Observations and models of oceanic macroturbulence:

meet the new bias same as the old bias

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with
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Sources and Sinks of Eddy Mesoscale Energy, 3/14/19, 10:40-11:00AM

Sponsors: NSF (OCE 1350795), ONR (N00014-17-1-2963), CARTHE

Old Bias—Reynolds Avg.—LowRes

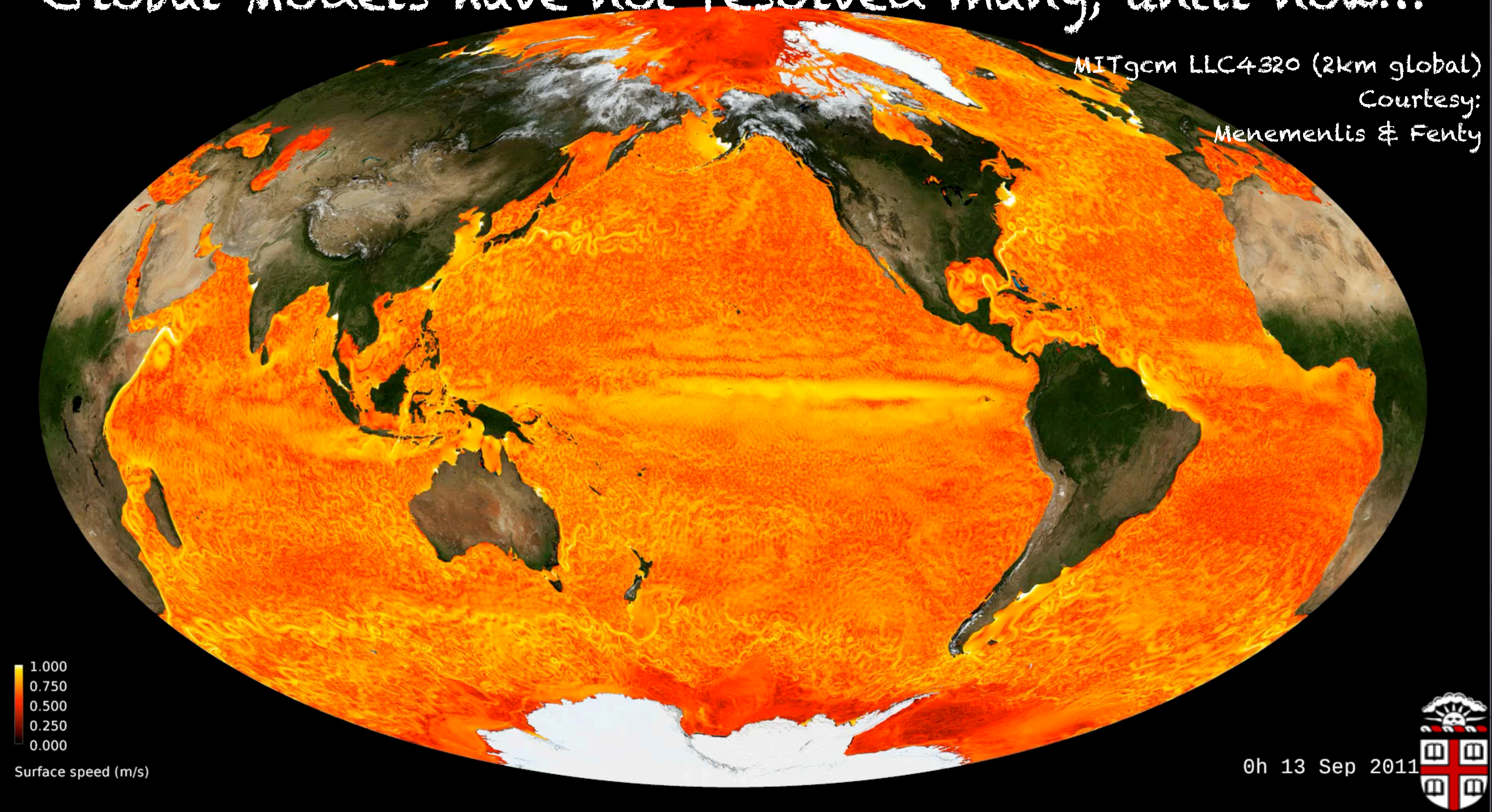
Questionable eddy parameterizations
Diversity of approaches, no cross-evaluation
Not much data to assess them
Unclear relationship of key impacts to params.

New Bias—Large Eddy Sims. (LES)

Questionable subgrid parameterizations
Diversity of approaches, no cross-evaluation
Not much data to assess them
Unclear relationship of key impacts to schemes.

Largest (Mesoscale) Ocean Eddies are Small vs. Earth

Global Models have not resolved many, until now...



Absent realistic global models, We studied "Cascade" Scalings

3D: Richardson/Kolmogorov/Smagorinsky/Corrsin

$$E \propto \epsilon^{2/3}\ell^{5/3}, \quad S_2 \propto \epsilon^{2/3}r^{2/3}, \quad \epsilon \propto \nu\alpha^2, \quad \nu = \mathrm{Pr}\,\kappa \propto \Delta x^2|\alpha| \propto \epsilon^{1/3}\ell^{4/3}$$

$\epsilon =$ conserved energy flux

2D: Barnier/Kraichnan/Leith

$$E \propto \eta^{2/3}\ell^{3}, \quad S_2 \propto \eta^{2/3}r^{2}, \quad \eta \propto \nu(\nabla\omega)^2, \quad \nu \propto \Delta x^3|\nabla\omega| \propto \eta^{1/3}\ell^2, \quad \kappa \propto ?$$

$\eta =$ conserved enstrophy flux

Quasigeostrophy: Barnier/Charney/QGLeith

$$E \propto \eta^{2/3}\ell^{3}, \quad S_2 \propto \eta^{2/3}r^{2}, \quad \eta \propto \nu(\nabla q)^2, \quad \nu = \kappa_{Redi} = k_{GM} \propto \Delta x^3|\nabla q| \propto \eta^{1/3}\ell^2$$

$\eta =$ conserved potential enstrophy flux

SQG?

Submesoscale: McWilliams/?/?F-K?

$$E \propto \ell^2, \quad S_2 \propto r^1, \quad d/dt(PE + KE) = ??, \quad \nu = ?, \quad \kappa = ?$$

QG & 2D Leith

$$\nu^* = \left(\frac{\Lambda \quad \Delta x}{\pi}\right)^3 |\nabla q^*|$$

Different (Pot'l) Vorticity Gradients:

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

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

$$\Lambda = 1$$

stretching needs "taming" where QG is a bad approx (equator, boundary layers, etc.)

Use gridscale nondims to determine when on the fly

$$Ro^* = \frac{U^*}{f\Delta x} \qquad Bu^* = \frac{{N^*}^2 \Delta z^2}{f^2 \Delta x^2} \sim {Ro^*}^2 Ri^*$$

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.

