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Effect of clouds and temperatures on model radiances in the night time Venusian atmosphere near $4.3 \mu\text{m}$

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Abstract

Visual and Infrared Thermal Imaging Spectrometer (VIRTIS-M) observations of Venus in the 4–5 μm region allow to study the night time thermal structure of the planet's upper troposphere and lower mesosphere from 50 to 105 km [RS95, GR08]. However there are significant cloud layers in that altitude range whose spatial structure mixes with the thermal structure of the atmosphere. Our immediate purpose is to study the impact of factors such as temperature, and the size, composition and vertical distribution of aerosols, on the outgoing radiance at the top of the atmosphere. In the longer run, this will aid to investigate the thermal structure and cloud morphology in the Venus atmosphere by comparison with measurements obtained with the VIRTIS-M instrument. The 4–5 μm region of the spectrum has been notably less explored than the thermal windows occurring shortwards of 2.3 μm [ME96], which calls for a thorough assessment of the analysis methodology.

Radiances and Brightness Temperature

Our forward model utilises the HITRAN 2008 database and the DISORT solver for the Radiative Transfer Equation.

Fig. 1: Radiances (solid curves, right axis) and brightness temperature (dashed curves, left axis) for $T(z)$ profiles (same figure, right panels) appropriate to low, mid and high latitudes. In all cases, the cloud-top altitude is 70 km.

Multiple-scattering and **non-scattering (emission and absorption only)** solutions are in **black** and **red**, respectively.

Note **A**: T_B increases moderately towards the short wavelengths for a monotonic $T(z)$; **B**: the impact of thermal inversion at mid and high latitudes on the band shape at $4.3 \mu\text{m}$; **C**: the band depth at $4.8 \mu\text{m}$; **D_1** and **D_2** : the inflections in the spectrum (**circles** in the figure) caused by atmospheric thermal inversion.

