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ISOLATED VORTICES OVER SEAMOUNTS: LABORATORY EXPERIMENTS AND NUMERICAL SIMULATIONS

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Summary We study the competition between the instability of isolated vortices and the nearly geostrophic balance in a rotating fluid of varying depth. The laboratory experiments were performed in a water tank placed on top of a rotating table and the numerical simulations were done with a vortex-in-cell method. The intrinsic vortex instability produces horizontally elongated vortex structures while the nearly geostrophic balance forces the vortices to remain on top of the seamount where they are generated. It was found that the condition for the topographic confinement of the laboratory vortices (which have a Rossby number of order one) is that the semount height be at least one half of the total fluid depth. This condition was confirmed by the numerical simulations.

EXTENDED SUMMARY

Seamounts are ubiquitous features of the ocean floor. They generate and trap eddies, enhance biological productivity and improve fish catch [1]. It is well known that the flow of a stream over topography may generate vortices: anticyclonic vortices form over seamounts, whereas cyclonic vortices form over seavalleys. It is also well known that a monopolar vortex over uneven topography is not steady: anticyclonic vortices migrate towards deeper water, whereas cyclonic vortices migrate towards shallower water.

Here we study the evolution of an isolated vortex over a seamount in a fluid which is otherwise at rest. Over a flat bottom the intrinsic instability would produce vortices with a horizontal extent which is substantially larger than that of the original vortex. The nearly geostrophic balance, however, prevents motion across isobaths and thus would force the vortices to remain on top of the seamount. The purpose of this study is to determine the conditions under which the vortex is trapped on top of seamounts of circular and square shapes.

The experiments were carried out in a square tank of 100 cm side and 50 cm depth mounted on a rotating table. In the center of the tank we placed circular or square mounts with horizontal extent (diameter or side length, respectively) of 20 cm and various heights (2.5, 5 and 10 cm). The tank was filled up to a depth of 20 cm and the whole system was set to rotate with a period of 7.5 s. Once the water reached a state of solid body rotation, a vortex was generated by cyclonically stirring the water inside a bottomless cylinder placed on top of the seamount. Dye was added after the stirring was stopped in order to visualize the flow. The vortex was released into the ambient fluid by vertically lifting the bottomless cylinder (Figure 1a). Owing to its vorticity distribution the vortex is unstable [2], and the anticyclonic vorticity accumulates on two opposite sides of the core vortex to form a tripolar vortex (Figure 1b). Over a flat bottom the tripole would slowly grow until an elongated shape would be reached; under certain conditions the tripole itself could become unstable and the whole structure would translate while performing a complicated unsteady motion [3]. In this case, however, the seamount was sufficiently high to keep the tripole confined within the water column located above the seamount (Figure 1d).

It was found that the vortices were effectively confined over the seamount when this had a height equal or larger than half the total fluid depth. This result is valid for circular as well as for square mountains. There is, however, a large difference in the evolution of a vortex confined by a circular mount and that confined by a square mount. The former reaches a nearly steady state, whereas the latter remains highly unsteady during the whole evolution. The unsteady motion of the core and the satellite vortices leads to intense stirring. This produces the numerous interlaced bands of dyed and clear water that are visible in the last stages (Figures 2c and 2d).

Numerical simulations with a vortex-in-cell model confirm the main experimental results, namely, the condition for the vortex to remain trapped and the effect of the seamount shape on the stirring properties of the vortex.