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

* = as resolved

QG & 2D Leith

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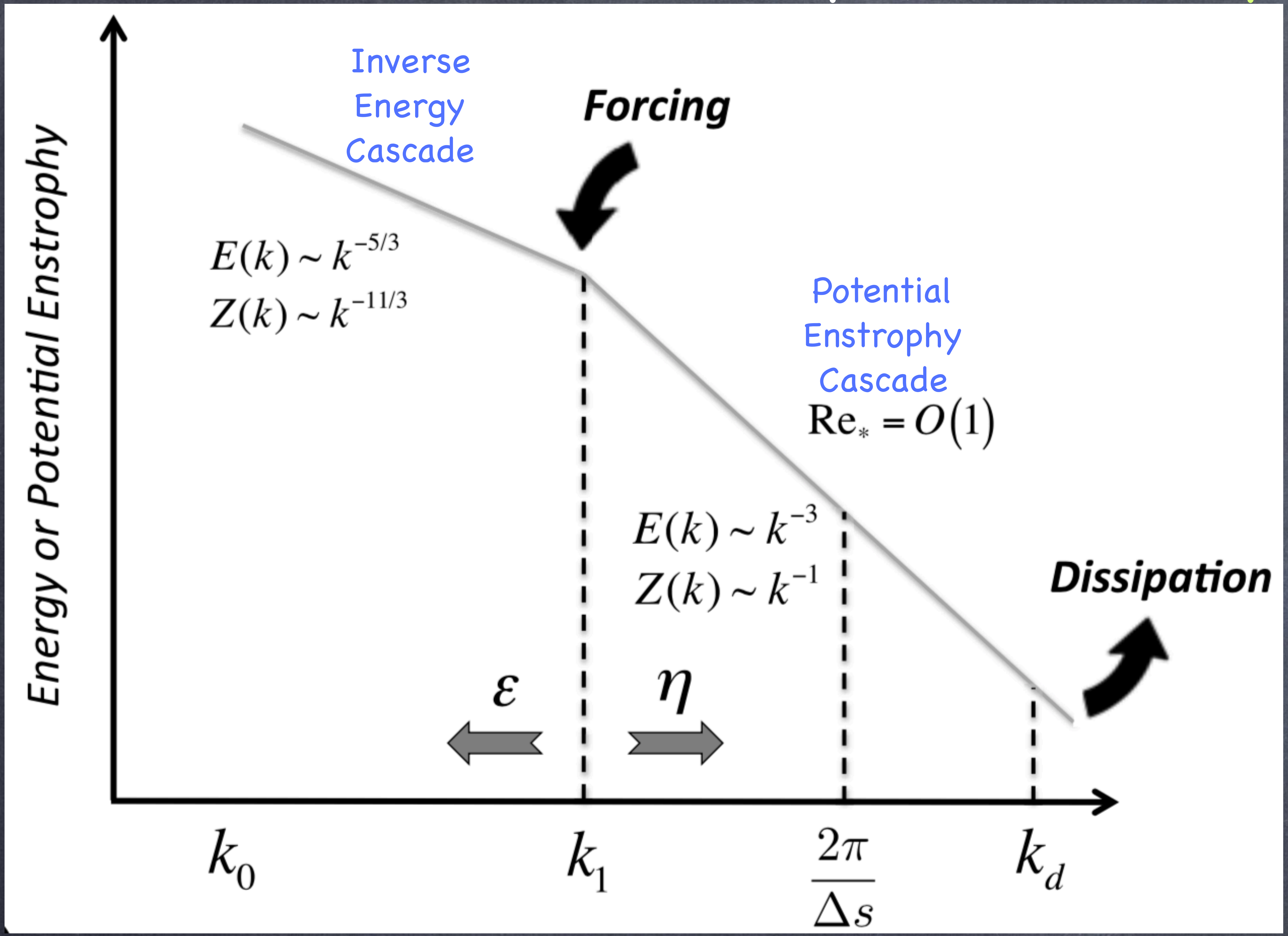
$$\Lambda = 1$$

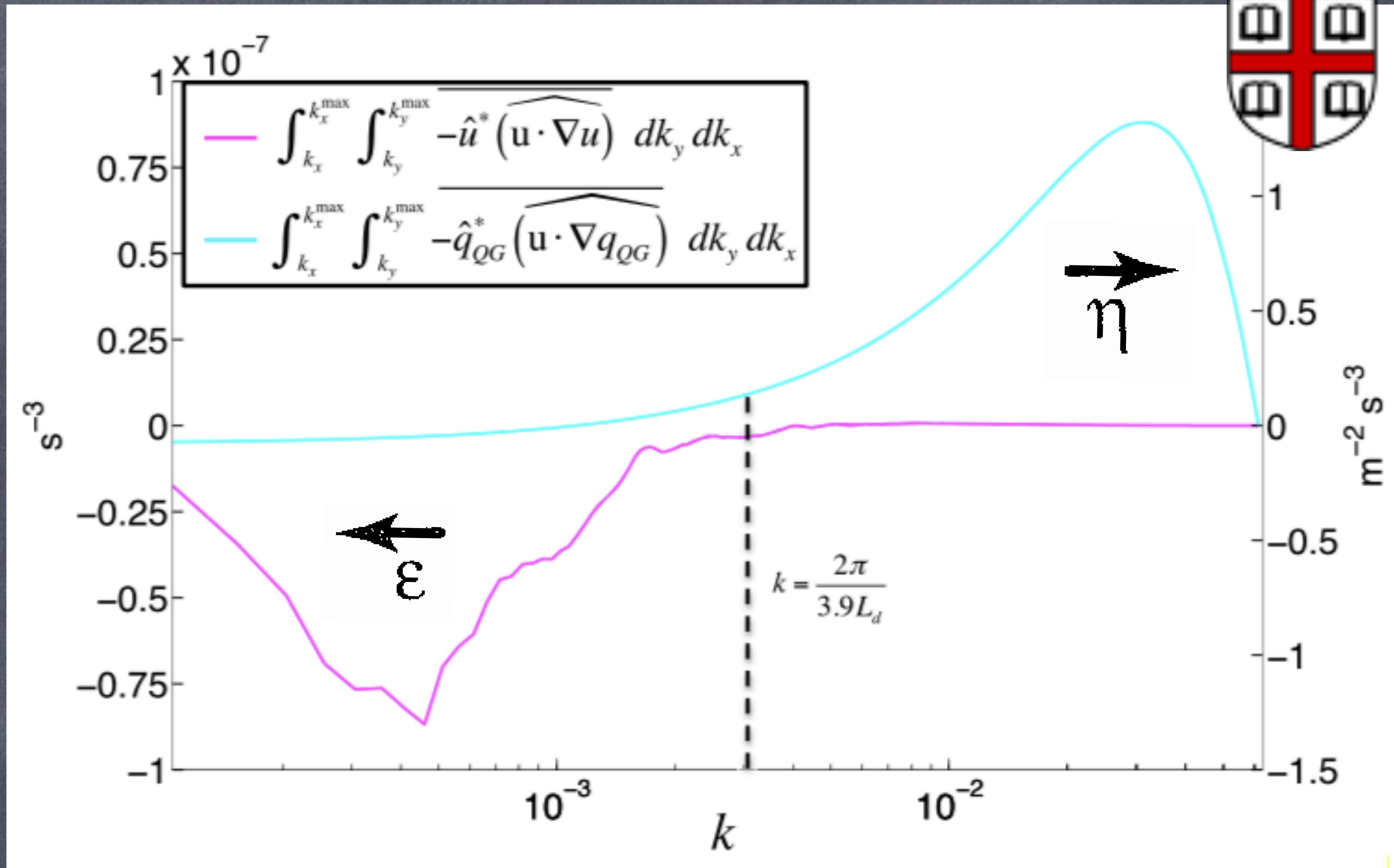
Also, different implications, because relative vorticity, buoyancy, T, S dissipation now must be consistent with PV:

