

# Langmuir-Submesoscale Interactions: Multiscale Simulations with the Craik-Leibovich Equations

TOS/ASLO/AGU 2012 Ocean Sciences Meeting, 20 February 2012, Salt Lake City, UT

---

Peter E. Hamlington and Baylor Fox-Kemper  
*University of Colorado, Boulder*

Luke Van Roekel  
*Northland College*

Peter P. Sullivan  
*National Center for Atmospheric Research*



**CIRES**  
Cooperative Institute for Research in Environmental Sciences

**NORTHLAND<sup>®</sup>**  
COLLEGE



Supported  
by NSF



# Background

Turbulence in the oceanic mixed layer (ML) is a superposition of processes at widely different scales

*At small-scales (1m-1km):* three dimensional Langmuir turbulence, wind-aligned vortices (Langmuir, 1938)

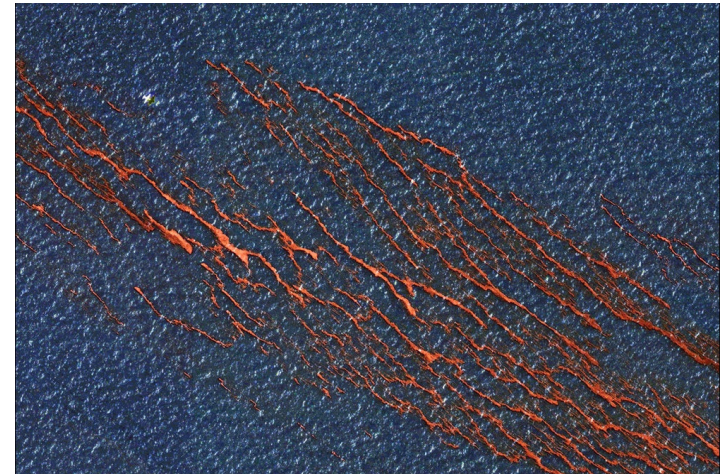
*At submesoscales (1-20km):* fronts and instabilities generate eddies that act to restratify the ML

*How do Langmuir turbulence and submesoscale processes interact?*

*Does vertical mixing by Langmuir turbulence affect frontogenesis by submesoscale instabilities?*

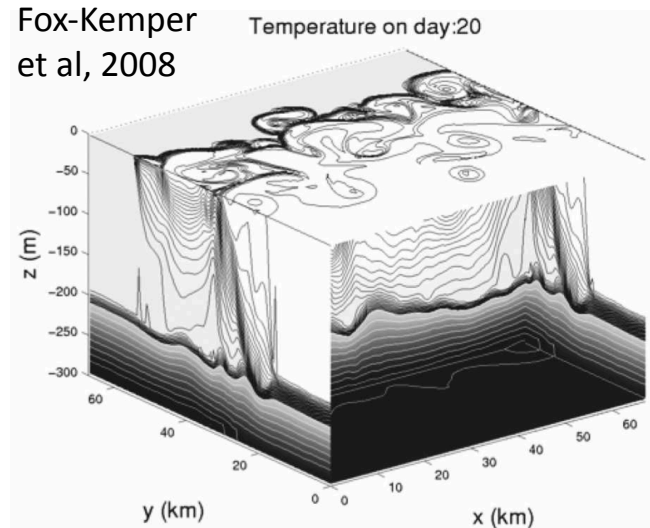
*Is the structure of Langmuir turbulence affected by submesoscale eddies?*

*What are relative contributions of Langmuir and submesoscales to mixing and dynamics?*



npr.org

Fox-Kemper  
et al, 2008



# Approach

Perform large eddy simulations (LES) of Langmuir turbulence with a submesoscale temperature front

Use NCAR LES model to solve Craik-Leibovich equations (Moeng, 1984, McWilliams et al, 1997)

$$\frac{\partial \rho}{\partial t} + \mathbf{u}_L \cdot \nabla \rho = \text{SGS} \quad \nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\boldsymbol{\omega} + f\hat{\mathbf{z}}) \times \mathbf{u}_L = -\nabla \pi - \frac{g\rho\hat{\mathbf{z}}}{\rho_0} + \text{SGS}$$

