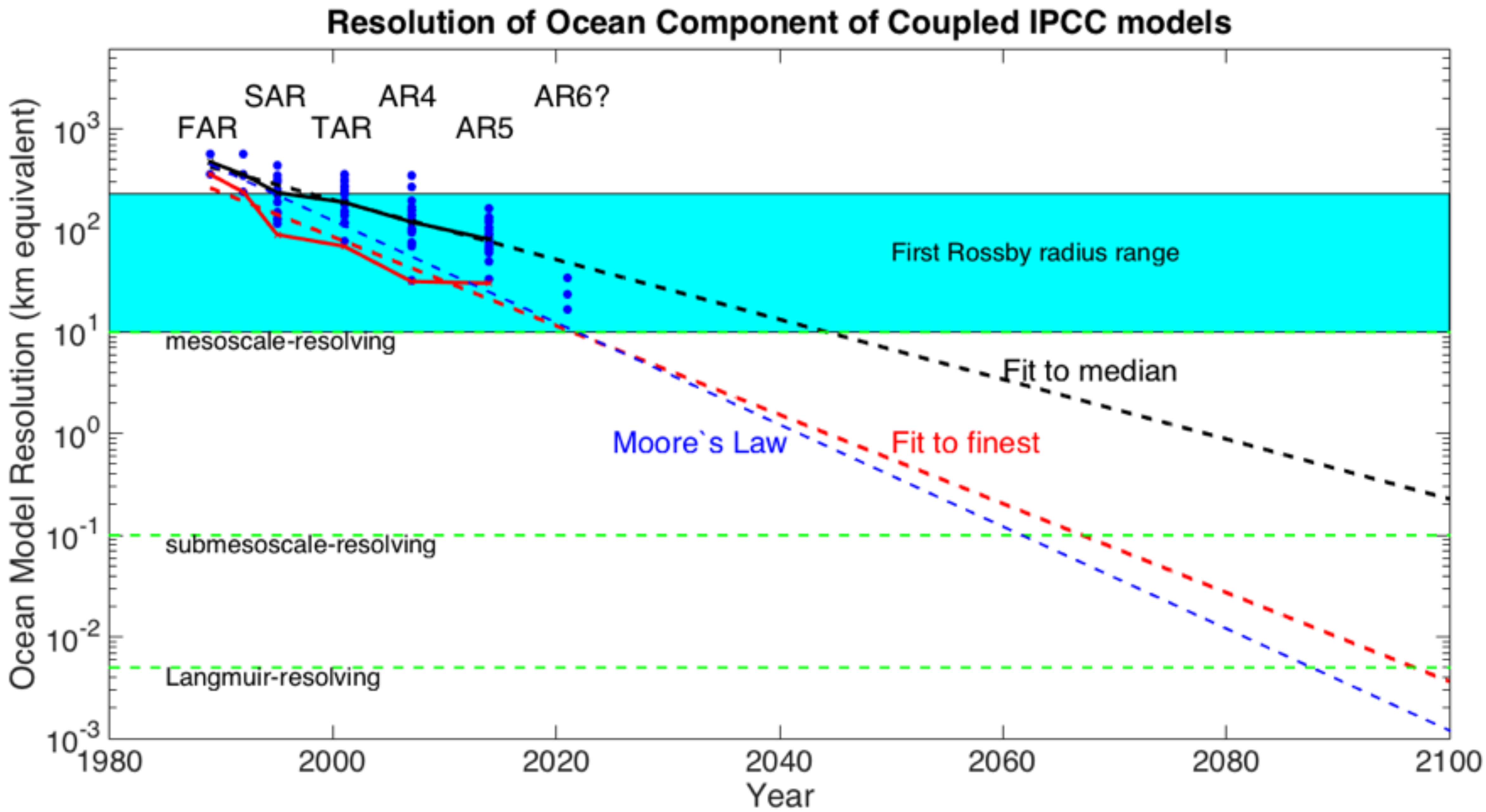
Parameterizations with and without Climate Process Teams

Baylor Fox-Kemper
Brown University, DEEP Sciences

Mixed Layer Eddy Sponsors: NSF **OCE-0612143, OCE-0612059,**
OCE-0825376, DMS-0855010, and OCE-0934737
Langmuir Sponsors: NASA ROSES-NNX09AF38G, NSF OCE-0934737, OCE-1258907,
NSF Kavli Institute for Theoretical Physics
Symmetric Instability Sponsors: The Gulf of Mexico Research Initiative,
NSF OCE-1350795, OCE-1258907, and OCE-0934737
QuasiGeostrophic Leith: NOAA C&GC, NSF **OCE-0612143**, OCE-1350795

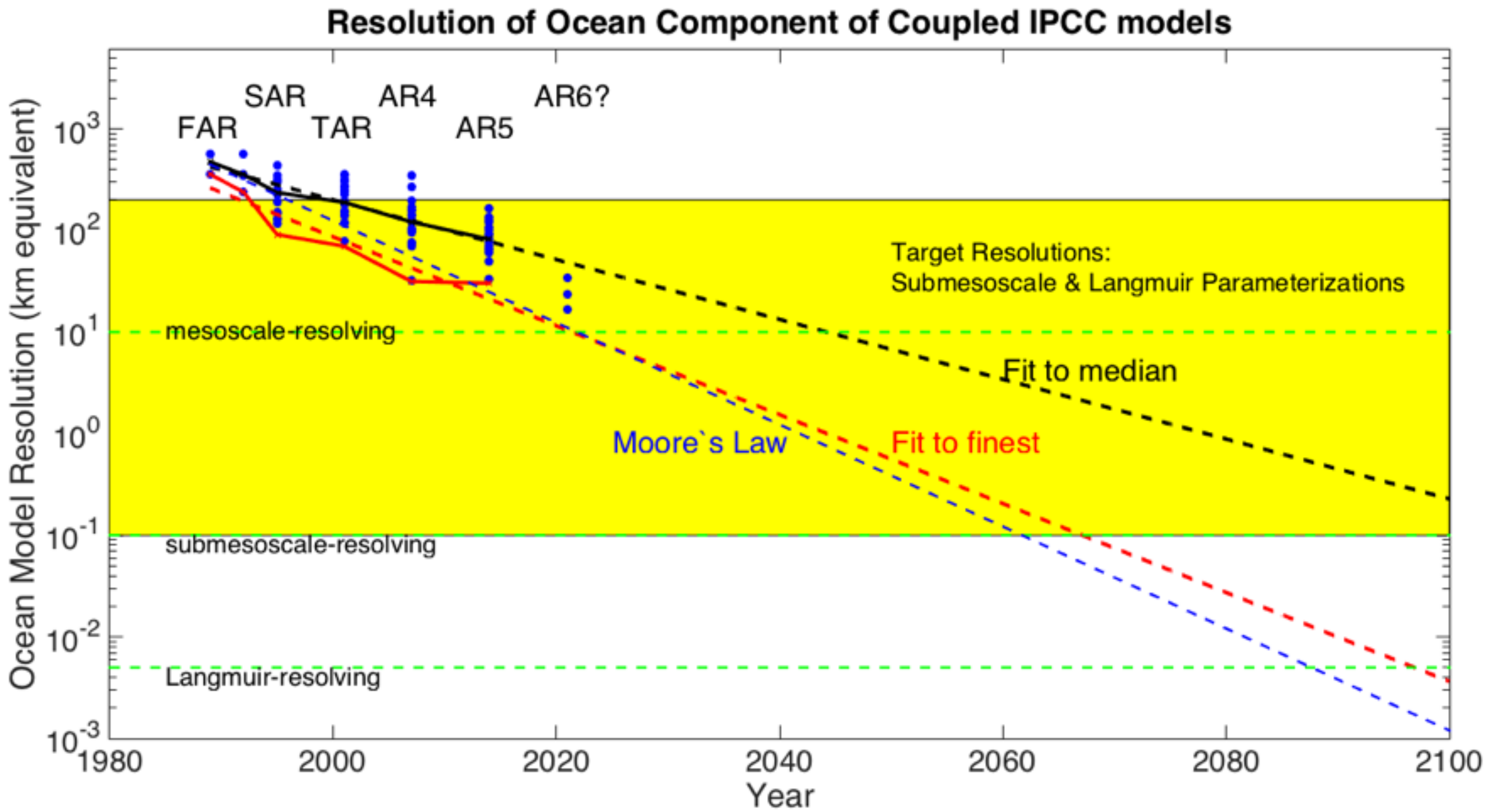
NSF: UCAR, TeraGRID, or XSEDE Computing every time, plus NOAA, NASA, IBM

Global Model Resolution is limited, and will be for centuries



BFK, S. Bachman, B. Pearson, and S. Reckinger. Principles and advances in subgrid modeling for eddy-rich simulations. CLIVAR Exchanges, 19(2):42-46, July 2014.

