REDUCING COUPLED MODEL BIASES THROUGH (OCEAN) MODEL IMPROVEMENTS AND INCREASED ATMOSPHERIC MODEL RESOLUTION IN CCSM4

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MOTIVATION

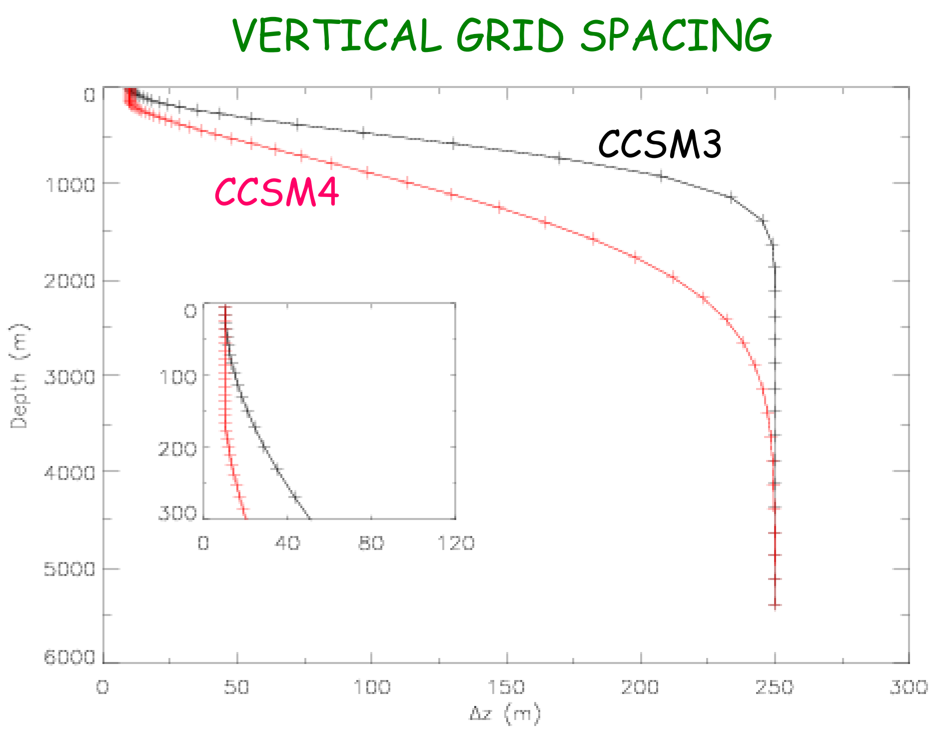
To show how far we have come since CCSM3 in reducing some of our major biases through improvements in model physics and numerics with a focus on the ocean model component.

OUTLINE

- Summary of new developments in the CCSM4 ocean component,
- Revisiting anisotropic horizontal viscosity formulation,
- A new gravity current overflow parameterization,
- Impacts of increased atmospheric model (horizontal) resolution,
- Summary and future plans.

PARTIAL SUMMARY OF THE NEW DEVELOPMENTS IN THE CCSM4 OCEAN COMPONENT (since CCSM3)

- Parallel Ocean Program (POP2) base code,
- Vertical resolution is increased to 60 levels (from 40) with accompanying changes in bottom topography (Yeager),

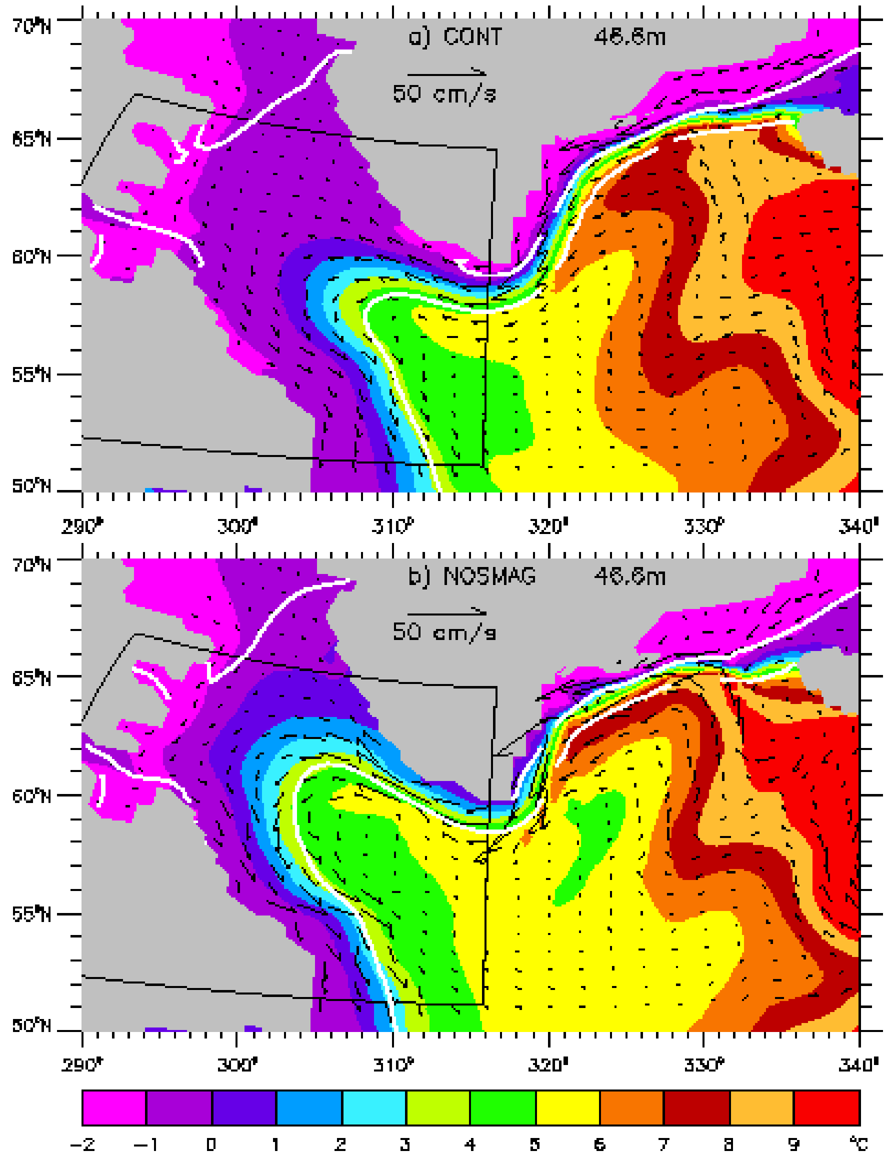


NEW DEVELOPMENTS (continued)

- Tidal mixing scheme (St. Laurent et al. 2002; Jayne 2009),
- Horizontally-varying internal wave breaking (background) vertical diffusivity and viscosity (Jochum 2009),
- Near-surface eddy flux parameterization (Ferrari et al. 2008; Danabasoglu et al. 2008), (Climate Process Team, CPT)
- Upper-ocean enhancement and deep-ocean reduction of both isopycnal and thickness diffusivity coefficients (Danabasoglu and Marshall 2007), (CPT)
- Submesoscale mixing parameterization (Fox-Kemper et al. 2008a; Fox-Kemper et al. 2008b), (CPT)
- Gravity current overflow parameterization for deep channel and shelf, i.e., open-ocean, overflows (Danabasoglu et al. 2009; Briegleb et al. 2009 – both in prep.), (CPT)
- Modified anisotropic horizontal viscosity scheme (Jochum et al. 2008).

ANISOTROPIC HORIZONTAL VISCOSITY

- Elimination of deformation rate dependency, i.e., no Smagorinsky (1993) type formulation,
- Much lower numerical (background) viscosity.



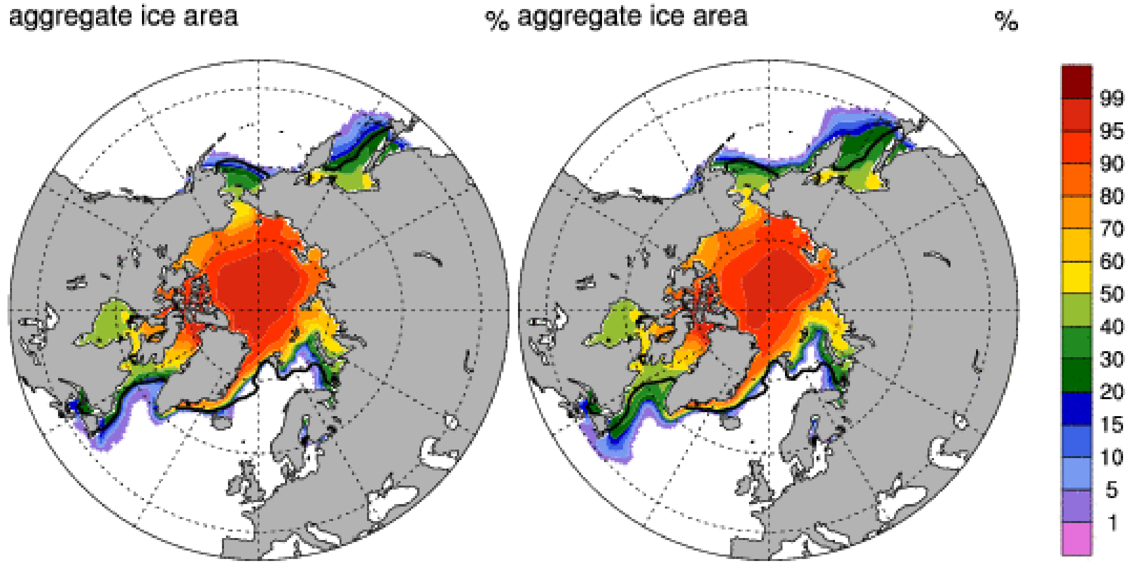
CCSM3 T42x1

Low Viscosity (LV)

Temperature (color) and horizontal velocity at 47 m depth

Jochum et al. (2008)