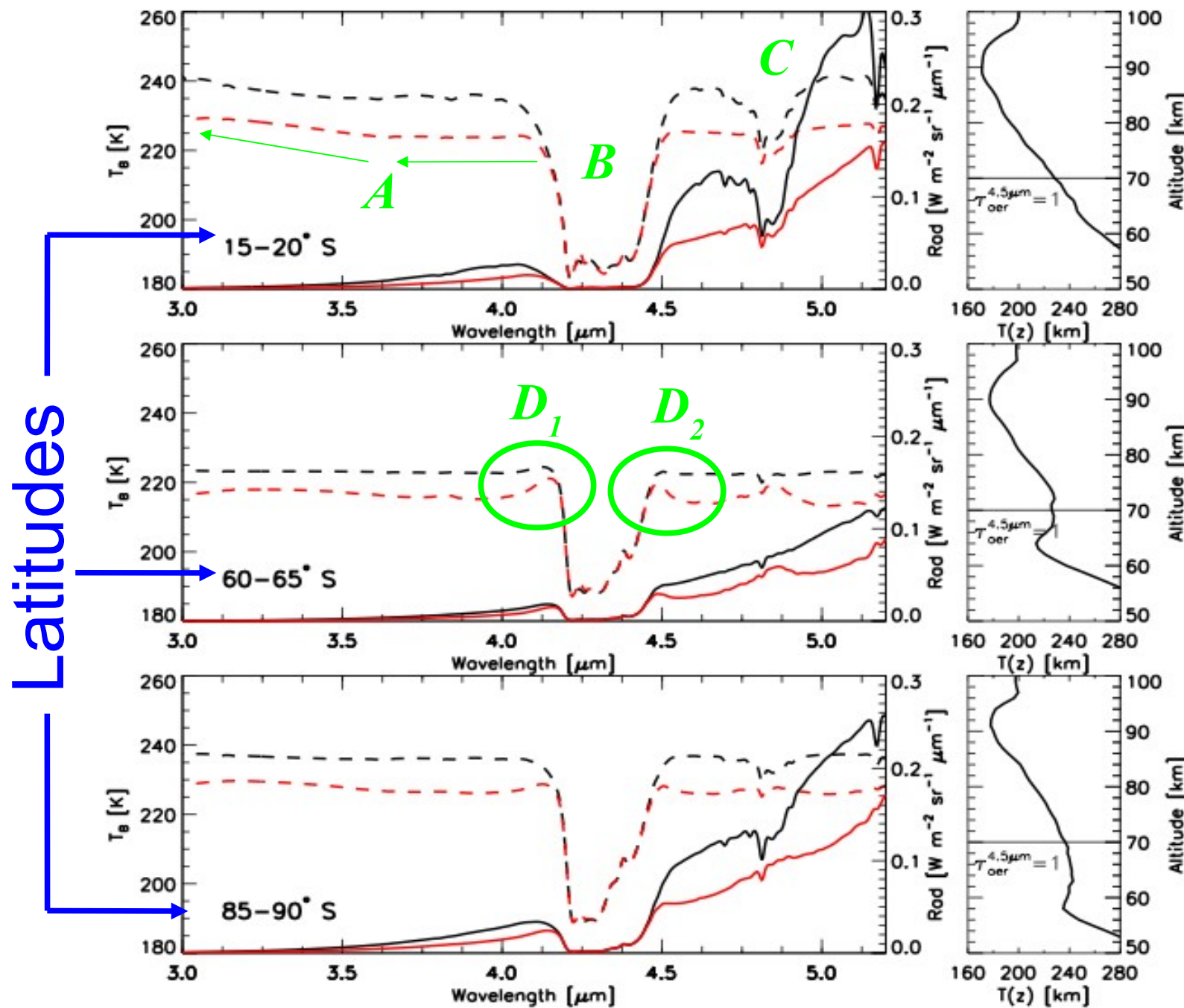
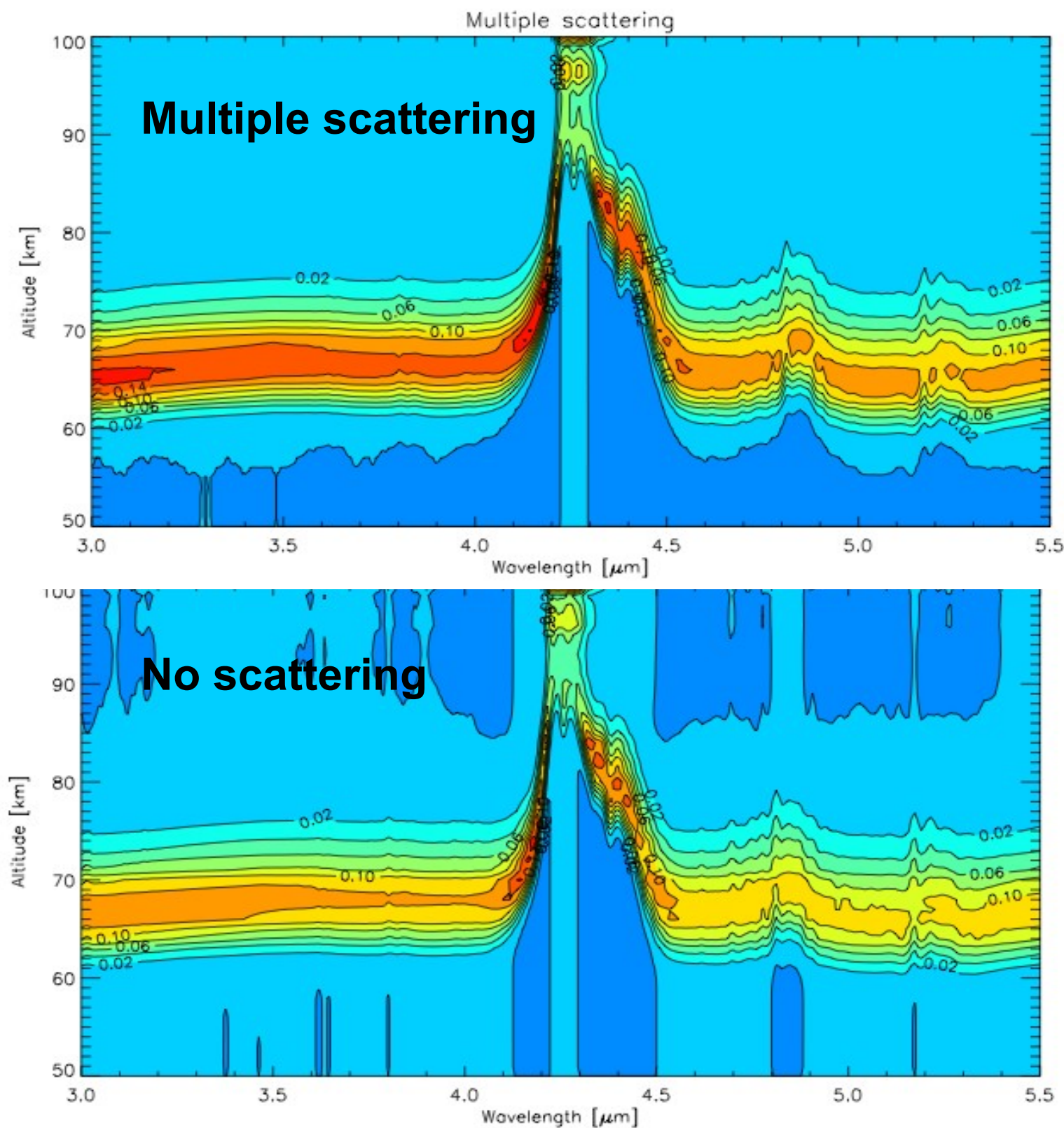