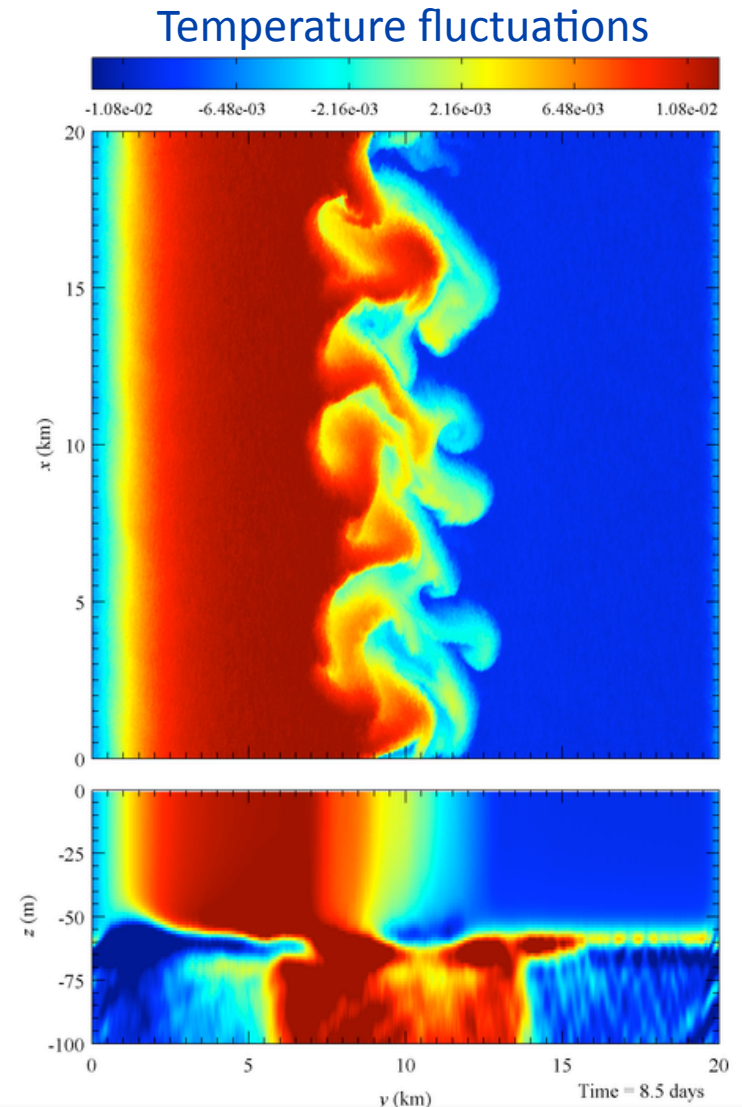
Computational parameters:

Domain size: 20km x 20km x -160m

Grid points: 4096 x 4096 x 128

Resolution: 5m x 5m x -1.25m

Wind makes a 30deg angle with respect to front, examine cases with and without Stokes drift forcing, for aligned and misaligned wind-waves



