Geophysical Research Abstracts
Vol. 15, EGU2013-834, 2013
EGU General Assembly 2013

Spontaneous Symmetry Breaking and Goldstone Modes for Barotropic Flows on a Sphere

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Two-dimensional turbulent flows display an inverse cascade of energy: energy injected at small scales cascades towards the large scales through nonlinear interactions. As a result, large scale coherent structures are ubiquitous in two-dimensional flows. Similarly, although baroclinic aspects are also present, the atmosphere and oceans of the Earth also feature large scale, long-lived coherent structures. Leaving aside baroclinicity for the sake of simplicity, the atmospheric or oceanic flow is amenable to equilibrium statistical mechanics methods: using the Miller-Robert-Sommeria theory, equilibrium states of the barotropic vorticity equation have been constructed. These states match well with numerical simulations.

In this contribution, we discuss a specific aspect of this theory, related to the occurrence of spontaneous symmetry breaking for barotropic flows on the surface of a sphere. In this case, the low-energy phase diagrams exhibit a second-order phase transition with spontaneous symmetry breaking, which possesses different properties depending on the statistical ensemble under consideration. More precisely, this is a special case of marginal ensemble equivalence, in which although the equilibrium states are the same in the microcanonical and canonical ensembles, the symmetry breaking properties are different. This difference is quantified through the notion of Goldstone modes. We also show that the Goldstone modes arising at statistical equilibrium play the same role as Rossby waves in a dynamical framework.