Retrieval of gases and aerosols vertical profiles considering multiple scattering from OMEGA/MEx limb observations

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Introduction:
The OMEGA instrument on board Mars Express (MEx) is an infrared spectrometer taking observations of the Mars atmosphere since 2004 in the 0.35 to 5.1 µm wavelength region (Bibring et al., 2004). Amongst all the observations, OMEGA observed the Mars atmosphere in limb geometry, during which radiances were measured with a spectral sampling of 7 nm (0.35-1.0 µm), 13 nm (0.93-2.65 µm), and 20 nm (2.51-5.1 µm) and an instantaneous field of view of 1.2 mrad. These measurements show a good coverage of the planet in terms of latitude, longitude and Ls.
In this work, we present an algorithm used to invert the limb observations using a Bayesian approach (Rodgers, 2000). In this scheme, the forward model, JACOSPAR, is a full radiative transfer code which accounts for multiple scattering of the Sun light by the atmospheric aerosols, in order to model the radiances with a high precision (Iwabuchi, 2006; Iwabuchi et al., 2009; Mahieux et al, 2018).
We intend to retrieve CO_2, H_2O and CO vertical profiles for the gas species, and water ice and dust vertical profiles for the aerosol species, which all show clear absorption and/or scattering structure in the considered wavenumber region.

The method:
Forward model. JACOSPAR is a multiple scattering radiative transfer code that uses the backward-propagating Monte Carlo method, and the dependent sampling approach in order to reduce the computation time (Marchuk et al., 1980). It calculates the scattering for a given number of wavenumber values and interpolates the radiance for the other wavenumbers (Iwabuchi, 2006; Iwabuchi et al., 2009; Mahieux et al, 2018). JACOSPAR accounts for the instrumental field of view in its calculations.
JACOSPAR also computes precise analytical Jacobians relative to the radiances with respect to the absorption and scattering extinction profiles. They are used to derive the Jacobians to volume mixing ratios (VMR) of the different atmospheric gases (CO_2, CO, H_2O) and aerosols (water ice and dust), as well as to the aerosols mean radius, which are used in the Bayesian algorithm.
We compute the aerosols single scattering albedo, phase function and extinction coefficients using the Mie theory (Wiscombe, 1980), for altitude constant modified-gamma size distributions taken from Kleinbohl et al. (2009), using refractive index of dust and water ice from Wolf and Clancy (2003) and Warren (1984), respectively.

Bayesian algorithm. We implemented the Bayesian algorithm approach developed by Rodgers (2000) using the Gauss-Newton method. Based on an *a-priori* atmosphere obtained from the GEM-MARS (Neary et al., 2017), we fit the logarithm of the different species VMR and the aerosols mean radius, assuming temperature and pressure conditions obtained from MCD for the latitude, longitude, time and Ls observation mean value.

Sensitivity study. We present a sensitivity study, conducted in different illumination geometries, to the different retrieved VMR profiles, which shows that the precision of the retrieved profiles is correlated with the distance of the MEx spacecraft to the impact point of the observations due to the field of view of OMEGA, as well as with the vertical sampling (vertical distance between two consecutive impact points). We show that the sensitivity to CO_2, H_2O and dust is reasonable, while is weaker for water ice and CO, due to their respective absorption strength and wavelength dependencies.

Results and discussion:
We searched for the best covariance values to the *a-priori* atmosphere in order to best fit the

OMEGA measured spectra, and we obtained good fits for the fraction of the observations that have already been inversed.

The vertical profiles derived from a few observations will be presented and discussed in different illumination geometries, geographical position and seasons, and compared to previous observations. We discuss variations of the different VMR vertical profiles as a function of time, latitude and Ls within the retrieved uncertainties, and compare with profiles from models, such as GEM-MARS. In particular, we focus on water and dust vertical profiles.

Future applications:

The code is intended to be applied to the inversion of the NOMAD (Vandaele et al., 2015) on board ExoMars limb observations, that will be carried out from end of 2017. One of the channels of NOMAD, LNO, is a high resolution echelle grating spectrometer using the AOTF technology to select the wavenumber ranges to be measured, working in the infrared from 2.2 to 3.8 μm.

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