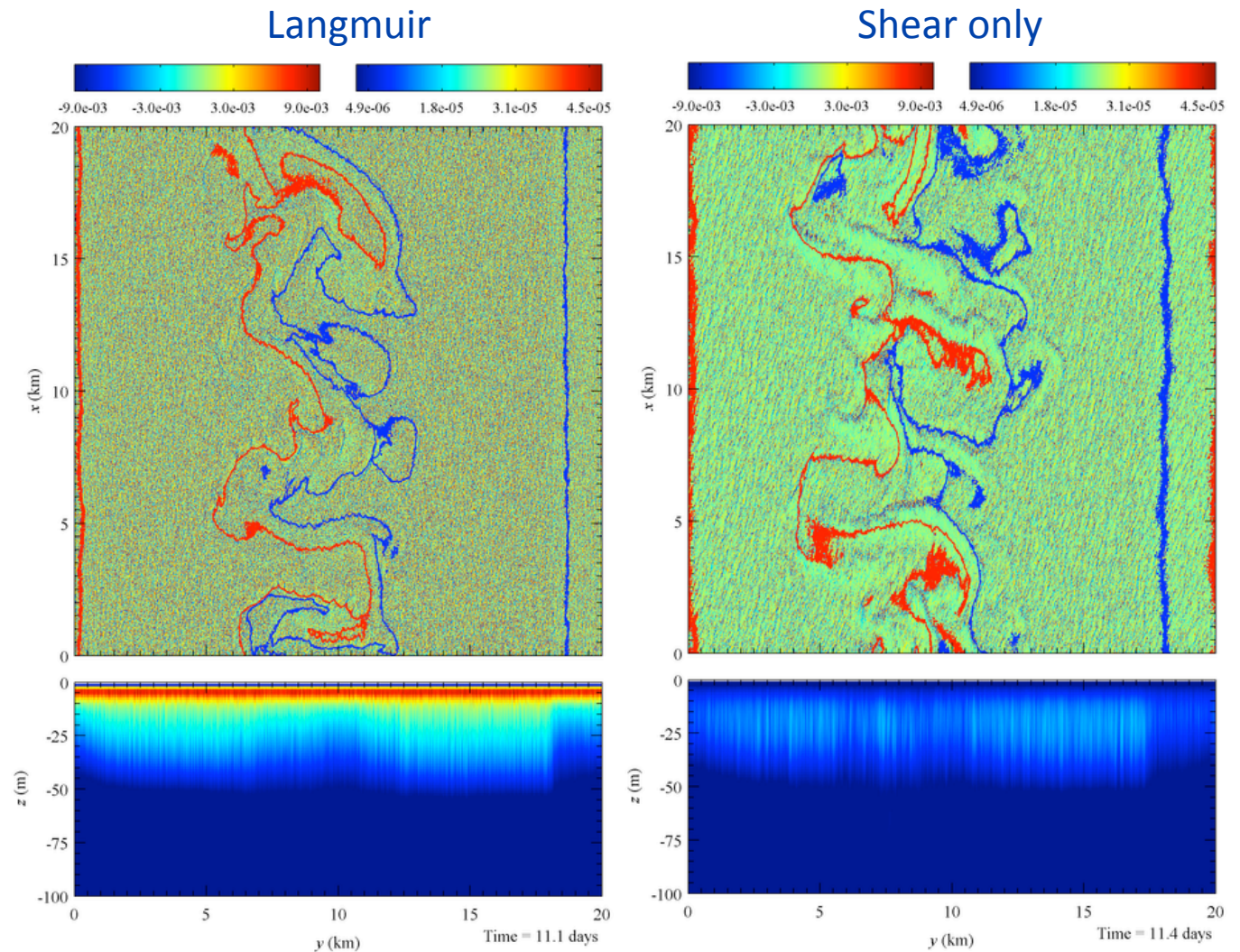
# Vertical Velocity and Variance

Vertical velocities are stronger in Langmuir simulations

Peak vertical mixing for Langmuir simulations is near the surface

Shear only simulations show decreased small-scale structure within eddy region

Langmuir simulations have nearly uniform small-scale structure throughout



# A Closer Look...

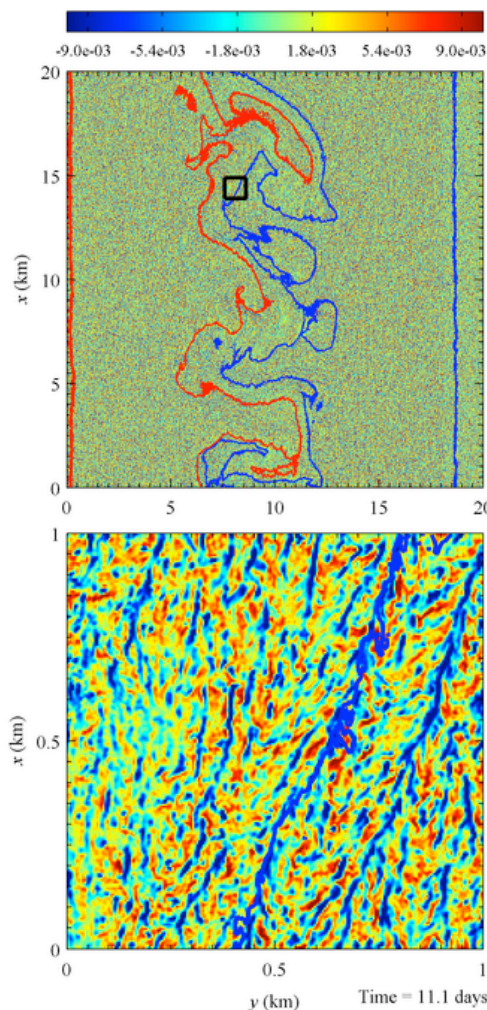
Zooming in to kilometer scale we see differences in small-scale structure

Langmuir simulations have stronger and more uniform small-scale fluctuations

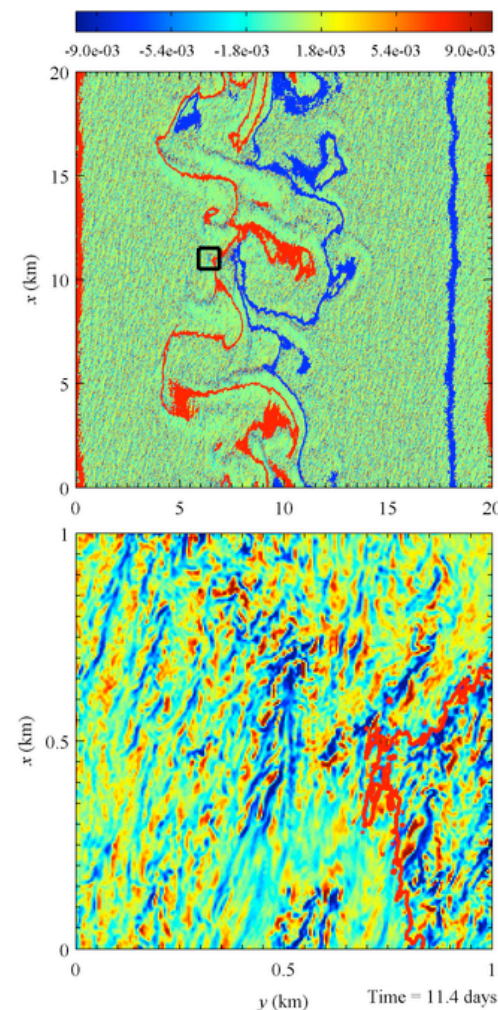
Shear only simulations have larger regions of weak small-scales, along with fringes of strong fluctuations

