

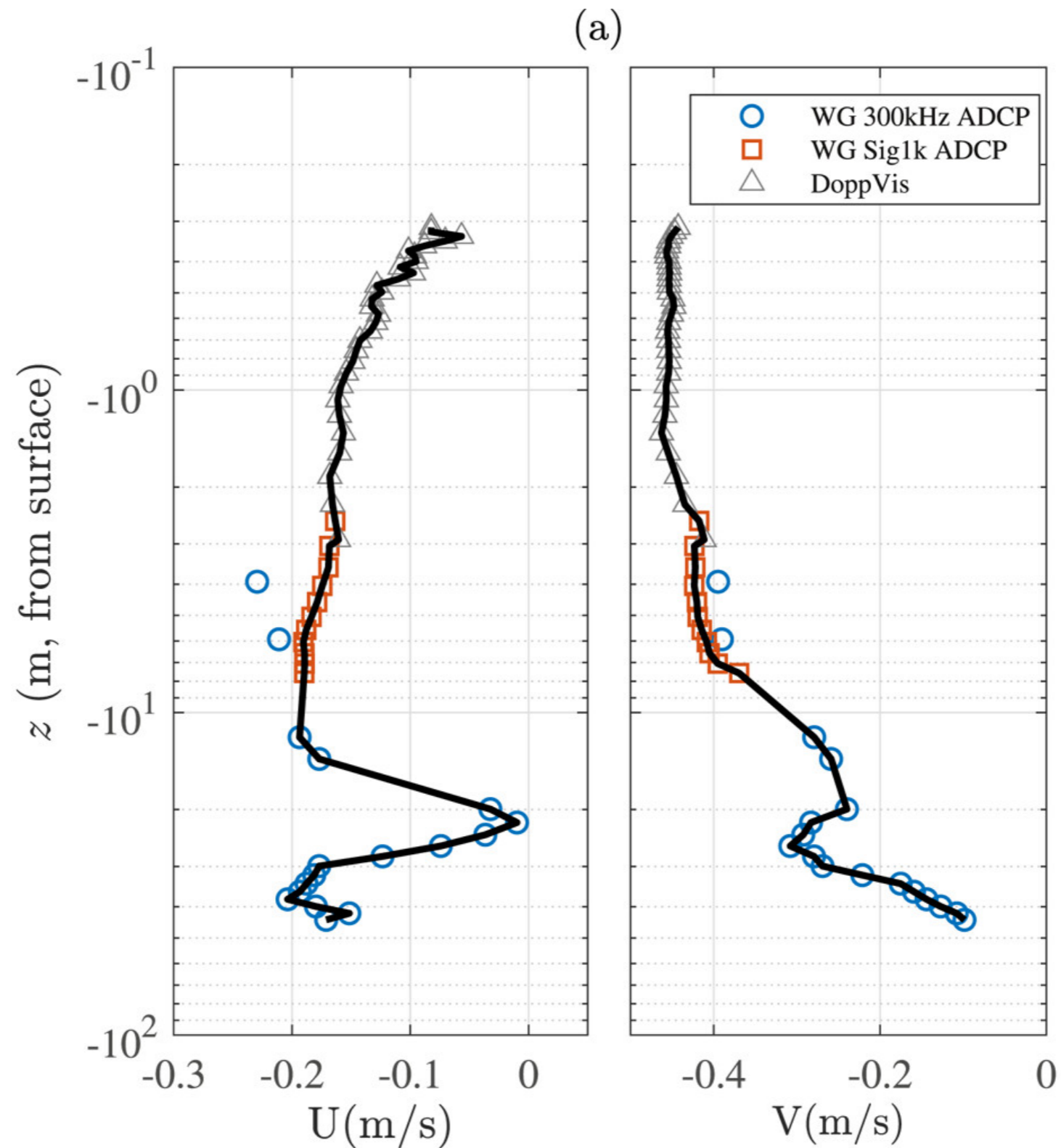


BROWN

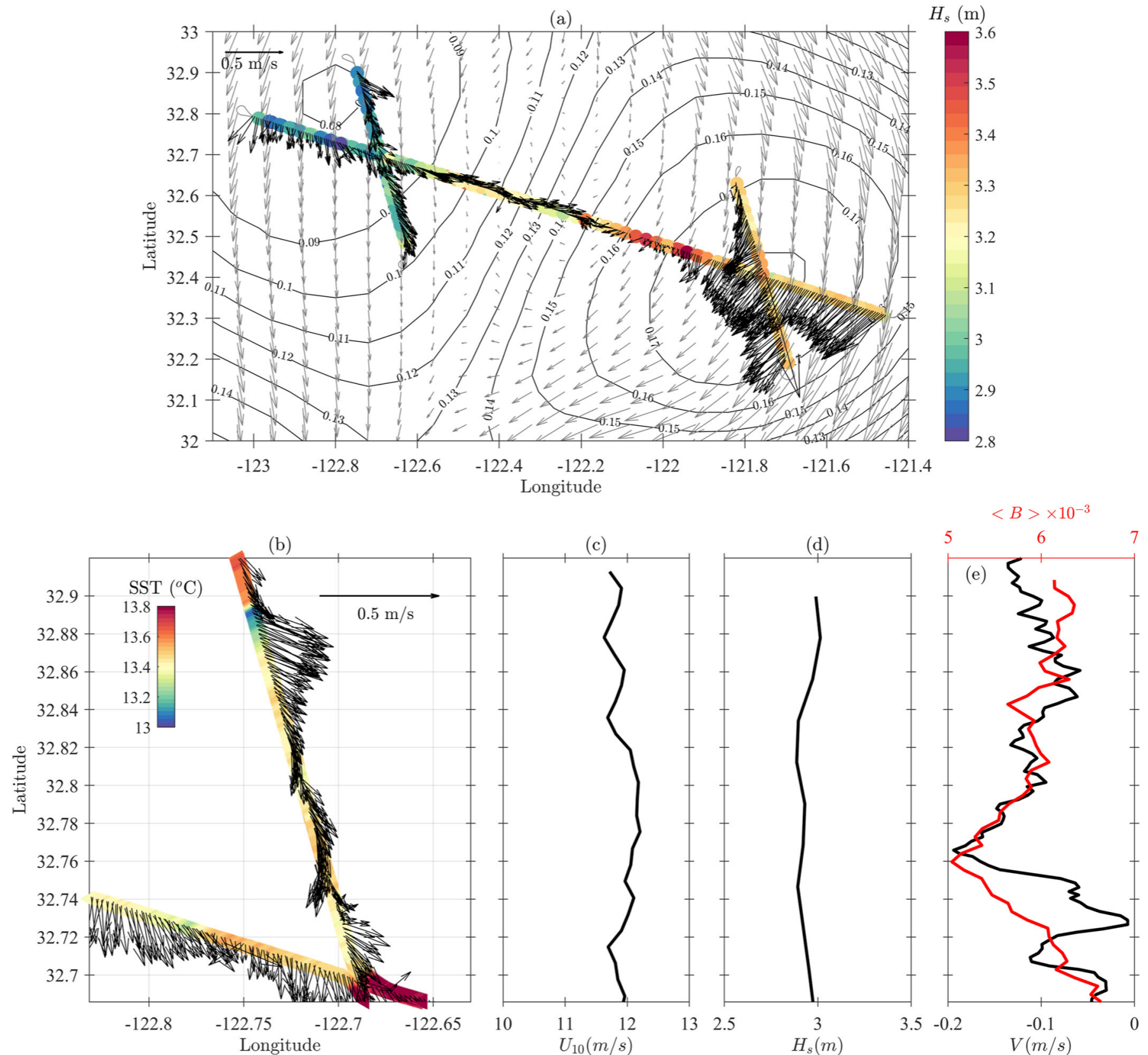
Frontal evolution with wave forcing

Mara Freilich, Lulabel Ruiz Seitz, Ryan Creedon, Nick Pizzo