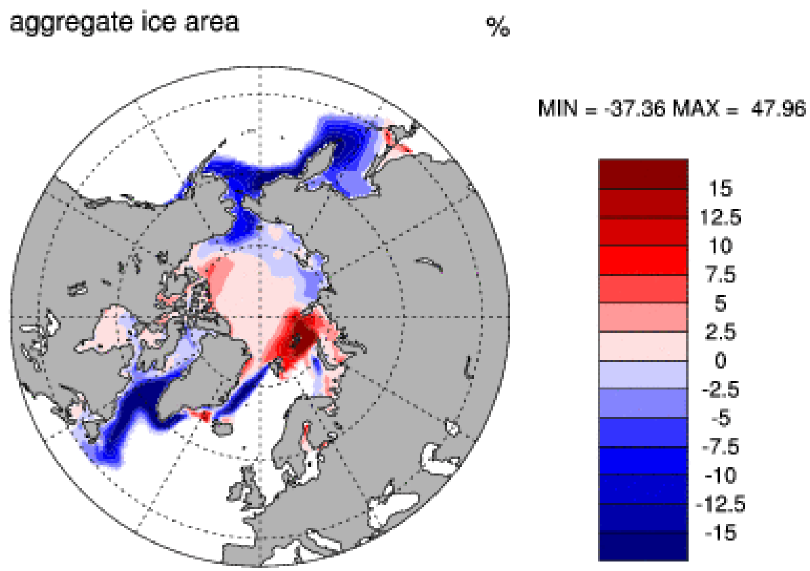
TIME-MEAN SEA ICE AREA IN THE NORTHERN HEMIPSHERE



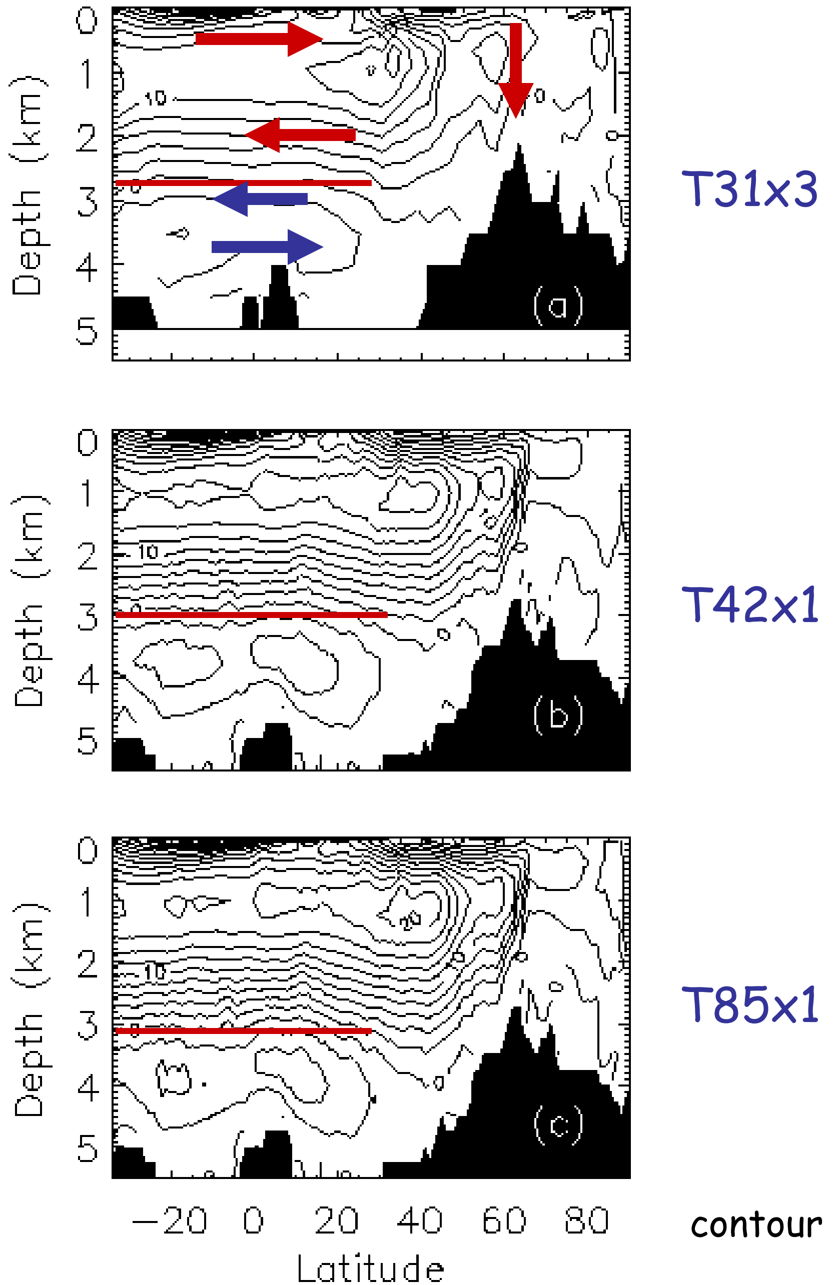
LV

CCSM3 T42x1

LV - CCSM3

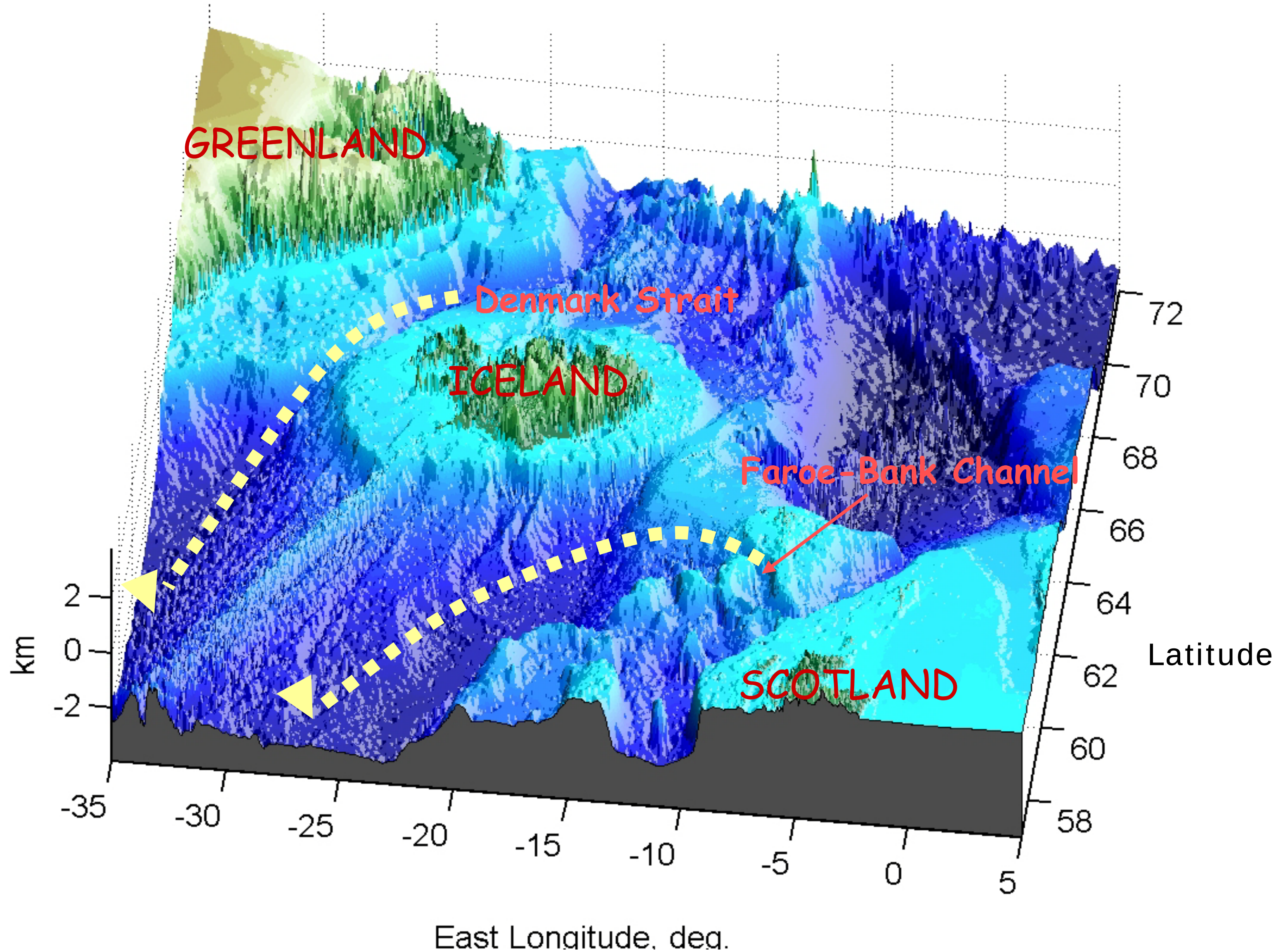


ATLANTIC MERIDIONAL OVERTURNING CIRCULATION IN CCSM3



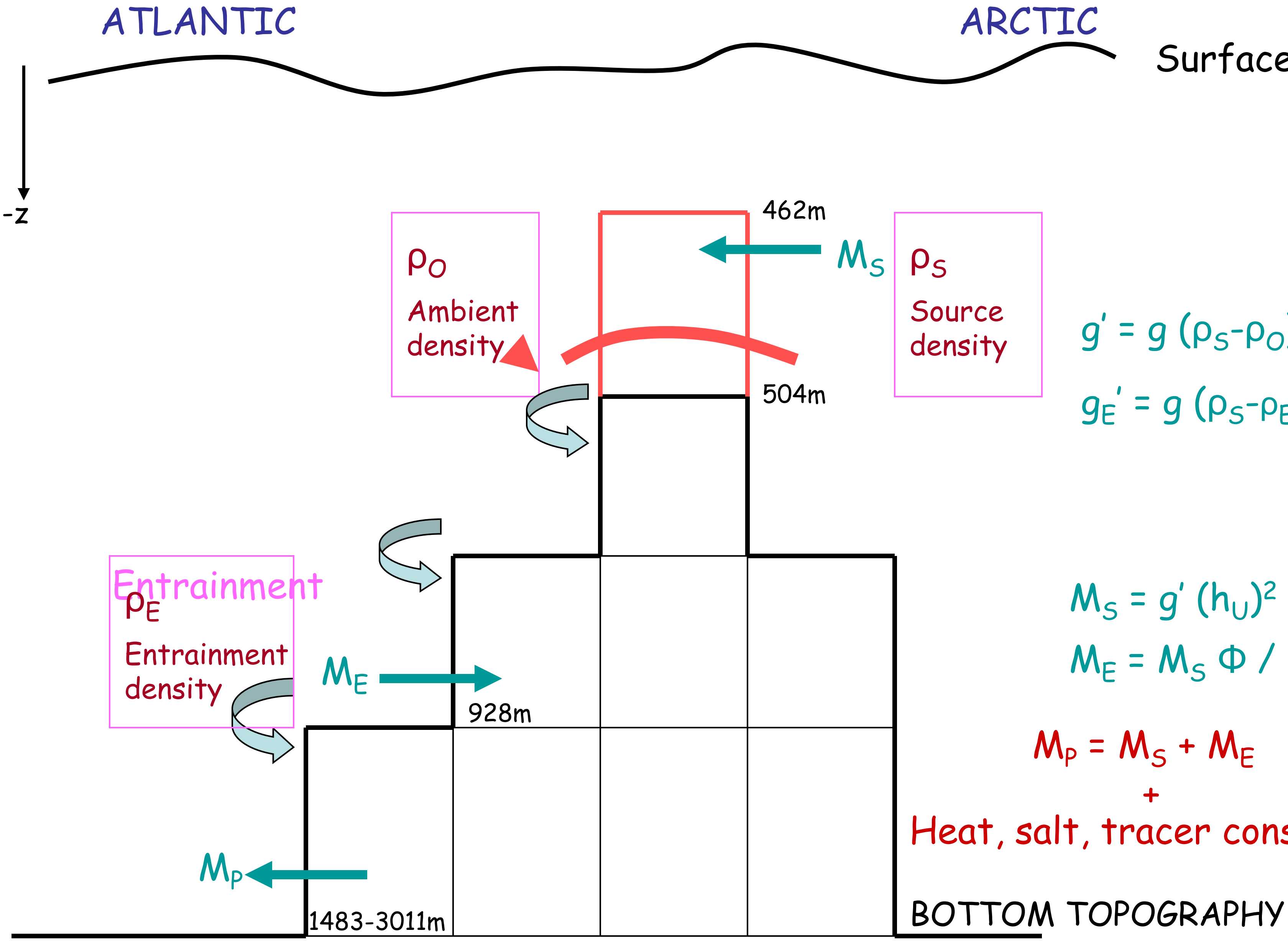
contour interval = 2 Sv

Bryan et al. (2006)


GREENLAND
Denmark Strait
ICELAND
Faroe-Bank Channel
SCOTLAND
km
2
0
-2
-35
-30
-25
-20
-15
-10
-5
0
5
East Longitude, deg.
72
70
68
66
64
62
60
58
Latitude

from J.Price

OVERFLOW PARAMETERIZATION (based on MSBC of Price and Yang 1998)