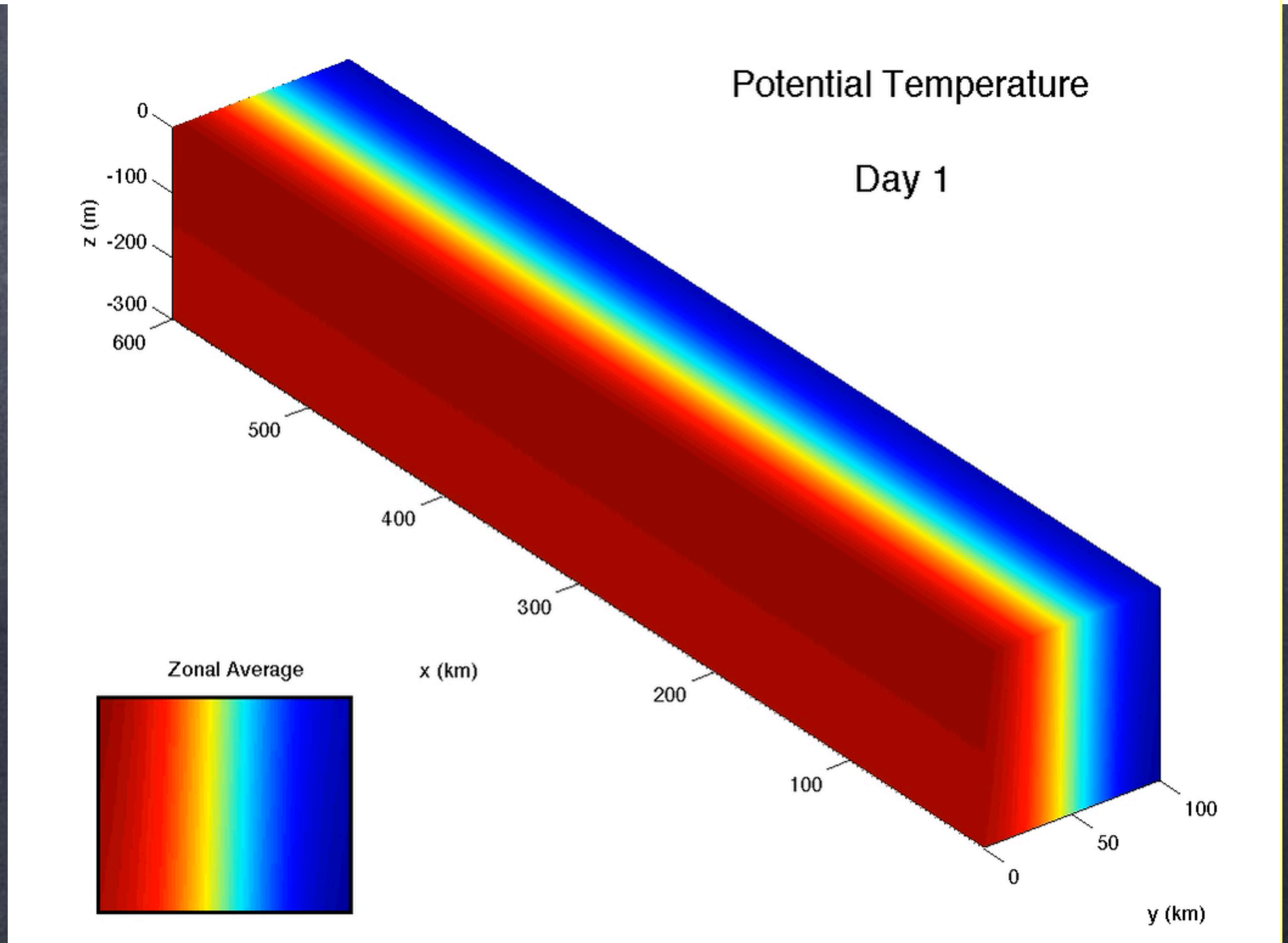
$$\frac{Dq^*_{qg}}{Dt} = -\nabla \cdot \overline{u' q'_{qg}} \approx \nabla \cdot \left[\nu^* \nabla q_{2d} + \kappa^*_{gm} \nabla \left(q_{qg} - q_{2d}\right)\right] \rightarrow \kappa^*_{gm} = \nu^* = \kappa^*_i$$

S. D. Bachman, B. Fox-Kemper, and B. Pearson. A scale-aware subgrid model for quasigeostrophic turbulence. Journal of Geophysical Research-Oceans, 122:1529-1554, March 2017.

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







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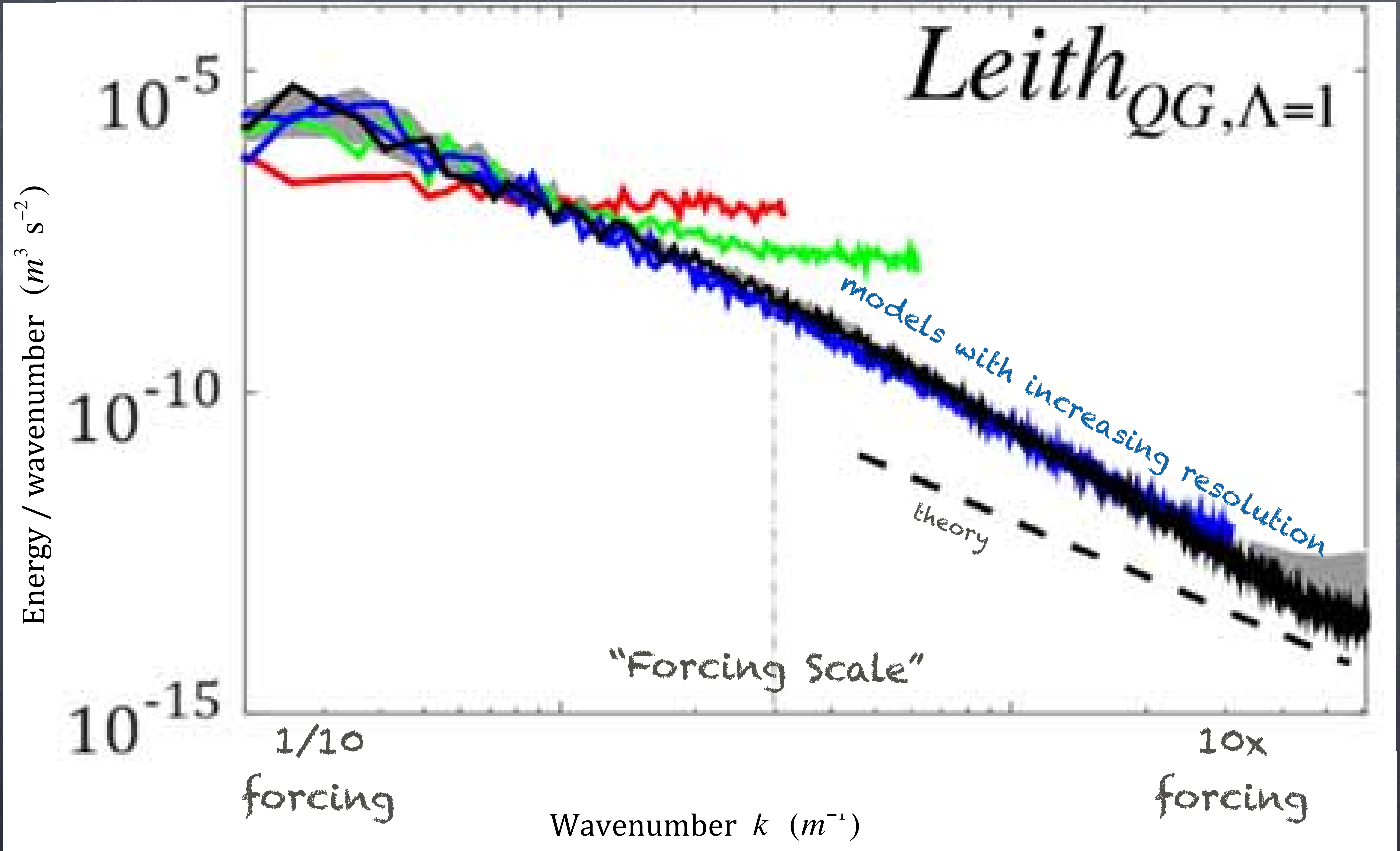
BFK, W. Pan and V. Resseguier. Data-driven versus self-similar parameterizations for Stochastic Lie Transport and Location Uncertainty. In preparation.