Can also examine other flow features in the future (e.g., cyclonic and anti-cyclonic eddies, sharp temperature gradients)

Langmuir



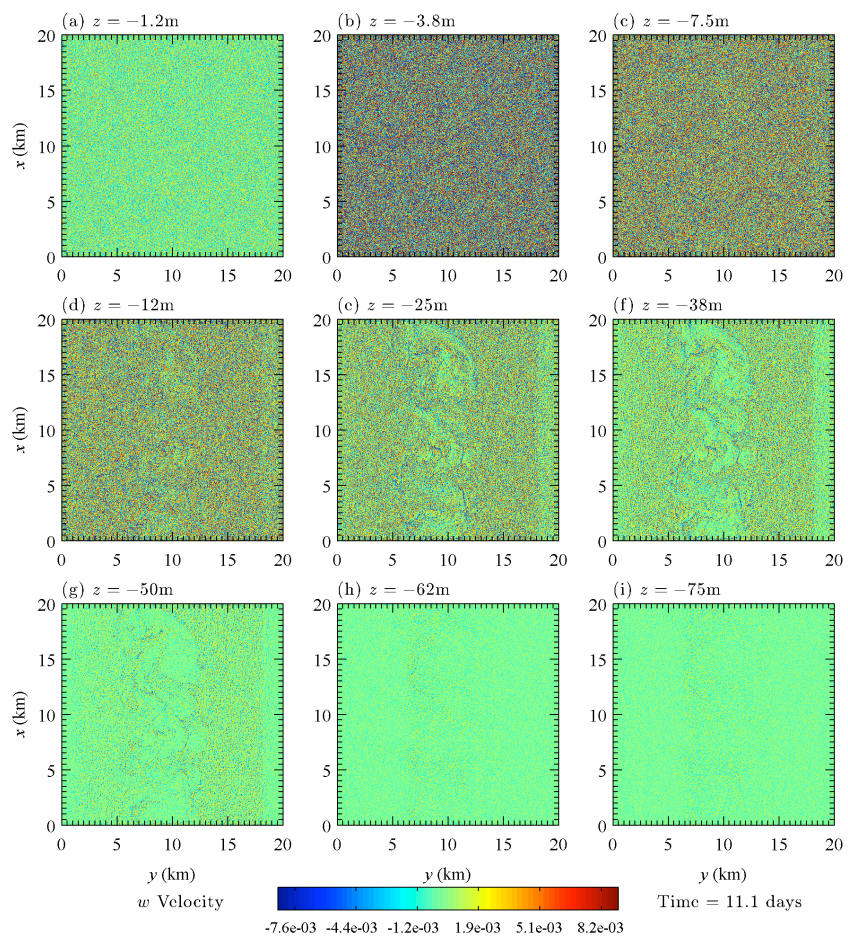
Shear only



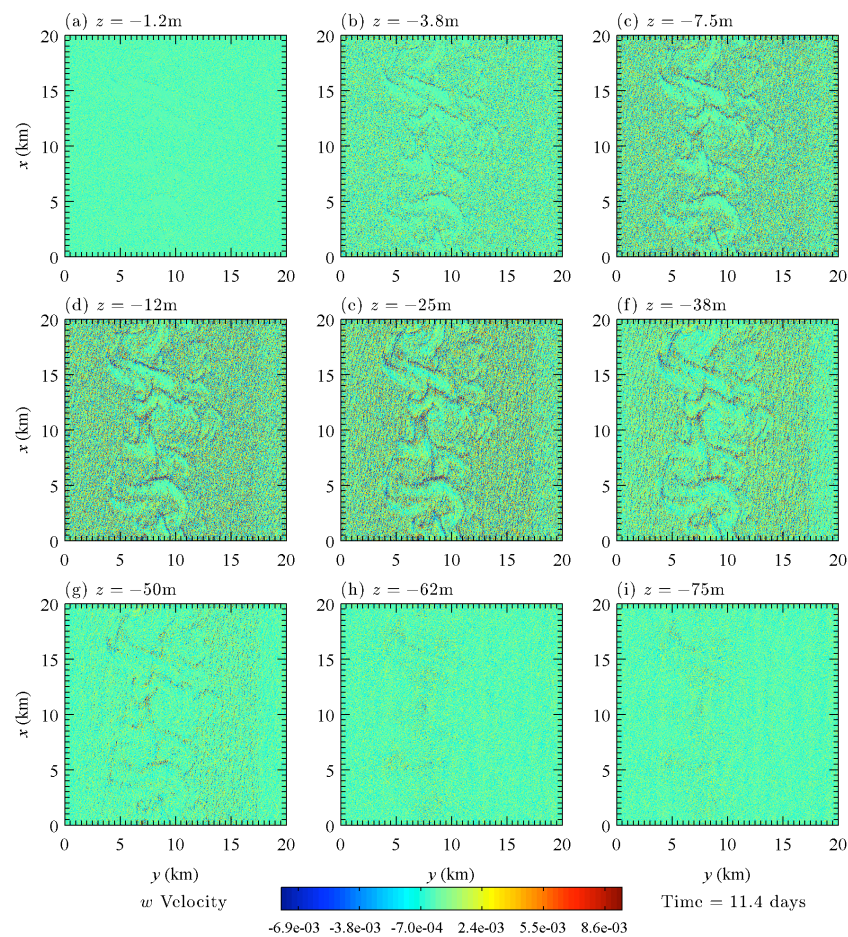
# A Deeper Look...