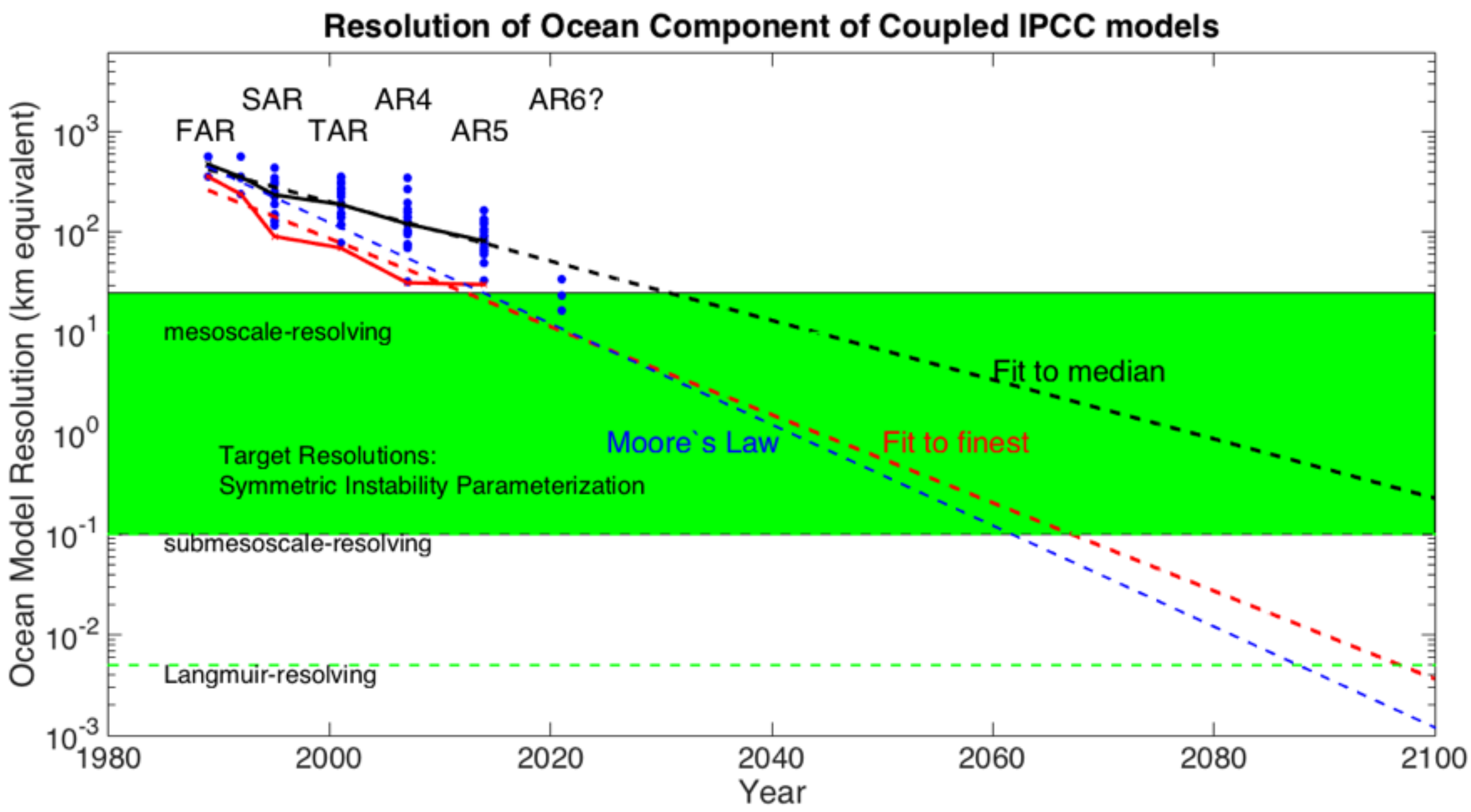
Some Parameterizations, e.g., Mixed Layer Eddy Restratification and Langmuir Turbulence, are built for standard climate models



BFK, G. Danabasoglu, R. Ferrari, S. M. Griffies, R. W. Hallberg, M. M. Holland, M. E. Maltrud, S. Peacock, and B. L. Samuels. Parameterization of mixed layer eddies. III: Implementation and impact in global ocean climate simulations. Ocean Modelling, 39:61-78, 2011.

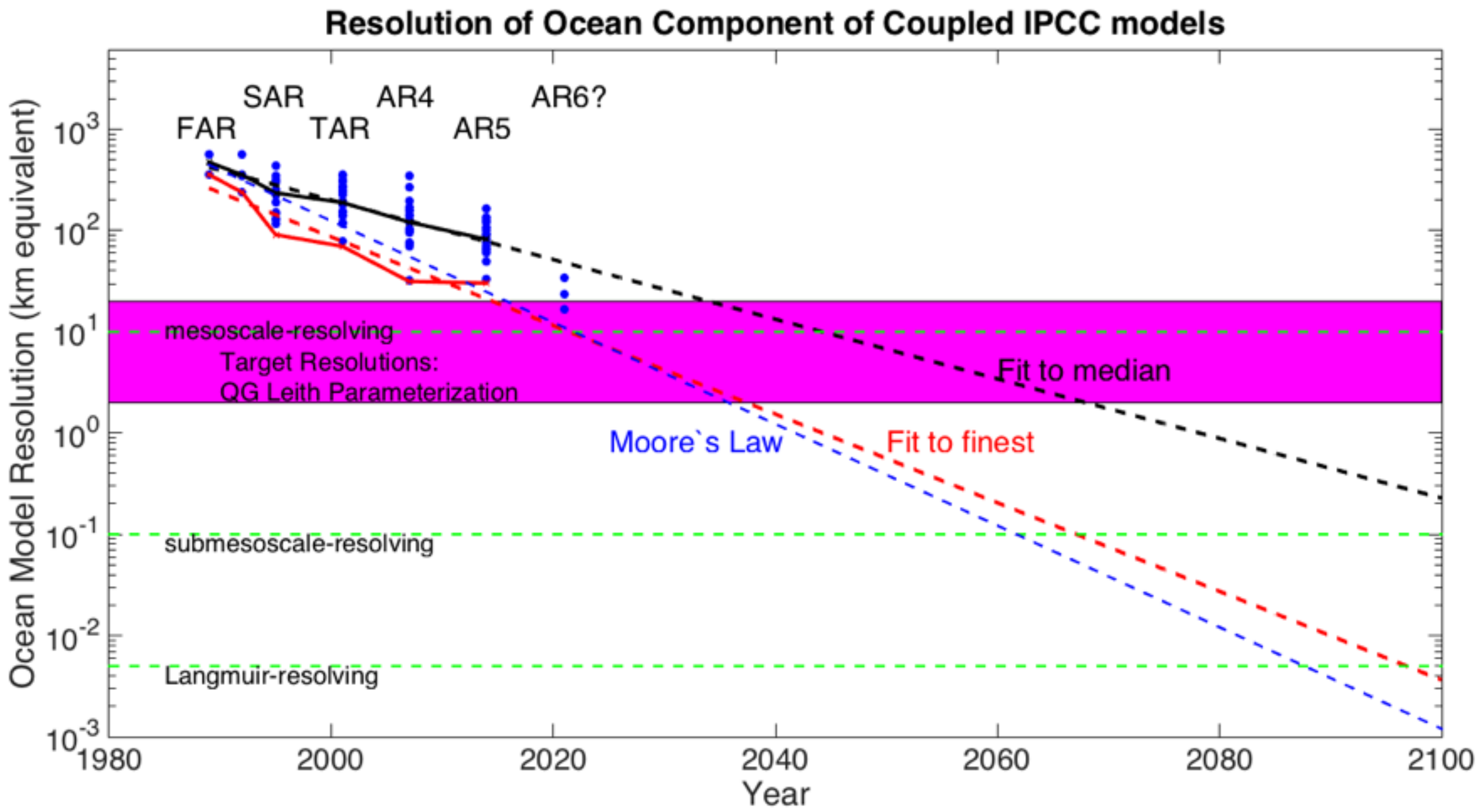
Q. Li, A. Webb, BFK, A. Craig, G. Danabasoglu, W. G. Large, and M. Vertenstein. Langmuir mixing effects on global climate: WAVEWATCH III in CESM. Ocean Modelling, 103:145-160, July 2016.

The Symmetric Instability parameterization requires resolved fronts, so mesoscale-resolving and submesoscale-permitting.



S. D. Bachman, BFK, J. R. Taylor, and L. N. Thomas. Parameterization of frontal symmetric instabilities. I: Theory for resolved fronts. Ocean Modelling, April 2016. Submitted.

