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# MAPPING THE MESOSPHERIC CO<sub>2</sub> CLOUDS ON MARS.

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## Introduction

In the early 1990s', the James Clerk Maxwell Telescope [1] recorded very low temperatures in the martian mesosphere close to the CO<sub>2</sub> condensation point at altitudes of 50-80km. Based on this and other evidence (emission spike at 4.3  $\mu\text{m}$  measured by Mariner 6 and 7 [2]), scientists suggested that mesospheric clouds should form in this part of the atmosphere, thanks also to observations from Pathfinder [3] that revealed temperatures below CO<sub>2</sub> condensation point in this region. As CO<sub>2</sub> is the major constituent of the martian atmosphere and there is very little water vapour in the mesosphere, it was the most likely candidate to condensate. Thus, the presence of mesospheric CO<sub>2</sub> ice clouds has been suggested, and then confirmed by spectro-imaging observations coming from satellite data (Mars Express, Mars Global Surveyor...). They have been observed in the equatorial mesosphere at the northern hemisphere summer and at northern and southern midlatitudes in autumn ([4], [5]). However, these observations did not allow analysis of their composition as they could be composed of water ice crystals or CO<sub>2</sub> ice crystals. In 2007, the presence of mesospheric CO<sub>2</sub> clouds was confirmed thanks to the OMEGA spectrometer on Mars Express revealing a CO<sub>2</sub> scattering peak around 4.24  $\mu\text{m}$ , within the CO<sub>2</sub> gaseous absorption band [6] during northern spring and summer at the equator and during northern autumn at northern and southern mid-latitudes. It was thought that most of the mesospheric clouds were composed of CO<sub>2</sub> ice. Moreover, carbon dioxide supersaturated pockets, which are atmospheric pockets colder than CO<sub>2</sub> condensation temperature, were observed close to detached aerosol layers [4], giving further evidence to the presence of CO<sub>2</sub> mesospheric clouds on Mars.

Several studies have been published on this topic (for instance, [4], [6], [5], [7]) and several years of observations have been then published, listing and mapping all the mesospheric CO<sub>2</sub> clouds observed as well as describing their internal structure ([8], [9]). Important questions remain such as what can we learn about their inter-annual variations, what is the source of the condensation nuclei and what are the limiting factors for CO<sub>2</sub> cloud formation. None of the current global atmospheric models of martian atmosphere have indeed been able to predict them neither their formation nor the required temperatures. These clouds can help us to understand the martian mesosphere. Some studies have developed

methods to detect and map the clouds but there are still a lot of data that have not been analysed yet (for example, about three martian years from OMEGA/Mars Express). Moreover, the detection algorithms need to be improved to process the data more efficiently.

All these data and studies are very important in order to be able to construct a climatology of martian clouds as complete as possible. This climatology will enable us to better characterise the mesospheric structure and dynamics, as very specific conditions (especially low temperatures and a source of condensation nuclei) are required for CO<sub>2</sub> ice condensation.

## Data

The main instrument used in this project is OMEGA (Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité) on Mars Express probe, which is an imaging spectrometer [10]. This instrument functions in several wavelength ranges: the visible and the near-infrared. As explained in [10], the total wavelength coverage of this instrument is between 0.38  $\mu\text{m}$  and 5.1  $\mu\text{m}$ , composed of three channels: one for the visible and the two others for the infrared wavelengths. As the CO<sub>2</sub> ice scattering peak is found at 4.24  $\mu\text{m}$ , the channel recording the long-infrared is mostly used for CO<sub>2</sub> cloud characterisation. The observations are composed of cubes, corresponding to the observational sessions (these sessions are named with the convention #orbit\_session, for instance #551\_3). These cubes are 3-dimensional objects with the following coordinate system: x,  $\lambda$ , y (x, y are the image dimensions and  $\lambda$  is the wavelength). The specific wavelengths are called in the following 'spectels' (for spectral element) and will be used to detect and map the clouds. About 8000 OMEGA datacubes spanning 6 full Martian years were used for this study.

