Interactions between *wave*-induced mean current and *wind*-induced shear current

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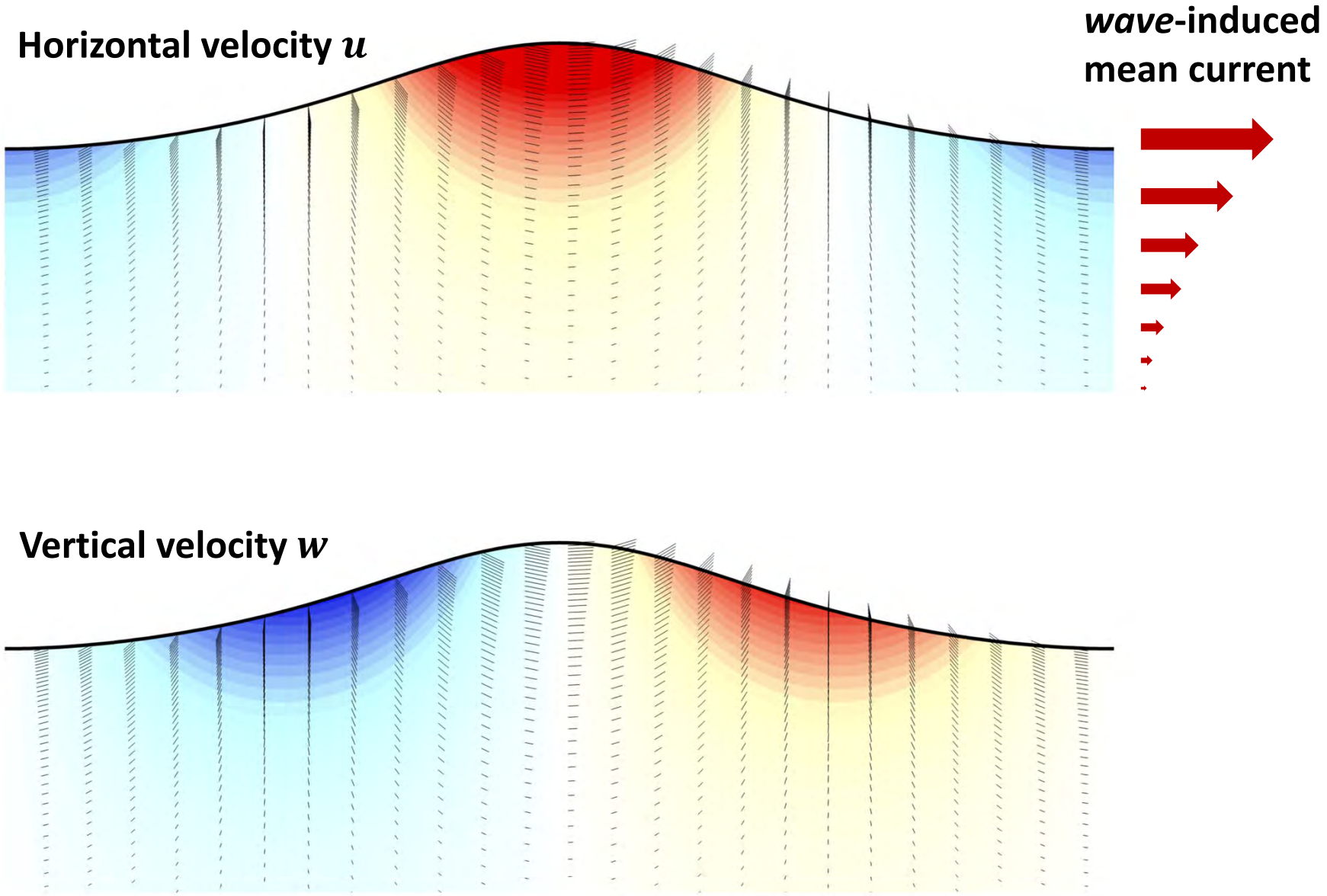
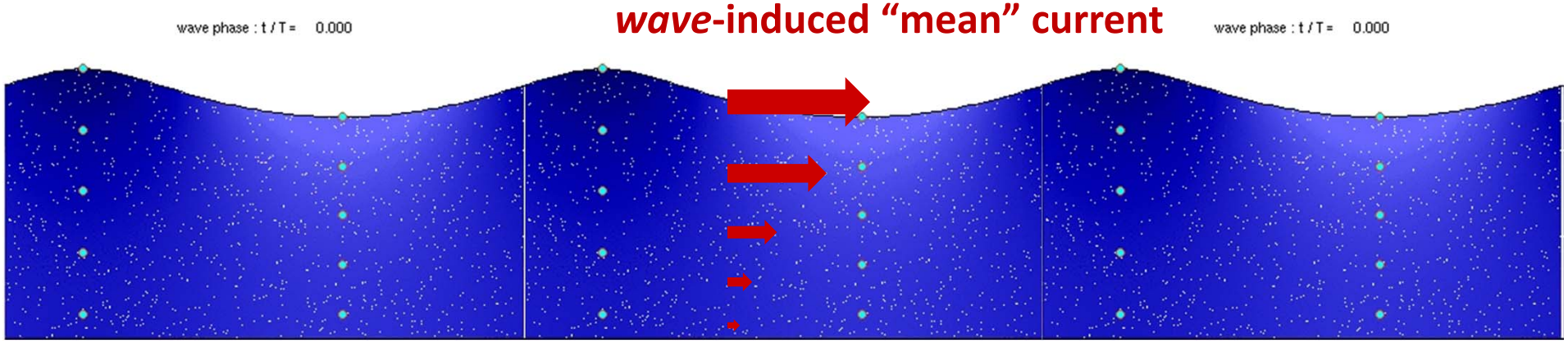
Interactions between *wave*-induced mean current and *wave*-induced shear current

Wu-ting Tsai
蔡武廷


Horizontal velocity u
wave-induced
mean current
Vertical velocity w

Stokes drift

wave-induced "mean" current

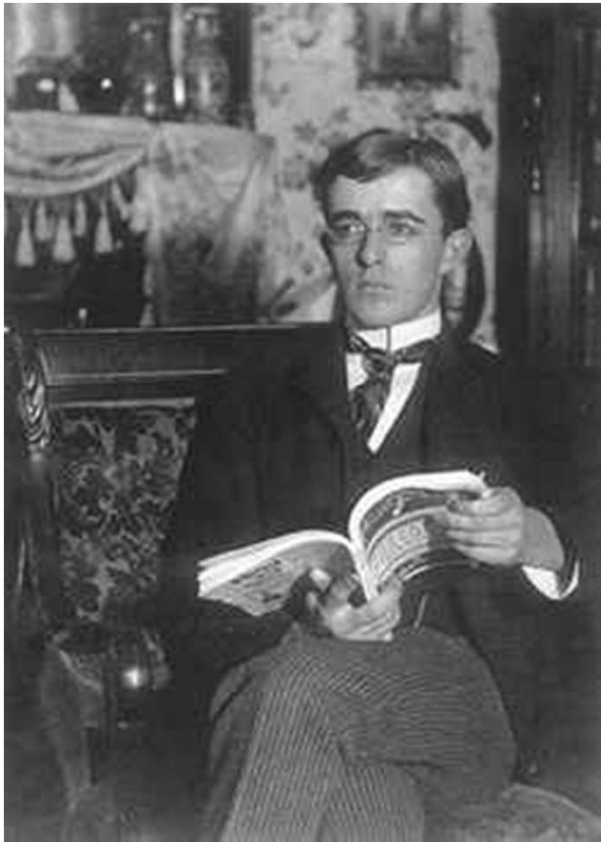


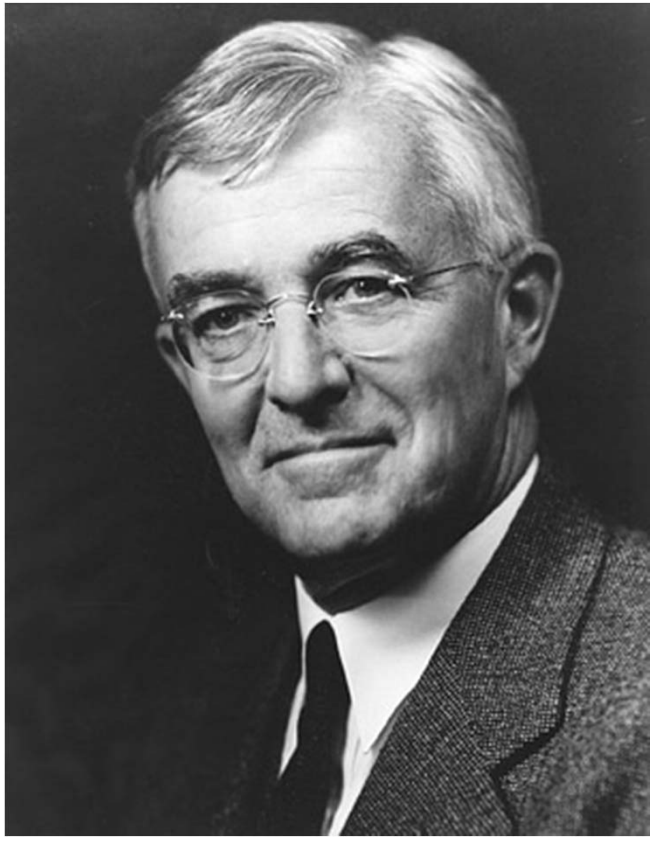
George Gabriel Stokes (1819 ~ 1903)

