Sigma_2 versus sigma_1 ….
Optimizing HYCOM's vertical coordinate

Rainer Bleck
NASA Goddard Institute for Space Studies,
New York
Dongxiao Zhang
NOAA Pacific Marine Environmental Lab,
Seattle

May 2013

The 3-D grid in geophysical fluids

- The distinguishing feature of geophysical fluid modeling is the pre-eminence of gravity.
- Mixing of vertical and horizontal forces in the dynamic equations must therefore be avoided at all cost.
- This is accomplished by making the z axis coincide with the direction of gravity.
- The other 2 coordinate directions **must** be perpendicular to the z axis. This way, gravity will not contaminate the force balance there.

The 3-D grid in geophysical fluids (cont'd)

- If ALE is applied in *z* direction, differential vertical motion of fluid particles will inevitably destroy the "horizontal" alignment of neighboring grid points.
- Once that happens, the horizontal force balance must be computed from information carried on sloping coordinate surfaces.
- This is the Achilles Heel of generalized-vertical coordinate modeling of geophysical fluids.

Vertical coordinate considerations

- σ_{pot}=*const.* coordinate layers make it easy to properly model subgrid-scale adiabatic mixing and overflows.
- In sloping coordinate layers, computation of the horizontal pressure gradient force is tricky.
- In σ_{pot}=*const.* layers, the PGF reduces (approx-imately) to a single term – a major advantage.
- HYCOM has traditionally used σ_2 (potential density referenced to 2km depth) as vertical coordinate. This choice was made to minimize regions in the world ocean where pot. density is multi-valued in the vertical.
- σ_1 appears to offer certain advantages (better: tradeoffs).

General recipe:

$$\nabla_z = \nabla_s - (\nabla_s z)\left.\frac{\partial}{\partial z}\right|_s$$

In particular:

(pressure gradient in u,v equations)

$$\boxed{\frac{1}{\rho}\nabla_z p} = \frac{1}{\rho}\nabla_s p + \nabla_s (gz)$$

Special nonsolenoidal cases:

(a) **s = p**

$$\boxed{\frac{1}{\rho}\nabla_z p} = \nabla_p (gz)$$

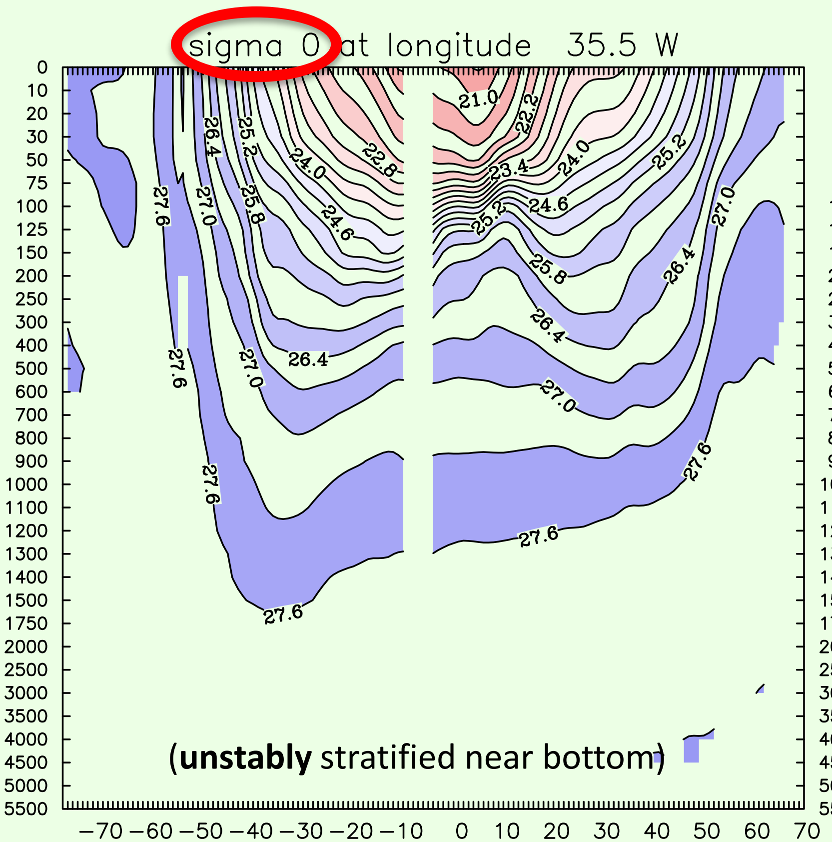
(popular in meteorology)

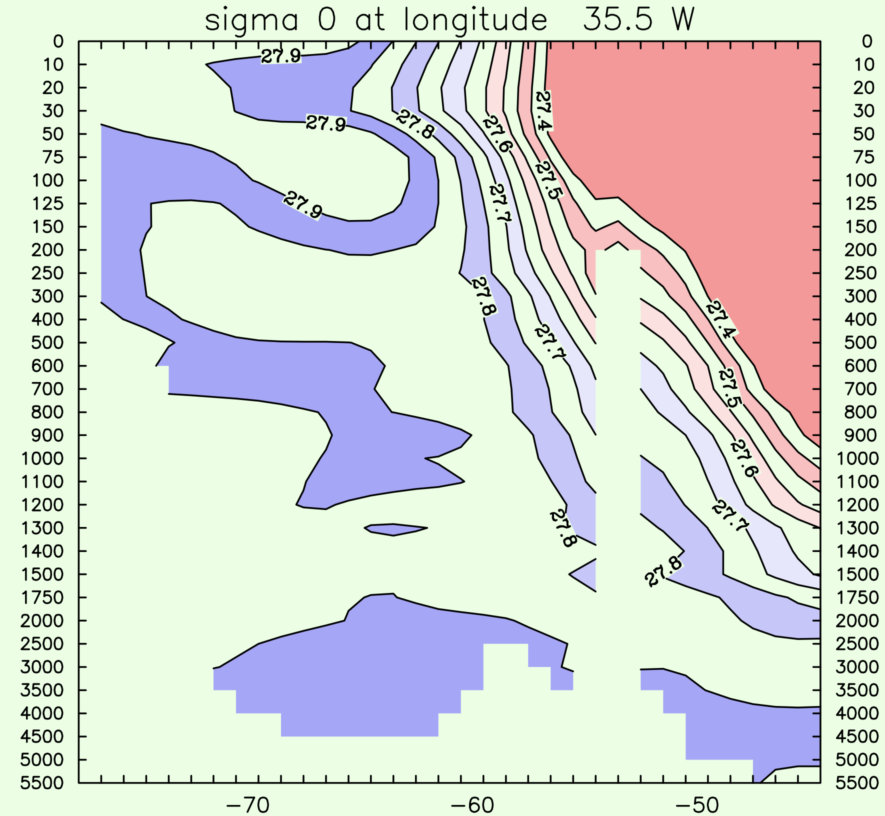
(b) **s = ρ**

$$\boxed{\frac{1}{\rho}\nabla_z p} = \nabla_\rho \left(\frac{p}{\rho} + gz\right)$$

(popular in oceanography)

