EXPERIMENTAL OBSERVATION OF DENSITY FLUCTUATIONS IN A STABLY STRATIFIED TURBULENT FLUID

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Abstract Using planar laser induced fluorescence, we present quantitative measurements of density fluctuations in a two-layer stably stratified fluid forced by an oscillating grid located at the bottom of the tank. The turbulence produced by the grid spreads rapidly in the lower layer and is blocked at the interface between the dense and and the light fluid. The interface height increases then slowly by entraining some of the fluid of the upper layer in the turbulent layer. We propose a new method to separate the "wave" part from the "turbulent" part of the density fluctuations. We then discuss the role of these density fluctuations in the dynamics of the mixed layer depth.

INTRODUCTION

The large scale dynamics of oceanic and atmospheric flows is strongly affected by the vertical structure of the density field. The shape of the local density profile depends on turbulent mixing events that usually involve small time and spatial scales that can not be directly simulated in global circulation models. Such mixing process must therefore be described and understood in detail in order to propose relevant parameterizations.

Here, we focus on an experimental idealization of a mixed layer : an oscillating grid generating turbulence is localized at the bottom of a stably stratified fluid made of two homogeneous layers (Figure 1, left). The turbulence rapidly spreads in the homogeneous bottom layer, and is blocked at the interface. The interface height increases then slowly by entraining some of the lighter fluid in the turbulent layer.

Previous studies discussed how the interface dynamics depends on turbulence properties and on the averaged density profile, see e.g. [1] and references therein. Yet, the role of density fluctuations in the interface dynamics (entrainment velocity, depth) has not been addressed. The current work fill this gap.

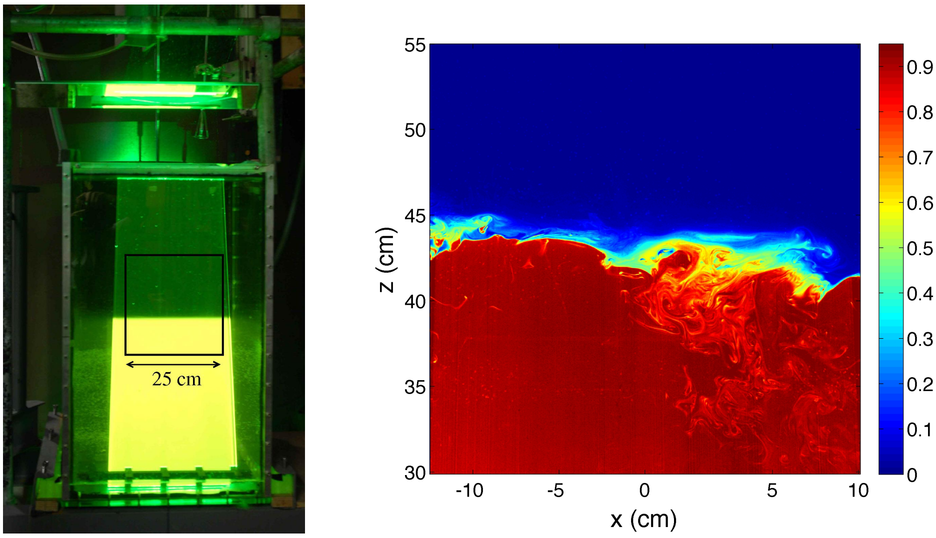

Figure 1. Left: experimental setup. Right: snapshot of the density field (red, close to one: dense fluid; blue, close to zero: light fluid) in the 25cm$\times$25cm area.

EXPERIMENTAL SETTINGS AND DATA ANALYSIS

Our experimental setting is very close to the seminal experiment of Rouse and Dodu [2]. The novelty is to use refractive index matching technics in order to quantitatively measure the density field with planar laser induced fluorescence. The lower layer is a mixture of water, salt and a fluorescent dye (Rhodamine). The upper layer is a mixture of water and ethanol. The two fluids have the same refractive index but different densities.

A typical density field around the interface is shown figure 1 (right). One distinguishes clearly a large scale wave structure (sloshing) superimposed with small scale turbulent fluctuations. We devised a method to extract the turbulent part from the wave part. The wave part defines the interface height variations $h(z,t)$. The turbulent part is used to construct the density distribution $p(\sigma,\zeta,t)$ where σ is a given density level and ζ the distance from the interface h.

DISCUSSION

An example of the temporal evolution of density fluctuations $p(\sigma,\zeta,t)$ is provided in Fig. 2. A key parameter of the problem is the Richardson number Ri defined as the ratio of potential energy associated with the density interface with the turbulent kinetic energy. We show how the shape of the density distribution $p(\sigma,\zeta,t)$ varies with Ri. We find that for a wide range of parameters, density fluctuations may provide a strong feedback on the evolution of the average density profile. We explain the consequences of these observations for modeling studies.

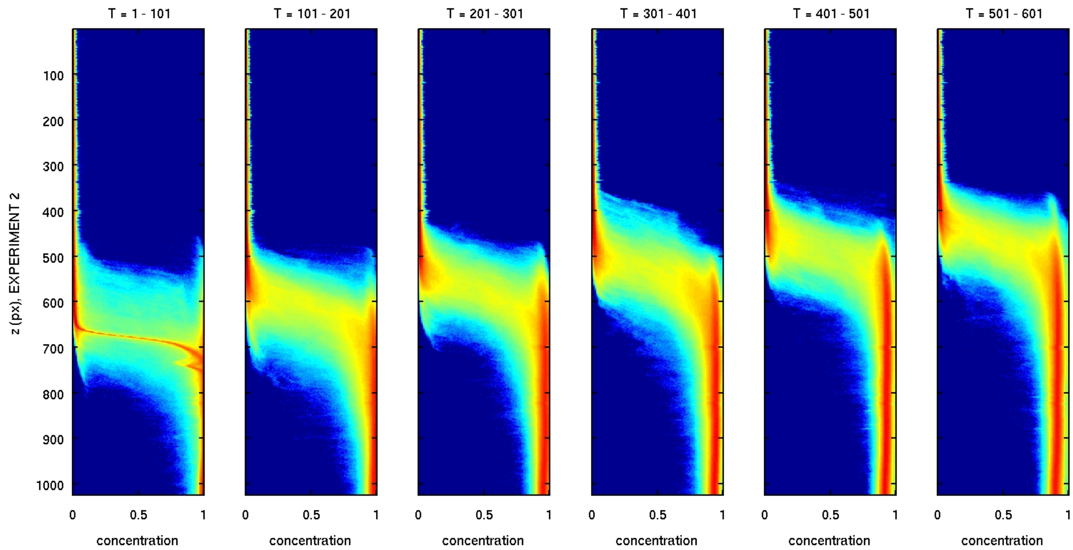

Figure 2. Temporal evolution of the density distribution $p(\sigma,z,t)$, which is normalized at each depth. The six panels correspond to successive times separated by 100 s. The vertical axis is the height z in pixels (here 1 px $= 0.25$ mm), the horizontal axis is the relative density level σ normalized between 0 and 1. The color scale varies logarithmically from 0 (dark blue) to one (dark red). We clearly see the progression of the interface height with time, the decrease of the mean density in the lower layer, and the presence of large density fluctuations around the density interface.

References

[1] H. J.S. . Fernando. Turbulent Mixing in Strafified Fluids *Annual Review of Fluid Mechanics* **23**: 455–493, 1991.

[2] H. Rouse, J. Dodu, Diffusion Turbulente a travers une discontinuite de densite *La houille blanche* **4**, 522-532, 1955.