Figure 1

Weighting Function $K = \partial T_B / \partial T_L$



The weighting matrix \mathbf{K} contains the derivatives of the brightness temperature (T_B) with respect to atmospheric temperatures (T_L).

\mathbf{K} gives a measure of the altitudes probed at specific wavelengths.

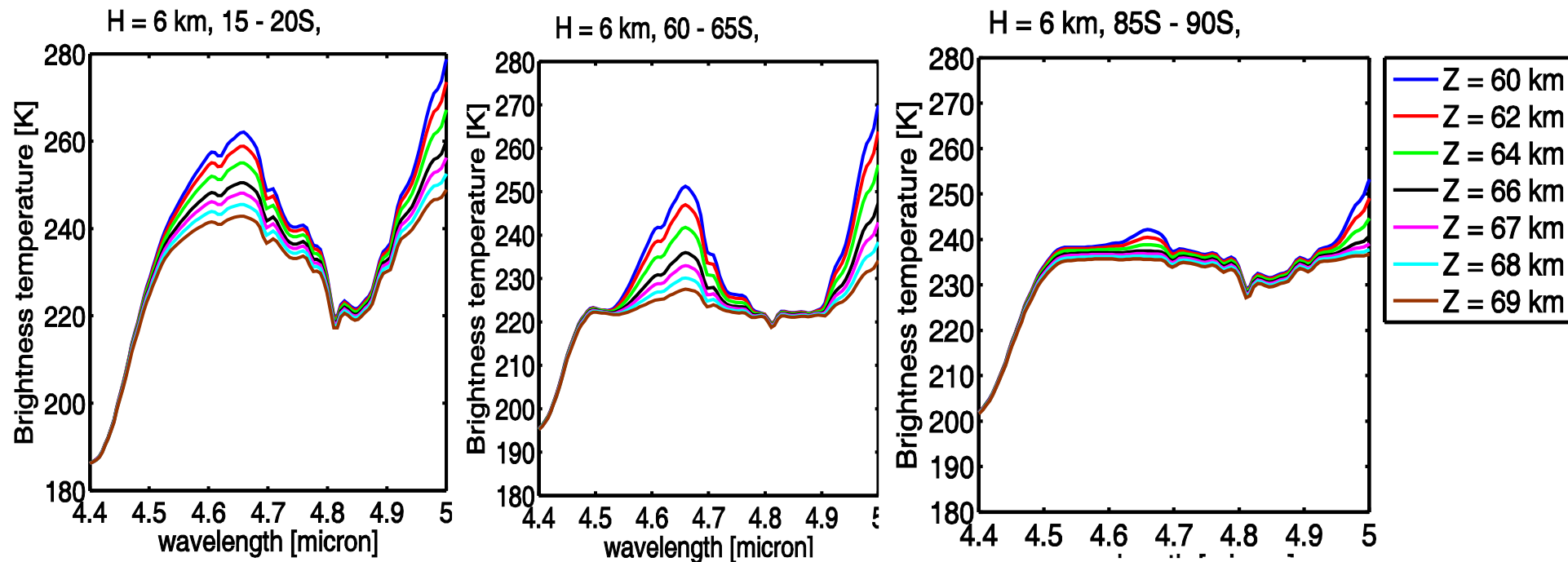
Fig. 2: Weighting functions for high latitudes. The altitudes probed range from 100 km at the core of the 4.3- μm band of CO_2 down to ~ 2 scale heights below the $\tau_{\text{nadir}} = 1$ level in the continuum at the shorter and longer wavelengths.