- Irish physicist and mathematician of Cambridge University

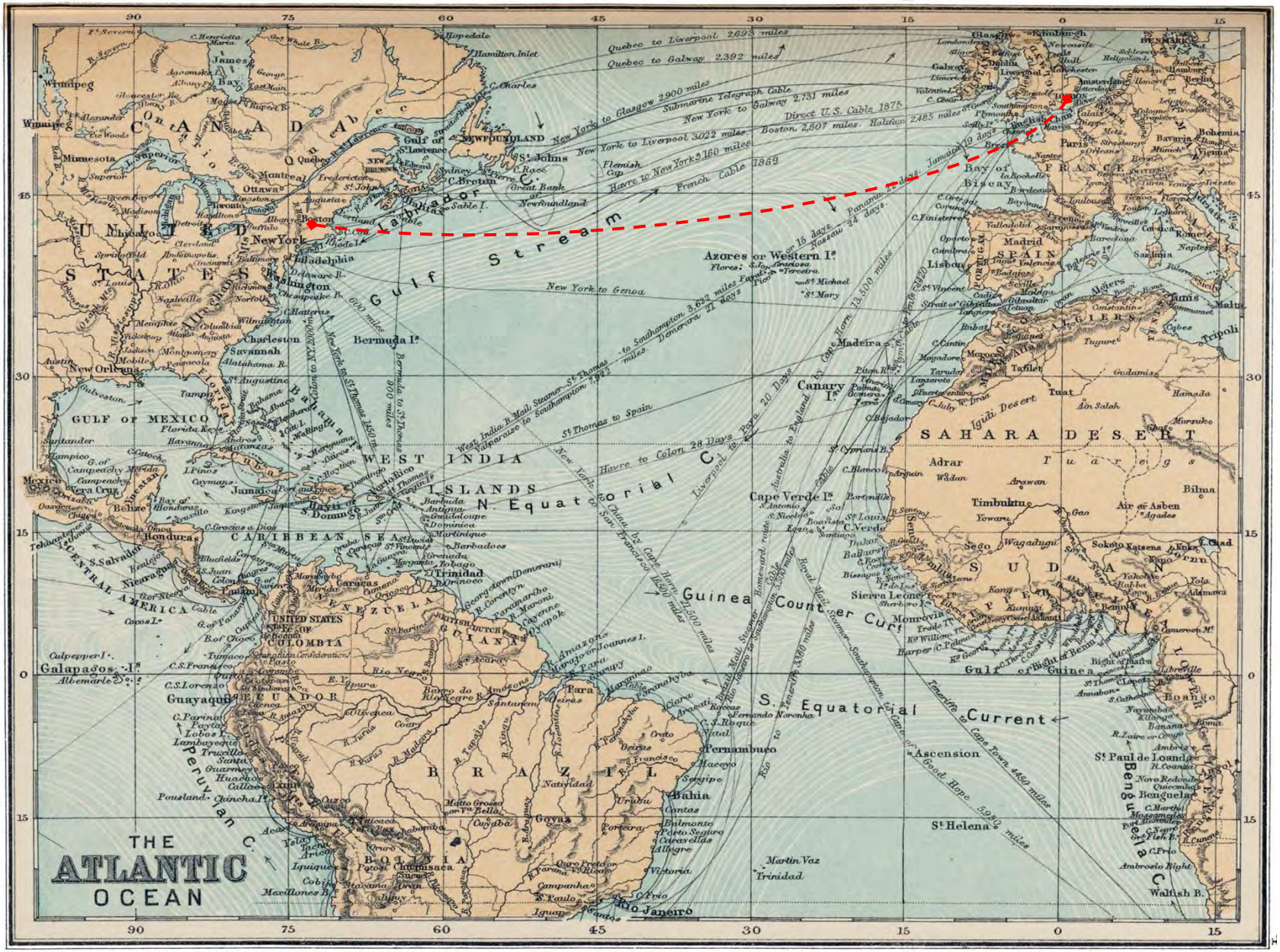
Irving Langmuir (31 January, 1881 ~ 16 August, 1957)

- American chemist, physicist, and industrial researcher worked at General Electric
- 1932 Nobel Prize laureate in chemistry





The story began in 1927 on an Atlantic crossing from New York to England...



Langmuir observed wind aligned streaks on the ocean surface.

From movie Dunkirk (2017)

