GENERATION OF INTERFACIAL SOLITONS BY INTERNAL-WAVE BEAMS

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Internal waves in fluids owe their existence to the restoring forces of gravity (in a stably stratified fluid) and the Coriolis force (in rotating fluids). Examples are the inertio-gravity waves in the ocean, a special class of which are those at tidal frequency (internal tides), which are generated by barotropic tidal flow over large-scale topography, such as the continental slope. Internal waves propagate not only horizontally but also vertically, the energy being usually concentrated in diagonal beams. In the ocean, it has been found that when such a beam impinges on the seasonal thermocline (a shallow layer where temperature decreases rapidly with depth), the beam may lose part of its energy to high-frequency solitary waves, so-called internal solitons; this phenomenon is referred to as “local generation of solitons”. Apart from oceanic observation, this phenomenon has been demonstrated in numerical experiments, but not, so far, in laboratory experiments. This project aims to fill this gap. To this end, experiments were carried out on the Coriolis Platform (LEGI Grenoble), in September 2008.

1. INTRODUCTION

Internal solitary waves (ISWs) are one of the most noticeable kinds of internal waves in the ocean, and their surface manifestation may be visible even from spacecraft; Synthetic Aperture Radar (SAR) has become one of the standard techniques to detect them. They often appear in groups, and the groups themselves usually appear regularly, every tidal period. This points to a tidal origin; barotropic tidal flow over topography creates internal tides, which, while propagating away from their source, may steepen and split up into ISWs. This is the common picture, in which the internal tide is regarded as a horizontally propagating, interfacial wave. In the early nineties, New and Pingree (1992) showed the first evidence of a very different generation mechanism of ISWs. The origin is still tidal, but the mechanism involves an internal tidal beam, generated over the continental slope, which first propagates downward, then reflects from the bottom, and finally, as its energy goes upward, impinges on the seasonal thermocline. This interpretation was corroborated by SAR imagery, showing a great increase in the number of ISWs in the central Bay of Biscay, just beyond the area where the beam approaches the surface (New and Da Silva, 2002). Recently, the same mechanism has been proposed to explain ISWs in the Mozambique Channel (Da Silva, New and Magalhaes, 2009).

In this paper we present results on laboratory experiments that were designed to create ISWs by the same mechanism, i.e. by an internal wave beam impinging on a pycnocline. The experiments were carried out on the platform Coriolis in Grenoble, France, in September 2008. This platform is best known for its usage as a rotating turntable (simulating the effects of Earth's rotation), but was in the present experiments used without rotation. Quantitative measurements of the velocity field and the pycnocline displacements were made using Particle Image Velocimetry and ultrasonic probes, respectively.

A vertically stratified layer of 80 cm was created by filling the tank from below with water whose salinity was gradually increased; this resulted in a layer whose density increased from 1.010 kg/m^3 at the top to 1.040 kg/m^3 at the bottom. Thus, a layer of near-uniform stratification was formed with N=0.6 rad/s, N being the buoyancy frequency. The first experiments were carried out with this layer. Then, a thin layer (approximately 4 cm) of fresh water was added from above on top of the uniformly stratified layer. This served as the upper mixed layer, while the sharp transition of density between the two layers ensured the presence of a pycnocline. The pycnocline tended to lose its sharpness rather quickly, especially during the experiments, and so new fresh layers were added after experiments, or sometimes the upper part of the water column was removed before adding fresh water. In this way, a whole range of different pycnoclines (in terms of peak value, thickness, and depth) was created, serving as varying background conditions for which the experiments were carried out

As a wavemaker, for the generation of an upward directed internal-wave beam, we used a recently developed device (Gostiaux et al., 2007), see Figure 1. It consists of stacked rectangular plates, each of which has two circular holes along its main axis; through these holes, they are connected by eccentric cams. This eccentricity ensures that the plates are shifted with respect to each other, forming a wave pattern. If the cams are now brought in rotation, the wave will propagate. In this case, this phase movement was chosen to be downward, in order that the energy propagates upward.

2. FIRST RESULTS

As the beam hits the pycnocline, it is transformed in two ways. On the one hand, higher harmonics are created, i.e. internal waves at multiple frequencies of the basic forcing frequency. Depending on the forcing frequency, a harmonic may be trapped in the pycnocline; this happens when its frequency exceeds the buuyancy frequency of the lower layer. In our experiments, we have found examples of this, and also of the opposite case, in which a harmonic may propagate as a beam into the lower layer. These results are evident from PIV analysis.

The acoustic probes, centered around the pycnocline, allow us to follow the evolution within the pycnocline, before, during and after the impact of the beam. An example is shown in Figure 2. At the impact zone, the response is close to sinusoidal (see second probe from below), suggesting a linear character. Farther away from the wavemaker, though, the signal becomes more asymmetric, and shows a steepening front which splits up into high-frequency waves. In a qualitative sense, at least, this is much like the way internal solitary waves are generated in the ocean.

