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Numerical modeling of cloud-level convection on Venus

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Venus is covered by clouds of sulfuric acid which float in the altitude region from 48 to 70 km. The clouds reflect about 80% of the incident sunlight and play a major role in the energy balance of Venus. A neutral stability layer has been known to exist at around 50-55 km in the middle and lower cloud region; this layer is considered as a region of convection driven by the heating of the cloud base by the upward thermal radiation from the lower atmosphere (Crisp et al., 1990). The convection is thought to play important roles in the transport of cloud-related materials, and thus constitutes an essential part of the cloud system.

On Venus, in a manner analogous to the Earth, energy fluxes of incoming shortwave radiation and outgoing longwave radiation do not balance each other out at each latitude: low latitudes are subjected to excessive shortwave heating, while high latitudes are subjected to excessive longwave cooling. Such energy imbalance should affect the structure of the cloud-level convection. Excessive heating and cooling occur also periodically with the period of the atmospheric super-rotation, because irradiation to a certain cloud-level air changes as it is advected by the super-rotation. Therefore, it is necessary to understand the latitude dependence and the diurnal variation of the structure of cloud-level convection. Baker et al. (1998; 2000) performed numerical experiments of cloud-level convection and studied the characteristics of convection such as the intensity, the aspect ratio and the penetration of plumes to the stable layer located above and below the convective layer. However, the latitude dependence and the diurnal variation were not addressed in their studies, and furthermore, their numerical model drives convection by diffusive heat fluxes from below and realistic radiative heating and cooling distributions were not introduced into the model.

In this study, I constructed a numerical model of cloud-level convection based on the non-hydrostatic meteorological model CReSS (Tsuboki and Sakakibara, 2007) and studied the latitude dependence and the diurnal variation of cloud-level convection. Longwave heating and cooling are taken from a one-dimensional radiative-convective equilibrium calculation for a globally-averaged condition made by Ikeda (2010), and shortwave heating is given as a function of the local time and the latitude. The magnitude of the vertical velocity is consistent with the Vega balloon measurements and the estimate by the mixing length theory, suggesting that the model reproduces convection of realistic strength. With respect to the latitude dependence, stronger and deeper convection occurs at high latitudes than at low latitudes. This result might explain the latitudinal tendency revealed by radio occultation observations that neutral stability layer in the cloud tends to be thicker (Tellmann et al., 2009) and gravity wave amplitudes are larger in the high latitude than in the low latitude (Tellmann et al., 2012). With respect to the diurnal variation caused by the advection of cloud-level atmosphere by the super-rotation, strong, deep convection occurs during nighttime rather than daytime. Such dependences on the latitude and the local time come from the unique mechanism of cloud-level convection: shortwave heating of the upper cloud layer suppresses convection, whereas longwave heating of the lower cloud and the longwave cooling of the upper cloud, which drive the cloud-level convection, do not vary much with the local time and the latitude.

Keywords: Venus, cloud, convection