Internal wave focusing by a horizontally oscillating torus: nonlinear aspects

Shmakova N.D., Ermanyuk E.V.
Lavrentyev Institute of Hydrodynamics, SB RAS (Russia)

Voisin B., Flór J.-B.
Laboratoire des Écoulements Géophysiques et Industriels, CNRS–UGA (France)

shmakova@hydro.nsc.ru

Dissipation due to nonlinear breaking of internal tides is believed to play an important role in the mixing of the abyssal ocean, and therefore in the large-scale ocean circulation.

In the laboratory, we generate the internal waves by an oscillating objects in a linearly stratified fluid. Over the past five decades the dynamics of particularly diverging internal waves have been considered, such as generated by cylinder (Mowbray & Rarity, 1967) or spheroid (Ermanyuk et al., 2011; Shmakova et al. 2017). However, the localized zones representing hot spots for incipient overturning may occur close to curved topographies owing to the concentration of energy due to wave focusing (Buijsman et al. 2014, Peliz et al. 2009). Ermanyuk et al. (2017) showed experimentally with a horizontally oscillating torus that in a linear regime the wave amplitude amplifies in the focal zone and increases linearly with increasing oscillation amplitude.

Here we investigate weakly nonlinear and nonlinear effects of focusing internal waves generated by a torus with radius b and a circular cross-section of radius a oscillating horizontally with amplitude A. LIF and PIV techniques are used to measure the isopycnal displacement and the velocity, respectively. The nonlinear effects are investigated in terms of wave slopes as a function of newly developed focusing number defined as $Fo = (A/a)\epsilon^{-1/2} f(\theta)$, which includes the amplitude increase due to focusing as $\epsilon^{1/2} = \sqrt{b/a}$ and the variation in energy with the propagation angle θ. The data obtained for different sizes tori predict the wave breaking for the critical value of $Fo \approx 0.23$. Below this value, nonlinear effects in the focal zone arise in the generation of the vertical mean flow and evanescent higher harmonics. Above the critical number the focal region is unstable due to triadic wave resonance (TRI) that is formed of the fundamental wave and two subharmonic waves generated in the focal zone. The observed TRI in three dimensional flow resembles closely the resonance obtained by Bourget et al. (2013) for a two-dimensional flow due to the symmetry of our problem, and thus with the amplitude maximum in the symmetry plane (Shmakova et al., 2019).

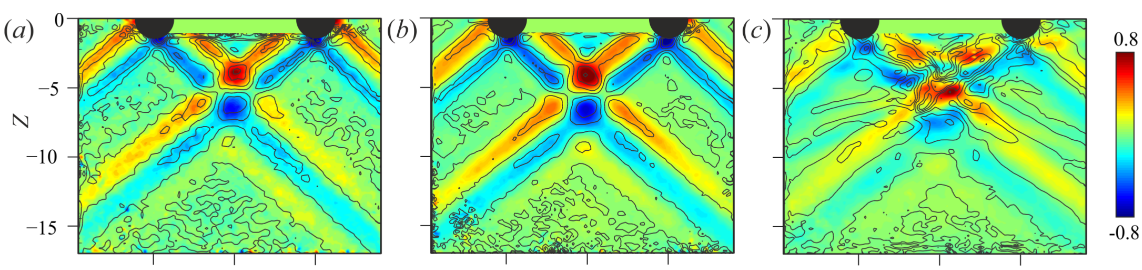

Figure 1: Instantaneous profiles of the normalized horizontal longitudinal velocity $u/(A\omega)$ (color) and contours of the horizontal transverse vorticity at rightmost torus position in the steady regime after 20 oscillation periods with (a) $Fo = 0.053$ (linear regime), (b) $Fo = 0.16$ (weakly nonlinear regime) and (c) $Fo = 0.33$ (nonlinear regime).