Collaborators: Luc Lenain and Kayli Matsuyoshi

Observations: sheared upper ocean Lagrangian velocity



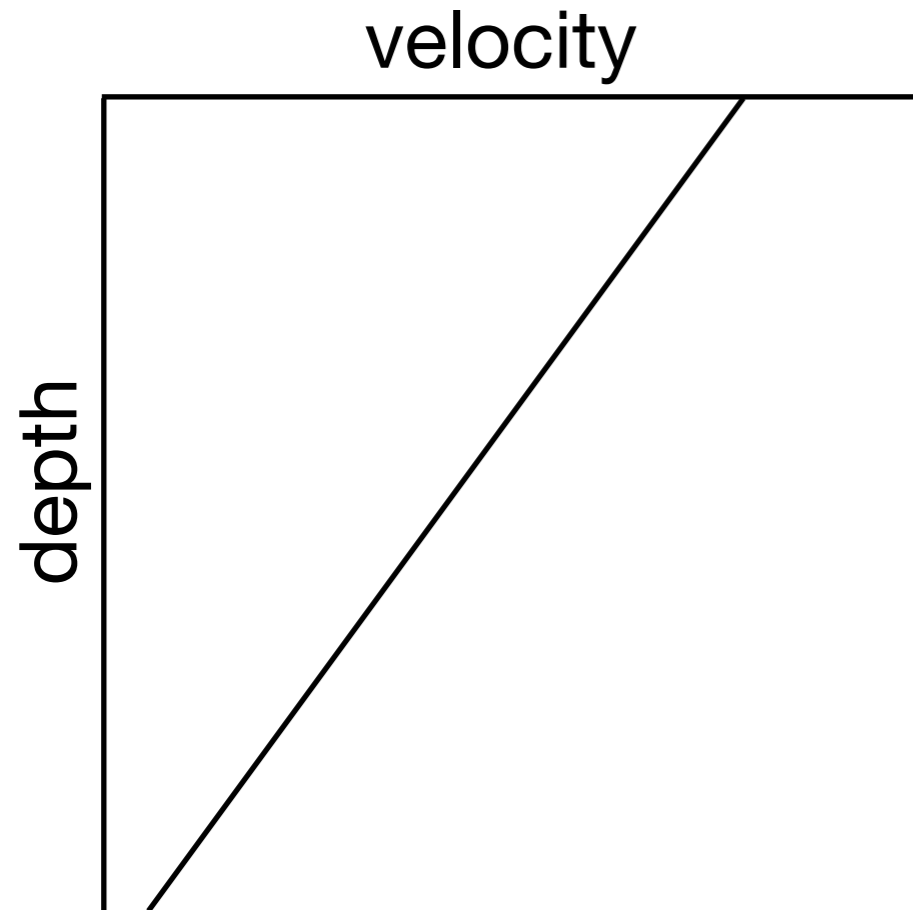
Observations: non-random distribution of waves around eddies



