Anisotropy and Tracer Diagnosis

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Ocean Model Working Group
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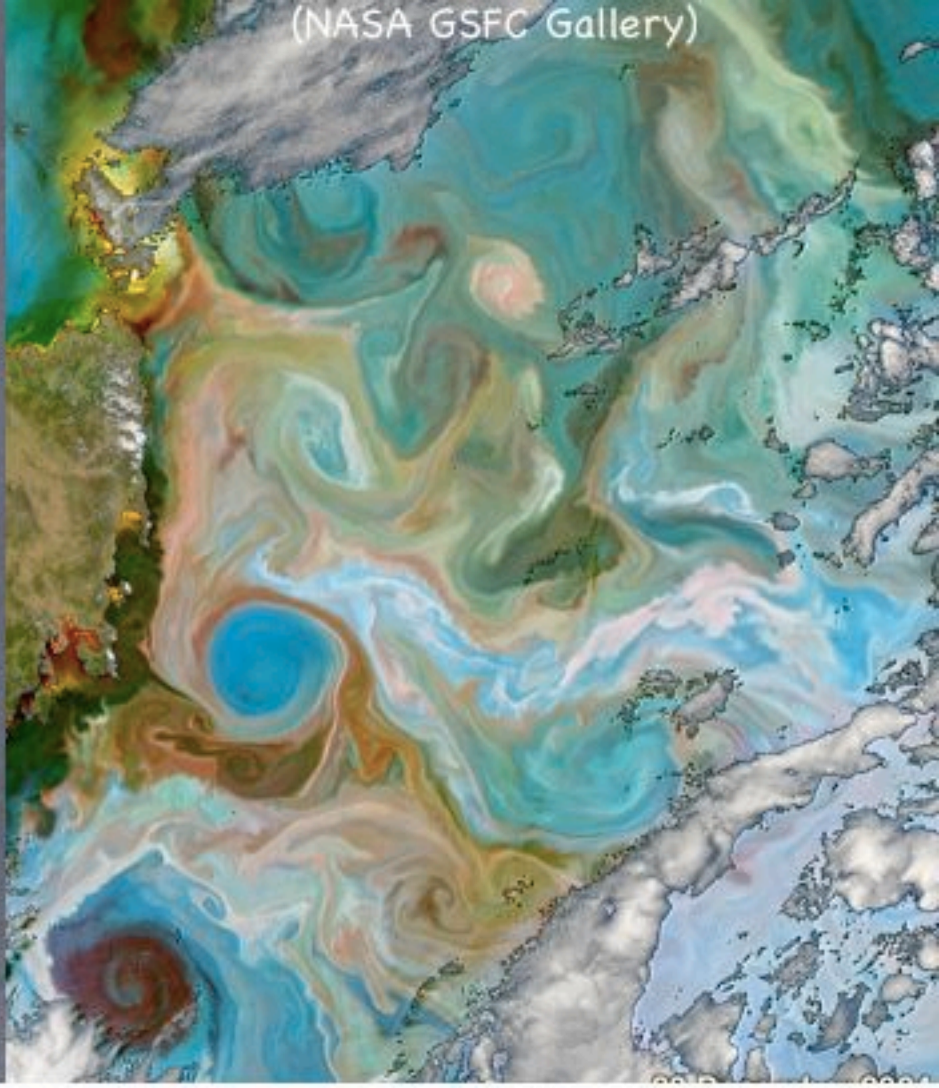
Mesoscale Parameterizations

- Researchers have already cast much darkness on this subject and if they continue their investigations we shall soon know nothing at all about it.
    - --Mark Twain

The Character of the Mesoscale

← 100 km



(Capet et al., 2008)

