Thermal fluxes and cooling rate of the Venus cloud layer

Yeon Joo Lee (leeyj@mps.mpg.de)[1,2], Dimitri Titov[3], Nikolay Ignatiev[4], Silvia Tellmann[5], Martin Pätzold[5] and Giuseppe Piccioni[6]
[1]Max Plank Institute for Solar System Research, Katlenburg-Lindau, Germany, [2] Institut für Geophysik und extraterrestrische Physik, TU Braunschweig, Braunschweig, Germany,
[4] ESA/ESTEC, Noordwijk, The Netherlands, [4]Space Research Institute (IKI), Moscow, Russia,
[5]Rhenish Institute for Environmental Research, Universität zu Köln, Cologne, Germany, [6]IASF/INAF, Rome, Italy

EGU2011-916

Introduction

✓Cloud layer of Venus is carrying an major role for radiative energy balance. Venus is covered by cloud with huge thickness, ~ 30 km. Therefore cloud is adding thermal opacity, Additionally cloud absorbs almost half of incoming solar radiation (Fig. 1) [1,2].

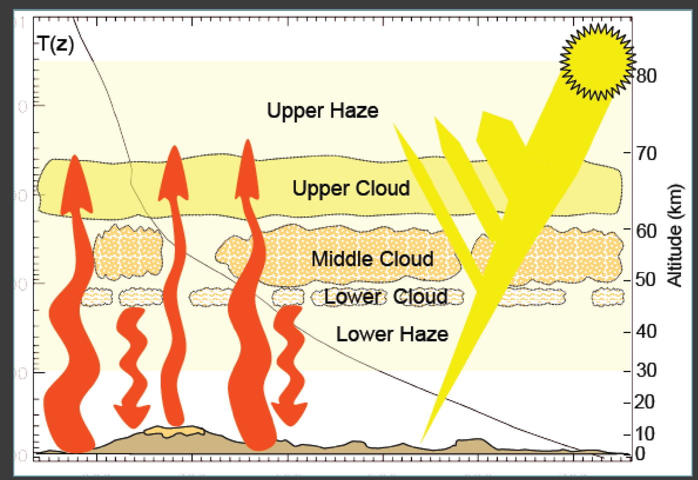


Figure 1. Scheme of radiative energy in Venus atmosphere [2]

✓On the other hand, through many wave number observations, it turns out that cloud shows latitudinal variation [3,4,5]. For example, 4.4-5 μm range analysis shows a clear decreasing tendency of cloud top from equator (~67.2 km) to pole (~62.8 km) with scale height changes [5] (Fig. 2).

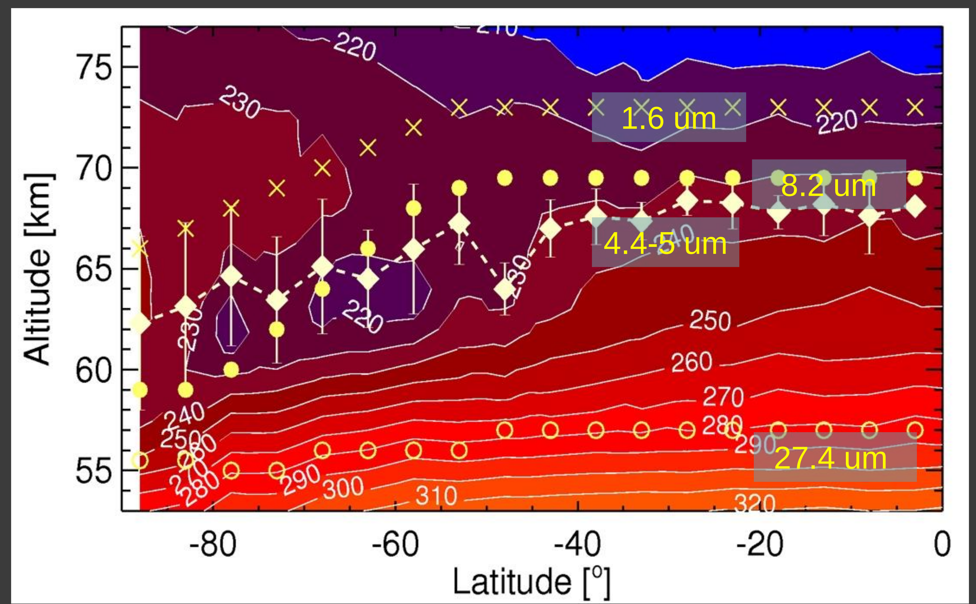


Figure 2. Latitudinal distribution of cloud top altitude [5]

✓This cloud top structure variance becomes interesting to investigate radiative energy balance at this level. Because cloud morphology, atmospheric dynamics and chemistry are related with cloud top [1,2]. And this study will help to understand about atmospheric conditions for remote sensing also.