$$g' = g\,(\rho_S - \rho_O)/\rho_{ref}$$

$$g_E' = g\,(\rho_S - \rho_E)/\rho_{ref}$$

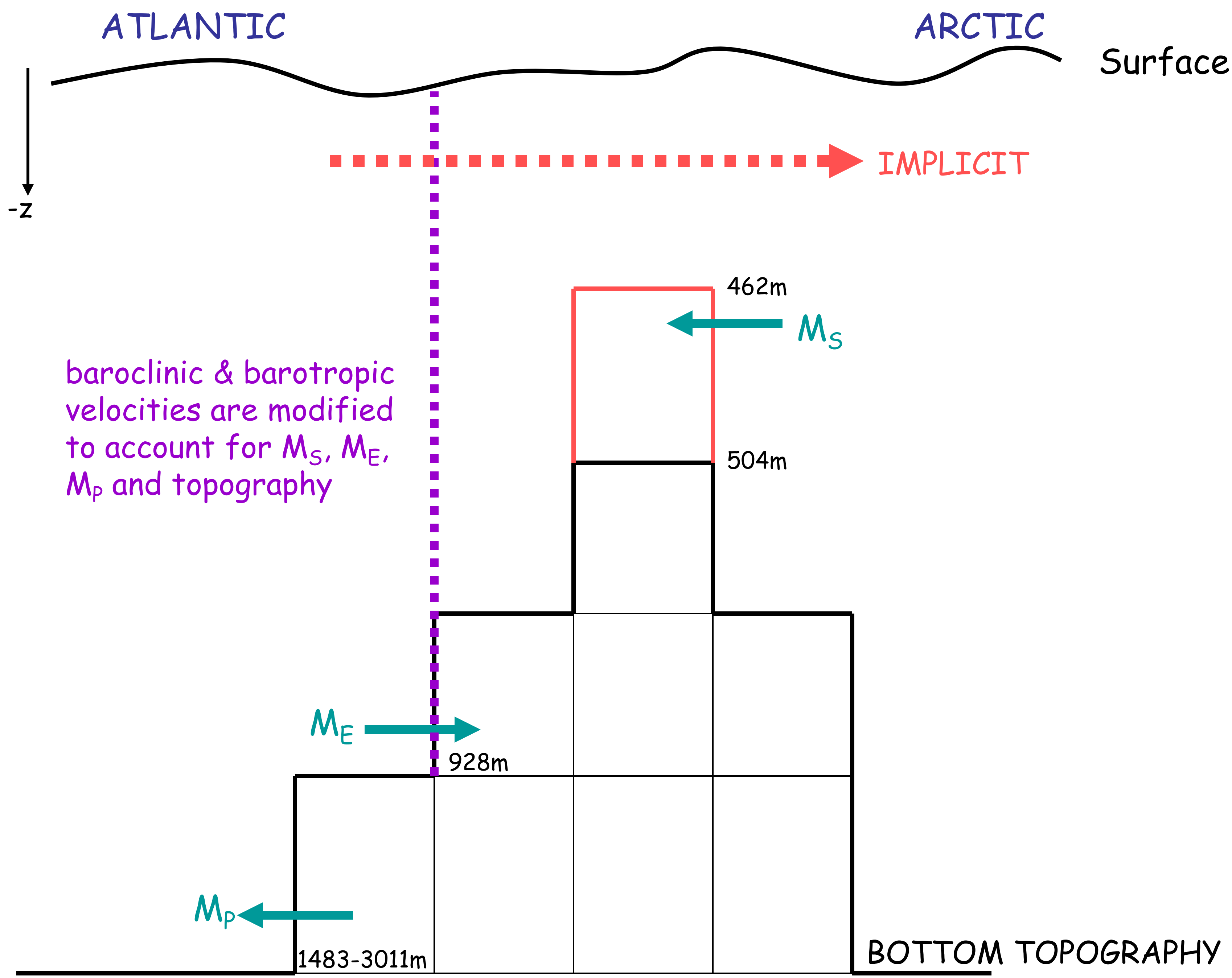
$$M_S = g'\,(h_U)^2 / 2f$$

$$M_E = M_S\,\Phi / (1 - \Phi)$$

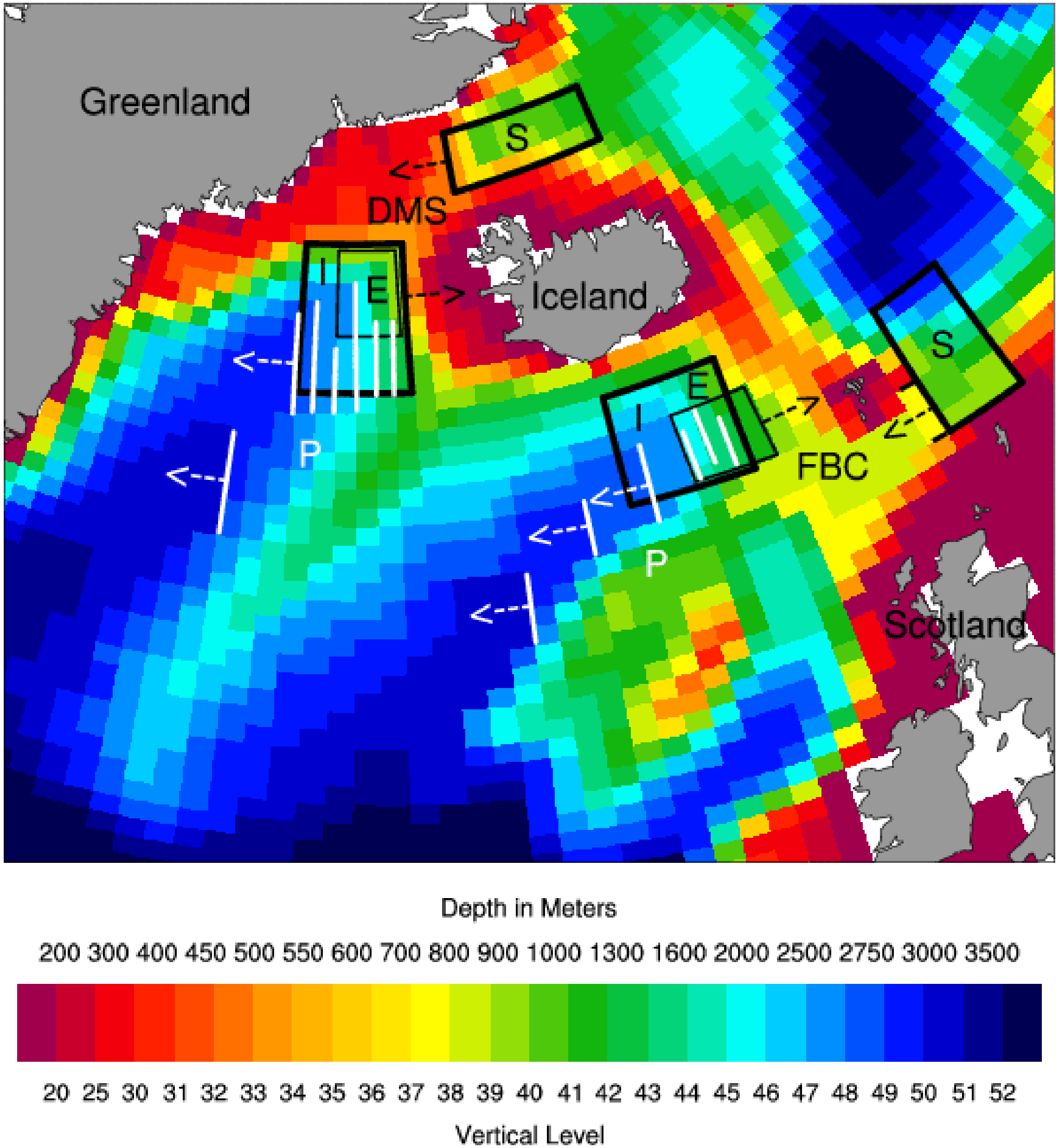
$$M_P = M_S + M_E$$

+

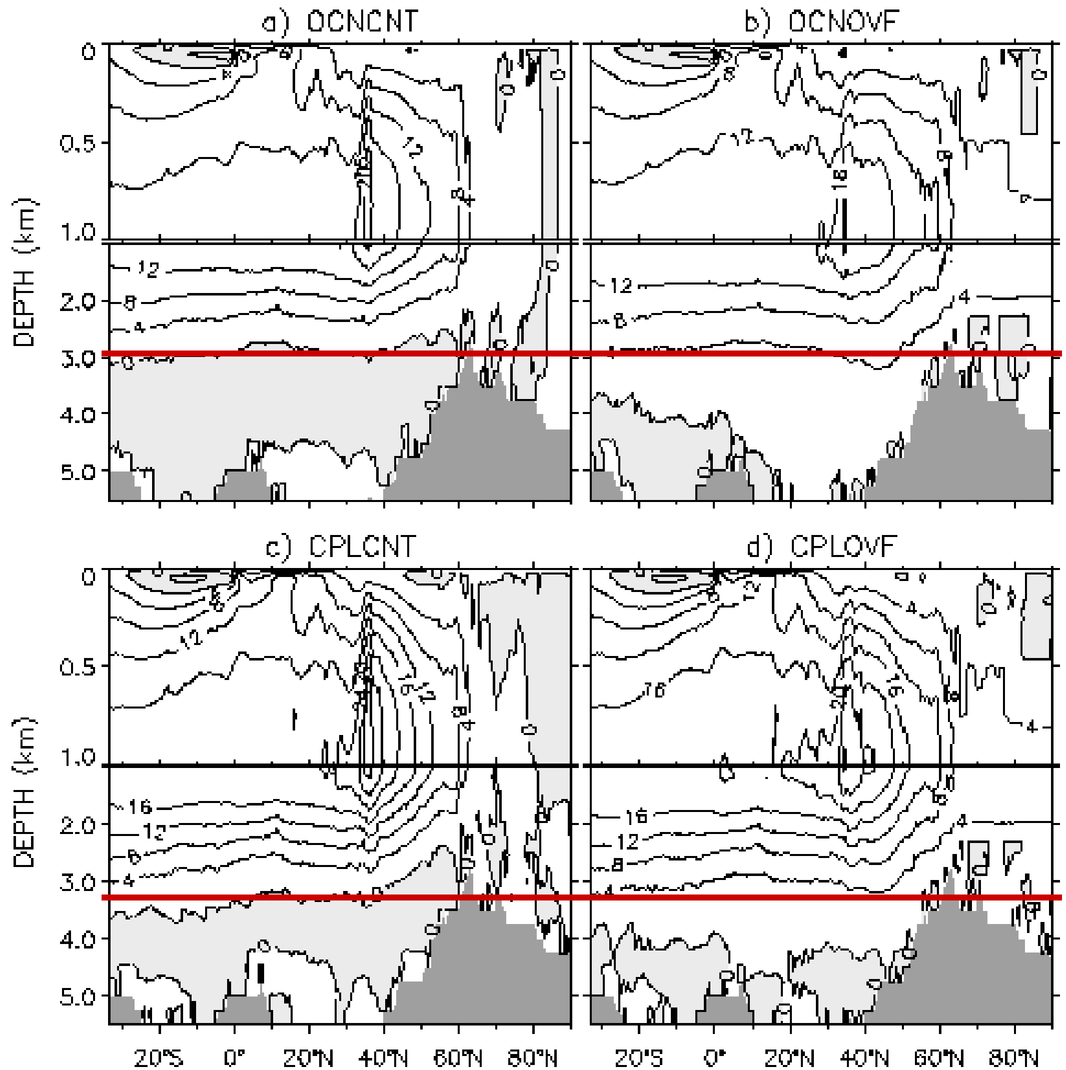
Heat, salt, tracer conservation


ATLANTIC
ARCTIC
Surface
-z
IMPLICIT
462m
M_S
baroclinic & barotropic velocities are modified to account for M_S, M_E, M_P and topography
504m
M_E
928m
M_P
1483-3011m
BOTTOM TOPOGRAPHY

BOTTOM TOPOGRAPHY OF THE x1 RESOLUTION OCEAN MODEL



ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (Sv)



Ocean-only control (OCNCNT)

Ocean-only w/ overflows (OCNOVF)

Coupled control (CPLCNT)

Coupled w/ overflows (CPLOVF)

170-year long ocean-only (normal-year forcing) and coupled CCSM4 simulations with 2° FV atmosphere and x1 ocean.

TEMPERATURE AND SALINITY DIFFERENCES FROM OBSERVATIONS AT 2649-m DEPTH

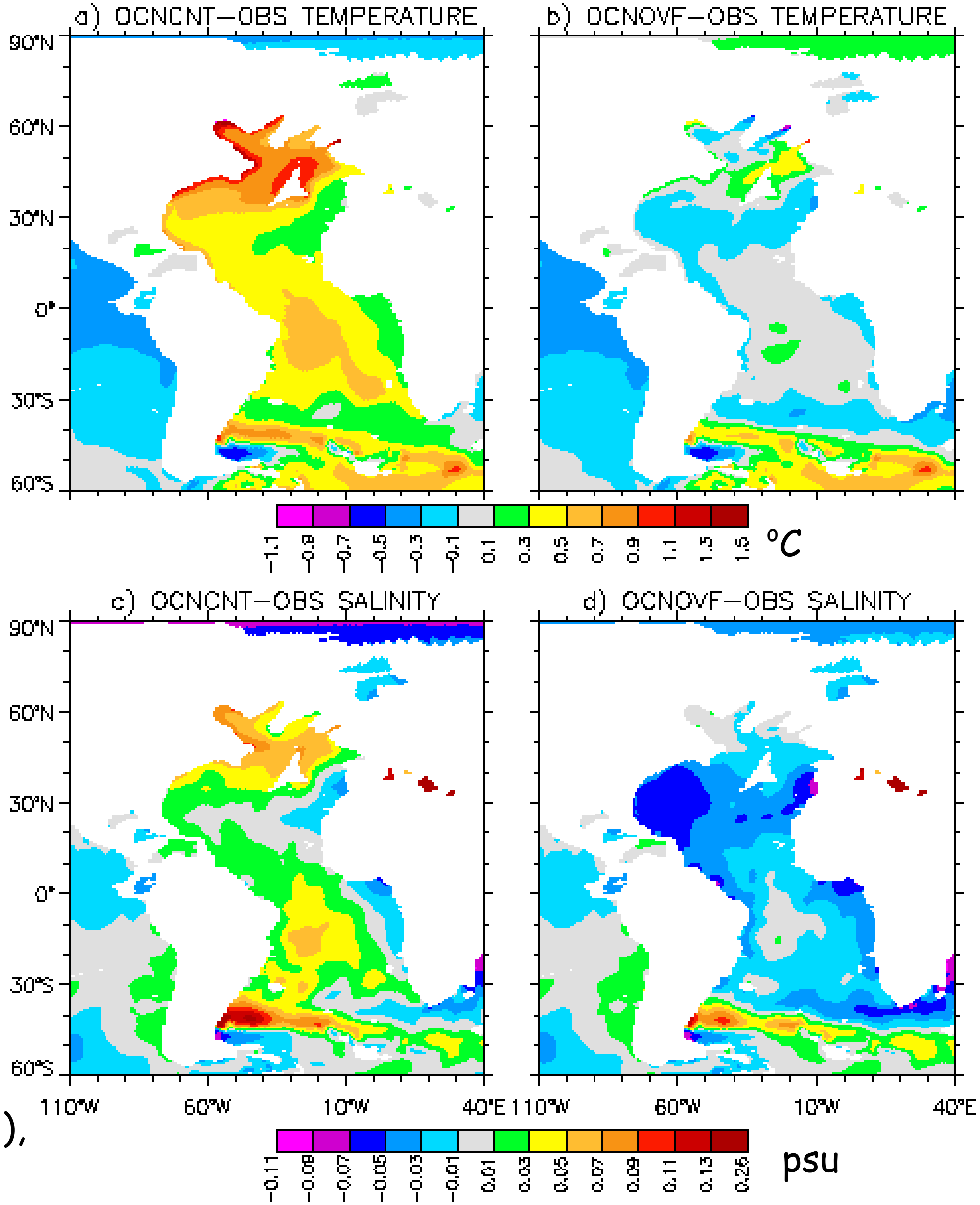
mean= 0.45°C

rms= 0.50°C

Ocean-only control

mean= 0.02 psu

rms= 0.03 psu



mean= -0.04°C

rms= 0.13°C

Ocean-only w/ overflows

mean= -0.03 psu

rms= 0.03 psu

Obs: Levitus et al. (1998), Steele et al. (2001)

