Inferences and Implications for Parameterizations from a Global Diagnosis of Mesoscale Tracer Stirring

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OMWG Meeting, 12/11 9:25-9:45

The Character of the Mesoscale

(Capet et al., 2008)

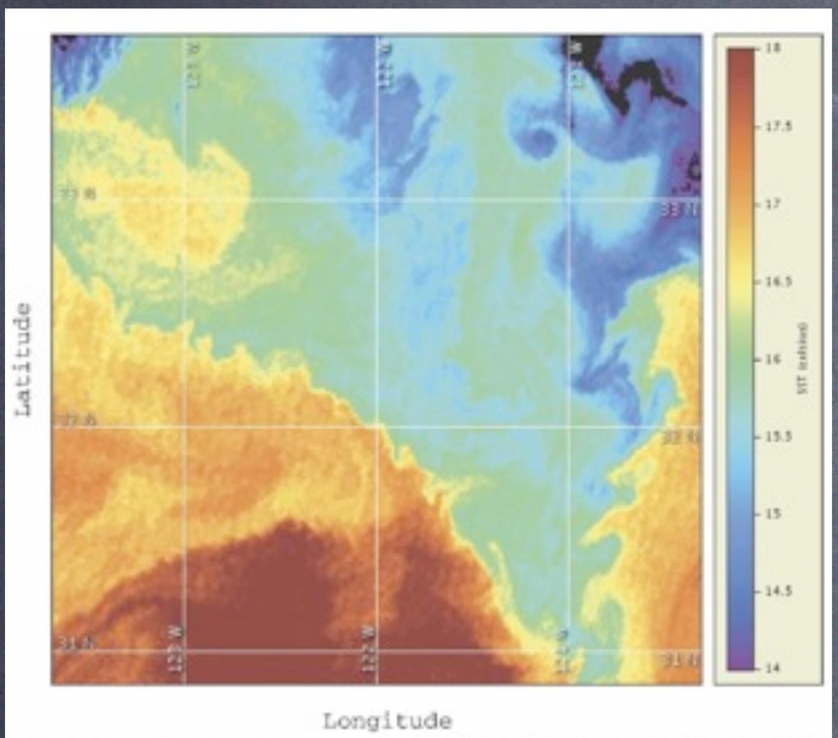
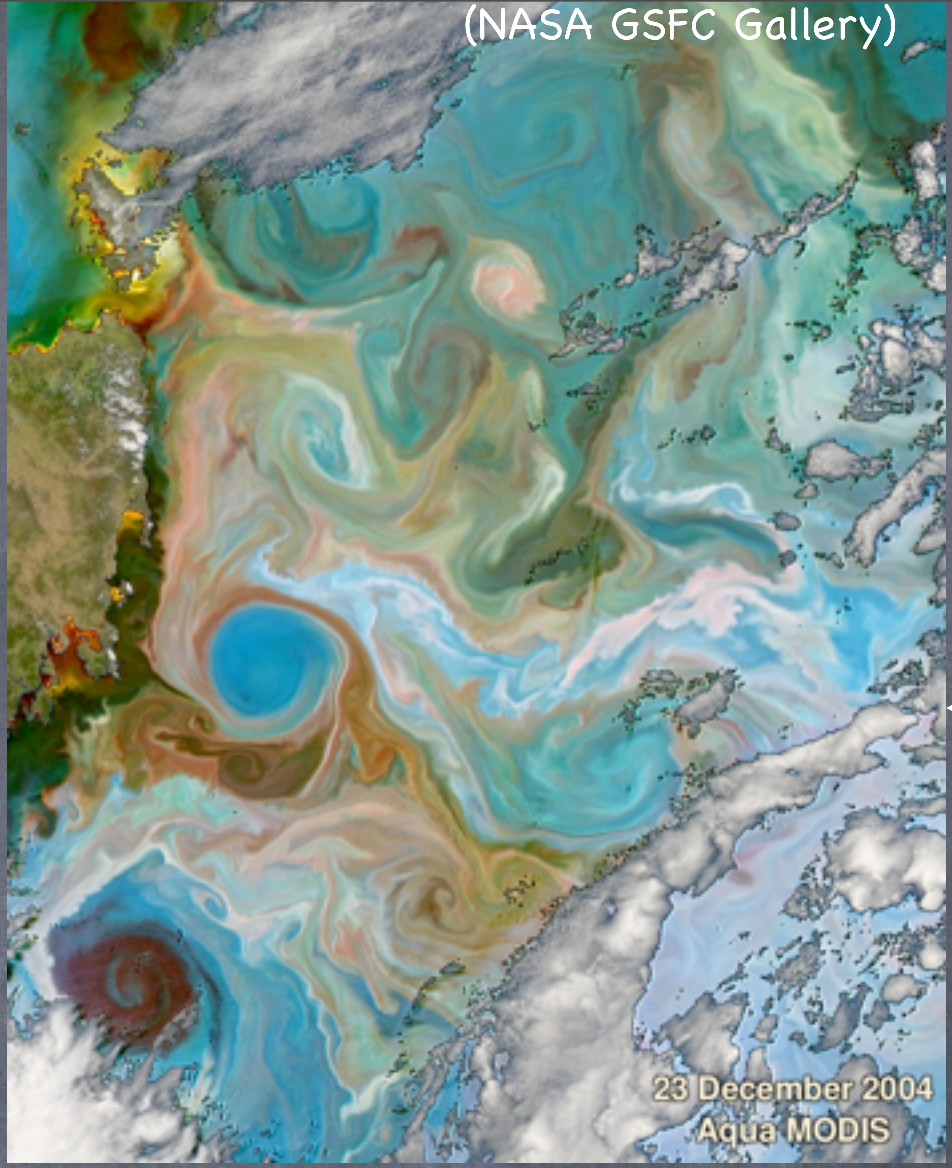


Fig. 16. Sea surface temperature measured at 1832 UTC 3 Jun 2006 off Point Conception in the California Current from CoastWatch (http://coastwatch.pfeg.noaa.gov). The fronts between recently upwelled water (i.e., 15°–16°C) and offshore water (≥17°C) show submesoscale instabilities with wavelengths around 30 km (right front) or 15 km (left front). Images for 1 day earlier and 4 days later show persistence of the instability events.

- Boundary Currents
- Eddies
- Ro=O(0.1)
- Ri=O(1000)
- Full Depth
- Projects on Fronts
- 100km, months

(NASA GSFC Gallery)



100 km

Eddy processes mainly baroclinic & barotropic instability.
Parameterizations of baroclinic instability (GM, Visbeck...).

Tracer Flux-Gradient Relationship

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

- Virtually all extant subgridscale eddy closures may be written as above, e.g.: GM, Redi, FFH
- Relates the eddy flux to the coarse-grain gradients
- May have a flow/property dependent $\mathbf{M}$: (FFH, Visbeck, Green, Held & Larichev, Stone, Canuto & Dubovikov, Griffies et al '05)
- May consider gridscale (FFH, Hallberg & Adcroft)
- Isopycnal & lagrangian coordinate versions possible/known

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

General Form

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yx} & M_{yy} & M_{yz} \\ M_{zx} & M_{zy} & M_{zz} \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

- Diagnostically: 9 elements requires at least 3 similar-transport tracers to specify uniquely
- Could vary tracer by tracer, or active tracer vs. passive, etc. In practice we don't do this.

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

Anistropic* Redi Form

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} K_{xx} & K_{xy} & \hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ K_{yx} & K_{yy} & \hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ \hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \tilde{\nabla}z\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

Yellow Elements are horizontal stirring

Blue Elements in Redi (1982) are symmetric and scaled to make eddy mixing along neutral surfaces

*Anistropic form due to Smith & Gent 04

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

Anisotropic* Gent-McWilliams

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} 0 & 0 & -\hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ 0 & 0 & -\hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ \hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & 0 \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

Antisymmetric Elements in GM (1990)
are scaled to overturn fronts, make vertical fluxes
extract PE, and restratify the fluid
equivalent to eddy-induced advection

Q: Same K as Redi?

*Anistropic form due to Smith & Gent 04 *Tensor Form (Griffies, 98)

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

Fox-Kemper, Ferrari, & Hallberg (2008) form (a mixed layer (submeso) eddy param.):

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} 0 & 0 & -\mathbf{\Psi_y} \\ 0 & 0 & \mathbf{\Psi_x} \\ \mathbf{\Psi_y} & -\mathbf{\Psi_x} & 0 \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

Antisymmetric Elements in Fox-Kemper, Ferrari, & Hallberg (2008) are scaled to overturn fronts, make vertical fluxes extract PE, and restratify the fluid, At a rate validated against eddying simulations!

Need a Natural, Mesoscale Eddy Environment to Test Out:

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = -\begin{bmatrix} M_{xx} & M_{xy} & M_{xz} \\ M_{yx} & M_{yy} & M_{yz} \\ M_{zx} & M_{zy} & M_{zz} \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

3 equations/tracer

9 unknowns ($\mathbf{M}$ components)

BY USING 3 or MORE TRACERS, can determine $\mathbf{M}$!!!

(a la Plumb & Mahlman ‘87, Bratseth ‘98)

Use a Natural, Mesoscale Eddy Environment to Test Out:

$$\overline{\mathbf{u}'\tau'} = -\mathbf{M}\nabla\overline{\tau}$$

We Use:

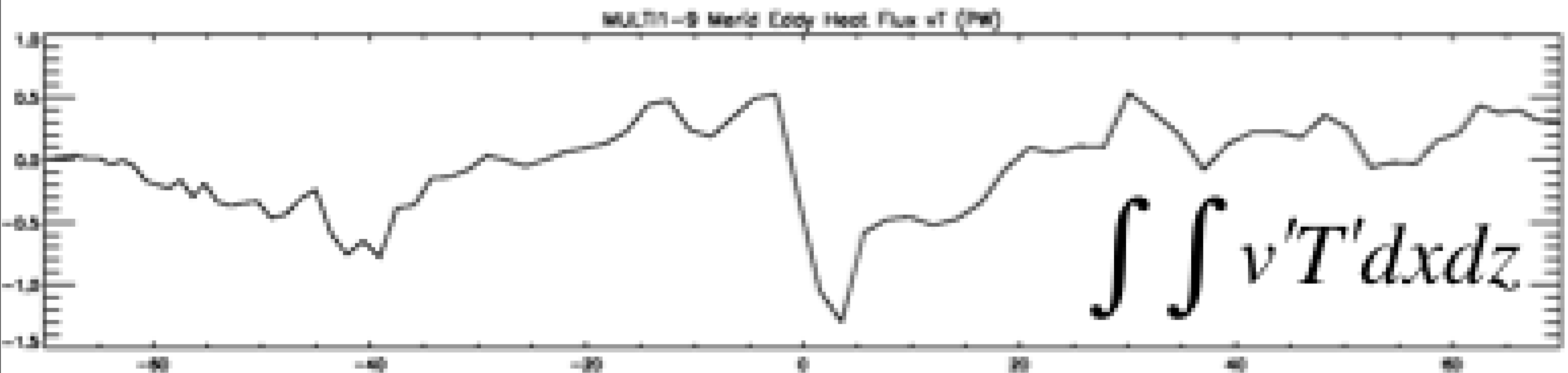
Years 16-20 of a Global 0.1 Degree Model (sim to Maltrud & McClean '06)

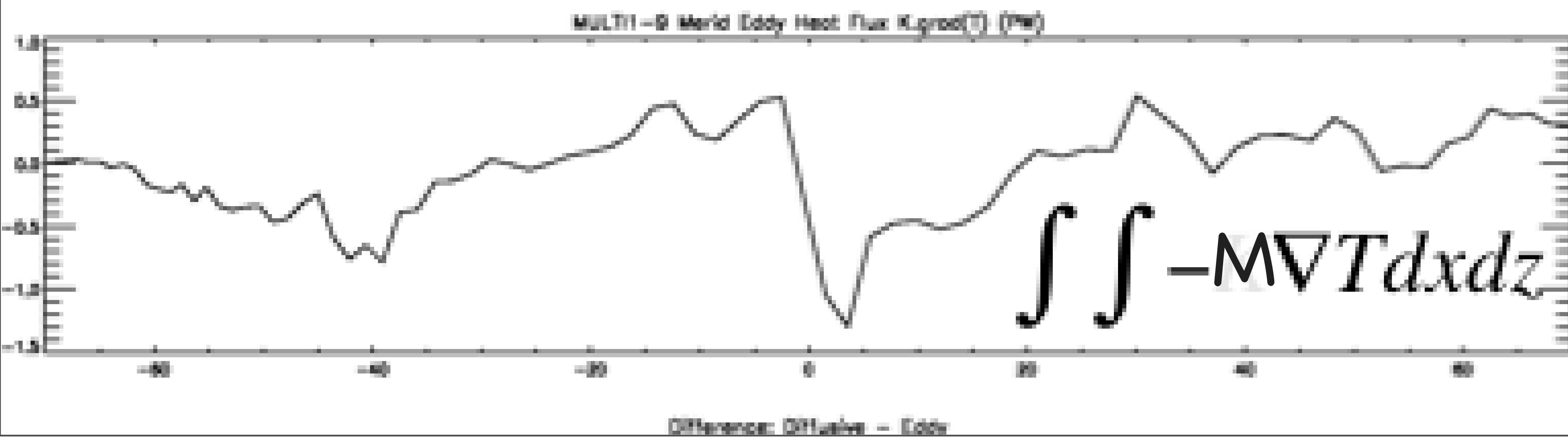
9 Passive Tracers To Overdetermine $\mathbf{M}$

Use a Natural, Mesoscale Eddy Environment to Test Out:

Testing the Diagnosis:

Note: T not used for diagnosis, active tracers are apparently transported as passive ones are!

