Latitudinal cloud structure in the Venusian northern hemisphere evaluated from Venus Express/VIRTIS observations with GCM simulations

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In this presentation, we show results of analyses of averaged latitudinal cloud characteristics in the northern hemisphere. The characteristics we analyzed are cloud opacity, temperature at cloud-top, and cloud-top altitude; they were determined from the VIRTIS (Visible and Infrared Thermal Imaging Spectrometer) High spectral resolution channel (VIRTIS-H) data set onboard Venus Express. We also analyzed the CO abundance under the cloud layer; this characteristic was determined from the VIRTIS Mapping channel (VIRTIS-M) data set. These results were compared with cloud particle tracking generated in a Venus General Circulation Model (VGCM) simulation, in order to interpret them with possible atmospheric circulation surrounding polar atmospheric structures.

§ 1 Observational Results and Discussions

From the observed latitudinal profiles, we found several features of the northern cloud (**Fig. 1**): (1) The cloud optical thickness surrounding the polar region (65–80° N) is 1.5 times larger than that in middle latitudes. This feature suggests that the amount of cloud particles in the polar region is greater than that in mid-latitudes, or the optical characteristics of cloud particles are different between the two regions. (2) The averaged cloud-top temperature gradually decreases from 40° N (232±2 K) to 70° N (223±5 K) and then increases from 70° N to the north pole (233±6 K). By contrast, the averaged cloud-top altitude monotonically decreases from the equator (68.2±1.6 km) to the north pole (58.3±1.0 km). These features suggest that the structure of the Venusian hot polar region has a lower cloud-top altitude. (3) The CO mixing ratio increases from 16±3 ppm at equatorial regions to 24±5 ppm at 70° N and then decreases to 19±5 ppm at 80° N. This profile is correlated negatively with the cloud-top temperature. Since CO under the cloud is transported from the upper cloud layer, the cold collar region could be formed by downwelling.

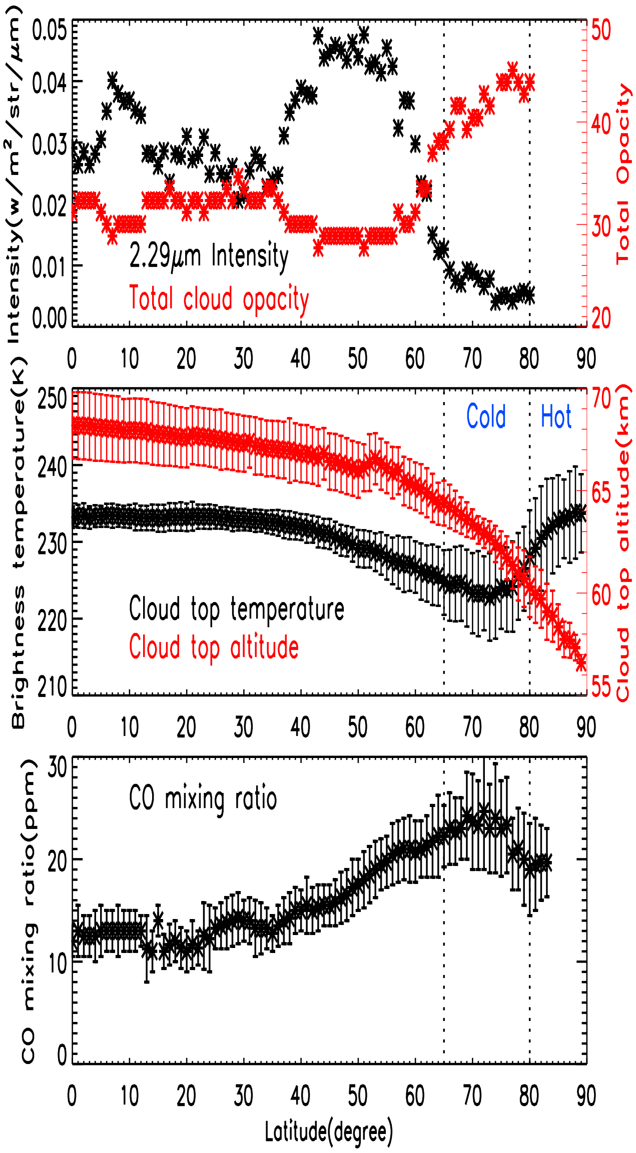

Fig. 1 Latitudinal variations: (top) (black) 2.29 um radiations and (red) total cloud optical depth (middle) (black) cloud top altitude and (red) cloud top temperature. (bottom) CO mole function.

