# Measuring mixing efficiency in experiments of strongly stratified turbulence

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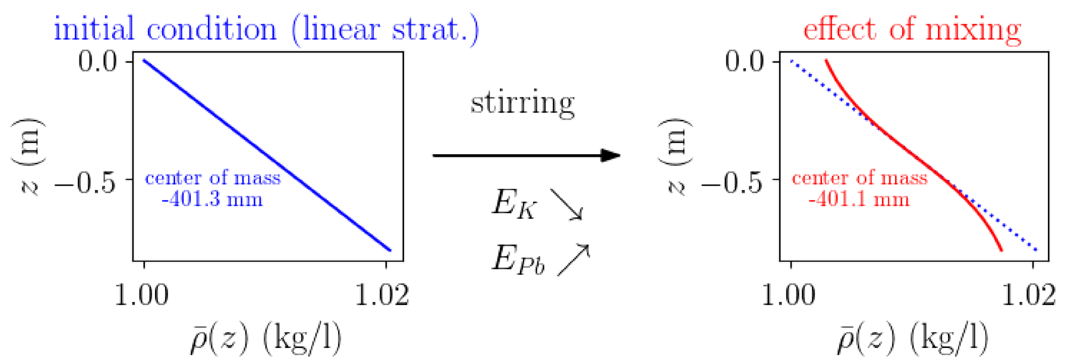
## 1 Introduction and motivations

**Mixing coefficient** $\Gamma = \frac{|\Delta E_{Pb}|}{\Delta E_K}$




- $\Delta E_K$ kinetic energy dissipation
- $-\Delta E_{Pb}$ increase background potential energy

**Simulations ocean/atmosphere are LES**

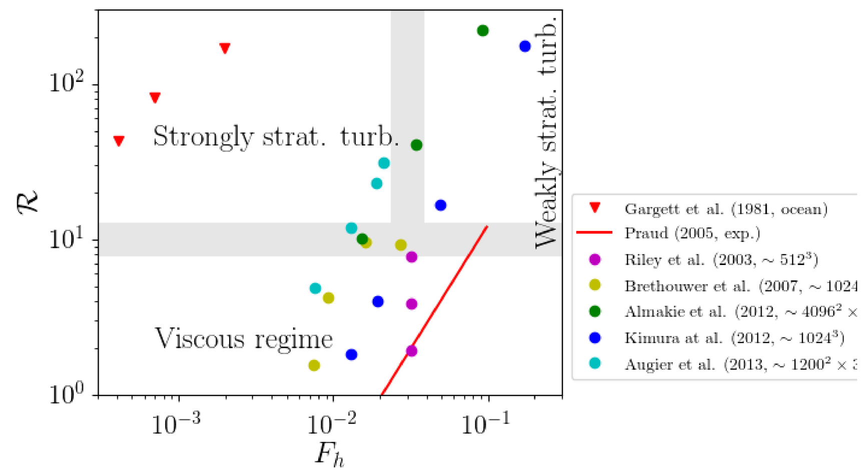
- Approximation with a turbulent diffusivity
$$-\boldsymbol{\nabla}\cdot[\boldsymbol{v}b_{tot}] \simeq \kappa_t \boldsymbol{\nabla}^2[b_{tot}]$$
- Approximation from a flux law
$$\langle wb_{tot}\rangle \simeq -\kappa_t d_z \bar b_{tot} = -\kappa_t N^2 \Rightarrow \kappa_t = \frac{C_{K\to A}}{N^2}.$$
- Approximation of the energy conversion $C_{K\to A}$
$C_{K\to A} = \Gamma\varepsilon_K$, with $\Gamma = 0.2$ a constant!

The dynamics of **rotating** and **stratified** flows depends on

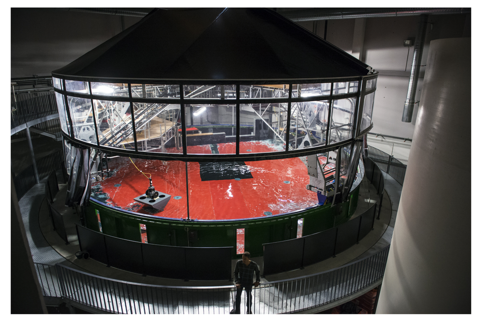
- $\mathcal{R} = \frac{\varepsilon_K}{\nu N^2}$ buoyancy Reynolds number (viscosity)
- $F_h = \frac{U_h}{NL_h}$ horizontal Froude number (stratification)
- $Ro = \frac{U_h}{fL_h}$ Rossby number (rotation)

$\Gamma(\mathcal{R}, F_h, Ro)$ ?