… in coastal water

Air Sea Interaction Tower offshore Cape Cod
≈24 m above ocean surface

... in lagoon

Rodeo Lagoon in
Marin County, California

… in lake

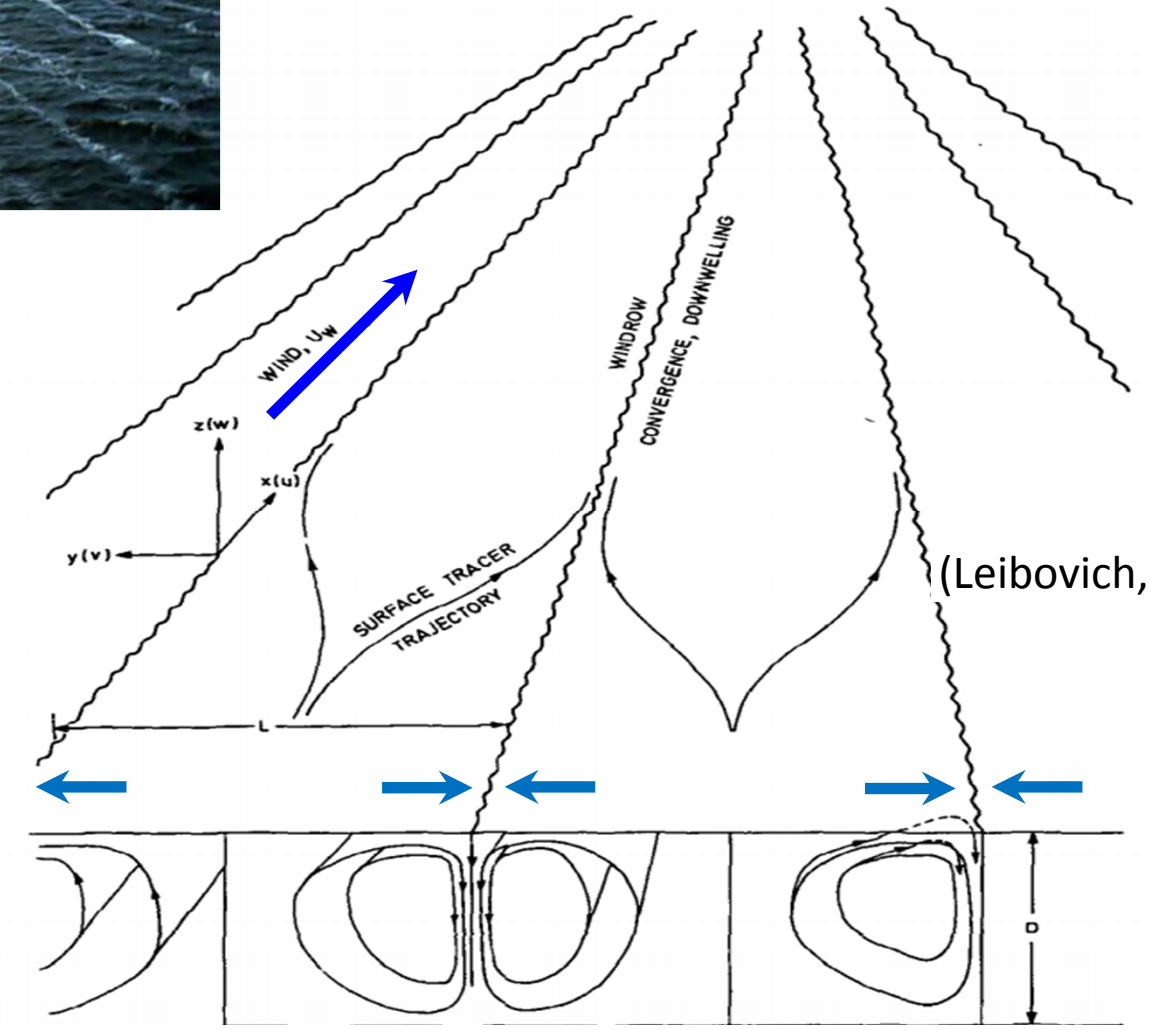
Quake Lake, Montana

... in river

Cambridge, MA

… in pond

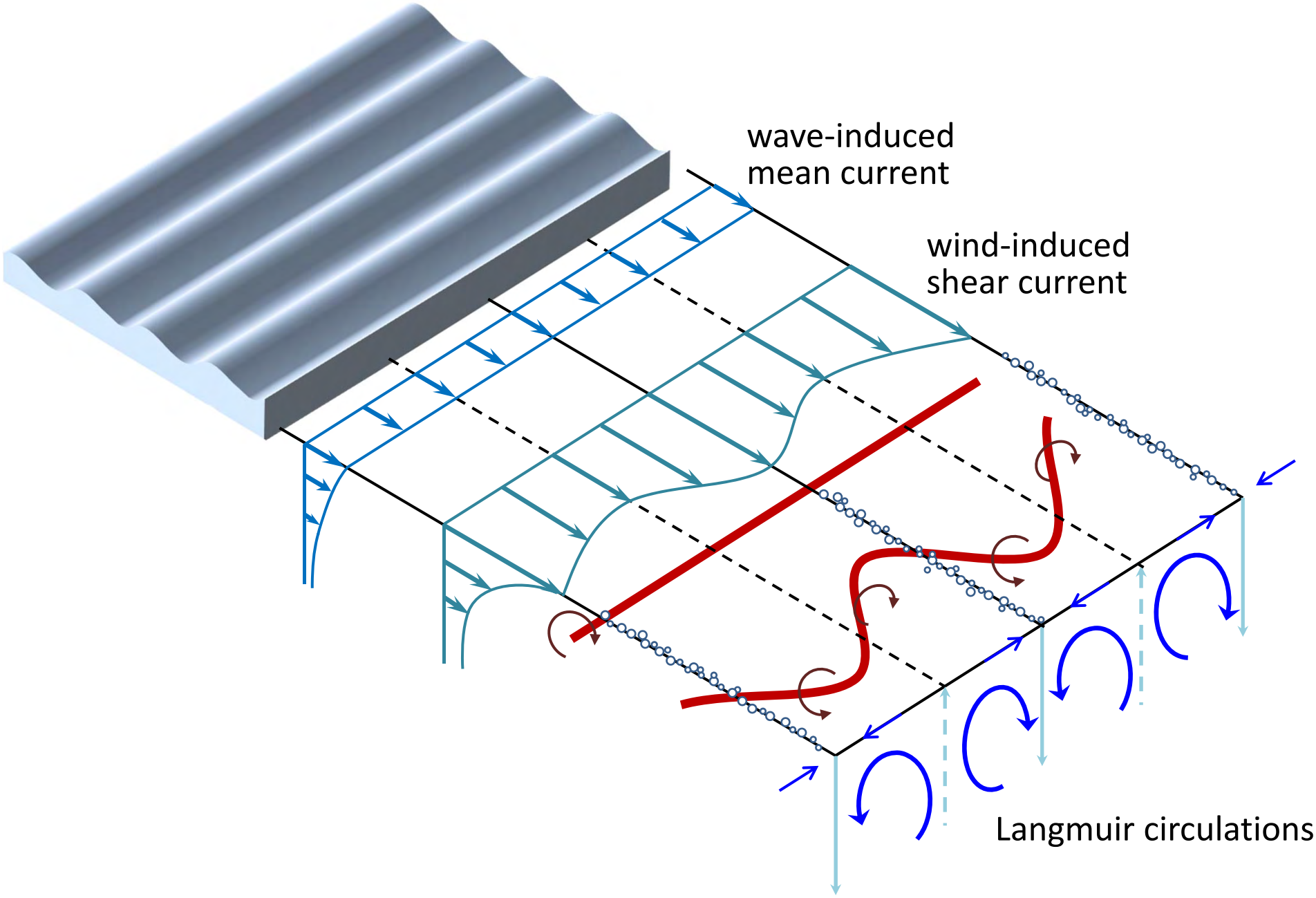
臺南布袋 魚塭



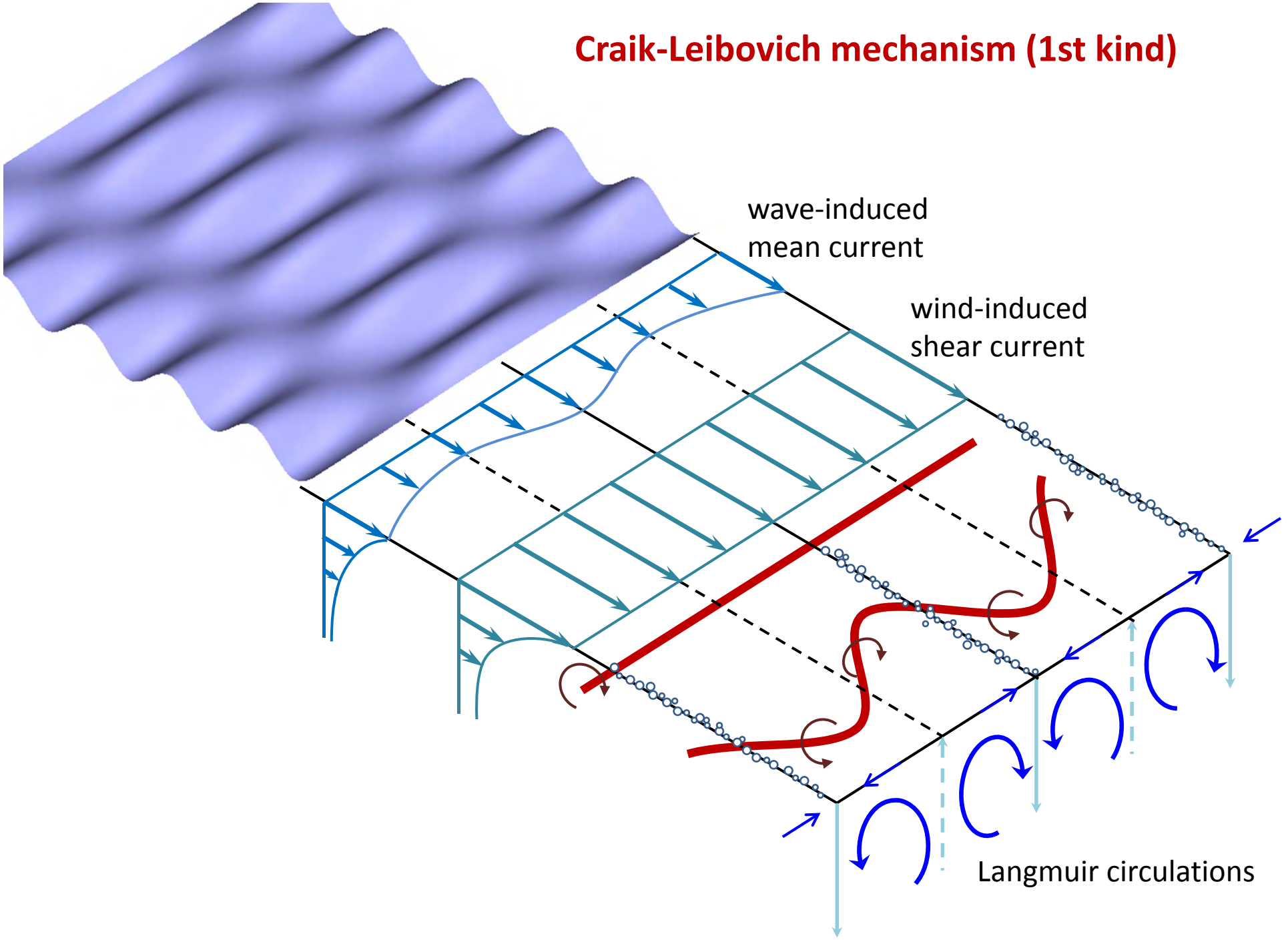
(Leibovich, 1983)

