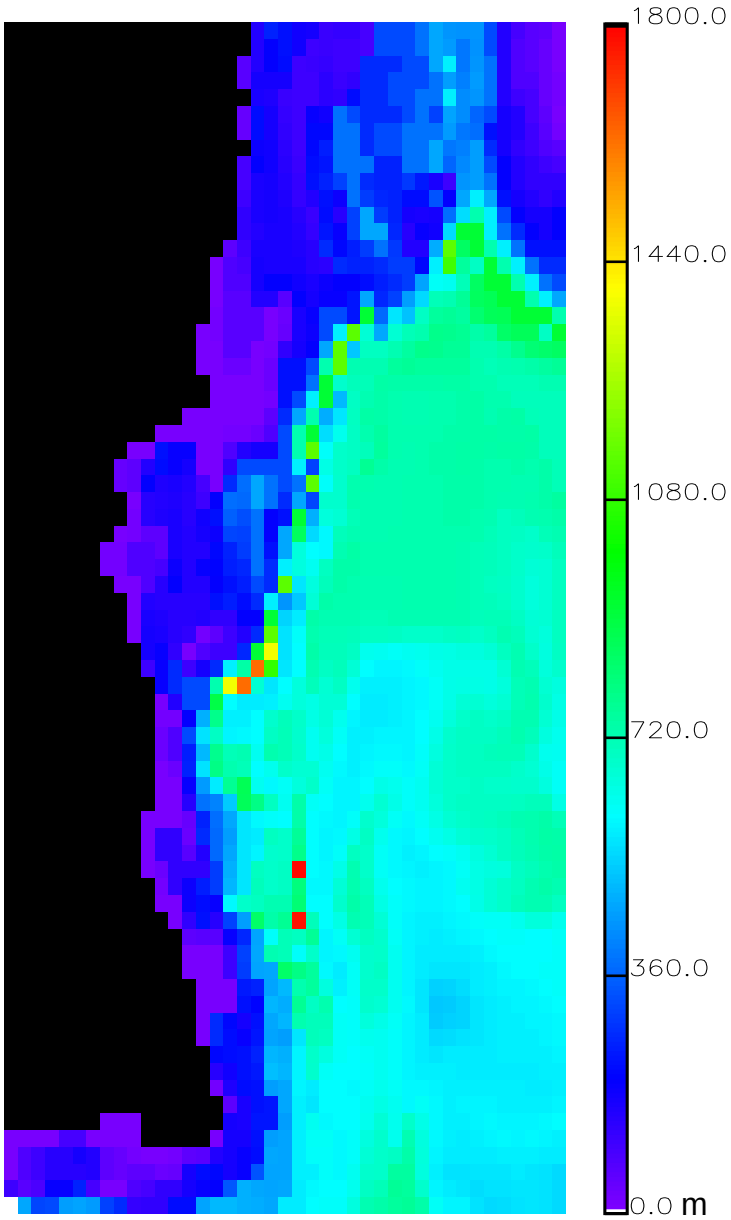
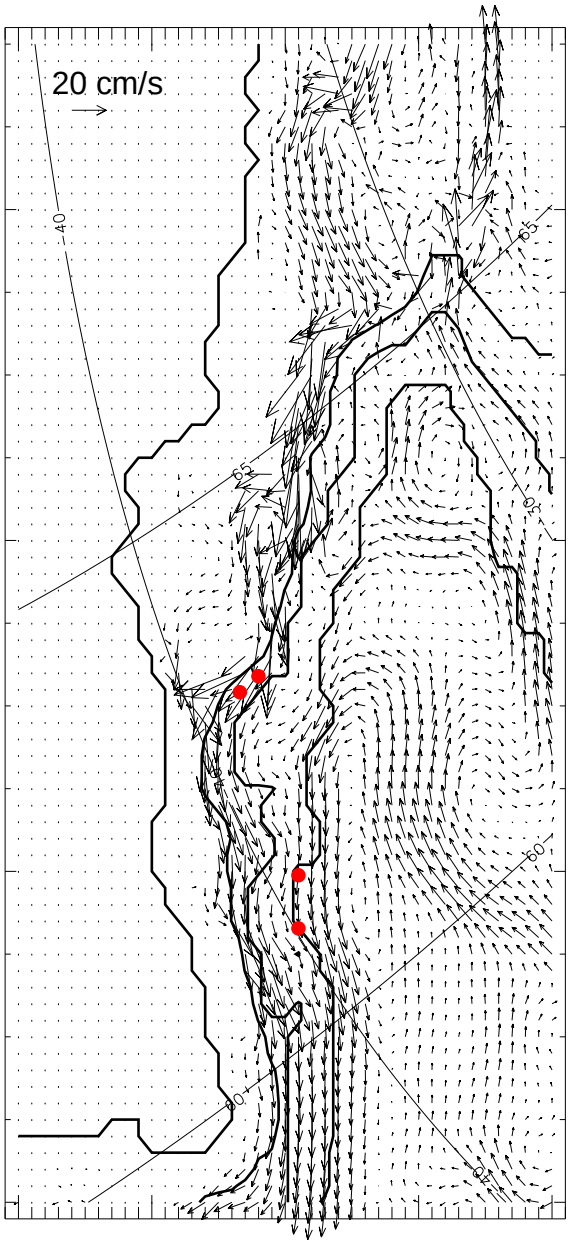