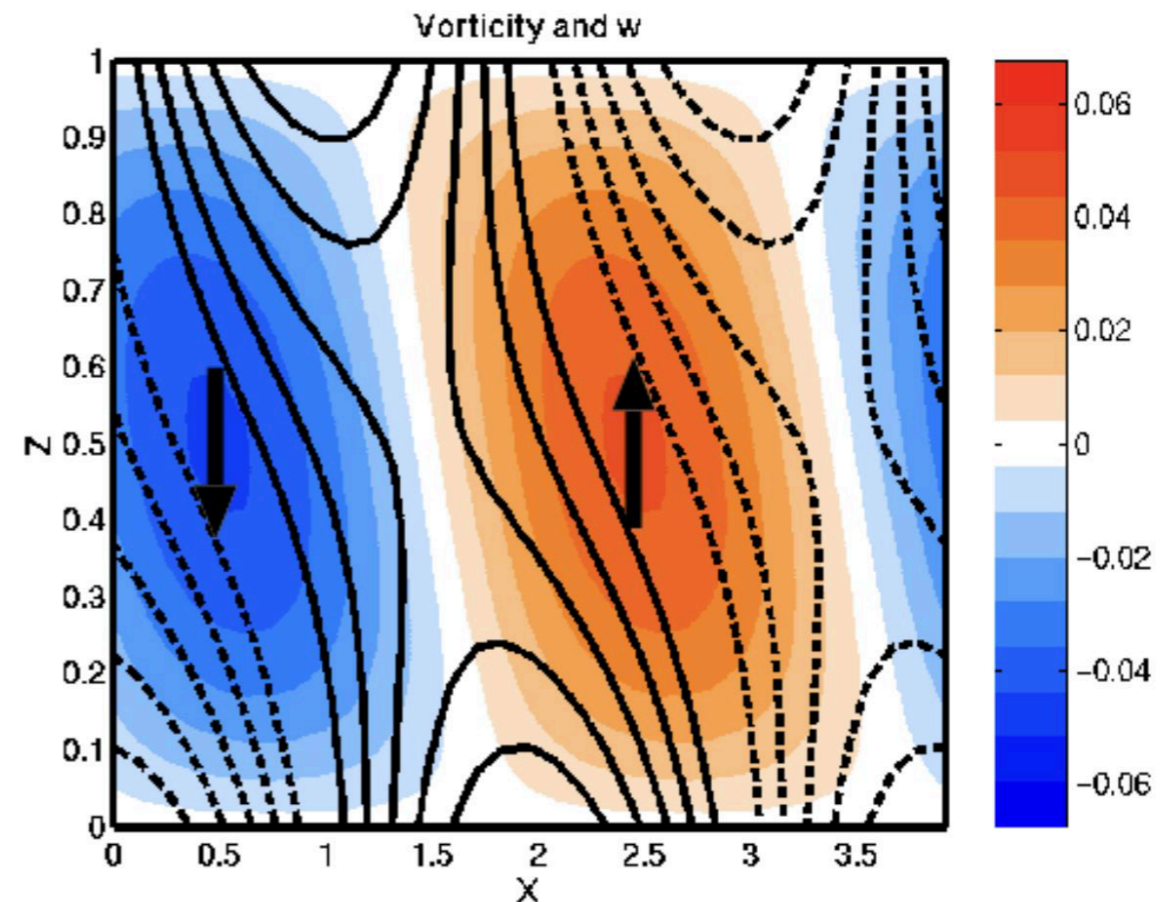
How do waves alter the coupling between wind and currents?

- How does Stokes drift alter baroclinic instability?
- How do waves affect the further growth of waves?
- What are the implications of wind-wave-current interactions for tracers, including biological tracers?