✓Our goal of this study is calculation of radiative energy balance in the Venus upper cloud layer. For the first, we managed a thermal emission in a broad wave number range.

Data and methods

✓Atmospheric gases:
CO_2 (96.5%), H_2O and SO_2 are considered.
- HITRAN08 [6]
- Line shape factor for CO_2 [7,8,9,11,12]

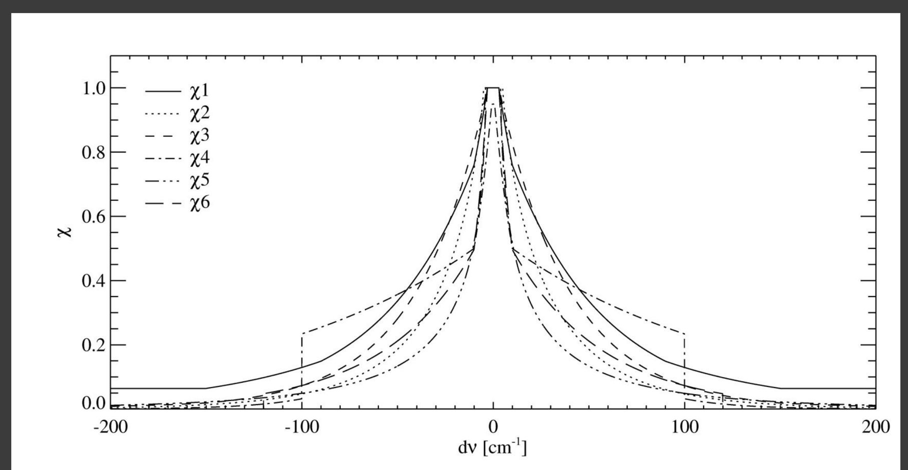


Figure 3. Line shape factors from each references (χ1[8], χ2[7], χ3[9], χ4[10], χ5[12] and χ6[11]).

- Cutoff: 200 cm^{-1} (CO_2) and 100 cm^{-1} (H_2O, SO_2)
- The fast and accurate method of line-by-line calculation [13]
- Rayleigh scattering [14]

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

✓50-8300 cm^{-1} (=0.38-200 μm) are considered for the thermal emission. It's divided into 14 sub-intervals (right table).

✓Temp. and Pres. profiles: VeRa+VIRA

✓Radiative Transfer Model: SHDOM [15]

Wavenumber [cm^{-1}]	marks	CO_2	H_2O	SO_2	UV unknown absorber
50 (= 200 μm)	L1				
390	L2				
1190	L3				
1810	L4				
2000 (= 5 μm)	L5				
2590	L6				
3000	L7				
3950	L8				
4650	L9				
5340	L10				
6050	L11				
7080	L12				
8190	L13				
8300	L14				
26000 (=0.385 μm)	L15				
50000 (= 0.2 μm)	L16				

CO_2 bands
overlapped by CO_2
non-overlapped CO_2
comparably weak

Atmospheric condition and cloud structure

✓Profiles of H_2O and SO_2 are taken from Fig. 4

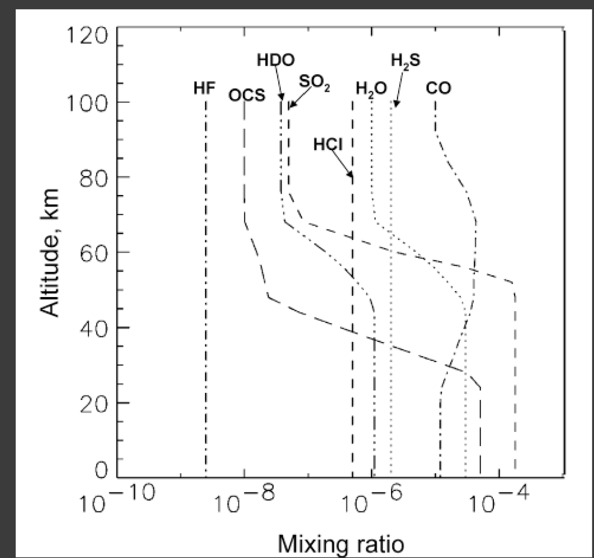
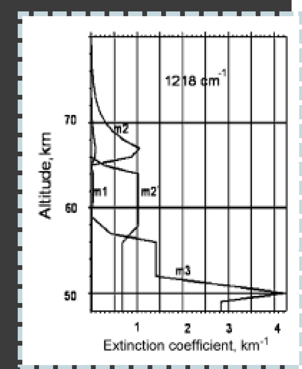


