# PARAMETERIZATION OF SUBMESOSCALE AND LANGMUIR-SCALE PROCESSES AND INTERACTIONS

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L. Van Roekel (Northland College),
& P.P. Sullivan (NCAR)

OS2012 Abstract 10618, 016: Dynamics and Observations of Submesoscale Oceanic Processes
Wed. 2/22/2012, 14:15-14:30, Room 251

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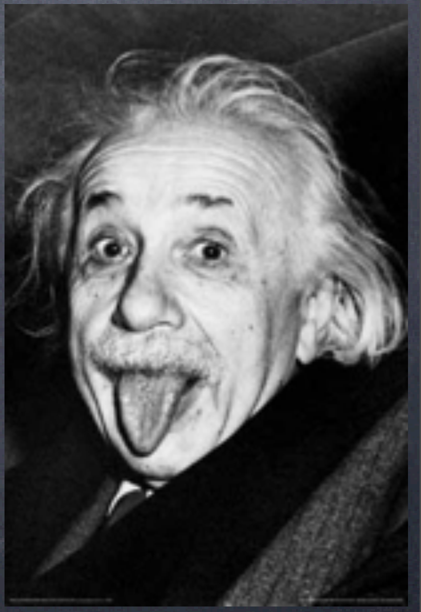
# Results

- Submesoscale mixed layer eddy restratification
- Langmuir turbulence mixing
  - Both are important to global surf. layer (10%)
  - Both are regionally more important (x2 to x4)
- Momentum=Langmuir, Stratification Change=Both
- Coupling between these scales exists! Parameterize?

# Parameterizations

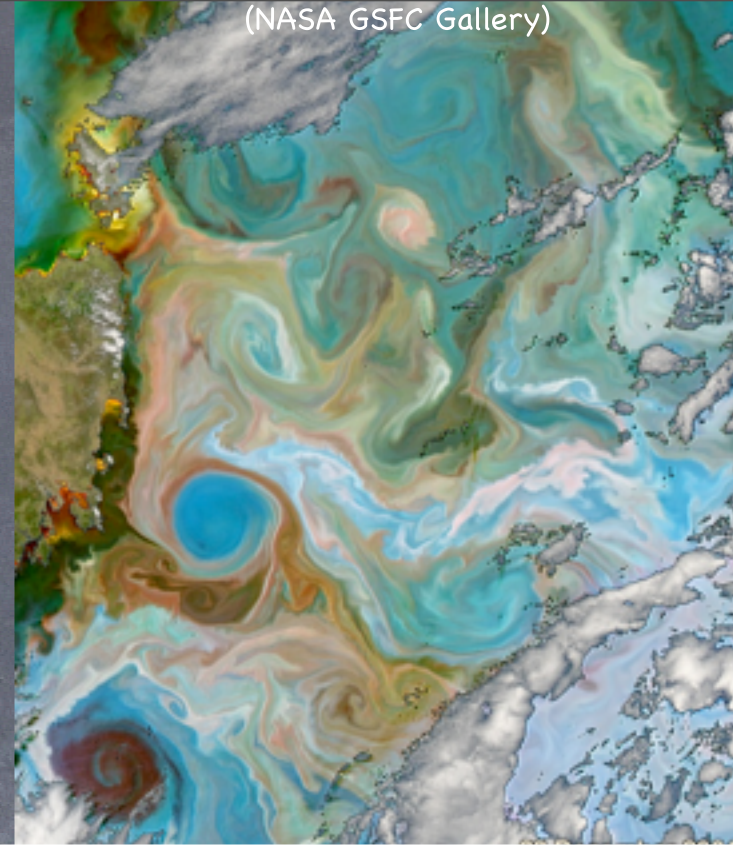
- Anyone who doesn't take truth seriously in small matters cannot be trusted in large ones either.
  - --Albert Einstein



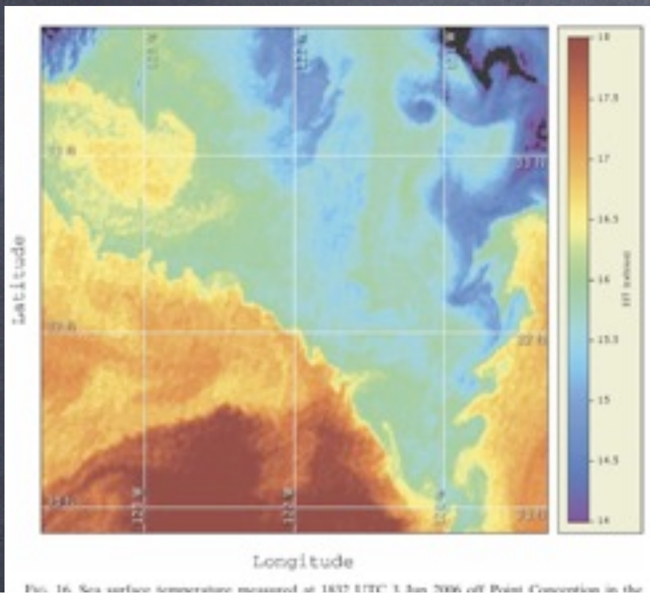
# The Character of the Submesoscale

10 km

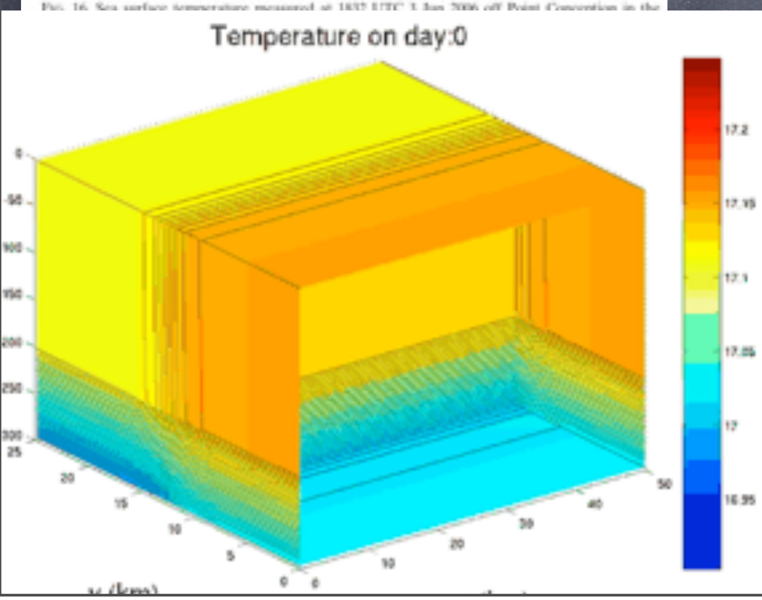
(NASA GSFC Gallery)



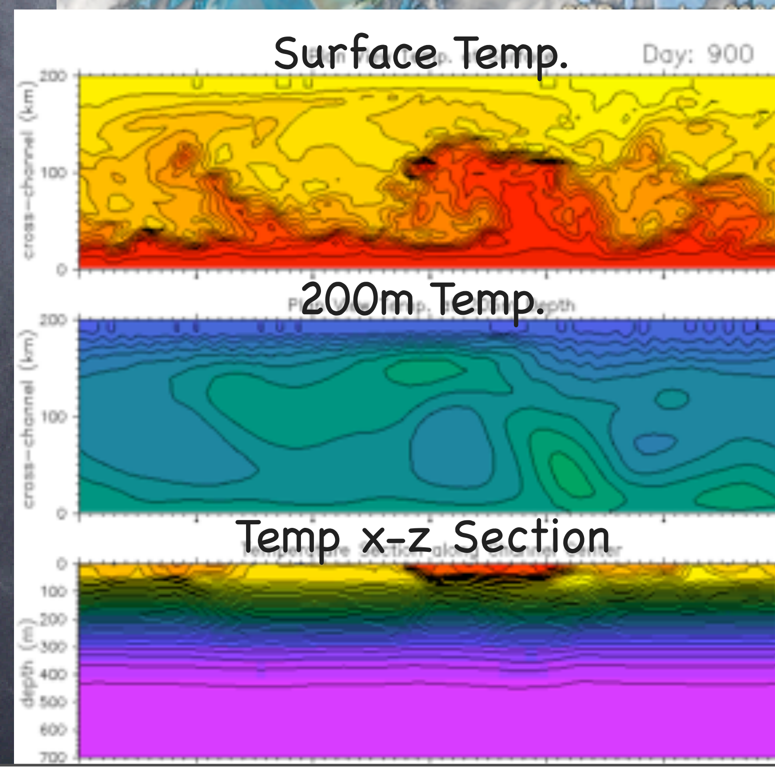
(Capet et al., 2008)




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

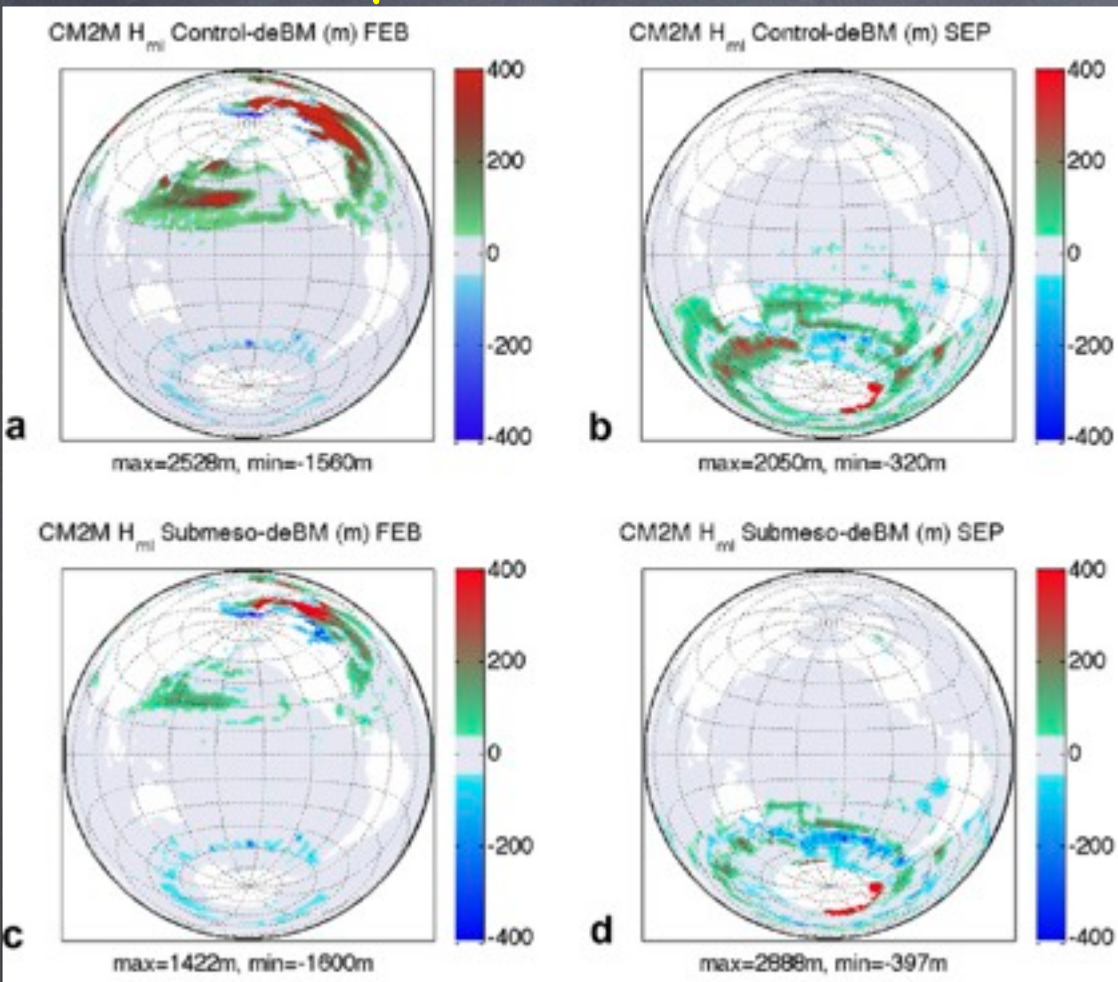



Eddy processes often baroclinic instability (Boccaletti et al '07, Haine & Marshall '98).



# Physical Sensitivity of Ocean Climate to Submesoscale Eddy Restratification:

## MLE implemented in CCSM (NCAR), CM2M & CM2G (GFDL)



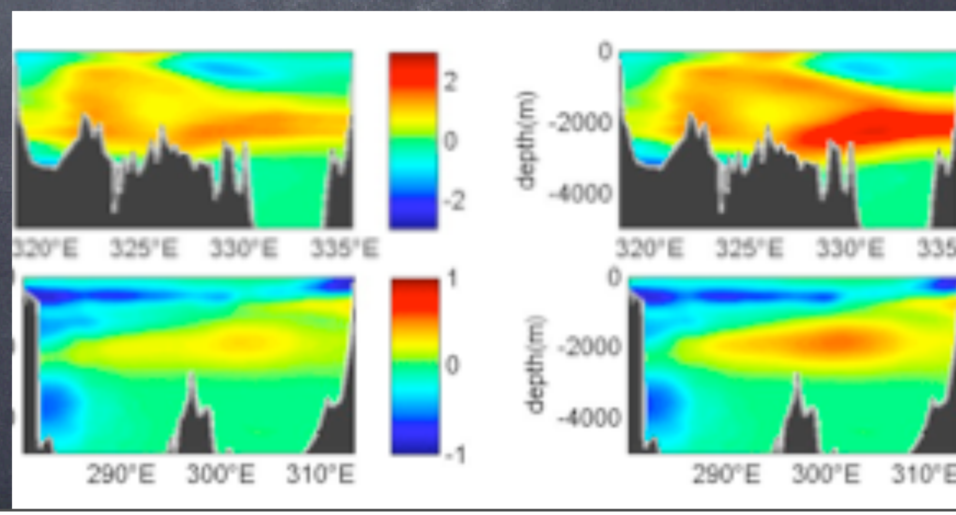

Bias w/o MLE

NO RETUNING NEEDED!!!

Improves CFCs (water masses)

Bias with MLE

Bias w/o MLE




Deep ML Bias reduced

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.

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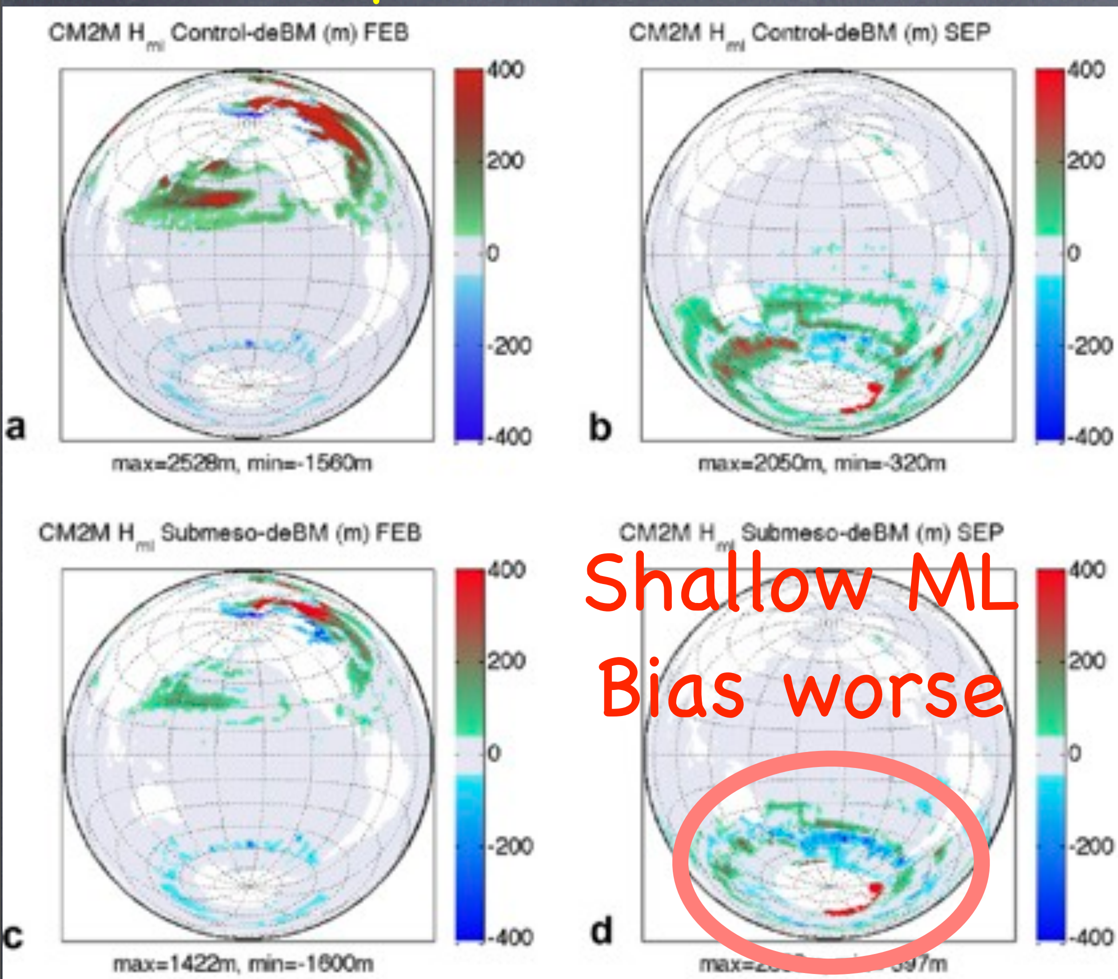



Shallow ML Bias worse

Deep ML Bias reduced

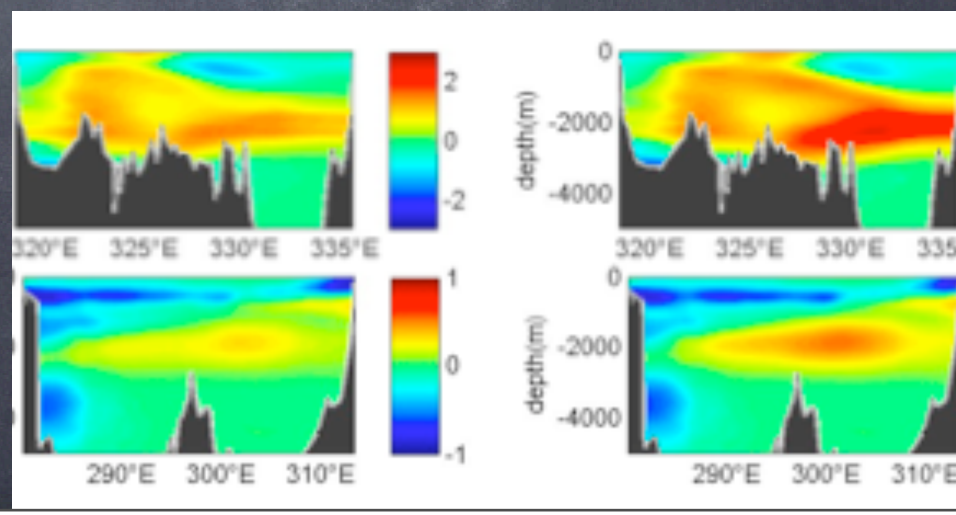
Bias w/o MLE

NO RETUNING NEEDED!!!

