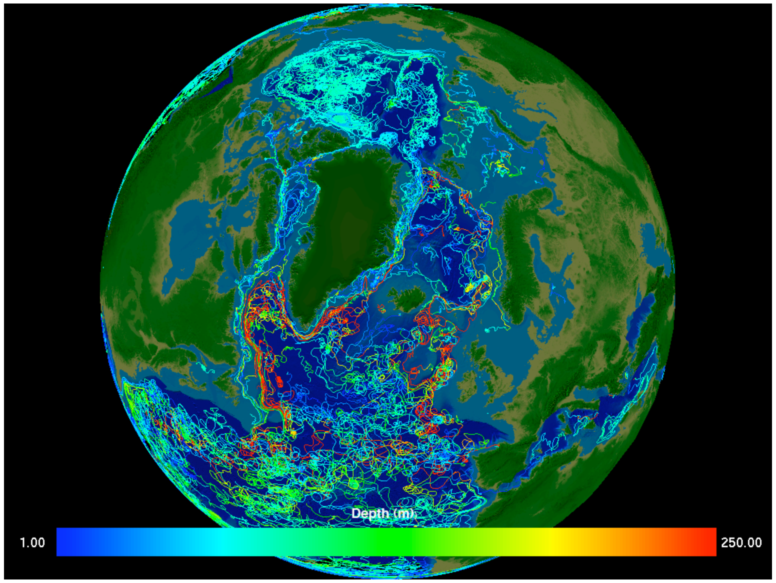


Ocean Model Metrics

Julie McClean
Scripps Institution of Oceanography

15 February 2007

WGNE/PCMDI Systematic Errors Workshop

San Francisco California

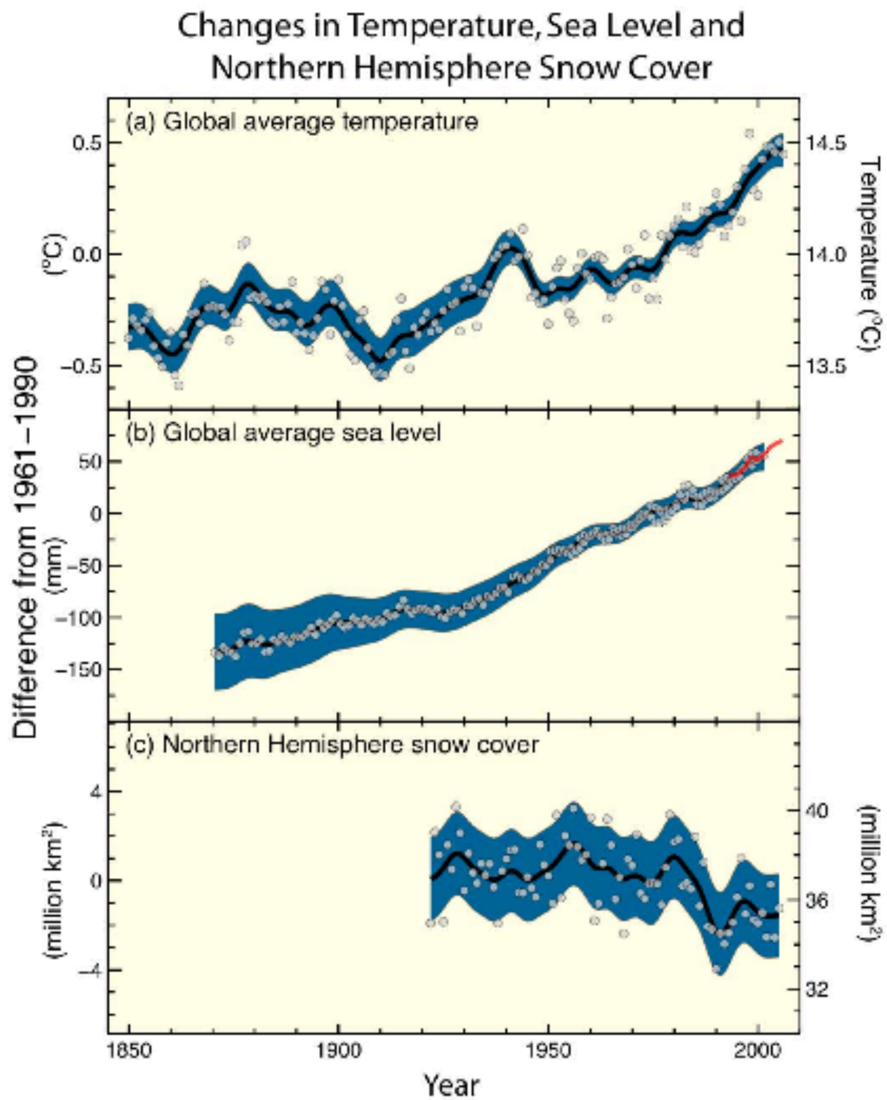


FIGURE SPM-3. Observed changes in (a) global average surface temperature; (b) global average sea level rise from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All changes are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c). {FAQ 3.1, Figure 1, Figure 4.2 and Figure 5.13}

CLIVAR WGOMD: June 2004

- What are key physical ocean processes that must be explicitly represented and/or parameterized in order to reduce uncertainty in the climate's response to anthropogenic forcing?

- How well do the global 1-degree class of models do with these processes?

- Will enhanced resolution resolve problems?

- What sorts of resolution are required for the different processes?

The Ocean Component of Coupled Climate Models

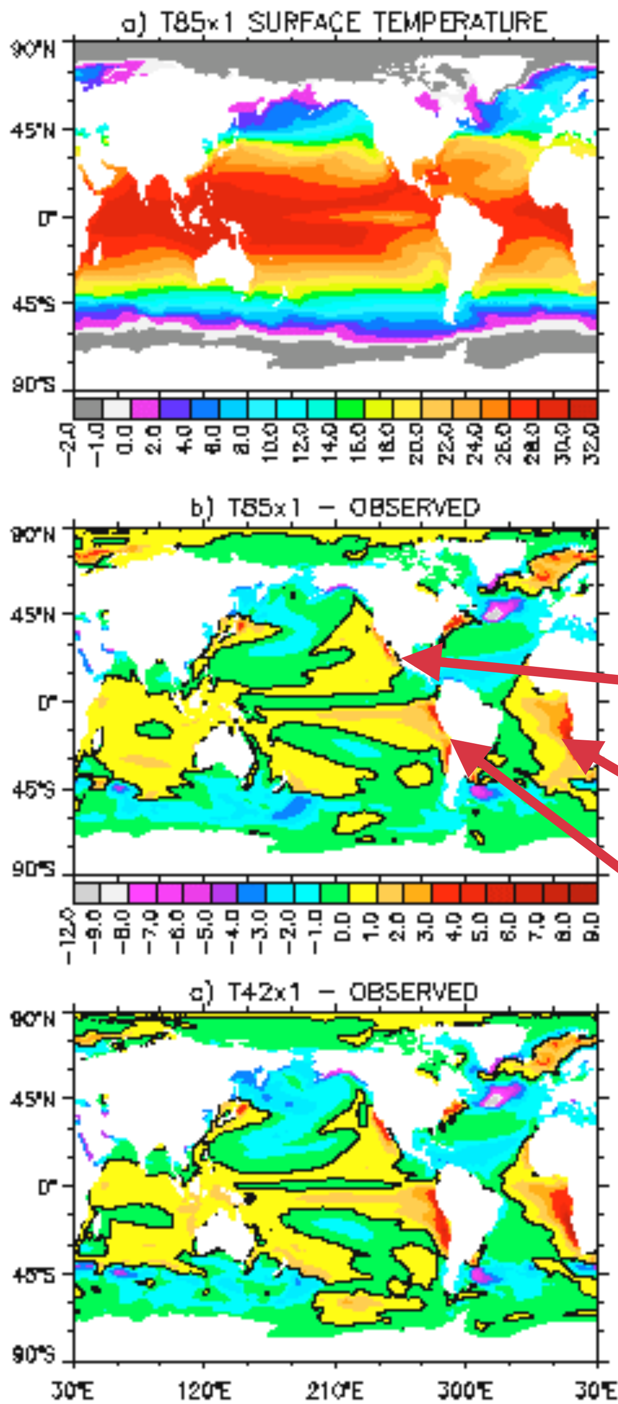
The importance of simulating the ocean as accurately as possible in climate studies results from its role *in storing and transporting heat, energy, freshwater, nutrients, and dissolved gases such as* CO_2*.*

The ocean acts as a heat capacitor in the coupled atmosphere-ocean system and hence acts as an *integrator of climate variability,* introducing long scales and slowing the rate of response to climate change forcing.

Variability intrinsic to the ocean interacts with the atmosphere over a range of time scales to *produce coupled modes of climate variability* such as ENSO, the NAO, and the SAM.

- The **fidelity** of coupled climate system dynamics depend on its **air/sea interactions**.
- The ocean model must supply realistic **sea surface temperature** fields to the atmospheric model.
- To do this the ocean model must realistically simulate all aspects of the hydrodynamical nature of the ocean. These include:
  - Energy levels
  - Mean, variability, and location of currents
  - Intrinsic scales
  - Modes of variability
  - Planetary waves
  - Water masses
  - Meridional heat and mass transports
  - Representation of sea ice (Not covered here; see Ivanova poster)

Sea Surface Temperature (SST):CCSM3/T85 simulation of present day climate



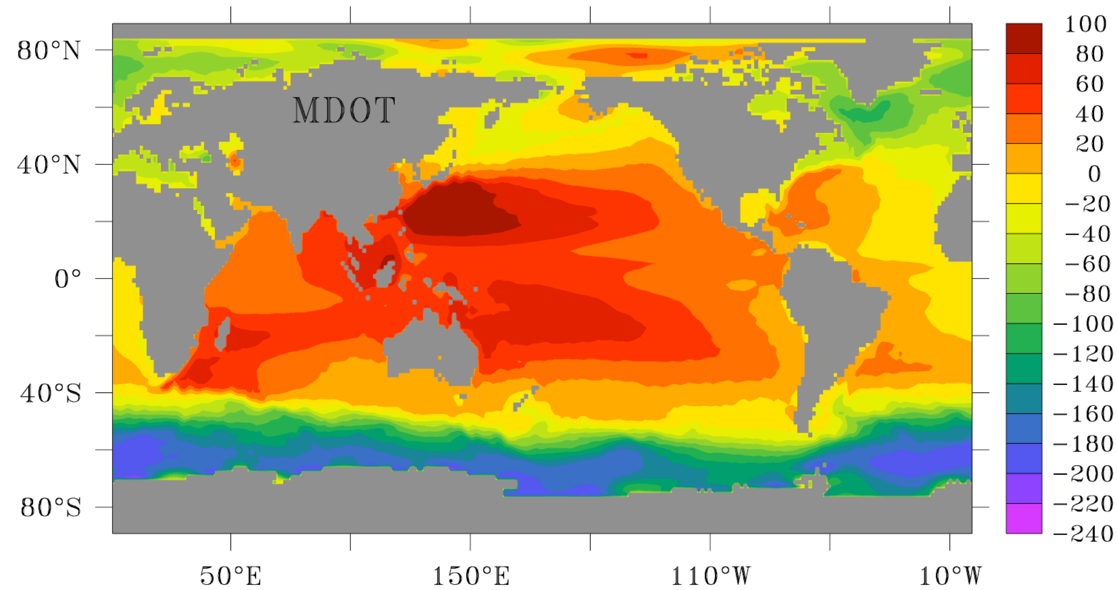
1.6°C

3.2°C

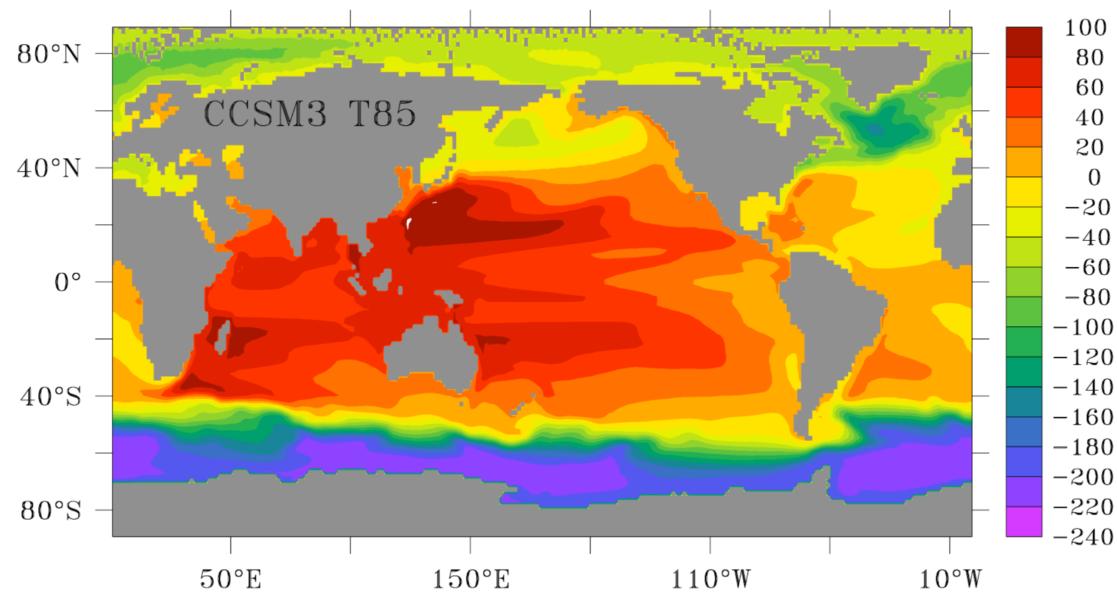
1.7°C

Largest positive biases occur along eastern boundaries of subtropical ocean basins. Within 15° of coast biases are:

Large and Danabasoglu, J. Climate, 2006

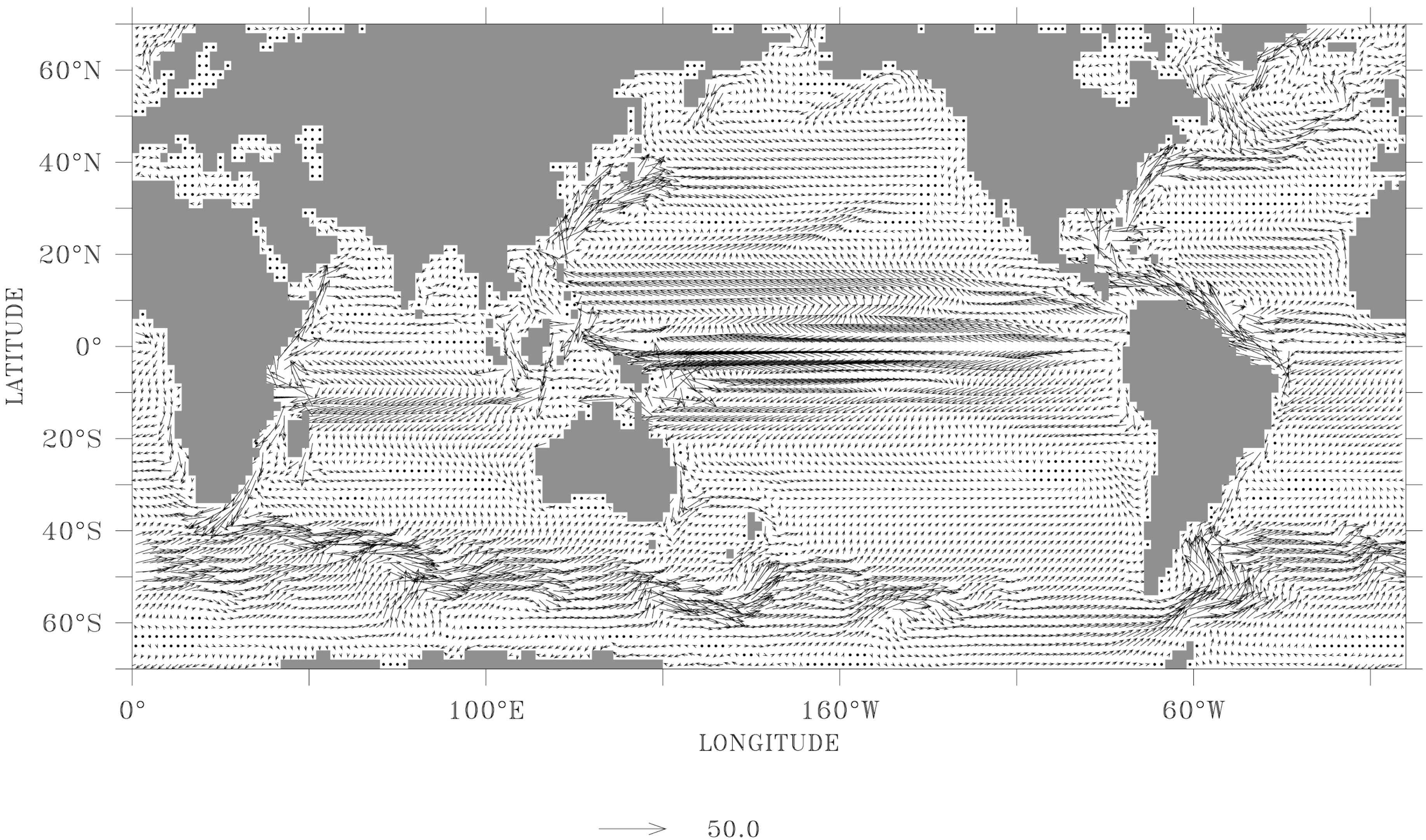


1992-2002 mean ocean dynamic topography data from Nikolai Maximenko (IPRC) and Peter Niiler (SIO)