Multiple-scattering (top figure) and non-scattering (bottom figure) \mathbf{K} s differ in magnitude and in the location of their maxima.

Figure 2. Iso-contours in Kelvin/Kelvin for $\partial T_B / \partial T_L$

Brightness temperature as a function $T_B(Z,H)$

H fixed; Z variable



Z fixed; H variable

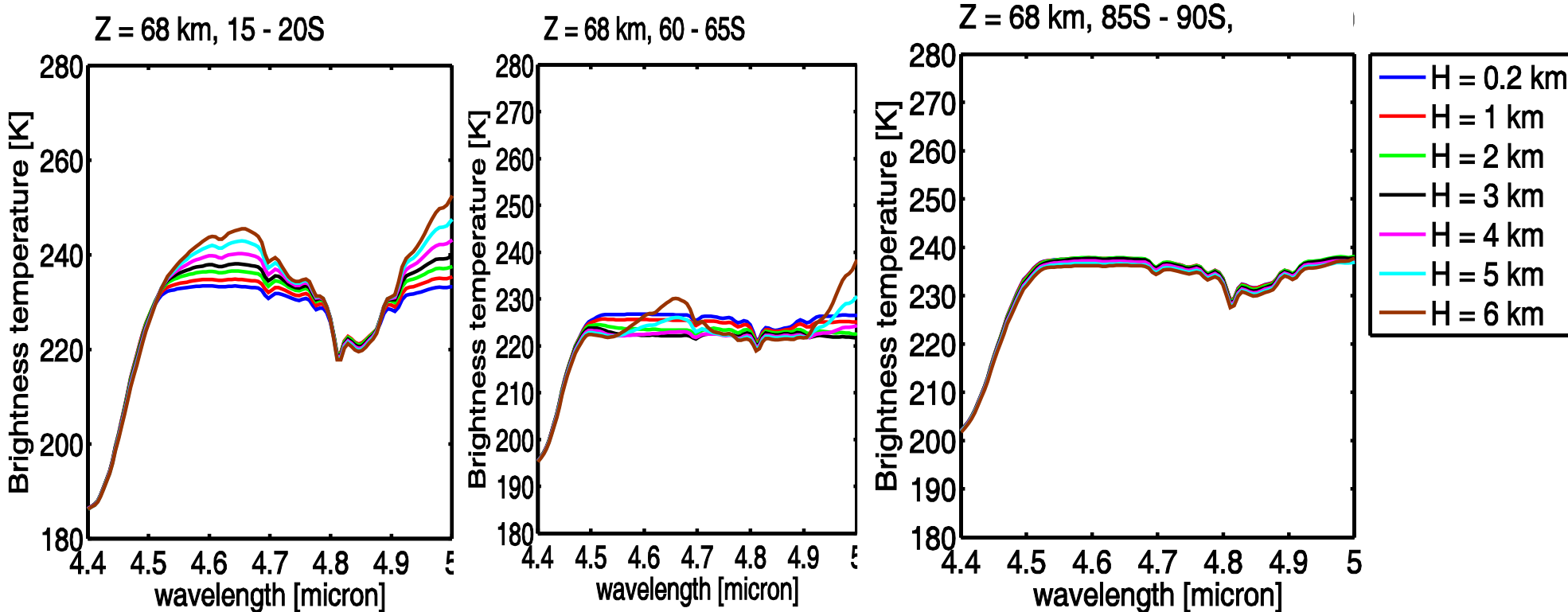


Fig. 3. The cloud top altitude Z and aerosol scale height H have a notable impact on the spectrum. Same $T(z)$ profiles as earlier. Emission angle of 25° . Calculations include multiple scattering.

The 'bump' at $4.65 \mu\text{m}$ means low CO_2 opacity. It is more apparent with thin clouds.

Significant differences $\delta T_B \sim 20 \text{ K}$ occur at 4.65 & $5.1 \mu\text{m}$ for different Z altitudes.

Figure 3.