Figure 4. Mixing ratio of minor gases [16]



Zasova et al.[17]

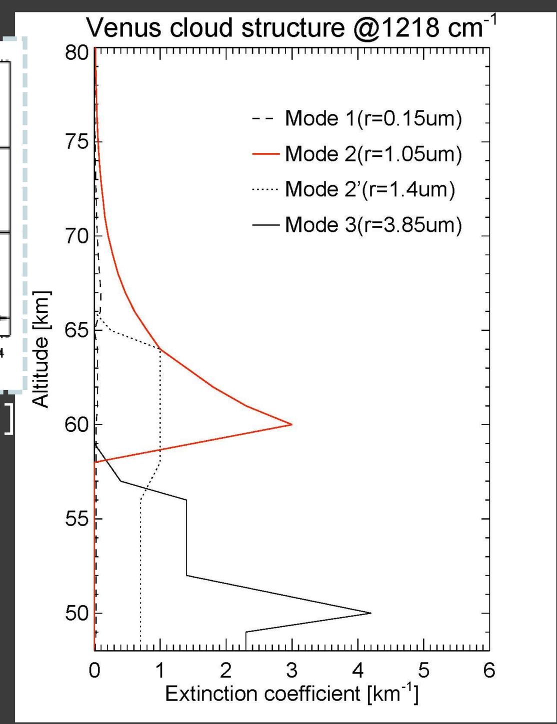


Figure 5. Example cloud extinction coefficient profile for low latitude cloud case.

✓Cloud profile is shown in Fig. 5. Mode 2 is from 4.4-5 μm observation of Venus Express [5] (Fig. 2) and other modes for mid-low cloud layer are from Zasova et al. [17].

✓Latitudinal upper cloud structure retrieved from 4.4-5 μm observation is used for this study and it's shown in the below table [5].

Upper cloud structure	Mid-low lat. (0S ~ 56S)	Cold collar (56S ~ 80S)	Polar region (80S ~ 90S)
Aerosol scale height (km)	3.8	2.1	1.7
Cloud top altitude (km)	67.2	64.7	62.8

