EPSC Abstracts
Vol. 12, EPSC2018-911, 2018
European Planetary Science Congress 2018

Retrieval and characterization of carbon monoxide (CO) vertical profiles in the Martian atmosphere from observations of PFS/MEX

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Abstract

While there has been substantial progress in our understanding of the Martian global carbon cycle during the last decade, some processes at play are still subject to many questions. This is notably due to the use of retrieval methods which have not exploited fully the satellite measurements. Among the species involved in this cycle, this work targets carbon monoxide (CO) and aims at fully investigating the possibility to retrieve CO vertical profiles from PFS/Mars Express infrared nadir observations. The retrieval method used is the optimal estimation and will be explained in details. Exploiting the framework of this method, the characterization of the retrieved profiles in terms of error budget and vertical sensitivity is deeply discussed. The influence of different parameters, such as the *a priori* constraints, is investigated and will be presented.

1. Introduction

The atmosphere of Mars, largely dominated by carbon dioxide (CO_2), is subject to a global carbon cycle that is still nowadays not completely understood. The recently reported but debated detection of atmospheric methane, combined with its large apparent seasonal variability, has challenged further the understanding of this cycle. Partly due to a lack of vertically-resolved profiles of the different species involved, questions remain on all processes (sources, sinks and transport pathways) affecting the atmospheric carbon reservoir on Mars.

This work targets especially carbon monoxide (CO). While climatology of the averaged CO mixing ratios, built from CRISM (Compact Reconnaissance Imaging Spectrometer for Mars) [1] and from PFS (Planetary Fourier Spectrometer) nadir observations [2], have been recently published and delivered important information regarding the CO latitudinal and seasonal variability, there has been no systematically retrieval of the CO vertical profile from Martian nadir observations. Development of synergies exploiting different spectral ranges or instruments to retrieve information on the CO vertical distribution has been tested [3], but these are difficult to implement. The goal of this work is to deeply investigate the possibility of retrieving CO vertical profiles from PFS nadir observations. This is performed on several single PFS spectra chosen to represent different conditions of CO on Mars. Using the optimal estimation method [4], the aim of the present study is also to characterize the retrieved CO profiles in terms of error budget and vertical sensitivity. In the longer term, this work will allow to retrieve CO profiles for a larger set of PFS measurements, and by building time series and distributions, to better understand the diurnal/seasonal cycle of CO in terms of sources, transport and photochemistry.

2. The PFS instrument

PFS [5] is a double pendulum Fourier transform interferometer orbiting around Mars on-board the Mars Express spacecraft. It covers a large spectral range in the infrared (250-8200 cm^{-1}) thanks to two different channels: the long wavelength (LW) channel, recording the Martian atmospheric spectrum between 250 and 1700 cm^{-1}, and the short wavelength (SW) channel, covering the spectral range 1700-8200 cm^{-1}. In this work, around 25 apodized spectra (spectral resolution of 1.3 cm^{-1})

recorded by the SW channel have been analysed. Simultaneous PFS LW channel observations are used to retrieve surface temperatures and vertical temperature profiles. The spectra have been selected based on the latitude, the solar longitude and the topography, to have a sample of measurements representative of the known spatial and temporal variations of CO on Mars. The selection was made also based on surface temperature and the value of the radiance at 2165 cm^{-1} to ensure sufficient signal-to-noise ratio.

3. Retrieval of carbon monoxide

The retrieval of CO vertical profiles has been performed on single spectra using the optimal estimation method [4]. The idea of this method is to find the CO profile that is consistent with both the PFS observation and the knowledge of the CO vertical distribution prior to the measurement. This method is implemented in the Atmosphit software [6], a versatile line-by-line radiative transfer code initially developed for Earth atmosphere, which is successfully exploited here for the retrieval of CO vertical profiles on Mars.

The optimal estimation offers a very adequate framework to characterize the retrieved Martian CO profiles in terms of error budget and vertical sensitivity. This is done extensively in this work using two output matrices from the retrieval: the total error covariance matrix (to discuss the retrieval errors) and the averaging kernel matrix (to discuss the vertical sensitivity and information content of the retrieval). Using this characterization framework, the influence of the choice of the *a priori* constraints on the retrieved profile is discussed. Specifically, two different *a priori* covariance matrices are built,

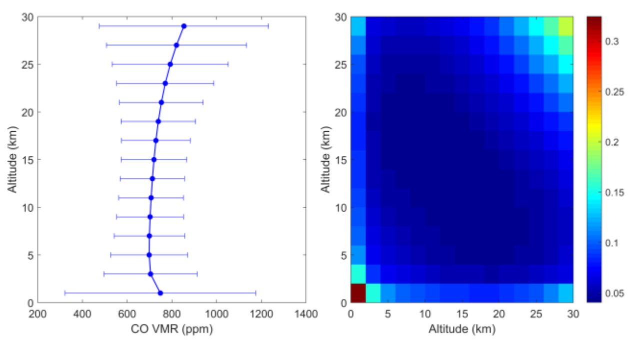

Figure 1: *A priori* profile (left) and covariance matrix (right) built using a large ensemble of CO profiles taken from the MCD database (climatology solar average scenario). The matrix is expressed in multiplicative factor. The error bars on the profile correspond to the square root of the diagonal elements of the matrix.

compared and tested. One consists of an ad hoc matrix that includes 50% of variability (diagonal elements) and whose off-diagonal elements are calculated using an exponential decay, considering a scale height of 11 km. The second matrix has been built using a large ensemble of CO profiles taken from the Mars Climate Database (MCD) [7,8], considering one Martian year for the climatology solar average scenario. This matrix is shown in Figure 1 along with its associated *a priori* profile. The influence of other parameters on the retrieved CO profile, such as emissivity or thermal contrast (temperature difference between the ground and the air above it) is discussed as well.

Acknowledgements

This work is funded by the FNRS CRAMIC project under grant number T.0171.16. PFS is funded by the Italian Space Agency under grant 2018-2-HH.0

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