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NONLINEAR TRANSFER OF INTERNAL-TIDE ENERGY AND THE EFFECT OF ROTATION: AN EXPERIMENTAL STUDY ON BOTTOM REFLECTION, SUBHARMONIC RESONANCE, AND SCATTERING AT A THERMOCLINE

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In the oceans, one of the primary sources of internal waves is the barotropic tidal flow over topography, creating internal tides. In the laboratory and numerical experiments described in this paper, we mimick this generation process by forcing a periodic flow over a slope embedded in a stratified fluid. The initial aim was to study higher harmonics generated by internal-tide beams reflecting from boundaries, but, as it turned out, so-called internal-wave attractors would form within a few periods, and were in fact the dominant feature. This paper deals with this phenomenon, which has not been previously studied in the context of internal tides. The experiments were carried out on the Coriolis Platform (LEGI Grenoble), in September 2006.

1. INTRODUCTION

The laboratory experiments were carried out on the rotating platform of the Coriolis Turntable, Grenoble. This facility is a 13.5m diameter basin that can be filled with salty water; during the process of filling, the salinity can be changed, so that a vertically stratified layer is formed. The platform actually serves as a turntable, and some experiments were carried out in a rotating frame, but they are not discussed in the present article.

A channel was formed in the middle of the basin by two vertical parallel walls set 4.50m apart. One end of the channel was closed by a rigid wall, which, by being brought in horizontal oscillation using a direct current motor, served as the driving force of barotropic (i.e. surface) tides. The peak-to-peak amplitude of the oscillation was 2a=12mm, and the period could be varied in a range from T=25 to T=75s. At the other end of the channel, a slope was added to produce a transition from the deepest part of the basin (depth: 0.9m) to a 'continental' shelf (depth: 0.15m). The lower part of the slope was linear, at an angle of 27.0 degrees with the horizontal, giving a steepness of 0.51. The distance between the piston and the base of the slope was 6.15m, forming the constant depth part of the channel. The linear part of the slope was connected with the shallow part of the basin (the `continental shelf') by a curved PVC sheet with a curvature radius of about 10m, such that slope discontinuities were avoided. In total, the slope thus covered a length of 2.08m and a height of 0.75m.

Further on the shelf, the channel was in open connection with the remainder of the basin by two lateral apertures, ensuring the fluid could loop until the back-plane of the piston. The entire basin was filled with a salty fluid such that the stratification was nearly linear, at least initially. During the experiments, however, stratification decreased noticeably at the top and bottom, which strongly affects the internal-tide propagation, as discussed below. Typical values of the buoyancy frequency N were 0.6rad/s.

The forcing imposed by the piston should be expected to produce a horizontally homogeneous transport in the channel, since the wavelength of the corresponding surface wave is of the order of 100m in the deep part of the channel, and at least 30m on the shelf, both values exceeding by far the actual length of the respective parts of the channel.

PIV observations were made through the wall of the channel which at one side was made of perspex plates. Cameras were set above the water and looked through a 45 degrees inclined mirror in the water. Using two cameras simultaneously (referred to as `cam1' and `cam2'), both DALSA 1024x1024 12bit at 1fps, only half of the basin could be covered with sufficient resolution. By repeating the experiment with the same cameras but at different positions (`cam3' and `cam4'), nearly all of the deepest part of the channel, from the shelf to the piston, was covered. Yet, as the density profile changed slightly from one experiment to the other, the matching between the two is of course not as good as it would have been if we had been able to cover the four positions simultaneously by four cameras; yet, the correspondence is satisfactory.

2. BAROTROPIC FORCING

The theoretical value of the forcing follows directly from the amplitude a and the excitation period T of the horizontally oscillating piston, assuming that the piston imposes a transport throughout the channel as if it were a closed pipe. However, during the post-analysis it was discovered that the actual barotropic currents (obtained from PIV), were invariably much smaller than the theoretical one, by about a factor of five. This must have been caused by significant leakage between the piston and the walls, although we have no direct evidence for this.

This surprising finding, that the actual barotropic current was five times weaker than would be expected from the excursion of the piston, is indirectly but independently corroborated by the numerical model runs. If we force the model using the assumed piston movement, we have a barotropic flow that in this case *is* given by the theoretical value (and thus is five times larger than observed); the baroclinic velocities (associated with the internal waves) produced by the model are then found to be about five times larger than observed. So, this, too, suggests that the actual barotropic tidal flows were much weaker than one would expect from the excursion of the piston.

