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Anisotropic baroclinic turbulence with convection, rotation and stratification: a laboratory study

Peter Read (1), Hélène Scolan (1,2), Roland Young (1,3)

(1) University of Oxford, Atmospheric, Oceanic & Planetary Physics, Physics, Oxford, United Kingdom (p.read1@physics.ox.ac.uk), (2) Laboratoire de physique, ENS de Lyon, Lyon, France (helene.scolan@univ-lyon.fr), (3) Laboratoire de météorologie dynamique, UPMC, Paris, France (roland.young@physics.ox.ac.uk)

The dynamics of atmospheres and oceans on Earth and other planets typically involve the interplay between convectively driven motions, background rotation and (dynamically- and radiatively-induced) stabilizing stratification. The resulting flows lead to the development of baroclinic instabilities, which may exert a strong influence on the mean stratification (via forms of "baroclinic adjustment") and active cascades of energy and enstrophy, which may be highly anisotropic in the presence of large-scale planetary vorticity gradients. Baroclinic adjustment effects have been suggested to lead to the suppression of an inverse energy cascade in the Earth's atmosphere, while planetary vorticity influences probably lead to the formation of zonal jets on various scales in the Earth's oceans and in gas giant planet atmospheres. The full complexity of such flows in nature, however, is both difficult to measure in detail and to capture in numerical models because of the need to parameterize unresolved scales of motion. In the present study, we investigate the roles of baroclinic adjustment and turbulent cascades of energy and enstrophy in a laboratory experiment which combines localized free convection and baroclinic instability in the presence of variable background rotation and a topographic beta effect. The results indicate that baroclinic instabilities will exert an influence on static stability under conditions not too far from marginal stability in the experiment. In fully developed turbulent flows, kinetic energy on large scales is energized by baroclinic conversion around the Rossby deformation scale from the potential energy field, leading to both an inverse KE cascade to large scales and a forward cascade to smaller scales, although the nature of the latter is still not well understood. The measurements also include thermal imaging of the free surface, which indicate a different kind of regime, perhaps akin to a form of surface quasi-geostrophic regime. This would have significant implications for the form of the energy spectrum and the nature of the energy cascades near the free surface, and will be discussed in the context of the possible importance of a tropopause as a focus for energy conversions in gas giant planets.