TRANSPORT OF PARTICLES BY INTERNAL WAVES

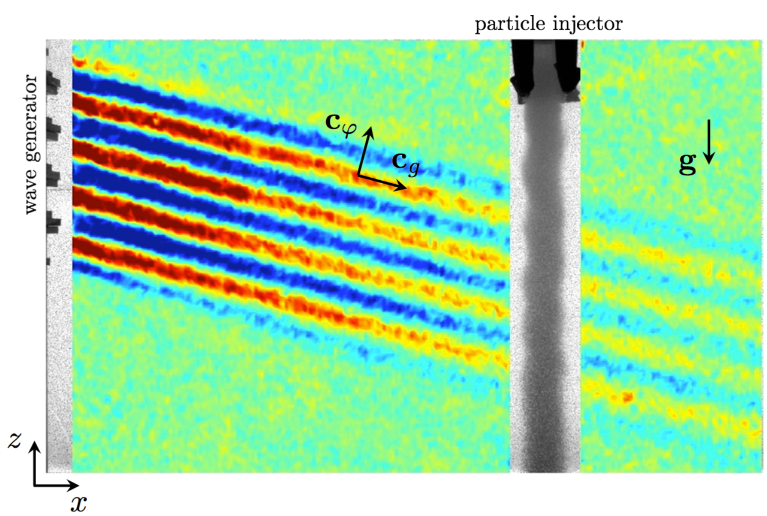
Ernesto Horne *[1,2], Diane Micard[1,2], Sylvain Joubaud[1], and Philippe Odier[1]
[1]*Laboratoire de Physique, École Normale Supérieure de Lyon, Université de Lyon, CNRS, Lyon, France*
[2]*Laboratoire de Mécanique des Fluides et d'Acoustique, UMR 5509, CNRS, École Centrale de Lyon, Université de Lyon, Écully, France*

Summary We study experimentally the effect of internal waves on slowly settling particles in a stratified environment. The granular column formed by the particles oscillates around an equilibrium position due to the presence of the internal gravity waves. Depending on the frequency and the amplitude of the internal waves, the column can even be displaced as a whole. Surprisingly, this displacement is directed towards the source of the waves. A resonant behavior of this displacement with the frequency of the internal waves is observed. A theoretical approach based on the drift induced by internal waves is developed.

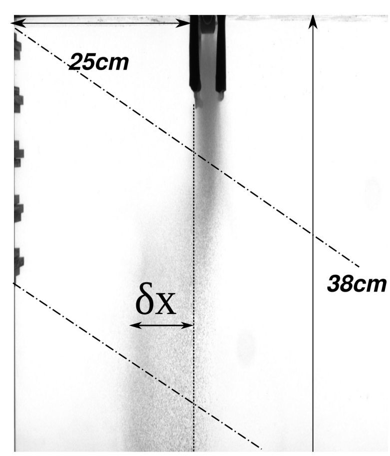
INTRODUCTION

The settling of organic particles from the upper layers of the ocean to the deep sea (known as oceanic snow) has an intense effect on global ocean properties. It is substantial for the development of diversified life in the benthic layer and it also sequesters large quantities of CO_2 from the atmosphere. The dispersion and concentration of these particles will be strongly attached to the dynamics of the ocean via its carrying fluid. Internal waves, omnipresent in the ocean, can act as a mechanism producing resuspension of particles lying in the boundary layers [1] and generate net transport of the oceanic snow that could play a role in the behavior of marine habitat [2].

Experimental and numerical efforts have been performed to understand the dynamics of a single body settling in a stratified environment [3], as well as the collective dynamics of particles settling in a stratified fluid [4]. In our work, we include an additional degree of complexity, by trying to study experimentally the main effects of an internal plane wave propagating through a column of slowly settling particles, in a stratified fluid.



(a)



(b)

Figure 1: (a) Snapshot of an internal wave beam passing through a column of settling particles. The column oscillates following the group velocity of the wave. The colormap indicates the intensity of the horizontal gradient of density. (b) Column displacement obtained for a particular set of control parameters. The value of the displacement after a given time is denoted δx. In both figures, the wave field is generated in the upper-left corner and propagates to the lower-right corner.