Classical model of instability



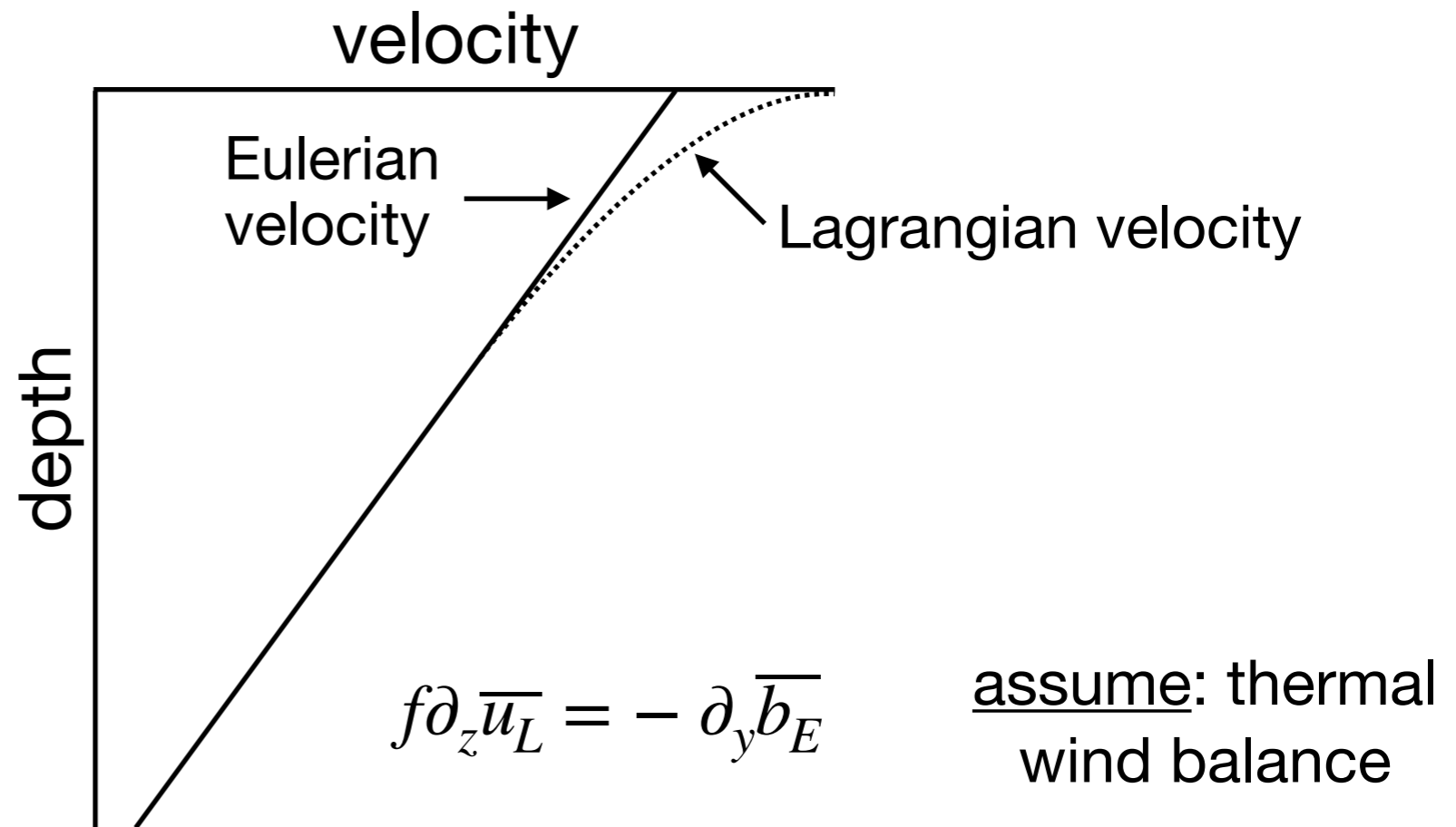
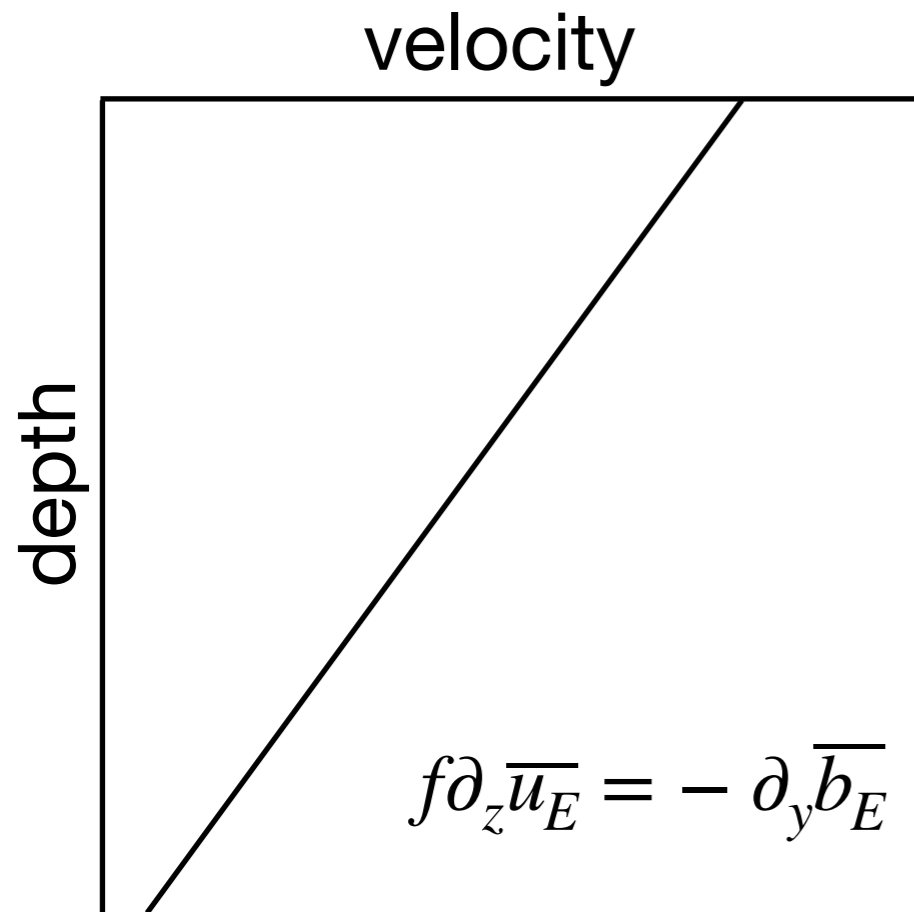
instability arises because of phase locking of edge waves



assume

- constant Richardson number
- thermal wind balance

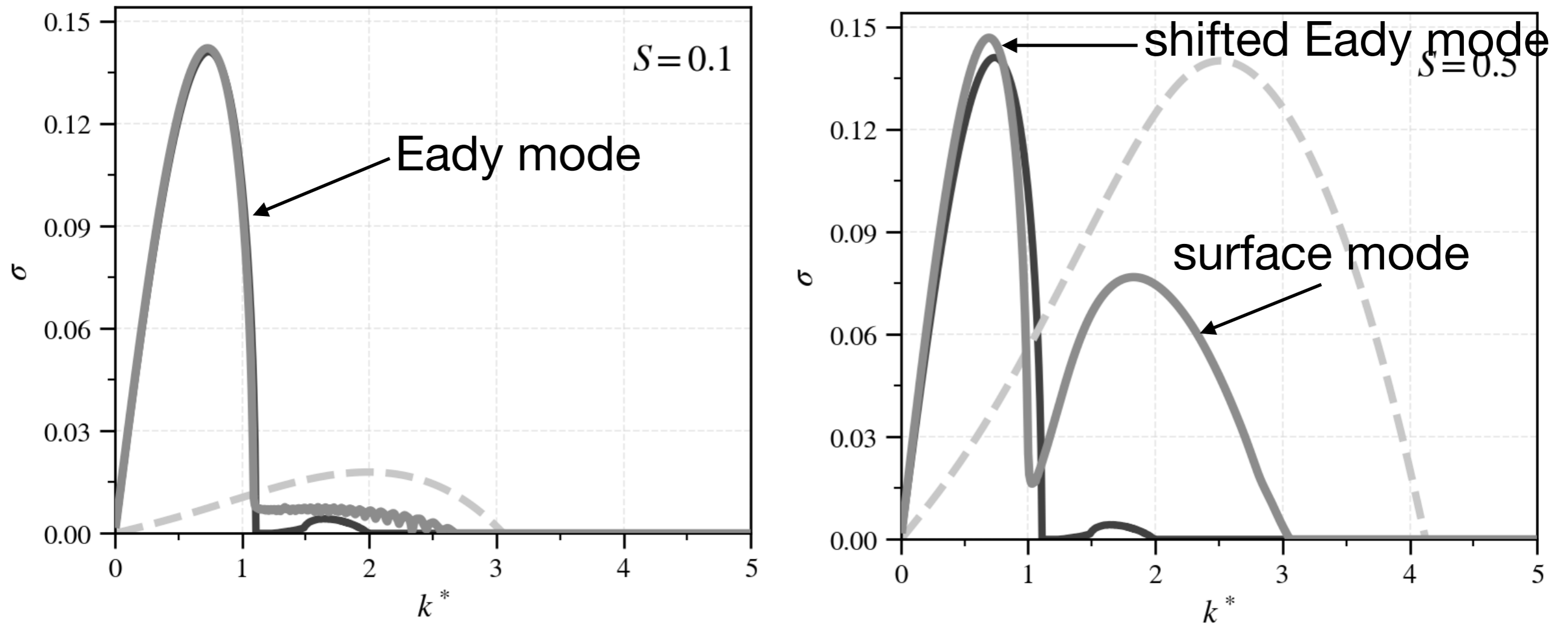
Modification of classical model of instability to include Stokes drift



