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Dayside cloud top structure of Venus retrieved from Akatsuki IR2 observations

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Abstract

We present the dayside cloud top structure of Venus as retrieved from 93 images acquired at a wide variety of solar phase angles (0-120˚) using the 2.02-µm channel of the 2-µm camera (IR2) onboard the Venus orbiter, Akatsuki, during the period from April 4 to May 25, 2016. In this presentation, we will overview the obtained results and discuss their interpretation.

1. Introduction

The clouds at altitudes between ~47 and 70 km on Venus cover the entire planet and play significant roles in chemistry, dynamics, and energy balance of the atmosphere. Altimetry of Venus' cloud top has been conducted by means of imaging, spectroscopy, and polarimetry in a broad range of wavelengths, from UV to mid-infrared, using data provided by Pioneer Venus Orbiter, Venera 15, and Venus Express. According to previous studies [1, 2, 3, 4, 5], the cloud top has an equatorially symmetric structure and the upper cloud boundary is vertically diffuse in the low and middle latitudes and gets sharper at higher latitudes. No considerable local time and long-term variations have been detected before.

2. Observations

Since December 7, 2015, Akatsuki has been conducting remote sensing observations of Venus from an equatorial elliptical orbit, using five cameras, ranging from UV to mid-infrared, and the radio occultation technique. Since the 2.02-µm channel of IR2 is located in a CO_2 absorption band, the sunlight reflected from Venus allows us to determine the cloud top altitude corresponding to a unit aerosol optical depth at 2.02 µm, with radiative transfer simulation.

3. Summary of results

The important findings of this study are:

- The observed solar phase angle dependence, and the center-to-limb variation, of reflected sunlight at low latitudes ($|\theta| \leq 30˚$) were used to derive a spatially-averaged cloud top structure characterized by cloud top altitude z_c, Mode 2 modal radius $r_{g,2}$, and cloud scale height H. The best-fit model was obtained by the combination of z_c = 70.3 km, $r_{g,2}$ = 1.07 µm, and H = 5.1 km. The estimated $r_{g,2}$ (converted into the effective radius $r_{eff,2}$ = 1.26 µm with geometric standard deviation $\sigma_{g,2}$ = 1.29) is in line with those of previous studies which have regarded it as the so-called 1-µm mode of the cloud particles responsible for the visible appearance of Venus [6]. The estimated H corresponds to the upper range of the previous measurements for 3.5-5.2 km [1]. This relatively large value, which allows the suspension of more scattering aerosols in the upper layer, was necessary to reproduce the steep phase curve with large solar phase angles.

- Cloud top altitudes at individual locations were retrieved by reproducing the radiance for each image pixel through changing cloud top altitude while keeping $r_{g,2}$ and H fixed. The averaged cloud top in low and middle latitudes ($|\theta| \leq 45˚$) was in the range 68-70 km. It rapidly decreased in higher latitudes ($50˚ \leq |\theta| \leq 60˚$) and was 61 km in high latitudes ($70˚ \leq |\theta| \leq 75˚$). This global pattern is qualitatively in agreement with those determined in previous studies [1, 2, 3, 4, 5], although the latitudinal descent with increased latitudes obtained in this study was steeper than those reported by most previous studies, partly because of the different choice of cloud scale height. The cloud top averaged in low latitudes ($|\theta| \leq 30^{\circ}$) indicated the tendency to increase from early morning (~7 h) and reach a maximum in the early afternoon (~14 h), followed by a decrease toward late afternoon (~17 h). However, the sensitivity tests clarified that this is subject to changes in temperature, Mode 2 modal radius, and cloud scale height. We conclude that for local time variation, the maximum change is 1 km at most. The magnitude of this change supports results for daytime and nighttime cloud top altitude [3, 4, 5].

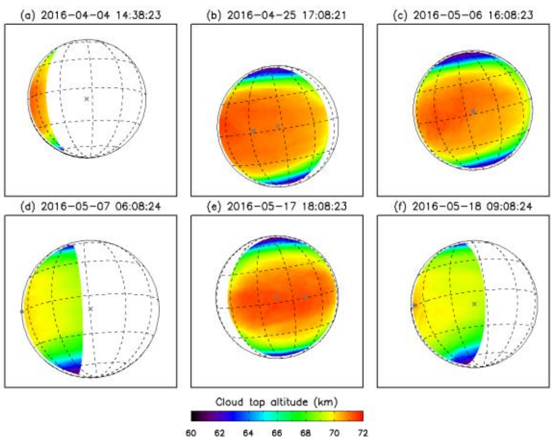

Fig. 1. Representative cloud top altitude maps retrieved from Akatsuki IR2 observations.

- Localized features with amplitudes smaller than several hundred meters appear in cloud top altitude maps after high-pass filtering. The long, zonal or tilted streaky features poleward of ~45˚ were clearly identifiable at the altitude of the cloud top and the two UV radiance maps. In contrast, the features in low and middle latitudes that are present in the cloud top altitude maps were usually faint with amplitude of <~100 m. These did not necessarily appear as local variations in cloud top altitude, where mottled and patchy patterns were seen in the UV channels, suggestive of the existence of convection and turbulence at the cloud top level. We also detected stationary gravity wave features in the 2.02-μm images. We were able to interpret the difference in radiance between the bright and dark appearances constituting stationary features as the differences in the altitudes of the cloud tops (peak-to-peak value: ~0.2 km).

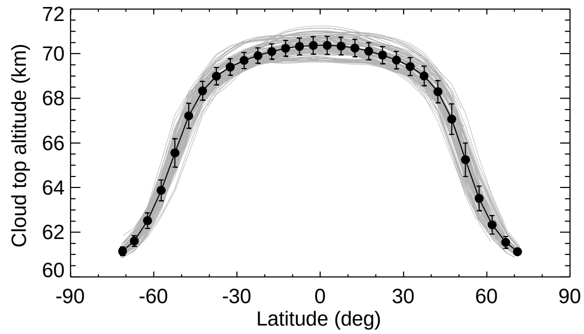

Fig. 2. Latitudinal variation of zonally-averaged cloud top altitude.

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