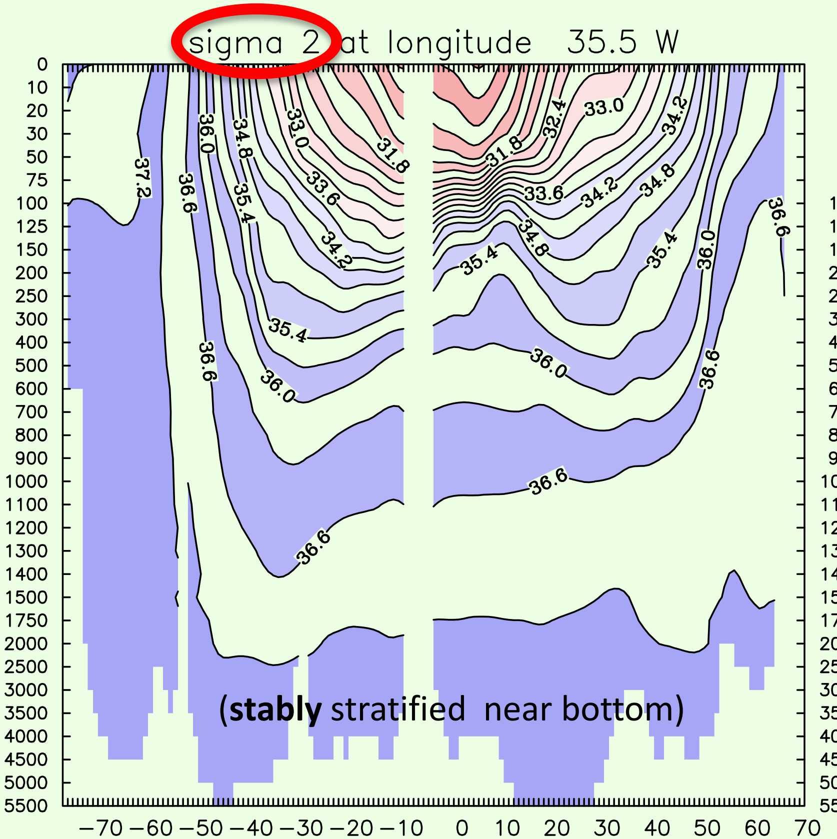
A meridional cross section showing observed σ_{pot} in the Atlantic

