EPSC Abstracts
Vol. 6, EPSC-DPS2011-1278, 2011
EPSC-DPS Joint Meeting 2011
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Meridional trend of thermal emission and cooling rate in the Venus cloud layer

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Abstract

Through a great depth of more than 20 km and global coverage, the Venus cloud layer plays an important role in the radiative energy balance. The Venus Express (VEx) observations showed that the cloud top properties significantly change with latitudes. Here we use the structure of the upper cloud derived from the joint analysis of the VeRa and VIRTIS observations to calculate the outgoing thermal flux and cooling rates and discuss the cloud effects.

1. Introduction

Since VEx started orbiting Venus in April 2006, it has observed various cloud formations from spectrometer and camera images [1]. In spite of dynamic changes of clouds in small scale, there is latitudinal global feature of cloud top altitude which has a decreasing tendency to poleward. VIRTIS observations in 4.5-5 µm range showed that cloud top altitude decreases from 67 km at the equator to 63 km in the polar regions while the scale height decreases from 4 to 2 km [2]. This result confirmed the previous studies at different wavelengths [3,4] (Figure 1).

This latitudinal structure of upper cloud layer is very important to understand many related physical phenomena in the mesosphere: superrotation, cloud morphology, chemistry, radiative energy balance and so on. The cloud layer plays an important role in the radiative energy balance. Firstly, it absorbs almost half of incoming solar radiation, and secondly the outgoing thermal radiation forms mainly at its top [5]. This study is focusing on the thermal radiation for the night side analysis, and investigating thermal cooling effects as a causative factor of anomalous thermal structure.

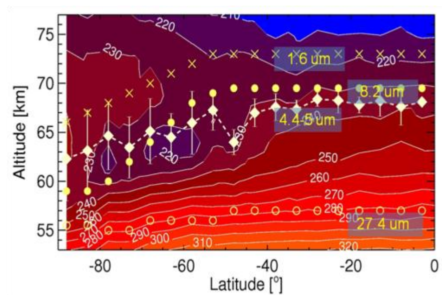

Figure 1: Latitudinal distribution of cloud top altitudes in different wavelengths.

2. Data and methods

We used radiative transfer model based on SHDOM [6] with line-by-line treatment of gaseous absorption bands [7]. Thermal flux is integrated in a broad wavelength range (4-200µm).

2.1 Gaseous absorption

The gaseous extinction includes CO_2, H_2O, and SO_2 absorption. Line parameters of each gas are taken from HITRAN08. Sub-lorentzian form factors and cutoff values of CO_2 are chosen carefully, since the CO_2 absorption is very crucial in the deep atmosphere.

Table 1: Sub-intervals for thermal emission calculation in a broad range. Approximate strong band locations of each gas are marked.

Wavenumber [cm^{-1}]	marks	CO_2	H_2O	SO_2
50 (= 200 µm)	L1			
390	L2			
1190	L3			
1810	L4			
2590 (=3.86 µm)	L6		(L5=2000 cm^{-1}, 5 µm)	

CO_2 bands
non-overlapped by CO_2

For convenience, the broad wavelength range is divided into 6 sub-intervals according to positions of strong CO_2 bands (Table 1).

2.2 Atmospheric condition and cloud structures

VeRa and VIRA combined data are used for whole atmosphere (0-100 km) for the latitudinal temperature and pressure profiles. Cloud layer is considered as three layered cloud with four modes properties based on the Venera and VEx observations [2,4]. The upper cloud structure parameters are based on 4.5-5 μm optical properties. The calculation takes Rayleigh scattering into account.

3. Results

Thermal structure of the Venus mesosphere strongly changes with latitude. At the low latitudes temperature profile gradually decreases with altitude. In the “cold collar” region a strong temperature inversion layer in 60-70 km altitude is observed (Figure 2). Outgoing thermal fluxes at the top of the atmosphere show big variances according to the cloud top altitudes with this latitudinal thermal structure. Low latitude case shows 138-201 W/m^2 outgoing fluxes when the cloud top changes from 71 to 61 km, and cold collar case shows 126-148 W/m^2 for the same cloud top range. With latitudinal cloud top altitude distribution, it results decreasing outgoing fluxes from equator to the cold collar region.

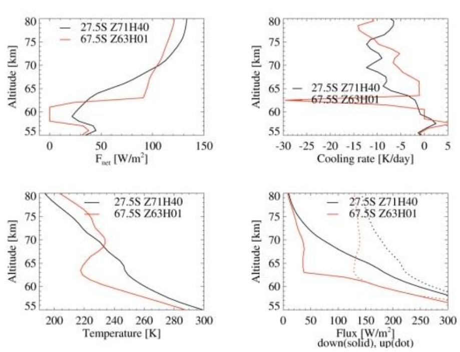

Figure 2: Comparison of thermal emissions in low latitude (black) and cold collar (red) conditions.

Figure 2 compares thermal fluxes and cooling rates calculated for the low latitude and cold collar cases. Low latitude case used high cloud top (71 km) with large scale height (4 km). Cold collar case used low cloud top (63 km) with very small scale height (0.1 km). Cold collar shows cloud boundary through sharp change of net flux. Although cloud top temperature is very low (217 K), sharp cloud boundary induces pronounced cooling rates by less downward flux from cloud-free condition above cloud top. This property is distinguishable with low latitude case which has moderate cooling rate near to the cloud top altitude.

6. Summary and Discussion

This study is trying to calculate latitudinal thermal emission based on the VEx observation. The extreme cloud cases are tested in Figure 2. The results show strong cooling (~30K/day) near to the cloud top in the cold collar despite low latitude case shows 10-15 K/day cooling rate. It is supposed to deepen temperature inversion layer right above cloud top. This result gives motivation for the detailed thermal emission calculation and discussion about cloud structure effects.

Acknowledgements

Y.J. Lee acknowledges a PhD fellowship of the International Max Planck Research School on Physical Processes in the Solar System and Beyond.

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