Evaluation of High-Resolution Simulations: Inferences from MOLES & SMOLES

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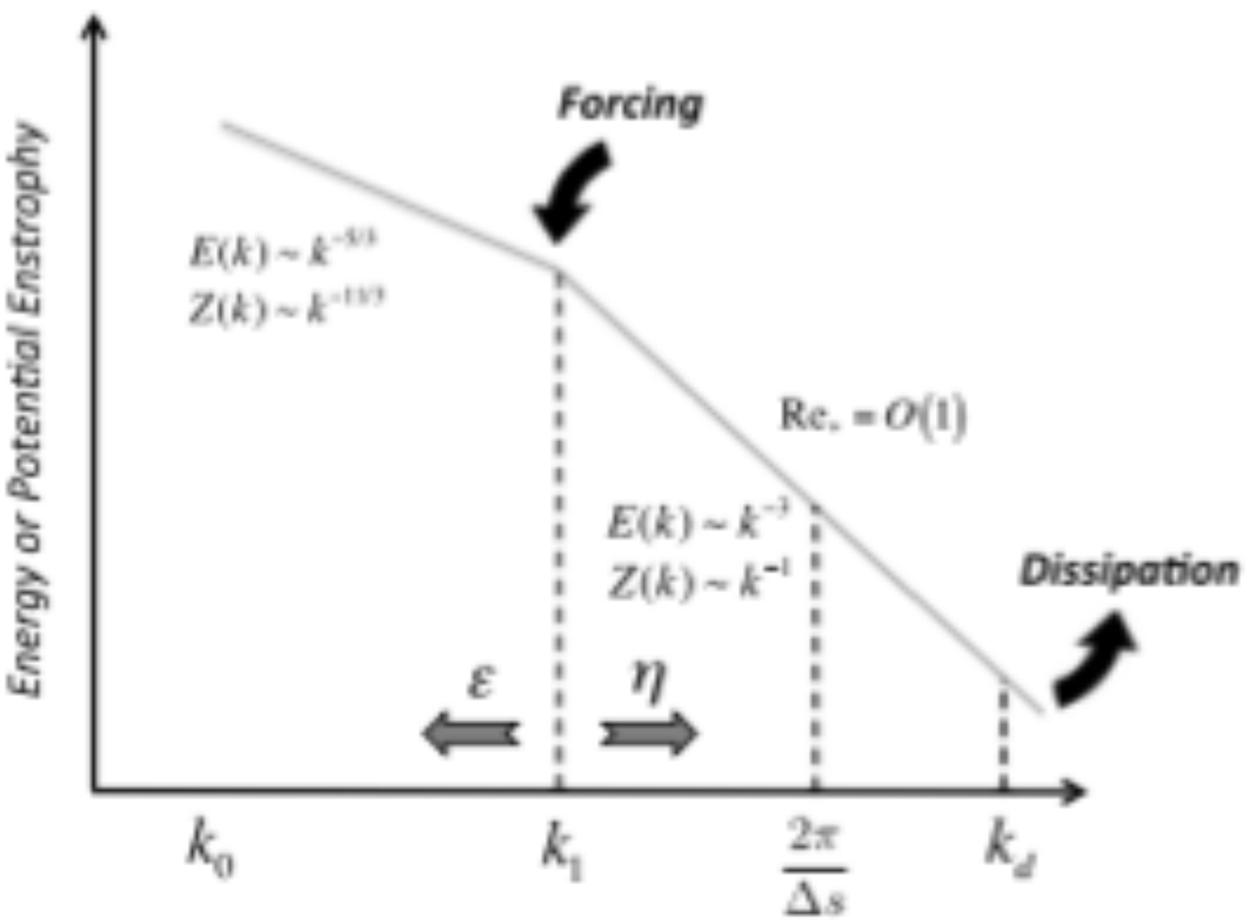
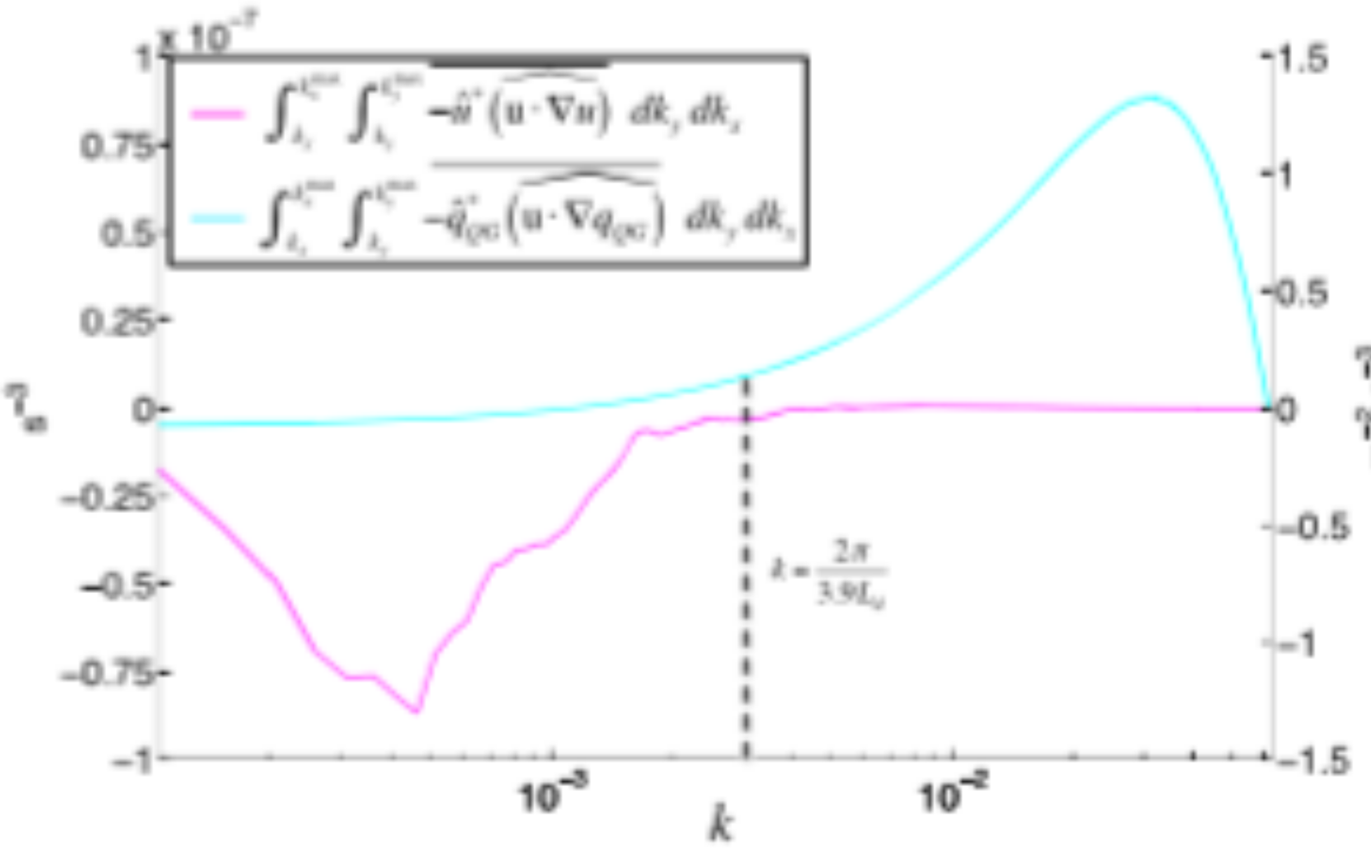
Baylor Fox-Kemper
Brown University

Traditional QG Turbulence View:

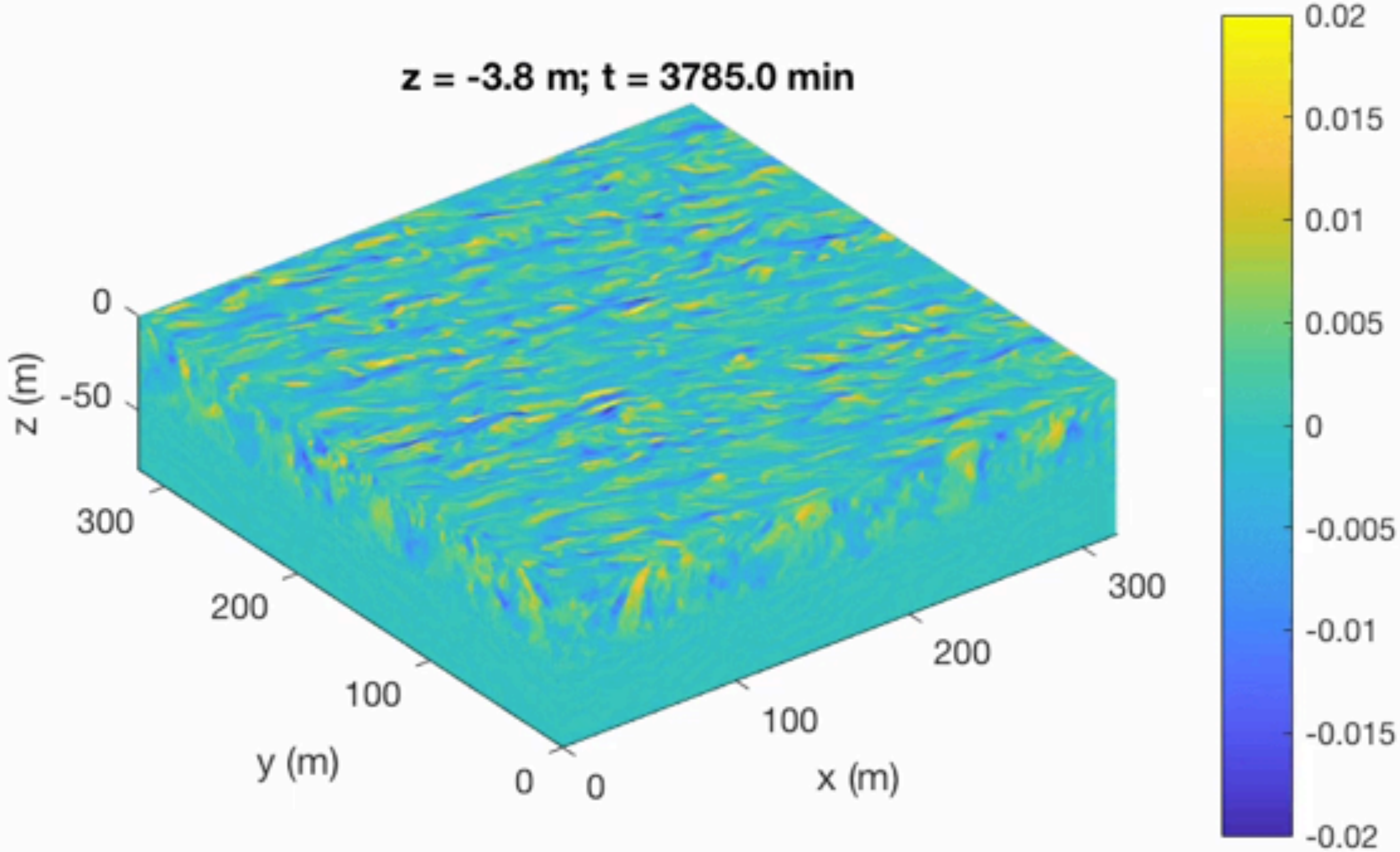




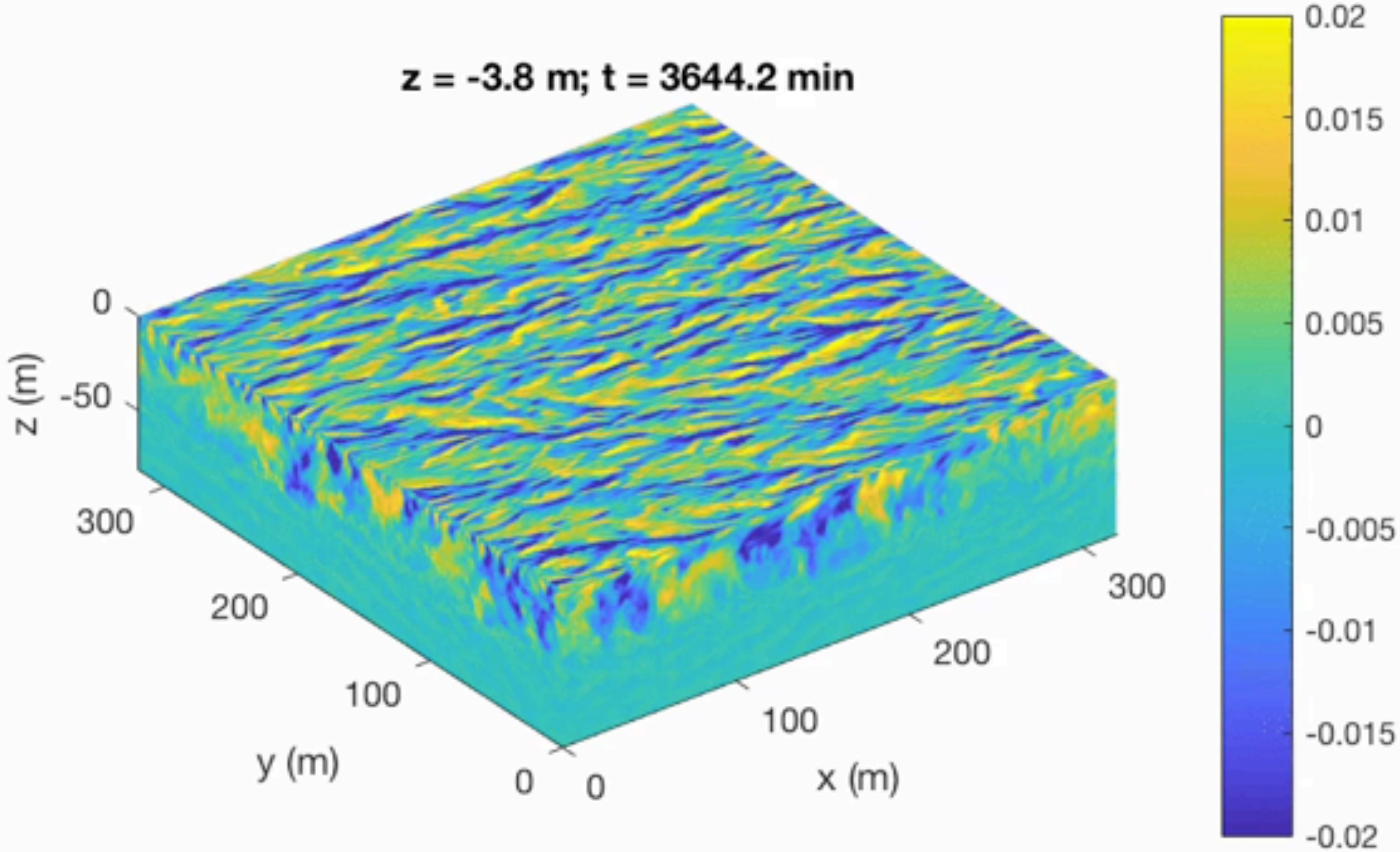
Support: CARTHE (GoMRI), Key Research Program of China (2017YFA0604100), NSF OCE-1350795 and ONR N00014-17-1-2963

Large Eddy Simulations: Boundary Layer Turbulence: Regardless of forcing becomes isotropic 3D forward cascade on small enough scales.

Wind-Only

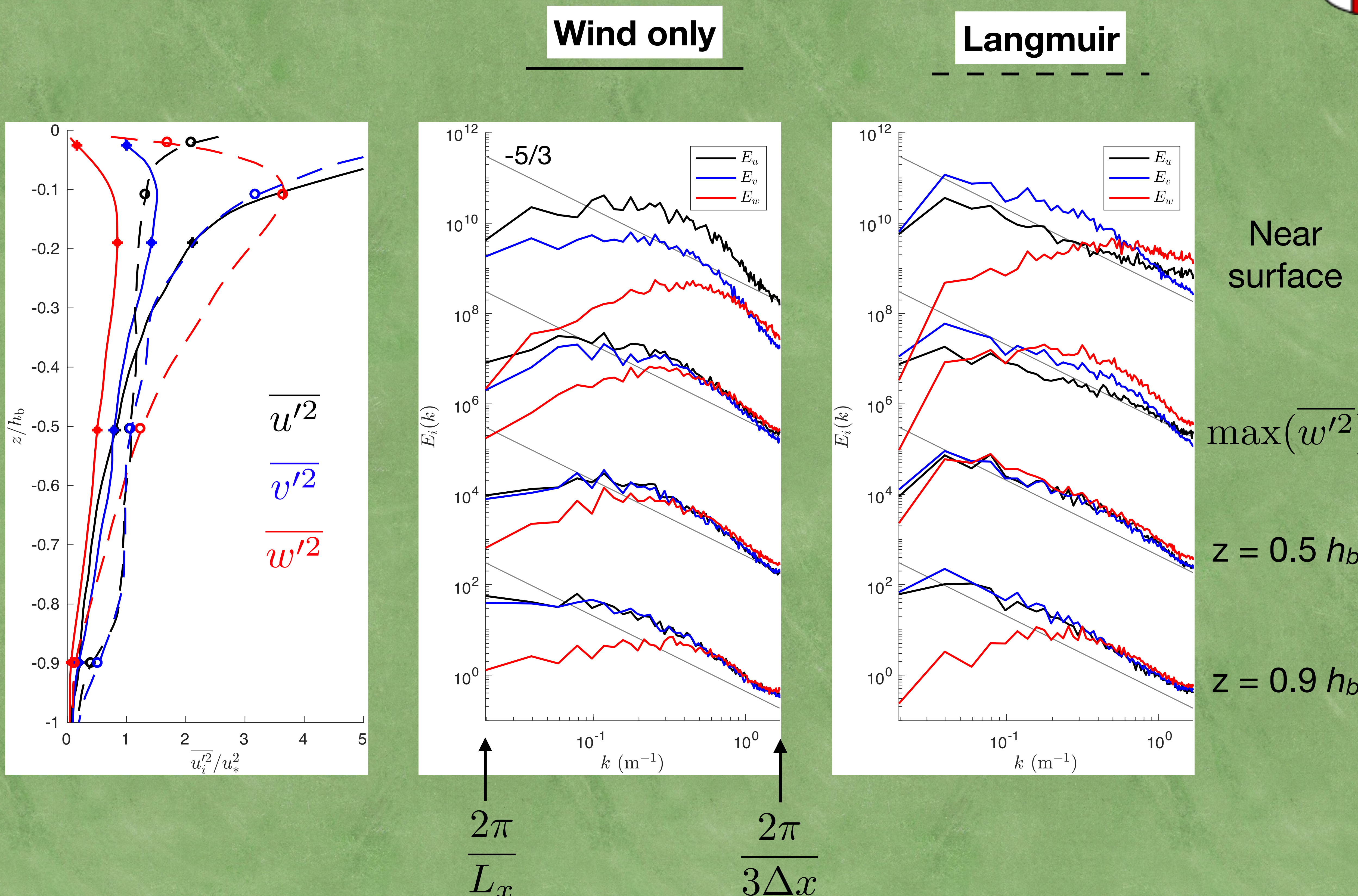


Langmuir (Wind & Waves)



Qing Li & BFK, 2018: Structures of Langmuir Turbulence. In prep.

LES of Boundary Layer Turbulence: Regardless of forcing becomes isotropic 3D forward cascade on small enough scales.



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GLAD Obs: Isotropic Forward Cascade from 30km?

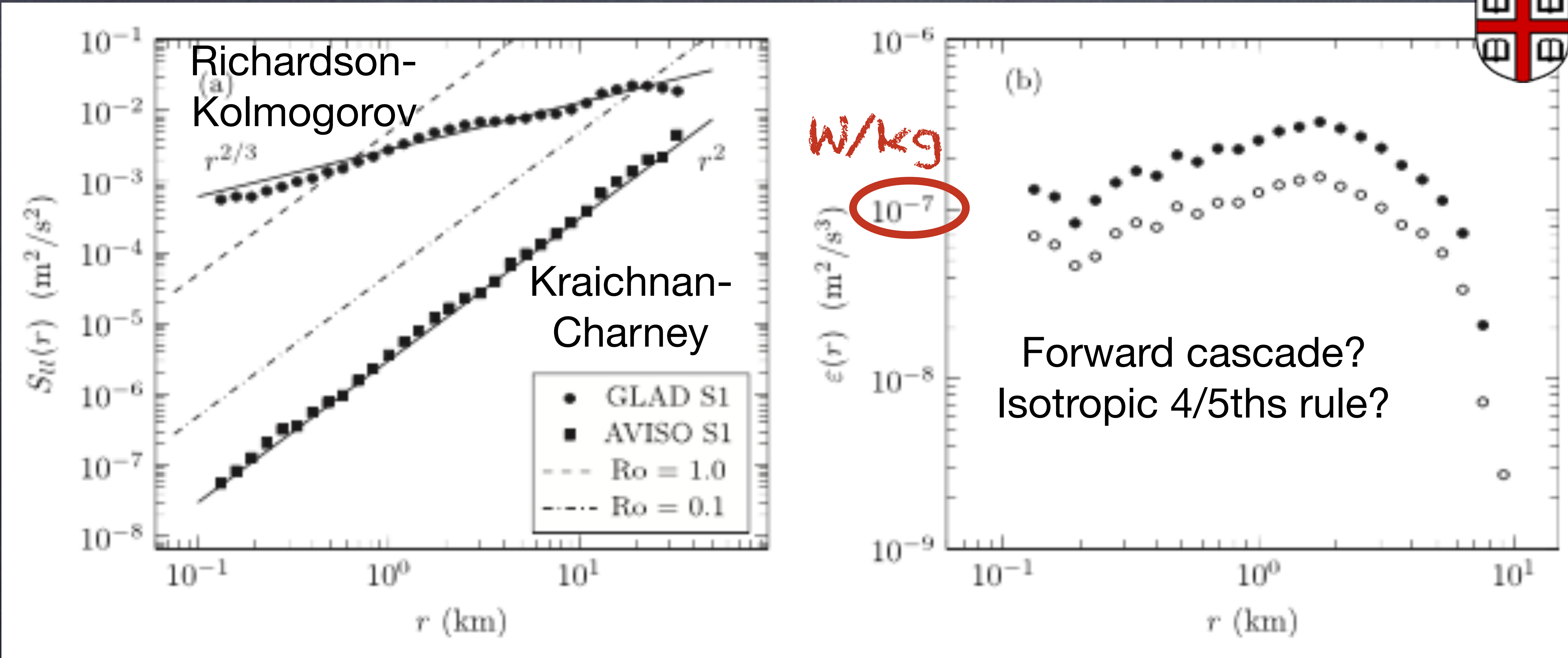


FIG. 7. (a) Second order longitudinal structure function versus separation distance showing Richardson-Kolmogorov, $r^{2/3}$, energy cascade scaling for GLAD data and Kraichnan, r^2, enstrophy cascade scaling for AVISO-based synthetic trajectories. (b) Sign-reversed third order longitudinal structure function scaled by r for the GLAD observations.

140TW (global)/(1.4 10^{21} kg)=10^{-7} W/kg

Winds: ~20TW global

Tides: 3.5TW global

D'Asaro et al (2011): Enhanced @ Fronts: 10^{-5} to 10^{-6} W/kg

Evidence of a forward energy cascade and Kolmogorov self-similarity in submesoscale ocean surface drifter observations

Andrew C. Poje, Tamay M. Özgökmen, Darek J. Bogucki, and A. D. Kirwan, Jr.