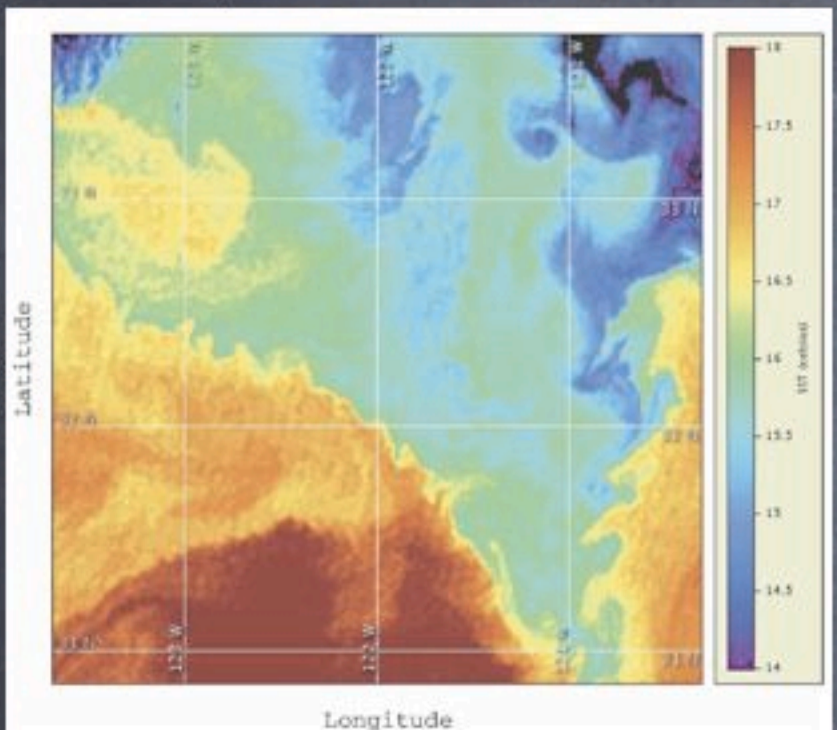
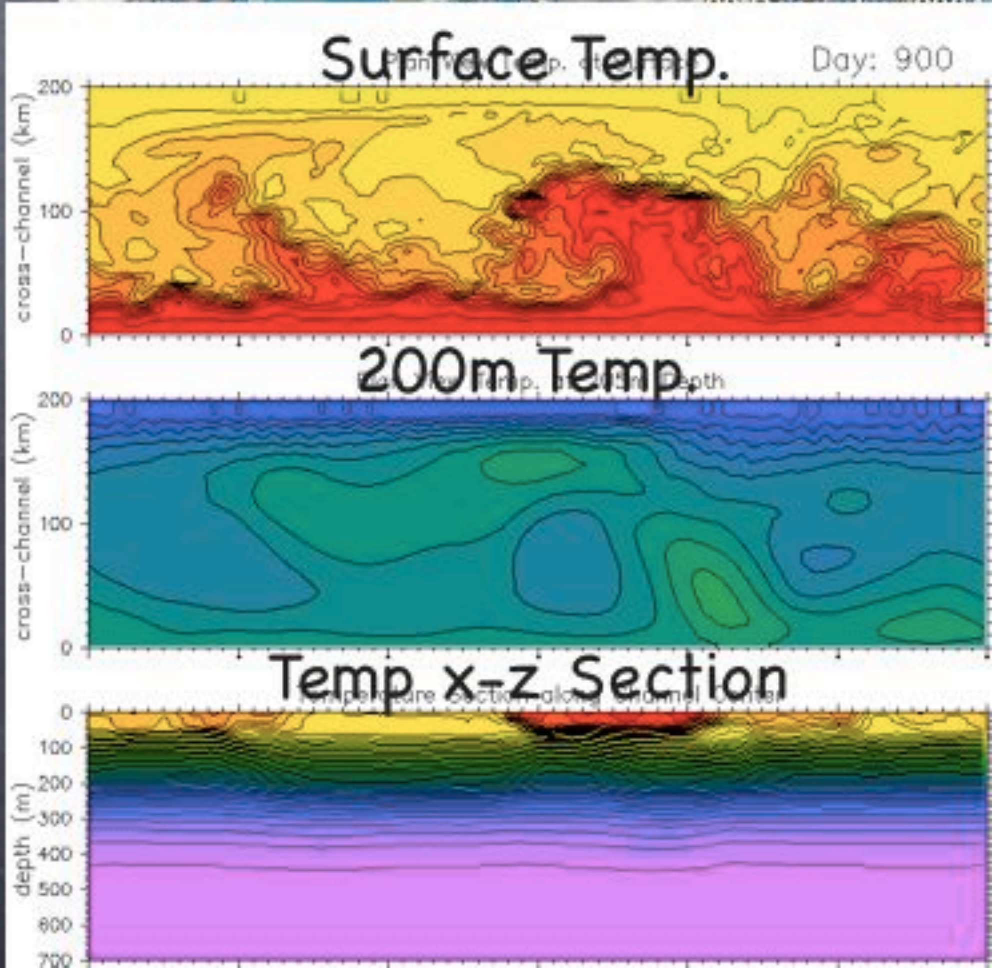
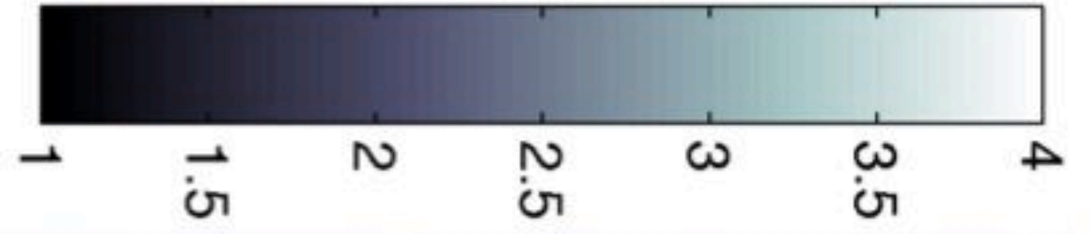


FIG. 16. Sea surface temperature measured at 1832 UTC 3 Jun 2006 off Point Conception in the California Current from CoastWatch (http://coastwatch.pfeg.noaa.gov). The fronts between recently upwelled water (i.e., 15°–16°C) and offshore water (≥17°C) show submesoscale instabilities with wavelengths around 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
- Eddies strain to produce Fronts
- 100km, months

