Langmuir Turbulence and Symmetric Instabilities in Submesoscale Fronts

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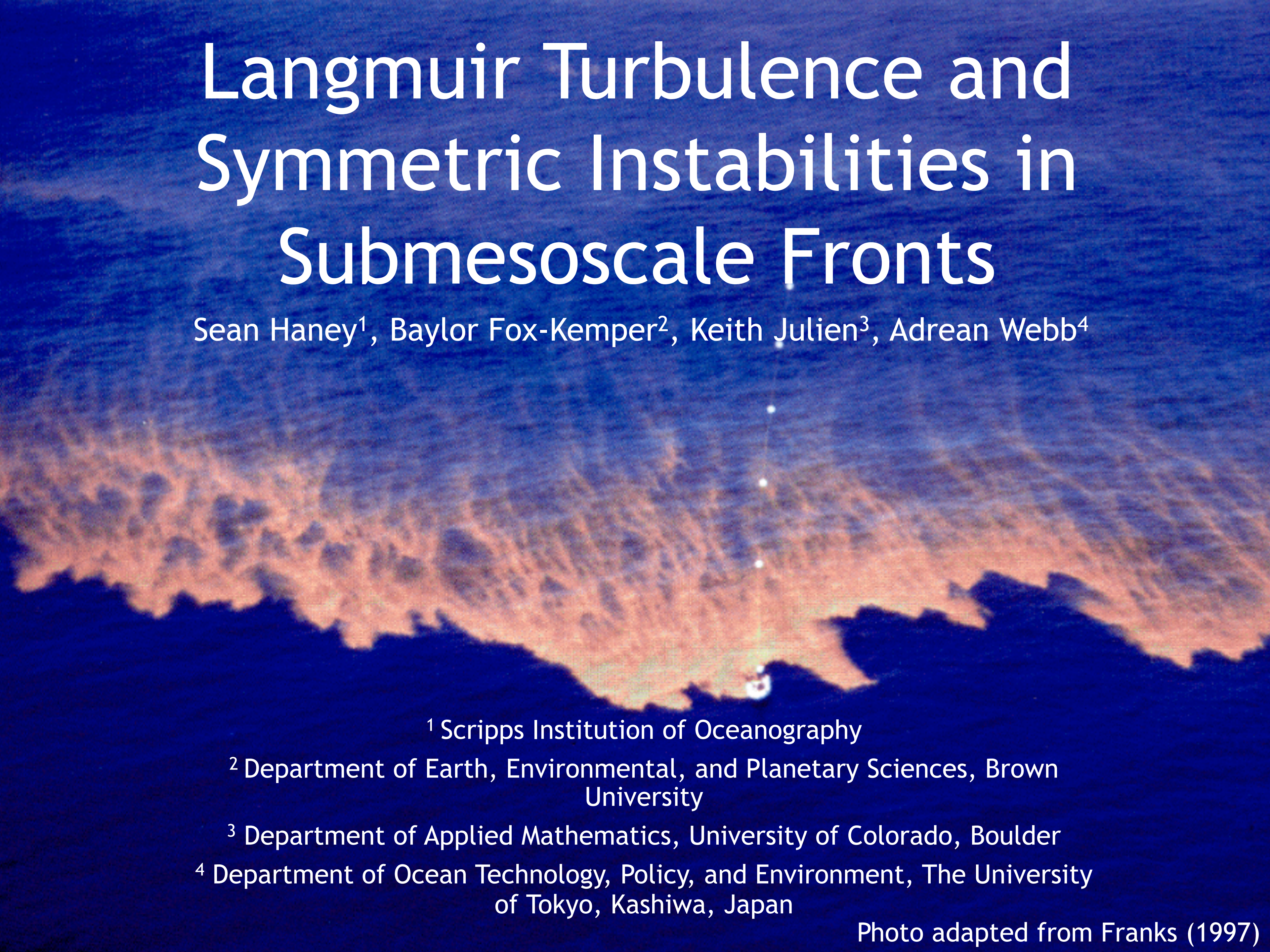
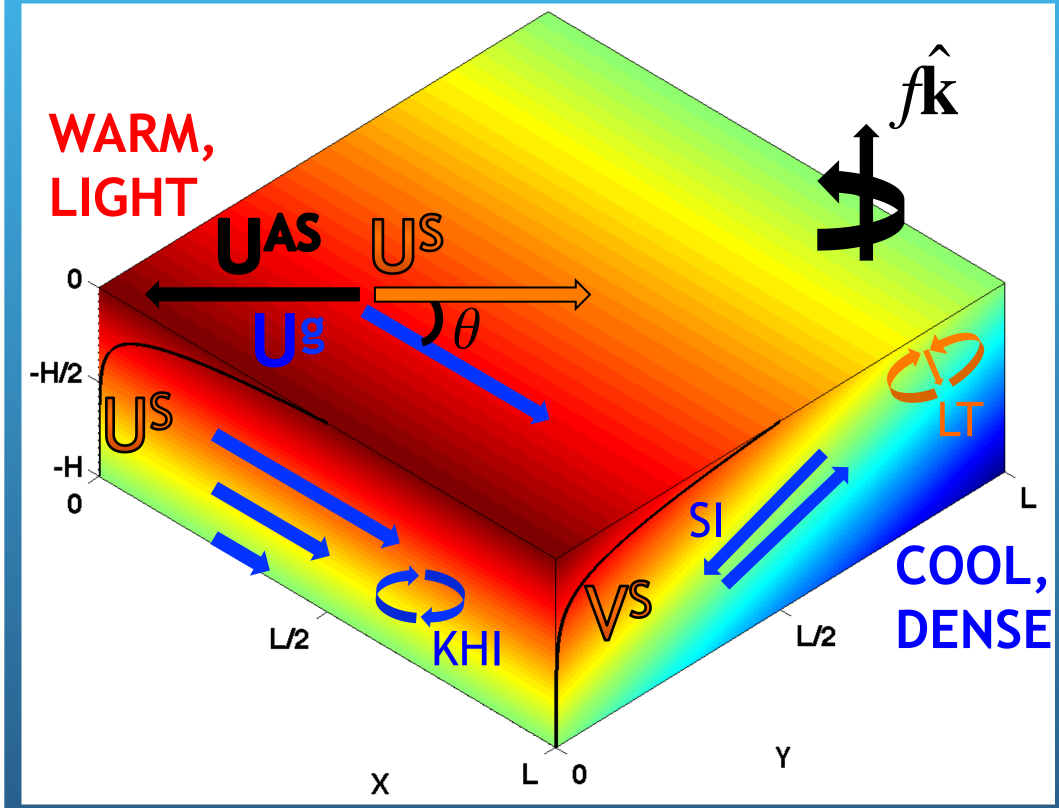


