EXPERIMENTS ON VERTICAL MOTIONS OF ROTATING FLOWS OVER VARIABLE TOPOGRAPHY

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Summary The evolution of barotropic vortices over topographic features in a homogeneous rotating fluid is studied experimentally. Two bottom topographies are used: a submarine axisymmetric mountain and a steep escarpment. The aim is to identify the main physical mechanisms observed in a vertical plane across the topographic gradients, as well as in a horizontal plane of motion. The vortices drift due to the relative vorticity redistribution associated with stretching and squeezing effects. During these processes, it is shown that subinertial oscillations are generated over the topography, which produce up-welling and down-welling motions observed in a vertical plane.

INTRODUCTION AND MOTIVATION

A commonly-used approach for modelling geophysical flows affected by the rotation of the Earth consists of performing laboratory experiments in a rotating system [1]. For a homogeneous fluid, the motion is predominantly given in the form of vertical columns, parallel to the rotating axis, in which vertical motions are usually one order of magnitude smaller than horizontal displacements. For this reason, experimental studies have been focused on the horizontal behaviour of the flow in order to represent two-dimensional flows. In the presence of topographic variations, fluid columns might experience stretching or squeezing effects which in turn imply variations in their relative vorticity. Nevertheless, the vertical velocity component is, again, much weaker than the horizontal components. This allows the use of quasi-two dimensional formulations in order to derive the horizontal velocity field or, equivalently, the vertical component of the relative vorticity.

In contrast to many previous studies, the aim here is to determine the structure of vertical motions during the encounter of vortices with a topographic feature. The main purpose is to gain a better understanding of the vertical displacements generated during this process from the experimental point of view. The experiments are performed at the Coriolis platform in Grenoble, France. The motivation arises from considering that vertical motions play a fundamental role on a large number of oceanic processes by transporting physical, biological and chemical properties. For instance, aggregations of plankton are frequently observed over shelf breaks and seamounts, as well as fish and cetacean populations. These aggregations are produced by different mechanisms, some of which might be closely related with the dynamics of the flow-topography interaction (see e.g. [2]).

EXPERIMENTS

Set-up

In all experiments the tank is filled with fresh water with a maximum depth H=85 cm, and set in solid-body rotation with a Coriolis parameter f=0.42 1/s, which gives a rotation period of T=30 s. Horizontal motions are observed with a camera mounted on top of the rotating platform. Vertical motions are recorded in a vertical plane across the topographic gradients. The fluid velocities are measured by using PIV. The flow is set in motion by producing a cyclonic vortex by gravitational collapse near the topographic feature. The experiments have a duration of 20 min (about 40 periods of the system, and of the same order of the Ekman time scale).

Submarine mountain

The seamount consists of a solid, axisymmetric structure, with maximum height of 30 cm. The radius of the mountain is R=50 cm, so the mean slope is about s=0.6. Several vortices are generated over an arbitrary radial line, such that the important parameter is the distance of the initial vortex to the edge of the seamount along this line.

Figure 2 shows a snapshot of the vertical component of the relative vorticity field in a typical experiment (horizontal plane). The vortex is generated at the southeastern flank of the seamount. After 560 s (about 19 rotation periods) the vortex has been displaced around the mountain along an anticyclonic trajectory (with shallow water to the right). The vortex performs several turns around the tip of the mountain. This motion corresponds to the topographic beta effect associated with the slope of the mountain, and it has been reported previously [3]. Note the anticyclonic circulation induced over the tip of the mountain.

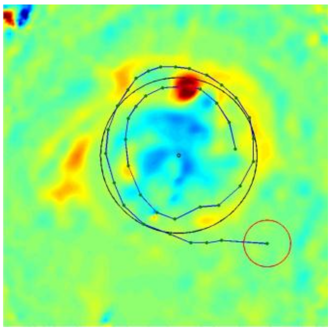

Figure 1. Surfaces of the horizontal relative vorticity field in a typical experiment with a submarine mountain. Red (blue) colours indicate positive (negative) values. The red circle indicates the initial position of the vortex. The black circle represents the rim of the mountain. The domain is an area of about 2m X 2m. The solid line is the trajectory of the vortex with a dot every 10 s.

The essential character of vertical motions is given by a radial inward and outward flow as the vortex rotates around the seamount. This is shown in Figure 3, where two snapshots of the vertical velocity component in a vertical section are presented for a single experiment. Consider the right flank of the mountain starting from the origin. Evidently, the flow is uphill at time t=105 s and turns downhill at time t=253 s. This oscillation was systematically observed, despite the high noise of the velocity measurements due to severe technical difficulties. The opposite motion occurs at the left flank of the mountain.

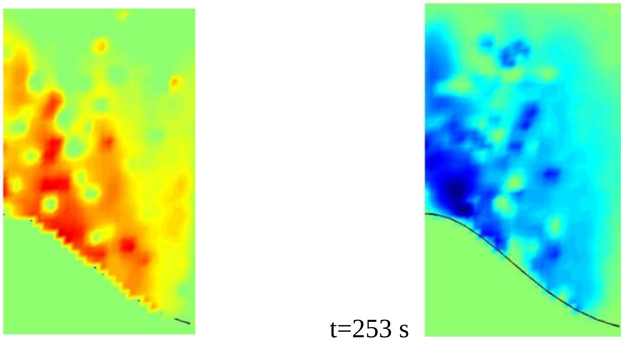

Figure 2. Surfaces of the vertical velocity component in an arbitrary vertical plane across the mountain at times 105 and 253 s. Red (blue) colours indicate up-welling (down-welling). The domain is a rectangle R X H (50cm X 85cm). Maximum absolute values are about 0.5 cm/s.

Escarpment

This topography refers to a steep sloping bottom. The topographic slope is 60 cm wide and a maximum height of 30 cm, so the slope is about 0.5. The analysis of experimental data for this case is now being carried out. Preliminary results show that vortices travel along the topography contours, and generate a wake of topographic waves behind them. Measurements of vertical velocities on two vertical planes are taken: across the topography gradients and along the escarpment. The results will be presented during the conference.

CONCLUSIONS

The motion of a barotropic vortex in a rotating tank with a submarine topographic mountain at the bottom is examined by means of laboratory experiments. The vortex drifts around the tip of the mountain in anticyclonic direction, generating negative vorticity over the summit. The oscillatory character of the flow during the vortex-mountain interaction was clearly identified from observations in a vertical plane across the topography. These oscillations have been also observed for the case of a steep escarpment, and they are related with topographic waves. It is concluded that upward and downward motions provide a mechanism for vertical transport, which might be relevant under different geophysical situations.

References

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