Vertical velocity as a function of depth shows variations in effects of submesoscale eddies

## Langmuir



## Shear only

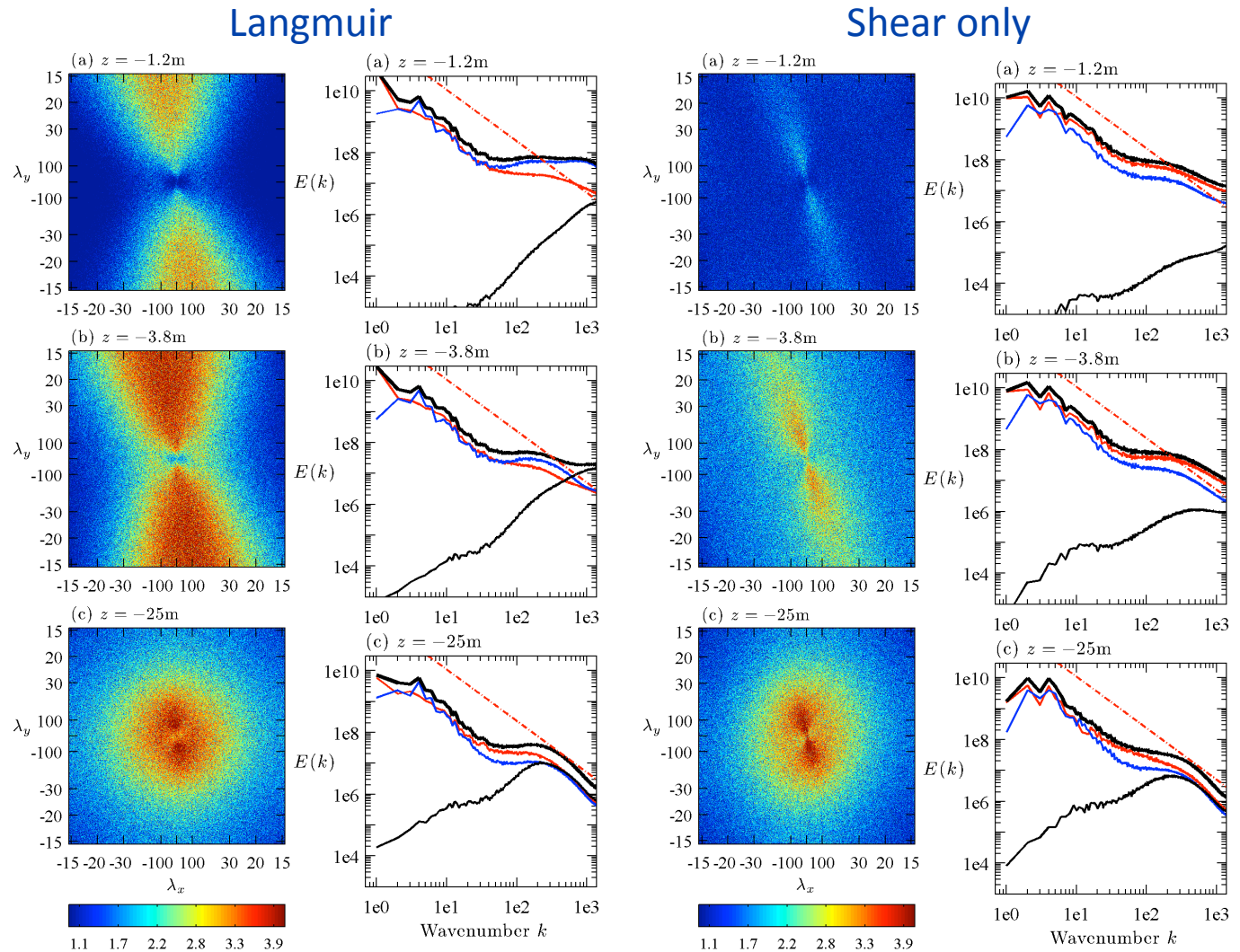


# Kinetic Energy Spectra

Vertical velocity spectra also show differences in small-scale structure as a function of depth

