Parameterizations of Eddies: Fluxes and Lognormal Dissipation

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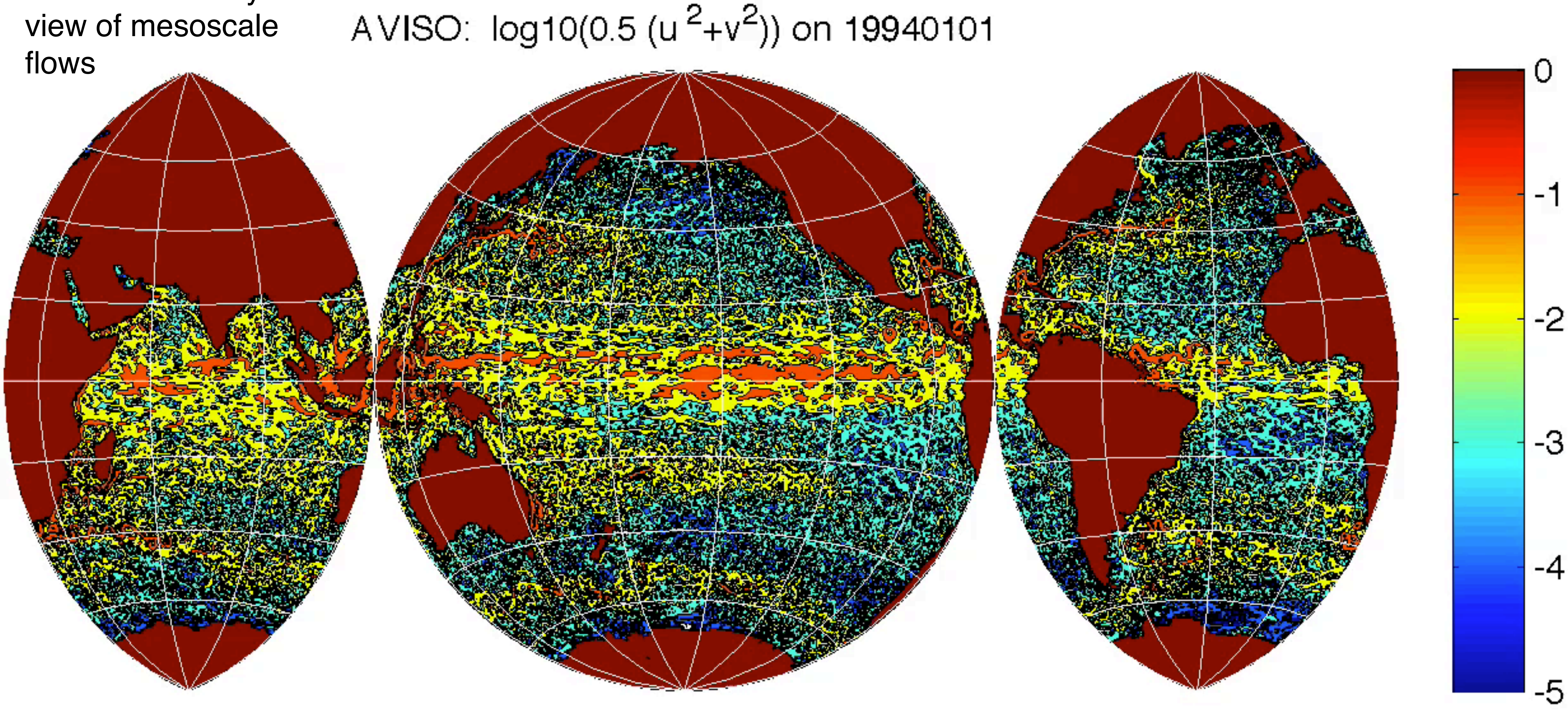
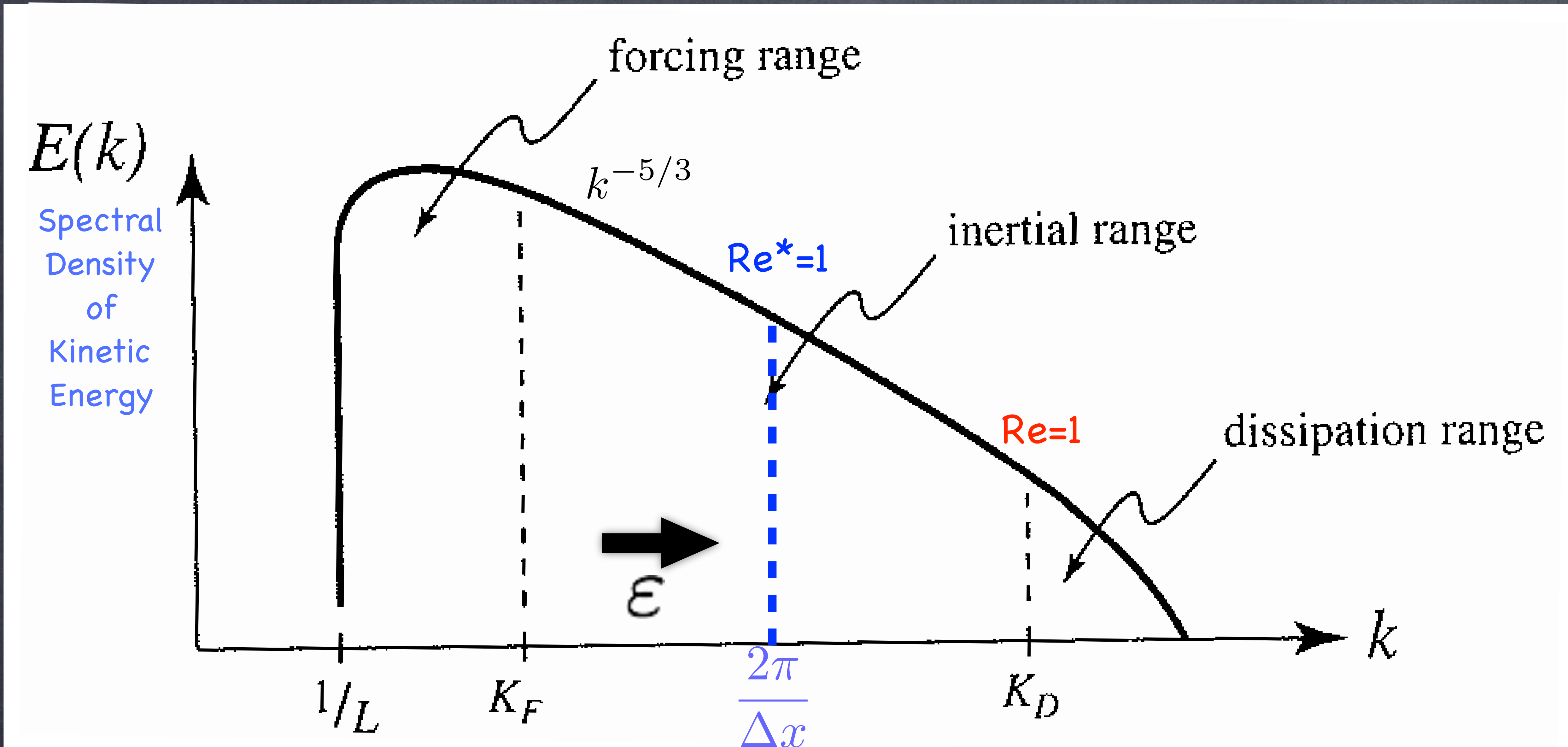
Satellite altimetry view of mesoscale flows



