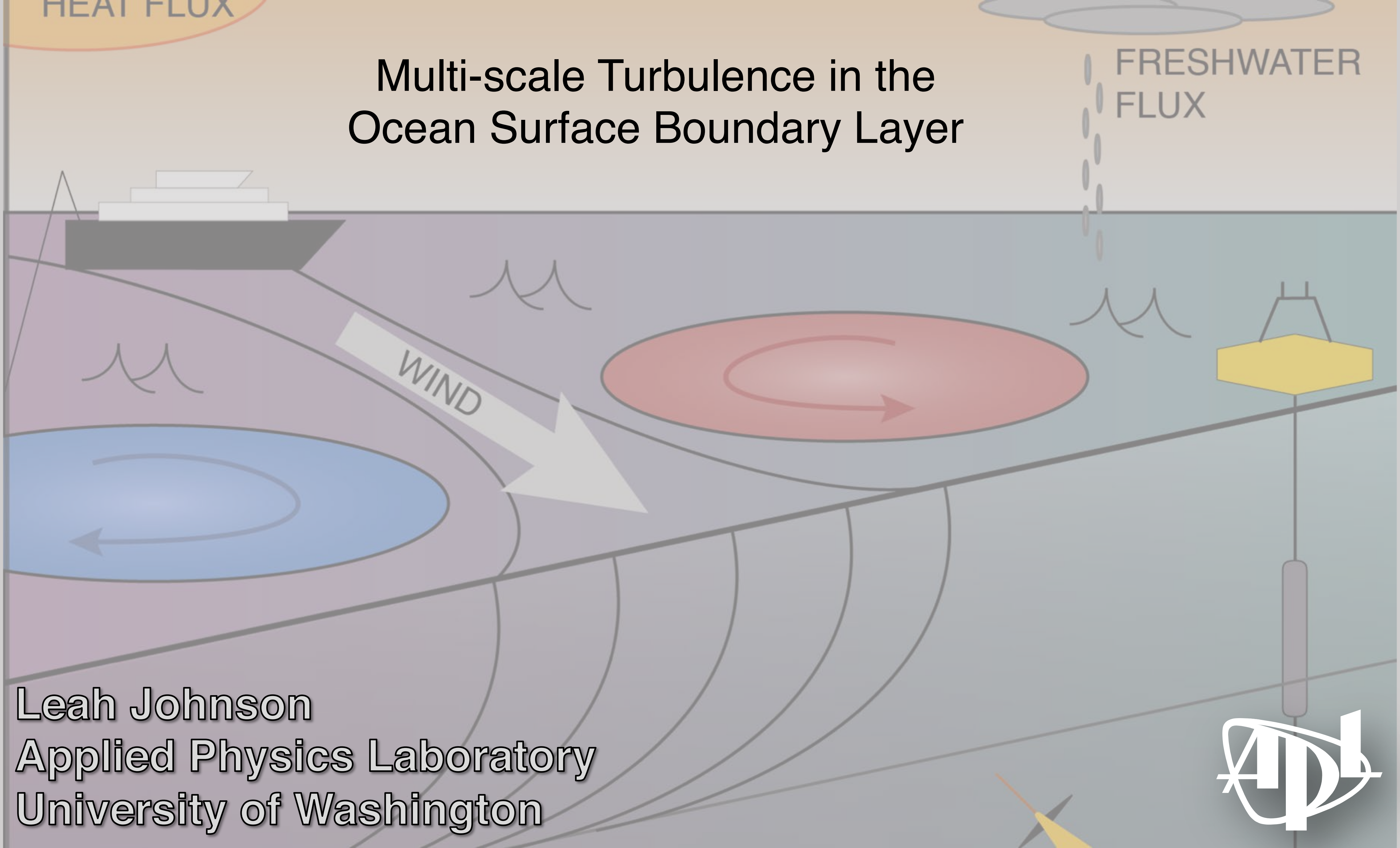
Multi-scale Turbulence in the Ocean Surface Boundary Layer



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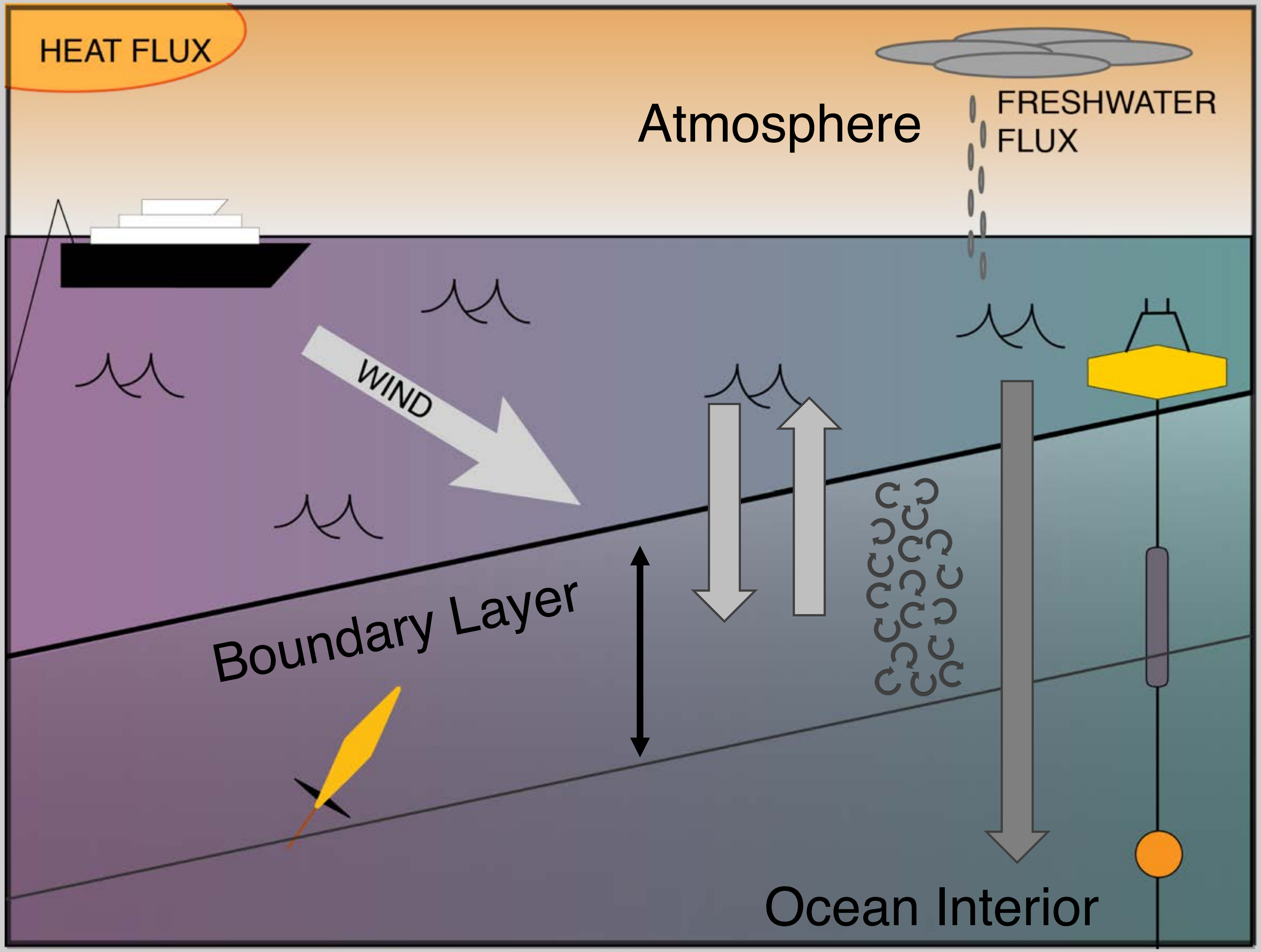
The Ocean Surface Boundary Layer

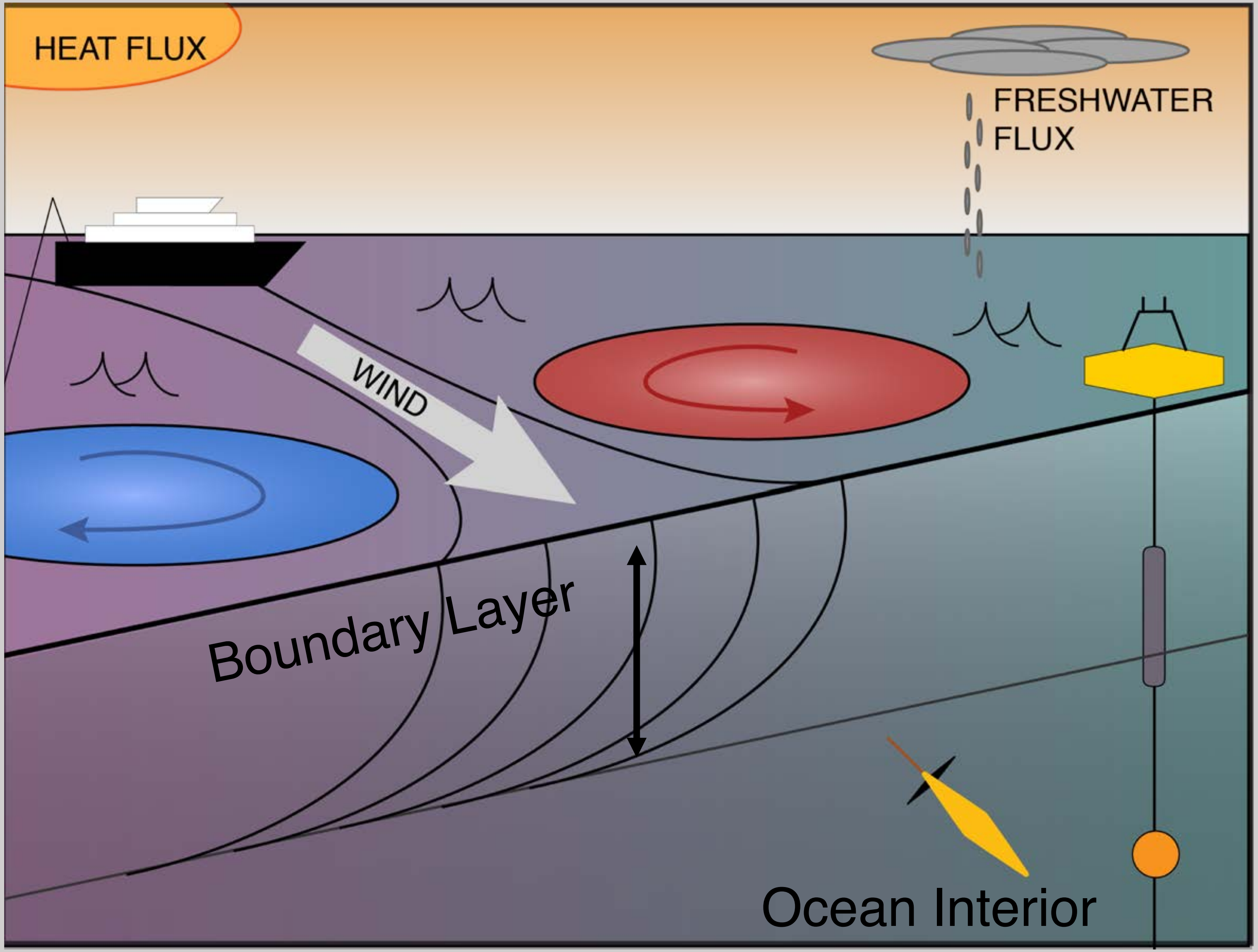


Boundary layers link the ocean and atmosphere systems

These systems exchange momentum, heat, carbon, oxygen.

All of these are modulated by the turbulence in the boundary layer

The Ocean Surface Boundary Layer



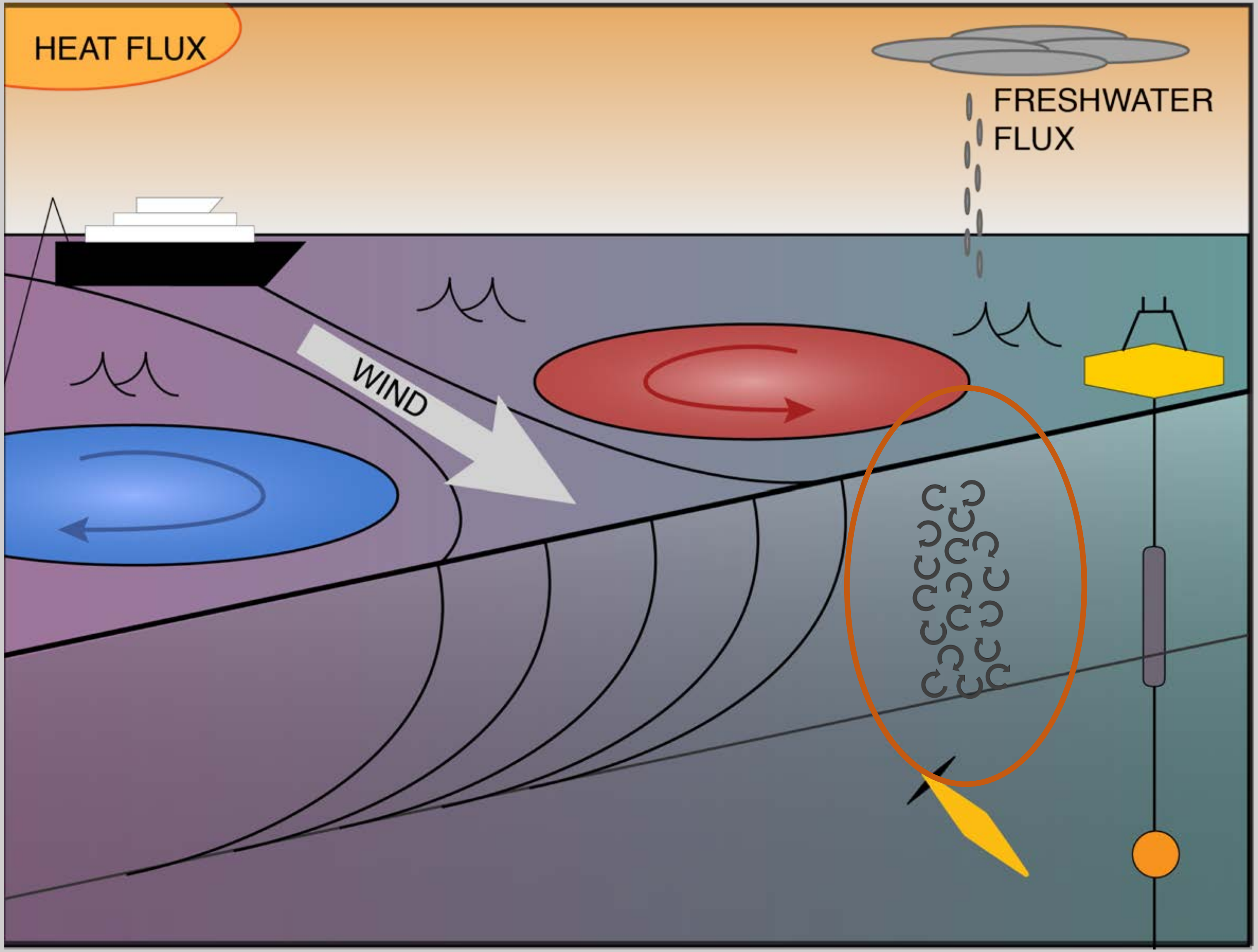
This turbulence defines the boundary layer

