The Ocean General Circulation

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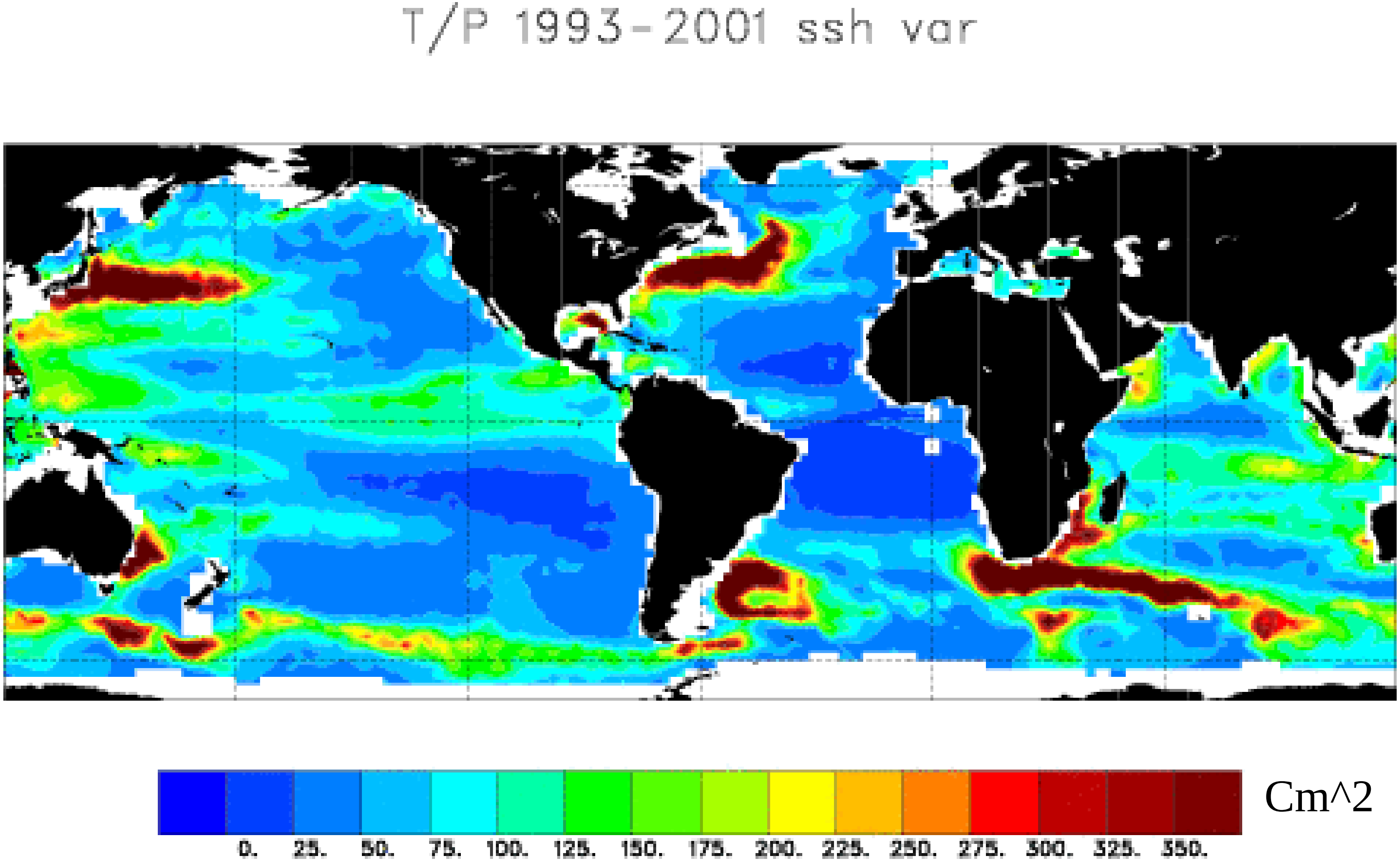
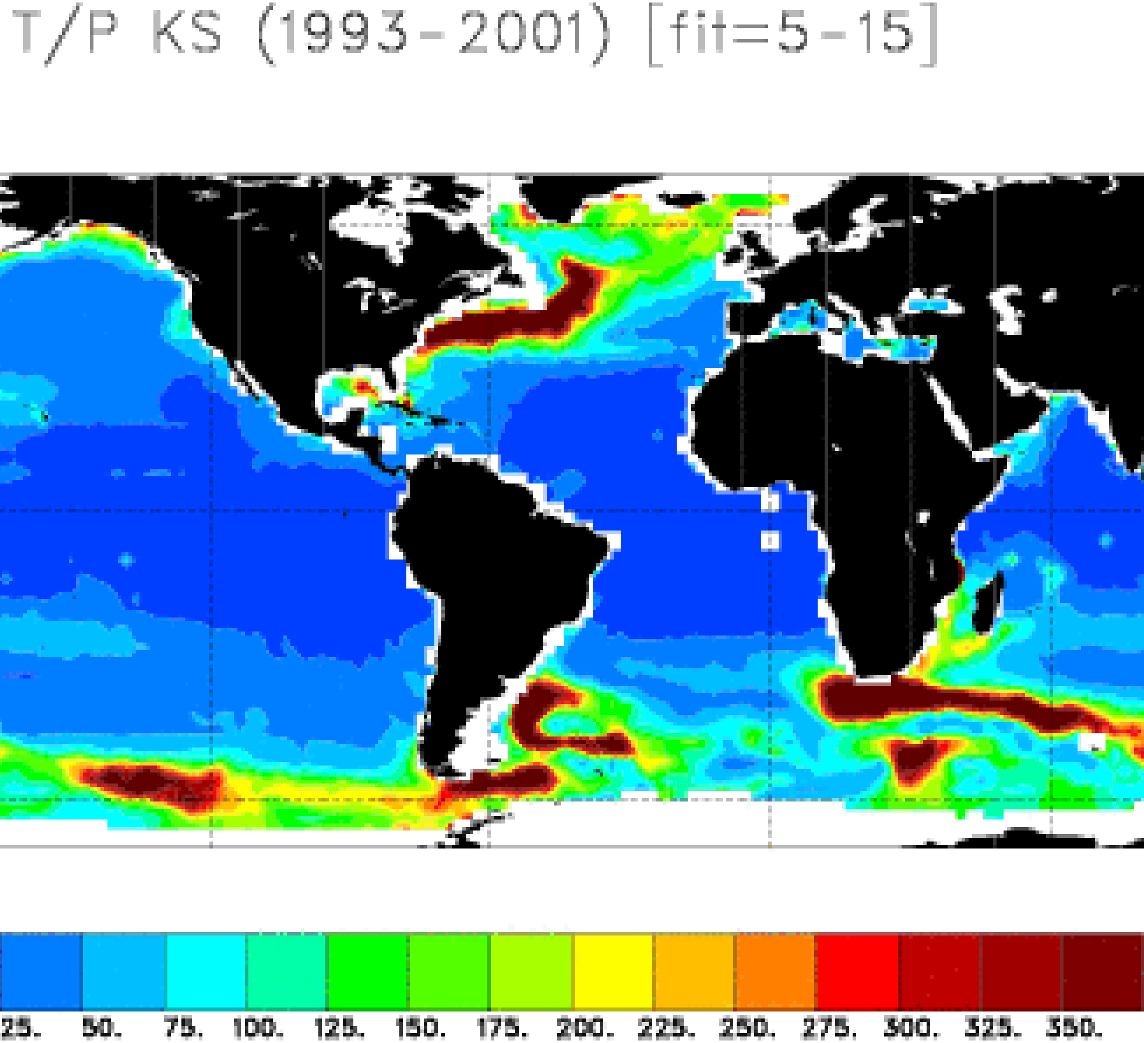
Arles, 20. November, 2003

SSH Variance, 9yrs.



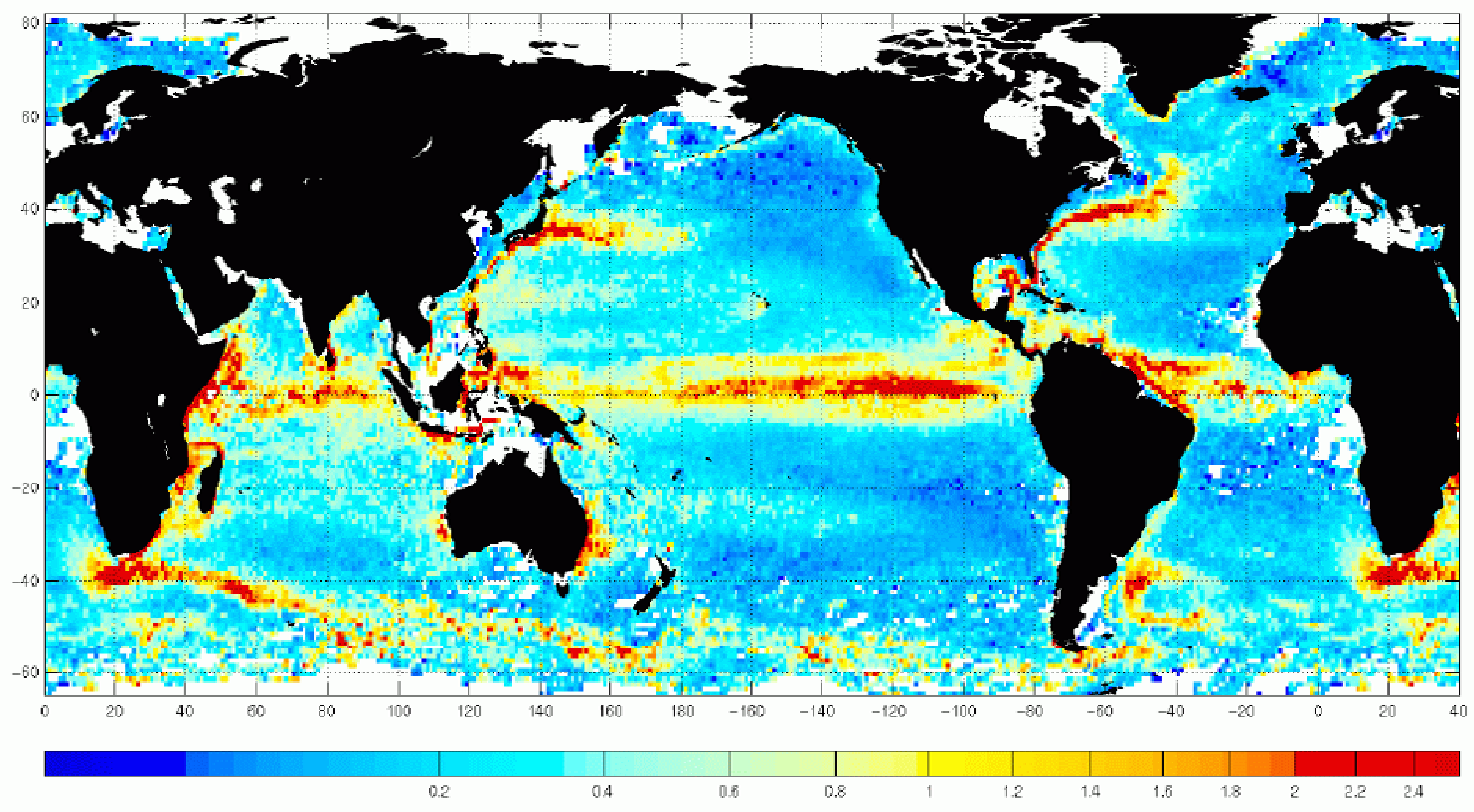
Eddy Velocity Variance (slope)



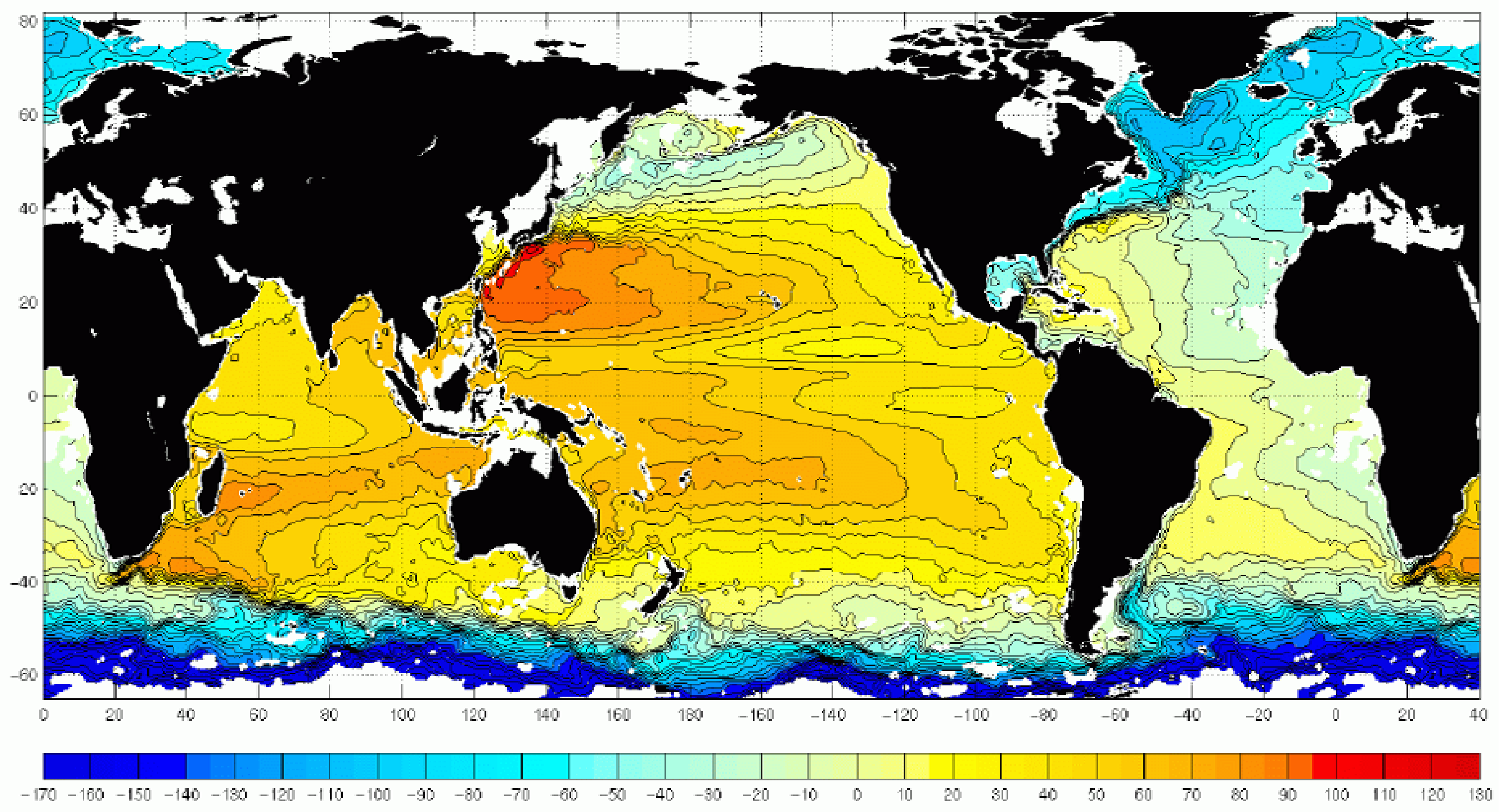
(cm/s)^2

Mean Kinetic Energy observed by Drifters (V*V/2g; cm)