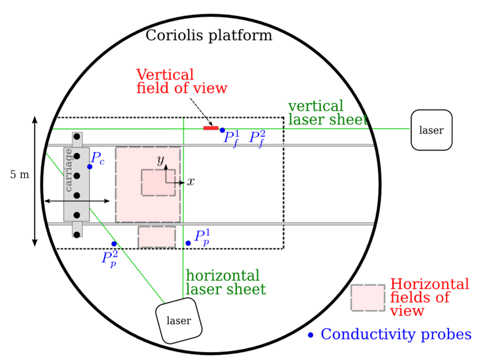
Very **difficult to reach the geophysical regimes** with **simulations** and **experiments**




## 2 Experimental setup and methods



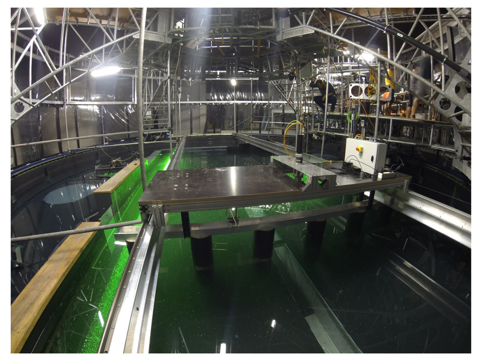
The Coriolis platform is a **huge rotating platform (13 m diameter)** designed to study rotating and stratified flows. Its large scale allows us to study geophysical turbulence at **large Reynolds number and relatively small $F_h$ and $Ro$.**




In the **MILESTONE project**, a linearly stratified fluid (water, salt and alcohol) is stirred by the periodic movement of an array of large cylinders (2 diameters: 25 and 50 cm).

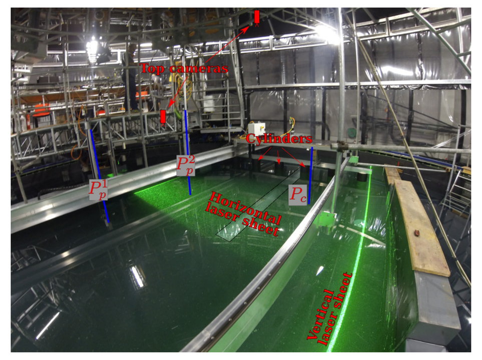
Our two main goals are:

- to test the theory of **strongly stratified turbulence** with an experiment,
- to **measure mixing coefficient** and study its variations with $\mathcal{R}$ and $F_h$.



**The movement of the carriage is periodic** and composed of constant acceleration and deceleration ramps over 50 cm and **5 m at constant speed**. This speed is varied from 1 cm/s up to 24 cm/s.

To be able to accurately measure the mixing, the slow experiments are very long (∼ 5 hours, i.e. more than 10 periods of oscillation of the carriage). In contrast, the mixing is fast for the larger velocity so it is difficult to get a lot of statistics.

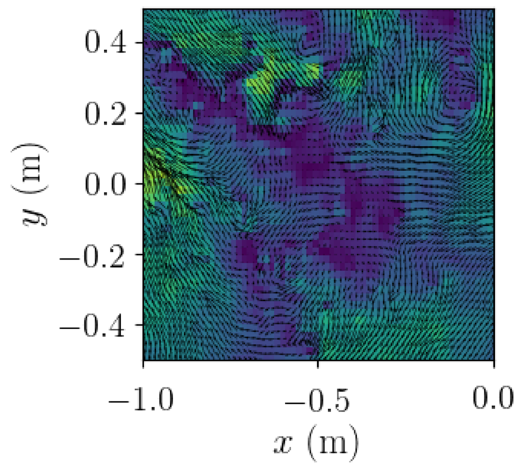


The velocity is measured by PIV (**horizontal scanning PIV** with up to 16 vertical levels and **vertical 2D PIV**).

