# Numerical Simulations of Free-Surface Turbulent Flows

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# Free-surface Flows

$$\nabla \cdot \vec{\boldsymbol{v}}_a = 0$$

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


$$\begin{cases} \dfrac{D(\eta - z)}{Dt} = 0 \\ \hat{n} \cdot [\boldsymbol{T}]_w \cdot \hat{n}^{\mathrm{T}} = \hat{n} \cdot [\boldsymbol{T}]_a \cdot \hat{n}^{\mathrm{T}} \\ \hat{t} \cdot [\boldsymbol{T}]_w \cdot \hat{n}^{\mathrm{T}} = \hat{t} \cdot [\boldsymbol{T}]_a \cdot \hat{n}^{\mathrm{T}} \end{cases}$$

$$\begin{cases} \dfrac{D(\eta - z)}{Dt} = 0 \\ \hat{n} \cdot [\boldsymbol{T}] \cdot \hat{n}^{\mathrm{T}} = -\sigma\kappa + \tau_n^s \\ \hat{t} \cdot [\boldsymbol{T}] \cdot \hat{n}^{\mathrm{T}} = \tau_t^s \end{cases}$$

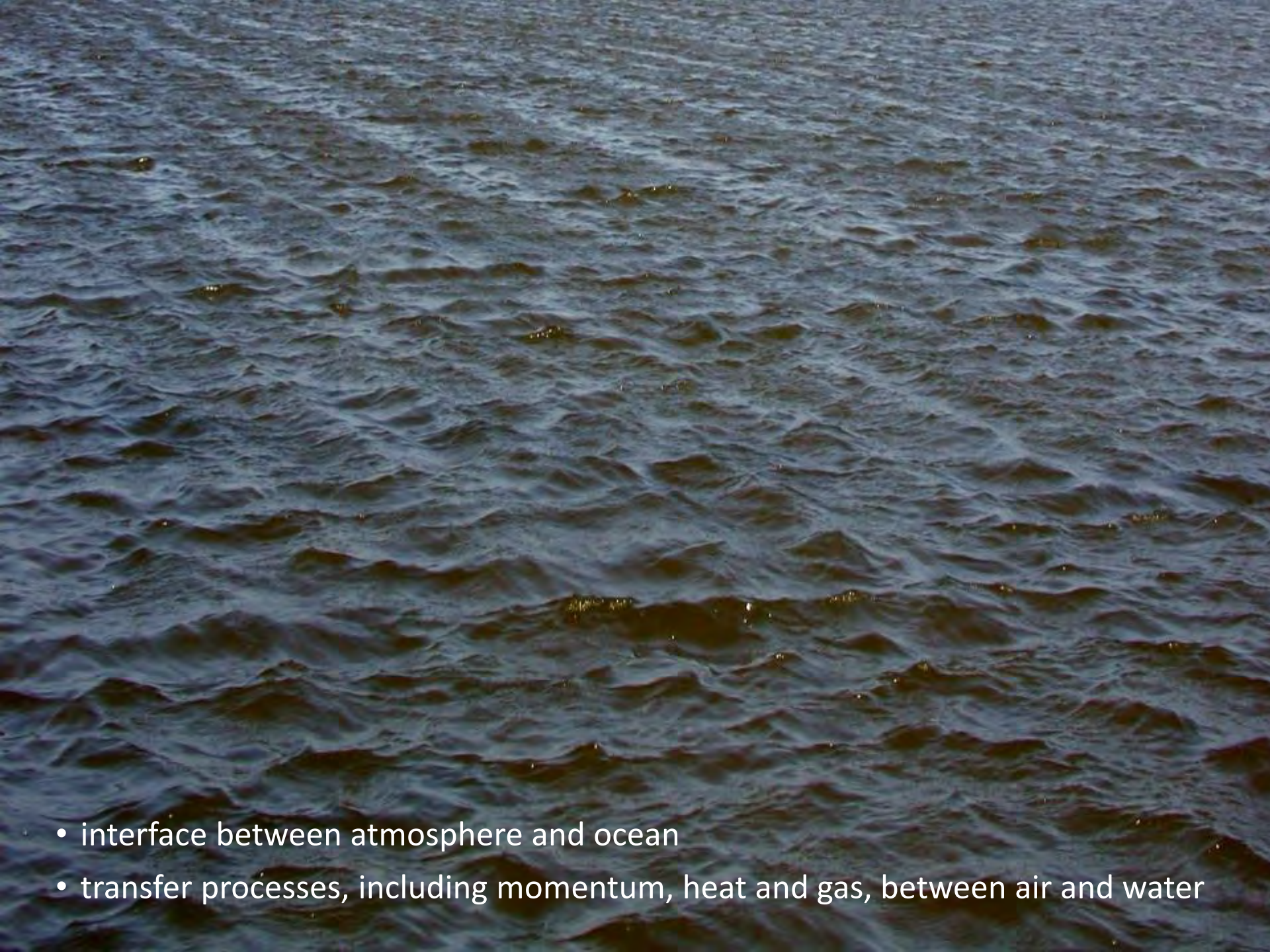
$$\nabla \cdot \vec{\boldsymbol{v}}_w = 0$$

