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Investigating Venus's clouds and hazes using CO_2 absorption bands in flux and polarization

Gourav Mahapatra (1), Loïc Rossi (2) and Daphne M. Stam (1)
(1) Faculty of Aerospace Engineering, TU Delft, The Netherlands, (2) Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS/IPSL), UVSQ Université Paris-Saclay, Sorbonne Université, CNRS, Guyancourt, France
(g.mahapatra@tudelft.nl)

Abstract

We compute total and polarized fluxes of sunlight that is reflected by Venus between 1.4 and 1.5 μm, a wavelength region with a strong CO_2 absorption band. Our computations show that the spectral variation of the polarized flux across the absorption band is very sensitive to the atmospheric structure and composition. Accurate spectropolarimetry across such absorption bands would provide unique information on the clouds and hazes in Venus's atmosphere.

1. Introduction

Multiple space and ground based observations have shown the significant spatial and temporal variation of Venus's clouds and hazes [1, 2]. Characterizing the horizontal and vertical structure of the clouds and hazes and their micro-physical properties (particle size, shape, composition), their roles in the planet's radiation budget and the atmosphere's dynamical and chemical processes, is key to understanding Venus's extreme climate.

In Earth remote-sensing, total flux measurements across strong O_2 absorption bands are routinely used to determine cloud top altitudes. A similar method to derive Venusian cloud top altitudes from CO_2 absorption bands in observations by the SPICAV instrument onboard ESA's Venus Express mission was used by [4]. Polarization measurements across absorption bands have been proposed to derive information on the vertical distribution of cloud and aerosol particles on Earth [3], but not yet on Venus. The degree of polarization across a gaseous absorption band in a reflected light spectrum will generally deviate from the degree of polarization in the adjacent continuum because with increasing absorption:
1. the ratio of (usually highly polarized) singly scattered light to (usually little polarized) multiple scattered light increases, and with that the degree of polarization of the reflected light increases, and
2. the altitude where most of the reflected light has been scattered increases. In a vertically inhomogeneous atmosphere, the polarization in the absorption band will thus be determined by different scatterers than outside the band (it can be higher or lower, depending on the particle properties, their distribution, and the geometries).

We will use radiative transfer computations to explore the spectral variation of total and polarized fluxes emerging from the top of Venus's atmosphere across a near-IR CO_2 absorption band. The SPICAV instrument [6] on Venus Express, performed polarization measurements across this band, and a comparison with those measurements will be the focus of future work.

2. Numerical algorithm

The reflected light is described by total flux I, and the linearly polarized fluxes Q and U (circularly polarized flux V is so small that it will be ignored). Our reference plane contains the local zenith and the direction of propagation of the reflected light, thus U of the reflected light is zero. The degree of (linear) polarization is thus defined as $P = -Q/I$, with a negative P indicating a polarization direction parallel to the reference plane and a positive P indicating a direction perpendicular to this plane.

Our atmospheres count 38 stacked layers, above a black surface. Each layer contains gas and, optionally, cloud or haze particles. The results presented here are for wavelengths from 1.4 to 1.5 μm. The cloud optical thickness is 30, and the haze optical thickness, 0.1. Scale height H describes the vertical distribution of the cloud and haze particles.

With our adding-doubling radiative transfer code we compute I and Q for different solar zenith angles (SZA) and nadir viewing angles. To avoid time-consuming line-by-line computations[1] across the CO_2 absorption band in this spectral region, we implemented the correlated k-distribution method (see [5] and references therein).

3. Results

Figure 1 shows the reflected I and P for two model atmospheres: one with only a cloud layer and another with a cloud and a haze layer above. The latter should be representative of Venus's equatorial atmosphere where cloud tops are expected to be close to 74 km [2] covered by a thin haze [1]. While in I, the haze is virtually invisible, its signal shows up as an absolute decrease of $|P|$ of about 5% in the deepest part of the absorption band. This change in P is due to the different single scattering polarization signatures of the haze and cloud particles (positive and negative, respectively).

Figure 2 shows I and P for the same atmospheres but for 3 solar zenith angles. Like before, the band depth in I is only sensitive to the SZA, not to the presence of haze. For the atmosphere with only the cloud, $|P|$ in the band changes with SZA, due to the change in the single scattering angle, and, hence, in P of the light that is singly scattered by the cloud particles. If the atmosphere contains a cloud and a haze, P changes sign, and thus direction, for the larger SZAs. The reason is that with a larger SZA, more of the reflected light has been scattered in the higher atmospheric layers, which contain the haze particles with their positive polarization single scattering signature at these scattering angles.

4. Summary

Our first computations show that measuring P of reflected sunlight across a CO_2 absorption band could help to identify and possibly constrain the thin, highly variable haze present above Venus's upper clouds. We will extend our analysis to a broad range of model atmospheres to come up with a retrieval algorithm for spectropolarimery across gaseous absorption bands.

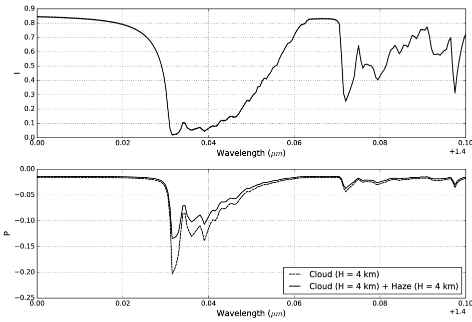

Figure 1: I and P for two different atmospheres: with a cloud layer, and with a cloud and haze layer. For each layer, $H = 4$ km. The SZA is 30°.

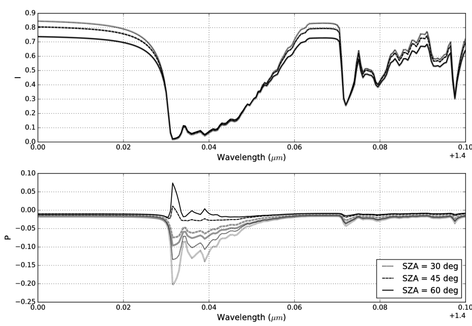

Figure 2: Similar to Fig. 1, but for 3 SZAs. Grey lines indicate the atmospheres with only cloud, and black lines the atmospheres with cloud and haze layers.

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[1] Including polarization for all orders of scattering requires even more computing time-consuming than total flux-only computations.