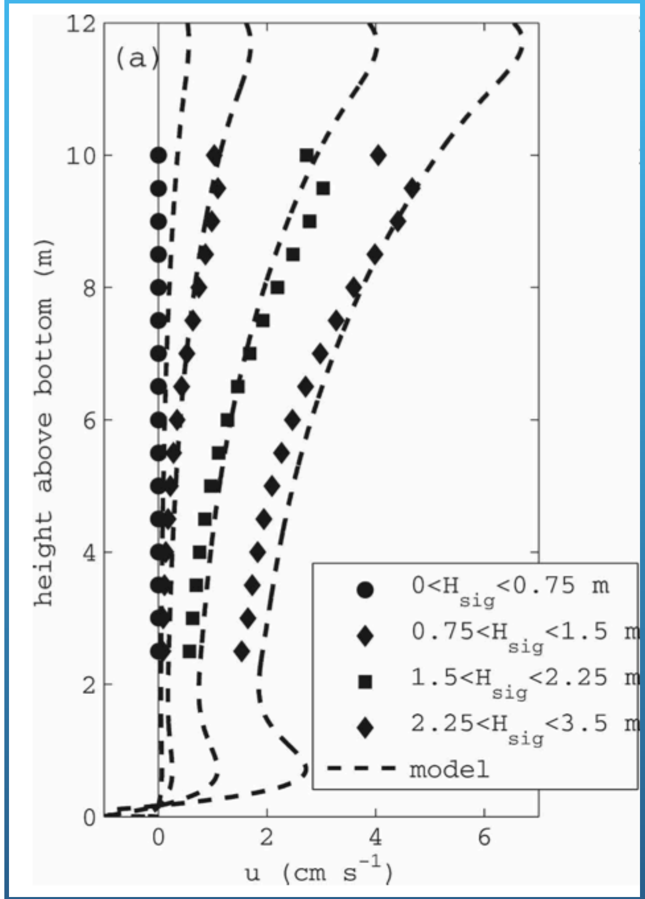
Photo adapted from Franks (1997)

Conspiring or Competing Shears?