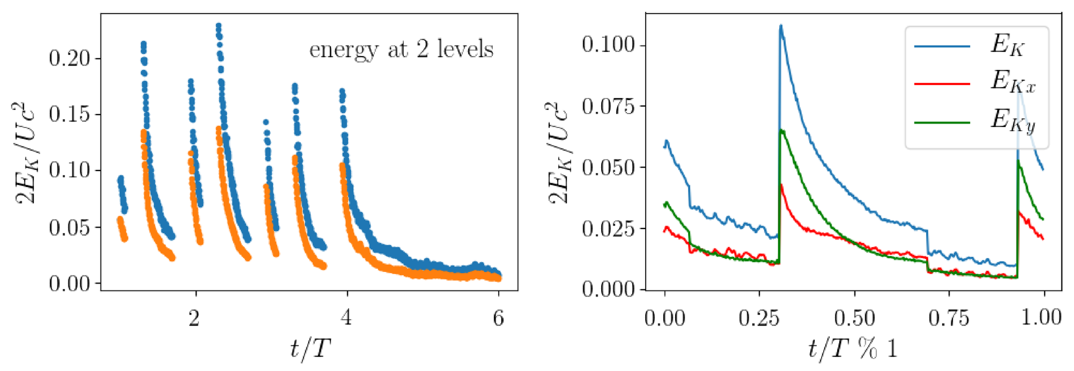
Density is measured with temperature and conductivity probes which are, static (to measure the density at the top and the bottom of the tank), attached to the carriage and attached to traverses to obtained **density profiles**.

- The experiment (movement of the carriage and of the probes, scanning PIV) is **controlled with an open-source Python package** called fluidlab.
- The **computation of PIV** fields is performed on the **cluster** of the LEGI with an **open-source Python package** called fluidimage.

