LABORATOIRE DES ECOULEMENTS GEOPHYSIQUES ET INDUSTRIELS

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Wind-mixed layer deepening in a rotating frame

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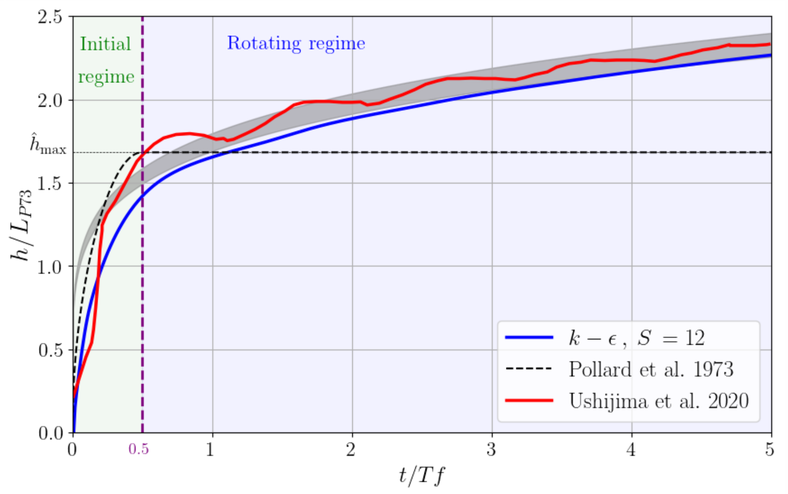
The shear produced at the base of the mixed layer erodes the stable stratification at a rate $t^{1/4}$

Background

Wind action on the ocean's surface induces turbulence primarily through surface waves and shear stresses. This turbulence erodes local stratification, creating a mixed layer where temperature and salinity are roughly uniform over the vertical.

The accurate representation of mixed layer depth in climate models is essential, as it influences ocean heat uptake, vertical mixing, and the carbon cycle.

In a pioneer work *Pollard et al, 1973* found a law for the deepening at a rate $t^{1/2}$. However they predict the deepening is arrested for $t > \pi/f$ to $h = 8^{1/4}\dfrac{u_*}{\sqrt{N_0 f}}$ because of inertial oscillations.



Analytical Method

Momentum Equations

$$q = u + iv, \qquad \frac{\partial}{\partial z}\left(\nu_t \frac{\partial q}{\partial z}\right) = \frac{\partial q}{\partial t} + ifq$$

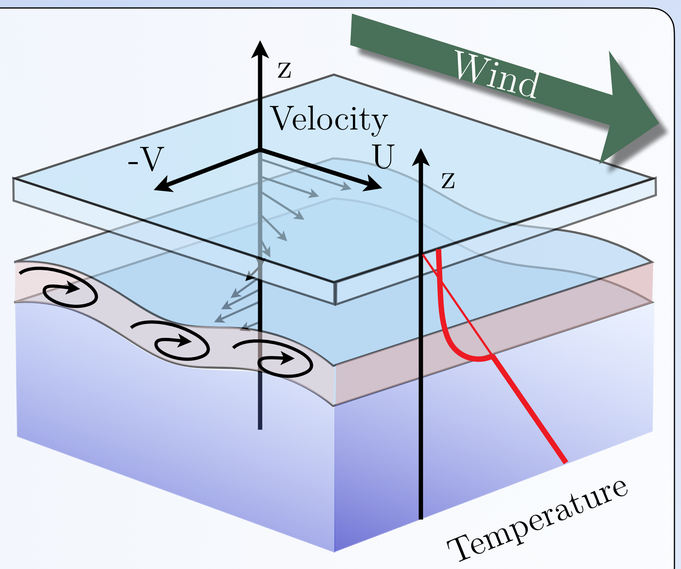
$$\frac{\partial b}{\partial t} = \frac{\partial}{\partial z}\left(\nu_t' \frac{\partial b}{\partial z}\right)$$

Non dimensional parameter

$S = \sqrt{N/f}$ S>3: Pollard's regime; S<3: Full Ekman layer

Typical vertical scale

$$L_{P73} = u_*/\sqrt{Nf}$$



Central Result

We investigate the dynamics of the wind-driven mixed layer in a rotating, linearly stratified ocean, and propose a scaling law for its long-term evolution