3D Turbulence Cascade

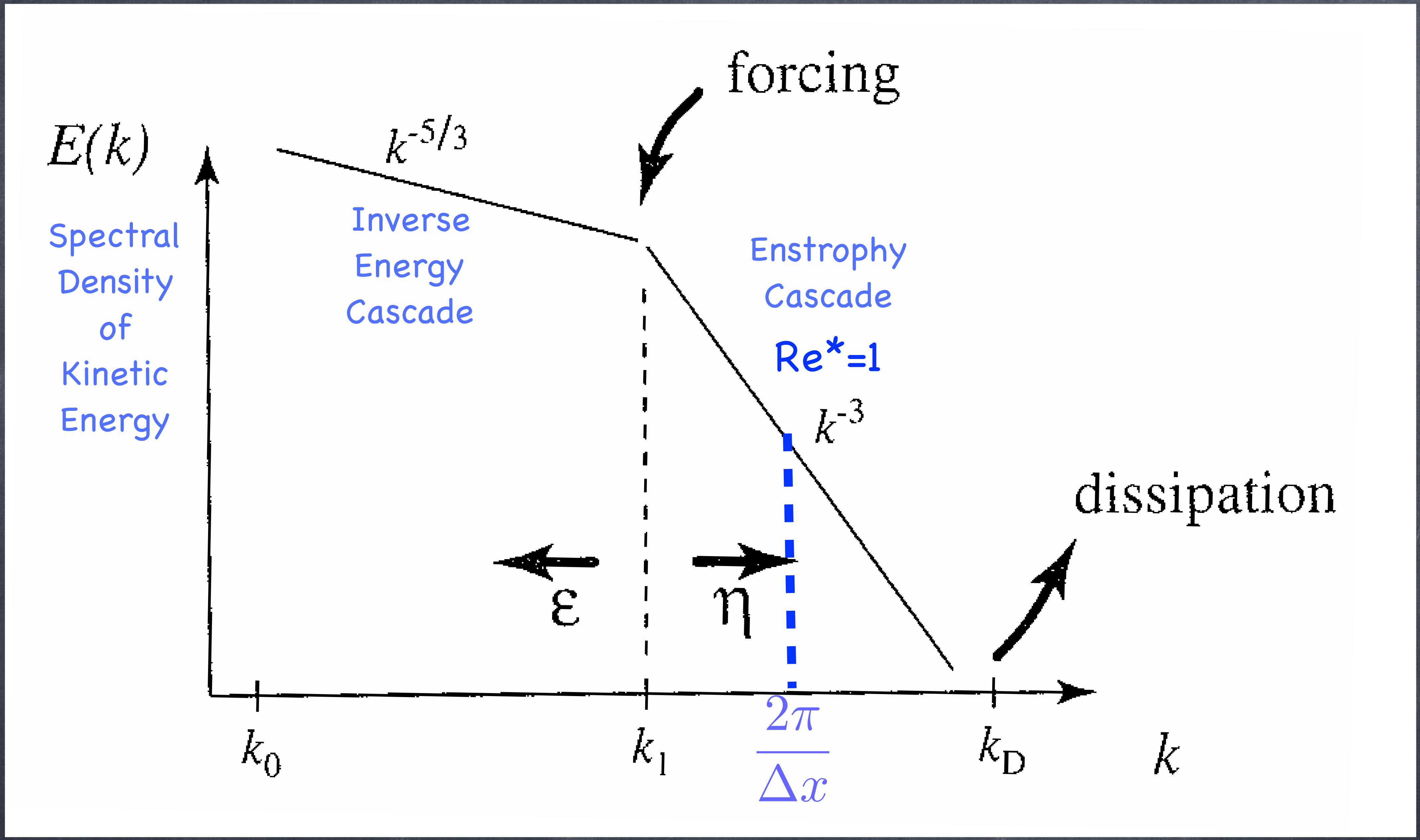


1963: Smagorinsky Scale & Flow Aware Viscosity Scaling,
So the Energy Cascade is Preserved,
but order-1 gridscale Reynolds #: $Re^* = UL/\nu_*$

$$\nu_{*h} = \left(\frac{\Upsilon_h \Delta x}{\pi}\right)^2 \sqrt{\left(\frac{\partial u_*}{\partial x} - \frac{\partial v_*}{\partial y}\right)^2 + \left(\frac{\partial u_*}{\partial y} + \frac{\partial v_*}{\partial x}\right)^2}$$