References

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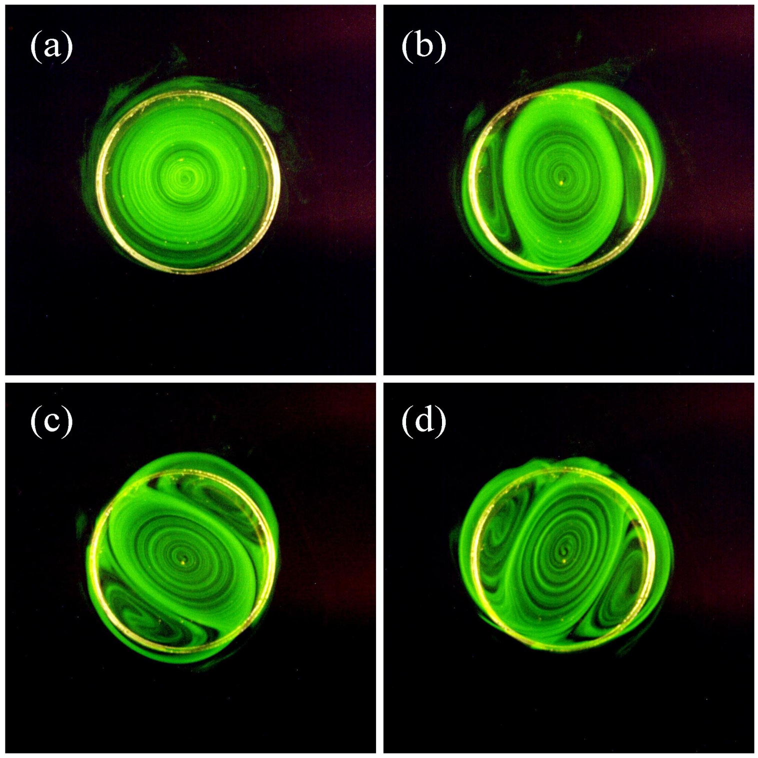

Figure 1. Experimental sequence showing the evolution of an unstable vortex on top of a circular seamount (the border is indicated by a bright circle). Pictures were taken at times $t = 8\tau/3$ (a), $t = 28\tau/3$ (b), $t = 12\tau$ (c), and $t = 16\tau$ (d), where τ=7.5 s is the rotation period of the water tank.

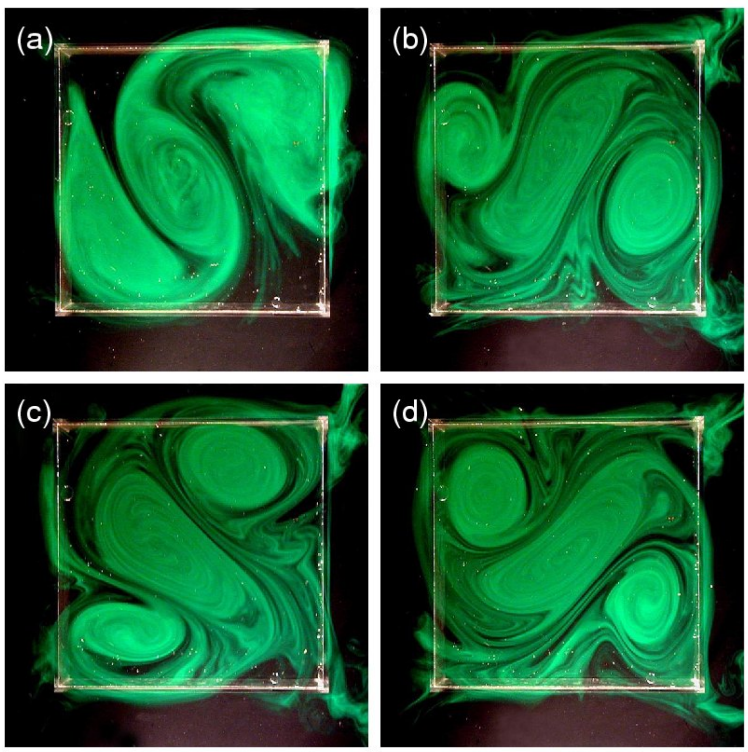

Figure 2. Same as figure 1, but now for a square seamount. Pictures were taken at times $t = 3\tau/$ (a), $t = 11\tau$ (b), $t = 14\tau$ (c), and $t = 19\tau$ (d).