THREE MARTIAN YEARS OF OBSERVATIONS OF MESOSPHERIC CO_2 CLOUDS ON MARS WITH OMEGA/MEX AND HRSC/MEX.

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Introduction:

During the last half a decade Mars has revealed a new phenomenon high in its atmosphere whose existence has been suggested already decades ago, but no observational proof had not been acquired before the Mars Global Surveyor and Mars Express missions. The condensation of CO_2 as clouds at high altitudes of the Martian atmosphere was already suggested as an explanation of observations by the Mariner probes (Herr and Pimentel 1970), as well as the substance composing the blue clouds observed by Mars Pathfinder in twilight (Schofield et al. 1997; Clancy and Sandor 1998). However, these observations could not be confirmed as CO_2 ice clouds and, in the case of Mariners, was quite probably an observation of CO_2 fluorescence (Lellouch et al. 2000; Drossart et al. 2006).

The first observations of very high-altitude haze layers came from SPICAM/MEx stellar occultations (Montmessin et al. 2006): in these observations the haze layers were observed near supersaturated regions of the temperature profile and were thus concluded to be probably composed of CO_2 ice crystals. Around the same time Formisano et al. (2006) suggested that a part of the reflectance observed in MEx/PFS spectra in near-infrared near the fluorescence peak at 4.3 microns might be coming from CO_2 clouds, but the authors did not explain the formation of the feature. The first spectroscopic identification of these clouds came from observations of OMEGA/MEx (Montmessin et al. 2007). In the presence of a cloud, the latter show a distinctive scattering peak inside a CO_2 absorption band around 4.3 microns that was shown by the authors to be the unambiguous signature of CO_2 ice. The OMEGA dataset was supported by limb observations of MOC and TES (on MGS) (Clancy et al., 2007) of high-altitude aerosol layers with very similar spatial and temporal distribution as the clouds observed by OMEGA. Inada et al. (2007) also reported the detection of mesospheric clouds in THEMIS-VIS data.

After the confirmation of the formation of CO_2 clouds in the Martian mesosphere by these first publications, additional climatologies were published in 2010 with several datasets from different instruments. Scholten et al. (2010) presented the MEx/HRSC dataset of high-altitude (>70 km) clouds that were discovered thanks to a distinct parallax of high-altitude atmospheric features in the stereo images of the instrument. Scholten et al. (2010) were able to show in some cases that the clouds HRSC observed were indeed CO_2 by comparing with simultaneous observations and spectroscopic identification by OMEGA. Määttänen et al. (2010a) published a companion study on OMEGA and HRSC data presenting 3 Martian Years (MY 27-29) of OMEGA observations of CO_2 clouds complemented by a selection of HRSC high-altitude cloud observations. Recently a large THEMIS-VIS dataset has been published as well (McConnochie et al. 2010). The climatology that can be compiled from all the aforementioned datasets covers altogether 6 Martian Years of data on high-altitude (CO_2) clouds.

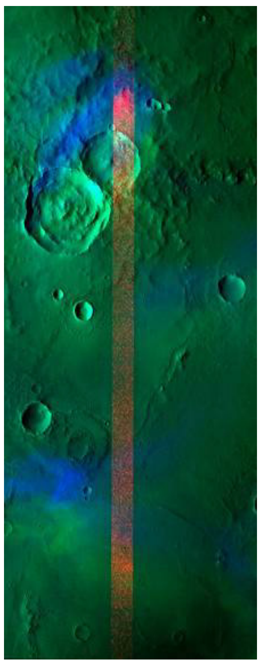

Figure 1: An example of a simultanous observation by OMEGA and HRSC. The green and blue images of HRSC are projected at the Martian surface, revealing the high-altitude clouds as misaligned green and blue hazes. We have superposed the simultaneous OMEGA data at 4.26μm in red.

Methods:

In this paper we will focus on the OMEGA and HRSC observations of high-altitude CO_2 clouds (Scholten et al. 2010; Määttänen et al. 2010a). We will also present the latest extension of this dataset with highlights of the observations from the first half of the present Martian Year (MY 30).

The CO_2 clouds can be observed in OMEGA data thanks to a specific spectral signature at 4.26μm, where a spectral peak of strong (resonant) scattering by CO_2 ice is observed inside a strong absorption band of gaseous CO_2. Sometimes this main peak is accompanied by a secondary peak at 4.32 μm that shows sensitivity to different parameters of the cloud (altitude, opacity, particle size).