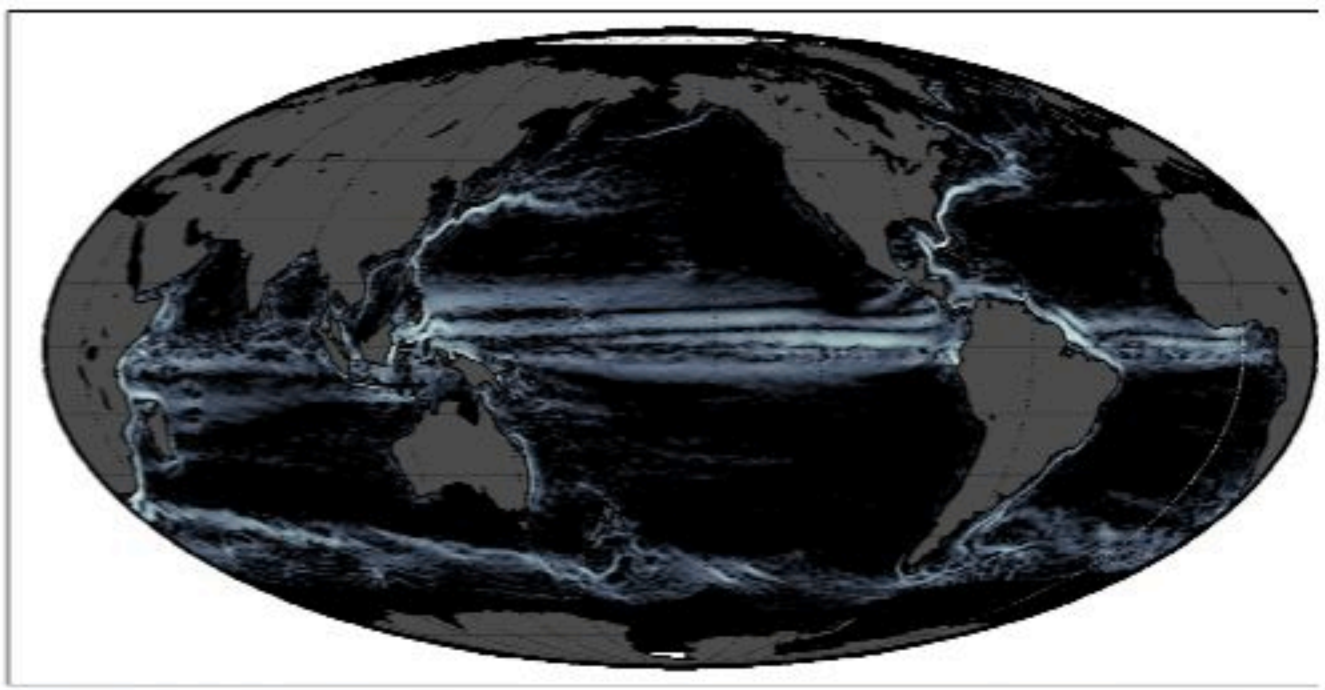


Eddy processes mainly baroclinic & barotropic instability. Parameterizations of baroclinic instability (GM, Visbeck...).