Where does ocean energy go?

Spectrally speaking



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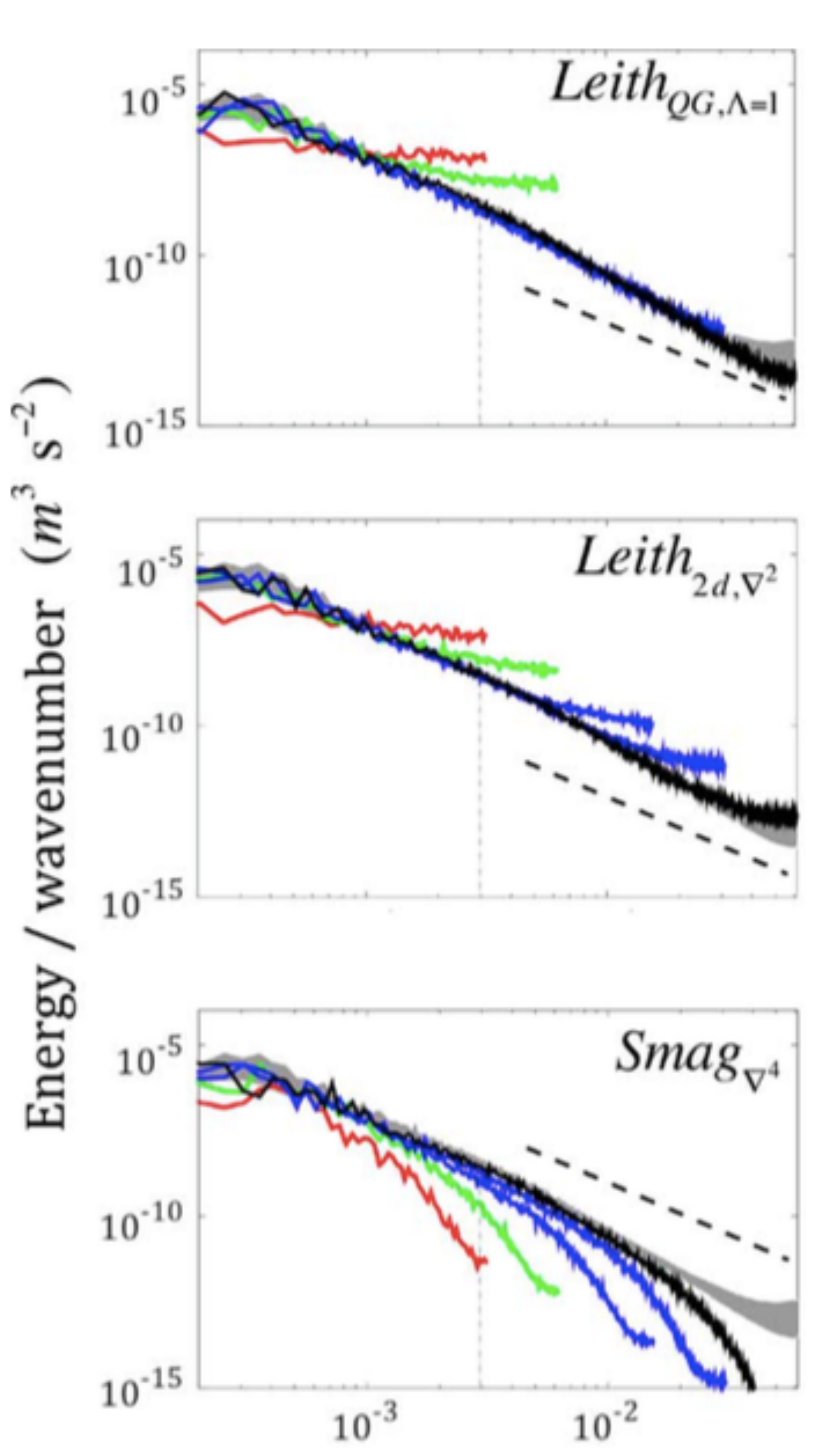


QG Leith:
Just Right!

2D Leith:
Too Noisy

3D Smagorinsky:
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.

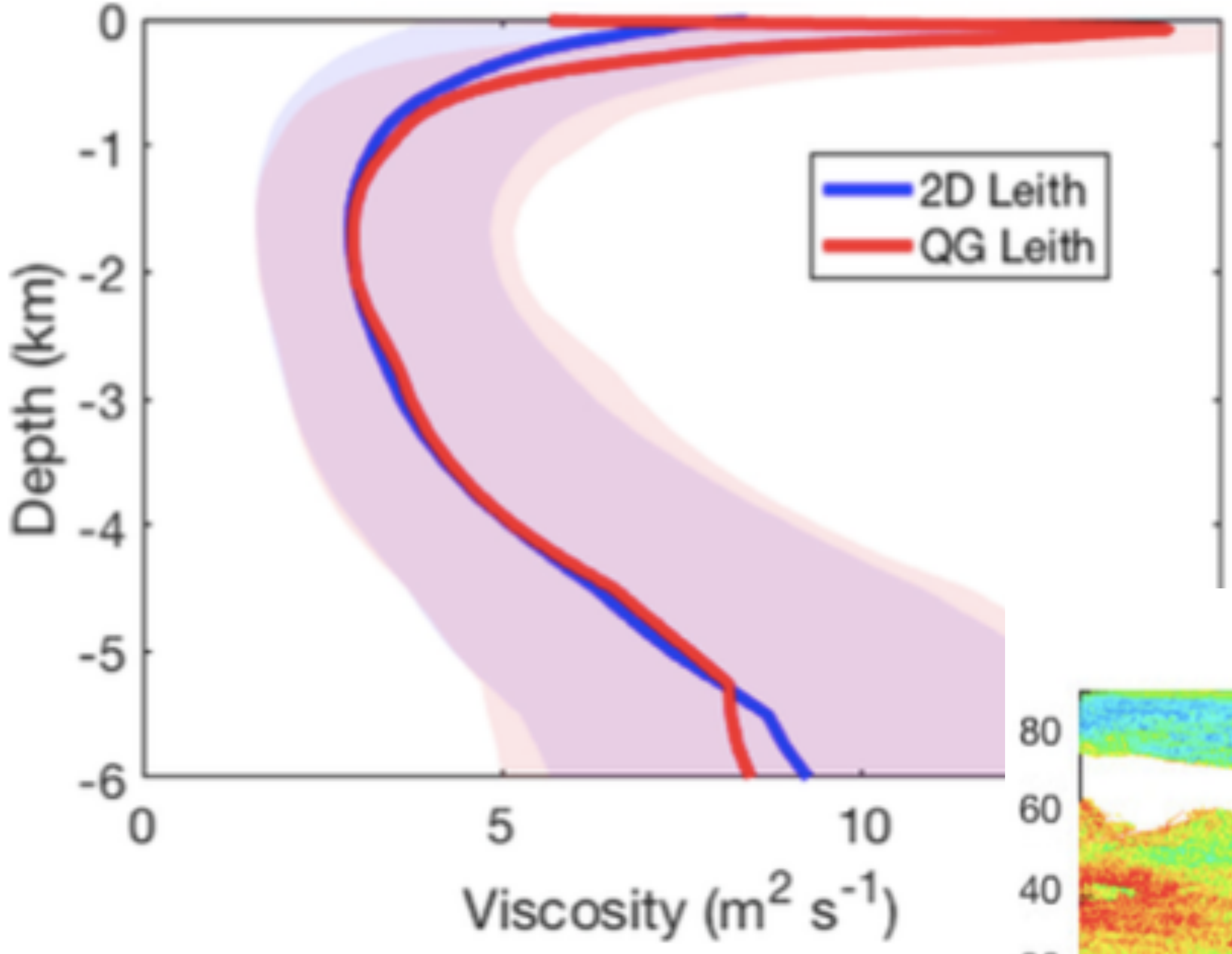
QG Leith:

