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Modons and multipolar coherent structures in a two-layer Rotating Shallow Water model

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Motivated by the recent results [2] on the existence of ageostrophic modons and other coherent multipoles [1] in the barotropic one-layer shallow-water model, we ask the question of their baroclinic counterparts. To answer it, we constructed exact steady-moving symmetric dipolar solutions of the quasigeostrophic limit of the two-layer rotating shallow water equations with free surface and show that they fall into two classes : quasi-barotropic and baroclinic. We use them both, with moderate Rossby numbers and certain reasonable values of depth and density ratios for the fluid layers, for initialisation of the numerical simulations of the full two-layer rotating shallow water model with well-balanced shock-capturing code, and show that both adjust to new ageostrophic asymmetric steady dipoles. These results indicate the existence of steady ageostrophic solutions of the two-layer rotating shallow water equations and give an example of "spontaneous imbalance" when the system leaves the initial balanced state by emitting inertia-gravity waves. The baroclinic and the barotropic velocity fields, though, behave differently for the two classes of solutions during such adjustment. These differences are quantified.

An increase in Rossby number changes the scenario of adjustment leading to the appearance of baroclinic hydraulic jumps inside the dipoles. Depending on the density ratio they lead to new coherent structures, namely shock-modons, the modons with incorporated shock, for weak stratification, or "riders": monopoles in the upper layer driven by dipoles in the lower layer, for strong stratification. The ageostrophic component of the flow of these new structures is strong, with a signature of wave capture at the edges, besides the shock in the middle. Yet, the inertia-gravity wave emission is practically non-existent during the collision process.

As in the one-layer rotating shallow water [1], the collisions between the ageostrophic modons may be either quasi-elastic, or produce new coherent structures: ageostrophic tripoles and nonlinear dipoles with strongly curved scatter-plot. This conclusion holds both for moderate and high Rossby-number colliding modons, with embedded shocks in the last case.

It should be stressed that production of tripoles and nonlinear dipoles by colliding symmetric dipoles is well-documented in the literature in the framework of the incompressible two-dimensional Euler equations (or equivalent QG equations on the f- plane). It is, however, rather surprising that baroclinicity and compressibility do not essentially affect these processes, even if colliding dipoles contain embedded shocks.

References

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