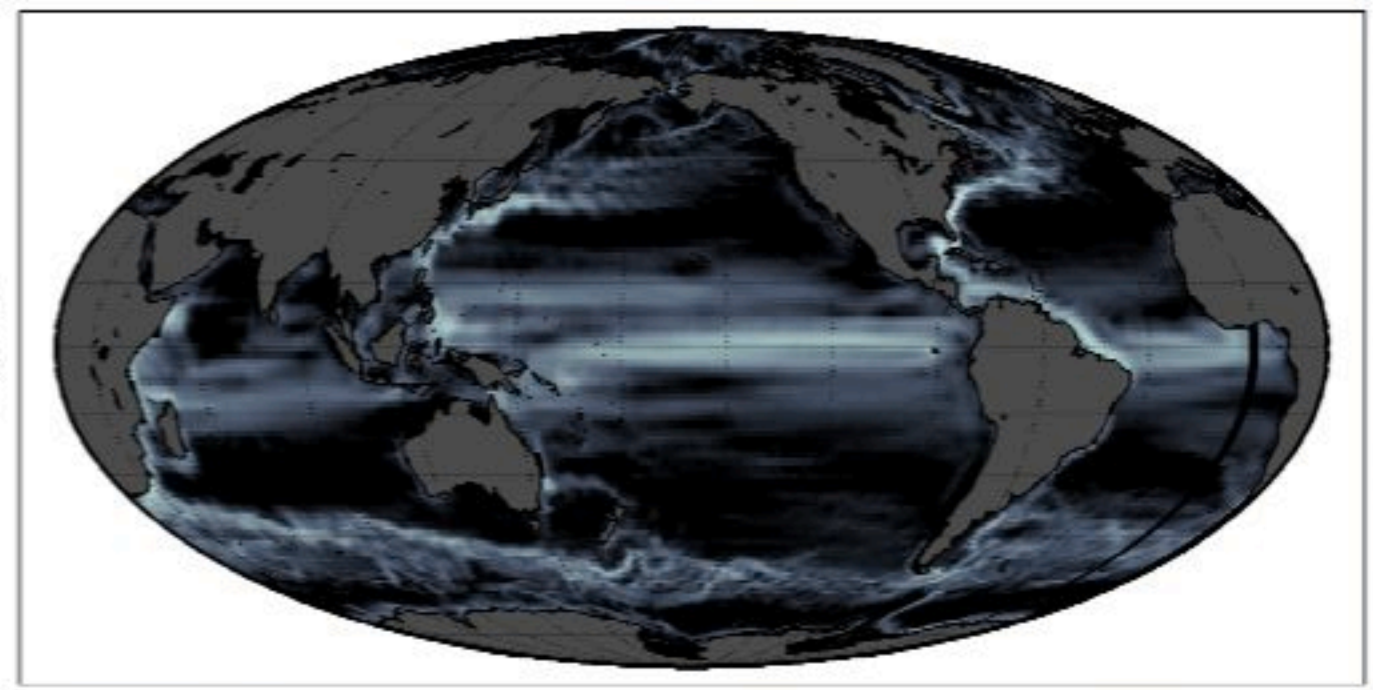


Comparing the Mean KE

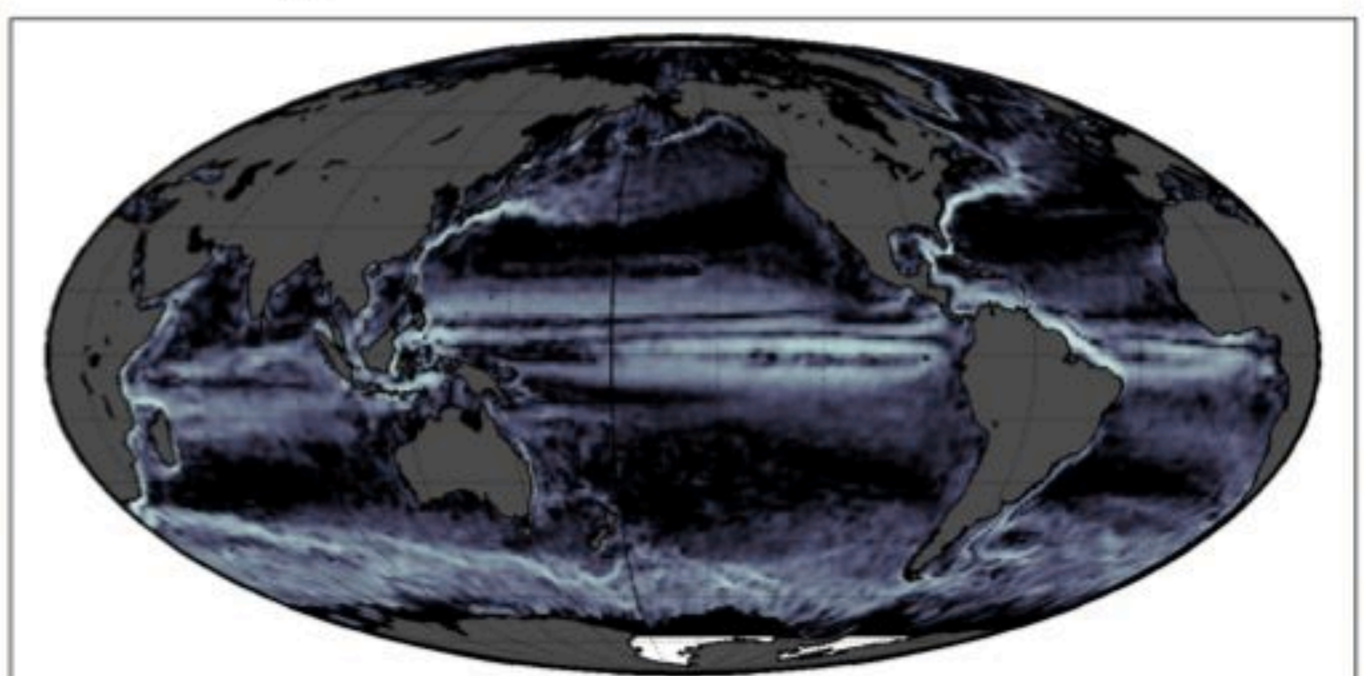
$\log_{10}$(Mean Kinetic Energy from AVISO 1993-2010 (cm^2/s^2))