## 3.1 Measuring kinetic energy decay



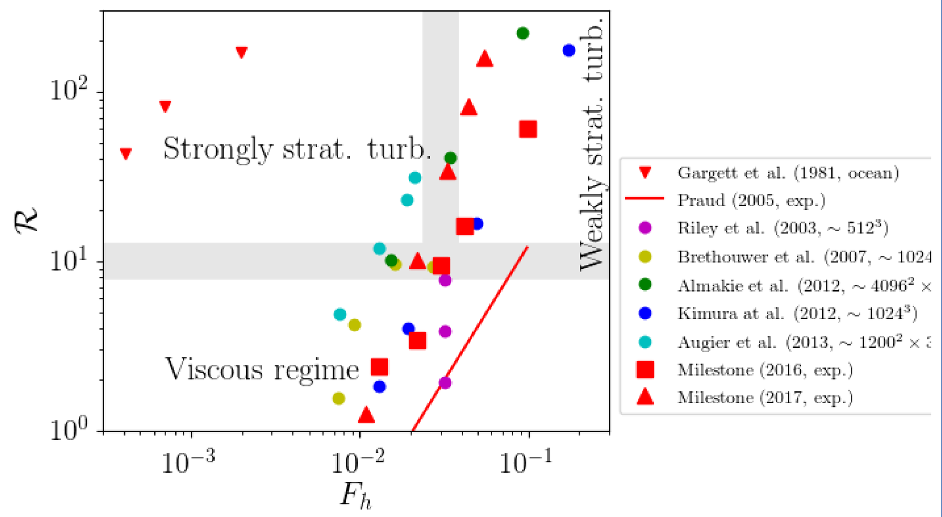

$\boldsymbol{v}_h(\boldsymbol{x}_h, z)$ for different levels from scanning PIV



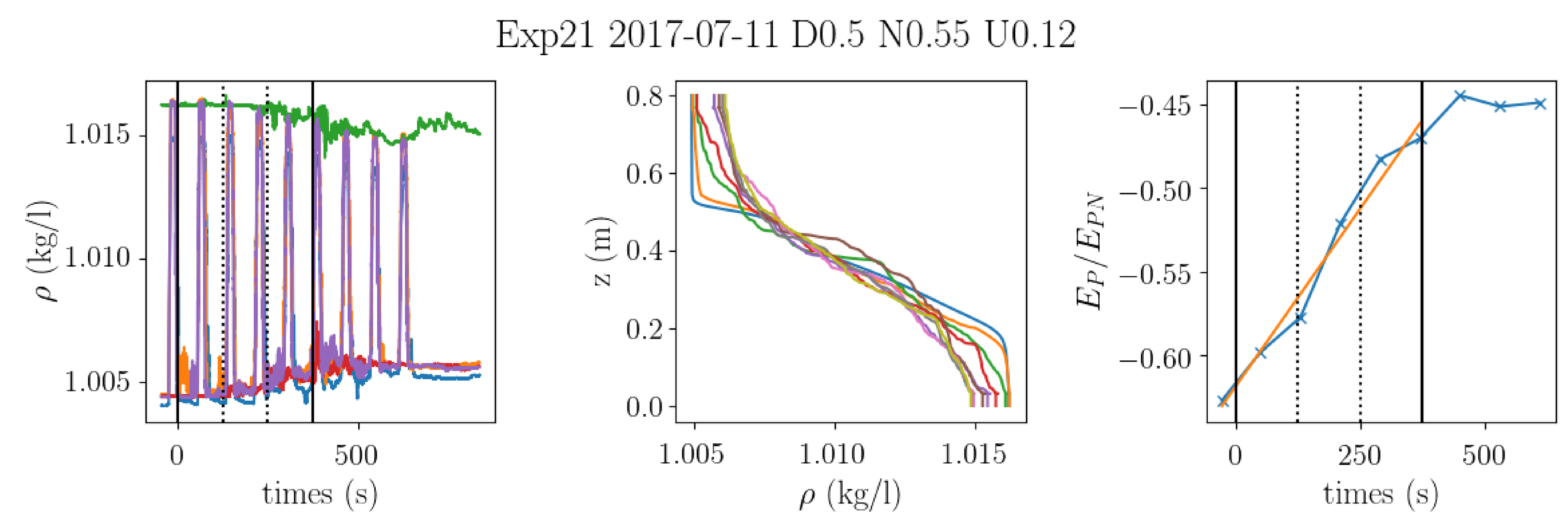

Kinetic energy and its decay
$\frac{dE_K}{dt} \Rightarrow \varepsilon_K \Rightarrow \mathcal{R}$ and $F_h$

### Comparison with other studies

By averaging the energy computed from several horizontal PIV fields (different vertical levels and periods of the carriage), we compute the kinetic energy and the kinetic energy dissipation.
Together with the mean Brunt-Väisälä frequency computed from the density profiles, we are able to estimate values of $\mathcal{R}$ and $F_h$ for each experiment.

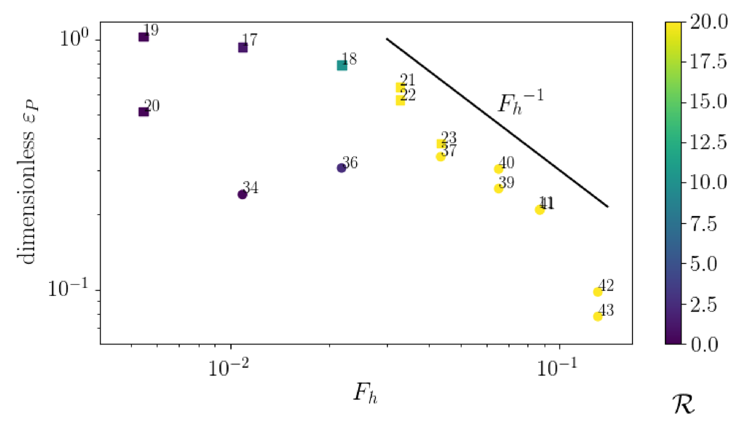



## 3.2 Measuring mixing




Evolution of the density, the space-averaged profiles and the background potential energy during one experiment (with three period of forcing).

## 4 Evaluation of the mixing coefficient




The rate of increase of the background potential energy normalized by an estimation of the dissipation of kinetic energy $3\times10^{-3}U_c{}^3/D_c$ is plotted as a function of the Froude number.

This quantity approximately proportional to the mixing coefficient is clearly not constant.

## 5 Open-science and open-source

Object-oriented open-source framework for studying fluid dynamics with Python:

`http://fluiddyn.readthedocs.io`
`https://bitbucket.org/fluiddyn`

- fluiddyn: base package containing utilities
- fluidlab: control of laboratory experiments
- fluidimage: scientific treatments of images of flows (PIV, ...)
- fluidfft: C++ / Python Fourier transform library (highly distributed, MPI, CPU/GPU, 2D and 3D)
- fluidsim: pseudo-spectral simulations in 2D and 3D
- fluidfoam: Python utilities for openfoam
- fluidcoriolis: run and analyze experiments in the Coriolis platform

Good quality software: documented, tested, continuous integration

## 6 Conclusions

- Experimental flows very close to the strongly stratified regime
- Good measurement of the mixing
- Many things to look at in the data (soon **open-data**)