TEMPERATURE AND SALINITY DIFFERENCES FROM OBSERVATIONS AT 2649-m DEPTH

mean= 1.41°C

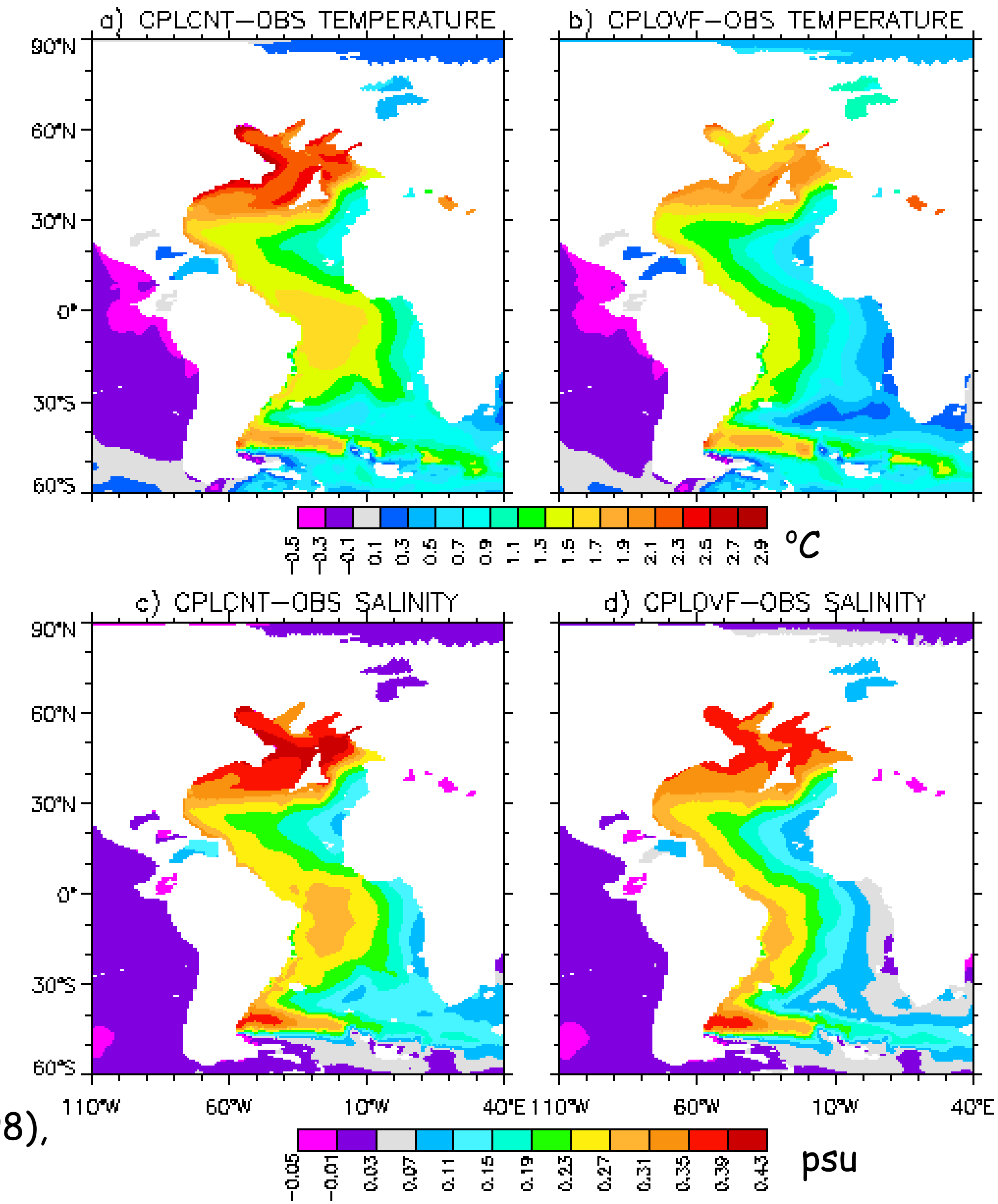
rms= 1.49°C

mean= 1.07°C

rms= 1.18°C

Coupled control

Coupled w/ overflows



mean= 0.24 psu

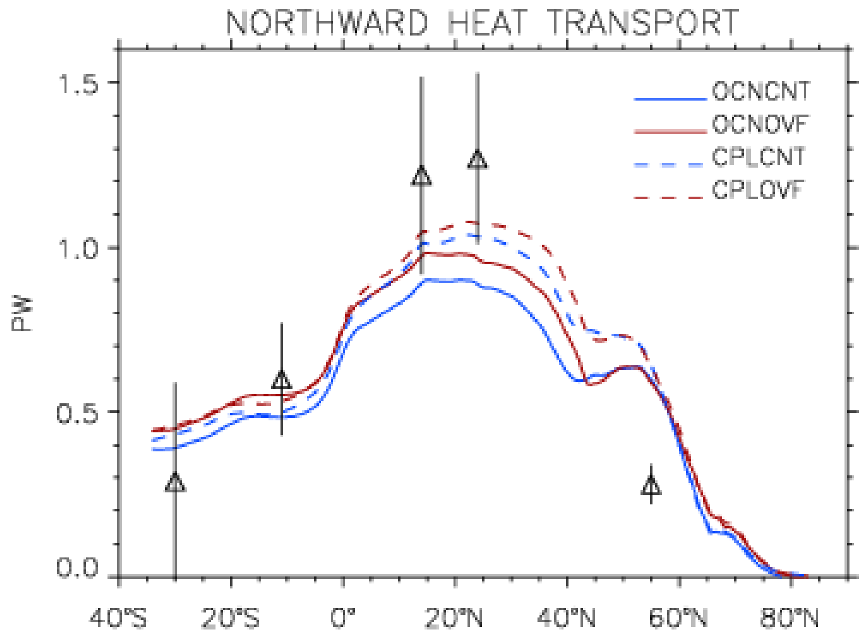
rms= 0.25 psu

mean= 0.21 psu

rms= 0.23 psu

Obs: Levitus et al. (1998), Steele et al. (2001)

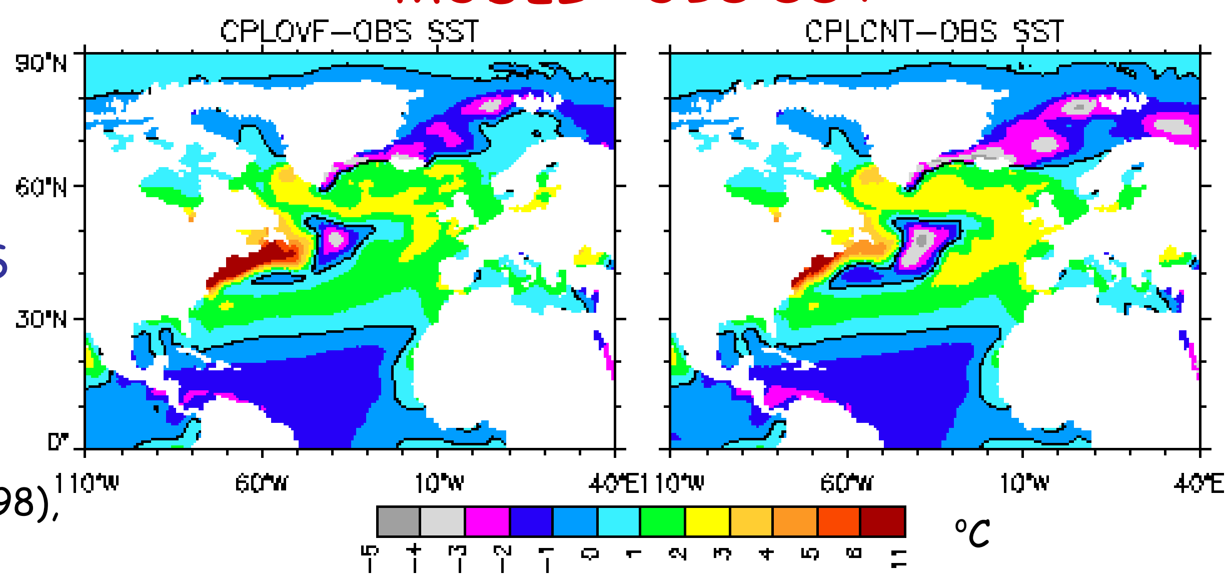
NORTHWARD HEAT TRANSPORT IN THE ATLANTIC OCEAN



Triangles with error bars show Bryden and Imawaki (2001) observational estimates.

MODEL - OBS SST

Coupled w/ overflows - OBS

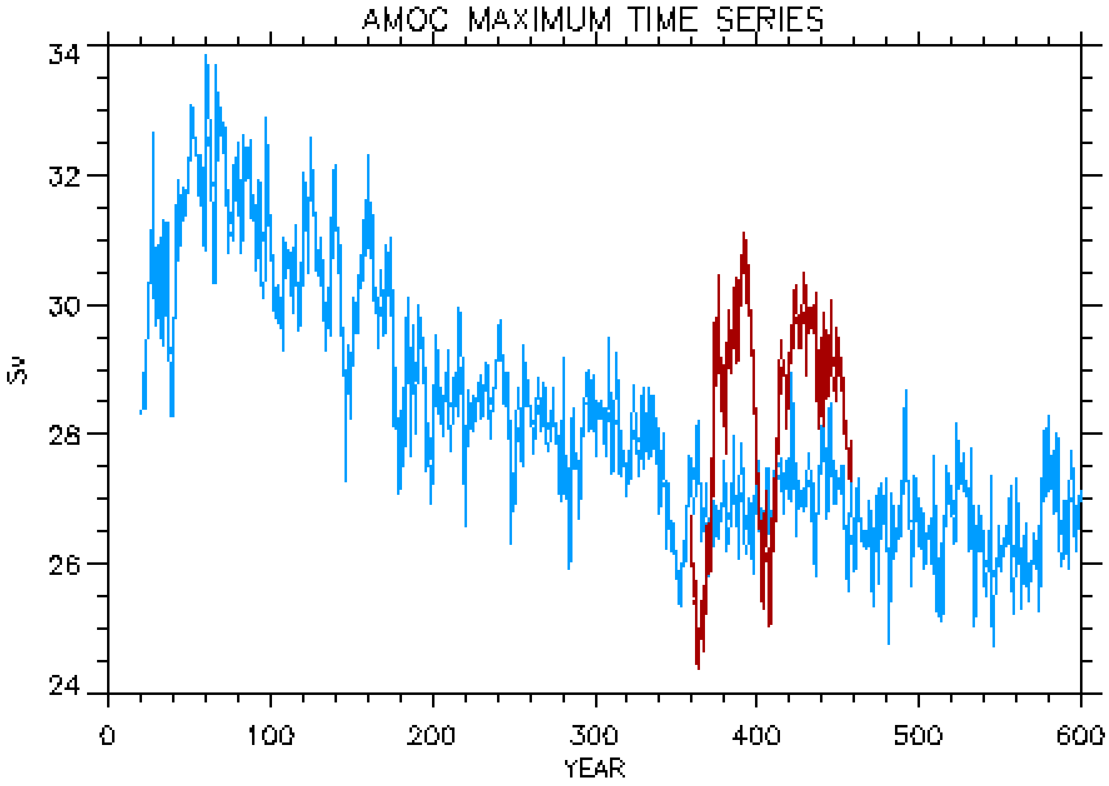


Coupled control - OBS

Obs: Levitus et al. (1998), Steele et al. (2001)

ATLANTIC MERIDIONAL OVERTURNING CIRCULATION MAXIMUM TIME SERIES

PRESENT-DAY CONTROL WITH TRACK I CCSM4



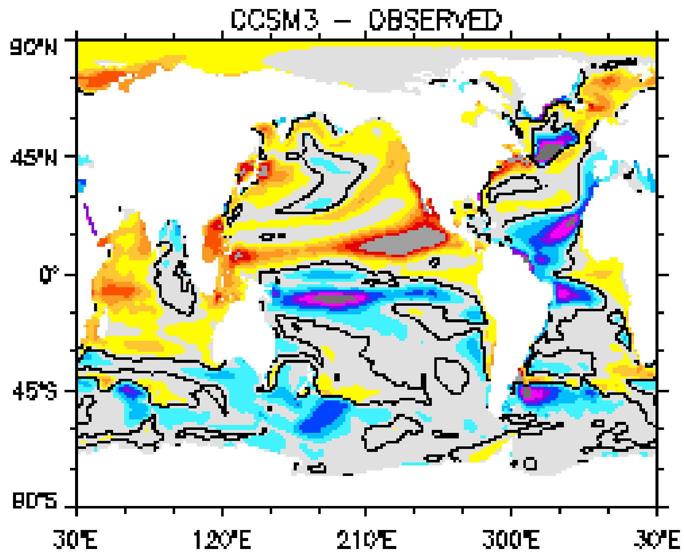
ROLE OF INCREASED ATMOSPHERIC MODEL RESOLUTION IN REDUCING COUPLED MODEL BIASES

Comparison of 3 simulations with observations:

1. CCSM3: T85x1 resolution, present-day control,
   upper-ocean biases documented in Large and Danabasoglu (2006)
2. CCSM4: 2°FVx1 resolution, pre-industrial control with track I,
3. CCSM4: 1°FVx1 resolution, pre-industrial control with track I.

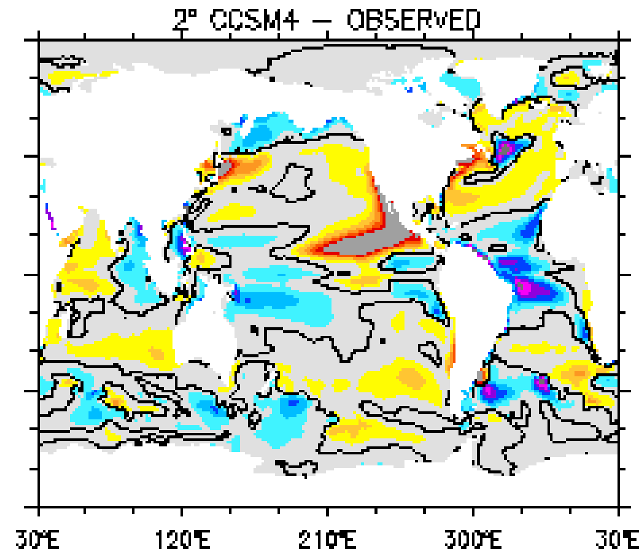
All simulations were tuned to produce near-zero energy flux at the top of the atmospheric model.