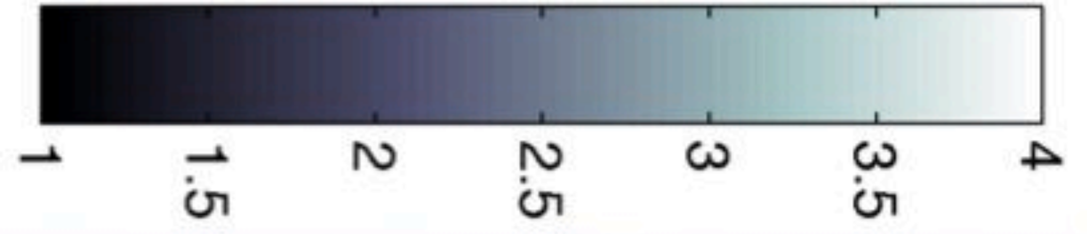


$\log_{10}$(Mean Kinetic Energy from Model (cm^2/s^2))



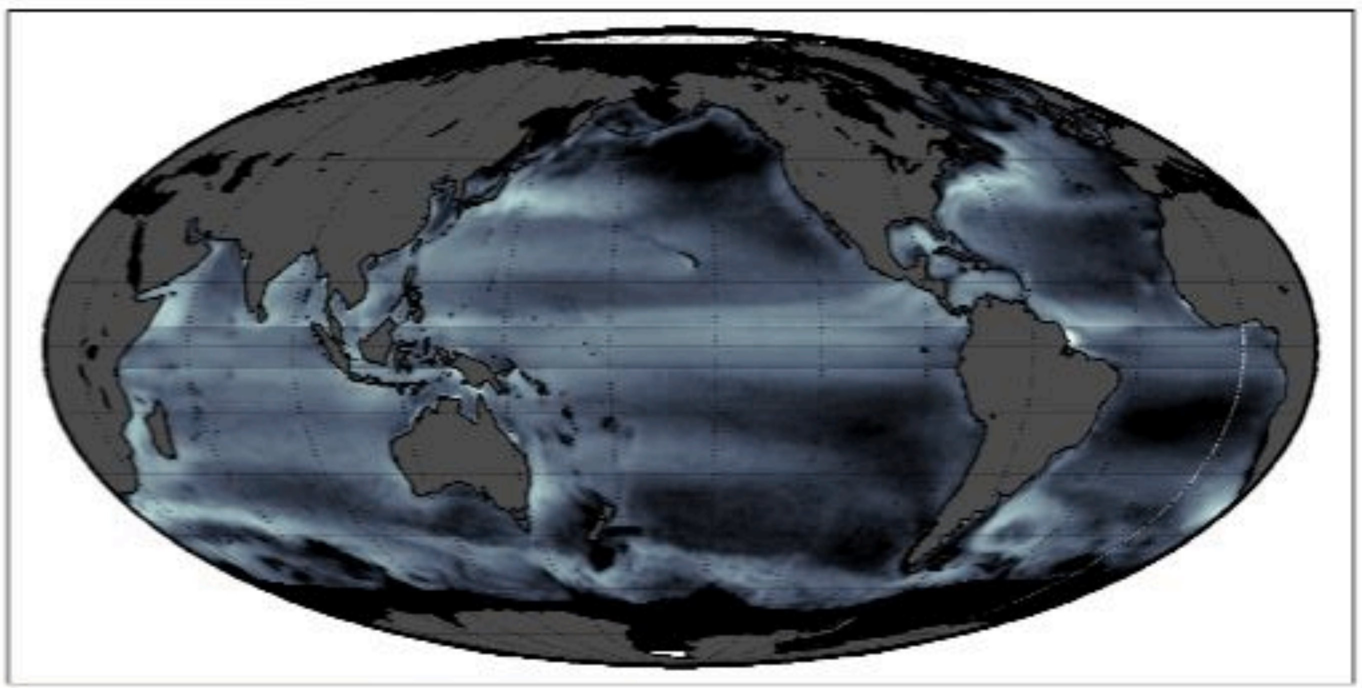
$\log_{10}$(Mean Kinetic Energy from Drifters (cm^2/s^2))



