DISTRIBUTION AND PROPERTIES OF CARBON DIOXIDE CLOUDS DERIVED FROM CRISM DATA.

M. Vincendon, **C. Pilorget, B. Gondet, J.-P. Bibring,** *Institut d'Astrophysique Spatiale, UniverSud Paris, Orsay, France (mathieu.vincendon@ias.u-psud.fr)*, **S. Murchie**, *Johns Hopkins University/Applied Physics Laboratory, Maryland, USA*.

Introduction: While carbon dioxide clouds probably contribute to the climate of numerous solar and extra solar planets [1], they can be currently studied on Mars only. CO_2 ice clouds are a common feature of the martian atmosphere: they form at most seasons and they are observed at both polar and equatorial latitudes. However, their detection is a thorny issue as ambiguities arise from the simultaneous presence of water ice clouds and surface CO_2 ice. The most robust characterization of CO_2 ice clouds at equatorial latitudes has been derived from the OMEGA dataset using direct spectroscopic identification [2]. Numerous studies based on indirect evidence for CO_2 clouds have also contributed to our current knowledge of these clouds [3]. However, the varying levels of confidence that can be associated with these indirect methods prevent their use as a robust diagnostic for CO_2 clouds properties. The near-IR OMEGA dataset remains the most reliable tool for their study, but may contain observational biases. Here we present a new independent method that makes it possible to detect CO_2 ice clouds using the near-IR CRISM dataset. Resulting detections of CO_2 ice clouds are analyzed to complete our knowledge of clouds occurrence and properties and assess biases associated with both direct and indirect detection methods previously reported. New limb and nadir OMEGA data are also presented.

Method: Although similar to OMEGA, the CRISM instrument cannot be used to identify CO_2 clouds in a similar manner due to its shorter wavelength range that does not include the 4.26 µm emission feature diagnostic of CO_2 ice clouds. However, as detailed in the following paragraph, the observation by CRISM of whitish clouds in the visible wavelengths without H_2O ice absorption features at near-IR wavelengths can be confidently associated with CO_2 clouds.

We have performed Mie and radiative transfer calculations to assess the impact of H_2O and CO_2 ice particles on the radiance measured in the near-IR, using optical indices by [4,5], a Mie model by [6] and a radiative transfer code by [7]. Examples of results are shown in Figure 1: the strong variations in the refractive indices of water ice about 3 µm create a strong diagnostic feature at this wavelength. This feature is observed for all grain sizes that can be detected at visible wavelengths (> 0.1 µm) and is already a few % deep for thin cloud barely detectable at visible wavelengths (optical depth 0.05). This feature is totally absent when a cloud is composed of CO_2 ice particles. Hence, the composition of ice clouds detected using their brightness at visible wavelengths can be assessed at near-IR wavelength using the presence or absence of the 3 µm feature

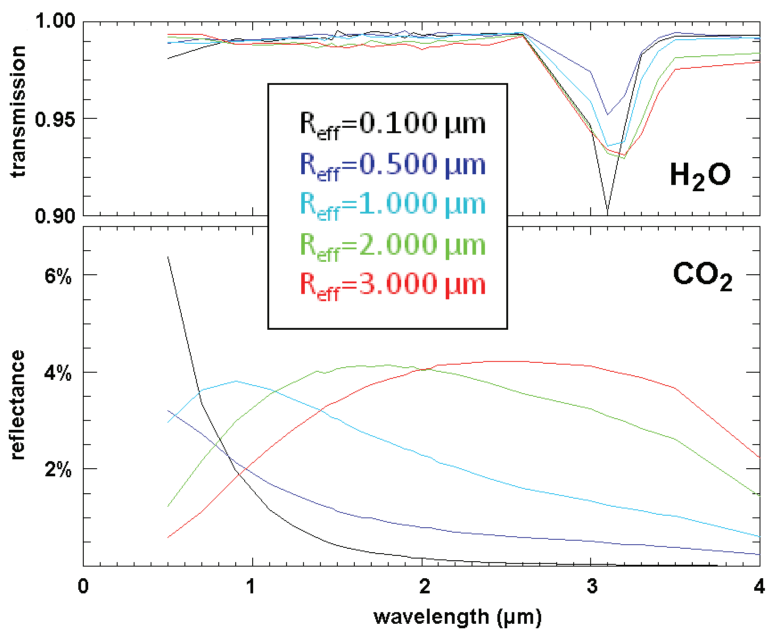

Figure 1: Radiative transfer modeling of cloud impact on visible and near-IR radiations for different mean grain sizes. The vertical optical depth at 0.5 µm is 0.1. Top: transmission of a water ice cloud, showing a strong feature at 3 µm observed for all grain sizes. Bottom: scattering component of a CO_2 ice cloud. Sub-micrometer clouds mainly scatter short wavelengths while µm size clouds scatter in the whole near-IR.