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

$$\nabla \cdot \vec{\boldsymbol{v}} = 0$$

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

- Free-surface boundary, on which the boundary conditions are satisfied, is also an unknown
- Length and time scales need to be resolved: gravity and capillary waves
  turbulence micro and coherent scales

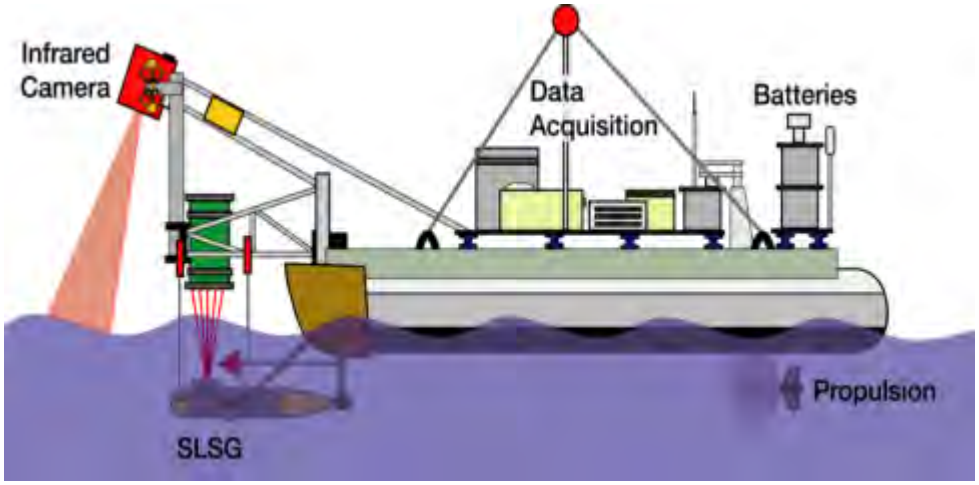


- interface between atmosphere and ocean
- transfer processes, including momentum, heat and gas, between air and water

## ➔ Surface temperature as a proxy for air-water gas flux

- Gas flux is difficult to measure, if possible.
- But, surface temperature can be measured with high accuracy and resolutions using infrared camera.
- Since, both temperature and dissolved gas are passive tracer …