§ 2 GCM Results and Discussions

In addition, we examined these features using cloud particle tracking in a VGCM. The VGCM is based on version 5.7b of a terrestrial GCM developed at the Center for Climate System Research / National Institute for Environmental Studies / Frontier Research Center for Global Change (CCSR/NIES/FRCGC) (Ikeda, 2011). In the model, we found that the cloud-top altitude was lower at high-latitude regions; there was a monotonic decrease in altitude from the equatorial region (67.3 km) to the north pole (59.3 km) (**Fig. 3**). The simulated residual mean circulation indicated the existence of a downwelling due to the Hadley circulation around the cloud-top at high latitude regions (**Fig. 4**). The simulated cloud-top temperature is approximately constant (234 K) from the equator to 40° N, gradually decreases to 70° N (228 K), and then increases toward the north pole (242 K) (**Fig. 3**). This indicates that the Venusian polar structures, the hot dipole and cold collar, may be produced by a decrease of cloud-top altitude in high latitudes due to atmospheric circulations.

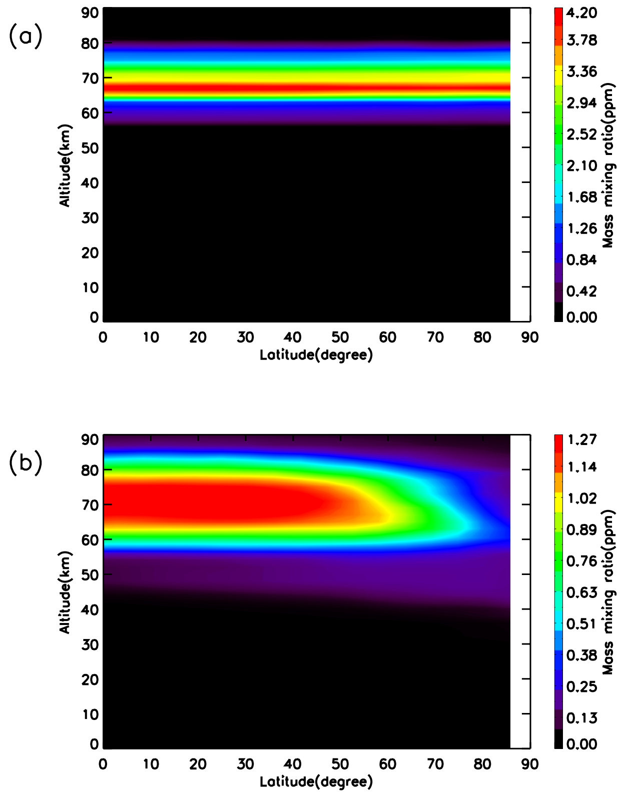

Fig. 2. The zonal-mean mass mixing ratio of Mode 2 cloud particles derived by the cloud particle tracking in our VGCM. The unit for the mass mixing ratio is ppm. (a) Initial distribution. (b) Distribution obtained after the run for one Venusian day (117 terrestrial days) from the initial distribution.

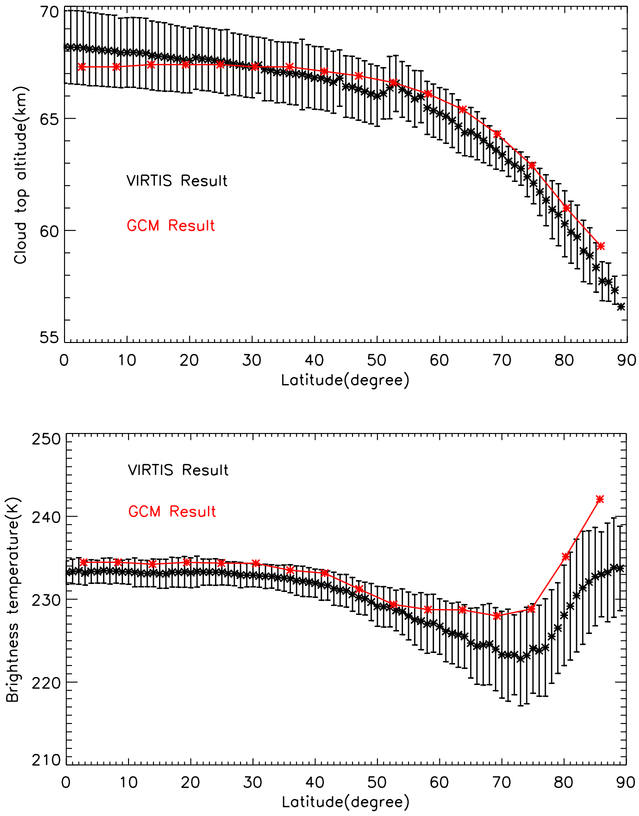

Fig. 3 (top) Cloud top altitude and (bottom) Cloud top temperature: (Black) investigated from VIRTIS-H observations and (Red) calculated from GCM simulations.