$$h \propto \sqrt{\frac{u_*}{Nf}}\,(tf)^{1/4}$$

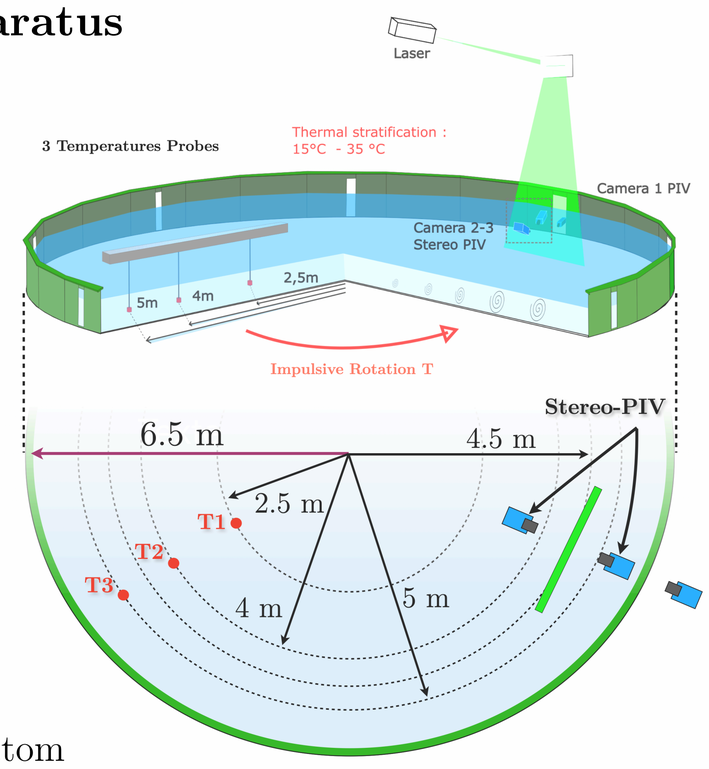
Experimental apparatus

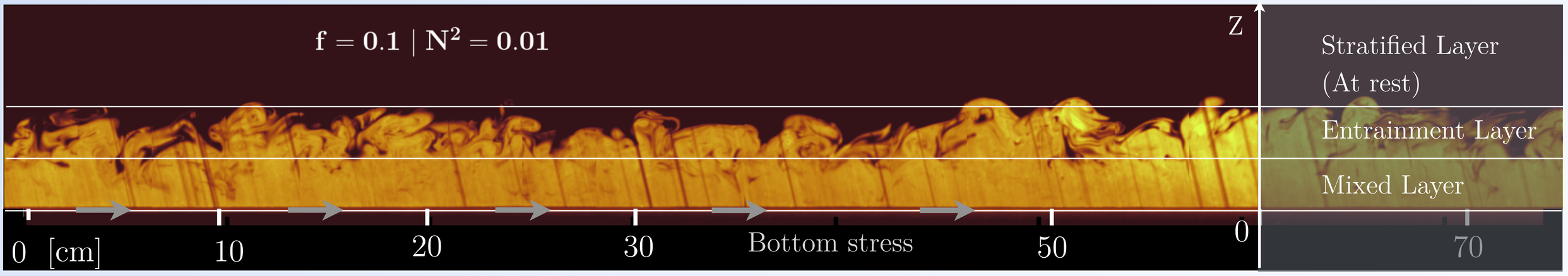
Dynamical observation:
- S-PIV (3 components)

Thermal stratification:
- Progressive filling (4h)
- From the bottom

Thermal acquisition:
- 3 thermals probes
- Vertical profiler

Tracers Observation:
- Dye (Rhodamine B)
- Injection from the bottom
- Illumination by Yag 5W laser



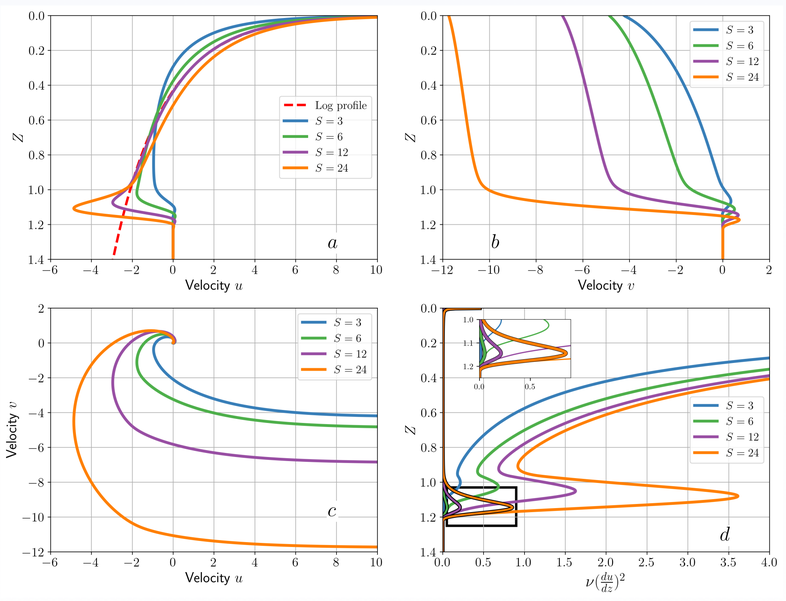


Self Similar solutions

$$\mathbf{u} = u_*\hat{\mathbf{u}}, \quad t = \hat{t}/f, \quad h_c = L_{P73}\hat{h}_c, \quad \nu_t = u_* h_c \hat{\nu}$$

$$\frac{\partial}{\partial Z}\left(\hat{\nu}\frac{\partial \hat{q}}{\partial Z}\right) = -\hat{c}Z\frac{\partial \hat{q}}{\partial Z} + S^{-1}\hat{h}_c\left(\frac{\partial \hat{q}}{\partial \hat{t}} + i\hat{q}\right)$$