2D Turbulence Differs

R. Kraichnan, 1967 JFM



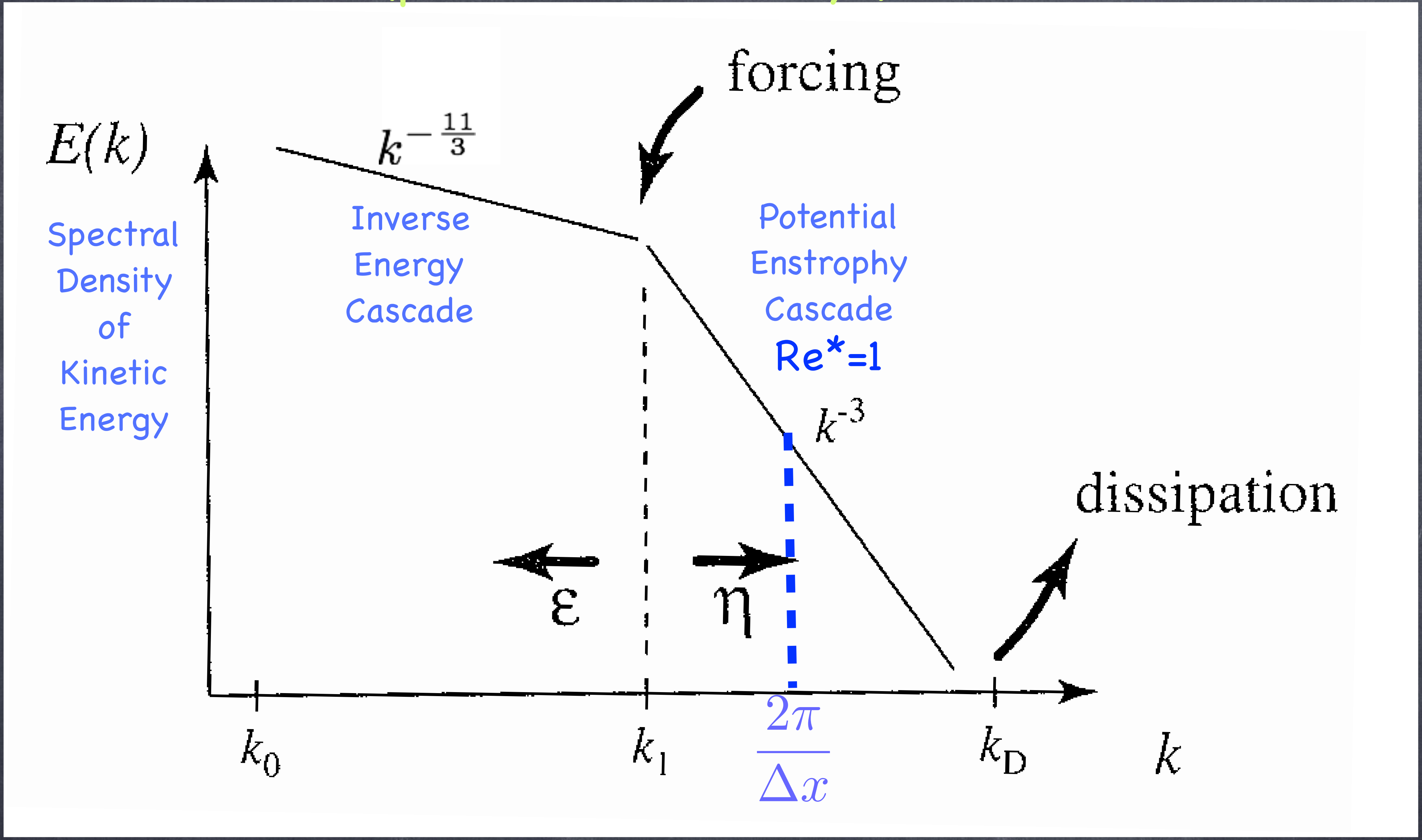
1996: Leith Devises Viscosity Scaling,
So that the Enstrophy (vorticity²) Cascade is Preserved

$$\nu_* = \left(\frac{\Lambda \Delta x}{\pi}\right)^3 \left|\nabla_h \left(\frac{\partial u_*}{\partial y} - \frac{\partial v_*}{\partial x}\right)\right|$$

Barotropic or stacked layers

QG Turbulence: Pot'l Enstrophy cascade (potential vorticity²)

J. Charney, 1971 JAS



$$q^*_{2d} = f + \hat{k} \cdot \nabla \times u^*$$

$$q^*_{qg} = f + \hat{k} \cdot \nabla \times u^* + \frac{\partial}{\partial z} \frac{f^2}{N^2} b^*$$

