6th Asia-Pacific Conference on Plasma Physics, 9-14 Oct, 2022, Remote e-conference

Atmospheric super-rotation dynamics of cloud-covered planets

M. Yamamoto[1] Y. Tsunoda[2] M. Takahashi[3]

[1] Research Institute for Applied Mechanics, Kyushu University, [2] Interdisciplinary Graduate School of Engineering Sciences, Kyushu University, [3] National Institute for Environmental Studies, Japan

e-mail (speaker): yamakatu@riam.kyushu-u.ac.jp

Atmospheric super-rotation (faster than the planet's solid-surface rotation) has been observed on cloud-covered planets and satellites (e.g. Venus and Titan). However, super-rotations in the cloud and aerosol layers are not fully understood in view of the geophysical fluid dynamics. In this presentation, we review the atmospheric super-rotation of terrestrial planets, discuss how the super-rotation is maintained, and compile the dynamical characteristics using the Rossby number defined by the ratio of inertial force to Coriolis force (*Ro*), based on the idealized GCM (general circulation model) experiments with the planetary rotation or size altered.[1]

In slowly-rotating planets like Venus (with planetary rotation of 243 Earth days) and Titan (with planetary rotation of 16 Earth days), aerosols and clouds absorb solar insolation and induce diabatic heating that drives the meridional circulation and super-rotation in the stratosphere where is stable (stratified) layer of the atmosphere above the troposphere. In GCMs of the slowly-rotating planets, super-rotations may be driven by meridional circulation with the help of the equatorward eddy momentum flux of Rossby waves. The dynamical process is well-known as the Gierasch–Rossow–Williams mechanism. Under an idealized Venus-like condition that the thermal constant and Ekman number are the same as those of the ISSI inter-comparison project of Venus GCM,[2] the present work investigates the sensitivity and dynamical similarity of super-rotation to planetary size and rotation for a dynamical regime of *Ro* = 5 to 23. In our idealized GCM,[3-4] planetary radius and rotation rate are altered from 2π/(240 Earth days) and 6050 km to 15-times large values, respectively.

Super-rotation and global-scale Hadley circulation are formed in the diabatic heating region, where corresponds to the stratospheric cloud and aerosol layers. The zonal jets are developed at high latitudes, where polar indirect circulations are formed. The global atmospheric circulation (zonal flow and meridional circulation) is dynamically similar to that for the same *Ro*. The vertically-integrated poleward heat fluxes by the zonal-mean meridional circulations are much greater than those of waves at low and mid latitudes. The global-scale zonal-mean meridional circulation transports heat poleward, whereas baroclinic wave and its-related indirect circulation do not strongly transport heat horizontally. The vertically-integrated poleward momentum fluxes of zonal-mean meridional circulation balance with the equatorward fluxes of waves. The eddy equatorward momentum flux contributes to the maintenance of the equatorial super-rotational flow. The zonal-mean meridional circulation transports the global-mean angular momentum upward, whereas the waves transport it downward. The horizontal and vertical angular momentum fluxes are dynamically similar to those for the same *Ro*. The time series of the waves and their related eddy momentum fluxes are also similar for the same *Ro* in the Hovmöller diagrams scaled by a planetary day.

In the high *Ro* experiments, super-rotation intensity (atmospheric rotation rate normalized by the planetary rotation) is large in the equatorial and high-latitude jet cores. Polar indirect circulations are formed by the heat flux of the baroclinic waves around the high-latitude jets. In these experiments, *fast* planetary-scale waves with periods shorter than the planet's rotation period are predominant. The strong equatorward eddy momentum fluxes are *intermittently* produced, whereas the poleward eddy momentum fluxes are produced sometimes when the poleward eddy heat flux is strong.

As *Ro* decreases, the high-latitude jet becomes stronger, but the polar indirect circulation and its related eddy heat flux become weaker. In the low *Ro* experiments, the fast equatorial super-rotation is also produced by the Gierasch–Rossow–Williams mechanism. However, the super-rotation intensity (atmospheric rotation rate normalized by the planetary rotation) is 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*, *slow* planetary-scale waves with a period longer than the planet's rotation period are predominant. The equatorward eddy momentum fluxes are *continuously* produced for low *Ro*.

References

[1] Y. Tsunoda *et al.,* J. Geophys. Res. Planets **126,** e2020JE006637 (2021)

[2] S. Lebonnois *et al.,* ISSI Scientific Report Series, **11,** 129-156 (2013)

[3] M. Yamamoto & M. Takahashi, J. Geophys. Res. Planets **121,** 558-573 (2016)

[4] M. Yamamoto & M. Takahashi, J. Geophys. Res. Planets **123,** 708-728 (2018)