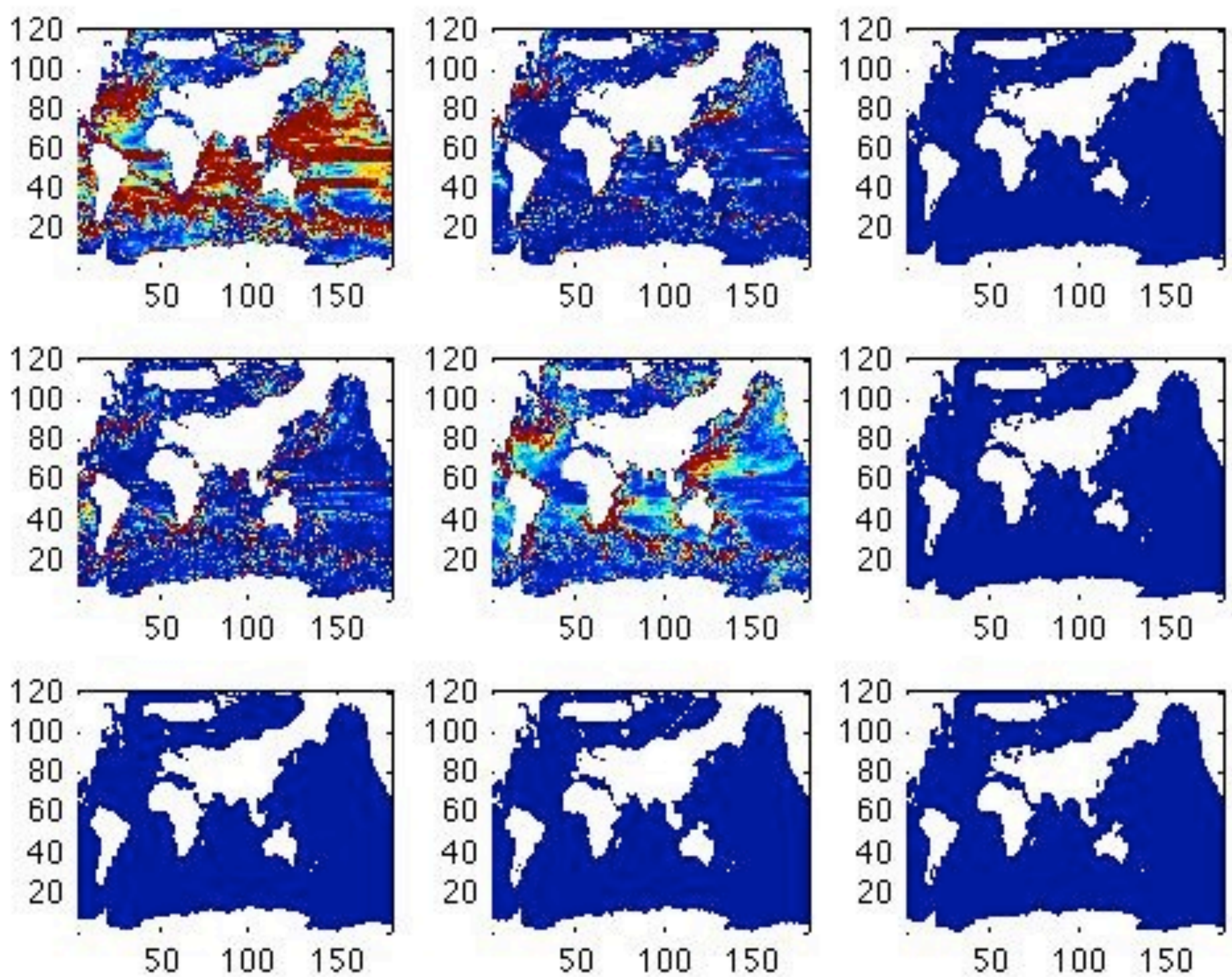


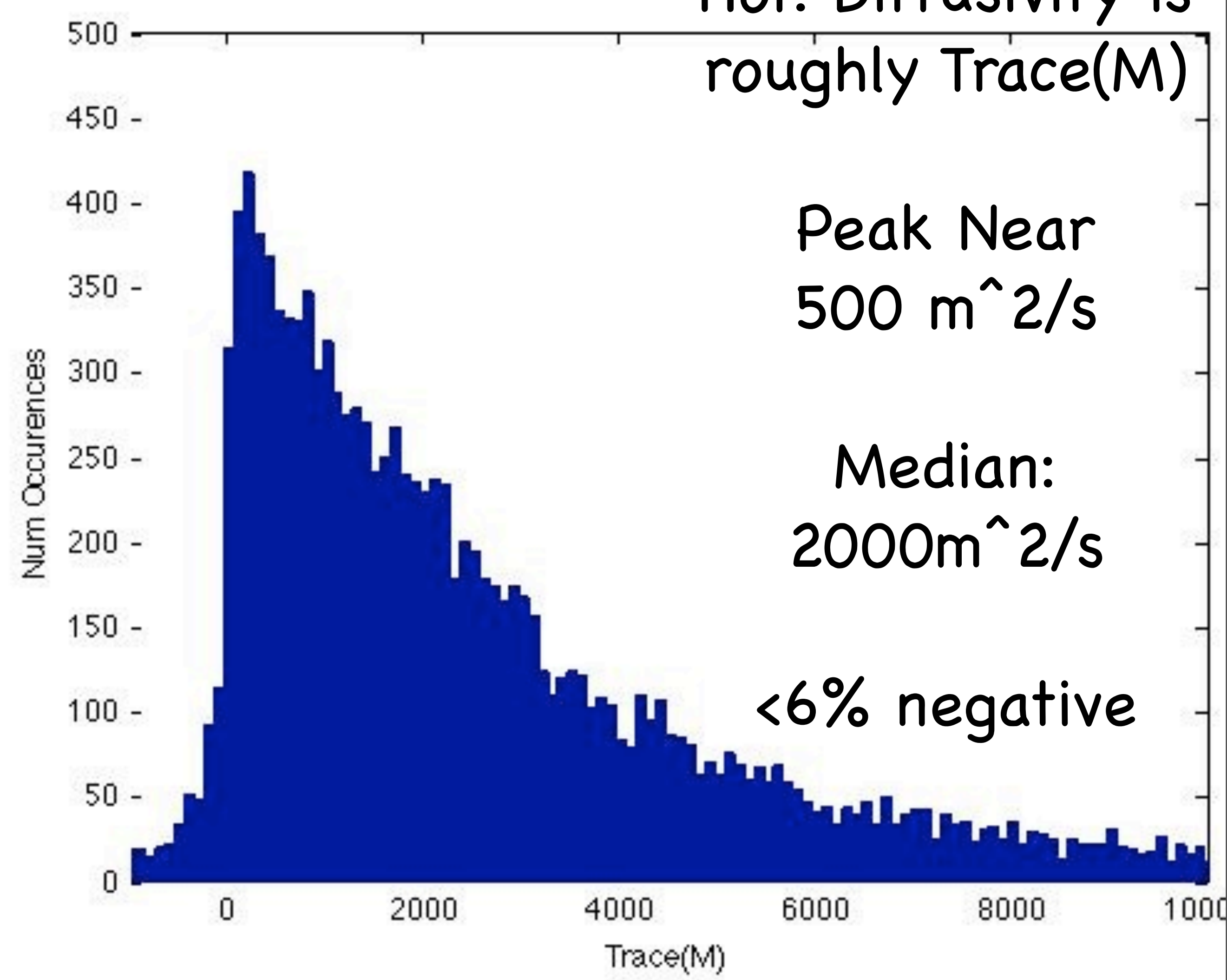


Use a Natural, Mesoscale Eddy Environment to Test Out:

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} K_{xx} & K_{xy} & \hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ K_{yx} & K_{yy} & \hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ \hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \tilde{\nabla}z\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

Correct shape/scale at 150m depth:





Hor. Diffusivity is roughly Trace(M)

Peak Near 500 m^2/s

Median: 2000m^2/s

<6% negative

Use a Natural, Mesoscale Eddy Environment to Test Out:

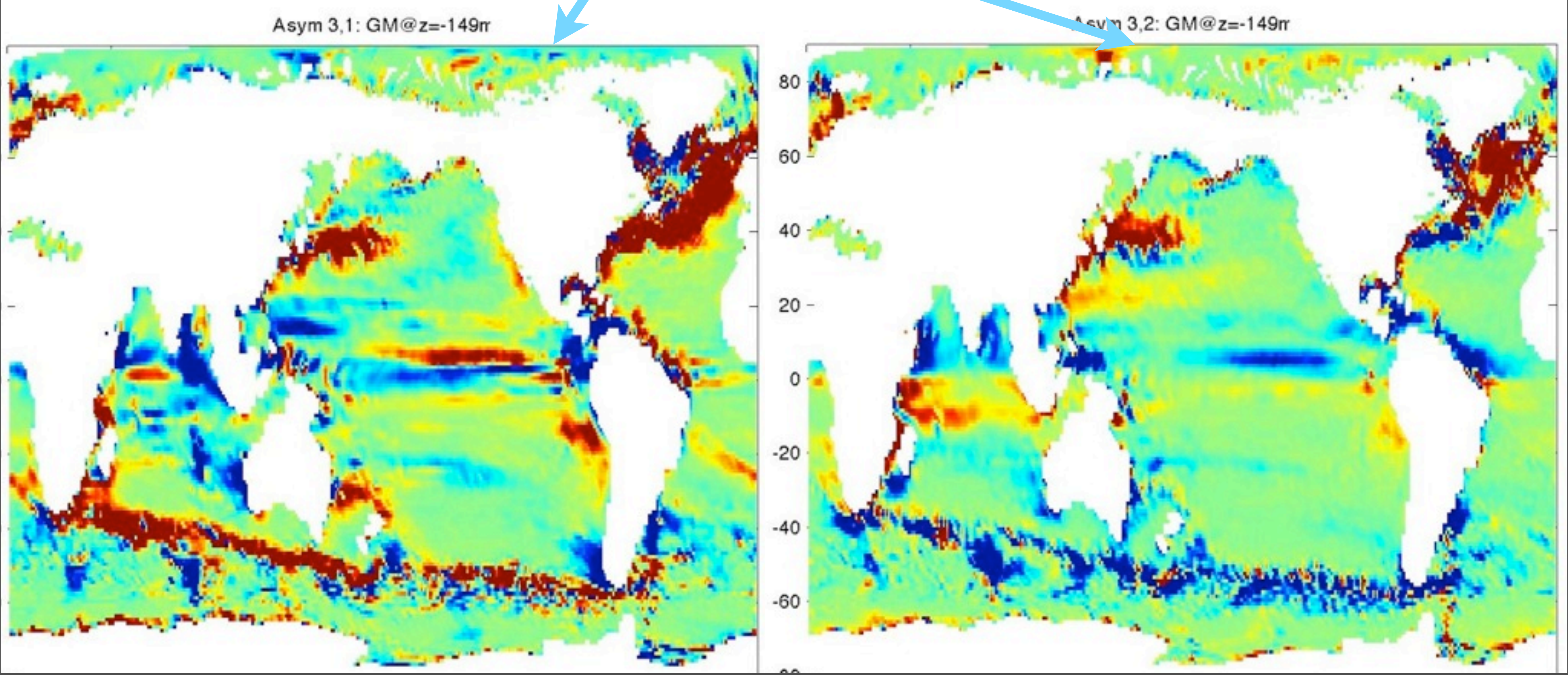
$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} 0 & 0 & -\hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ 0 & 0 & -\hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ \hat{\mathbf{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \hat{\mathbf{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & 0 \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$

Result 1: Antisymmetric (GM) Elements scale with corresponding Symmetric (Redi) elements in extratropics.

Thus, GM/Redi basic shape of M is roughly correct (some detailed validation remains)

Use a Natural, Mesoscale Eddy Environment to Test Out:

$$\begin{bmatrix} \overline{u'\tau'} \\ \overline{v'\tau'} \\ \overline{w'\tau'} \end{bmatrix} = - \begin{bmatrix} 0 & 0 & -\mathbf{\hat{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ 0 & 0 & -\mathbf{\hat{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} \\ \mathbf{\hat{x}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & \mathbf{\hat{y}}\cdot\mathbf{K}\cdot\tilde{\nabla}\mathbf{z} & 0 \end{bmatrix} \begin{bmatrix} \overline{\tau}_x \\ \overline{\tau}_y \\ \overline{\tau}_z \end{bmatrix}$$



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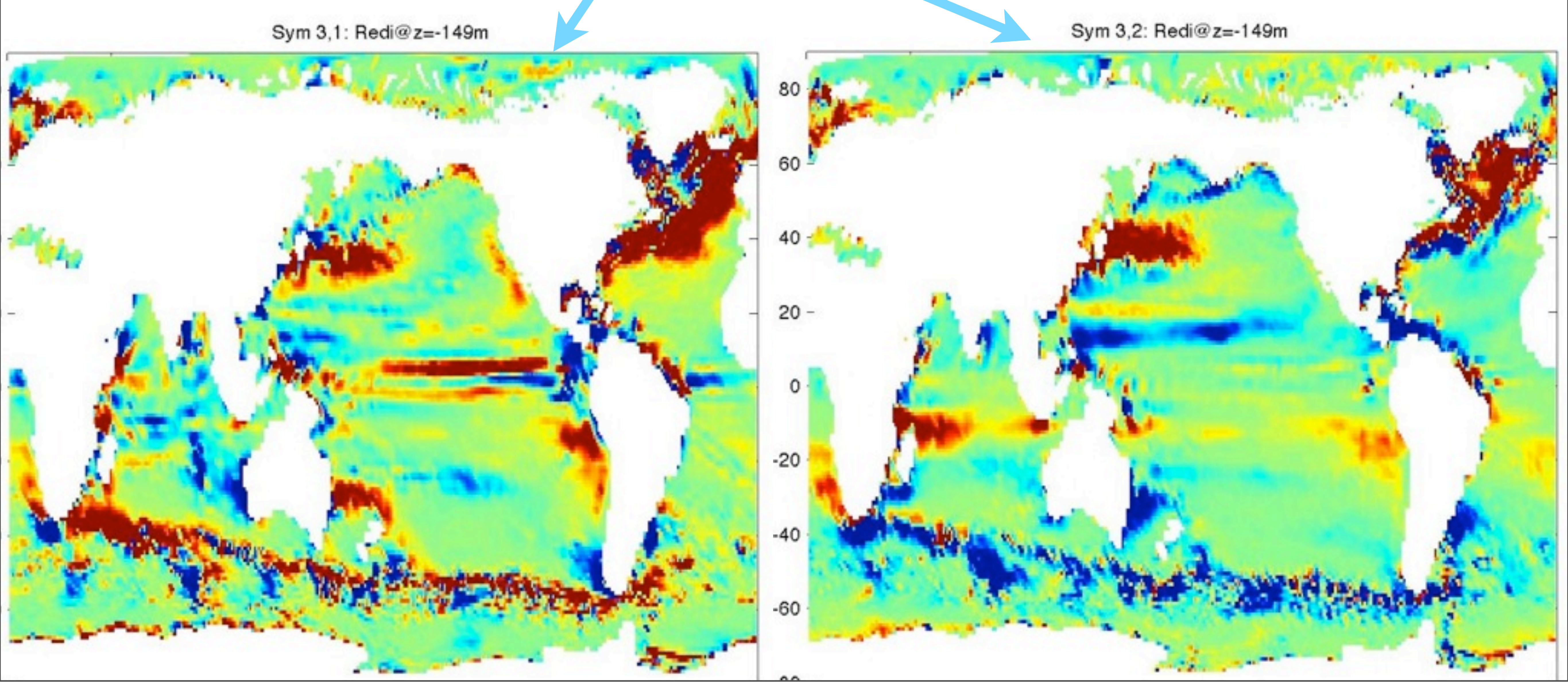

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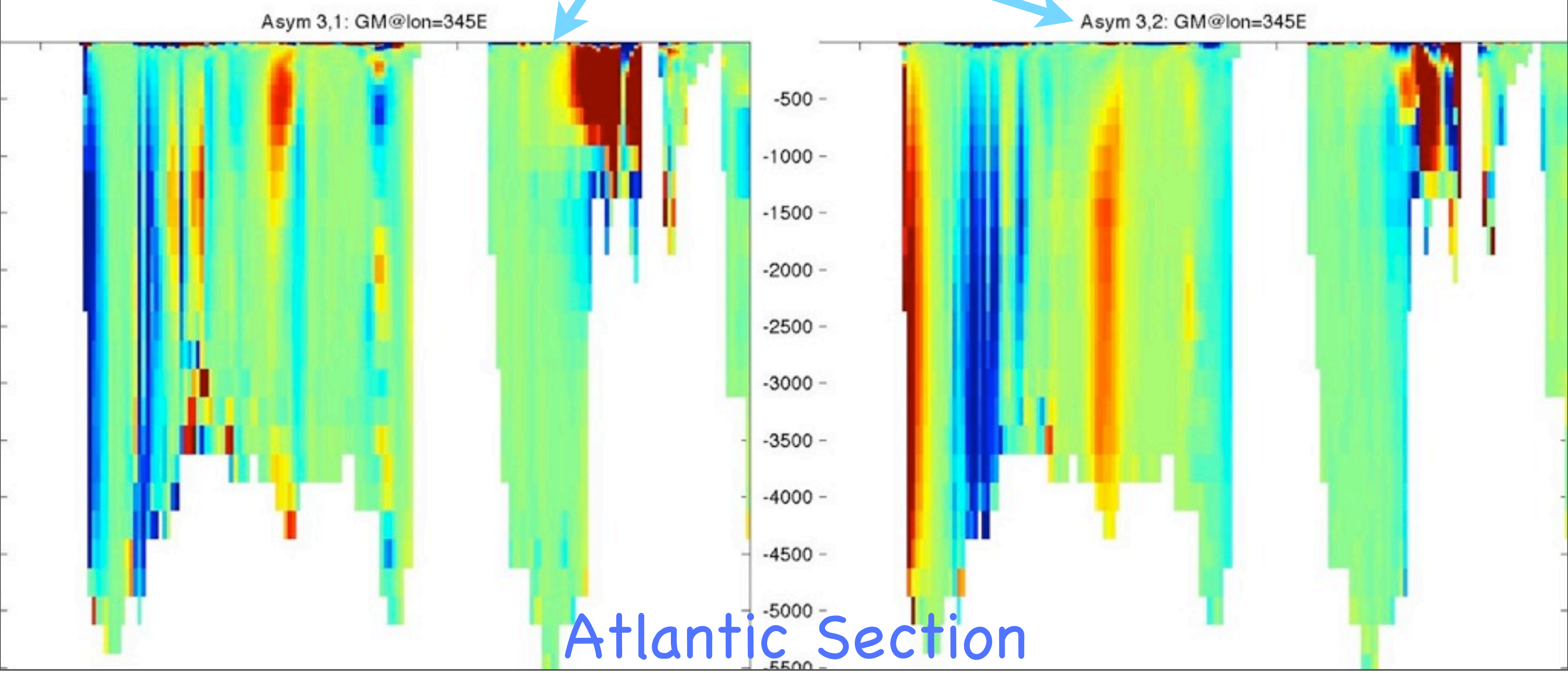

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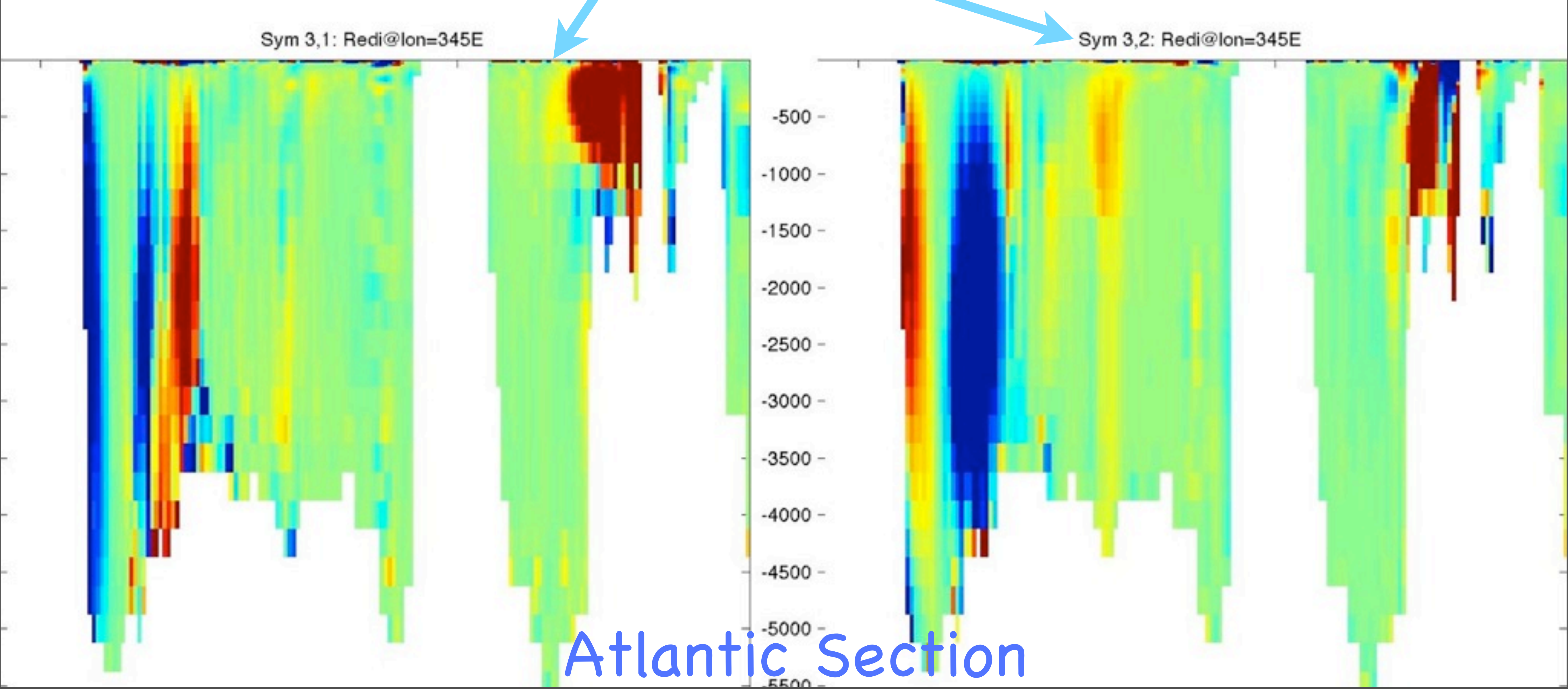