Improves CFCs (water masses)

Bias with MLE

Bias w/o MLE

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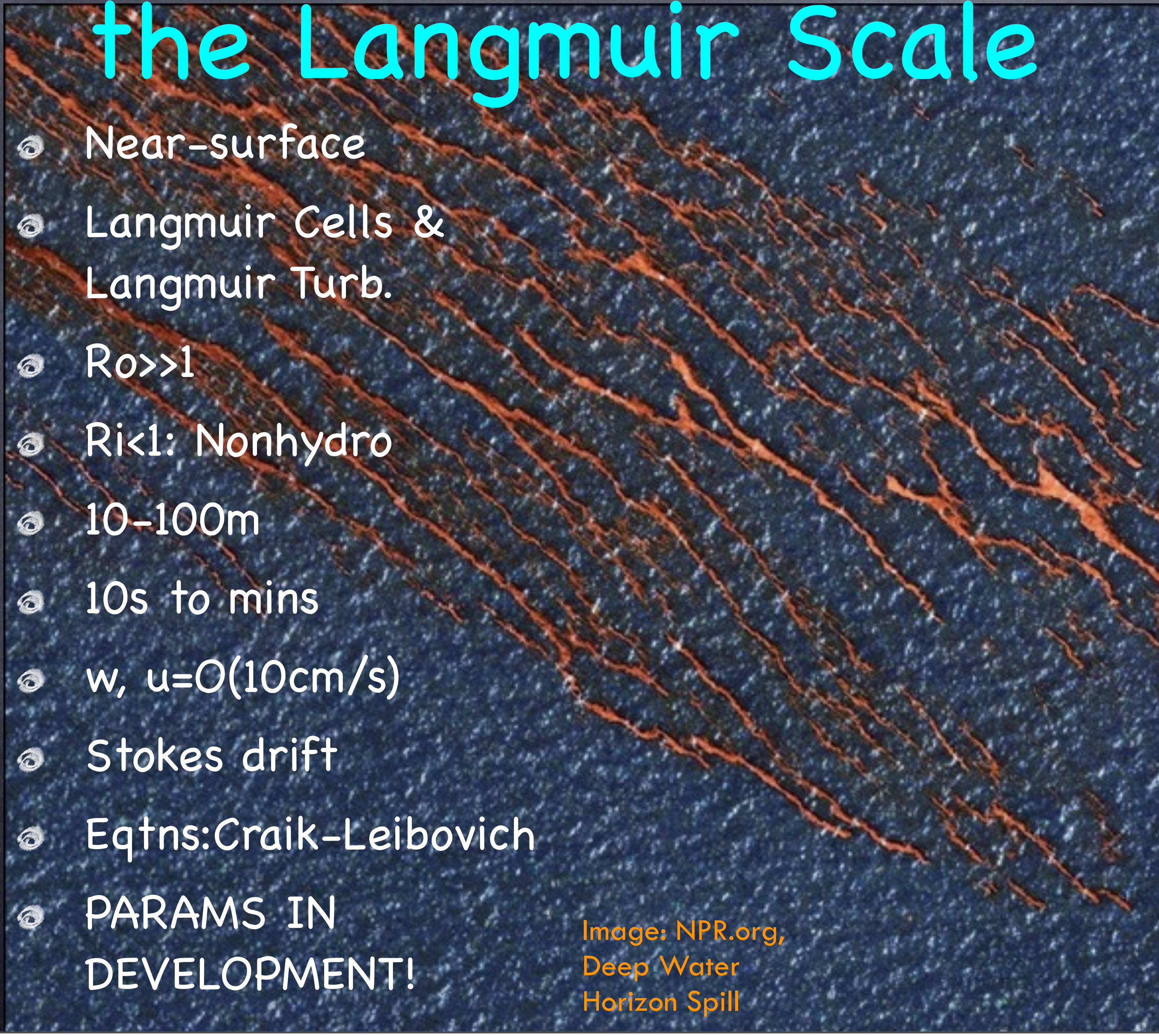
# The Character of the Langmuir Scale



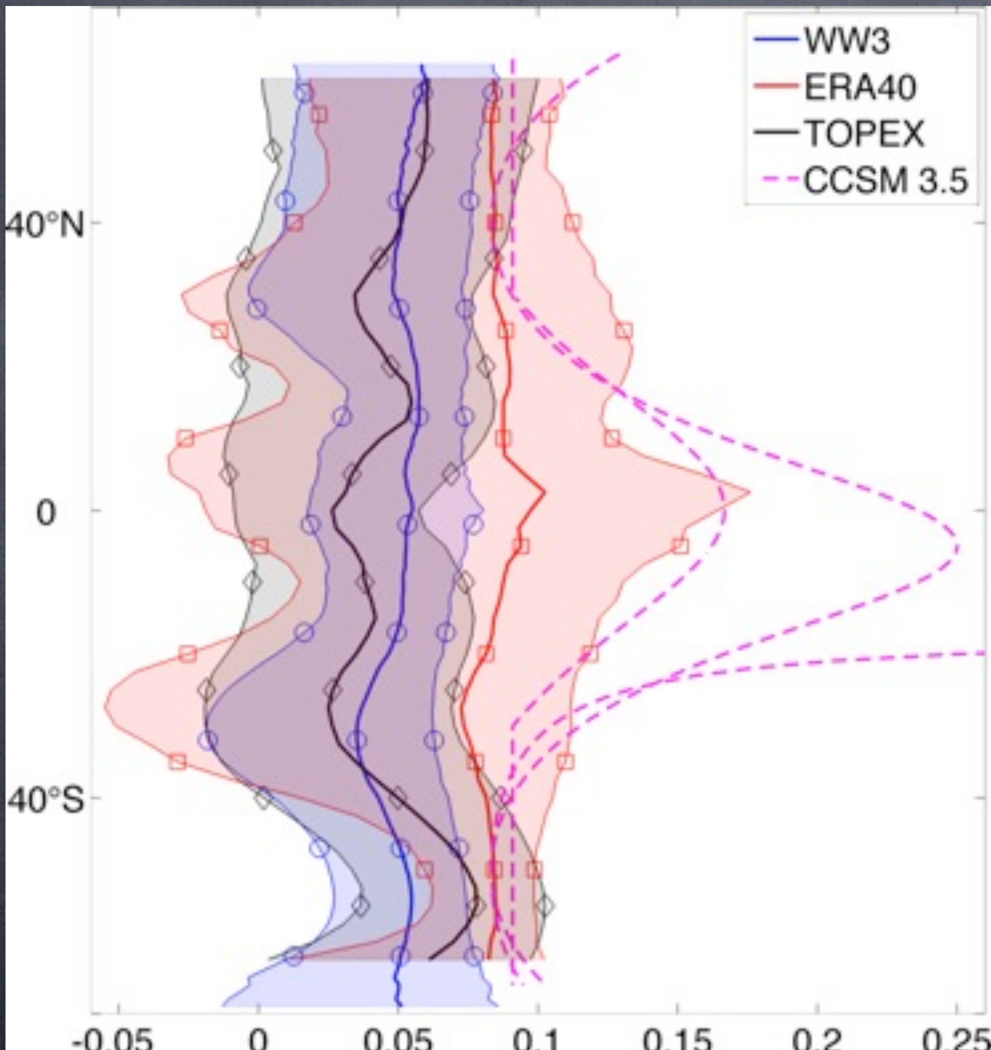
- Near-surface
- Langmuir Cells & Langmuir Turb.
- Ro>>1
- Ri<1: Nonhydro
- 10-100m
- 10s to mins
- w, u=O(10cm/s)
- Stokes drift
- Eqtns:Craik-Leibovich
- PARAMS IN DEVELOPMENT!

Image: NPR.org, Deep Water Horizon Spill

*Figure 1a* Illustration of Langmuir circulations showing notation used in this review and surface and subsurface motions.

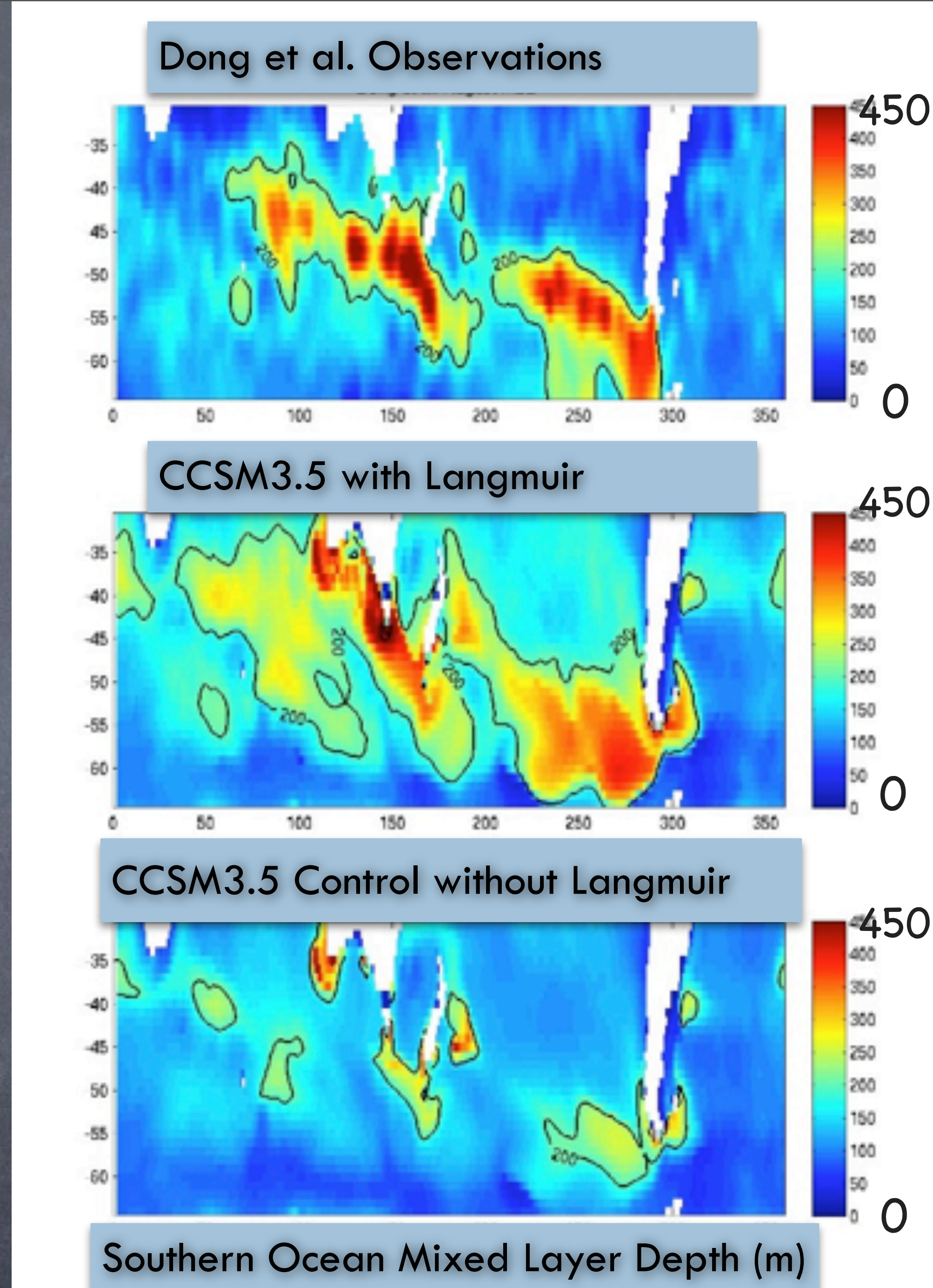
image: Leibovich, 83

# Langmuir Mixing Estimate from Climatology (Wind->Wave)



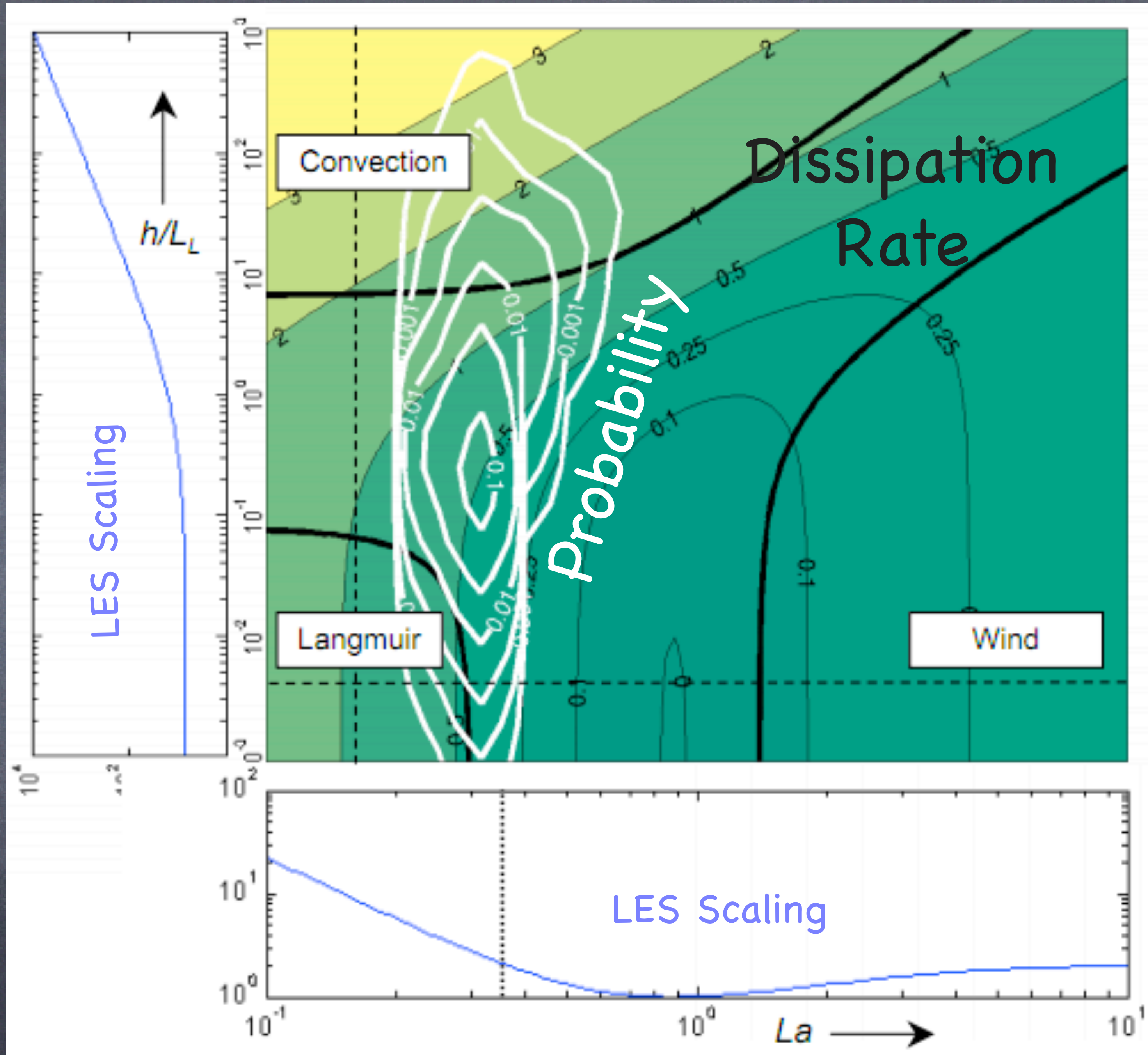

La²

UNDERESTIMATES WAVE IMPACT




Crude estimate of the effect of Langmuir mixing in a forward ESM on MLD (m)

Data + LES, Southern Ocean mixing energy: Langmuir (Stokes-drift-driven) and Convective



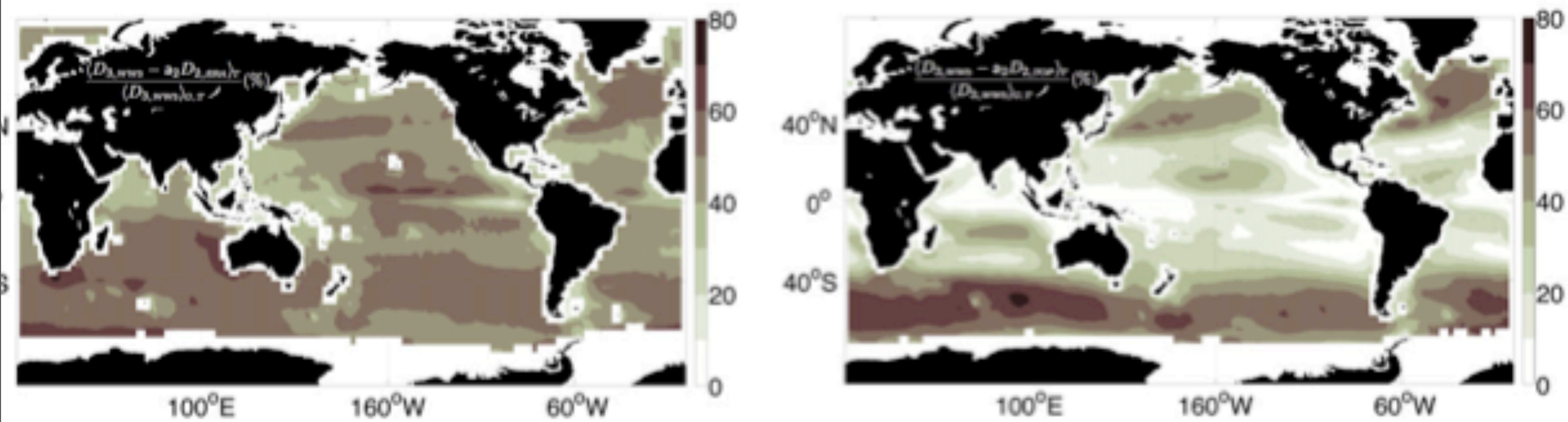

But, how well do we know Stokes drift? (Turb. Lang. #=La $= u^*/u_s$)

S.E. Belcher, A.A.L.M. Grant, K.E. Hanley, B. Fox-Kemper, L. Van Roekel, P.P. Sullivan, W.G. Large, A. Brown, A. Hines, D. Calvert, A. Rutgersson, H. Petterson, J. Bidlot, P.A.E.M. Janssen, and J.A. Polton. A global perspective on mixing in the ocean surface boundary layer. *Geophysical Research Letters*, 2011. In revision.