POTENTIAL TEMPERATURE DIFFERENCES FROM OBSERVATIONS AT 95-m DEPTH



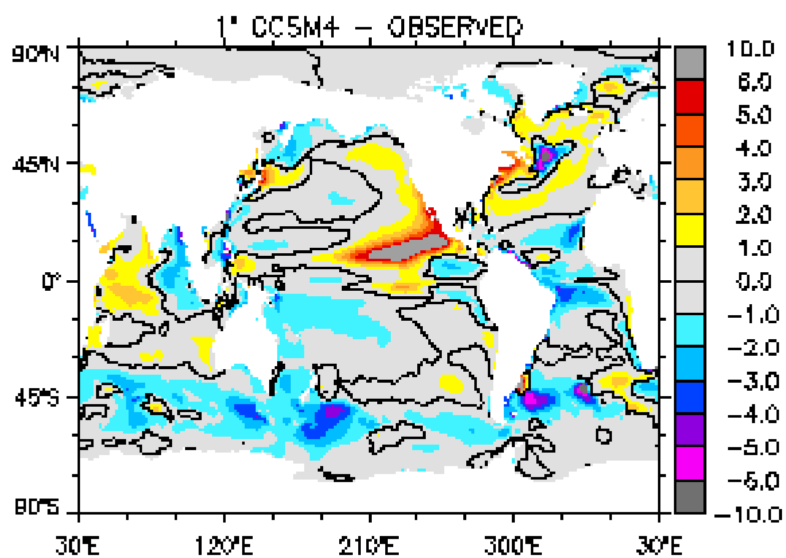
mean= 0.32°C

rms= 2.04°C



mean= 0.23°C

rms= 1.71°C



mean= -0.14°C

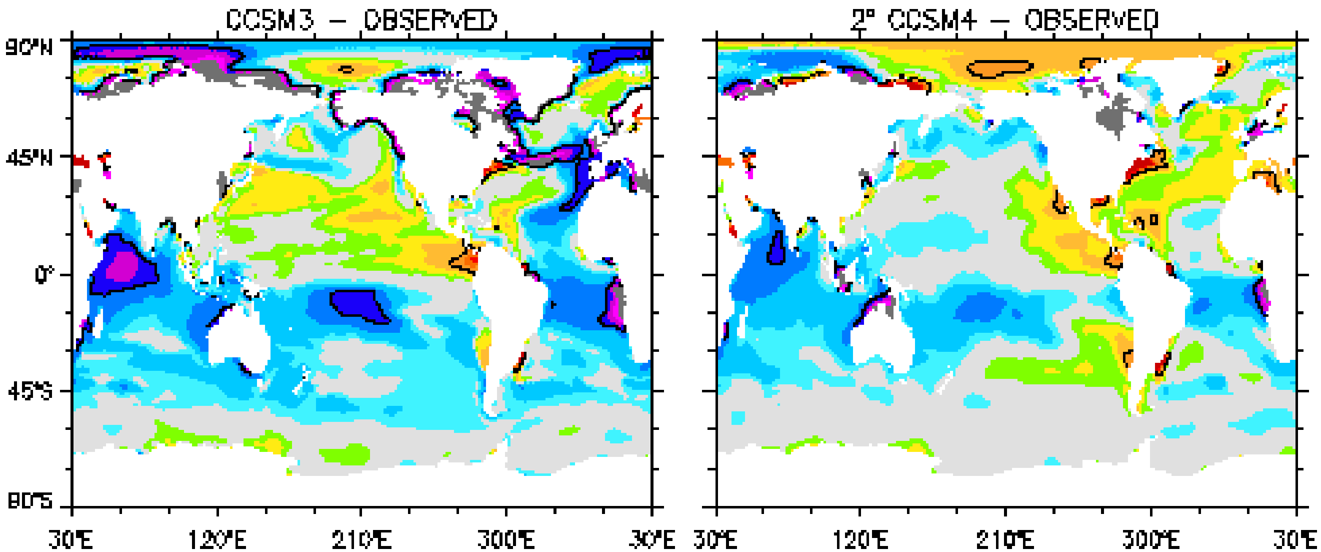
rms= 1.51°C

Obs: Levitus et al. (1998),
Steele et al. (2001)

SURFACE SALINITY DIFFERENCES FROM OBSERVATIONS

mean= -0.39

rms= 1.12

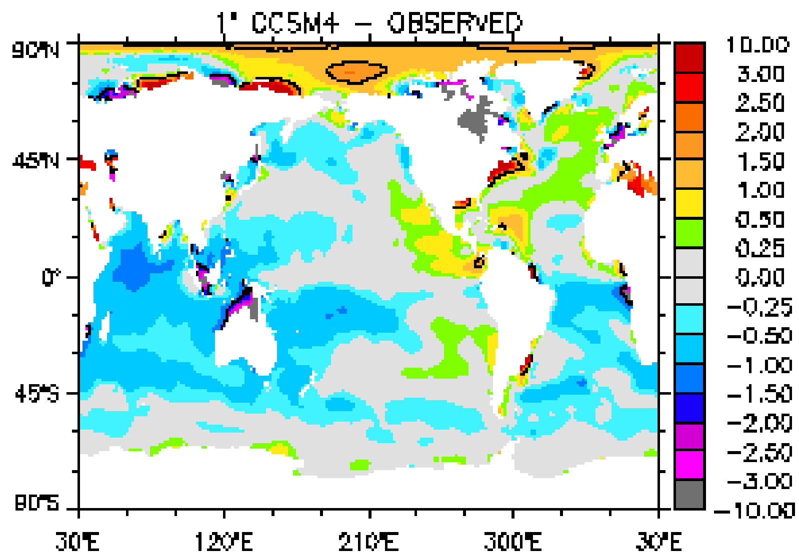


mean= -0.13

rms= 0.80

mean= -0.19

rms= 0.75

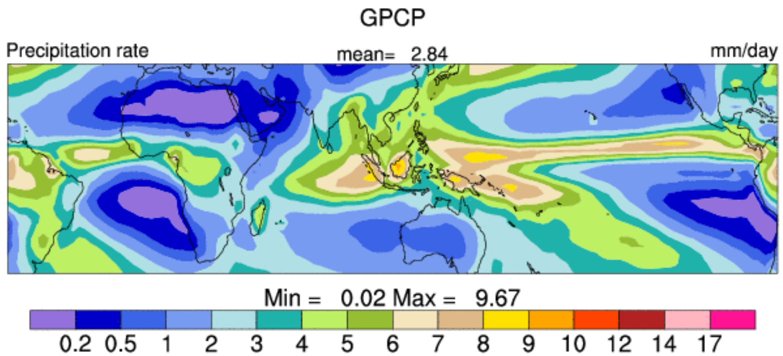


psu

Obs: Levitus et al. (1998), Steele et al. (2001)