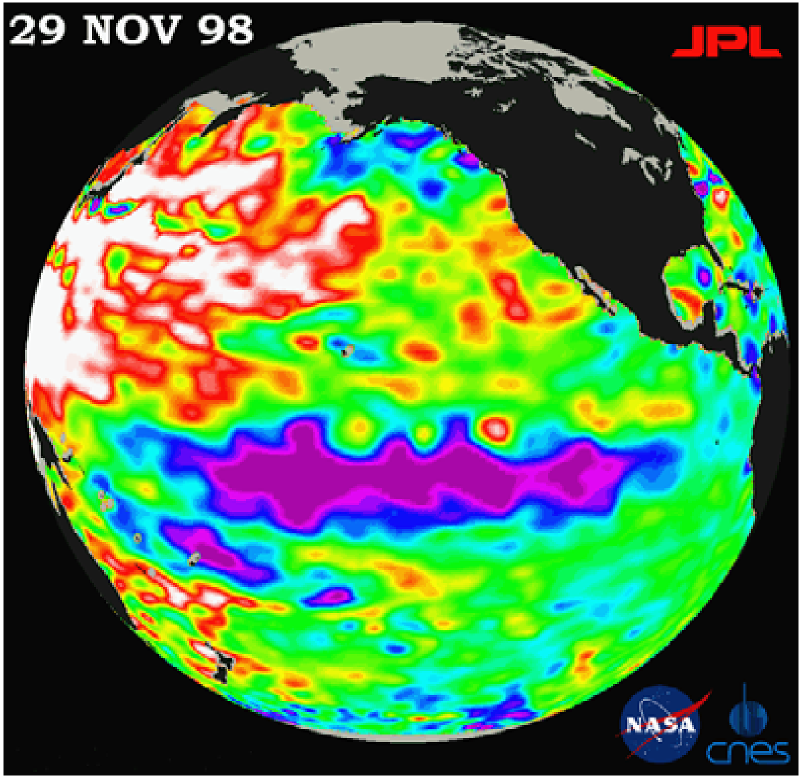
Niiler, Maximenko et al.

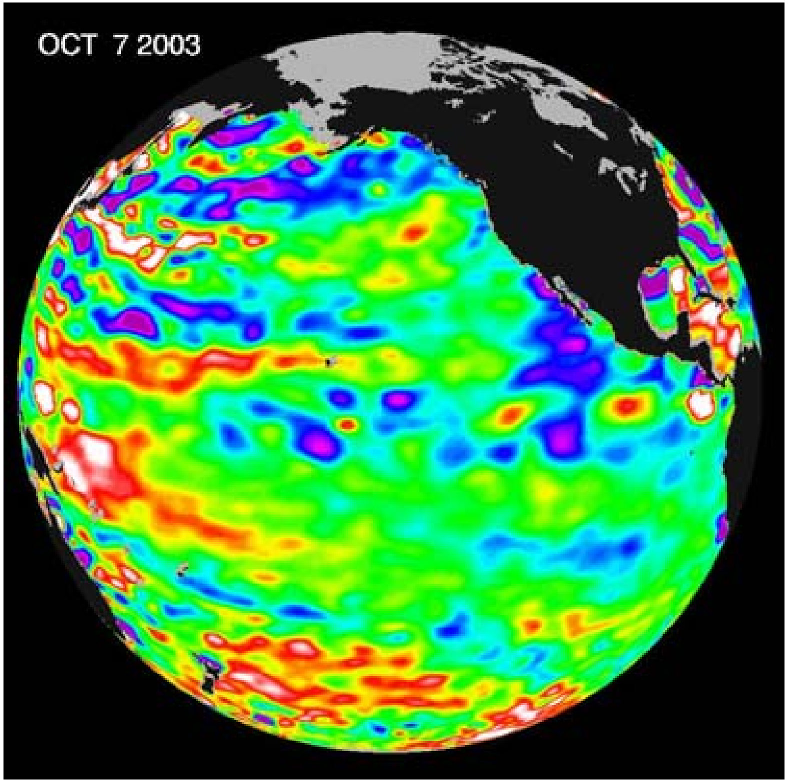


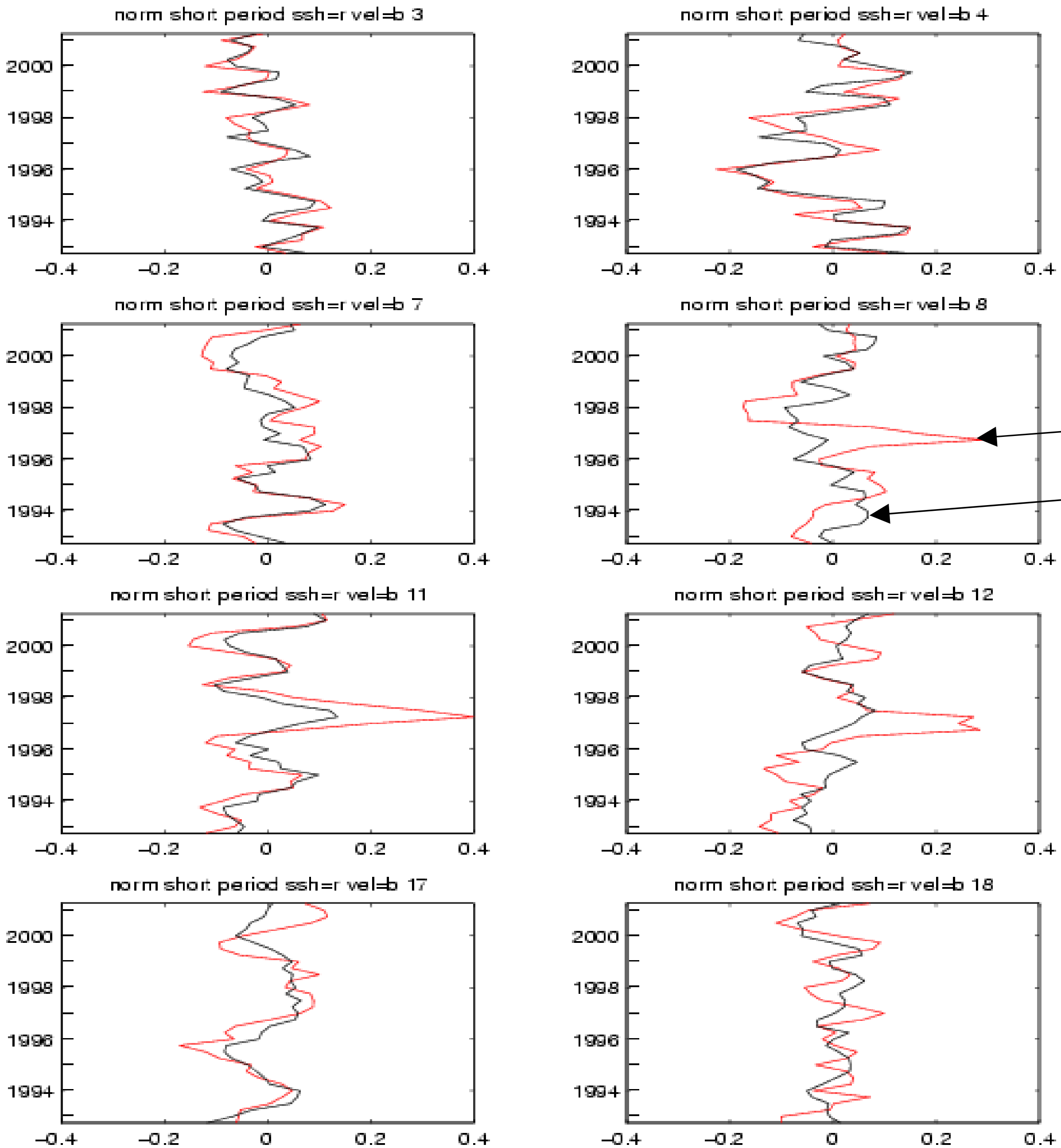
Dynamically Balanced Mean Sea Level Derived from Joint Analysis of Drifter and Altimeter Data (1992 – 2002)



Large-scale Sea Level Changes:



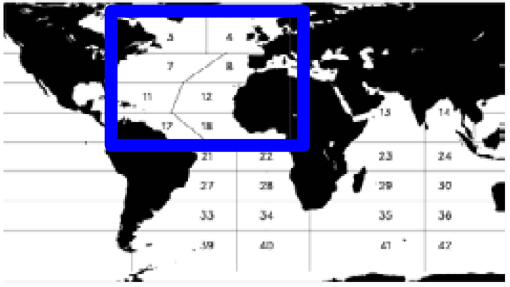




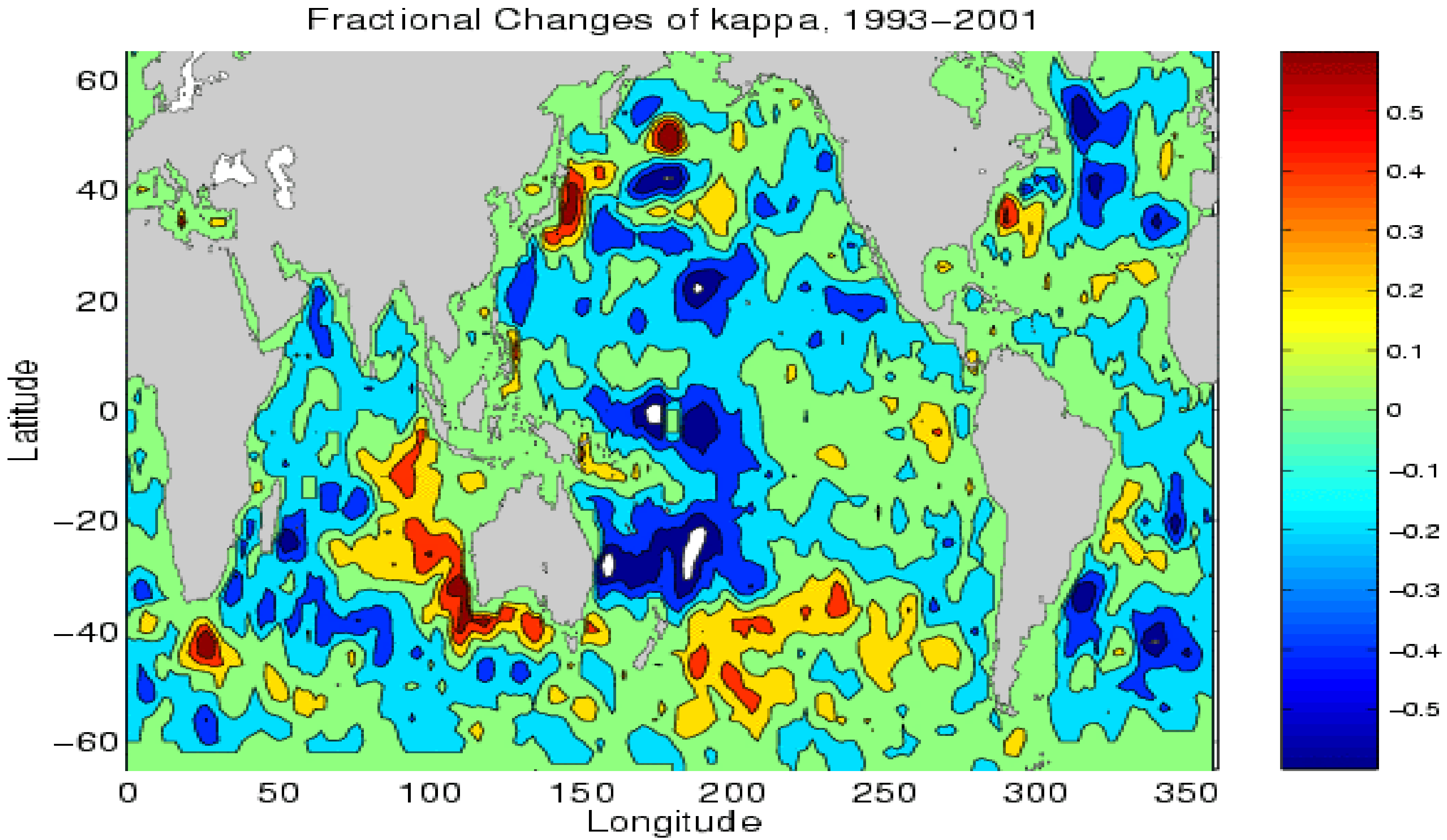
Spectral Analysis of SSH and vel.: Energy on periods <150 days.

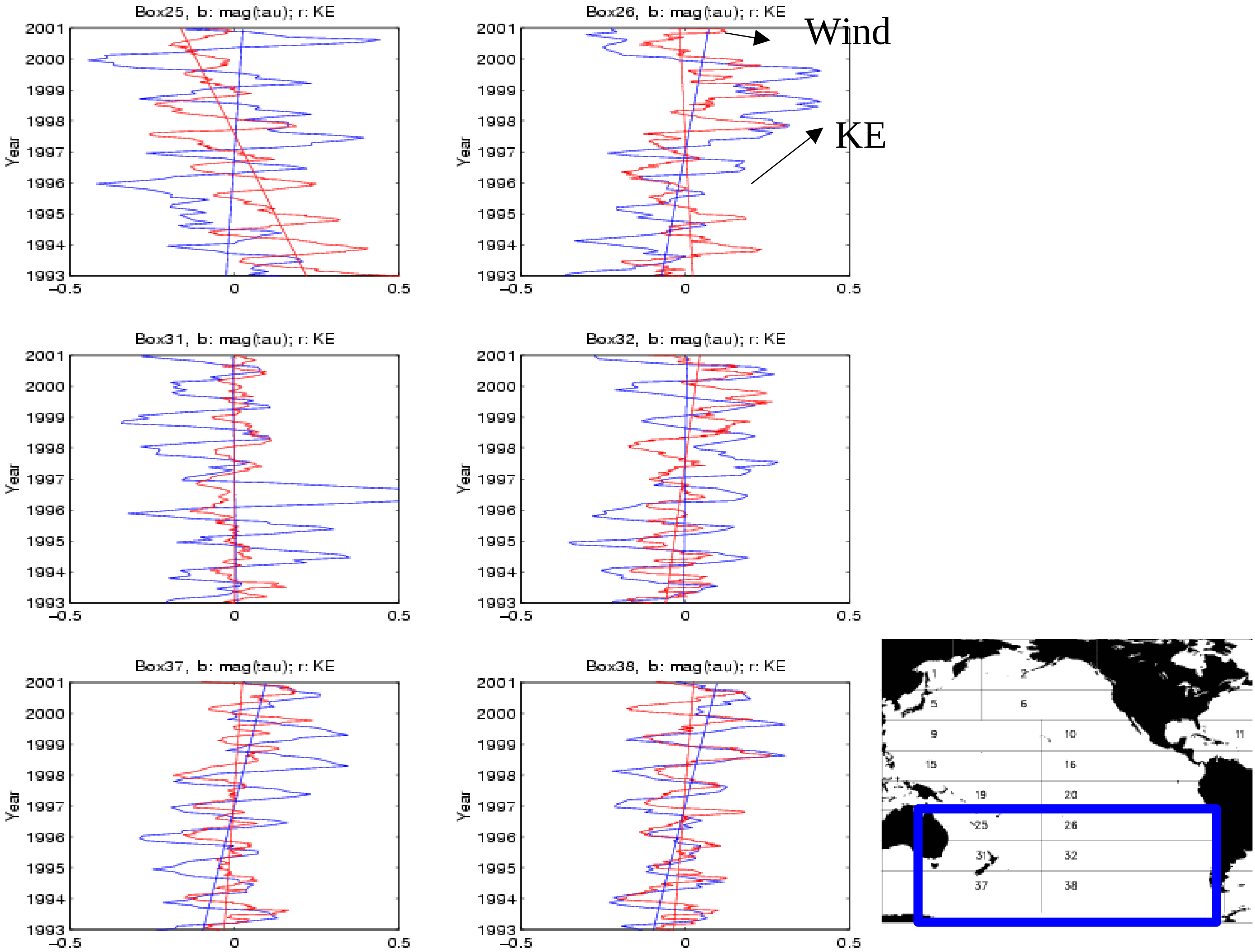
SSH

Vel.