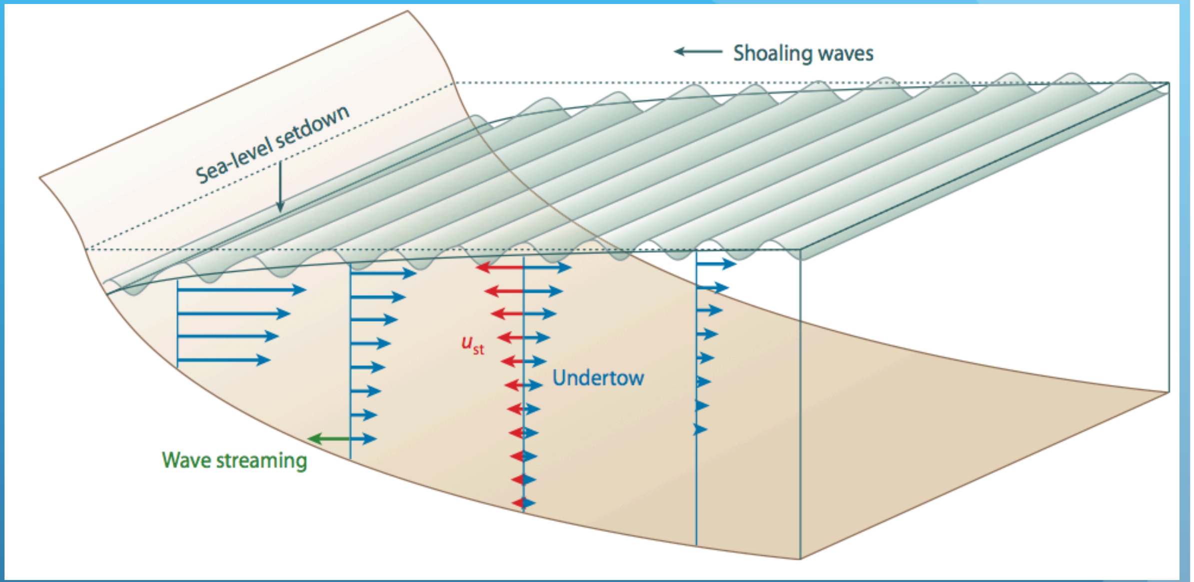


- Symmetric instability (SI) is unstable when the PV takes the opposite sign to f, though often the criterion Ri<1 is referred to.
- How might the addition of Stokes shear change the criterion for SI?
- How does Langmuir turbulence (LT) behave in the presence of a front (with geostrophic shear, vertical/horizontal stratification, etc.)?

Anti-Stokes Flow is Observed in Cross-Shelf Transport



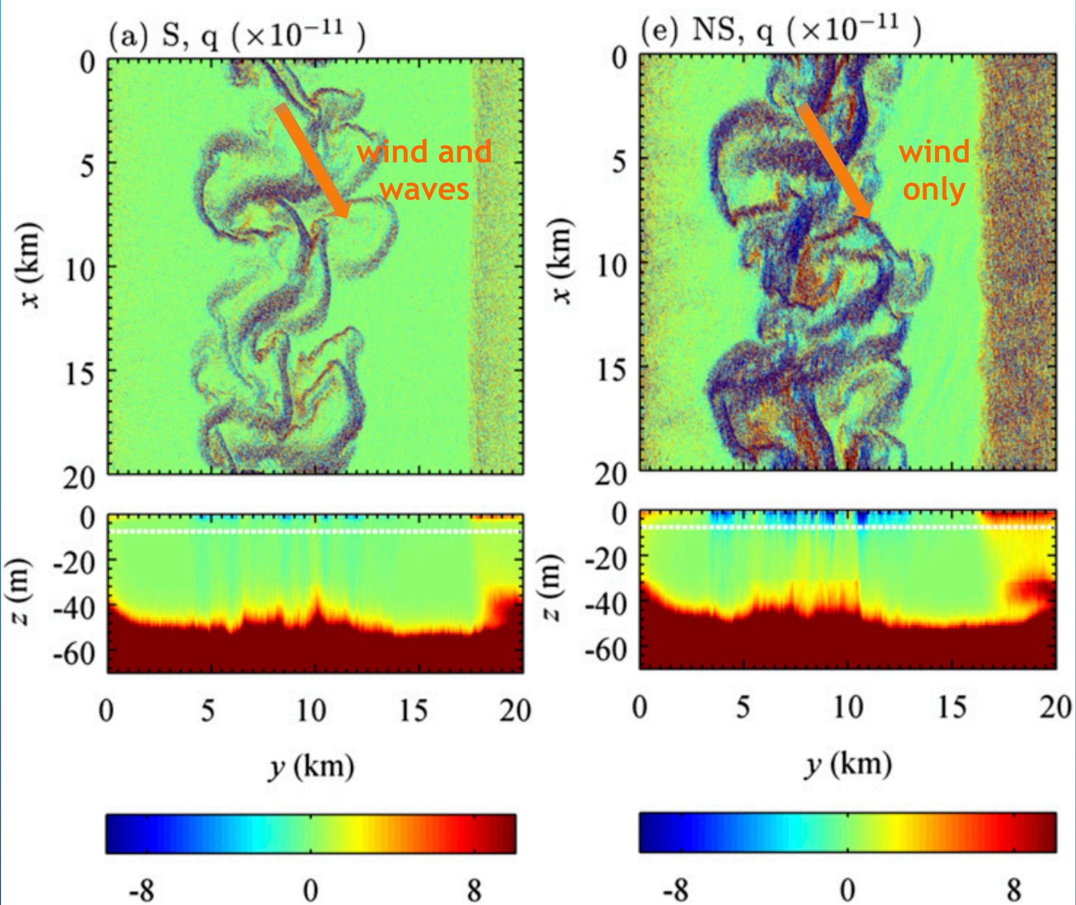
ADCP vs Anti-Stokes flow
Martha's Vineyard Coastal Observatory
Lentz et al. 2008



Lentz and Fewings 2013

"…the model profiles with small eddy viscosity… or the $-u^{st}$ [anti-Stokes] profiles accurately reproduce the magnitude and vertical structure of the bin-averaged cross-shelf velocity profiles."