  ➔ surface temperature ≈ distribution of gas flux

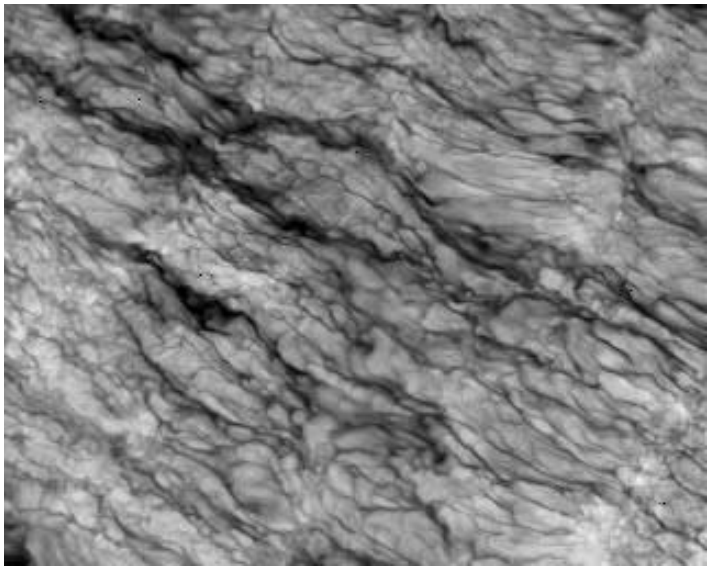


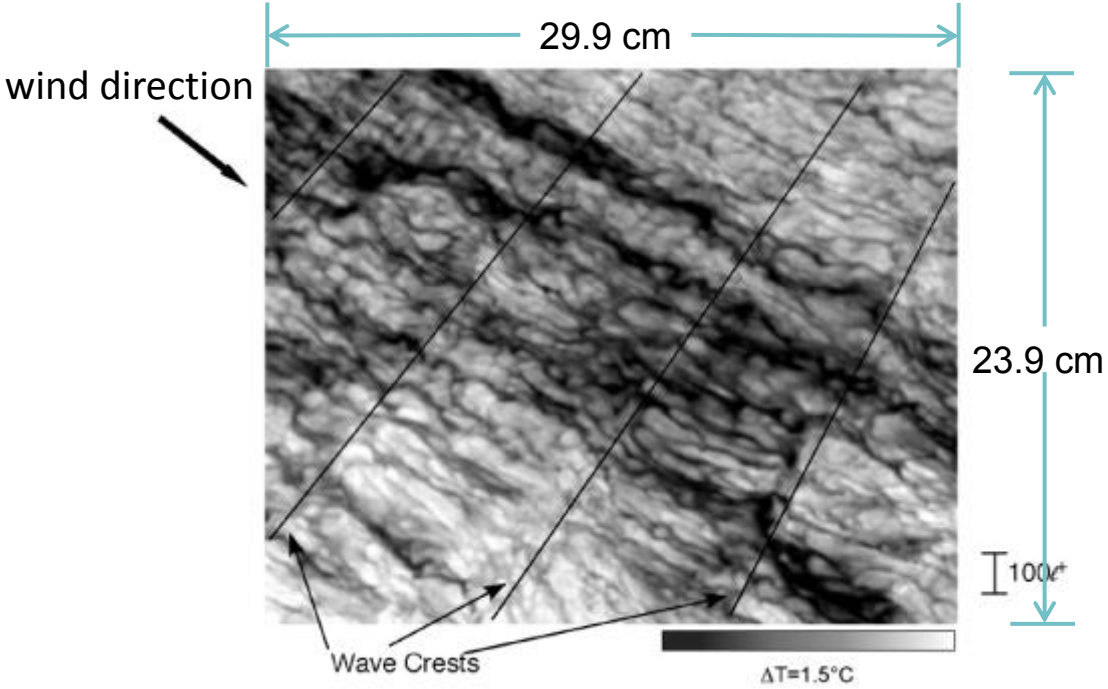

**Scanning Laser Slope Gauge**

**LADAS Catamaran in GasEx 2001 cruise**

# ➔ Do surface waves enhance air-water gas flux?

- Wind generates waves and gas flux increases with wind speed
  - ➔ surface waves enhance air-water gas transfer



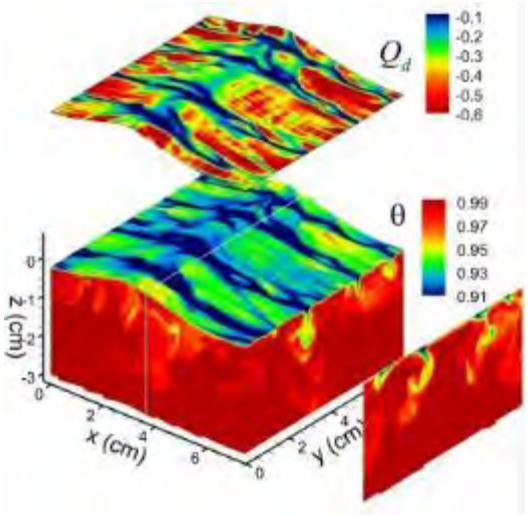



➔ Where are waves ?

➔ Signatures of streaks are more significant than that of waves !

- Is temperature a good proxy of gas flux?
- Thermal signatures of waves << streaks
  contribution on gas flux by waves << processes induce streaks (?)
- What process induces along-wind streaks? Is it Langmuir circulation?

