Vertical propagation of the large stationary gravity waves in the Venus atmosphere

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The Longwave Infrared Camera (LIR) onboard Akatsuki detects thermal radiation from the cloud-top and derives a temperature distribution from an image obtained by LIR. A bow-shaped temperature structure with a meridional scale of about 10,000 km extending from Aphrodite Terra to the northern and southern polar regions was discovered by the observation by LIR just after the Venus orbit insertion. This temperature structure was located at the same position for four earth days at least, although the westward wind has a speed of 100 m/s. This temperature structure is interpreted as a stationary gravity wave excited by a flow over a mountain below the apex of the bow. In addition, it was found from the observation by LIR from December 7, 2015 to February 28, 2017 that similar temperature structures repeatedly appear above the mountains with a peak height of 5 km or higher and a width of 3 km or wider in the low latitude region when they are in the afternoon. Navarro et al. (2018) proposes an excitation mechanism of theses stationary gravity waves, which are generated by a diurnal cycle of static stability near the surface. The stationary gravity waves are reproduced by adapting the gravity wave stress to their general circulation model.

The finding of the stationary features at the cloud-tops means that the stationary gravity waves propagate vertically through the neutral layer existing at the altitudes of the cloud layer of the Venus atmosphere. Radio occultation measurements by Akatsuki showed that the thickness of the neutral layer is thicker in the morning (~10 km) than in the evening (~5 km) in the low latitude region. Bougher et al. (1997) mentioned the possibility of topographical gravity waves with horizontal wavelength longer than 100 km can propagate vertically through the neutral layer. However, detailed aspects have not yet been investigated.

We investigated how the gravity waves vertically propagate through the neutral layer by a numerical simulation using spherical sigma coordinate primitive equations developed by Imamura (2006) and Fukuhara et al. (2017). In the model the longitude and latitude are divided into 120 and 60 grids with an equal interval of 3 degree and the altitude range from 5 to 80 km is divided into 100 layers with a thickness of about 1 km. The basic wind field is longitudinally uniform. The zonal wind field is given to match the observation results. Furthermore, the meridional wind field is set to 0 to ignore the influence of meridional circulation. Assuming the cyclostrophic balance, the meridional temperature field is determined from the zonal wind field given as the basic field. To investigate the influence due to the difference in the thickness of the neutral layer in the local times, experiments were conducted by giving vertical profiles of the static stability with the different thicknesses of the neutral layer (0 km, 5 km, and 10 km) as initial states. To simulate terrain disturbance, we apply a two-dimensional Gaussian-function temperature forcing with an amplitude of 2 K and with a half-width of 6 degree at the altitude of 5 km centered at (180E, 0N) degree as the lower boundary condition. In our model, only the disturbance field evolves in time, and the basic field keeps its initial condition.

In order to compare the observation results of LIR and the simulation results under the same condition, the horizontal structure of the temperature disturbance obtained by the simulation is weighted by the weighting function of LIR and vertically integrated. As a result, the maximum temperature disturbance amplitude (MTDA) over the equator was 1.14 K for the cases of neutral layer thickness of 0 and 5 km. Even for the thickness of 10 km, MTDA is 0.85 K, which is sufficiently larger than the detection limit of LIR (= 0.3 K). This result shows that the stationary gravity waves can pass through the neutral layer, though the amplitude is damped more or less when passing through the neutral layer.