What's really happening in models in the QG regime?

- Examine energy cycling/cascades in global, 10km resolution simulations (Mesoscale Ocean LES: MOLES)
  (mesoscale & equatorial submesoscale permitting)
- Determine if there is evidence of forward energy cascade across horizontal scales
  (i.e., dissipation of EKE by horiz. friction)
- See if result is sensitive to subgrid scheme
- CAN'T BE ISOTROPIC:
  Depth < Horizontal Grid Spacing

B. Pearson and BFK, 2018: Lognormal turbulence dissipation in global ocean models. Physical Review Letters. In press.

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.

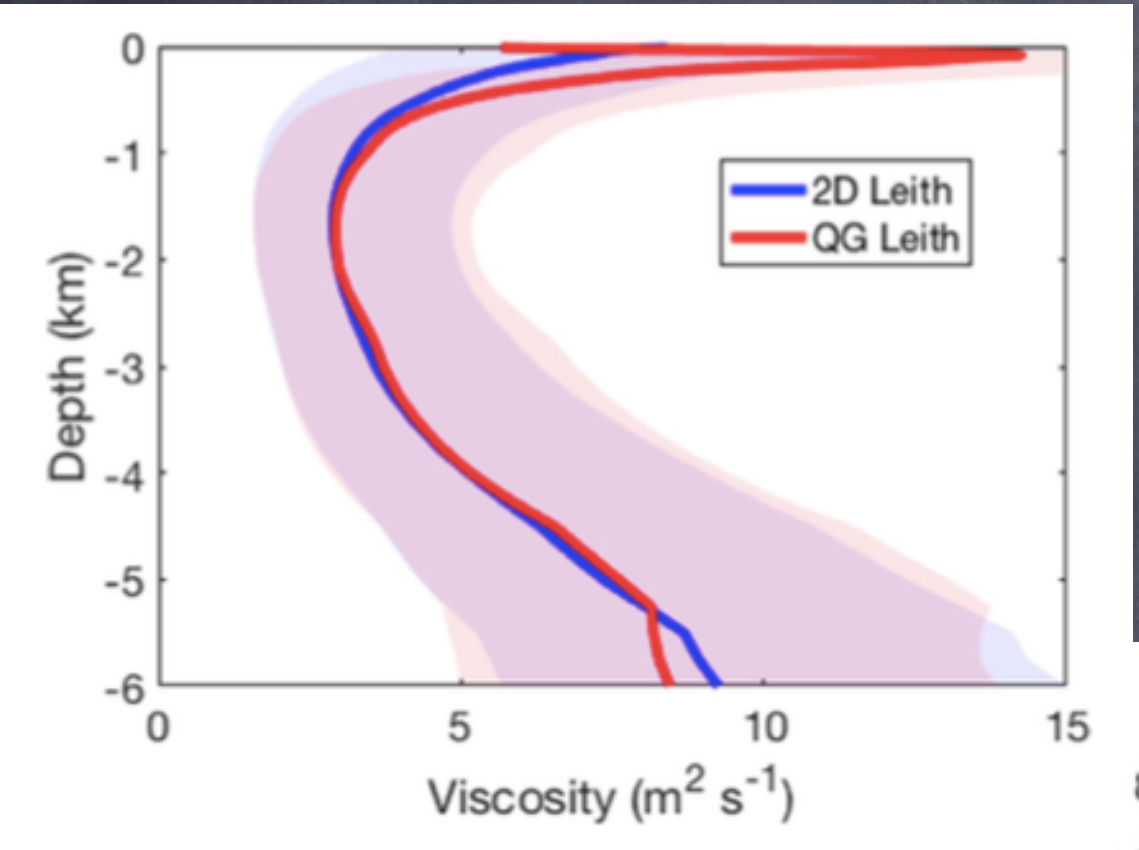
S. D. Bachman, BFK, and B. Pearson, 2017: A scale-aware subgrid model for quasi- geostrophic turbulence. Journal of Geophysical Research–Oceans, 122:1529–1554.

QGLeith: Basics

$$\nu_{qg} = \left(\frac{\Delta_h \Lambda_{qg}}{\pi}\right)^3 \sqrt{|\nabla_h q_{qg}|^2 + |\nabla_h (\nabla_h \cdot \mathbf{u})|^2}$$

Momentum uses Laplacian horizontal diffusion

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



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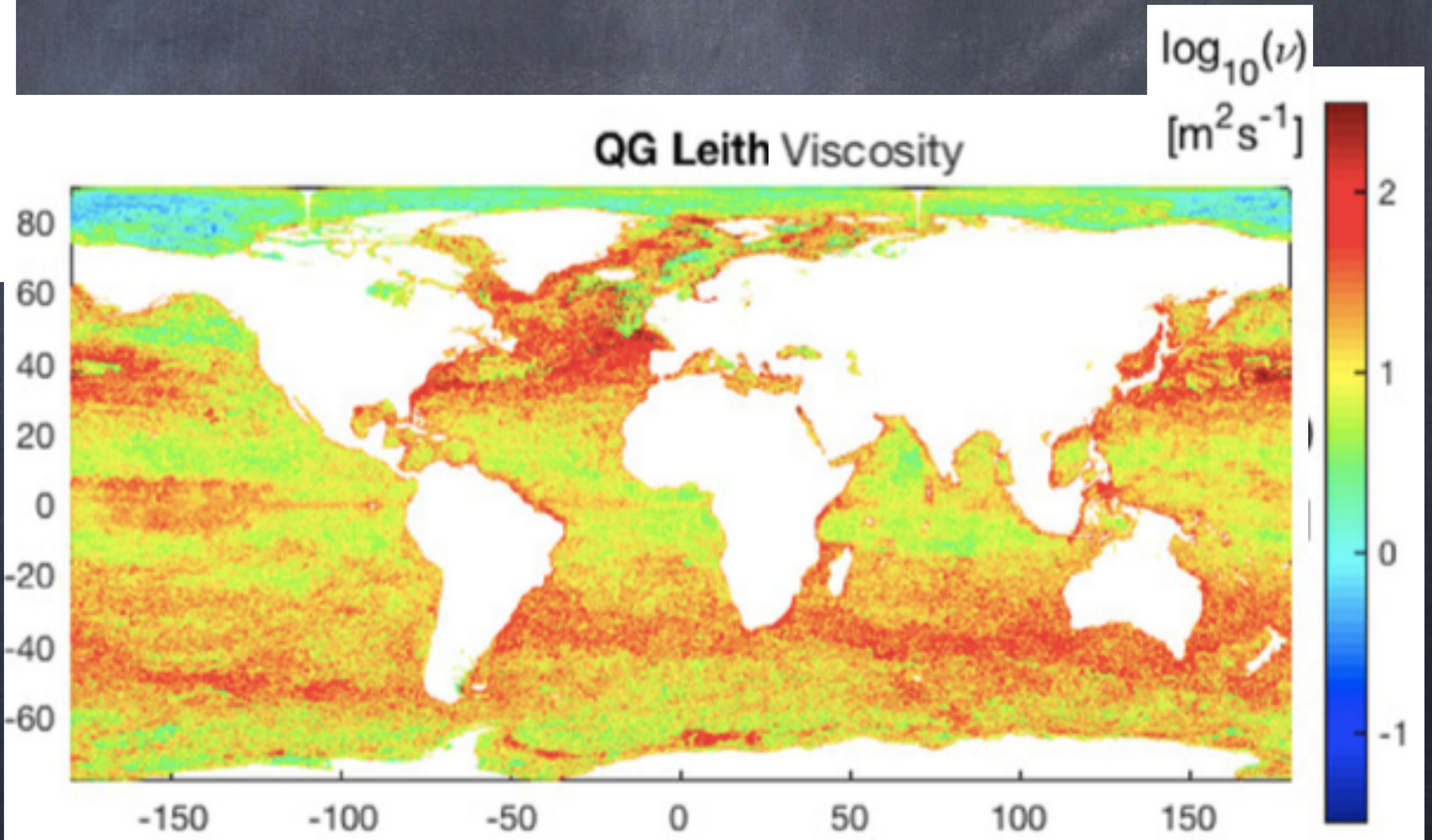
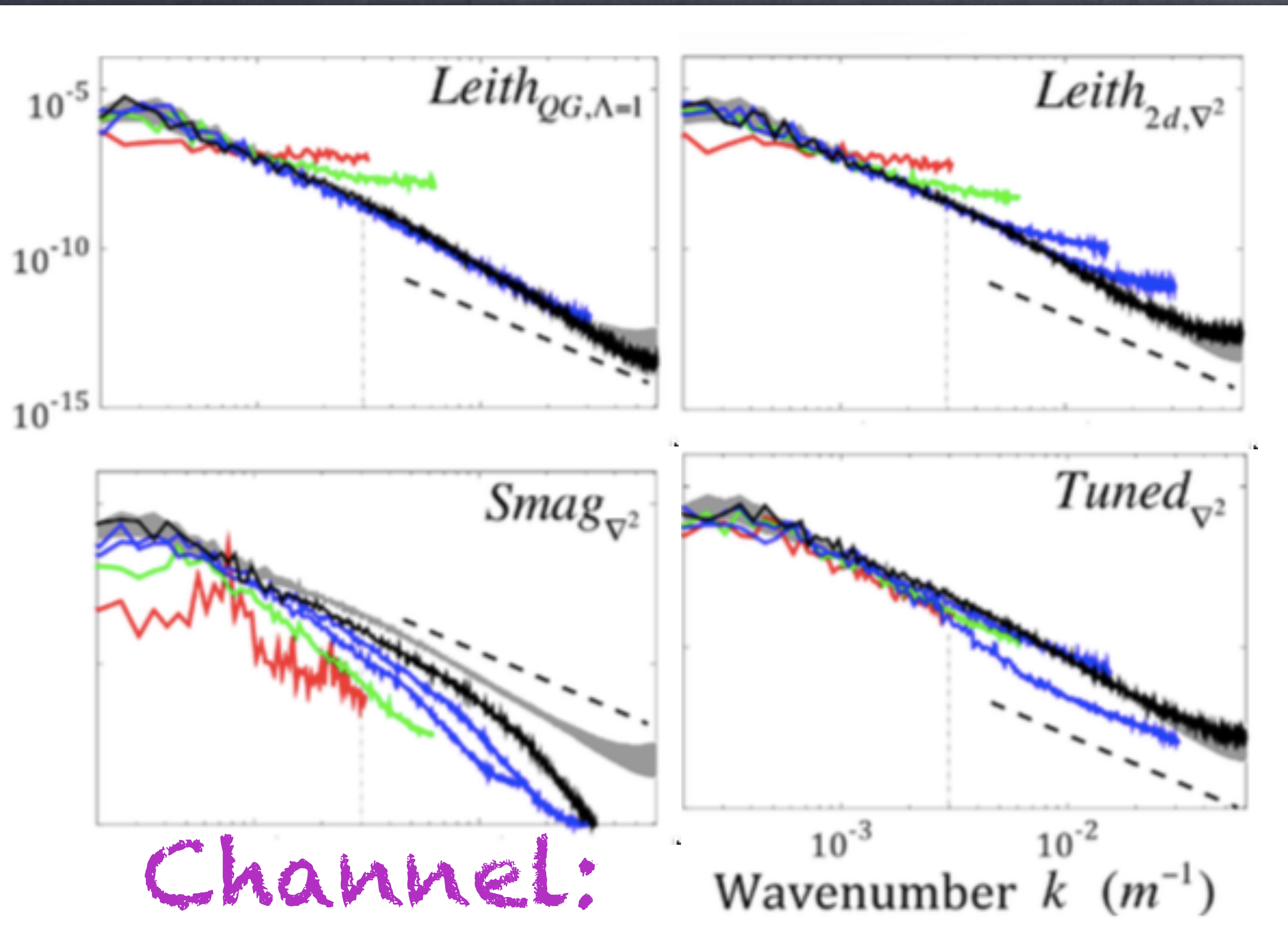