However, the instrument has to be calibrated before any observations. At the beginning of each orbit around Mars, OMEGA measures the radiometric response to a calibration light (that is a lamp inside the instrument). This measure has also been done on Earth to give a reference calibration level to OMEGA. This level should not change because the flux from the lamp is constant (the lamp's aging does not have a significant influence on this value). However, due to unknown thermo-mechanical issues, it is subject to important variations that strongly affect the measured radiance (see Figure 1). Thus, in

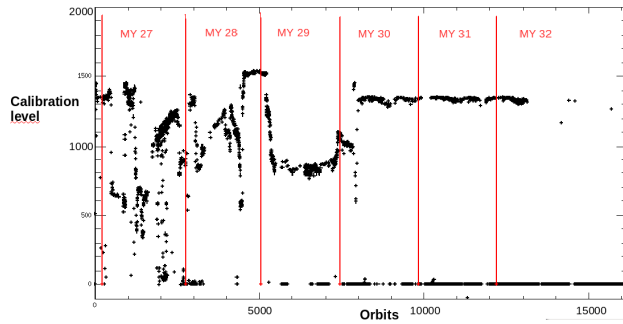


Figure 1: Calibration level with respect to orbits for the L-channel (long infrared).

order to use the observations from OMEGA, a transfer function has been empirically implemented to calibrate the data with respect to the reference level measured on Earth [11]. This method has been validated by analysing the temperature inside the instrument and comparing it with models [12]. In addition, we have discovered that short-circuit may occur during picture integration, which forces us to delete some pixel lines to avoid false detection. The calibration analysis is thus very important in order to be sure that a given cube is suitable for scientific study.

Finally, when OMEGA has detected a cloud, we check HRSC (High-Resolution Stereo Camera also on-board Mars Express) images from the same orbit (if they are available from the Planetary Data System) to verify the detection in the visible and to put the cloud in a larger context (see Figure 2). Combination of observations by the two instruments has been also done by [8] and [9].

### Detection method

The method we are using has been implemented in [8] to the observations from OMEGA to detect and map the clouds. As already explained, the  $\text{CO}_2$  ice causes scattering peaks on the spectrum at certain wavelengths. Particularly, there are two peaks that may be observed: the first at  $4.24\mu\text{m}$  or  $4.26\mu\text{m}$ , which reveals the presence of a cloud, and the second at  $4.32\mu\text{m}$ , which may reveal properties (size of the crystals, optical thickness...) about the cloud itself. An example of such a spectrum is given in Figure 3. However, noise, due to fluorescence or caused by the instrument itself (dark current for instance), could perturb the observations and the fluxes observed. We are looking for detecting the clouds above the  $3\sigma$  limit of the background noise. We assume this noise to be Gaussian and we constrain it according to the method explained in [8]. When the noise level has been calculated, we just retrieve the signal above the  $3\sigma$  noise limit. This ensures a cloud detection probable at 99.87%. To do that, the mean value and variance of

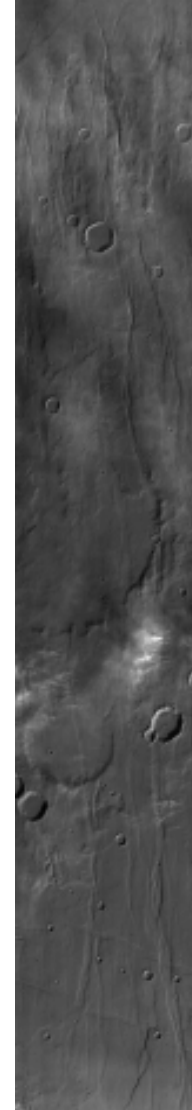


Figure 2: Image taken with HRSC corresponding to the orbit #C635\_1 (C means 12 here, which gives the orbit 12635) (source: pds-geosciences).

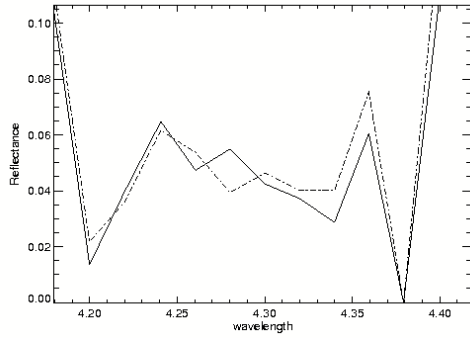


Figure 3: Spectra obtained from OMEGA with the cloud detection method for the orbit #7537\_4: the solid line shows one spectral peak at  $4.26\mu\text{m}$  and the dashed one shows two peaks, the second at  $4.32\mu\text{m}$ .

noise are derived with an iterative process.