Forced at the surface, wind, waves, freshwater, heat flux

Interact with a complicated lateral density and flow field

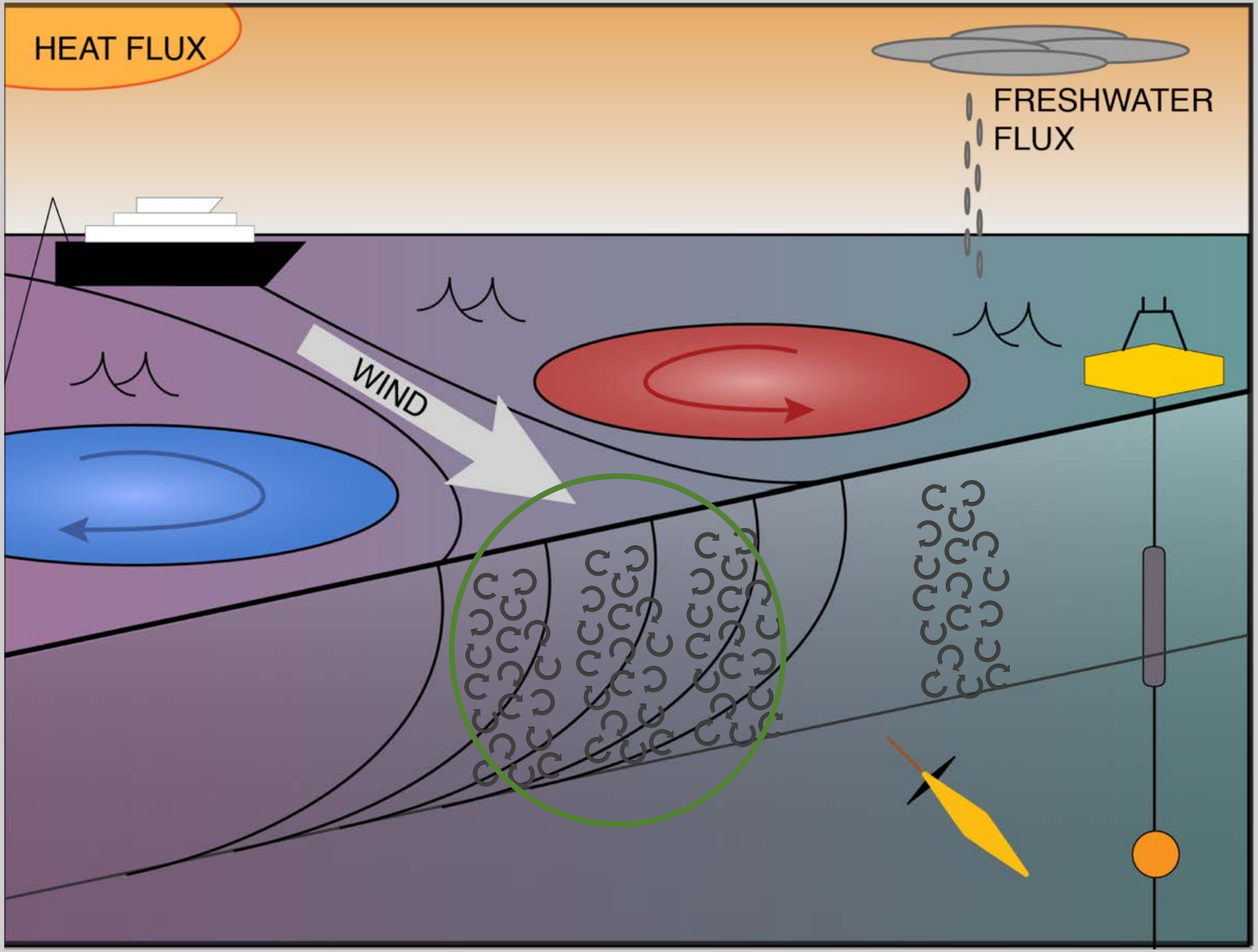
Highly variable in space and time

The Ocean Surface Boundary Layer



Develop BL parameterizations assuming horizontal homogeneity

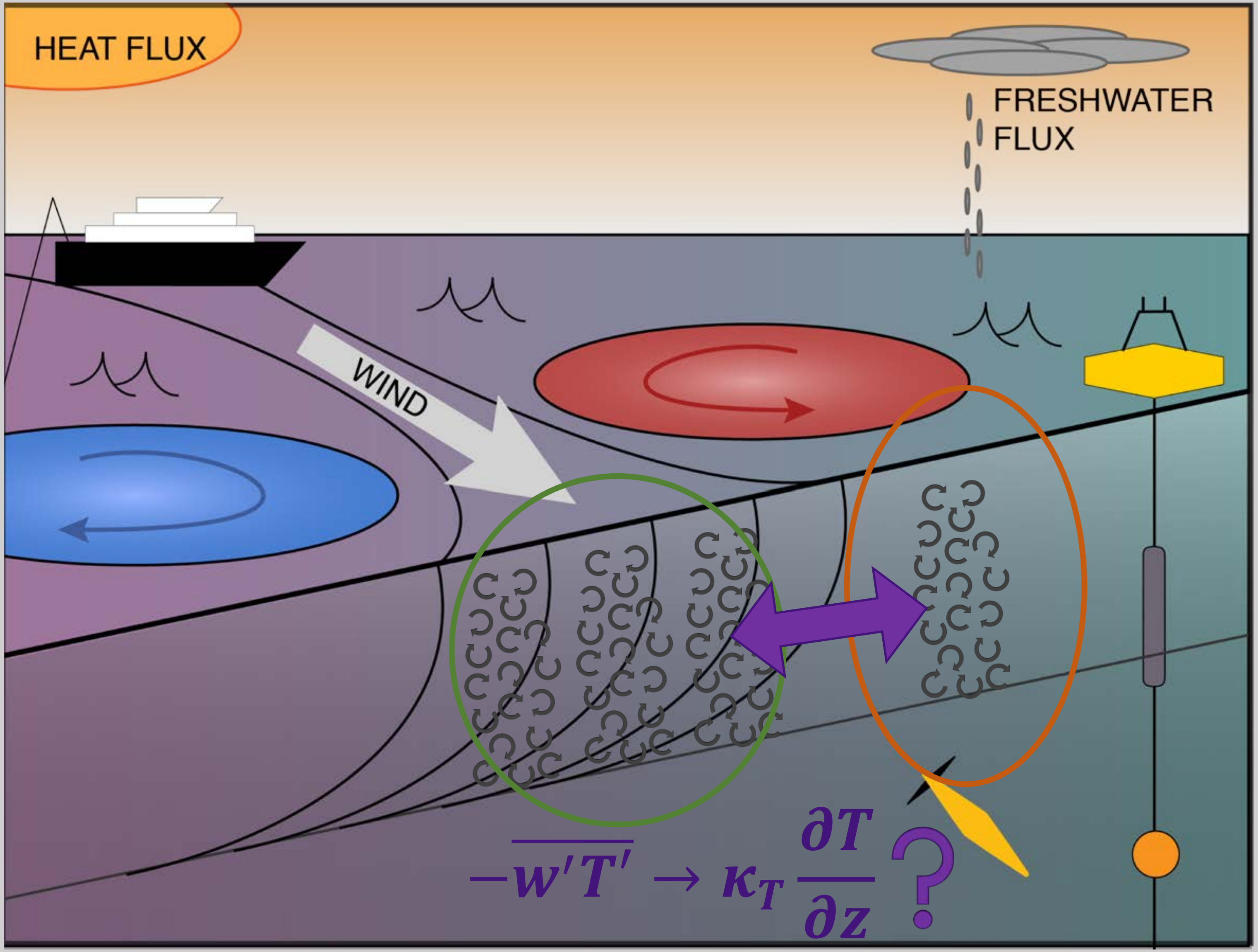
The Ocean Surface Boundary Layer



Develop BL parameterizations assuming horizontal homogeneity

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

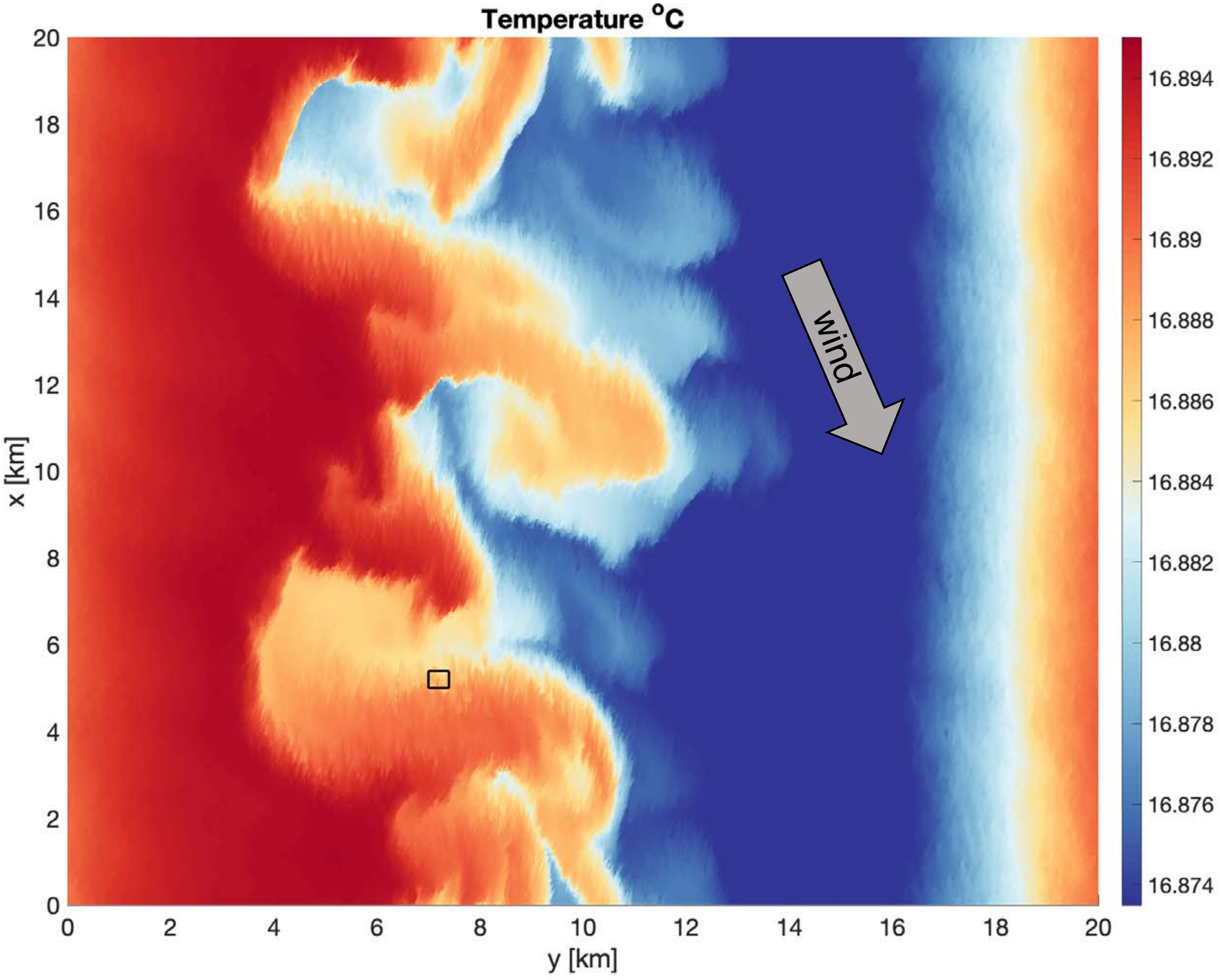
The Ocean Surface Boundary Layer



Develop BL parameterizations assuming horizontal homogeneity

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

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



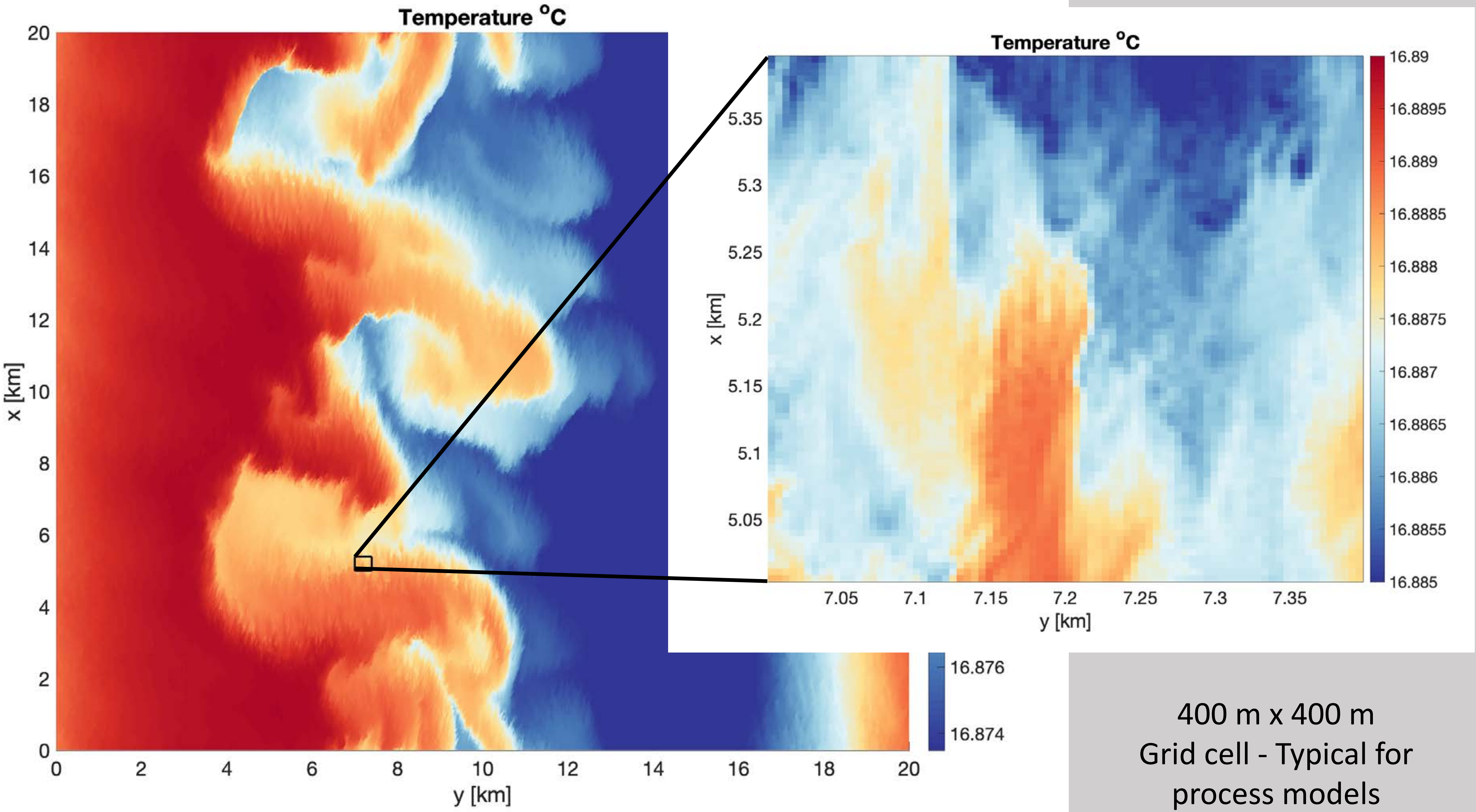
Resolution:
4.9 m x 4.9 m x 1.25m

Periodic domain

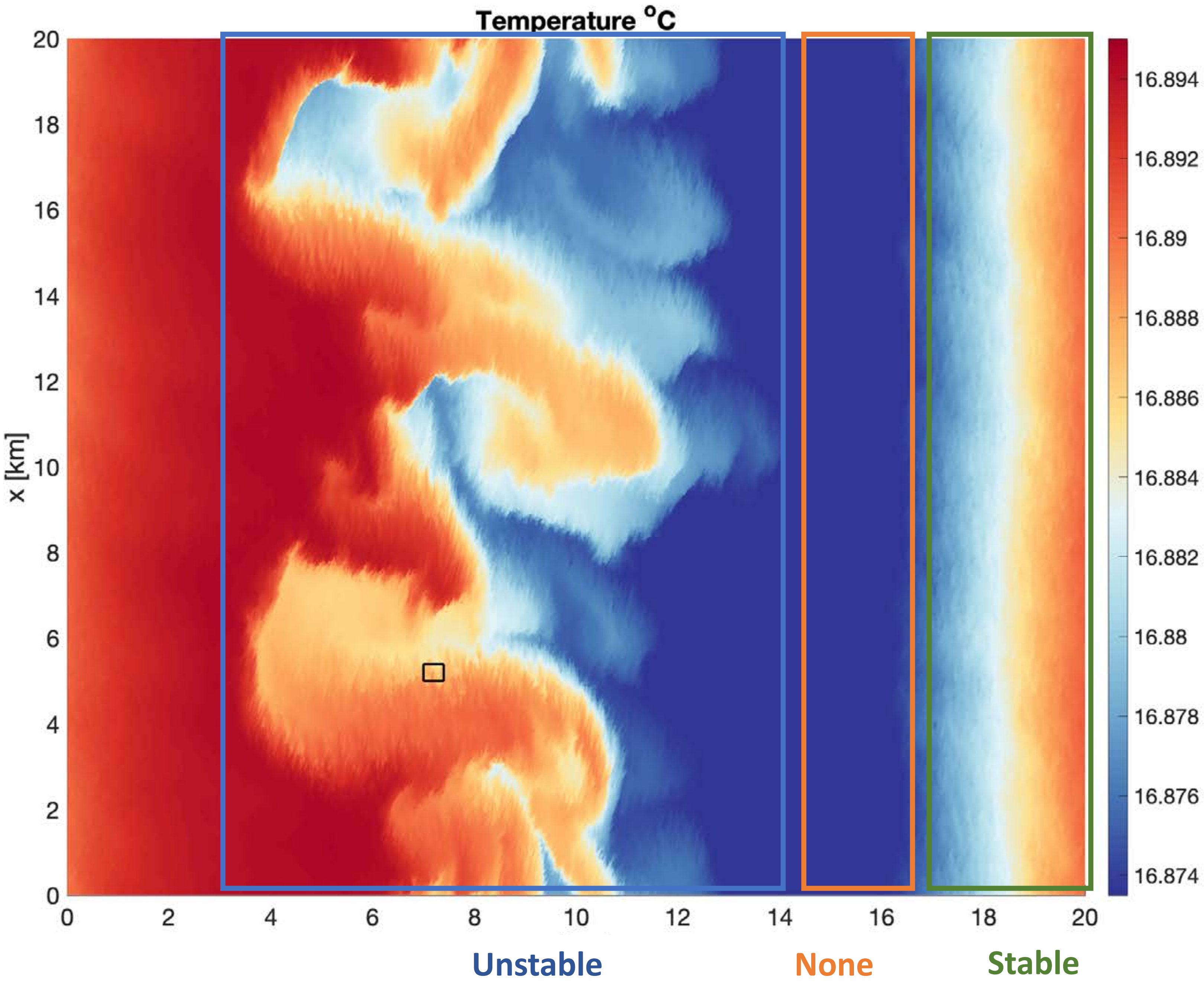
T = 10 days

Q_{MLE} ~ 25 W m^{-2}
Q_{EBF} ~ 15 W m^{-2}

References:
Hamlington 2014
Bodner 2020



400 m x 400 m
Grid cell - Typical for process models