Mesoscale Ocean LES (MOLES): QGLeith



MITgcm in
Idealized Domain.
Resolutions from coarse to
very fine
in terms of resolving
deformation radius
High vert. resolution

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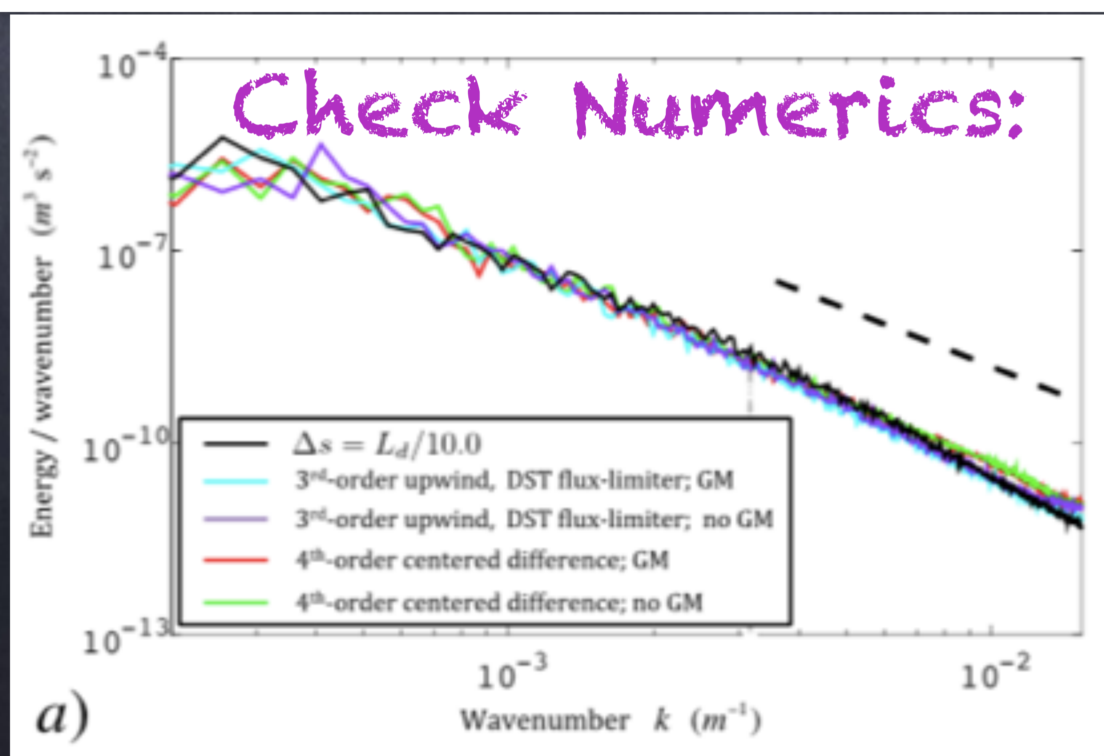

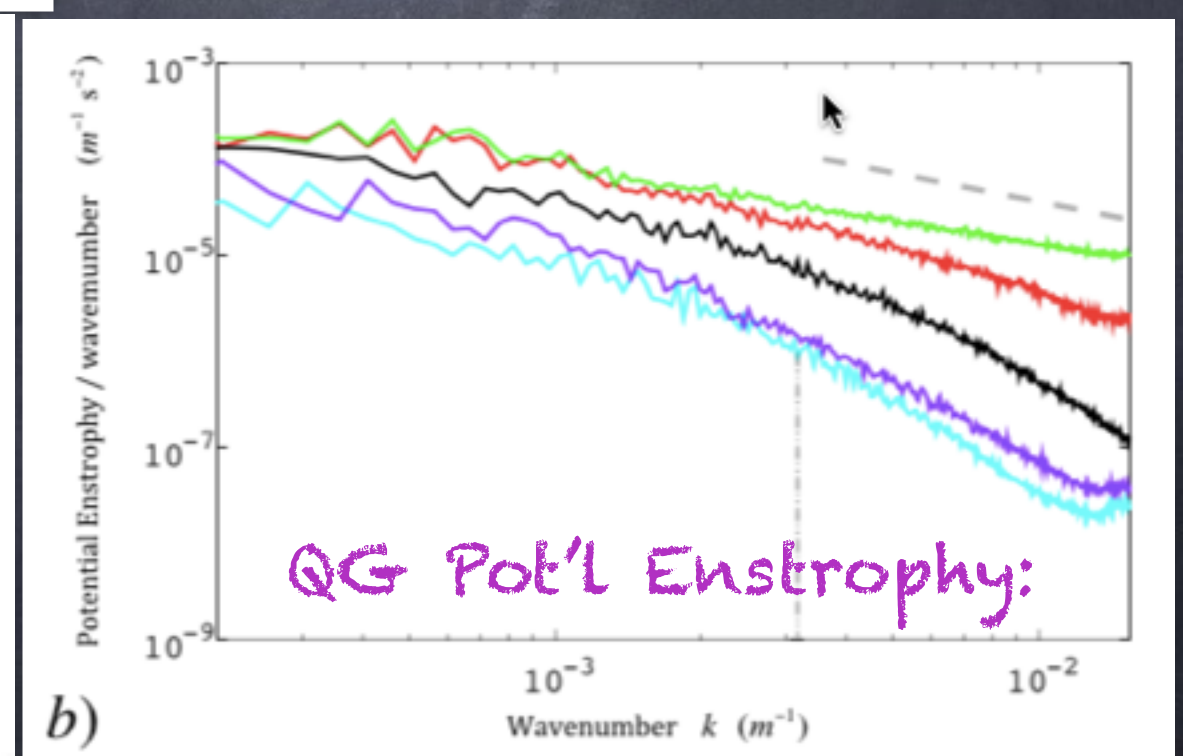

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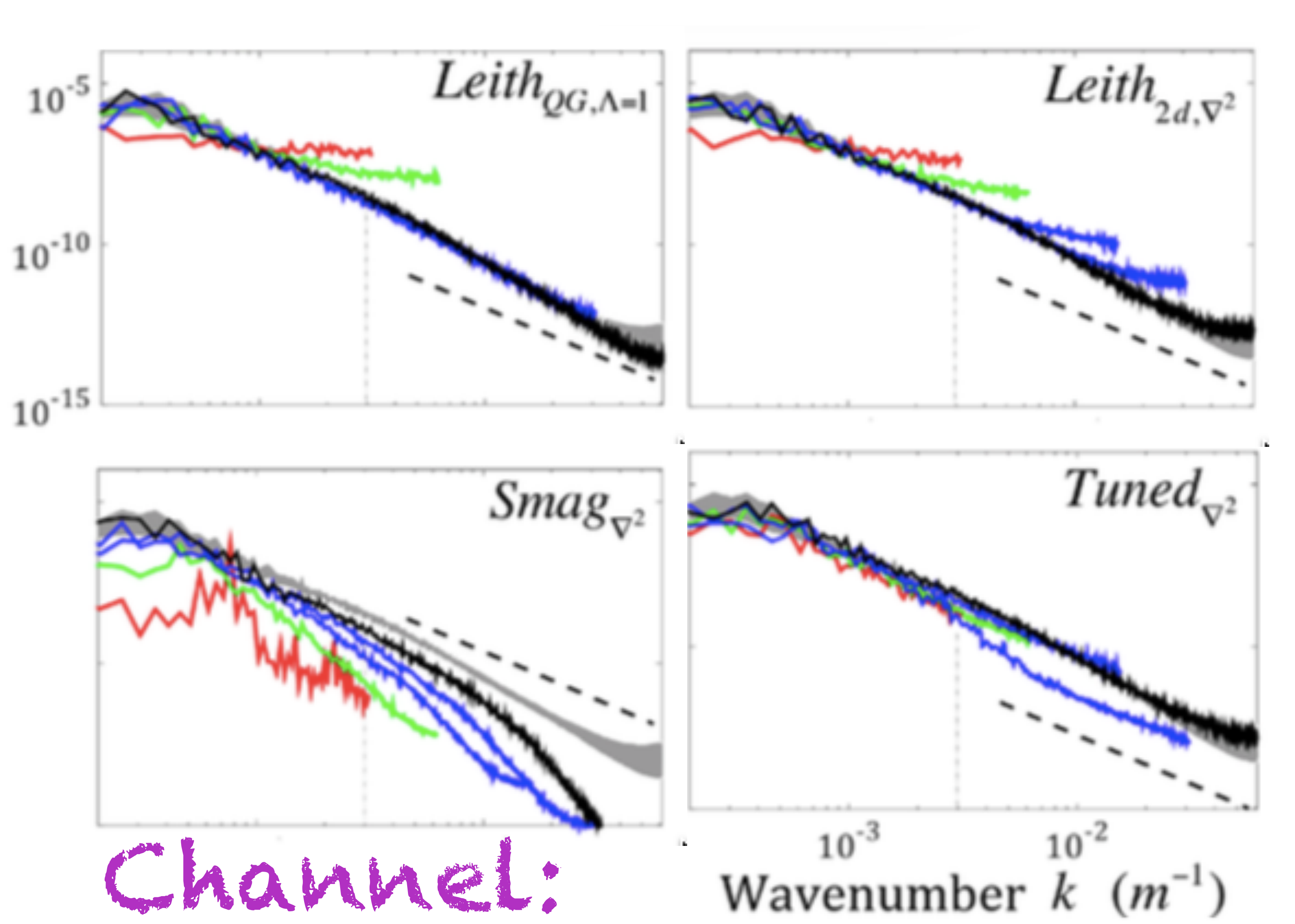
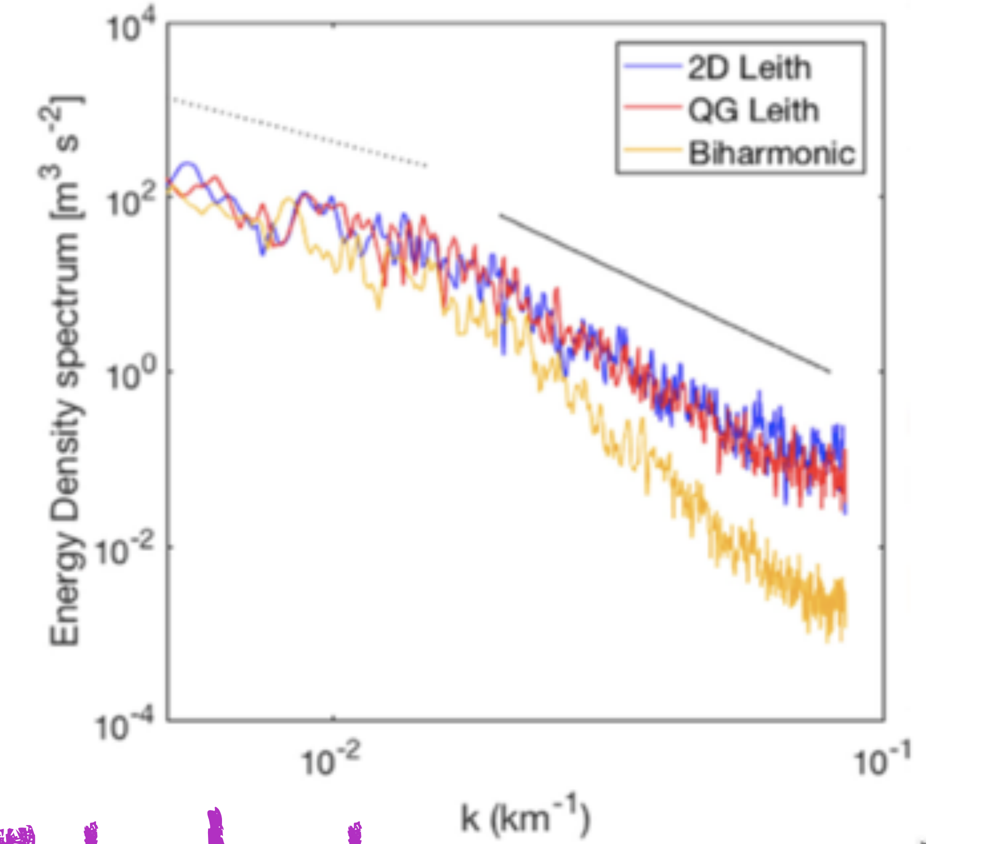
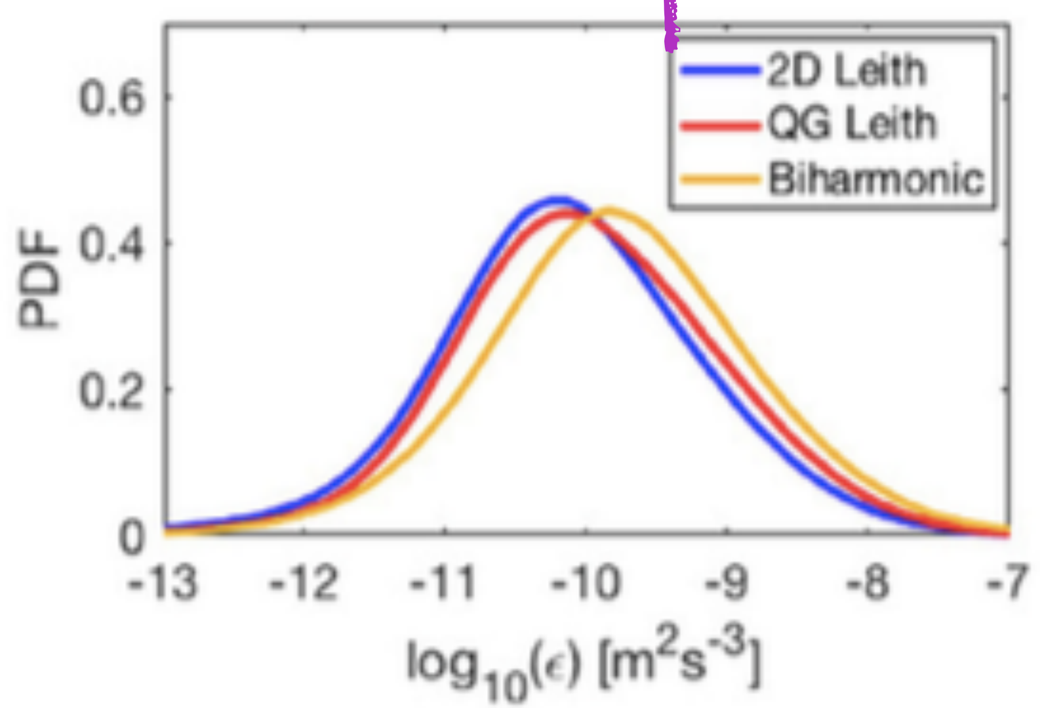