Stokes Drift Affects PV

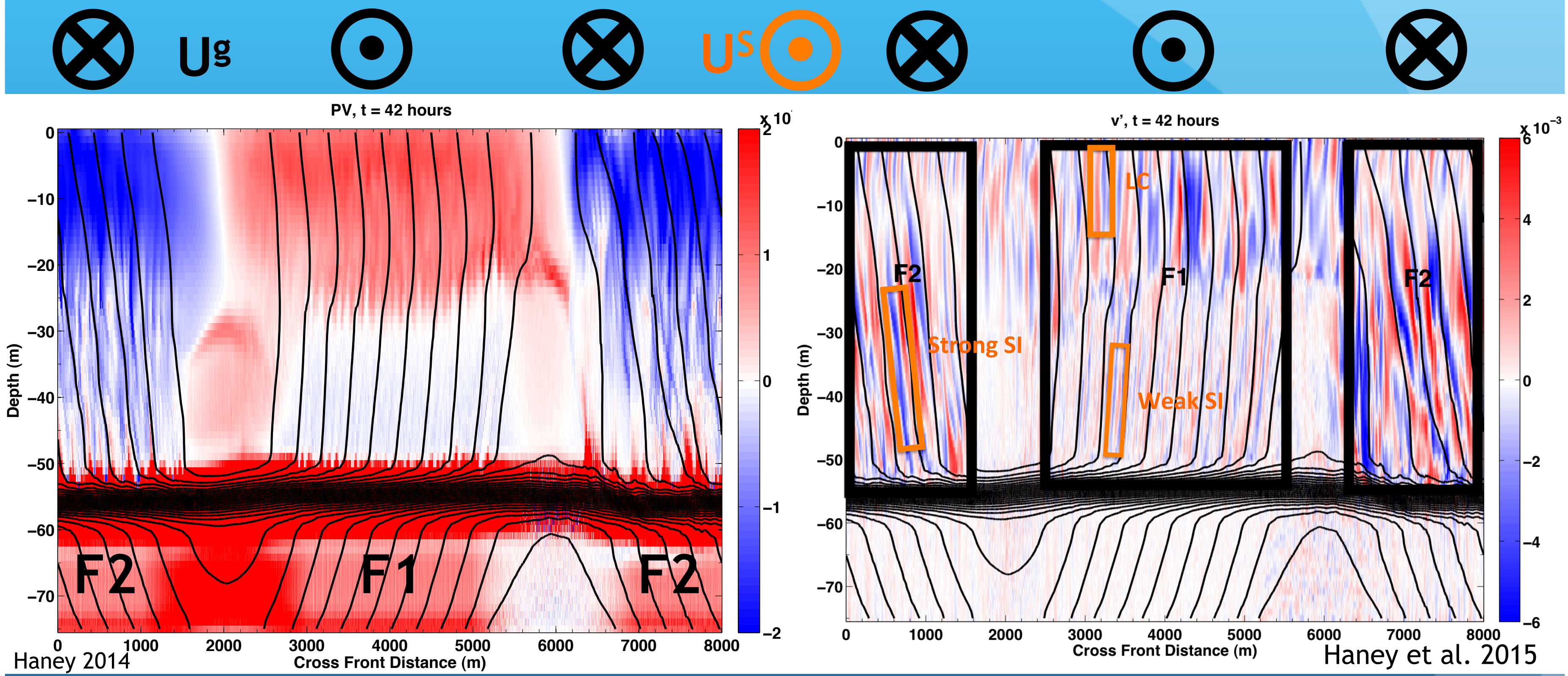


Adapted from Hamlington et al. 2014

- Weaker negative PV when waves are propagating down front.
  - Is Stokes drift energizing SI?
  - Is LT destroying the PV before SI kicks in?
  - Is the PV flux different?
- The waves (Stokes drift) cannot create or destroy PV, but can sharpen or slump fronts (See Nobuhiro Suzuki's poster) thereby possibly making the PV flux different than the waveless case.

