Zonostrophic beta-plumes, zonal jets and particle diffusivity in locally-forced shallow water experiments

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Eddy-driven zonal jets and Rossby waves are common features of planetary atmospheres and oceans, organising the large-scale flow and influencing the dispersion and transport of material tracers and constituents. In the presence of relatively weak friction and forcing, zonal jets form a dominant component of the flow in a regime known as "zonostrophic", characterized by strongly anisotropic energy spectra and the formation of slowly evolving systems of alternating zonal jets[1,2]. This regime is characterized by two scales, $L_\beta \sim (\epsilon/\beta^3)^{1/5}$ and $L_R \sim (U_{rms}/\beta)^{1/2}$, where ϵ is the transfer rate of the inverse energy cascade and β is the radial gradient of the Coriolis parameter, and their ratio, known as the zonostrophy index, $R_\beta = L_R/L_\beta$[2]. In unaveraged flows, zonal jets become discernible at $R_\beta \sim 2$ while much stronger jets are found for $R_\beta \gg 1$. Achieving such high values of R_β in a laboratory is a non-trivial task. The zonally-banded atmospheres of the gas giant planets are probably well inside such a regime with $R_\beta \sim 5$[3], though the Earth's atmosphere and oceans are in a more friction-dominated state where $R_\beta \sim 1.5 - 1.8$[1,2]. In this study we have investigated the flow obtained in a rapidly rotating fluid on a topographic beta-plane in a cylindrical tank, subject to localised periodic mechanical forcing along a radius. The experiments were carried out in the 5 m diameter rotating tank at the Turlab facility in Turin, Italy under the European High-Performance Infrastructures in Turbulence (EUHiT) programme[4]. Horizontal velocity measurements were obtained using PIV in a horizontal plane a short distance below the free surface, while discrete particles floating on the surface were tracked to obtained their Lagrangian trajectories. The flow exhibited the spontaneous formation of persistent zonal jets, topographic Rossby waves and intense vortical eddies close to the forcing. The large-scale flow was found to lie within the zonostrophic regime with a zonostrophic index $R_\beta \gtrsim 2.0$ in at least some cases. This contribution will present the first results from the analysis of these experiments, focusing on characterising the potential vorticity dynamics of the large-scale flow and its particle transport properties.

Références

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