New instability arises in coupled system

$$S = \frac{U_{s_0}}{\Lambda H}$$

without a Stokes shear force (Haney et al. 2015)



Physical mechanism for secondary instability

$$\partial_t u + \overline{u}_L \partial_x u + w \Lambda - f v + \partial_x p = 0$$

velocity anomaly
advection

geostrophic
terms

$$\partial_t b + \overline{u}_L \partial_x b + v \partial_y b + w N^2 = 0$$

buoyancy anomaly advection

Key

Λ Eulerian shear

u_s Stokes velocity

\overline{u}_L mean
Lagrangian
velocity

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Lagrangian
thermal
wind

$$\partial_y \overline{b}_E = -f \partial_z \overline{u}_L$$

$$\partial_y \overline{b}_E = -f(\Lambda + \partial_z u_s)$$

Key

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buoyancy anomaly advection

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thermal
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Key

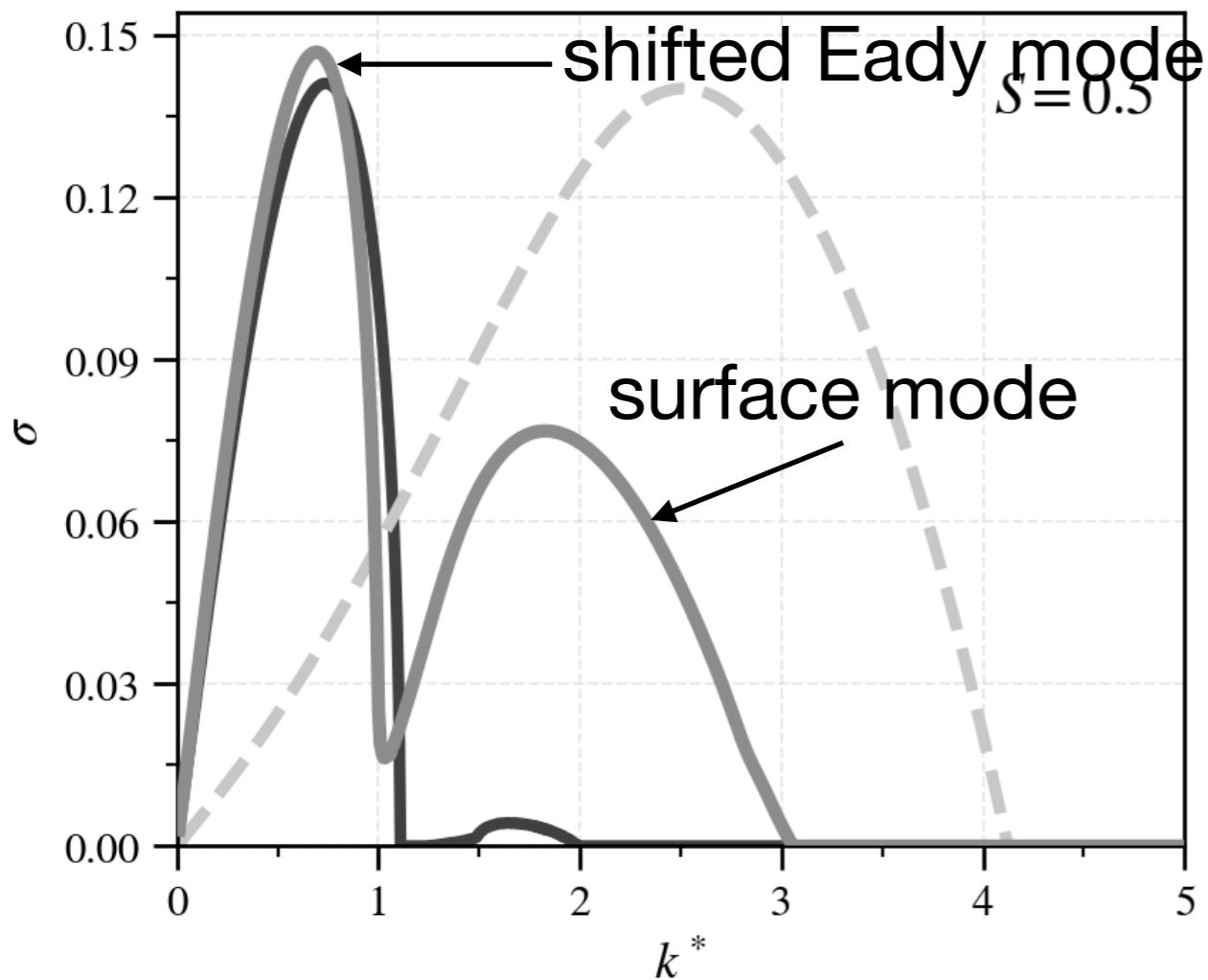
Λ Eulerian shear

u_s Stokes velocity

\overline{u}_L mean
Lagrangian
velocity

New instability arises in coupled system

$$S = \frac{U_{s_0}}{\Lambda H}$$



- Eul. background only
- Eul. background + Stokes
- - - Stokes only

- Generation of a surface-trapped mode
- Results from buoyancy-shear asymmetry
- **Significant for modeling of submesoscale and surface-enhanced instabilities**

