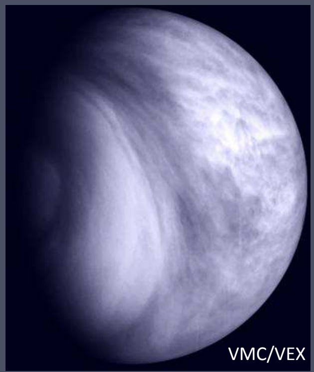
Radiative forcing variations induced by the cloud top structures in the Venus mesosphere



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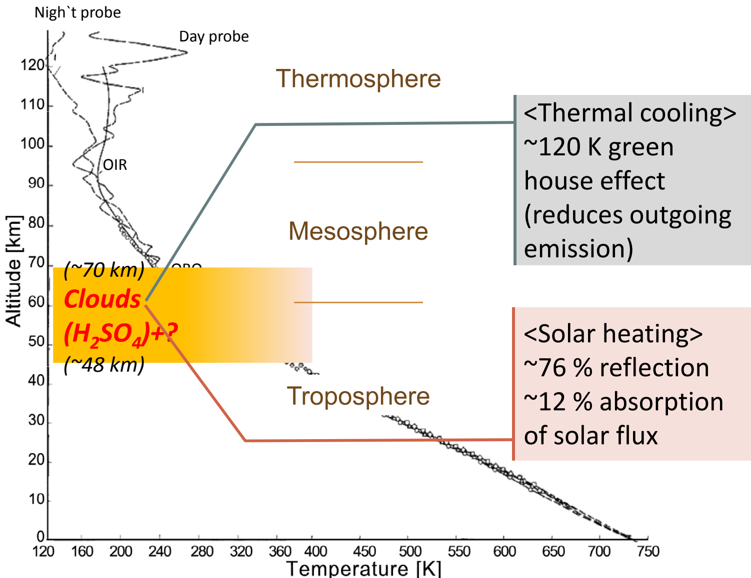
- Abstract:

The thick clouds of Venus are located from ~48 km to ~70 km altitude. As these clouds cover the globe completely with large opacity, they play an important role in the radiative energy balance. Especially the upper cloud layer, above ~60 km altitude, is a significant factor for both thermal emission and incoming solar radiation. Around 76 % of solar radiation is reflected back into space by the clouds, and ~12 % of solar flux is absorbed by unknown UV absorbers in the upper cloud layer [Crisp 1986; Crisp and Titov, 1997]. Also, the clouds absorb a large fraction of the outgoing thermal emission from the hot surface and deep atmosphere, making them the second strongest greenhouse agent in the Venus atmosphere [Bullock, 1997]. The cloud tops determine the outgoing emissions to space by their own temperatures. Since many observations have revealed various upper cloud layer structures [Ignatiev et al., 2009; Lee et al., 2012], the radiative energy balance in the Venus mesosphere can be affected by changes in the upper cloud layer structure. Therefore knowing the radiative energy balance is important for a better understanding of many unsolved problems in the upper cloud layer, e.g., strong horizontal retrograde winds (super-rotation), temperature inversion layer (cold collar), and polar vortex.

This presentation will start from the observational data analysis to retrieve cloud top structures, and shows the variations of radiative forcing depending on the upper cloud structures. At the end, meridional trends of radiative energy balance of the Venus mesosphere will be shown.

The atmosphere of Venus

VENUS
96.5 % CO_2
3.5 % N_2
~150 ppm SO_2
~30 ppm H_2O



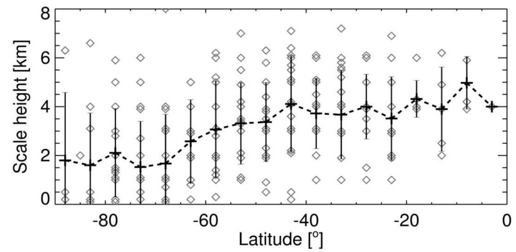
[Seiff et al., 1985]

The cloud tops from observation

A joint analysis of data from VeRa and VIRTIS/Venus Express

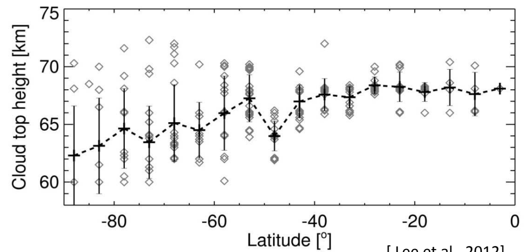
- Aerosol scale height (H)