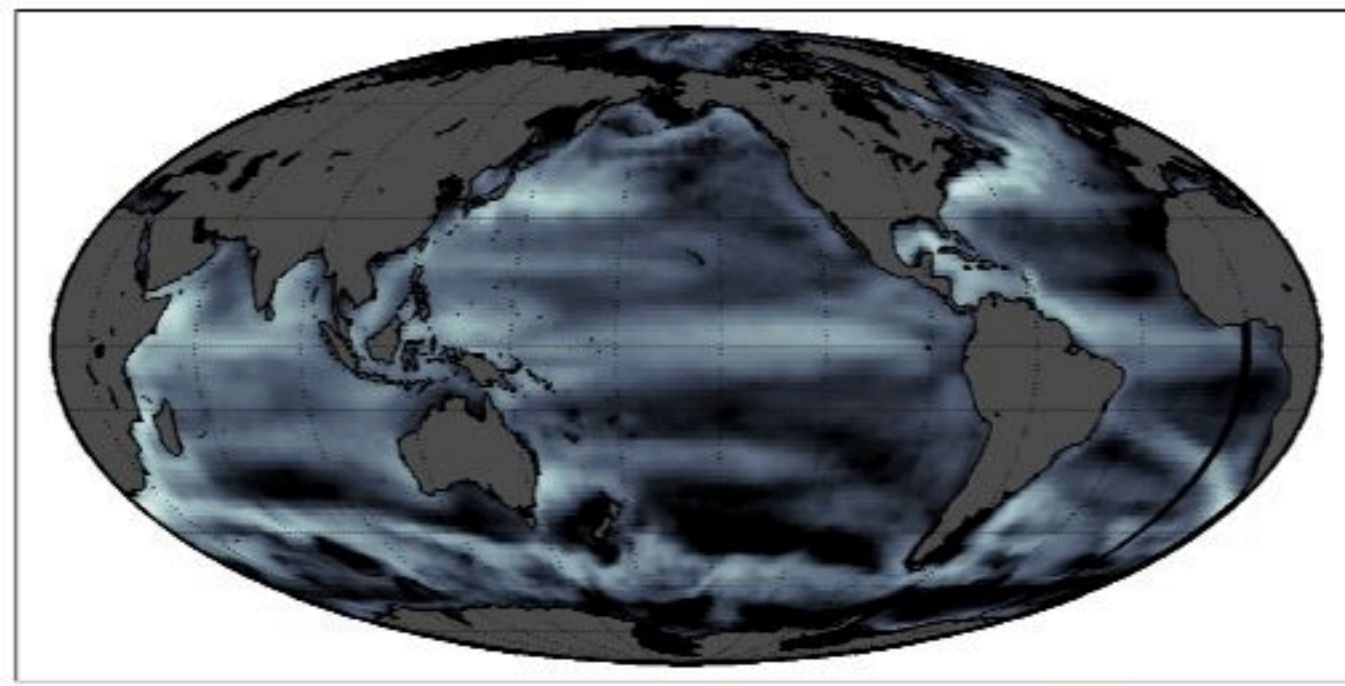


Comparing the EKE

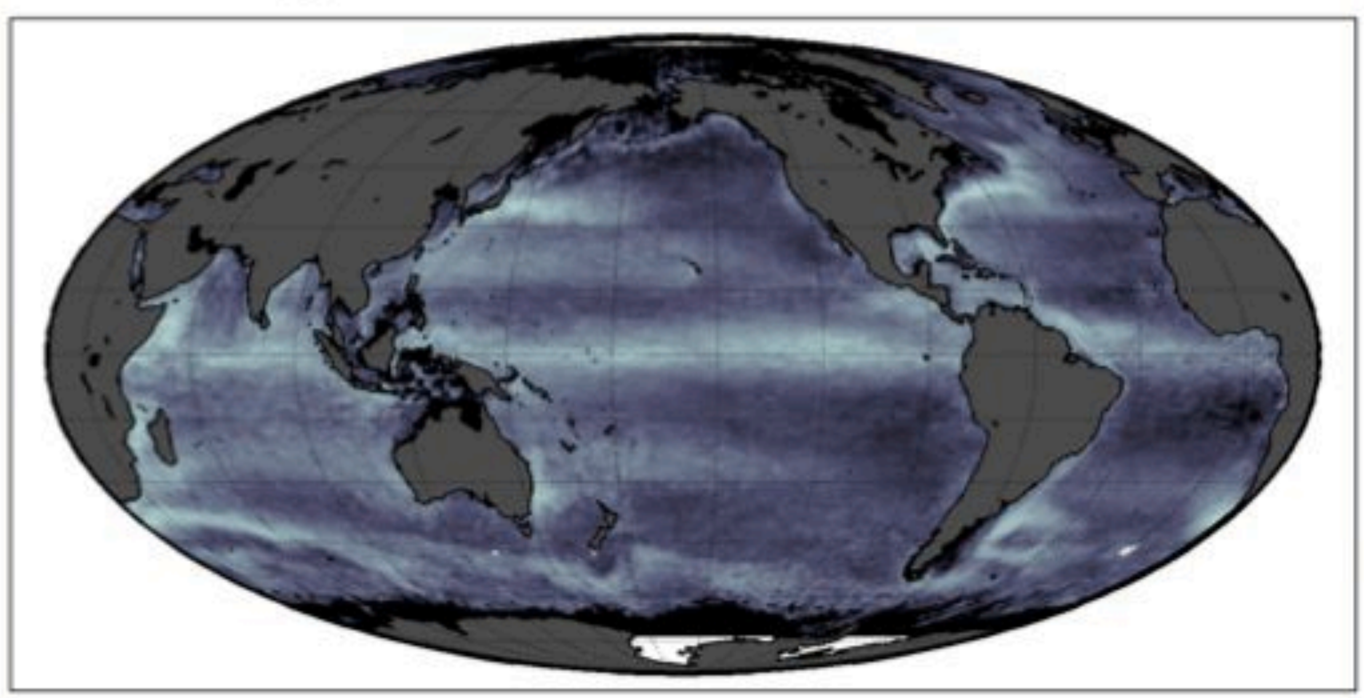
$\log_{10}$(Eddy Kinetic Energy from AVISO 1993-2010 (cm^2/s^2))