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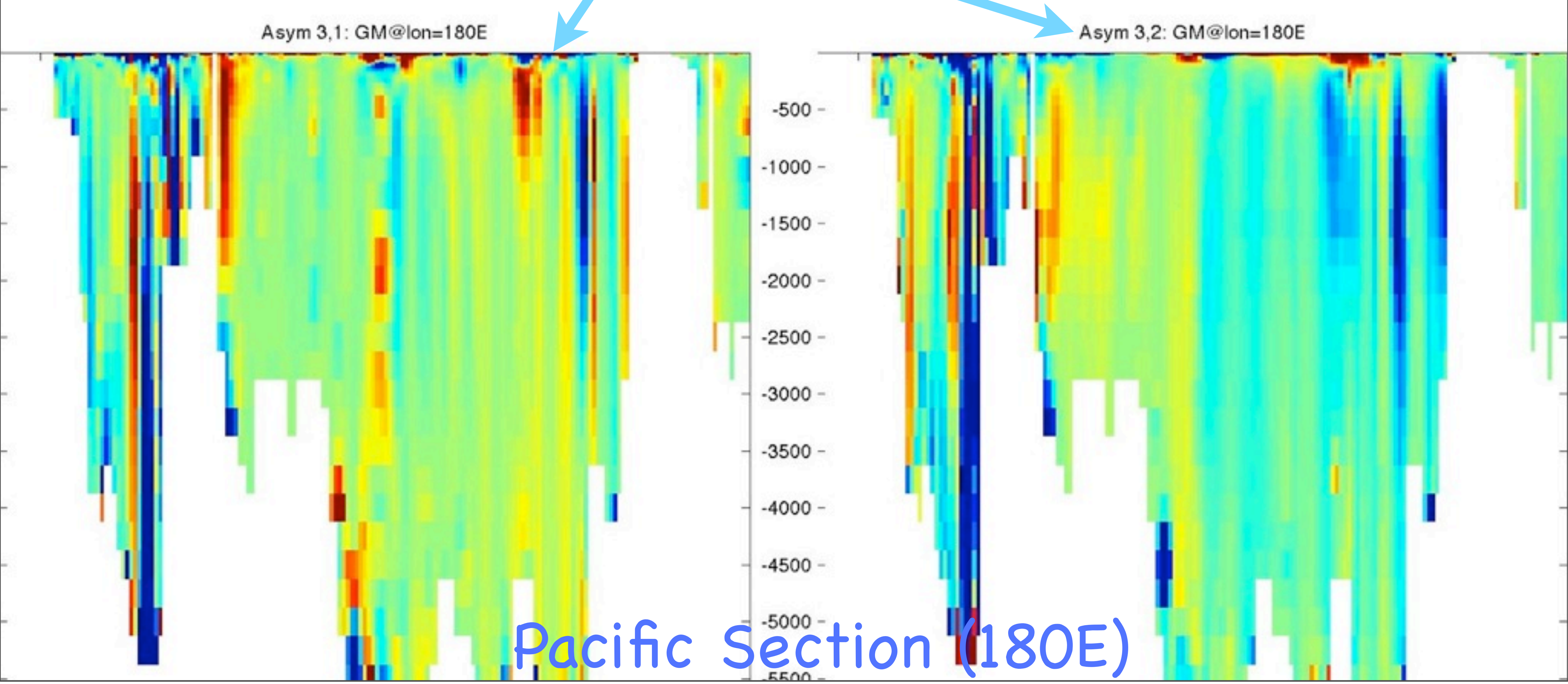

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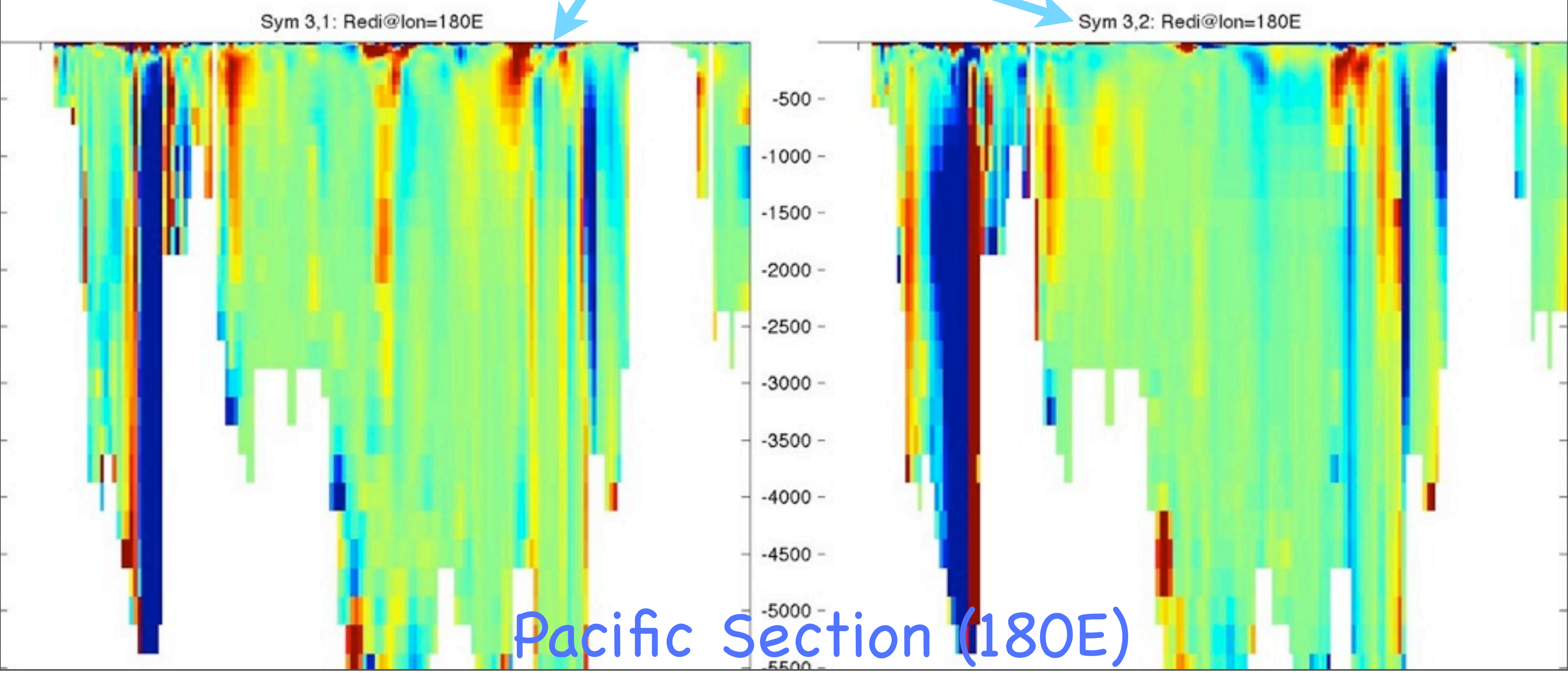
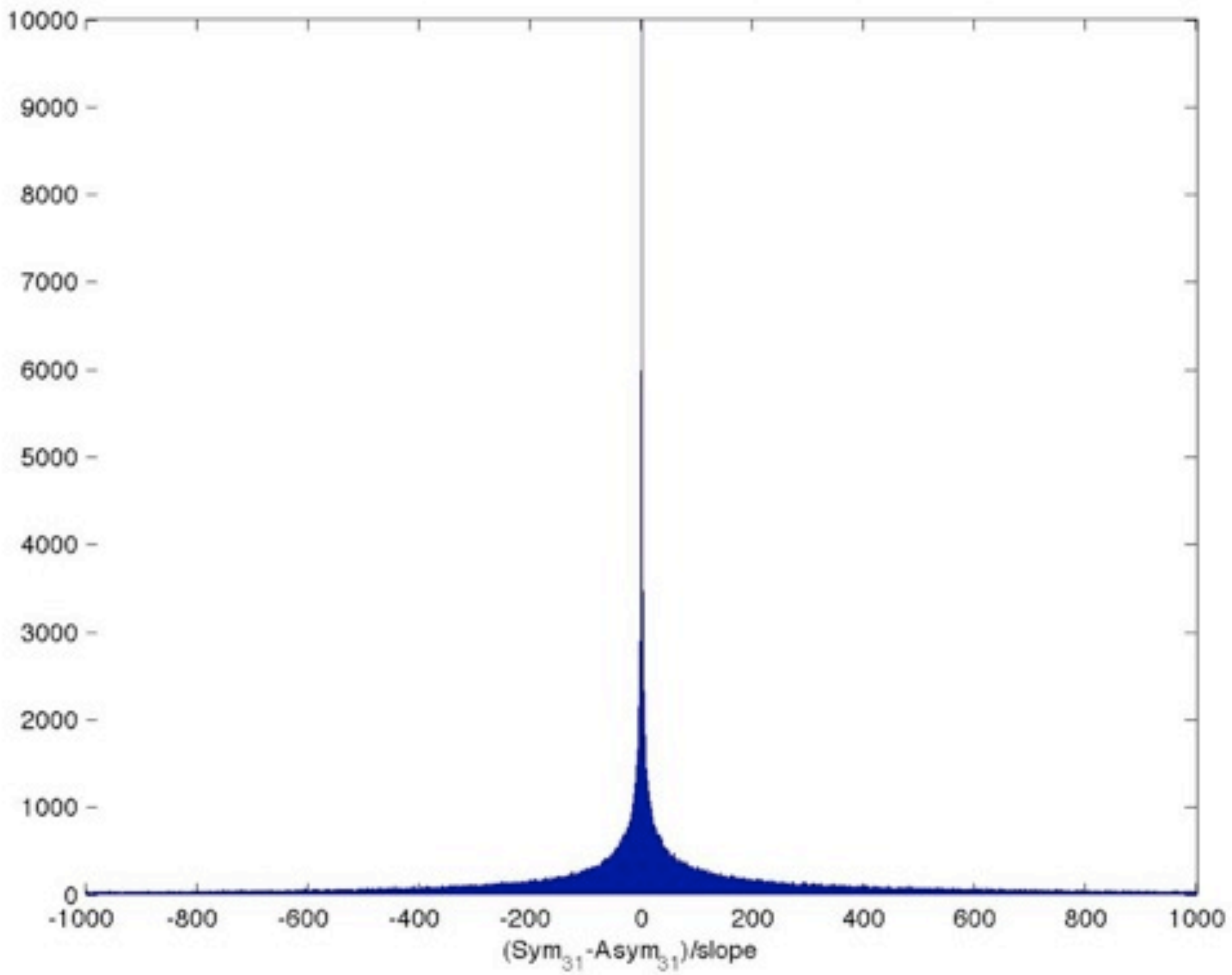
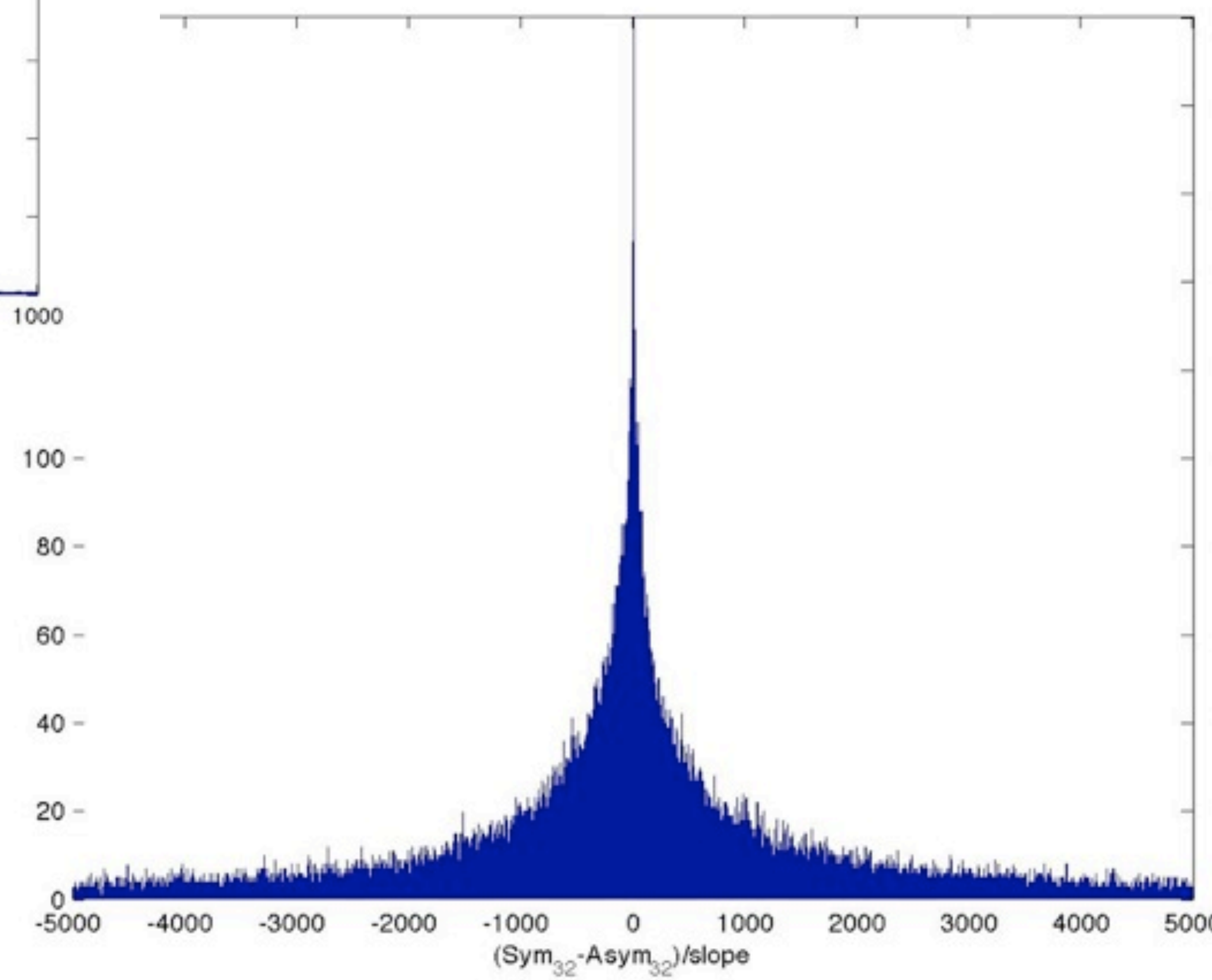


Pacific Section (180E)

Histograms of |K| Sym & Asym differences





These are clearly peaked near 0, but the distribution has big tails!