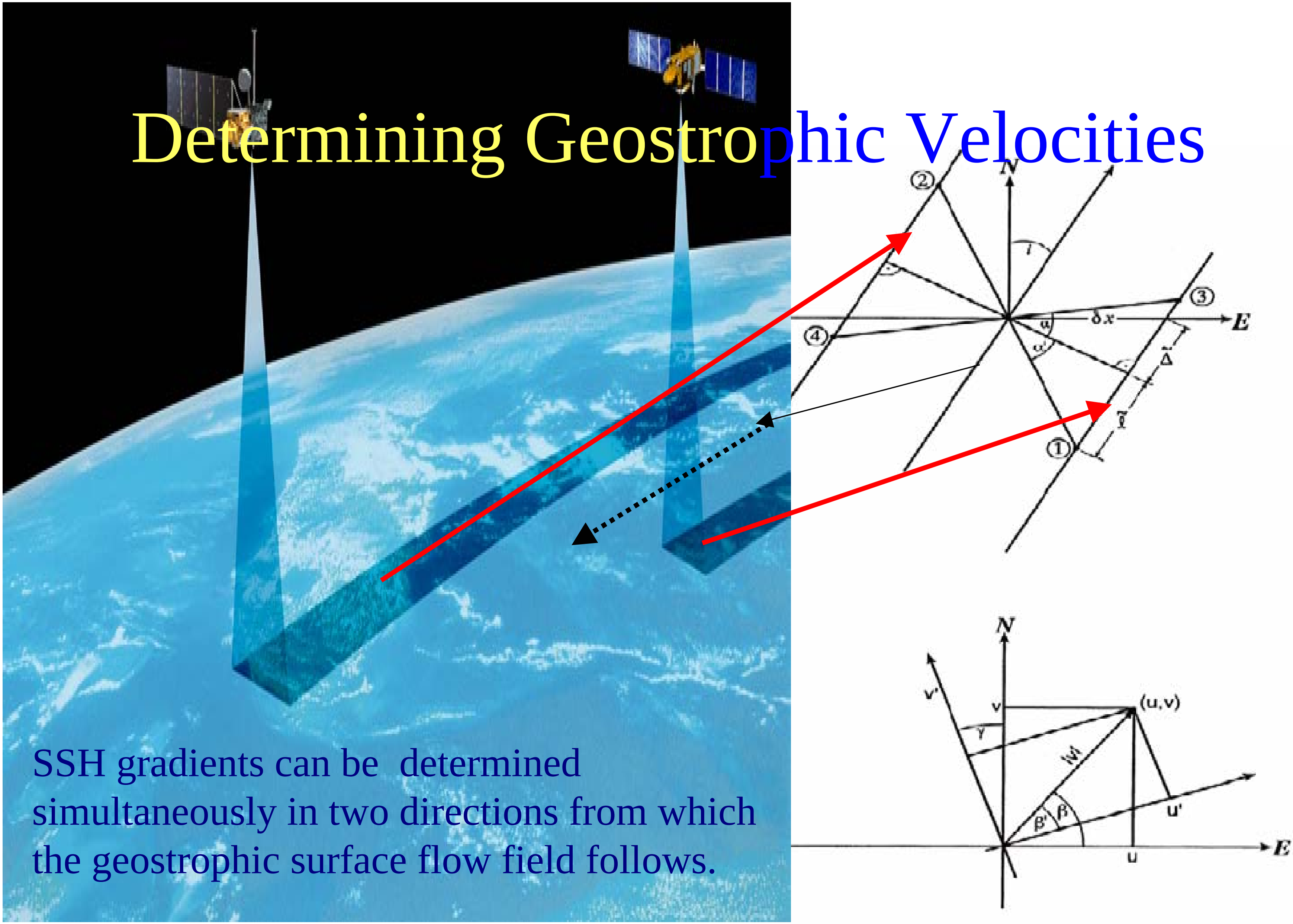


Changes in Eddy Variability



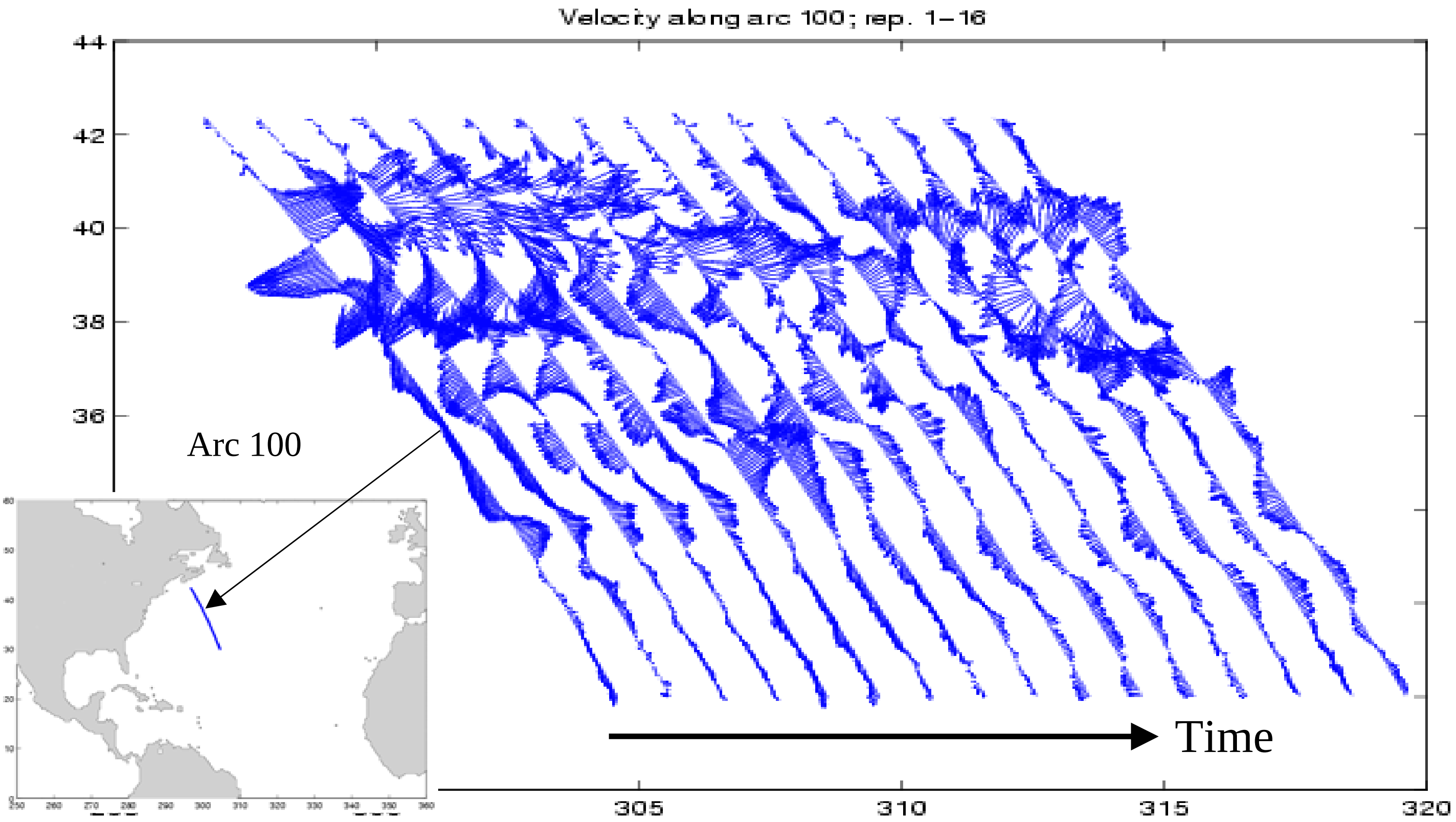

Box25, b: mag(tau); r: KE
Box26, b: mag(tau); r: KE
Wind
KE
Box31, b: mag(tau); r: KE
Box32, b: mag(tau); r: KE
Box37, b: mag(tau); r: KE
Box38, b: mag(tau); r: KE
Year
2001
2000
1999
1998
1997
1996
1995
1994
1993
−0.5
0
0.5
1
2
5
6
9
10
11
15
16
19
20
25
26
31
32
37
38

Determining Geostrophic Velocities

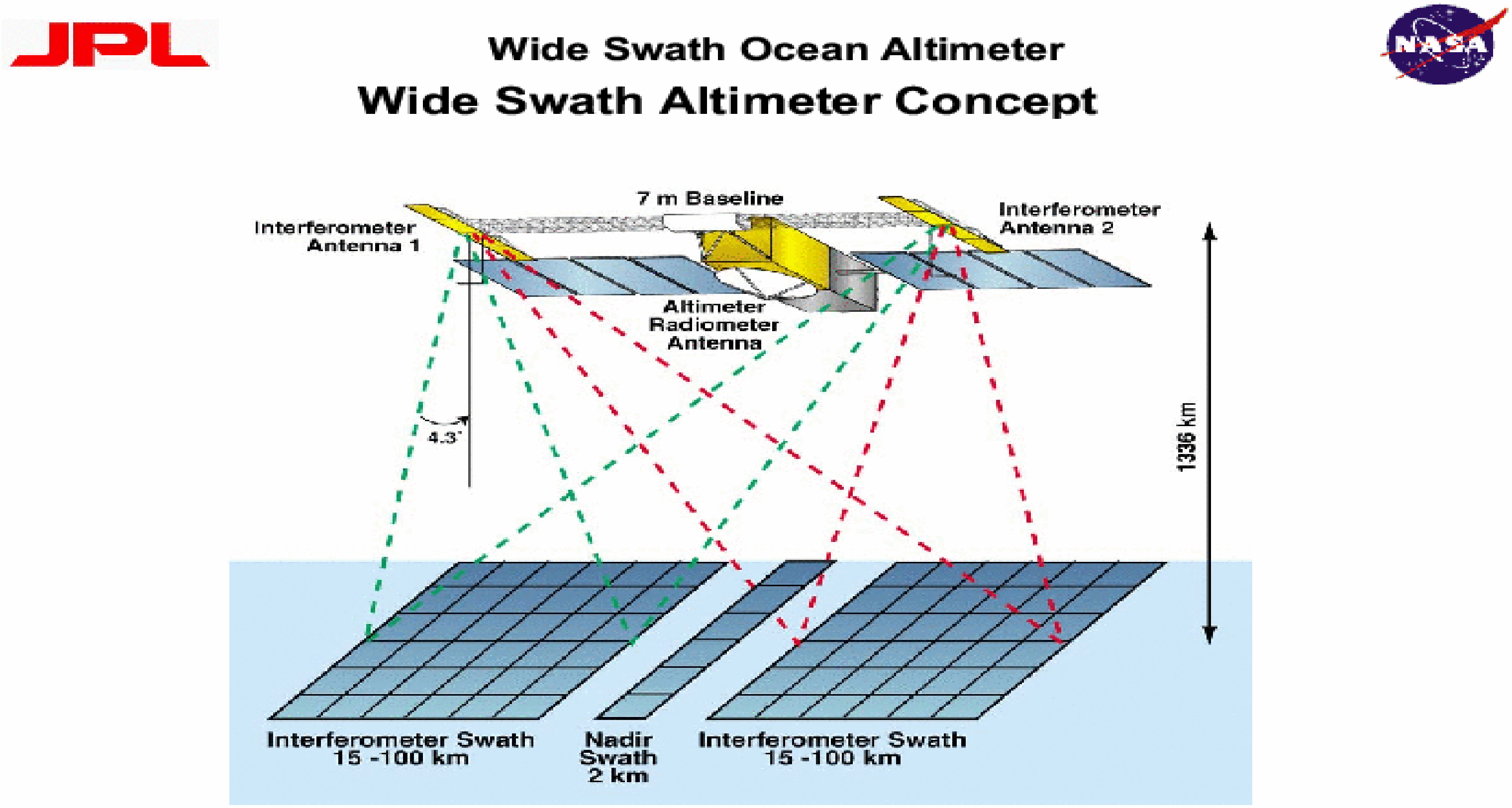


SSH gradients can be determined simultaneously in two directions from which the geostrophic surface flow field follows.