Along front

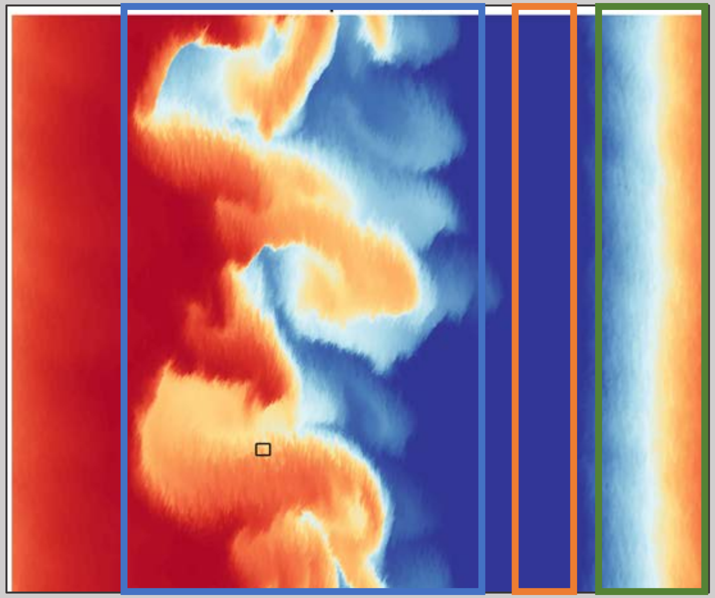
$$c^a = \bar{c}^a + c^s$$

$$c^s = \bar{c}^s + c^t$$

Submesoscale Turbulence

What does turbulence look like in a submesoscale sized grid (400m) ?

Do current turbulence parameterizations capture this mixing?

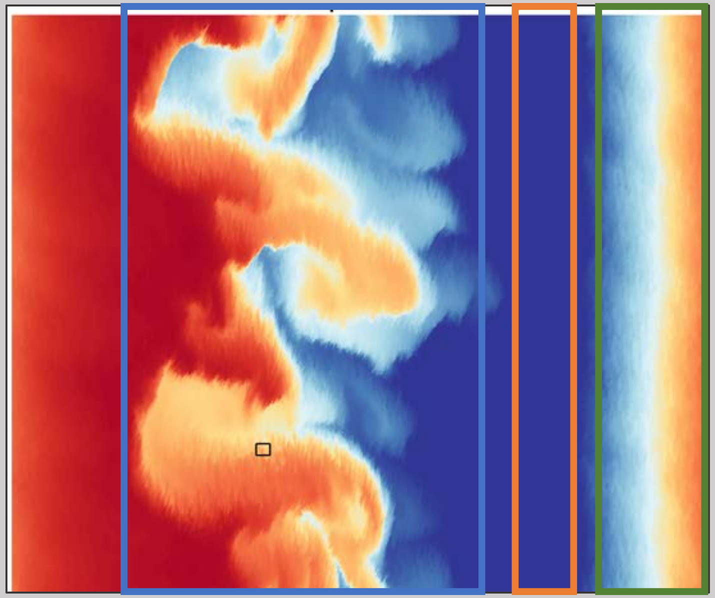


Along front

Submesoscale

Turbulence

$$c^a = \bar{c}^a + c^s \qquad c^s = \bar{c}^s + c^t$$

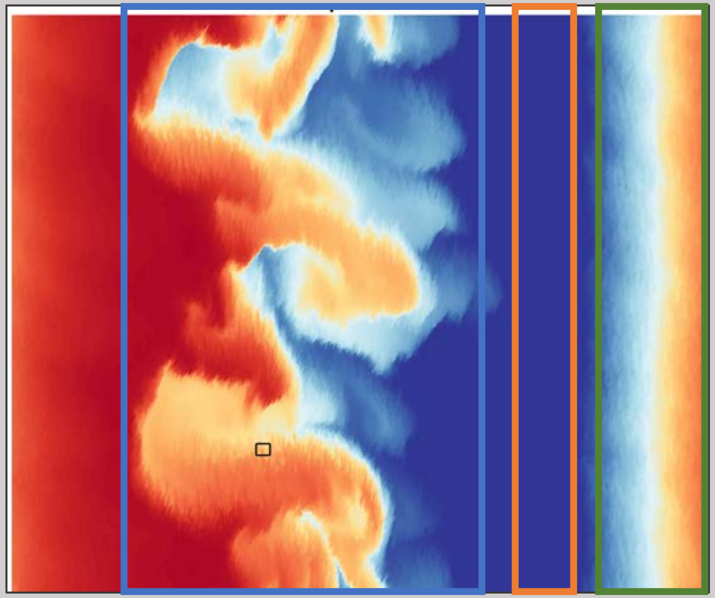


Along front　　Submesoscale　　Turbulence

$$c^a = \bar{c}^a + c^s \qquad c^s = \bar{c}^s + c^t$$

Along front　　Submesoscale　　Turbulence

$$\frac{\partial \overline{b^a}}{\partial t} = \underbrace{-\overline{v^a} M^2 - \overline{w^a} N^2}_{\text{Along front}} \underbrace{- \frac{\partial}{\partial y}\overline{\bar{v}^s \bar{b}^s} - \frac{\partial}{\partial z}\overline{\bar{w}^s \bar{b}^s}}_{\text{Submesoscale}} \underbrace{- \frac{\partial}{\partial y}\overline{v^t b^t} - \frac{\partial}{\partial z}\overline{w^t b^t}}_{\text{Turbulence}}$$