NSEF & Diabatic/ Transition Layer

- Danabasoglu & Marshall
- Danabasoglu, Ferrari & McWilliams
- Ferrari, McWilliams, Canuto, Dubovikov
- Surface-intensified GM, no boundary condition issues, no over-restratificiation of Mixed Layer by Eddies

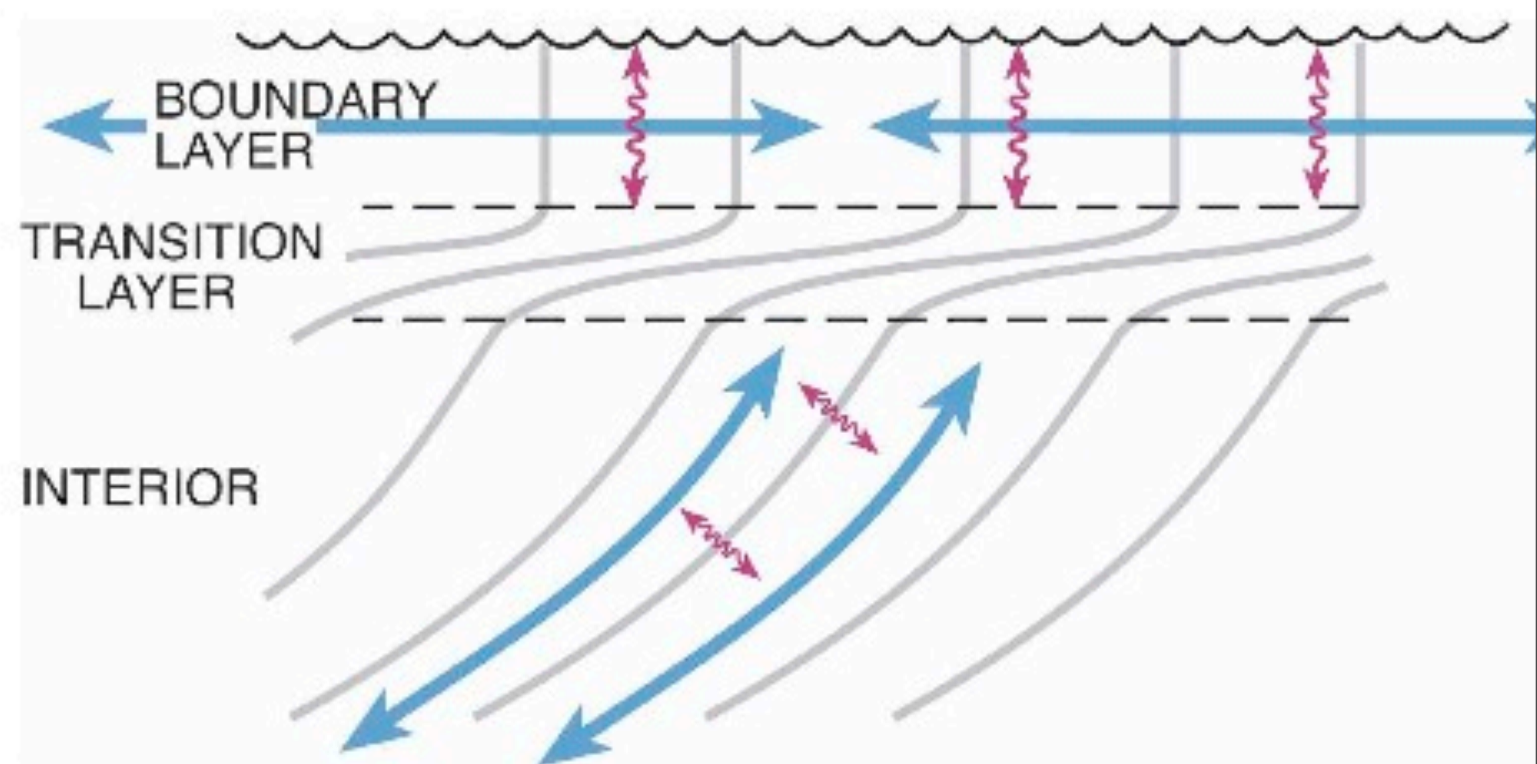
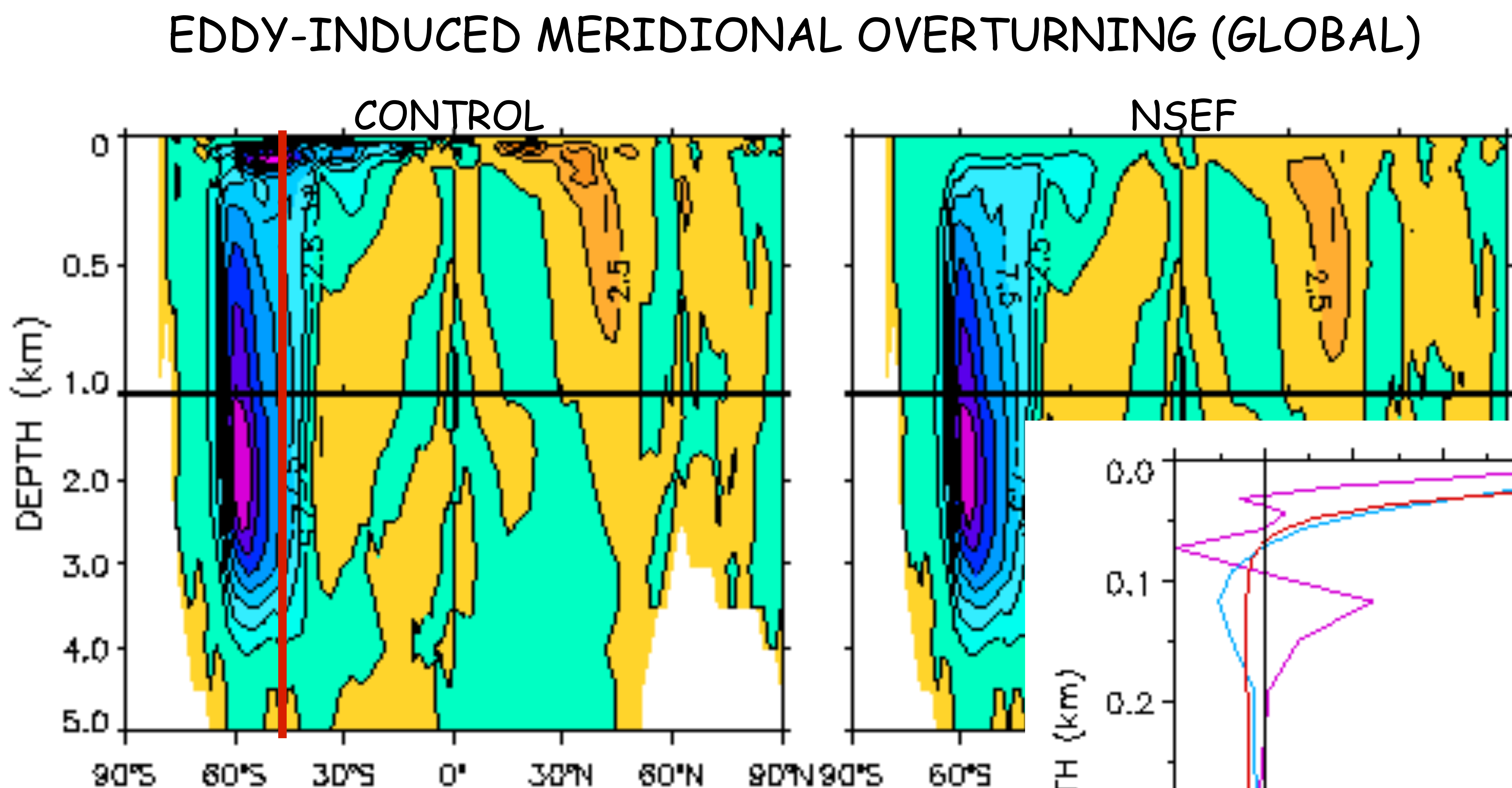
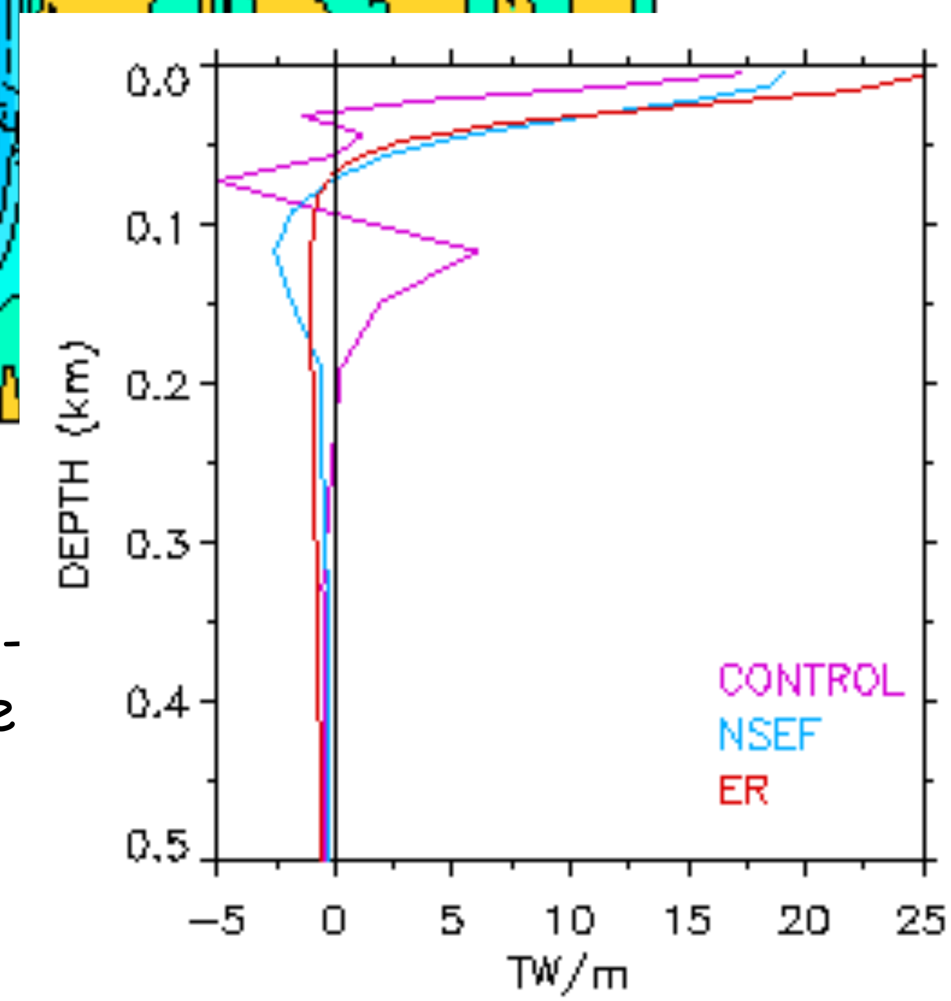


FIG. 2. A conceptual model of eddy fluxes in the upper ocea
Mesoscale eddy fluxes (blue arrows) act to both move isopycr
surfaces and stir materials along them in the oceanic *interior*, b
the fluxes become parallel to the boundary and cross density su
faces within the *BL*. Microscale turbulent fluxes (red arrows) m

Near-surface eddy flux scheme
(Ferrari, McWilliams, Canuto, Dubovikov)



Vertical profile of zonally-integrated total advective heat flux at 49°S



A new eddy parameterization (Ferrari, Griffies, Nurser & Vallis)

- The eddy streamfunction is given by the elliptic problem

$$\left(c^2 \frac{d^2}{dz^2} - N^2\right)\tilde{\mathbf{\Psi}} = -\kappa \nabla \bar{b}$$

$$\tilde{\mathbf{\Psi}} = 0, \quad z = 0, -H$$

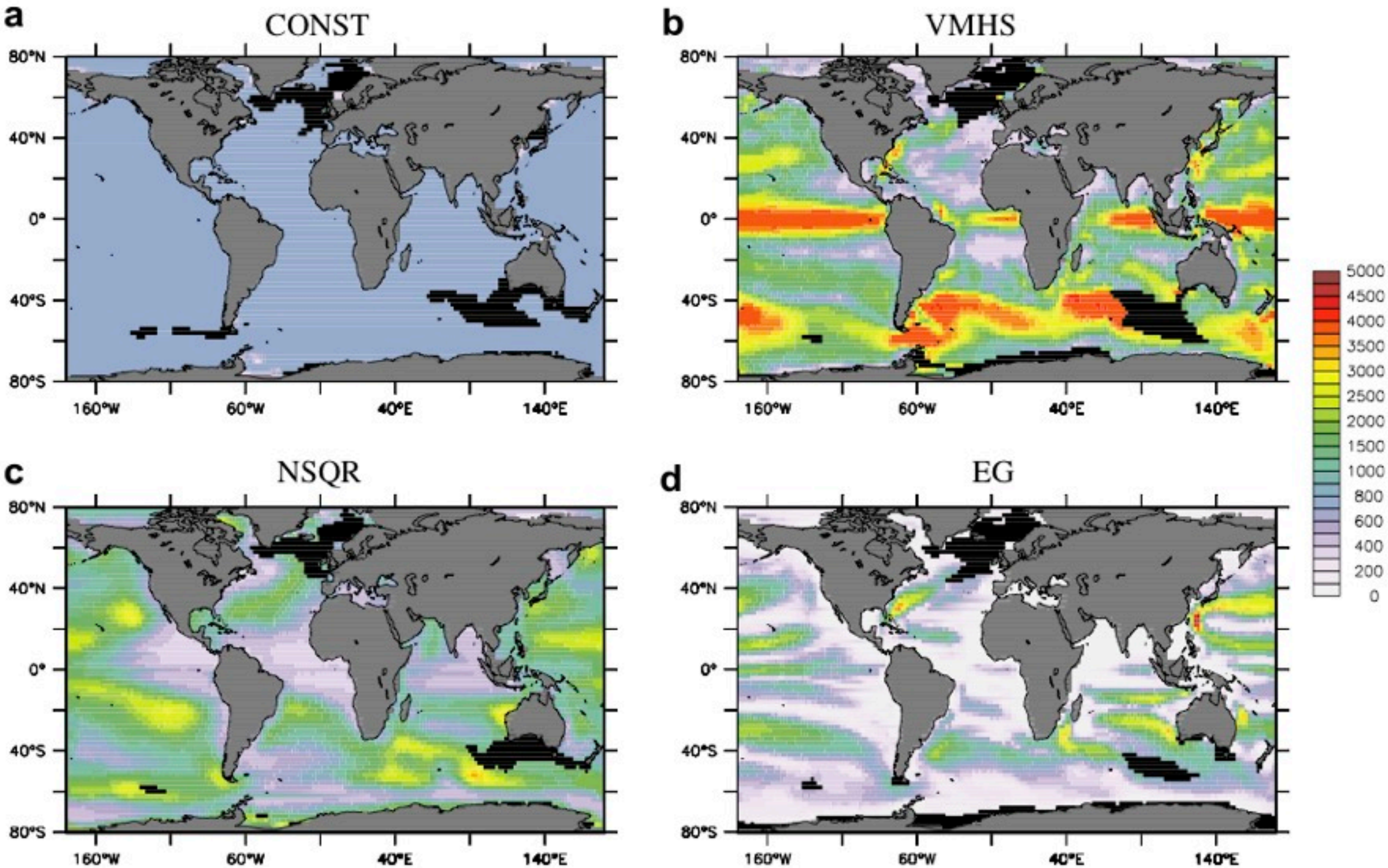
Properties of the new parameterization

- releases mean available potential energy
- the eddy transport vanishes at the ocean boundaries
- the eddy transport is dominated by the first baroclinic mode (if c is set to speed of first baroclinic mode)
- does not require any tapering function
- reduces to GM for c=0

noaaresearch

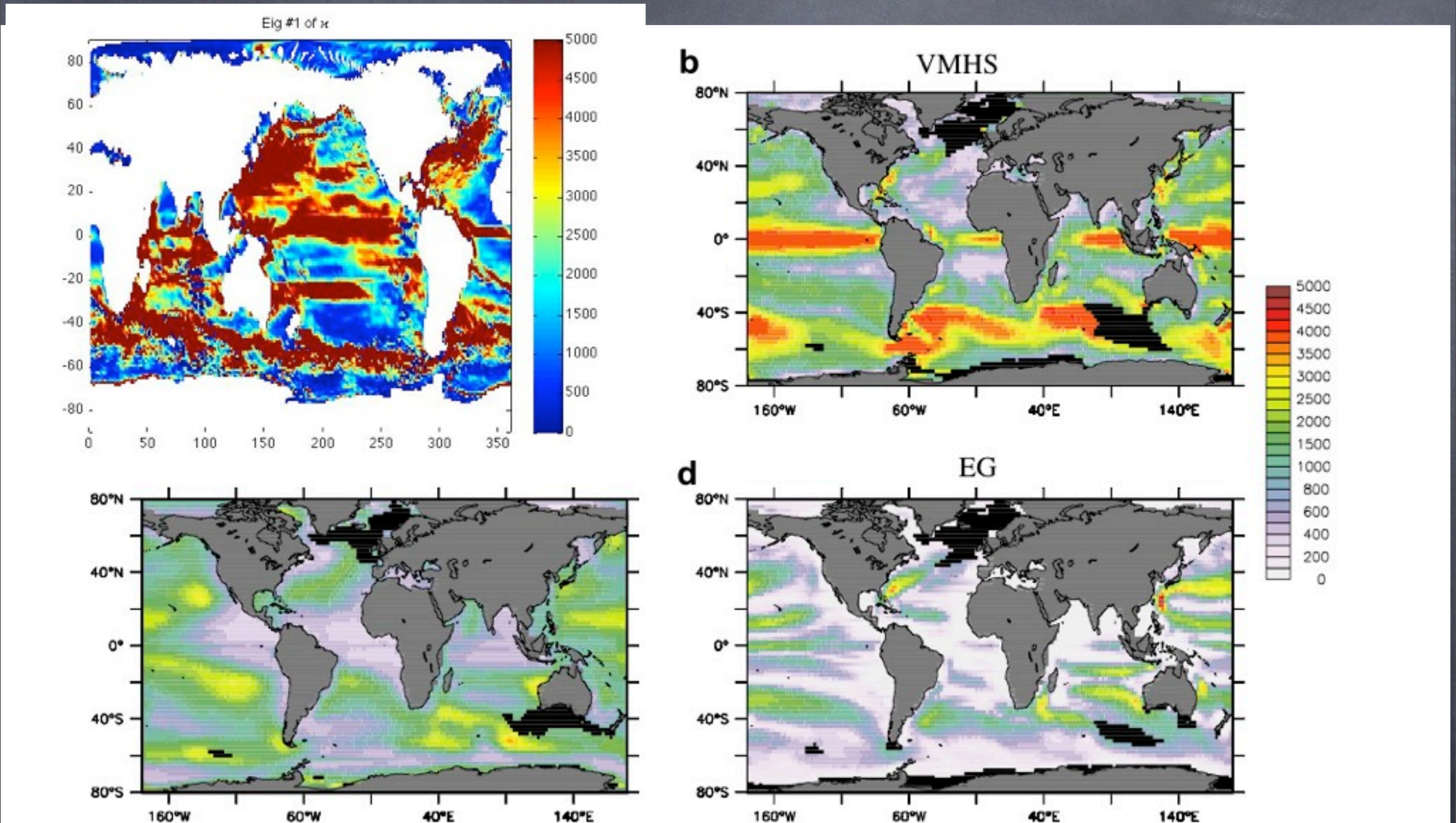
GFDL

Eden, Jochum, Danabasoglu:



g. 1. Annual mean thickness diffusivity (K) in m^2/s at 300 m depth in experiment CONST (a), VMHS (b), NSQR (c) and EG (d) after 500 years integration. Values of K are own for the interior region only, i.e. values of K in the (seasonal maximum) diabatic surface and transition layer are not shown and shaded black. Note the non-linear colour ale for the thickness diffusity. Note also that the data have been interpolated from the model grid to a regular rectangular grid of similar resolution prior to plotting. The nd mask in the figure (taken from Smith and Sandwell (1997)) differs therefore slightly from the model's land mask.