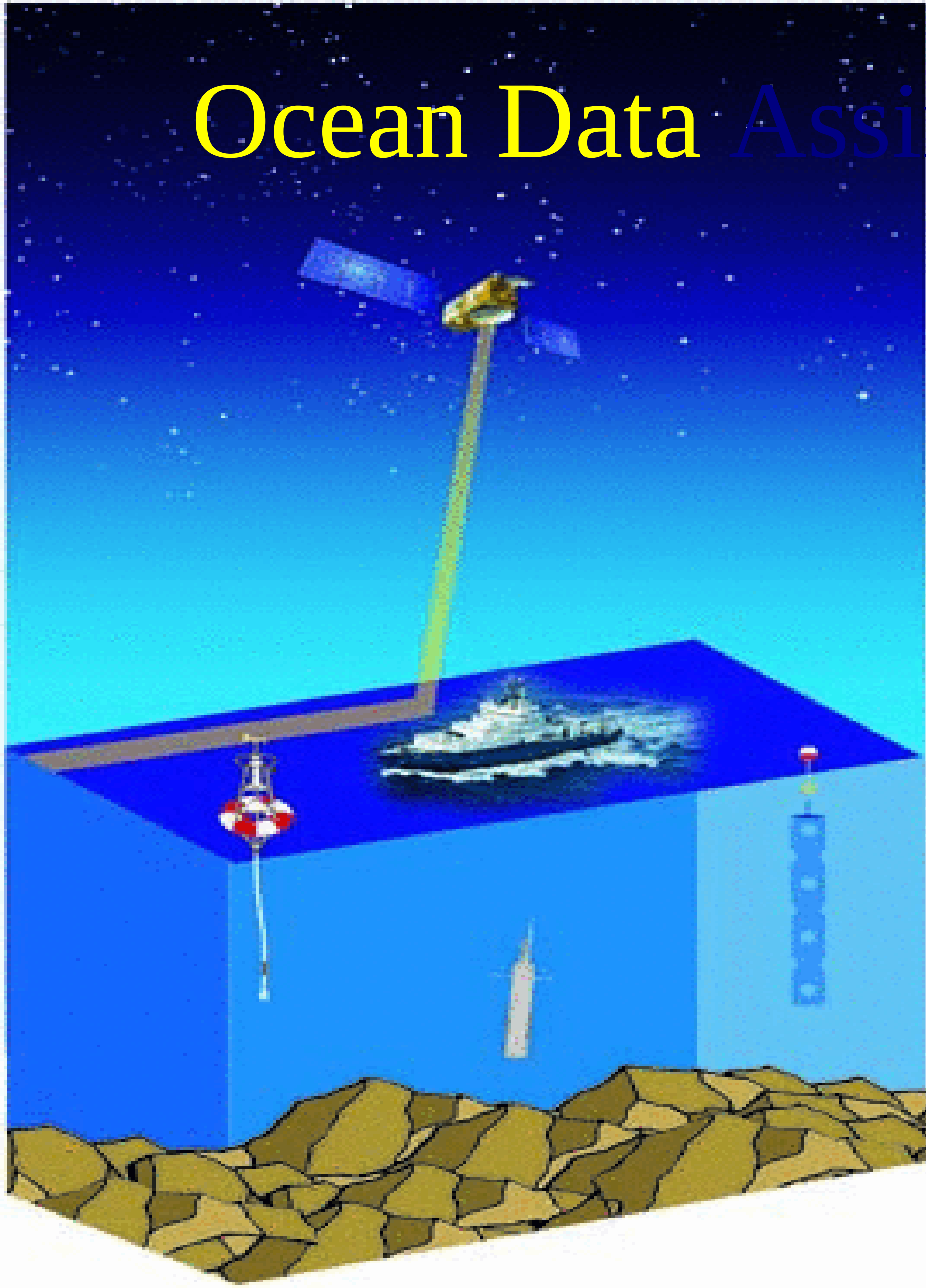
Timeseries of Velocity Anomalies



Determining Geostrophic Velocities



Ocean Data Assimilation



Goal:
Dynamic synthesis of all available data, including the marine goid and LOD and wobble observations.

Different Approaches:

- Simple (nudging, filters)
- Rigorous (smoothers) which preserve model dynamics.

“Estimating the Circulation and Climate of the Ocean”

http://www.ecco-group.org

- NOPP node to advance rigorous data assimilation into an operational tool.
- To describe the global ocean circulation at time scales of days to decades.
- To employ sustained ocean/data syntheses.
- **Global** pilot effort of GODAE and CLIVAR.

The ECCO Effort:

- **Involves groups at MIT, JPL, and SIO.**
- **Employs all available observations as constraints: altimetry, SST, scatterometry, XBT, hydrographic sections, PALACE/ARGO, drifter, SSS, surface fluxes, etc.**
- **Uses ECCO ocean general circulation model employing advanced assimilation methods: adjoint model and Kalman filter/smoother.**
- **Near-realtime estimates: 1-1/3 degree from 1992 to present; every week provided through ECCO LAS.**
- **The global synthesis (reanalysis): 1 degree, 11yrs finished.**
- **50yrs with 1 degree resolution underway.**
- **Working toward goal of ¼ degree global near-real time smoother solution.**

The Methodology

Cost Function

$$J = \sum_t \left(\mathbf{y}(t) - \mathbf{E}(t)\,\mathbf{x}(t)\right)^T \mathbf{R}^{-1}(t)\left(\mathbf{y}(t) - \mathbf{E}(t)\,\mathbf{x}(t)\right), \quad (1)$$

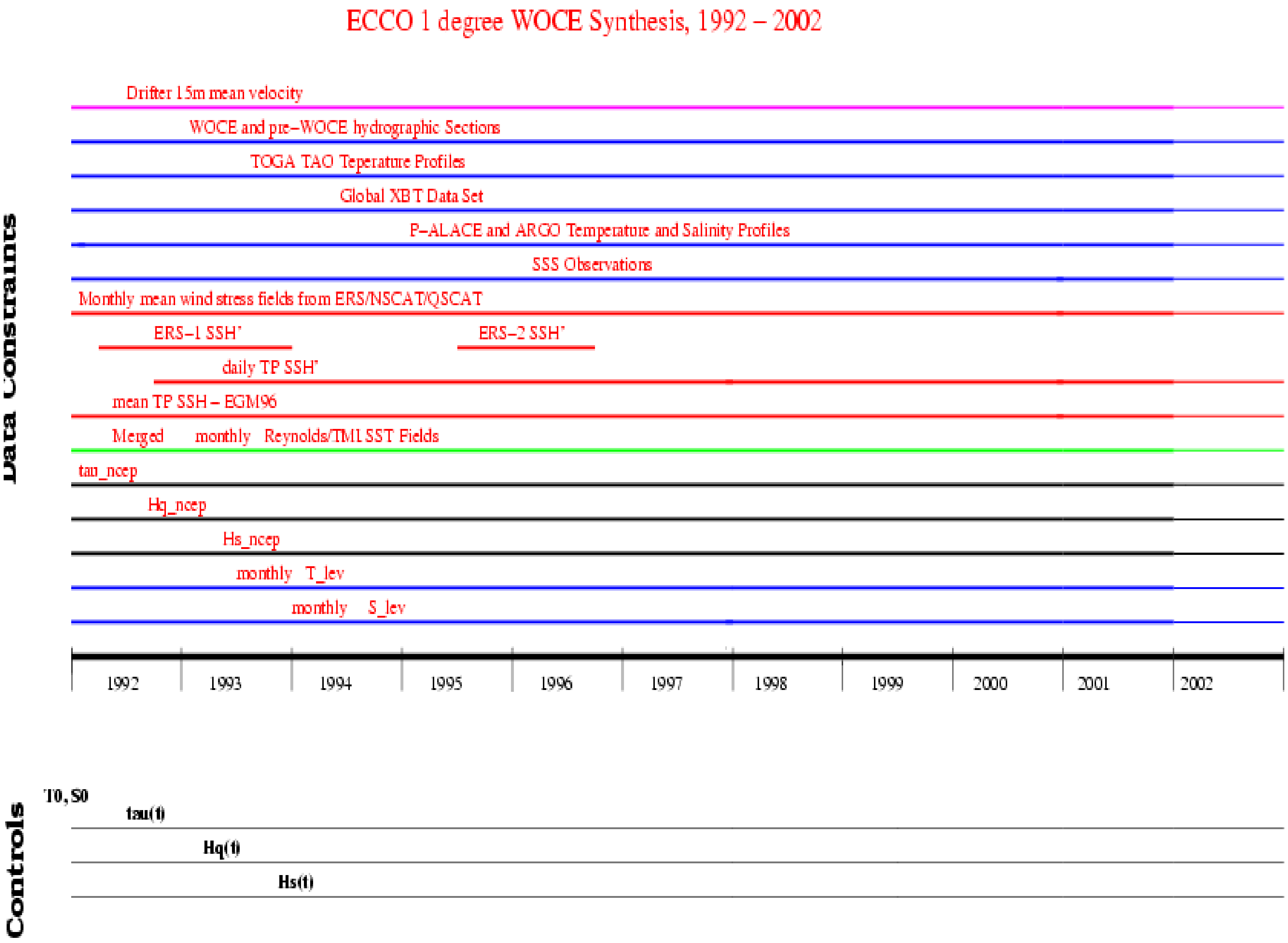
Model

$$\mathbf{x}(t+1) = \mathcal{F}[\mathbf{x}(t), \mathbf{q}(t), \mathbf{u}(t), \varepsilon(t), t], \quad (2)$$

Penalty-function type cost function

$$J' = \sum_t \left[\left(\mathbf{y}(t) - \mathbf{E}(t)\,\mathbf{x}(t)\right)^T \mathbf{R}^{-1}(t)\left(\mathbf{y}(t) - \mathbf{E}(t)\,\mathbf{x}(t)\right) + \varepsilon(t)^T \mathbf{Q}^{-1} \varepsilon(t)\right] (3)$$

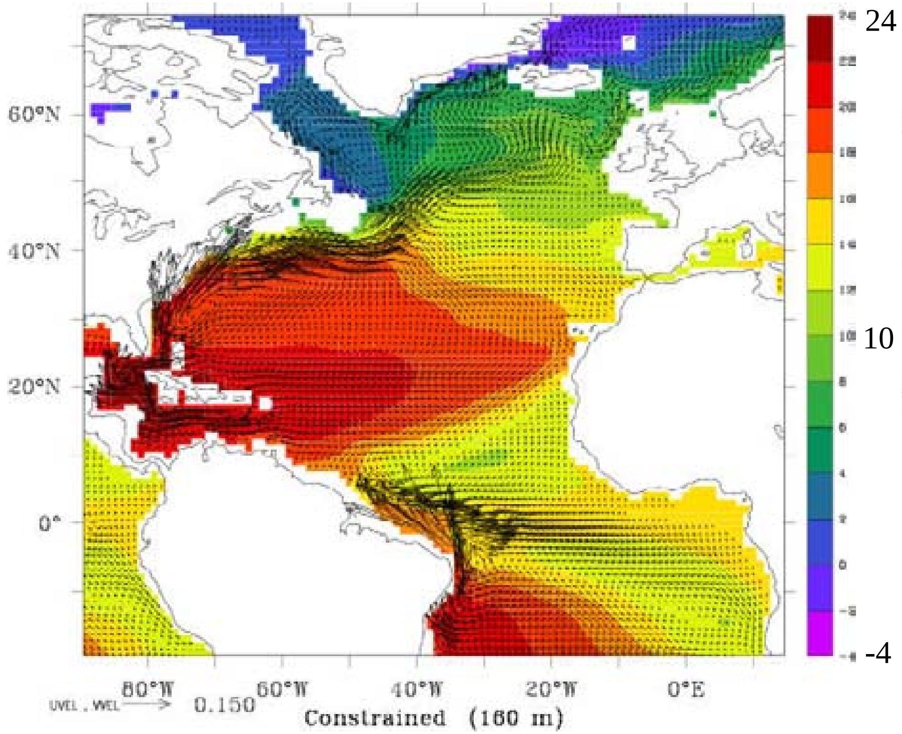
The model can be imposed upon the objective function either by using Lagrange multipliers (constrained optimization), or in an unconstrained optimization form with a penalty-function type of formulation.


ECCO 1 degree WOCE Synthesis, 1992 – 2002
Data Constraints
Drifter 15m mean velocity
WOCE and pre–WOCE hydrographic Sections
TOGA TAO Teperature Profiles
Global XBT Data Set
P–ALACE and ARGO Temperature and Salinity Profiles
SSS Observations
Monthly mean wind stress fields from ERS/NSCAT/QSCAT
ERS–1 SSH'
ERS–2 SSH'
daily TP SSH'
mean TP SSH – EGM96
Merged monthly Reynolds/TMI SST Fields
tau_ncep
Hq_ncep
Hs_ncep
monthly T_lev
monthly S_lev
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
Controls
T0, S0
tau(t)
Hq(t)
Hs(t)

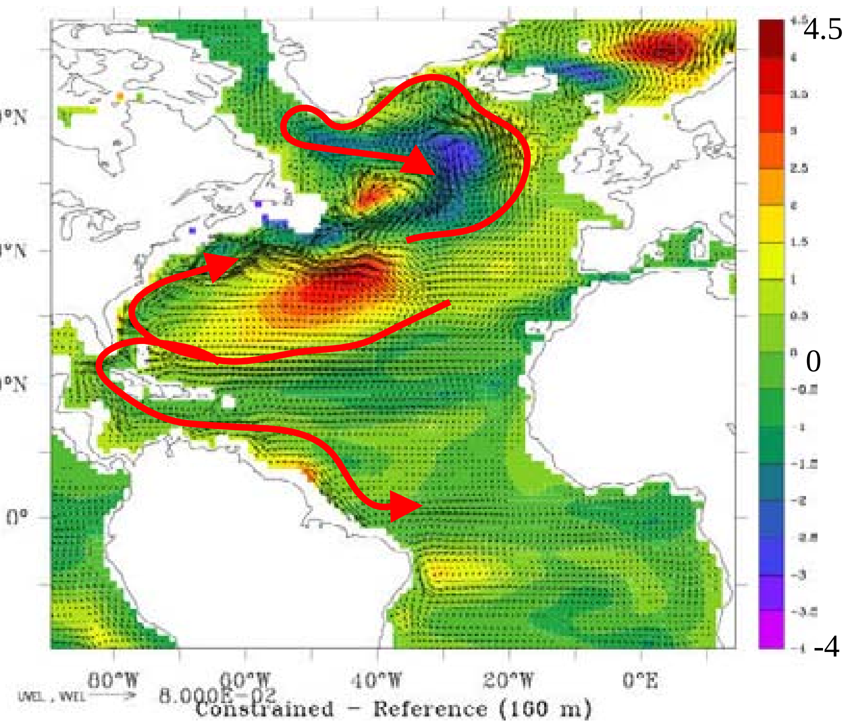
The Mean Circulation, Atlantic:

