SYNERGETIC INVESTIGATION OF CO AND CH_4 ON EARTH AND MARS USING ASIMUT-ALVL.

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Introduction

In preparation of the ExoMars Trace Gas Orbiter (EMTGO) mission and in the framework of an ESA tender entitled "Synergetic SWIR and IR retrievals of near-surface concentrations of CH_4 and CO for Earth and Planetary atmospheres", synergies between different types of infrared instruments are investigated through the analysis of carbon monoxyde and methane retrievals.

CO and CH_4 measurements have been performed both by Earth-based spectrometers and several space instruments orbiting Mars, i.e. the PFS instrument on Mars Express or CRISM on MRO. Several future missions to Mars are under preparation but not all of them contain instruments able to perform a spectroscopic inventory of the neutral atmosphere. Indeed the only mission that will embark such instruments is EMTGO, to be launched in 2016.

The remote sensing of CO and CH_4 from space can be performed in different spectral domains (in particular Thermal Infrared (TIR) and the Short-Wave Infrared (SWIR) domains) and with different geometries (nadir observation viewing or limb observation viewing). Because each of these spectral regions and geometries has its pros and cons, the possibilities to combine these types of measurements in a synergetic way are studied here in order to better exploit the available data, in particular to assess the near-surface processes. The challenge is to better capture CO and CH_4 information as close as possible to the associated sources, for better addressing the understanding, quantification or monitoring of sources and sinks.

CO is a non-condensable gas and its seasonal behaviour can be used to constrain the expected behaviour of other non-condensable gases (e.g. CH_4). The CO seasonal-spatial distribution is in fact very similar to that of Argon (the reference non-condensable gas on Mars). Strong deviations from the expected distribution, such as those observed for methane, may represent additional indication of the presence of active local sources.

A synthetic dataset of spectra was created for various scenarios. Different parameters were chosen to get a statistical sample of spectra. Then retrievals were performed according to two ways: non-synergetic and synergetic. The results of the fitting procedure and the benefits of the synergies will be discussed in this communication.

Spectral dataset

Testing the synergies on existing instruments and datasets is not possible at the moment due to the lack of measurements. Therefore, a synthetic dataset of spectra of the Martian atmosphere has been created. Scenarios have been defined varying sites on the planet, solar longitudes, CO and CH_4 volume mixing ratios, aerosol loadings, instrument types, observation modes and solar zenith angles for nadir and tangent heights for solar occulations. Two instrument types have been defined: one is a grating spectrometer (GS) working between 2.2 and 4.4 microns and the other is a Fourier Transform spectrometer (FTS) measuring on a broader range, from 2 to 25 microns. Relative Signal-to-Noise ratio, spectral sampling and resolution have been estimated according to the performances planned for the EMTGO mission and are given in the Table 1. We consider that these two instruments can perform solar occultations and nadir observations.

	GS	FTS
Instr. lineshape	gaussian	boxcar
Wn range	2500-4600	500-5000
Spectral sampling	0.1	0.1
Resolution		
Nadir	0.30	1.6
SO	0.15	0.2
SNR		
Nadir	1000	500
SO	4000	1000

Table 1: Instrument specifications. Spectral sampling, final resolution and wavenumber range are given in cm^{-1}.

IASB-BIRA developed the ASIMUT code initially for Earth observation missions (IASI and ACE-FTS). The code was then adapted for planetary atmospheres, in particular those of Venus [Vandaele et al., 2008] and Mars [Drummond et al., 2011]. ASIMUT is a modular program for radiative transfer calculations in planetary atmospheres. It has been developed to exploit the synergy existing between the growing number of different instruments working under different geometries. The main particularities of the software are:

- The possibility to retrieve columns and/or profiles of atmospheric constituents simultaneously from different spectra, which may have been recorded by different instruments or obtained under different geometries. This allows the possibility to perform a combined retrieval, e.g., of a ground based measurement and a satellite-based one probing the same air mass, or from spectra recorded by different instruments on the same platform;
- The analytical derivation of the Jacobians;
- The use of the Optimal Estimation method (OEM), using diagonal or full covariance matrices;
- Its portability;
- Its modularity, hence the ease to add future features.