Steady solutions (Ekman Spiral) ***Inertial oscillations***

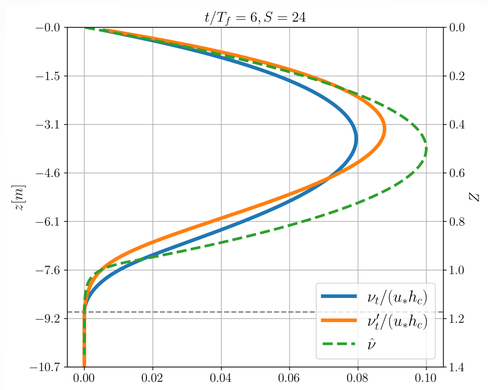


Turbulent Viscosity

$(z,t) \to (Z = -z/h_c, \hat{t})$

h_c: top of the entrainment layer

δ: scale of exponential decay



Quadratic profile:

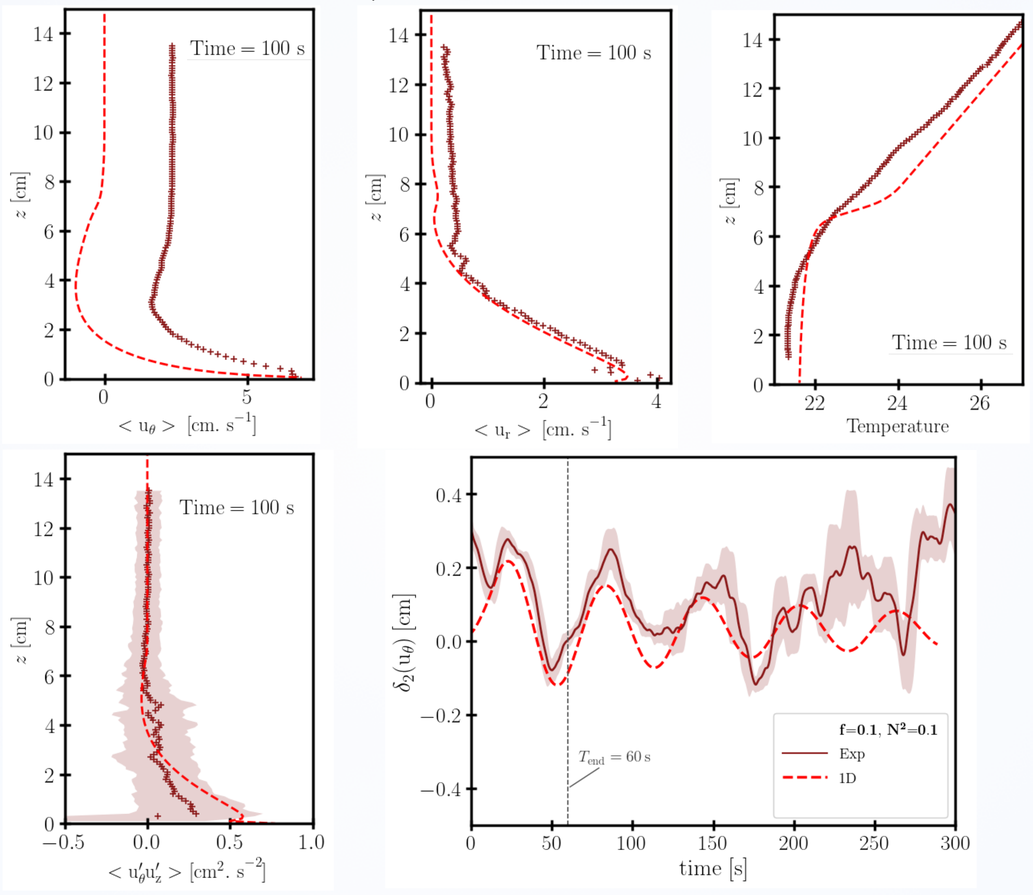
$$\hat{\nu} = \kappa Z(1-Z), \quad \text{for } Z < Z_0$$

$$\hat{\nu} = \hat{\nu}_0 e^{-(Z-1)/\delta}, \quad \text{for } Z \geq Z_0$$

$$Z_0 = 1 - \delta + \frac{1}{2}\left(\sqrt{1+4\delta^2} - 1\right)$$

$$\hat{\nu}_0 = \kappa Z_0(1-Z_0)e^{(Z_0-1)/\delta} \simeq \frac{\kappa}{e}\delta$$

Comparaison 1D/Experimental entrainment



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