90S ~ 80S	1.7 ± 2.4 km
80S ~ 56S	2.1 ± 2.0 km
56S ~ 0S	3.8 ± 1.6 km



- Cloud top altitude (Z)

90S ~ 80S	62.8 ± 4.1 km
80S ~ 56S	64.7 ± 3.2 km
56S ~ 0S	67.2 ± 1.9 km

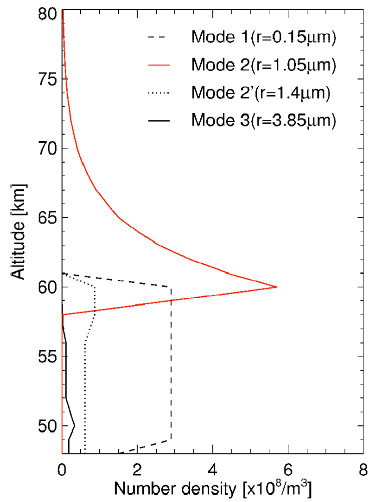


[Lee et al., 2012]

Data and methods

- Latitudinal T and P profiles (0-100 km): Venus express observation and VIRA
- Gaseous absorption: CO_2 (96.5%), H_2O, and SO_2 (HITRAN08)
- Radiative transfer model: SHDOM
- Thermal cooling: 3.8-200 µm
  Solar heating: 0.2-5.0 µm
- Clouds: Sulfuric acid (75%) four-mode size distribution [Zasova et al., 2007] with unknown UV absorber [Tomasko et al., 1985]

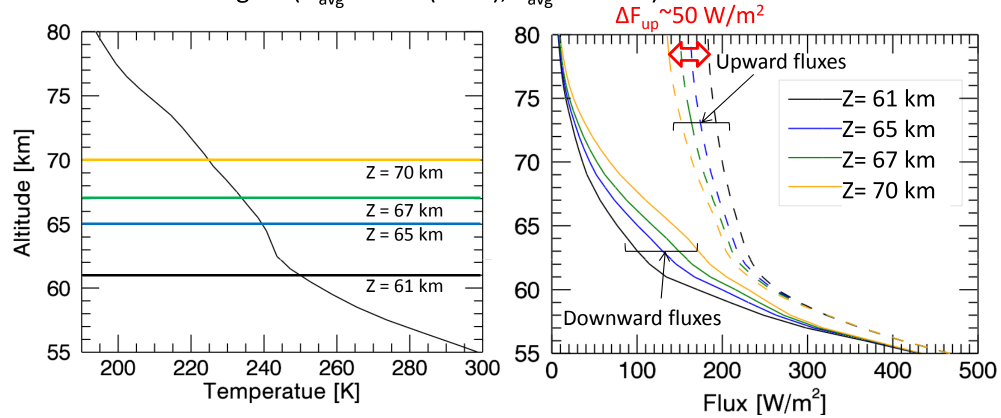
Clouds vertical distribution of this study



Sensitivity of thermal flux (1)

The effects of the cloud top (Z) on the upward fluxes

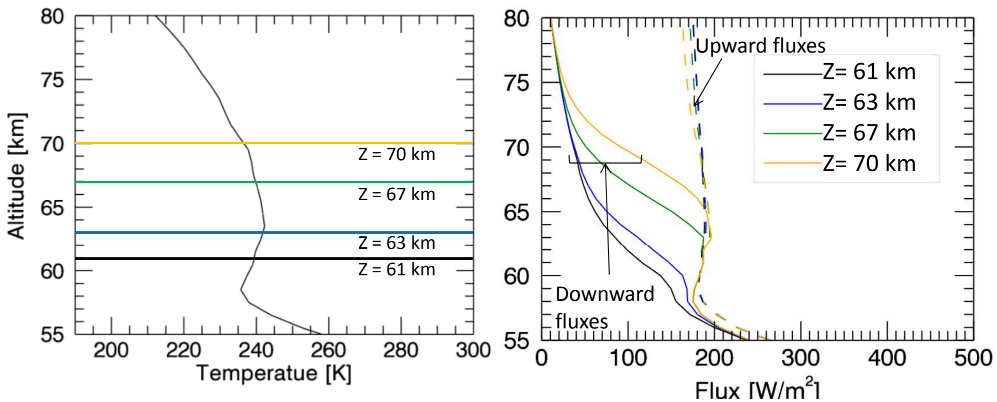
Low latitude region (H_{avg}= 4 km (fixed), Z_{avg} = 67 km)



Sensitivity of thermal flux (2)