# How well do we know Stokes Drift?

Reanalysis vs wave model

Altimetry vs wave model




(e) $\langle D_{3,WW3} - a_2 D_{2,ERA}\rangle_T / \langle D_{3,WW3}\rangle_{G,T}$ (%)

(f) $\langle D_{3,WW3} - a_2 D_{2,TOP}\rangle_T / \langle D_{3,WW3}\rangle_{G,T}$ (%)

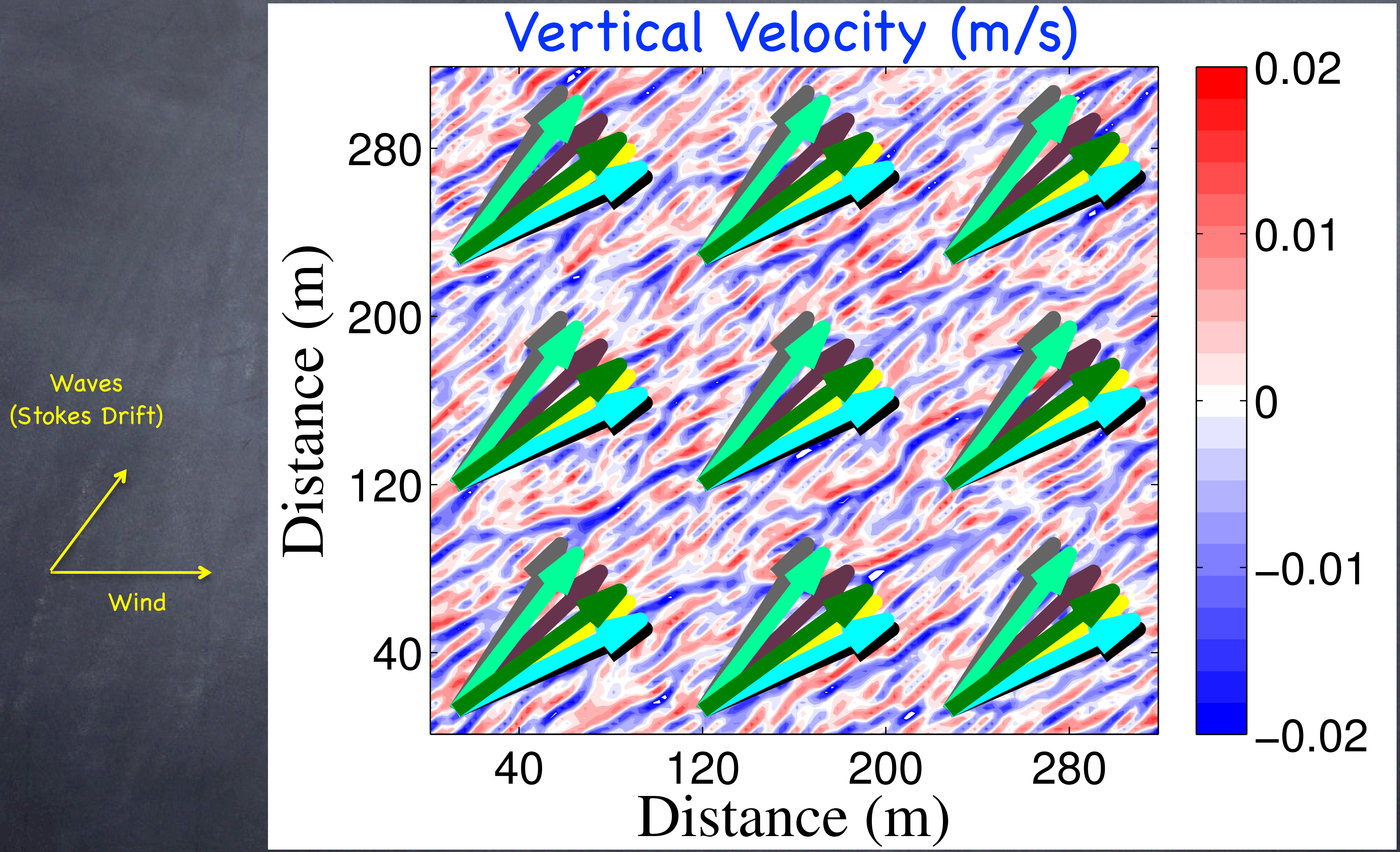
**Fig. 4.** $D_2$ Comparison of ERA40 reanalysis and TOPEX satellite data with WW3 using eight year means (1994–2001).

## Within a factor of 2.

Assuming full-development (e.g., McWilliams & Restrepo, 1999) is worse

A. Webb and B. Fox-Kemper. Wave spectral moments and Stokes drift estimation. *Ocean Modelling*, 40(3-4): 273-288, 2011

# Real World Forcing: Misaligned Wind & Waves

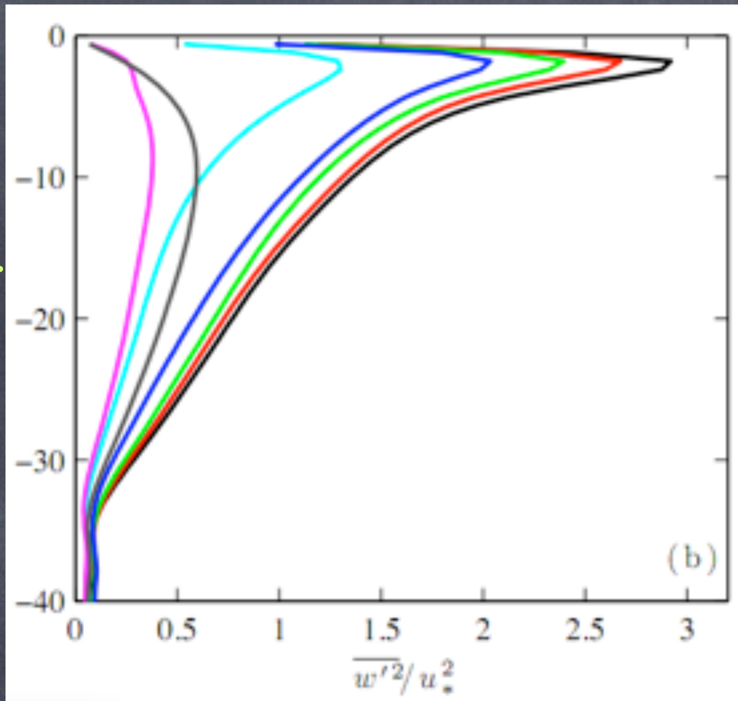



L. Van Roekel, B. Fox-Kemper, P. P. Sullivan, P. E. Hamlington, and S. R. Haney. The form and orientation of Langmuir cells for misaligned winds and waves. *Journal of Geophysical Research-Oceans*, 2012. Submitted.

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

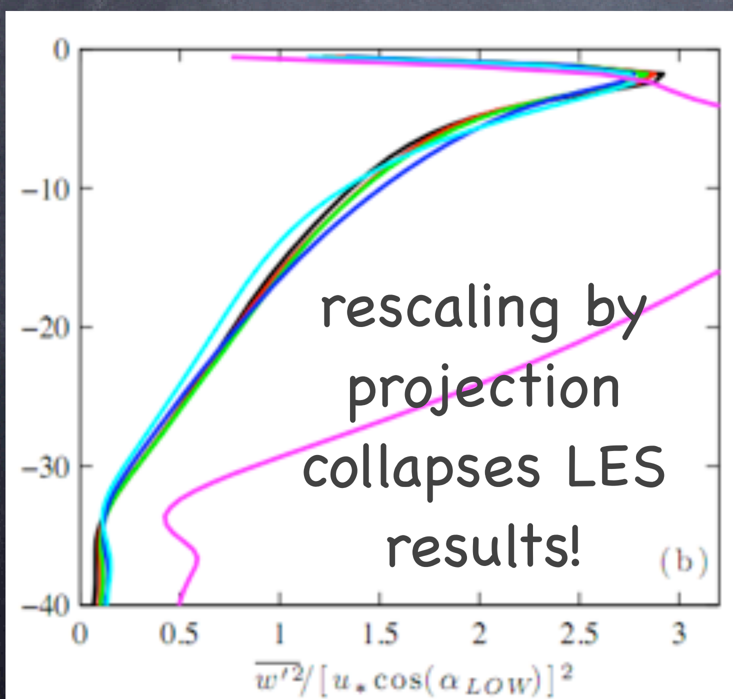
<$w^2$>

depth




rescaled <$w^2$>

depth




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

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

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

# A theory for LC direction!

L. 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*, 2012. Submitted.

# Wind and wave forced, dying submeso filament

$$\overline{Ro} \approx 0.1$$

$$\overline{Ri} < 1$$

$$La_t \approx 0.3$$

Computational parameters:
Domain size: 20km x 20km x -160m
Grid points: 4096 x 4096 x 128
Resolution: 5m x 5m x -1.25m

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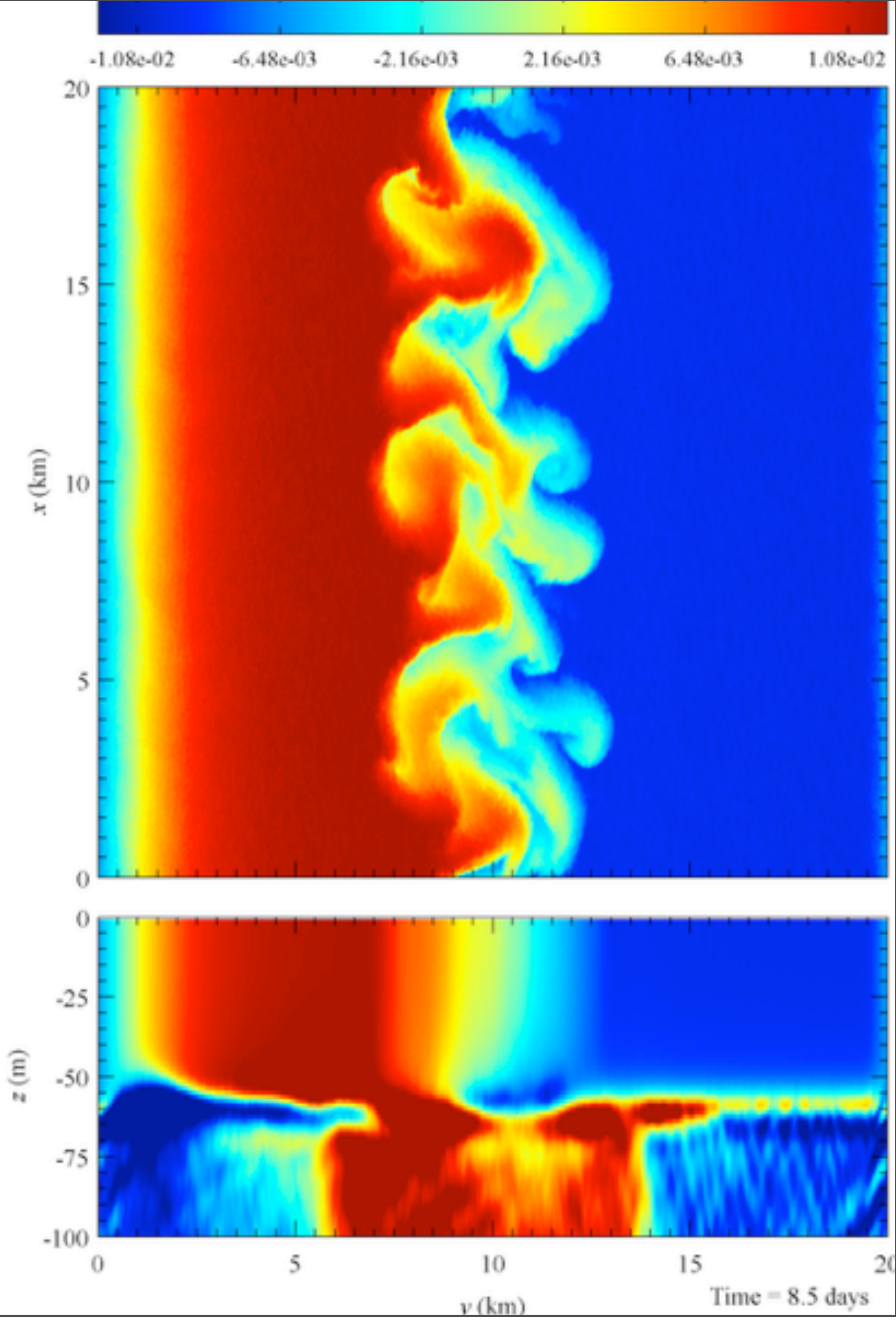

# Coupling between Langmuir and Submeso?

Wind Only

Stokes & Wind

2 runs:
Both spindown of submesoscale filament

Right -->
Stokes & Wind

<-- Left
Wind Only

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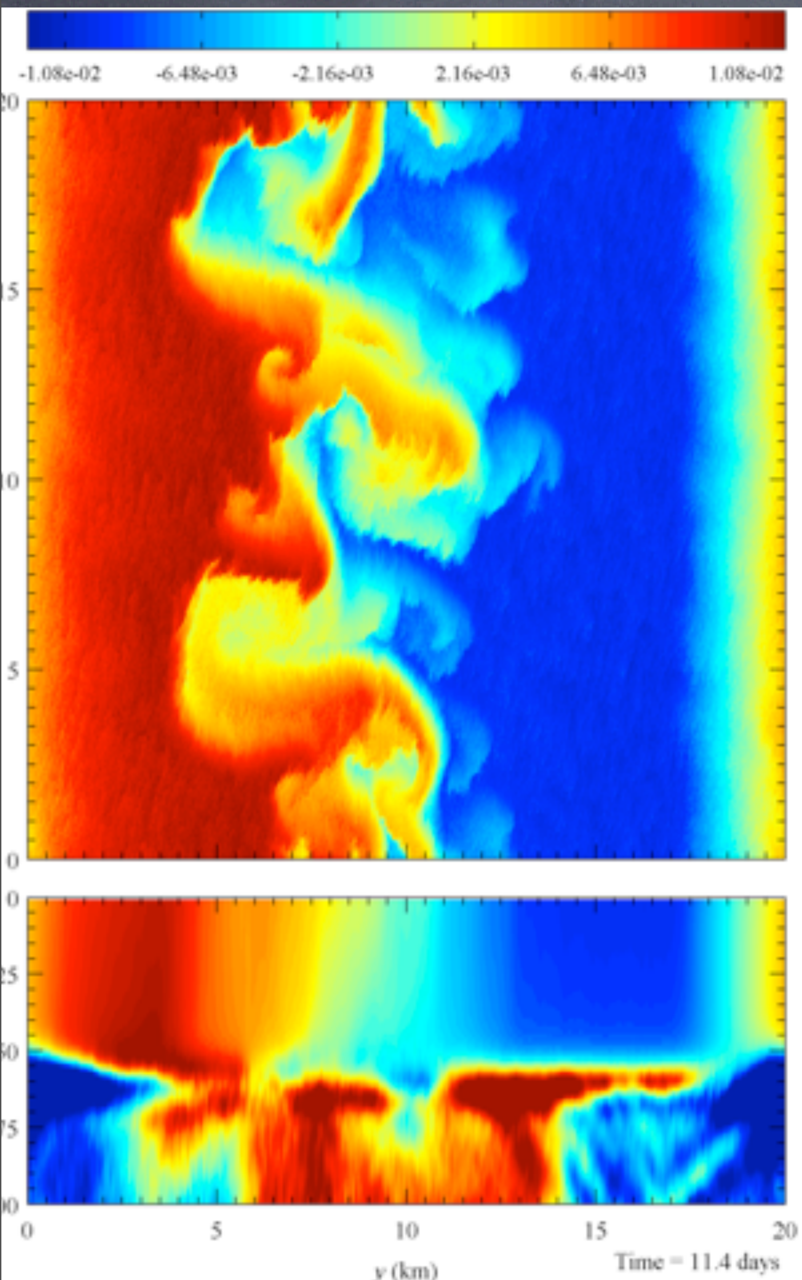