Surface streaks are induced by Langmuir circulations

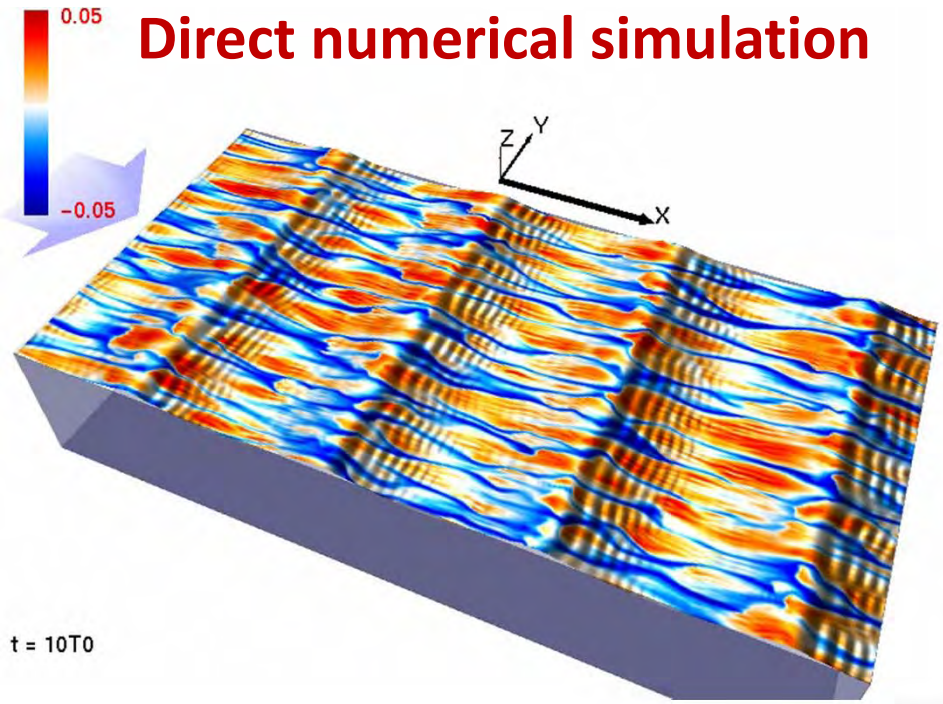
Craik-Leibovich mechanism (2nd kind)



Craik-Leibovich mechanism (1st kind)

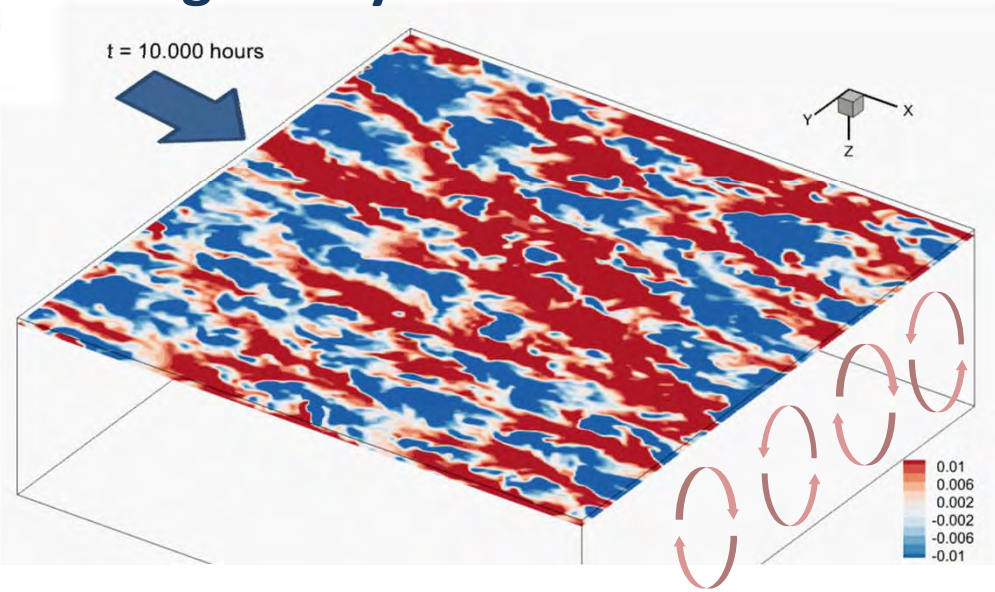


Direct numerical simulation



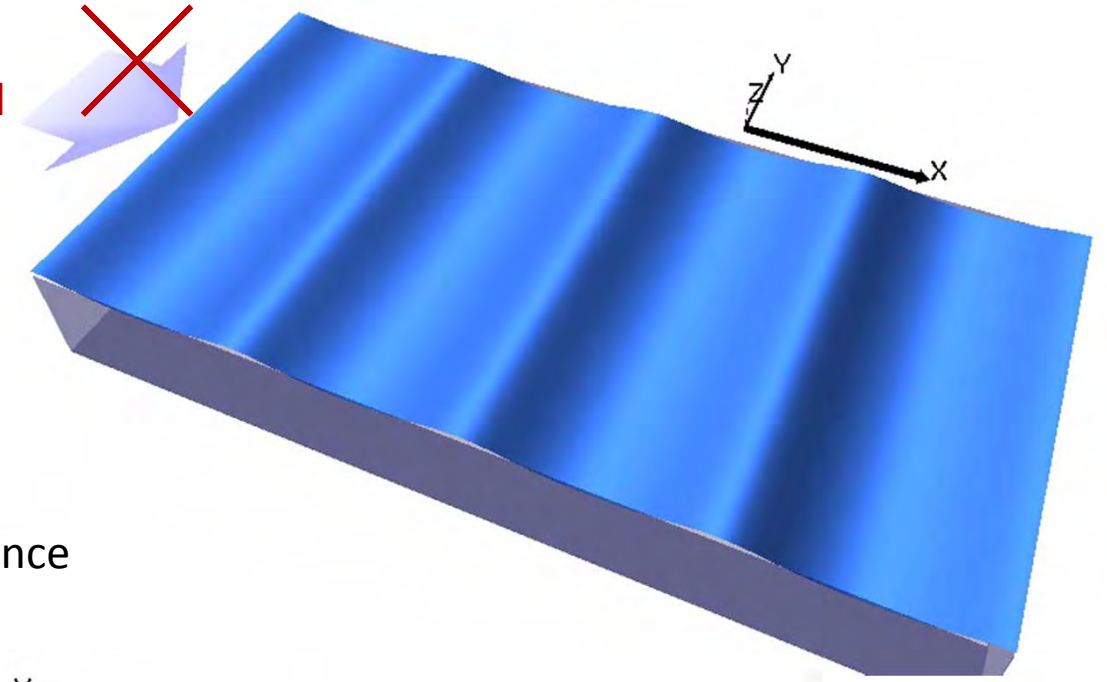
- How surface waves enhance air-sea exchange.

