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Six-year operation of the Venus Monitoring Camera (Venus Express): spatial and temporal variations of the properties of particles in upper clouds of Venus from the phase dependence of the near-IR brightness

O. S. Shalygina[1,2], E. V. Petrova[3] and W. J. Markiewicz[2]
[1]Technische Universität Braunschweig, Institute for Geophysics and Extraterrestrial Physics (IGEP), Braunschweig, Germany (o.shalygina@tu-braunschweig.de), [2]Max-Planck-Institut für Sonnensystemforschung, Göttingen, Germany, [3]Space Research Institute, Russian Academy of Sciences, Moscow, Russia

1. The VMC data

Since May, 2006, the Venus Monitoring Camera (VMC) [1] has been imaging Venus in four narrow spectral channels centered at the wavelengths of 0.365 µm (UV), 0.513 µm (VIS), 0.965 µm (NIR1), and 1.010 µm (NIR2). It took around 300 000 images in four channels covering almost all the latitudes, including night and day sides.

We analyze the whole set of the VMC data processed to October, 2012, *i.e.* the data from orbits 60 – 2 352 obtained in the phase angle range $\alpha = 0° – 140°$. The data for the fixed incidence angles Z_0 and latitudes ((30°N ... 70°S) ± 2° with step 10°) were selected and distributed among the the 1°-intervals of the emission angle Z and the local solar time (LST) interval 6 – 18 h. For every Z, the 1°-binning by a phase angle was done, and the mean value and the standard deviation in the bins were calculated. The latter turned out to be very small, usually less than 0.01%. Each value of brightness obtained in such a way corresponds to a specific combination of photometric angles Z_0, Z, α, and the modeling was performed for each of them.

2. Modeling the phase dependence of brightness

To estimate the properties of cloud particles, we modeled the phase dependence of brightness retrieved from the dayside images obtained in NIR1 VMC channel. The choice of the NIR wavelength decreases the number of free parameters, since there is no NIR absorption in the Venus clouds. The radiative transfer calculations were performed for the plane-parallel atmospheric layers, and the single scattering phase functions were found with the Mie theory. The standard gamma size distribution of cloud particles was assumed; the effective radius R_{eff} was varied from 0.9 to 1.4 µm (the 1-µm mode), the effective variance ν_{eff} was mainly fixed at 0.07. The real refractive index m_r of the 1-µm mode was varied from 1.44 (typical of H_2SO_4) to 1.49.

Since submicron particles are known to be ubiquitous in the Venus clouds and hazes, their presence was also taken into account. Their properties were assumed as $R_{\mathrm{eff}} = 0.23$ µm, $\nu_{\mathrm{eff}} = 0.18$, and m_r corresponding to H_2SO_4. For submicron particles in the clouds the sulfur composition was considered as well. For the haze submicron particles, the larger radii, up to 0.9 µm, were also tested. The percentage of submicron particles N_{smb} in the main cloud layer, and the optical depth of the overcloud haze τ_{haze} were varied [2, 3].

The total number of models was 1 024 (see the on-line supplementary material of [3]). Most of them were calculated only for one value of the optical depth of the clouds $\tau = 30$, since the sensitivity of the phase profiles to this parameter was found to be relatively small. The best fits were chosen automatically by the least square method.

The examples of the best fits are shown in fig. 1. They illustrate the tendency in the behavior of submicron particles: the submicron particles are detected in the haze and/or clouds mostly in the morning. Of course, this fact does not mean that there is no submicron mode in the afternoon and in the evening in the Venus clouds; this only means that its amount diminishes, and the NIR1 channel cannot distinguish it, because its sensitivity to submicron particles is low (as compared to UV).

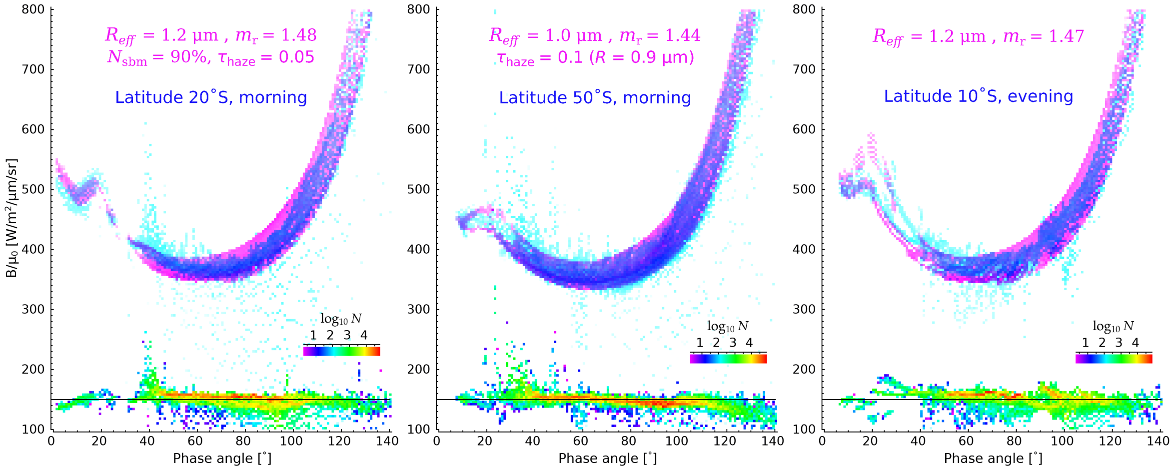

Figure 1: Examples of the best model fitting for the data obtained in the morning (LST = 6 − 10 h; two left panels) and in the evening (LST = 16 − 18 h; right panel) at Z_0 = 70° and different latitudes. Superposition of cyan (observation) and magenta (model) colors produces dark blue color. The parameters of the models are specified in the plots. Every point in the observational profile (cyan color) corresponds to the specific combination photometric angles Z_0, Z, and α. The model (magenta color) was calculated for each of these points according to its photometric conditions. Deviations of the model from the observations ($\frac{1}{2}(Data - Model) + 150\,\mathrm{W\,m^{-2}\,sr^{-1}\,\mu m^{-1}}$) are shown at the bottom of each plot, where N is the number of observations at the given photometric conditions (see color scale). Orbits 60 − 2 352.

3. Summary

The following temporal and spatial variations of the sizes and refractive index of cloud particles were found from the phase dependencies of brightness measured by the NIR1 VMC channel:

- The presence of particles with $R_{\mathrm{eff}} \approx 0.9\,\mu\mathrm{m}$ in the clouds and/or the overcloud haze is pretty confident at latitudes 40°S − 60°S.
- In general, the particles at low latitudes are somewhat larger than in the regions closer to the southern pole ($R_{\mathrm{eff}} = 1.2 - 1.4\,\mu\mathrm{m}$ versus $0.9 - 1.05\,\mu\mathrm{m}$).
- The refractive index of cloud particles at latitudes 40°S − 60°S is usually smaller than that closer to the equator ($m_r = 1.44 - 1.45$ versus 1.45 − 1.47 with sporadic spikes up to 1.49).
- No clear tendency in the temporal behavior of the refractive index and sizes of cloud particles during the local day is observed. The exception is the presence of small submicron particles ($R_{\mathrm{eff}} = 0.23\,\mu\mathrm{m}$) detected mostly in the morning within the clouds and/or in the haze above the clouds.

The procedure and results of this analysis are described in detail in [3].

References

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