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Flow pattern formation in two dimensional turbulence on a rotating hemisphere

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Flow pattern formation is studied for the two-dimensional incompressible Navier-Stokes flow on a rotating hemisphere. In a series of numerical experiments, we have found that flow patterns propagate westwardly on a rotating hemisphere when it is bounded by the meridional line, while we have also found an emergence of eastward circumpolar flow at high latitudes on a rotating southern hemisphere.

Here in this presentation, we discuss an effect of the boundary condition on the formation of the circumpolar flow in a freely decaying 2D Navier-Stokes flow on the rotating southern hemisphere, by comparing numerical results for the rigid and the stress-free boundary conditions at the equator.

In the numerical procedure, the flow region is mapped onto a unit circular disk on a plane using a stereographic projection, where the equator is mapped to a boundary of the unit disk. An advantage of this mapping method is that it is a conformal mapping where the nonlinear term and the Laplacian term are transformed in a similar manner, and thus the transformed equation is quite similar to the usual fluid equation on the plane disk, meaning that we can easily apply several numerical method developed so far for the planer fluid equation. For numerical analysis, the stream function is given by finite Fourier series and Chebyshev-polynomial series. The expansion coefficients are calculated by the collocation method. In the case of rigid boundary condition, each of the basis functions satisfy the rigid boundary conditions. In the stress-free case, on the other hand, the tau method is employed to satisfy the boundary condition. The second-order Runge-Kutta method and Crank-Nicolson method are used for time integration. The viscosity coefficient is taken to be 0.0009976 and the rotation rate of the sphere 400, with the unit radius of the sphere and the kinetic energy of the flow field of O(1).

The initial flow field was first generated on the full-sphere by randomized flow field with a specified energy spectrum, and was multiplied by a mask function whose support is included in the southern hemisphere. We first make 16 initial flow fields of the same energy spectrum in this way, and then make another 16 initial flow fields by reversing the direction of the velocity of the first 16 initial conditions. These 32 initial conditions were made use of for an ensemble study. For the rigid case, the eastward circumpolar flow is formed in the polar region from any randomized initial flow fields. The ensemble mean shows the dominance of the eastward flow over the southern hemisphere, suggesting that the formation of eastward zonal flow is a robust property in the case of the rigid boundary.

In the case of the stress-free boundary, on the other hand, the ensemble mean of 32 runs shows the formation of the westward flow in the mid- and high-latitudinal regions, when the initial flow field active almost uniformly on the southern sphere. It should be stressed that the direction of the circumpolar flow is opposite to that for the rigid boundary case. We note that the direction of the circumpolar flow is reversed to eastward if the active region of the initial flow field is confined only to the high-latitudinal region.

For the uniformly active initial field, therefore, the boundary condition has a strong influence on the formation of the circumpolar flows, through the selective dissipation of the angular momentum at the boundary at the rigid case, and the redistribution of the angular momentum made by Rossby waves. But it is numerically found that the wave activity alone cannot be an index of the generation of the zonal flow in the present cases.