$\log_{10}$(Eddy Kinetic Energy from Model (cm^2/s^2))



$\log_{10}$(Eddy Kinetic Energy from Drifters (cm^2/s^2))



Mesoscale Eddy Parameterizations all have the form:

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

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

With John Dennis & Frank Bryan, we took a POP0.1° Normal-Year forced model (yrs 16-20)

Added 9 Passive tracers--restored x,y,z @ 3 rates

Kept all the eddy fluxes for passive & active

Coarse-grained to 2°, transient eddies, tracers to $\mathbf{M}$

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

Sym Part=Anisotropic* Redi

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

AntiSym Part=Anisotropic* GM

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

Yellow $\mathbf{K}$ are horizontal turbulent diffusivity

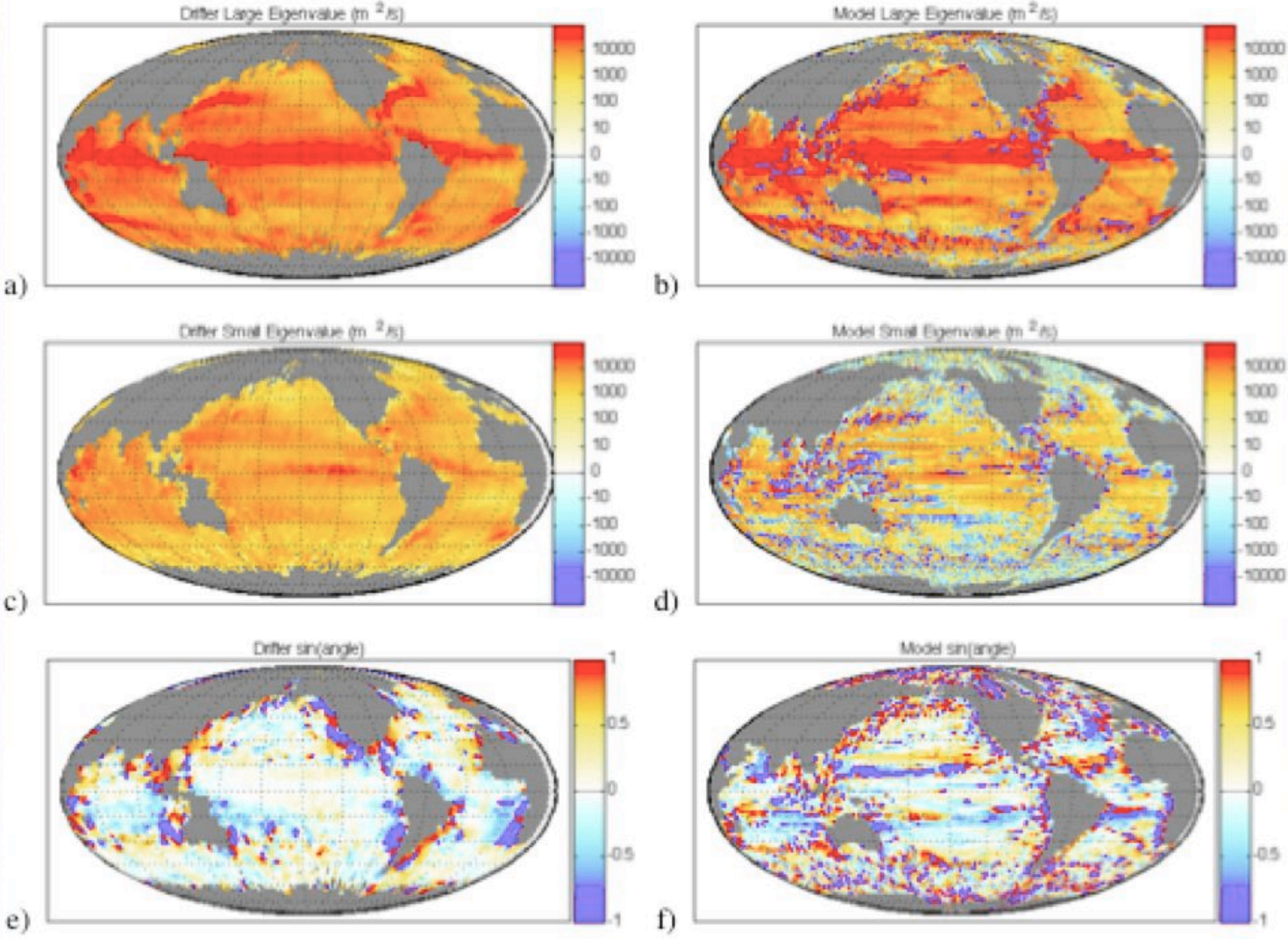
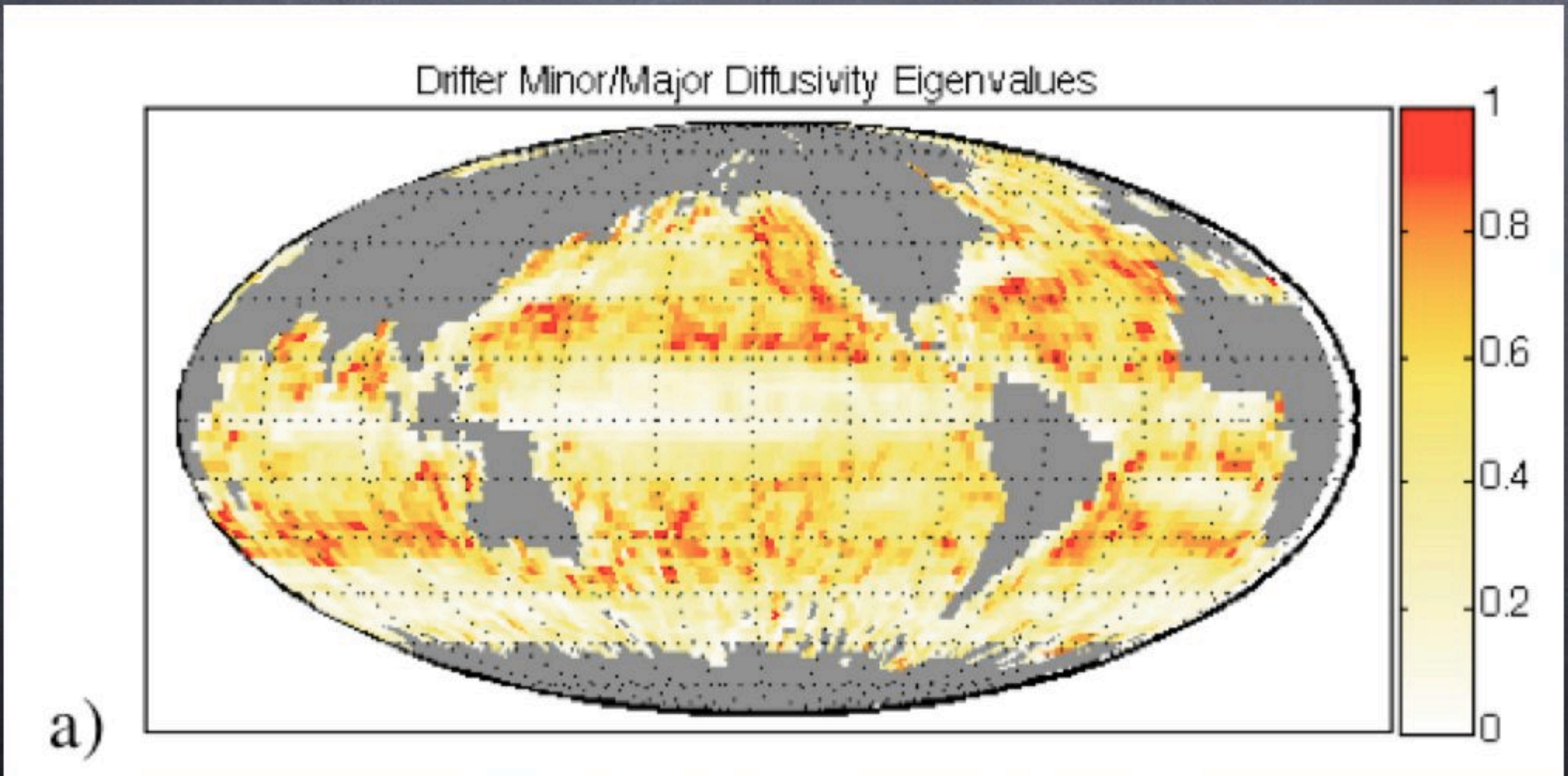