*Ernesto Horne. Email: ernesto.horne@ec-lyon.fr

EXPERIMENTAL SET-UP

A rectangular test tank of size $80 \times 17 \times 42.5$ cm^3 is filled with a linearly salt-stratified fluid with a buoyancy frequency $N \simeq 1$ rad·s^{-1}. Internal plane waves are introduced into the system by an internal wave generator, consisting of stacked moving plates. This wave maker is built so that the frequency, phase shift and amplitude of each plate can be controlled independently. The gradient of density of the wave field is then observed using Synthetic Schlieren technique.

A quasi-2D granular column is formed by injecting polystyrene grains ($d = 200$ μm , $\rho_p = 1.05$ g·cm^{-3}) at the surface. After some time, a stationary homogeneous column (width $d_c \simeq 3$ cm) is produced with a packing fraction $\phi \sim O(10^{-2})$.

RESULTS

For the particle concentrations explored we do not detect a difference in the amplitude of the waves between the cases with and without column of particles: the particles have no influence over the waves.

We observe that internal waves produce an oscillatory effect on the column as shown in figure 1(a). It oscillates with a phase velocity equal to the phase velocity of the waves. It is remarkable that oscillations are observed outside the wave beam as well. In addition, frequencies not contained in the wave spectra are measured within these oscillations, which could be consequence of non-linear effects of the waves in the column or because of collective effects of the particles.

The column can also be displaced as a whole (see figure 1(b)). This displacement is observed to be always towards the generator. It was measured for experiments presenting two different density gradients (in our case large density gradient implies small sedimentation velocity). For the largest sedimentation velocity (figure 2(a)), the displacement is very small for small amplitudes of the wave and is independent of the frequency. For larger amplitudes, it increases with the frequency. For the case with smaller sedimentation velocity and larger amplitude, we observe a resonant behavior of the displacement with the frequency (figure 2(b)).

CONCLUSIONS

We have developed a set-up capable of performing experiments to study the interaction between internal gravity waves and particles in suspension. We observed two main effects produced by internal waves over the column: it oscillates around an equilibrium position and it is displaced as a whole toward the source of the waves. The dependency of the displacement of the column has been measured as a function of the density gradient and amplitude of the waves for a range of frequencies of the incoming waves. In addition, a model which considers the drift produced by the internal waves [5] and the excursion time of the particles in the wave beam achieves to explain the direction of displacement of the column.

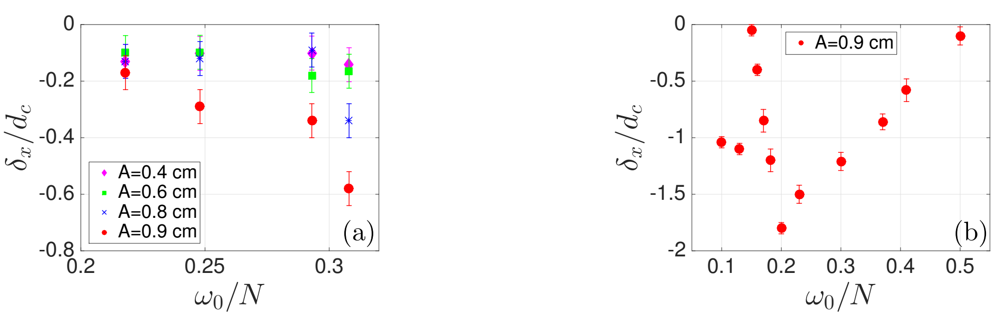


Figure 2: Displacement of the column after 500 seconds ($\delta x < 0$: the motion is towards the generator) normalized by the width of the column d_c as a function of the forcing frequency ω_0 normalized by the buoyancy frequency N. (a) $N = 0.8$ rad·s^{-1} (large sedimentation velocity) and $A = 0.4$ cm, 0.6 cm, 0.8 cm and 0.9 cm. (b) $N = 1.1$ rad·s^{-1} (small sedimentation velocity) and $A = 0.9$ cm.

References

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