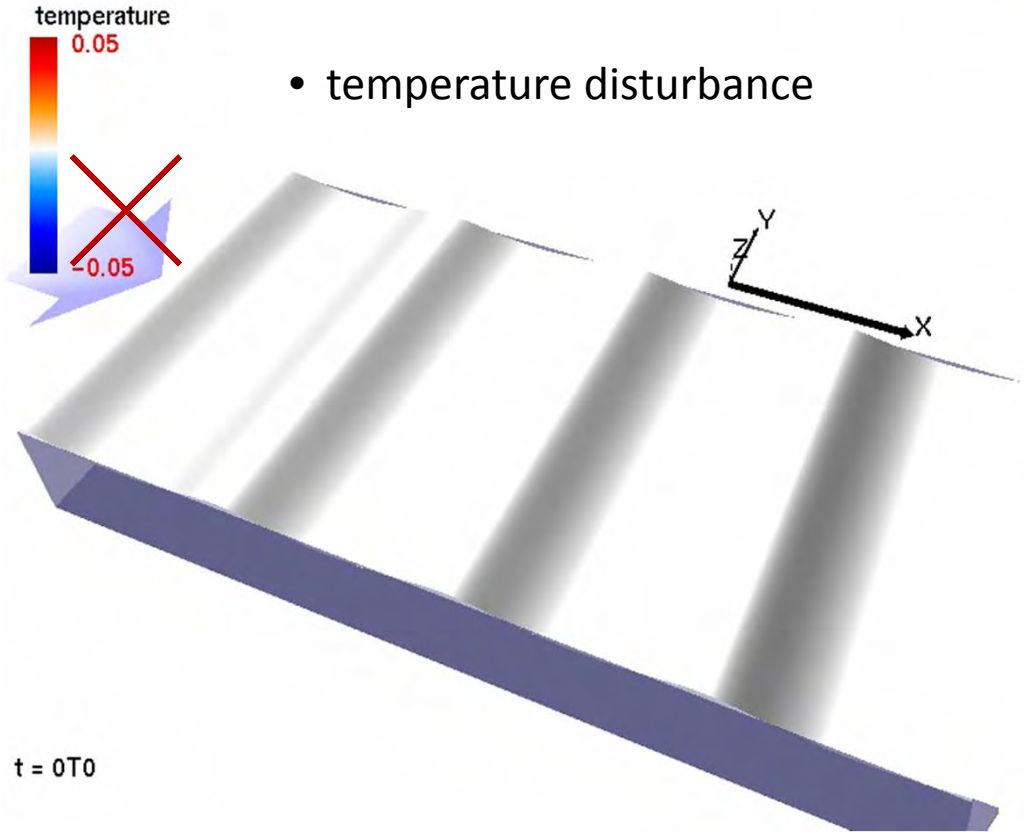
Large-eddy numerical simulation



- How Langmuir circulations enhance mixed-layer mixing and deepening?

➔ Numerical simulation of *free-propagating* wave



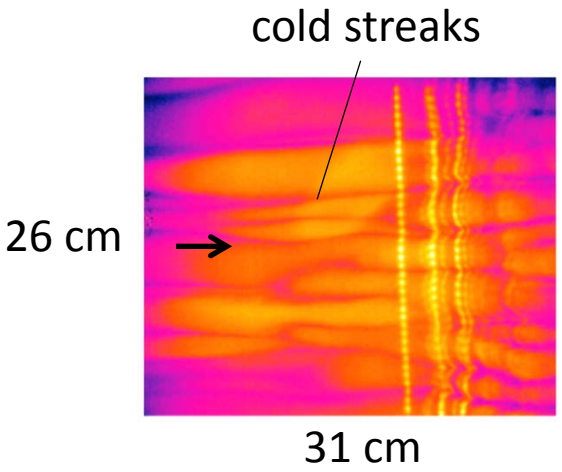


- temperature disturbance

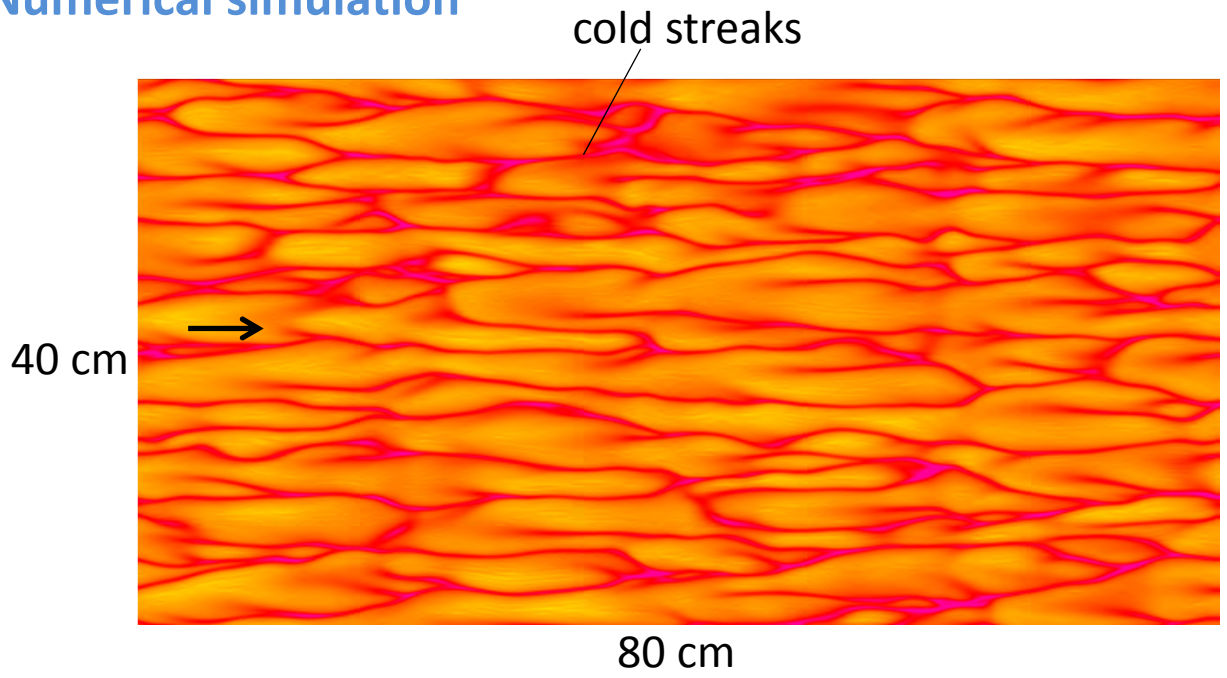
- Add small white-noise random disturbances in the initial conditions

- Random disturbances grow
- Form elongated streaks
- One order of magnitude smaller than that on wind waves

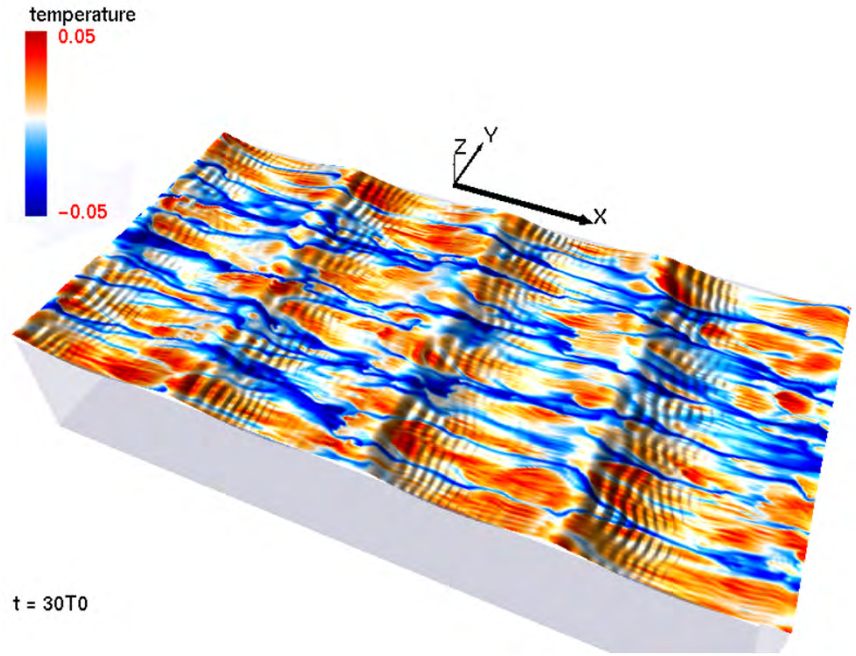
➔ **Infrared image** (Savelyev *et al.*, 2012, *JGR*)



