Retrieval of surface properties in the NIR nightside windows of Venus

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Introduction

**Scope**

- Obtain global scale deep atmosphere and surface information
- Use of Venus’ spectra in the NIR nightside transparency windows
- Retrieve parameters from single-spectrum and multi-spectrum regularization
- Discussion of surface emissivity retrievals

_Venus Express_
Introduction

Background

• Global view of surface topography by radar observations (Magellan)
• Global view of surface radar reflection and scattering (limited information about material and texture)
• Global surface composition properties poorly known
• In situ data from Venera and Vega landers (local/regional information)
**Introduction**

**Geological surface units**

- **Fortunian** (*Tesserae*)
- **Sigrunian** (*tectonic belt/rift systems*)
- **Lavinian** (*basaltic plains, ridge belts*)
- **Rusalkian** (*wrinkle ridges, shield plains*)

**Old area**
- Max. about 1 Gy

**Young area**
- Middle age: 600-800 Mio. y

**Alilan** (*lobate and smooth plains, coronae*)

**Aurelian** (*eolian impact sediments*)

Basilevsky and Head, 2008
Images: Magellan

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Chart 4
**Surface material**

- **Basaltic plains- Tholeiide to basic basalt?** (Morphology, basaltic volcanism, Venera-Vega landers composition: Basilevsky and Head, 2003; Kuchinas et al., 1996; Ivanov et al., 1996; Basilevsky et al., 1995; Nikolaeva, 1989; Barsukov, 1992; Surov, 1997; Fegley et al., 1997; Klingelhöfer and Fegeley, 2000)
- **Steep-sided domes – different viscosity?** (Basilevsky and Head, 2009)
- **Tessera – more felsic?** (above standing material and bright radar reflectance above 5 km altitude: Pettengil et al., 1997 – key to the older surface forming processes)
- **Weathering: Carbonate vs pyrite model?** (Fegely et al., 1997; Pettengill et al. 1983)

**More global chemical-mineralogical and physical-textural analyses required!!!**
Introduction

Atmosphere and surface studies

• Radar studies provide only limited results in respect to the global surface composition
• Studies at optical wavelengths require sophisticated methods to extract information about the lower atmosphere and surface of Venus on global scales
• New measurements of VIRTIS/VEX in the NIR nightside windows created a new data base for such studies
**Spectral measurements**

- **Systematic atmospheric and surface mapping by VIRTIS/VEX**
- **Data base: VIRTIS-M-IR subsystem**
  - 1.0 – 5.1 µm
  - 2D imaging + spectral + temporal dimension
- **Spectral observation in the NIR nightside transparency windows permits atmospheric sounding from the ground to the base of thermosphere**
**VITIS-M-IR spectral data (dayside)**

![Graph showing the spectral data of VITIS-M-IR on the dayside of Venus, with annotations for cloud scale height and top altitude, and CO$_2$ NLTE emission.](image-url)
VITIS-M-IR spectral data (nightside)

Cloud scale height and Top altitude

CO₂ NLTE emission

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Chart 7
VITIS-M-IR spectral data (nightside, troposphere)

- Cloud scale height and Top altitude
- H₂O, HCl
- O₂ airglow
- H₂O, CO, COS, SO₂
- CO₂ NLTE emission

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Chart 7
VITIS-M-IR spectral data (nightside, +mesosphere)

Chart 7

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Cloud scale height and Top altitude

Radiance [W / (m² sr μm)]

Wavelength [μm]

H₂O, HCl

H₂O, CO, COS, SO₂

CO₂ NLTE emission

O₂ airglow

T(z)

Lower cloud

Upper cloud

Dayside OR137 (ET 0.02)

Nightside OR150 (ET 3.30)

Nightside OR151 (ET 0.36)

Nightside OR088 (ET 1.00)
Methods – Radiative Transfer Model (RTM)

Multi-Window Retrieval Technique (MWT)

Elements of RTM-MWT

- **RTM** simulates observed radiances in dependence of atmospheric and surface parameters
- **RTM** key elements are absorption, emission and multiple scattering by gaseous and particulate constituents
- **MWT** makes simultaneous use of information from different atmospheric windows of an individual spectrum
- **MWT** provides an iterative optimization of atmospheric and surface parameters until the simulated spectrum well fits the measurement for all utilized windows
**Comparison of VIRTIS-M-IR data and fitted simulation**