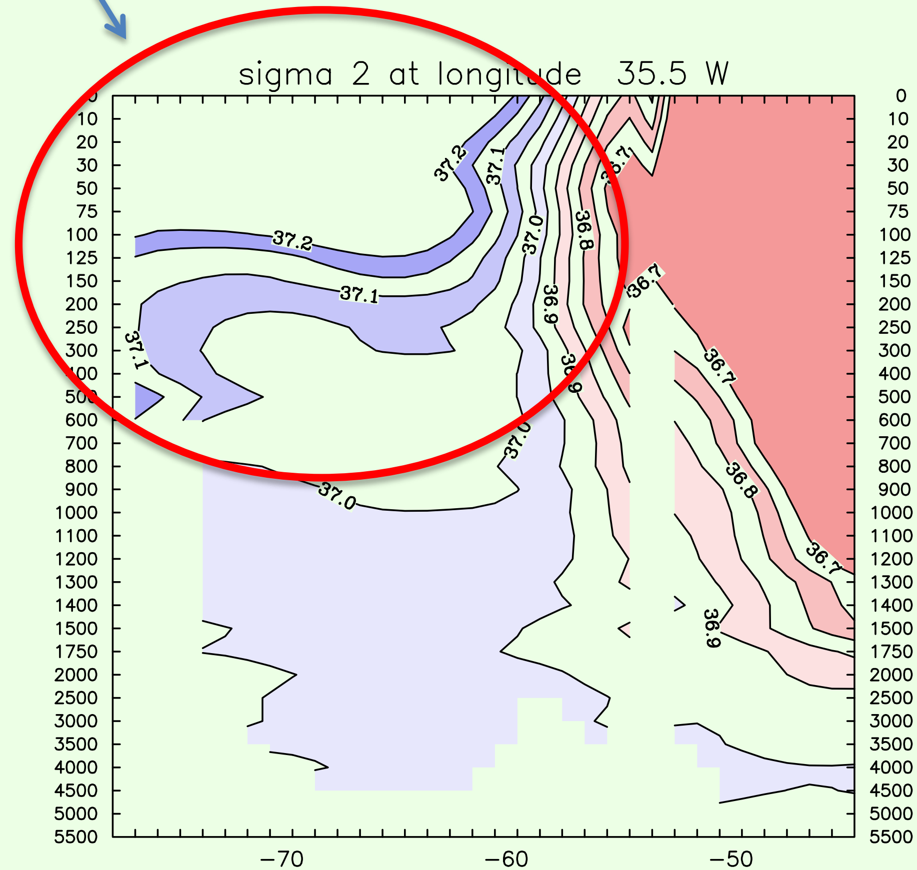


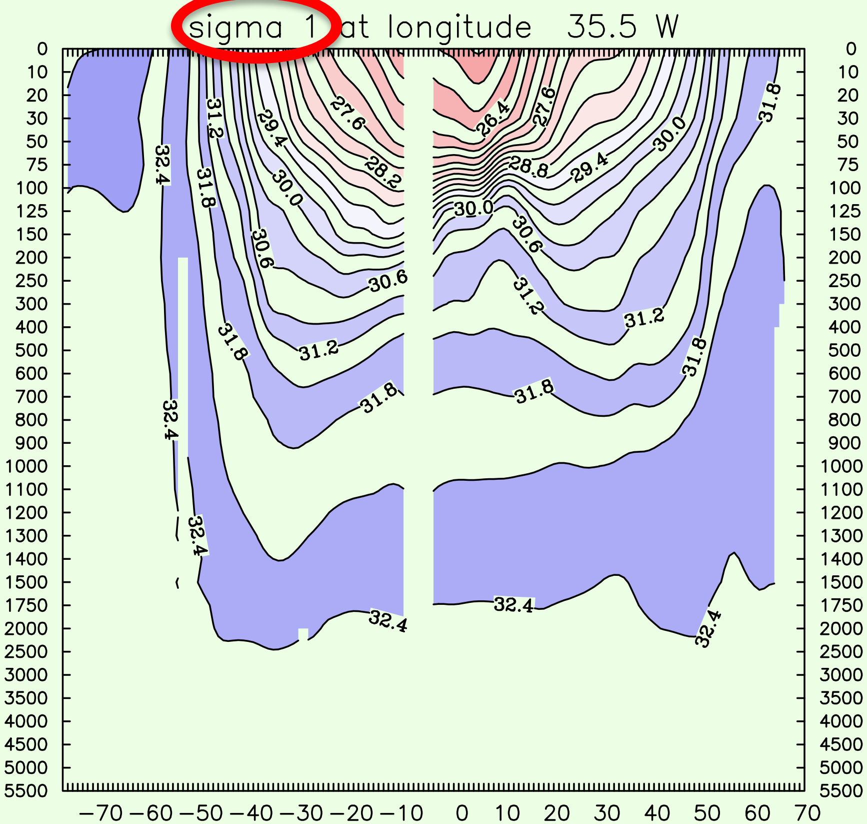


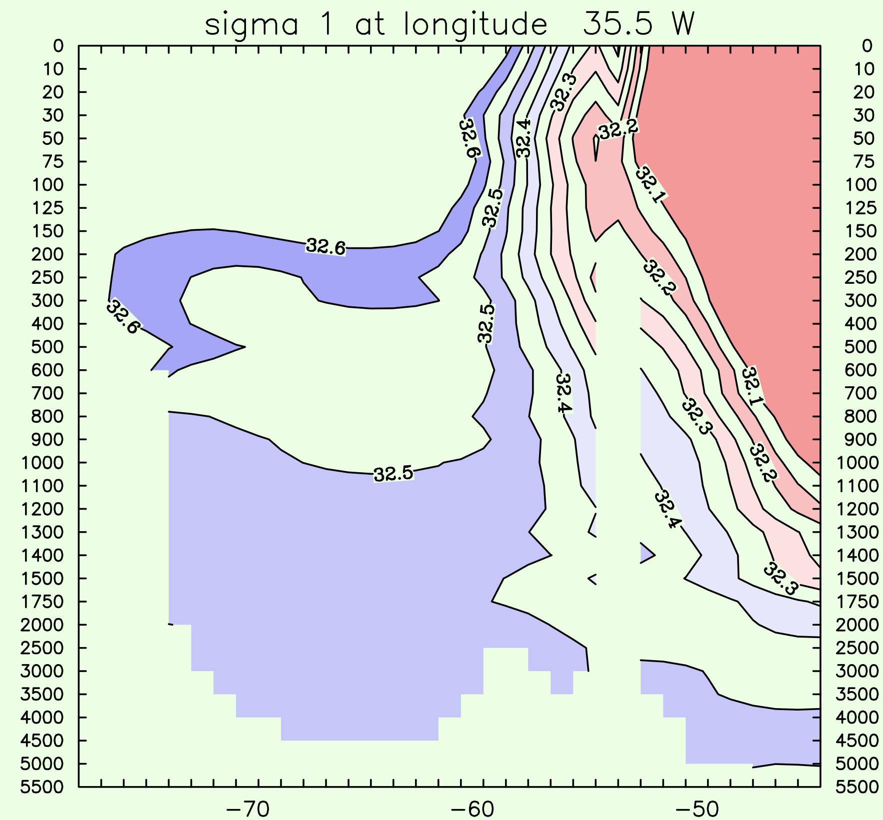
Definition: σ = density minus 1000 kg/m^3

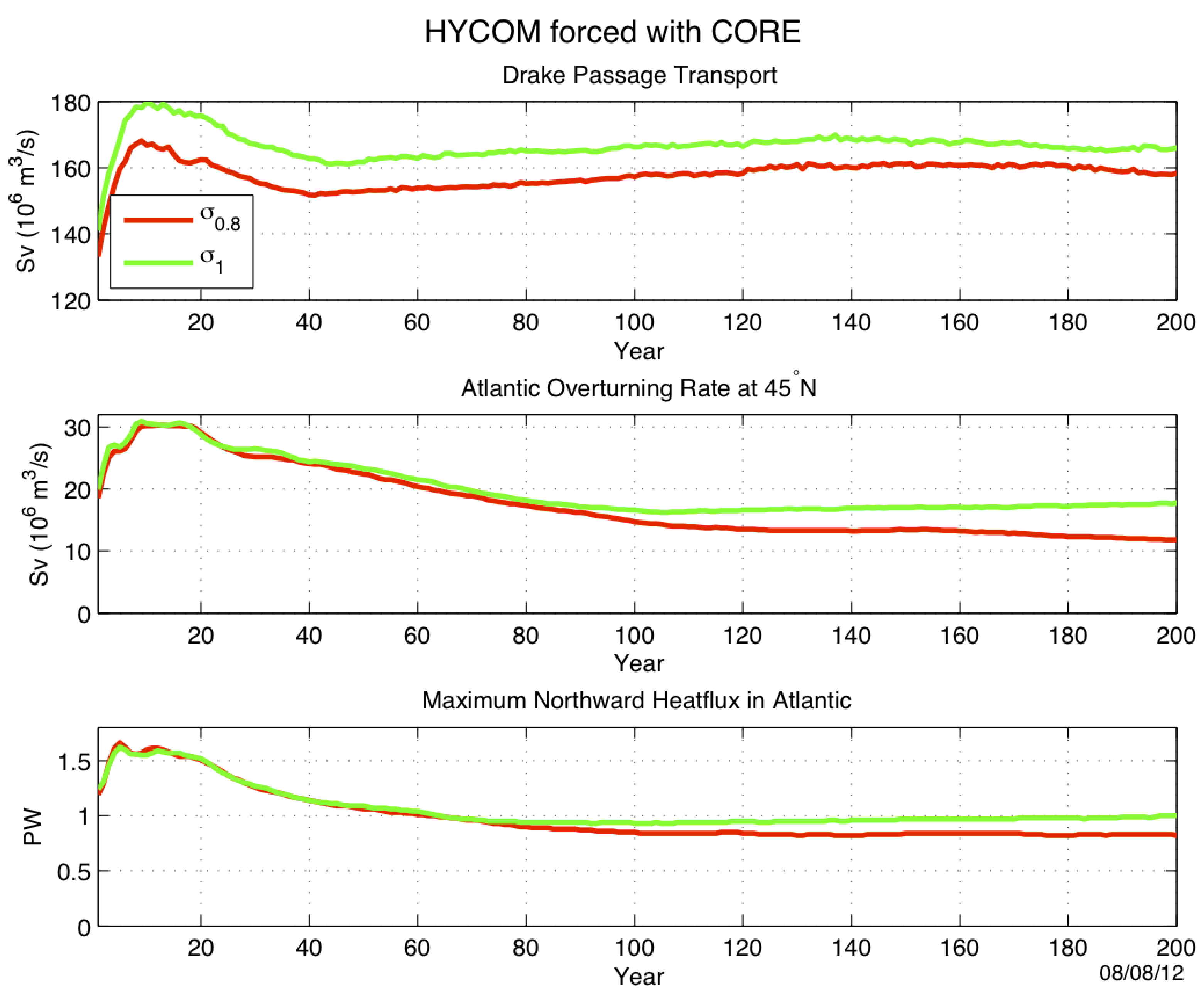
static instability






sigma 1 at longitude 35.5 W
0 10 20 30 50 75 100 125 150 200 250 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1750 2000 2500 3000 3500 4000 4500 5000 5500
−70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60 70

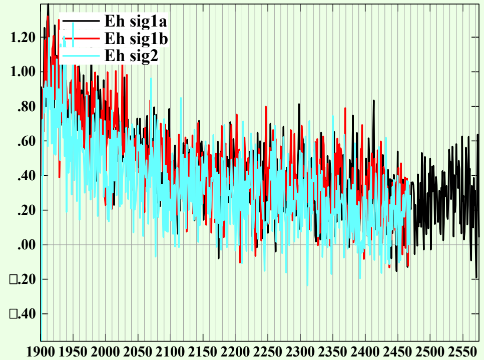

sigma 1 at longitude 35.5 W
0 10 20 30 50 75 100 125 150 200 250 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1750 2000 2500 3000 3500 4000 4500 5000 5500
−70 −60 −50