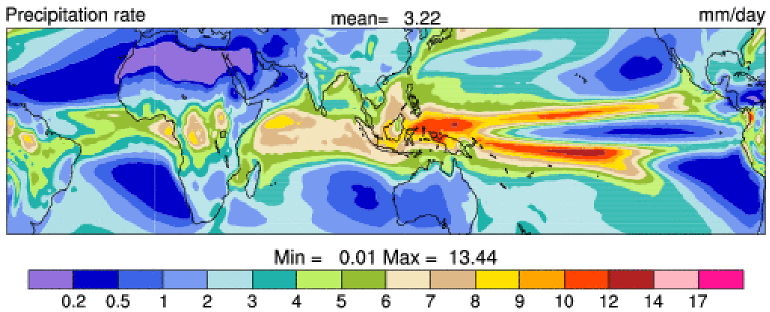
TROPICAL PRECIPITATION RATE

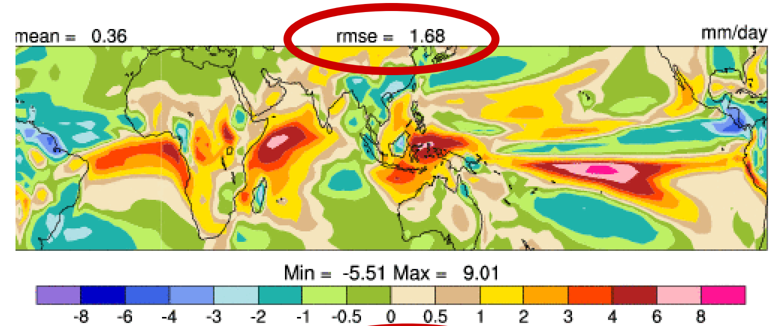
Observations



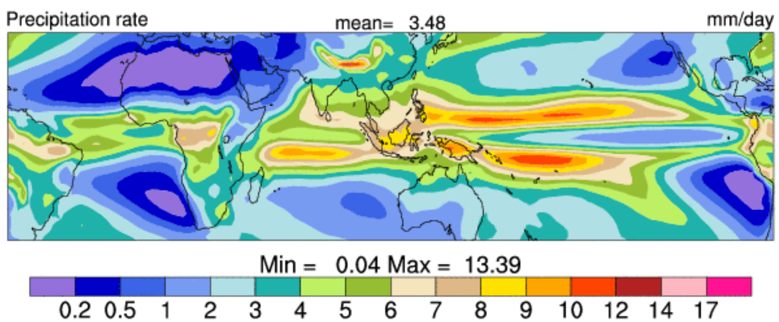
model - observations

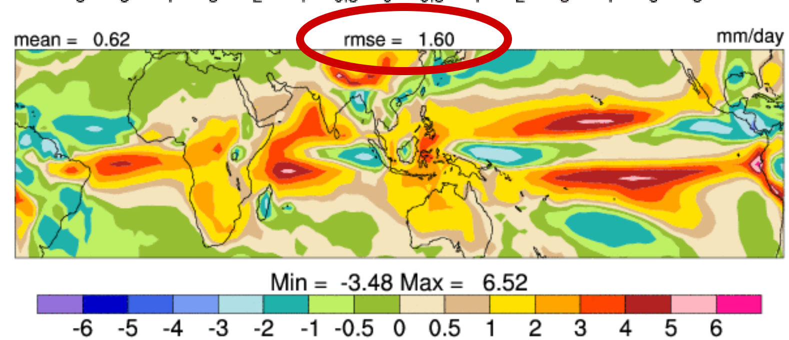
CCSM3



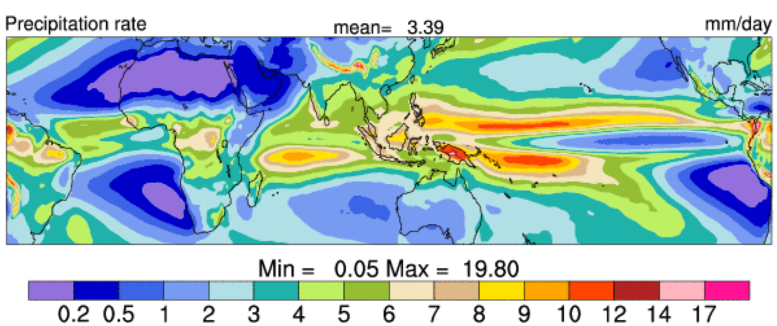


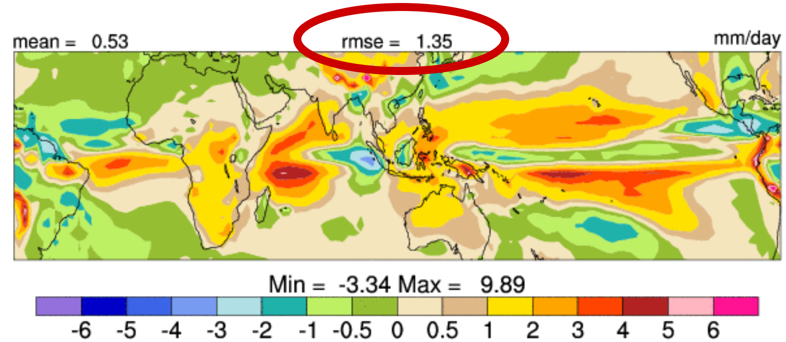
2° CCSM4

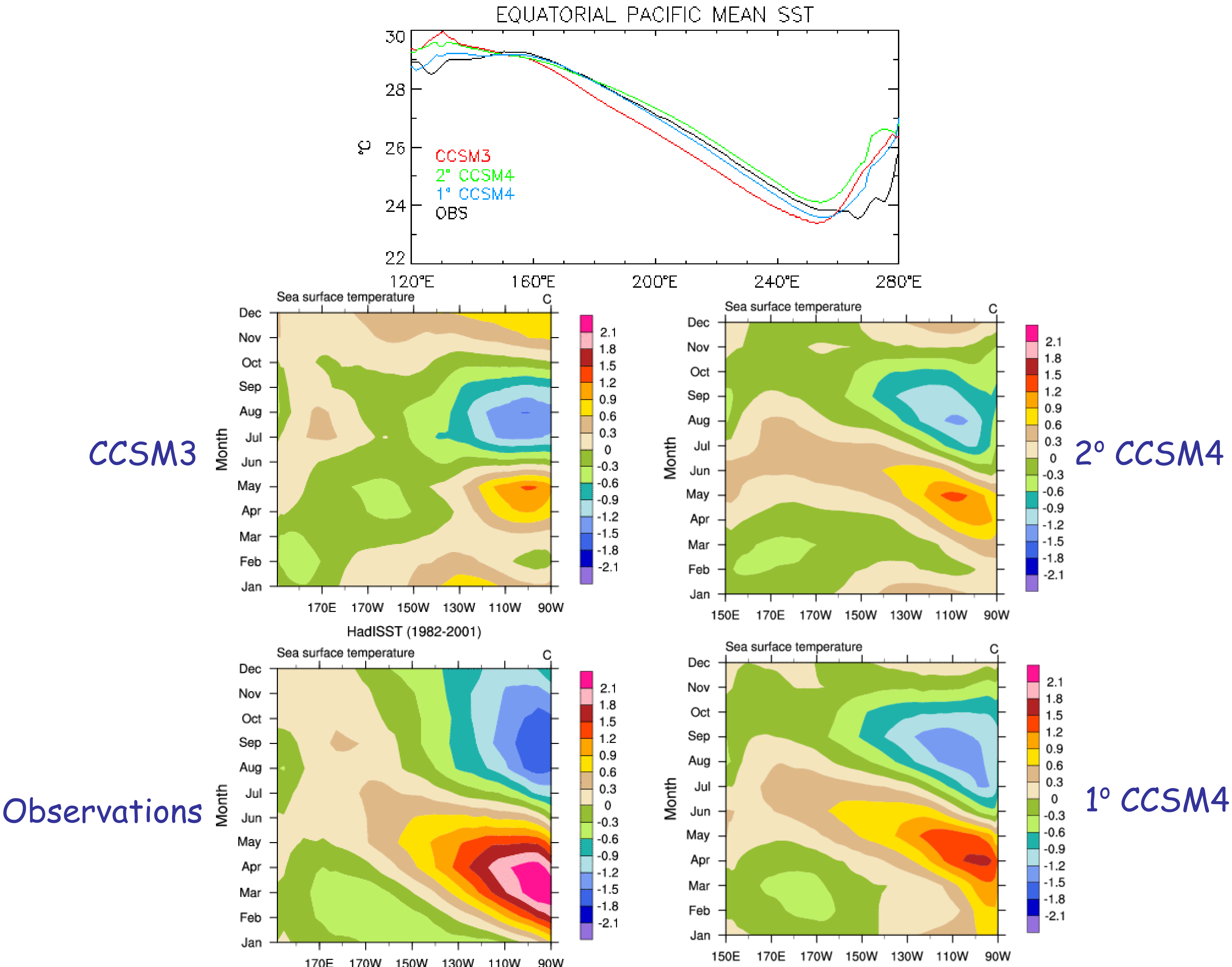




1° CCSM4

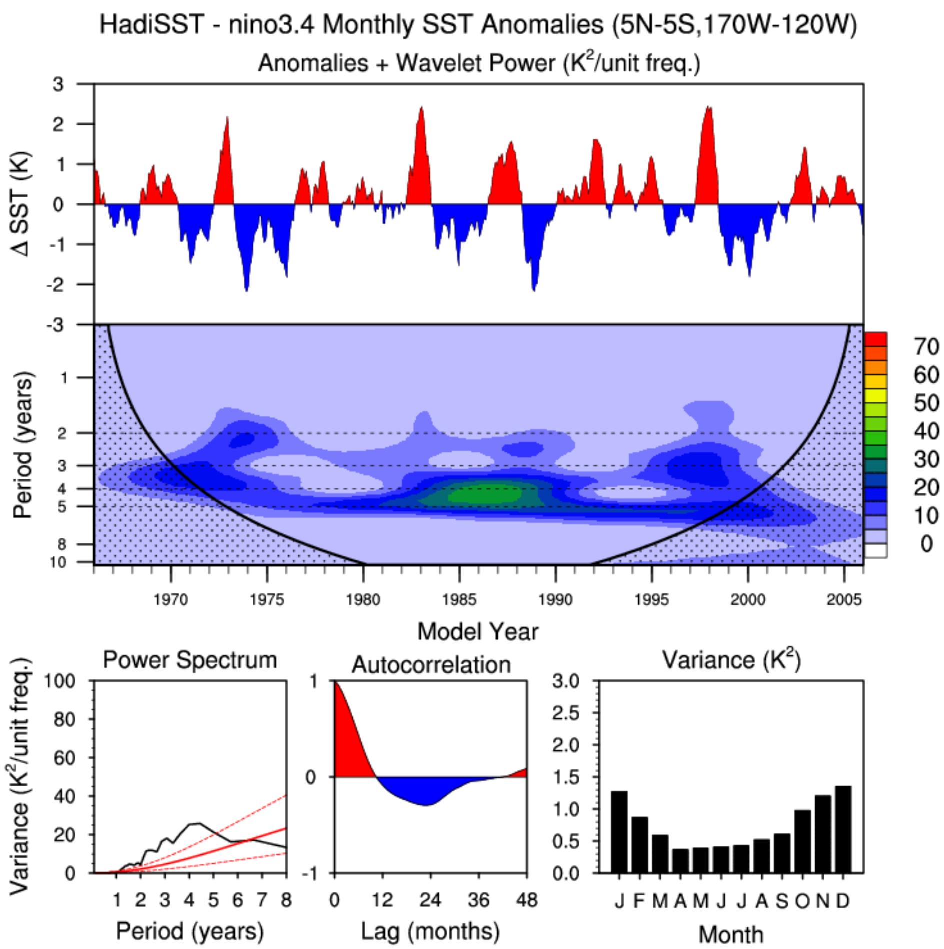




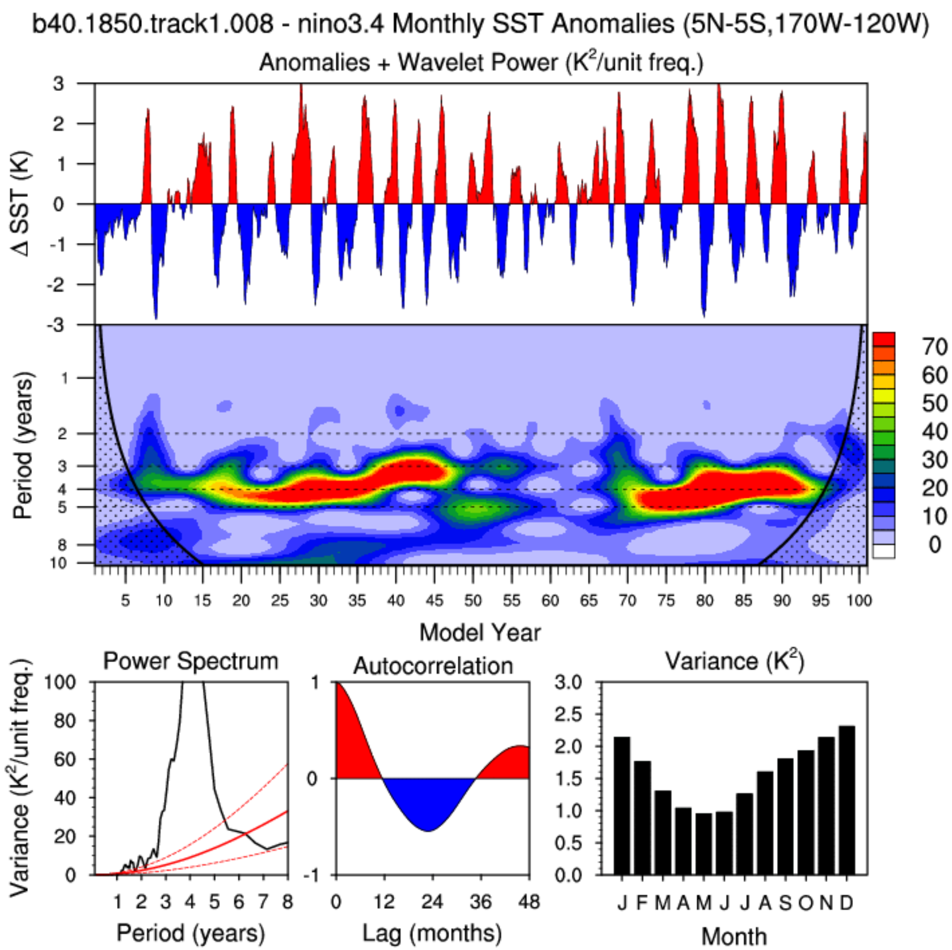

EQUATORIAL PACIFIC MEAN SST
°C
30
28
26
24
22
120°E
160°E
200°E
240°E
280°E
CCSM3
2° CCSM4
1° CCSM4
OBS
CCSM3
2° CCSM4
Observations
1° CCSM4
HadISST (1982-2001)
Sea surface temperature
C
Month
Dec
Nov
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
150E
170E
170W
150W
130W
110W
90W
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0
-0.3
-0.6
-0.9
-1.2
-1.5
-1.8
-2.1