The CO signature at 4.6 μm

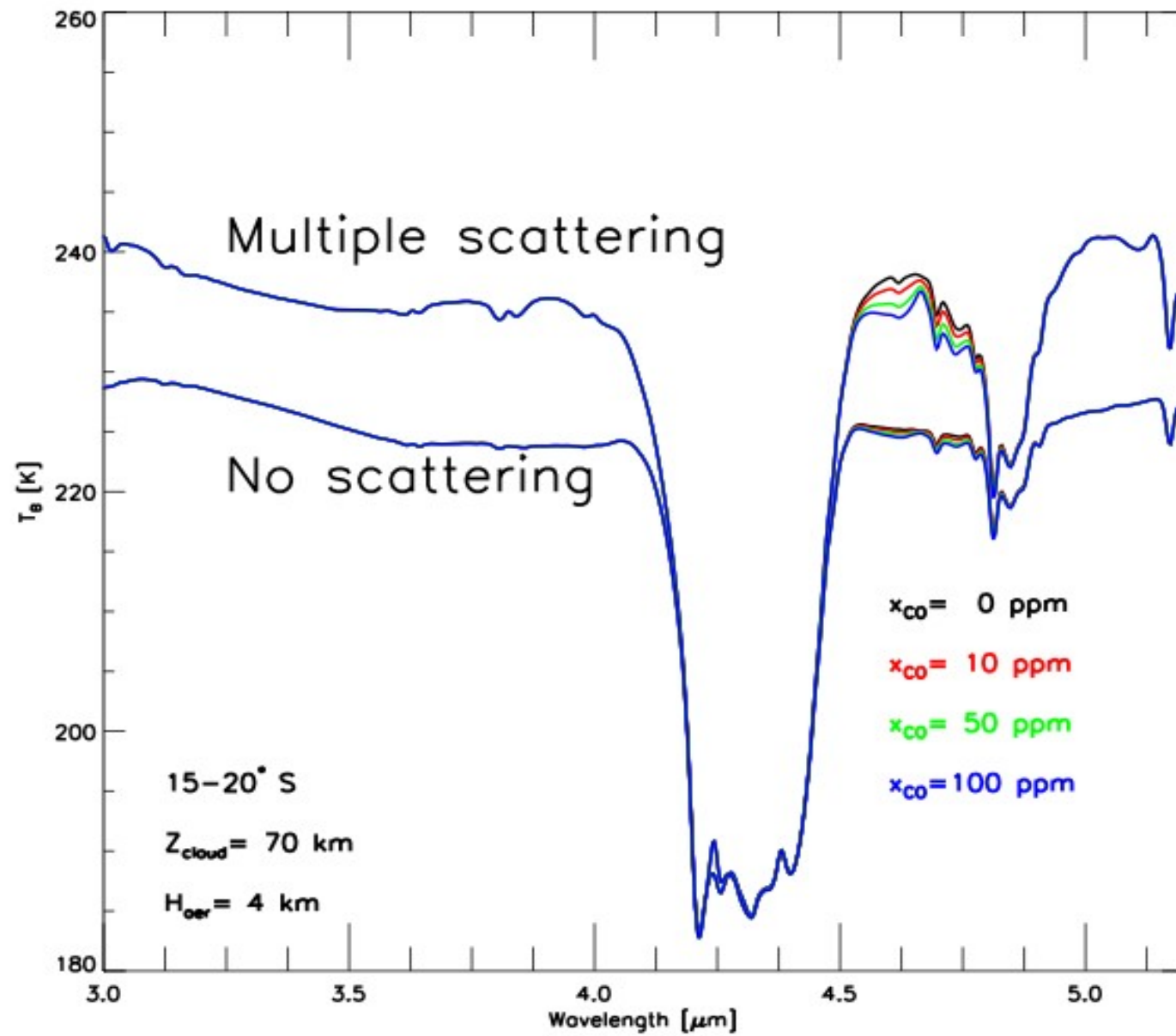


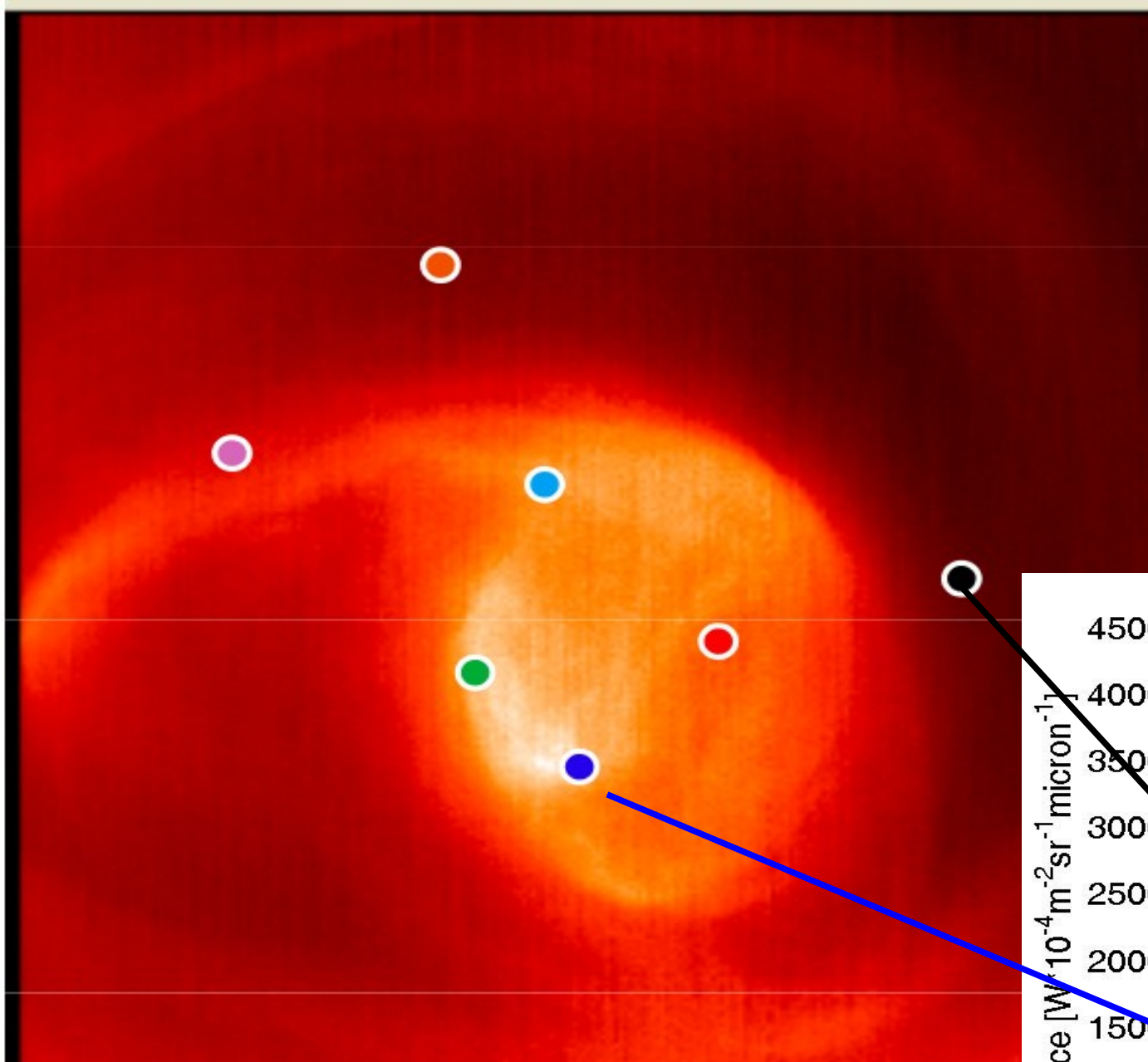
Figure 4.

Carbon monoxide exhibits a strong feature at 4.6 μm that enables the retrieval of the mesospheric CO mixing ratio [IR08].

Fig. 4: The effect of CO on the spectrum extends from 4.5 to 4.75 μm . Forming within the optically thick clouds, multiple scattering enhances the CO signature.

The CO feature partially blends with the CO_2 window at 4.65 μm .

VIRTIS observations



The southern polar vortex exhibits complex dynamical structures. *Fig. 5* shows VIRTIS spectra (solid curves) of bright and dark regions retrieved from images of the southern pole at 5.1 μm .

The synthetic spectra (dashed curves) explore the sensitivity of the outgoing radiance to the atmosphere's temperature profile and the aerosol's H and Z parameters.