Results and discussion: About 200 clouds (CO_2 or H_2O) have been detected at visible wavelengths in the CRISM dataset ranging from 60°S to 60°N. The spatial and seasonal distribution of CO_2 ice clouds are shown in Figure 2, and an example of CRISM observation is provided in Figure 3. CRISM detections compared very well with most direct or indirect detections previously reported on the basis of OMEGA, TES and HRSC data [2, 3, 8, 9]: all clouds are within ± 20° latitude, mainly located near Valles Marineris and Terra Meridiani. Cloud activity peaks between Ls 10° and Ls 30°; clouds are observed up to Ls 140°. This distribution is not biased by observational constraints, and a very distinct distribution is observed for H_2O clouds (Figure 2). No CO_2 ice clouds have been detected using CRISM in the 30 – 40° latitude range where SPICAM has reported high altitude clouds interpreted as being composed of CO_2 ice [10]. A survey of OMEGA limb data for similar latitudes and seasons reveal the presence of high altitude water ice clouds extending up to 80 km that could be confused with CO_2 clouds when no spectroscopic identification are performed (Figure 4).

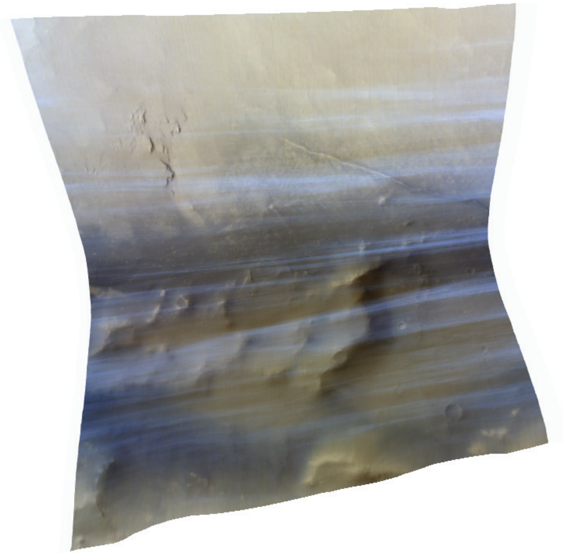

Figure 2: Example of CRISM high resolution (20 meters per pixel) observation of a CO_2 ice cloud. The image is about 10 km wide, north is on top. All CO_2 ice clouds correlate with this specific East-West filament morphology. CRISM observations are obtained at about 15.00 local time.