Channel:

ACC in Global!



Global:
100m Dissipation



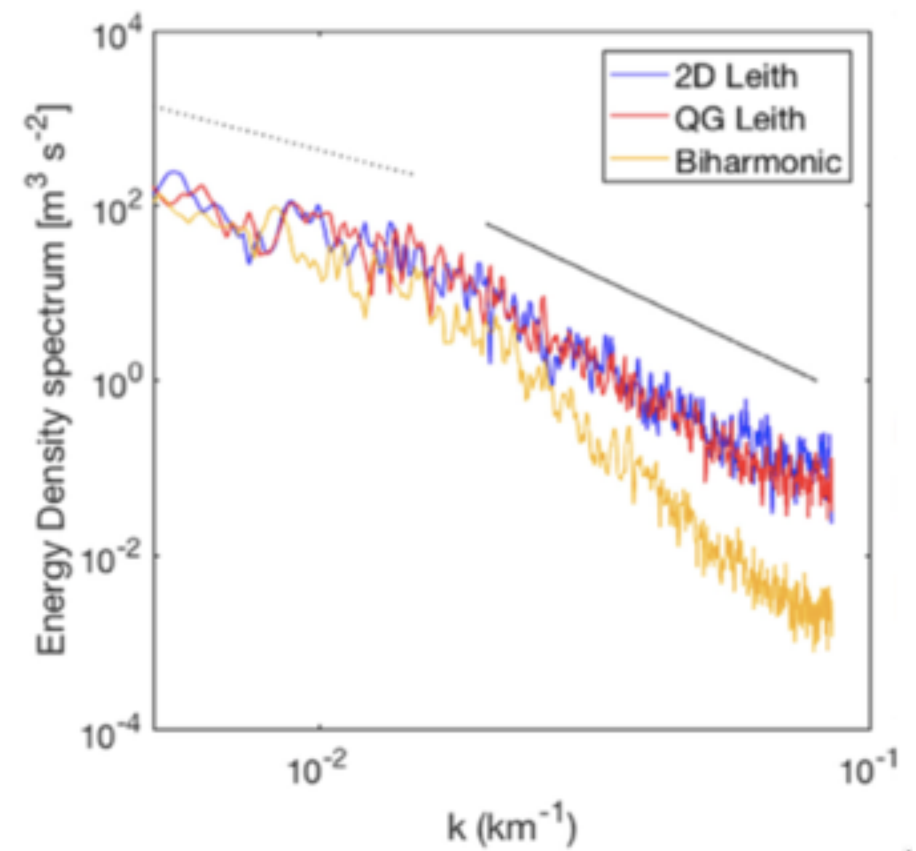
Global, POP, realistic forcing
10km (nominal) global
42 vertical levels
(most in upper 200m)

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.

Mesoscale Ocean LES (MOLES): QGLeith

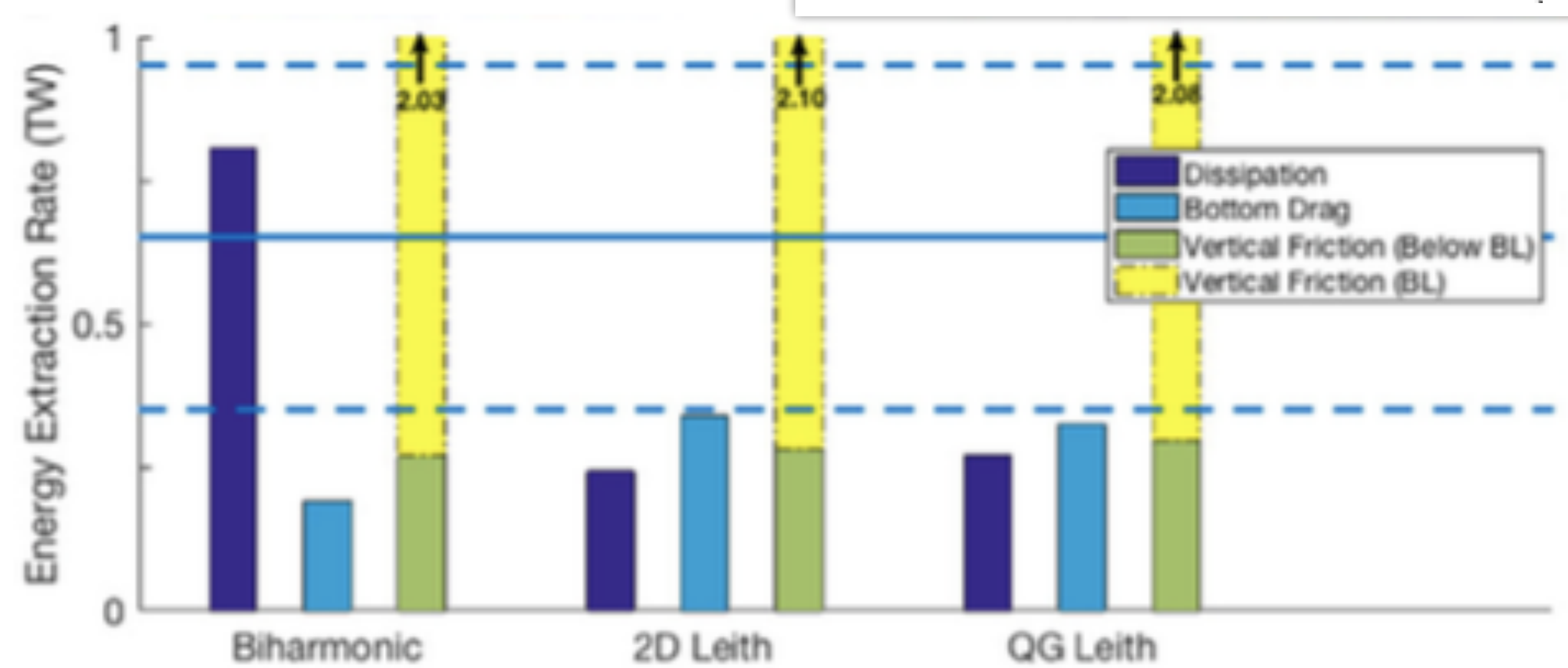
There is a (weak) forward energy cascade that's sensitive to subgrid

ACC in Global!



2.8TW/Mo=
=0.5 10^{-9} W/kg
=1/50
of Poje et al.

Global KE Sinks



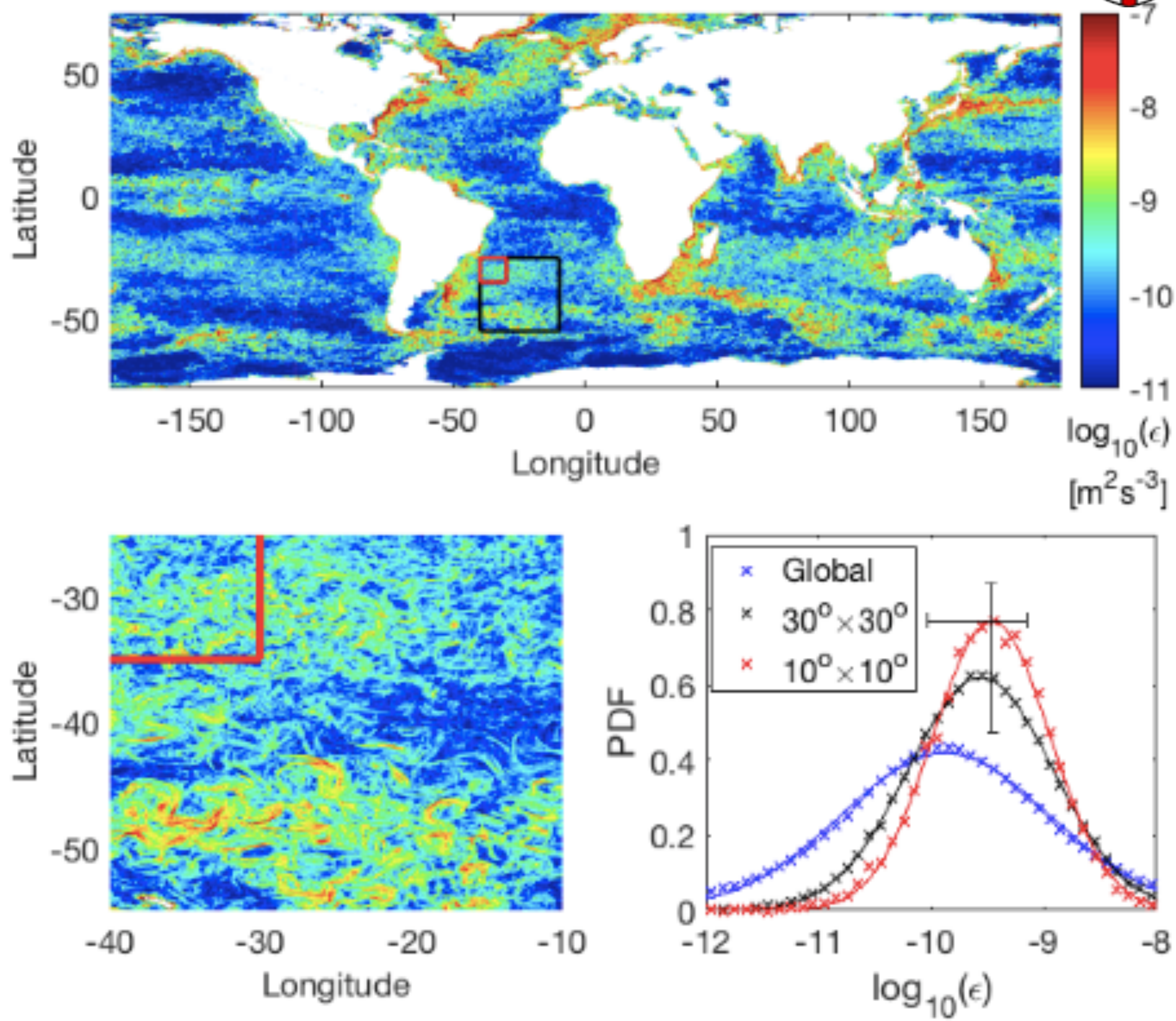
B. Pearson, BFK, S. D. Bachman, and F. O. Bryan, 2017: Evaluation of scale-aware subgrid mesoscale eddy models in a global eddy-rich model. Ocean Modelling, 115:42–58.

