

Simulation of sulfuric acid cloud distributions by a Venus GCM for the comparison with observations

*Hiroki Karyu¹, Takeshi Kuroda¹, Naoki Terada¹, Yasumasa Kasaba¹, Masaru Yamamoto², Masaaki Takahashi³, Kohei Ikeda⁴

1. Tohoku University, 2. Kyushu University, 3. University of Tokyo, 4. National Institute for Environmental Studies

The coupling between the mode distributions of sulfuric acid clouds and atmospheric dynamics is a key to understand Venusian cloud structures, but has not well been investigated. Haus et al. (2014) detected the meridional distributions of the total cloud opacity observed by the Visible and InfraRed Thermal Imaging Spectrometer (VIRTIS) aboard Venus Express (VEX), and showed that the cloud optical thickness reached the maximum in both equatorial and polar region.

Previously we have implemented the scheme of condensation, evaporation, and sedimentation processes of sulfuric acid clouds (cloud droplets are assumed to be composed of 75 % sulfuric acid, and supersaturation is not considered) together with the atmospheric chemistry for the formation of H_2SO_4 vapor into a Venus general circulation model (VGCM) for the investigation of the cloud formation and circulation systems, and showed that the total cloud thickness became the largest in the equatorial region and decreased towards the pole (Kasaba et al., 2016 AGU Fall Meeting, <https://agu.confex.com/agu/fm16/meetingapp.cgi/Paper/140404>). On the other hand, a recent study by Ando et al. (2020) using a different VGCM showed that the cloud mass loading was significantly larger in the polar region than in the equatorial region. The difference of the cloud implementation method between those two studies is the treatment of cloud particle distributions. Crisp (1986) defined four modes of cloud particle sizes from the Pioneer Venus observation, as mode 1 (effective radius of $0.49 \mu\text{m}$, mode 2 ($1.18 \mu\text{m}$), mode 2' ($1.40 \mu\text{m}$) and mode 3 ($3.65 \mu\text{m}$). Kasaba et al. (2016) considered the formations of all four modes, while Ando et al. (2020) considered only modes 1 and 2, which resulted in the difference of sedimentation velocity. As both results were partly consistent with the VIRTIS observations, so the combination of the two studies would produce better fits.

In this study, we have improved the cloud formation scheme from our previous study (Kasaba et al., 2016) for a better reproduction of observed cloud distributions. In Kasaba et al. (2016) the cloud particle formation ratios in the middle and lower altitude ($\sim 50\text{-}60 \text{ km}$) are uniform in all latitudes, but in this study we decreased the formation of mode 3 clouds in higher latitudes. The newly implemented mass formation ratio of mode 3 was defined to be a half of Kasaba et al. (2016) in the latitudes of >70 degrees, and replaced to mode 2' for another half, to mimic the particle size of formed clouds defined in Ando et al. (2020) in the polar region. Also, a linear interpolation of the ratio from the original one was implemented between 50 and 70 degrees, and the vertical eddy diffusion coefficient in the cloud layer is set to be lower than Kasaba et al. (2016).

In comparison with Kasaba et al. (2016), this study produced improved latitudinal distribution of cloud opacity at $1 \mu\text{m}$ wavelength, which was qualitatively consistent with the VIRTIS observation (Haus et al., 2014). Also, the latitudinal distributions of cloud mode factors seen in Fig. 18 of Haus et al. (2014) are also well reproduced. The thickness of mode 3 clouds are the highest in poles, nevertheless of the lower production rate than in low-latitudes.

For the investigations of the cloud formation process, we are analyzing cloud production and loss rates

due to advection, sedimentation, and vertical eddy diffusion. Because of the low vertical eddy diffusion coefficient, more H_2SO_4 vapor remains in the upper cloud. Consequently, the H_2SO_4 vapor is transported to the polar region by the downwelling of the Hadley circulation, and the thickness of polar clouds increases. Cloud formation around 40 km also increases slightly. This may be the result of coupling between the increase of polar clouds and equatorward advection by the return branch of the Hadley cell extended from the pole to the equator.

In addition, we are conducting spectrum analyses on temperature, wind, and cloud mode distributions to investigate the relationship between waves and cloud fluctuation. Equatorial Kelvin-wave-like structures are found in the lower cloud layer, and cloud fluctuation is synchronized with the waves. It could be useful to understand cloud morphology observed by Akatsuki, such as disruption in the lower cloud layer interpreted as a Kelvin wavefront (Peralta et al., 2020). Although other types of waves exist and seem to be correlated with cloud fluctuation, further investigation is needed to interpret the causality between them.

Keywords: Venus, Sulfuric acid cloud , General Circulation Model