Eden, Jochum, Danabasoglu vs. Eigenvalue #1



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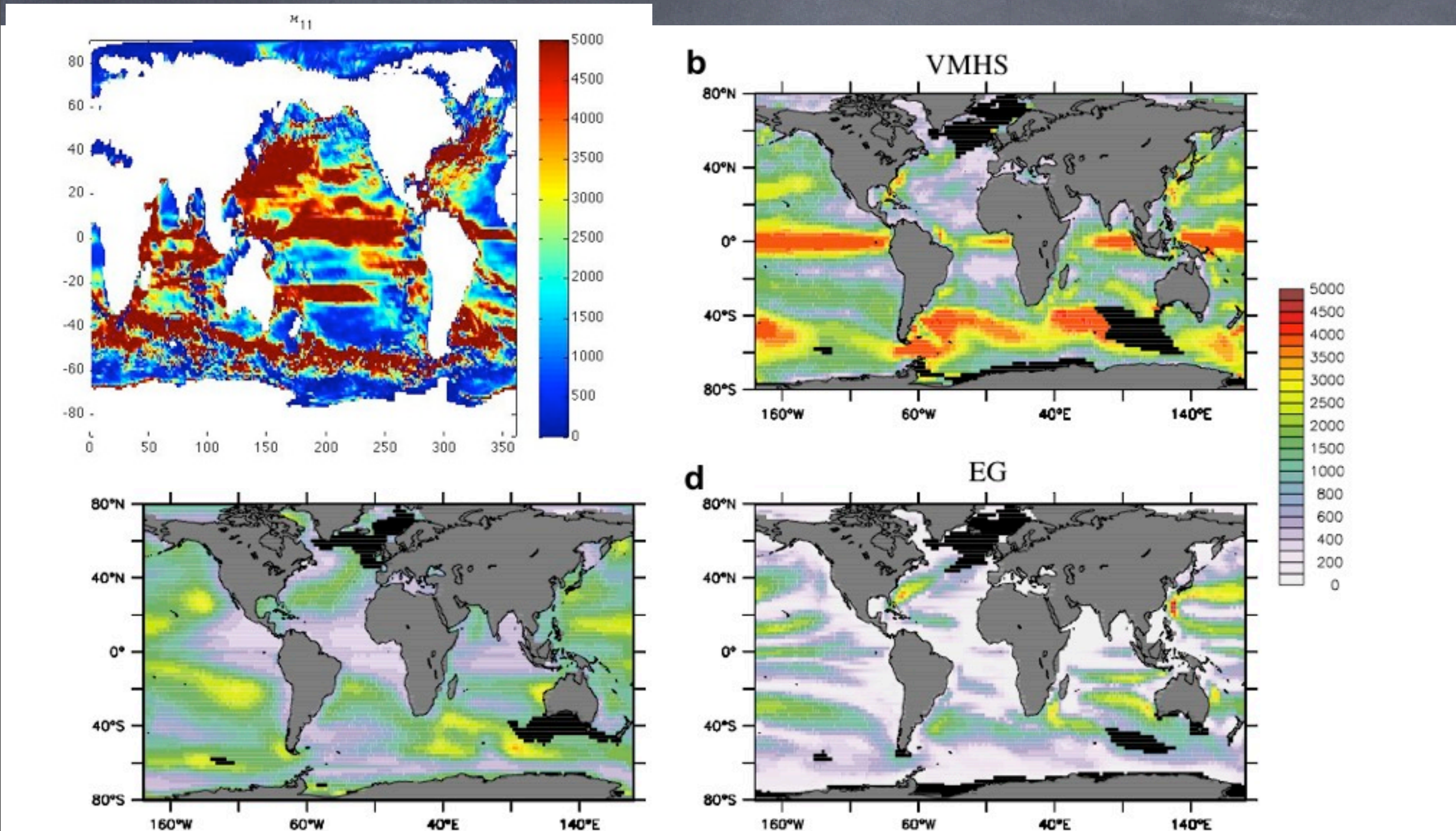
Eden, Jochum, Danabasoglu
vs. M_{22}



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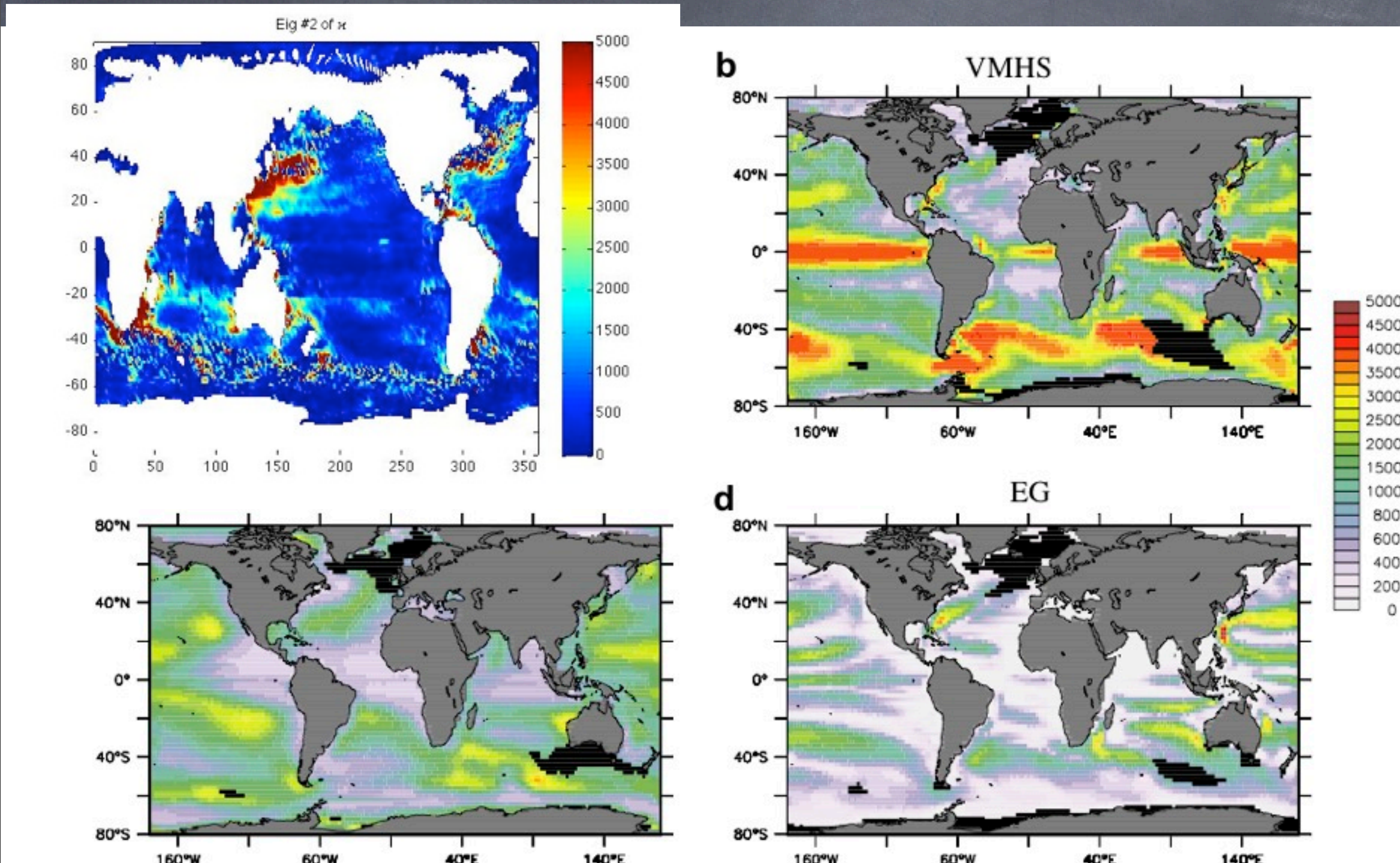
Eden, Jochum, Danabasoglu
vs. Eigenvalue #2



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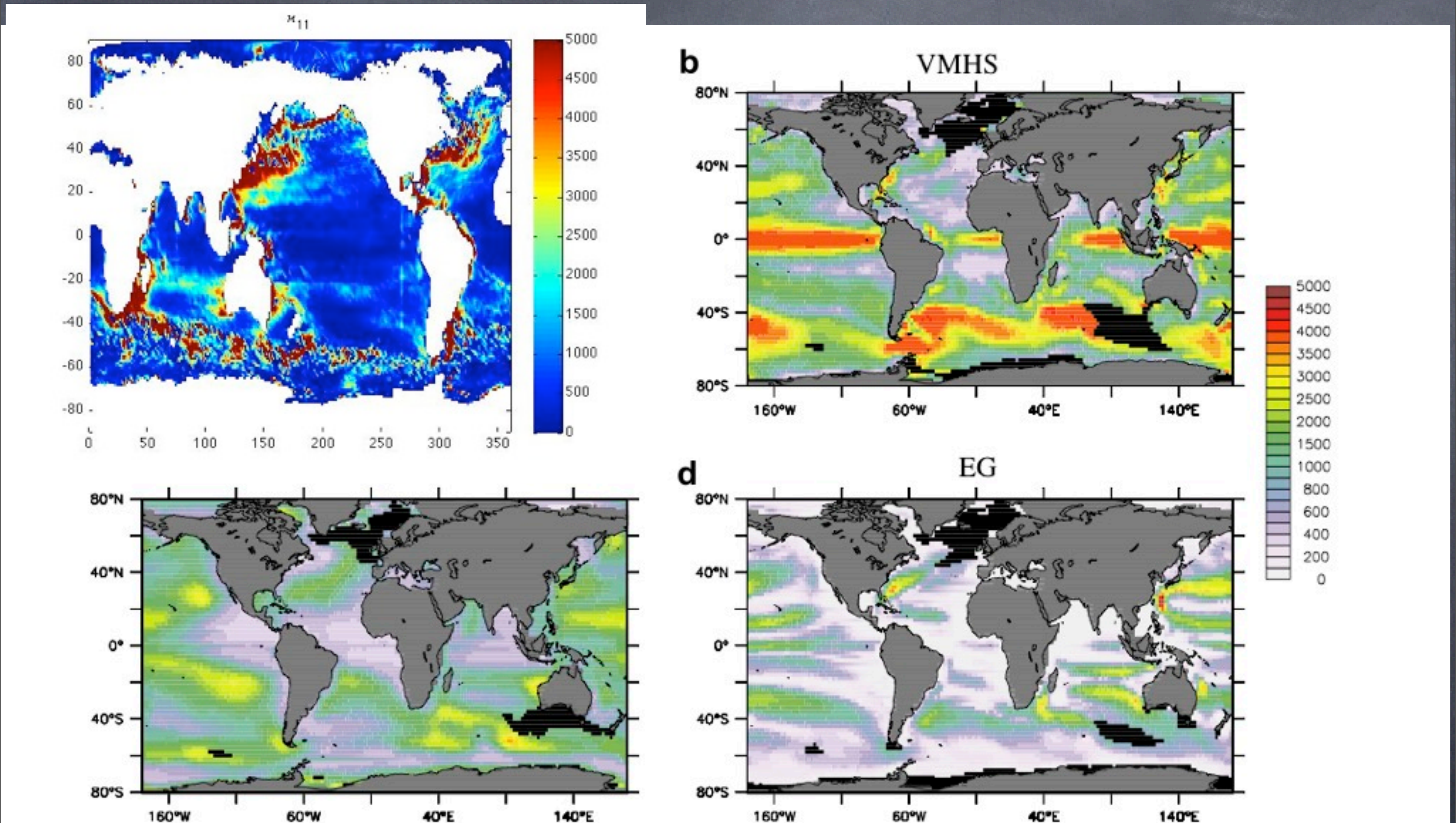
Eden, Jochum, Danabasoglu vs. M_{11}



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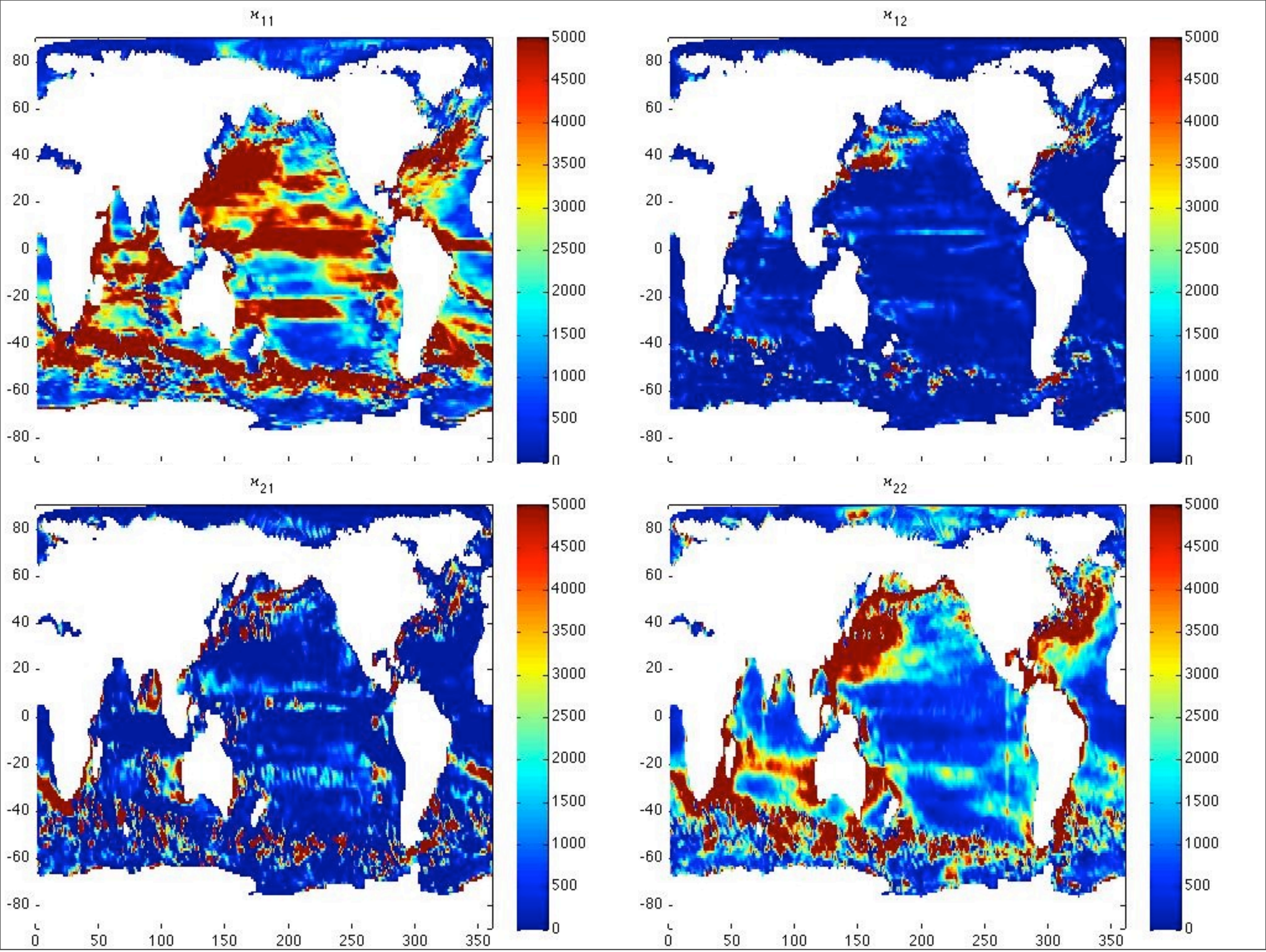
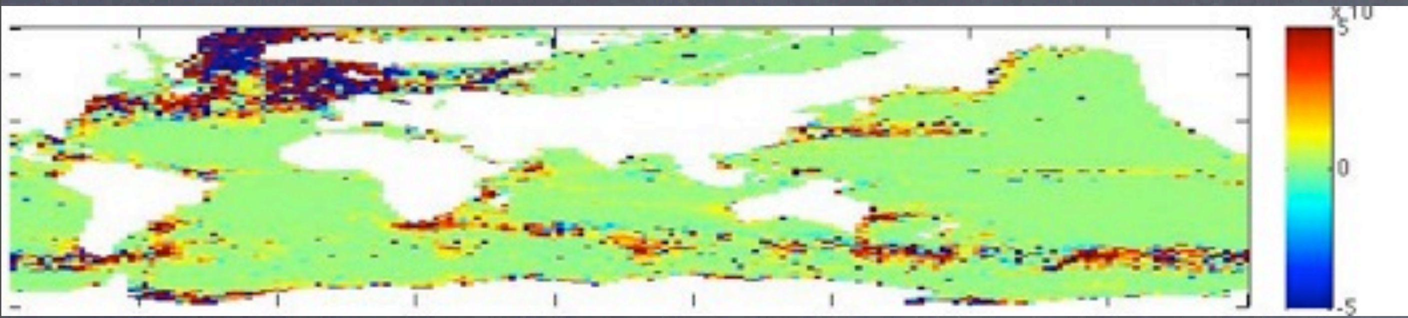


κ_{11}
κ_{12}
κ_{21}
κ_{22}
80
60
40
20
0
-20
-40
-60
-80
0
50
100
150
200
250
300
350
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0



Conclusions

- Passive Tracers are used in a global 0.1 model to diagnose Mesoscale Flux-Gradient Relationship

- Resembles $\mathrm{GM} \approx \mathrm{Redi}$ with O(500 to 2000m^2/s at 150m depth, but long tails...)