The QG Leith parameterization requires large mesoscale eddies resolved, but smallest are parameterized (Mesoscale Ocean Large Eddy Simulation)



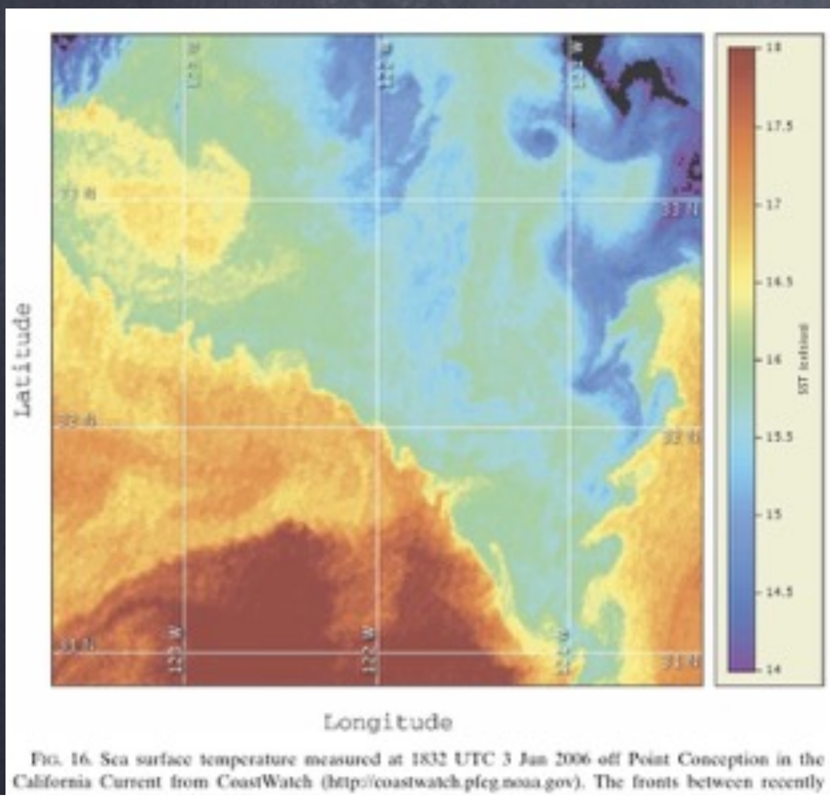
B. Pearson, BFK, and S. D. Bachman. Evaluation of scale-aware subgrid mesoscale eddy models in a global eddy-rich model. Ocean Modelling, November 2016. Submitted.

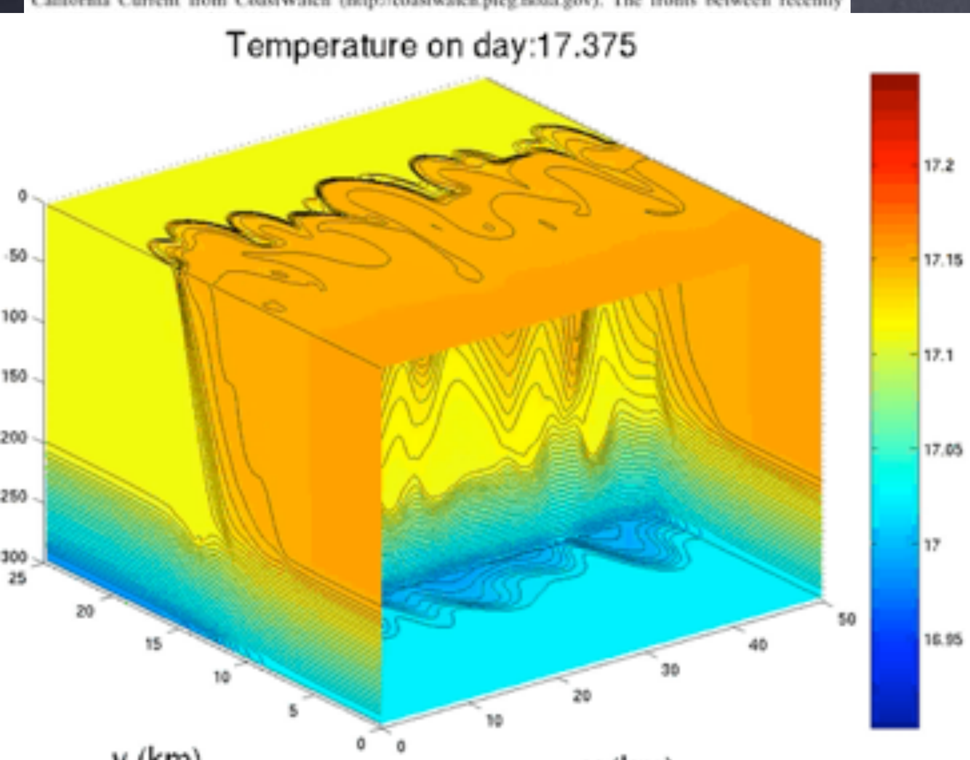
S. D. Bachman, BFK, and B. Pearson. A scale-aware subgrid model for quasigeostrophic turbulence. Journal of Geophysical Research-Oceans, November 2016. Submitted.

Mixed Layer Eddy Restratification

← 10 km

(Capet et al., 2008)