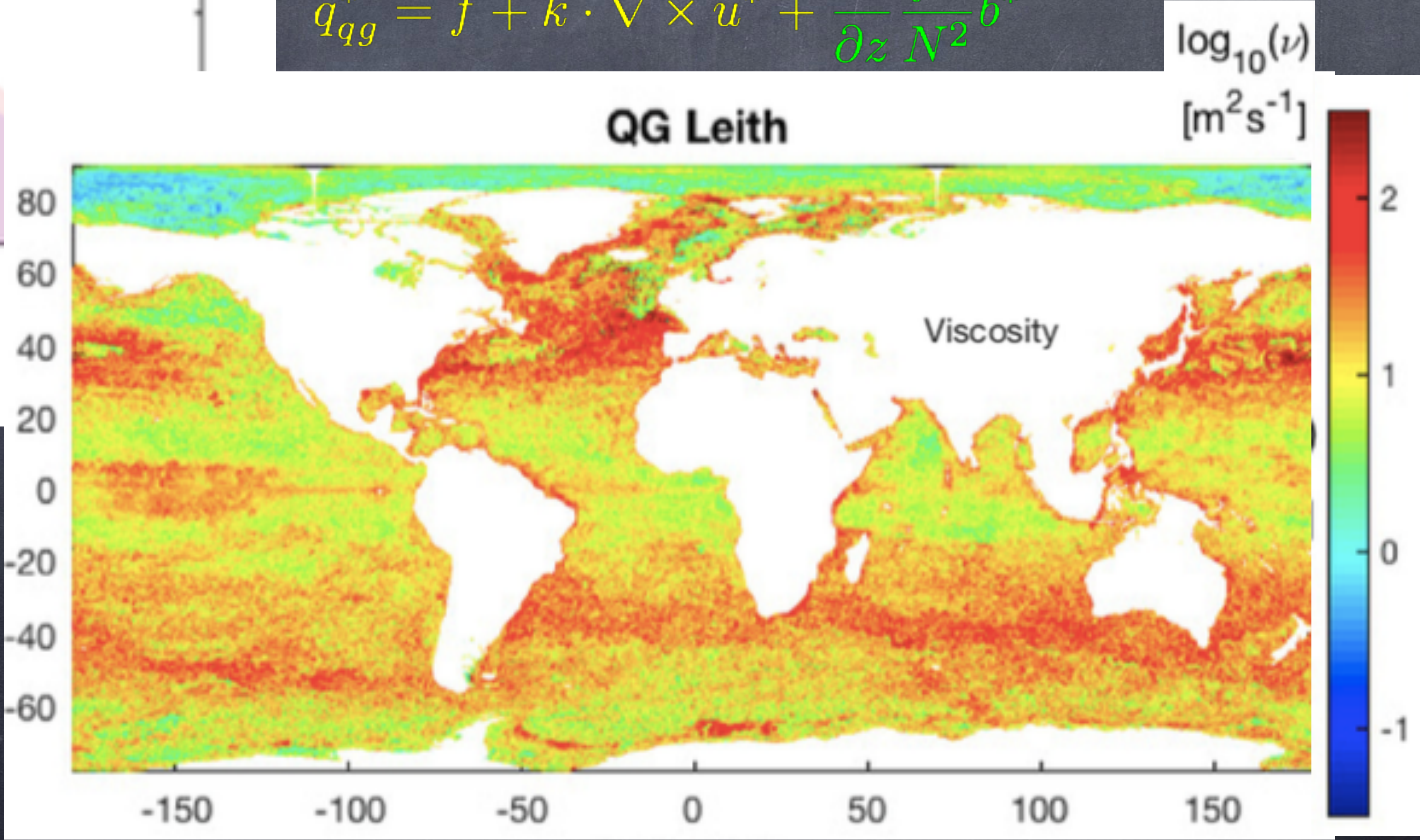
Works OK in an idealized flow:
Let's try it in a realistic, 10km CORE-forced global model!