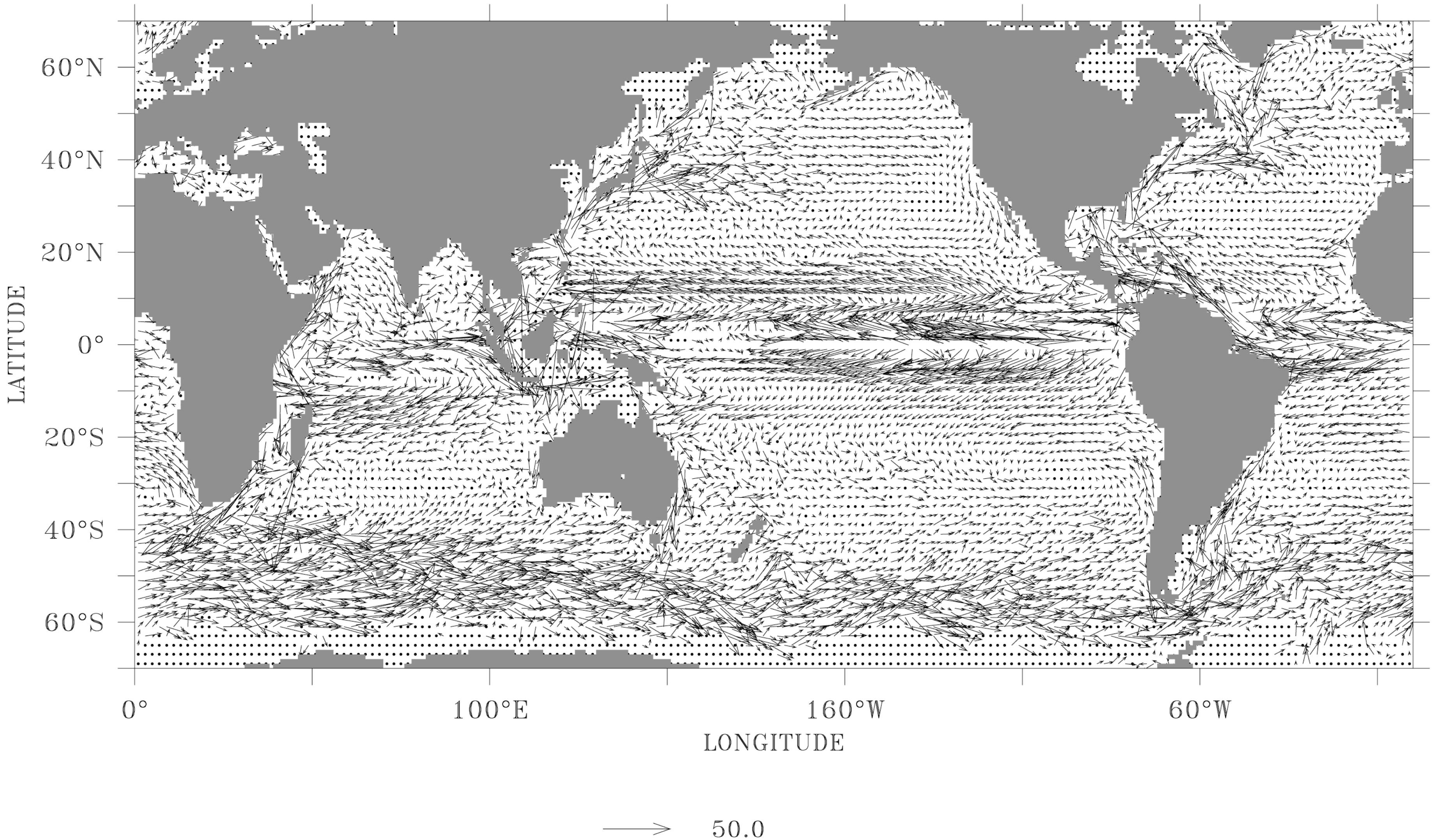


Mean Sea Surface Height (cm) from CCSM/T85, Yrs 690-699

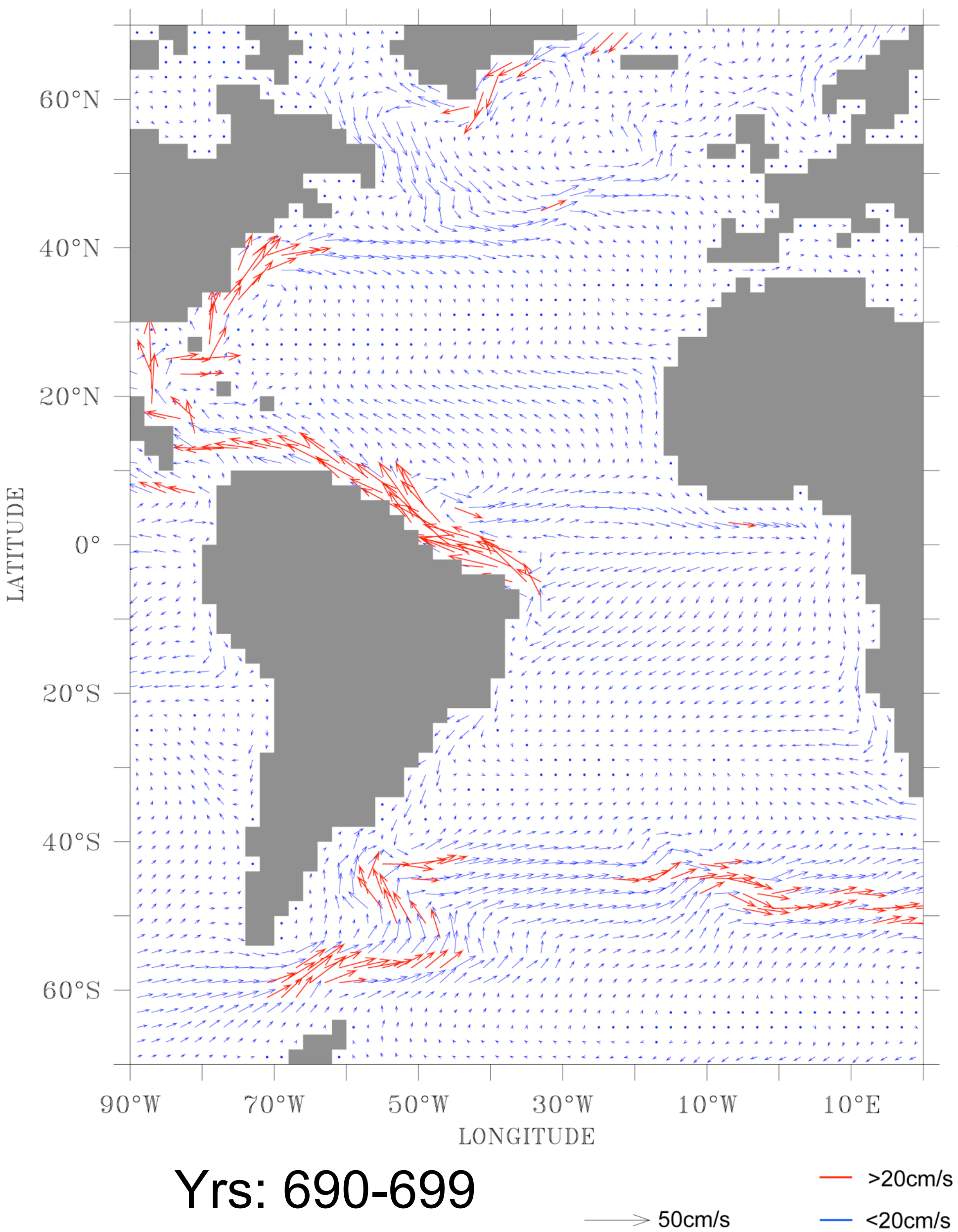
Mean velocity vectors (cm/s): CCSM3 T85, Yrs 690-699

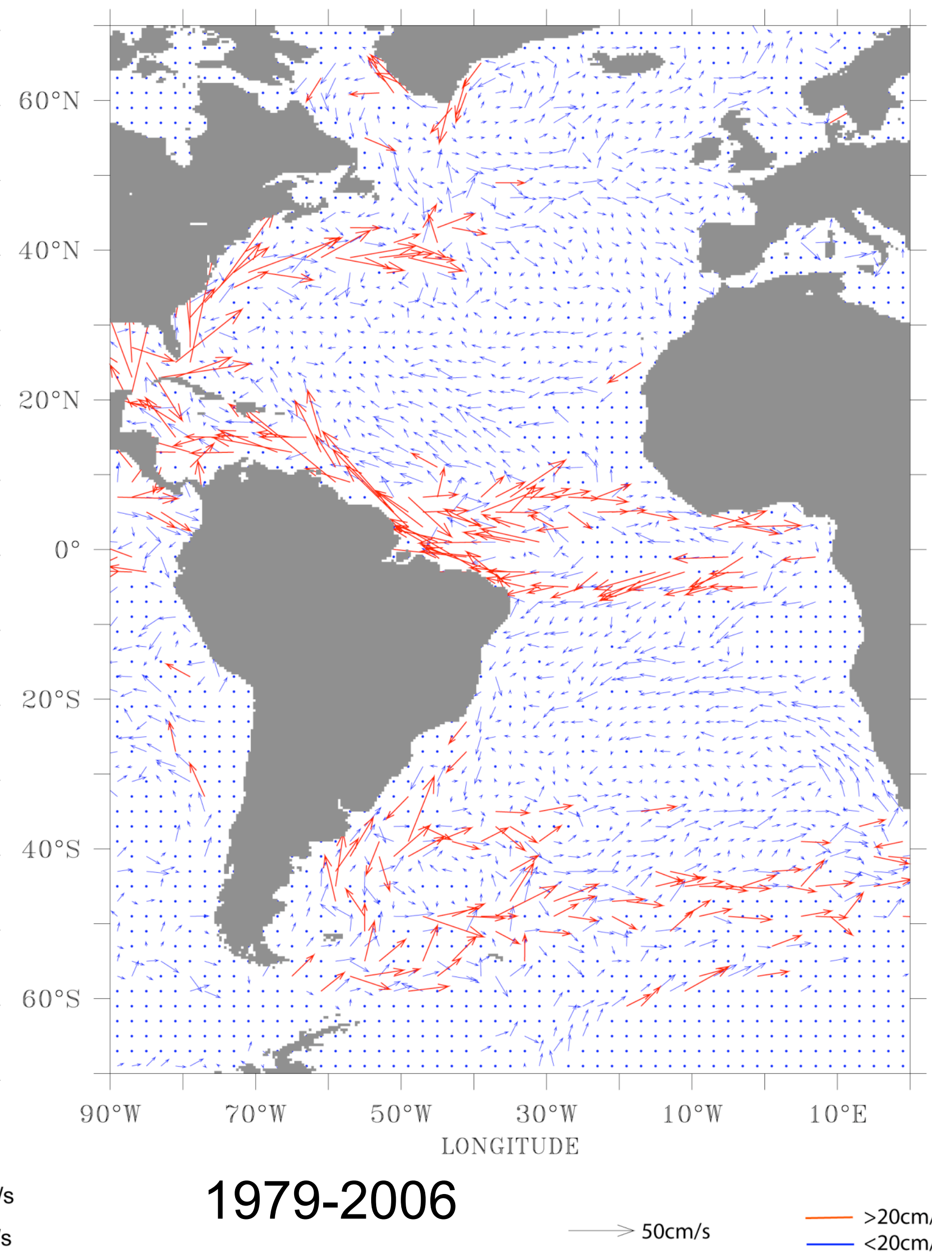


Mean velocity vectors (cm/s): Drifter Data, Yrs 1979-2006



Mean velocities @15m: CCSM3/T85 (left) Drifting buoys (right)

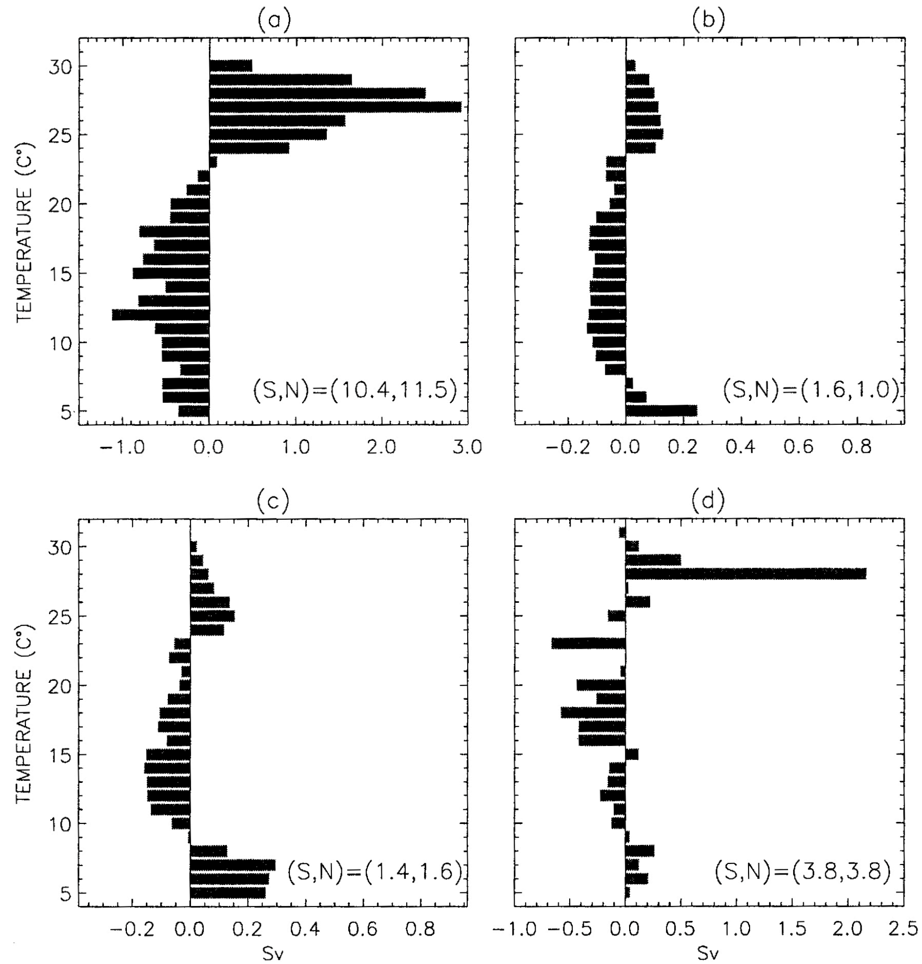




Model/Data Comparison of Eulerian and Eddy-Induced Meridional Overturning in the Tropical North Pacific

Coarse OGCM: eddy effects Gent-McWilliams and anisotropic viscosity

Data: Repeated hydrographic sections: Roemmich, Cornuelle, & Weller, 2001

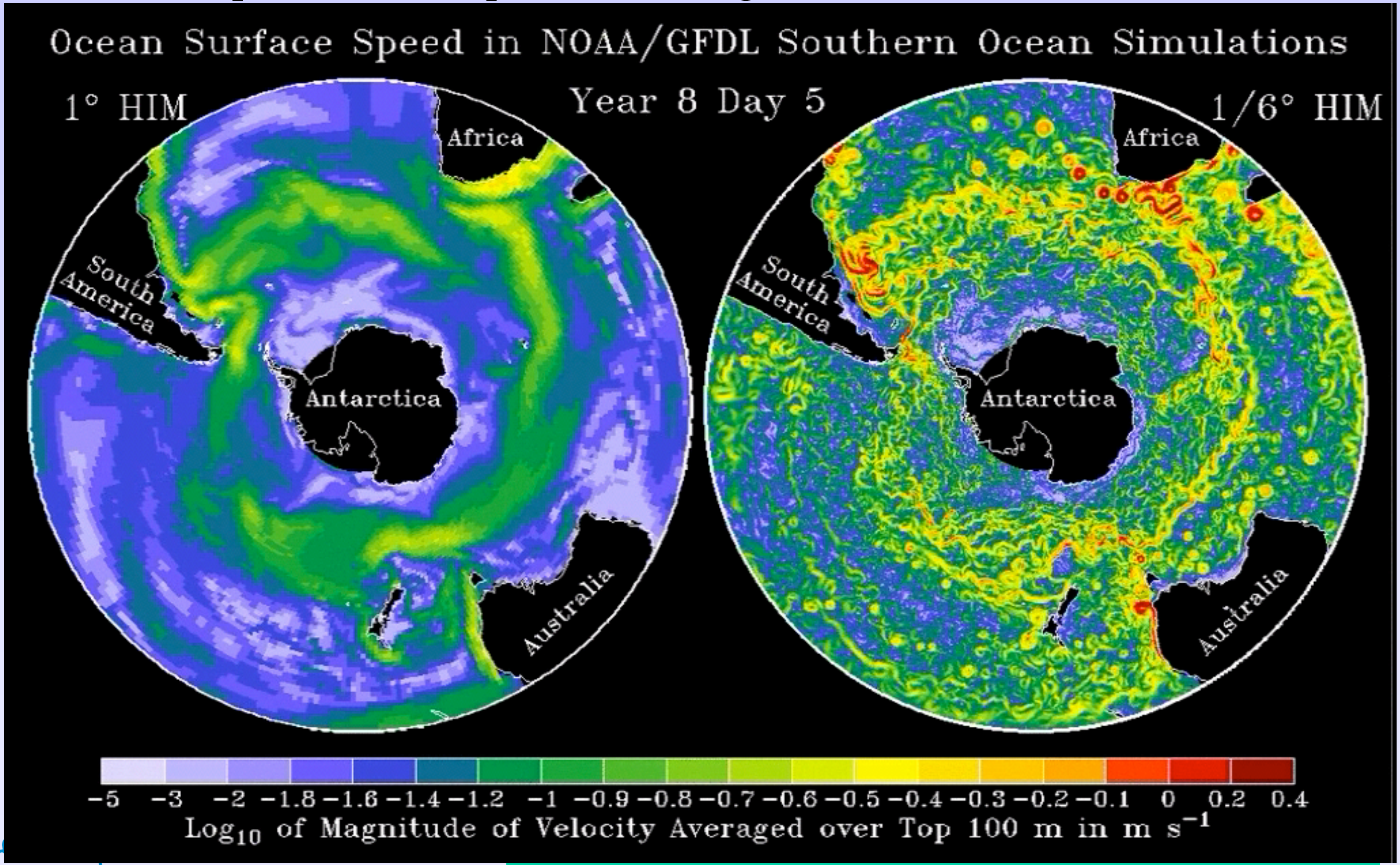


Time-mean, normal transport in temp. bins ($\delta\theta = 1^{o}$C) in the upper ocean ($\theta \geq 5^{o}$C), averaged in time (8 yr.), and integrated along the repeated hydr. ship track in the tropical North Pacific: (a) modeled Eulerian, $\overline{T}_{\perp}(\theta)$ (Sv); (b) modeled eddy-induced, $\overline{T}^{*}_{\perp}(\theta)$(Sv); (c) as in (b) except based only on θ (S=35psu); (d) measured eddy-induced transport $\overline{T}^{*}_{\perp}(\theta)$ (Roemmich and Gilson 2001). Numerical labels: total southward and northward transports in the upper ocean.

