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Mechanism for the formation of equatorial superrotation in forced shallow-water turbulence with Newtonian cooling

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The zonally banded patterns and latitudinally alternating zonal jets are striking features of the atmospheres of Jupiter and Saturn. To explain the origin of these zonal structures, a series of studies considers large-scale motions within a shallow surface layer of a planetary atmosphere. One of the models for this ”shallow layer” theory is forced shallow-water turbulence on a rotating sphere. This model can reproduce zonal structures and also other features observed in Jupiter and Saturn, such as vortical motions predominating in the polar region and zonal jets having larger amplitudes near the equator (Scott and Polvani, 2007). However, a problem of this model was that it cannot produce a robust equatorial superrotation, as observed in Jupiter and Saturn. This problem was overcome by Scott and Polvani (2008). They revealed that forced shallow-water turbulence can produce robust strong equatorial superrotation, if Newtonian cooling is adopted as the dissipation process instead of Rayleigh friction.

The purpose of the present study is to elucidate the mechanism of the robust formation of equatorial superrotation reported by Scott and Polvani (2008). It is shown that the Newtonian cooling term distorts the structure of the Hough modes. This distortion can be visualized as either the westward or eastward tilting of the equiphase line with increasing the absolute value of latitude; the structural change of the Hough modes leads to the acceleration of the zonal-mean flow. A statistical analysis based on a weak-nonlinear theory predicts that stochastically excited Hough modes generate a prograde equatorial jet, the profile of which is quantitatively consistent with that of the ensemble-averaged zonal-mean flow obtained in nonlinear time-evolutions. The predicted prograde equatorial jet originates mainly from the acceleration produced by Rossby modes, the equiphase line of which is tilted westward by the Newtonian cooling term.

(This work was recently published as Saito and Ishioka (2015))

References:

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