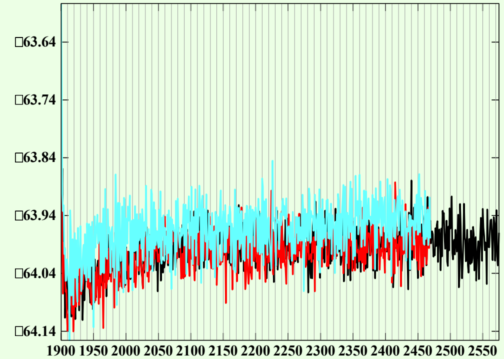
HYCOM forced with CORE
Drake Passage Transport
180
160
140
120
Sv (10^6 m^3/s)
σ0.8
σ1
20
40
60
80
100
120
140
160
180
200
Year
Atlantic Overturning Rate at 45°N
30
20
10
0
Sv (10^6 m^3/s)
Year
Maximum Northward Heatflux in Atlantic
1.5
1
0.5
0
PW
Year
08/08/12

modelE coupled with HYCOM

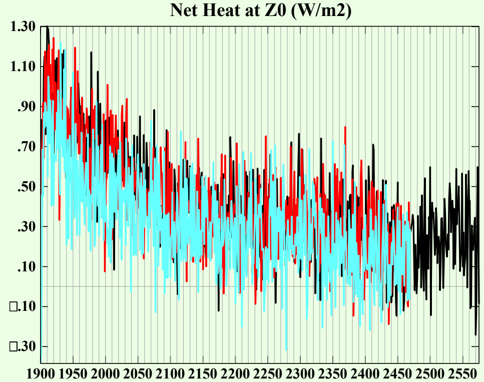
Net Radiation at TOA (W/m2)



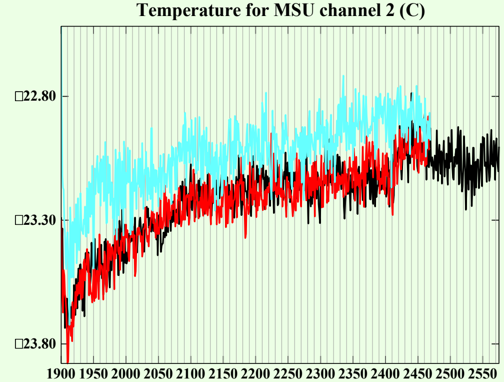
Temperature for MSU channel 4 (C)



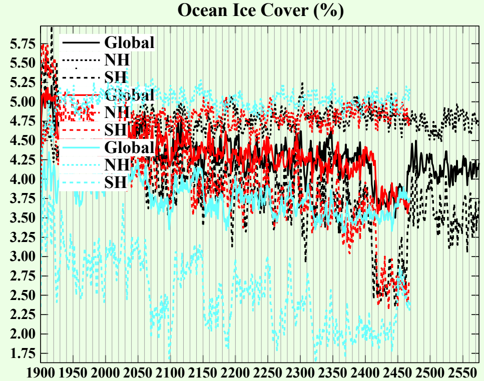
Net Heat at Z0 (W/m2)



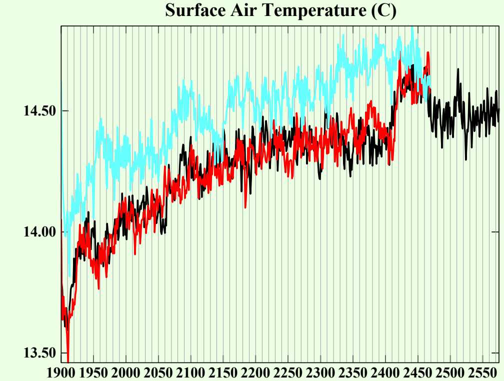
Temperature for MSU channel 2 (C)



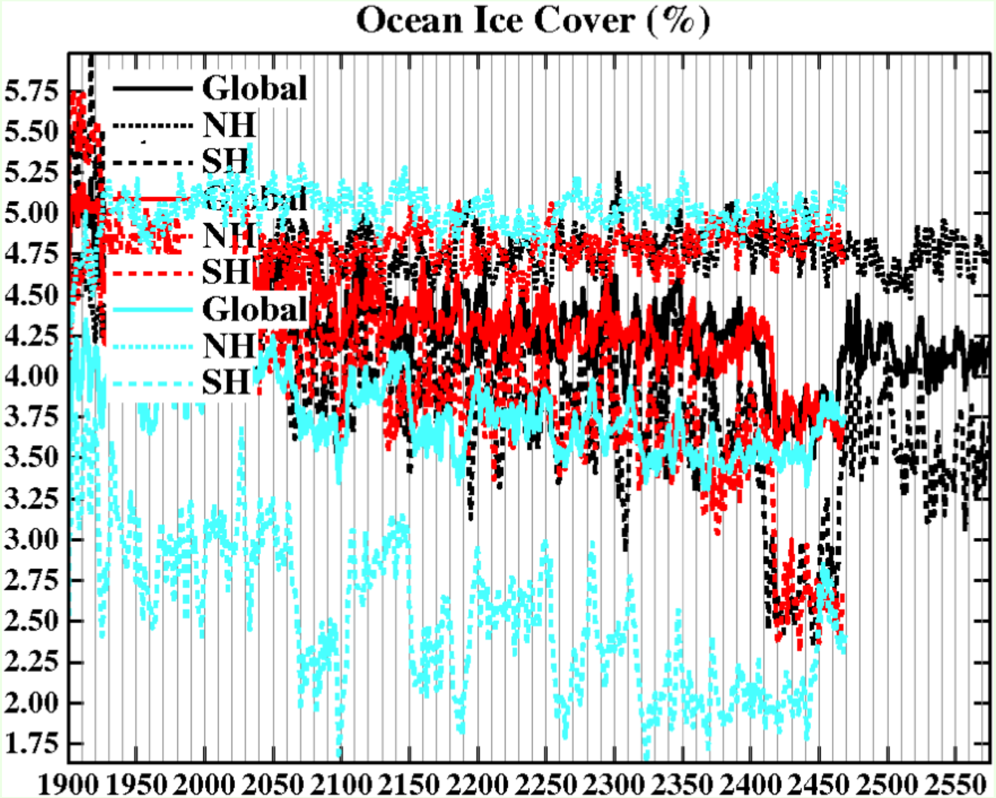
Ocean Ice Cover (%)