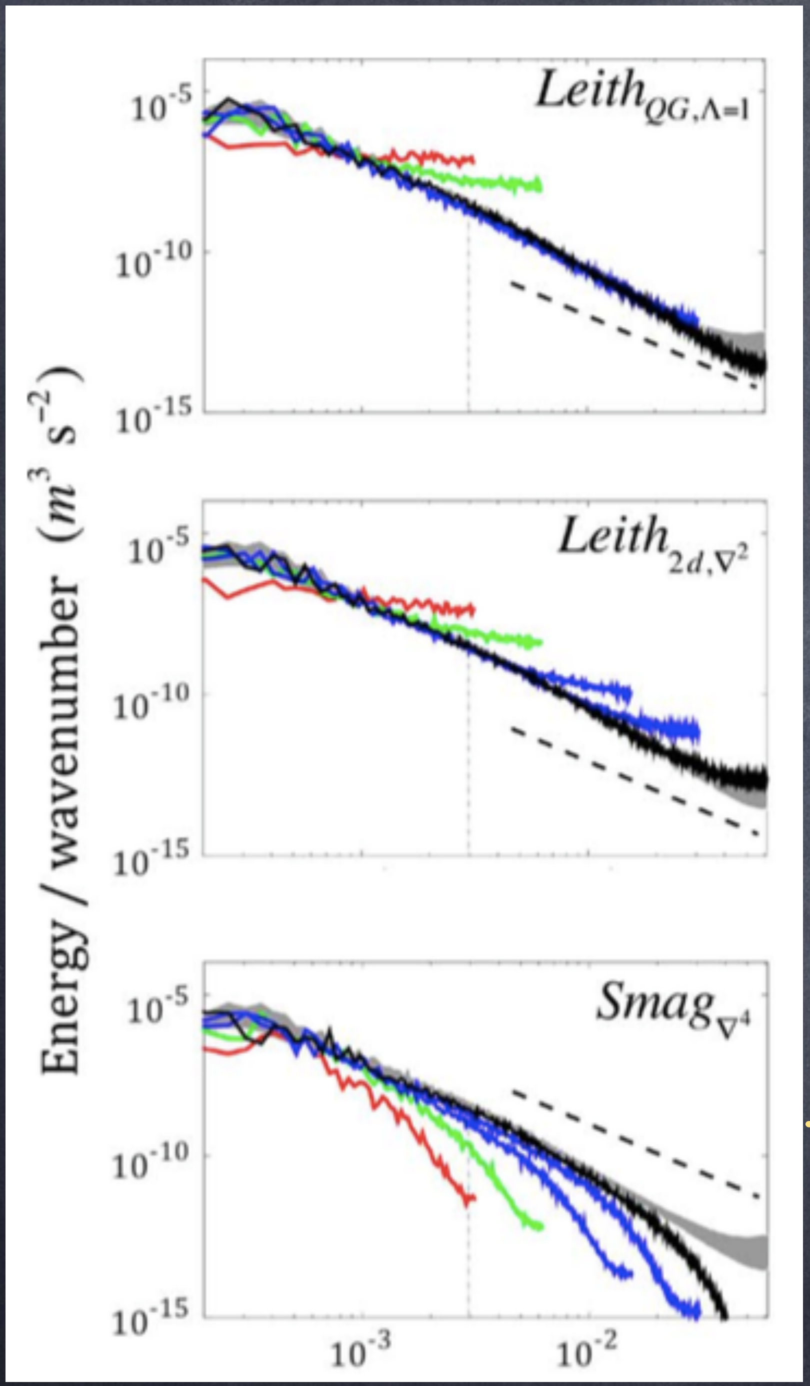
$$\nu_{qg} = \kappa_{Redi} = \kappa_{GM} = \left(\frac{\Lambda_{qg} \Delta x}{\pi}\right)^3 |\nabla q_{qg}| \,.$$

B. Fox-Kemper and D. Menemenlis. Can large eddy simulation techniques improve mesoscale-rich ocean models? In M. Hecht and H. Hasumi, editors, Ocean Modeling in an Eddying Regime, volume 177, pages 319-338. AGU Geophysical Monograph Series, 2008.

What does it do?

Spectrally speaking in

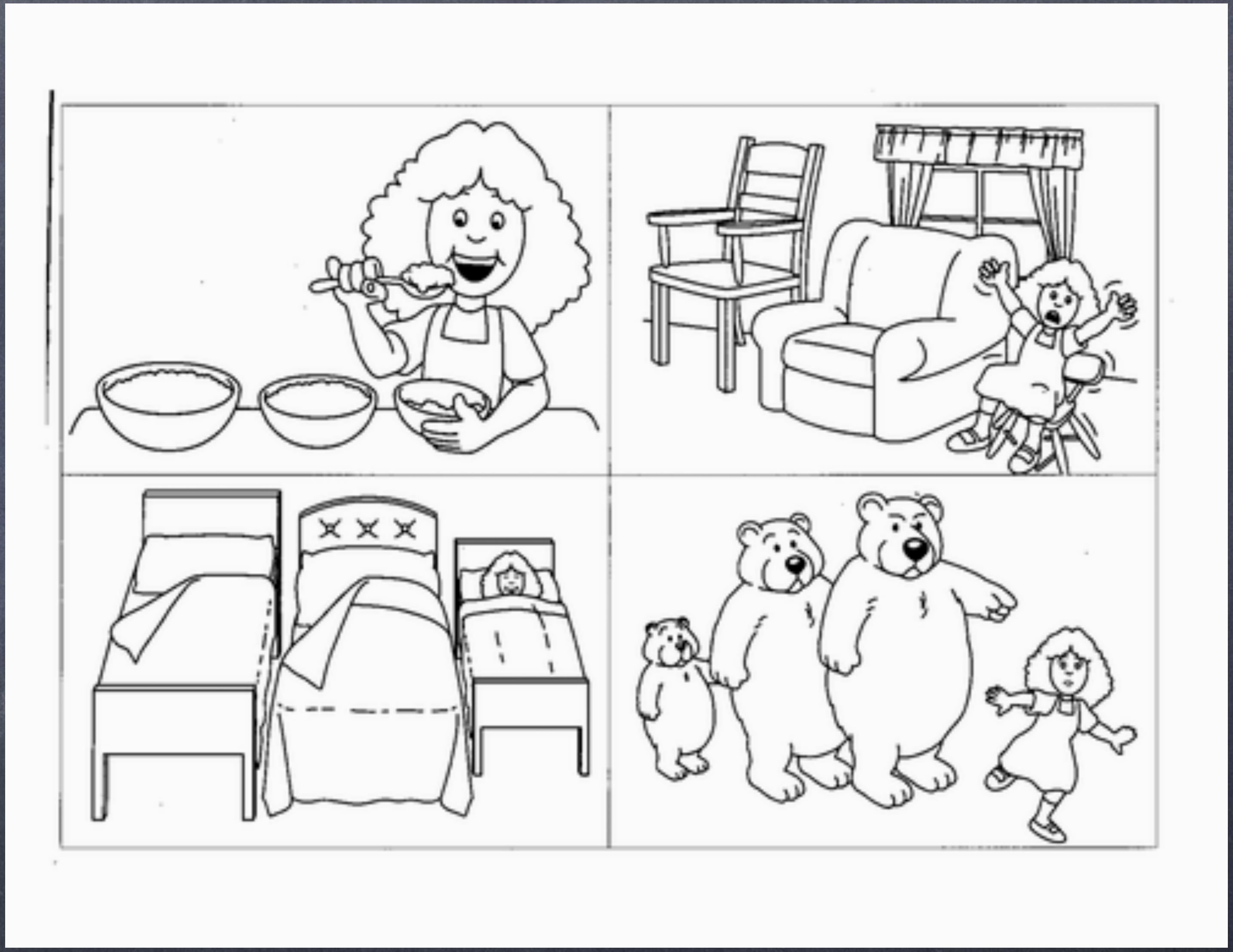
Idealized Channel Tests
with an inverse energy and forward potential enstrophy cascade