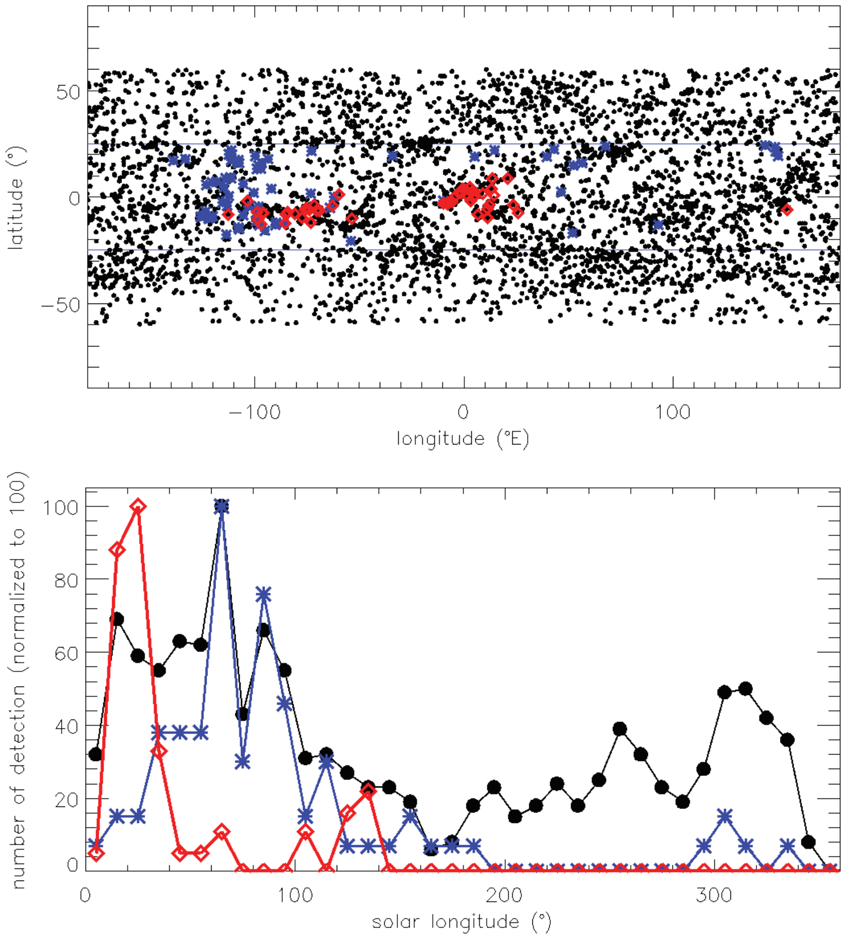

Figure 3: Spatial and seasonal distribution of CRISM CO_2 cloud (red, from a survey in the 60°S – 60°N latitude range) compared to CRISM water ice cloud detections in the 25°N-25°S range (blue ; water ice clouds are also observed at other latitudes) and compared to the total number of CRISM observations for the relevant solar longitude range or latitude range (black points).

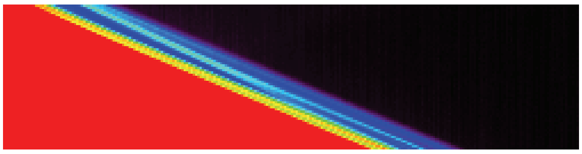

Figure 4: OMEGA limb observation above a latitude of 35°S acquired at Ls 150°. The planet is in red, the outer space is in black. Bright atmospheric layers extending up to 80 km are detected (green / light blue). These layers show features at 1.5 µm and 3 µm diagnostic of a predominant water ice composition.

CRISM data makes it possible to study in details cloud morphology thanks to its high spatial resolution (Figure 3). All observations of CO_2 ice clouds show distinctive cirrus-type morphology, with elongated stripes in the east – west direction. This morphology is consistent with HRSC observations: while OMEGA low resolution observations showing blurred structure have been interpreted as the evidence for a convective activity in these clouds [2], HRSC higher resolution observation have revealed that most of the cloud morphology was cirrus type [9], with only a few unresolved areas that could potentially correspond to small convective cells. At the even higher CRISM resolution, we observe only cirrus-type morphologies, without any blurred, cumuliform areas that could correspond to convective areas.

The CO_2 cloud morphology is specific to CO_2 clouds: H_2O clouds never show such a well defined stripes structure. On the contrary, blurred structures are often observed for CRISM H_2O clouds.

Finally, it is also possible to use the CRISM dataset to estimate particle size and optical depth of CO_2 clouds. Near-IR wavelengths are indeed strongly sensitive to these properties given their expected range (see Figure 1). The mean grain size of CO_2 ice clouds is typically about 1 to 1.5 µm, and the optical depth at visible wavelengths is typically about 0.1 to 0.2, in agreement with OMEGA estimates.

References: [1] Forget & Pierrehumbert 1997, Science 278, 1273-1276. [2] Montmessin et al. 2007, J. Geophys. Res. 112, E11S90. [3] Clancy et al. 2007, J. Geophys. Res. 112, E04004. [4] Schmitt et al. 1998, Solar System Ices [5] Warren 1984, Applied Optics, vol 23, 1206-1225. [6] Mishchenko & Travis 1998, J. Quant. Spectrosc. Radiat. Trans. 60, 309-324. [7] Vincendon et al. 2007, J. Geophys. Res. 112, E08S13 [8] Määttänen et al. 2010, Icarus 209, 452-469. [9] Scholten et al. 2010, Planet. Space Sci. 58, 1207-1214. [10] Montmessin et al. 2006, Icarus 183, 403-410.