+ Temperature structure dependence

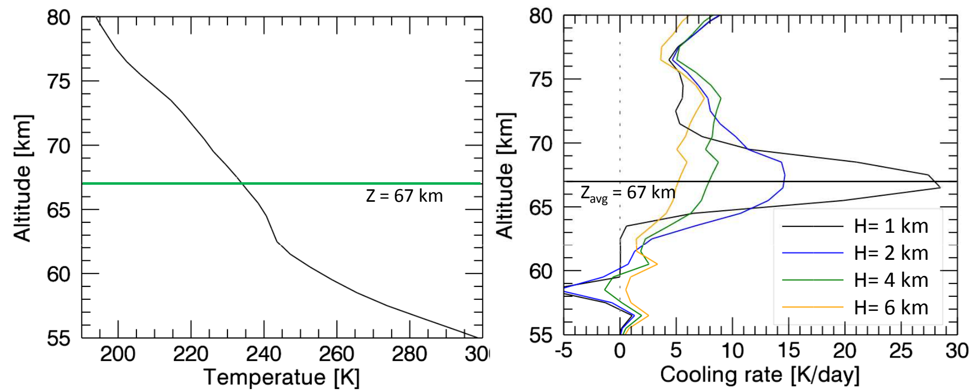
Polar region (H_{avg}= 1.7 km (fixed), Z_{avg} = 63 km)



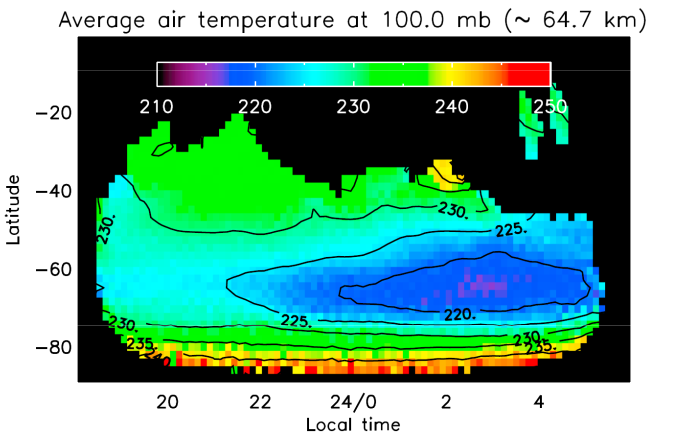
Sensitivity of thermal flux (3)

The effect of the aerosol scale height (H) on the cooling rate at the cloud tops

Low latitude region (H_{avg}= 4 km, Z_{avg} = 67 km(fixed))



Sensitivity of thermal flux (4)