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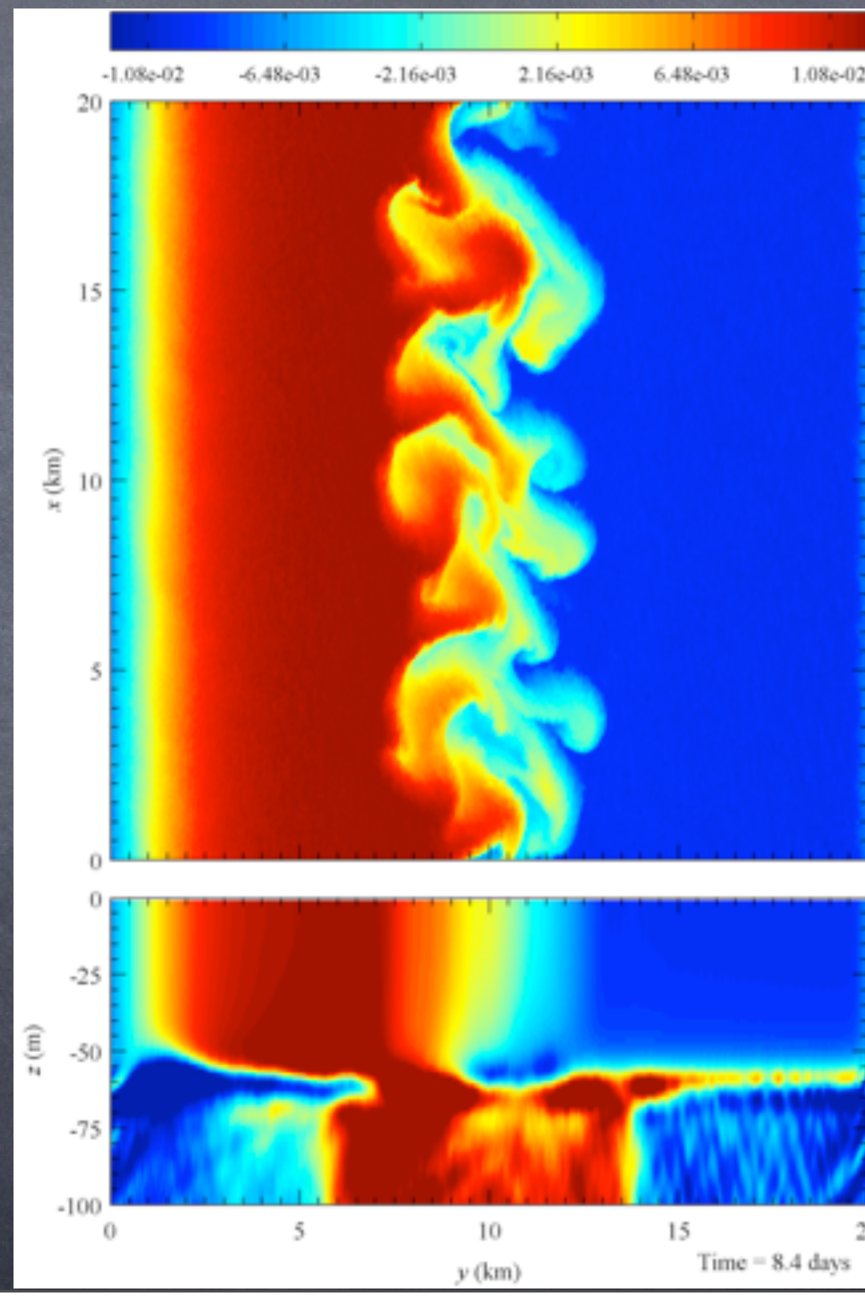

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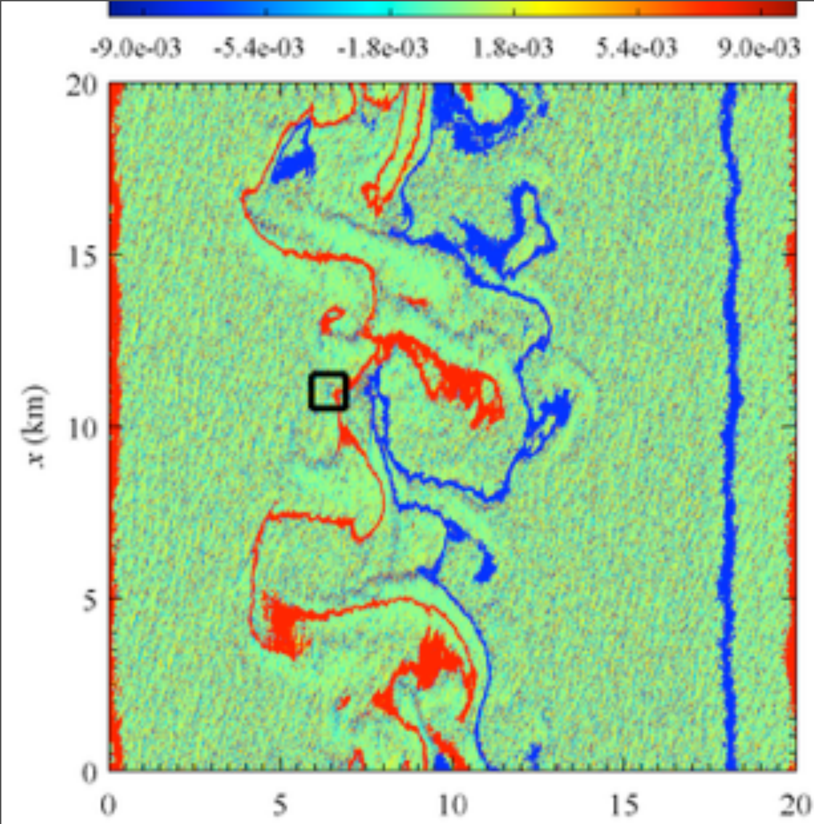


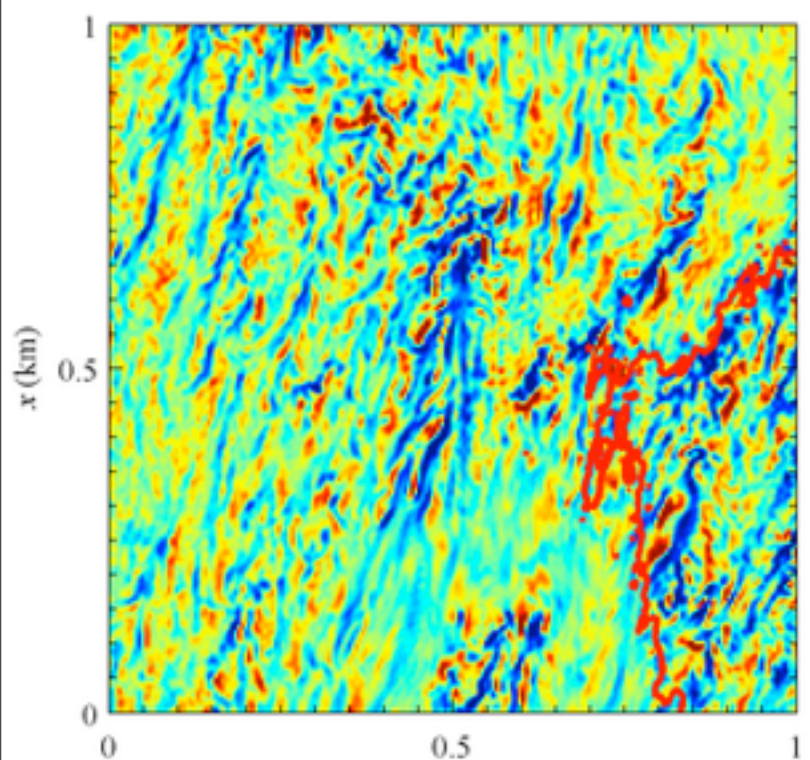


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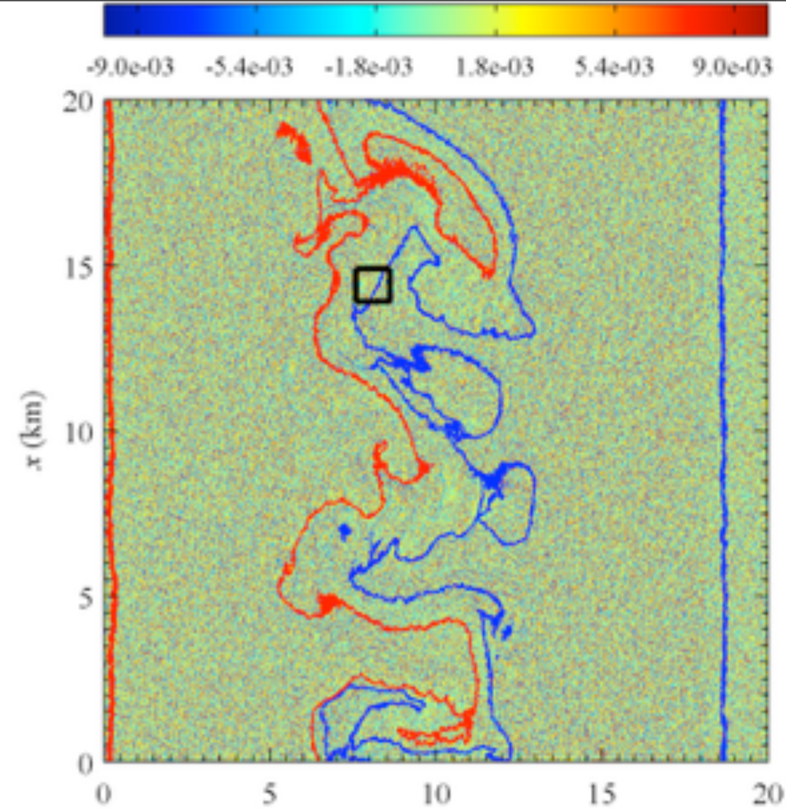
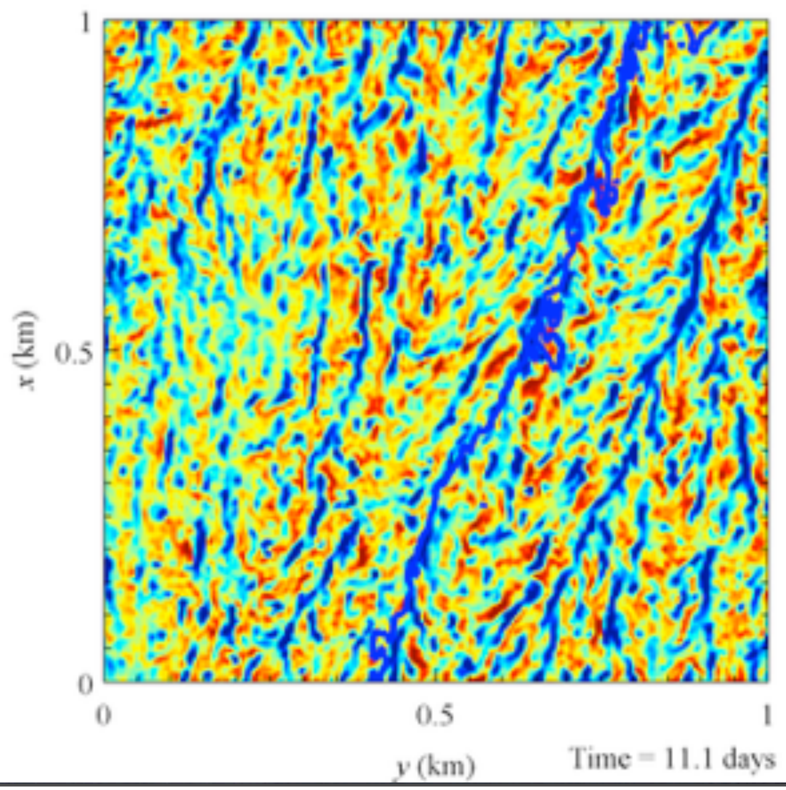
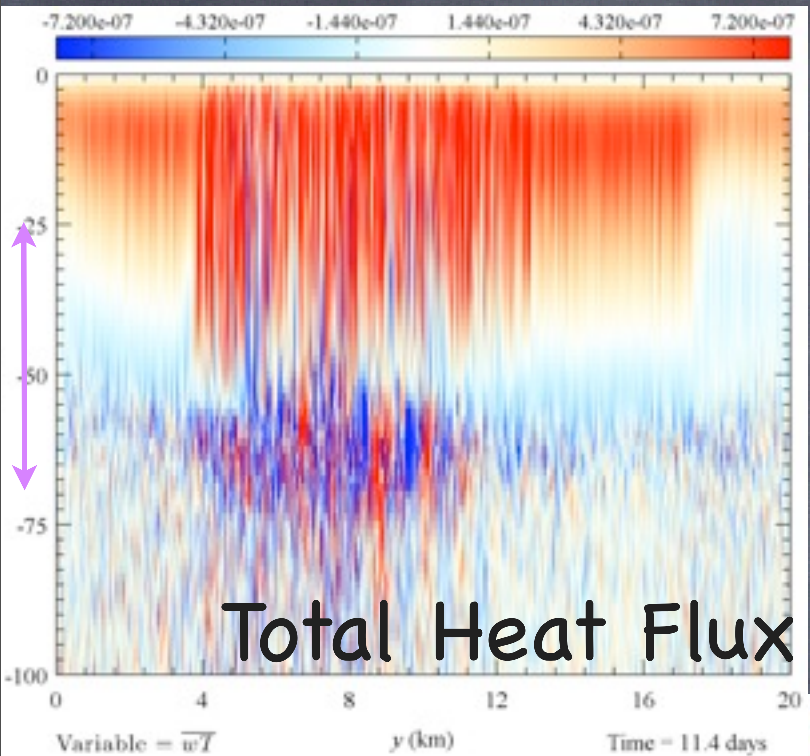
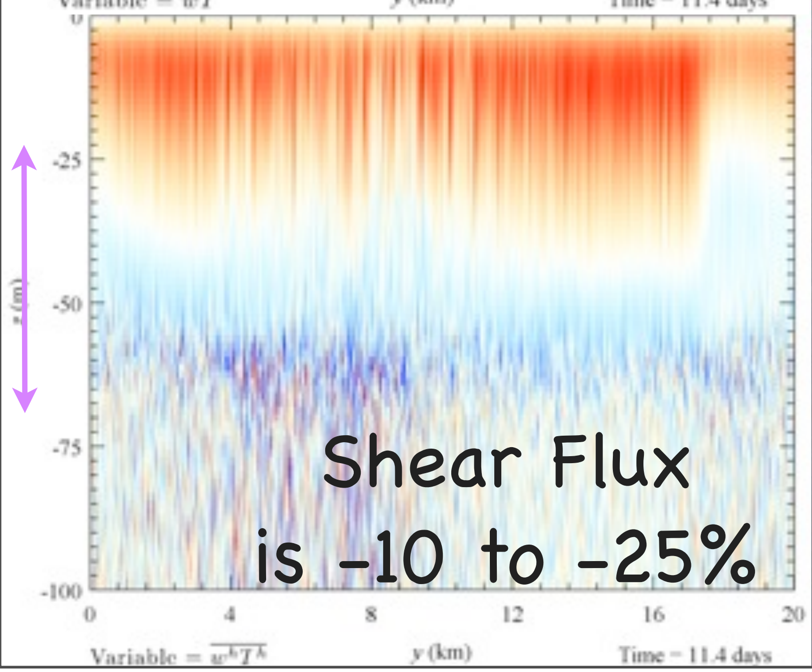


# Heat <wT>.  Upper=Total, Lower=small-scales only

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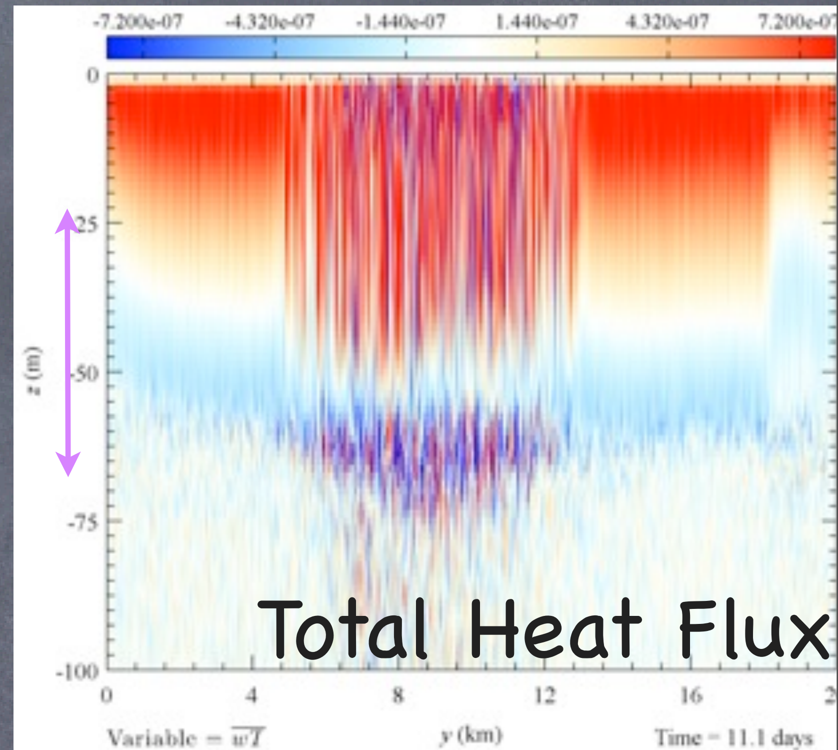
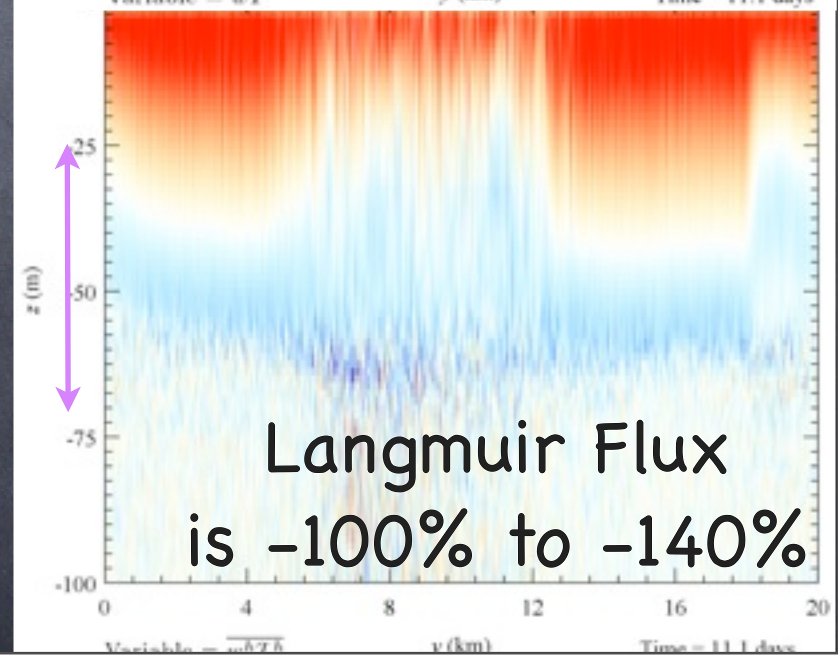
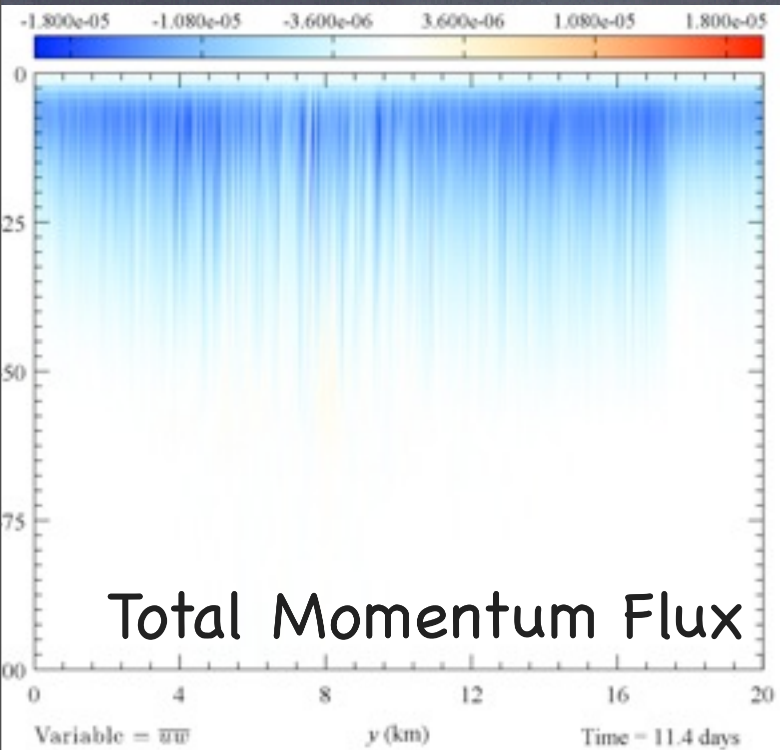
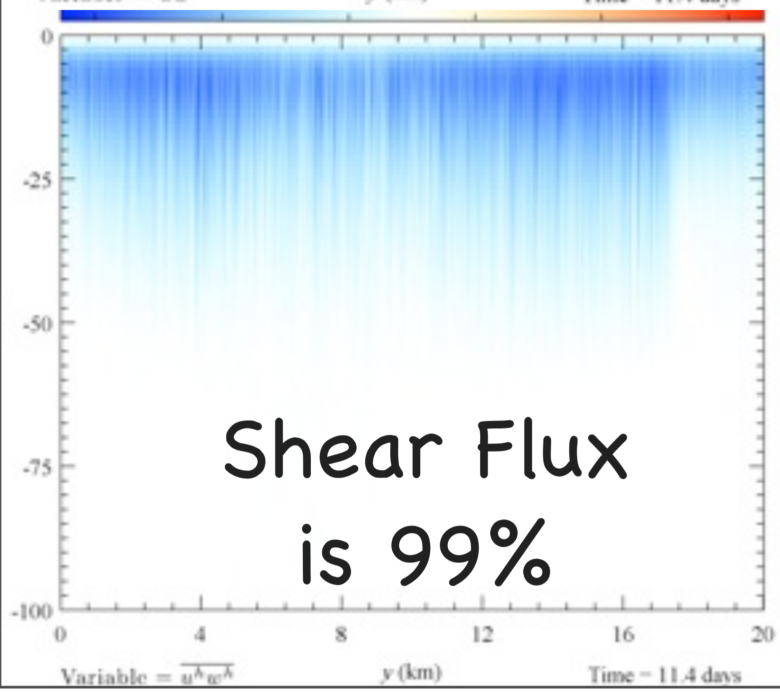