The HRSC observes the surface in stereo through 9 different channels or filters looking at nadir or slightly inclined off nadir. It sees high-altitude atmospheric features through the parallax (in the direction of the orbit) they exhibit in the images taken through two filters at different angles and at slightly differing times. The parallax enables determination of the cloud altitude and the shift perpendicular to the orbit of the cloud features in the different images gives an estimate of the cloud (wind) speeds.

OMEGA dataset of MY 27-29:

Statistics Analysis of OMEGA data has revealed the spectroscopic signature of CO_2 ice clouds at 3-sigma level on 51 orbits (in 64 individual images). The clouds are mostly observed near the equator (+/-20°), but some exceptional cases of midlatitude clouds were observed as well. The observation times vary between 08LT-17.30LT, depending on the satellite orbit, and the clouds are mostly found in a limited longitudinal range that spans from -120°E through the prime meridian to 25°E, with some clouds observed at around 230-245°E.

Near-equatorial clouds The near-equatorial clouds are typically observed during the first half of the Martian year, the first clouds appearing right at the spring equinox (Ls=0°) or immediately after. An exceptionally early start of the cloud season was observed at the end of MY 29 when the first cloud of the new equatorial cloud season formed at Ls= 330°. The clouds are observed until Ls=60°, after which a pause of about 30 degrees of Ls has been observed in the dataset of MY 27-29. The clouds reappear at Ls=90° or slightly before, and continue to form until Ls=135°. We are as of now unable to clearly distinguish interannual variations based on the OMEGA dataset because of uneven spatial and temporal coverage during different years, but at least we can state that the seasonality and spatial distribution of the positive cloud observations agree well with previous studies (Clancy et al. 2007), pointing to small interannual variations on average. The clouds are mostly daytime clouds, with the exception of 10 cases observed in the morning (8-11 LT), but the observational coverage in local time is quite limited.

Midlatitude clouds OMEGA has observed two midlatitude clouds: one in the southern hemisphere (MY 27, reported already by Montmessin et al. 2007, and observed simultaneously by HRSC, Scholten et al. 2010) and another in the northern one (Määttänen et al. 2010a). Both clouds formed around 45-50° latitude during the local autumn (Ls=54° at 50°S, Ls=250° at 45°N). Local times of these clouds vary, the southern one being observed at 08 LT and the northern one at 14 LT.

Shadow observations OMEGA has observed twice the shadow of clouds, which enables, as shown by Montmessin et al. (2007), the estimation of the cloud altitude, opacity and the effective radii of the particles from the observed attenuation of sunlight in the shadow. Montmessin et al. (2007) performed the calculations for the cloud on average, and Määttänen et al. (2010a) refined the study by calculating the properties (opacity and effective radius) for each cloud pixel. The cloud opacities go up to 0.5-0.6 with mean values of 0.14 and 0.25 for the two observations, and the effective radii are compatible with a unimodal distribution with sizes mainly comprised between 1 and 3μm.

OMEGA dataset of MY 30:

Statistics In the first half of the MY 30 OMEGA has observed near-equatorial CO_2 clouds on 11 orbits. The clouds are, as usual, confined very close to the equator and at the same longitudinal range as in the previous years. One new cloud shadow observation has been acquired, but the shadow is so faint that decent contrasts, required for the opacity and effective radius analysis, are difficult to identify.

Differences One cloud was observed already in very early spring, at Ls=330° in MY 29, as expected based on the LMD/MGCM (Forget et al. 1999, Gonzalez-Galindo et al. 2009) simulations that show the cold season at the cloud altitudes starting at this time of the year. Thus we think this cloud was indeed one of the first clouds of the MY 30 cloud season. The equatorial cloud formation is divided in two distinct periods around the aphelion, the first one ending by Ls=55° in MY 27-29. In MY 30 the cloud formation continued up until Ls=65°. This is the closest observation to the aphelion made so far, and thus the first part of this cloud season was exceptionally long, starting at Ls=330° and continuing up to Ls=65°.

Selected HRSC observations of MY 27-29:

Dataset and statistics The HRSC observations were checked for high-altitude clouds in all orbits during a limited period in the beginning of MY 29, and in addition in all the orbits of MY 27-28 where OMEGA had observed CO_2 clouds. The whole HRSC dataset adds up to 28 high-altitude cloud observations with 11 simultaneous observations with OMEGA. The near-equatorial clouds were observed in the same latitude-longitude ranges as the OMEGA clouds, with the addition of a simultaneous observations of the southern midlatitude cloud with OMEGA, and a new midlatitude cloud at 45°S (Ls=73°, 08 LT).