## ➔ Yes, surface temperature is a good proxy of gas flux

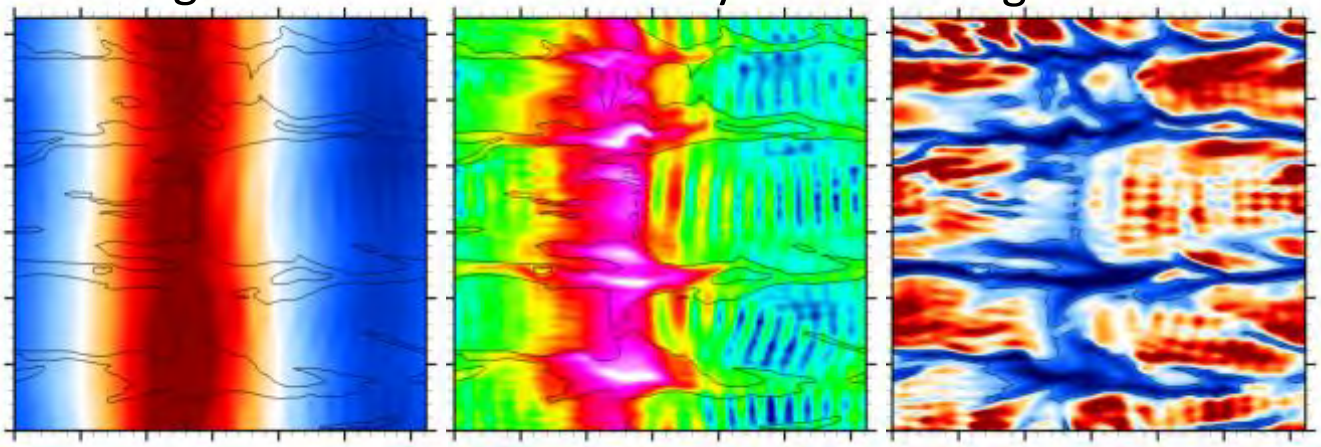



simulation

surface roughness

downwind velocity

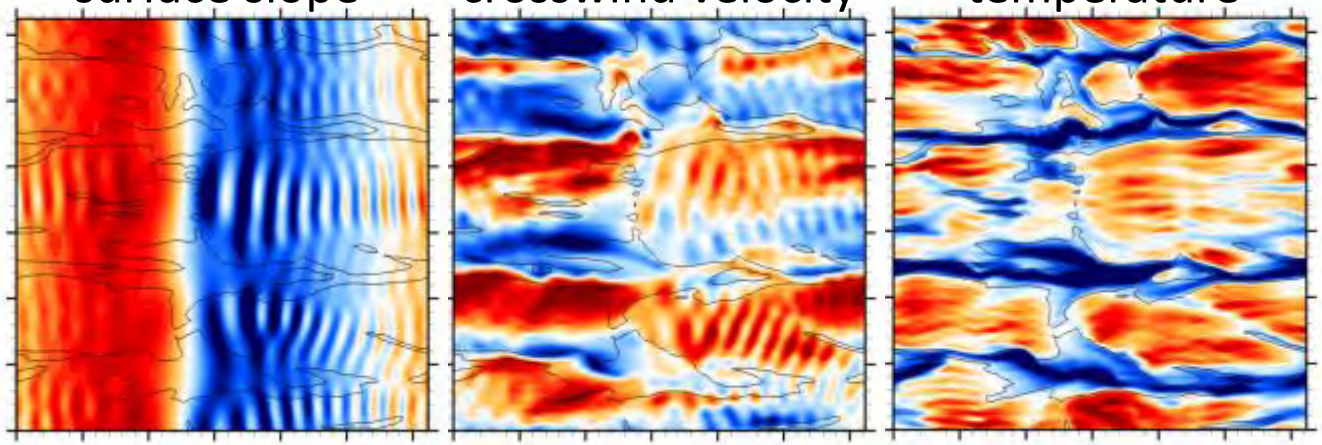
gas flux



