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Cloud distribution simulated by a Venus GCM

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Abstract

We construct a simple cloud model for a Venus general circulation model (GCM), which includes condensation, evaporation and sedimentation of sulfuric acid cloud particles and condensable gases (H_2O and H_2SO_4 vapors). The cloud distribution reproduced in the model is the thickest and thinnest in high- and mid-latitudes, respectively. The mixing ratio of H_2O and H_2SO_4 vapor increase with latitude in the cloud and the sub-cloud levels, which are qualitatively consistent with previous measurements. In low-latitudes, the moderately thick cloud with zonal wavenumber 1 and 2 structures is formed and changes in time significantly. These structures would be associated with atmospheric waves in the cloud layer.

1. Introduction

It is well known that Venus is globally covered by thick clouds composed of small droplets of sulfuric acid [1]. Pioneer Venus probe measurements indicated that the cloud consists of three layers (upper, middle, and lower clouds) in the equatorial region, and the cloud particle size and number density are different among these layers. Some infrared measurements showed that the brightness, which is the thermal emission from the lower atmosphere below the cloud layer, temporally varies and has an apparent zonal wavenumber-1 structure in low-latitudes [2, 3]. It is usually bright and dark in mid- and high-latitudes, respectively, implying that the cloud is thin and thick in mid- and high-latitudes, respectively.

Although a lot of optical measurements have been conducted in the Venus missions, the mechanisms how the cloud structure and distribution shown in the measurements are maintained. One of the useful methods is a numerical model. In the present study, we construct a simple Venus cloud model for our GCM named AFES-Venus and reproduce the three-dimensional distribution and structure of the cloud.

2. Model description

2.1. Cloud physics in the model

For simplicity, we consider H_2O and H_2SO_4 vapors as the cloud material and do not include the chemical cycles of H_2SO_4. Initially, the altitude distribution of H_2O vapor mixing ratio is given by its saturation mixing ratio above 30 km altitude, and that below the level is fixed to be 30 ppmv. There is no H_2SO_4 vapor at the initial stage. H_2SO_4 vapor is photochemically produced at 62 km altitude and thermally decomposed below 35 km altitude. We assume that the clouds are composed of H_2SO_4-H_2O droplets, which are produced only when both H_2O and H_2SO_4 vapors are saturated. Otherwise, the cloud particles evaporated. Mole concentration of H_2SO_4 in the cloud particle is fixed to be 85%. The saturation vapor pressures of H_2O and H_2SO_4, which depend on temperature and the mole concentration of H_2SO_4 in the cloud particle [4, 5]. On the assumption that the shape of cloud particle is sphere, the sedimentation velocity is given by the Stokes velocity.

2.2. GCM settings

AFES-Venus is a spectral model which solves a three-dimensional primitive equation on a sphere. The resolution of the model used in this study is T42L120, i.e. the horizontal and vertical grid widths are ~2.8125° and ~1 km, respectively. The model atmosphere is driven by the three-dimensional solar heating given between 0–90 km altitudes. The infrared radiative transfer process is simplified by a Newtonian cooling scheme. A reference temperature field, to which the model temperature is relaxed, is based on the Venus International Reference Atmosphere (VIRA) and horizontally uniform. Venus is assumed to rotate in the same direction as Earth, then the super-rotation directs from west to east in the present model. Numerical integration was conducted for 40 Earth years. The model atmosphere reached a quasi-equilibrium state within about 40 years. The data interval is 6 hours, and we mainly analyzed the data obtained in the last 1 Earth year.

3. Results

3.1. Latitude-height distribution

Figure 1a shows a latitude-height distribution of zonally and temporally averaged cloud mass loading, which is defined as a product of the cloud mixing ratio and the atmospheric density. The maximum mass loading is located at 43–53 km altitudes in latitudes of 70˚N–90˚N. In low-latitudes, the mass loading is moderately large with a local maximum located at 47 km altitude. As a result, the cloud thickness takes its minimum in mid-latitudes. Figure 1b shows a latitude-height distribution of zonally and temporally averaged H_2O vapor mixing ratio. It does not largely change with latitude below 50 km but significantly increases with latitude in the cloud layer above 50 km. A latitude-height distribution of the zonally and temporally averaged H_2SO_4 vapor mixing ratio is shown in Figure 1c. It has a maximum at 43 km altitude in high-latitudes. Since the mass loading is the largest at 47–55 km altitudes in these latitudes (Figure 1a), the H_2SO_4 vapor is reproduced by the sedimentation and evaporation of the cloud particles there.

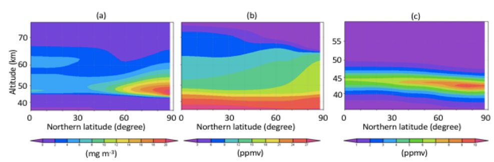

Figure 1: Latitude-height distribution of the zonally and temporally averaged (a) mass loading, (b) H_2O vapor and (c) H_2SO_4 vapor mixing ratios. The data are averaged for 2 Venus days (234 Earth days). The altitude ranges of (a) and (b) are 35–75 km, and that of (c) is 35–60 km.

3.2. Horizontal distribution

Figure 2 shows a horizontal distribution of the column integrated mass loading obtained at 40 Earth years, which approximately represents the cloud thickness. The column integrated mass loading obtained in the present model is the largest in high-latitudes poleward of 60˚, and it is the smallest in mid-latitudes. Wave-like structures with zonal wavenumbers-1 and 2 are seen in low-latitudes. These characteristics are qualitatively consistent with previous infrared measurements [1, 2]. The present result suggests that such a cloud variation could be caused by atmospheric waves such as Kelvin waves and thermal tides. The detailed process by which the cloud mass loading is affected by the atmospheric waves should be investigated in the future.

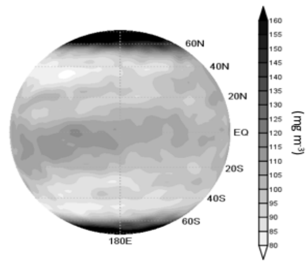

Figure 2: Horizontal distribution of the vertically added up mass loading in the orthogonal plot is shown in (a). The longitudinal range is fixed to be 45˚E–225˚E. The time of these data is 40 Earth years from the calculation start.

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