Just Right

Too Noisy

Too Smooth



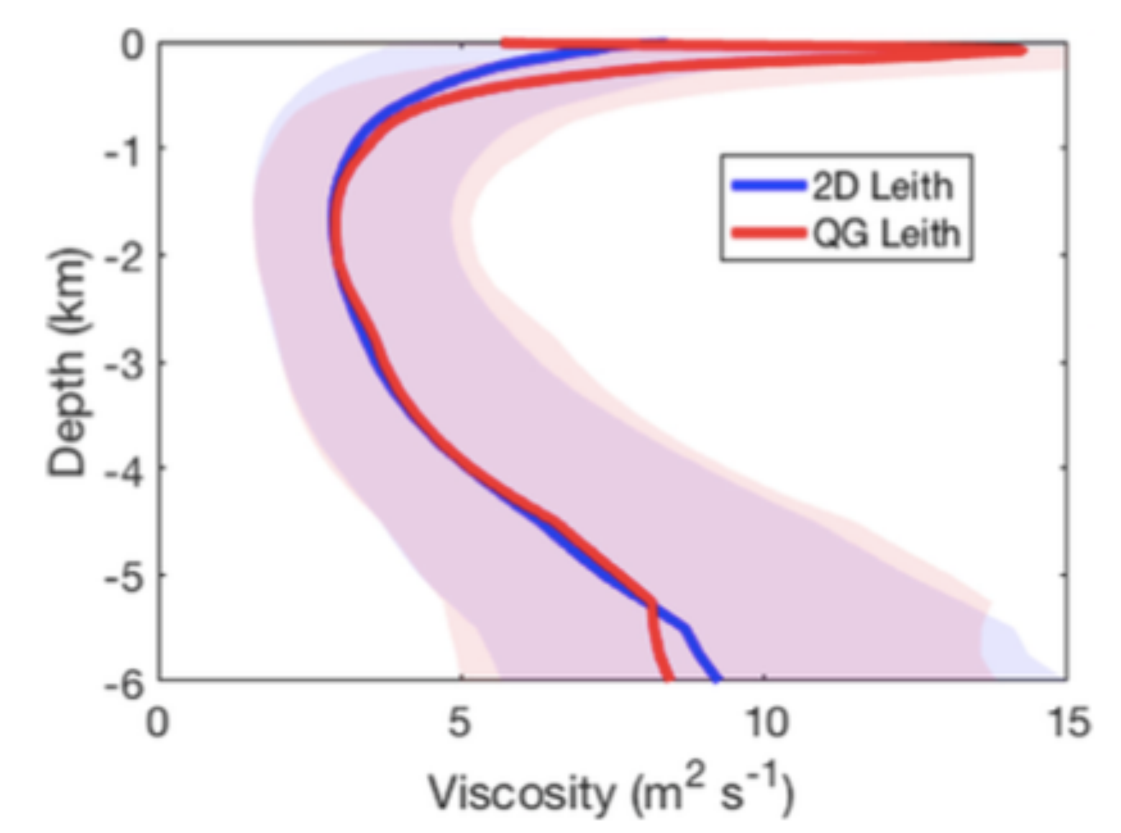
S. D. Bachman, B. Fox-Kemper, and B. Pearson, 2017: A scale-aware subgrid model for quasi- geostrophic turbulence. Journal of Geophysical Research–Oceans, 122:1529–1554. URL http: //dx.doi.org/10.1002/2016JC012265.