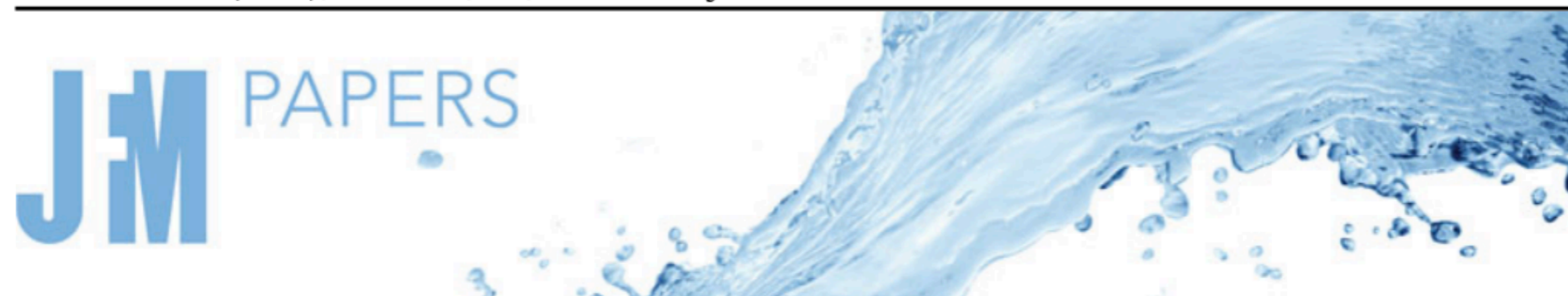
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How do waves affect the further growth of waves?

Wave-induced mean flow significantly suppresses wave growth rate, especially at high wavenumbers

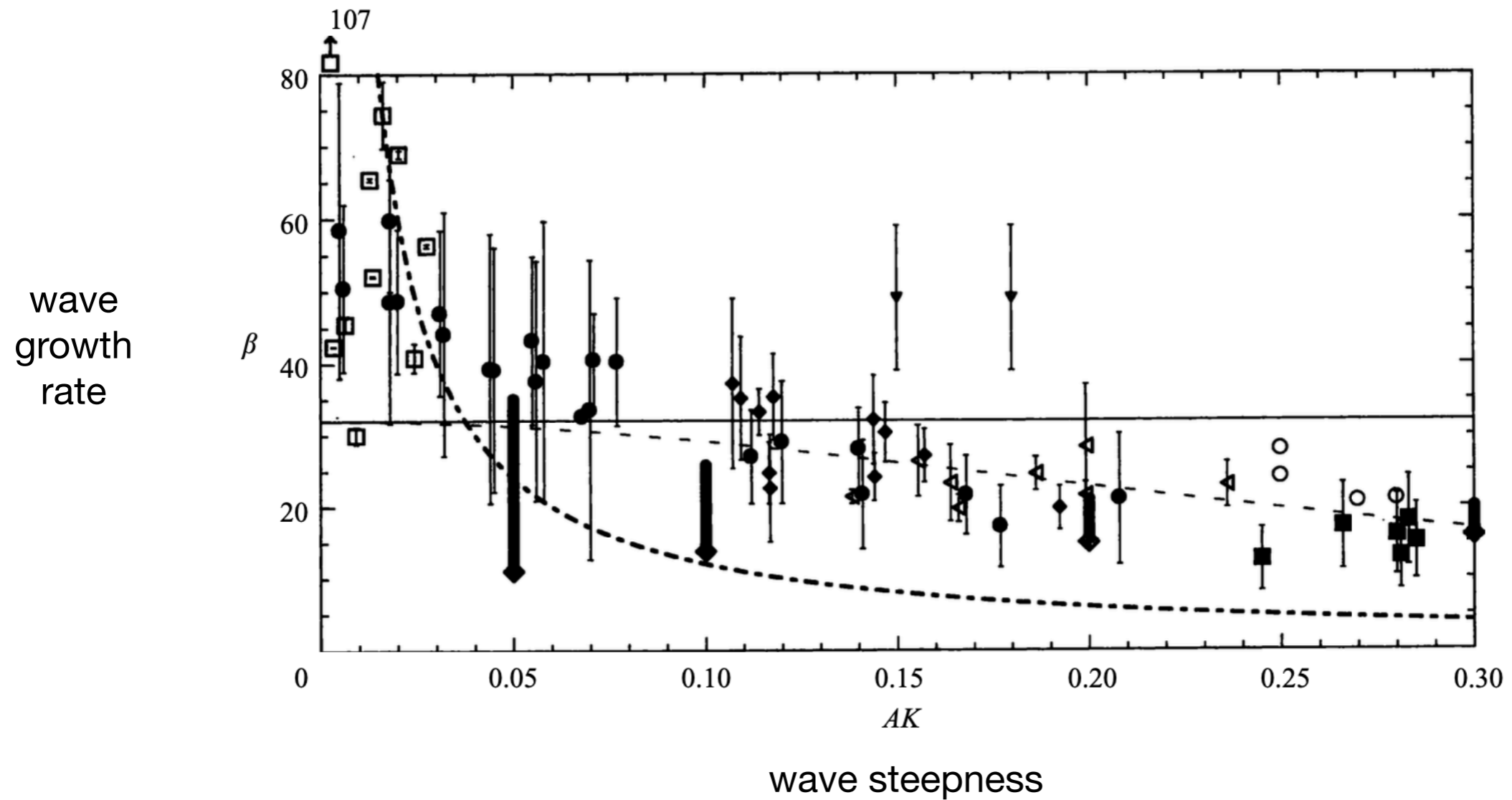
J. Fluid Mech. (2026), vol. 1032, A9, doi:10.1017/jfm.2026.11348



