Stability of flow patterns in a circular domain on a rotating sphere

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An ocean current is known to be intensified in the westward boundary layer like the Kuroshio Current and the Gulf Stream. In the framework of the beta plane approximation, Stommel 1948 and Munk 1950 first obtained a linear solution of a single gyre flow which represents the westward intensification. Since then, the dynamical properties of the gyre flows has been studied intensively in beta plane, especially by introducing the wind-forcing resulting in a two-gyre flow (Cessi and Ierley 1995, Shi et al. 1995, McCalpin and Haidvogel 1996, Primeau 1998, Berloff and McWilliams 1999, Dijkstra and Molemaker 1999, Chang et al. 2001, Nauw and Dijkstra 2001, Ghil et al. 2002, Primeau 2002, Simonnet and Dijkstra 2002, Dijkstra 2005). As the Reynolds number is increased, the two-gyre flow experiences a pitchfork bifurcation, and afterward a Hopf bifurcation. In theoretical studies, two-layer models have often been employed to discuss instabilities and flow patterns and detailed chaotic behaviors. (Katsman et al. 1998, Sakamoto 2004).

In the context of the atmospheric motion, on the other hand, using a rectangular box with cyclic boundary conditions on the beta plane, Rhines (1975) first conducted a numerical experiment of the beta plane turbulence to find an emergence of a zonal band structure. Williams (1978) first performed a numerical simulation of 2D incompressible turbulence on a rotating full-sphere, and reported a similar band structure formation. From 1990s, high resolution simulations of the 2D incompressible turbulence on a rotating sphere have been performed to find fundamental properties of fluid motion, and have found several differences between the turbulence on the beta plane and on the rotating sphere, on the latter of which, for example, there appear strong westward circumpolar jets (Yoden and Yamada 1993, Nozawa and Yoden 1997, Hayashi et al. 1998, 1999, Takehiro et al. 2007).

When a flow region is restricted to a part of a rotating sphere, the boundary effect should be quite important to flow pattern formation. Recently Taniguchi et al. performed a numerical study of freely-decaying 2D Navier-Stokes flow on a rotating southern hemisphere with the equator being the boundary (Taniguchi et al. 2005, Taniguchi et al. 2006), and they found that a zonal current is formed in the course of time development, but the direction of the current strongly depends on the boundary condition.

When the boundary of the rotating hemisphere is a meridional line (i.e. vertical hemisphere), on the other hand, the zonal flow is inhibited geometrically and Taniguchi et al. (2002) showed numerically that in the freely decaying case with no wind forcings, flow patterns in the vertical hemisphere are dominated by westwardly propagating Rossby waves.

In this case, we study the stability of a steady barotropic flow of westward intensification under a wind forcing, on a rotating vertical

hemisphere with the rigid boundary condition. Taniguchi et al. (2006) studied a steady westward intensified flow in a three-gyre case under a wind forcing, and found that a Hopf

bifurcation arises as the forcing is intensified. The position of the maximum amplitude of the oscillation is located near the point of the boundary layer separation.