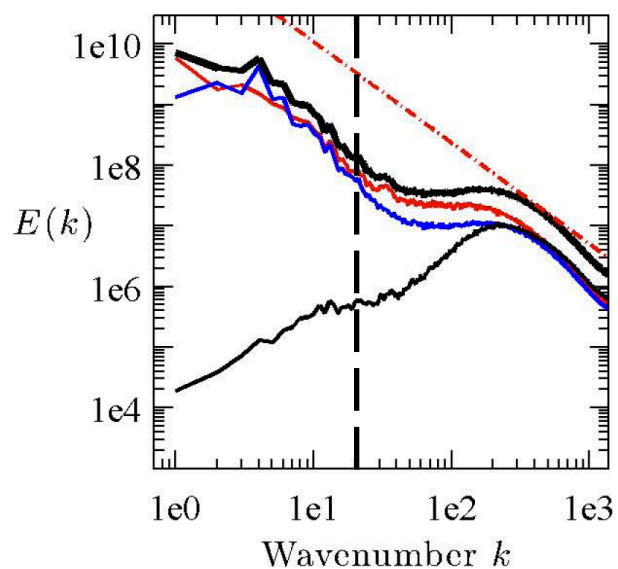
Langmuir turbulence makes a strong small scale contribution that is lost with depth