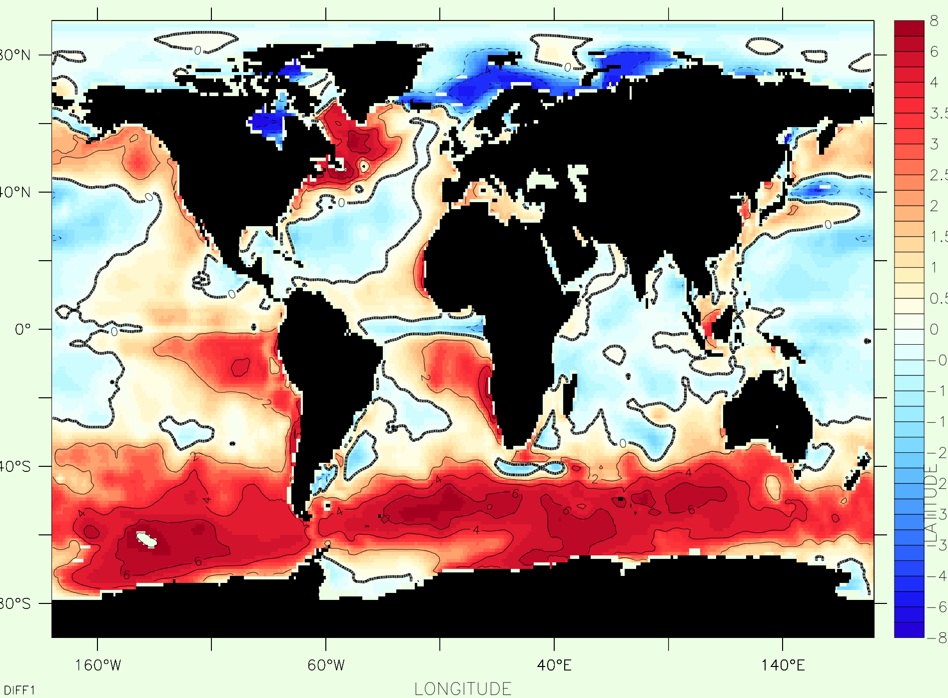
Surface Air Temperature (C)



Not enough ice?
Too much ice?