In our VGCM simulations, the mass stream function shows an upward flow in equatorial regions and a downward flow in high-latitude regions at the cloud-top level (**Fig. 4**). Although the mass stream function indicates the presence of complicated atmospheric circulations inside the cloud layer (from 50 km to 70 km), a typical Hadley circulation from the equator towards the polar regions can be clearly seen above the cloud layer (from 70 km to 90 km). A downward flow due to the Hadley circulation explains why the cloud-top altitude decreases toward the pole.

Next, we discuss a fundamental question about the Venusian polar vortex having a hot dipole region surrounded by a cold collar. On Earth, the temperature of the polar region is colder than the surrounding regions because the jet streams isolate cold air at high latitudes from warm air at low latitudes. With this point of view, it can be assumed that the formation and maintenance mechanisms of the Venusian polar vortex are different.

In our VGCM simulations, the temperature at the 70 km level in the polar region is colder than the corresponding temperature at 60–70° N (**Fig. 5**). This occurs because heating by the absorption of solar radiation at the polar region is smaller than that at low- and mid-latitudes. However, observed thermal radiations emitted from the cloud-top should be affected not only by horizontal temperature profiles but also by the cloud-top altitude. If the cloud-top temperature is estimated by considering the latitudinal change of the cloud-top altitude, it can be seen that the hot polar region in the lower altitude is surrounded by a cold region (see the red line on **Fig. 5**). This result suggests that the observed structure of the Venusian polar hot dipole and cold collar is due to a decrease in cloud-top altitude toward the polar region due to the Hadley circulation.

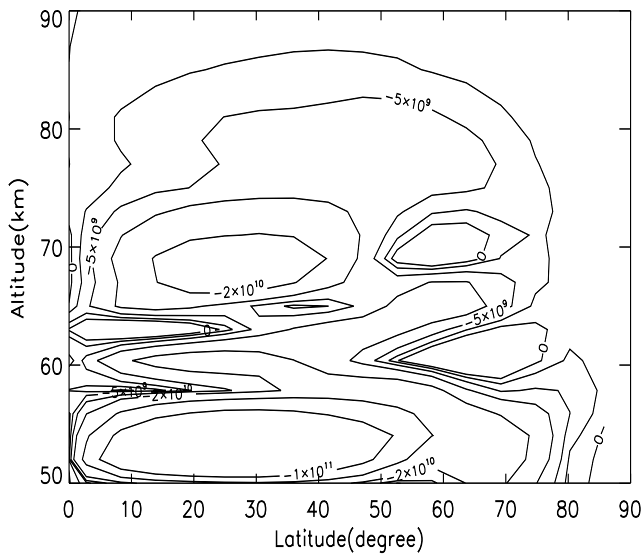

Fig. 4 Mass stream function (kg/s) around cloud top level calculated from GCM simulations.

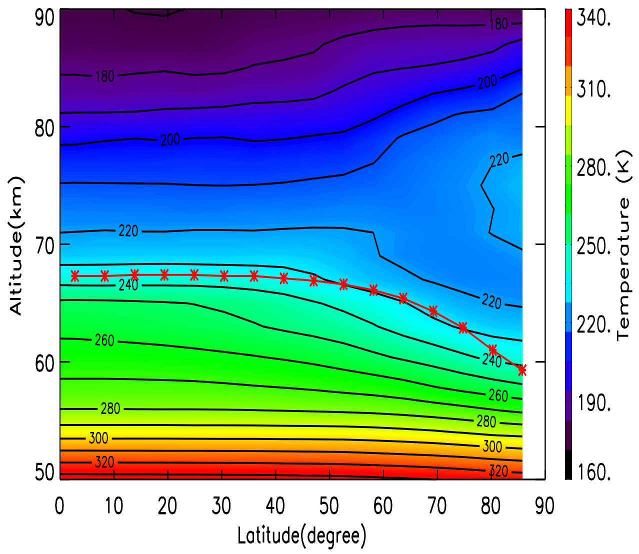

Fig. 5 The latitude–altitude temperature profile and cloud top altitude (red line) calculated from GCM simulations.

§ 3 Future Suggestions

Improvements of the VGCM simulations are needed for further studies. We are now implementing the production and decomposition of H_2SO_4 cloud particles and CO molecules in VGCM simulations. The studies in this paper could potentially be expanded by future satellite observations, the payloads onboard the Akatsuki spacecraft (Nakamura et al., 2007). Also, it may be possible to investigate the cloud opacity, cloud-top altitude and CO mixing ratio by IR2 (the 2 μm camera) and the cloud-top temperature by LIR (Long-wave Infrared Camera) from 2016.

Reference

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