MOLES: Global dissipation

A (weak) forward energy cascade

...

that's lognormally distributed



B. Pearson and BFK, 2018: Lognormal turbulence dissipation in global ocean models. Physical Review Letters. In press.

Lognormal Dissipation Consequences?

- Lognormal dissipation (Yaglom, '66) results in a variable that is forward cascaded, intermittently, but always forward. Pearson & BFK extend to QG Pot'l Enstrophy cascade.
- Multiplicative, not additive, stochastic parameterizations tend toward log-normality
- When measurements of energy are related to the global mean: consider the log of the measurements—that's what's normally and symmetrically distributed about the mode.
- The mean, or integrated dissipation, are dominated by only a few regions (here 90% happens in 10% of area)

B. Pearson and BFK, 2018: Lognormal turbulence dissipation in global ocean models. Physical Review Letters. In press.

CARTHE:
Consortium for Advanced Research on the Transport of Hydrocarbons in the Environment

"Lagrangian ocean analysis: fundamentals and practices", Erik van Sebille et al. (2017)

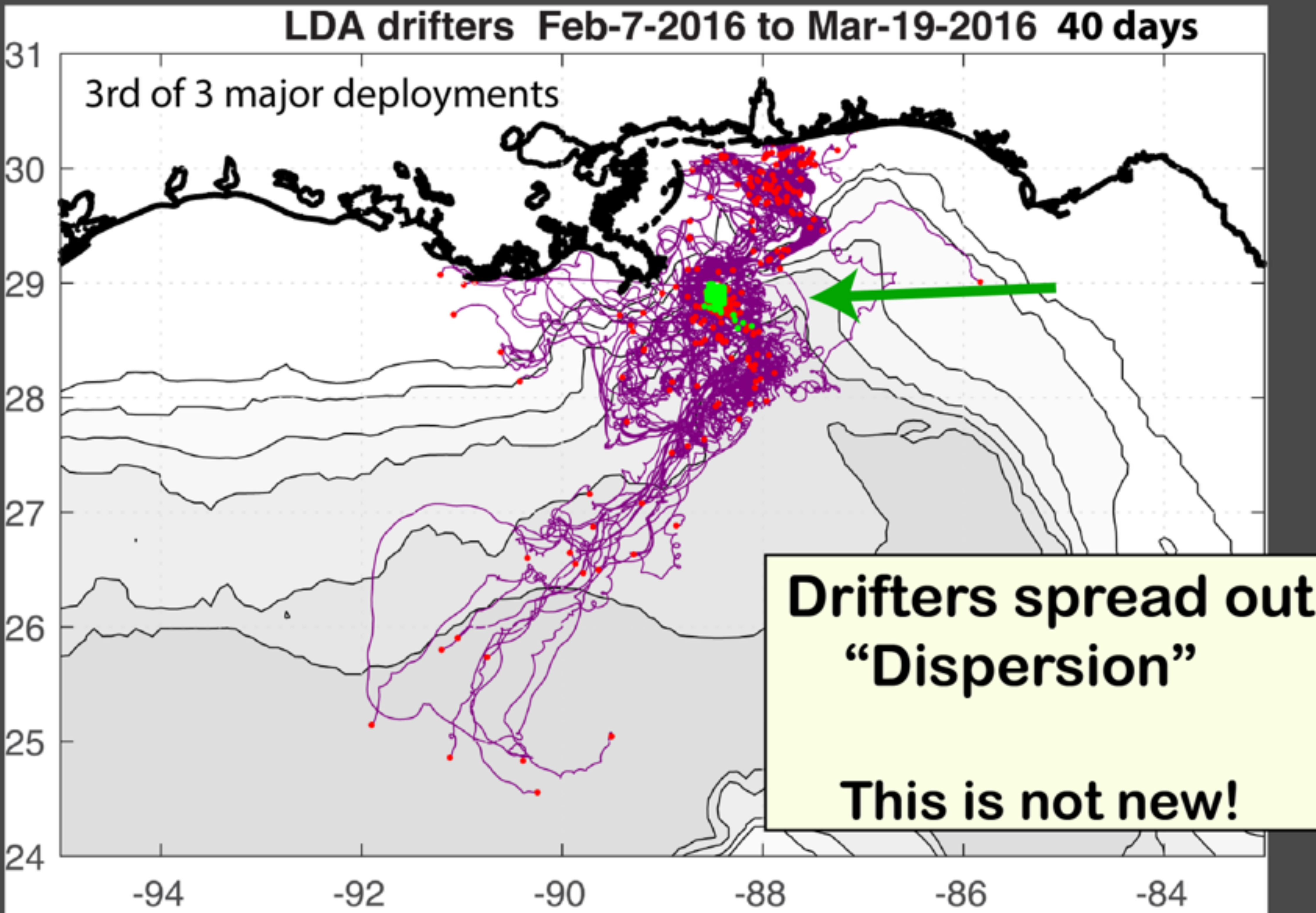
- "Trajectories for virtual particles map out pathlines of the velocity field [...] Statistics of the trajectories then define particle pathways and their associated time scales."
- But, do they? How biased are these statistics because they are "observed" on Lagrangian trajectories?
- Floes in Eddies: How different are the area-based statistics, e.g., ice concentration to ice volume because the floes are bunched up in convergence zones?