$$\nu^* = \kappa_i^* = k_{GM}^* \propto \Delta x^3 |\nabla q|$$

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

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





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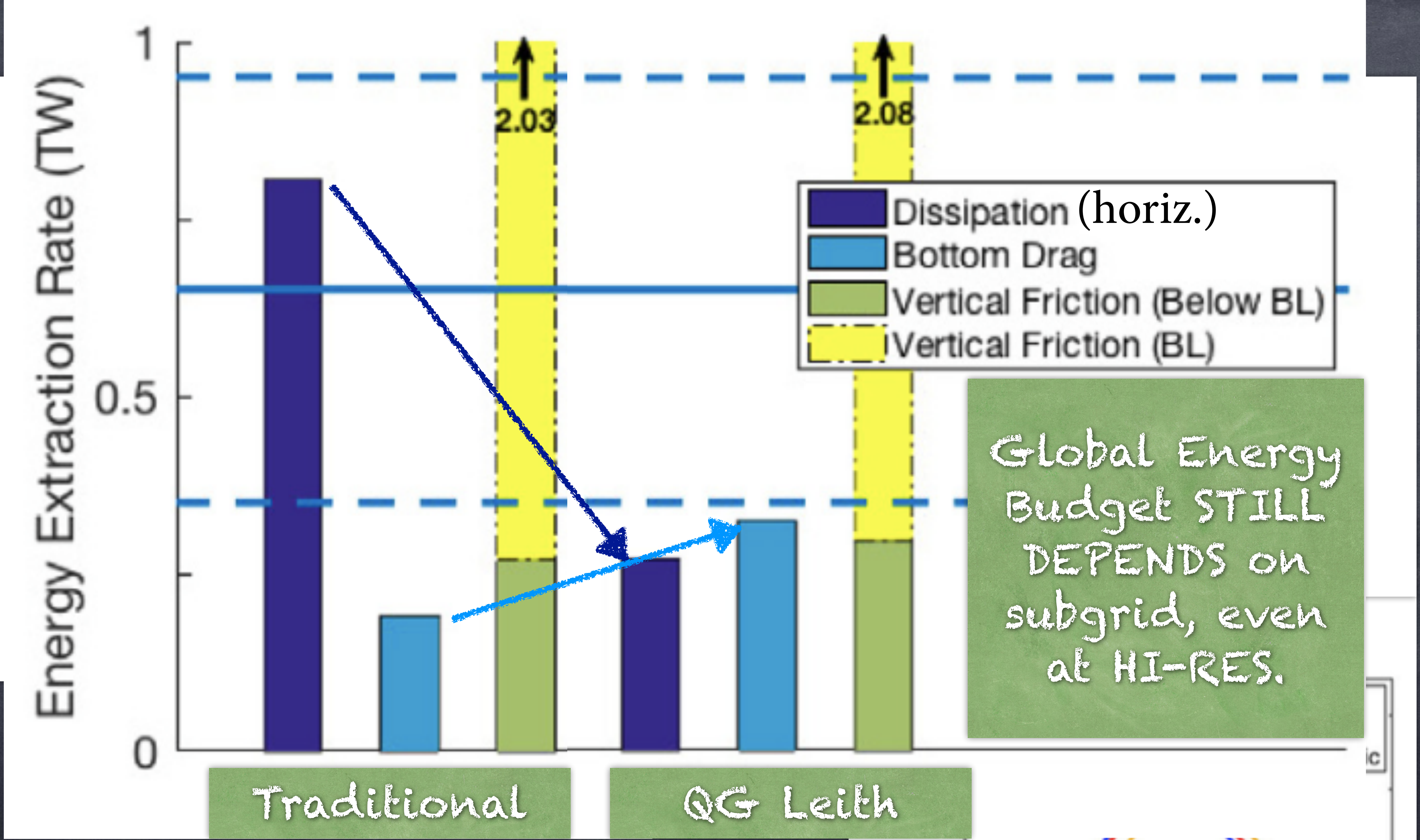
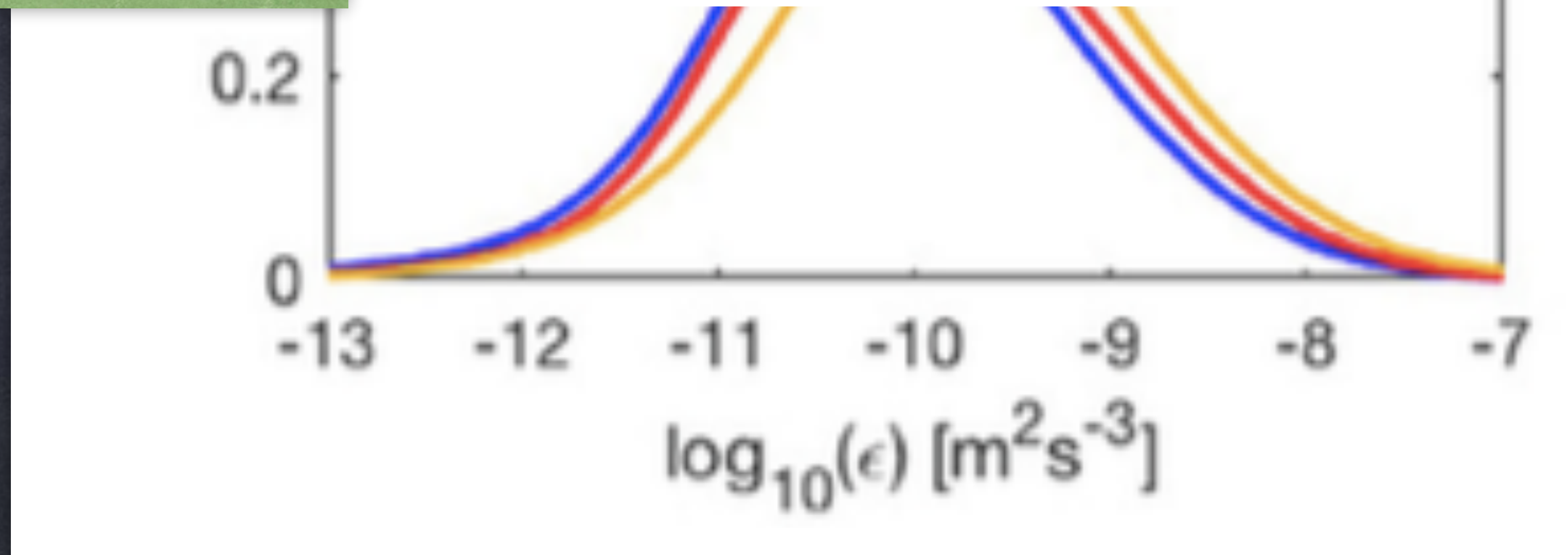


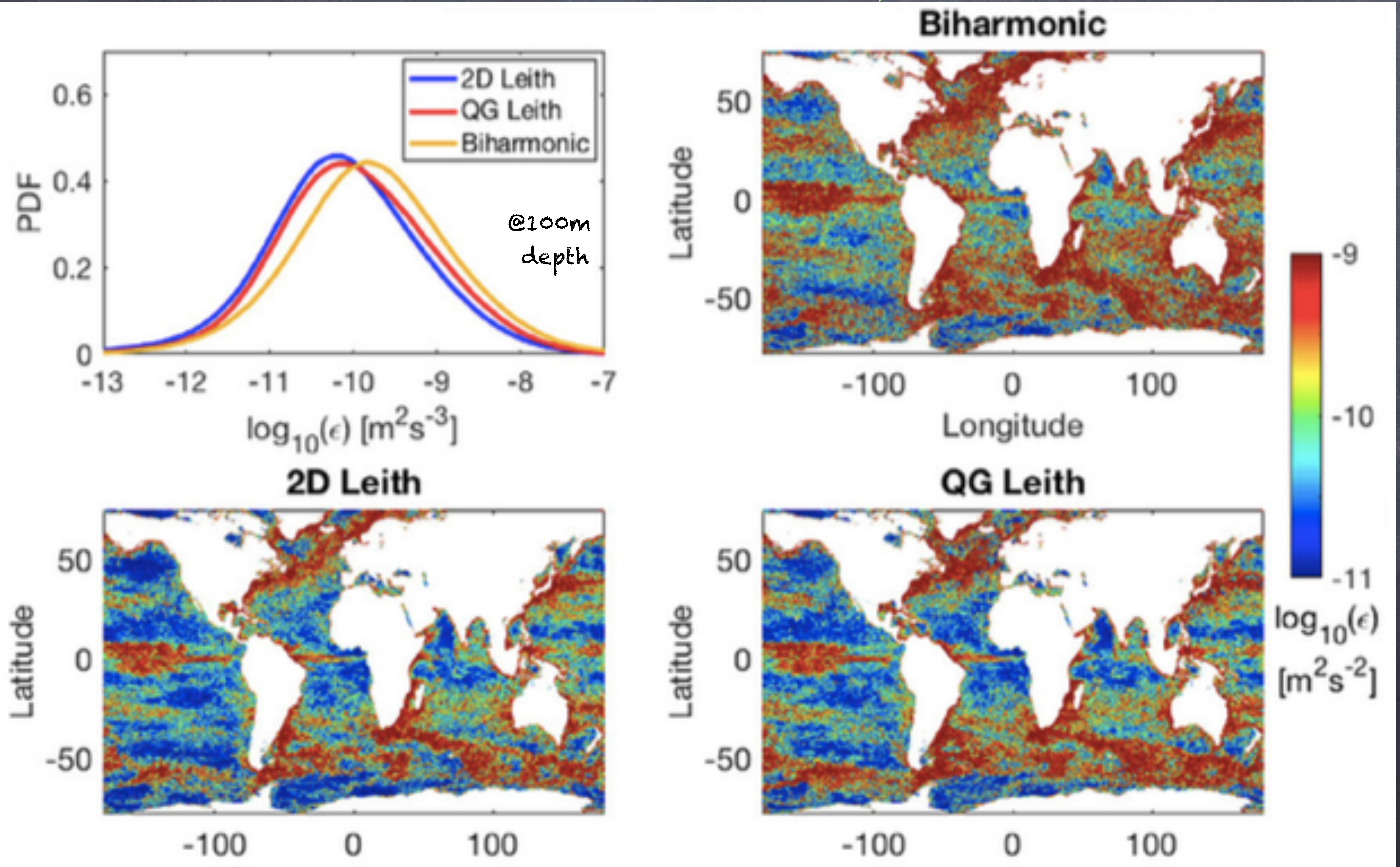
Global Energy Budget STILL DEPENDS on subgrid, even at HI-RES.



(most in upper 200m)

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.

Energy Dissipation is Approx. Lognormally distributed– AND knows where the Gulf Stream is!