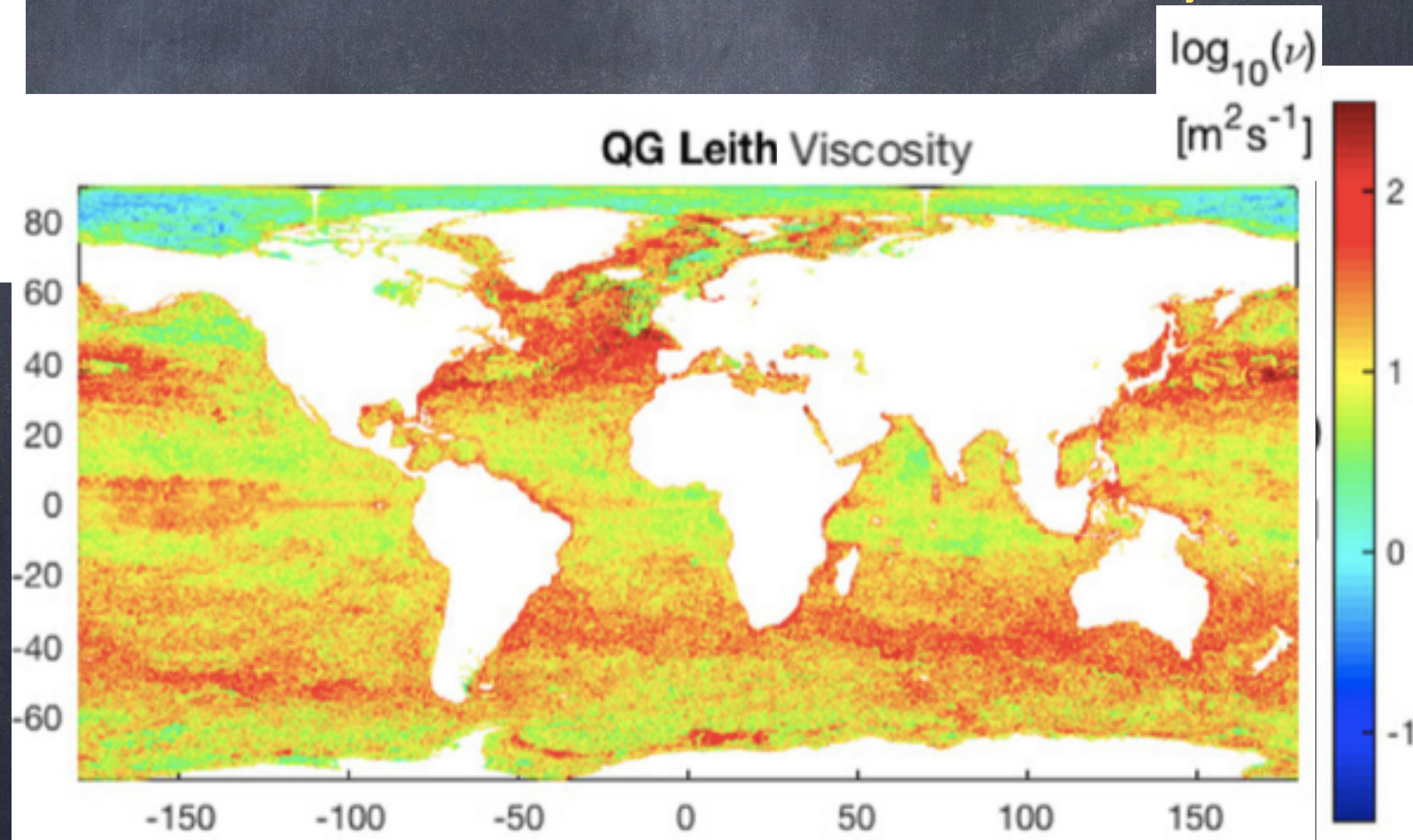
QGLeith: Global Realistic Model

$$\nu_{qg} = \kappa_{Redi} = \kappa_{GM} = \left(\frac{\Lambda_{qg}\Delta x}{\pi}\right)^3 |\nabla q_{qg}|.$$

Momentum uses Laplacian horizontal diffusion

Active & Passive Tracers use GM scheme w/ diffusivity/transfer coeff. matched to viscosity





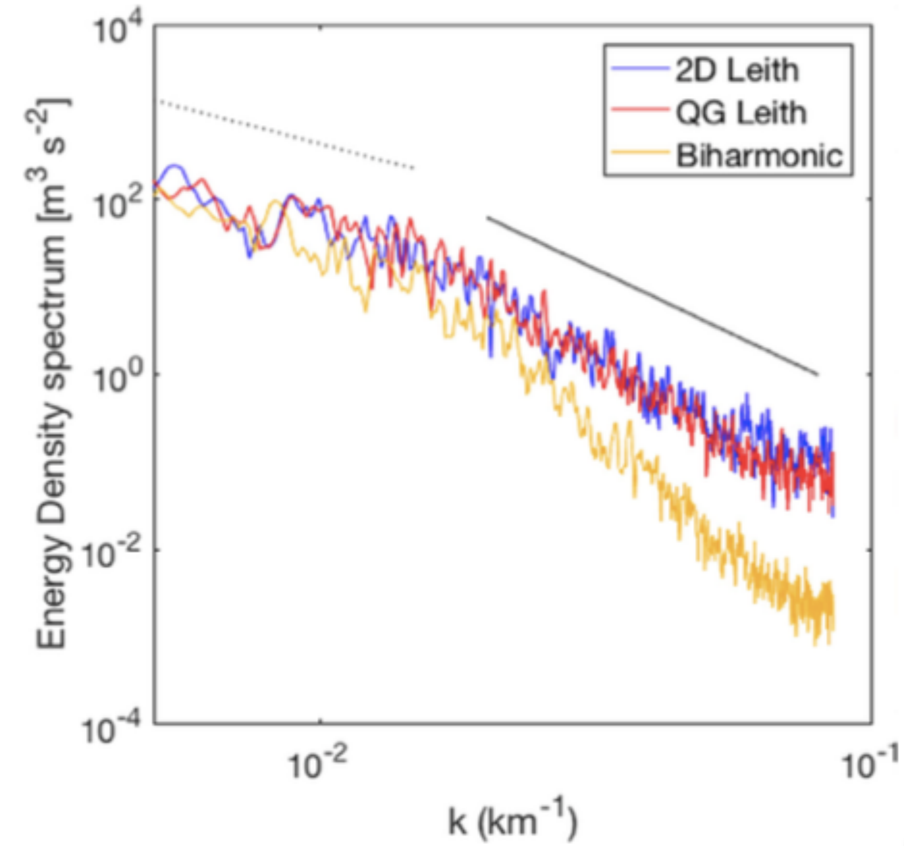
S. D. Bachman, BFK, and B. Pearson, 2017: A scale-aware subgrid model for quasi-geostrophic turbulence. Journal of Geophysical Research–Oceans, 122:1529–1554.

B. Pearson, BFK, S. D. Bachman, and F. O. Bryan, 2017: Evaluation of scale-aware subgrid mesoscale eddy models in a global eddy-rich model. Ocean Modelling, 115:42–58.

