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Sensitivity and similarity of superrotation to planetary size and rotation in an idealized Venus-like GCM

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In slowly-rotating planets like Venus and Titan, aerosols and clouds induce diabatic heating that drives the meridional circulation and superrotation. In idealized Venus-like AGCMs, superrotations are driven by meridional circulation with the help of the equatorward eddy momentum flux. This is well-known as the Gierasch–Rossow–Williams mechanism (Gierasch, 1975; Rossow and Williams, 1979). Under a Venus-like condition that the thermal constant and Ekman number are the same as those of Lebonnois et al. (2013), the present work investigates sensitivity and similarity of superrotation to planetary size and rotation for a dynamical regime of Ro = 5 to 23 (where Ro is Rossby number). In our model (Yamamoto and Takahashi 2016, 2018), planetary radius and rotation rate are altered from 2π/(240 days) and 6050 km to 15-times large values, respectively.

The general circulation structures are similar to those for the same Ro. For all cases, the vertically-integrated poleward heat fluxes of the zonal-mean circulations are much greater than those of waves at low and mid latitudes. The vertically-integrated poleward momentum fluxes of zonal-mean circulation balance well with the equatorward fluxes of waves. The eddy equatorward momentum flux contributes to the maintenance of the equatorial superrotation. The zonal-mean meridional circulation pumps the global-mean angular momentum upward, whereas the waves transport it downward. These vertically-integrated and global-mean angular momentum fluxes are also similar to those for the same Ro. The similar structures of waves and their momentum transport processes are found in the Hovmöller diagrams scaled by a planetary day.

For high Ro, superrotation magnitudes normalized by the planetary rotation are large in the equatorial and high-latitude jet cores. At high latitudes, indirect circulations are formed by the heat flux of the baroclinic waves around the high-latitude jet. In these cases, the strong equatorward momentum fluxes are intermittently produced, whereas the poleward momentum flux sometimes occurs when the poleward heat flux is strong. Fast planetary-scale waves with periods shorter than the rotation period are predominant.

As Ro decreases, the jets are developed at high latitudes, but the polar indirect circulation and its related eddy heat flux become weaker. For low Ro, the fast equatorial superrotation is still produced by the Gierasch–Rossow–Williams mechanism.However, the normalized superrotation magnitudes are relatively small in the equatorial and high-latitude jet cores, associated with the large planetary size and fast planetary rotation rate. In contrast to high Ro, the equatorward momentum fluxes are continuously produced for low Ro. In these cases, slow planetary-scale waves with a period longer than the rotation period are predominant.