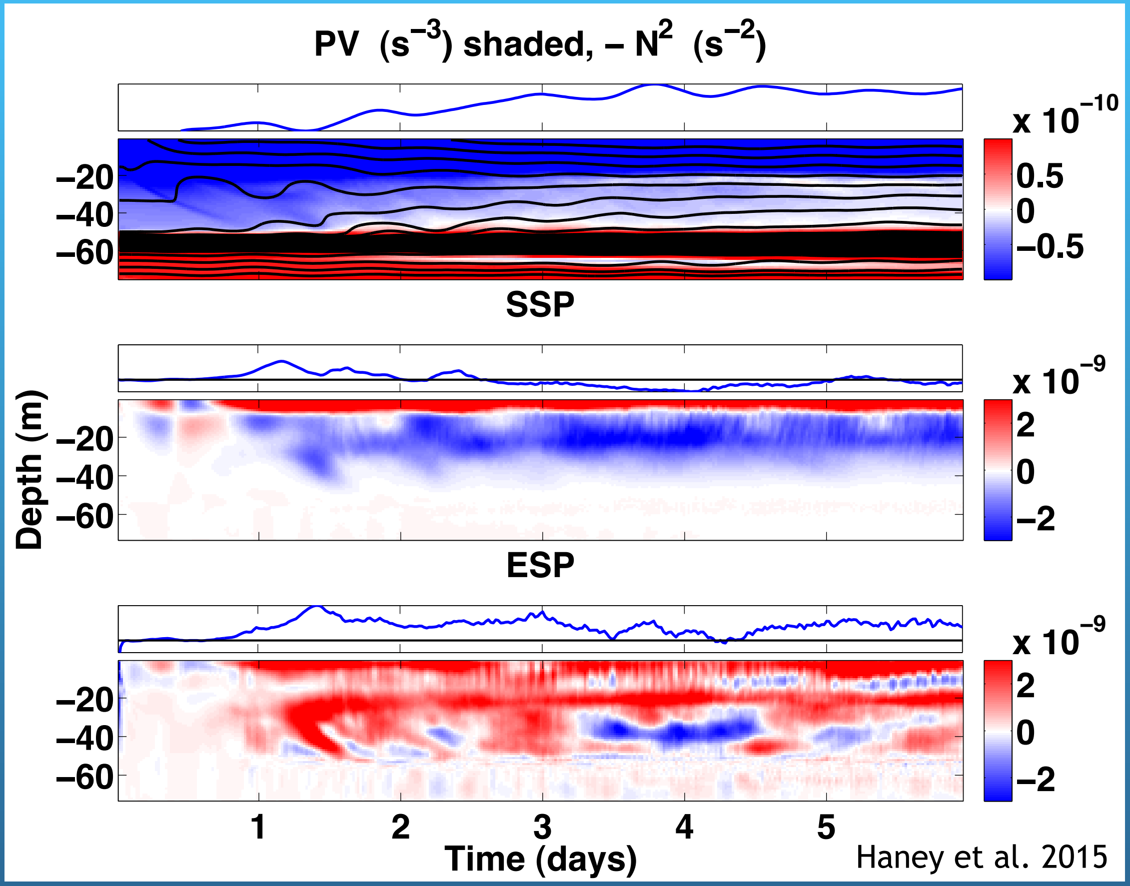
PV<0 is Nesessary for SI with Stokes

Ri = 0.5, μ = 2



- Repeating Hoskins (1974) with linear Stokes profile shows that PV<0 is necessary for SI.
- Stokes-Ekman-Front layer yields an Ekman transport to the left, destabilizing F1 while stabilizing F2.

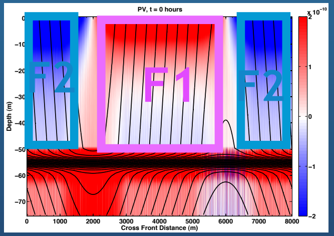
Stokes Shear does NOT Energize SI



$$SSP = -\overline{\mathbf{u}'w'} \cdot \overline{\mathbf{U}}_z^S$$

$$ESP = -\overline{\mathbf{u}'w'} \cdot \overline{\mathbf{U}}_z$$

- SSP<0 where SI dominate the flow.
- SI can only extract energy from down front shear.
- Therefore down front waves (Stokes drift) that may come along with down front winds would not energize SI.