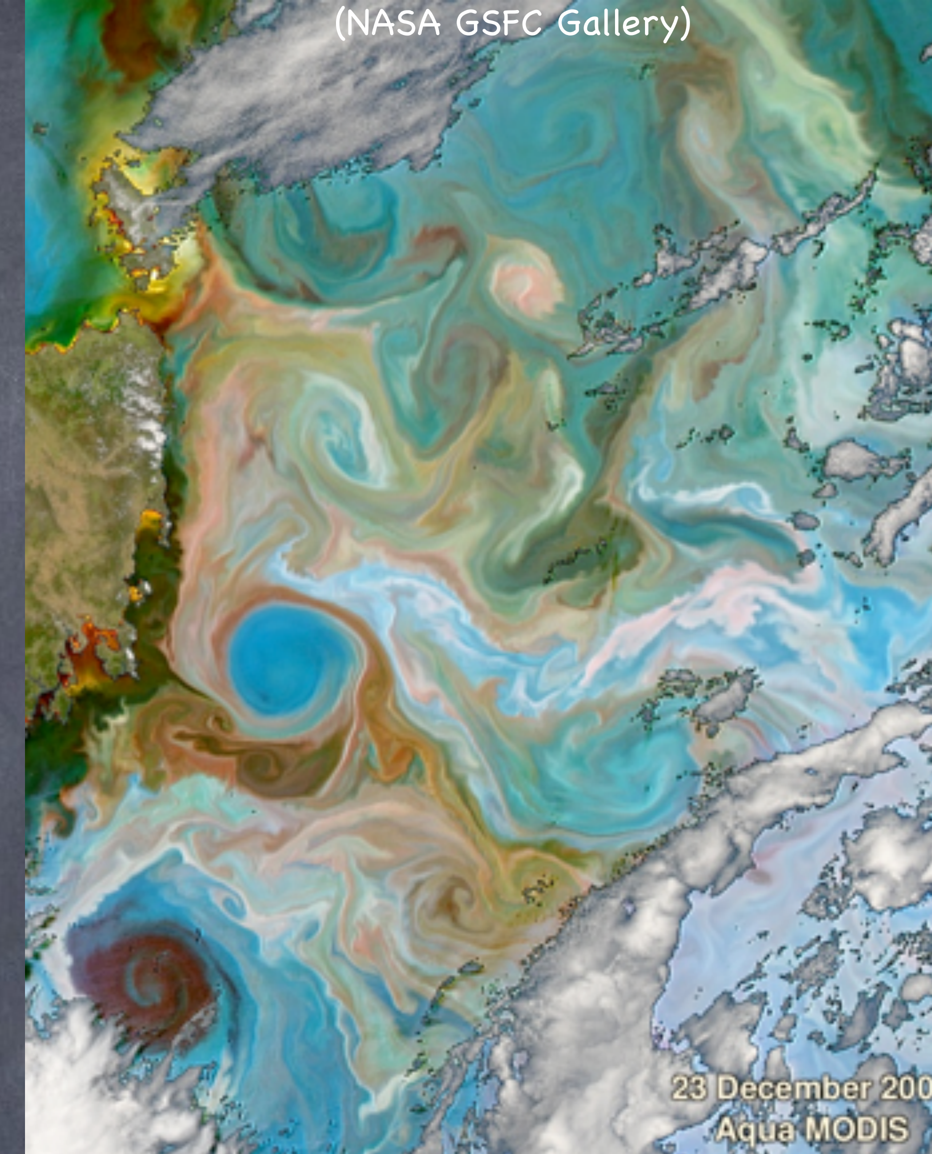


- Fronts
- Eddies
- Ro=O(1)
- Ri=O(1)
- near-surface
- 1-10km, days

Eddy processes often baroclinic instability

Parameterizations of baroclinic instability emphasize restratification

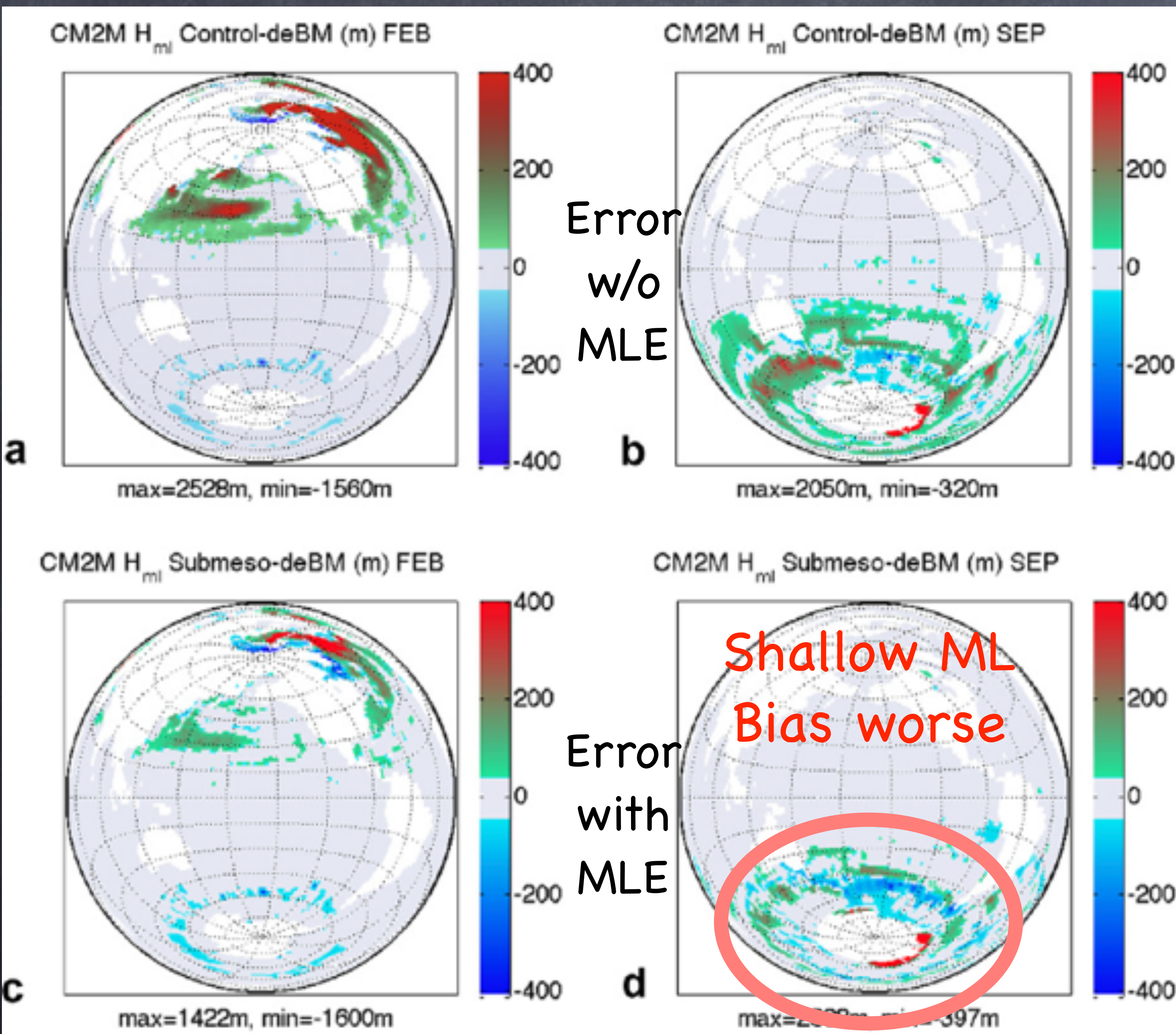
(NASA GSFC Gallery)



BFK, R. Ferrari, and R. W. Hallberg. Parameterization of mixed layer eddies. Part I: Theory and diagnosis. Journal of Physical Oceanography, 38(6):1145-1165, 2008

BFK, G. Danabasoglu, R. Ferrari, S. M. Griffies, R. W. Hallberg, M. M. Holland, M. E. Maltrud, S. Peacock, and B. L. Samuels. Parameterization of mixed layer eddies. III: Implementation and impact in global ocean climate simulations. Ocean Modelling, 39:61-78, 2011.

Physical Sensitivity of Ocean Climate to MLE: (submeso) Mixed Layer Eddy Restratification



Also:

Improves CFCs (water masses)

Improves T&S (water masses)

Improves Sea Ice & Climate Sensitivity (ML Heat Capacity)

A consistently restratifying,

$$\overline{w'b'} \propto \frac{H^2}{|f|} \left|\nabla_H \bar{b}\right|^2$$

and horizontally downgradient flux.

$$\overline{\mathbf{u}'_H b'} \propto \frac{-H^2 \frac{\partial \bar{b}}{\partial z}}{|f|} \nabla_H \bar{b}$$

B. Fox-Kemper, G. Danabasoglu, R. Ferrari, S. M. Griffies, R. W. Hallberg, M. M. Holland, M. E. Maltrud, S. Peacock, and B. L. Samuels. Parameterization of mixed layer eddies. III: Implementation and impact in global ocean climate simulations. *Ocean Modelling*, 39:61-78, 2011.

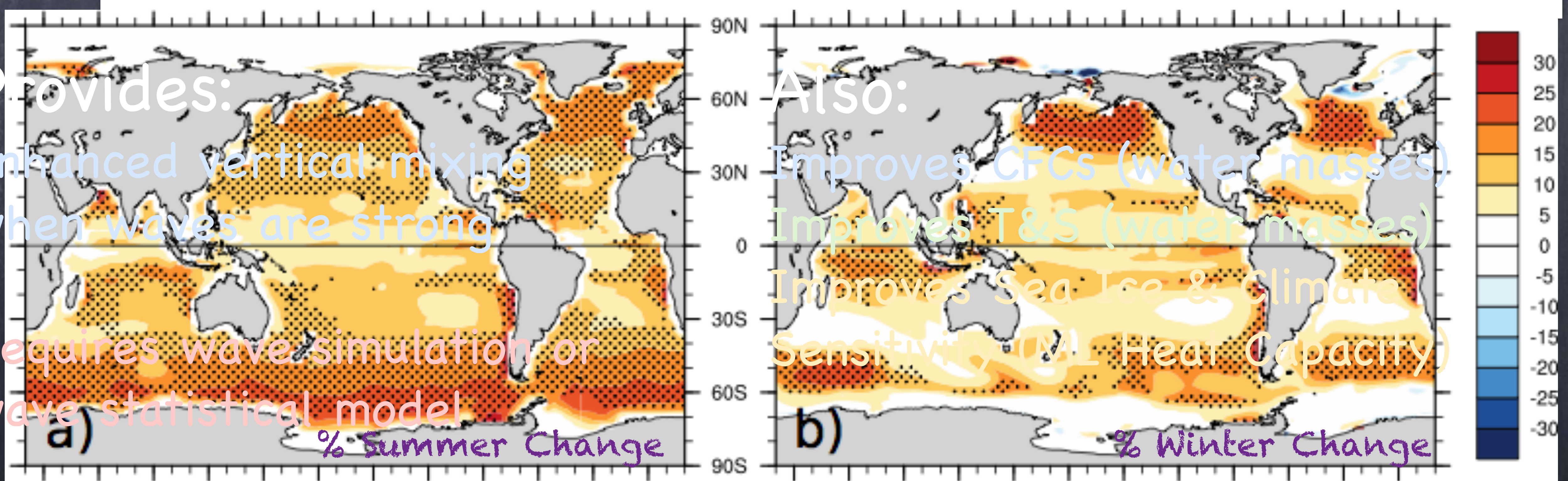
Parameterization of Langmuir Turbulence

- Near-surface
- Langmuir Cells & Langmuir Turb.
- Ro>>1
- Ri<1: Nonhydro
- 1-100m (H=L)
- 10s to 1hr
- w, u=O(10cm/s)
- Stokes drift
- Eqtns: Wave-Averaged
- Params: McWilliams & Sullivan, 2000, Harcourt & D'Asaro 2008, Van Roekel et al. 2012
- Resolved routinely in 2170

Image: NPR.org, Deep Water Horizon Spill

Langmuir Mixing: Boundary layer Depth Improved

	Case	Summer Global	Summer South of 30°S	Summer 30°S-30°N	Winter Global	Winter South of 30°S	Winter 30°S-30°N
Control	CTRL	10.62±0.27[a]	17.24±0.48	5.38±0.14	43.85±0.38	57.19±0.76	12.57±0.28
		(13.40±0.19)[b]	(21.73±0.32)	(6.71±0.09)	(45.50±0.40)	(56.53±0.59)	(16.16±0.29)
Competition	MS2K	15.37	15.47	17.03	119.91	171.92	40.31
	SS02	36.79	63.83	7.54	99.32	164.34	17.39
3 versions of Van Roekel et al	VR12-AL	9.06	13.47	6.49	40.45	50.33	14.52
	VR12-MA	8.73±0.30	12.65±0.47	6.61±0.22	40.99±0.37	51.78±0.65	14.23±0.30
		(11.83±0.29)	(18.13±0.62)	(7.52±0.16)	(42.02±0.39)	(50.78±0.67)	(15.67±0.35)
	VR12-EN	8.95	10.52	8.91	41.94	52.98	19.58



dotted when statistically significant

Provides:

Enhanced vertical mixing when waves are strong

Requires wave simulation or wave statistical model

Also:

Improves CFCs (water masses)

Improves T&S (water masses)