# Momentum: <uw>. Upper=Total, Lower=small-scales

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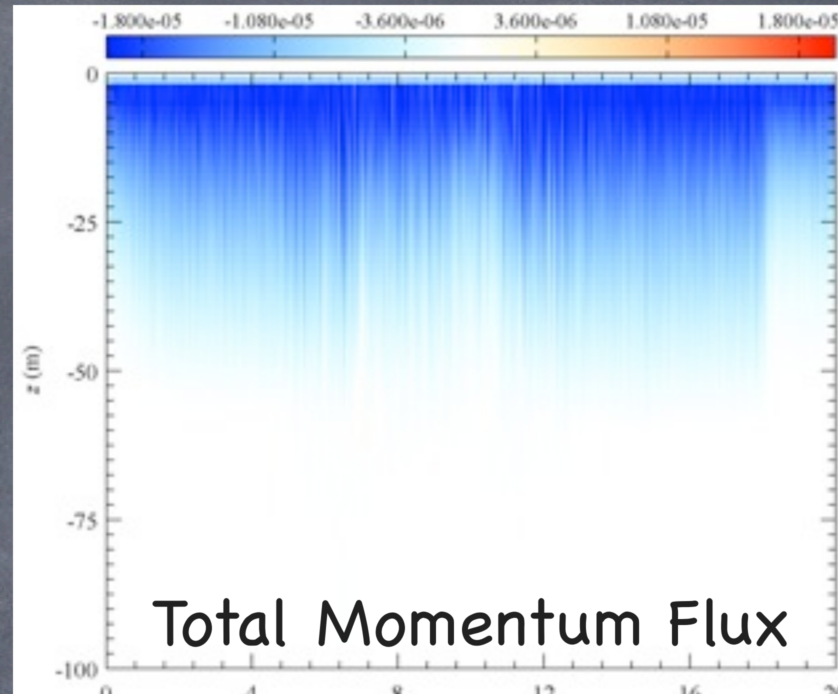


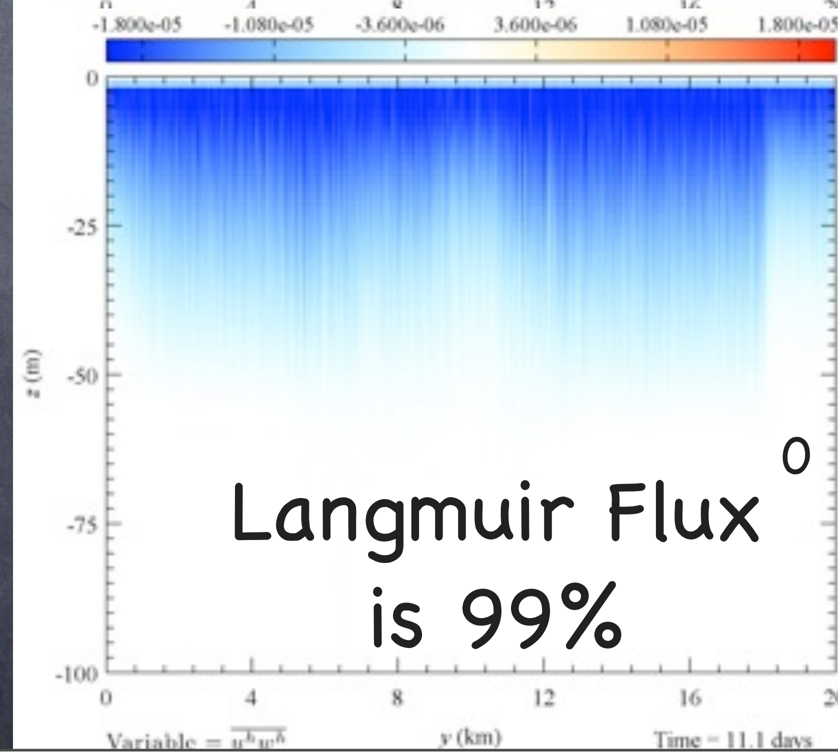

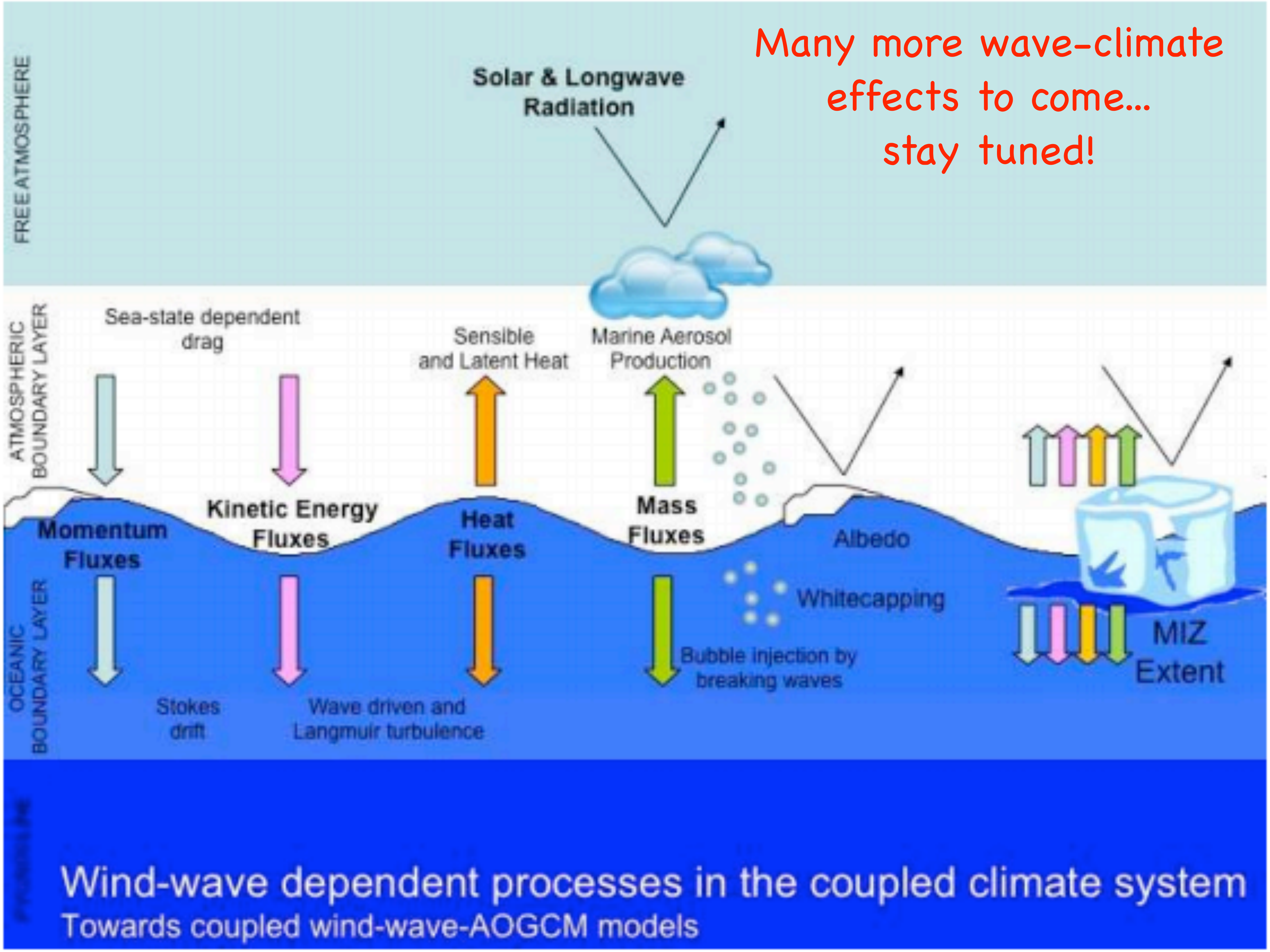


L. Cavaleri, B. Fox-Kemper, and M. Hemer. Wind waves in the coupled climate system. *Bulletin of the American Meteorological Society*, 2012. Accepted.

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# All papers at: fox-kemper.com/research


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.

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If you want to know about the symmetric tensor, see Scott Bachman's Poster!

$$\overline{\mathbf{u}'b'} = \mathbf{R}\nabla\bar{b}$$

$$\mathbf{R} = \mathbf{S} + \mathbf{A} = \begin{bmatrix} \kappa & \kappa S - \psi \\ \kappa S + \psi & \kappa S^2 \end{bmatrix}$$

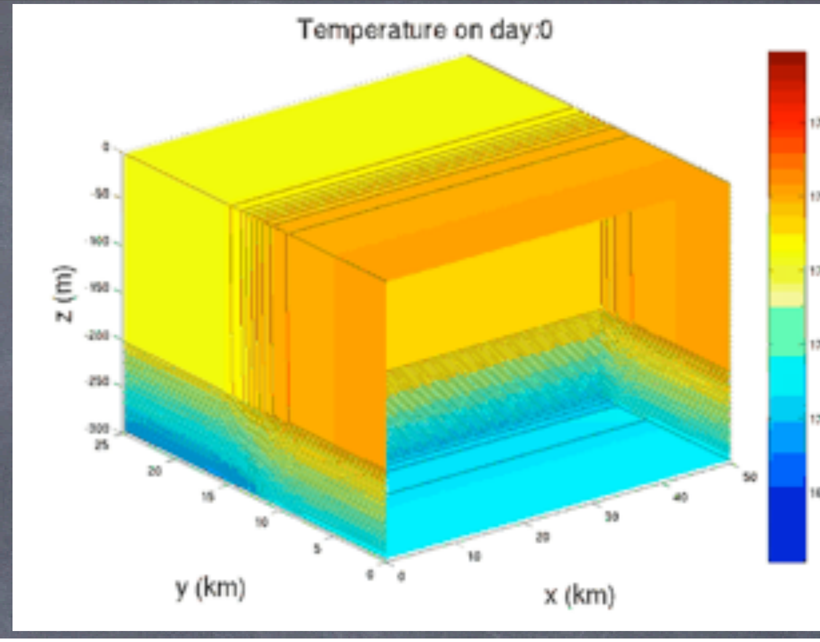
# Mixed Layer Eddy Restratification

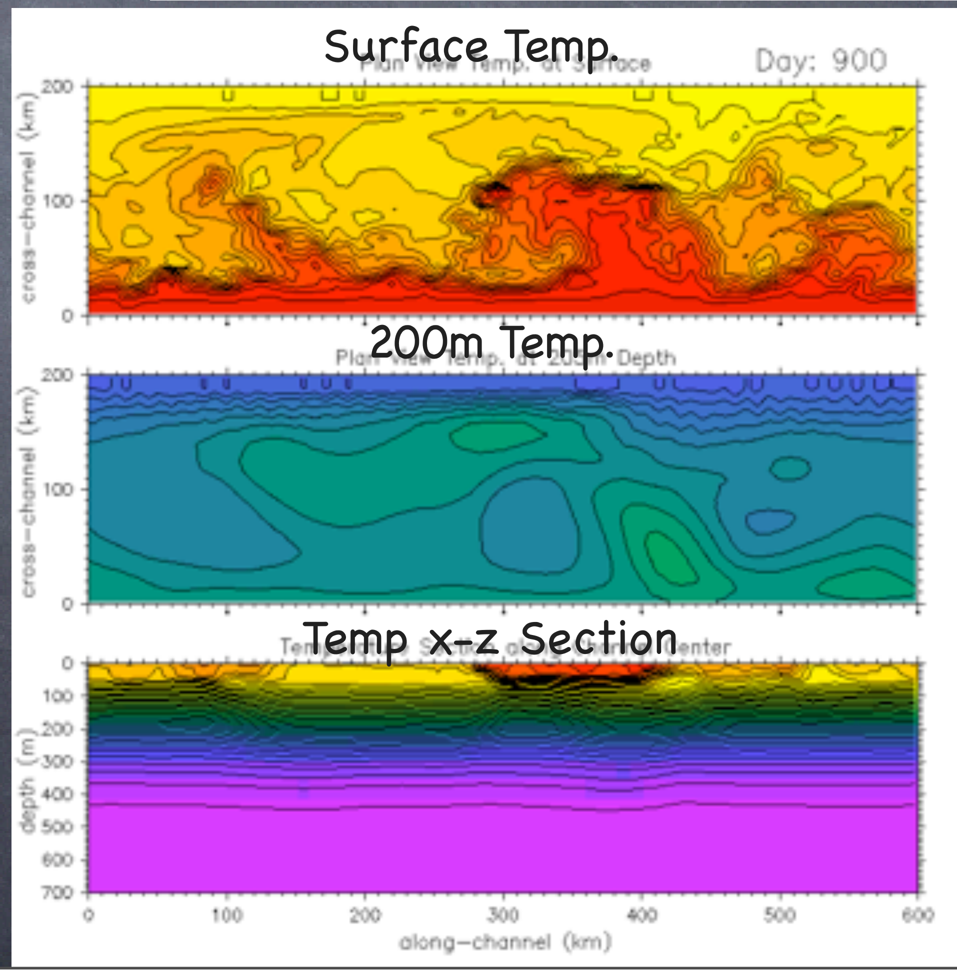
Estimating eddy buoyancy/density fluxes:

$$\overline{\mathbf{u}'b'} \equiv \mathbf{\Psi} \times \nabla\bar{b}$$

A submeso eddy-induced overturning:

$$\mathbf{\Psi} = \frac{C_e H^2 \mu(z)}{|f|} \nabla\bar{b} \times \hat{\mathbf{z}}$$