Basically, the so-called local mean value and variance of each spectel in the band is computed ( $m_{local}$  and  $\sigma_{local}$ ) for the whole cube. Considering that the average variance of the noise should be identical for each wavelength, a mean variance can be computed as well ( $\sigma_{global}$ ). This value is then re-used in the calculation of the new local mean value and variance of noise at  $4.26\mu\text{m}$  (wavelength corresponding to the presence of a cloud) by removing all the data above  $3\sigma_{global}$ . With an iterative process, the 'true' mean value and variance of the noise can be found and then removed from the observations, all that is left is the signal above  $3\sigma$  enabling to map the clouds [8]. Nevertheless, this method has limits for instance if the cloud signal and the noise can not be statistically differentiated (i.e. if the cloud signal is too faint) or if the cloud is only present in a small number of spectels. This is the method we are going to use in this project to detect and map the  $\text{CO}_2$  ice clouds on Mars (as in [8]). An example is given in Figure 4.

By assuming the background noise distribution inside a cube to be Gaussian, the remaining cloud signal above  $3\sigma$  can also be fitted by a Gaussian curve (see Figure 5)

## Results

As already mentioned, about 8000 datacubes are being studied. For now, 67 show unambiguous  $\text{CO}_2$  ice clouds signature. Some of their properties can be found in [8]. The final results of the past 6 Martian years will be presented at the workshop.

In order to improve the detection method, we tried to correlate the results from  $4.26\mu\text{m}$  with the signal in the visible band. If a cloud is present, it can be indeed seen by eye. However, none of our tentatives to find

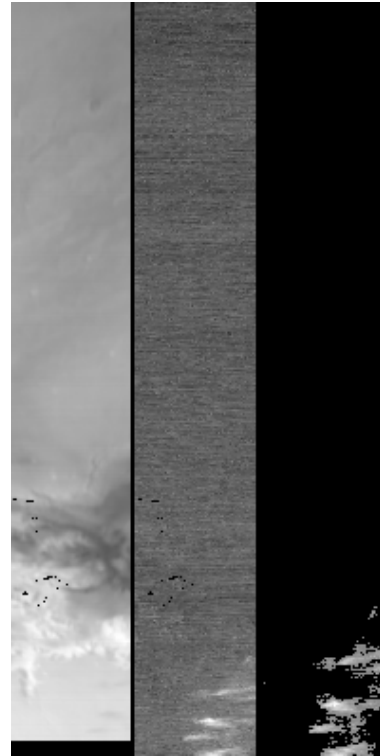


Figure 4: Images taken by OMEGA for the orbit #7537\_4: on the left is the image at  $0.489\mu\text{m}$ , on the center is the image at  $4.24\mu\text{m}$  in which the cloud is much more conspicuous and finally on the right is the image obtained with the detection method in which the noise has been removed. The black lines correspond to deleted pixels due to OMEGA calibration. This detection has been validated by [7].

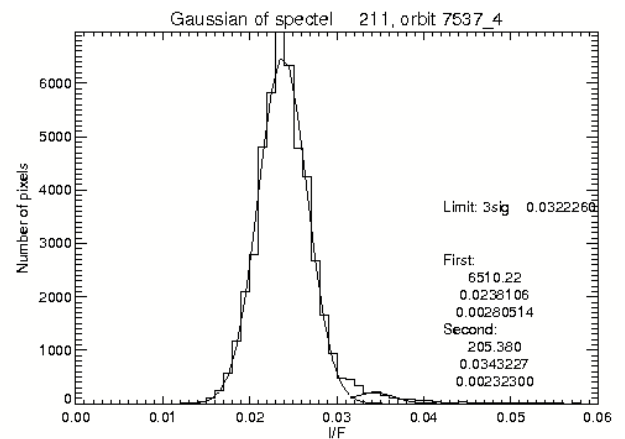


Figure 5: Example of the reflectance distribution at the cloud wavelength for the orbit #7537\_4.

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a correlation between the infrared and the visible band have been successful yet. The variations in albedo of the martian surface may be very different according to the considered region and its effect is difficult to account for.

### Perspectives and conclusions

We will construct and present a climatology of new clouds by classifying them according to their location and season. We will analyse inter-annual variabilities and correlations with other atmospheric parameters. We also hope to find new observations of cloud shadows, which will enable to have a more precise calculation of their particle size and optical thickness ([6], [8]). Thus, this project will improve the current cloud climatology of Mars, enabling a better understanding of the mesosphere and helping determine how the clouds could form at such high altitudes.

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