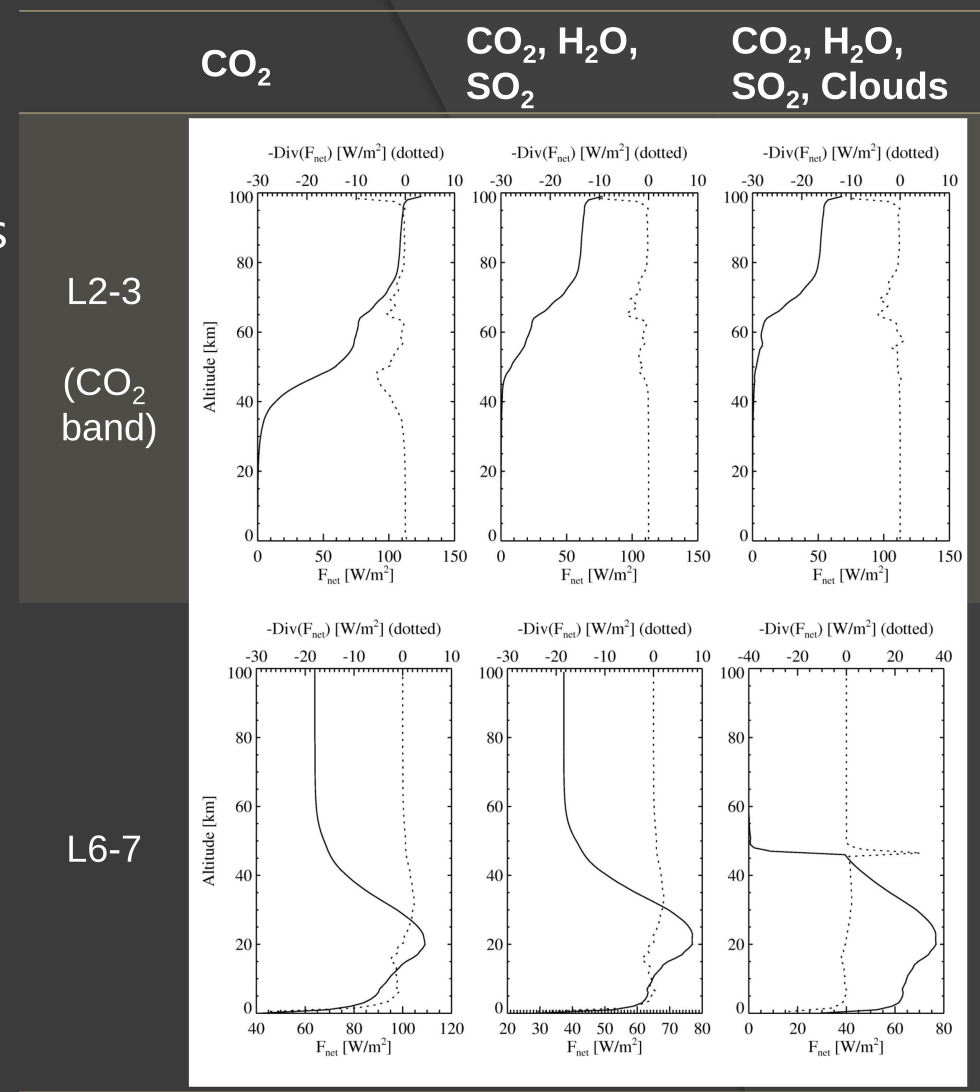
References
[1] Esposito et al., 2007, Exploring Venus… (AGU 176-Esposito et al. Eds.)
[2] Crisp, 2007, Greenhouse effect and radiative balance on Earth and Venus (presentation)
[3] Zasova et al., 1993, Icarus, SO_2 in the middle atmosphere of Venus …
[4] Igantiev et al. 2009, JGR, Altimetry of the Venus cloud tops from the Venus Express obs.
[5] Lee et al., 2010 (submitted), Icarus, Vertical structure of the Venus cloud top from …
[6] Rothman et al., 2008, JQSRT, The HITRAN 2008 molecular spectroscopic database.
[7] Winters et al., 1964, JQSRT, Line shape in the wing beyond the band head of the 4.3 μ …
[8] Meadows and Crisp, 1996, JGR, Ground-based NIR observations of the Venus nightside …
[9] Tonkov et al.,1996, AO, Measurements and empirical modeling of pure CO2 absorption…
[10] Lellouch et al., 2000, PSS, The 2.4-45 μm spectrum of Mars observed with the IR …
[11] Pollack et al., 1993, Icarus, NIR light from Venus' Night side: A spectroscopic analysis
[12] Ignatiev et al., 1999, PSS, Water vapour in the middle atmosphere of Venus…
[13] Titov and Haus, 1997, PSS, A fast and accurate method of calculation of gaseous …
[14] Hansen and Travis, 1974, SSR, Light scattering in planetary atmospheres.
[15] Evans, 1998, JAS, The Spherical Harmonics Discrete Ordinate Method for 3-D Atm. …
[16] Titov et al., 2007, Radiation in the atmosphere of Venus (AGU 176-Esposito et al. Eds.)
[17] Zasova et al., 2007, PSS, Structure of the Venus atmosphere.

Results

✓Comparisons of the thermal emissions according to the atmospheric compositions (low latitude condition).

$$F_{net} = F^{\uparrow} - F^{\downarrow}$$

$$H = -\nabla \cdot F_{net} = \frac{1}{c_p \rho}\left(-\frac{dF_{net}}{dz}\right)$$