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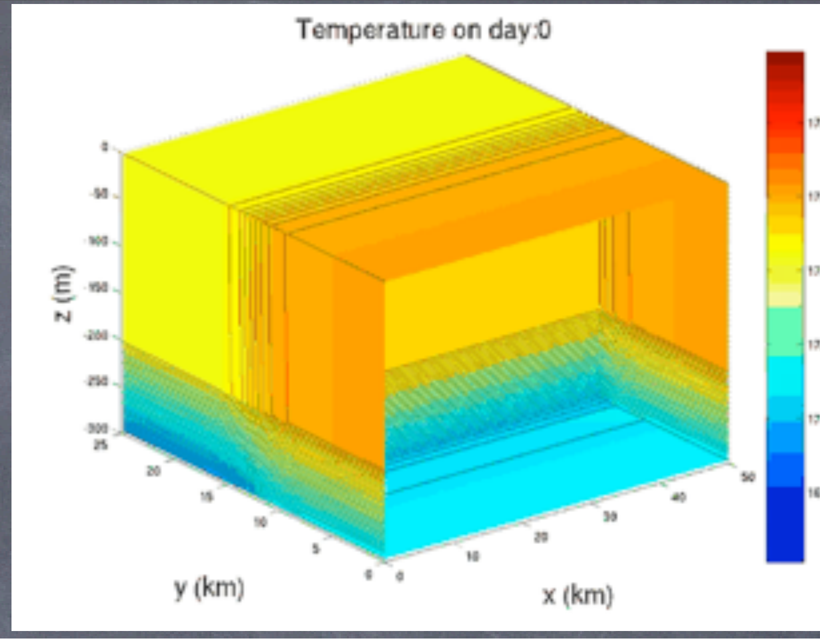
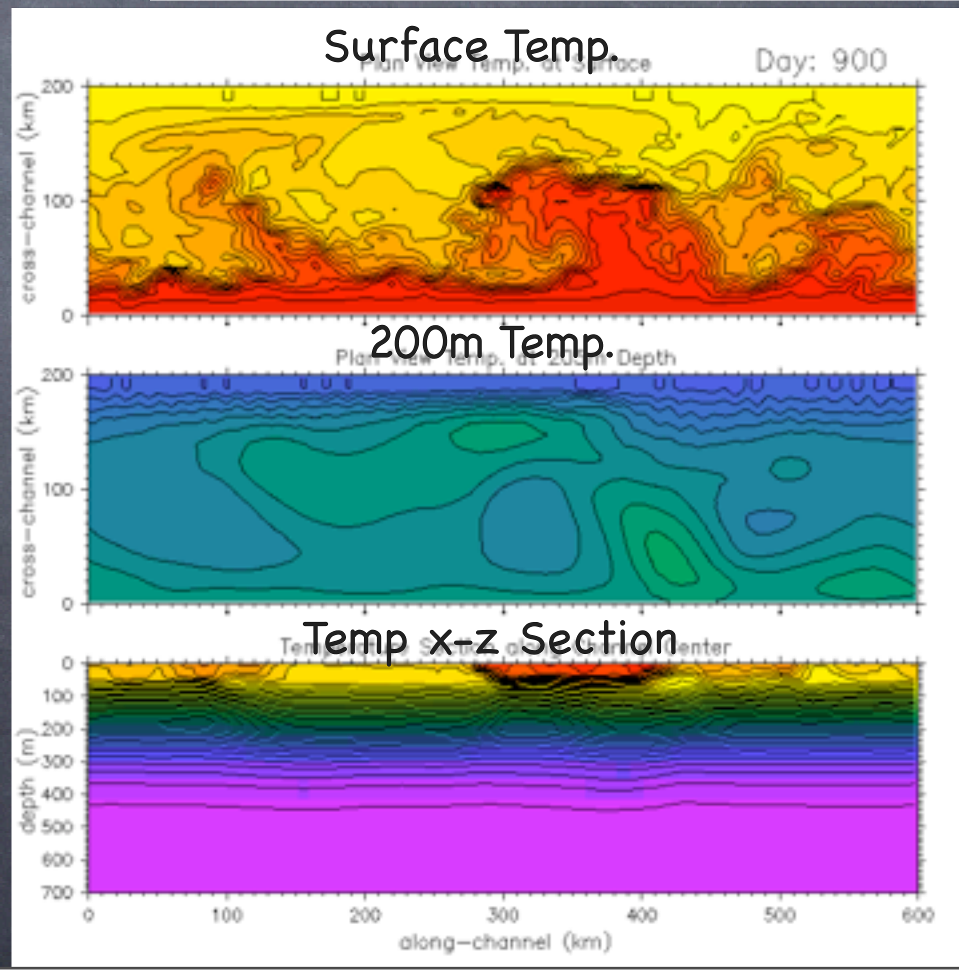
in ML only:

$$\mu(z) = 0 \text{ if } z < -H$$



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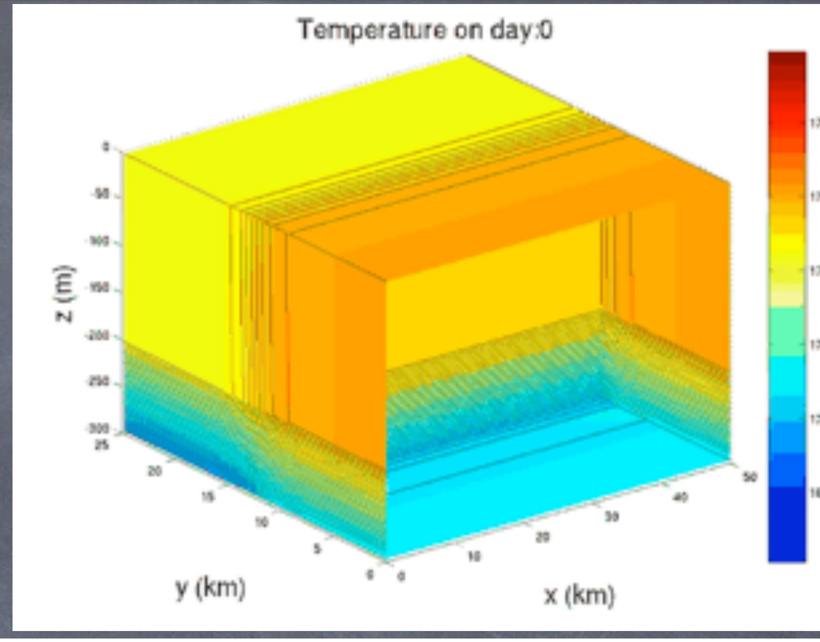
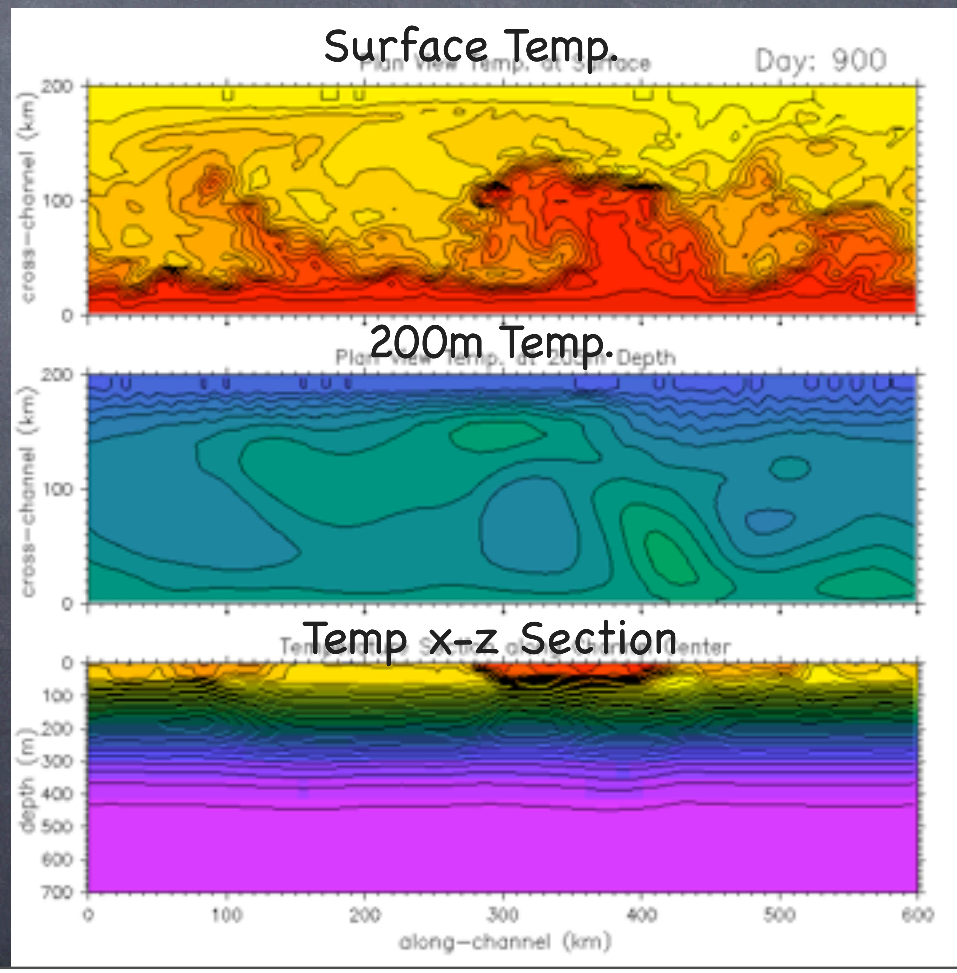
For a consistently restratifying,

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



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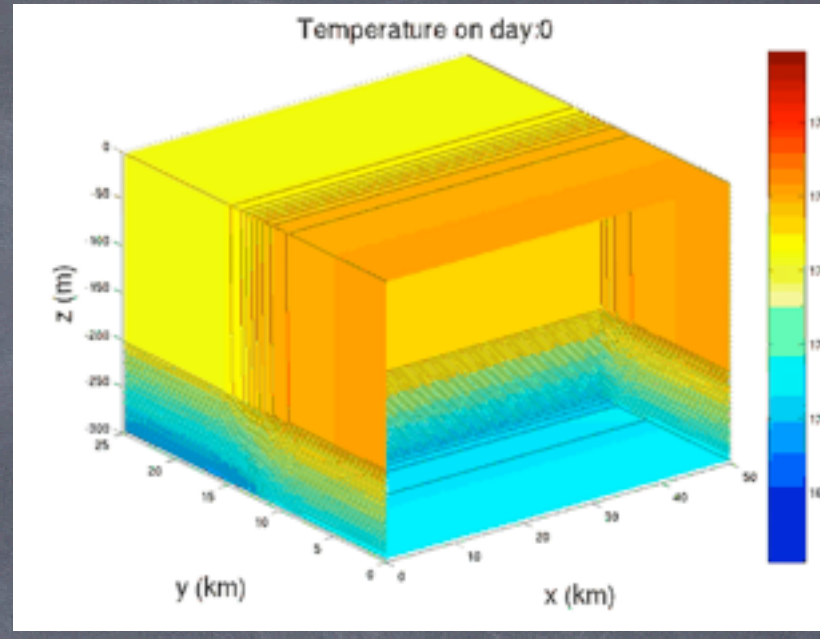
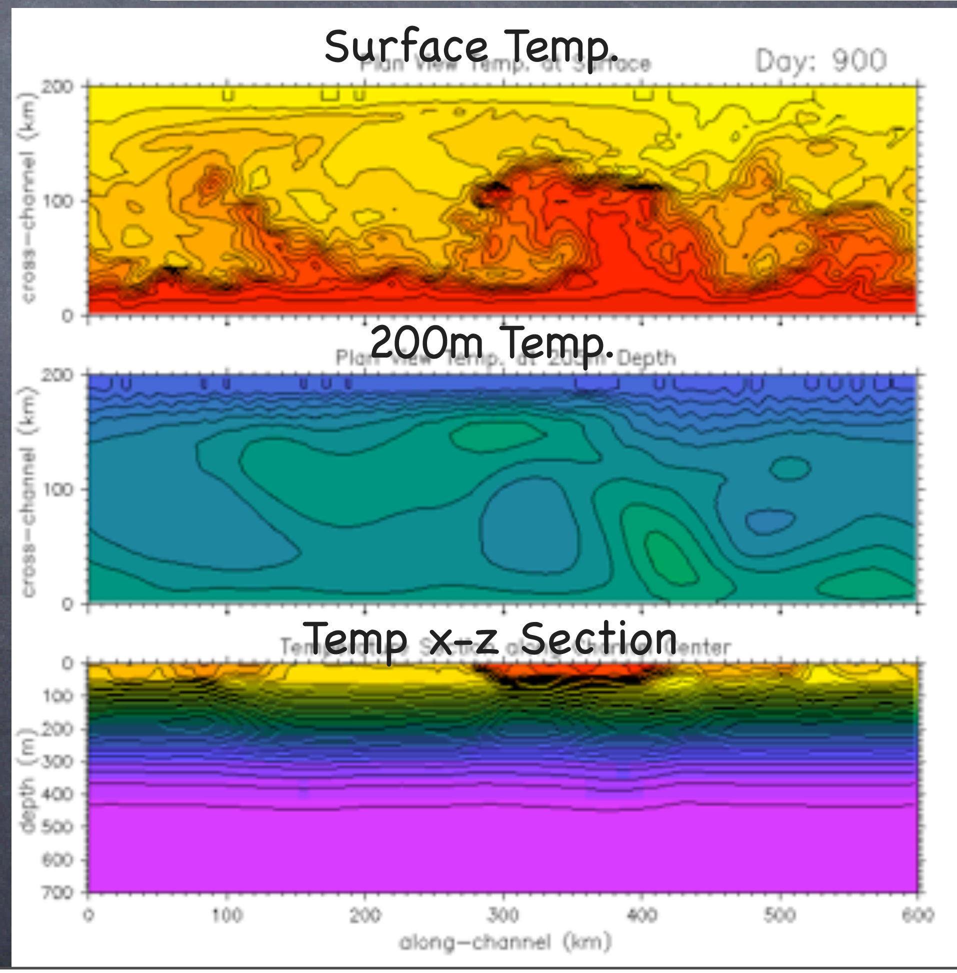
For a consistently restratifying,

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

and horizontally downgradient flux.

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



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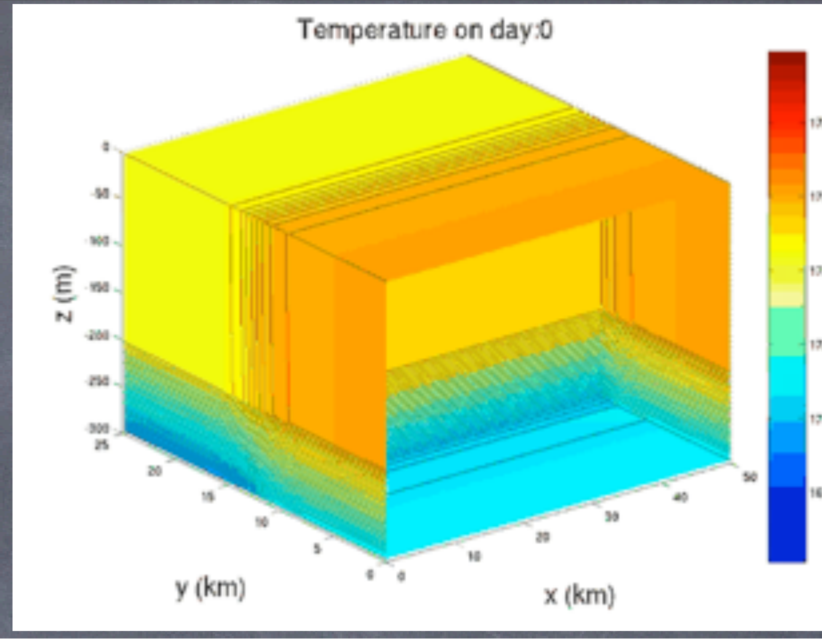
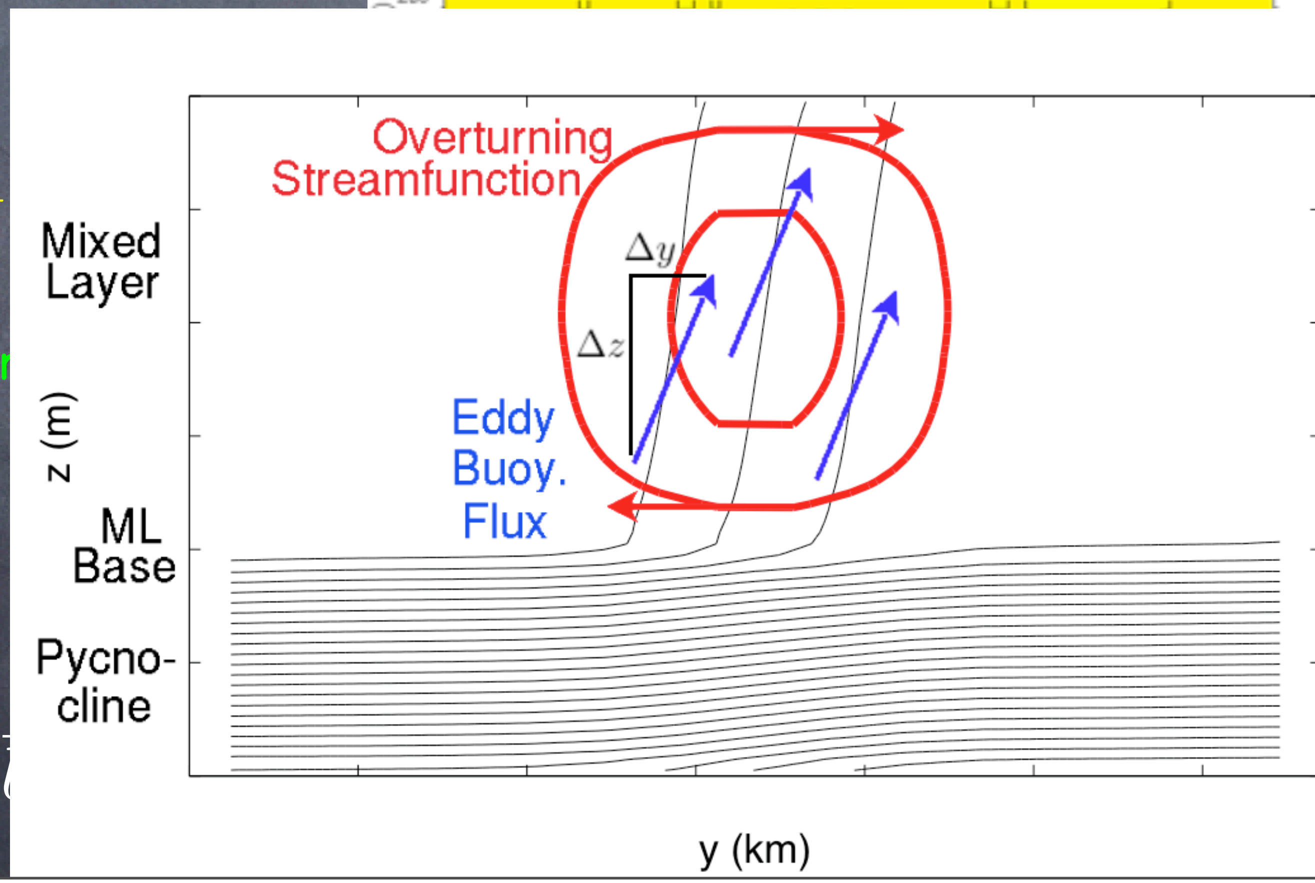






