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Analyses of spectroscopic and atmospheric parameter influences on radiative heating and cooling rates in the middle and lower atmosphere of Venus

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Abstract

Radiative fluxes and temperature change rates in the middle and lower atmosphere of Venus (0-100 km) are calculated over the broad spectral range 0.125-1000 µm applying a radiative transfer model. Responses of these quantities to both spectroscopic model parameter changes and atmospheric parameter variations are examined in great detail. A new model for the unknown UV absorber is proposed. The calculated radiative cooling/heating rates are very reliable at altitudes below 95/85 km at fixed atmospheric conditions with maximum uncertainties of about 0.25 K/day. Heating uncertainties may reach 3-5 K/day at 100 km. Cooling rates strongly respond to variations of atmospheric thermal structure, while heating rates are less sensitive. Except for episodic SO_2 boosts, the influence of mesospheric minor gas abundance variations is rather small, but variations of cloud mode parameters may significantly alter radiative temperature change rates up to 50% in Venus' lower mesosphere and upper troposphere.

1. Radiative transfer model

A sophisticated radiative transfer model (RTM) is applied to calculate radiance and flux spectra in dependence on spectroscopic and atmospheric parameters. The RTM considers absorption, emission, and multiple scattering by gaseous and particulate constituents [1, 4] at infrared (0.7-1000 µm), visible (0.4-0.7 µm), and ultraviolet (0.1-0.4 µm) wavelengths. Look-up tables of quasi-monochromatic absorption cross-sections of gaseous constituents in the infrared and visible spectral ranges are calculated on the basis of a line-by-line procedure for a variety of temperature and pressure values being representative for Venus' atmosphere at altitude levels between the surface and 140 km. These tables are generated for different sets of spectroscopic parameters including very fine spectral sampling steps down to 0.0001 cm^{-1}, different spectral line catalogues, and variations of line profiles with respect to line cut and sub-Lorentz structure. Laboratory data on UV absorption cross-sections of CO_2, H_2O, OCS, and HCl are considered. Mie scattering theory is applied to derive wavelength-dependent micro-physical parameters of Venus' cloud modes.

Apart from spectroscopic studies, present investigations are devoted to detailed analyses of individual atmospheric parameter influences. This ensures a better understanding of possible responses of calculated output quantities with respect to the atmospheric energy balance. Thus, initial atmospheric standard models are selected here rather than utilizing parameter fields that have been recently retrieved from VIRTIS-M-IR data [1-3]. Both initial and retrieved features encompass altitude profiles of temperature, minor gas abundances, and cloud mode particle densities as well as cloud mode chemical composition.

Consideration of an additional atmospheric absorber is required to fit observations of Venus' spectral Bond albedo shortward of 0.8 µm down to 0.32 µm. A new model for the unknown UV absorber being located at altitudes between 57 and 70 km is developed [4]. It is not directly linked to cloud particle modes 1 or 2, and thus, permits an investigation of the absorbers' radiative effects regardless of its chemical composition.

2. Results

On global average, half of the solar flux received at the top of atmosphere (TOA, 667 Wm^{-2}) is absorbed by CO_2 and cloud mode 1 and 2 particles at altitudes above 74 km. The sum of direct and diffuse downward solar fluxes attains the 50% level of TOA flux at 55 km. About 5% of solar TOA flux reaches the surface. The globally averaged Bond albedo of Venus results as 0.763 in accordance with previous findings. The global average of solar net flux deposited on the planet is 158.1 Wm^{-2}, and the corresponding outgoing thermal net flux is 159.7 Wm^{-2} for the used initial atmospheric standard models. Exact TOA global radiative equilibrium is achieved by moderate adjustments of cloud mode and UV absorber abundances.

The use of absorption cross-section databases at a spectral point distance of 0.01 cm^{-1} is shown to be sufficiently accurate over the entire spectral range. Based on an attentive separation of ranges that are dominated by strong or weak gaseous absorption bands, an optimum point distance grid is defined that considerably accelerates the time expensive monochromatic flux calculations without introducing significant accuracy losses (< 0.1 K/day below 85 km, <1.5 K/day at 100 km). Largest uncertainties of temperature change rates may result when different spectral line catalogues are used. At 100 km, they may reach 3.0 (0.3) K/day for heating (cooling), while the deviations with respect to net heating would partly compensate between 70 and 90 km. The use of different sub-Lorentz profiles and line cut conditions does not significantly alter cooling and heating results above 50 km, but for accurate thermal flux and cooling rate calculations in the region of the cloud base (48 km) the use of a line cut condition of at least 250 cm^{-1} is recommended. It is concluded that the calculated cooling and heating rates at fixed atmospheric conditions are very reliable at altitudes below 85 km with maximum uncertainties of about 0.25 K/day. Cooling uncertainties do not increase between 85 and 95 km, but heating uncertainties may reach 3-5 K/day at 100 km. The use of equivalent Planck radiation as solar insolation source should be avoided, since it seriously overestimates solar heating shortward of 0.4 µm.

There is a very strong response of cooling rates to variations of atmospheric thermal structure, while heating rates are less sensitive. Except for observed episodic strong SO_2 abundance boosts, the overall response of the radiative energy balance on minor gas abundance variations is rather small in the mesosphere, but such variations (especially H_2O and SO_2) may become more important near the cloud base. The influence of mode 1 cloud particles is found to be comparatively small (<0.12 K/day at 70 km when halving the column abundance). Changes of mode 2, 2’, and 3 parameters (cloud top and base altitudes, column abundances, upper scale heights) may significantly alter radiative temperature change rates up to 50% in Venus’ lower mesosphere and upper troposphere. The new nominal model for the unknown UV absorber provides 50% more heating at 68 km compared with a neglect of this opacity source.

Preliminary results on net radiative forcing in the atmosphere of Venus as functions of latitude and altitude (neglecting cloud parameter changes with latitude at this stage) indicate a broad net cooling region between 70 and 80 km with a strong increase of cooling toward the poles. A net rate gradient is also observed at 65 km where heating prevails at low latitudes. At altitudes above 80 km, net heating dominates the low and mid latitudes, while net cooling prevails at high latitudes leading to a dominant global average net heating. The observed thermal structure in the Venus mesosphere can only be maintained by dynamical processes, therefore.

3. Outlook

Upcoming studies will consider improved models of middle and lower atmospheric parameters of Venus that have been retrieved from VIRTIS-M-IR data [1-3] with respect to latitude and local time dependent thermal structure and meridional variations of cloud features and minor gas distributions. Based on the present results, variations of cloud mode abundances and cloud top and base altitudes are expected to considerably alter the results on atmospheric radiative energy balance of Venus.

References

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