Along front — Submesoscale — Turbulence

$$c^a = \bar{c}^a + c^s \qquad c^s = \bar{c}^s + c^t$$

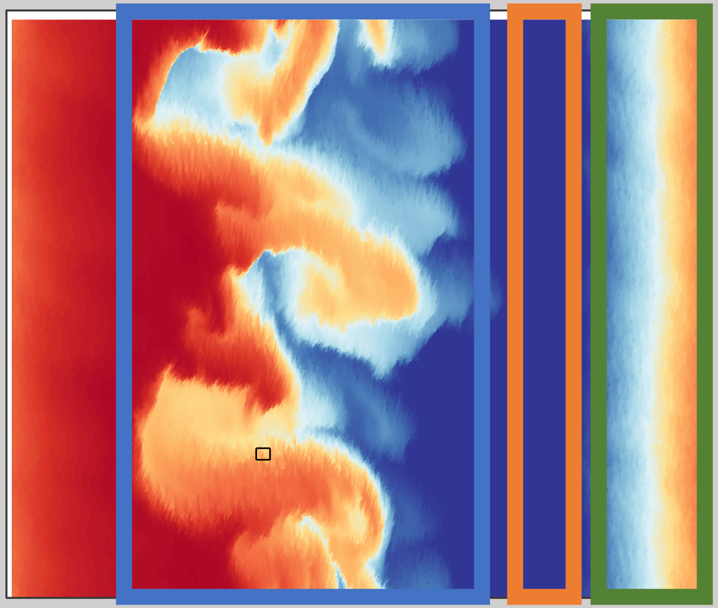
Along front — Submesoscale — Turbulence

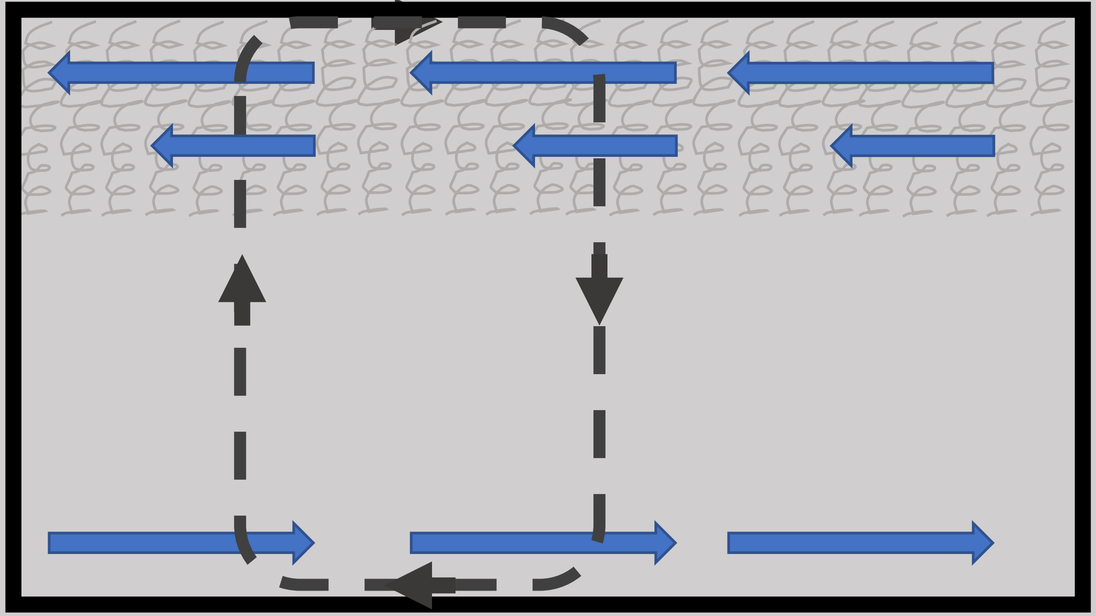
$$\frac{\partial \overline{b^a}}{\partial t} = \underbrace{-\overline{v^a} M^2 - \overline{w^a} N^2}_{\text{Along front}} \underbrace{- \frac{\partial}{\partial y}\overline{\bar{v}^s \bar{b}^s} - \frac{\partial}{\partial z}\overline{\bar{w}^s \bar{b}^s}}_{\text{Submesoscale}} \underbrace{- \frac{\partial}{\partial y}\overline{v^t b^t} - \frac{\partial}{\partial z}\overline{w^t b^t}}_{\text{Turbulence}}$$

$$\frac{\partial \overline{b^a}}{\partial t} = \underbrace{\nabla \cdot \left(\Psi^a \times \nabla \overline{b^a}\right)}_{\text{EKMAN}} + \underbrace{\nabla \cdot \left(\Psi^e \times \nabla \overline{b^a}\right)}_{\text{EDDY}} + \underbrace{\frac{\partial}{\partial z}\left(\kappa N^2\right)}_{\text{Mix}} + RES$$

EKMAN — EDDY — Mix

RES → residual horizontal fluxes





EBF (Thomas 2005)

$$\frac{\tau \times \nabla b}{f \rho_o}$$

MLE Fox-Kemper 2008

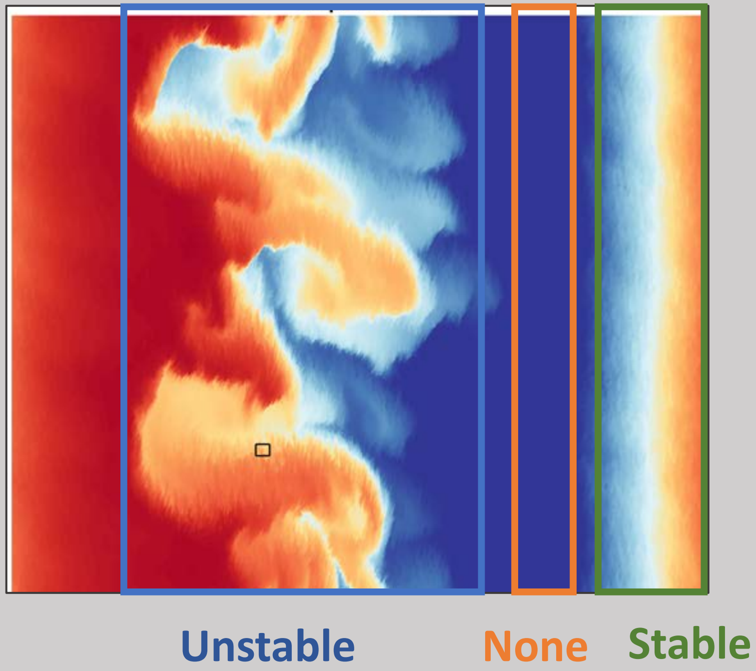
$$c_e \frac{\overline{\nabla b^a}^2 H^2}{f}$$

COMMON SCALINGS CAN BE USED TO ASSESS THE STRENGTH OF THESE TERMS

HOW GOOD OF AN ASSUMPTION IS THIS? →

$$\kappa N^2$$

Your favorite κ here

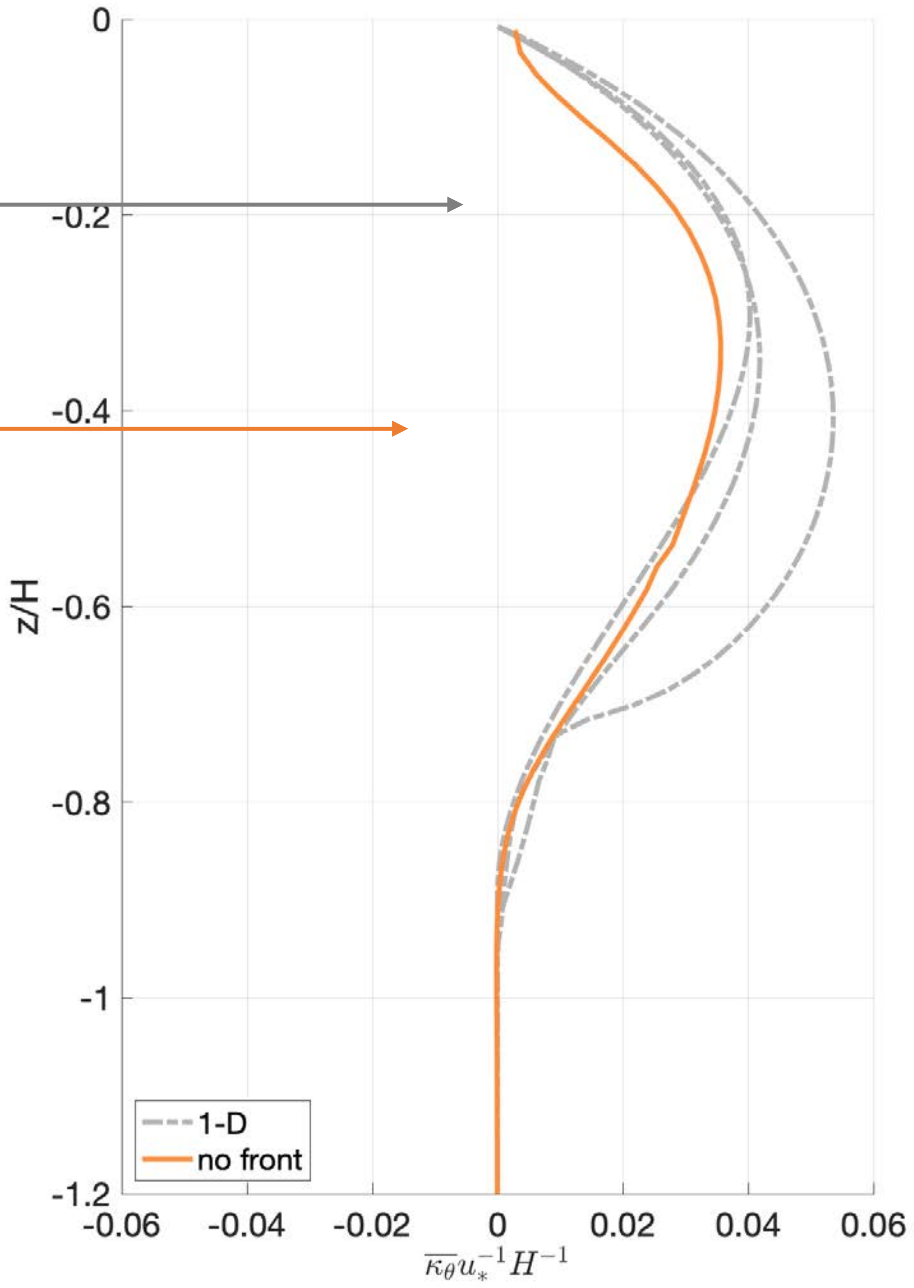


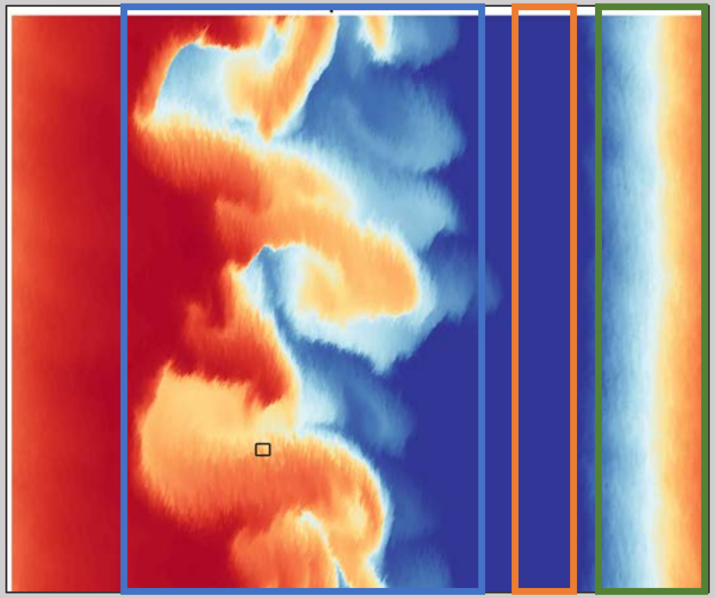
1D models have different parameterized physics