CARTHE / LASER Strategy

Use massive (~1000) surface drifter arrays as surrogate for oil

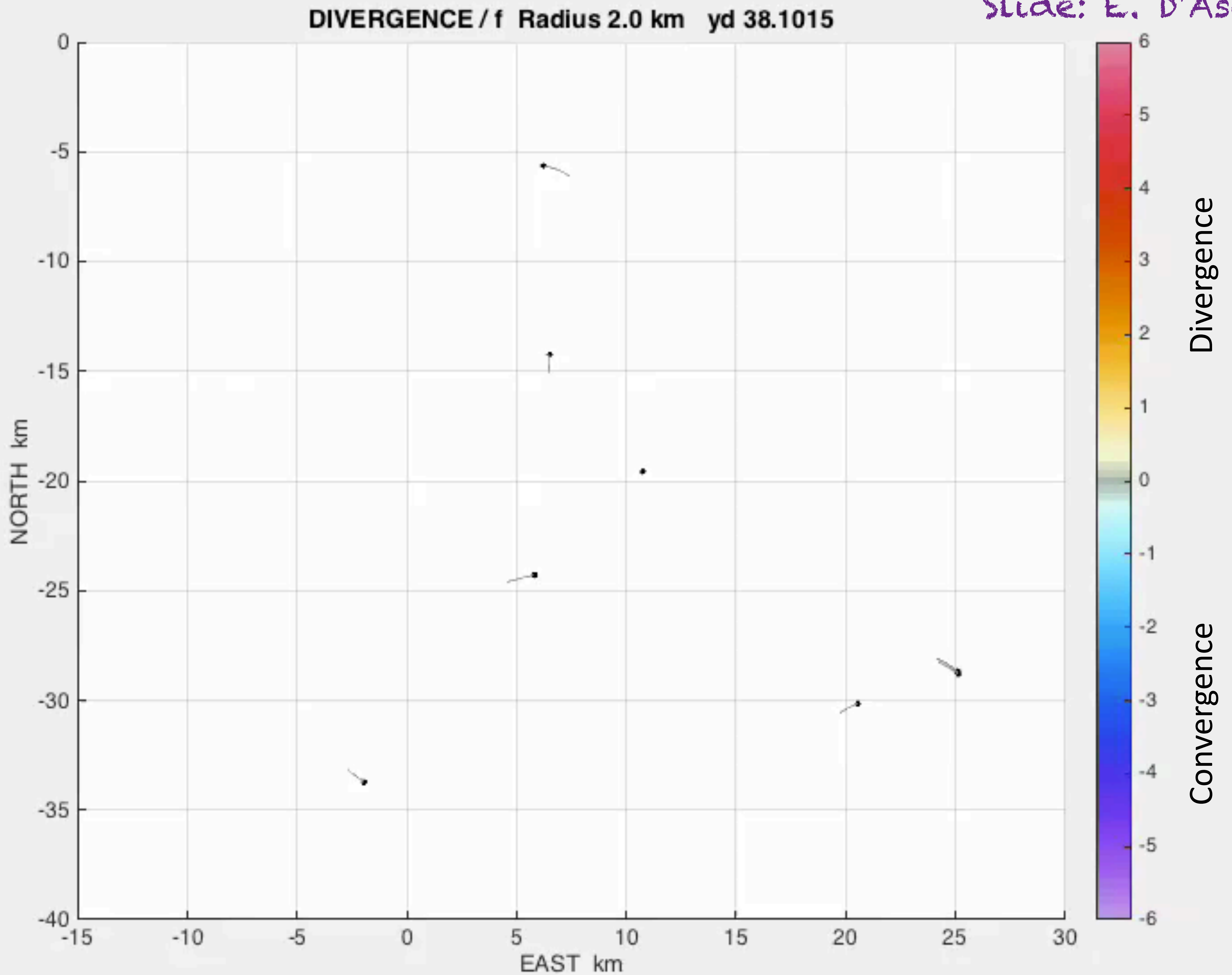
323 Drifters 1 km grid

Slide: E. D'Asaro



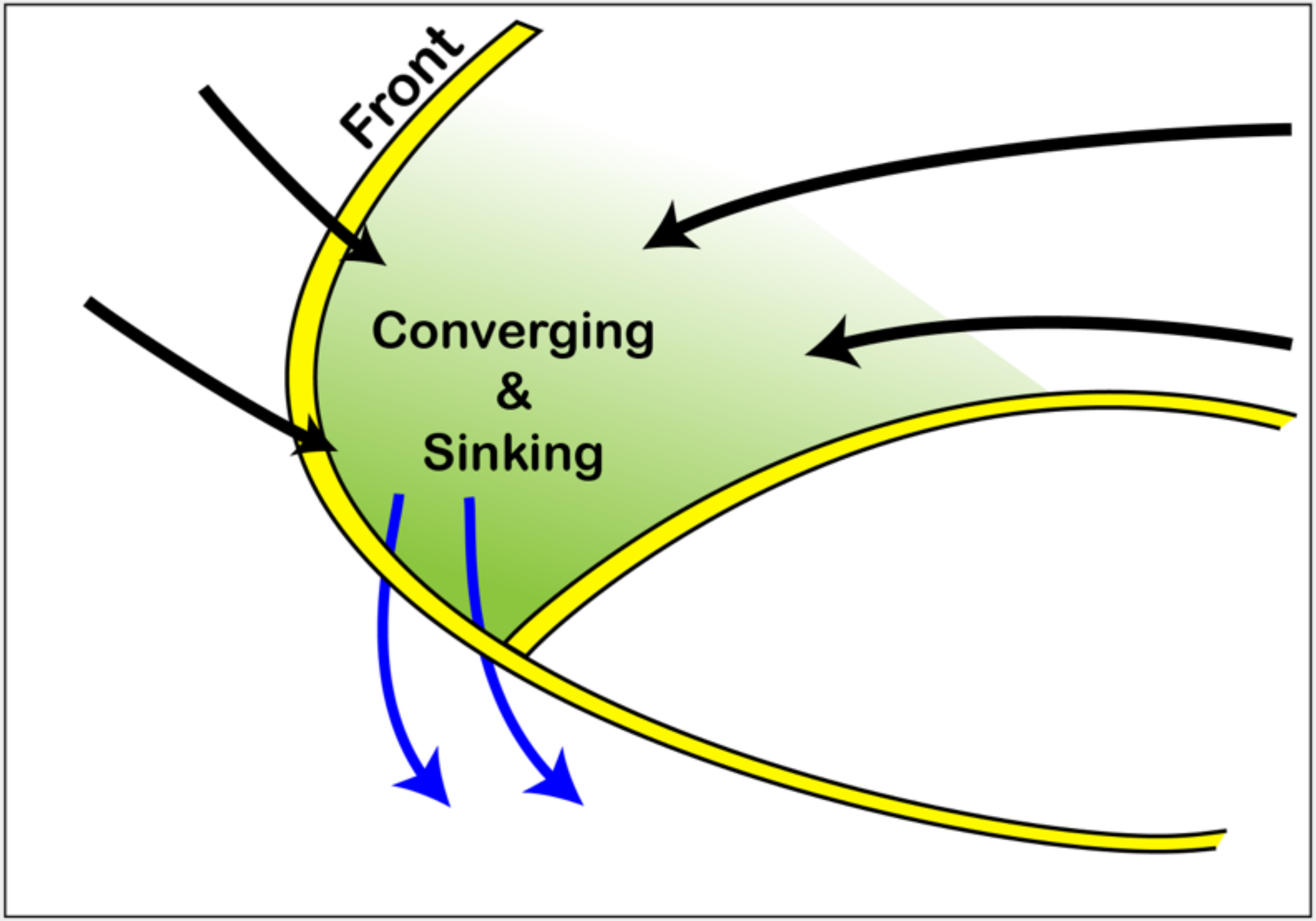
DIVERGENCE from plane fit of velocity from all drifters in a 2km radius

Slide: E. D'Asaro

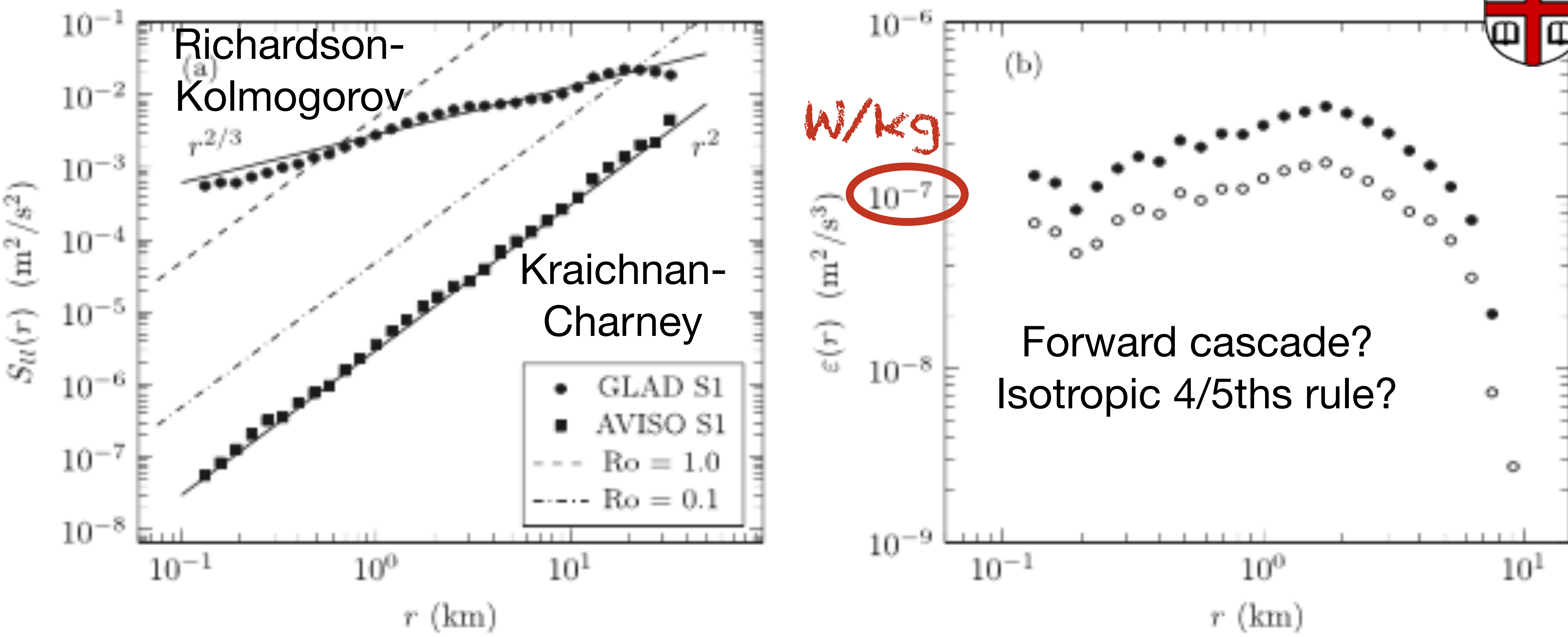


Three-Dimensional Circulation at the Zipper

Slide: E. D'Asaro



GLAD: Isotropic Forward Cascade from 30km?



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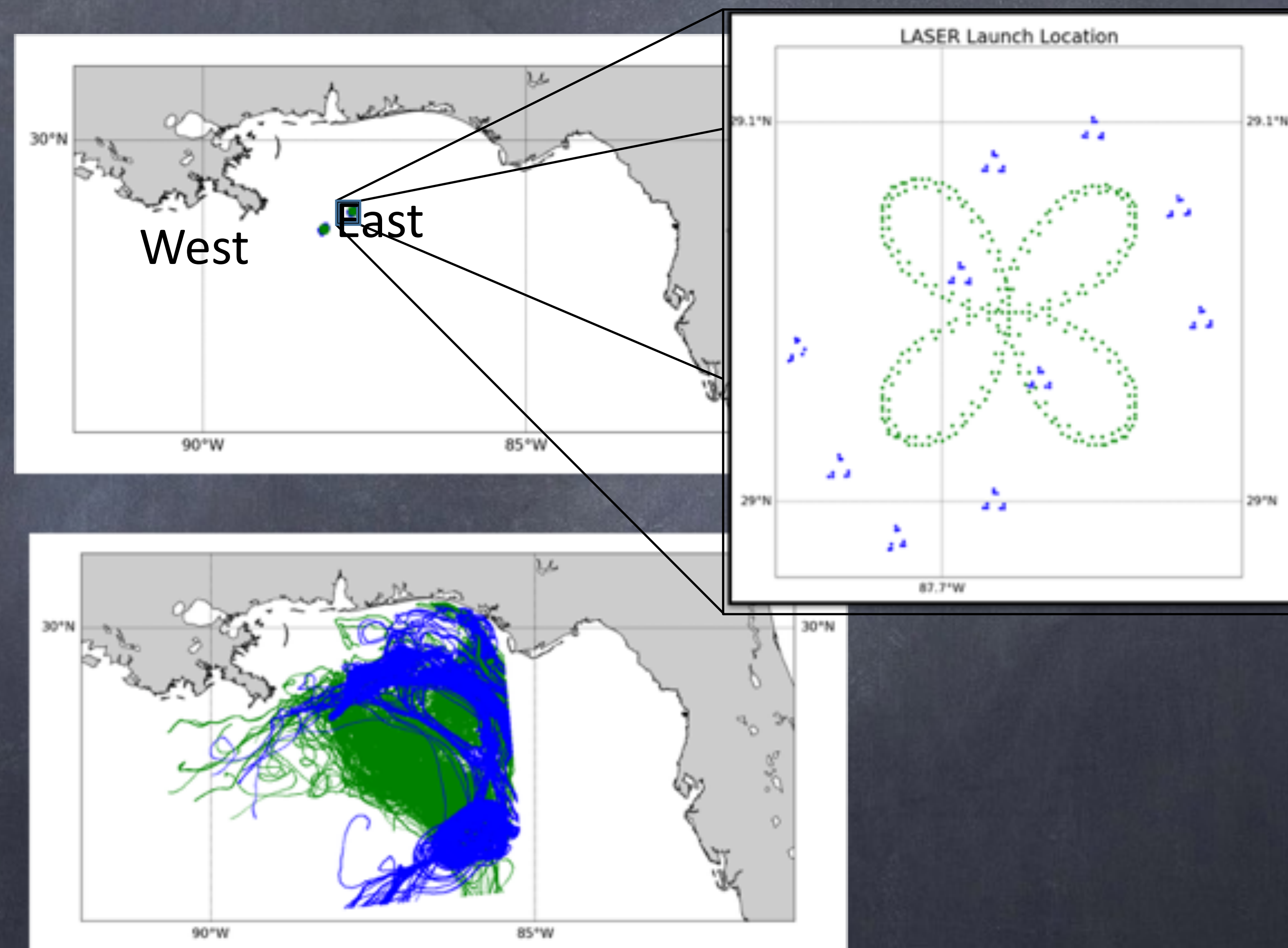
Lagrangian vs. Eulerian Cascades

- Regional Ocean Modeling System (ROMS) operating at 500m resolution (climatology)

- Synthetic trajectories were launched within and advected using the Lagrangian TRANSport Model (LTRANS) v.2b

- The launch patterns, locations of deployment, and time of year all mimic GLAD (summer, West) and LASER (winter, East)