McWilliams and Danabasoglu, 2002 (JPO)

Role of eddies in Southern Ocean

- Eddies can alter sensitivity to forcing changes (e.g., winds) of Southern Ocean overturning.
- How well are the boundary currents, rings, etc. parameterized in coarse models? Depends on the questions being asked.



Hallberg & Gnanadesikan, 2006, *JPO,* 36, 2232-2252.

Why Fine-Resolution Global Ocean Models?

More realistic representation of:

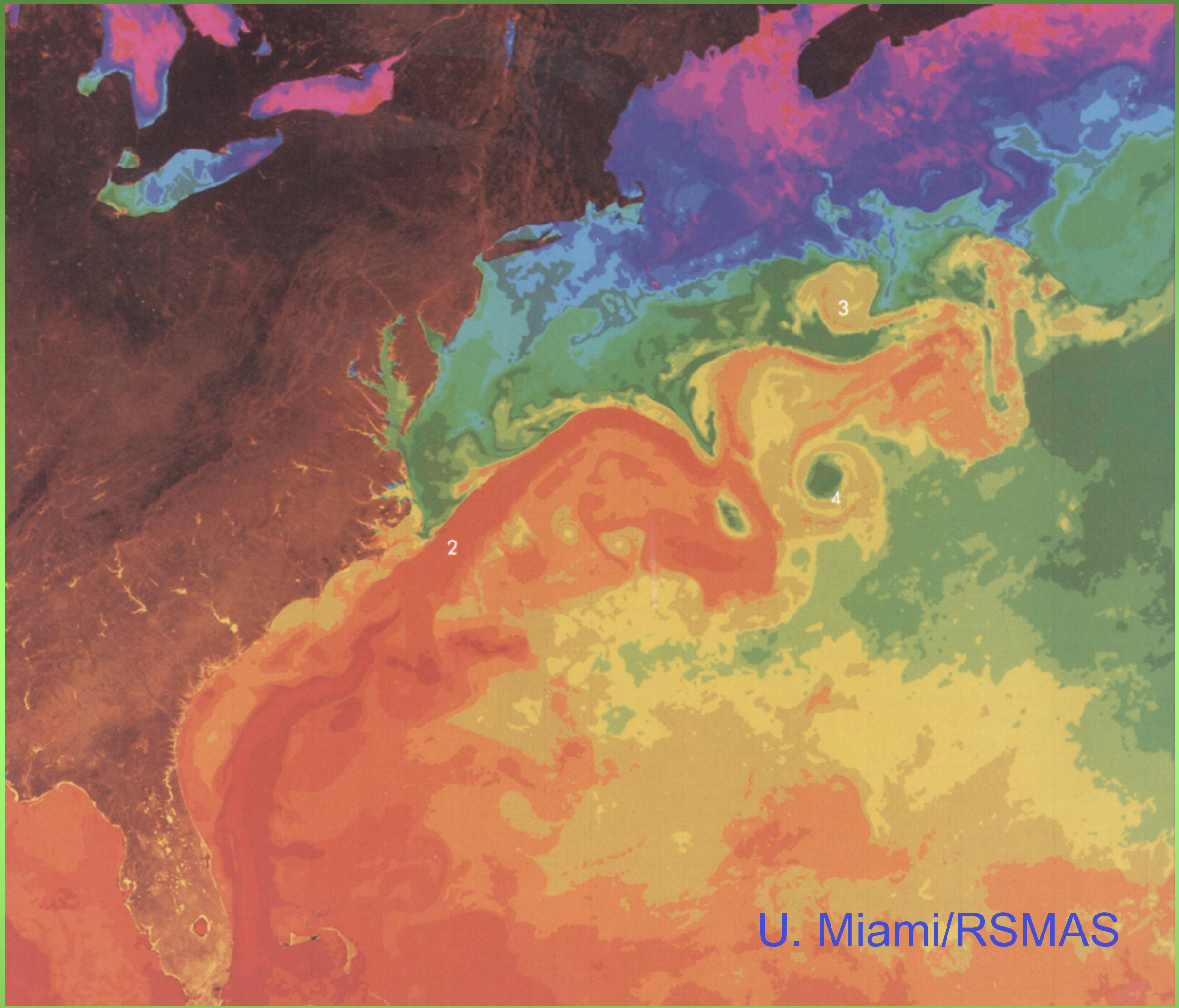
– ocean-bottom bathymetry and coastal geometry.

–Narrow mean currents such as: Gulf Stream, ACC, open-ocean zonal jets

–Mesoscale (20-150 d and 50-500 km): generally accounts for the majority of energy in the ocean circulation

– Fronts: for air-sea interactions in a fully coupled model. Large SST errors result from path errors.

–Realistic eddy growth rates and decay time scales.

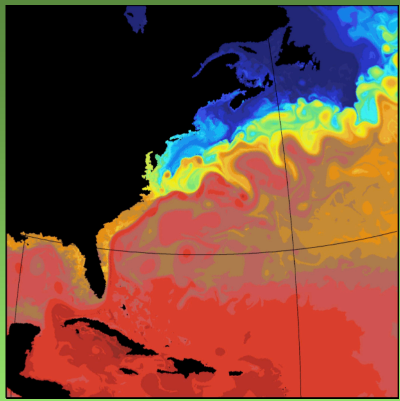


Gulf Stream

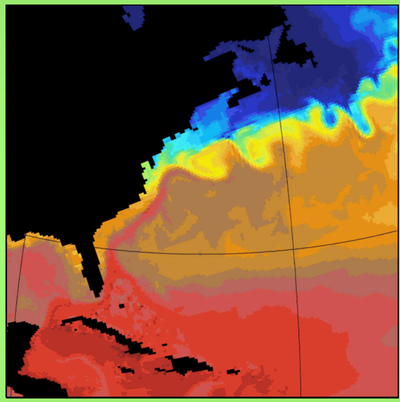
Heat Transport

~1.3 PW

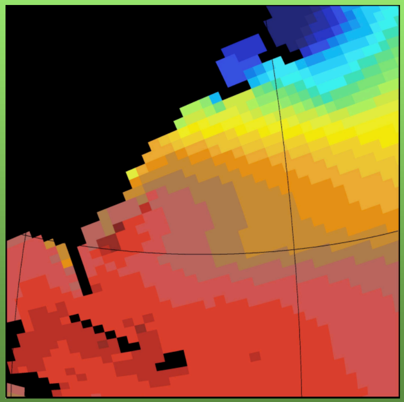
Comparison of SST from AVHRR and 3 global ocean models that differ only in horizontal resolution. Each is run for 1 model year, and all are initialized from WOCE SAC climatology. Courtesy, David Webb & Andrew Coward (SOC)



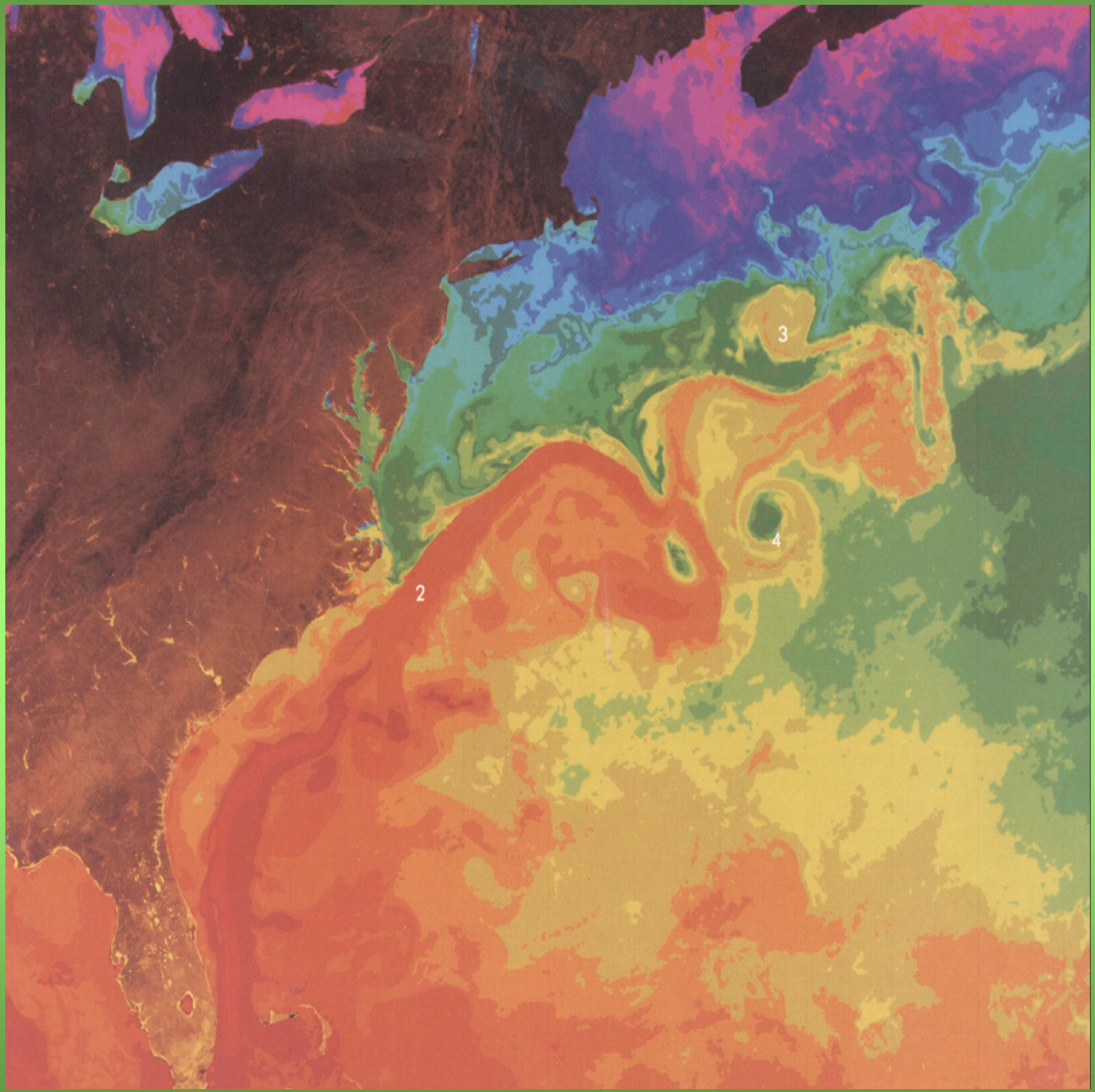
1/12°



1/4°



1°

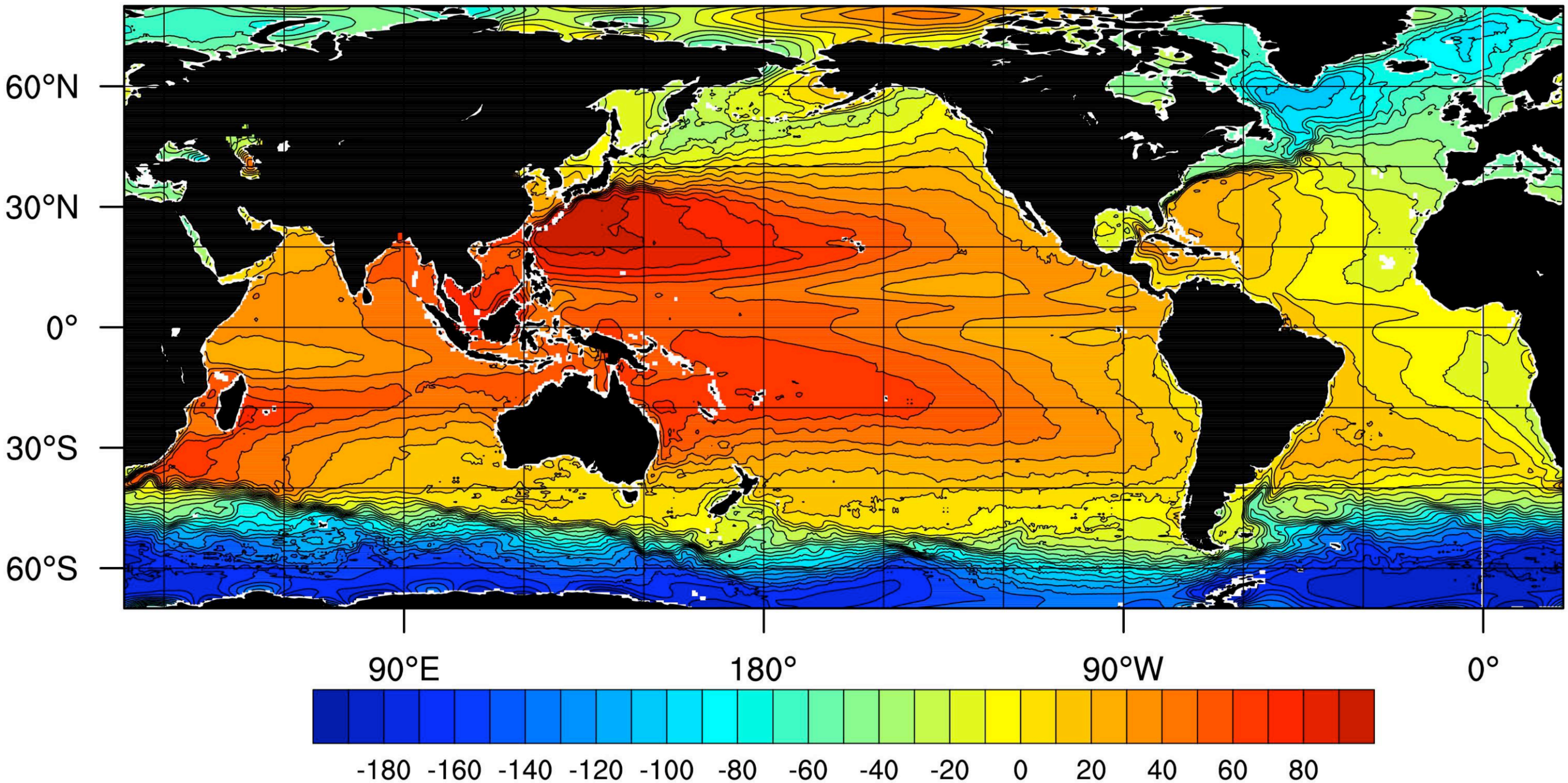


1/12° 1/4° 1°

AVHRR: U. Miami/RSMAS

Long-term Mean Global Sea Level

1992-2002 Mean Dynamic Ocean Topography (0.5°)

