Laboratory modelling of momentum transport by internal gravity waves and eddies in the Antarctic circumpolar current

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Abstract

Wakes in stratified fluids have been an active field of research of Emil Hopfinger (e.g. Hopfinger (1987) – J. Geophys. Research) topics undergoes new developments in the context of the dynamics of the Antarctic Circumpolar current, a strong source of ocean mixing with impact on Earth climate. Recent field campaigns in the Southern Ocean have revealed that the interaction of this current with bottom topography can radiate internal gravity waves whose momentum transport contributes to friction (Naveira-Garabato et al. 2004, Nikurashin Ferrari 2010). An additional contribution to friction is due the eddy wakes produced behind obstacles. These problems have been much studied in the context of atmospheric dynamics, and several laboratories experiments in a linearly stratified fluid have been performed, for instance Baines (1995), Dalziel et al. (2011). Those previous experiments were however constrained by lateral boundaries and did not reach the fully turbulent regime for the eddy wakes. Moreover the Coriolis effect was not investigated although it is much relevant in the oceanic case due to the small Rossby number.

We have reproduced the wake of a spherical cap in a linearly stratified fluid on the 'Coriolis' rotating platform, 13 m in diameter. A uniform circular current around the tank is produced by a small change of tank rotation speed (spinup) which persists by inertia for the duration of the experiment, typically 15 minutes, over which the flow conditions can be considered quasi-steady with a slow decay by friction. The sphere radius is 80 cm, and the cap height is 20 cm (69 cm in diameter) while the total water depth is 90 cm. The non-rotating case is obtained by introducing a small tank rotation while the water remains at rest by inertia. This is compared to a rotating case with a ratio $f/N = 2.5$ of the Coriolis parameter f to the buoyancy frequency $N = 0.5\ \mathrm{s}^{-1}$. The flow velocity is varied from 3 cm/s to 12 cm/s which allows us to cover the relevant range of Froude numbers. Velocity fields are measured by Particle Imaging Velocimetry in horizontal planes illuminated by a laser sheet.

Confirming a classical result, we find that the lower part of the flow goes around the obstacle, initiating the vortical wake, while the upper part goes above it, initiating the wake of stationary internal waves. These two wakes are visualized in the figure shown, respectively on the left and right hand sides. As expected, the vertical boundary between these two

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regions is lowered for increasing Froude number, as the flow more easily moves above the topography. We find that the wave part quantitatively compares with the linear theory of Voisin (2007).

Background rotation change the waves into inertia-gravity regimes and introduce an asymmetry between anticyclonic and cyclonic eddies of the wake. Cyclones organize into coherent vortices. The momentum transport associated with these different features is measured both from local quantities (Reynolds stress and wave flux) and by the global decay of the flow under the effect of topographic drag.

In a second part of the study, still under way, we analyse in a similar way the effect of a pattern of 20 identical caps in an attempt to reproduce the effect of a random topography. The mean current is expected to interact with the waves through a process of excitation of inertial waves by sub-harmonic instability, as obtained in two-dimensional numerical simulations by Labreuche et al. (2015). An alternative mechanism of momentum transport, discussed by Nikurashin et al. (2013), involves the eddies directly generated by the topography and the additional eddies produced by the baroclinic instability of the current vertically sheared by the induced bottom friction. We analyse our results in comparison with both approaches.