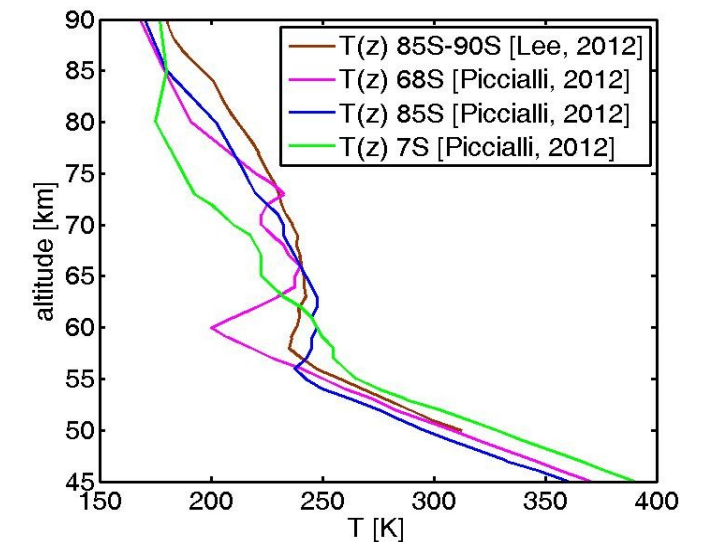
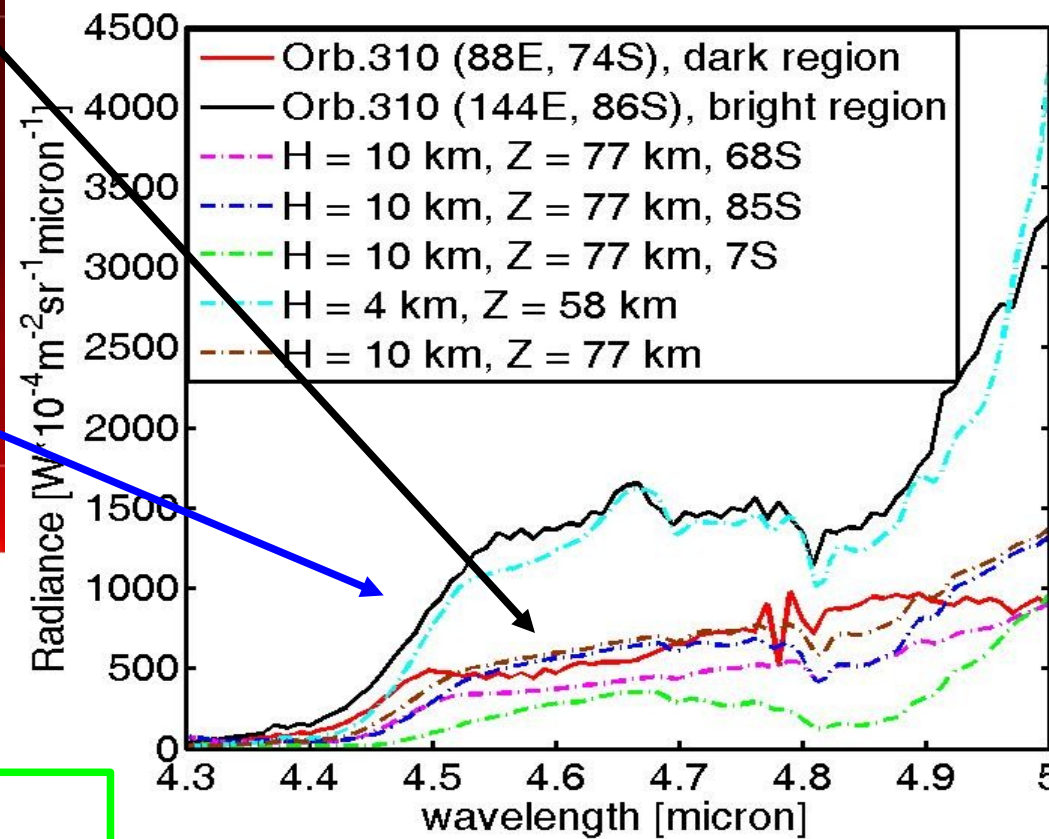


Figure 5.

Conclusions and outlook

Our model produces realistic thermal radiances in the 3–5 μm interval. Multiple scattering within the clouds is a key factor in the interpretation of observed VIRTIS spectra. Various strategies are being considered to implement the model for the radiance and the **K** matrix into a retrieval algorithm [RO00]. This will ultimately give us the capacity to retrieve temperature profiles and some insight into the cloud structure from VIRTIS-M spectra. Simultaneous determinations of the temperature profile and the velocity field are essential to infer the potential vorticity function.

References

- [GR08] Grassi et al. (2008), JGR, 113; E00B09
- [IR08] Irwin et al. (2007), JGR, 113; E00B01
- [ME96] Meadows & Crisp (1996), JGR, 101; 4595
- [RO00] Rodgers (2000), Inverse methods for atmo. sounding, World Scientific
- [RS95] Roos-Serote et al. (1995), Icarus, 114; 300