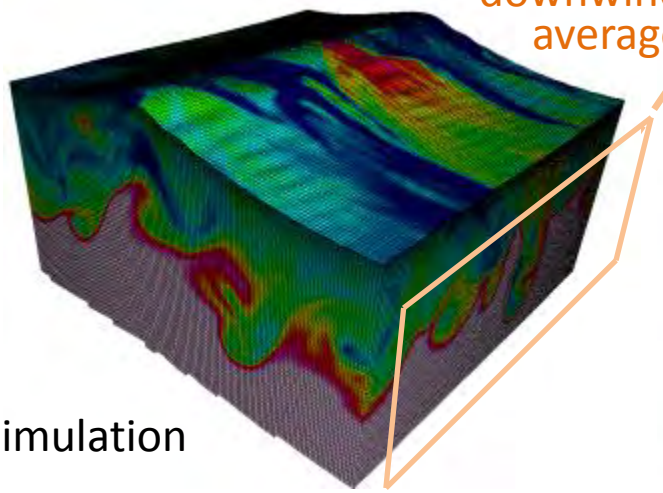
surface slope

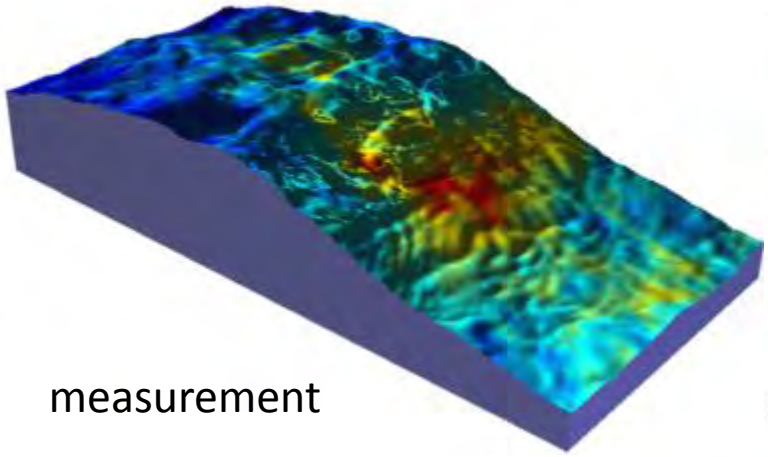
crosswind velocity

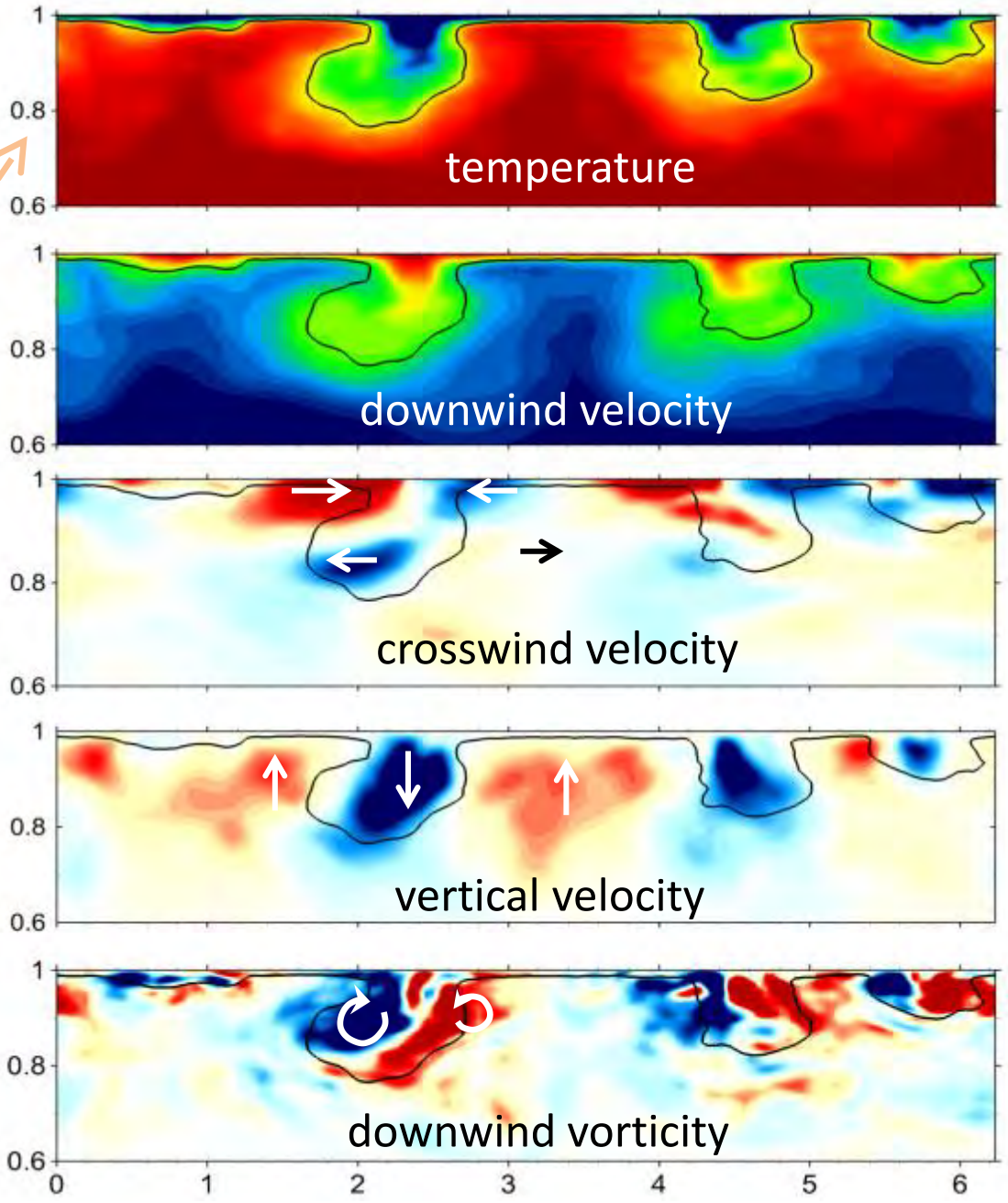
temperature



# ➔ Surface streaks are induced by streamwise