# Sensitivity of Climate to Submeso: AMOC & Cryosphere Impacts

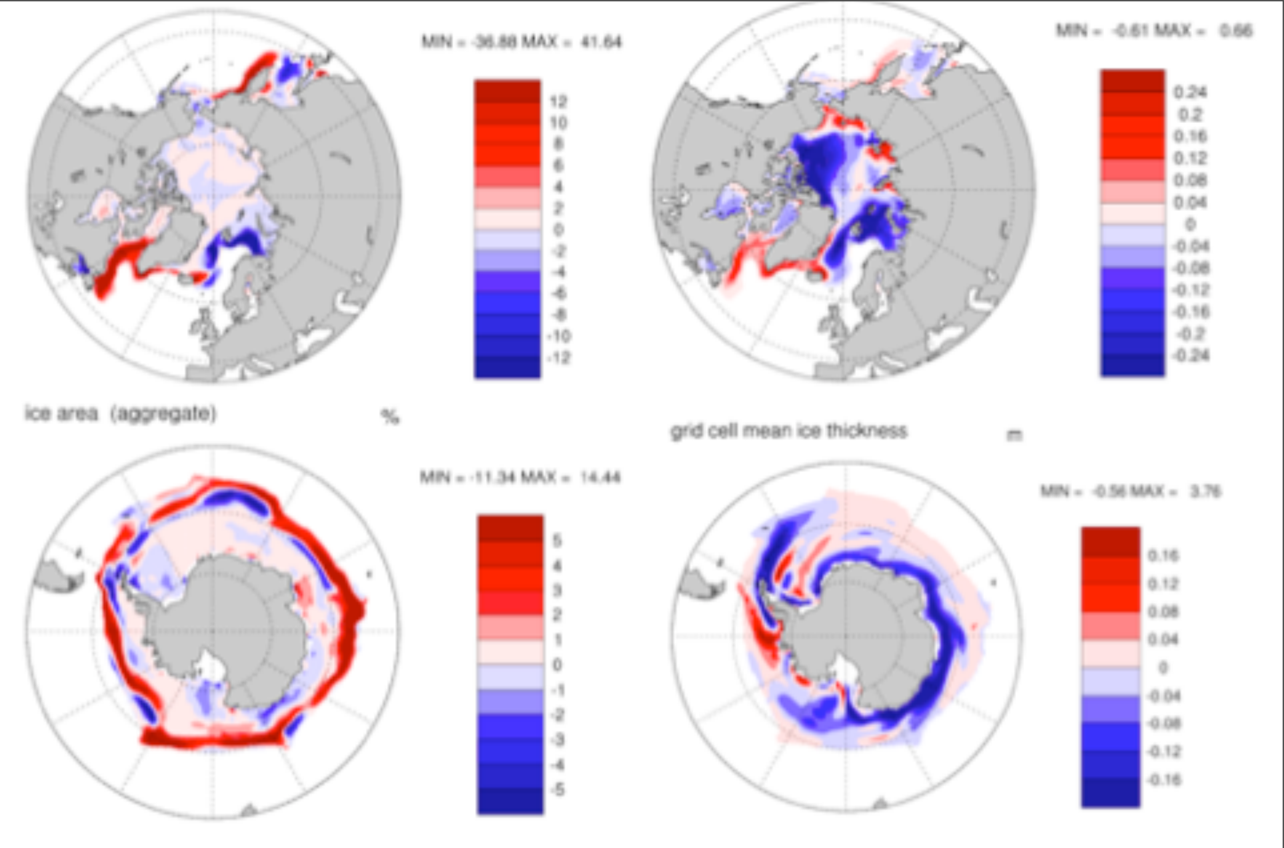
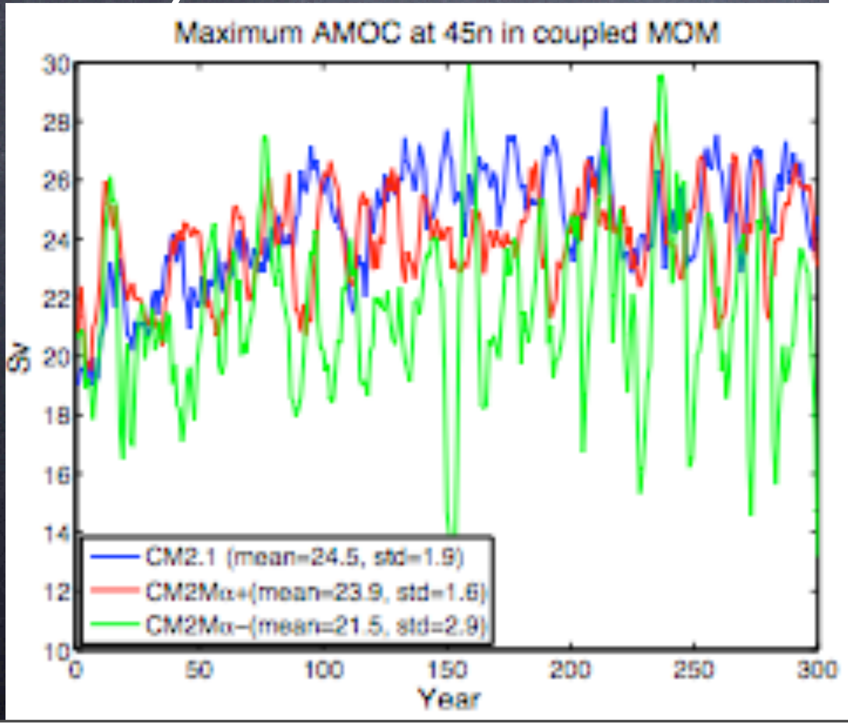



Figure 10: Wintertime sea ice sensitivity to introduction of MLE parameterization ($CCSM^+$ minus $CCSM^-$): January to March Northern Hemisphere a) ice area and b) thickness and July to September Southern Hemisphere c) ice area and d) thickness.

May Stabilize AMOC




Affects sea ice

NO RETUNING NEEDED!!!

These are impacts:
bias change unknown

# Submeso Param. in Data?

Submesoscale activity over the Argentinian shelf
X Capet, EJ Campos, AM Paiva - Geophysical Research Letters, 2008

Impact of atmospheric coastal jet off central Chile on sea surface temperature from satellite observations (2000–2007),
L Renault, B Dewitte, M Falvey, R Garreaud… - J. Geophys. Res, 2009

Interactions between a Submesoscale Anticyclonic Vortex and a Front*
C Chavanne, P Flament… - Journal of Physical …, 2010

Mixing rates across the Gulf Stream, Part 2: Implications for nonlocal parameterization of vertical fluxes in the surface boundary layers
R Inoue, RR Harcourt… - Journal of Marine …, 2010

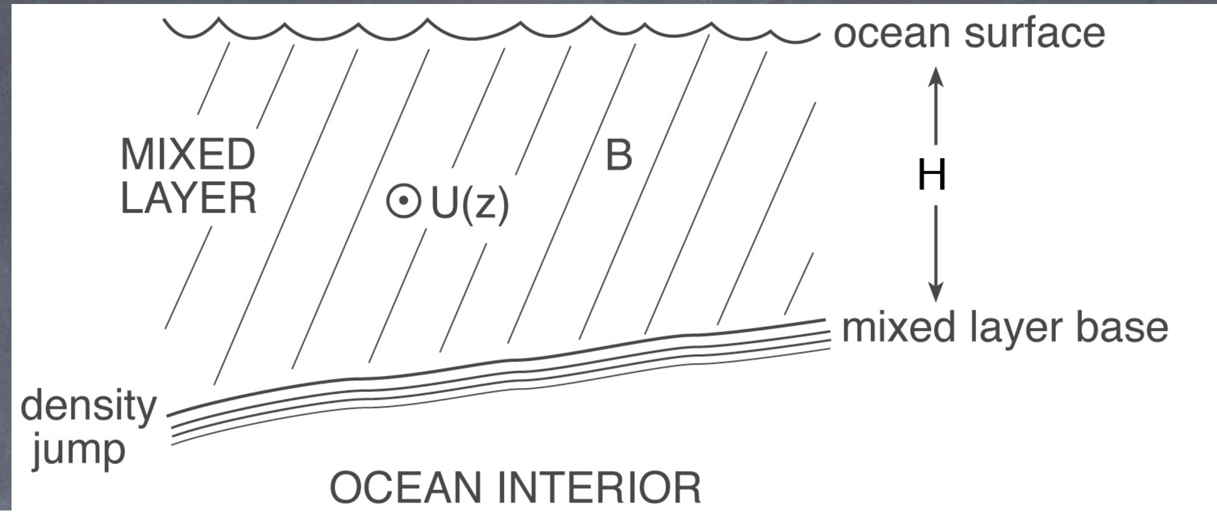
Spatial variability and temporal dynamics of surface water pCO2,[Delta] O2/Ar and dimethylsulfide in the Ross Sea, Antarctica
PD Tortell, C Guéguen, MC Long, CD Payne… - Deep Sea Research …, 2011

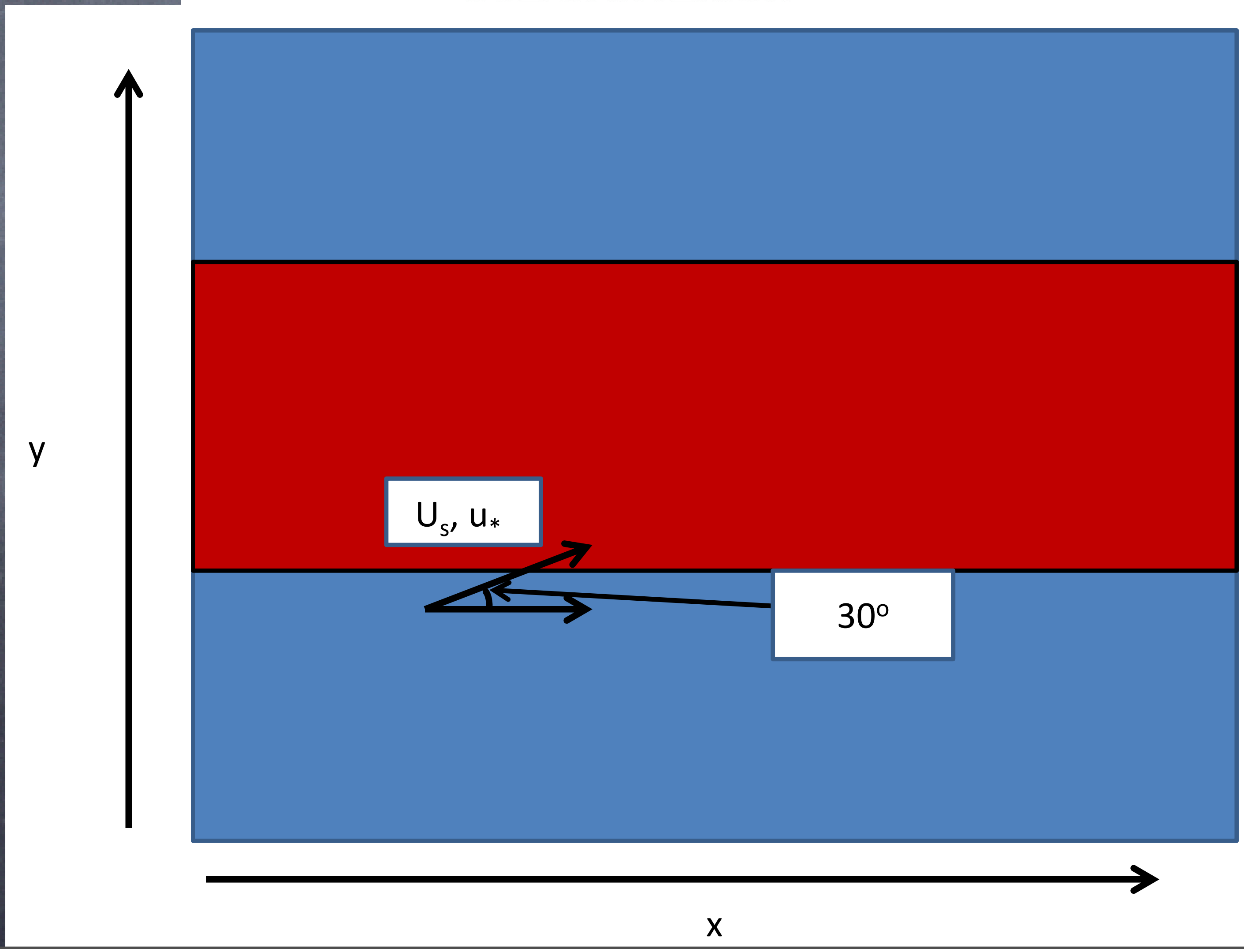
Submesoscale activity over the Argentinian shelf
[PDF] from imarpe.pe
X Capet, EJ Campos, AM Paiva - Geophysical Research Letters, 2008

# Multiscale

- Langmuir & Submeso resolving LES
- 20kmx20kmx0.3km
- Grid 4096x4096x128
- 5x5x<1m resolution
- Compromises--wind, front, wave, size, etc
- Leif tells us how the winds wil

km



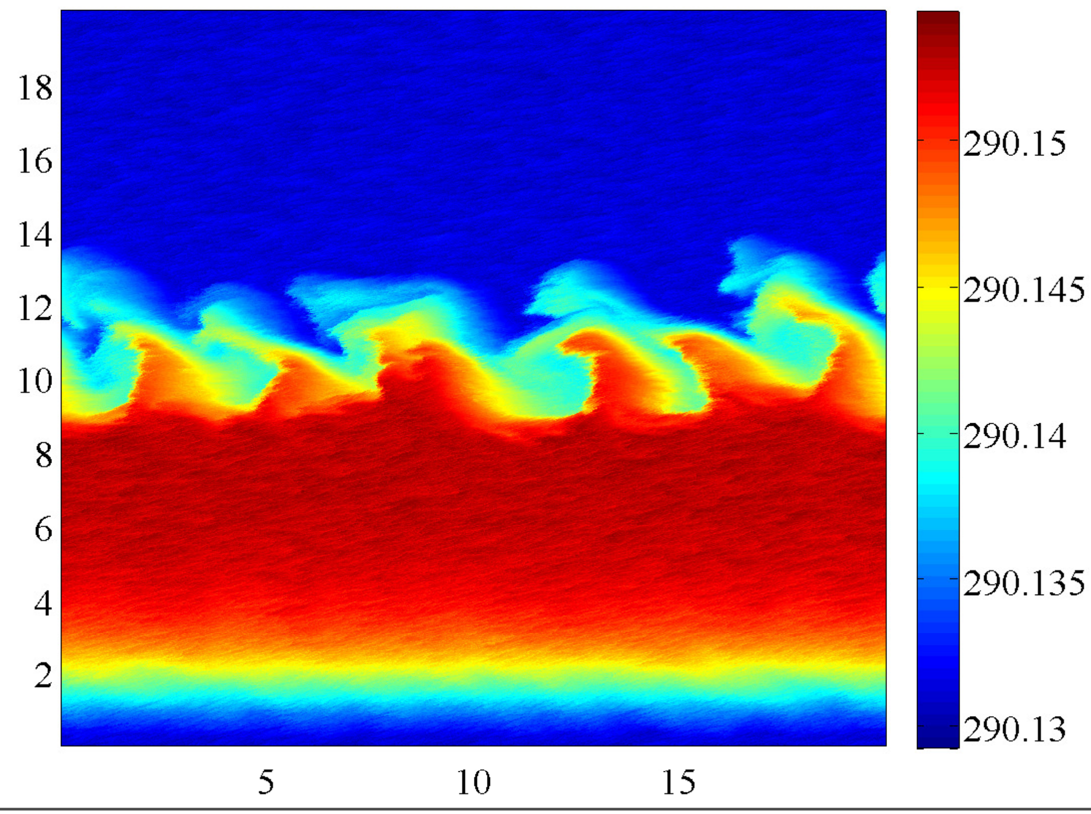



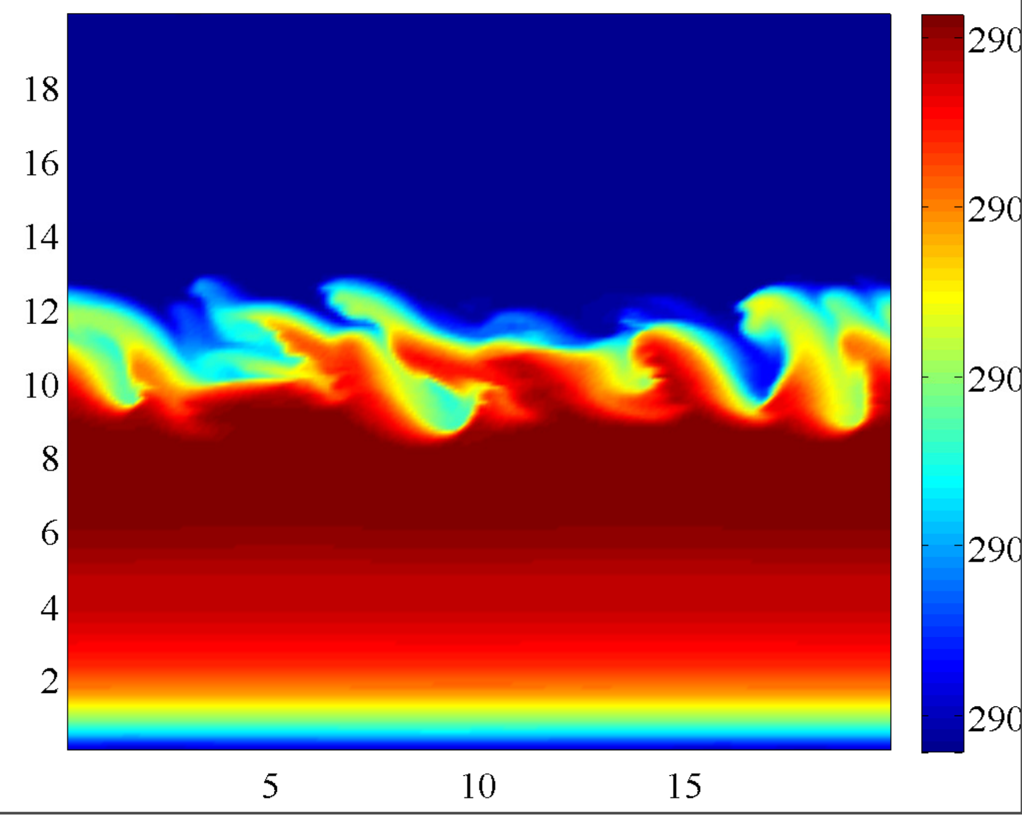
# Coupling Langmuir to Submesoscale?