Energy Dissipation Stats are Self-Similar

A (weak) dissipation of energy with pot'l enstrophy cascade

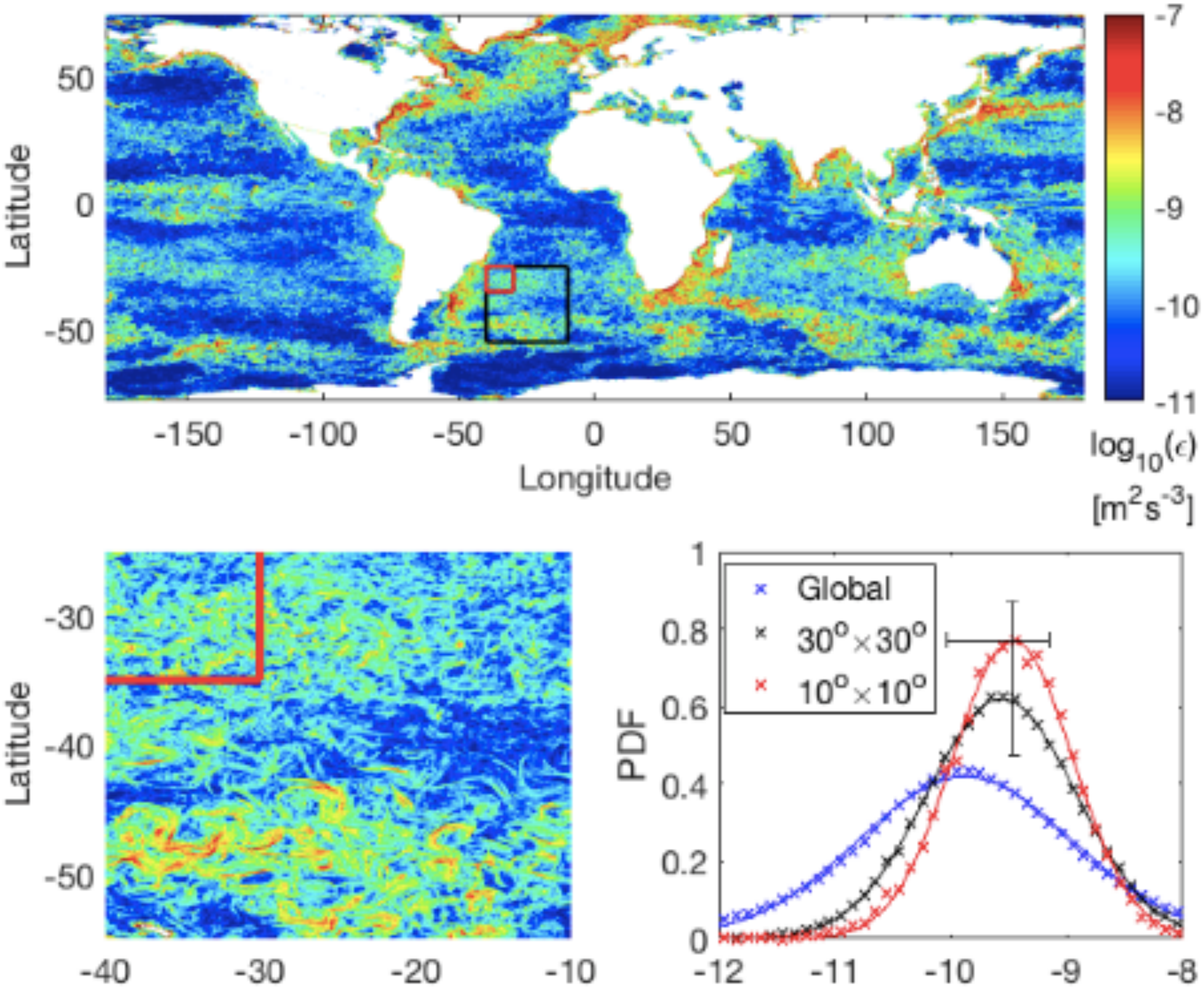
...

approx. lognormally distributed

(super-Yaglom '66)

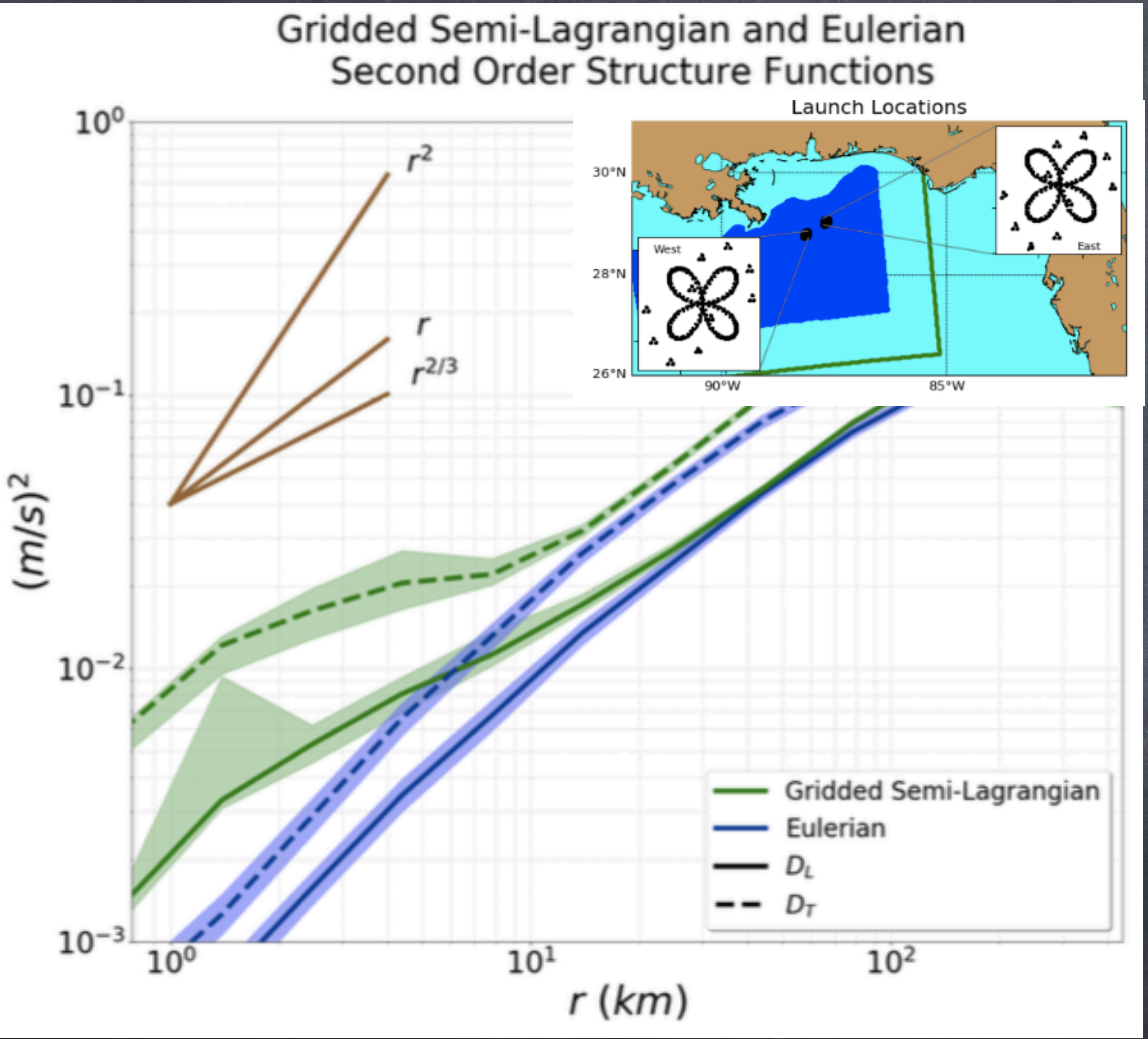
...