vortices

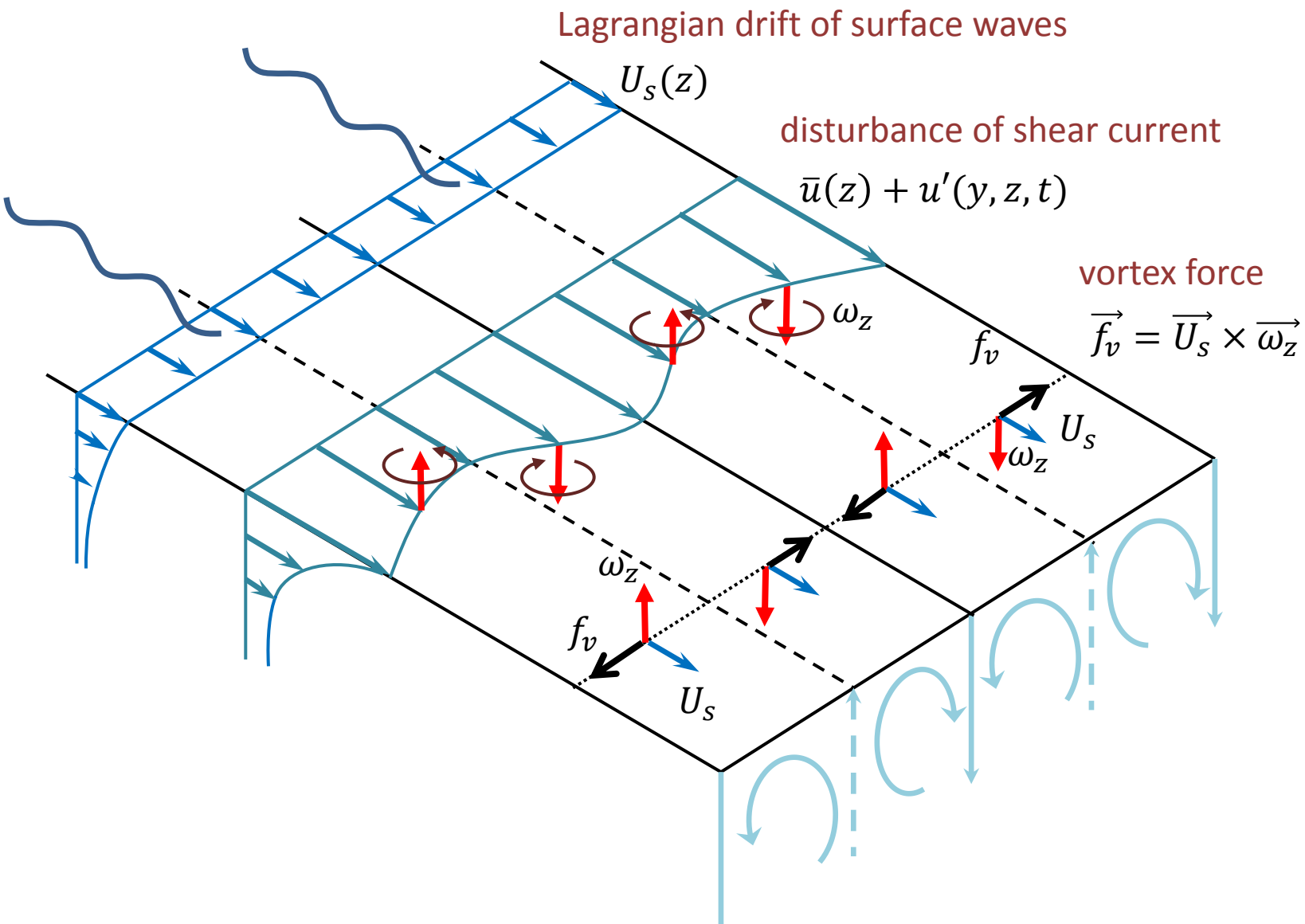


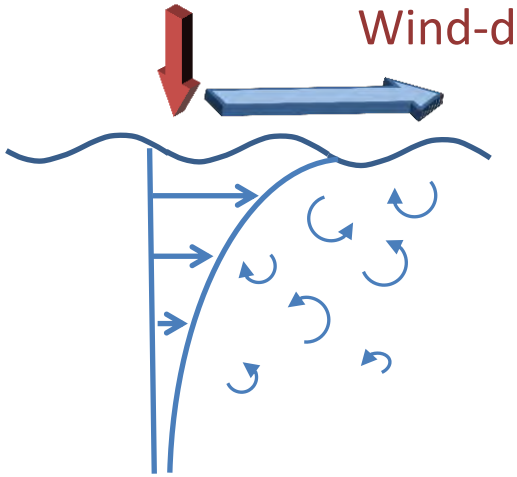



## ➔ How are these streamwise vortices formed?

**Are they Langmuir circulations formed by Craik-Leibovich mechanism?