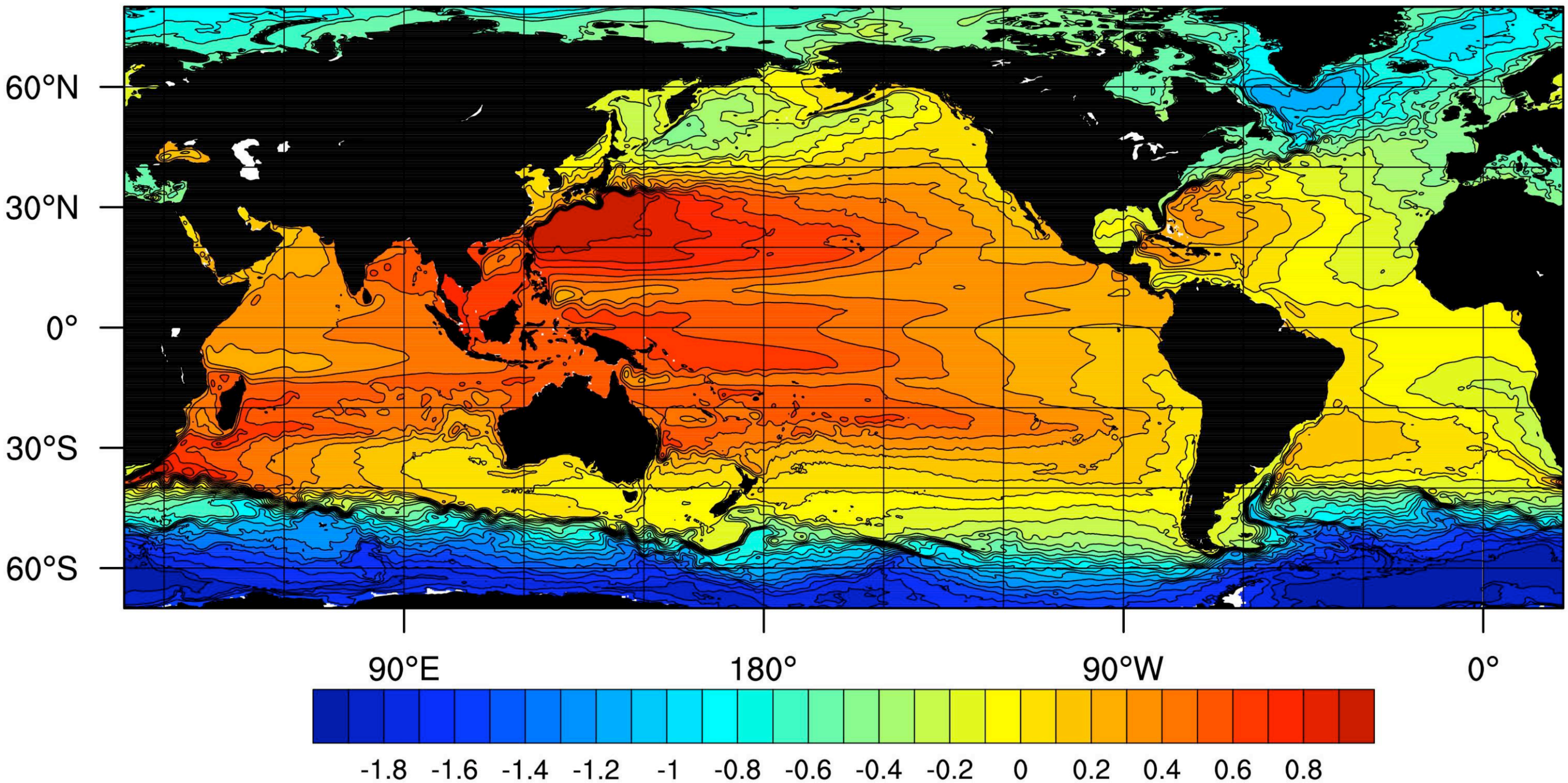


The 1992-2002 mean ocean dynamic topography data has been obtained from Nikolai Maximenko (IPRC) and Peter Niiler (SIO)

Metzger, 2005

Long-term Mean Global Sea Level

1/12° global HYCOM



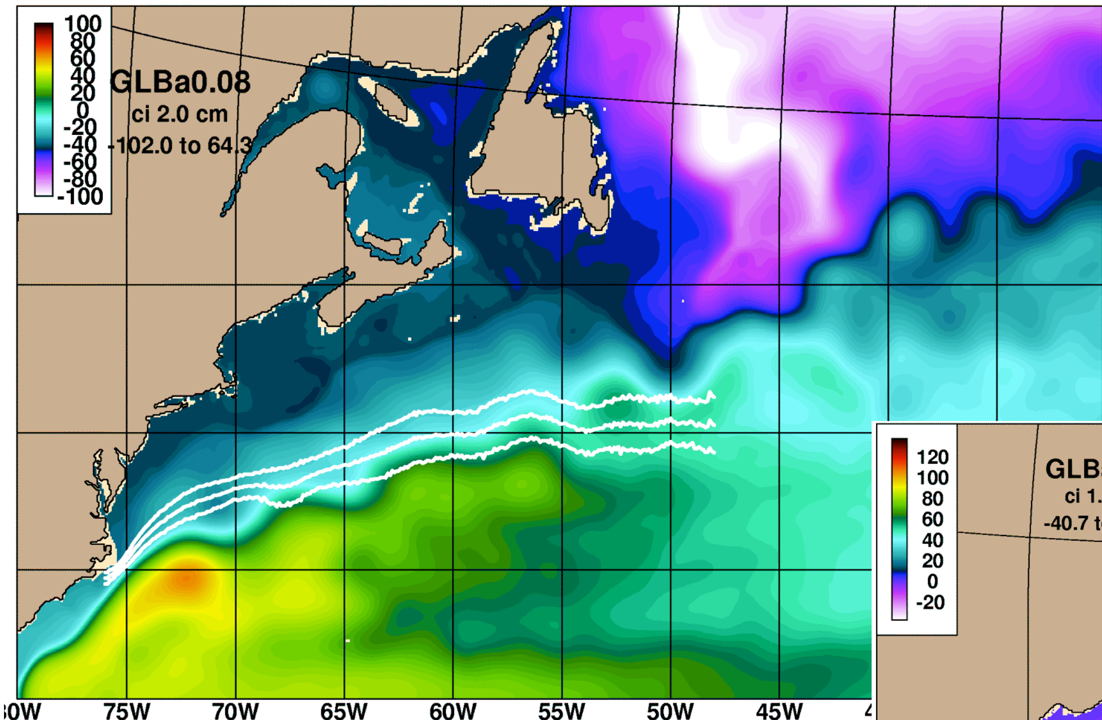
5 year model mean using climatological ECMWF wind and thermal forcing
HYCOM mean shifted by 10 cm

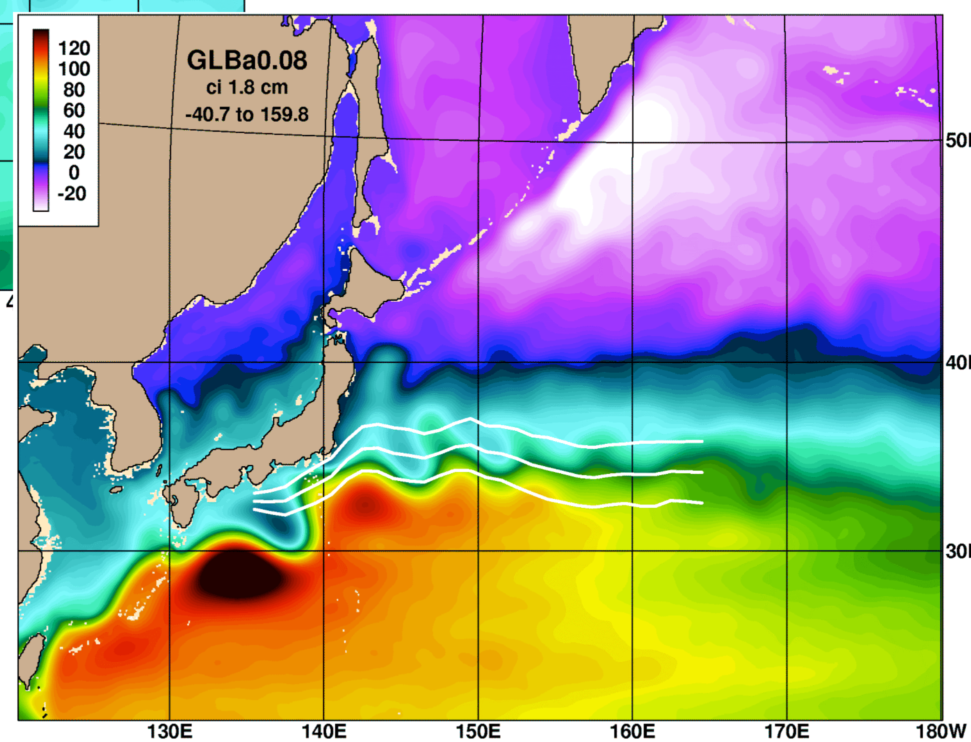
Metzger, 2005

1/12° Global HYCOM

Mean Gulf Stream and Kuroshio pathways

Metzger, 2005

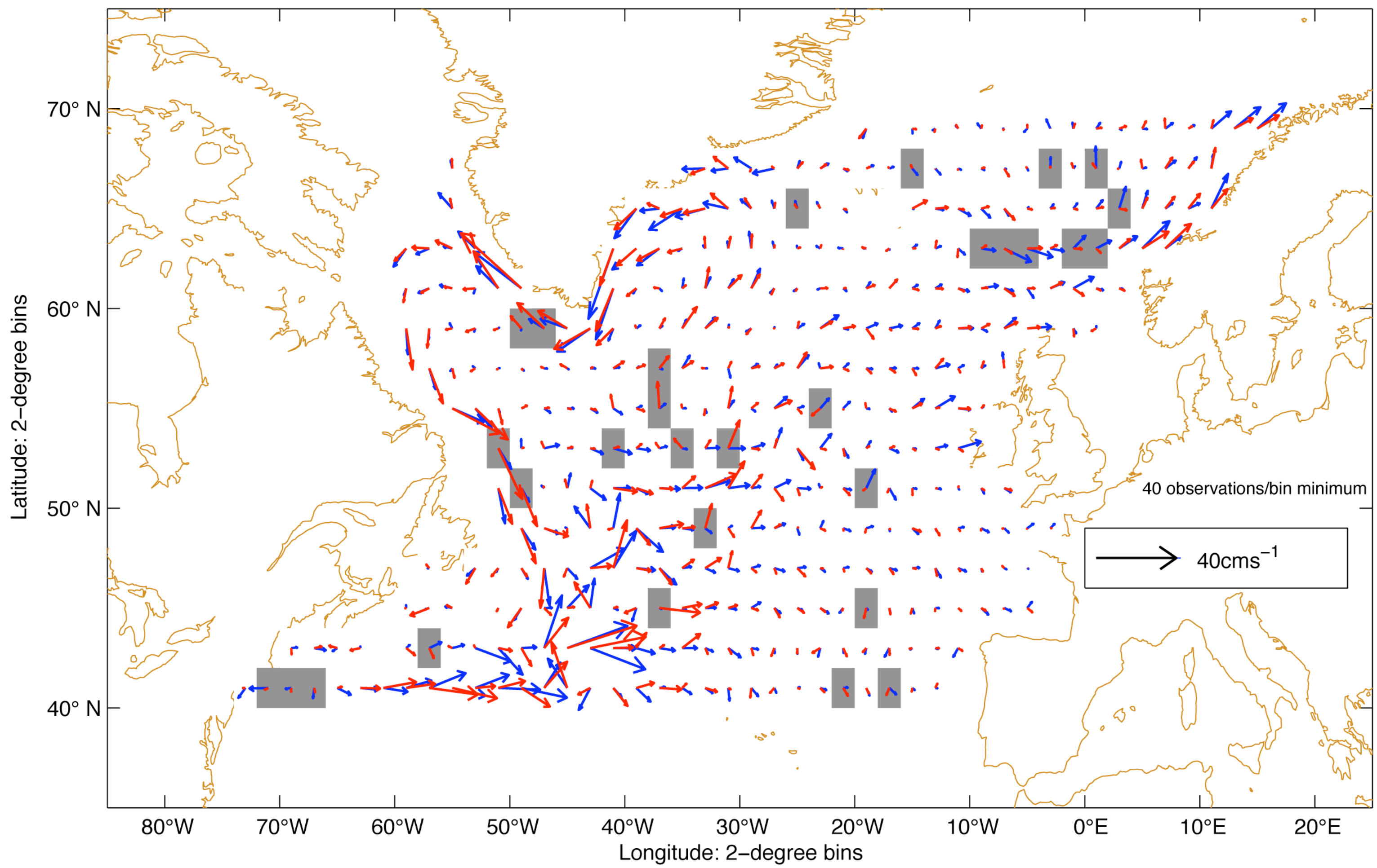




Mean over five model years

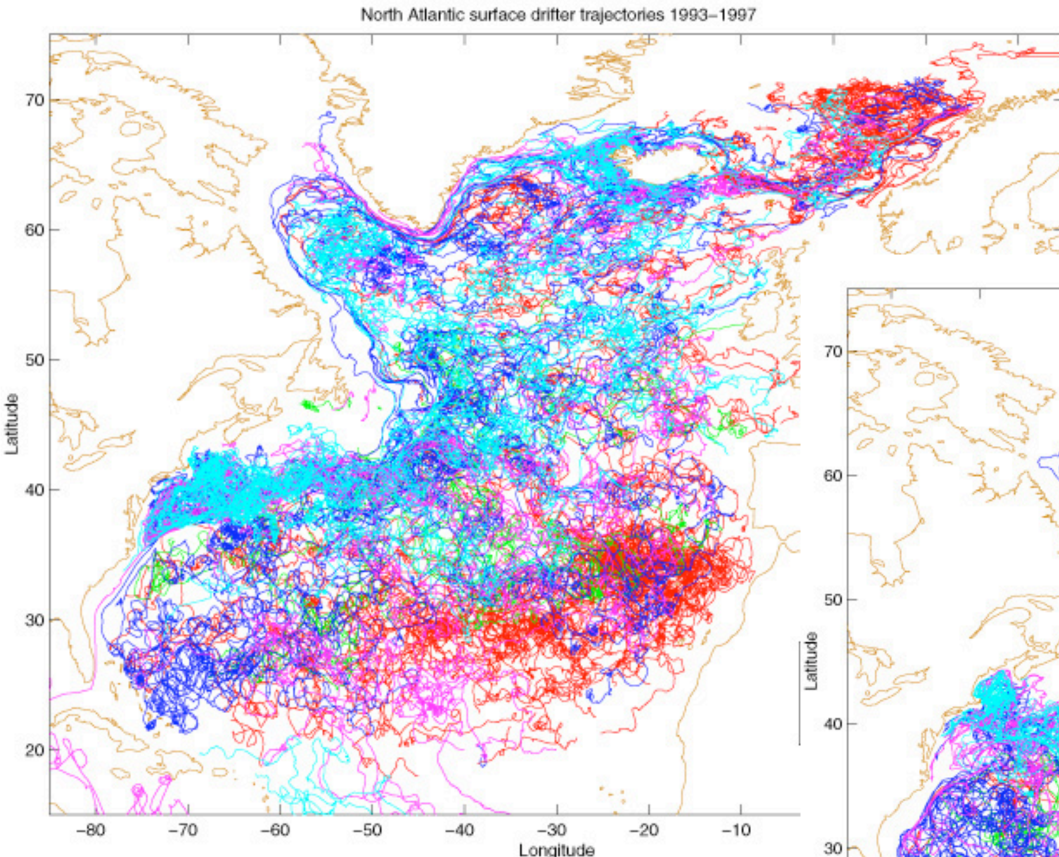
ERA15 climatological wind & thermal forcing