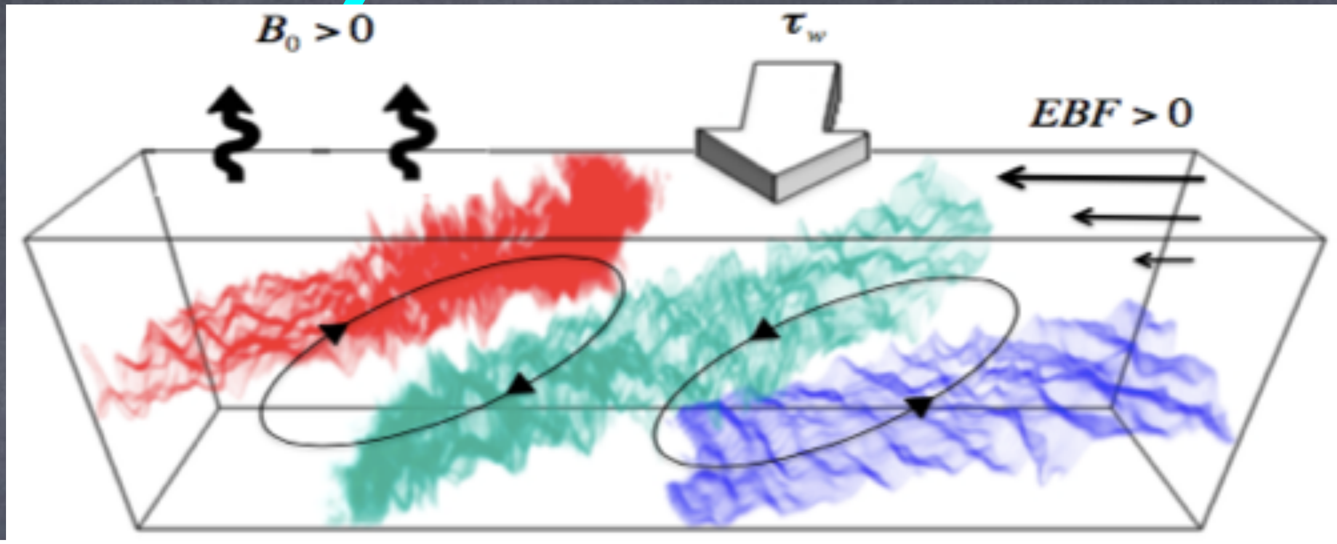
Improves Sea Ice & Climate Sensitivity (ML Heat Capacity)

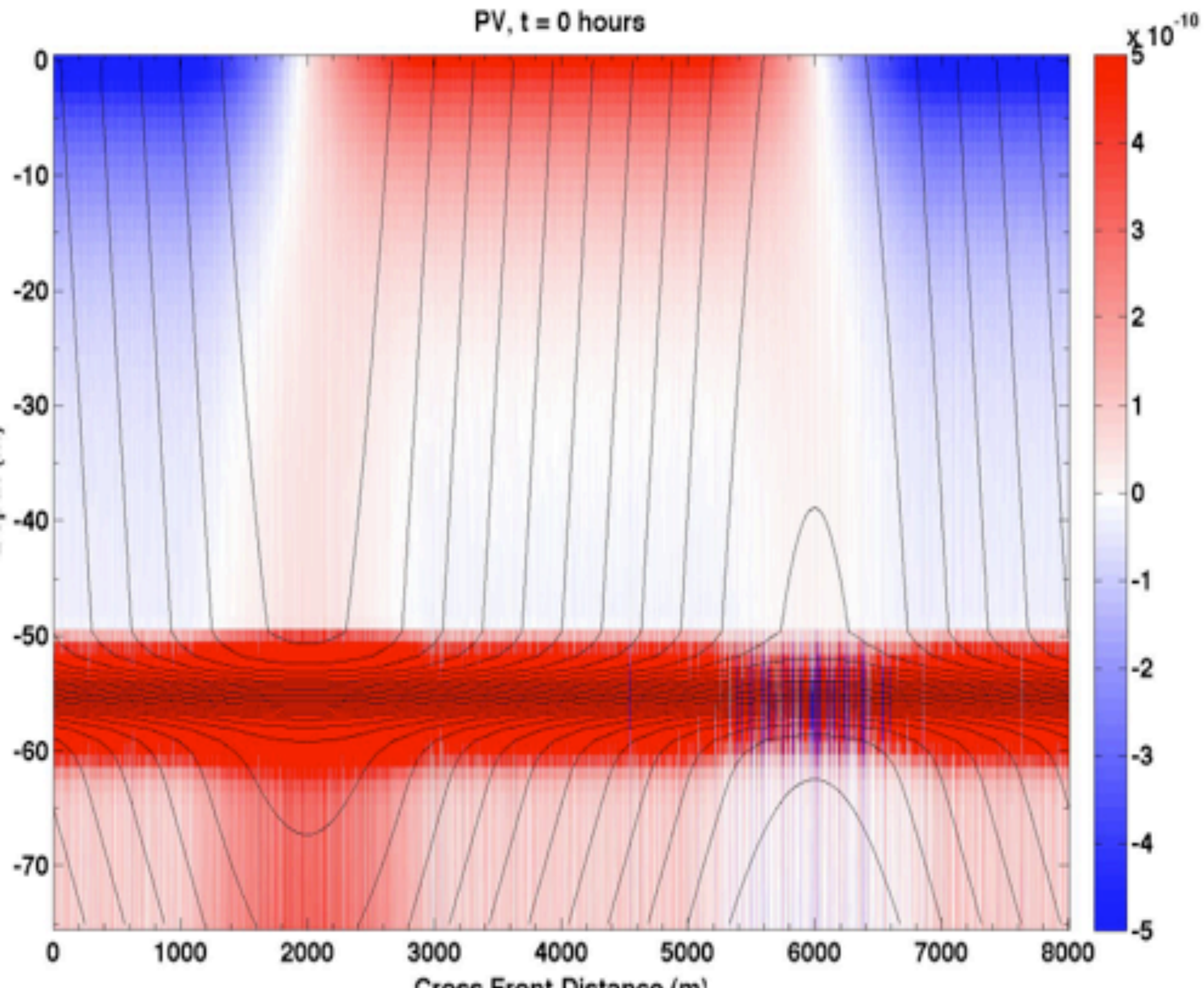
L. P. Van Roekel, BFK, P. P. Sullivan, P. E. Hamlington, and S. R. Haney. The form and orientation of Langmuir cells for misaligned winds and waves. Journal of Geophysical Research-Oceans, 117:C05001, 22pp, May 2012.

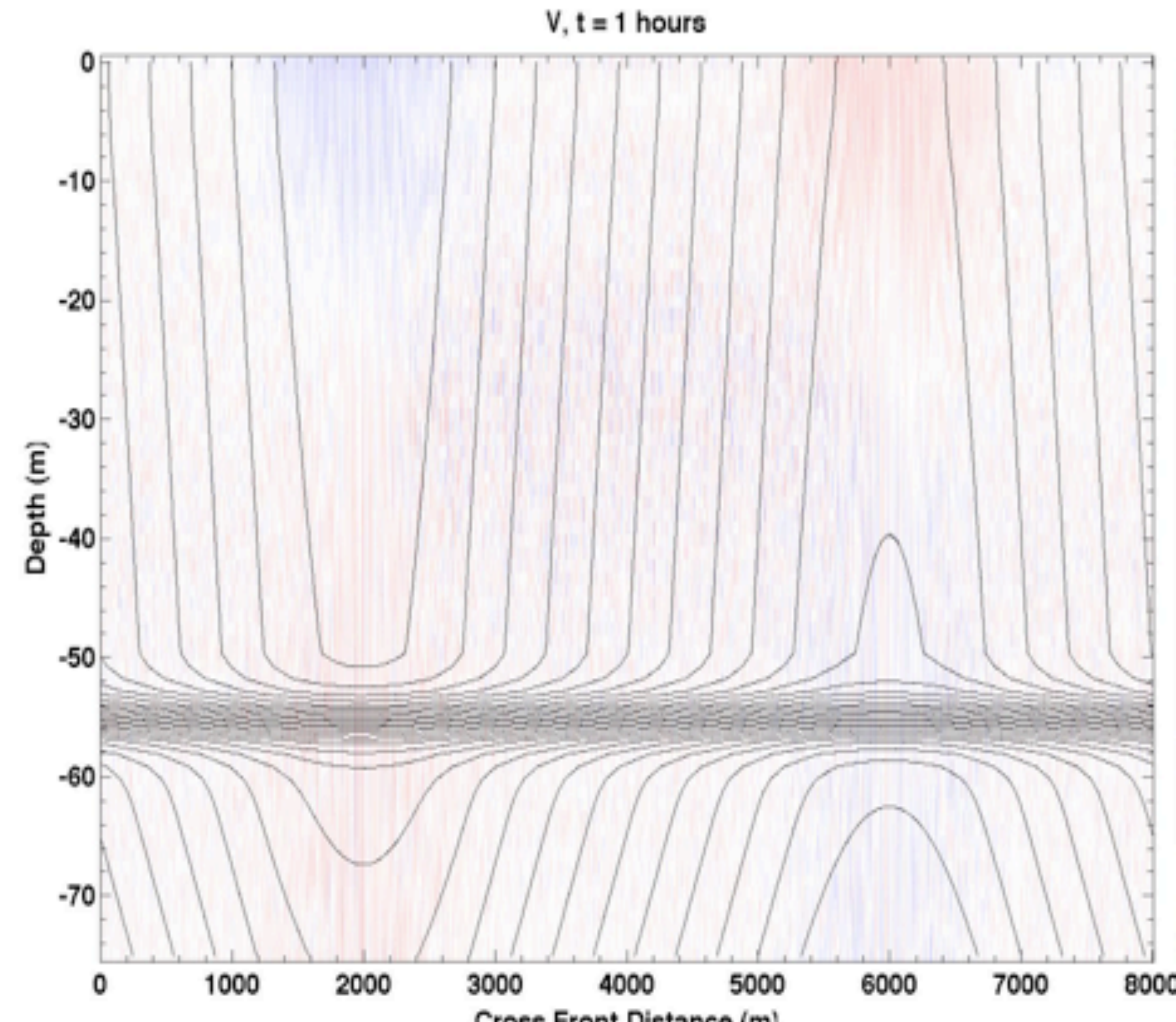
Q. Li, A. Webb, BFK, A. Craig, G. Danabasoglu, W. G. Large, and M. Vertenstein. Langmuir mixing effects on global climate: WAVEWATCH III in CESM. Ocean Modelling, 103:145-160, July 2016.