Altitudes The altitudes of the clouds were analyzed in all but one HRSC observation: the clouds form mainly at 59-87 km altitudes with a slight trend for higher altitudes towards the equator. The midlatitude clouds were observed at the lower end of the range, at 53-62 km. The clouds seem to be forming at higher altitudes in early spring than later in spring and summer. However, the dataset is compiled with observations from different years, all the early spring observations being from MY 29, so we cannot yet state if this is a real trend or an interannual effect.

Cloud speeds The cloud speeds (comparable to the mesospheric wind speeds) were analyzed in 20 cases. The equatorial winds blow from the east with varying, but fairly high speeds, going up to 110m/s. In one case of the midlatitude clouds the wind speeds were westerly with lower magnitudes (5-42 m/s). The wind directions and speeds are in the range expected by Mars General Circulation Model predictions.

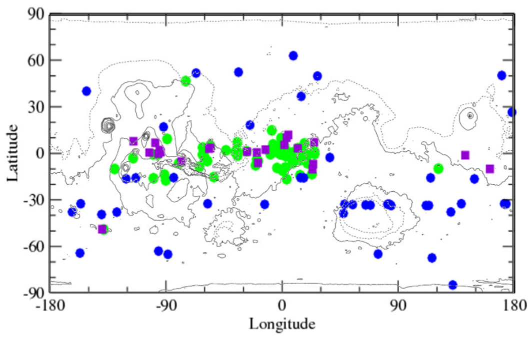

Figure 2: Global map of high-altitude cloud observations by OMEGA (in green) and HRSC (violet). Included are also observations of subfreezing temperatures by SPICAM (in blue, Forget et al. 2009).

Comparison with other datasets:

Statistics of near-equatorial clouds The three extensive equatorial cloud datasets, TES&MOC (Clancy et al. 2007), OMEGA (Määttänen et al. 2010a), and HRSC (Scholten et al. 2010), agree well on the spatial and temporal distribution of these clouds with minor differences in the timing and length of the aphelion pause, which might be due to interannual variations or merely to differences in observational coverage. THEMIS observed a handful of equatorial clouds that fit well the climatology derived from the other instruments (McConnochie et al. 2010). The altitudes observed by MOC&TES and by HRSC agree, even if the observed range of HRSC altitudes is larger. THEMIS altitude range is of the same scale as the one observed by HRSC. The wind speeds from THEMIS and HRSC agree pretty well: both instruments observe easterly winds with THEMIS range being 5-90 m/s, nearly the same as HRSC. The effective radii from OMEGA (2 µm) are in the same range as one THEMIS observation (1.5 µm), with its other two being in a lower range of 50-100 nm. The latter daytime observations fit pretty well with the SPICAM stellar occultation particle sizes (80-130 nm) of clouds observed at 01 LT in the southern subtropics at 90-100 km altitude. The dataset is still too small and it is still too early to say anything conclusive about the differing particle sizes and any local time variations, but the comparison of daily variations of cloud altitude and particle sizes may turn out fruitful (Määttänen et al. 2010b, DPS abstract; Määttänen et al. 2011b, this conference).

Statistics of midlatitude clouds OMEGA and HRSC observed altogether 3 midlatitude clouds, one in the northern and two in the southern hemisphere. Only the two HRSC-observed clouds in the southern hemisphere have associated altitude determinations (53-62 km), and the speed of only one of them has been determined (5-42 m/s). McConnochie et al. (2010) published an extensive THEMIS-VIS dataset of northern midlatitude clouds with altitude and speed determinations. Their midlatitude clouds are observed in a range of 45-70 km with associated westerly wind speeds of 0-120 m/s.

Summary of 6 Martian Years of data The datasets listed in the Introduction and above sum up to 6 Martian years of CO_2 cloud observations. We are still far from a complete coverage giving the possibility for drawing definitive conclusions on interannual variations, but the main features of the equatorial clouds and their properties are emerging. With scarse determinations of cloud particle sizes and opacities, we are still lacking information on the cloud properties that could be inferred from further analysis of OMEGA data and data from other instruments as well. These datasets will continue to grow with the continuing Mars Express observations and will be completed with analyses from other instruments and missions.

Conclusions

We have presented a dataset of 3 Martian Years of observations of high-altitude CO_2 clouds with OMEGA and HRSC on Mars Express and compared these observations to other published work. The clouds seem to have a quite regular seasonal behavior, even though we cannot draw definitive conclusions on interannual variability in the lack of full observational coverage. Extensions of existing datasets as well as analyses of new ones will help in filling the gaps and improving our knowledge on the cloud properties. The cloud observation dataset provides a rare source of information on mesospheric variables, such as temperature and winds, and can be used to constrain Global Climate Models.

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