VIRTIS/VEX Surface and Near Surface Observations of Venus’ Northern Hemisphere

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Abstract
Nightside emission measurements by the Visible and Infrared Thermal Imaging Spectrometer (VIRTIS) on the Venus Express (VEX) spacecraft were used to estimate the potential for the extraction of Venus surface information. A suite of orbits over the northern hemisphere was selected for footprints that cover surface elevations from -2000 m to 6000 m. First, a preliminary radiative transfer calculation technique was applied to simulate Venus nightside radiation. The variability of the emission window radiances with respect to cloud opacity and surface elevation was modeled and is discussed in direct comparison to the measurements. An initial extraction of topographic information was performed and compared with Magellan radar data.

Introduction
VIRTIS, the Visible and Infrared Thermal Imaging Spectrometer, see [3], [4], is the first instrument operating in an orbit around Venus with the capability to systematically investigate the nightside emission of the planet in the near-infrared atmospheric windows. These emissions show a high variability. This is mainly a consequence of variations in cloud opacity and surface elevation, but differences can also be due to changes in atmospheric temperature and absorber contents, as well as variations of surface emissivity. While the largest amount of information about the surface and deep atmosphere-surface interaction is obtained from the spectral windows located between 1.00 and 1.35 µm, the windows at 1.74 and 2.3 µm provide information about atmospheric temperature and composition below the main cloud deck. We focus our work on the development of a quantitative approach to extract surface information from VIRTIS measurements. A quantitative evaluation of the measurements requires detailed radiative transfer simulations that include appropriate spectral line databases, deep atmosphere continuum absorption features, and multiple scattering effects due to the dense cloud deck.

Data Selection
The data were selected from VIRTIS-M-IR nightside measurements over the northern hemisphere of Venus. To ensure minimal atmospheric influence on the measured signatures, only pushbroom observations with small observation angles close to nadir were selected. For a thorough description of the data selection, as well as the data correction and preparation procedure, see [1].

Radiative transfer simulations
A preliminary radiative transfer model is used to simulate VIRTIS spectra. It includes absorption, emission, and multiple scattering by atmospheric gaseous and particulate constituents in planetary atmospheres. The model is based on the approach of Haus and Titov [2] and is applied to Venus as described in [1]. Look-up tables of quasi-monochromatic absorption cross-sections of gaseous constituents are calculated on the basis of a line-by-line procedure. Empirical continuum absorption coefficients are determined from a Venus “reference spectrum” as correction values that are applied to fit the measured reference spectrum. Mie scattering theory is applied to derive the microphysical parameters of the H2SO4 clouds. Multiple scattering in the dense cloudy atmosphere is considered using a Successive Order procedure. The synthetic quasi-monochromatic intensity spectra at the model top level of the atmosphere are convolved with the VIRTIS spectral response function.

Fig. 1 Comparison of VIRTIS measurement (solid line) and radiative transfer simulation (dashed line). The surface elevation is -1.0 km. The spectral range covers the atmospheric windows located at 1.02, 1.10, 1.18, 1.28, 1.31, 1.74, and 2.3 µm.

Results
At a constant surface elevation the radiance dependence on cloud opacity is simulated. Below 1.5 µm conservative scattering is the dominating cloud feature. In this case, the clouds do not contribute to thermal emission, but act as a strong attenuator of radiation that originates from below the cloud deck and emerges into space. Little spectral dependence of upwelling radiation is added by the clouds below 1.5 µm. Therefore, it is possible to use radiance ratios in the 1.0-1.35 µm window range to eliminate cloud interferences. According to the measurements and the simulations, the radiance ratios of the 1.10, 1.18 and 1.31 µm windows with respect to the 1.02 µm window are independent from the cloud influence, whereas for...
the 1.74 and 2.3 µm windows the ratios decrease with increasing cloud opacity, see [1].

The surface windows at 1.02, 1.10 and 1.18 µm exhibit a clear dependence of transmitted radiation on topographical features and, thus, on surface thermal emission. The radiance decreases with increasing elevation, since high elevation surfaces are cooler and emit less thermal radiation than surfaces at lower elevations. An elevation change of 12 km results in a surface temperature change of 100 K. The surface elevation (temperature) does not influence the 1.31, 1.74, and 2.3 µm window radiances. Since the radiance at 1.02 µm is the most sensitive against elevation changes, the ratios are calculated using this window. Figure 2 shows a very good correlation between measurements and simulation.

![Figure 2](image)

Fig. 2 Comparison of measured (points) and simulated (lines) radiance ratios as a function of surface elevation.

This correlation between the ratios of the surface window radiances and the topography can be used to extract surface information for Venus. Higher elevations result in lower radiances in the windows at 1.02 µm and 1.18 µm (Figure 3 a). But it is difficult or even impossible to verify this trend for smaller topographical variations. The radiance ratios, however, reflect even small variations in topography, as is shown in Figure 3 b.

![Figure 3](image)

Fig. 3 (a) Mean radiances at 1.10, 1.18, and 2.30 µm and (b) the radiance ratio 1.18 / 1.02 compared with Magellan topography as a function of latitude for VEX orbit 113, in the vicinity of Beta Regio.

In general, the VIRTIS and Magellan topographies correlate (see Fig. 4), but differences occur in localized areas. These data might hint at local variations of the deep atmospheric temperature profiles and composition, or point to a difference in surface materials.

![Figure 4](image)

Fig. 4 a) Magellan topography near Beta Regio, in the latitudinal measurement swaths smoothed to the predicted 100 km surface resolution limit [5] comparable with the VIRTIS data.

b) Topography extracted from VIRTIS data. The radiance ratio for each pixel is mapped to the elevation according to the linear fit of 1.18/1.02 in Fig. 2, and depicted in the same color coding as the Magellan elevation. The black edging is used to stress the pixel footprints.

Conclusions

The VIRTIS-M nightside IR data are a valuable basis for systematic and continuous surface and deep atmosphere studies of Venus. The observed high variability of measured signatures is mainly due to spatial variations of cloud optical depth and surface elevation. The VIRTIS measurements and radiative transfer simulations show correlation between the radiance ratios in the emission windows between 1.0 and 1.35 µm and the surface elevation. This allows the determination of the surface topography. Differences from the Magellan topography have been observed in localized areas. In the first approximation, the radiance ratios are a function of surface temperature. Future studies will focus on a separation of atmospheric and surface radiance contributions in the measured VIRTIS signals and a possible deconvolution of surface temperature and emissivity. These objectives can only be achieved through further development of the radiative transfer simulations in order to eliminate the masking of the Venus nightside windows by far wing and pressure-induced absorptions of the deep atmosphere constituents.

References