The different radiation contributions such as the Sun contribution (direct or reflected on the surface), the surface emission contribution and the thermal atmospheric emission contribution are taken into account. The spectra can be simulated in the IR and in the UV as well. The surface is considered to be Lambertian, but a more complex treatment is possible as well. ASIMUT has been coupled to SPHER/TMATRIX and (V)LIDORT codes [Spurr et al., 2001] to include the complete treatment of the scattering effects into the radiative transfer calculations. Aerosols are included in the ASIMUT code, either as extinction (ASIMUT) or full scattering species (ALVL, through the call to (V)LIDORT).

Runs were done with data from GEM-Mars, a Global Circulation Model (GCM), used to produce an a priori atmosphere corresponding to the selected scenarios. The GEM-Mars GCM is based on the Canadian operational weather forecast model for the Earth, GEM [Cote et al., 1998]. It was transformed for Mars first at York University, for GEMv3.1.2, under the acronym GM3 [Moudden and McConnell, 2005, 2007]. Since 2010, it is developed under the acronym GEM-Mars at BISA under GEMv3.3.0 and GEMv4.2.0. GEM-Mars is a grid-point model with a semi-implicit, semi-Lagrangian advection scheme. There are 102 vertical levels ranging from the surface up to 140 km. The horizontal resolution is typically 4°× 4°. The timestep is typically 30 mars-minutes (1/48 of a sol). There are physical routines for radiation, soil, surface, planetary boundary layer, eddy and molecular diffusion, CO_2 ice condensation, surface pressure change, water cycle (clouds, frost, polar caps), chemistry (carbon and hydrogen species, photochemistry and gas-phase chemistry),... The GCM reproduces the observed CO_2 polar ice cycle, as well as the related surface pressure change. Also surface temperature and temperature profiles are comparable to observed data. Vertical profiles of pressure, temperatures, dust and molecular species (shown on Figure 1) were used as input in the line-by-line code ASIMUT-ALVL [Vandaele et al., 2006].

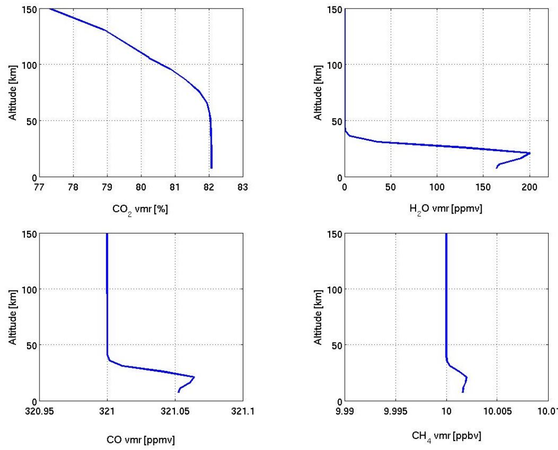

Figure 1: Vertical profiles for CO_2, H_2O, CO, CH_4 used as input in ASIMUT-ALVL.

Instrument specifications, wavenumber range, observation geometry and state of the atmosphere are given as input elements. Spectra were simulated according to the various scenarios selected and given in the Table 2.

Scenarios	
Ls	30-60 120-150 210-240 300-330
Molecules to simulate CO and CH_4 content	CO_2, H_2O, CH_4, CO, O_3 low / high
Aerosols loadings Rayleigh scattering	none / clear / low / high included
[nadir] Solar zenith angles	30° / 45°
[SO] Tangent heights in km above the surface	1,3,5,10,15,20,25,30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 125
Emission temperature of source nadir SO	 Surface temperature (GEM-Mars) 5780.0K

Table 2: Scenario description for each location, each instrument and each viewing geometry.

To obtain a statistical sample, we randomly added noise to these simulated spectra. Batch of 50 spectra were created for each of the scenarios. This led to a spectral dataset of 320000 spectra.

Retrieval procedure

To obtain the best efficiency out of ASIMUT-ALVL, small spectral ranges were determined. These spectral windows will be used to do the retrievals, one range can be precised for each species. A way to determine the best microwindows is to use the Gain matrix, or contribution function, G defined as:

$$G = S_a K^T (S_y + K S_a K^T)^{-1} \tag{1}$$

with S_a is the covariance of a (prior estimate of the state) about the true state, K is the Jacobian matrix ($K_{jl} = \partial_{yj}/\partial_{xl}$) and S_y is the covariance of y about the perfect measurements that would arise from this true state [A. Dudhia et al., 2002].