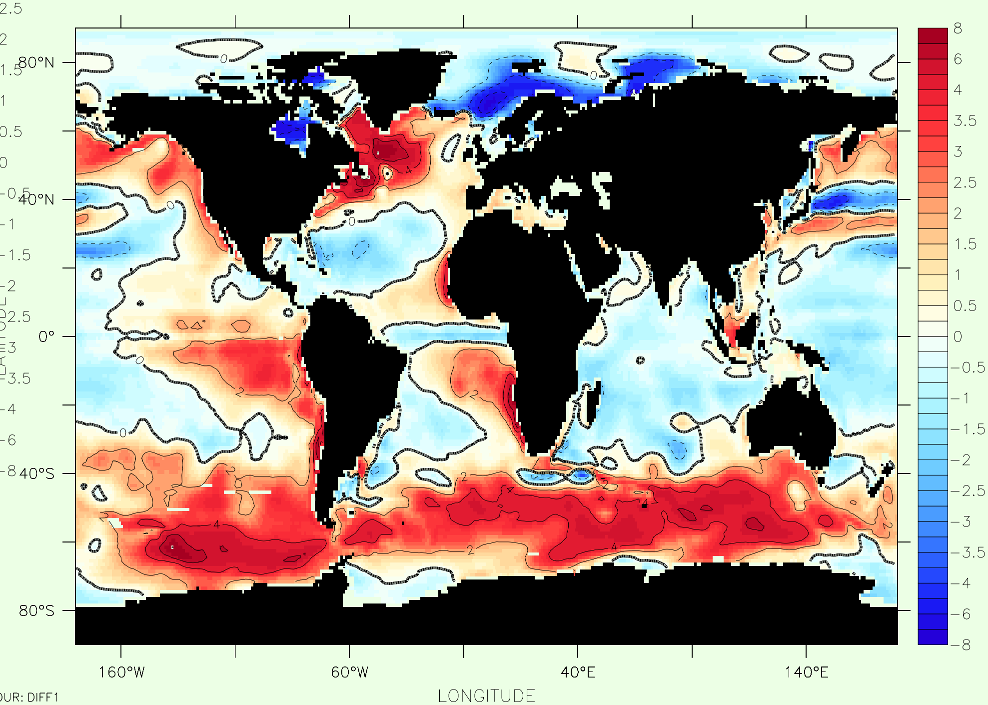


DEPTH (m) : 0
TIME : 16-JAN 06:00

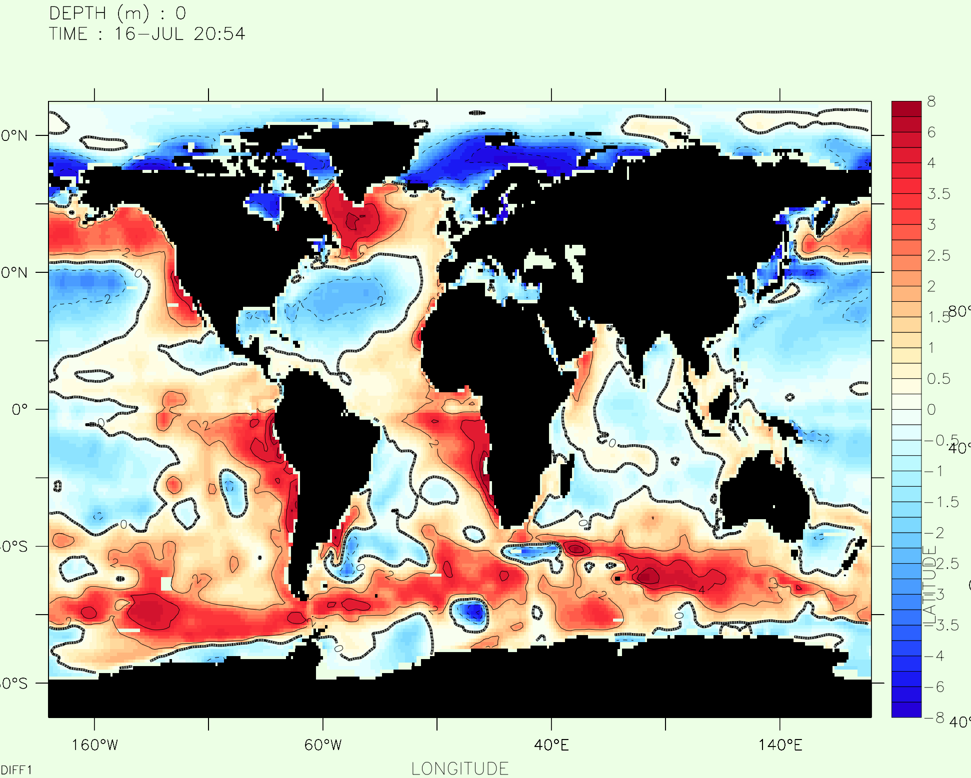


DIFFERENCE SST(Eh_sig2-LEVITUS) Month=JAN

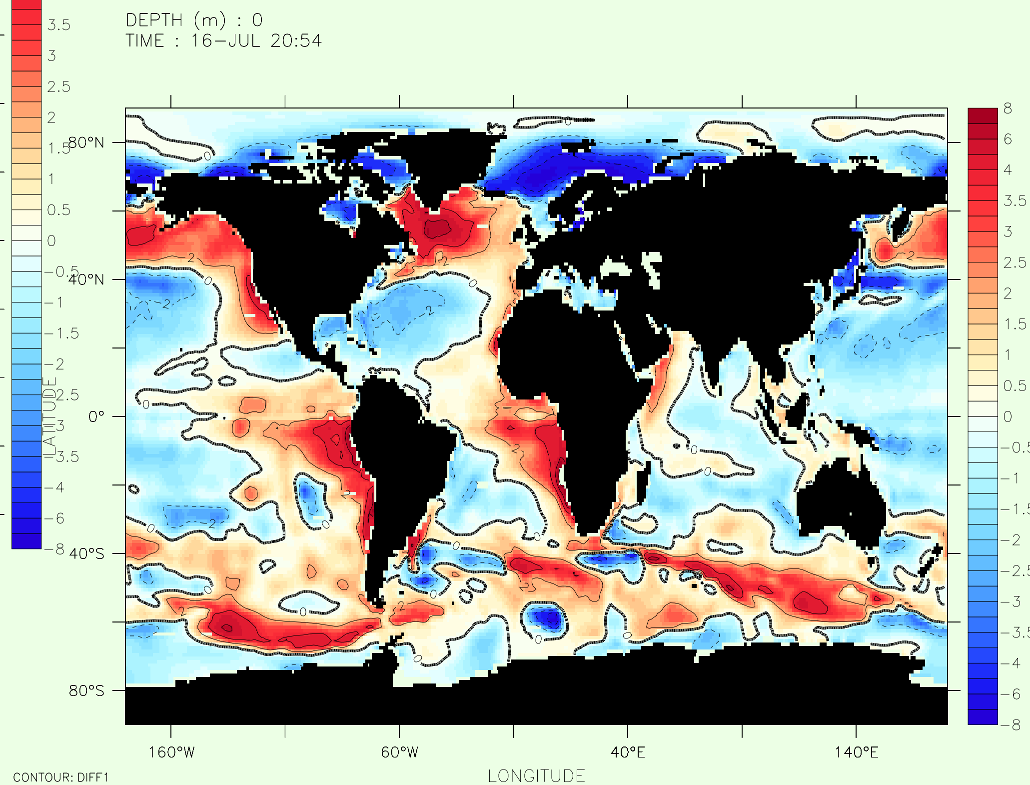
DEPTH (m) : 0
TIME : 16-JAN 06:00