From Scratch... No interpolation!

LES, Near-Surf. Temp. No Stokes Drift

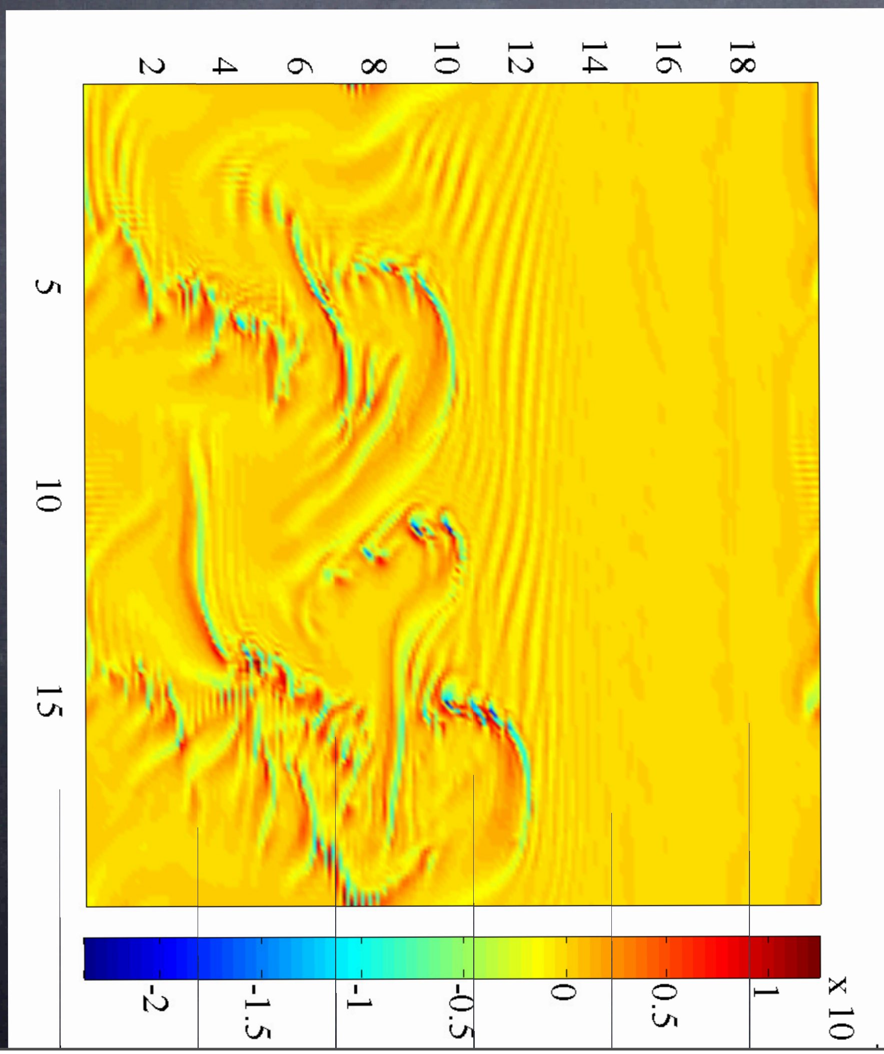
MITgcm Near-Surf. Temp. Submeso-Only Res.



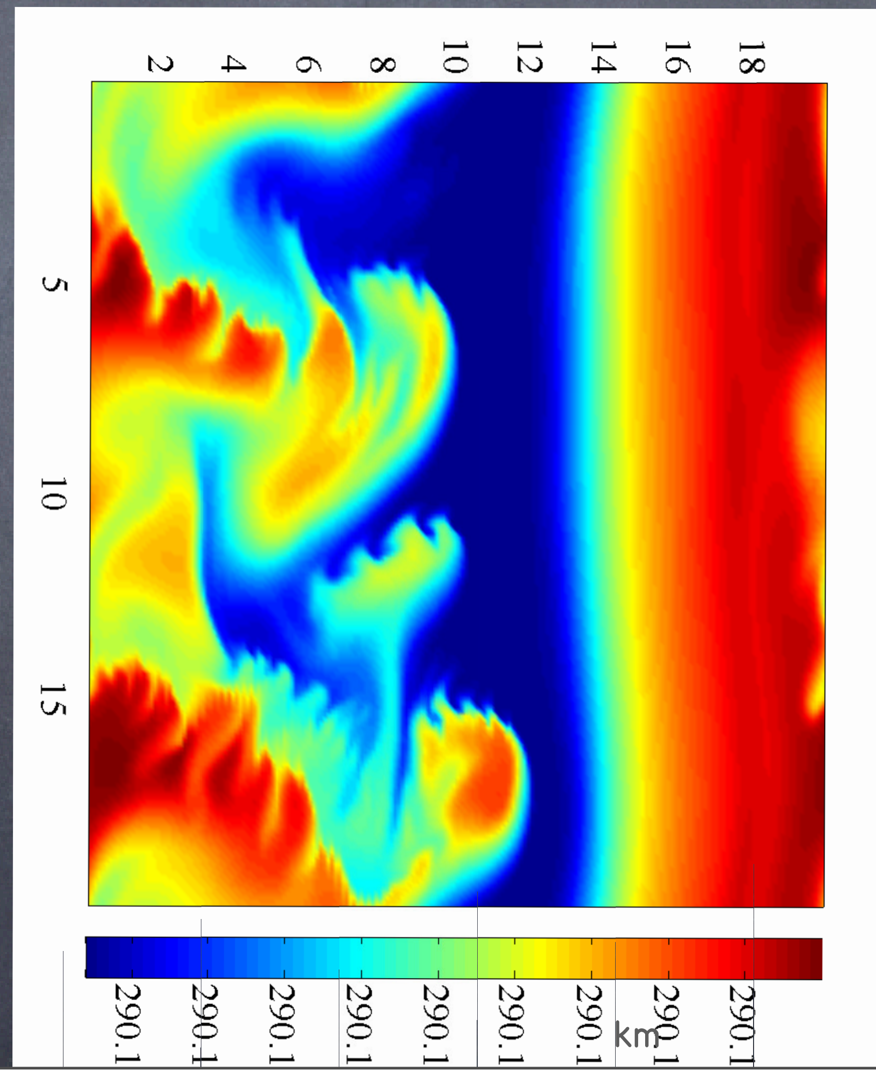



# The Scales, and the Sim

Day 6.5 of a Submeso
Resolving run
Vert. Velocity=w




Day 6.5 of a Submeso
Resolving run
Near Surf. Temp



# The Scales, and the Sim

$$f^2 < \left| f \frac{\partial \overline{v}}{\partial z} \right| = M^2 < (3f)^2$$

$$\overline{Ro} \approx 0.1$$

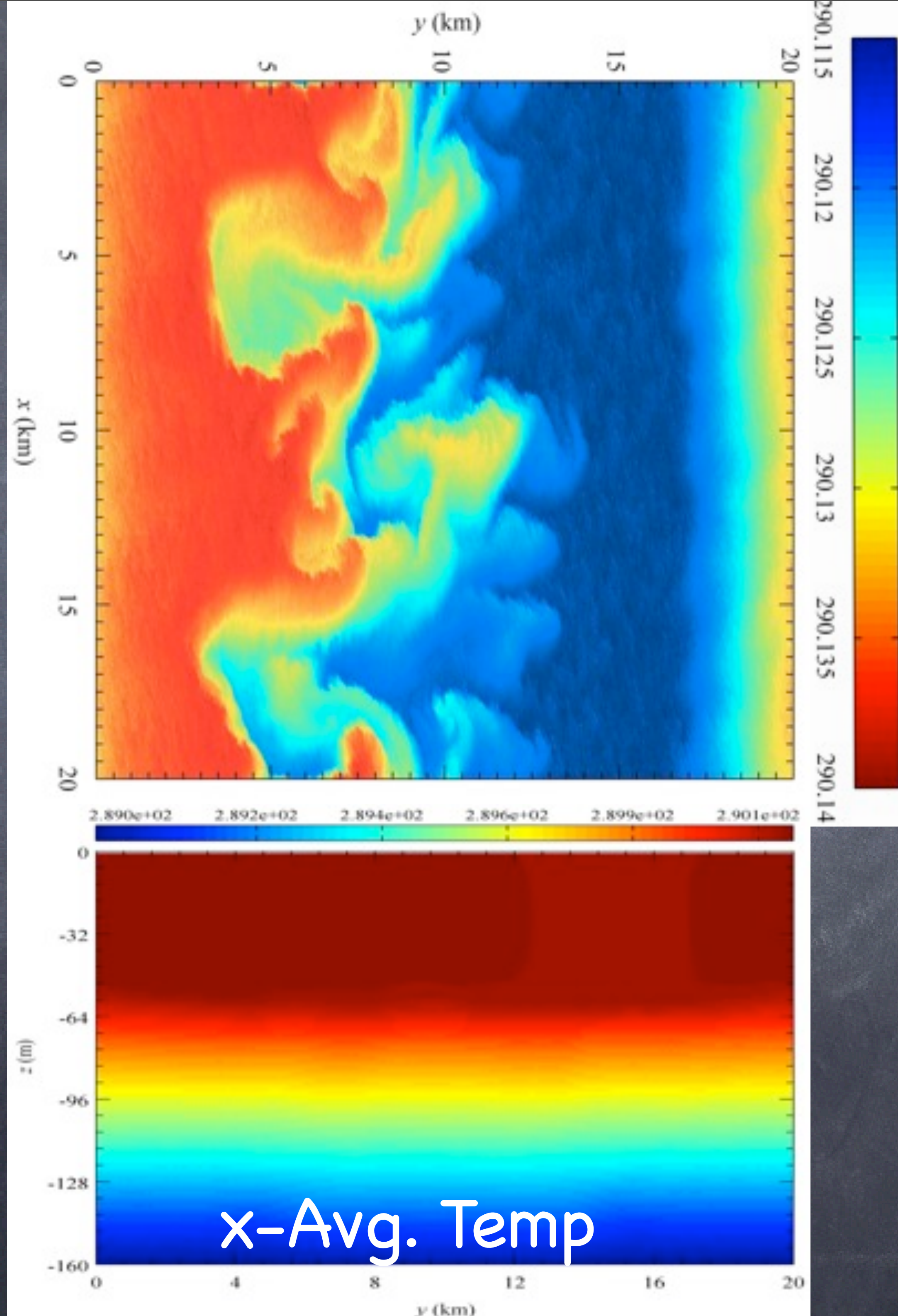
km km

$$\overline{Ri} < 1$$

km

Wind & Fronts Only

No Stokes Drift




-0.015

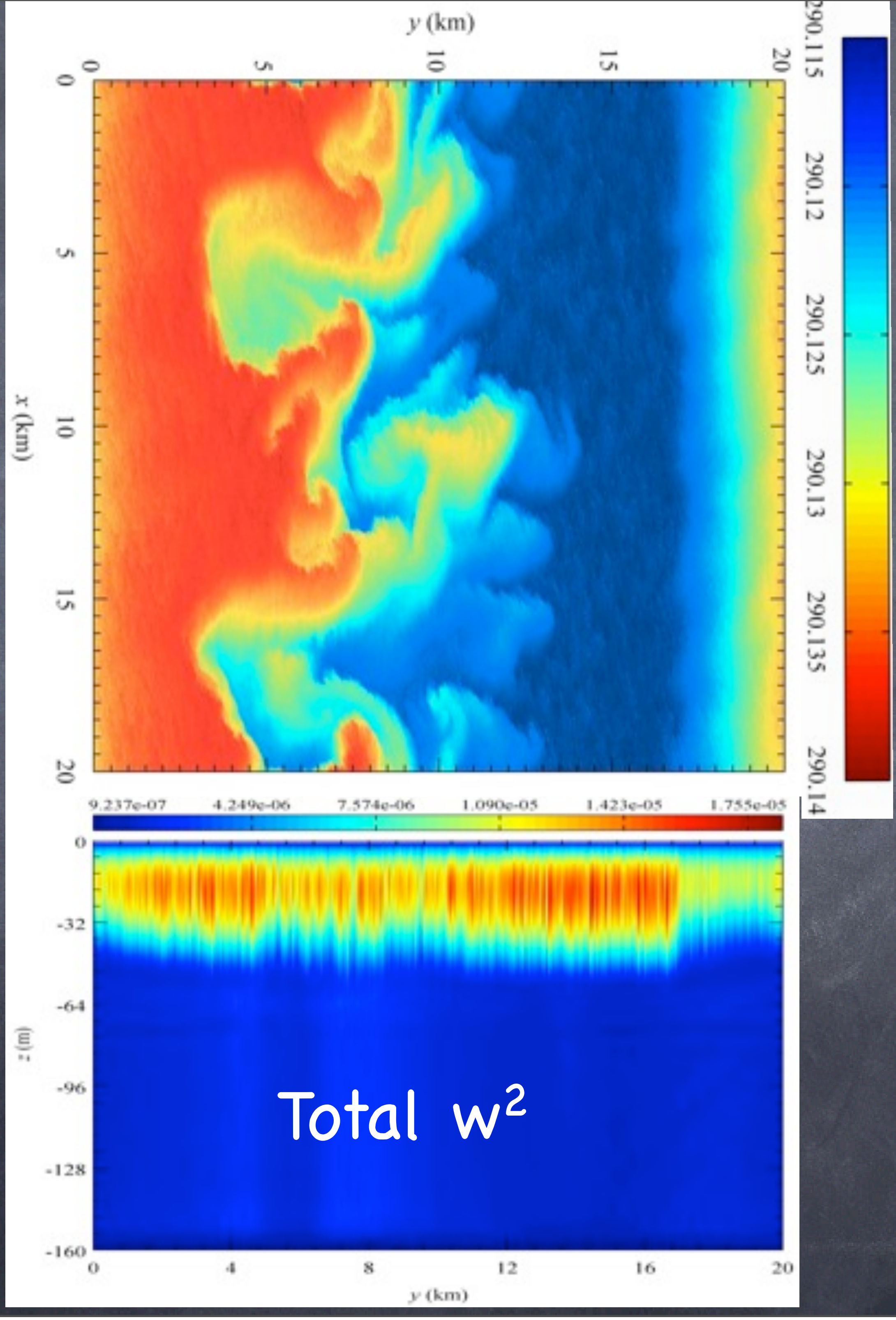
Surf. Temp (K)

+0.015

Temp (K)

Wind & Fronts Only

No Stokes Drift



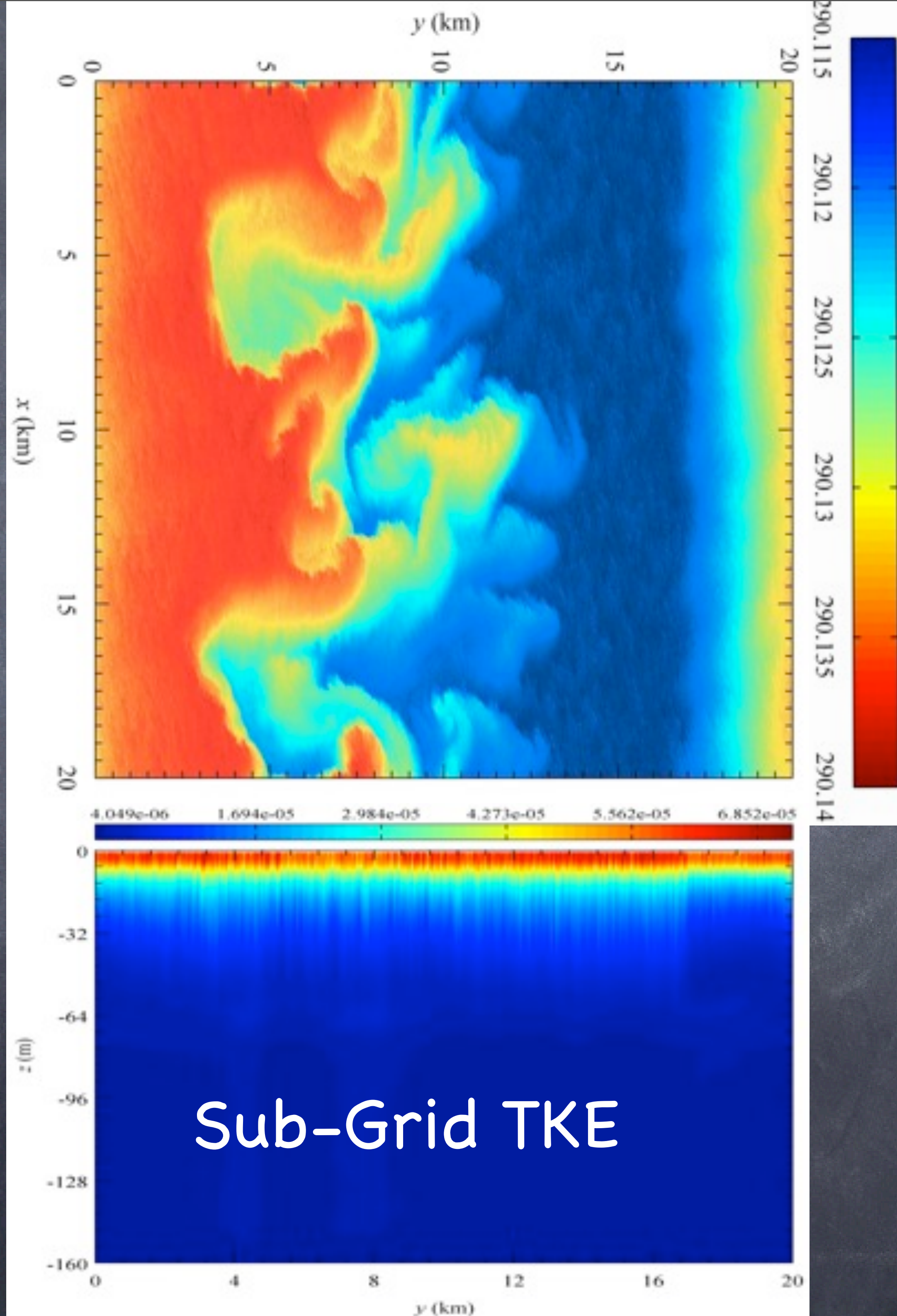

Surf. Temp (K)

$w^2$ ($m^2/s^2$)

$< (400m/d)^2$

Wind & Fronts Only

No Stokes Drift




Surf. Temp (K)

$w^2$ ($m^2/s^2$)