Mathematically an ill-posed problem remains, since different state vectors can parameterize the same spectrum equally well!
Methods – Multi-Spectrum retrieval Technique

Multi-spectrum retrieval Technique (MST)

• **Regularization of retrieval by incorporation of available a priori mean values and standard derivations of the parameters to be retrieved**

• **Incorporation of physically reasonable spatial-temporal a priori information on atmospheric parameters**

  Context of adjacent measurements is considered: Each spectrum can be related to its adjacent measurements (not only single measurements are analyzed)!!!

• **Determination of common parameters**

  Considerable enhancement of reliability of retrieved emissivity!

Kappel et al., 2012
Multi-spectrum retrieval Technique (MST)

- **Input:** Standard spectrum to analyze
- **Jacobians** – derivatives of simulations for perturbations
- **Total cloud abundance from 1.31 µm window**
- **Modal abundances from 1.30-2.30 µm**
- **Cloud mode altitude profiles from Haus et al., 2012 – in preparation**
- **Assumptions on deep atmosphere temperature variations**

*Kappel et al., 2012*
Multi-spectrum retrieval Technique (MST)

<table>
<thead>
<tr>
<th>Neglected parameter</th>
<th>Assumed perturb.</th>
<th>Impact</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cloud mode 1 abundance</td>
<td>50%</td>
<td>21%</td>
<td>wider spect. range?</td>
</tr>
<tr>
<td>Cloud 1 &amp; 2 bottom or top</td>
<td>1 km</td>
<td>≤ 1%</td>
<td>neglect</td>
</tr>
<tr>
<td>Cloud 1 &amp; 2 &amp; 3 bottom, 2' &amp; 3 top</td>
<td>1 km</td>
<td>≤ 5%</td>
<td>wider spect. range?</td>
</tr>
<tr>
<td>H$_2$SO$_4$ concentration</td>
<td>75%–85%</td>
<td>9%</td>
<td>2.55 μm peak</td>
</tr>
<tr>
<td>Surface elevation</td>
<td>100 m</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>Temperature profile around 0 km</td>
<td>1 K</td>
<td>13%</td>
<td>lat. trends in emiss.?</td>
</tr>
<tr>
<td>Temperature profile around 25 km</td>
<td>1 K</td>
<td>8%</td>
<td></td>
</tr>
<tr>
<td>CO$_2$ opacity correction</td>
<td>tbd.</td>
<td>tbd.</td>
<td>multi-spectrum retr.</td>
</tr>
<tr>
<td>Minor gases</td>
<td>tbd.</td>
<td>tbd.</td>
<td>V-H</td>
</tr>
</tbody>
</table>

Noise impact: ≈ 10% for Gaussian noise with 2 · std. dev. = 1 mW/(m$^2$ sr μm)

Outlook:
- Utilize wider spectral range. Retrieve emissivity as parameter common to measurements repeatedly covering a surface spot
Example for retrieved surface emissivity as a function of deep atmospheric temperature profile (not well known below 40 km):
In situ data only close to the equator; VIRA below 32 km extrapolated; GCM suggests latitude trend
New results – surface emissivity

Scatterplot – Emissivity retrieval at 1.02 µm in the region of Idunn Mons as a function of surface elevation: Emissivity is considered as common parameter
**New results – surface emissivity**

*Topography near Idunn Mons, overlayed with retrieved common 1.02 µm surface emissivity map* (99 surface bins with about 15 repetitions)

**Isolated emissivity anomaly:**
- Recent volcanic activity?
- Different surface material?
- Different surface texture?
- Different weathering conditions?

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Summary

- **RTM-MWT** results show a good agreement of simulated and measured spectra
- **MST** enhanced reliability for quantitative deep atmosphere/surface data coming from the Venus’ nightside emission – first 2D maps of REAL surface emissivity at 1.02 µm

Outlook

- Better disentanglement of cloud modes; utilize wider spectral range; retrieve emissivity as common parameter from repeated measurements covering the same surface spot
Summary and outlook

**Next target areas**

![Chart 14](image-url)