Symmetric Instability

- Convecting Fronts
- Ro=O(>1)
- Ri=O(1/4 to 1)
- 0.1km, hours



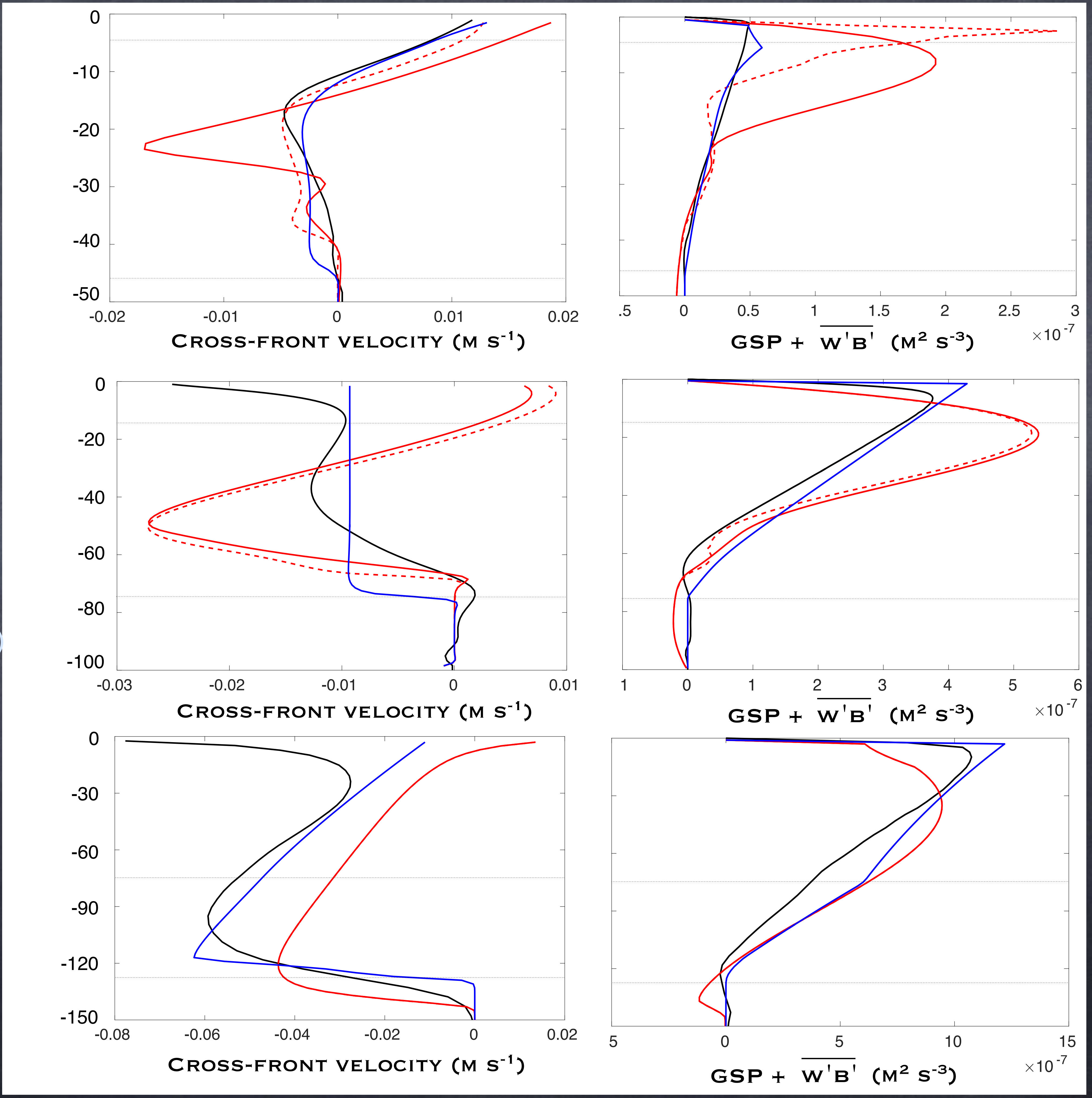




S. D. Bachman, BFK, J. R. Taylor, and L. N. Thomas. Parameterization of frontal symmetric instabilities. I: Theory for resolved fronts. Ocean Modelling, April 2016. Submitted.

S. Haney, B. Fox-Kemper, K. Julien, and A. Webb. Symmetric and geostrophic instabilities in the wave-forced ocean mixed layer. Journal of Physical Oceanography, 45:3033-3056, December 2015.

Results vs. KPP and LES ('truth')



Versus LES from

Top: Taylor and Ferrari (2010)
Mid: Thomas and Taylor (2010)
Bot: Thomas et al. (2013)

Working on more realistic simulation comparison to Hamlington et al. (2014) now.

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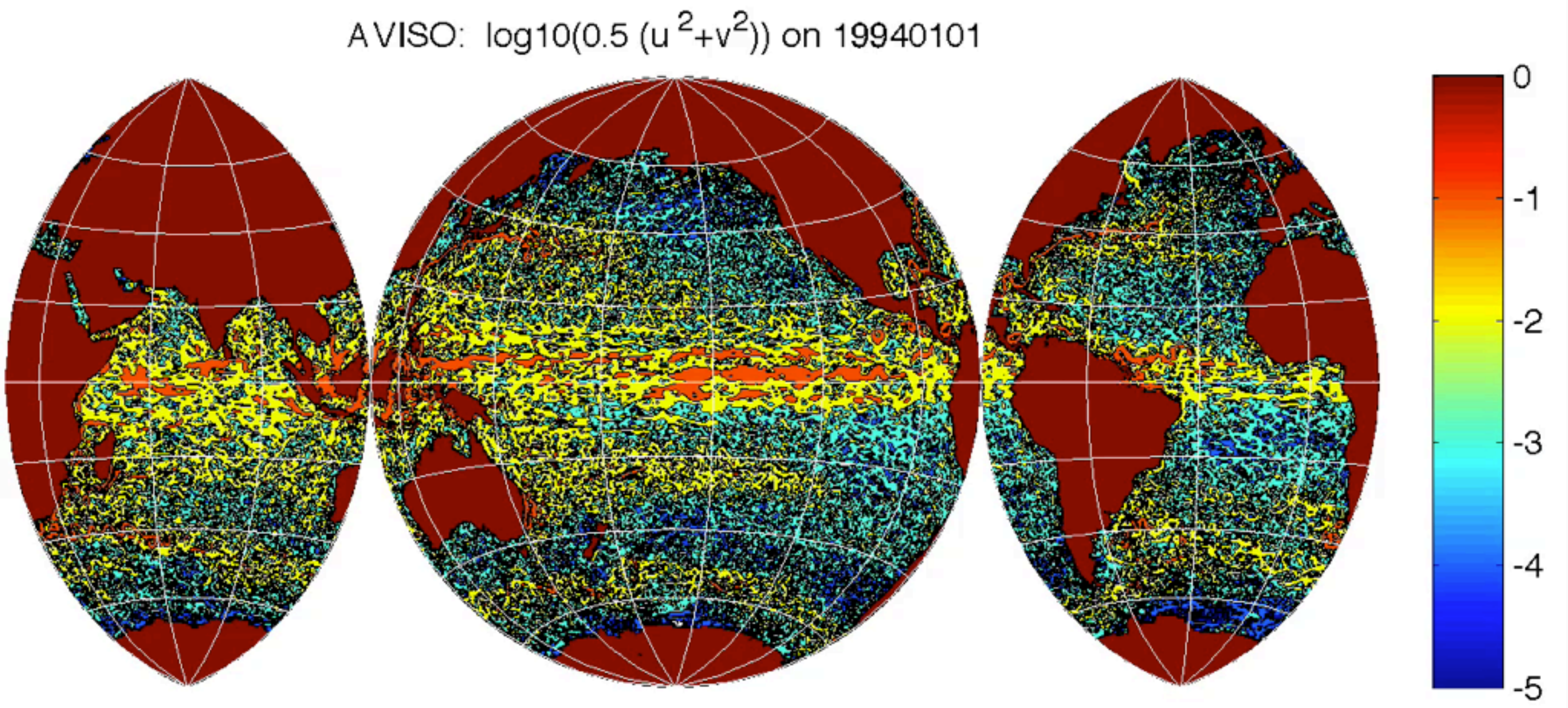
(NASA GSFC Gallery)



Traditionally, no eddies were resolved (100km grid)

Bleeding edge models resolve Large Eddies, but not All Eddies:

Mesoscale Ocean Large Eddy Simulations

BFK 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.

S. D. Bachman, BFK, and B. Pearson. A scale-aware subgrid model for quasigeostrophic turbulence. Journal of Geophysical Research-Oceans, November 2016. Submitted.

