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INSTITUT DE MECANIQUE DES FLUIDES

Amphithéâtre Nougaro - allée du Professeur Camille Soula, Toulouse

Laboratory experiments and simulations for solitary internal waves with trapped cores

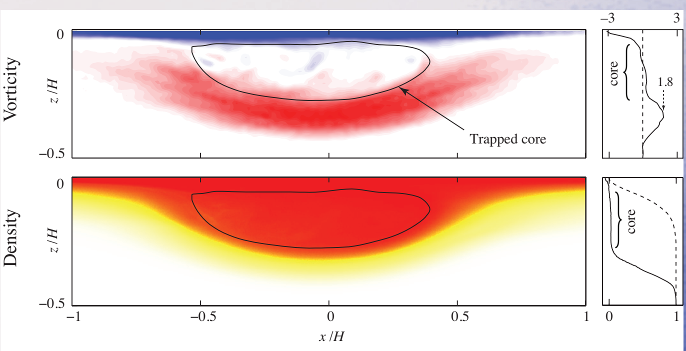
Paolo Luzzato-Fegiz (Churchill College, Cambridge)

Solitary internal waves are common in the atmosphere and oceans. Under a wide range of background conditions, these internal waves can develop recirculating fluid regions, known as “trapped cores” (e.g. Stastna & Lamb 2002, Lien et al. 2012). It has been proposed that trapped-core waves may be important for transporting mass, energy, and biological matter across the continental shelf (Shroyer et al. 2010, Scotti & Pineda 2004). They may also exert large forces on underwater structures (such as oil risers), and their breaking can cause significant mixing, thereby redistributing and dissipating energy within the ocean.

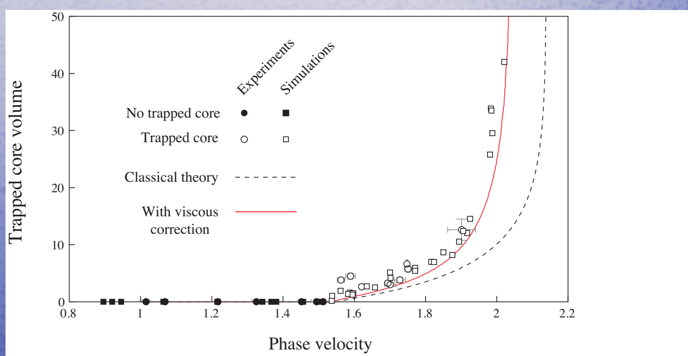
However, several fundamental wave properties, including mass and energy transport, as well as core circulation and density structure, remain to be quantified experimentally; in particular, core properties are essential as inputs to theoretical models (King et al., 2011). Furthermore, laboratory experiments to date have observed instabilities even in regimes where theory predicts stable waves. In order to resolve these outstanding questions, a key prerequisite, for laboratory measurements, involves simultaneously accessing the velocity and density fields with sufficient resolution. Two issues also prevent precise comparisons between experiments and available theoretical models. Firstly, at large wavelengths, theories can fail to yield a converged solution (e.g. Helfrich & White 2010). Secondly, at the laboratory scale, viscous effects are not negligible, whereas theoretical models are inviscid.

In this work, we develop a technique for high-resolution, simultaneous measurements of velocity and density in stratified flows, using pulsed-laser, co-planar Particle Image Velocimetry and Laser-Induced Fluorescence. We are thereby able to extract properties including kinetic and potential energies, minimum Richardson number, as well as trapped core size, circulation and density structure. To examine waves with longer wavelengths, we complement these results with numerical simulations, which are in good agreement with our experiments. Furthermore, by introducing additional controls on our experimental conditions, we are able to obtain a wide regime of stable waves.

To overcome the issues affecting theoretical models, we introduce to these flows techniques from numerical bifurcation theory, obtaining a method that can compute waves with arbitrary large wavelength. In addition, we propose a simple theoretical extension, which accounts for boundary layer effects in an otherwise inviscid flow. The resulting model is in good agreement with our experiments and simulations, and yields accurate predictions for trapped-core volume, kinetic and potential energy, and minimum Richardson number.



Normalised vorticity (top) and density (bottom) fields for a solitary internal wave with a trapped-core. The black contours denote the core region. The right-hand panels show vertical profiles at the wave trough; dashed lines show background conditions.



Transport volume versus phase velocity according to our experiments and simulations (symbols), classical theory, and our modified model accounting for viscous effects.

contact : sig_communication@imft.fr