Derivation of vertical profiles of SO_2 in the Venus cloud layer by the Akatsuki radio occultation measurements.

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Introduction: On Venus, sulfuric acid (H_2SO_4) clouds exist at the altitudes from 45 to 70 km, covering the entire planet. This thick cloud layer plays a key role in controlling the heat budget in Venus atmosphere. One of the missing information in the cloud layer is the vertical distribution of the sulfur dioxide (SO_2), which is one of the main chemical compounds in forming the H_2SO_4 clouds.

The previous observations of the SO_2 vertical distribution at the cloud layer were limited to the in-situ measurements by the VEGA probes [1]. The two probes measured the vertical profiles of the SO_2 mixing ratio from the surface to the altitude of 60 km. In addition to the in-situ measurements, radio occultation (RO) measurements of the Venus Express derived the mean SO_2 mixing ratio at 51-54 km [2].

Extending the method adopted in the Venus Express RO measurements, we have derived the vertical profiles of SO_2 mixing ratio in the cloud layer (50-55 km) by the RO measurements in the Japanese Venus orbiter, "Akatsuki".

Data and method: We analyzed the Akatsuki RO data obtained at the low latitudes (40°S-40°N) during 5 Earth years (2016-2021). In the RO measurements, we utilize the absorption of the radio waves transmitted from the spacecraft to the Earth, which pass through the Venus atmosphere. Time series data of received intensity can be obtained, and the distribution of mixing ratio of trace substances can be obtained from the time variation of radio wave intensity with the attenuation of the radio waves.

In the frequency domain used in the Akatsuki RO measurements (8.4 GHz), the gaseous species including CO_2, N_2, H_2SO_4 vapor and SO_2 contribute to the attenuation of the radio waves in the Venus atmosphere. In addition to the absorption by the constituents in the Venus atmosphere, the defocusing loss, the directional error of the transmitter antenna and Earth's atmosphere also contribute to the attenuation. We removed those effects from the original radio wave's intensity to obtain the residual attenuation. The concentrations of H_2SO_4 vapor and SO_2 are then derived by subtracting the attenuations caused by CO_2 and N_2. Finally, we assume that H_2SO_4 vapor is not supersaturated in the Venus cloud layer and any attenuations which exceed the saturation curve of H_2SO_4 vapor attribute to the absorption by SO_2.

Error analysis: We conducted the error analysis of the SO_2 mixing ratio retrieved as follows:

Effect of the interplanetary plasma and Earth's atmosphere. As mentioned above, the radio waves emitted from the spacecraft orbiting Venus is also attenuated by the Earth's atmosphere. The significance of this effect was estimated by analyzing the short time-scale variations appearing in the time series of the received radio wave intensity before/after the occultation. We found that the error of the SO_2 mixing ratio possibly exceeds 100% at 50-55 km due to those effects, suggesting that the precision of the individual observation was not high. Therefore, we averaged all the vertical profiles of SO_2 to improve the signal-to-noise rations.

Uncertainty of the H_2SO_4 saturation mixing ratio. The H_2SO_4 saturation mixing ratio depends not only on temperature but also on the mass concentration and the size of the cloud particles. The higher the mass concentration and the smaller the particle size, the greater the H_2SO_4 saturation mixing ratio. Numerical models suggest that the mass concentration of H_2SO_4 is higher than 98% at 50 km and nearly 90% at 55 km [3]. The radius of the Venus cloud particles ranges from submicron (mode 1) to several microns (mode 3) [4]. We estimated the uncertainty of the H_2SO_4 saturation mixing ratio were 25-50%.

Uncertainty of the absorptivity of CO_2, N_2 and H_2SO_4 vapor. We examined the uncertainties in the absorptivity of CO_2 and N_2 combined and H_2SO_4 vapor. These were ~3 % and ~10 %, respectively. Considering all the uncertainties in the *absorptivity of the gases*, SO_2 mixing ratios derived in this study have an uncertainty of ~30 %.

Result of the SO_2 mixing ratio retrieved: The averaged vertical profile showed the SO_2 mixing ratio of about 300 ppmv and 50 ppmv at the altitude of 50 km and 55 km, respectively, decreasing with increasing altitude. Those are consistent with the previous observations of the VEGA probes and the Venus Express RO measurements. Additionally, we found a local time dependence of the SO_2 mixing ratio in the cloud layer, which was smaller in the daytime than in the nighttime, being similar with the previous observations conducted above the cloud layer [5]. The long-term variations were not detected in the present study.

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References: [1] Bertaux et al. (1996) J. Geophys Res 101(E5), 12709–12745. [2] Oschlisniok et al.

(2021) Icarus, Volume 362, 2021. [3] Hashimoto and Abe (2001) J. Geophys. Res., 106(E7), 14675– 14690. [4] Knollenberg and Hunten, J. Geophys. Res. 85, 8039 (1980) [5] Marcq et al. (2020) Icarus, Volume 335, 2020.