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

$$-\overline{w^t b^t} = \kappa N^2$$

Mix





Unstable None Stable

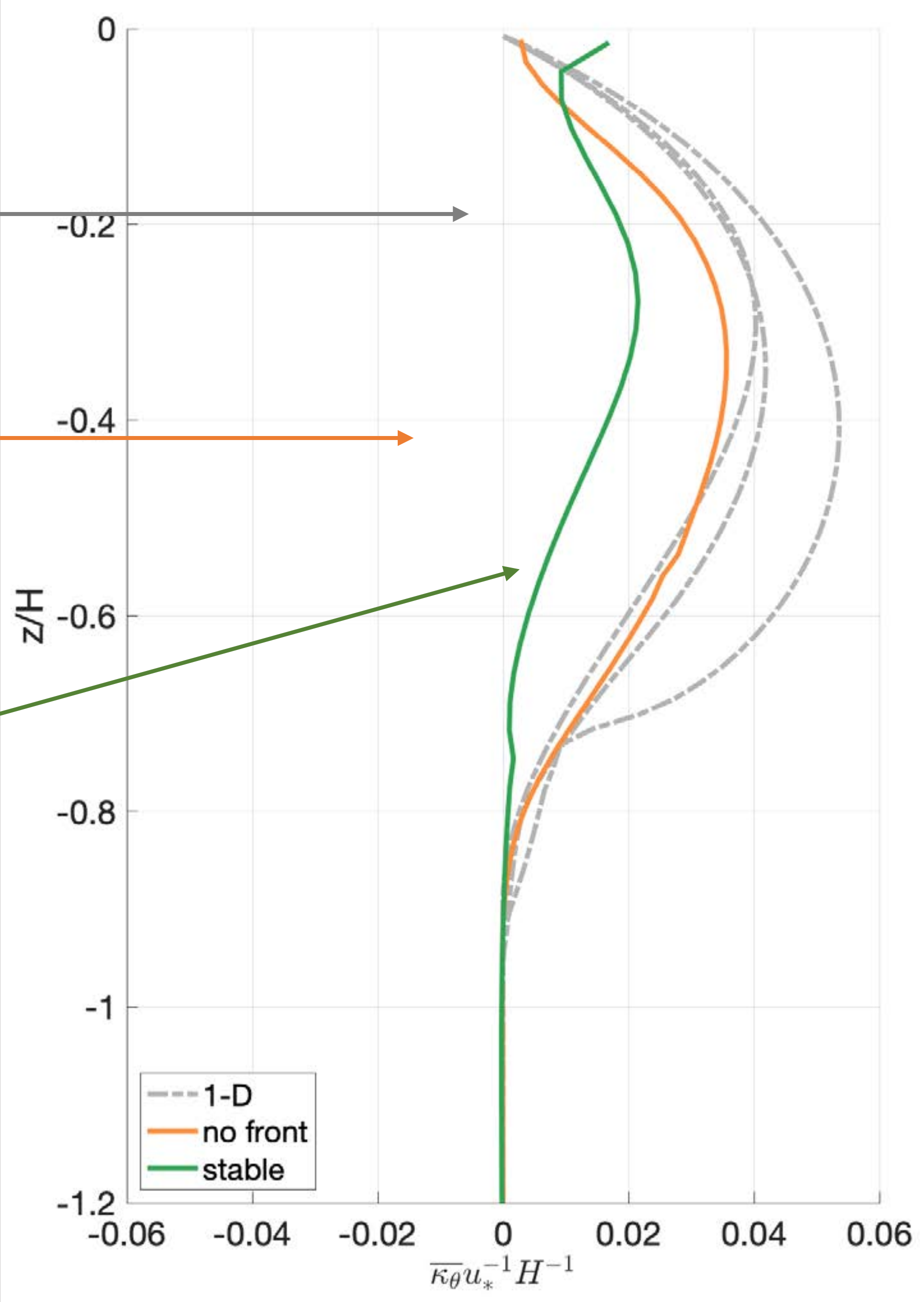
$$-\overline{w^t b^t} = \kappa N^2$$

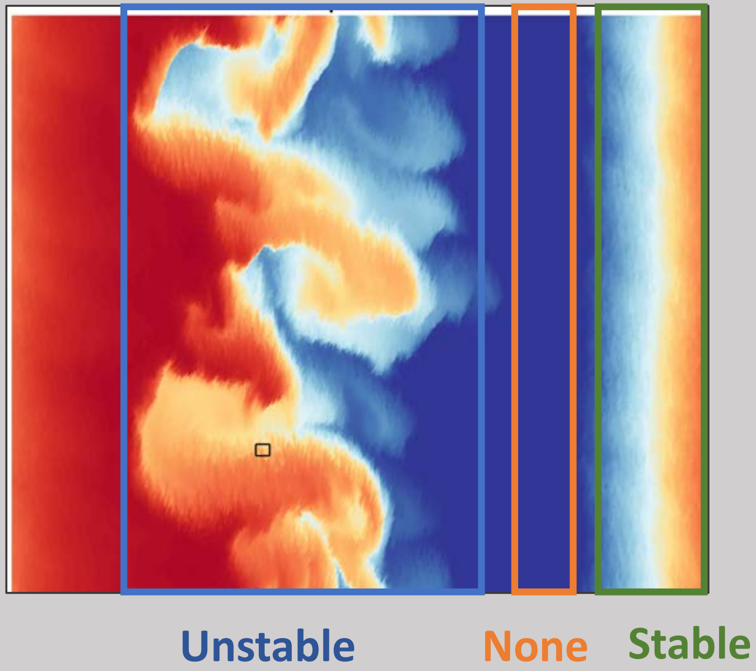
Mix

1D models have different parameterized physics

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

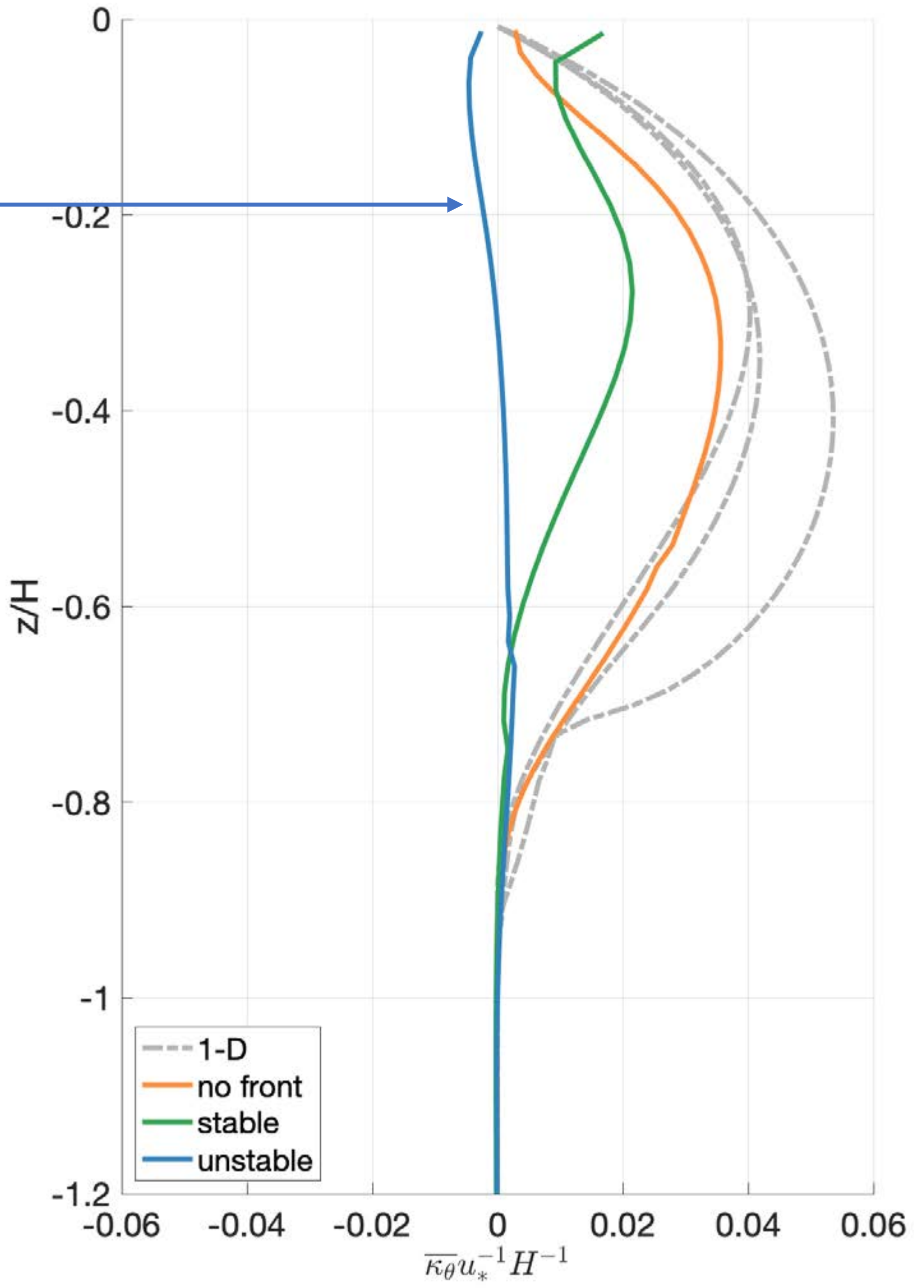
Suppressed mixing in **stable** region

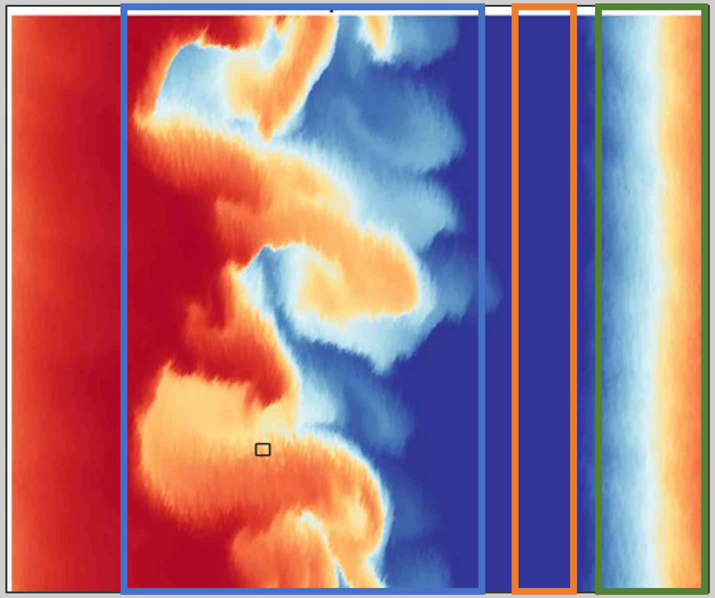




Mixing in **unstable** region near zero

$$\underbrace{-\overline{w^t b^t} = \kappa N^2}_{\text{Mix}}$$





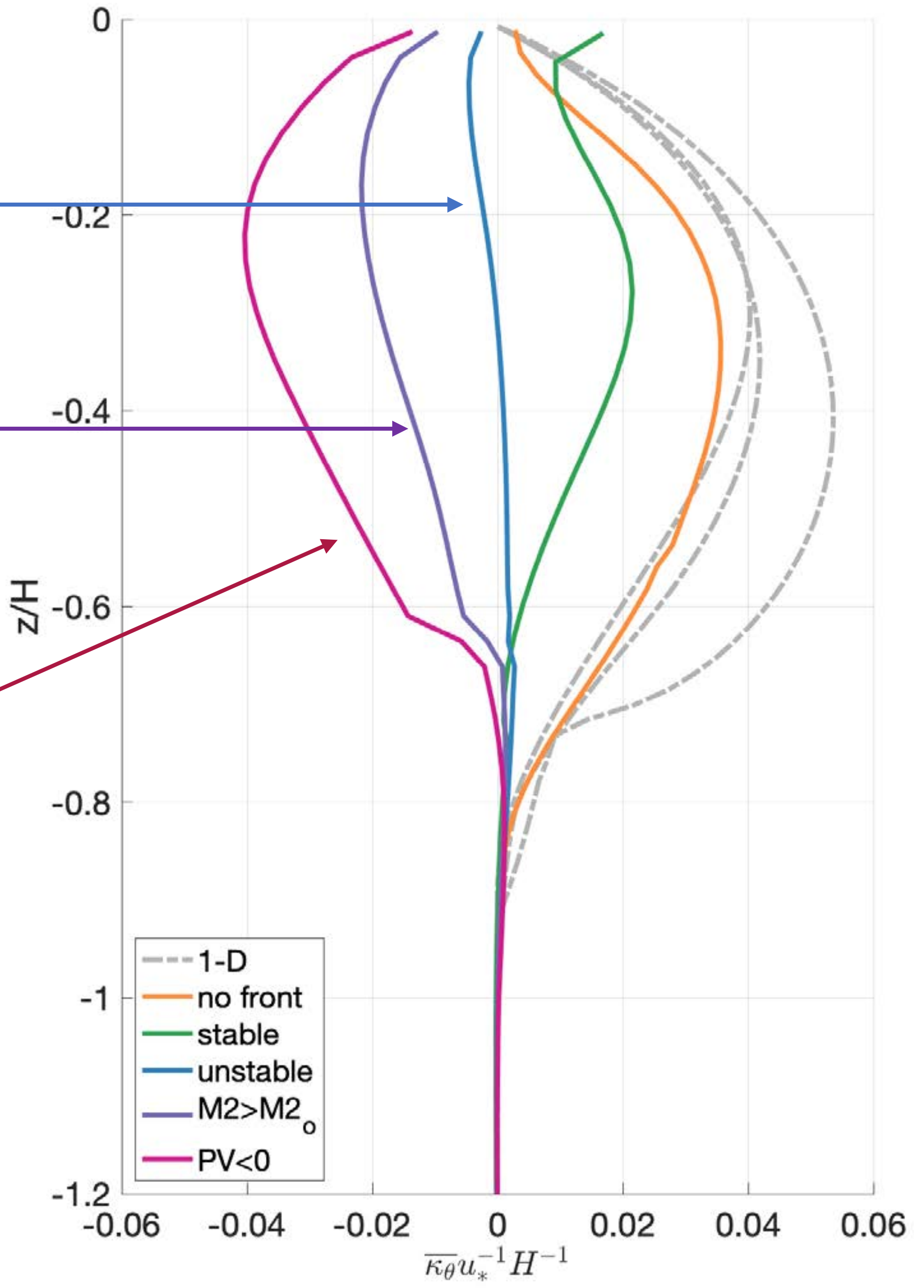
Mixing in **unstable** region near zero

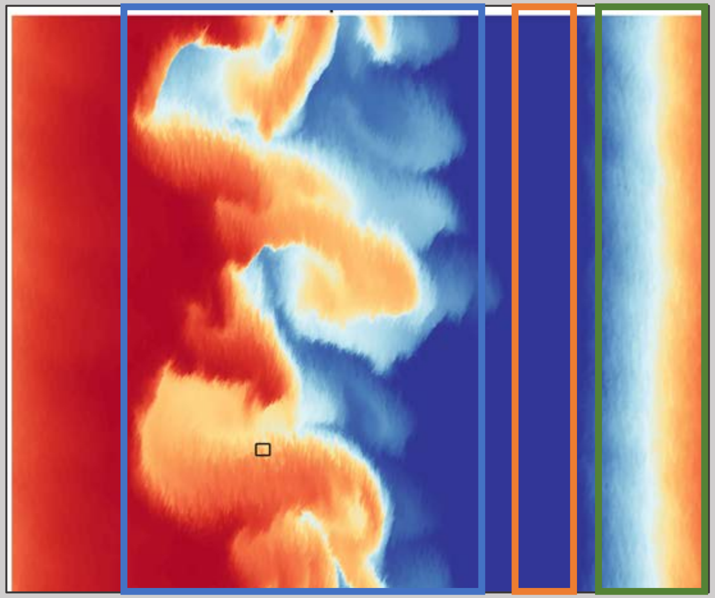
Strong fronts have counter gradient fluxes