**

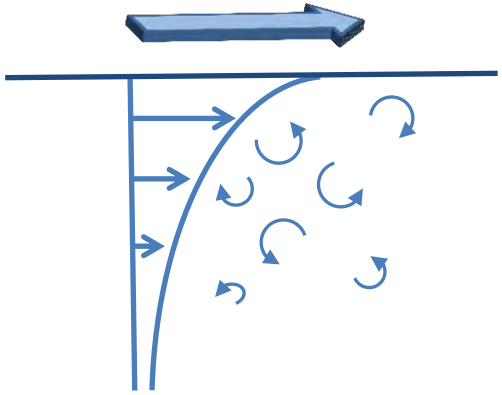


Wind-driven shear flow + wave

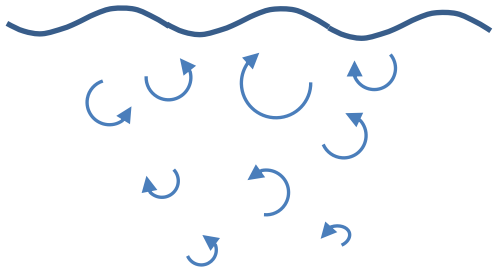


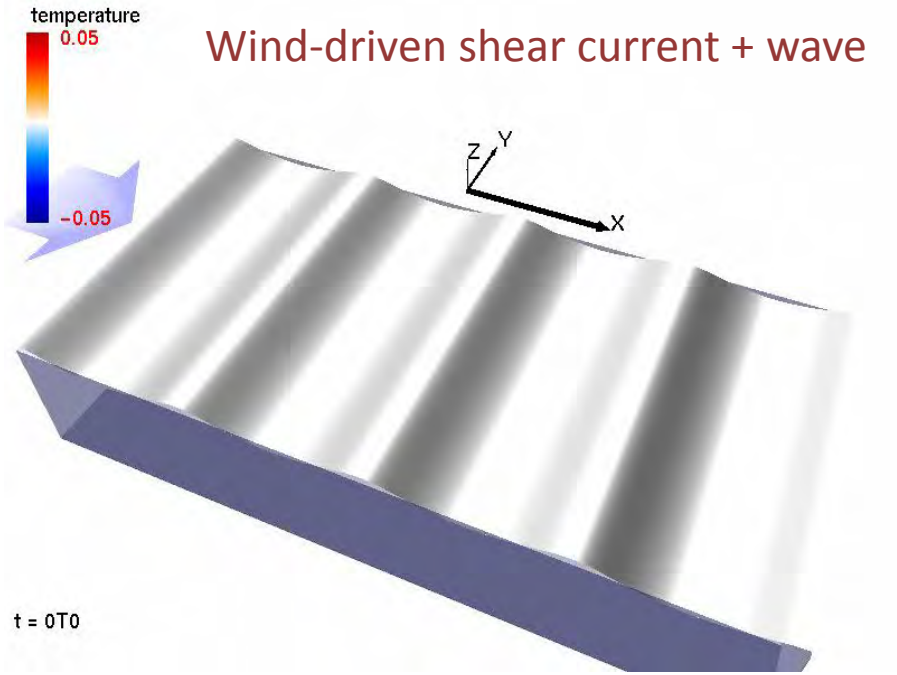
➔ **Decompose into two canonical problems:**

