An uppermost haze layer above 100 km found over Venus by the SOIR instrument onboard Venus Express
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1. Introduction
- The clouds above Venus consist of a main cloud deck located between 47 and 70 km surrounded by thinner hazes above and below. The upper haze layer was observed at altitudes as high as 90 km [Esposito et al., 1983].
- The haze optical properties up to 90 km were presented in Wilquet et al. (2009, 2012). Wilquet et al. (2012) reported that the aerosol extinction coefficient is significantly smaller at high altitudes than in the equatorial region.
- SO and SO₂ mixing ratios were shown to increase with altitude from 85 to 105 km [Belyaev et al., 2012; Mahieux et al., 2015]. These observations were tentatively explained by the existence of a still unknown source of SO and SO₂ at high altitudes. One possible source could be the photodissociation of SO₂, which results from the evaporation of H₂SO₄ droplets. For example, Zhang et al. (2012) showed important chemical pathways for sulfur species related to aerosols. Additionally, it has been speculated that aerosols and sulfur compounds are connected by condensation and evaporation [Zhang et al., 2012]. However, upper limit measurements of H₂SO₄ using submillimeter ground-based observations make this suggestion unlikely [Sando et al., 2019]. Clearly, what occurs above 90 km is not yet understood.

2. SOIR / Venus Express
- Solar Occultation at Infrared (SOIR)
  - Wavelength: 2.3-4.2 µm
  - Wavelength resolution: 0.1-0.2 nm
  - Venus atmosphere and haze at high altitude (70-220 km) are observed continually.

- At the beginning of an occultation, the solar light path does not traverse the Venus atmosphere. SOIR starts recording solar spectra at the outer edge of the atmosphere to obtain at least 40 spectra and to define the reference Sun spectrum. For tangent altitudes lower than 220 km, the observed transmittances are calculated by dividing the spectrum recorded at the current time by the reference Sun spectrum. At lower altitudes, the instrument line of sight penetrates deeper into the atmosphere, and continuum absorption occurs due to haze and atmospheric molecules such as CO₂. At the end of an occultation, the signal becomes zero, because the solar light is completely absorbed by the clouds and atmospheric species.

3. Analysis
- The gas transmittance $T_{gas}$ due to atmospheric molecules (i) is calculated as
  \[ T_{gas} = \exp(-\sigma_i n_i) \]
  where $\sigma_i$ is the total optical thickness of species i, integrated along the full line of sight (LOS): $\sigma_i = \int \sigma_i \cdot n_i \cdot dx$
  where $n_i$ and $n$ are the absorption cross section and the number density of species i, respectively. $T_{gas}$ is obtained by dividing $T_{obs}$ (observed transmittance) by $T_{gas}$ at each observed altitude:
  \[ T_{gas} = \frac{T_{obs}}{T_{gas}} \]
  \[ \tau_i = \int \sigma_i \cdot n_i \cdot dx \]

4. Results
- Haze appear to be present at altitudes above 90 km.
- Extinction coefficient profiles show an obvious change in the slope at ~95 km. Extinction coefficients at low latitudes are larger than those at high latitudes.

5. Discussion
- The optical properties of the upper haze layer at altitudes above 90 km were studied in this work.
- A significant increase in the normalized extinction coefficient was observed above 90 km at both high and low latitudes, which could be linked to the vertical profiles of SO and SO₂.
- It is considered that sources of haze are transported upwards at a velocity larger than the sedimentation velocity from the cloud deck. The transported aerosols then evaporate or react to produce SO and SO₂ at high altitude.
- At high altitudes, haze particles are produced by chemical processes involving SO and SO₂. Since the normalized extinction increases at high altitude, we propose that the size of aerosol particles that are produced is smaller than those of transported aerosol particles.

6. Summary
- The properties of haze layer (70-90 km) were also studied. Extinctions at low altitude are larger than those at high altitude.
- Normalized extinctions are constant at both high and low latitudes.