The role of Lagrangian drift in the generation of surface waves by wind

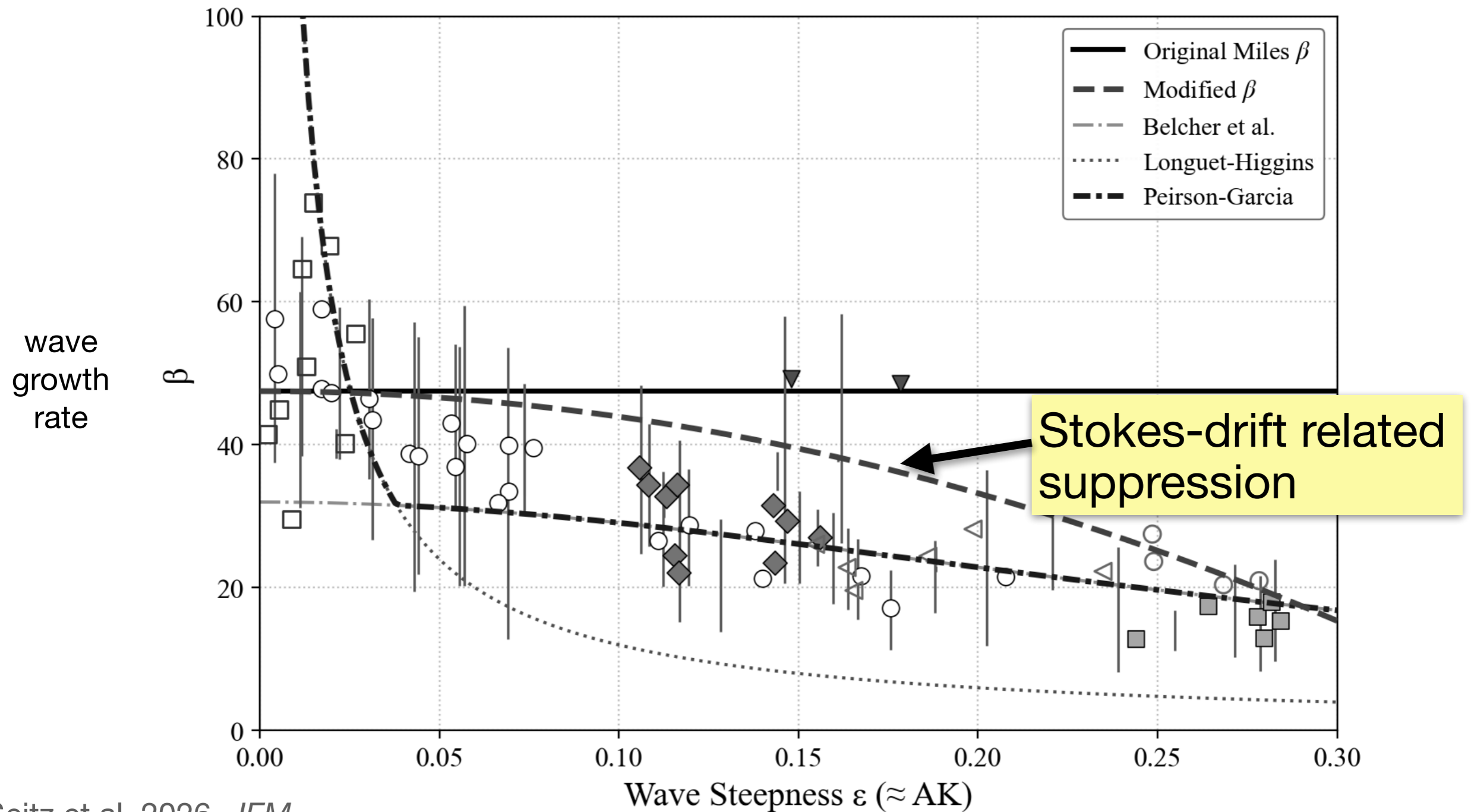
L.R. Seitz¹ , Mara A. Freilich^{1,2}  and Nick Pizzo³ 

