Geophysical Research Abstracts
Vol. 15, EGU2013-4649, 2013
EGU General Assembly 2013

Dynamics of a dipolar gyre on the beta-plane

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The behavior of a dipolar gyre forced by localized source and sink on a beta-plane is studied in the framework of a single-layer shallow-water model. The setup is similar to rotating table experiments by Colin de Verdière (1977). A linear analytical solution is found. It consists of a dipolar gyre, composed of one central zonal jet that connects to two external zonal jets through western boundary currents. Nonlinear numerical experiments are performed varying the intensity of the forcing, inverting the position of the source and sink, and changing the distance between the source and the sink. Results confirm qualitative observations found in previous laboratory experiments: i) When the central zonal jet is directed westward, the system becomes unstable and water mass is exchanged between the two gyres; ii) When the central zonal jet is eastward, the system remains stable, even at high pumping/injection rates, and the two gyres remain isolated from each other. We investigate the origin and the dynamics of that instability using potential vorticity arguments. Results show that within the unstable configurations, the necessary condition for instability (PV-gradient inversion) derived by Charney and Stern (1962) is always verified inside the westward zonal jet. On the other hand, stable configurations do not complete the criteria. Although the western boundary currents can in some cases fulfill the criteria, our simulations do not seem to show any instabilities originating from the latter. To discriminate whether the observed instability comes from the perturbations released by the source and the sink or whether it is linked to the intrinsic instability of the zonal central jet, a linear stability analysis of the mean state is performed. The role played by the western boundary currents and their connection to interior zonal jets also retain particular attention. Understanding the stability of these simple circulations is probably an important prerequisite to rationalize the much more complex eddy and wind driven mean gyres of the ocean.