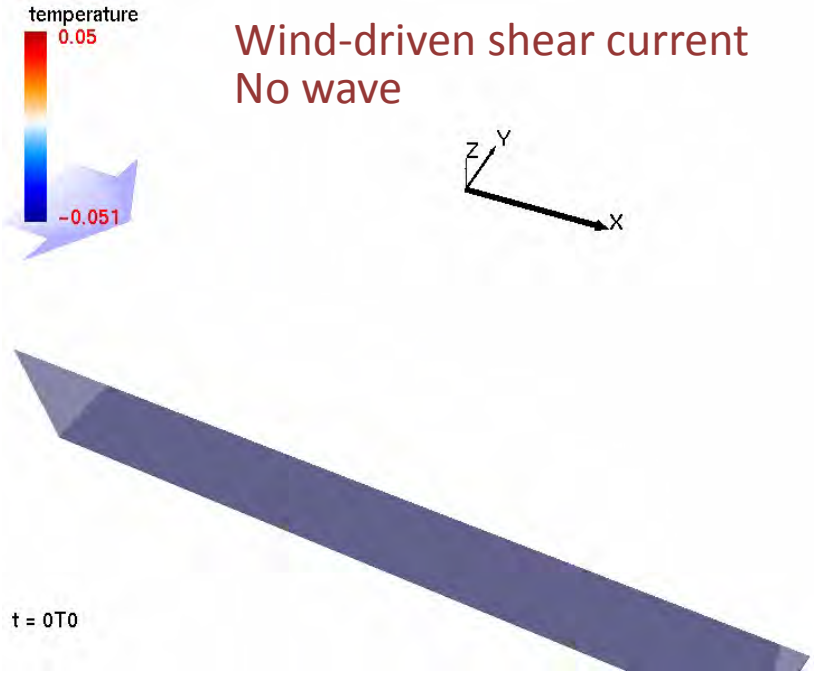
Wind-driven shear flow
No wave

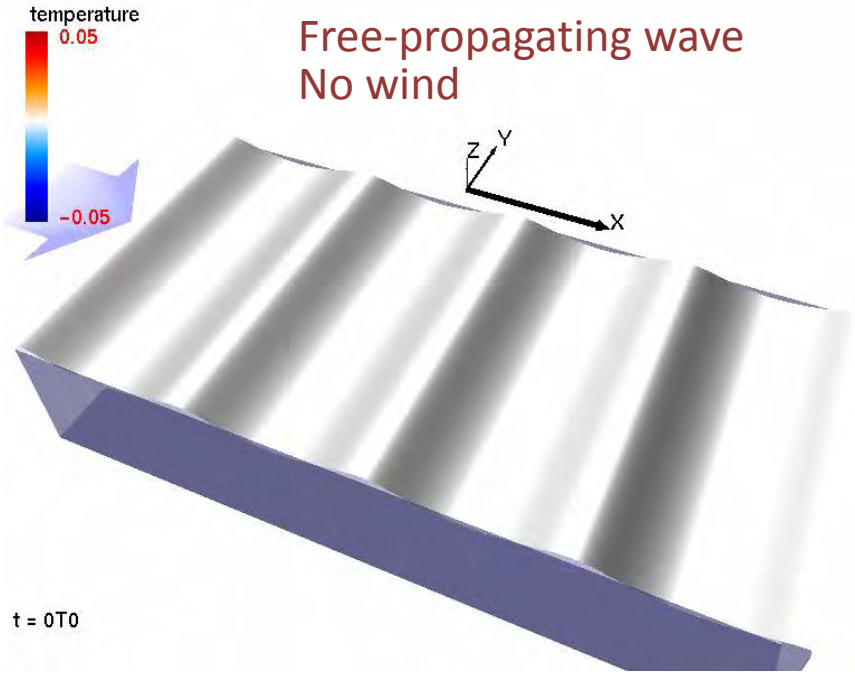


Free-propagating wave
No wind

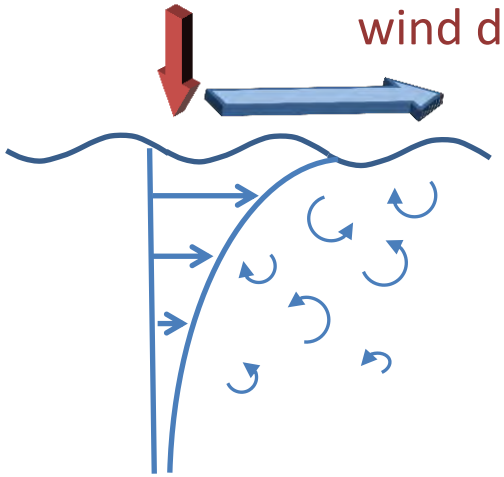



temperature
0.05
-0.05
Wind-driven shear current + wave
Z
Y
X
t = 0T0

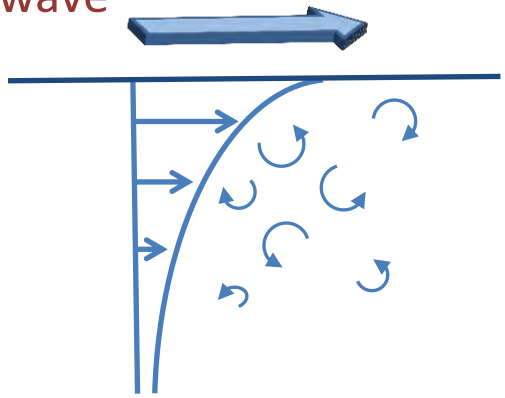

temperature
0.05
-0.051
Wind-driven shear current
No wave
Z
Y
X
t = 0T0


temperature
0.05
-0.05
Free-propagating wave
No wind
Z
Y
X
t = 0T0

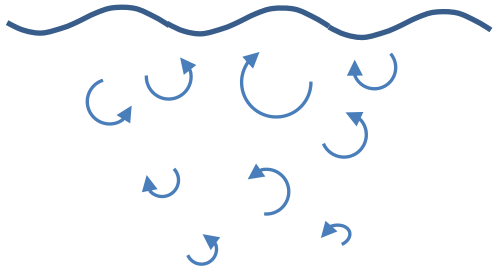
wind driven shear flow + wave



wind-driven shear flow
no wave



free-propagating wave
no shear current



- No wave-current interaction mechanism of Craik-Leibovich
- But surface streaks with similar length scales form

➔ **Mechanism that induces streamwise vortices & streaks are still unclear (to us)**