PV<0 has strongest counter gradient fluxes

$$-\overline{w^t b^t} = \kappa N^2$$

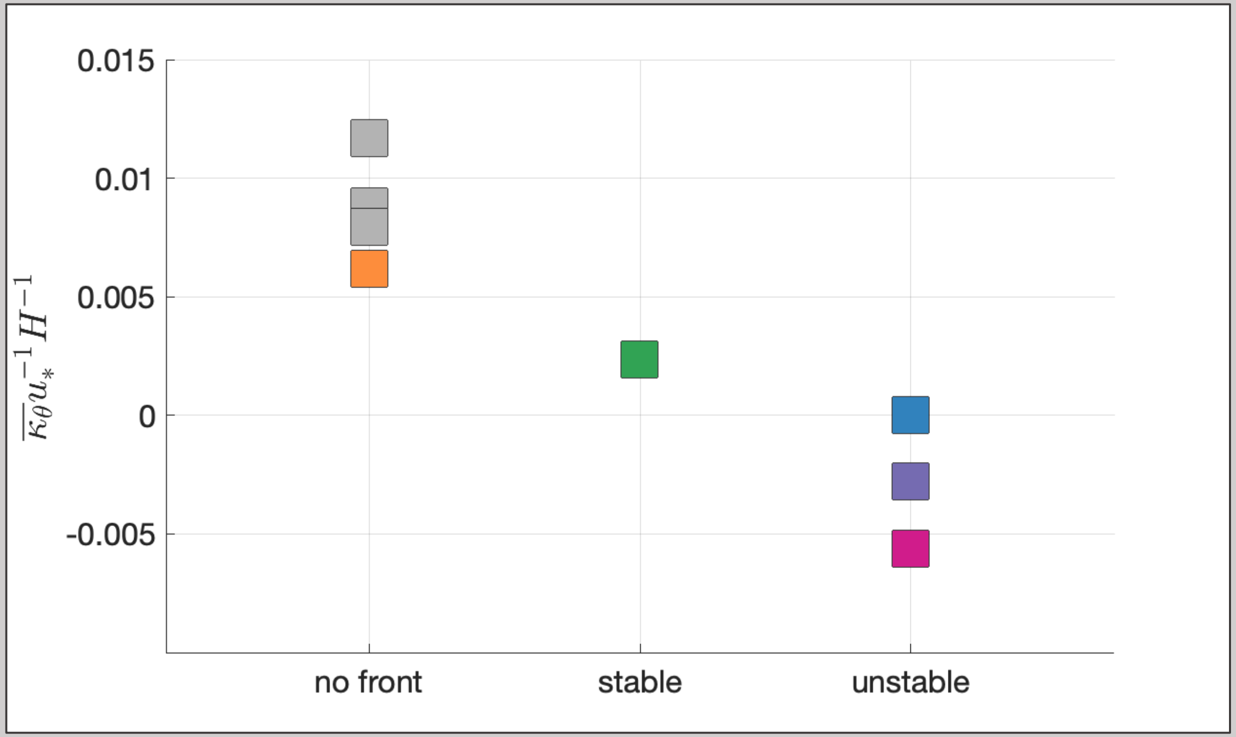
Mix

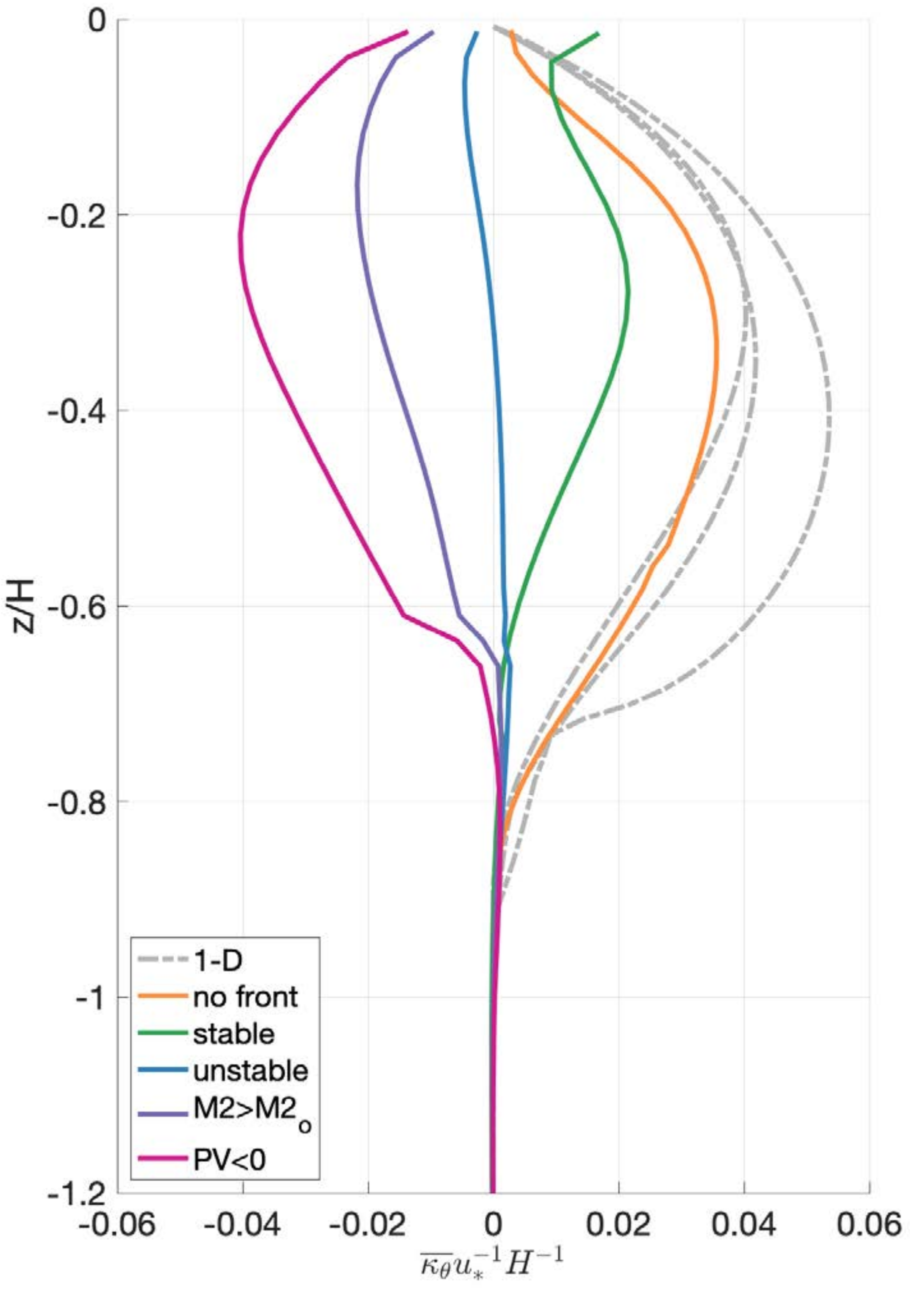


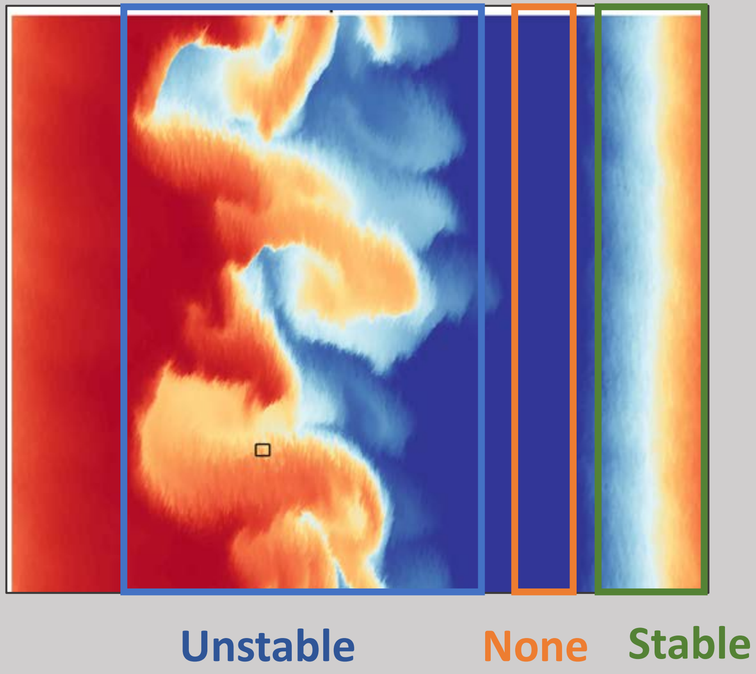


RECAP

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





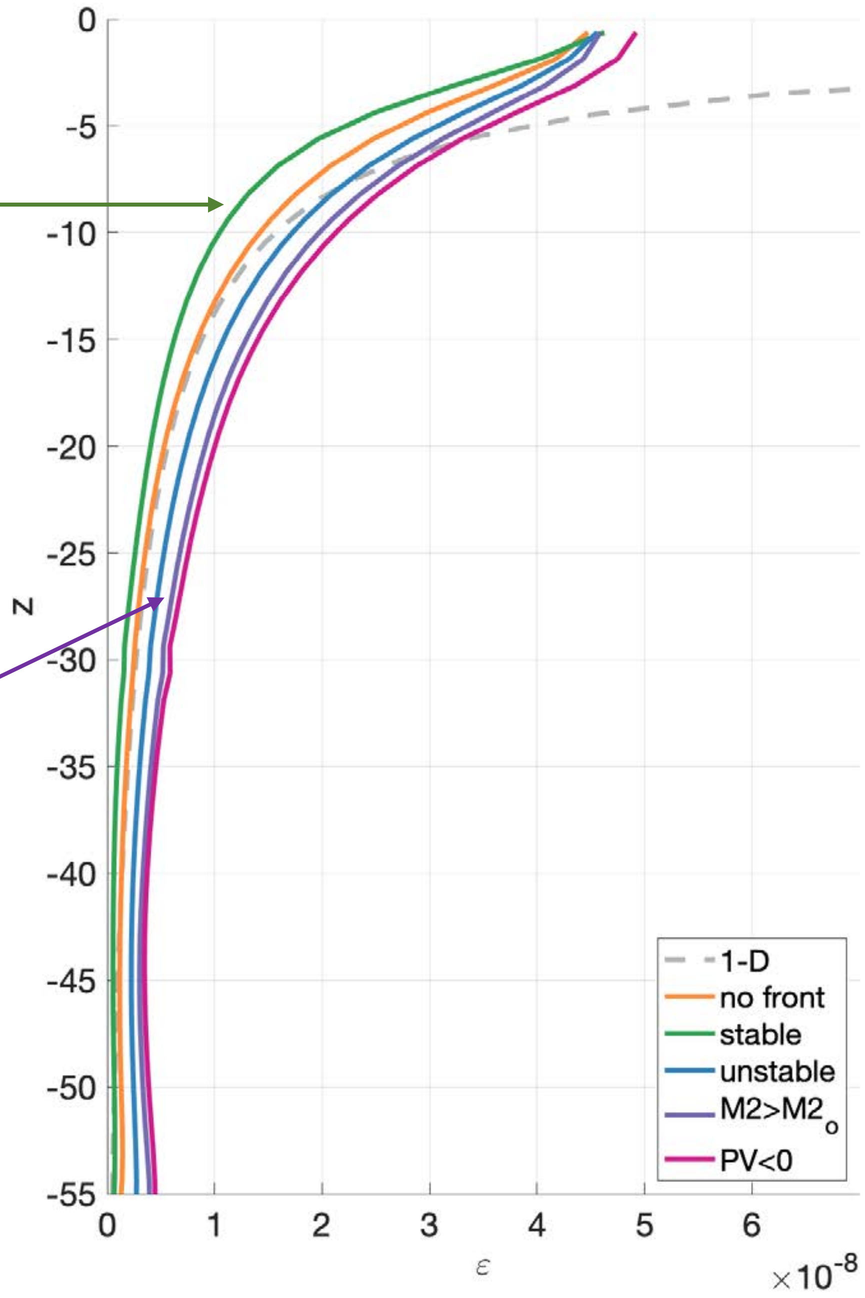


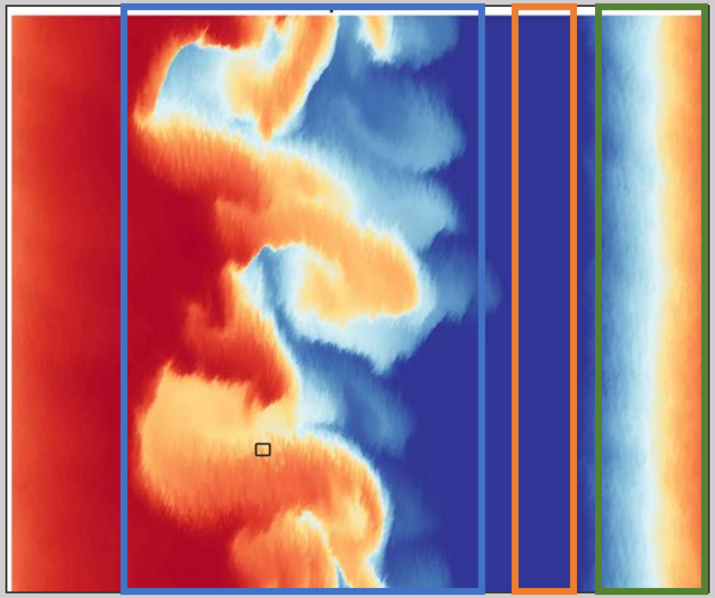
$$\varepsilon \sim \frac{u_*^3}{0.4z}$$

Turbulent Dissipation Rate

Dissipation rate is suppressed in **stable**

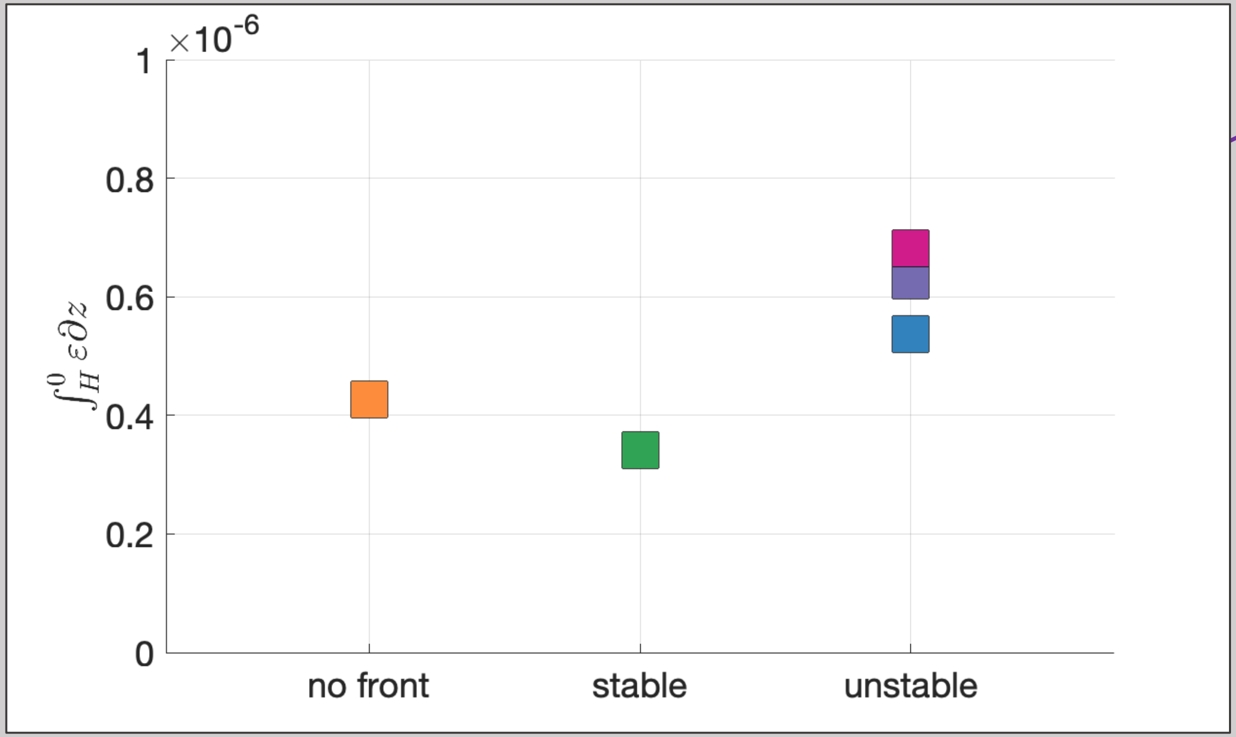
Strong fronts and **PV<0** have larger dissipation rates