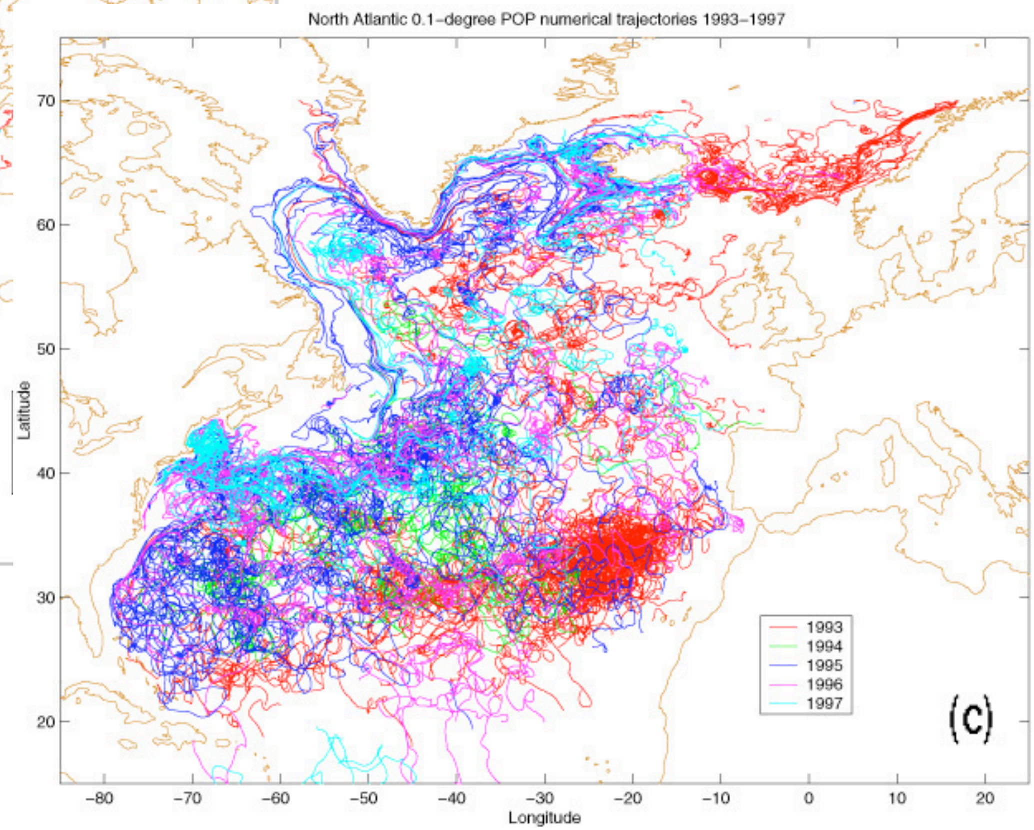
29 June 2006

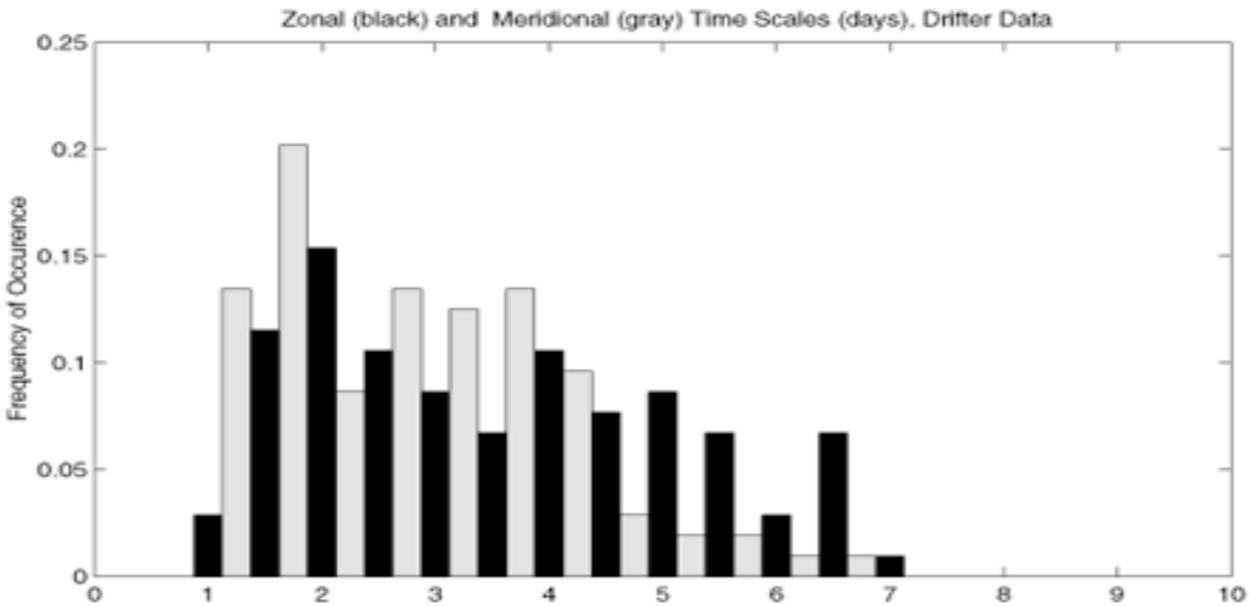


James Test: (0.95% confidence level) using 2° x 2° binned mean drifter (blue) velocity vectors (cms^{-1}) and masked 0.1° POP (red) velocities (cms^{-1}). Gray shaded bins are those where the null hypothesis of equal means is rejected with a possibility of being wrong 5% of the time. Bins are not included which contain less than 40 observations (McClean et al. 2006)

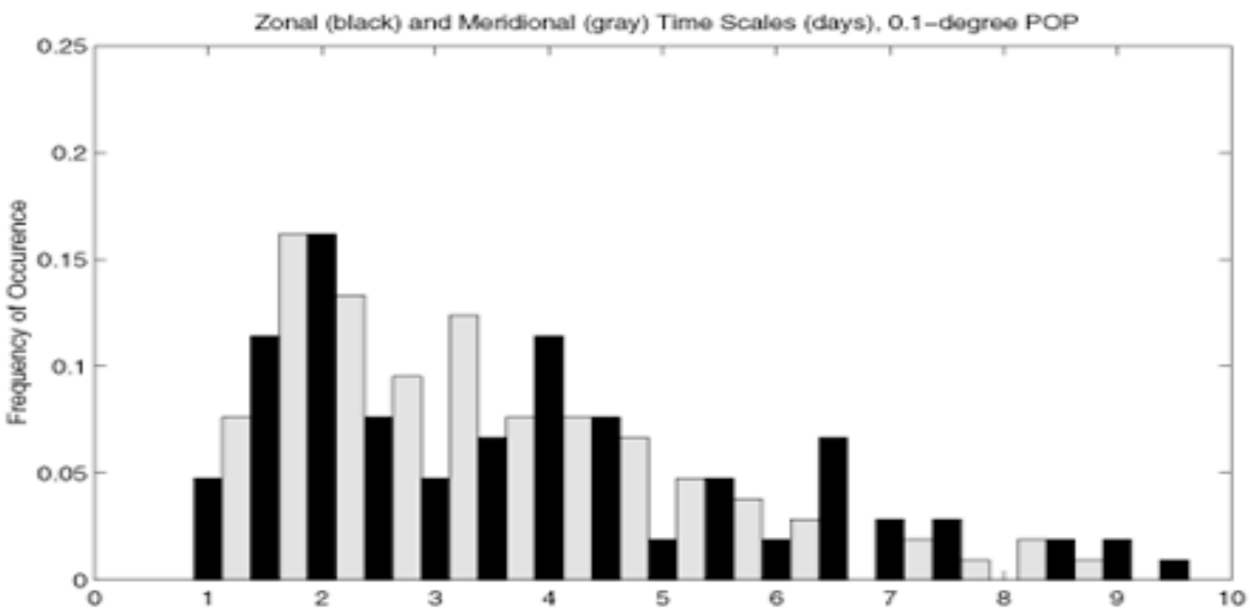
Surface drifter tracks (left) and North Atlantic 0.1°, 40-level POP numerical trajectories for 1993-1997 (McClean, Poulain, Pelton, & Maltrud, JPO, 2002)







Lagrangian Time scales (days)

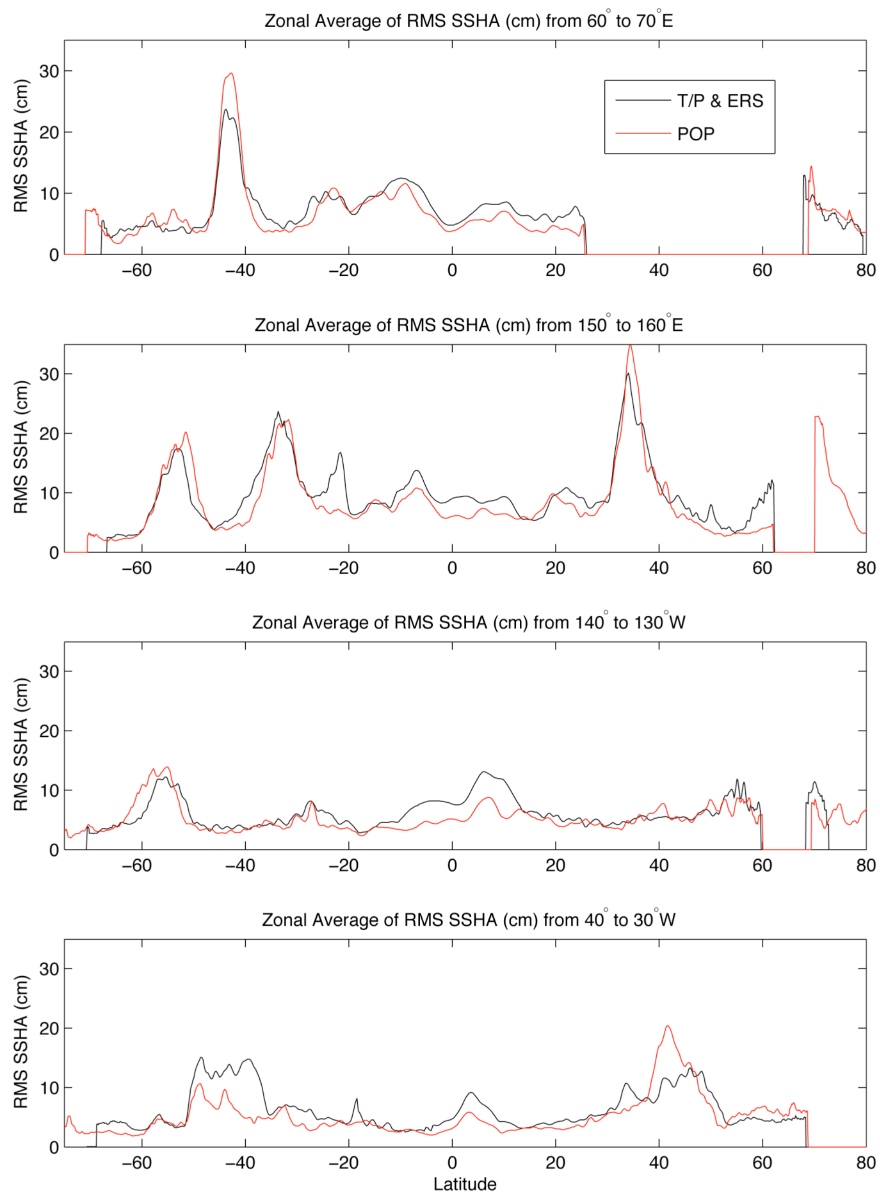


McClean,Poulain, Pelton, & Maltrud, JPO 2002

1998-2000 Zonal Averages of RMS SSHA (cm)

T/P and
ERS 1&2

POP



Indian 60°-70°E

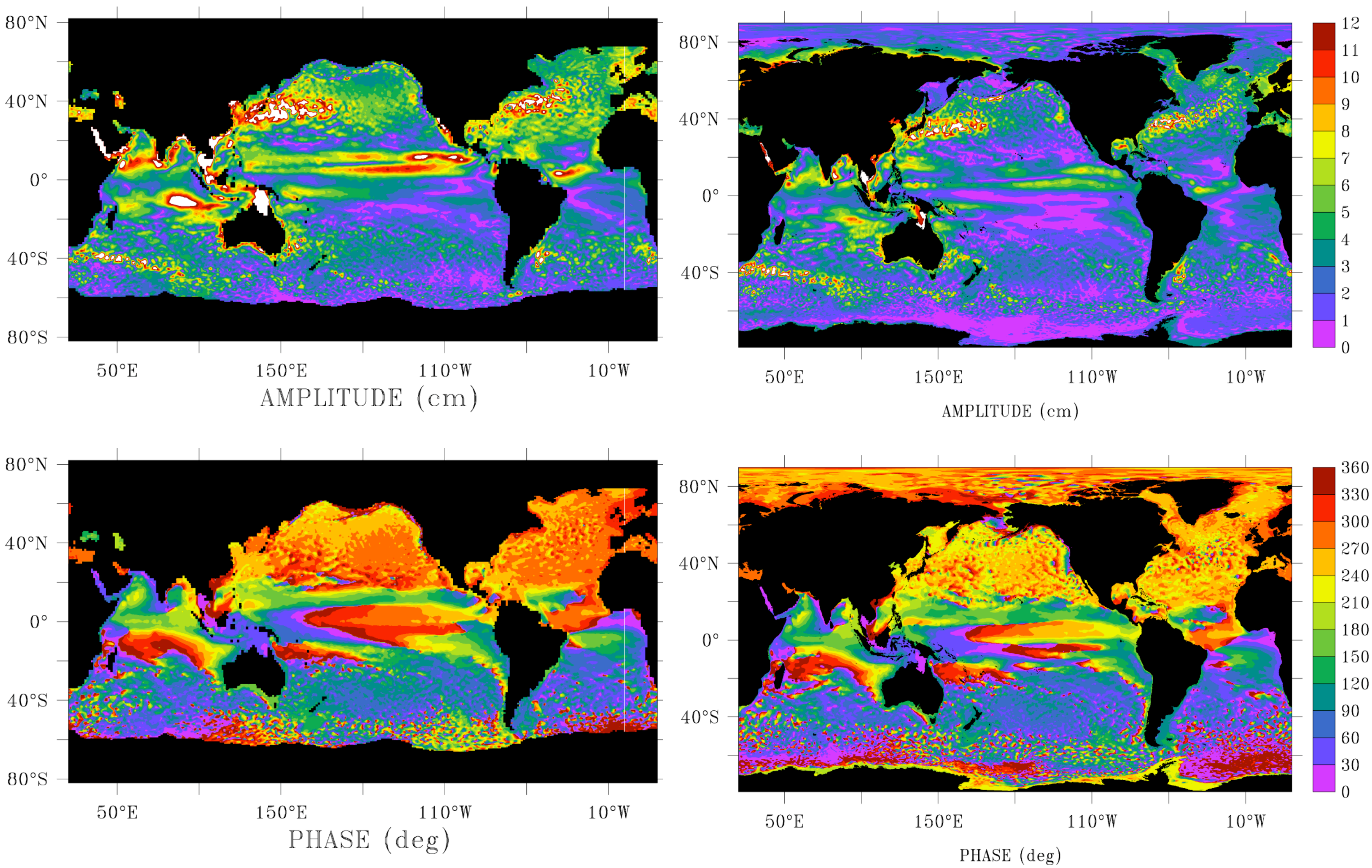
Western Pacific 150°-160°E

Eastern Pacific 140°-130°W

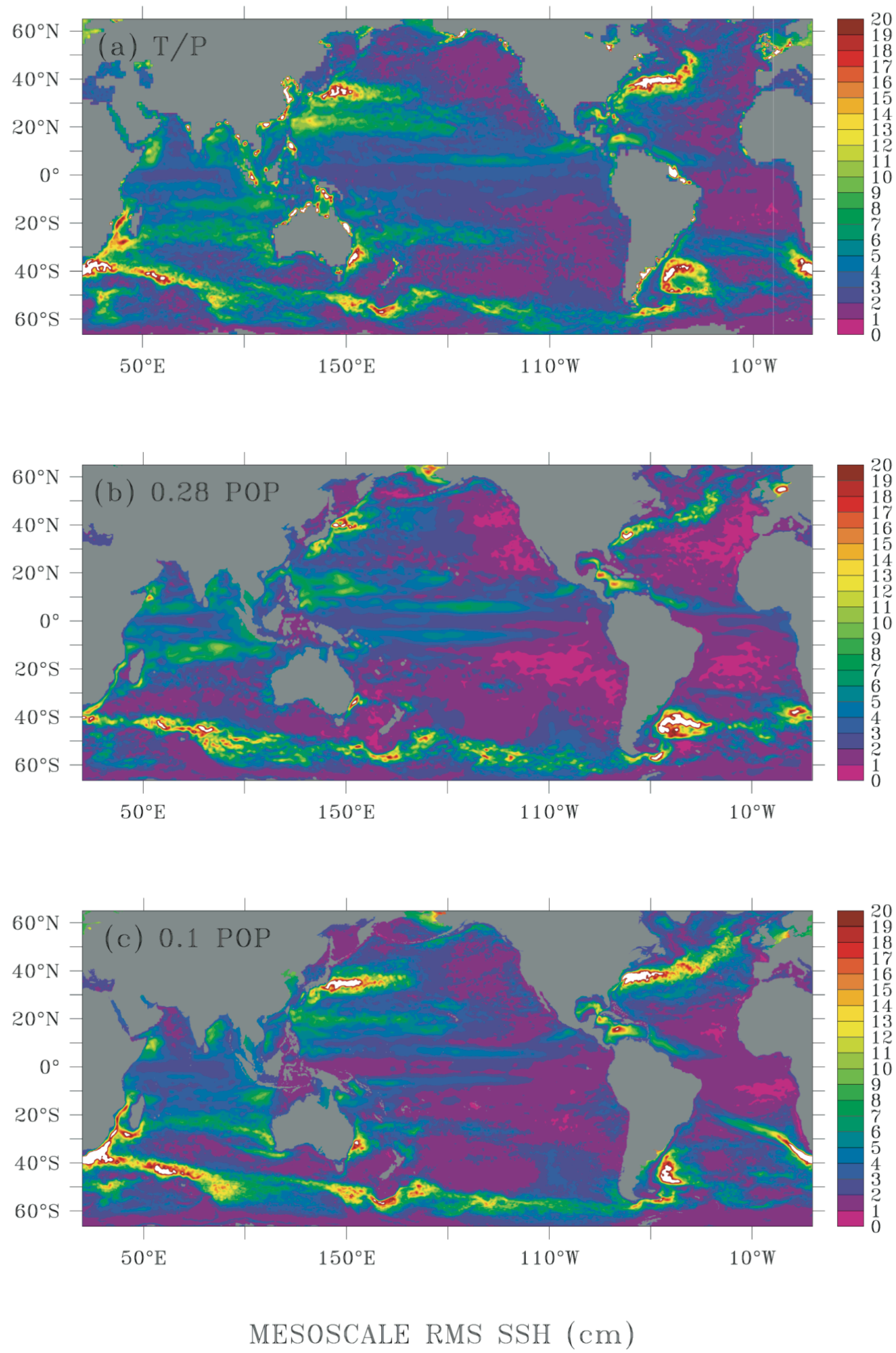
Western Atlantic 40°-30°W

McClean, Maltrud, and Bryan 2006

SSHA Annual Cycle: Amplitude &phase T/P &ERS (LHS) and POP 0.1° (RHS)



Mesoscale (20-150d) RMS SSHA (cm)