✓Comparisons of thermal emissions along the latitude

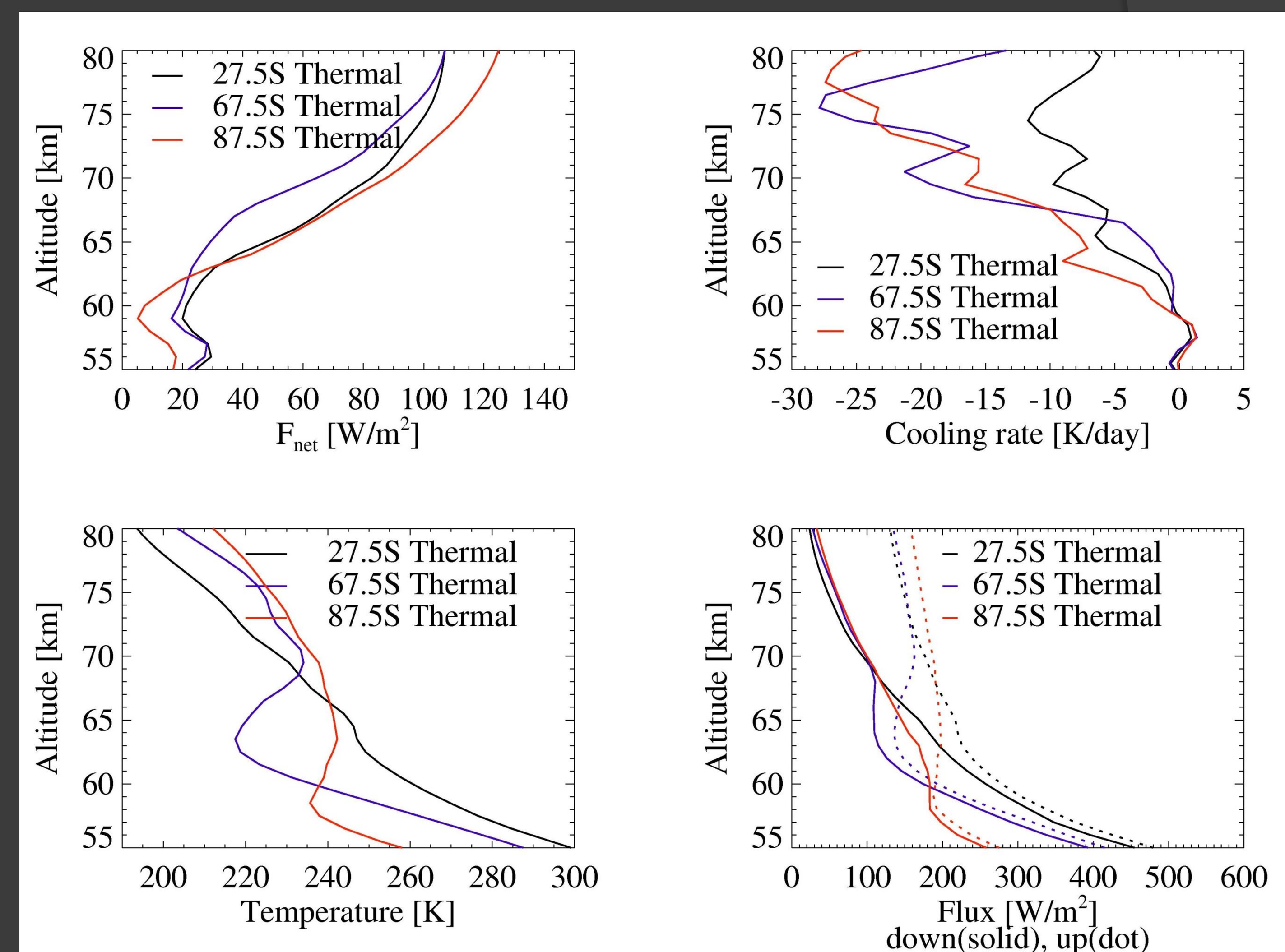


Figure 6. Thermal emissions (50-8300 cm^{-1}) under three latitudinal conditions.

Summary and further study

✓Venus thermal emission is calculated in a broad wave number range. In this study, latitudinal upper cloud structure and temperature profile, from Venus Express observation, are considered.
✓Strong absorption of atmospheric gases and cloud effects are shown in thermal fluxes.
✓Fig. 6 shows the change of thermal fluxes along the altitude and latitude. There are pronounced cooling rates in the cold collar and polar region (up to -28 K/day), which is twice stronger than the cooling rate in the low latitude. The tendency is resulted by the dependence of cloud top height, aerosol distribution and atmospheric temperature.
✓This thermal flux calculation needs to be tested for the minor gases profiles and cloud structures to get similar data with observations and other model studies. Solar heating is still an ongoing work for the energy balance calculation.