ENSO CHARACTERISTICS

OBSERVATIONS

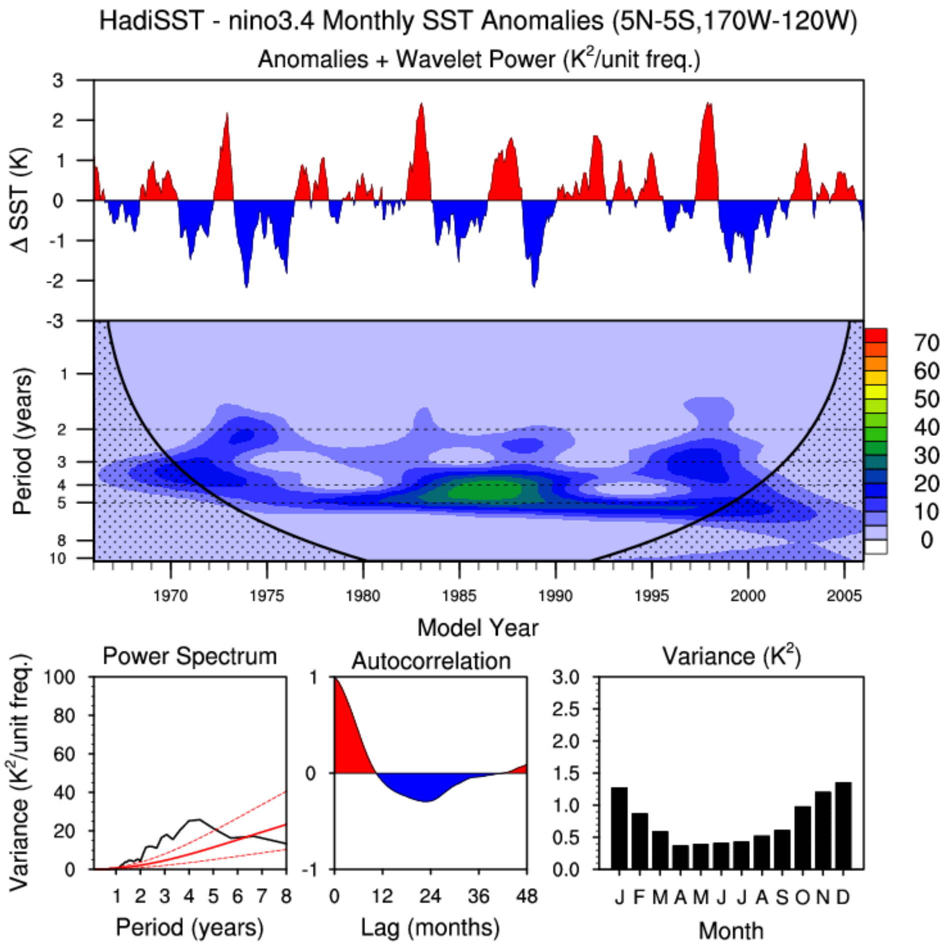


2° CCSM4

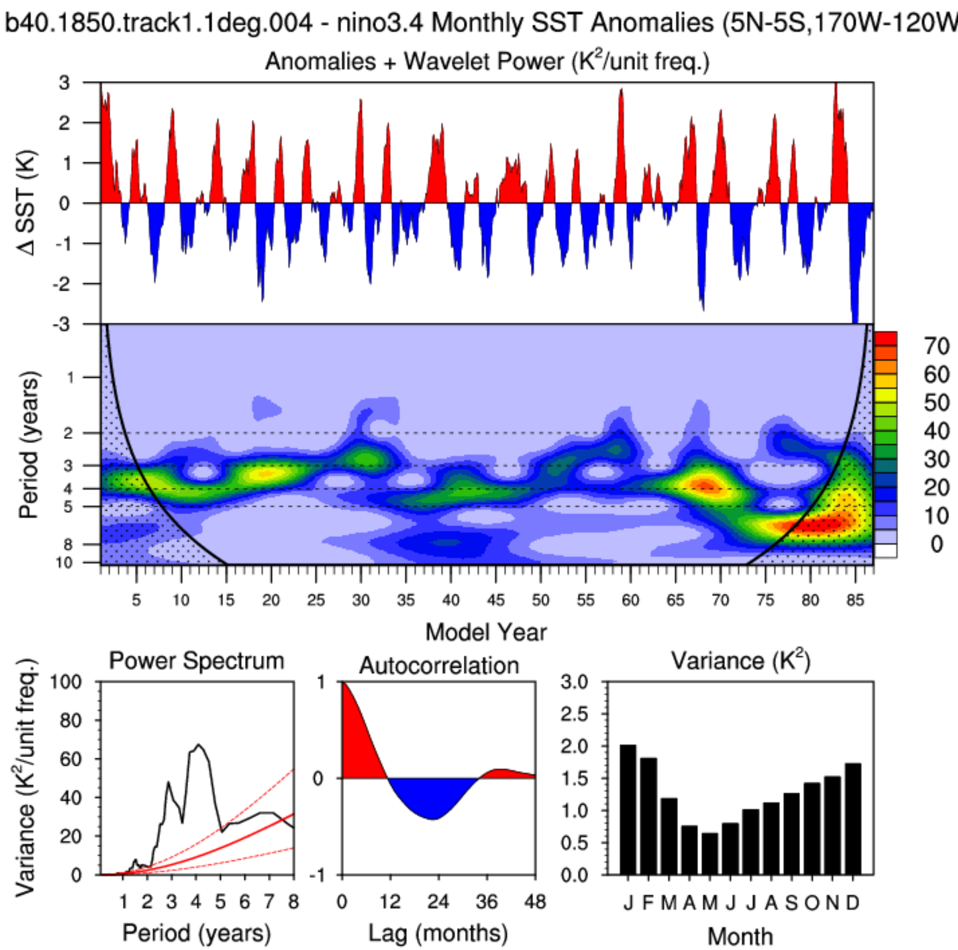


ENSO CHARACTERISTICS

OBSERVATIONS



1° CCSM4

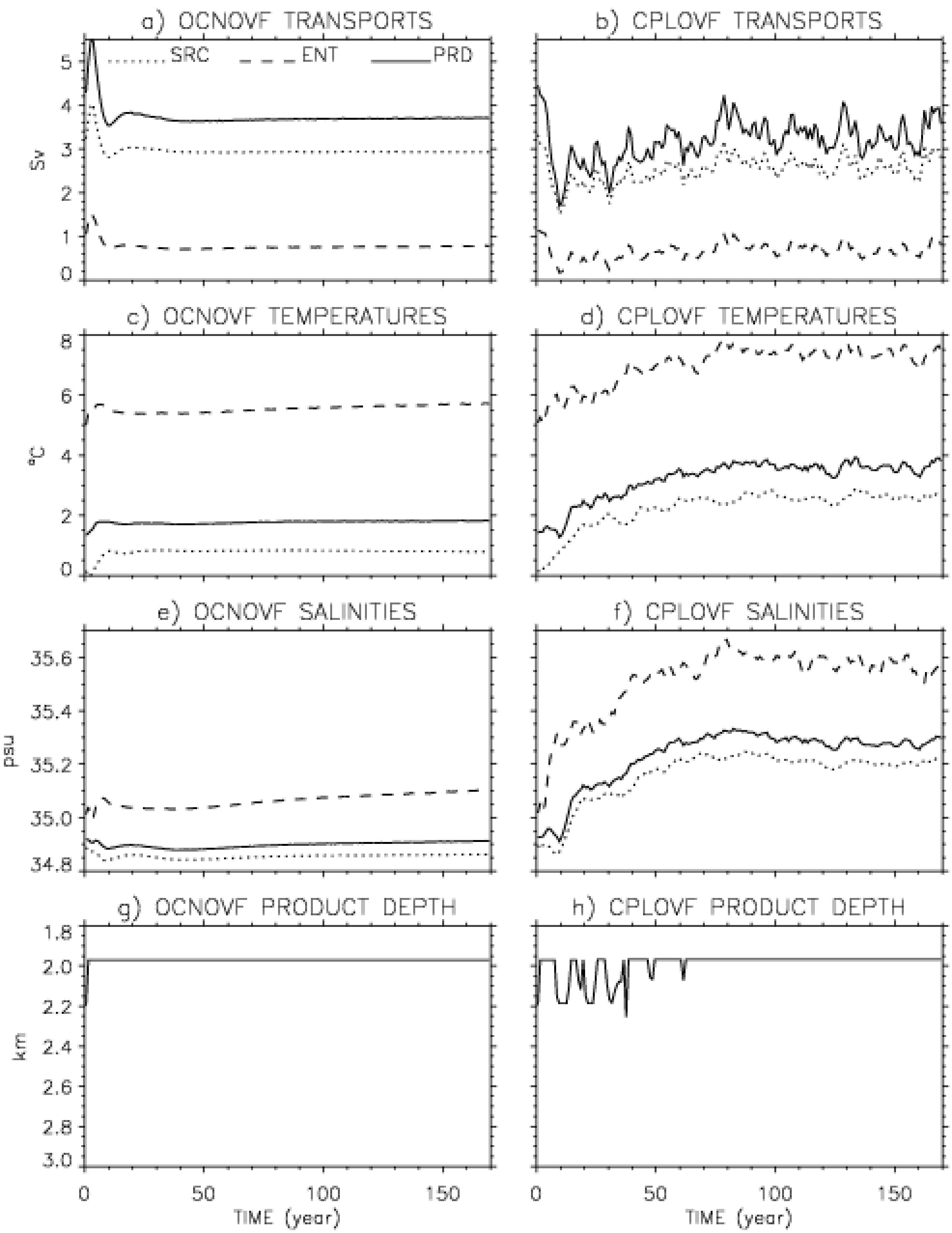


SUMMARY

- New developments / improvements in ocean model physics and numerics,
- Combined with improvements in other component models and 1° FV atmospheric model in CCSM4 reduce some of our major biases in coupled simulations in comparison with CCSM3 simulations.

ONGOING & FUTURE WORK

- Continuing model development (e.g., mesoscale eddy diffusivities, Langmuir parameterization, switch to HYPOP, etc.),
- Contribute to nested modeling efforts, i.e., ROMS in POP,
- Role of ocean in decadal predictability and prediction,
- Eddy-permitting / resolving experiments: Science and coordination,
- Low resolution CCSM4: ?? FV atmosphere and x3°-60 level ocean.

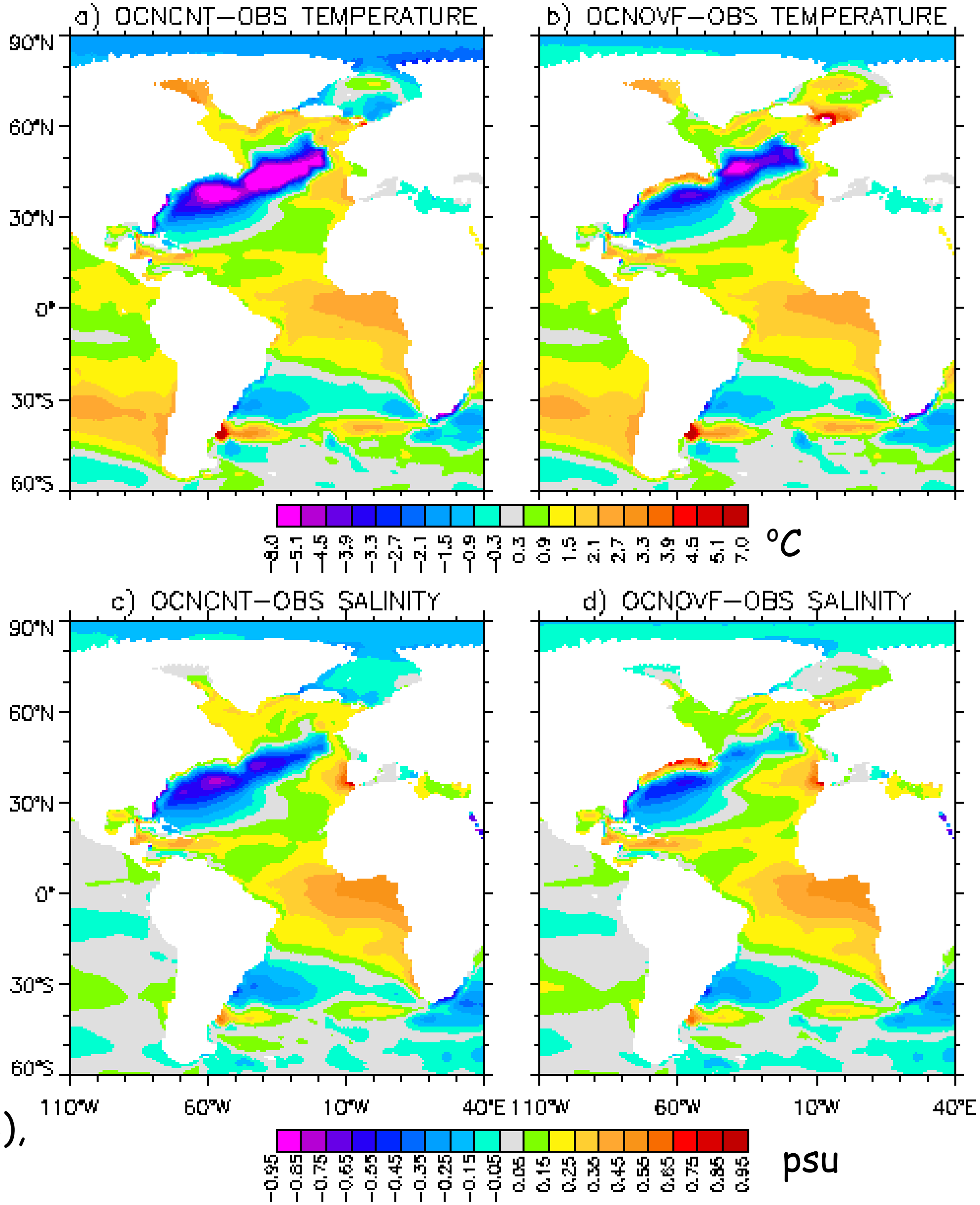


a) OCNOVF TRANSPORTS
b) CPLOVF TRANSPORTS
SRC
ENT
PRD
Sv
c) OCNOVF TEMPERATURES
d) CPLOVF TEMPERATURES
°C
e) OCNOVF SALINITIES
f) CPLOVF SALINITIES
psu
g) OCNOVF PRODUCT DEPTH
h) CPLOVF PRODUCT DEPTH
km
TIME (year)
TIME (year)

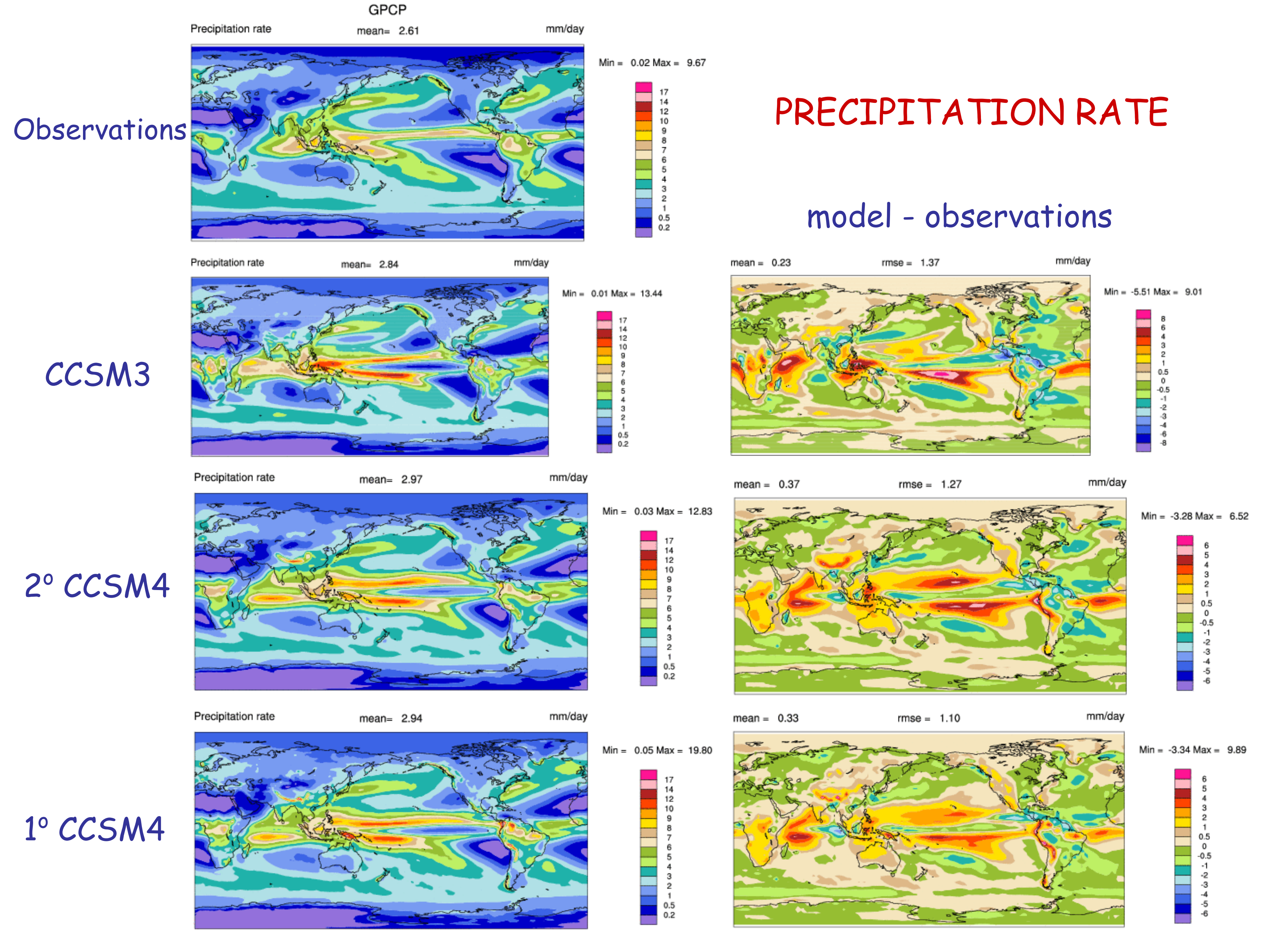
TEMPERATURE AND SALINITY DIFFERENCES FROM OBSERVATIONS AT 409-m DEPTH

Ocean-only control

Ocean-only w/ overflows



Obs: Levitus et al. (1998), Steele et al. (2001)