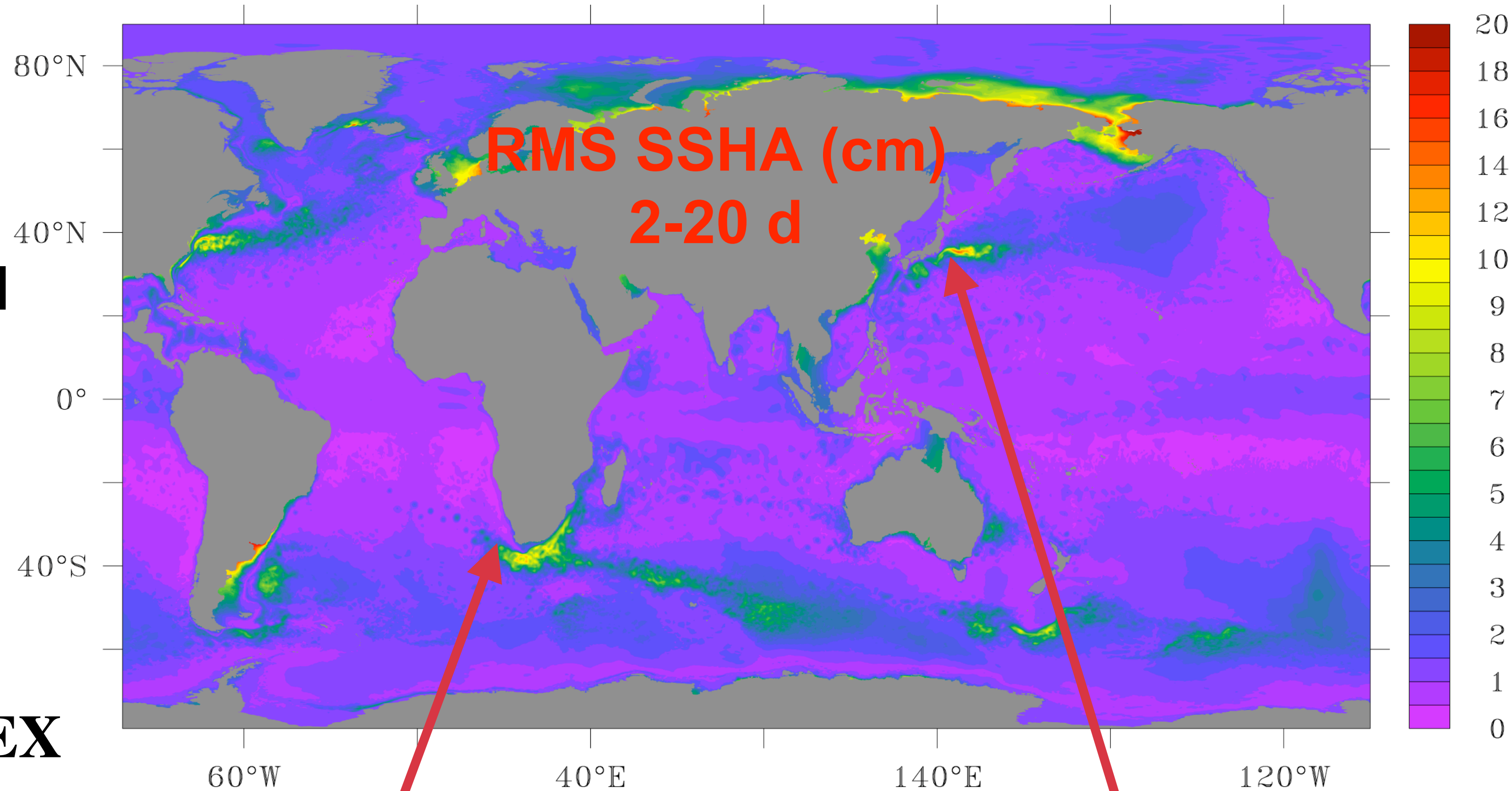


T/P and ERS 1&2

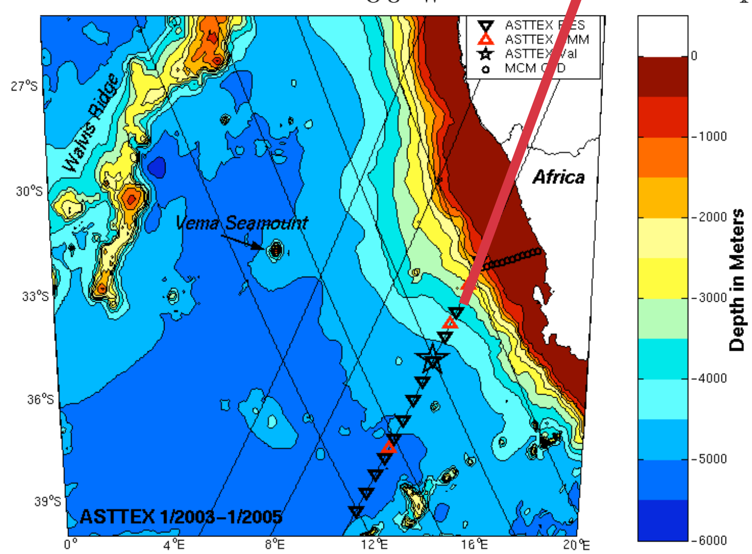
0.28° POP
McClean et al. 1997

0.1° POP

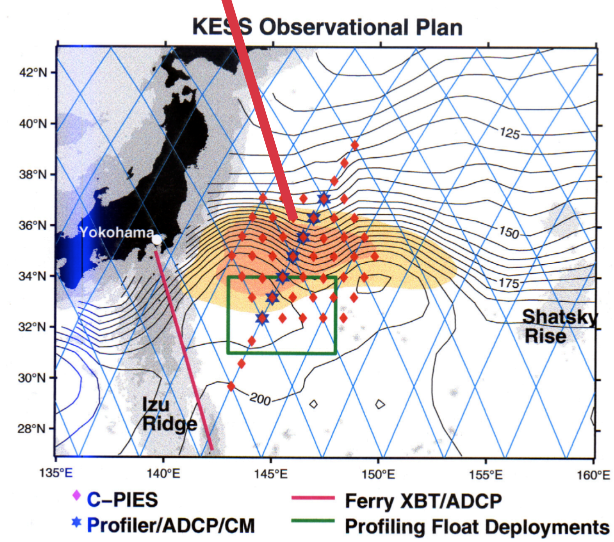
0.1° Global POP



ASTTEX



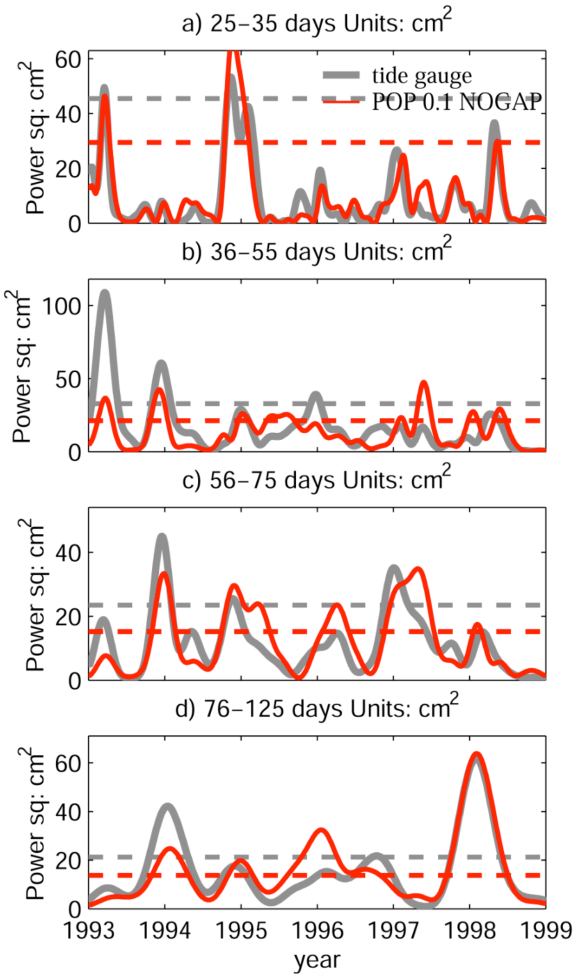
KESS

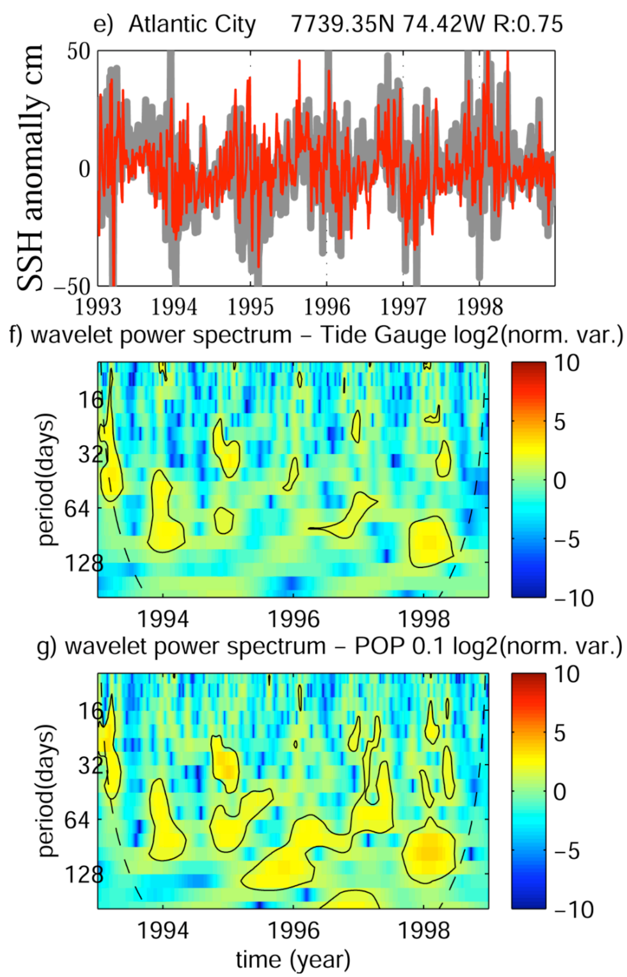


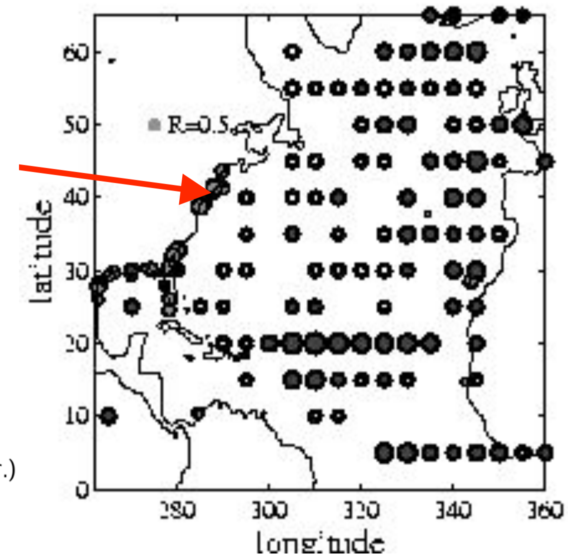
How Realistic is the High Frequency Signal of a 0.1° Resolution Ocean Model?

Tokmakian & McClean, JGR (2003)

Wavelet decomposition of SSH anomaly signal near Atlantic City







Correlations (above):
model/tide gauge - gray
model/Topex - black,open
open 0.4-0.5, black >=0.5

e) Time series, at 3 days for the model (black line) and the tide gauge measurements (gray line) - units of cm.

f) wavelet power spectrum for tide gauge data in log2 of normalized variance units

g) same as f, except for the model.

a-d) averaged power squared for temporal bands 30days, 45.5 days, 65.5 days, and 100.5days. Dashed lines 95% signif. Level model gray line, tide gauge black

Contoured lines show significant signal at the given periods for a white noise spectra and the dashed lines shows the confidence interval for the time series.

Length Scales (km)

1994-2001

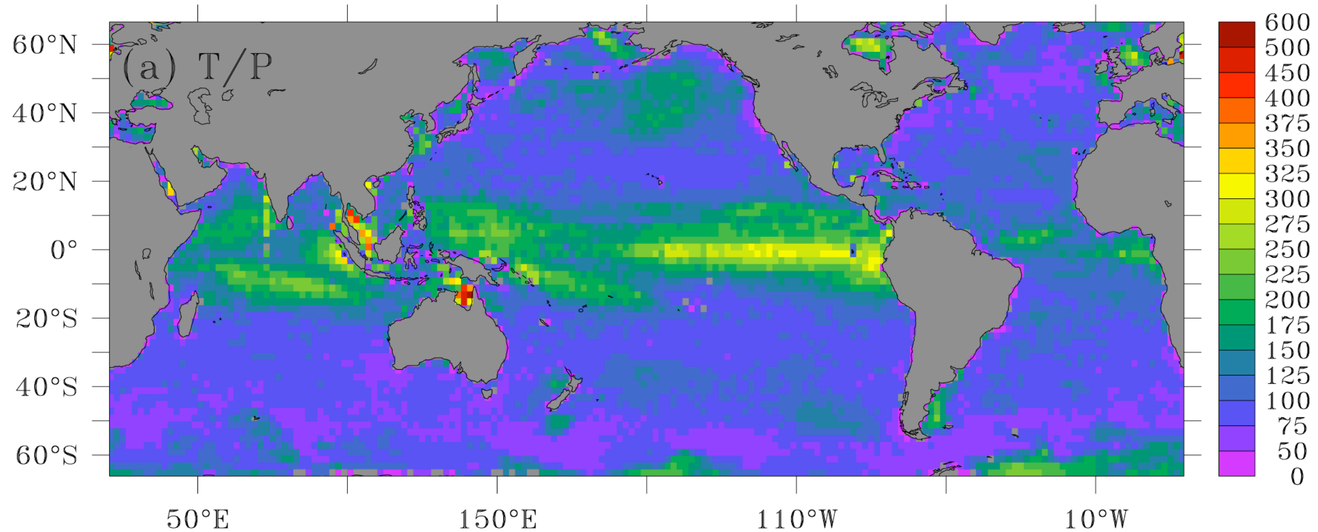
$$L^2 = \frac{\langle \hat{h}\hat{h} \rangle}{\langle \hat{h}'\hat{h}' \rangle}$$

$\hat{h}$: SSH residuals

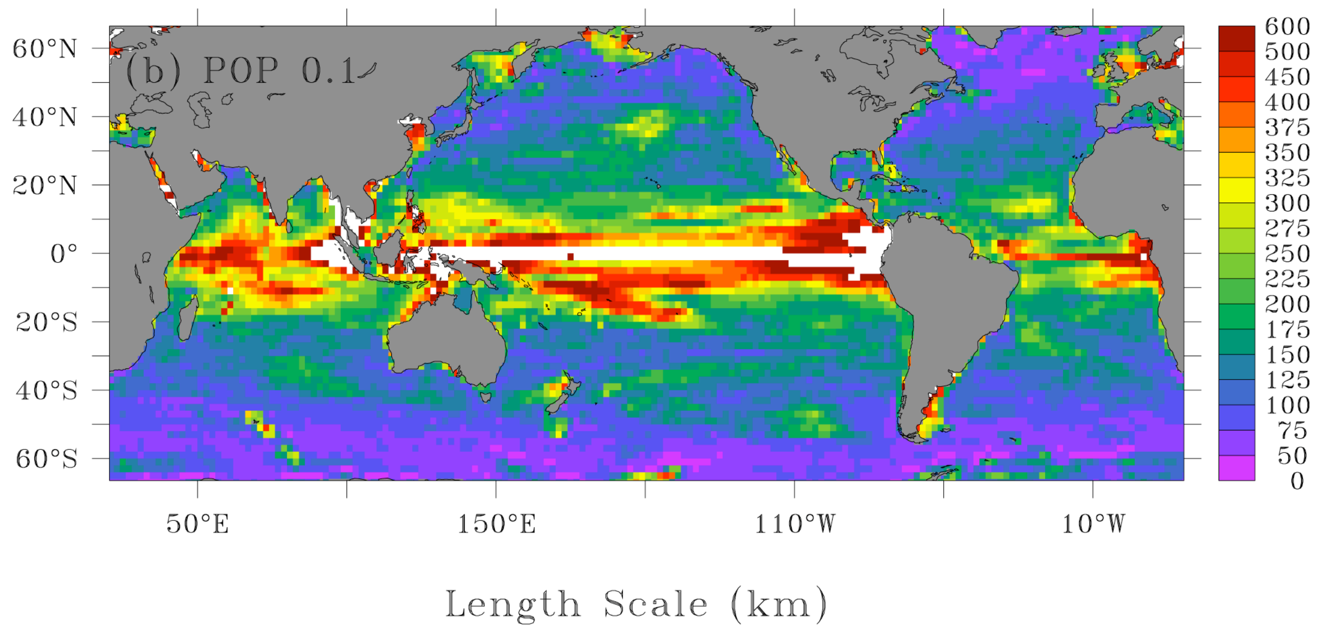
$\hat{h}'$: their slopes in a given direction