- Strongly anisotropic (mostly zonal, strong flow)

- Depth-dependent Streamfunction: MLB intensified changes behavior in diabatic/mixed layer

- K does not scale well with Mean KE or N^2

- Active vs. Passive tracers apparently not an issue

- M_{zx} & M_{xz} are O(along-iso), detailed contrast later

Comparisons with Marshall et al.

Ferreira, Marshall, Heimbach 05

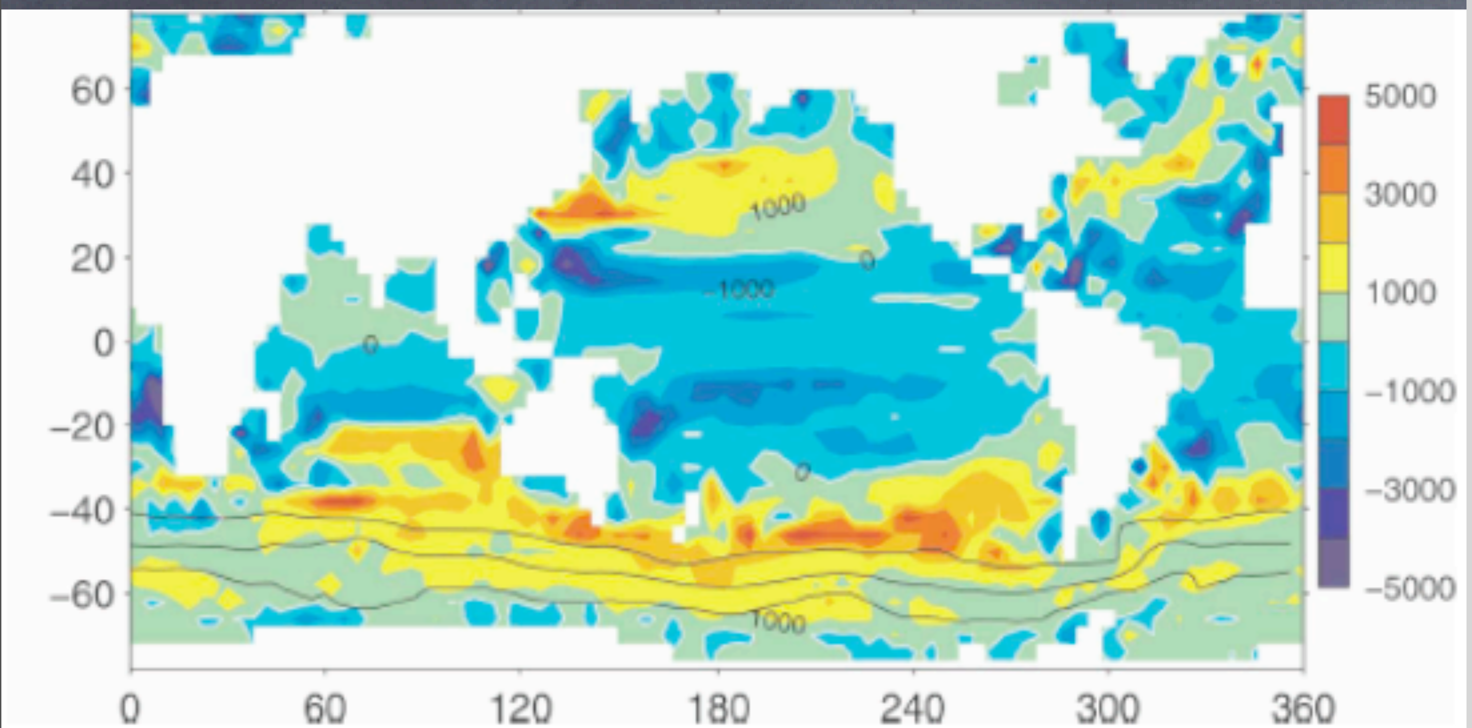
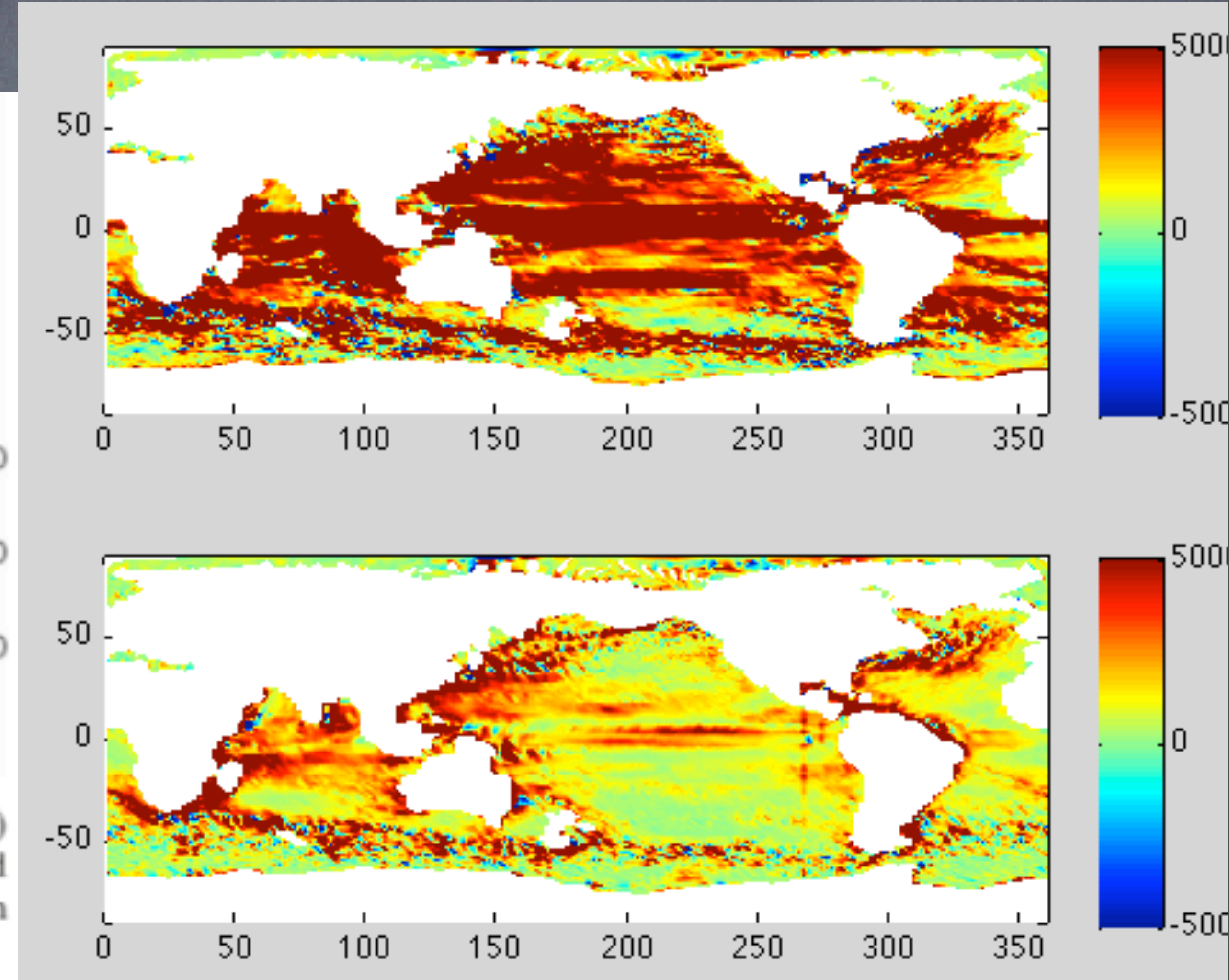
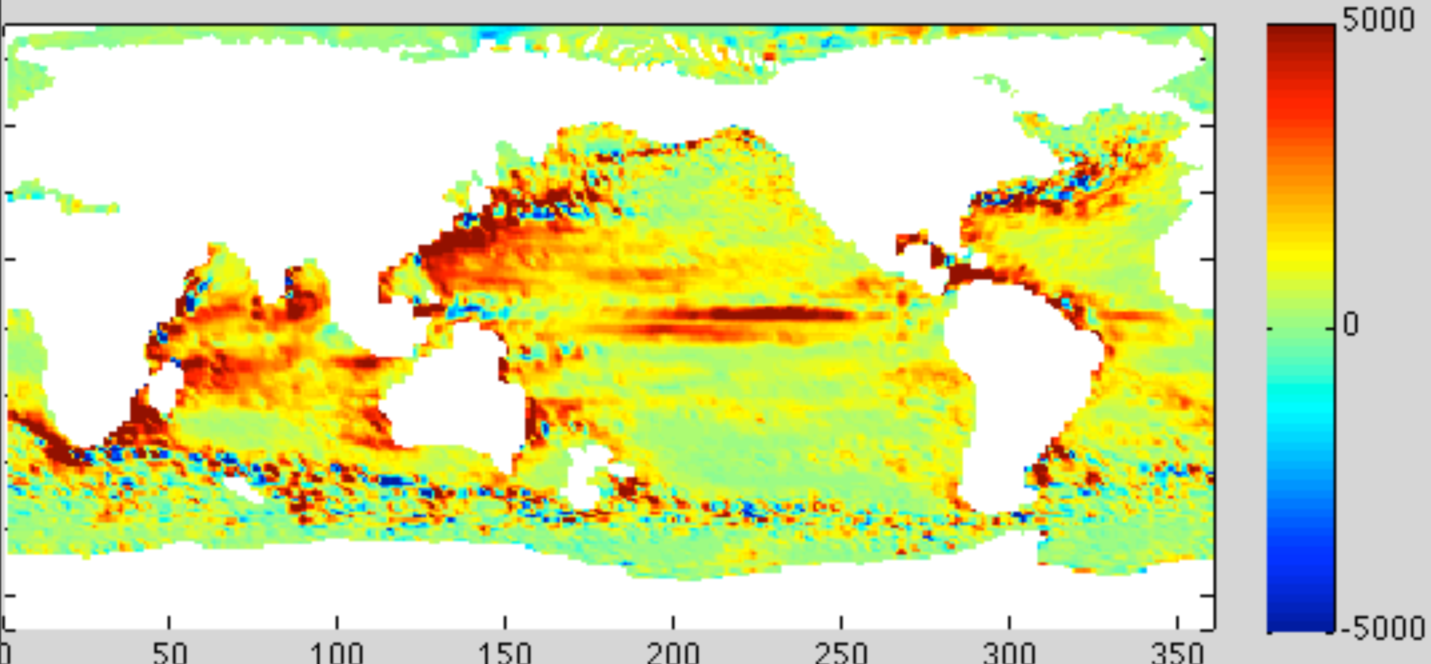
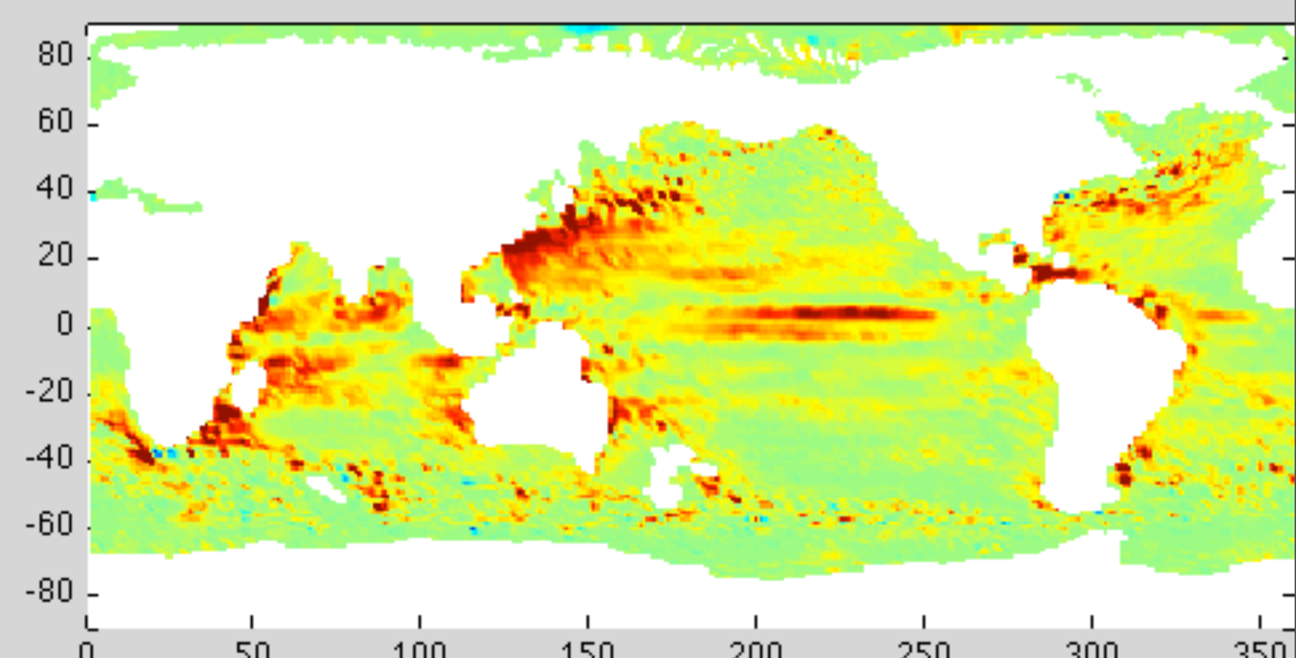


FIG. 12. Inferred horizontal eddy diffusivity κ ($m^2 s^{-1}$): (top) zonal mean and (bottom) vertical mean over the thermocline (0–1200 m). The contour intervals are (top) 500 and (bottom) 1000 $m^2 s^{-1}$. The thick line indicates the zero contour. Also indicated in the bottom panel are the 10-, 70-, and 130-Sv contours of the barotropic streamfunction.



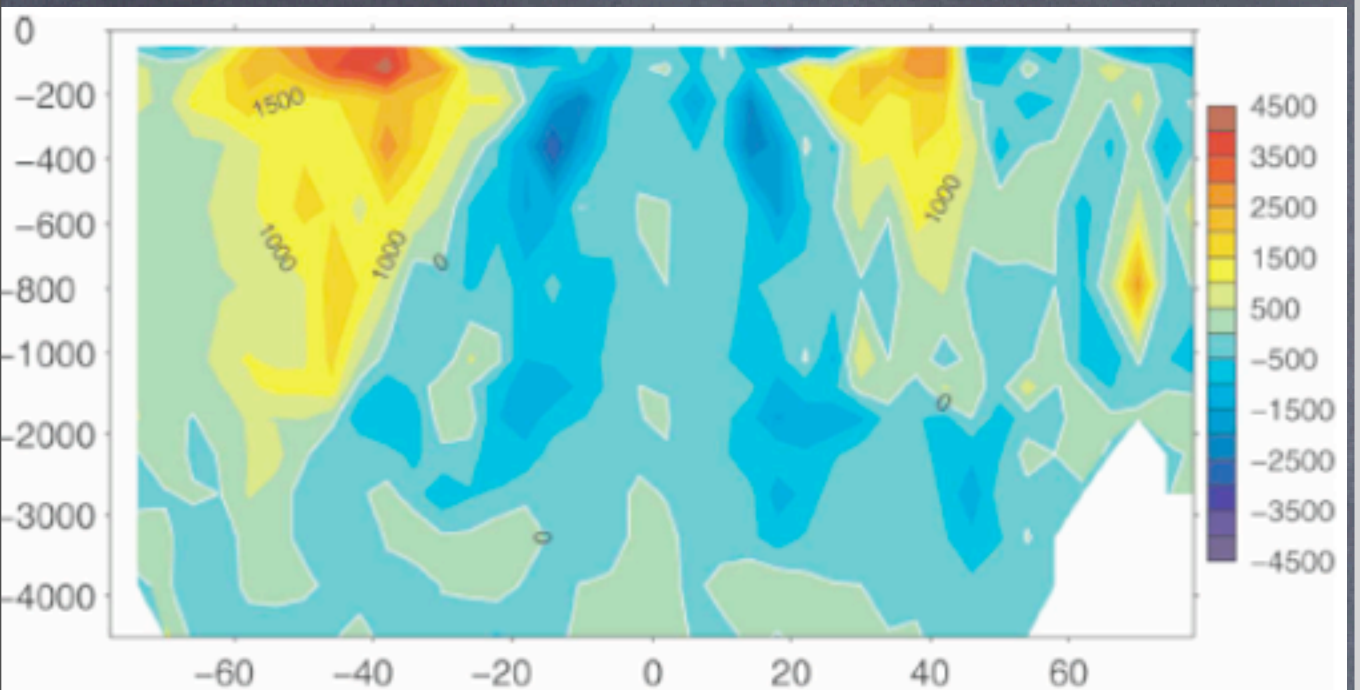




Re(2nd eigenvalue)

(2nd eigenvalue of symmetric M)

Comparisons with Marshall et al.