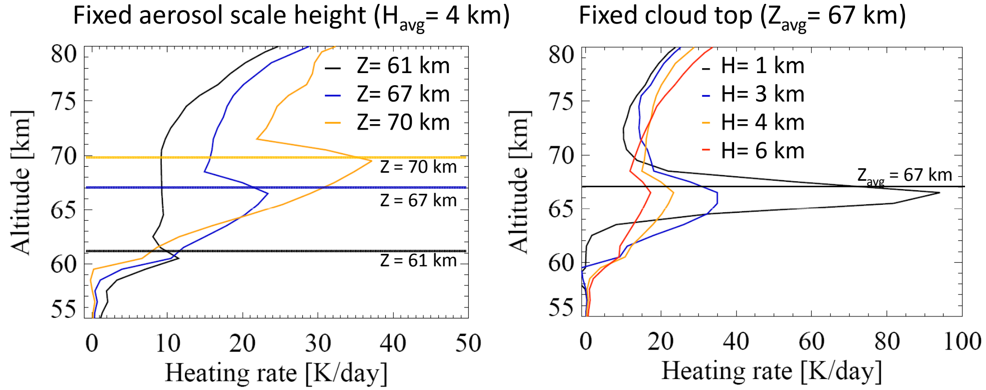


[Grassi et al., 2010] Night side, VIRITS

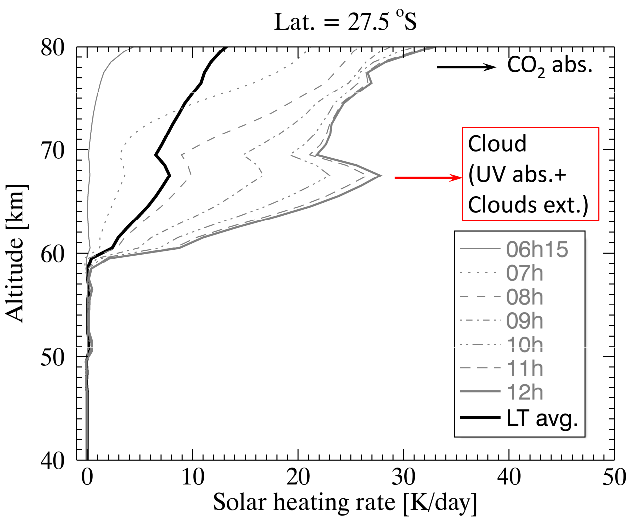
Sensitivity of solar heating rate

The effects of the changes in the cloud top structures on the solar heating rate

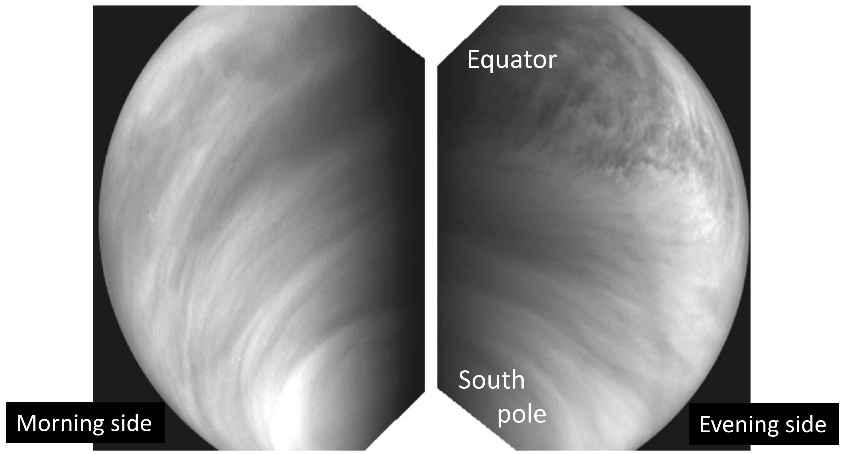
Low latitude region (Z_{avg}=67 km, H_{avg}= 4 km)



Local solar time dependence



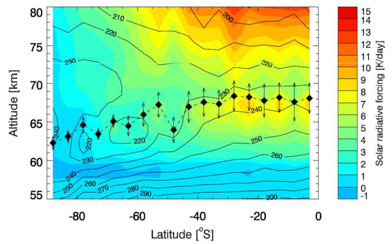
Local solar time dependence



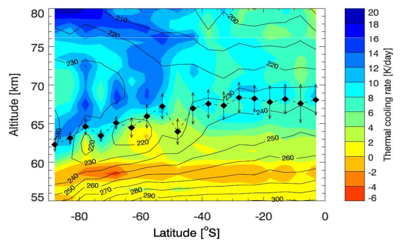
[Titov et al., 2012] VMC UV channel images

Meridional trends of radiative forcing

Solar heating rate (diurnal avg.)



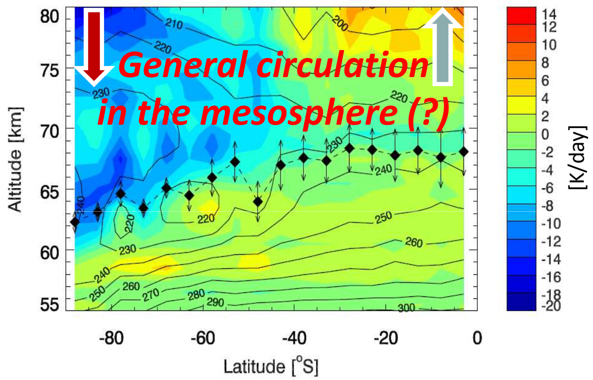
Thermal cooling rate



♦ Cloud top altitude ↕ Aerosol scale height

Net radiative forcing

(= Solar heating – thermal cooling)



Summary of results

- Cloud effects on thermal emission
  - Lower cloud top increases outgoing thermal flux (ΔF_{up}~50 W/m^2).
  - Small scale height (<1-2 km) makes a significant peak of the thermal cooling rate at the cloud tops (~15-30 K/day).
- Cloud effects on solar radiation
  - High cloud tops and small scale heights result in strong solar heating rates at the cloud tops.
  - At the sub-solar point, solar heating rates at the cloud tops can be enhanced up to ~40 K/day by increasing cloud top altitudes, and up to ~95 K/day by decreasing aerosol scale heights.
- Meridional trends of the net radiative forcing
  - Unbalance, which requires a Hadley-like circulation in the Venus mesosphere.