In both cases, vertical velocities are strongest at small scales



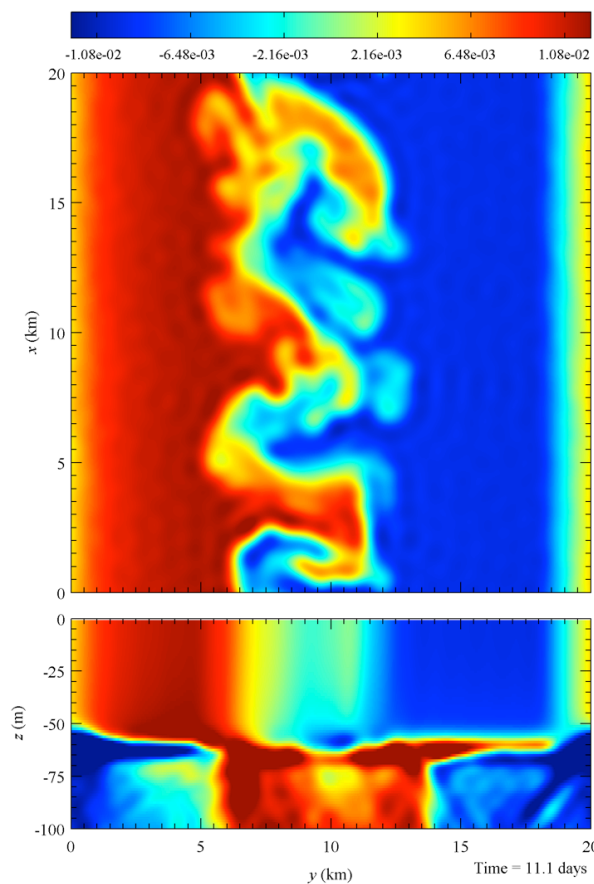
# Scale Decomposed Fields

Separate Langmuir turbulence and submesoscales by filtering at roughly 1km

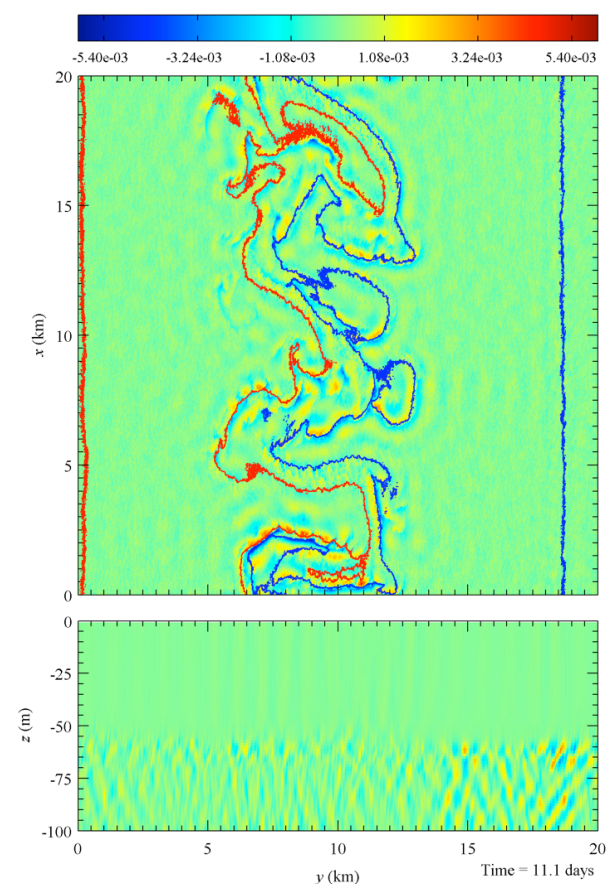


Ideal filtering would take into account wind-wave direction

Low-pass



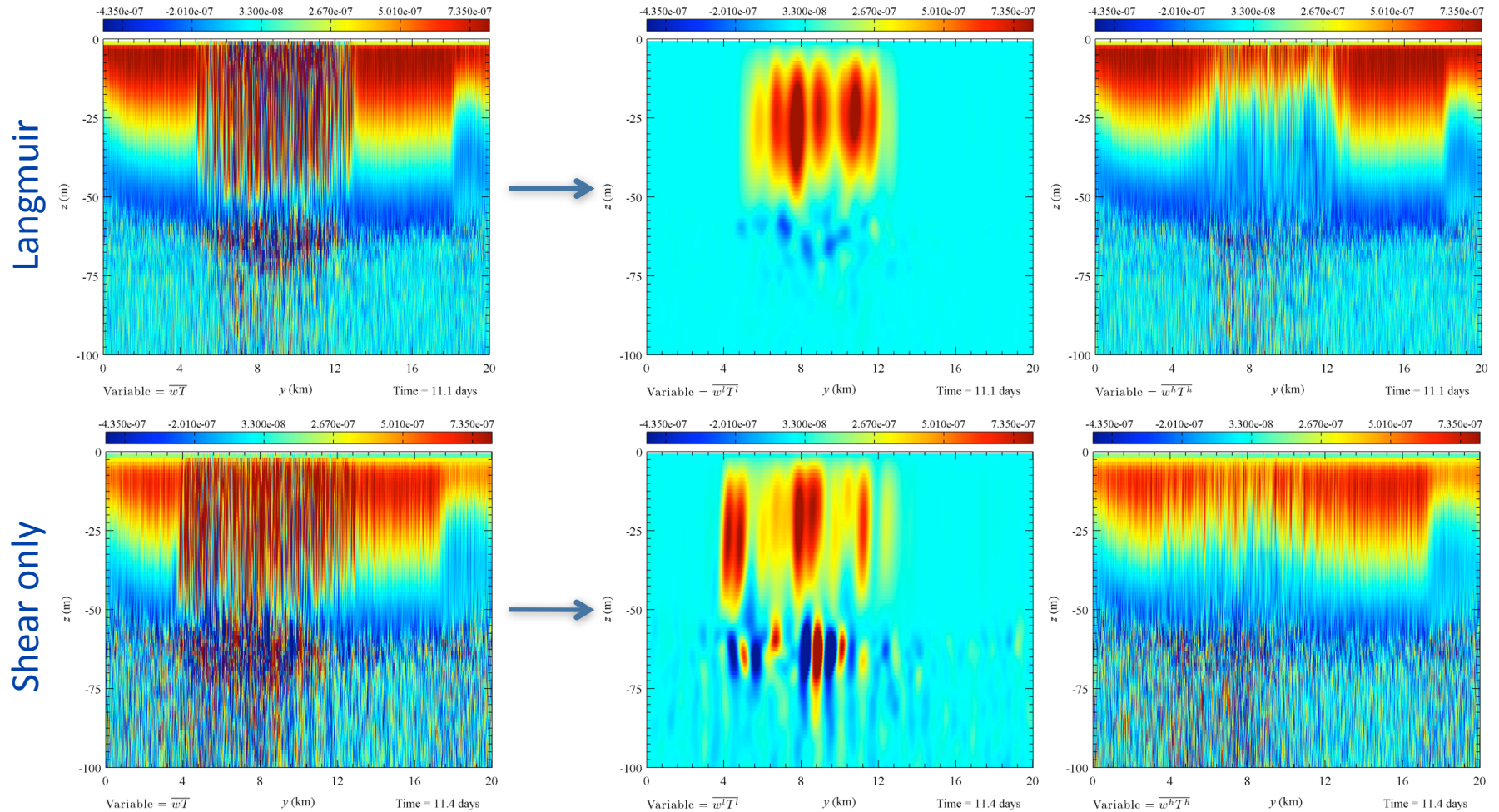
High-pass





# Multiscale Transport

We can calculate budgets and multiscale fluxes from the decomposed fields, e.g.  $\langle w'T' \rangle$