90% of KE dissipation in 10% of ocean

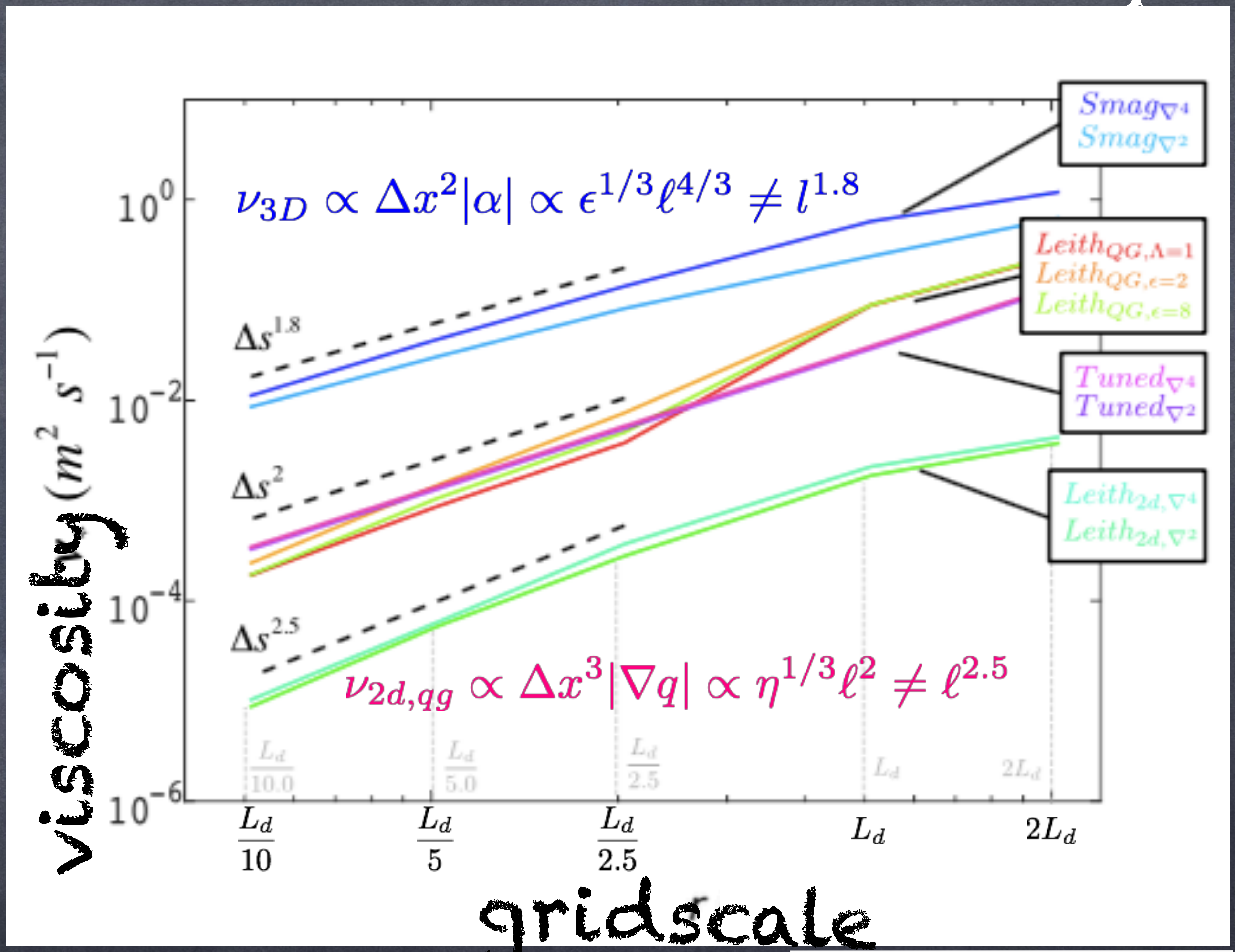


B. Pearson and BFK. Log-normal turbulence dissipation in global ocean models. Physical Review Letters, 120(9):094501, March 2018.

'Observed' scale-sensitivity?



J. Pearson, B. Fox-Kemper, R. Barkan, J. Choi, A. Bracco, and J. C. McWilliams. Impacts of convergence on Lagrangian statistics in the Gulf of Mexico. Journal of Physical Oceanography, 49(3):675-690, March 2019.



Some Theory/Model combos are inconsistent

(e.g., Smagorinsky in a QG regime)

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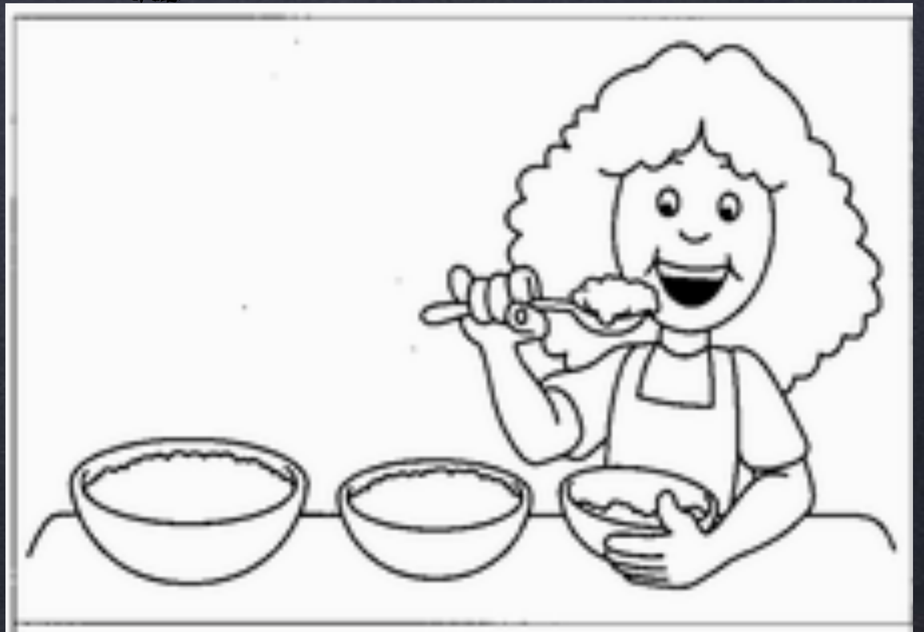

Under "Cascade" Scalings, new bias is a little different

Grounded Param: Following Smagorinsky's 3D approach, we built schemes suitable for mesoscale-permitting ocean models, where 2D or QG cascades rule.

Intercomparison: By comparing across schemes, the Goldilocks test, the self-consistent scaling test, and numerical robustness select QGLeith

Eval. Data (challenges): lognormal dissipation, together with limited observing platforms (e.g., drifters), makes observing dissipation & scalings challenging.

Key Impacts: Global KE budget, major currents, adiabatic scheme. Watermasses? Heat uptake?

On Redi-ness

$$\nu = \frac{\partial_z \left(k_{gm} \frac{\nabla_h b}{\partial_z b} \right)}{\partial_z \left(\frac{\nabla_h b}{\partial_z b} \right) - \frac{\partial_y f}{f}} \approx k_{gm} + \frac{\partial_z k_{gm}}{\partial_z \left(\ln \frac{|\nabla_h b|}{\partial_z b} \right)}$$

$$k_{gm} = \nu - \frac{\int_{-H}^{z} \frac{\nabla_h b}{\partial_z b} \partial_z \nu - \nu \frac{\partial_y f}{f} \, \mathrm{d}z}{\frac{\nabla_h b}{\partial_z b}} \approx - \frac{\int_{-H}^{z} \frac{|\nabla_h| b}{\partial_z b} \partial_z \nu \, \mathrm{d}z}{\frac{|\nabla_h| b}{\partial_z b}}$$