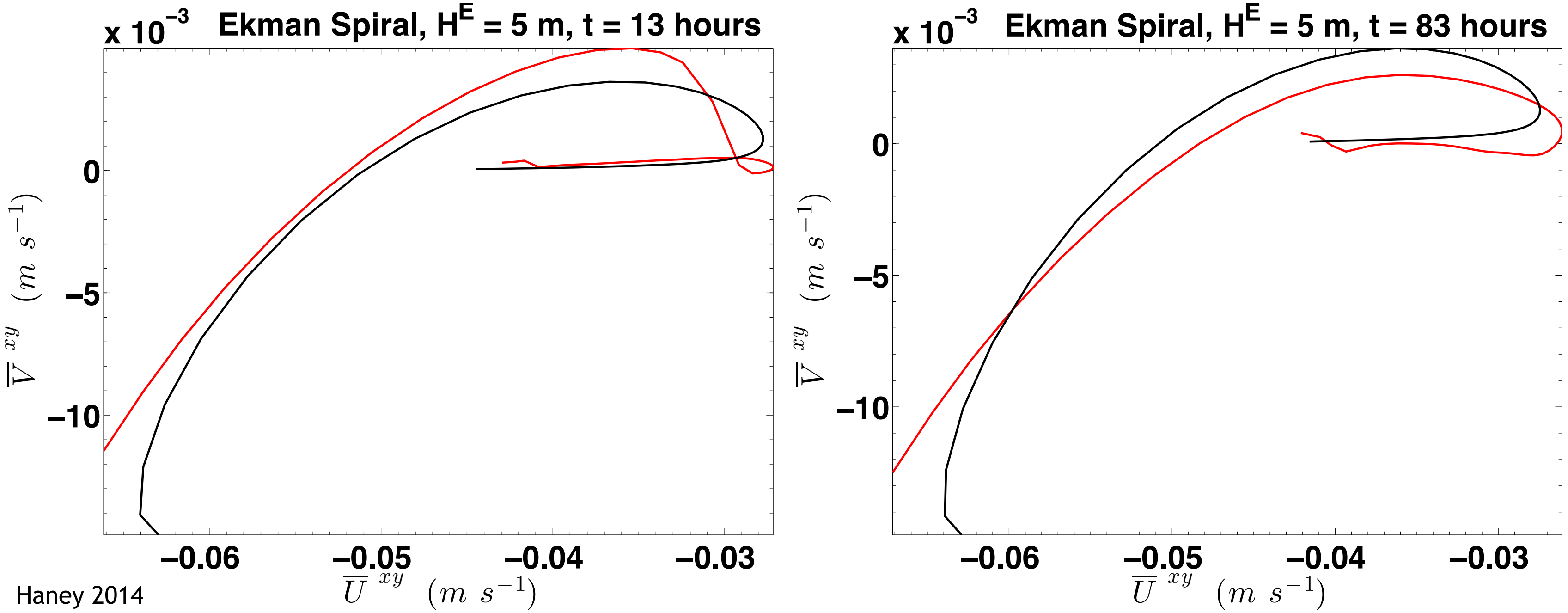
Stokes-Ekman-Front Layer

– Analytic Solution

$$U + iV = H^E \left[\tau^{wind} - U_z^g \Big|_0 - \frac{U_z^S \big|_0}{(H^E / H^S)^2 - 2i} \right] e^{z/H^E} + U^g + \frac{U^S}{(H^E / H^S)^2 - 2i} e^{z/H^S}$$

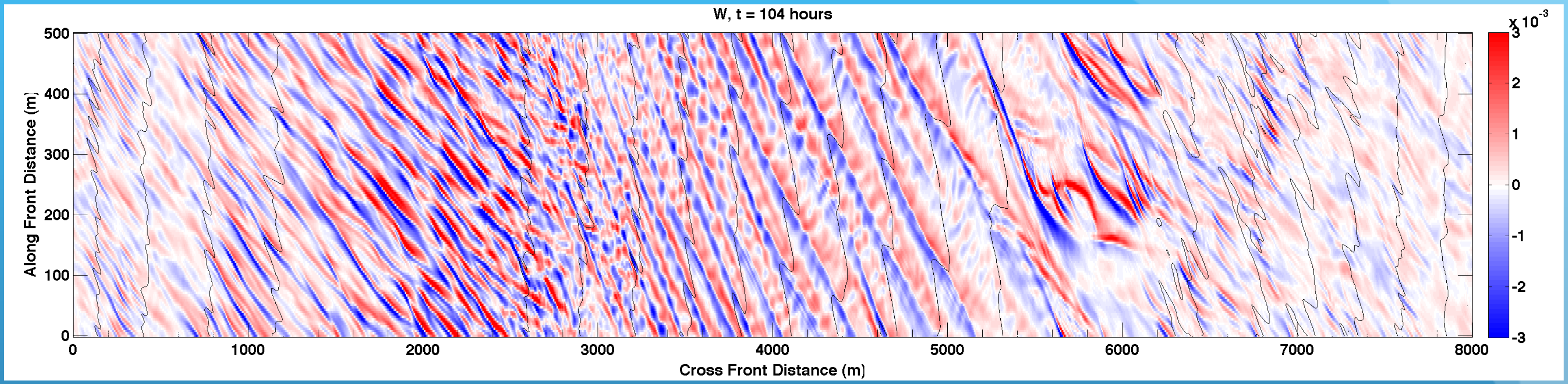
Gnanadesikan and Weller (1995), Polton et al. (2005), McWilliams et al. (2014)