Tennekes and Lumley, 1972

T/P



0.1° POP

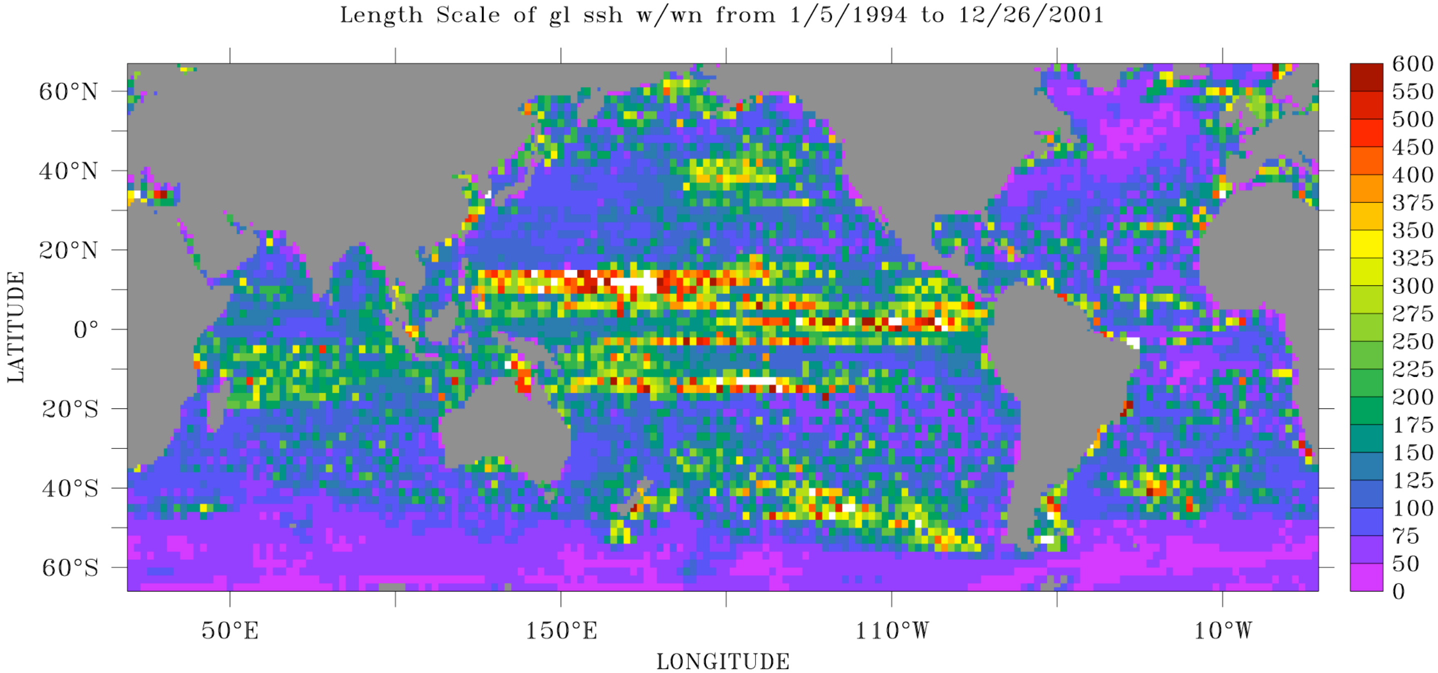


The altimeter-derived SSH residual contains noise, so:

$$L^2 = \frac{<\hat{h}\hat{h}>}{<\hat{h}'\hat{h}'>} = \frac{<hh> + <\varepsilon\varepsilon>}{<h'h'> + <\varepsilon'\varepsilon'>}$$

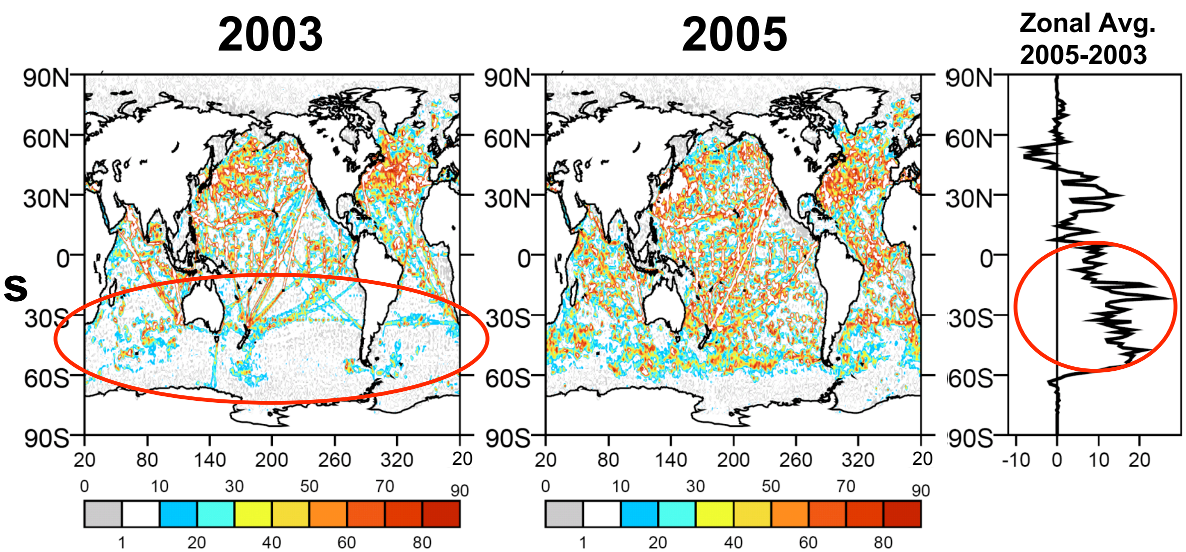
Where $<\varepsilon\varepsilon>$ is the noise in SSH and $<\varepsilon'\varepsilon'>$ is the noise in the slopes.

We added scaled white noise to the model SSH and recalculated the length scales. Altimeter error is 2-4 cm. Note reduction of equatorial scales



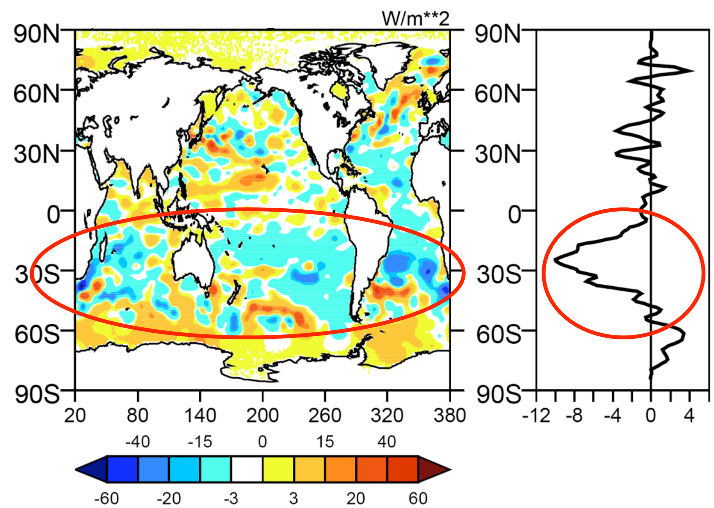
Coverage changes 2003-2005

Number of Observations in Ishii 6.2 (Top 700m)



OHC Change 2005-2003 (W/m²)

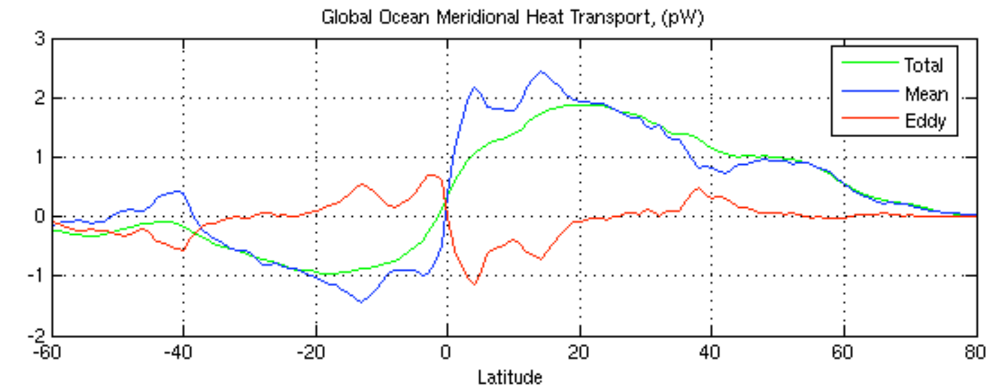
With ARGO – No ARGO



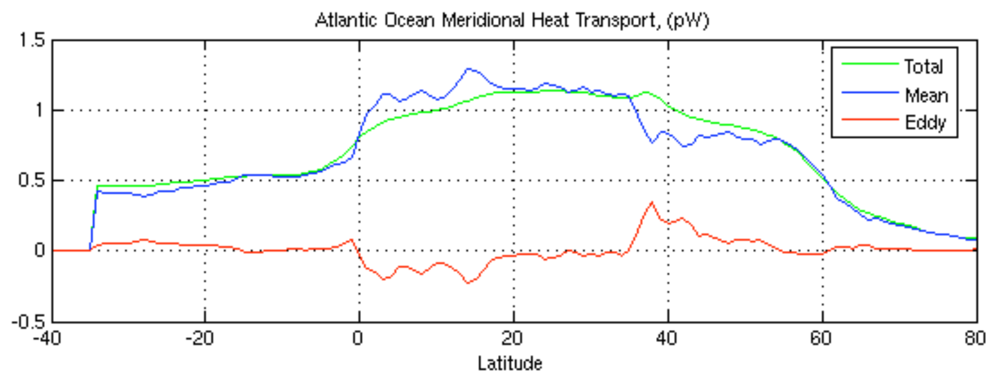
See Achutarao poster

Meridional heat transport (PW) for 1997-1999

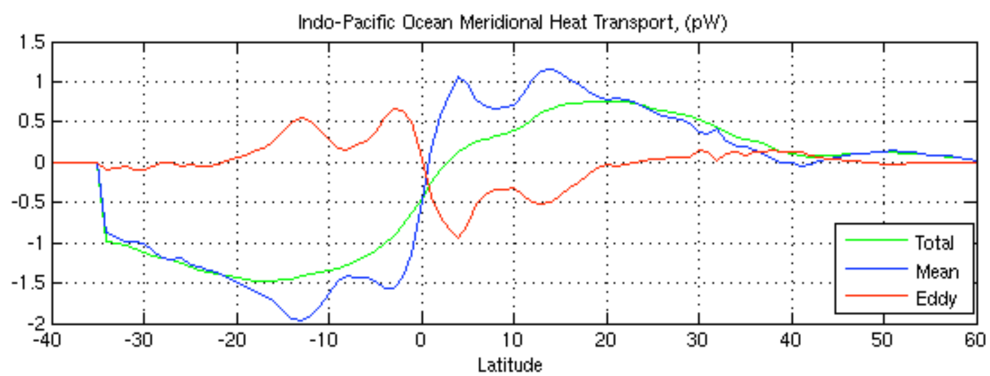
Global



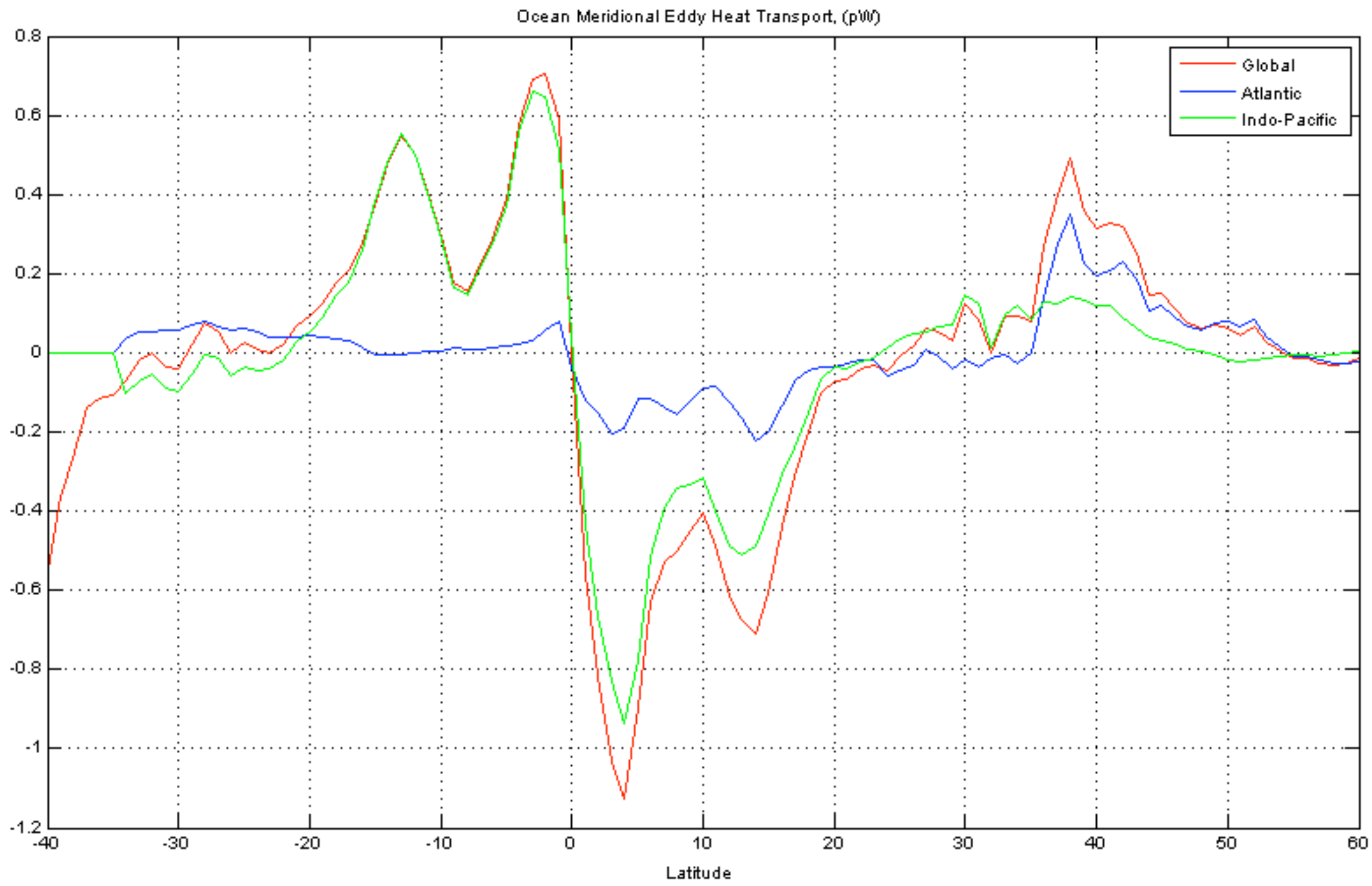
Atlantic



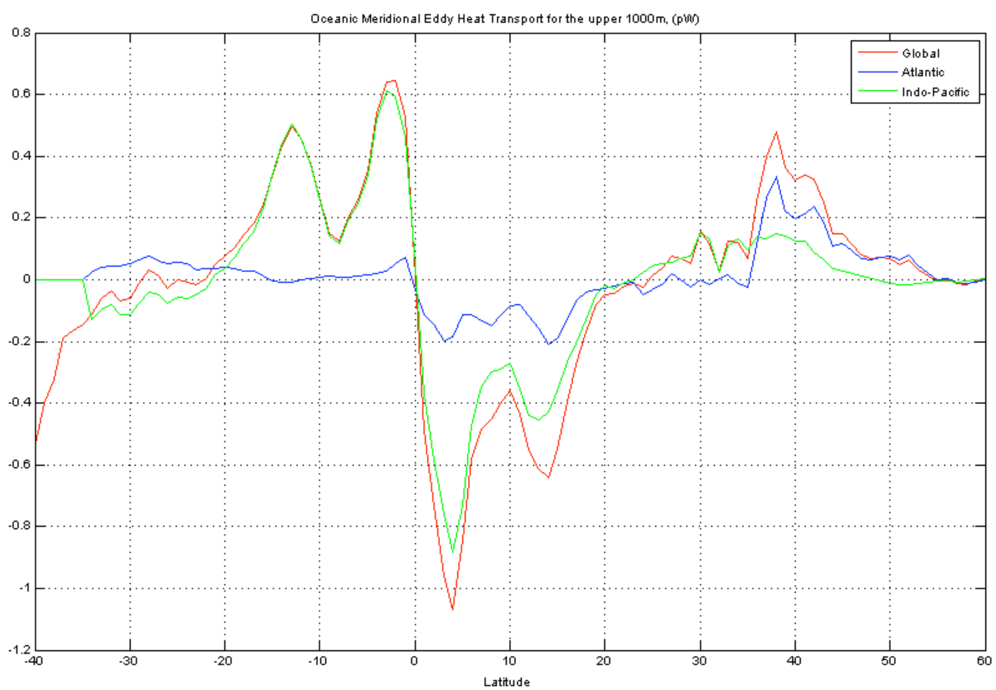
Indo-
Pacific

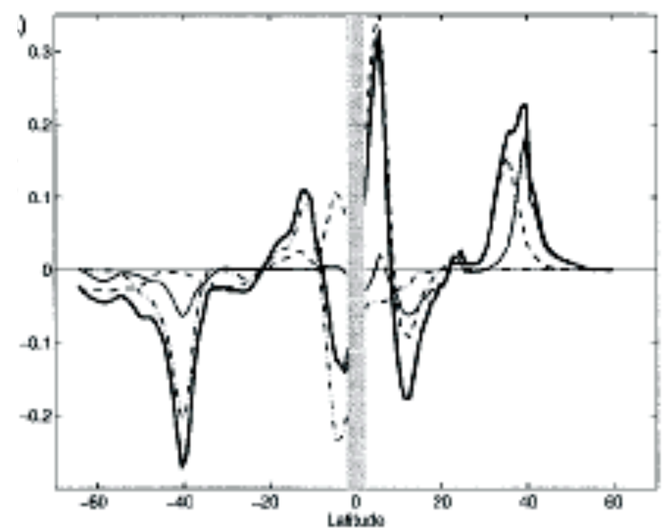


Zonally-Integrated Meridional Eddy Heat Flux (PW): Global (red), Atlantic (blue) Indo-Pacific (green) from 0.1° POP: 1997-1999