Comparison with experimental data

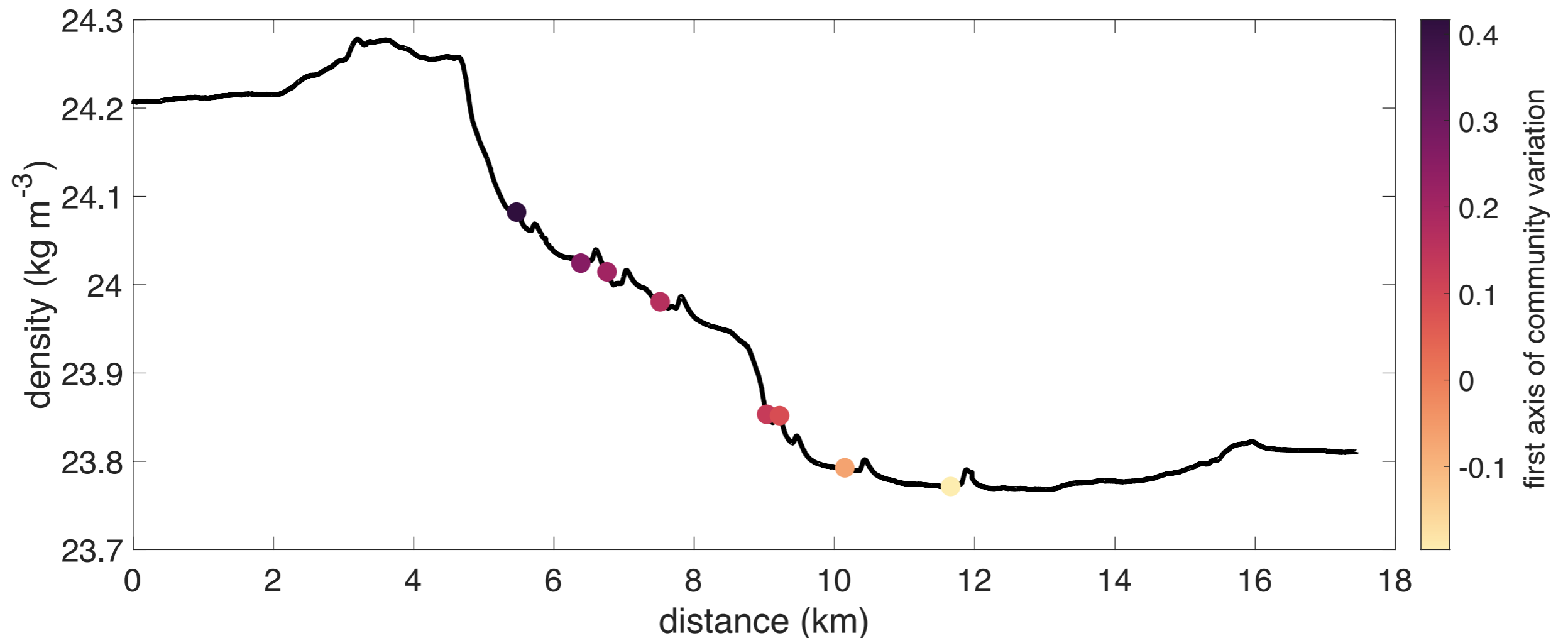


Comparison with experimental data

Wave-induced mean flow significantly suppresses wave growth rate, in alignment with experimental observations.



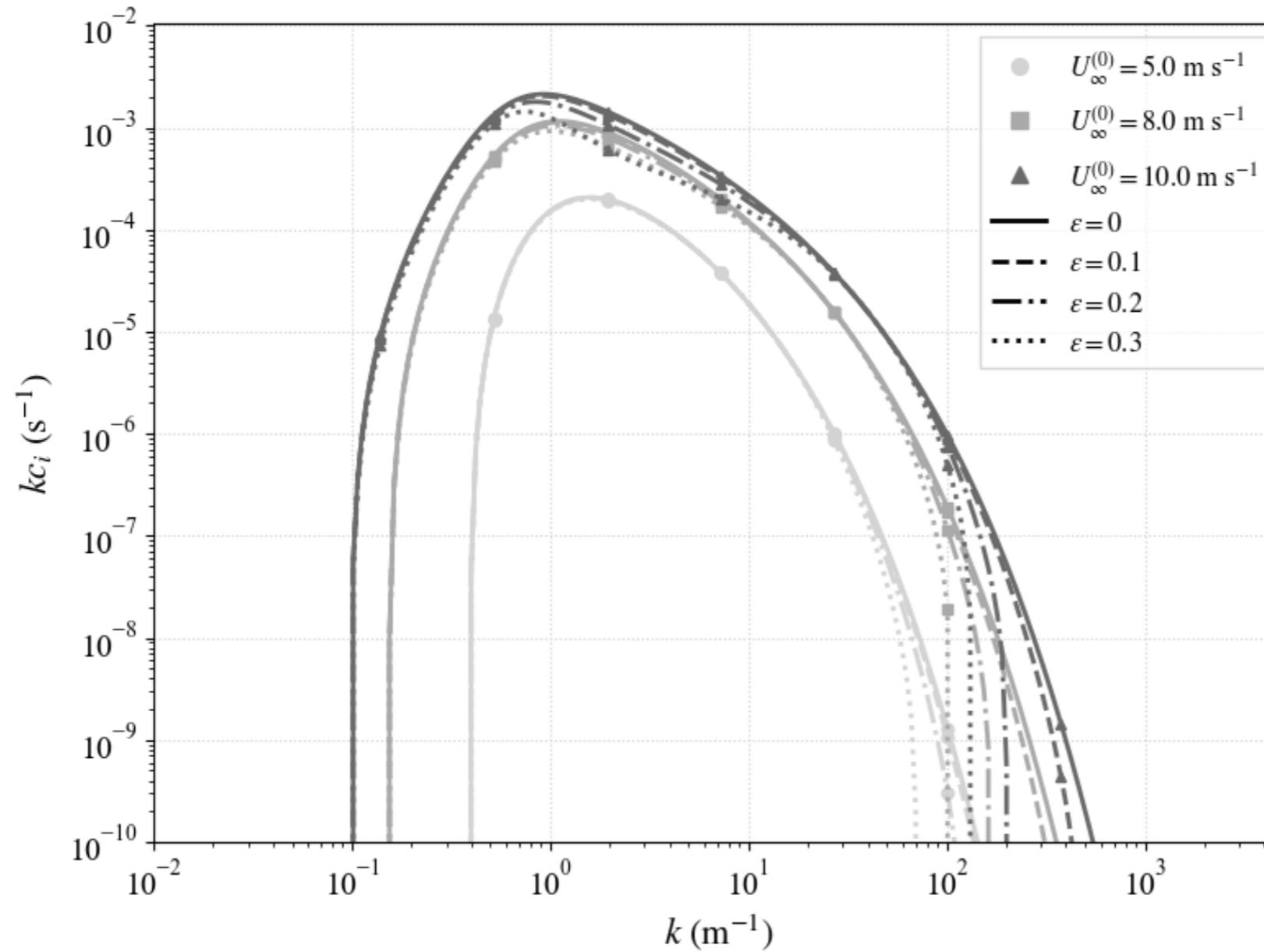
What are the implications of wind-wave-current interactions for tracers, including biological tracers?



Conclusions

- Emergence of a surface-trapped instability mode that results from interactions between Stokes drift and mixed layer shear.
- New explanation of the observed phenomenon of suppression of wave growth with increased wave slope.
- Implications for processes involving relative wind (should use Lagrangian velocity).
- Biological communities vary on the scales of coupled instabilities.

The wave-induced mean flow significantly modifies the growth rate, especially at high wavenumbers



With surface tension