DIFFERENCE SST(Eh_sig1b-LEVITUS) Month=JAN

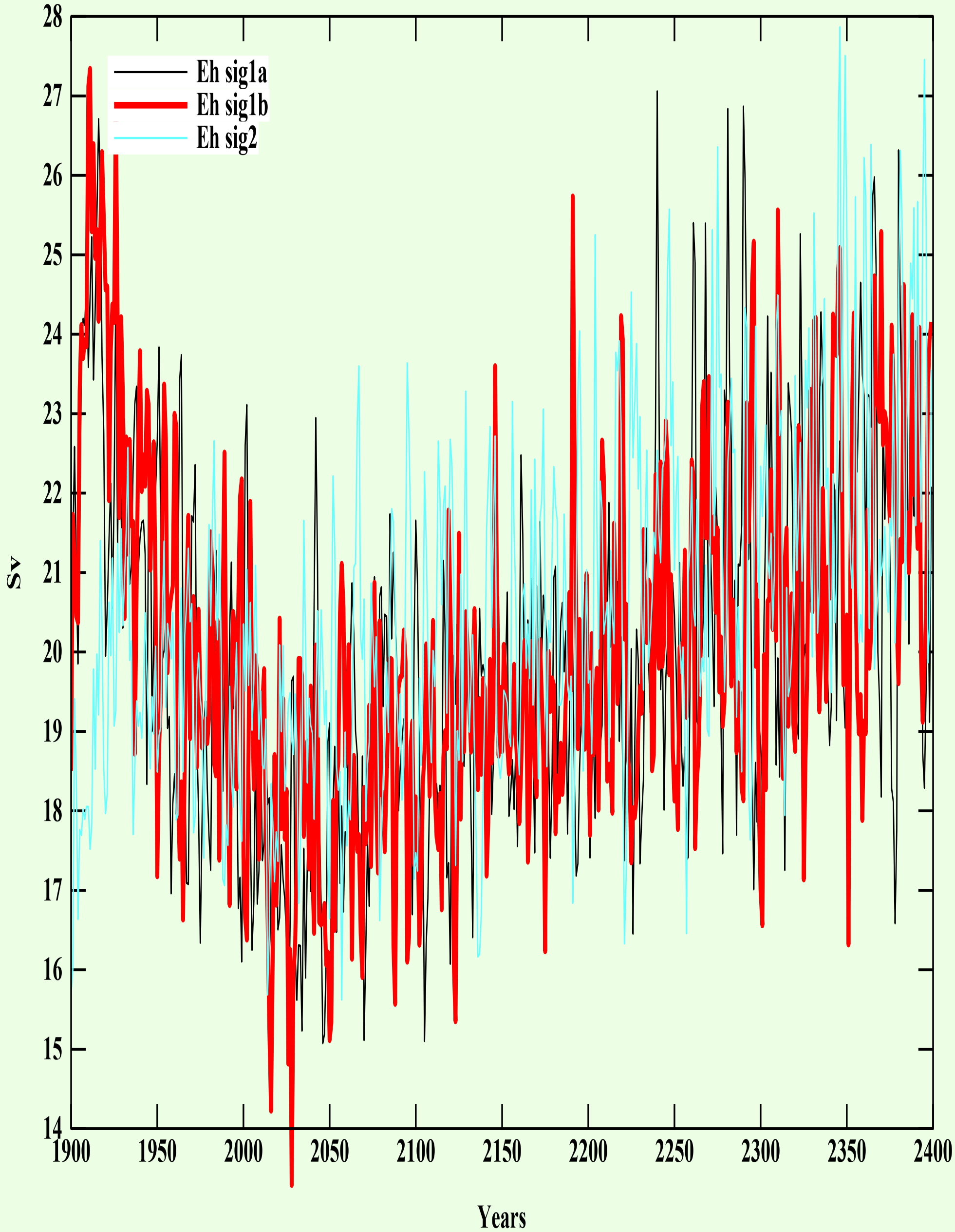


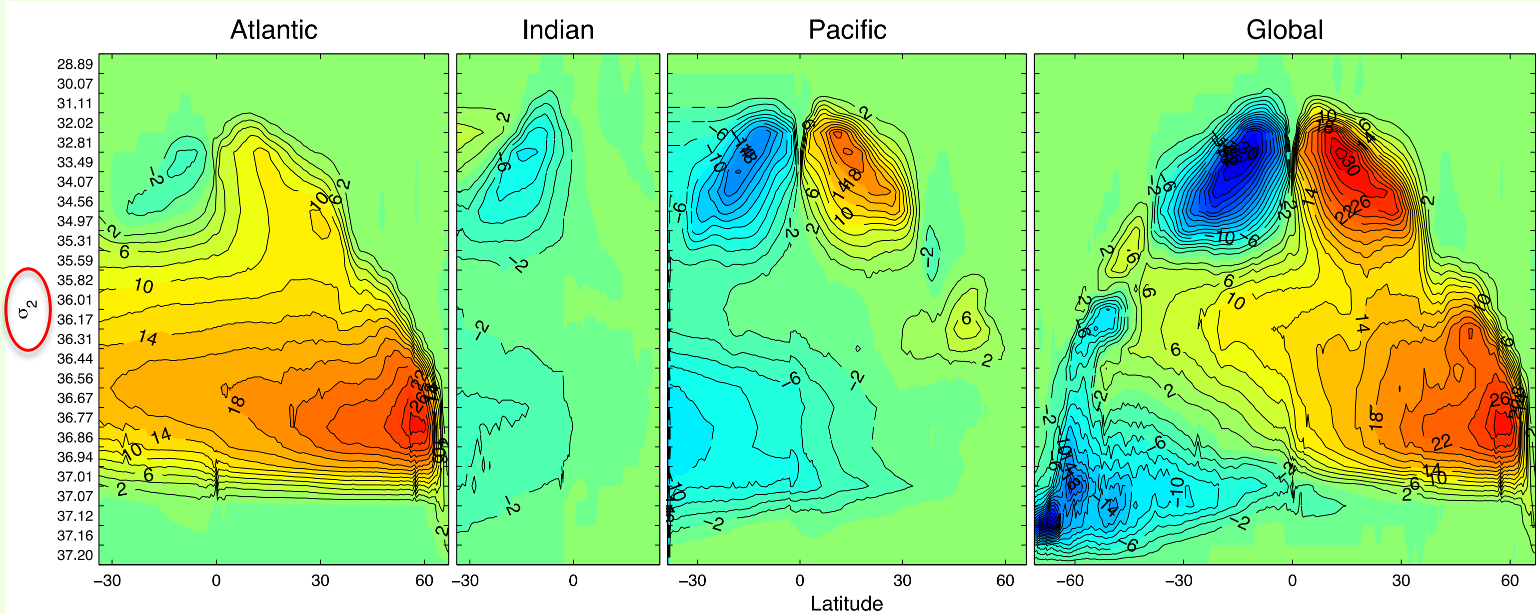
DIFFERENCE SST(Eh_sig2–LEVITUS) Month=JUL



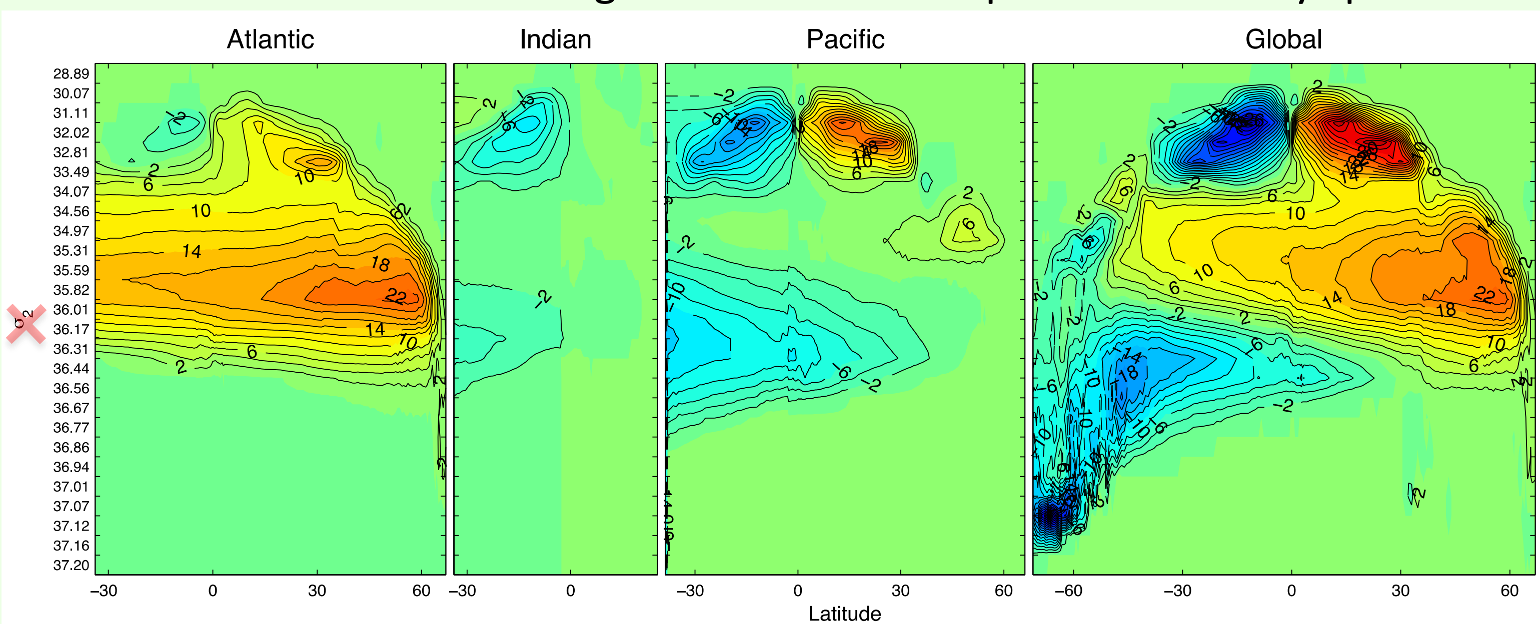
DIFFERENCE SST(Eh_sig1b–LEVITUS) Month=JUL