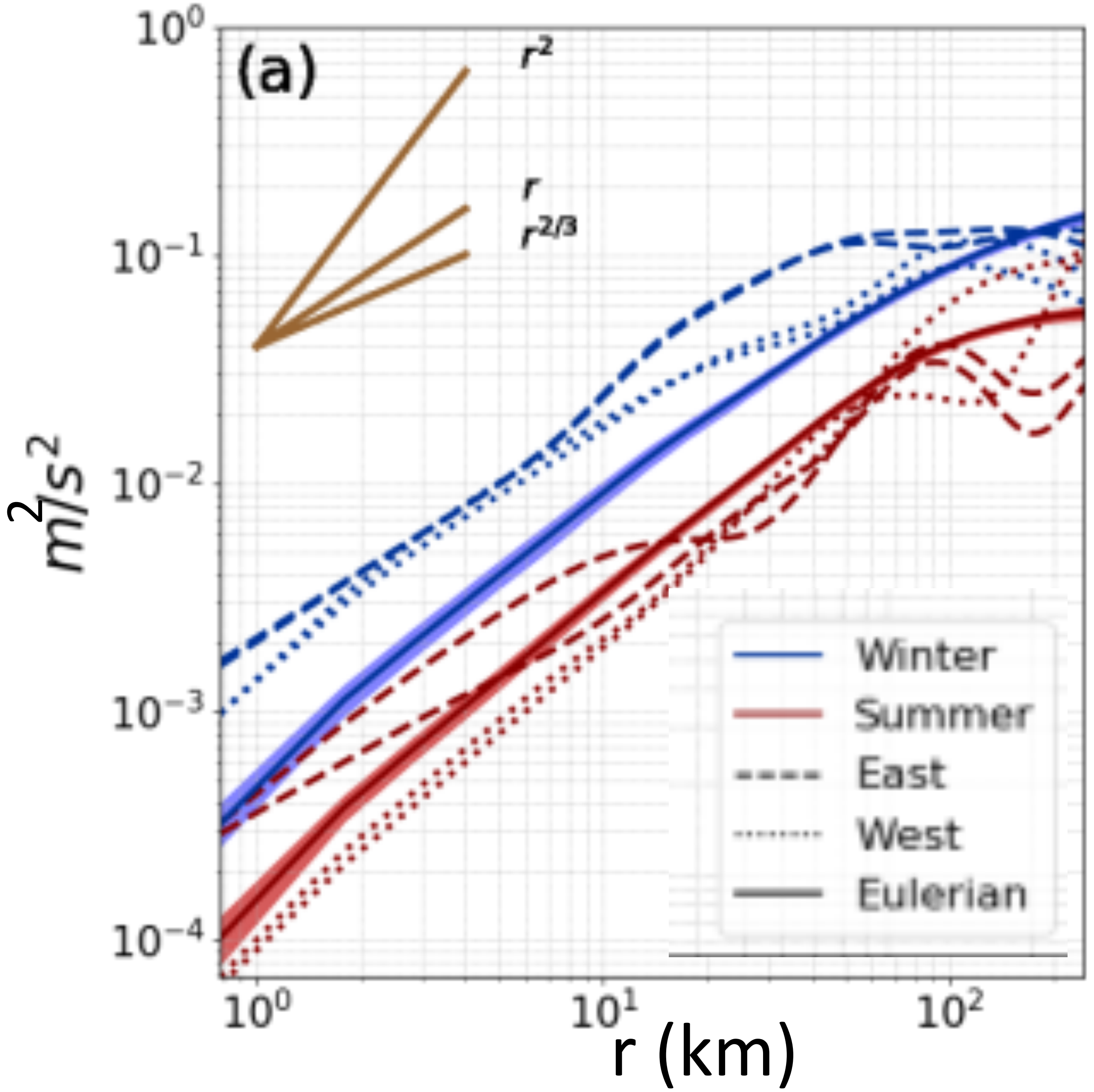
- Here Eulerian=model grid sampling & Lagrangian=sampling at trajectory locations



J. Palmer, BFK, R. Barkan, A. Bracco, J. Choi, J. C. McWilliams, 2018: Impacts of convergent zones on structure function statistics in the Gulf of Mexico. Geophysical Review Letters. In prep.

Eulerian vs. Lagrangian: L. is biased toward sampling convergent fronts &tc.

$$D_L = \overline{\left([\mathbf{u}(\mathbf{x}+\mathbf{r}) - \mathbf{u}(\mathbf{x})] \cdot \mathbf{r}/|r|\right)^2}$$



In the Barkan et al., Choi et al. ROMS (500m) models, we compare Eulerian (solid) statistics to Lagrangian (dashed & dotted)

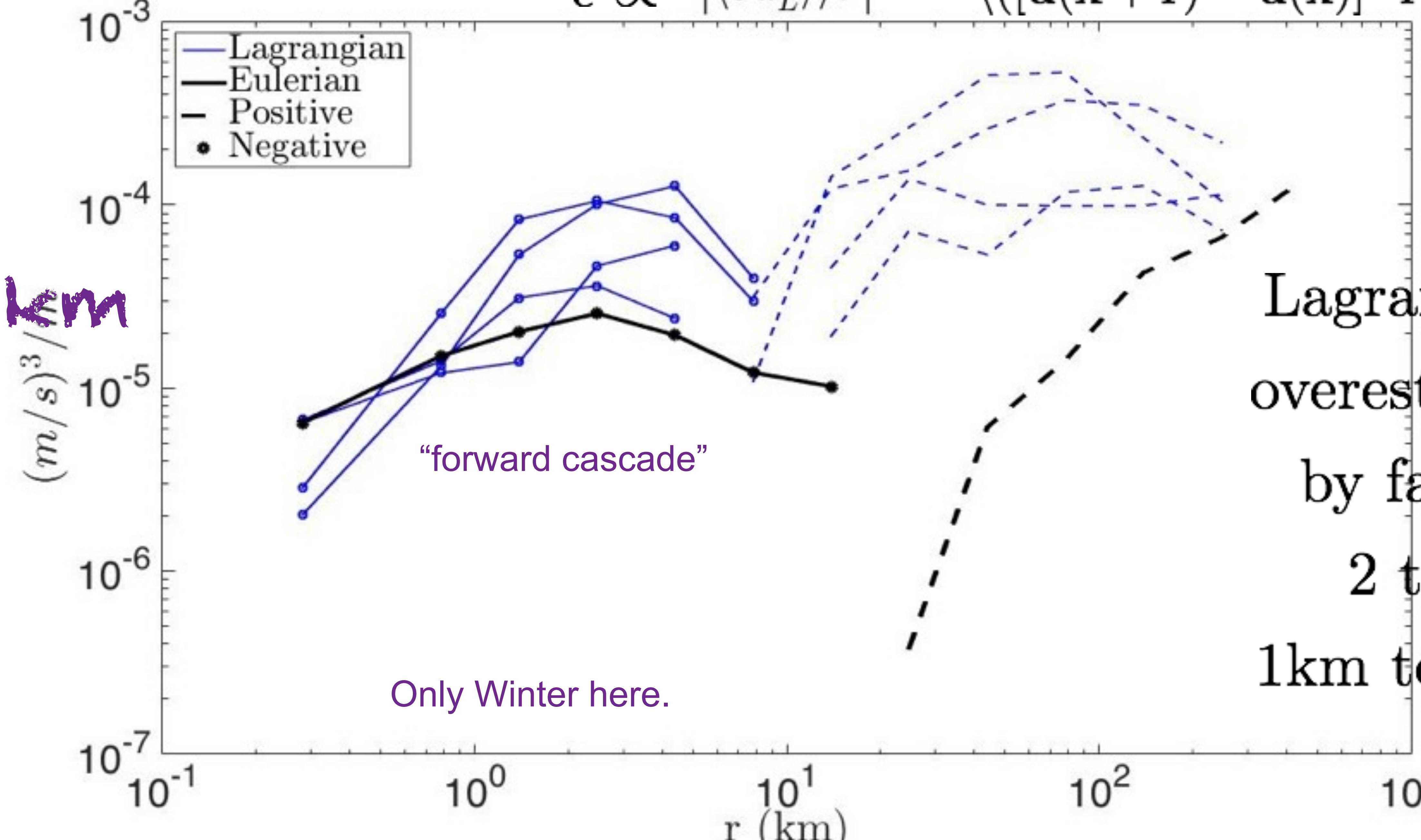
O(3x) larger Lagrangian than Eulerian 2nd Order SF in Winter when submesoscale is strong & resolved

Lagrangian slope is shallower—More like Kolmogorov-Richardson than unbiased Eulerian version.

J. Palmer, BFK, R. Barkan, A. Bracco, J. Choi, J. C. McWilliams, 2018: Impacts of convergent zones on structure function statistics in the Gulf of Mexico. JPO. In prep.

Eulerian vs. Lagrangian:
L. is biased toward sampling convergent fronts &tc.

$$\epsilon \propto \left|\langle \delta u_L^3 \rangle / r\right| = \langle ([\mathbf{u}(\mathbf{x}+\mathbf{r}) - \mathbf{u}(\mathbf{x})] \cdot \mathbf{r}/|\mathbf{r}|)^3 \rangle / |r|$$



Lagrangian ϵ overestimates by factor of 2 to 8 on 1km to 10km

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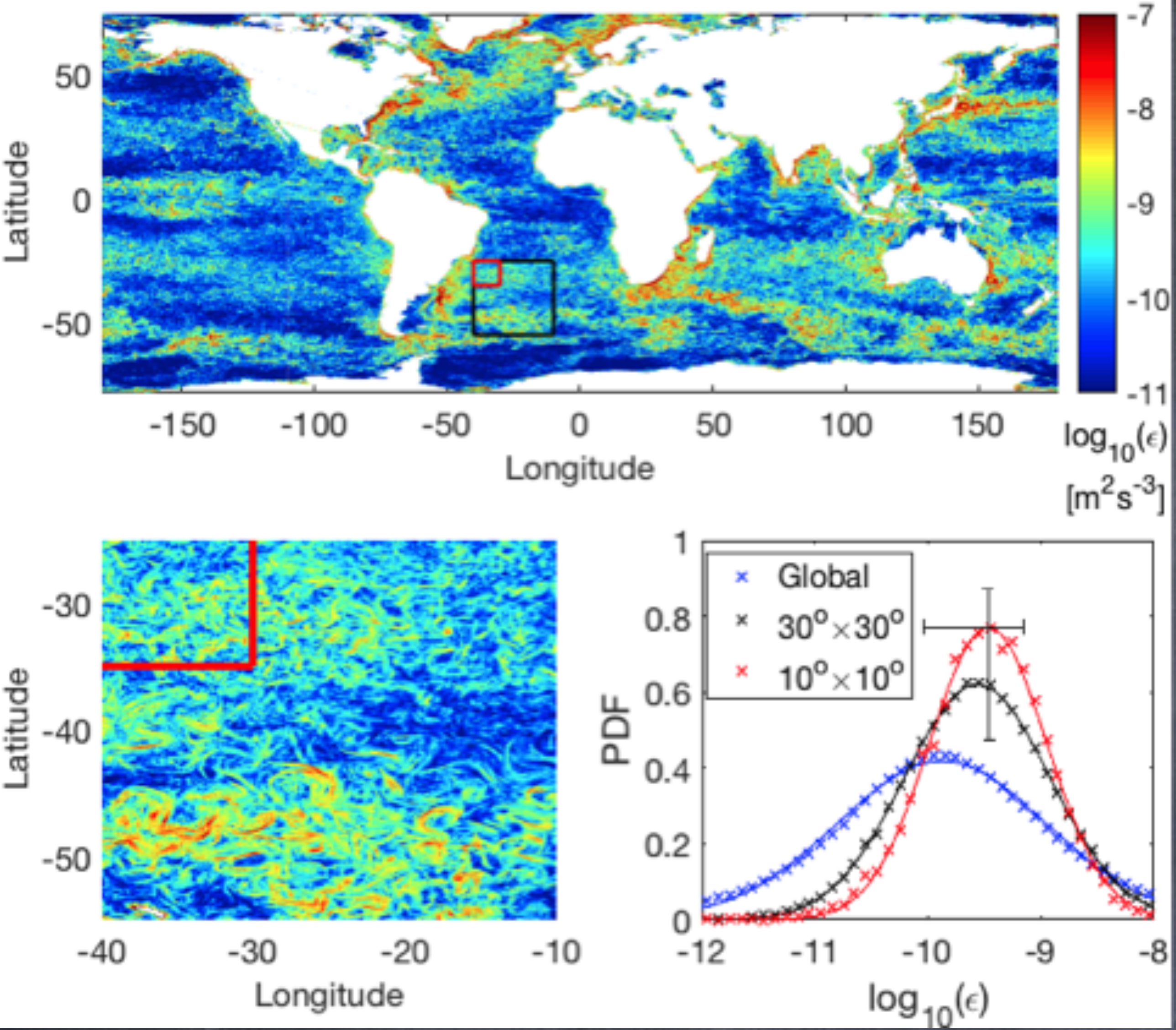

MOLES & drifters: Conclusions

Dissipation of energy and QGPE is extremely localized (90% of total in 10% of regions)

Kinetic energy is dissipated (weakly) within QG Pot'l Enstrophy Cascade

50x smaller sink of EKE than Poje et al.
(lognormal: +1.5 st.dev., Lagrangian biased by 2x to 8x):
Known Unknowns:
Lognormality tail.
Drifters biased toward fronts.

Unknown Knowns:
Concentrate EKE into OSBL?
Wind work underestimated.

Subgrid scheme matters
for leading order EKE budget!