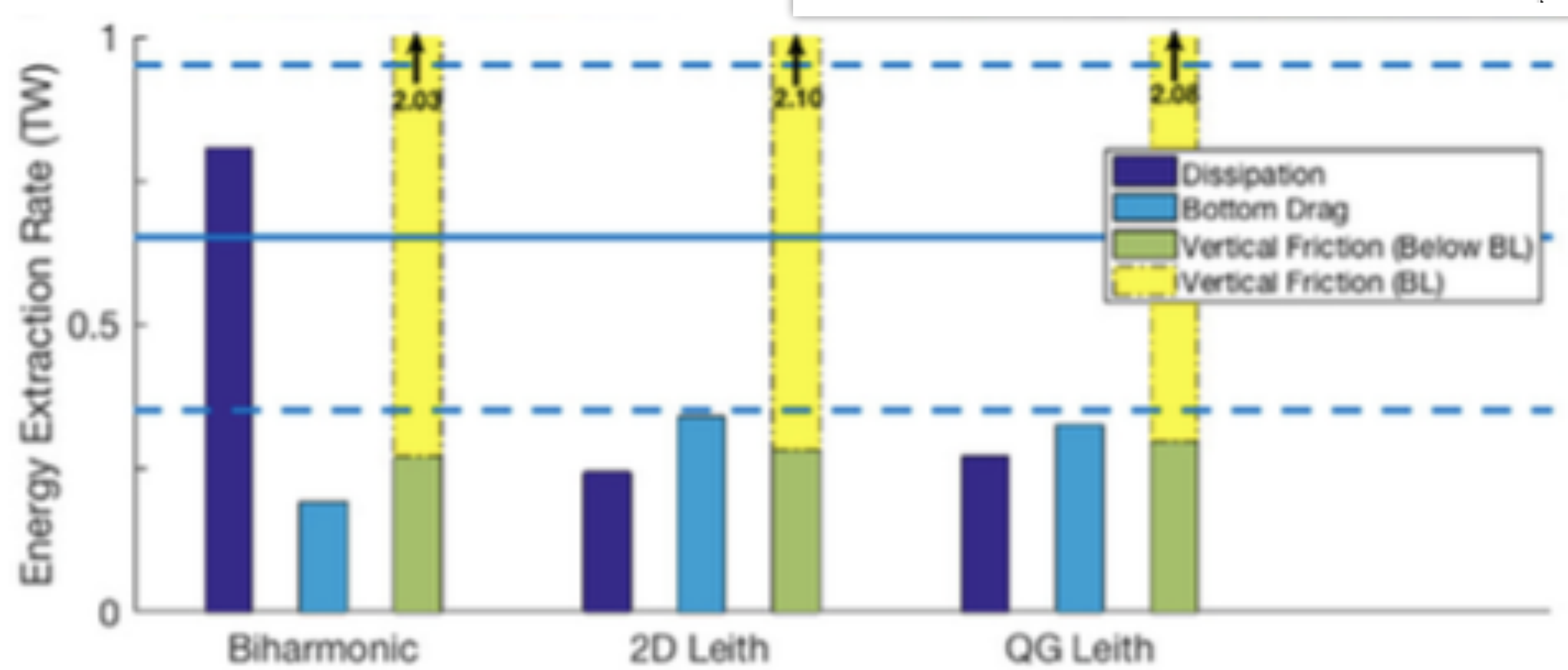
Realistic Global Models–comparing schemes

There is a (weak) forward energy transfer that's sensitive to subgrid

ACC in Global!



Global KE Sinks



B. Pearson, BFK, S. D. Bachman, and F. O. Bryan, 2017: Evaluation of scale-aware subgrid mesoscale eddy models in a global eddy-rich model. Ocean Modelling, 115:42–58.

Global dissipation

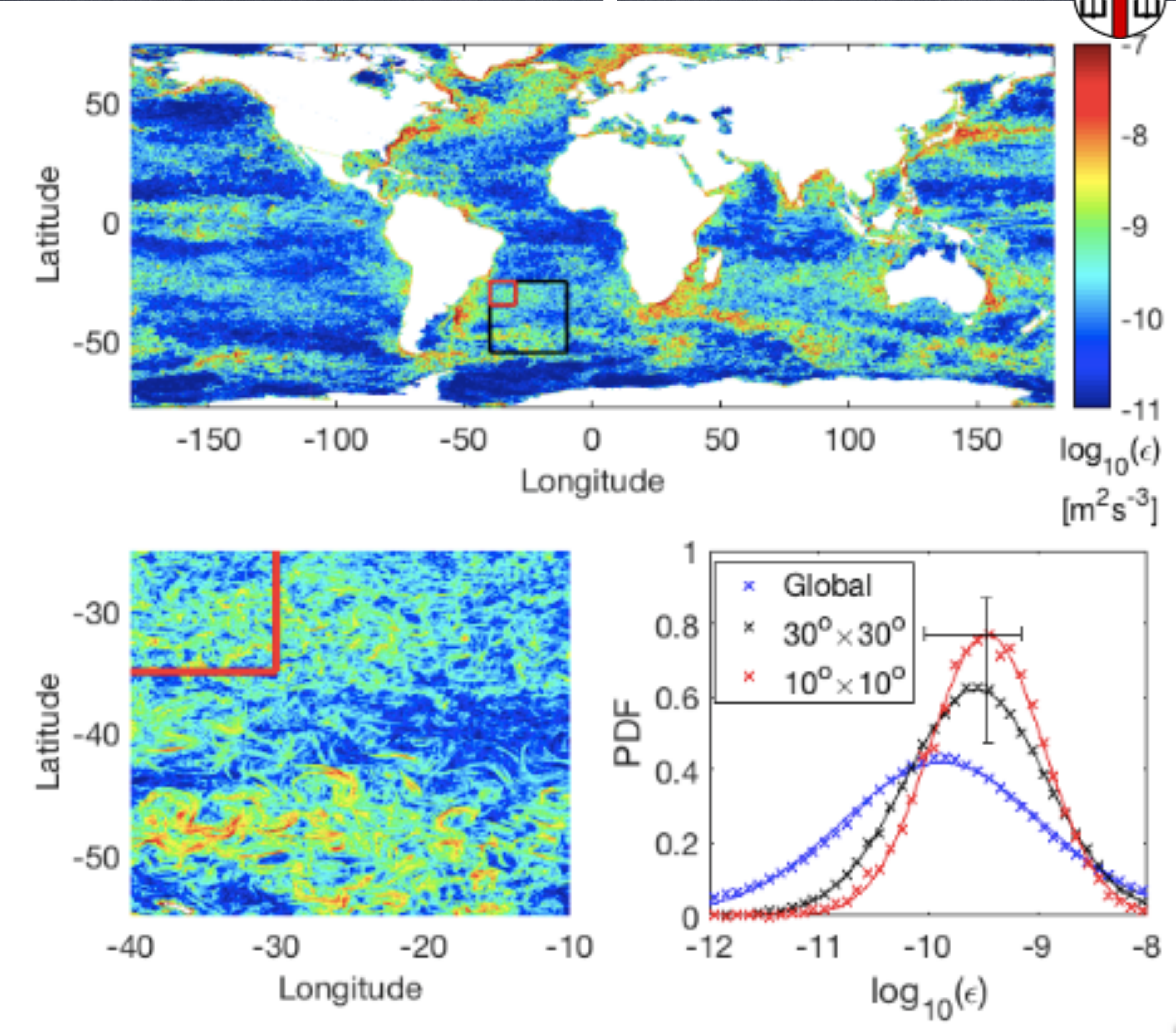
A (weak) dissipation of energy in enstrophy cascade