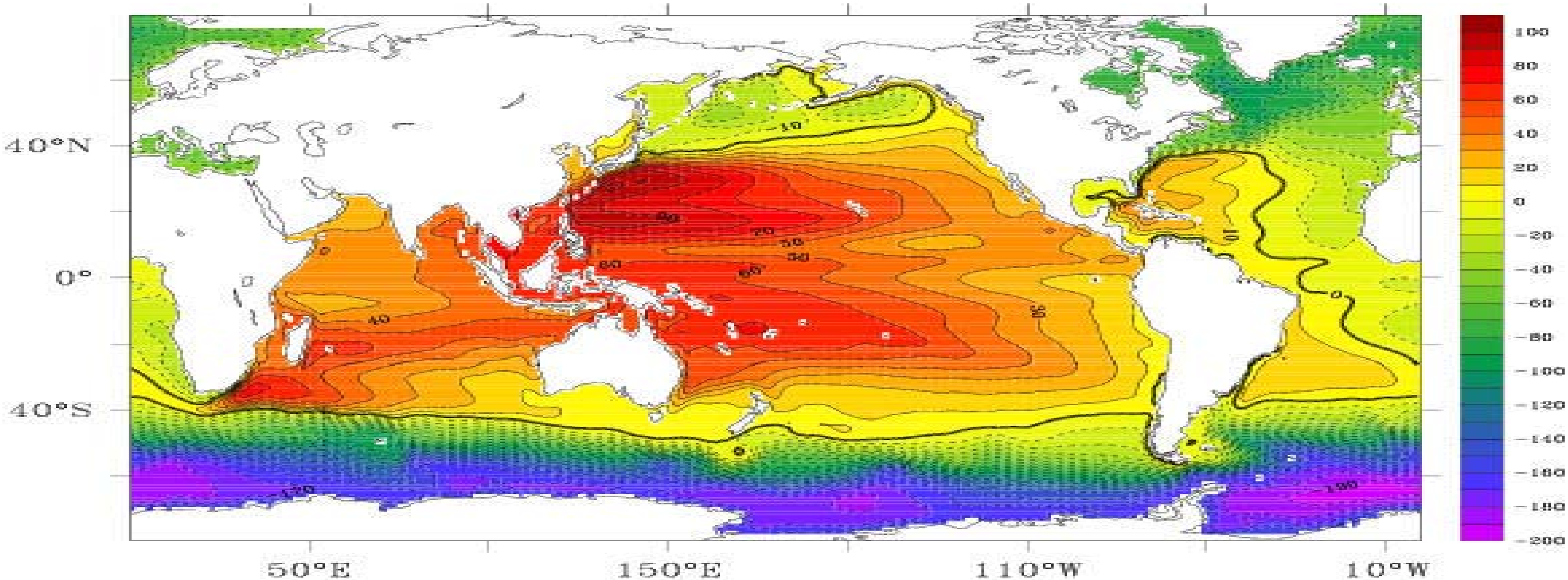
Velocity and temperature, 160 m

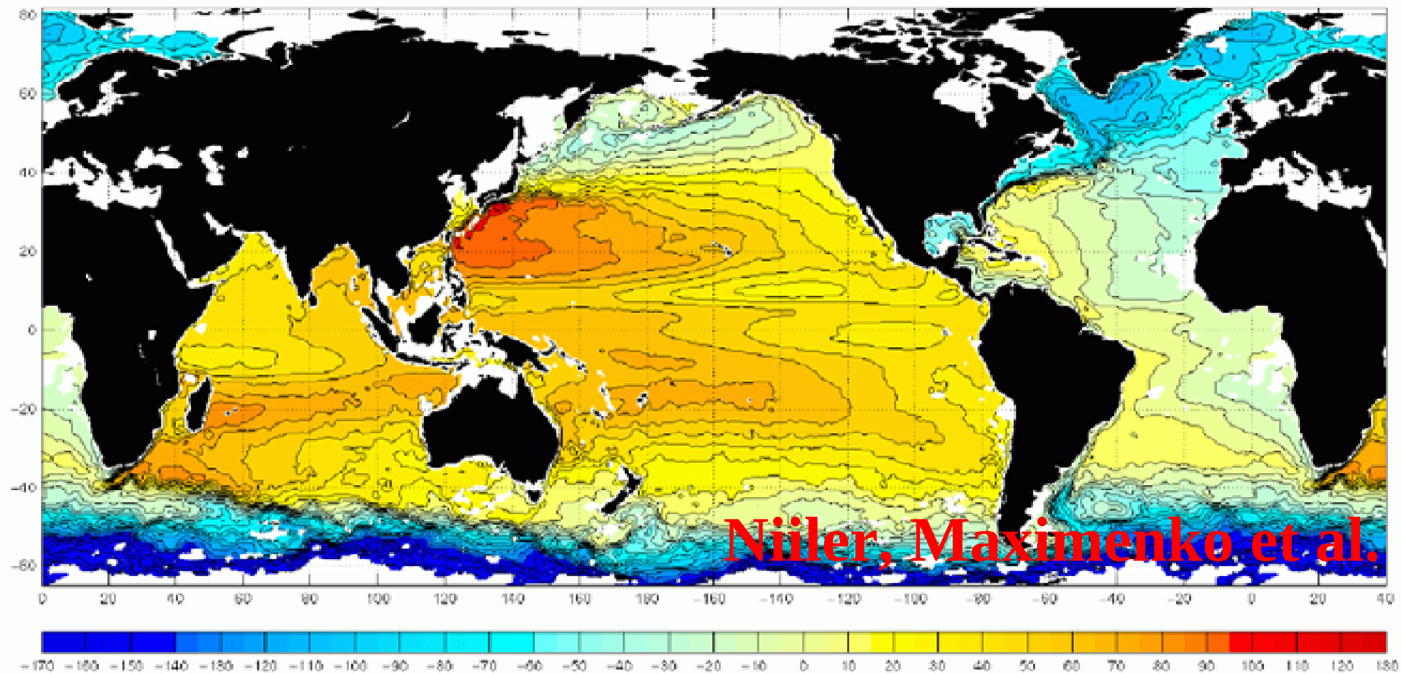
Constraint



Constraint - Ref.

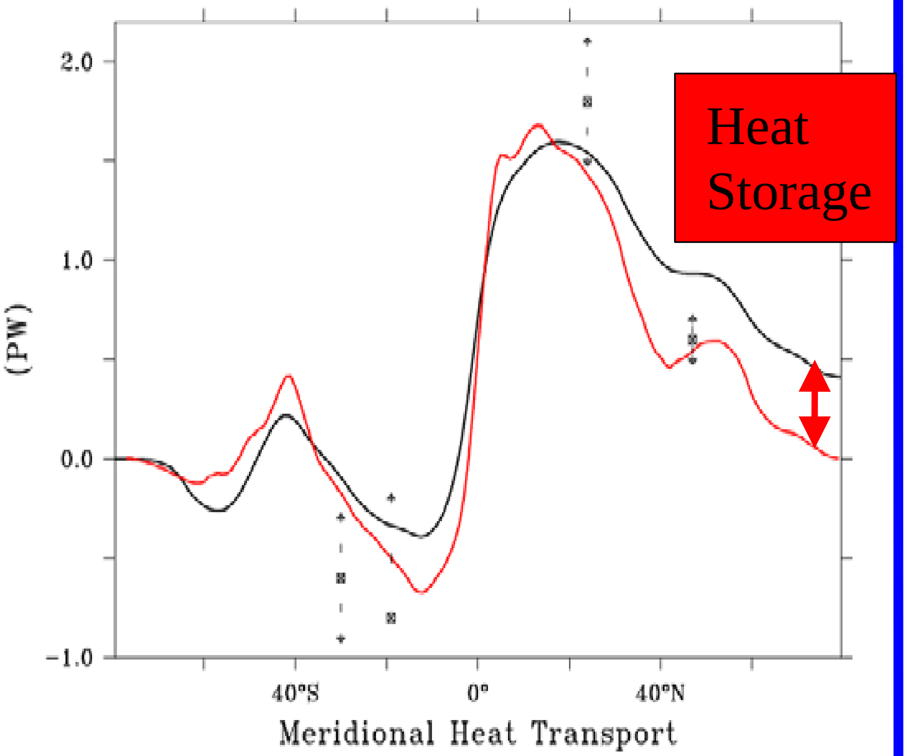



40°N
0°
40°S
50°E
150°E
110°W
10°W
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200

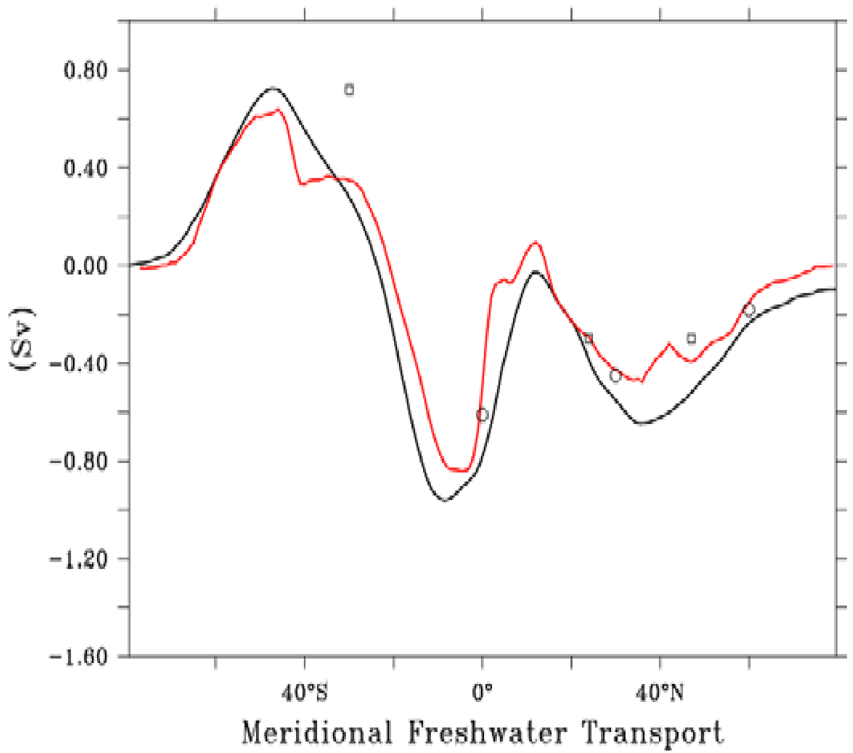

Niiler, Maximenko et al.
80
60
40
20
0
-20
-40
-60
0
20
40
60
80
100
120
140
160
180
-160
-140
-120
-100
-80
-60
-40
-20
0
20
40
-170
-160
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0
10
20
30
40
50
60
70
80
90
100
110
120
130