Year 28

Max Mixed Layer Depth



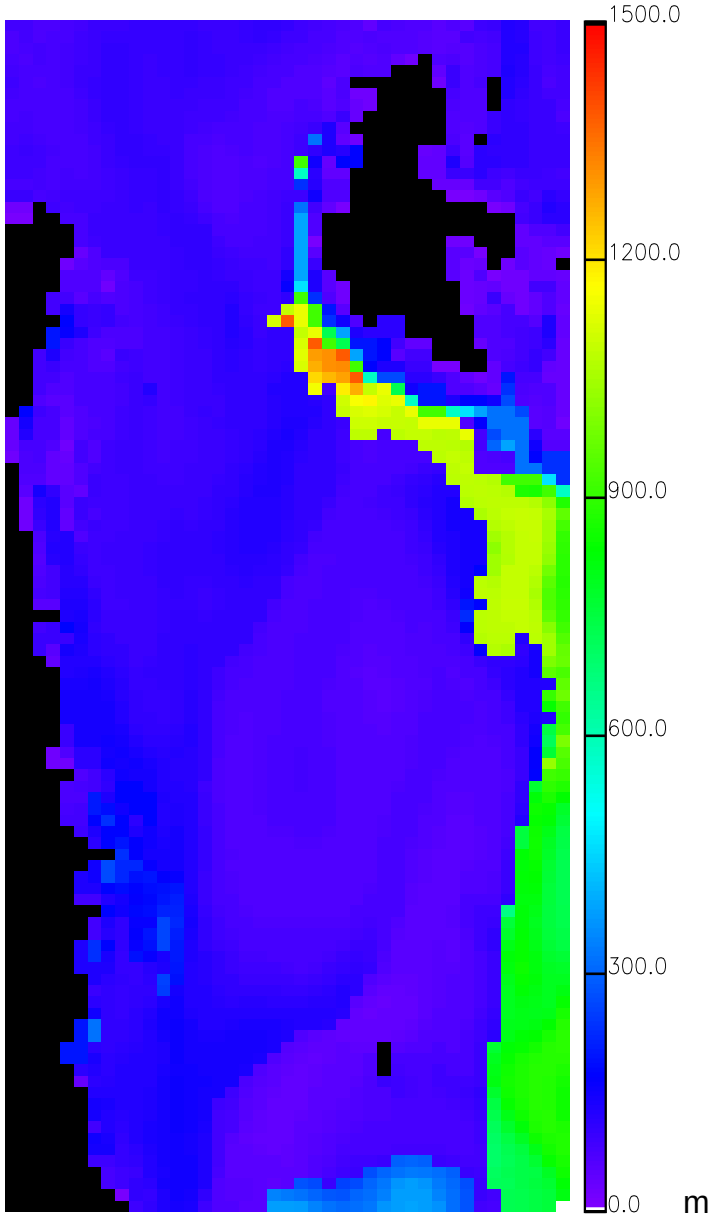
112-m Velocity



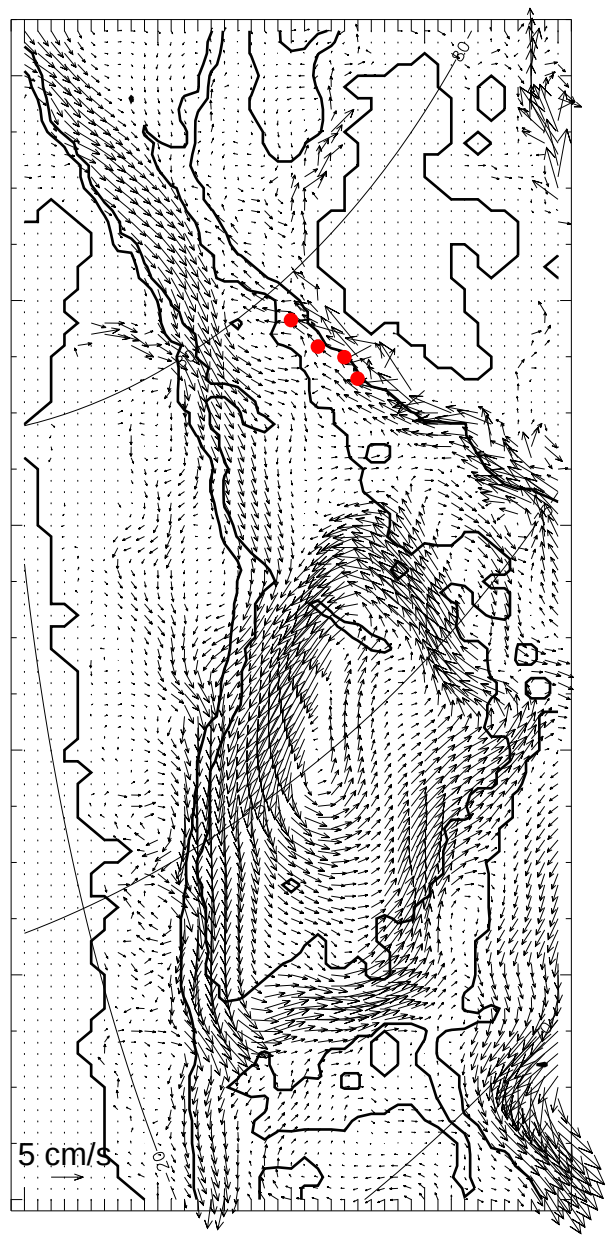
Contours 0, 1200, 1800, 2400 m

Year 21

Max Mixed Layer Depth



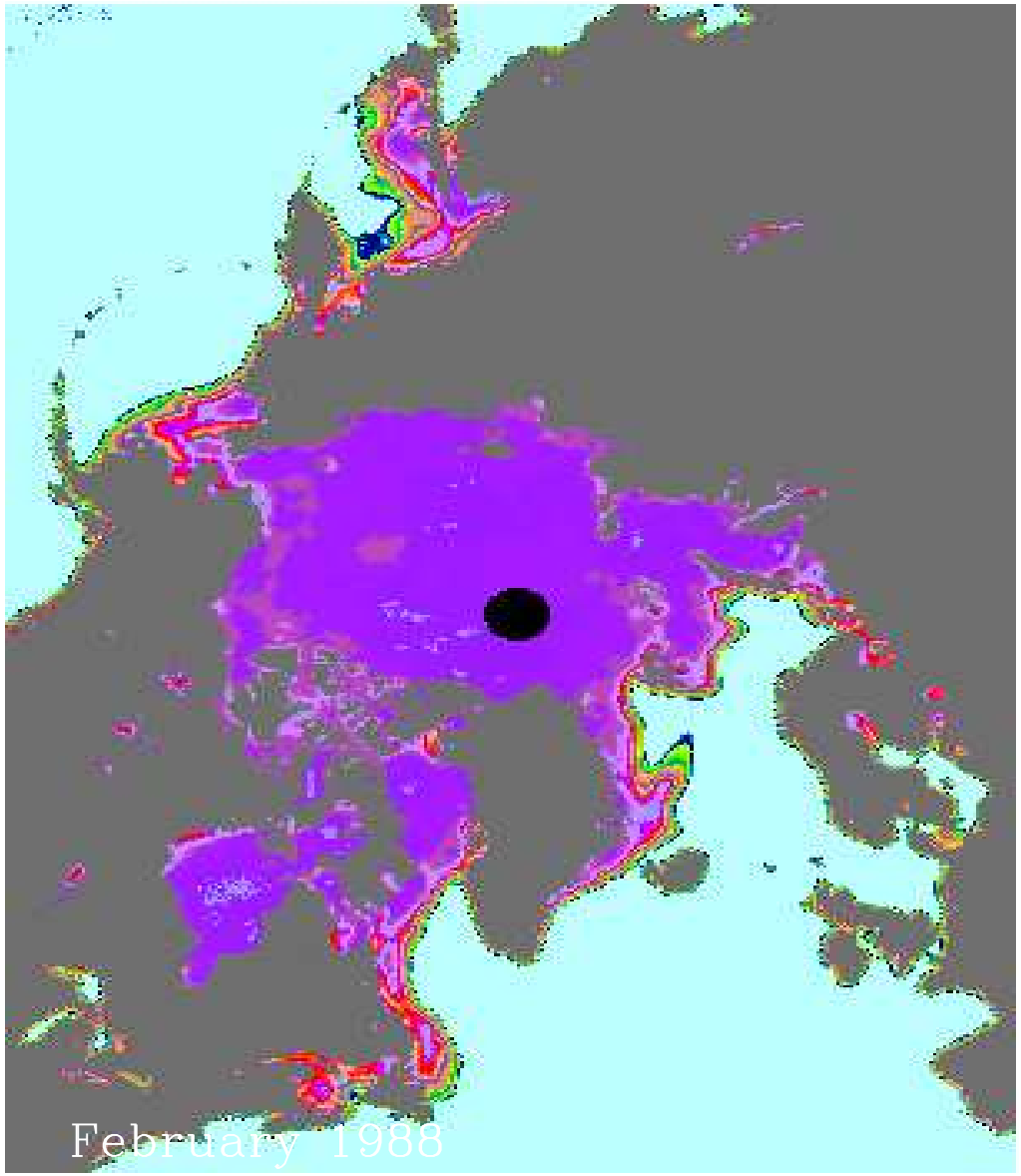
112-m Velocity



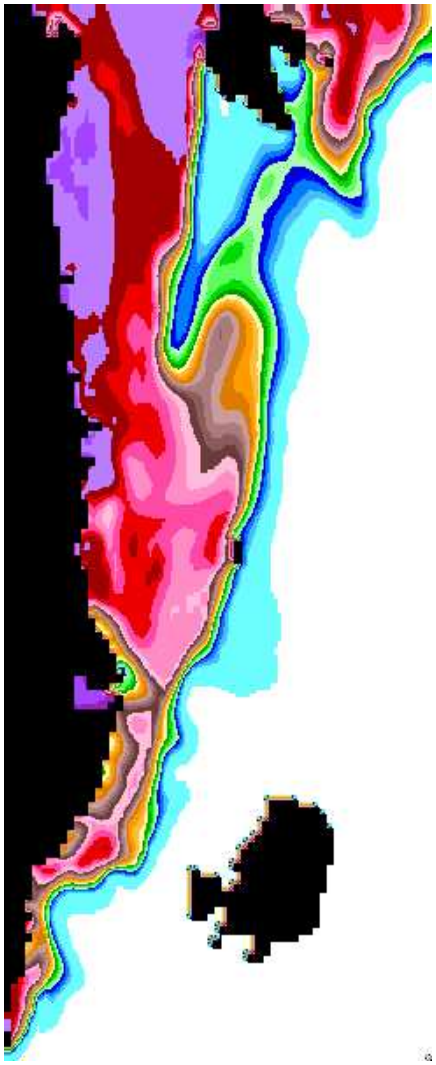
Contours 0, 1200, 2400 m

Ice Concentration

SSM/I



0.4



Summary

Meridional overturning circulation in the North Atlantic appears to be robust in the 0.4° simulation. It gradually weakens in the 3° simulations, which overturn excessively in the Southern Ocean.

Northern hemisphere transport and circulation are reasonable in the 0.4°.

CAVEAT: 25 years isn't enough.

Critical model ingredients

- Resolution of melting and freezing
- Mixing parameterizations in the ocean model
- Surface salinity restoring obscures modeling issues

Future work

Convection and the fresh water budget warrant a closer look in the 0.4°.

Interaction of sea ice physical processes with the ocean circulation needs more study.

Special thanks to Mat Maltrud, Matthew Hecht, Rainer Bleck