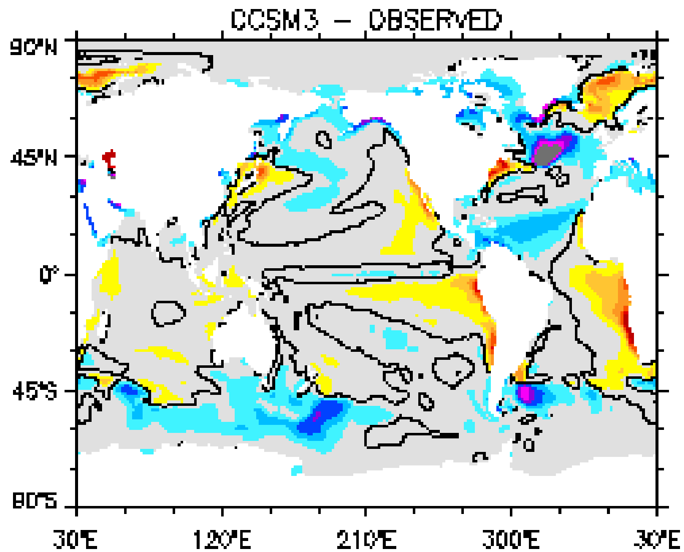


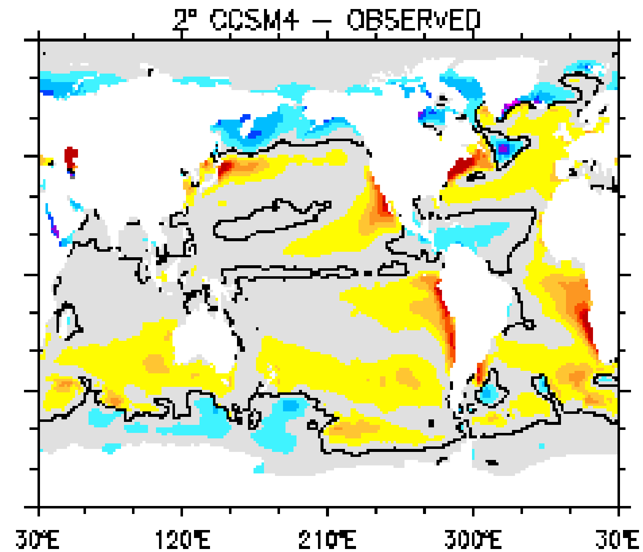
PRECIPITATION RATE
model - observations
Observations
GPCP
Precipitation rate
mean= 2.61
mm/day
Min = 0.02 Max = 9.67
17 14 12 10 9 8 7 6 5 4 3 2 1 0.5 0.2
CCSM3
Precipitation rate
mean= 2.84
mm/day
Min = 0.01 Max = 13.44
mean = 0.23
rmse = 1.37
mm/day
Min = -5.51 Max = 9.01
8 6 4 3 2 1 0.5 0 -0.5 -1 -2 -3 -4 -6 -8
2° CCSM4
Precipitation rate
mean= 2.97
mm/day
Min = 0.03 Max = 12.83
mean = 0.37
rmse = 1.27
mm/day
Min = -3.28 Max = 6.52
6 5 4 3 2 1 0.5 0 -0.5 -1 -2 -3 -4 -5 -6
1° CCSM4
Precipitation rate
mean= 2.94
mm/day
Min = 0.05 Max = 19.80
mean = 0.33
rmse = 1.10
mm/day
Min = -3.34 Max = 9.89

SST DIFFERENCES FROM OBSERVATIONS

mean= -0.06°C

rms= 1.29°C



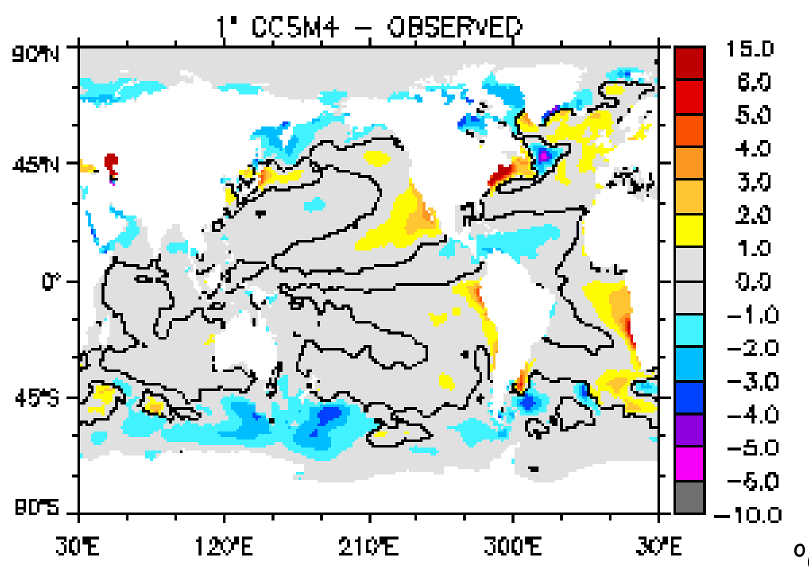


mean= 0.63°C

rms= 1.44°C

mean= -0.01°C

rms= 1.07°C

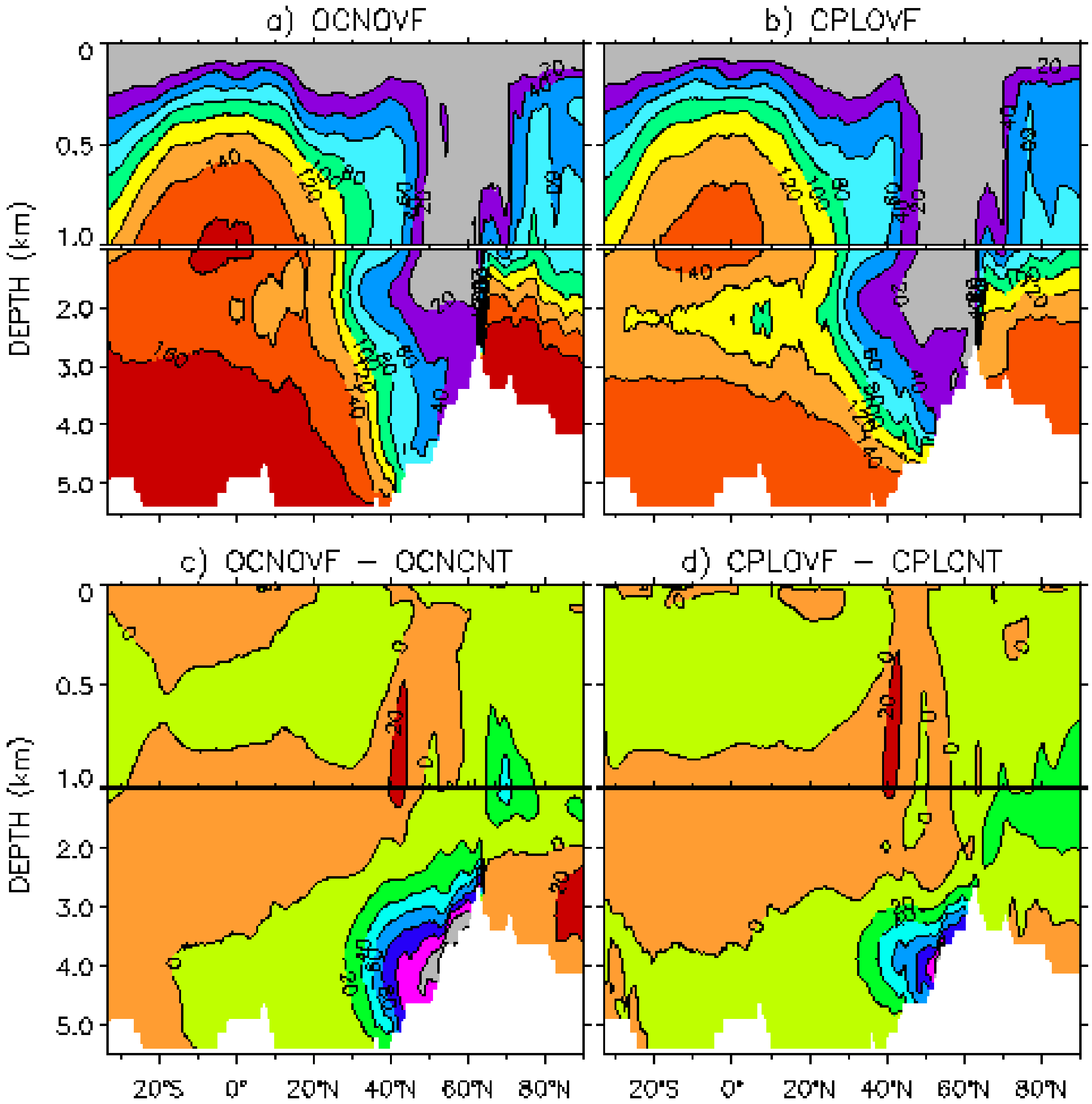


Obs: Levitus et al. (1998), Steele et al. (2001)

ZONAL-MEAN IDEAL AGE FOR THE ATLANTIC AND ARCTIC OCEANS (years)

Ocean-only w/ overflows

Coupled w/ overflows



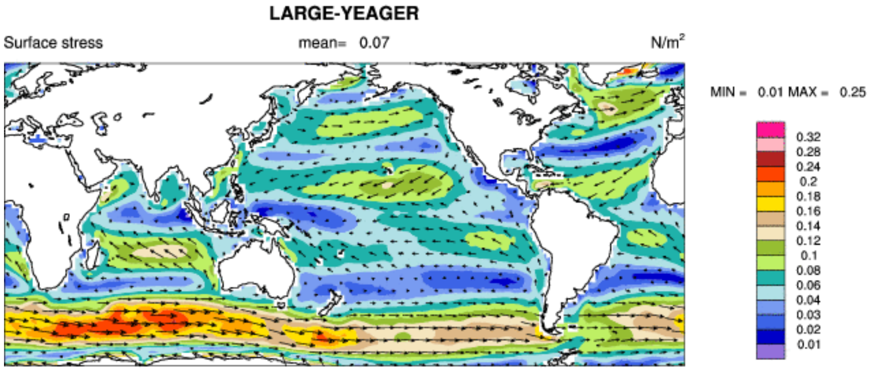
Ocean-only w/ overflows - control

Coupled w/ overflows - control

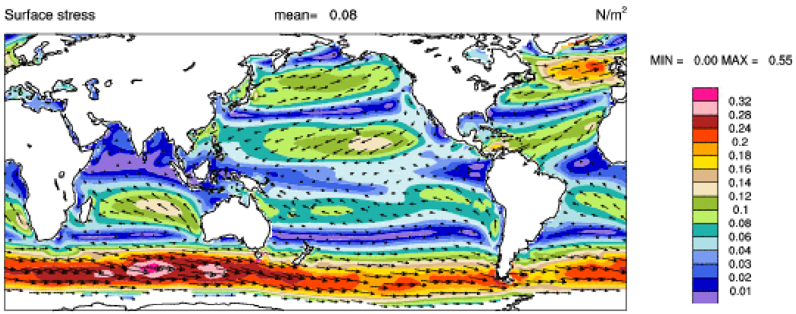
WIND STRESS

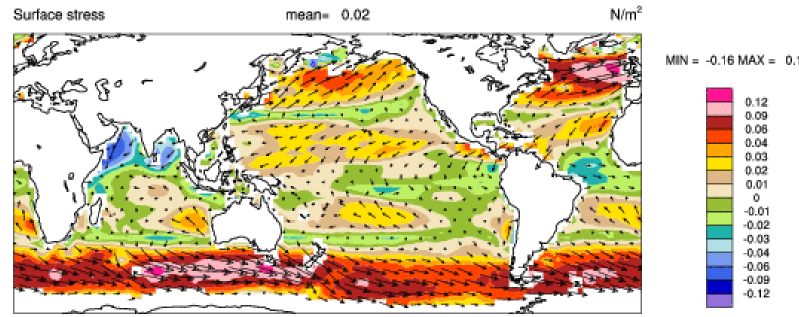
model - observations

OBS

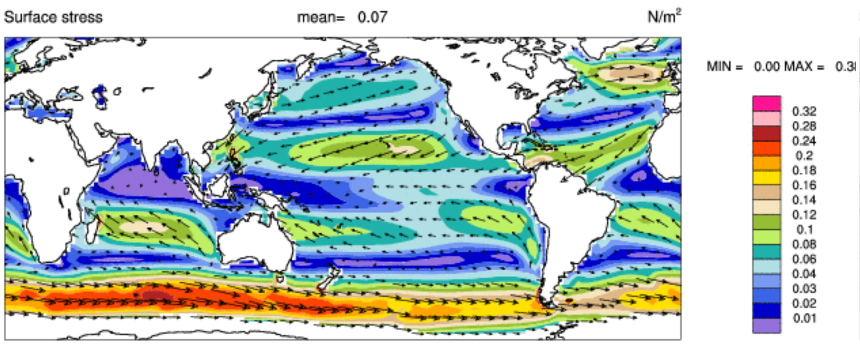


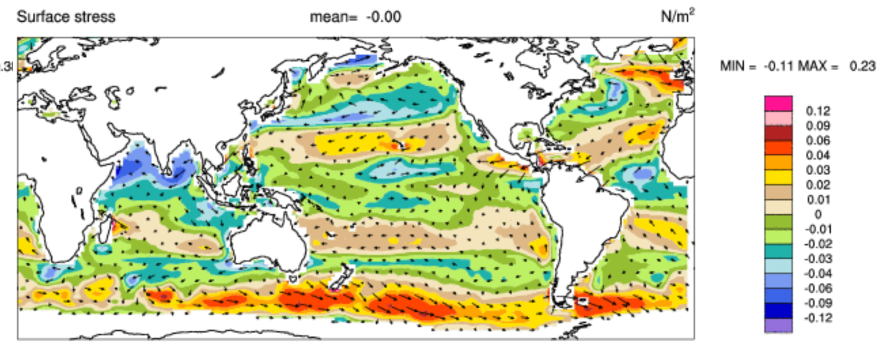
CCSM3





2°CCSM4





1°CCSM4