Multi-scale Turbulence in the Ocean Surface Boundary Layer

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Boundary layers link the ocean and atmosphere systems. These systems exchange momentum, heat, carbon, oxygen. All of these are modulated by the turbulence in the boundary layer.
Forced at the surface, wind, waves, freshwater, heat flux are highly variable in space and time. They interact with a complicated lateral density and flow field, defining the boundary layer between the ocean surface and the ocean interior.
The Ocean Surface Boundary Layer

Develop BL parameterizations assuming horizontal homogeneity
Use BL parameterization in process models to study impact of BL turbulence on frontal dynamics

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How is BL turbulence modified in the presence of horizontal variability?

Use BL parameterization in process models to study impact of BL turbulence on frontal dynamics.

Develop BL parameterizations assuming horizontal homogeneity.

How is BL turbulence modified in the presence of horizontal variability?
Resolution: 4.9 m x 4.9 m x 1.25 m

Periodic domain

\[ T = 10 \text{ days} \]

\[ Q_{\text{MLE}} \approx 25 \text{ W m}^{-2} \]

\[ Q_{\text{EBF}} \approx 15 \text{ W m}^{-2} \]

References:
Hamlington 2014
Bodner 2020
What does turbulence look like in a submesoscale sized grid (400m)?

Do current turbulence parameterizations capture this mixing?

\[ c^a = \bar{c}^a + c^s \]
\[ c^s = \bar{c}^s + c^t \]
Along front:  \[ c^a = \bar{c}^a + c^s \]

Submesoscale:  \[ c^s = \bar{c}^s + c^t \]

Unstable  None  Stable
Along front Submesoscale Turbulence

\[ c^a = \bar{c}^a + c^s \]
\[ c^s = \bar{c}^s + c^t \]

\[ \frac{\partial \overline{b^a}}{\partial t} = -\nabla^a M^2 - \overline{w^a N^2} - \frac{\partial}{\partial y} \overline{v^s b^s} - \frac{\partial}{\partial z} \overline{w^s b^s} - \frac{\partial}{\partial y} \nu^tb^t - \frac{\partial}{\partial z} \nu^tb^t \]


\[
\frac{\partial b^a}{\partial t} = -\nu^a M^2 - \tilde{w}^a N^2 - \frac{\partial}{\partial y} \tilde{v}^s \tilde{b}^s - \frac{\partial}{\partial z} \tilde{w}^s \tilde{b}^s - \frac{\partial}{\partial y} \nu^t b^t - \frac{\partial}{\partial z} \nu^t b^t
\]

\[
\frac{\partial b^a}{\partial t} = \nabla \cdot (\Psi^a \times \nabla b^a) + \nabla \cdot (\Psi^e \times \nabla b^a) + \frac{\partial}{\partial z} (\kappa N^2) + \text{RES}
\]

Along front  \quad \text{Submesoscale}  \quad \text{Turbulence}

\[
c^a = \bar{c}^a + c^s
\]

\[
c^s = \bar{c}^s + c^t
\]

**Along front Submesoscale Turbulence**

**EKMAN**  \quad **EDDY**  \quad **Mix**

**residual horizontal fluxes**
COMMON SCALINGS CAN BE USED TO ASSESS THE STRENGTH OF THESE TERMS

HOW GOOD OF AN ASSUMPTION IS THIS?

\[ \frac{\tau \times \nabla b}{f \rho_o} \]

EBF (Thomas 2005)

\[ \frac{\nabla b a^2 H^2}{c_e f} \]

MLE Fox-Kemper 2008

\[ \kappa N^2 \]

Your favorite \( \kappa \) here
1D models have different parameterized physics

Mixing in no front agrees with 1D models

\[-w^t b^t = \kappa N^2\]
1D models have different parameterized physics.

Mixing in **no front** agrees with 1D models.

Suppressed mixing in **stable** region.

\[-w^t b^t = \kappa N^2\]
Mixing in unstable region near zero

\[ -w^t b^t = \kappa N^2 \]

Mix
Mixing in **unstable** region near zero

**Strong fronts** have counter gradient fluxes

**PV<0** has strongest counter gradient fluxes

\[-w^t b^t = \kappa N^2\]
RECAP

Submesoscale resolving models with parameterized mixing are missing important turbulent fluxes.
Turbulent Dissipation Rate

\[ \varepsilon \sim \frac{u_*^3}{0.4z} \]

Strong fronts and PV < 0 have larger dissipation rates.

Dissipation rate is suppressed in **stable**.
RECAP

Turbulent dissipation is suppressed in **stable** and enhanced in **unstable**.
Turbulence statistics vary across regimes
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• Traditional scalings for BL turbulence are modified in the presence of submesoscale fronts.
• Turbulence is suppressed in regions of lateral restratification
• Small scale overturnings in unstable fronts result in counter-gradient fluxes, contrary to OSBL theory under neutral BLs
• Turbulence statistics in actively unstable regions tend to be highly variable, posing a challenge for observations.