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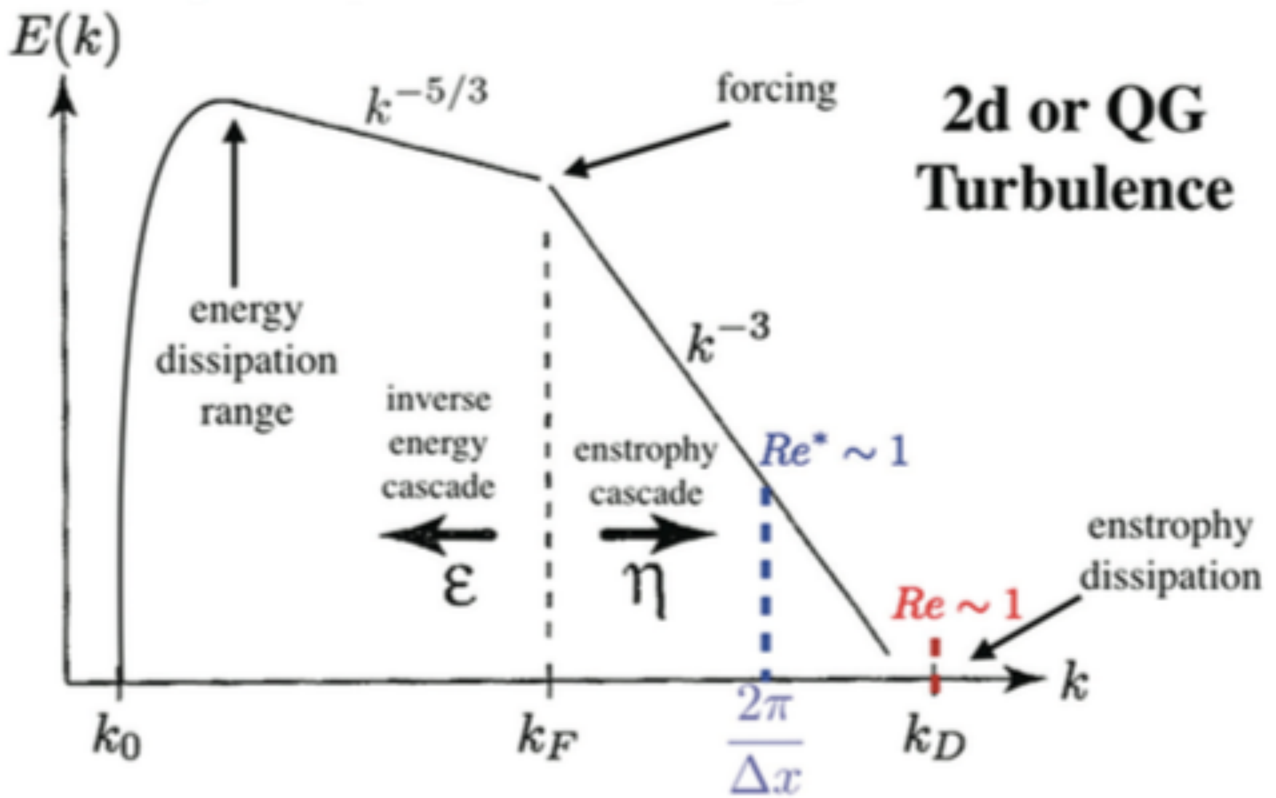
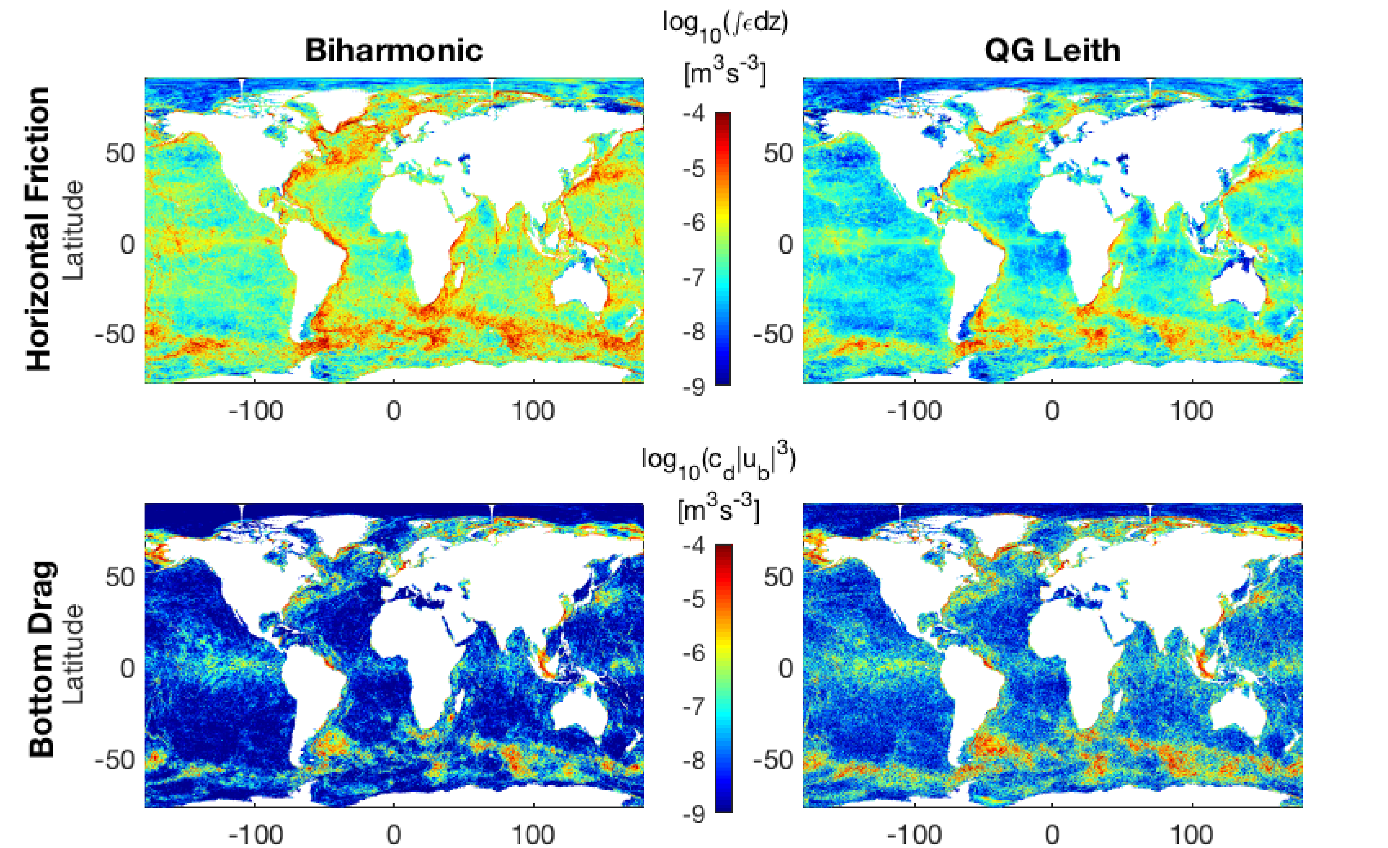
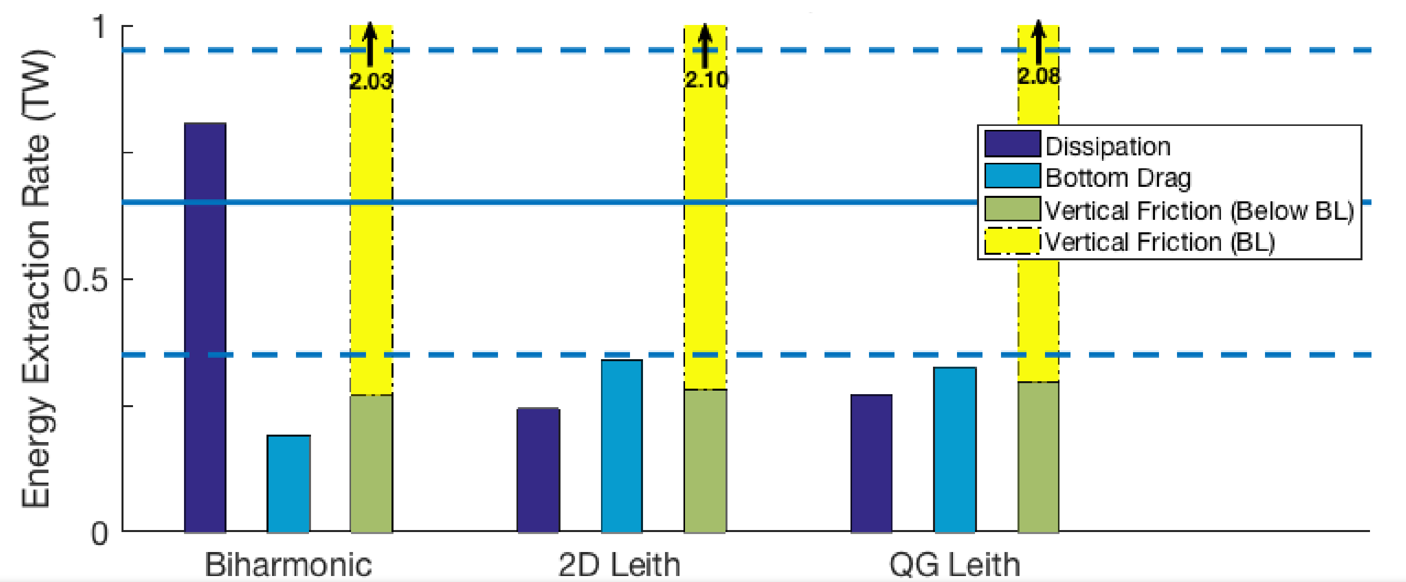




