CO_2 ICE COMPOSITION AND EVOLUTION ON MARS : A RADIATIVE TRANSFER INVERSION.

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Introduction: The CO_2 cycle on Mars [1] is the predominant climatic factor on the red planet. It consists in the condensation of a part of the atmosphere into seasonal CO_2 ice caps during the polar night, and its sublimation during spring. This cycle triggers various seasonal surface processes, such as cold gas jets and flows [2]. CO_2 ice acting as a cold trap for water, this cycle has also an impact on the water cycle on Mars [3]. The characterization of these seasonal deposits and their evolution appears as a key to constrain the exchanges between the surface and the atmosphere, the seasonal processes and in general the Martian climate. We propose a radiative transfer inversion to retrieve quantitatively the surface state (composition, grain size, compacity, surface roughness…). This method is based on the construction of a synthetic spectral database, and the comparison of actual CRISM hyperspectral data with it.

Method :

CRISM dataset. The inversion method presented can be used with any hyperspectral instrument. We chose CRISM on board MRO [4], for its spatial resolution, and targeted observations, and because it takes measurements of the same place always at the same local solar time. That allows to follow the evolution of the surface during the season, without taking into account daily variations. The data is corrected from the atmospheric contributions (gas and aerosols) [5], using pressure prediction for gases [6] and aerosols optical thickness estimations from M. J. Wolff [7]. We used for the inversion the *247* CRISM wavelengths within the range *1* µm - *2,6* µm.

Direct model: synthetic spectral database. The first step is to sample the parameters space. The direct model is an analytic multi-layer radiative transfer model [8]. We consider a contaminated CO_2 ice slab over the regolith (see on Figure 1). The parameters to be sampled are: the thickness of the slab, the proportion and grain size of water ice and the proportion of Martian dust in intimate mix in the slab. We use for water and CO_2 the optical constants estimated by B. Schmitt and S. Douté [8], and we determined for the dust a couple of grain size and optical constants that is consistent with the orbital data, using a Monte Carlo method based on Shkuratov model [9]. The direct model computes high resolution spectra, that are then down sampled to the resolution of CRISM instrument, using its spectral PSF [4]. We also added the possibility of a linear mixing within a pixel between the contaminated slab described above and optically thick dust. This mix describes the possibility of a granular deposit at the surface as well as a pixel composed of patches of ice over the regolith.

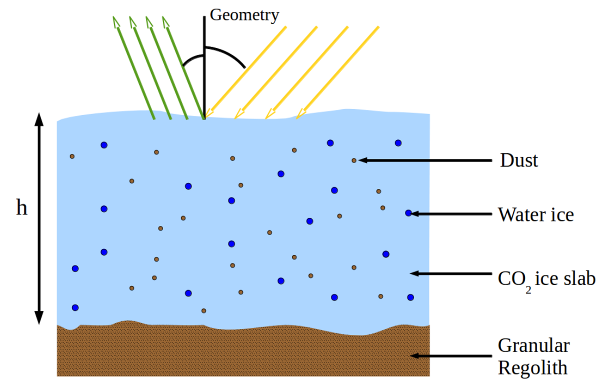

Figure 1 : Description of the surface model. A slab of CO_2 ice, contaminated with water ice and dust grains upon the regolith. The free parameters are: the slab thickness, water ice content and grain size, and dust content.

Inversion. The inversion consists in the comparison of a measure to the whole database, using a likelihood function *L* described as :

$$L = \exp\left(-\frac{1}{2} \times {}^{t}\left(d_{sim} - d_{mes}\right)\overline{\overline{C}}^{-1}\left(d_{sim} - d_{mes}\right)\right)$$

where d_{sim} and d_{mes} are respectively synthetic and measured spectra, and *C* is a $n_b \times n_b$ covariance matrix, n_b being the number of spectral bands used. *C* is the covariance matrix of the measured spectra we expect. In the bayesian framework under gaussian hypothesis, it shall represent the state of uncertainty of the data [10]. *C* will traduce (i) the uncertainties of the measure itself (noise), (ii) the uncertainties we expect from the atmospheric corrections (aerosols optical thickness...), and (iii) the uncertainties in the estimation of the geometry (incidence and emergence), due to local topography. The interest of using such a matrix instead of a much easier least squares method, is that the evaluation of the likelihood of a simulation is determined with a physical criterion, and uncertainties on each parameters are estimated.

Results: We used this method to follow the evolution of the same CRISM pixel throughout the local spring, until the total sublimation of the seasonal ice layer (see Figure 2). This pixel is located in Richardson crater dune field (72,0085°S/179,4218°E). The preliminary results show good agreement of our look up table with the data. The figure 2 shows the CO_2 slab thickness as a function of time for the said pixel. It is decreasing as expected from general sublimation of the seasonal cap. The Mars Climate Database [6] gives results of the same order of magnitude but always larger. That could be due to a local effect of slope. The results on the slab contents in impurities, the water ice grain size and the linear mixing at the surface with optically thick dust are also consistent, and will be discussed. Nevertheless, we cannot retrieve the slab content in dust, its manifestation being too close to the atmospheric aerosols effect.

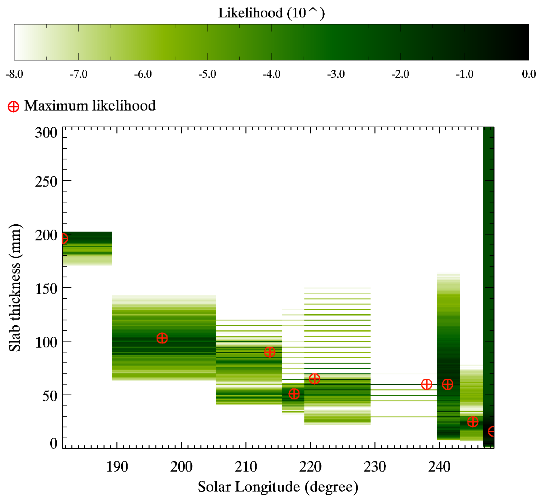

Figure 2 : Preliminary result showing the evolution of the slab thickness throughout the local spring during the Martian year 28. The levels of green represent in log scale the likelihood of the parameter value for a given observation, the maximum being marked with a circled red cross.

Discussion and conclusion: This study shows that our method is able to retrieve quantitatively most of the characteristics of the icy surface with reasonable uncertainties. The CRISM data used for these inversion has been corrected in gas and aerosols using M. J. Wolff estimations for the aerosols optical thickness [5]. It seems that the atmospheric aerosols optical thickness is sometimes overestimated in our cases, resulting in a overcorrection of the spectra. The high uncertainty on the dust content in the slab could be improved using a more precise method of atmospheric correction. Besides, as the geometry of the illumination and the measure has an important impact on the spectrum, it is important to get information on the local topography. For a large number of inversions, it is necessary to have digital terrain models.

References :

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