Global Ocean Heat and Freshwater Transports

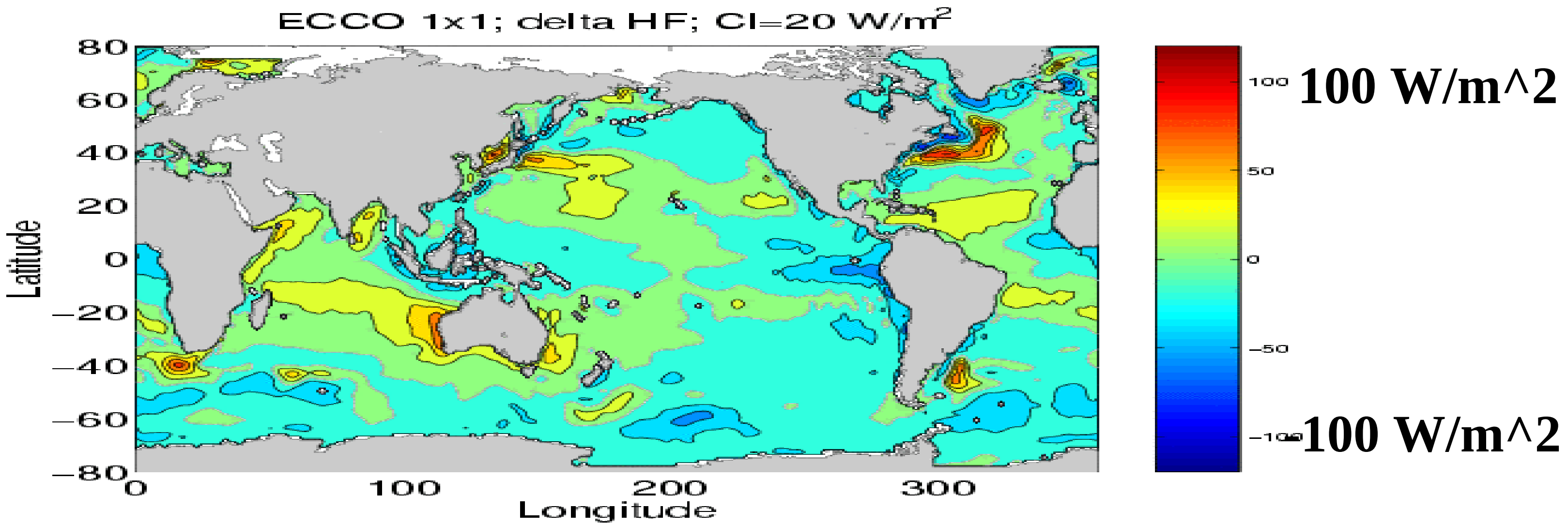
Heat Transport

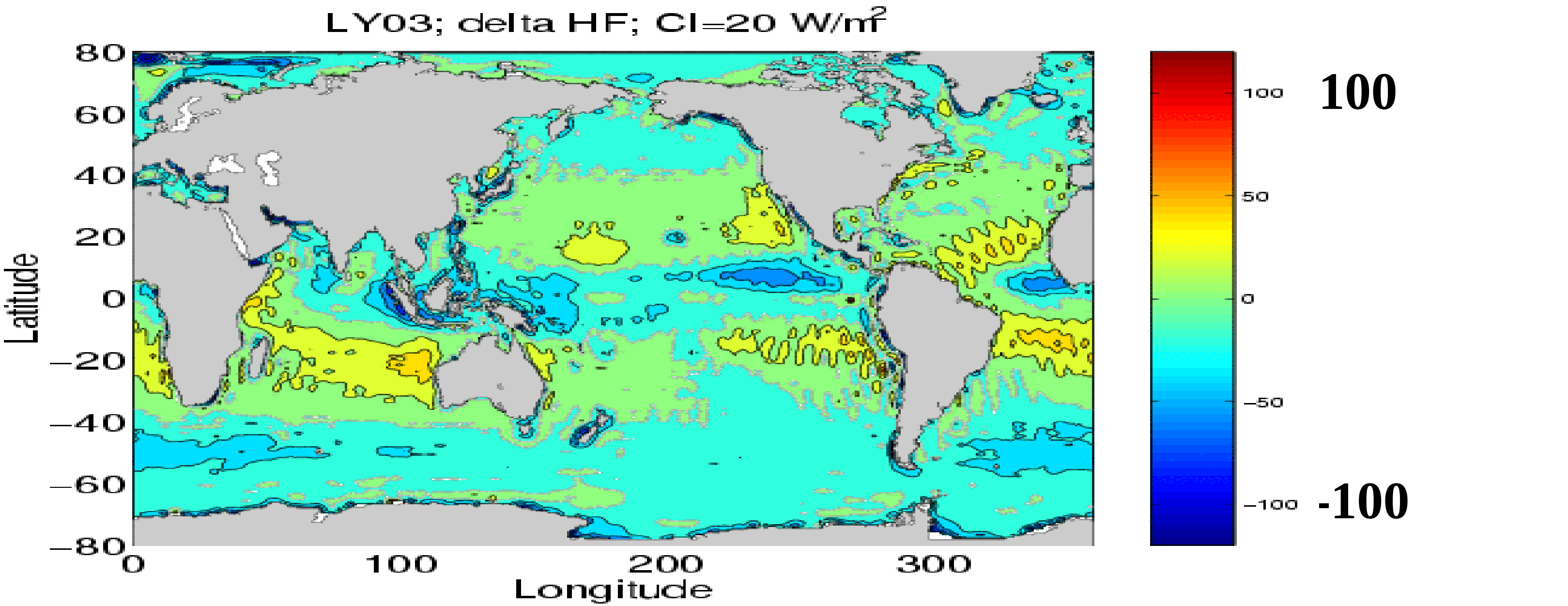


Freshwater Transports



Surface Heat Flux Estimates

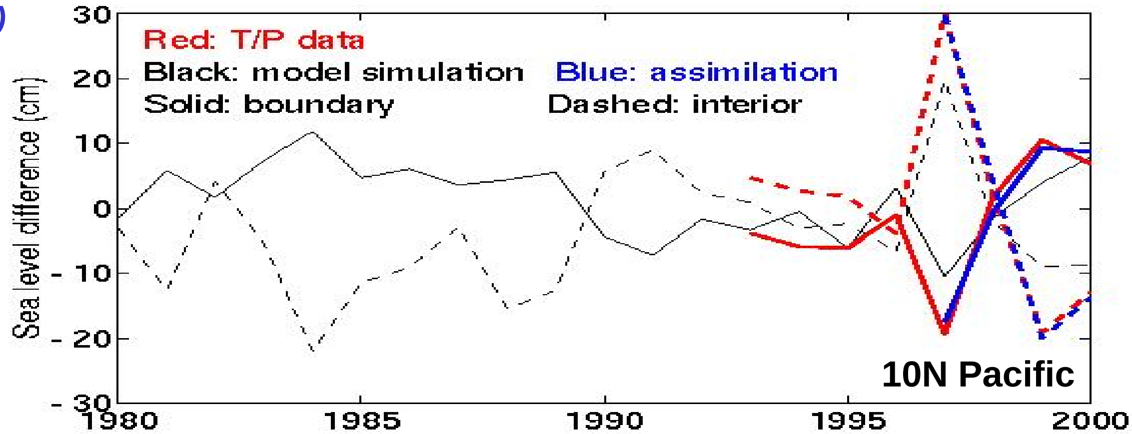




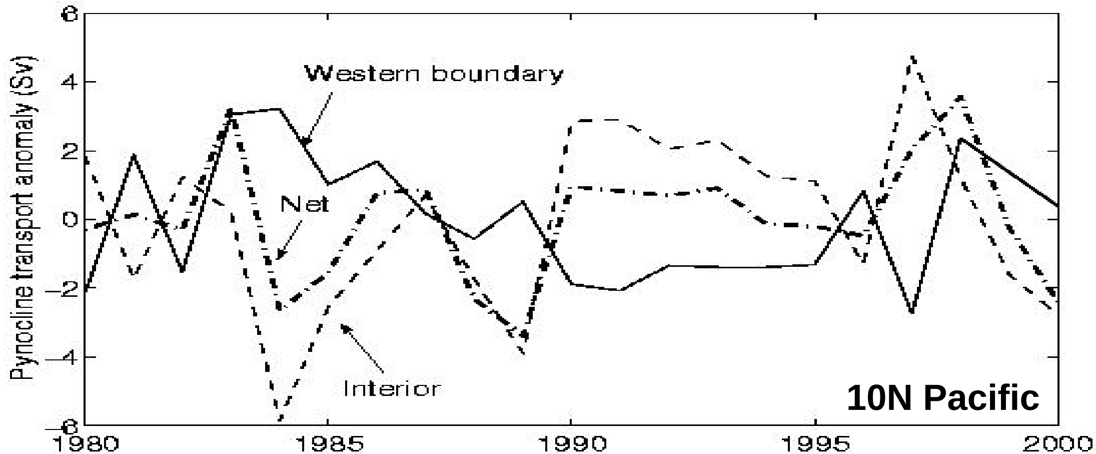
Tropical-subtropical mass exchange: variability vs. mean

Lee & Fukumori (2003)
J. Climate, Dec. Issue.

Counteracting changes of sea-level slope across LLWBC & interior



Anti-correlated pycnocline transports via LLWBC & interior

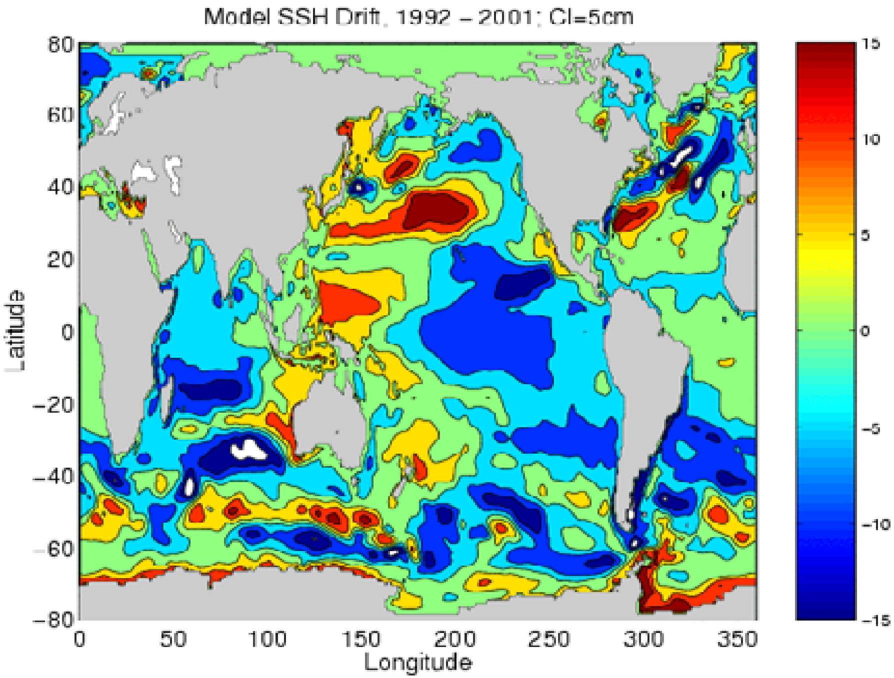


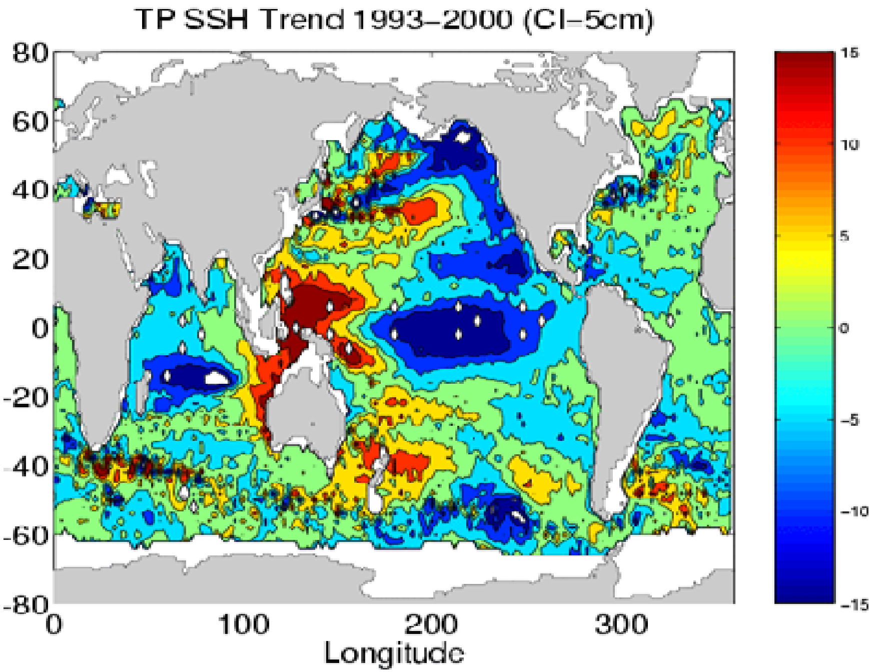
Variability: boundary & interior flow out of phase, the latter larger.
Mean: boundary & interior flow same direction, the former larger.

SSH Drift 1993 – 2002

ECCO Estimate

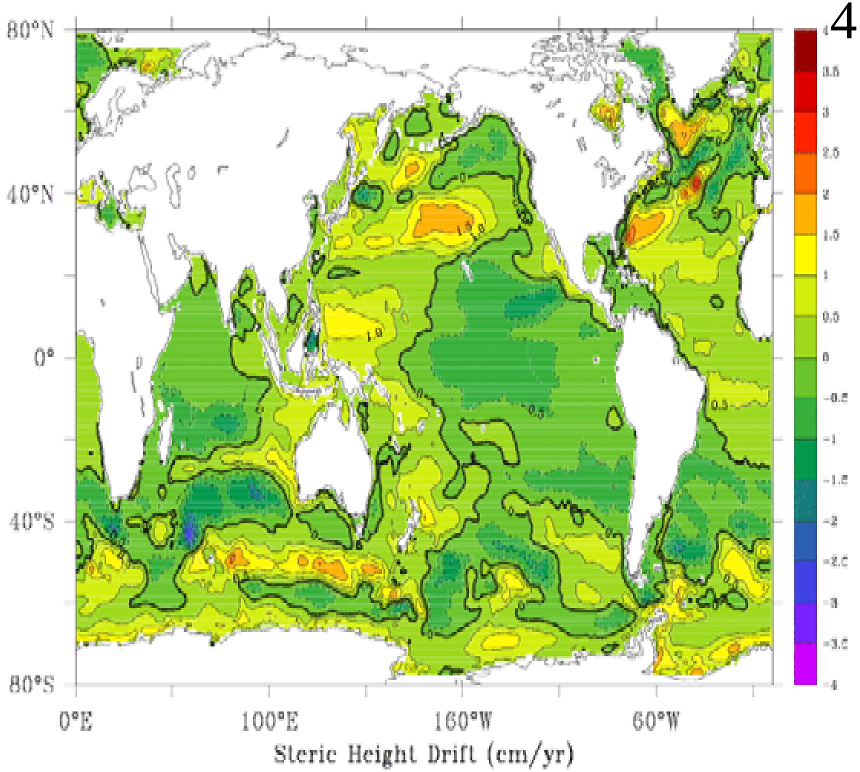
T/P Observations



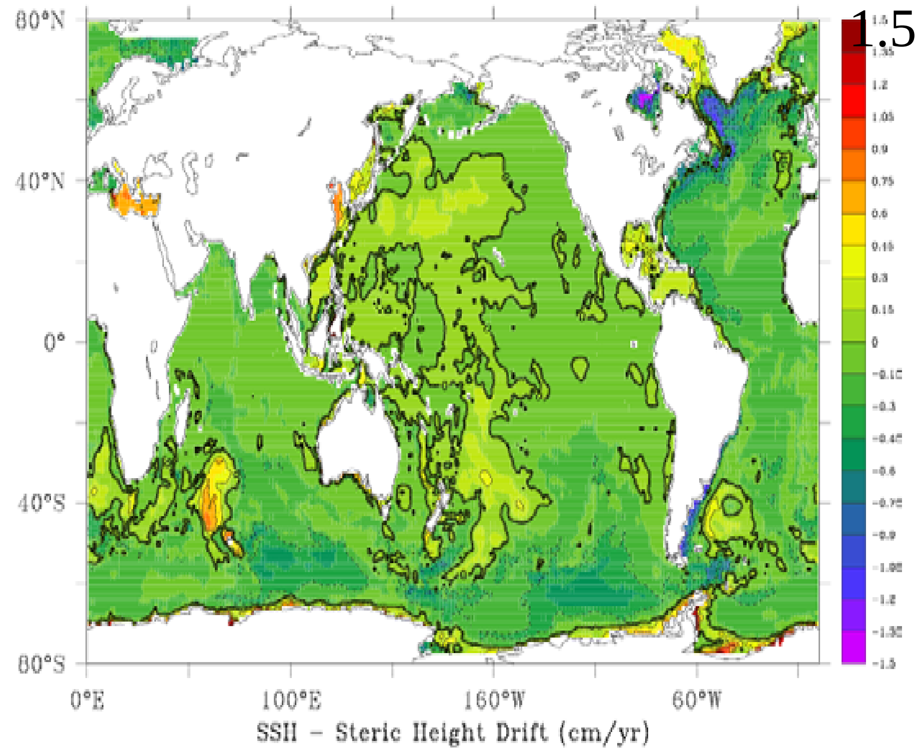


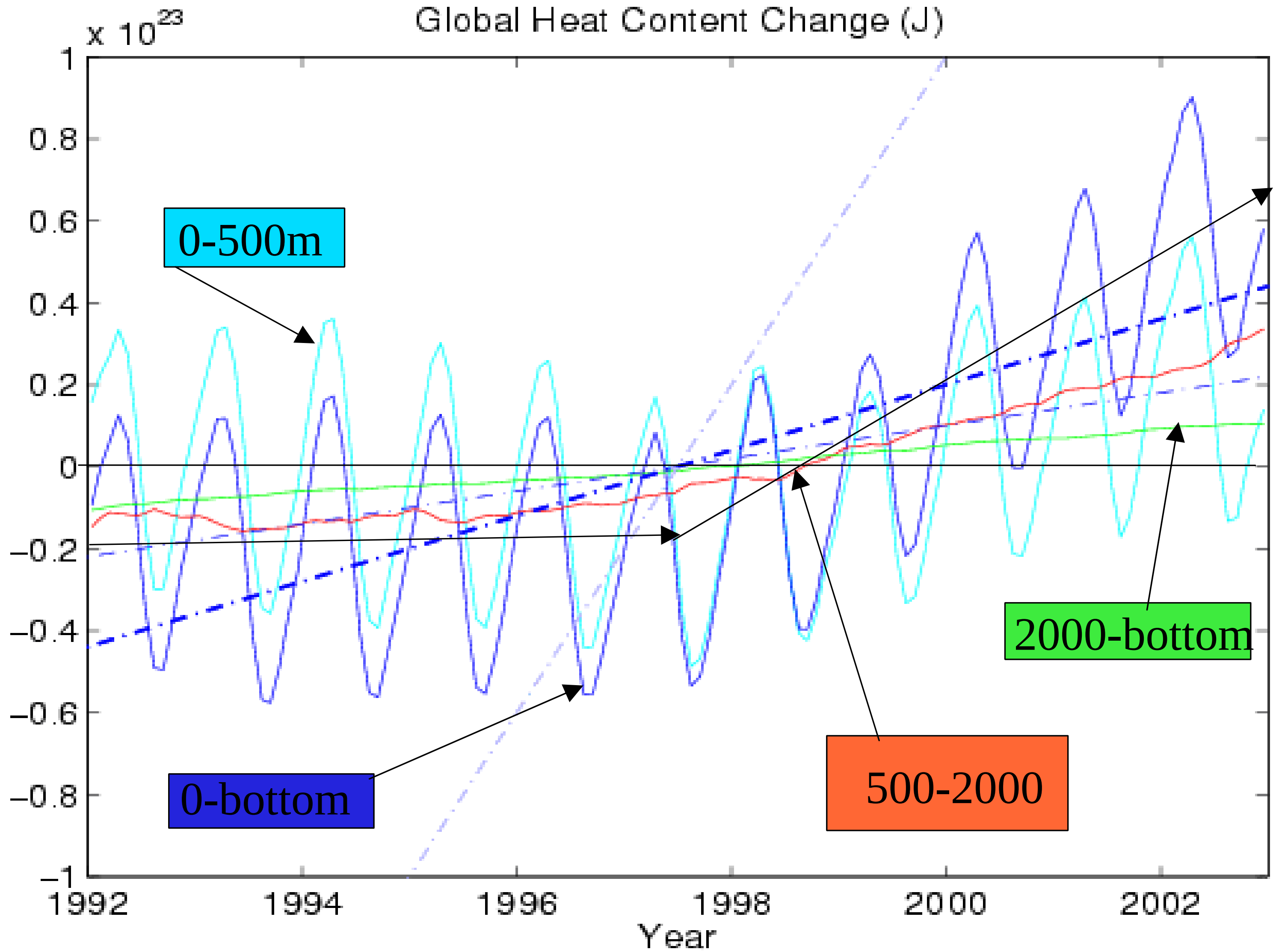
Steric SSH Changes and Mass-Induced SSH Changes

