Equilibrium State of Quasi-geostrophic Point Vortices of Mixed Sign

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ABSTRACT

Geophysical flows are subject to strong influence of the buoyancy and the Coriolis force. Both effects suppress vertical fluid motion, and geophysical flows are considered to be two-dimensional at the lowest order of approximation. There have been a number of theoretical and numerical studies on two-dimensional vortex systems. In actual geophysical flows, different flow patterns are allowed on different horizontal planes. The 'quasi-geostrophic (QG) approximation' incorporates this three-dimensionality. In QG turbulence, the vorticity field develops coherent vortex structures and their interactions dominate the dynamics of the turbulence, as in 2D turbulence. Recently, our group investigated the statistical properties of mono-disperse QG point vortices in an infinite fluid domain, numerically and theoretically.[1-3] In numerical simulations, axisymmetric equilibrium states were found to form, whose radial vorticity distributions depended both on the vertical distribution of vortices and the total energy of the vortex system. The most probable distributions were determined for various vertical distributions, based on the maximum entropy theory, explaining the dependence of the equilibrium radial distributions on the energy.

In this paper, we focus on the equilibrium state of QG point vortices of mixed sign. Numerical simulations under the periodic boundary condition are performed using a fast special-purpose computer for molecular dynamics (MDGRAPE-3, GRAPE-DR). The clustering of vortices and the two-dimensionalization are observed for higher energy states. It is shown that they are the solutions of the mean-field equation (sinh-Poisson equation) obtained from the maximum entropy theory. For lower energy, three-dimensional equilibrium states are found, which are the solutions of sinh-Poisson equation with 3D Laplacian operator.

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