At present, one of the main challenges of the project lies in disentangling the harmonics from the “solitons”. It is clear that there are two distinct physical mechanisms are at work, the result of which is however intertwined, so far as the pycnocline is concerned.

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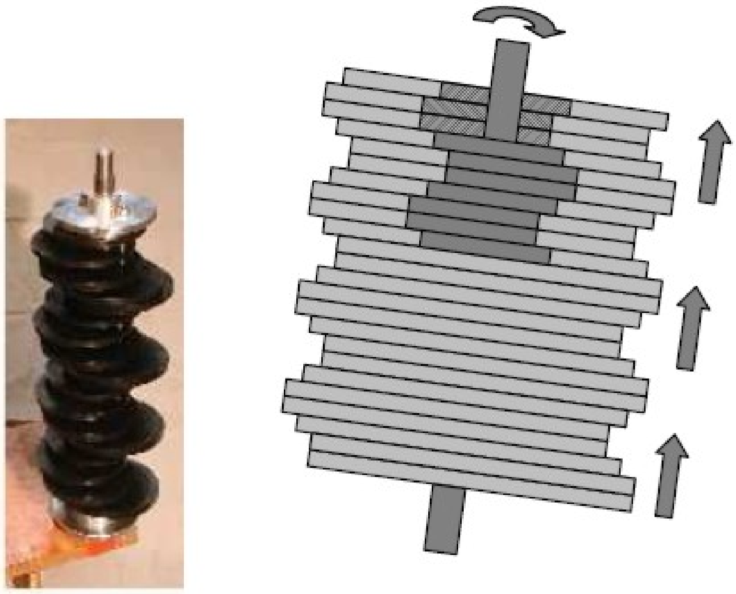

Figure 1: Principle of the wavemaker as used in these experiments (from Gostiaux et al. 2007)

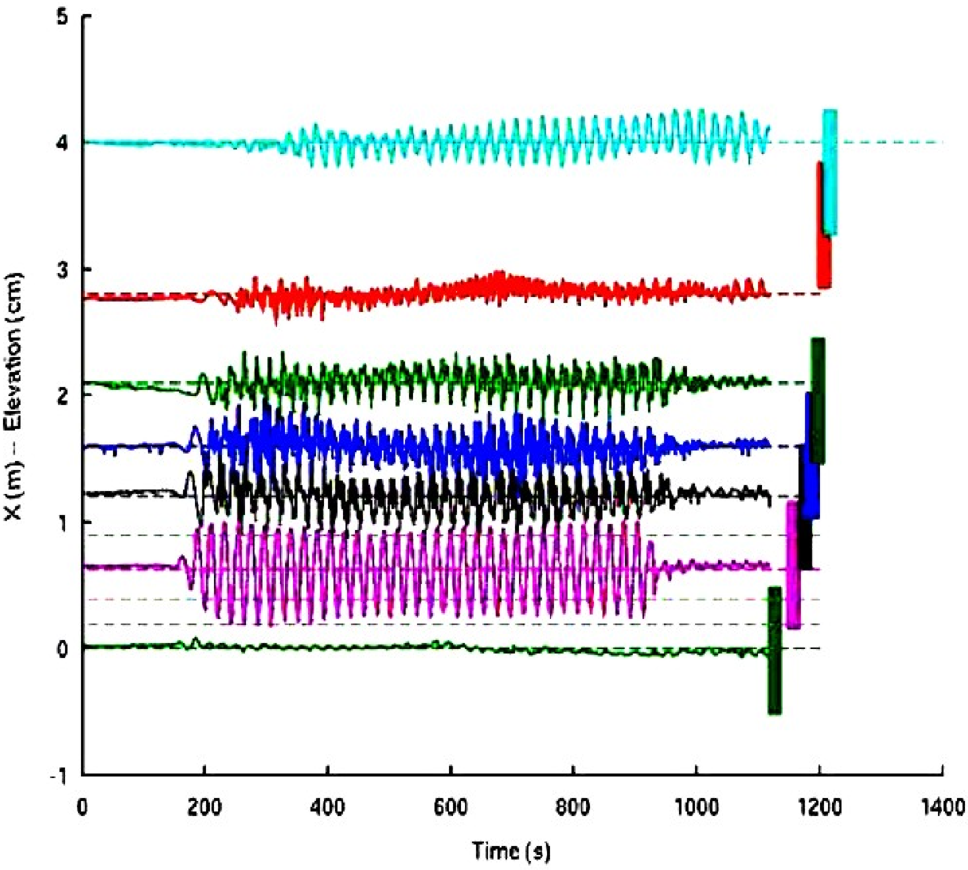

Figure 2:
Signals of acoustic probes during one experiment. The vertical axis has a twofold meaning. For each individual probe, it indicates the vertical excursion of the pycnocline (in cm). The rest level indicates the distance from the wavemaker (in meters). Thus, the lowest profile is of that closest to the wavemaker, and higher ones are increasingly far from it.