Superrotation of the Venus atmosphere simulated by an atmospheric general circulation model

Kohei Ikeda[1]; Masaru Yamamoto[2]; Masaaki Takahashi[3]

[1] CCSR, Univ. Tokyo; [2] RIAM, Kyushu Univ.; [3] CCSR, Univ. of Tokyo

Rapid zonal flow with a velocity near 100 m s^{-1} has been observed at the cloud top on Venus. The surface rotational speed is very slow (1.8 m s^{-1} at the equator). Therefore, the speed of the zonal flow at the cloud top is 60 times faster than that of the solid surface. The fast zonal flow prevails from the surface to the cloud top, where the zonal wind speed reaches the maximum. This phenomenon, known as superrotation, is a dynamical problem of the Venus atmosphere. Several mechanisms that might maintain the superrotation have been proposed, but the true mechanism is still unclear.

In this study, the mechanism of the superrotation in the Venus atmosphere is investigated by an atmospheric general circulation model. The model used in this study is based on the atmospheric general circulation model (AGCM) version 5.7b developed at the Center for Climate System Research/National Institute for Environmental Study/Frontier Research Center for Global Change (CCSR/NIES/FRCGC).

In the previous studies using AGCMs, radiative process has been simplified by solar heating and Newtonian cooling, and the superrotation has not been reproduced under realistic conditions. In this study, we develop a new Venus AGCM, in which radiative transfer is calculated, and try to reproduce the superrotation under the realistic condition.

The vertical structure of temperature below 70 km is well reproduced in the moedl. Longitudinally averaged zonal wind is about 70 m s^{-1} at the equatorial cloud top. Below 55 km, the zonal wind is less than 5 m s^{-1} and very weak compared with observations. Maintenance mechanism of the superrotational flow in the middle atmoshphere is investigated by estimating the momentum balance.In the equatorial cloud layer, the mean zonal flow is maintained by the acceleration due to waves and deceleration due to vertical advection by mean meridional circulation. Above the cloud, where the mean zonal wind decreases with height, the deceleration due to the waves and the acceleration due to the vertical advection are balanced. The production of the momentum flux due to the waves is dominated by thermal tides.

Although the superrotational flow of about 70 m s^{-1} is developed by thermal tides in the middle atmosphere, the superrotational flow cannot be reproduced in the lower atmosphere. We assume that small-scale gravity waves which are not resolved in the model are important for the maintenance of the superrotation in the lower atmosphere. The momentum flux of the small scale gravity waves is estimated by parameterization.

The superrotation simulated in the experiment with the gravity wave parameterization is consistent with observations. Zonal flow increases with height from the surface to the cloud top, where the zonal wind speed reaches about 100 m s^{-1}. Forced gravity waves with westerly phase speed are absorbed at the critical levels and accelerate the westerly mean zonal flow. On the other hands, the forced easterly waves have no critical levels and can propagate above the cloud layer. Above the cloud layer, they are dissipated by thermal damping. Forced easterly waves play an important role in vertical wind shear in the upper atmosphere. In the middle atmosphere, the superrotation is maintained by the momentum transports due to thermal tides and momentum advection by the mean meridional circulation.

In this study, we succeed in sumulating the superrotation in a realistic Venus AGCM and provide a new promising mechanism. The momentum transport due to small-scale gravity waves is essential to maintain the superrotation in the lower atmosphere.