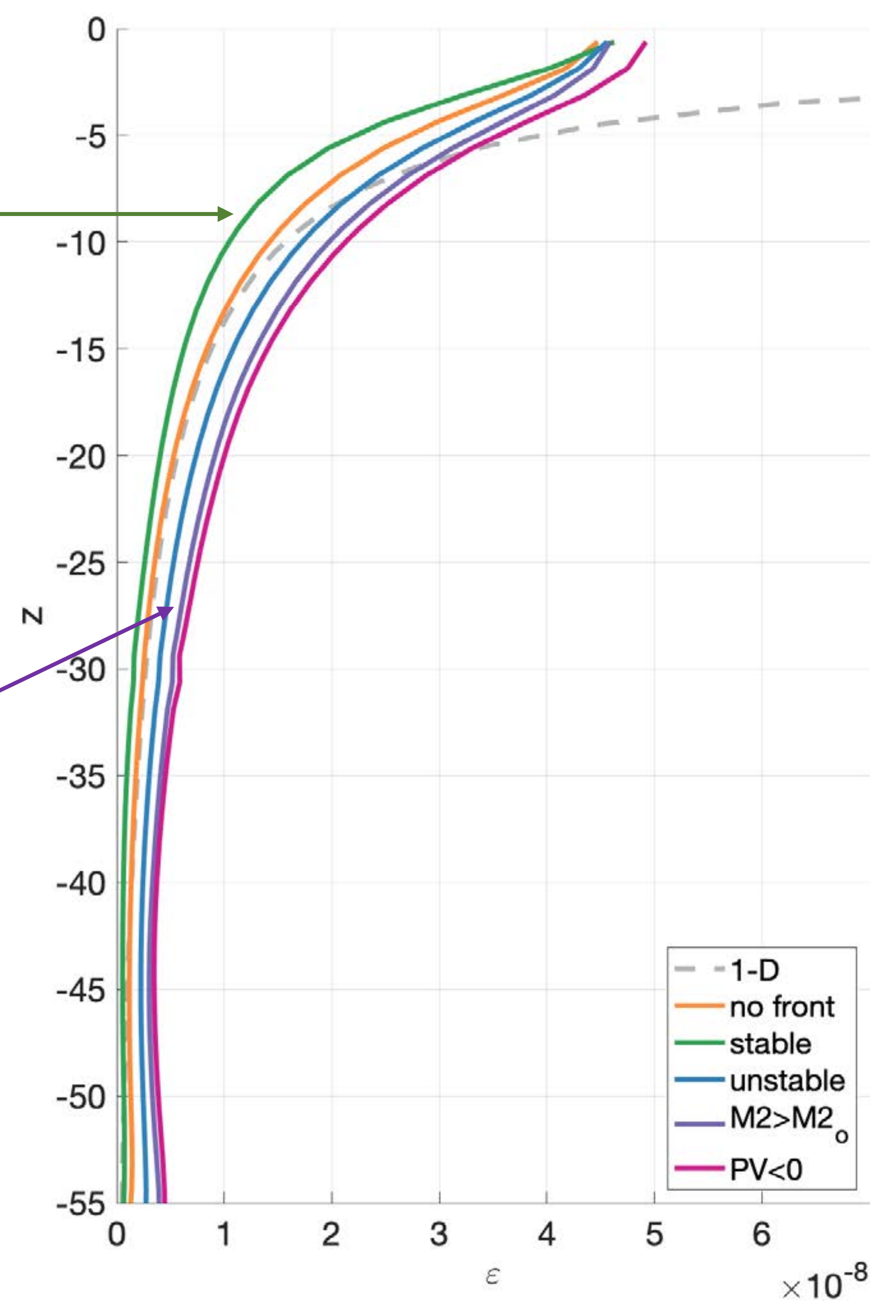


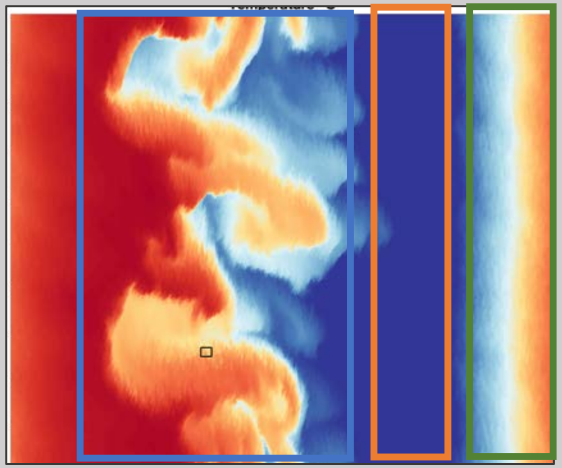


RECAP

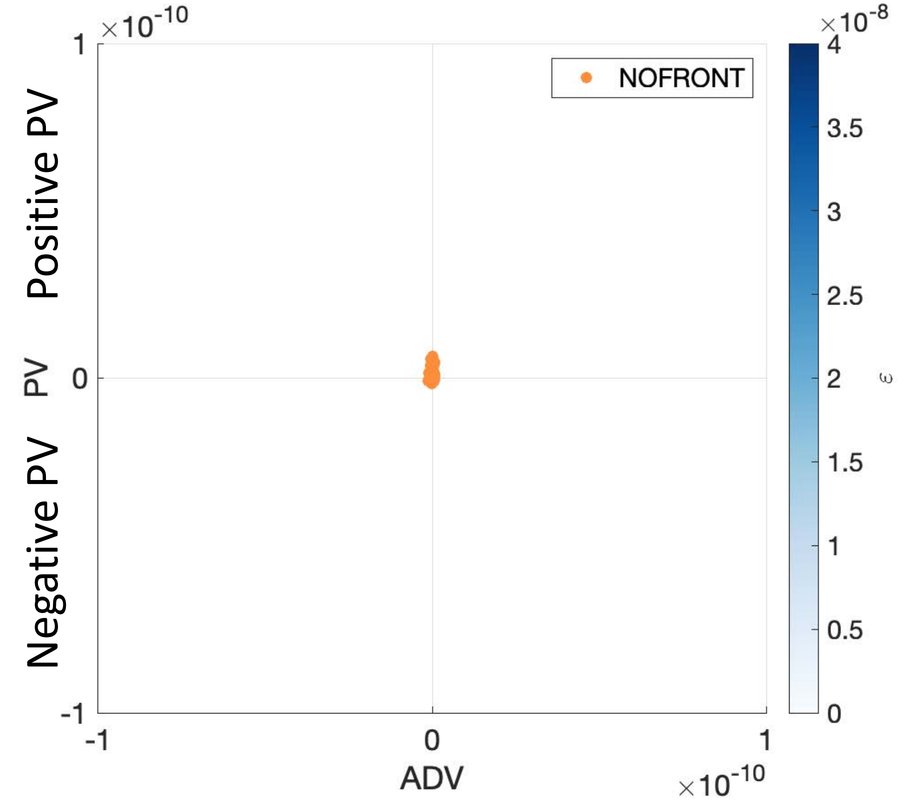
Turbulent dissipation is suppressed in **stable** and enhanced in **unstable**.

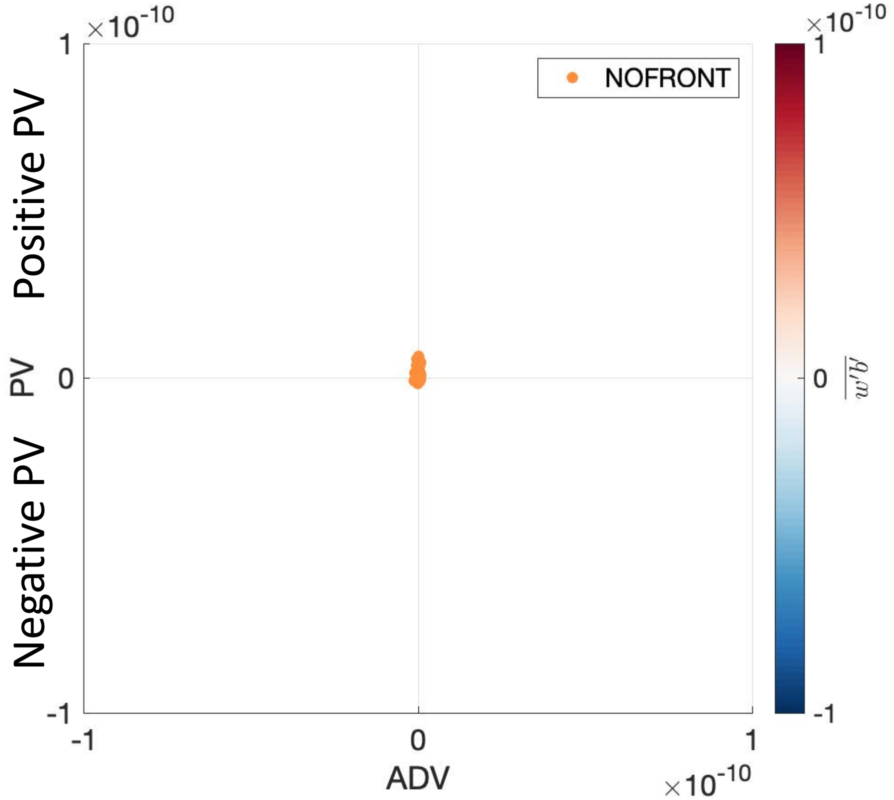




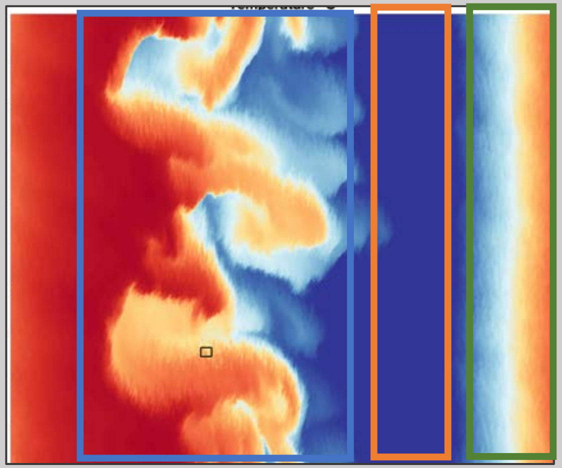


Turbulence statistics vary across regimes





Mixing Restratification Mixing Restratification



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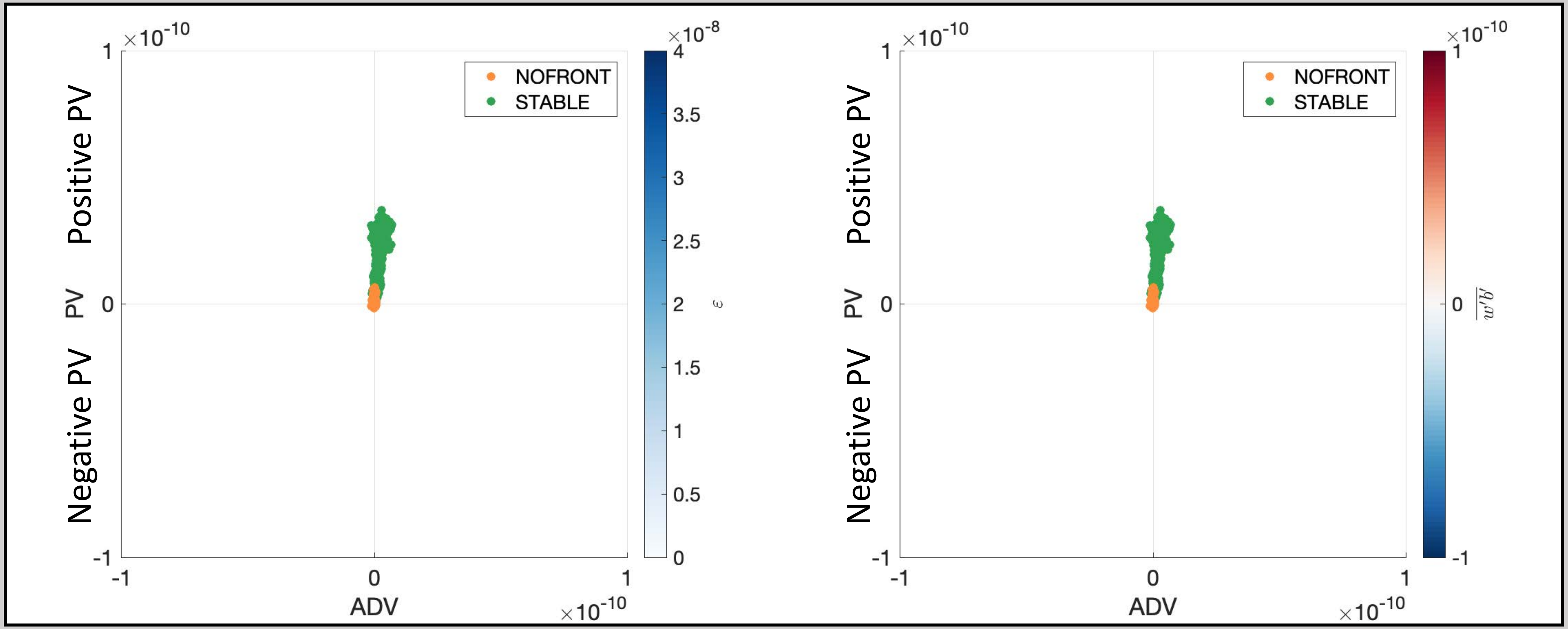

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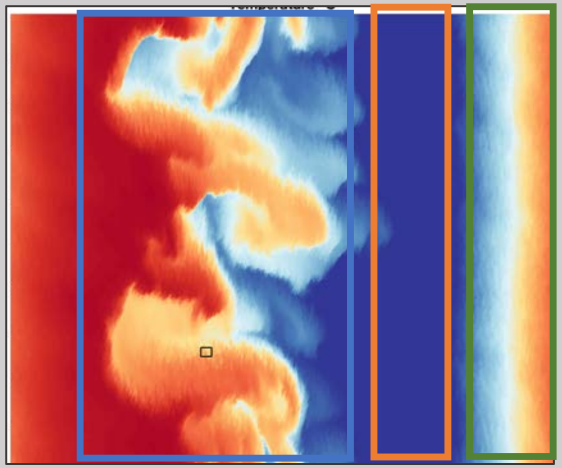