The determination of these windows takes on a strategic dimension for the GS. The principles of measurement of this instrument relies on the diffraction of the light in different orders. The breadth of an order of diffraction depends on the wavelength. We determined the best microwindows considering on one hand the G matrix over the whole spectral range, as shown on Figures 2 for CO_2 and on the other hand the definition of the orders of diffraction of the SOIR instrument onboard Venus Express [D. Nevejans et al., 2006], state-of-the-art orbiting GS.

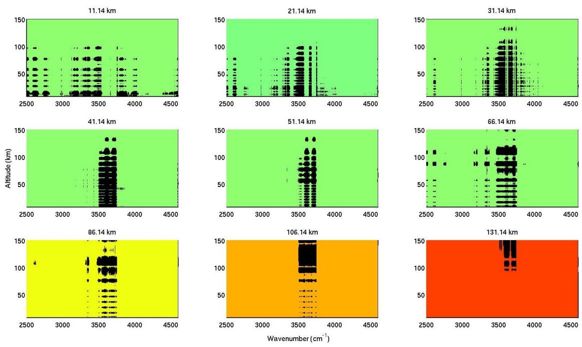

Figure 2: Gain matrix at different altitudes for CO_2 in the spectral range of the grating spectrometer

Figure 2 shows that an identical spectral windows may not be used on the entire altitude range. For other molecules, like CO and CH_4, only one band is visible in Infrared and the spectral windows can be chosen more easily. This is shown on Figure 3 centered around the Q-branch of ν_3 band of methane.

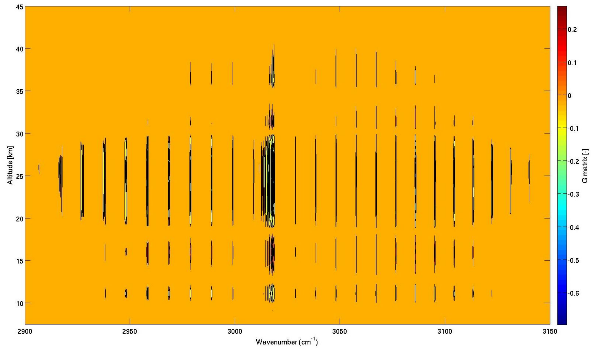

Figure 3: Gain matrix for CH_4 obtained from a solar occultation spectrum at 21.14 km of altitude.

To perform the retrievals, an a priori atmosphere has to be given as an input. This atmosphere was defined using the same O_3 vertical profile and the same altitude scale, pressure and temperature profiles than used for the simulated spectra. The volume mixing ratios of CO_2, H_2O, CO, CH_4 were modified.

Carbon monoxide absorption bands are located at 2.3 μm and 4.7 μm. Therefore we used the two bands separately depending on the instruments considered. Methane has absorption bands both in the TIR and SWIR. The most intense absorption is around 3.3 μm and will be aimed at with the GS. The band at 7.7 μm is less intense and is at the limit of detection in the FTS spectra.

Non-synergetic retrievals

Starting from the inputs described in the section above, each spectrum was treated on its own in nadir. In solar occultation, we had to consider batches of spectra representing the same scenarios but simulated for various tangent heights.

The procedure of non-synergetic retrievals consisted in defining 4 spectral windows on which retrievals of various species can be made. The retrievals were performed simultaneously on all windows.

The results of the retrievals will be discussed. In particular, we will describe the parameterization (state vectors, a priori information, number of spectra inverted, ...). The performances in terms retrievals and uncertainties will be analysed.

Synergetic retrievals

Synergies of different kinds will be considered.

First a Level 1 to Level 1 (L1/L1) synergy will be developed. For instance, CO and CH_4 will be retrieved simultaneously using different bands using both instruments. This case will be tested as well in nadir as in solar occultations viewing geometries.

The second case of synergy is the Level 2 to Level 1 (L2/L1) synergy. A L2 type of data, retrieved in a first step will be used as an a priori information during the retrieval of L1 spectra. For instance, CO and CH_4 nadir retrieval (L1) with complementary (L2) information: application to GS and FTS in nadir view to improve retrieval from the GS nadir spectra of the CH_4 band using L2 data (H_2O, aerosols) retrieved from the FTS spectra looking down at the same surface area.

Similarly to what was done for the non-synergetic retrievals, results of the synergetic analysis will be discussed, in terms of parameterization implemented and uncertainties. The benefits of the synergies will be highlighted.

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