Figure 2: Surface drifter (a,c,e) and model (b, d f) neutral diffusivity eigenvalues and eigenvalue direction (sin(angle) from zonal).

Drifter Eigenvalue Ratios Strong Anisotropy



Shear Dispersion?

Taylor (53), WR Young (many), KS Smith (05)

Cross-Jet

$$\kappa = D_\phi .$$

Along-Jet

$$D_\chi = -\langle U \chi_{\mathrm{eqm}} \rangle = \kappa^{-1} \sum_{n=-\infty}^{\infty} \frac{|\hat{U}_n|^2}{k_n^2},$$

Zonal Jets–Noodle Instabilities

- Maximenko et al. (05)
- Kamenkovich, Berloff, Pedlosky (2009)

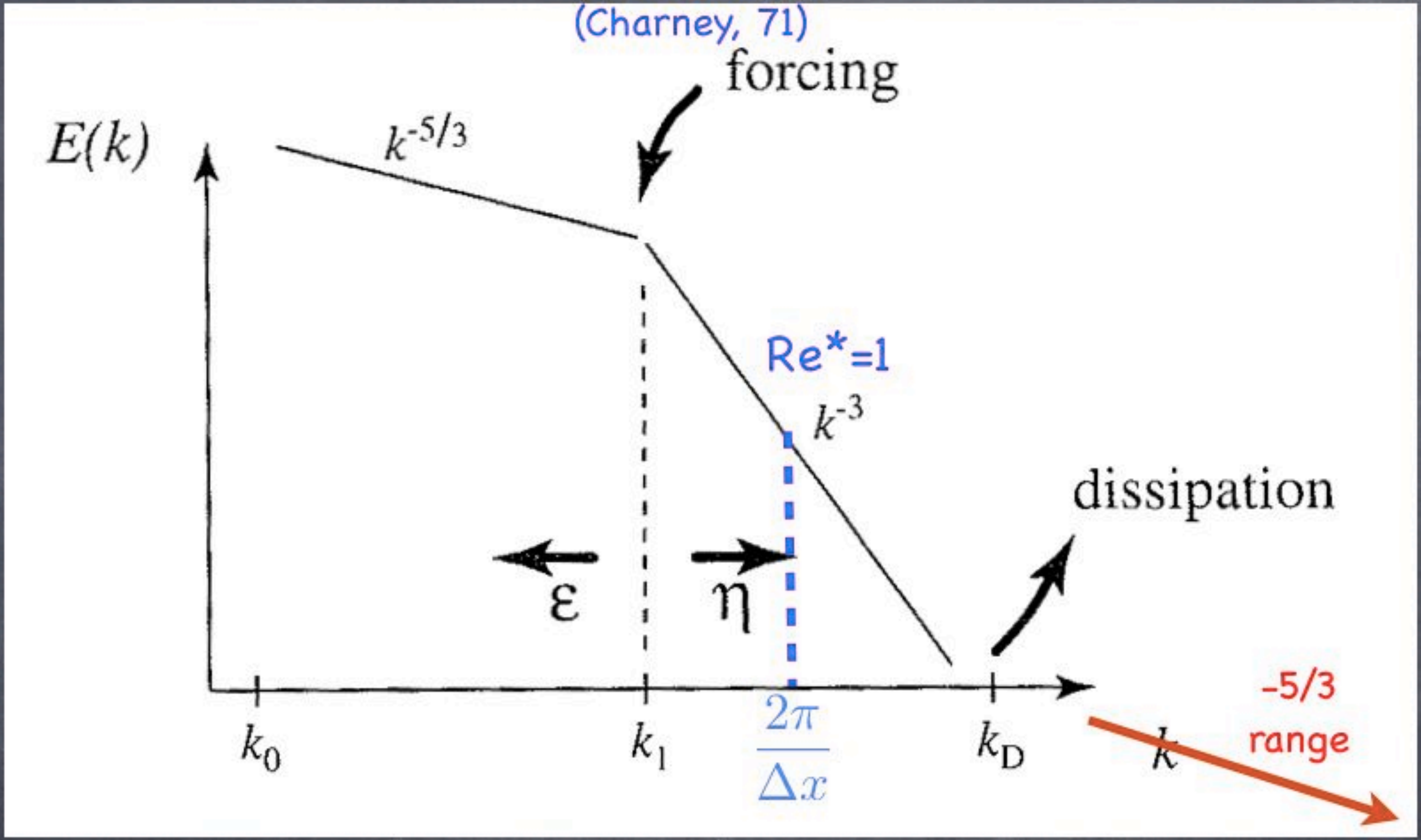
Westward Eddy Streets

- Chelton et al (07)

Conclusions

- Taylor (1921) and Taylor (1953) big part of K
  - Symmetric tensor
  - Shear Dispersion
- May also be some beta-plane effects--unclear
- Drifters and Model Agree
- Plug it through Dukowicz & Smith, get GM & Redi version with $K_{gm}=K_{redi}$

MOLES Turbulence Like Pot'l Enstrophy cascade, but divergent

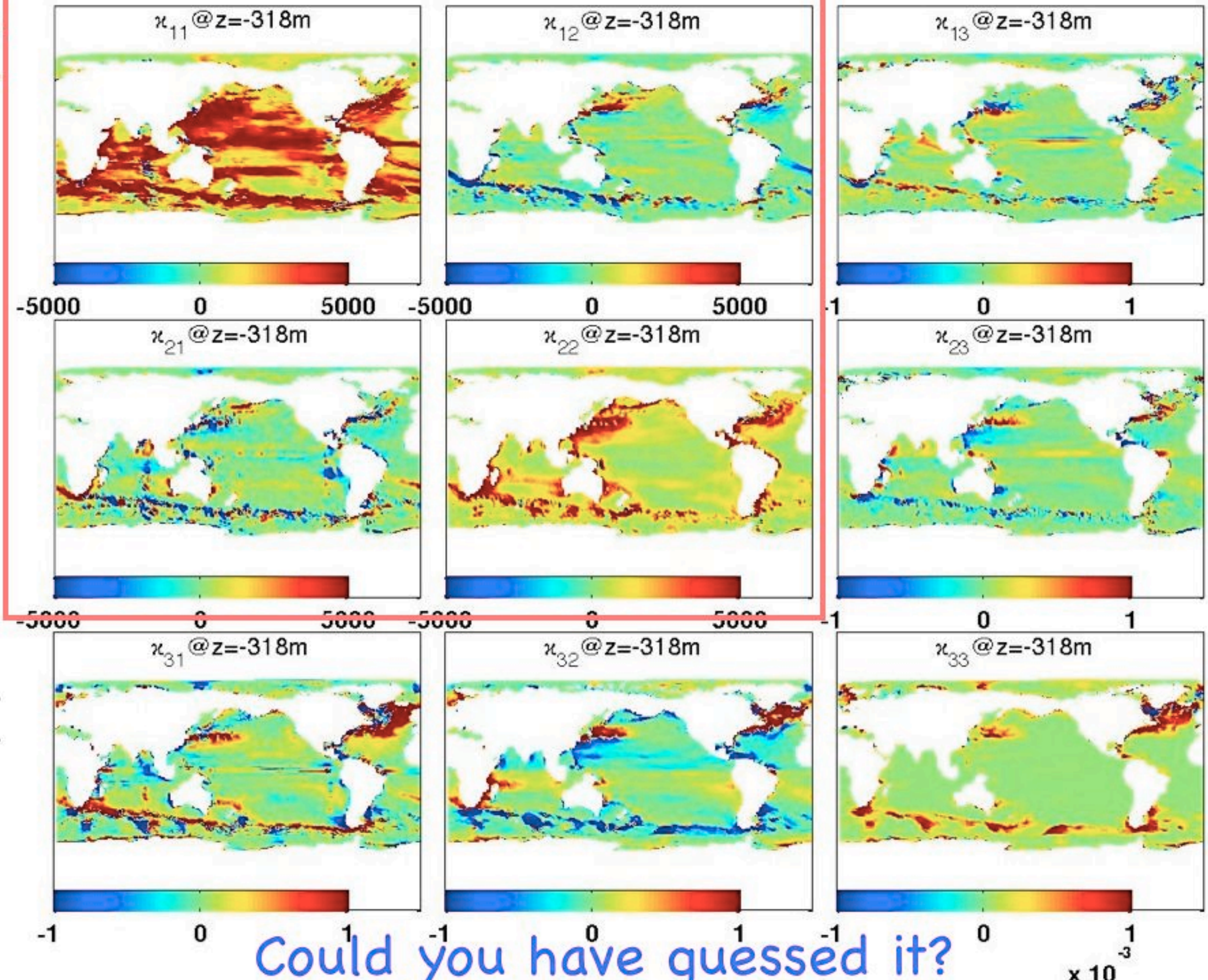


2008: F-K & Menemenlis Revise Leith Viscosity Scaling,
So that diverging, vorticity-free, modes are also damped

$$\nu_* = \left(\frac{\Delta x}{\pi}\right)^3 \sqrt{\Lambda^6 |\nabla_h q_{2d}|^2 + \Lambda_d^6 |\nabla_h (\nabla_h \cdot \mathbf{u}_*)|^2}.$$

K

M



Could you have guessed it?

Result: Strong Anisotropy Along/Across Isopycnals