$$\nu_{qg} = \left(\frac{\Delta_h \Lambda_{qg}}{\pi}\right)^3 \sqrt{|\nabla_h q_{qg}|^2 + |\nabla_h (\nabla_h \cdot \mathbf{u})|^2}$$

$$= \kappa_i = \mu_{gm}$$



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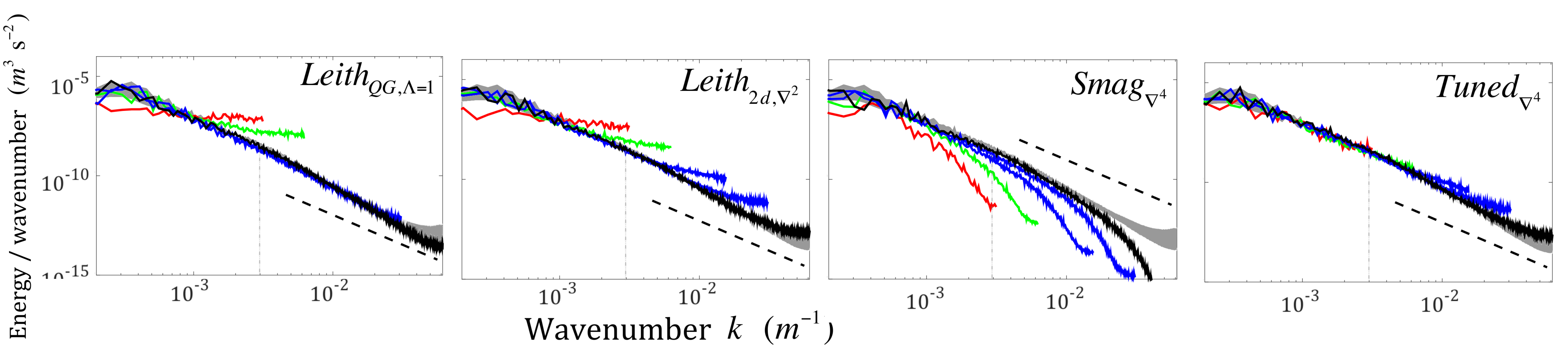


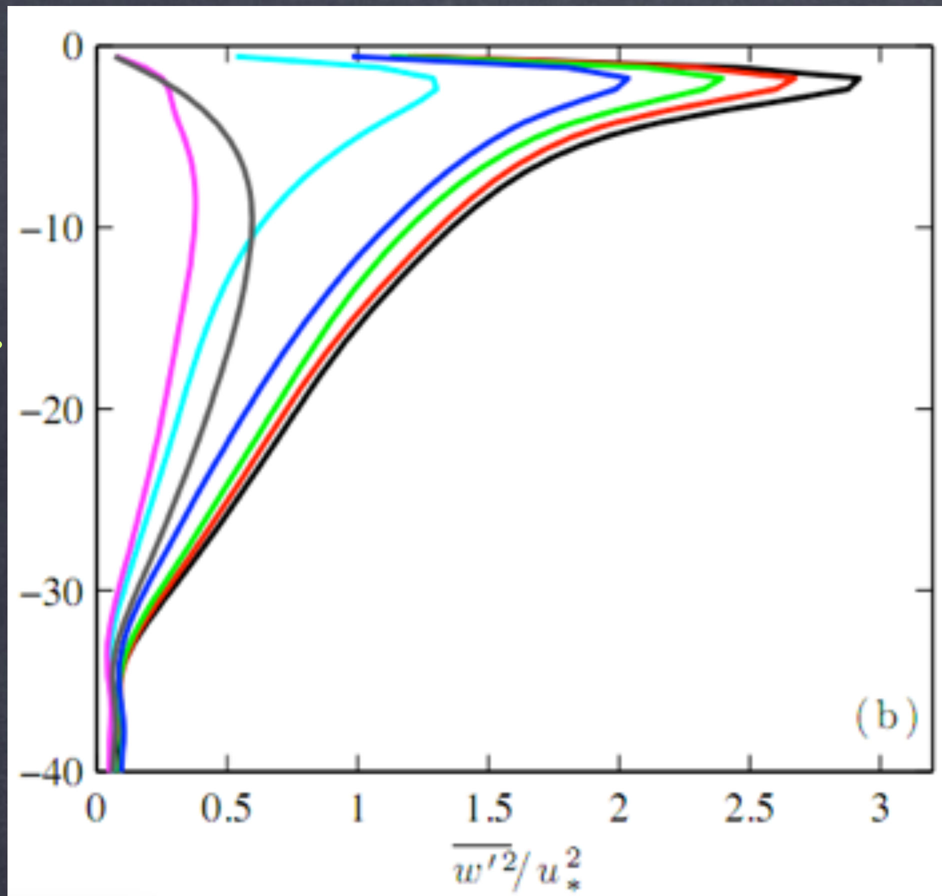
Conclusions

- Parameterizations wanted! Go out and make one, no CPT req'd!
  - We are finding the "equations of motion" relevant for discretized oceans.
  - Match these to the need—what model class are they intended for, how long will they be needed
- Many processes probably affect climate, not all are amenable
- It is the parameterization that allows you to estimate how big their effect is

- Advantages of CPT
  - Implementation Assistance from Modeling Centers
  - Audience
- Dis-advantages of CPT
  - Climate models are not the only target
    - (NWP, regional pollution, coastal models, etc.)
  - 3-5 yr timescale likely not enough to start from scratch.

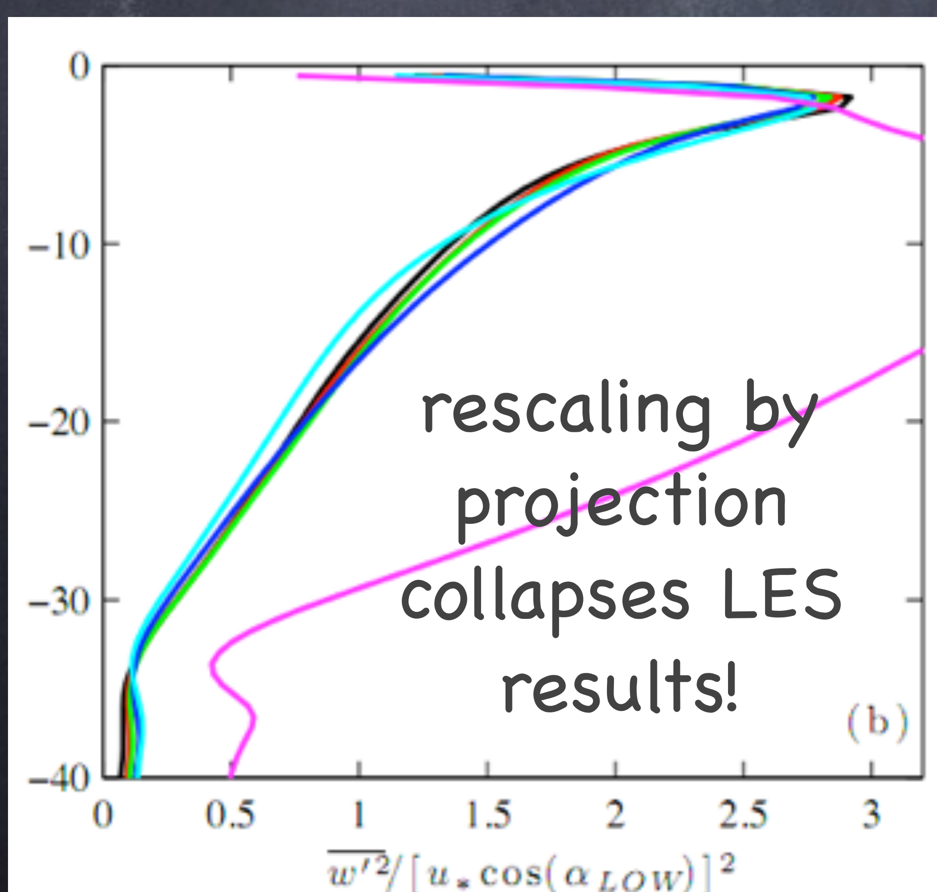
<w^2>

depth



rescaled <w^2>

depth



Generalized Turbulent Langmuir No., Projection of u*, u_s into Langmuir Direction

$$\frac{\left\langle \overline{w'^2} \right\rangle_{ML}}{u_*^2} = 0.6\cos^2(\alpha_{LOW})\left[1.0+(3.1La_{proj})^{-2} + (5.4La_{proj})^{-4}\right],$$

$$La_{proj}^2 = \frac{|u_*|\cos(\alpha_{LOW})}{|u_s|\cos(\theta_{ww}-\alpha_{LOW})},$$

$$\alpha_{LOW} \approx \tan^{-1}\left(\frac{\sin(\theta_{ww})}{\frac{u_*}{u_s(0)\kappa}\ln\left(\left|\frac{H_{ML}}{z_1}\right|\right)+\cos(\theta_{ww})}\right)$$

A scaling for LC strength & direction!

L. P. Van Roekel, B. Fox-Kemper, P. P. Sullivan, P. E. Hamlington, and S. R. Haney. The form and orientation of Langmuir cells for misaligned winds and waves. Journal of Geophysical Research-Oceans, 117:C05001, 22pp, 2012.