# Non-Dimensional Maps

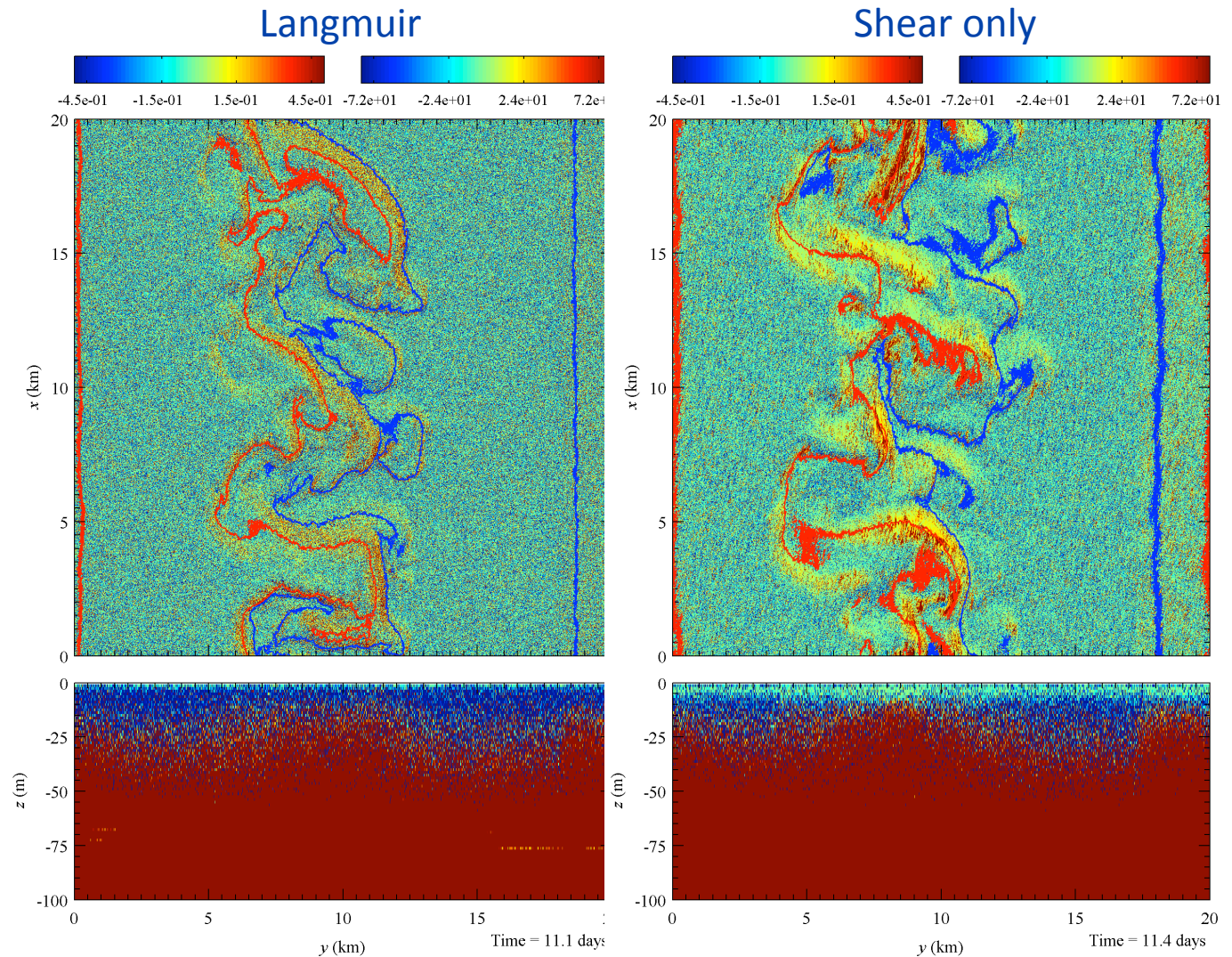
Richardson number provides another way to separate submesoscale features and Langmuir turbulence

$$N^2 = -g d(\rho/\rho_0)/dz$$

$$Ri = N^2 / (du/dz)^2$$

At surface, increased  $Ri$  near submesoscale eddies, but this is weakened by Langmuir

Within mixed layer, convective overturning; strong stratification below



# Summary and Conclusions

---

Performed LES of Craik-Leibovich equations to examine interactions between Langmuir turbulence and submesoscale processes

Langmuir turbulence creates strong small scale vertical mixing near the surface, and appears to be resistant to effects of submesoscale eddies (near the surface)

Submesoscale eddies weaken small-scale structures in shear-only fields; similar weakening is observed in Langmuir simulations at sufficient depth

There are indications that submesoscale features are slower to develop in the Langmuir simulations; a signature of Langmuir effects on the submesoscale?

---

Continue scale decomposition analysis; budgets and non-dimensional parameters

Condition analysis on different regions of the flow

Examine detailed structure near interesting submesoscale features

Analysis of asymptotic equations

# Fields