Zonally-integrated eddy heat transports from the top 1000m of the water column from POP (left) and Stammer (1998, JPO) (right). The latter estimates were calculated from $v'T'=\rho C_P \kappa\, \partial T/\partial y$, where $\kappa=2\alpha K_E T_{alt}$, $\alpha=0.05$, K_E is an estimate of near-surface eddy energy from altimetry, and T_{alt} are time scales from altimetry

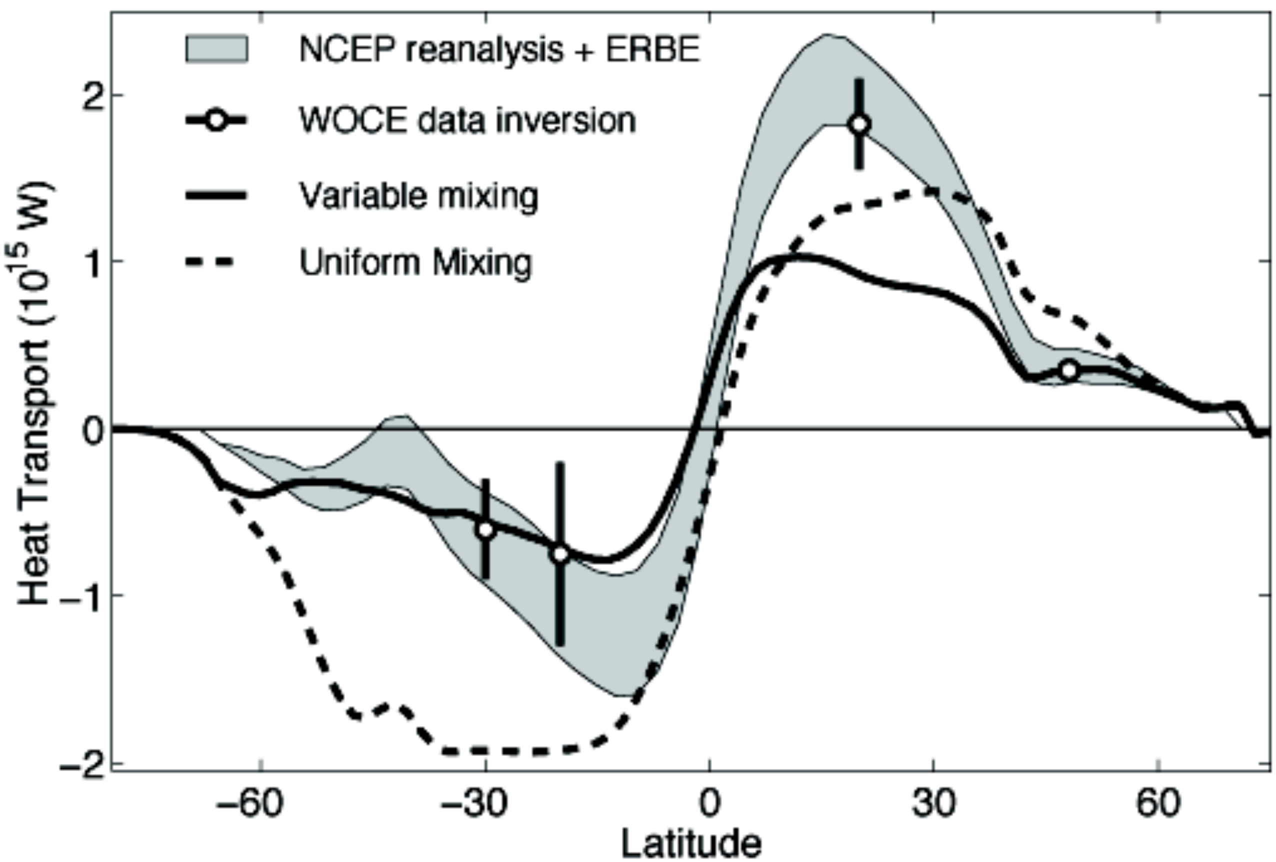




Tidally-Driven Circulation in a Global OGCM
Simmons, Jayne, Laurent, & Weaver

- Parameterization incorporated into a coarse resolution global OGCM that explicitly accounts for tidal energy source for mixing. Mixing evolves both spatially & temporally with the model state
- 3 cases:
  - Tidal mixing parameterization: variable mixing
  - Uniform mixing 0.9 $cm^2 s^{-1}$
  - Arctangent mixing profile: 0.3 $cm^2 s^{-1}$ in upper ocean, 1.3 $cm^2 s^{-1}$ below 2500 (Bryan and Lewis, 1979)

Global Meridional heat transport from the OGCM with the tidally-driven mixing parameterization, from a WOCE inversion (Ganachaud and Wunsch 2000, Nature), and from weather prediction model reanalysis and satellite data (Trenberth and Caron, 2001)



Conclusions

- Best representation of energy levels, intrinsic scales, etc. as depicted by observations by eddy-resolving simulations with realistic forcing. Data with near-global or basin-scale coverage have provided an excellent means of comparing modeled and observed statistical quantities.

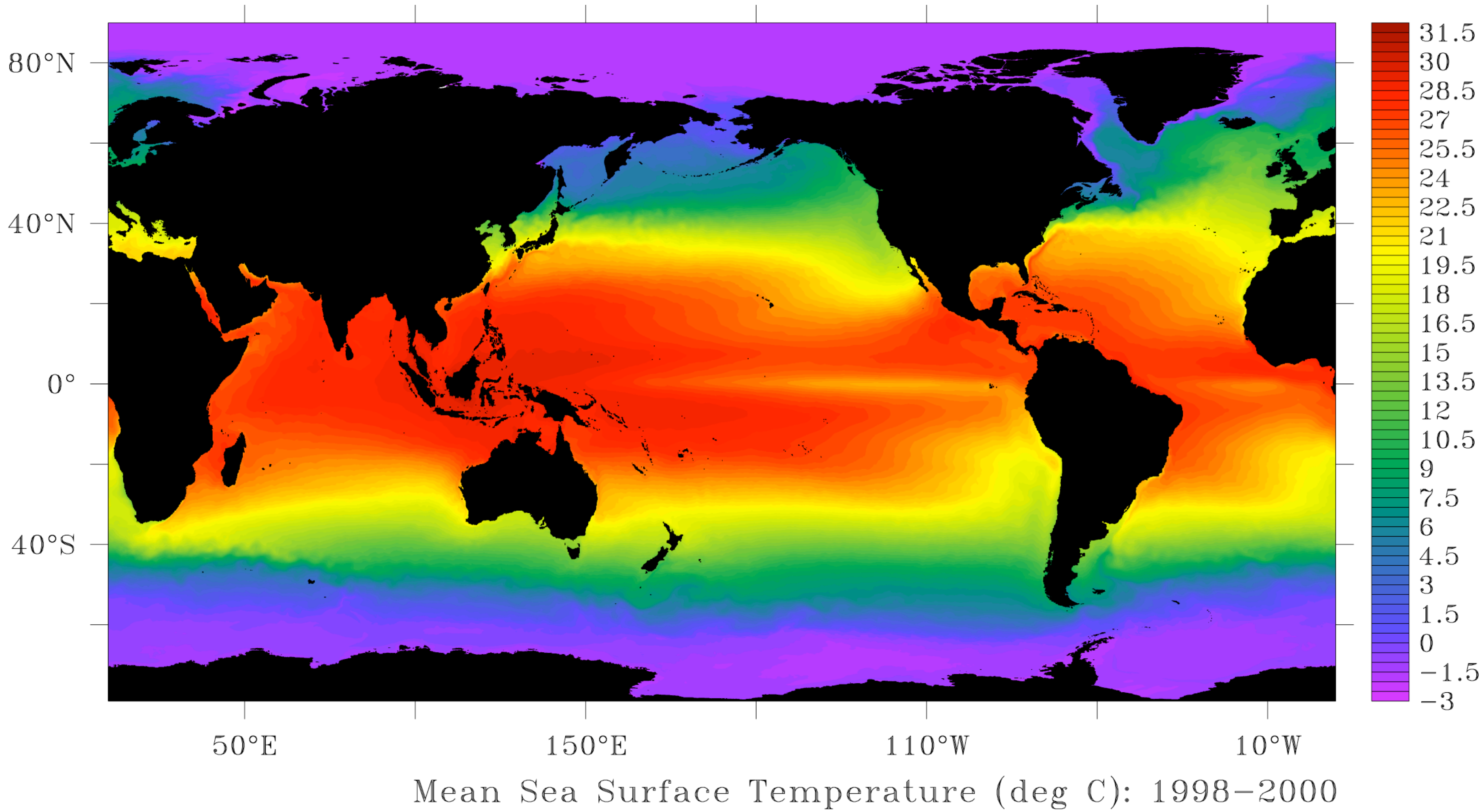
- Continuing improvements of parameterizations *e.g.*bottom and planetary boundary layers,eddy mixing, tidal mixing. Need more observational estimates for parameterizations.

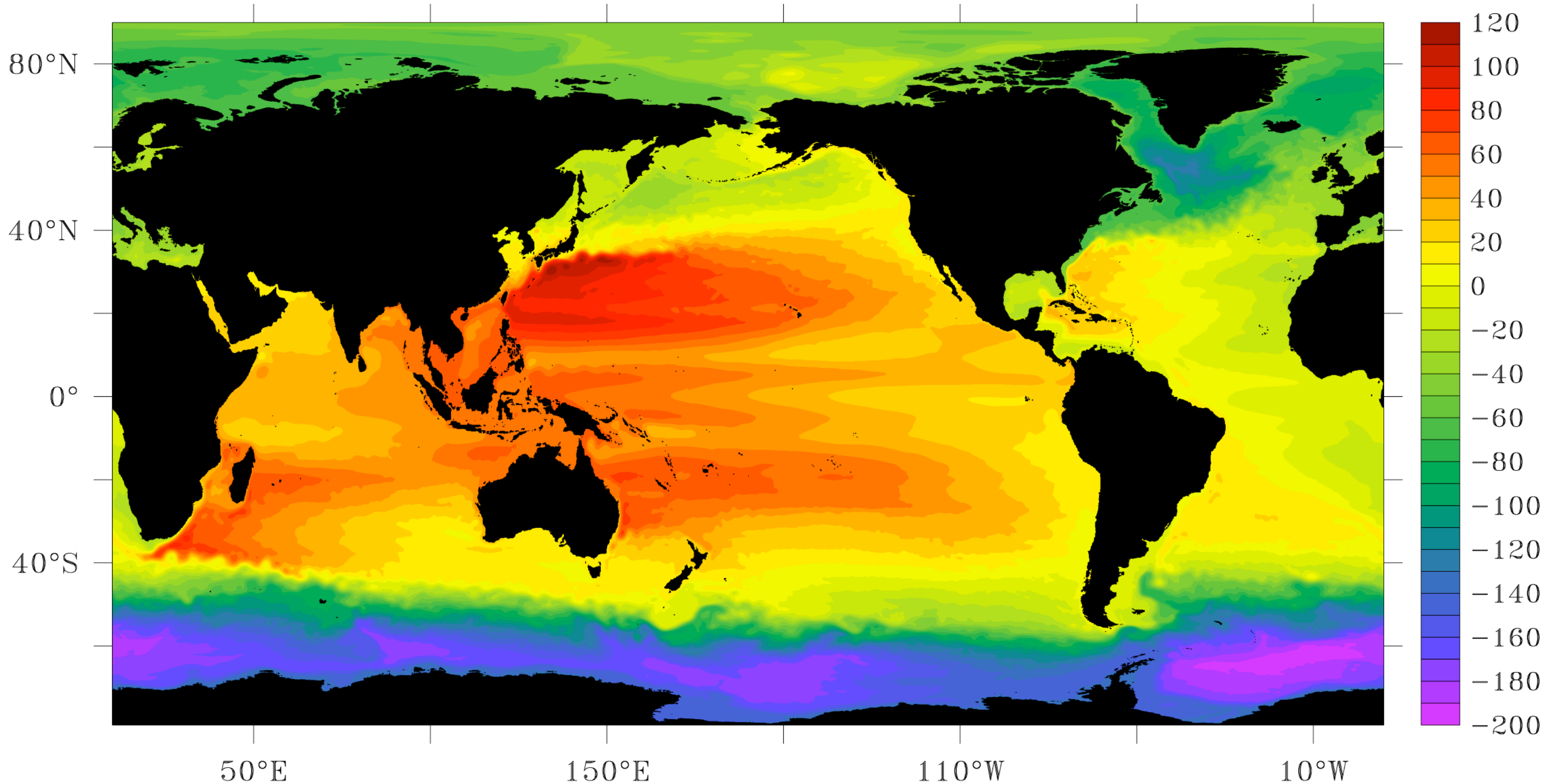
The Way Forward

- A one-day meeting was held at the IPRC at the University of Hawaii in 2006 to discuss ocean model metrics for synoptic forecasting, process studies, and climate applications.

- The workshop report will appear shortly at: http://www.ocean.washington.edu/people/faculty/luanne/metricsworkshop.html

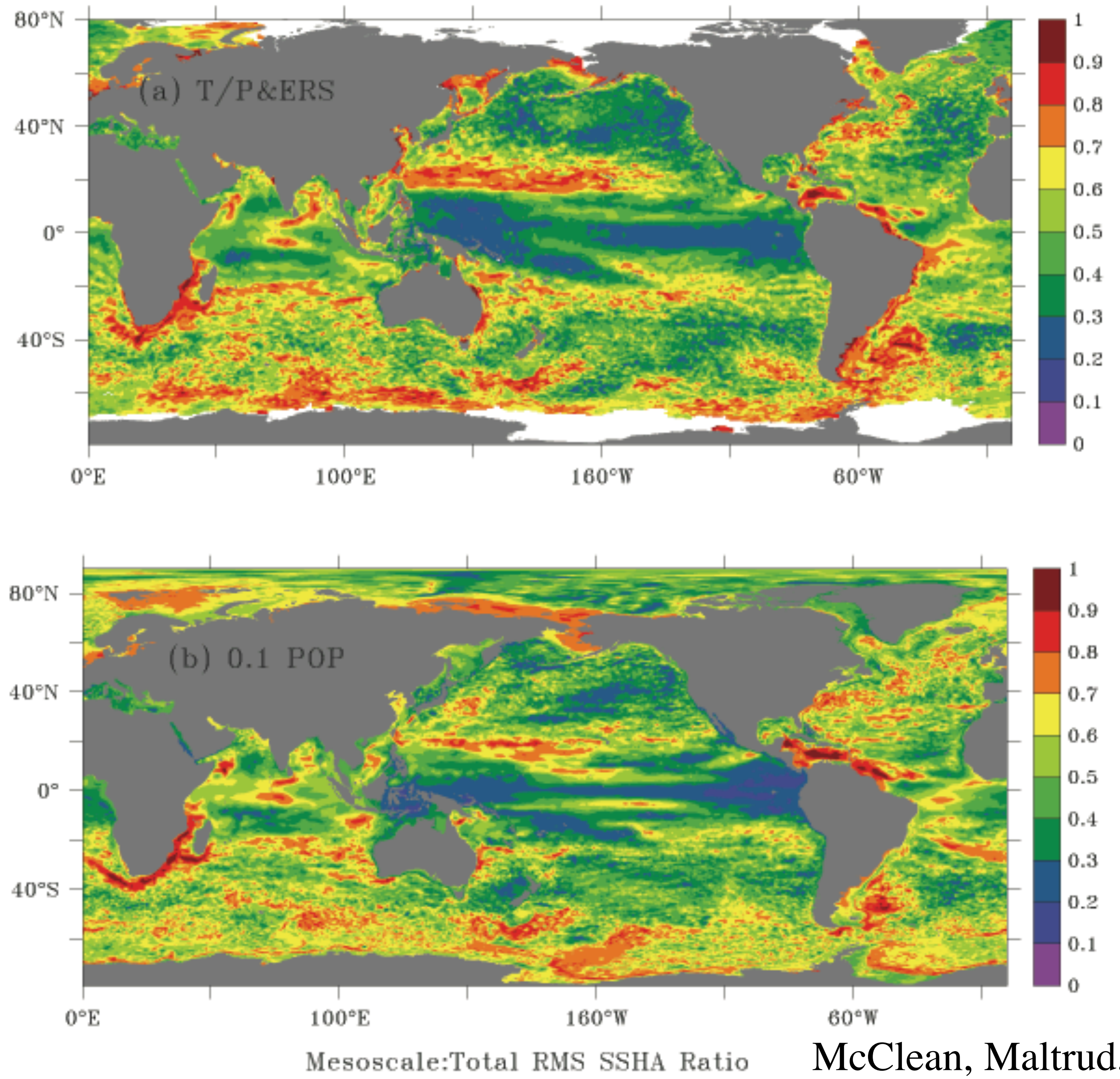
Global 0.1°, 40-level POP





Mean Sea Surface Height (cm): 1998−2000

Ratio Mesoscale : Total RMS SSHA 1997-2001



McClean, Maltrud, and Bryan 2006