Steric Height Changes (cm/yr)

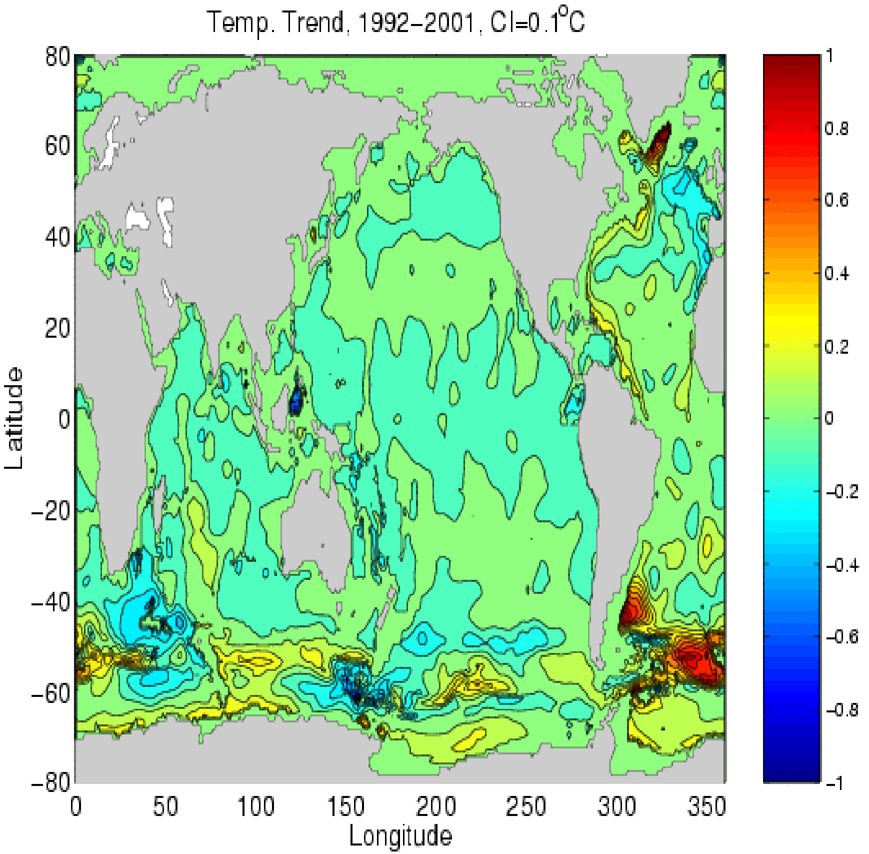


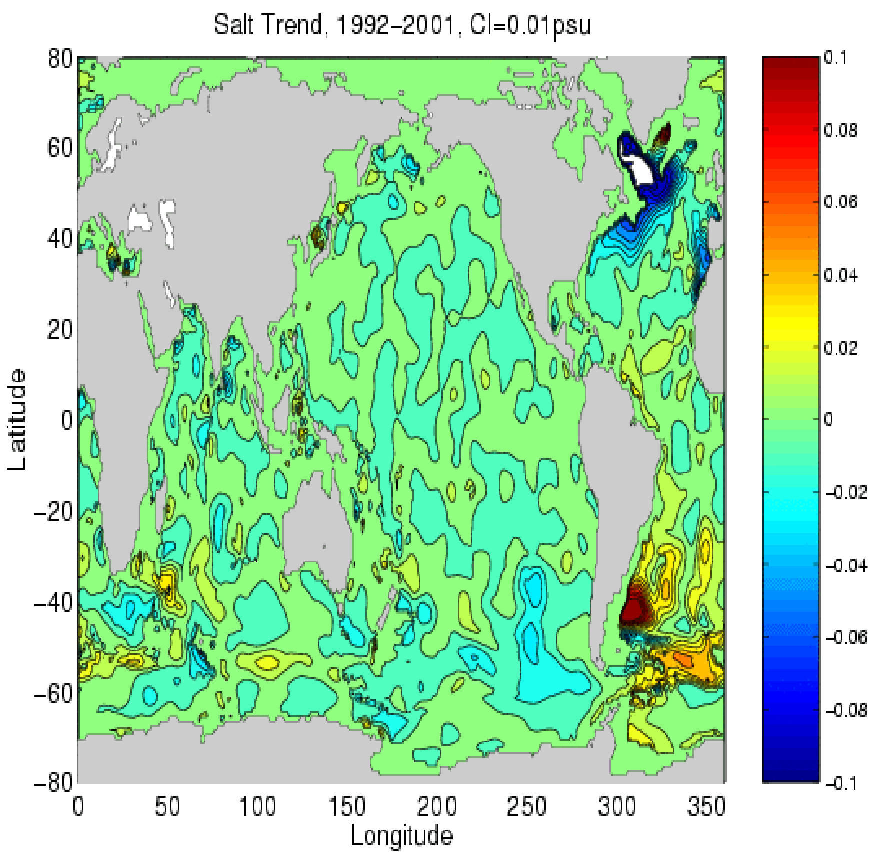
Mass-induced Changes (cm/yr)



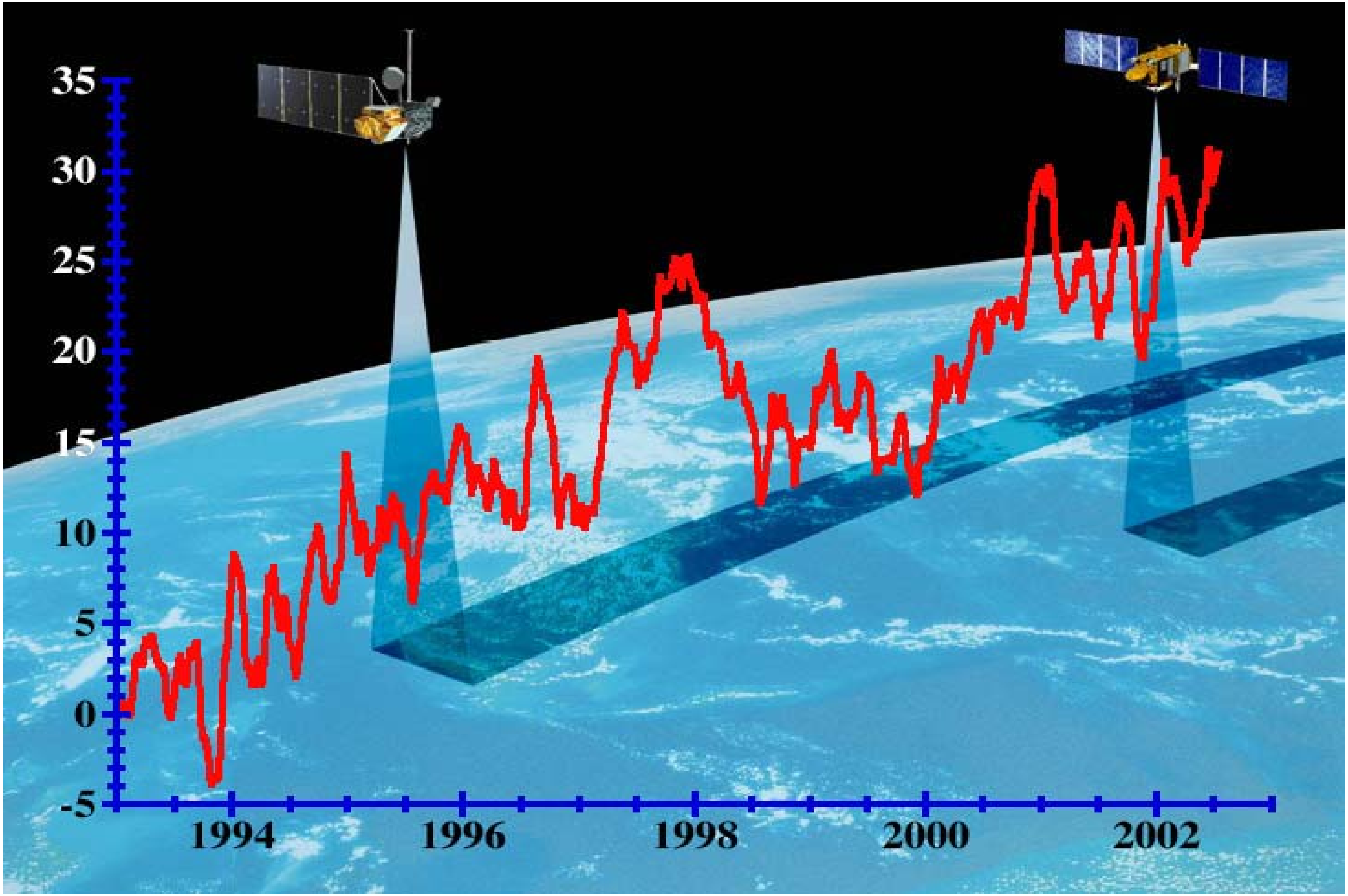

Global Heat Content Change (J)
x 10^23
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
1992
1994
1996
1998
2000
2002
Year
0-500m
0-bottom
500-2000
2000-bottom

Abysal Temperature and Salt Drifts

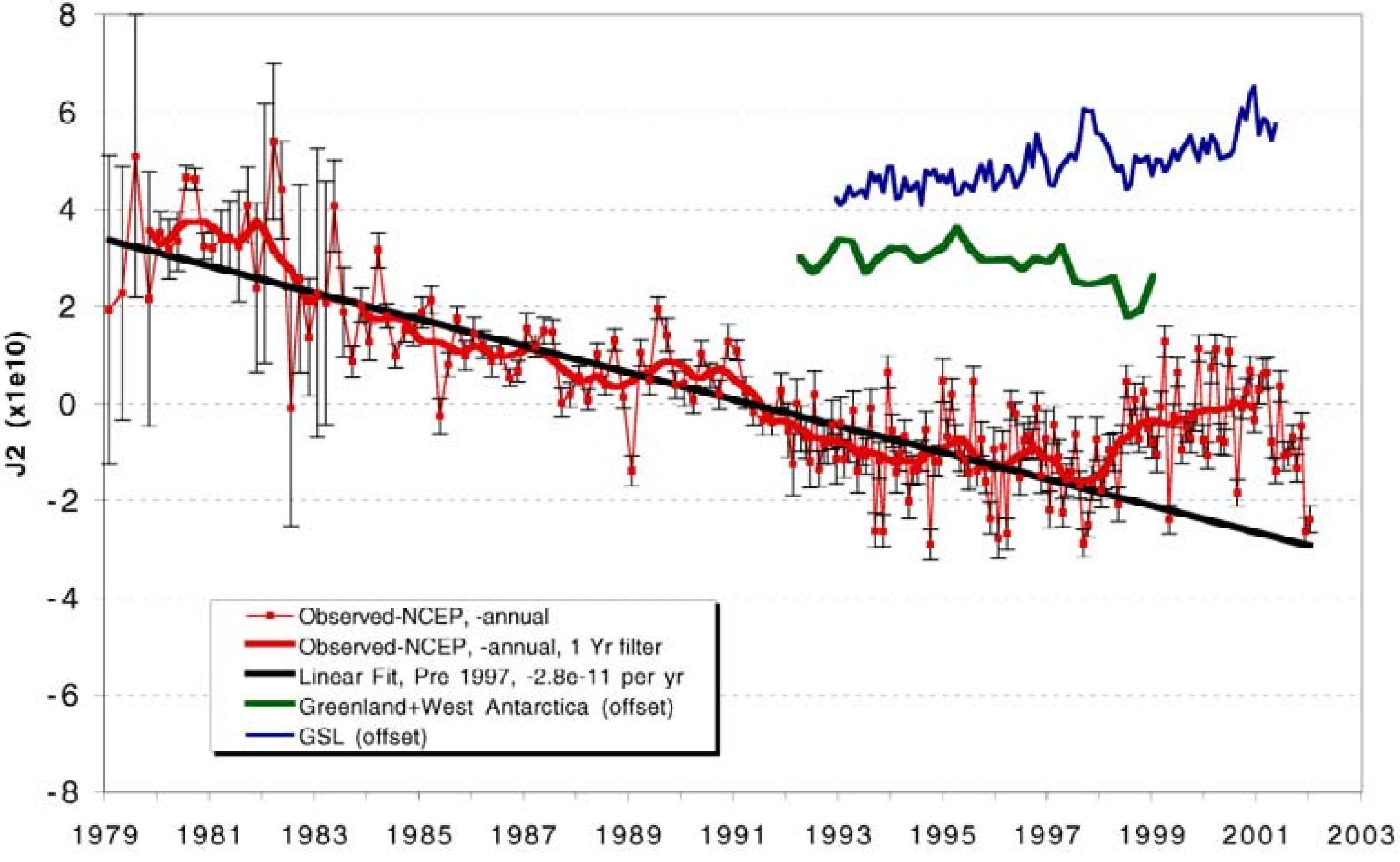




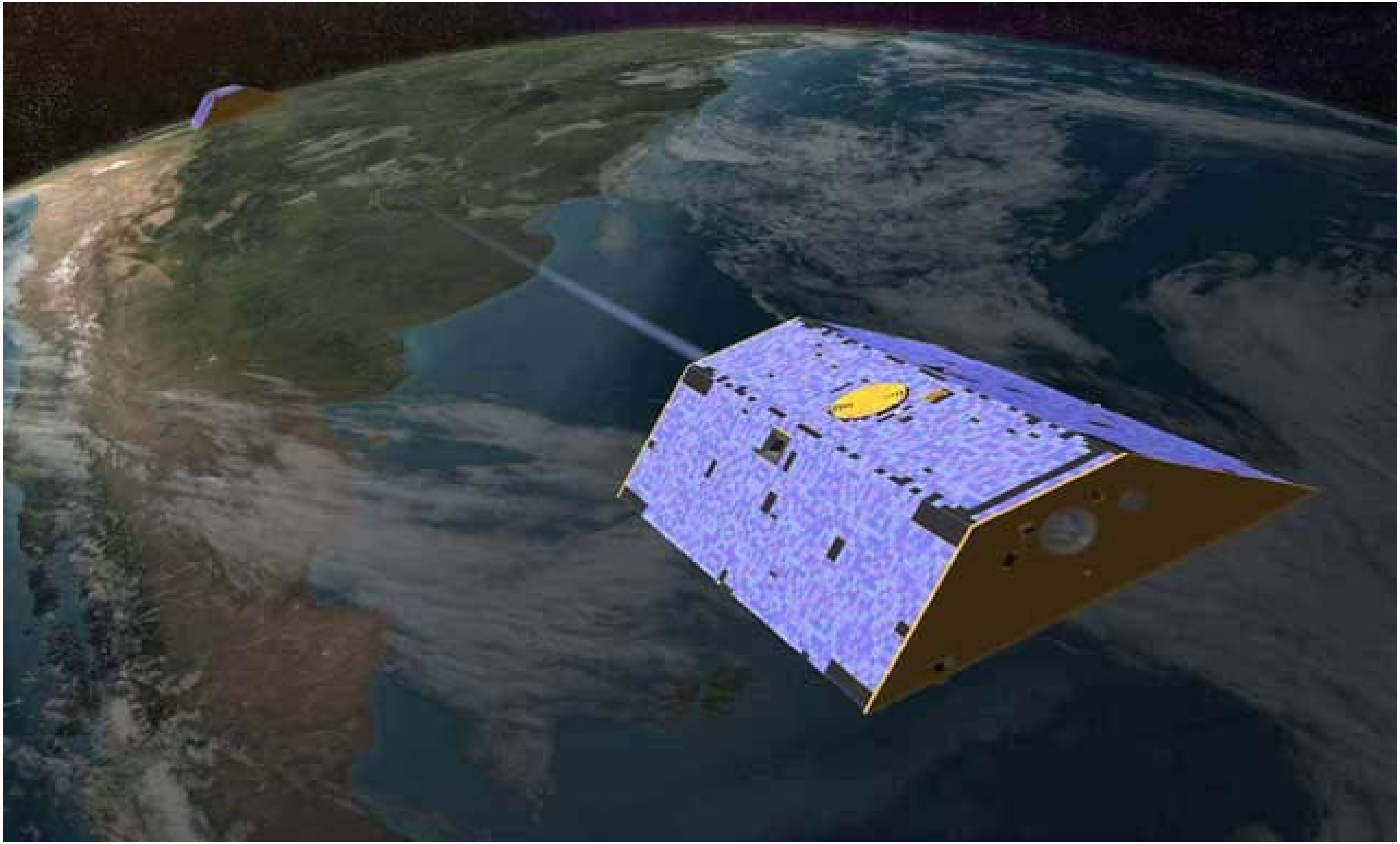
Global Sea Level Rise:



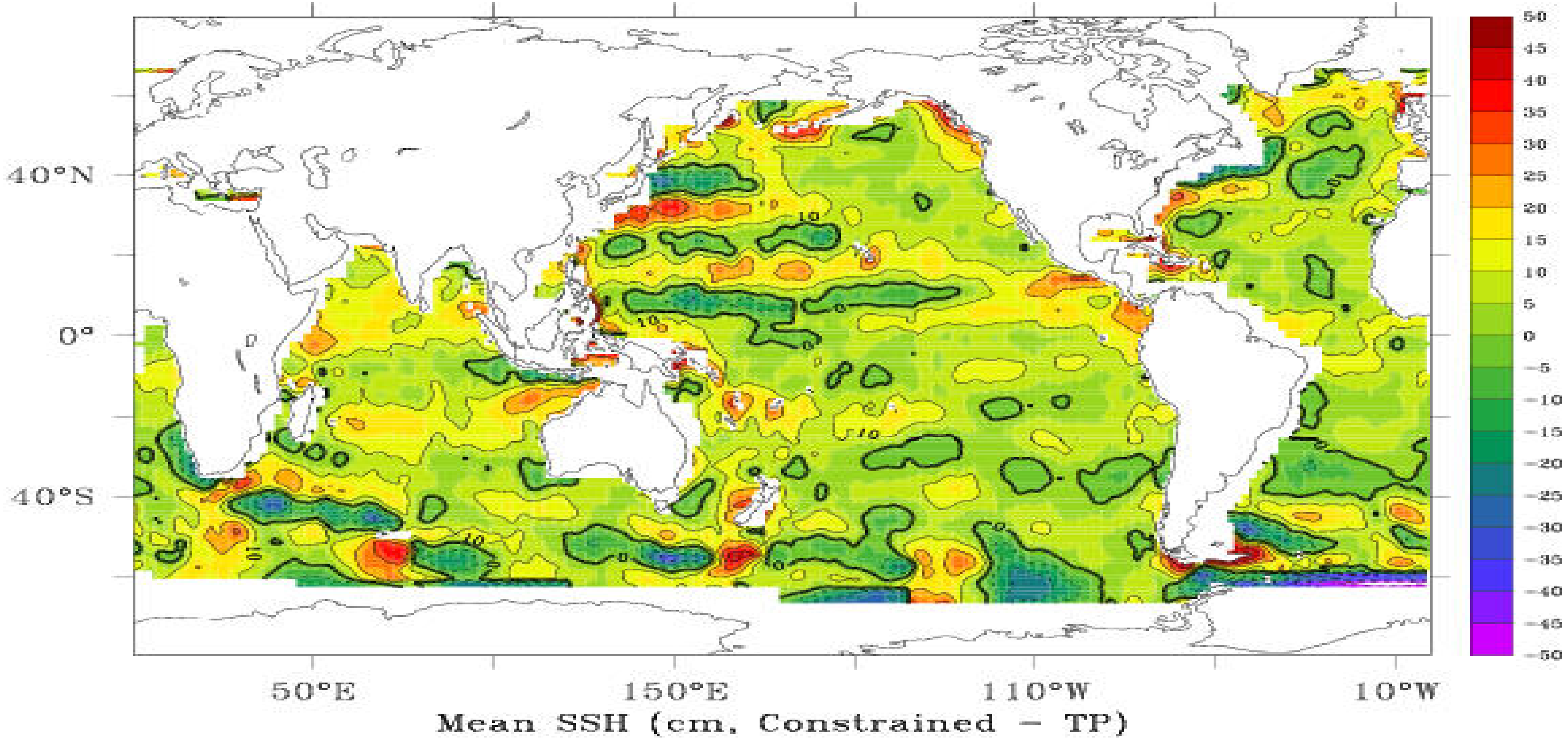
Cox and Chao, 2002



GRACE: Gravity Change



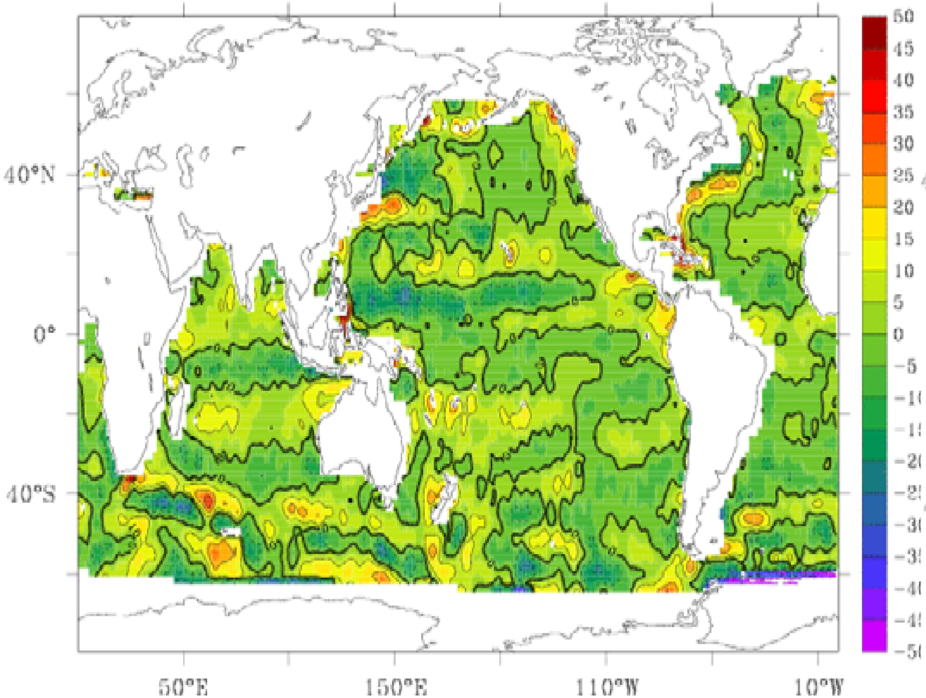
The Mean Residual SSH



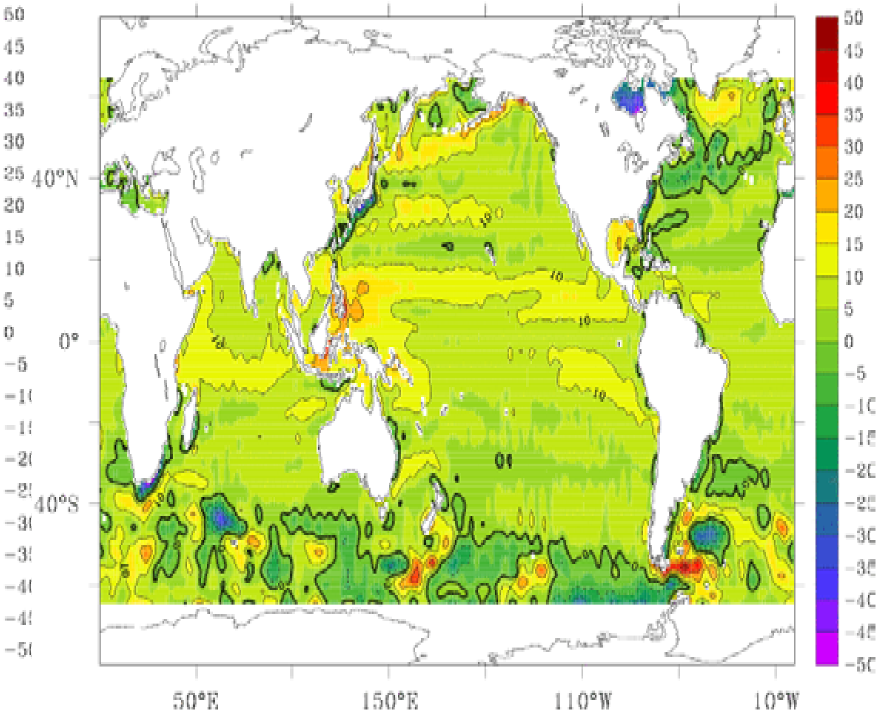
Residual SSH values point toward inconsistencies in the EGM96 geoid errors.
Ocean state estimation helps in determining geodetic information.

The Mean Ocean Circulation, global

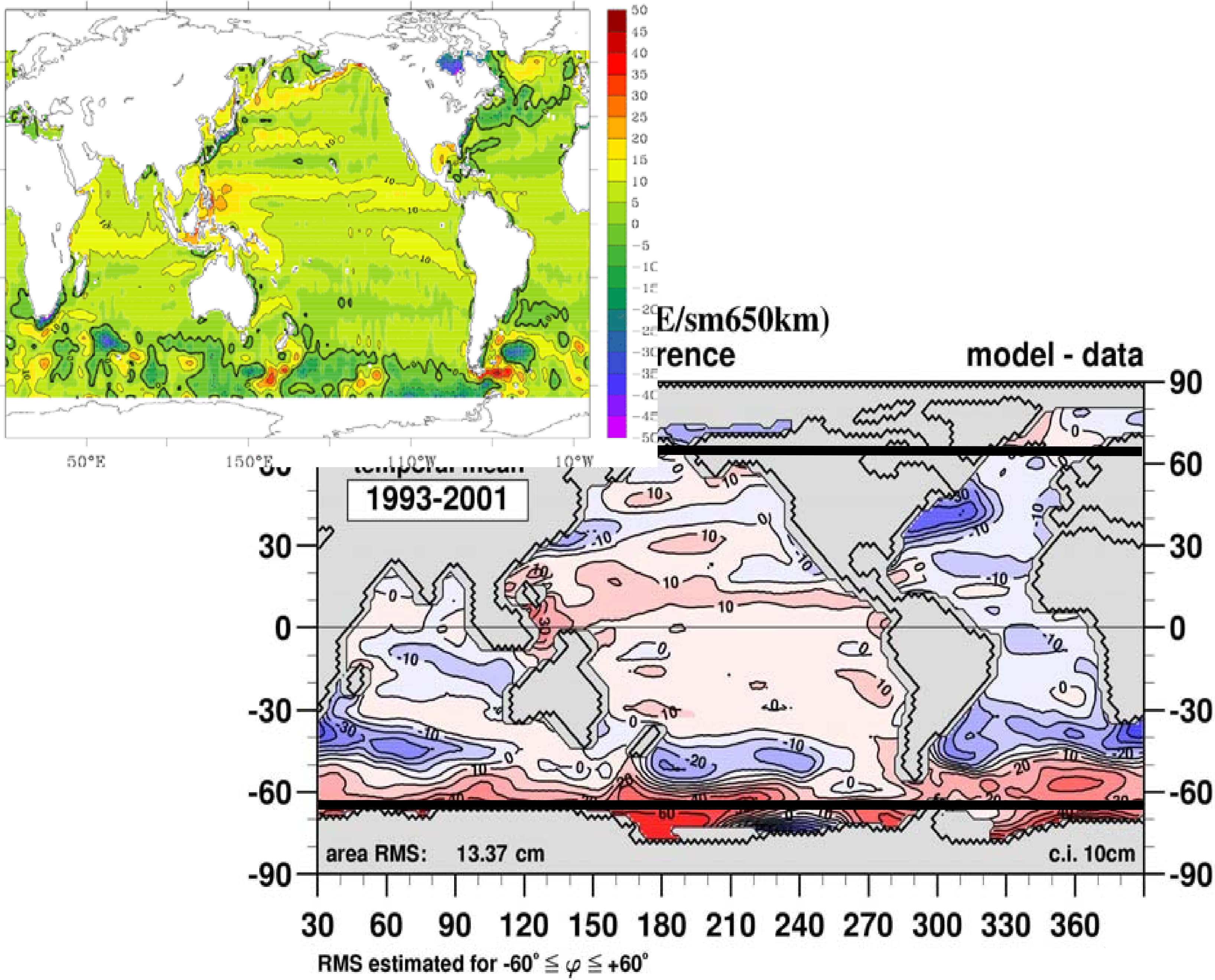
GRACE – EGM96 (cm)



ECCO – GRACE (cm)



Residual SSH values decrease significantly with use of GRACE geoid. New residuals do show dynamical structures. The ECCO estimate of a marine geoid is close to GRACE results.



40°N
0°
40°S
50°E
150°E
110°W
10°W
50
45
40
35
30
25
20
15
10
5
0
−5
E/sm650km)
rence
model - data
1993-2001
area RMS: 13.37 cm
c.i. 10cm
90
60
30
0
-30
-60
-90
30 60 90 120 150 180 210 240 270 300 330 360
RMS estimated for -60° ≦ φ ≦ +60°

Summary

- Altimetry has proven invaluable for ocean circulation and climate studies.
- Many new climate applications are expected.
- Interanual to decadal variability looms large and needs to be a primary focus of a JASON-ARGO analysis.
- New opportunities for studies of the mesoscale and its theory are available now or are anticipated.
- Estimation has become a tool that provides a global syntheses of altimetry and other data in routine manner.
- Pilot ¼ degree smoothing is anticipated to be available at the end of the 5 year ECCO project as a backbone of CLIVAR and GODAE.
- First ECCO science applications include transport computations, surface fluxes, ocean variability, vorticity and energy budgets, angular momentum, etc.
- Ocean data are being used to understand and estimate air-sea fluxes.
- First interdisciplinary applications include CO2 sequestering, ocean mixing, seasonal prediction, climate observing system design.