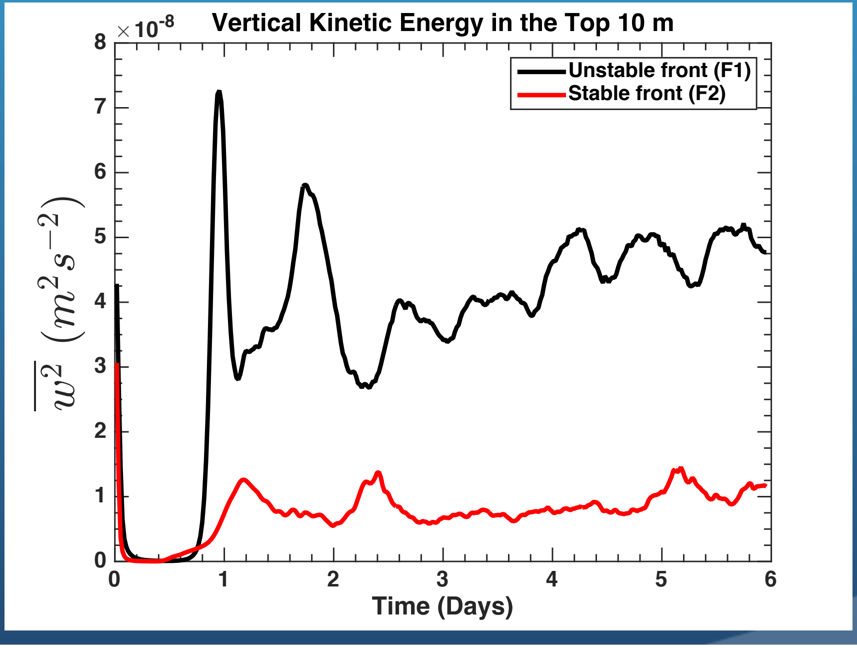
– Horizontal average from LES



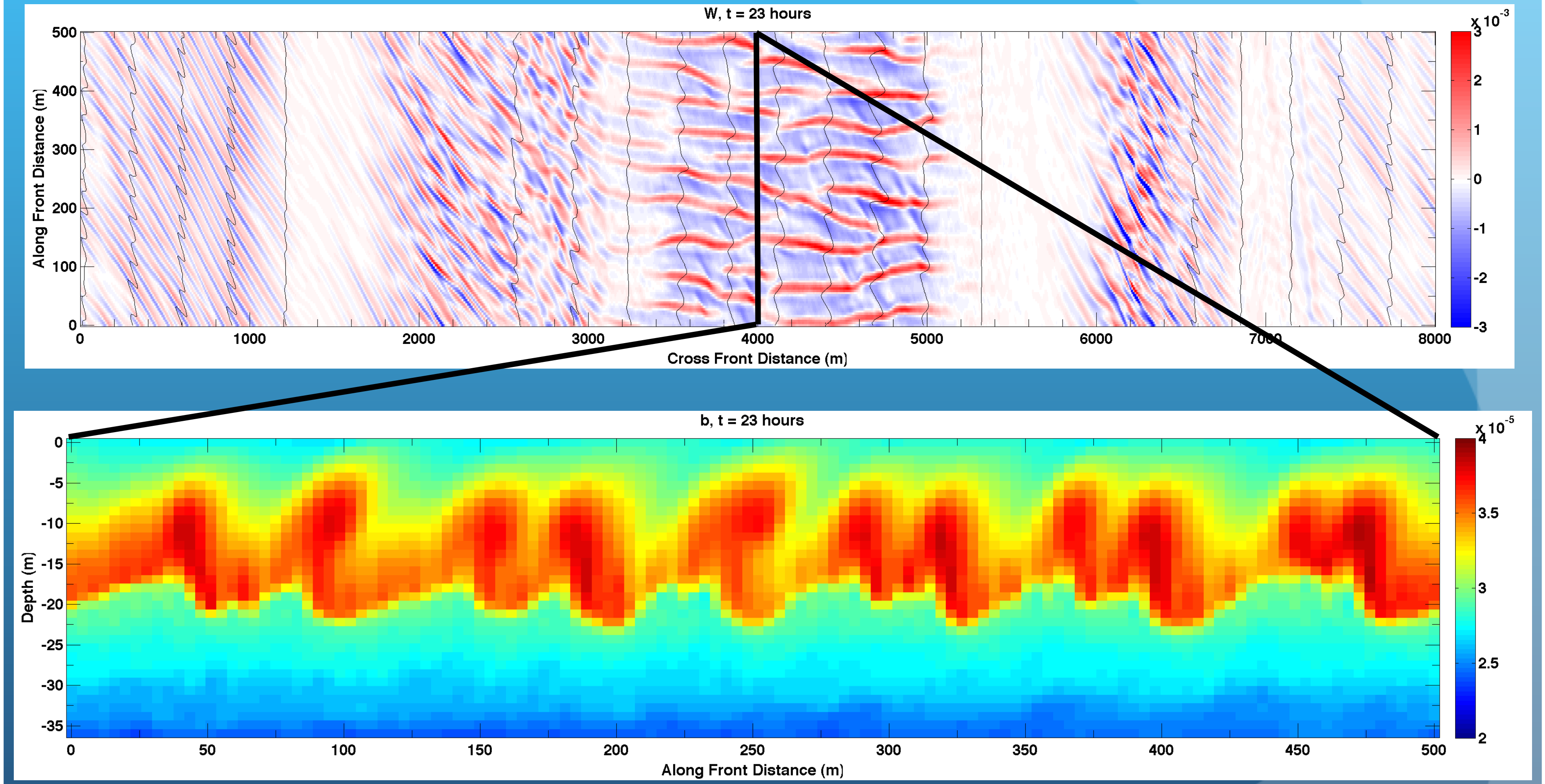
Haney 2014

Ekman Re/Destratification Strengthens/Weakens LT



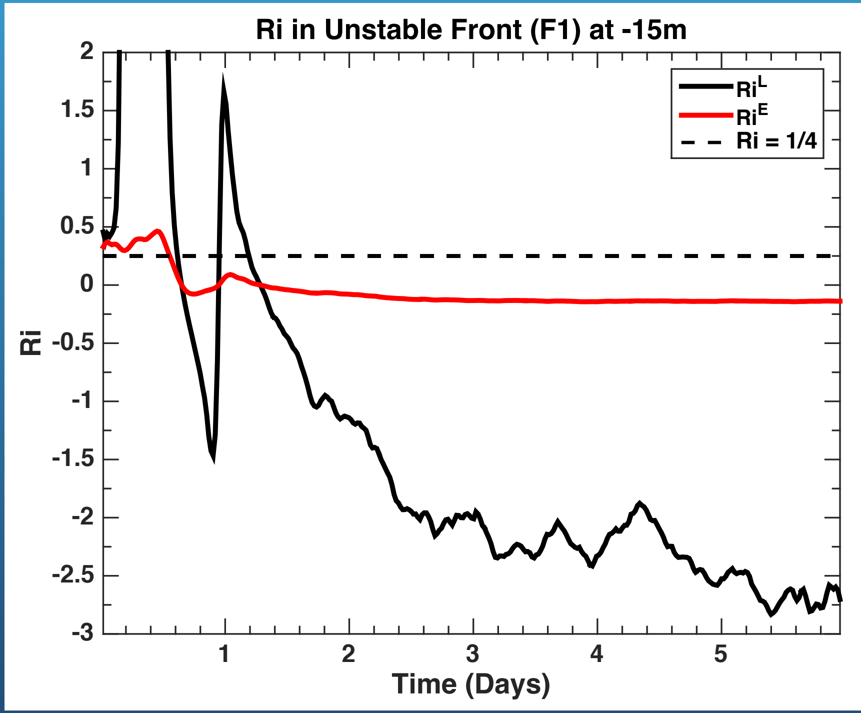


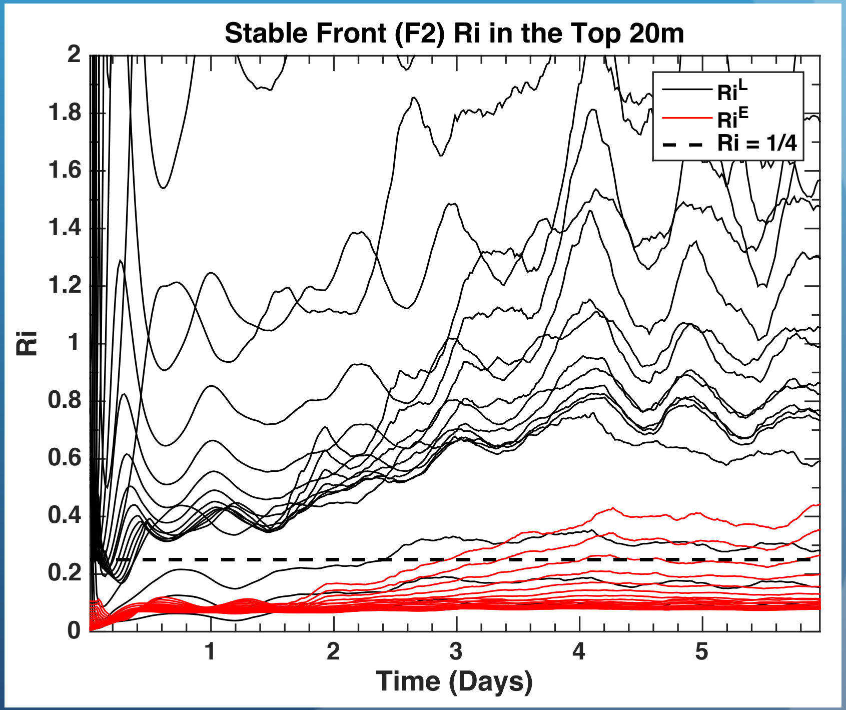
KH Instabilities in the Unstable Front



KHI Care about both the Lagrangian and Eulerian Shear

- Necessary Criteria for KHI (Holm 1996):
  - $Ri^L < 1/4$ (note Lagrangian Ri)
  - Inflection point in the Eulerian flow





Summary

- SI is indifferent to the type of shear imposed, and only cares about the sign of the PV.

- Anti-Stokes flow (or any ageostrophic shear) decouples the total Eulerian shear from the buoyancy gradient.
  - Observational estimates of PV must be based on Eulerian shear if SI are of interest.

- SI are NOT energized by Stokes drift.

- LT is enhanced (suppressed) by the Ekman induced destratification (restratification) of the front.

- KHI form when $Ri^L < 1/4$, and the Ri^E has an inflection point as predicted by Holm (1996).

More on symmetric and geostrophic instabilities in the mixed layer:

S. Haney, B. Fox-Kemper, K. Julien, A. Webb, Symmetric and Geostrophic Instabilities in the Wave-Forced Ocean Mixed Layer: 2015. Journal of Physical Oceanography, 45(12): 3033-3056. doi: http://dx.doi.org/10.1175/JPO-D-15-0044.1.