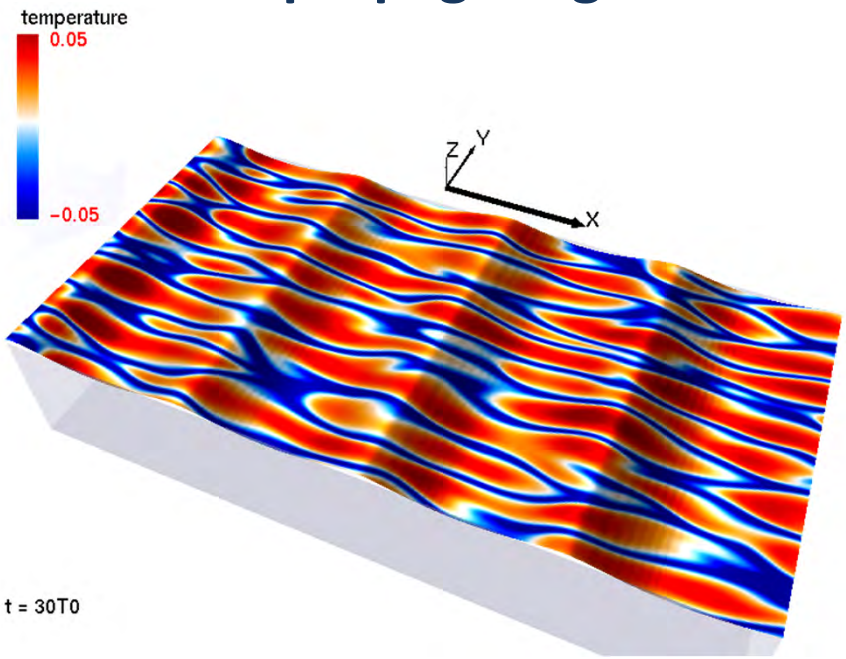
➔ **Numerical simulation**

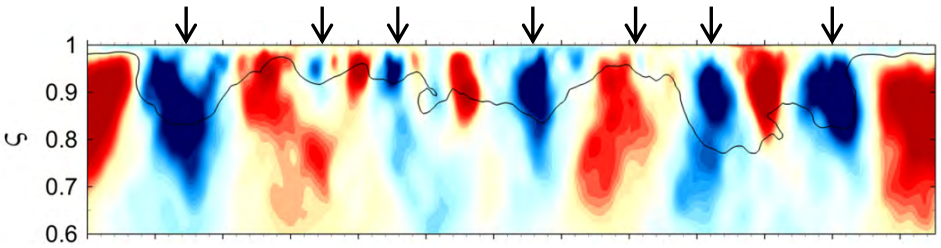


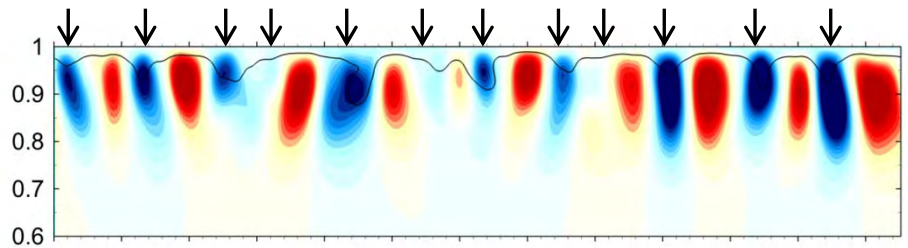
wind-driven waves



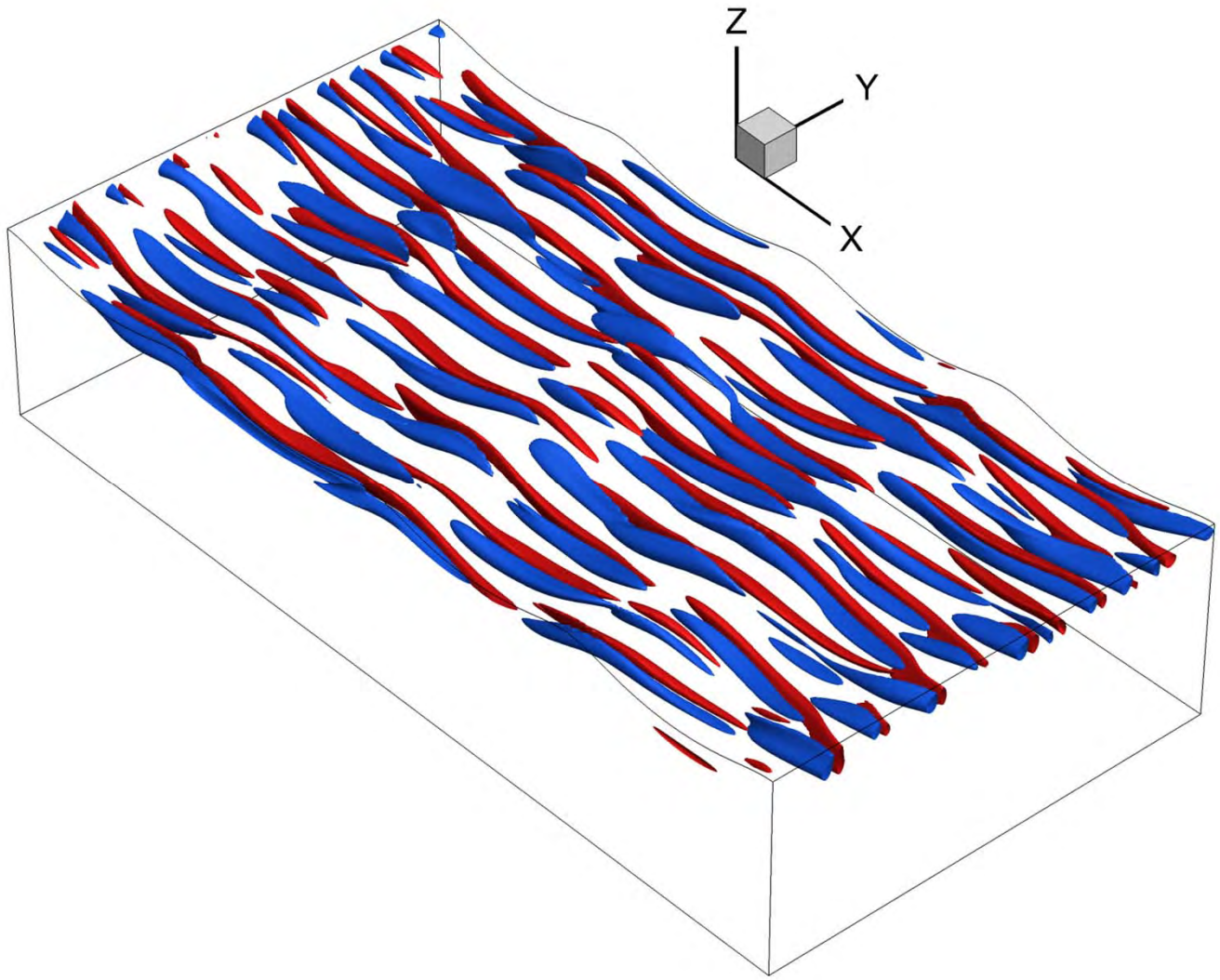
free-propagating waves

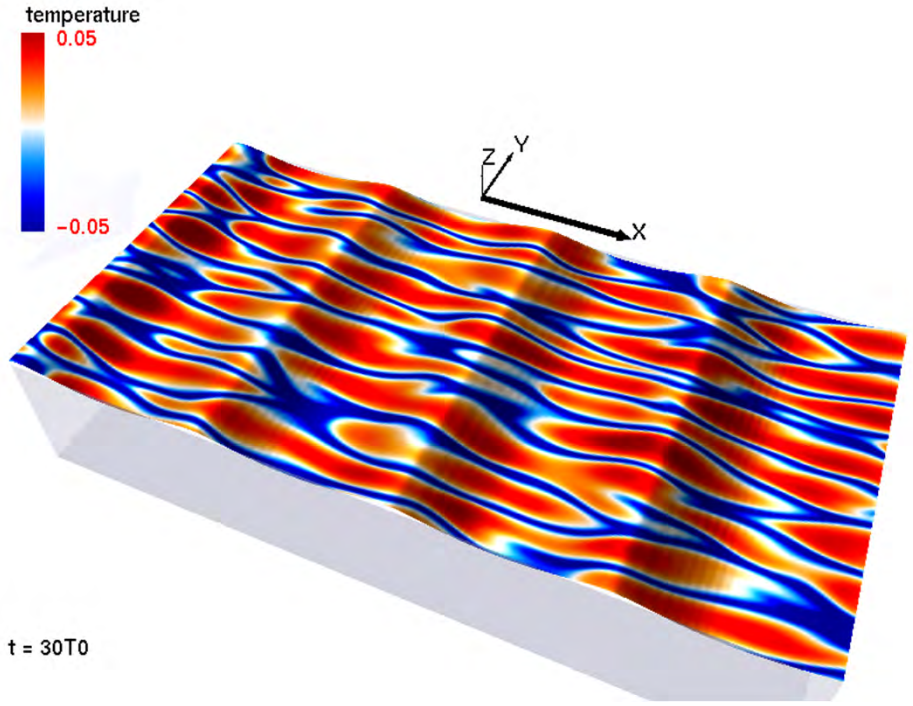






Induced by Langmuir circulations → **Induced by Langmuir circulations too?**


Z
Y
X



Are these streaks induced by Langmuir circulations?