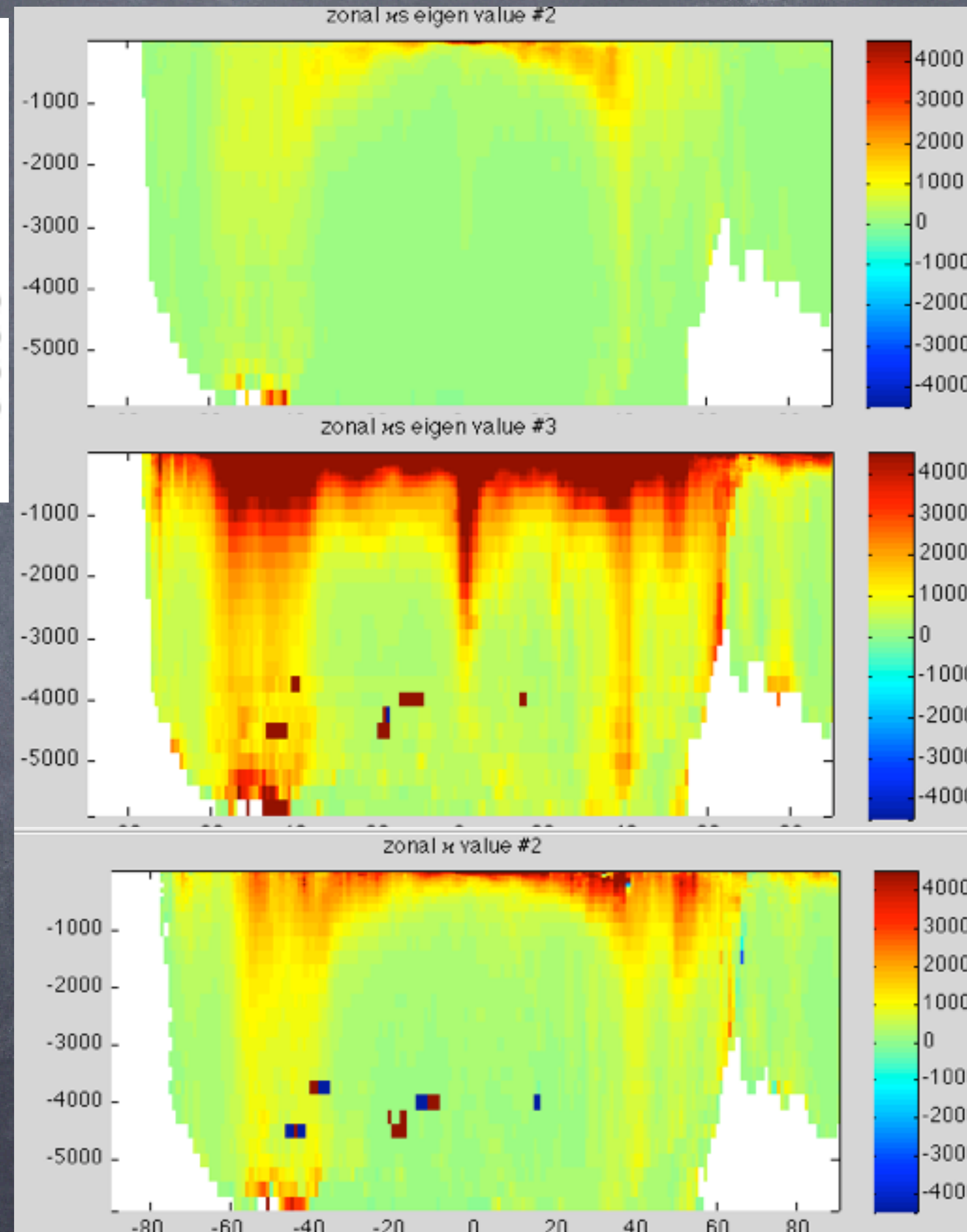
Ferreira, Marshall, Heimbach 05

Zonal mean (scalar) diffusivity

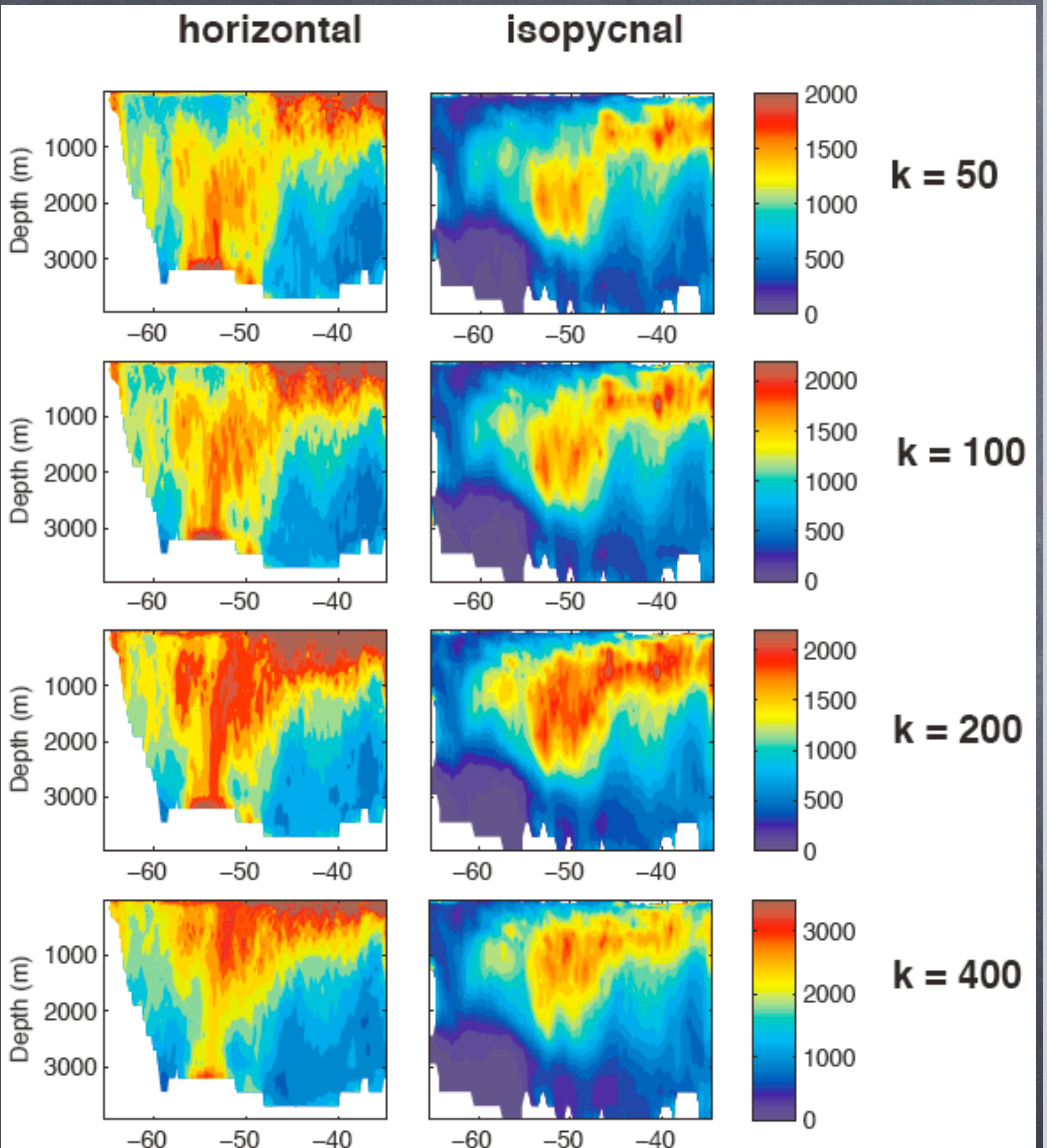
vs.

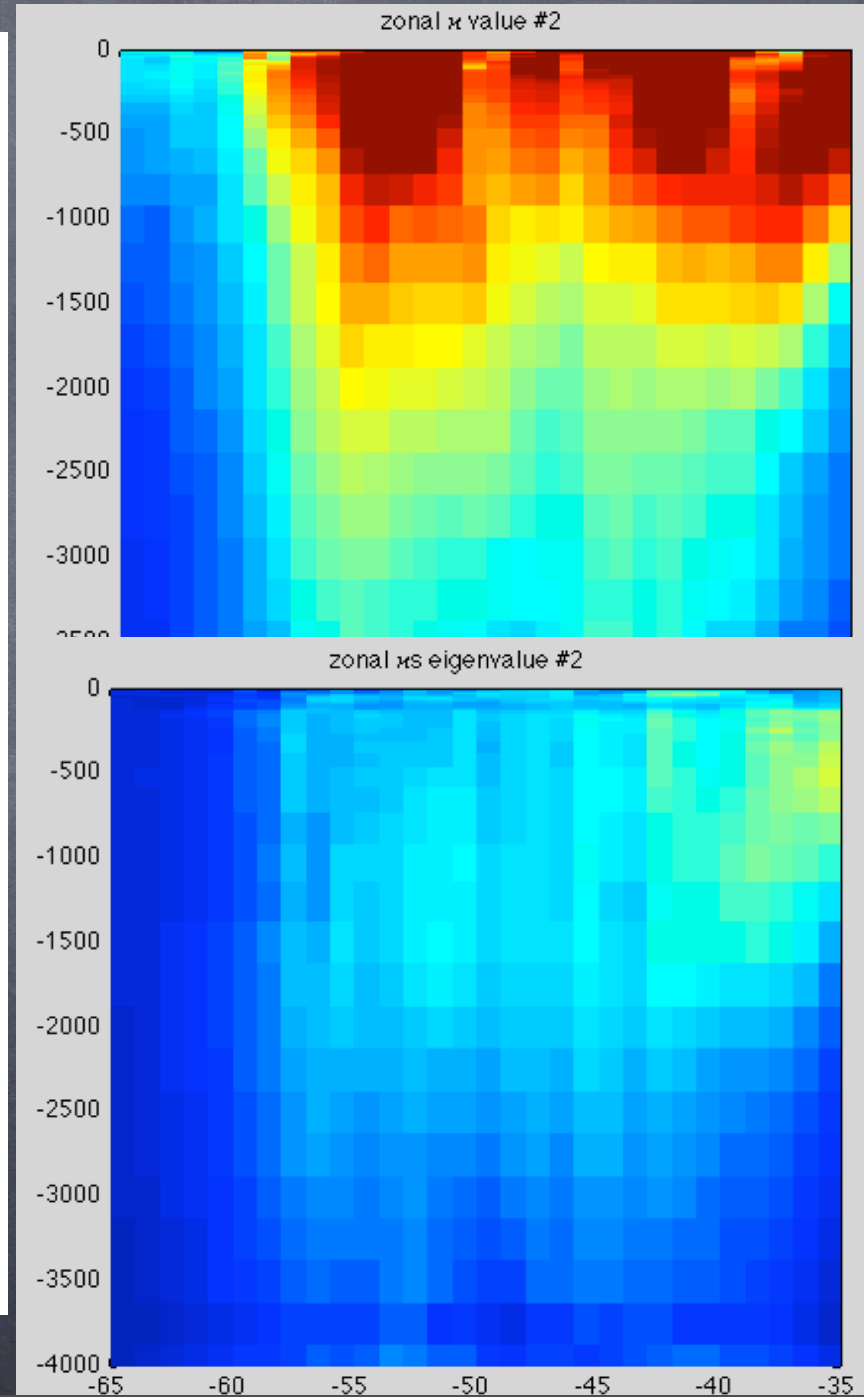
Eigenvalues of the symmetric tensor

Same shape--no negatives!



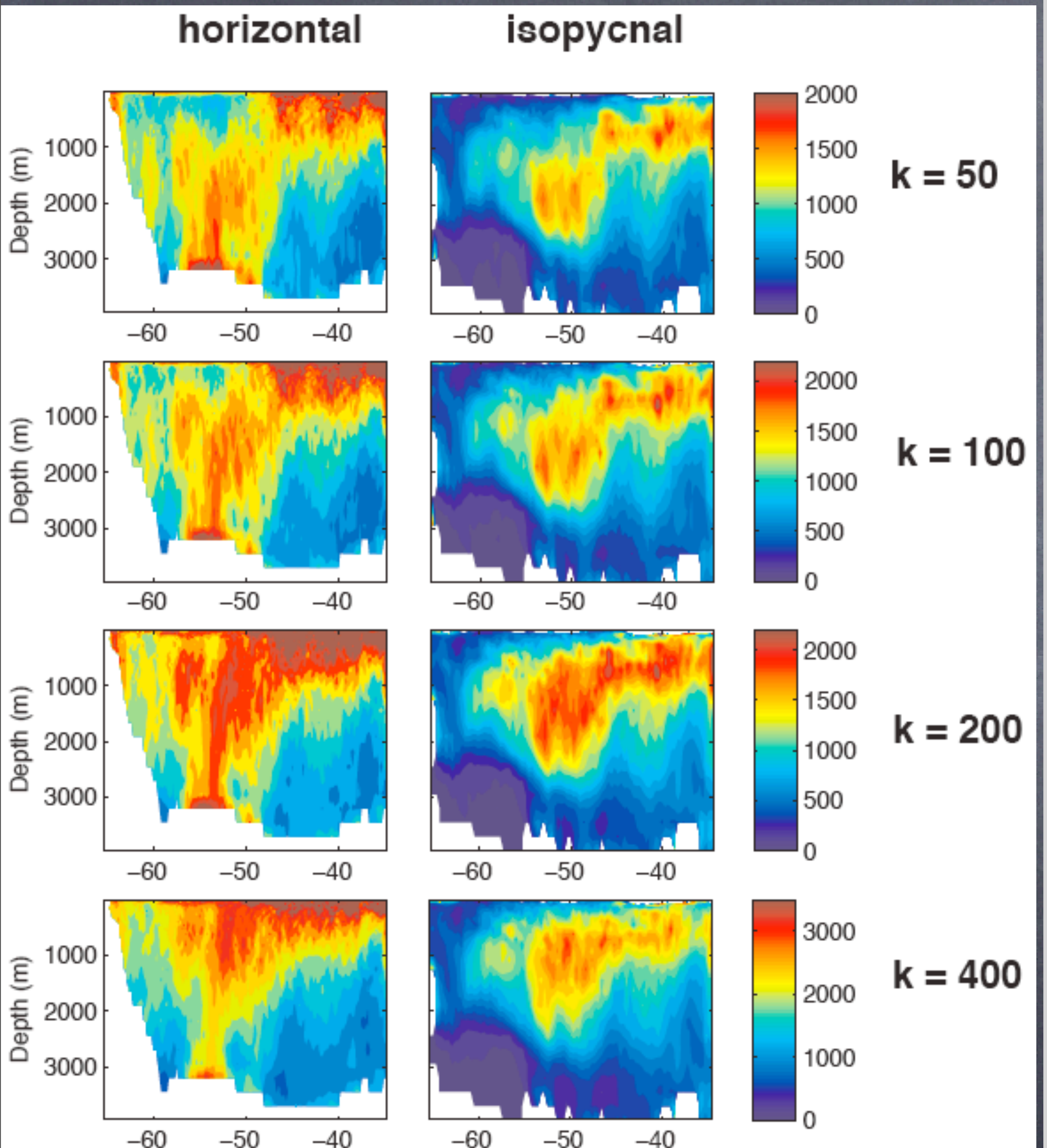
Comparisons with Marshall et al.



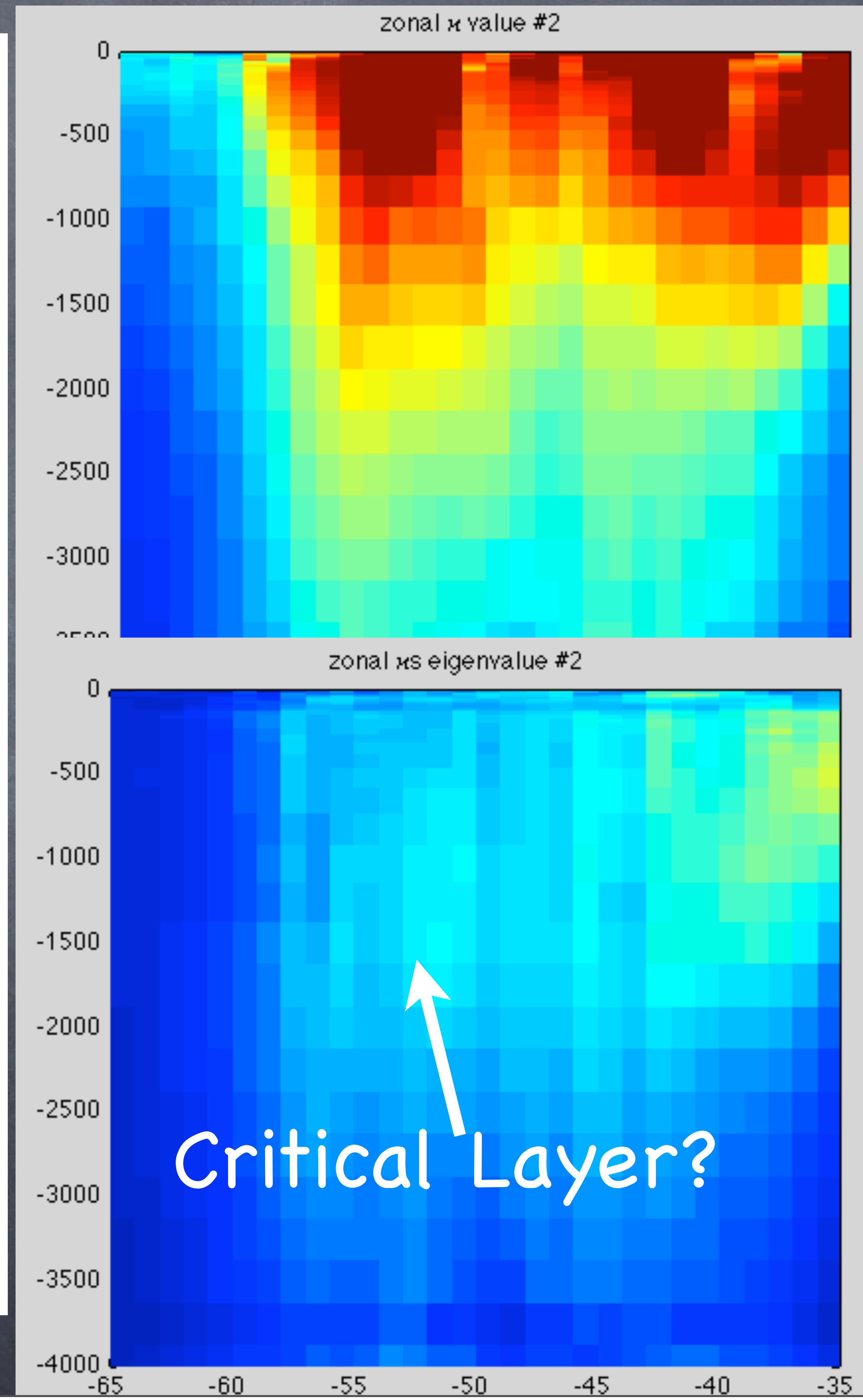


Abernathy et al 09

Comparisons with Marshall et al.