3. ATTRACTORS

In semi-enclosed basins, internal-wave energy may for certain ranges of frequencies be accumulated at closed ray patterns, called internal-wave attractors. This concept goes back to Maas & Lam (1995) and was experimentally confirmed by Maas et al (1997). In our experiments, too, the dominant feature appeared to be the internal-wave attractor, which forms already within the first few forcing periods (an example is shown in Figure 1).

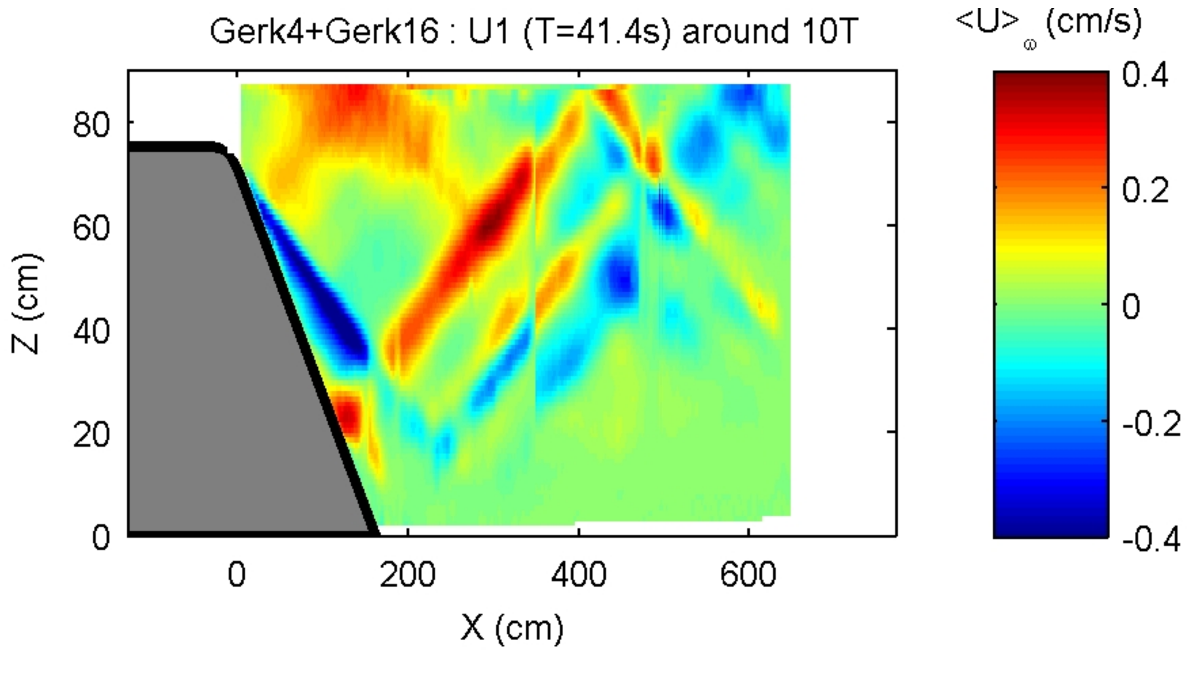

Figure 1:
Results from an experiment in which the barotropic tide had a period of 41.1 s, showing a snapshot after 10 forcing periods. The cross-slope horizontal velocity U is shown. The energy is already focussed along a certain path. Note also the transition near X=350; on the left the velocity was obtained from an experiment with two cameras on that side; on the right, it was obtained from another experiment a few days later, for the same parameters but with the cameras displaced.

The forcing mechanism considered here is fundamentally different from the one adopted in Maas et al. (1997), where the basin was brought into vertical oscillation, generating internal waves -- of half the forcing frequency -- throughout the basin by parametric sub harmonic instability. In our experiments, by contrast, the forcing is concentrated at the slope region, where a continual conversion of energy takes place from surface tides to internal tides.

The primary focus of this project is, of course, on the laboratory experiments, but numerical model results for a similar geometry and forcing allow us to probe deeper into some aspects (such as the conversion rates) which are not accessible from the laboratory data. We used a model that was previously used for internal-tide generation in the ocean (Gerkema 2002; Gerkema et al. 2004).

Comparison between laboratory and numerical experiments show a qualitative agreement in most cases, but the margin of uncertainty -- in for example the density profile measured with probes -- is such that the pattern of attractors as found numerically may vary quite considerably within that margin. In that sense, a meaningful quantitative (and sometimes even qualitative) comparison is elusive.

Still, the main outcome of these experiments stands firm, namely that internal-tide attractors turned out to form quickly and be a dominant feature. This is likely to be of relevance for the oceanic situation.

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