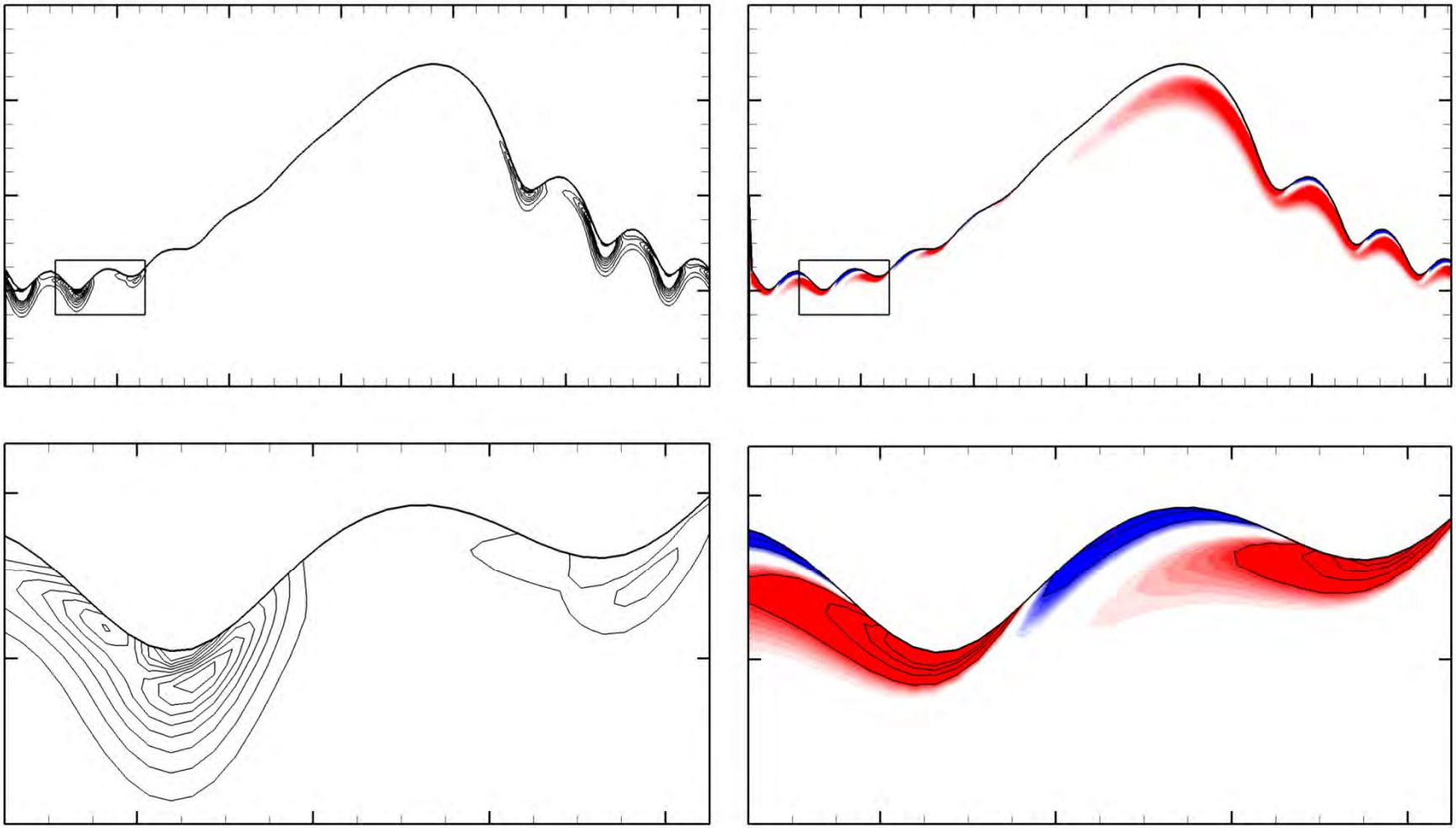
Langmuir circulations arise from interaction between *wave*-induced mean current and *wind*-induced shear current.

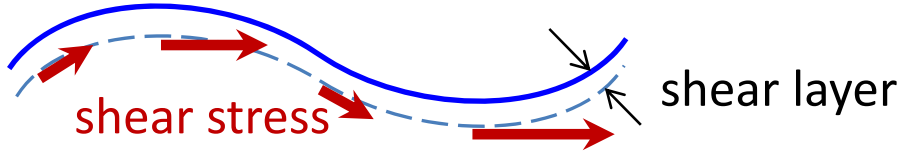
1. **Does *wave*-induced shear current exist?**
2. **Are the vortices induced by the Craik-Leibovich mechanism?**

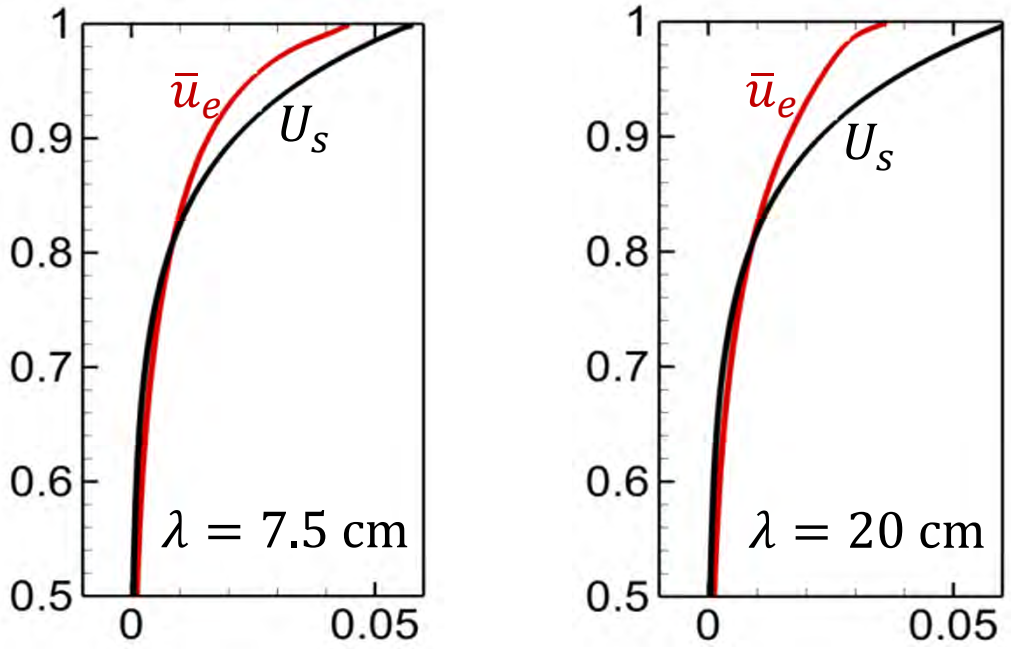
1. Does *wave*-induced shear current exist?

dissipation rate ~ velocity strain

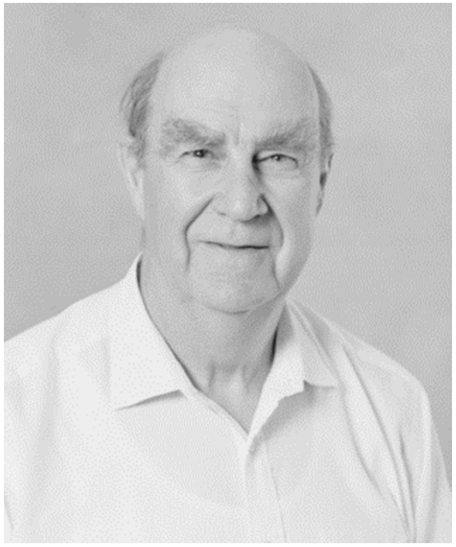
vorticity







Yes, wave-induced shear current indeed exist!