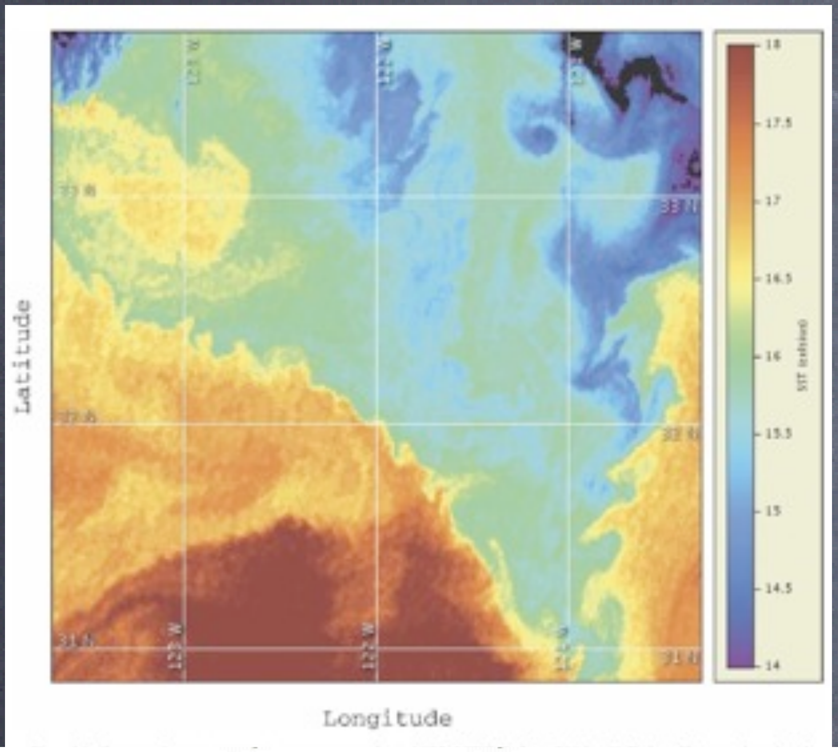


Abernathy et al 09

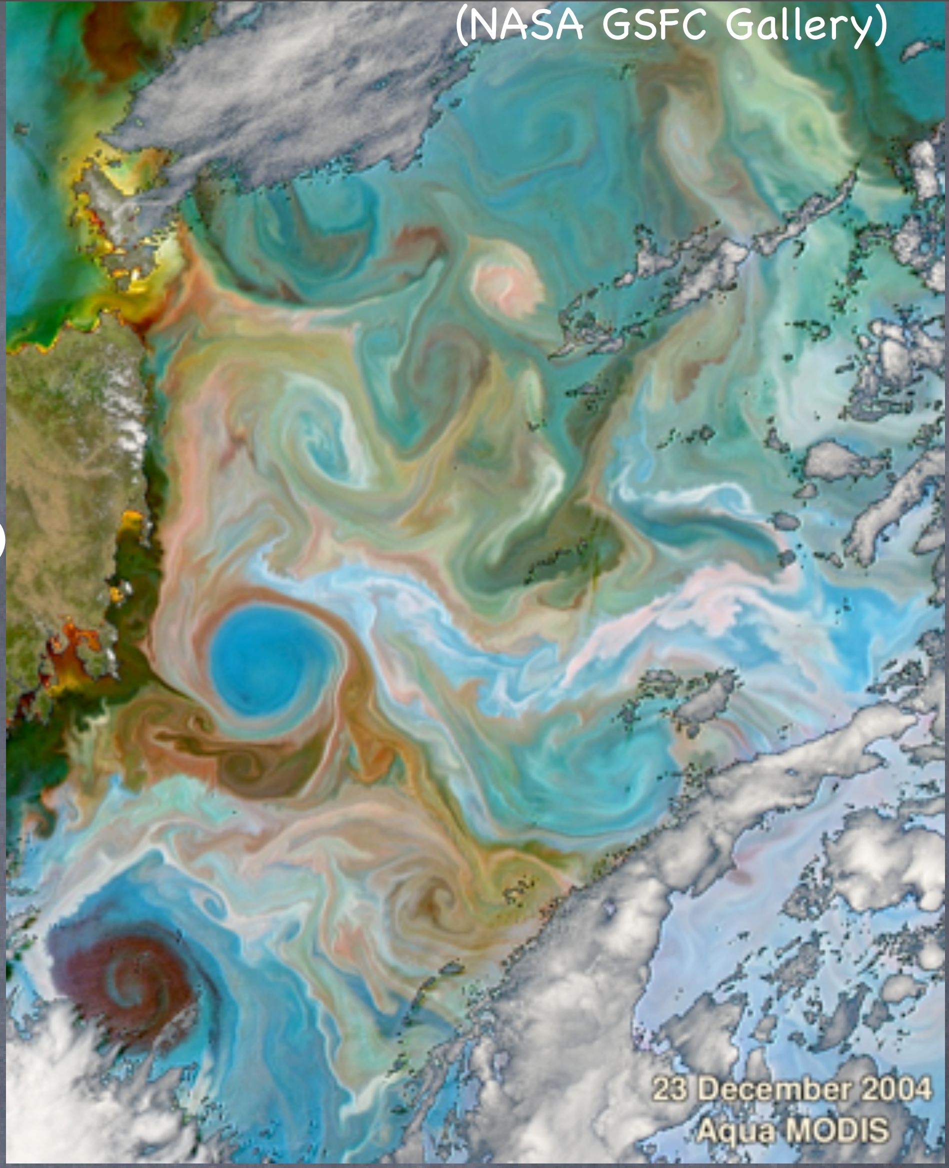


The Character of the Submesoscale

(Capet et al., 2008)

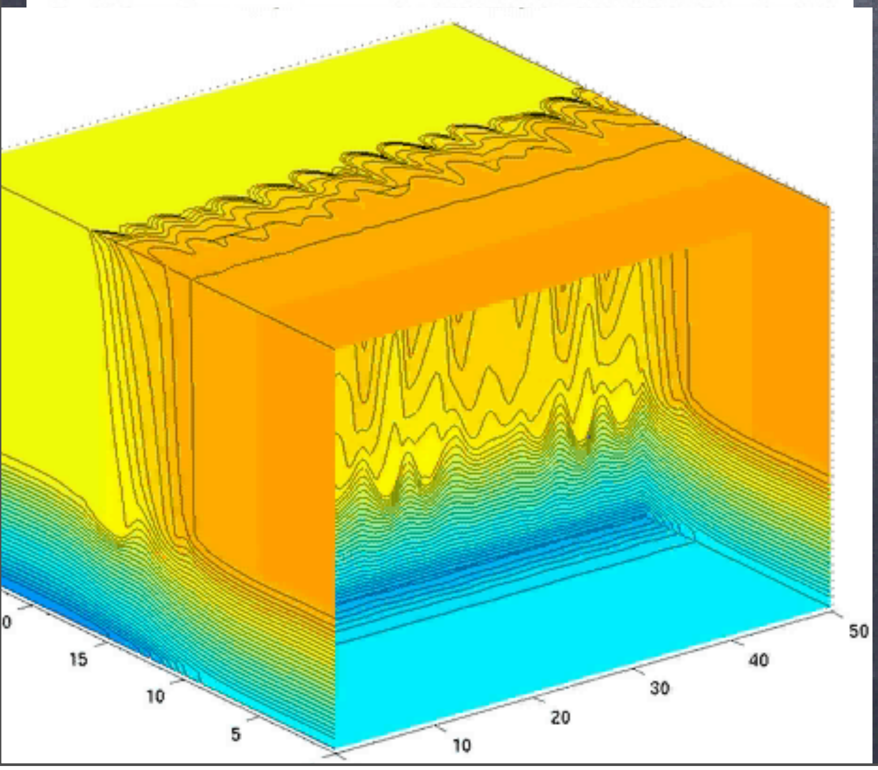


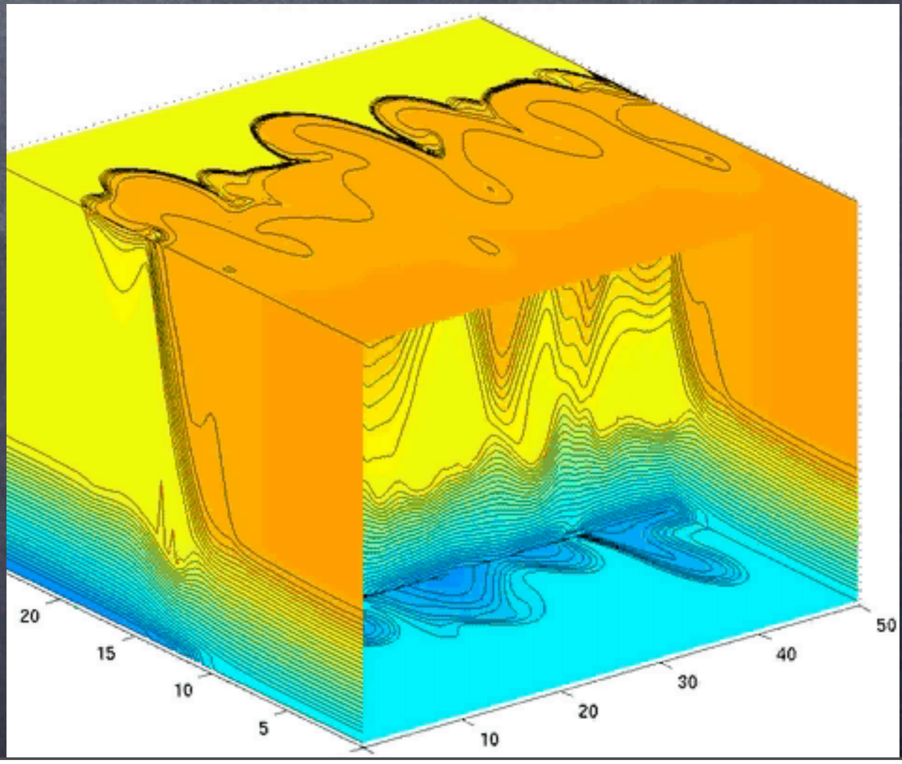
(NASA GSFC Gallery)



10 km

- Fronts & ageo wind
- Eddies
- Ro=O(1)
- Ri=O(1)
- near-surface
- 10km, days
- Parameterizations of eddies (FFH)





The Character of the Finescale

(Capet et al., 2008)

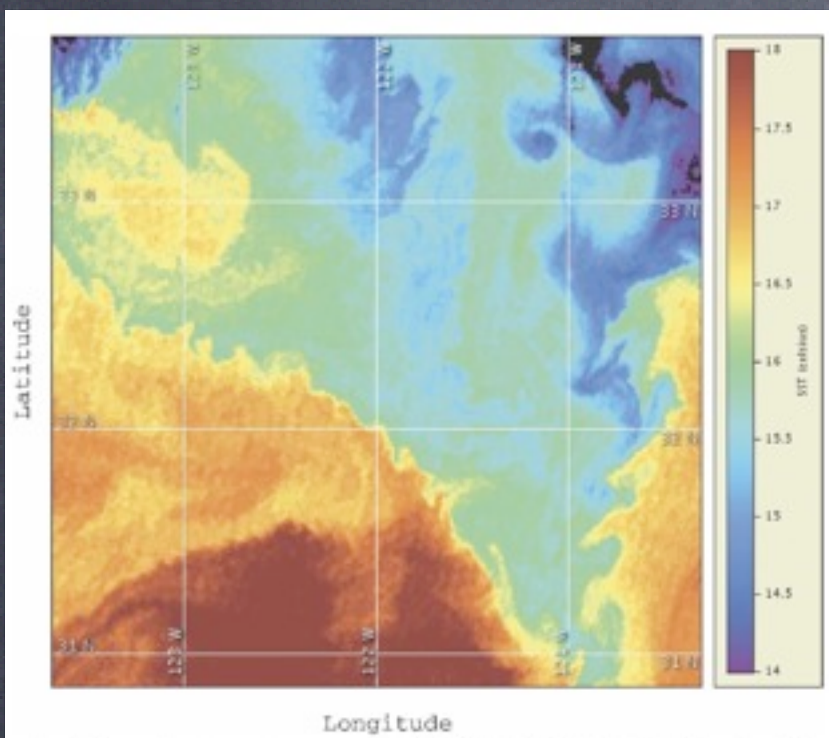
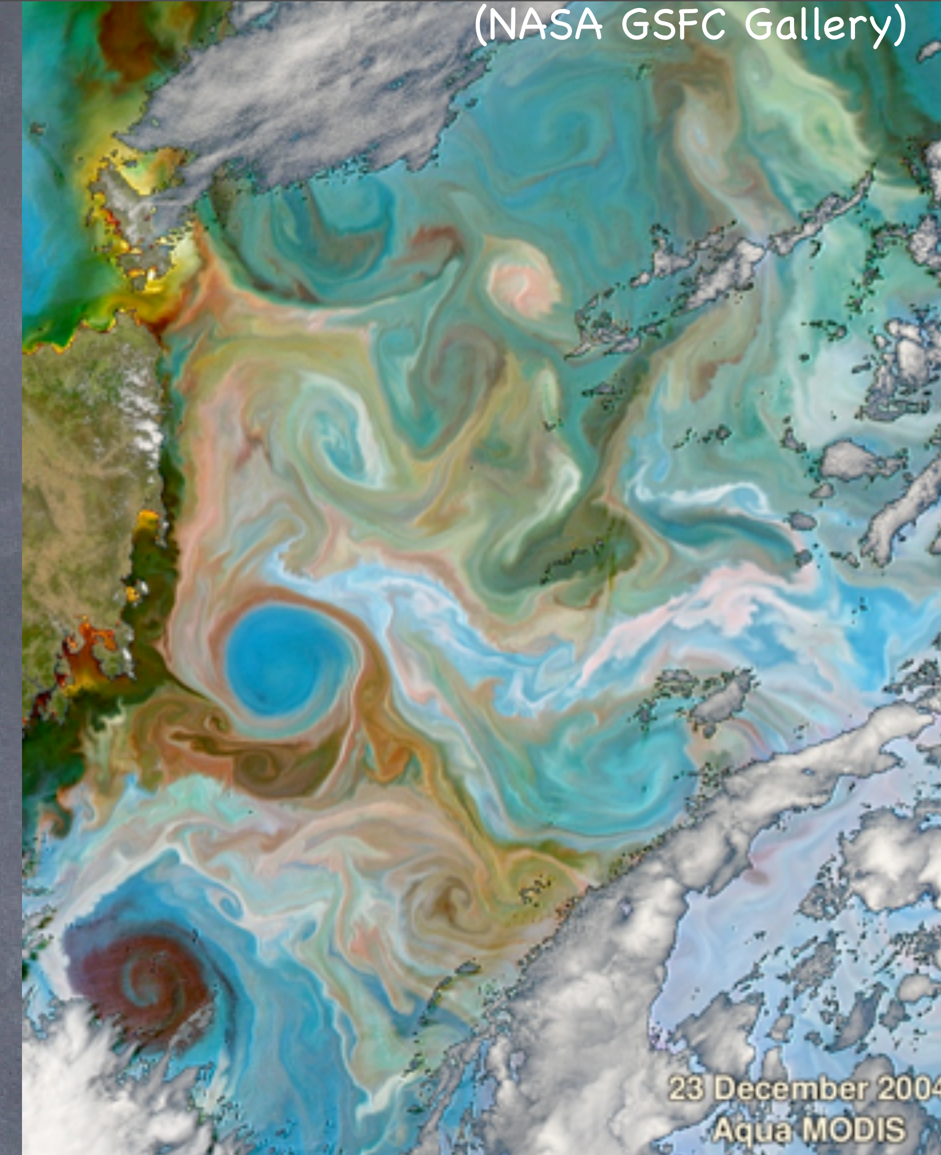


FIG. 16. Sea surface temperature measured at 1832 UTC 3 Jun 2006 off Point Conception in the California Current from CoastWatch (http://coastwatch.pfeg.noaa.gov). The fronts between recently upwelled water (i.e., 15°–16°C) and offshore water (≥17°C) show submesoscale instabilities with wavelengths around 30 km (right front) or 15 km (left front). Images for 1 day earlier and 4 days later show persistence of the instability events.

- 3d
- turbulent
- Ro>>1
- Ri<1 to <<1
- near-surface, bottom
- surface wave (Langmuir, breaking)
- internal waves/loss of balance/nonhydrostatic
- <100m, minutes-hrs.

(NASA GSFC Gallery)



100 m