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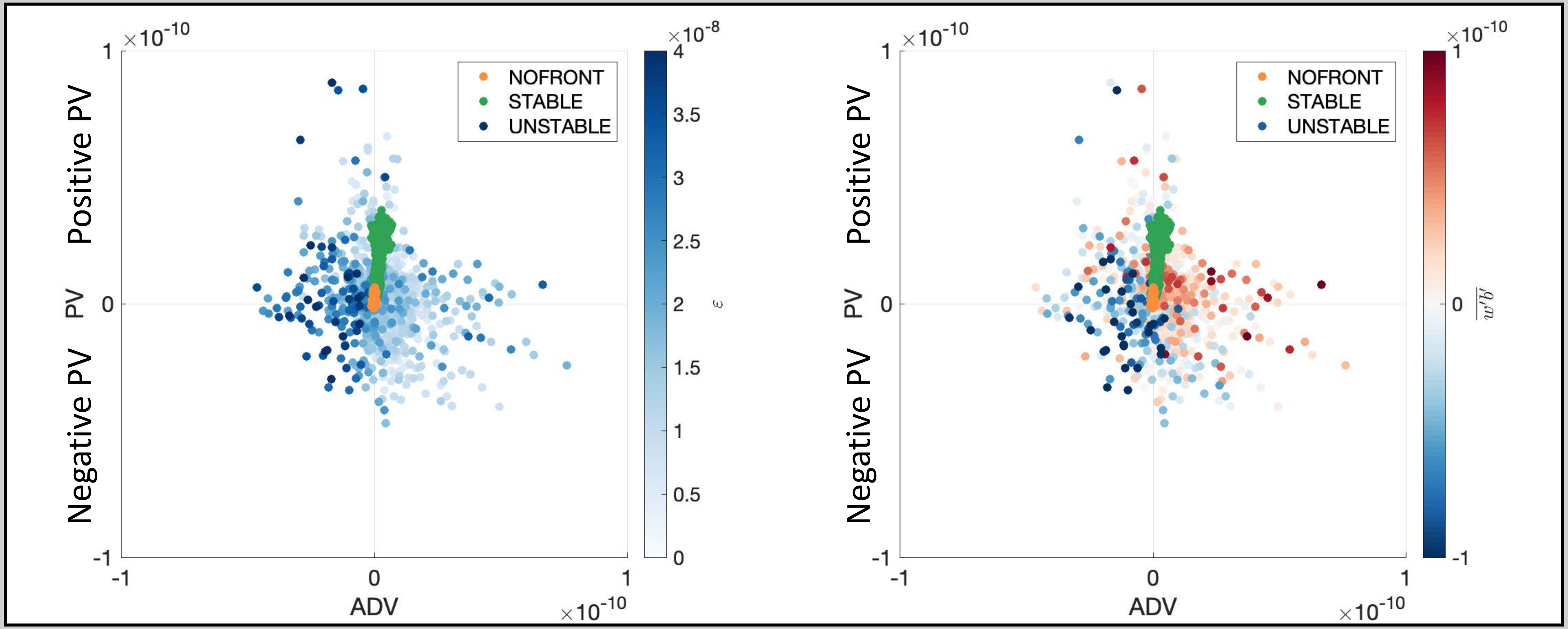
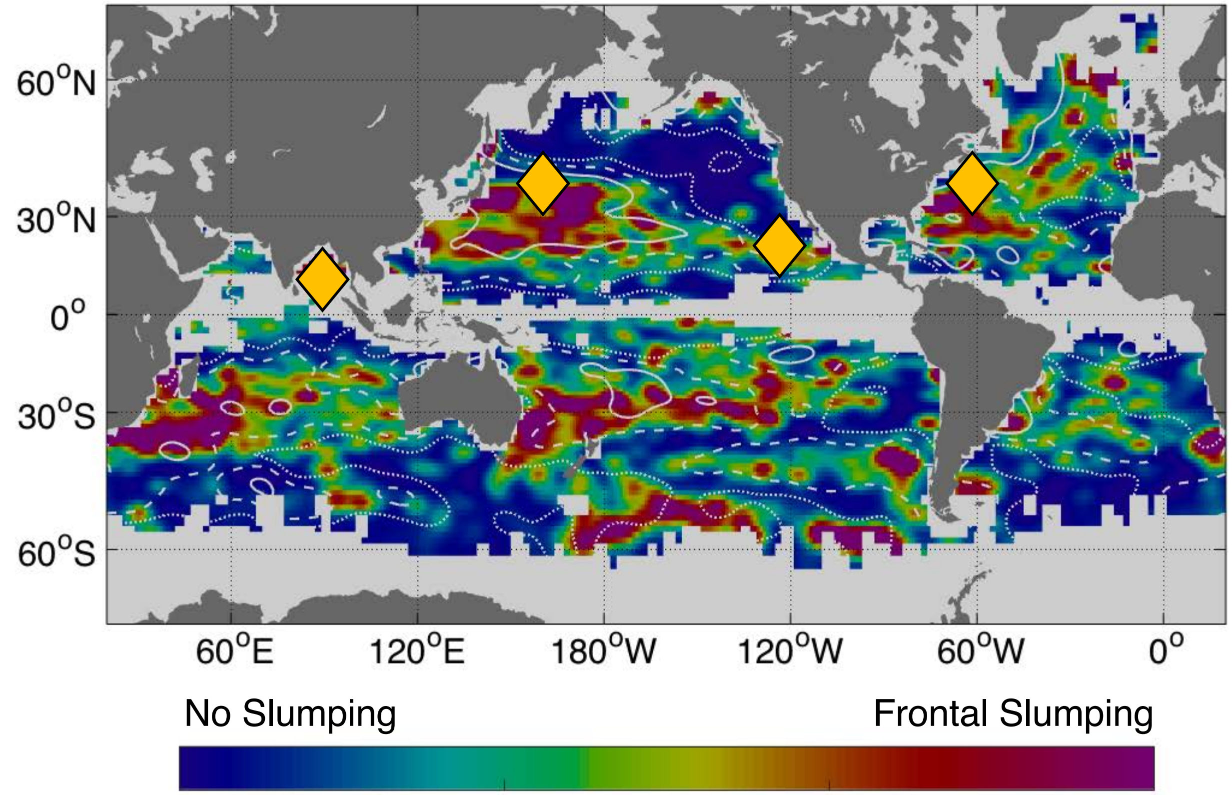
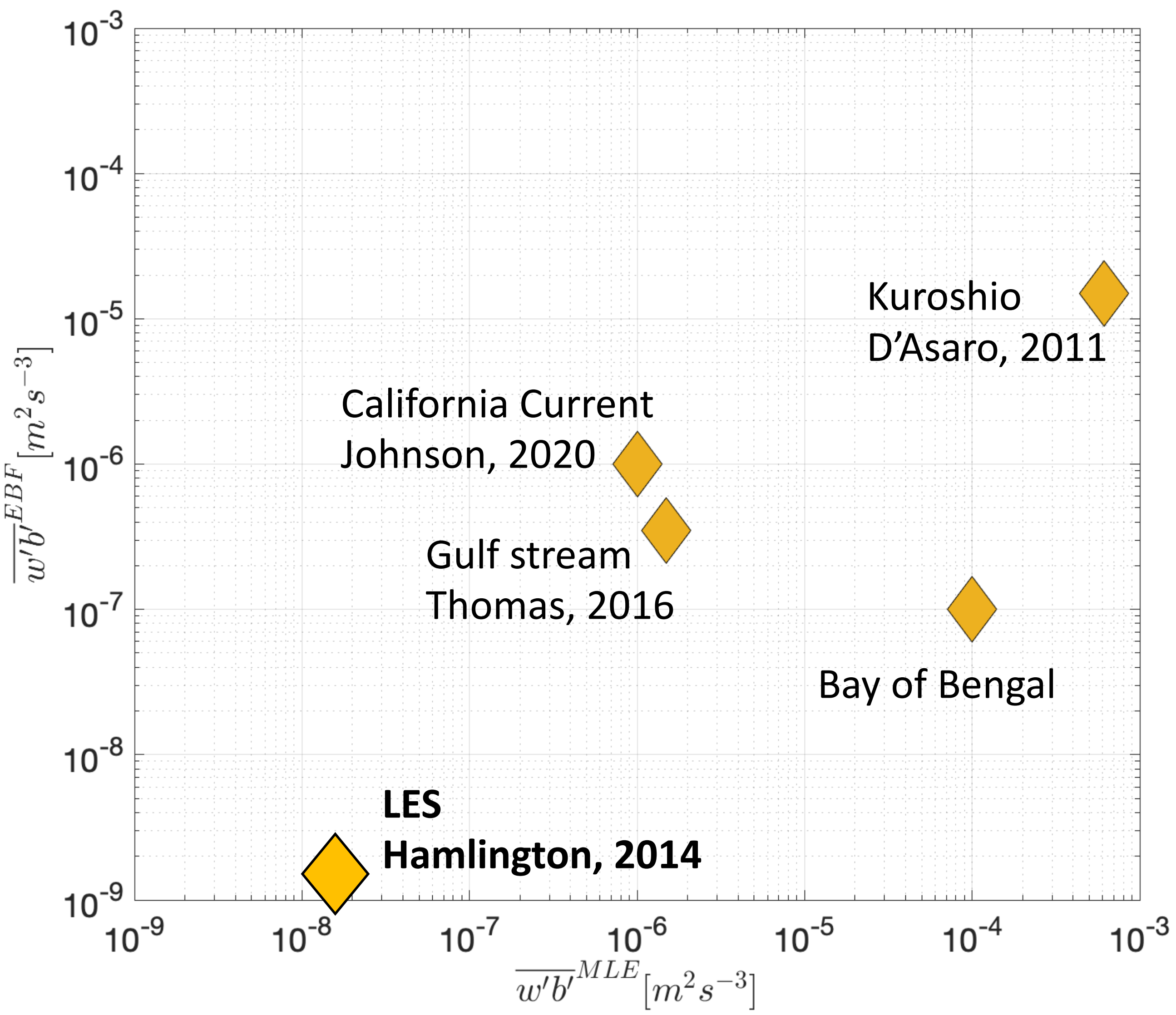


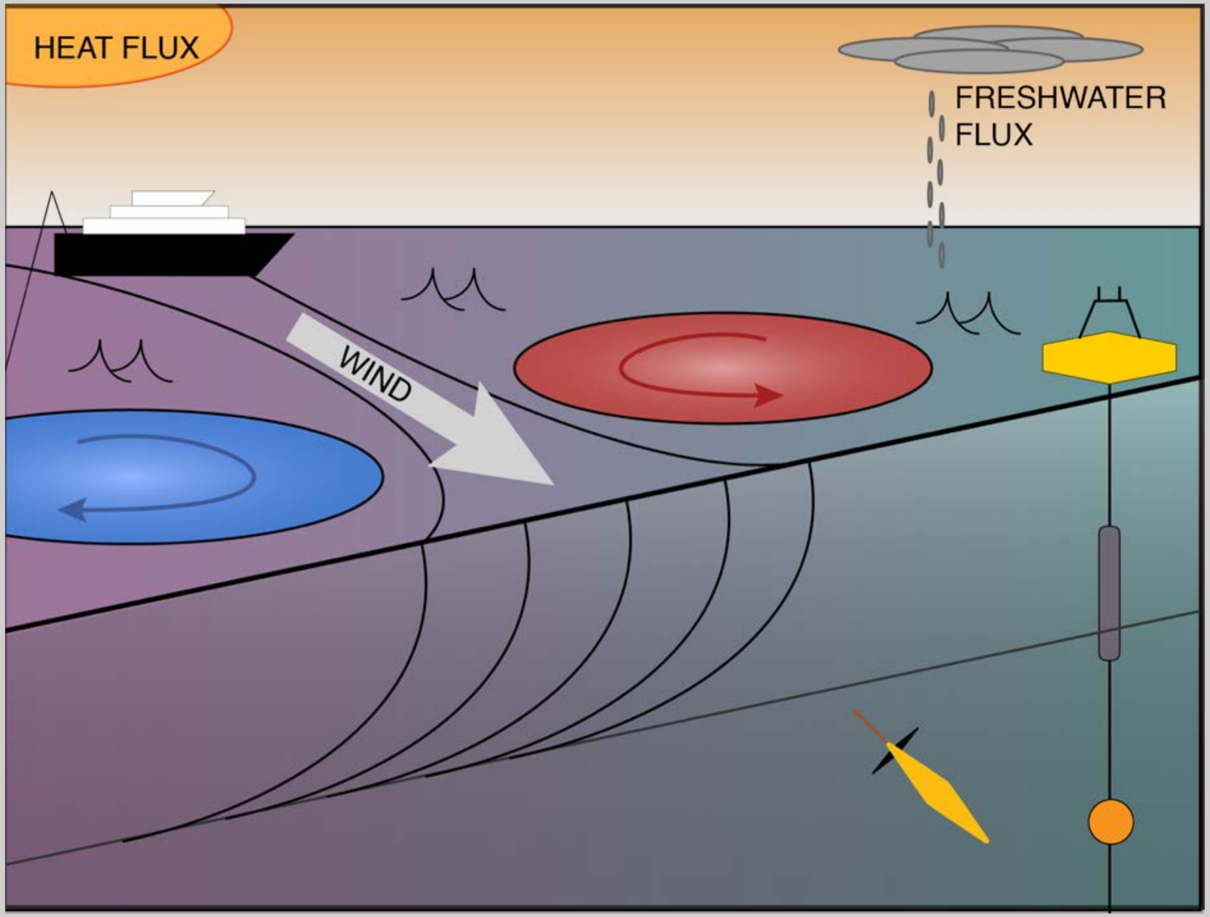
Mixing Restratification Mixing Restratification



Johnson, et al. 2016. JPO



FINAL SUMMARY



- 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.