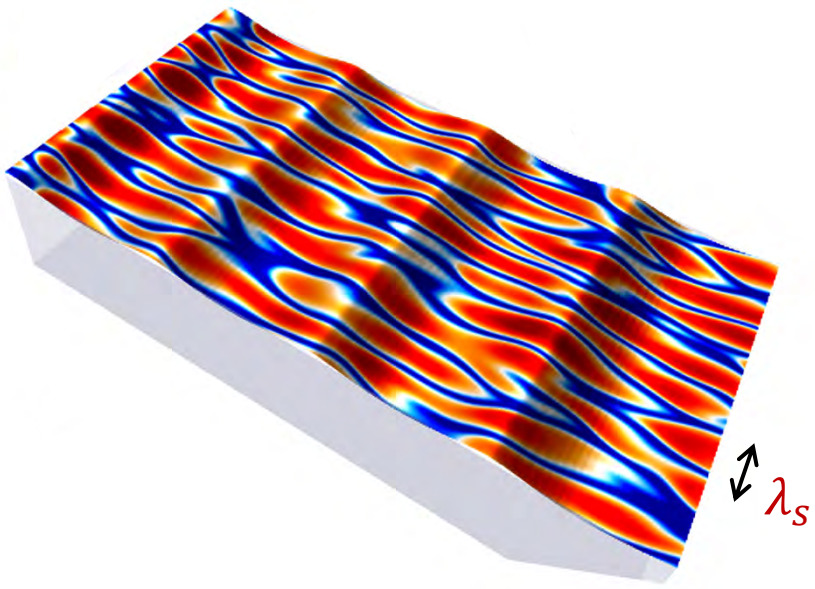


Longuet-Higgins, M.S. (1925 ~ 2016)

Mass transport in the boundary layer at a free oscillating surface

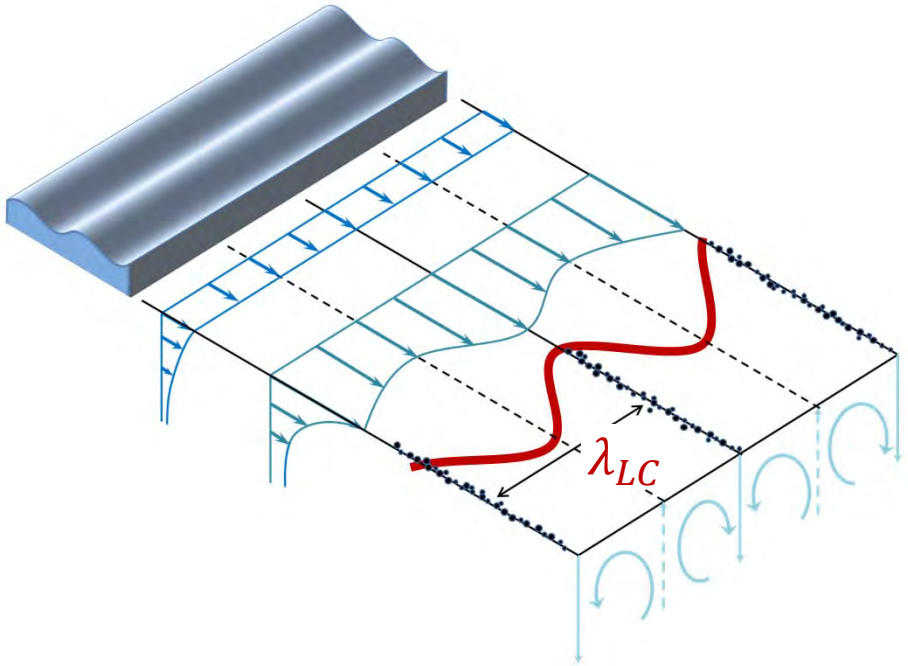
J. Fluid Mech., 8, 1960, 293-306

2. Induced by the Craik-Leibovich mechanism?



$$\frac{\partial \boldsymbol{v}}{\partial t} + \boldsymbol{v} \cdot \boldsymbol{\nabla} \boldsymbol{v} = -\frac{1}{\rho} \boldsymbol{\nabla} p + \nu \boldsymbol{\nabla}^2 \boldsymbol{v}$$

Boundary conditions on wavy surface



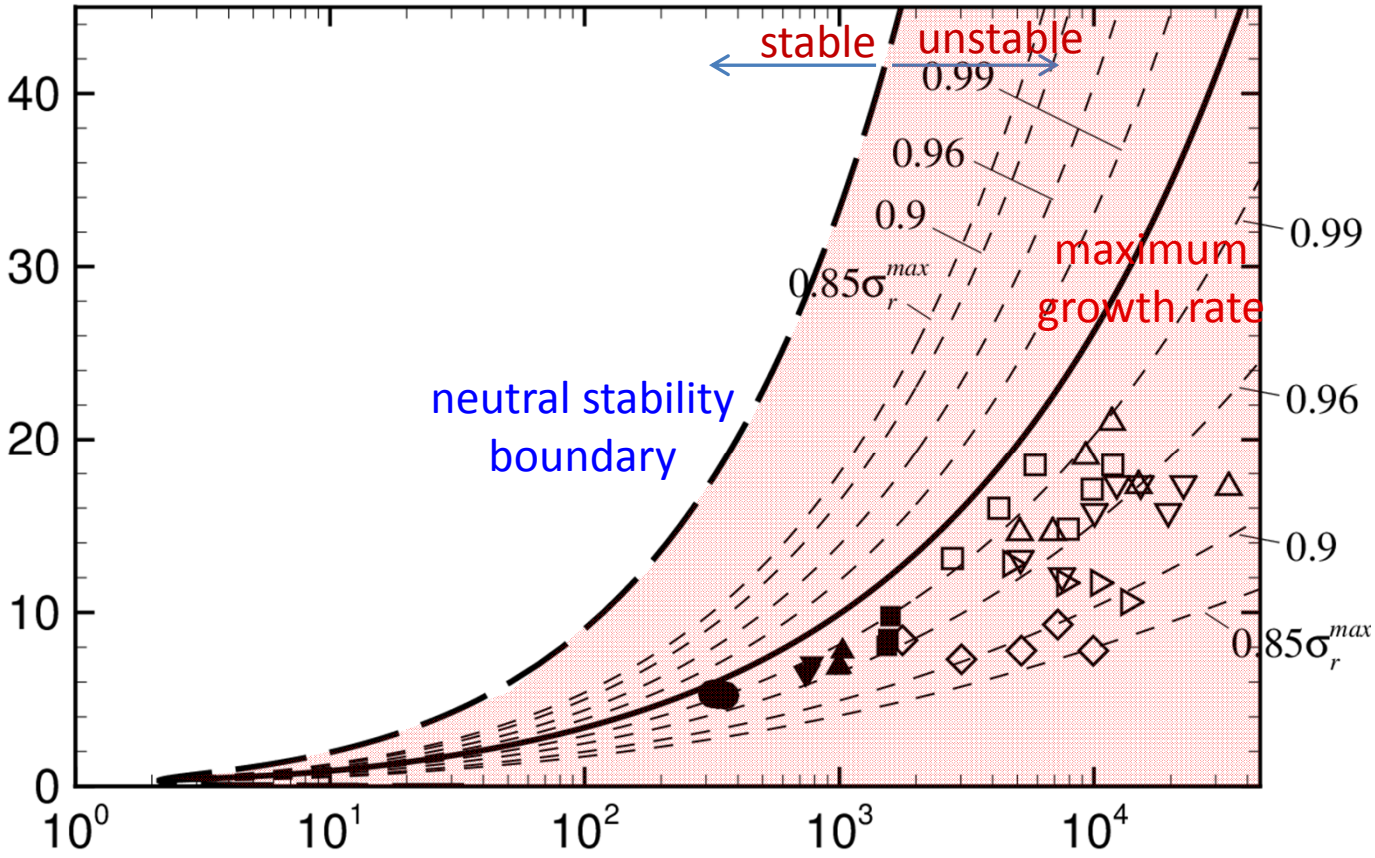
$$\frac{\partial \langle \boldsymbol{v} \rangle}{\partial t} + \langle \boldsymbol{v} \rangle \cdot \boldsymbol{\nabla} \langle \boldsymbol{v} \rangle = -\frac{1}{\rho} \boldsymbol{\nabla} p + \nu \boldsymbol{\nabla}^2 \langle \boldsymbol{v} \rangle + \boldsymbol{U_s} \times (\boldsymbol{\nabla} \times \langle \boldsymbol{v} \rangle)$$

If $\lambda_s \approx \lambda_{LC}$ of the most unstable perturbation

➔ The streaks are formed by Langmuir circulations.

$$\ell = \frac{\lambda}{\lambda_{LC}}$$

$$\ell_s = \frac{\lambda}{\lambda_s}$$



$$La^{-1} = \sqrt{2}\frac{(a\omega)a}{\nu}$$

Yes, the vortices are induced by the Craik-Leibovich mechanism.

***wave*-induced mean current**

***wind*-induced shear current**

***wave*-induced shear current**