...

Dissipation is lognormally distributed

90% of dissipation in 10% of ocean

B. Pearson and B. Fox-Kemper. Log-normal turbulence dissipation in global ocean models. Physical Review Letters, 120(9):094501, March 2018.



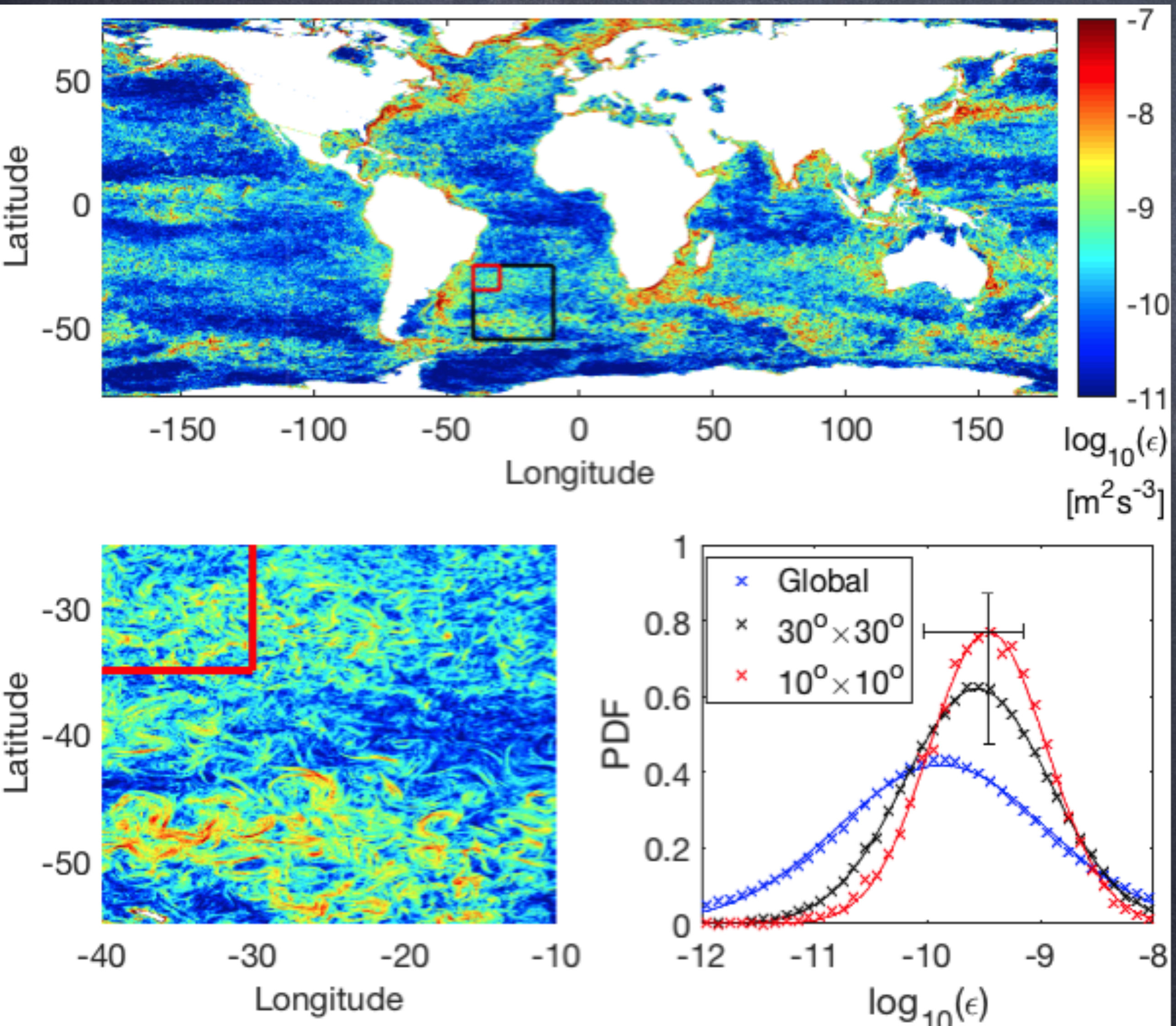
Conclusions

Subgrid scheme matters
for leading order EKE budget
and numerical stability
Even at 2km-10km resolution!

A new scheme (QGLeith)
has been developed for models
resolving the deformation radius

It is adiabatic in tracers, more
dissipative than 2DLeith and less
dissipative than Smagorinsky

For all high-res models, energy
dissipation is extremely
localized: lognormal distribution
(90% of total in 10% of regions)



All papers at:
Fox-Kemper.com

Lognormally distributed—AND knows where the Gulf Stream is!