North Atlantic Overturning

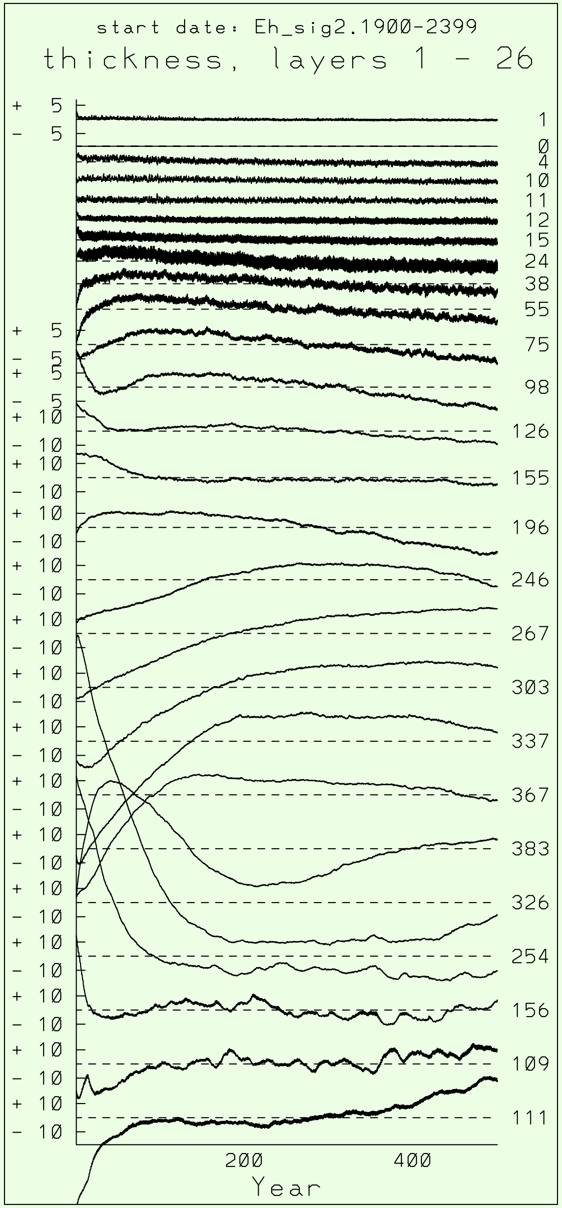


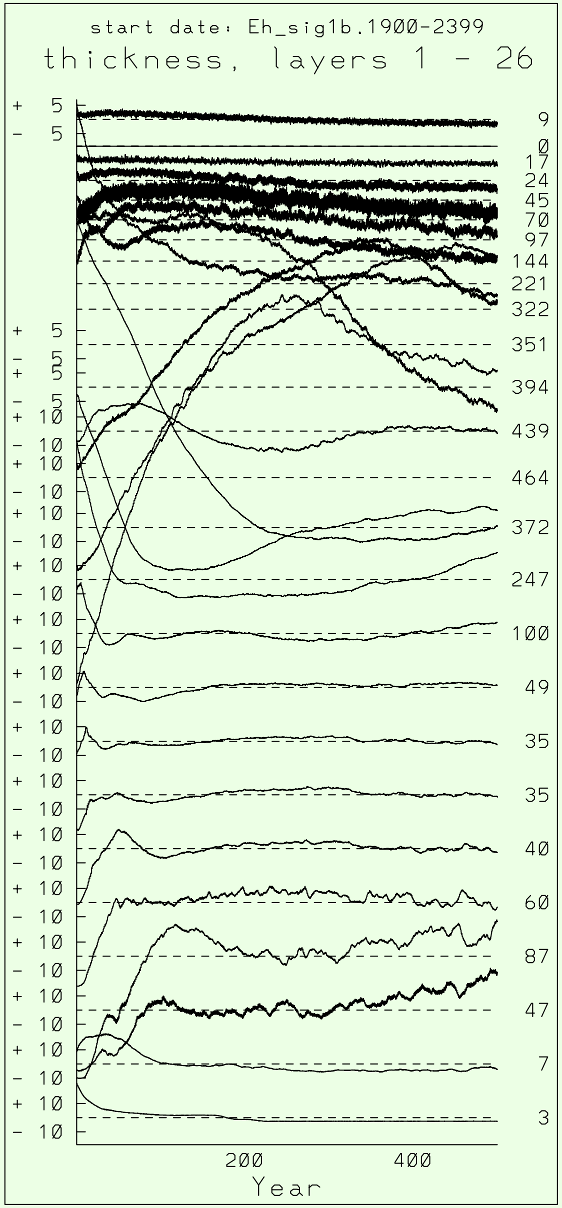


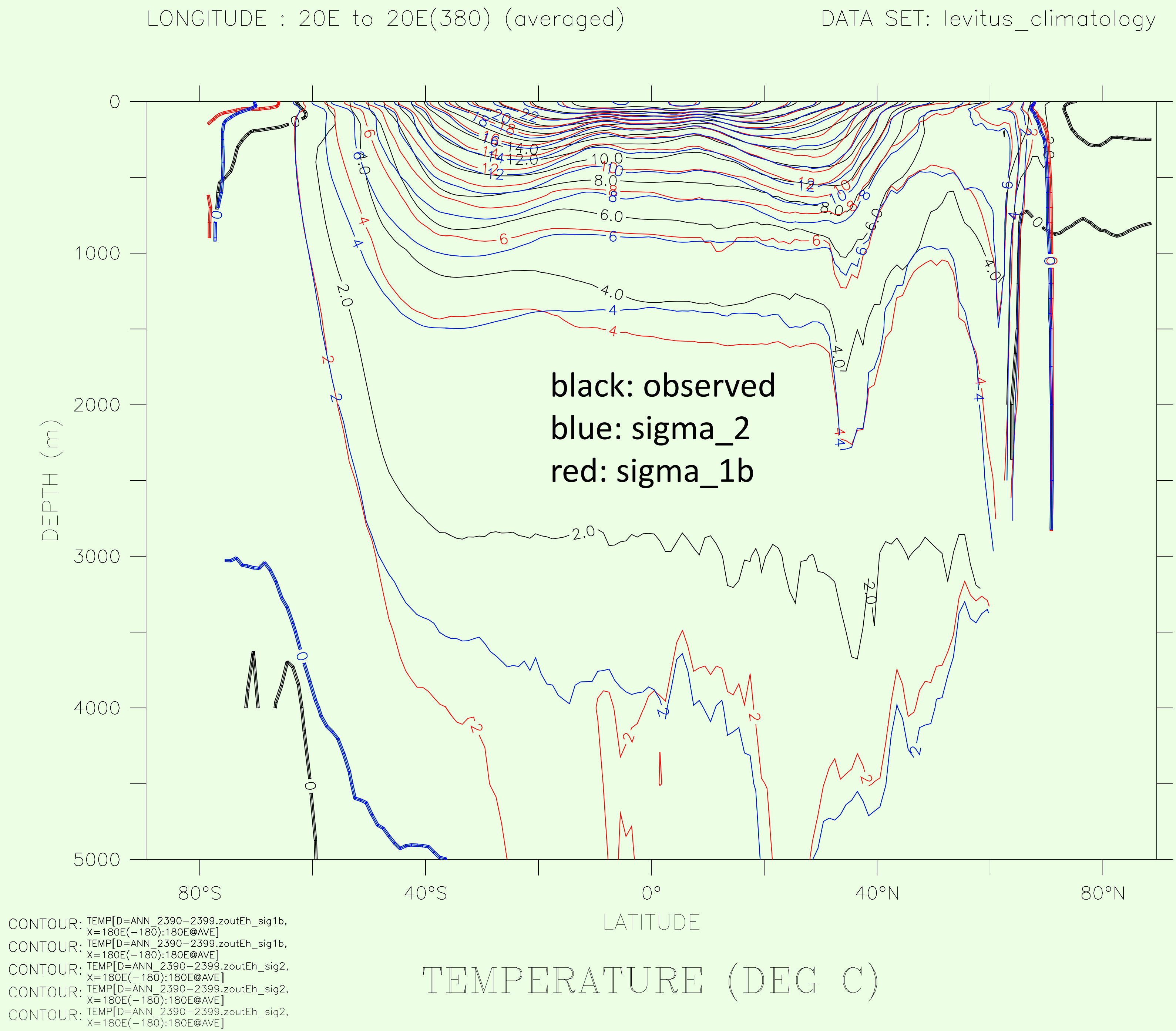
Meridional overturning streamfunction in potential density space



Layer mass census (thickness drift in m)







LONGITUDE : 20E to 20E(380) (averaged)
DATA SET: levitus_climatology
black: observed
blue: sigma_2
red: sigma_1b
DEPTH (m)
LATITUDE
80°S
40°S
0°
40°N
80°N
0
1000
2000
3000
4000
5000
CONTOUR: TEMP[D=ANN_2390-2399.zoutEh_sig1b, X=180E(-180):180E@AVE]
CONTOUR: TEMP[D=ANN_2390-2399.zoutEh_sig1b, X=180E(-180):180E@AVE]
CONTOUR: TEMP[D=ANN_2390-2399.zoutEh_sig2, X=180E(-180):180E@AVE]
CONTOUR: TEMP[D=ANN_2390-2399.zoutEh_sig2, X=180E(-180):180E@AVE]
CONTOUR: TEMP[D=ANN_2390-2399.zoutEh_sig2, X=180E(-180):180E@AVE]
TEMPERATURE (DEG C)

The sum of model defects is (remarkably) constant across ocean models