MESOSPHERIC CO_2 CLOUDS ON MARS: DETECTION, PROPERTIES AND ORIGIN. A. Määttänen[1], B. Gondet[2], F. Montmessin[1], H. Hoffmann[3], F. González-Galindo[4], A. Spiga[5], C. Listowski[1] and J.-P. Bibring[2], [1]Université Versailles St-Quentin; Sorbonne Universités, UPMC Univ. Paris 06; CNRS/INSU, LATMOS-IPSL, 11 boulevard d'Alembert, 78280 Guyancourt, France, anni.maattanen@latmos.ipsl.fr. [2]Institut d'astrophysique spatiale. CNRS (UMR8617) and Université Paris-Sud 11, Bâtiment 121, 91405 Orsay, France. [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institute of Planetary Research, Rutherfordstrasse 2, 12489 Berlin, Germany. [4]Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain. [5]Laboratoire de Météorologie Dynamique, CNRS/UPMC/IPSL, Paris, France.

Introduction: The mesospheric CO_2 clouds are one of the major discoveries of the European Space Agency mission Mars Express (MEx). At the time of the last International Mars Conference in 2007 they had just been discovered by OMEGA after previous hints from SPICAM and PFS [1,2] and other inconclusive observations from many years before [3,4,5]. Since 2007 their study has attracted several instrument and modeling teams. A recent review of mesospheric clouds on Mars and on Earth has been presented in [6]. This abstract presents a review of the studies performed with OMEGA/MEx, accompanied by HRSC/MEx, and the modeling efforts that permit us today to draw a clearer picture of the formation of these exotic clouds.

The first spectroscopic identification of these clouds came from observations of OMEGA/MEx [7]. OMEGA observes the presence of a CO_2 cloud as a distinctive scattering peak at 4.26 µm, which is an unambiguous signature of CO_2 ice. MOC and TES/MGS limb observations [8] supported the OMEGA discovery showing very similar spatial and seasonal distributions of high-altitude clouds. Also [9] reported high-altitude cloud observations in the THEMIS-VIS/MOd data. Later on large datasets were published on high-altitude clouds: OMEGA/MEx [10], HRSC/MEx [11], THEMIS-VIS/MOd [12] and CRISM/MRO [13]. The latest addition to the hunt of mesospheric clouds came from MCS/MRO [14]. The two instruments that are able to directly distinguish the CO_2 composition of the clouds are OMEGA (through their spectral signature at 4.26 µm) and CRISM (through elimination of water ice composition in absence of water ice absorption features). The high-altitude cloud climatology that can be compiled from all the aforementioned datasets covers altogether 9 Martian Years (MY). The general features of the high-altitude clouds allow us to divide them in two groups: equatorial and midlatitude clouds. The equatorial clouds are by far the most frequently observed.

OMEGA/MEx: The OMEGA dataset, unambiguously detecting the CO_2 clouds, is the longest to date collecting observations of the CO_2 ice clouds from MY 27 up to the present MY 32. [10] published a combined study of OMEGA observations of CO_2 clouds from MY 27-29 complemented by a selection of HRSC high-altitude cloud observations. OMEGA observations from MY 30 were published in [13]. The most recent observations were reported in several conferences [15,16,17, *and Gondet et al., this conference*].

The OMEGA dataset has mapped the spatial distribution of the CO_2 clouds, which shows a clear pattern of tropical confinement (+/-20°N) with some cases of midlatitude clouds (45-50°N/S) observed at local autumn in both hemispheres. The clouds seem also to form within certain longitudinal corridors. OMEGA has also revealed interannual variations with respect to the onset of the cloud season. The first clouds appear at +/-30° of Ls around the spring equinox (Ls=330° to Ls=30°). Overall the seasonality of the tropical CO_2 ice clouds seems to follow a clear pattern of a main formation burst in the beginning of the year until just before the summer solstice, and a new formation period some time after the solstitial pause. The length of this pause seems to vary somewhat, with MY 29 showing clouds even at summer solstice. In MY 27 the pause was short with cloud formation resuming immediately after the summer solstice, but in MY 30 there was a clear solstitial pause of almost one martian month (over 25° of Ls). No equatorial CO_2 clouds have been observed after Ls=150°.

OMEGA can not directly infer the altitude of the clouds, but they must be above 40 km to be seen within the 4.3 µm absorption band of gaseous CO_2. However, simultaneous HRSC observations have allowed for the determination of altitudes of some OMEGA clouds, and cloud shadow observations have enabled estimating the altitudes of these clouds through geometry. These data show that the equatorial clouds form mostly between 60 and 80 km, and the midlatitude clouds below 60 km. Other datasets agree on the altitude ranges. The OMEGA dataset has also permitted the first ever in-cloud mapping of particle size and opacity through rare observations of the cloud shadow at the planet's surface [10].

HRSC/MEx: High-altitude clouds were also observed through their distinct parallax in the stereo observations of HRCS/MEx. [11] presented the MEx/HRSC dataset of these clouds, and they were able to show that in some cases they were formed of CO_2

ice by comparing with simultaneous observations by OMEGA. These observations provide the first high-resolution images of CO_2 ice clouds. One particularity of the HRSC observations is that they give directly access to cloud altitudes (through observation geometry and orbit-wise parallax between images) and speeds (through cloud movement between images in the direction perpendicular to the orbit). The cloud speeds are directly proportional to the local wind speeds, giving access to rare estimates of mesospheric winds on Mars.

Recipe of formation from modeling: As [5] already suggested, the mesospheric clouds might form in supersaturated pockets created by the interference of thermal tides and gravity waves. This idea has been looked into by [18,19]. The temperature and wind fields of the LMD Mars Global Climate Model (GCM) were analyzed and a good correlation was found with the locations and timing of the coldest mesospheric areas and mesospheric cloud observations [18]. In addition, the indirect wind measurements provided by the HRSC/MEx were compared with the wind fields of the GCM, showing good agreement in some cases, but some discrepancies as well. [18] showed that the diurnal migrating thermal tide and nonmigrating tides could explain the latitudinal and longitudinal distribution of the clouds, and their different formation altitudes at night and during the day. However, the coldest temperatures predicted by the model remained above the condensation temperature of CO_2, so the tides themselves were not able to initiate cloud formation. A plausible cause that might be able to cool the atmosphere enough is mesoscale gravity waves left unresolved by GCMs.

Gravity waves (GW) form when the circulation encounters an obstacle or another phenomenon forcing it to move vertically, the movement being afterwards compensated by the buoyancy in a stably stratified situation. This oscillating movement is then propagated horizontally and vertically as a GW, which can be damped by the thermal structure and/or wind fields of the atmosphere. [19] studied theoretically the propagation of a typical GW, modeled by the LMD mesoscale model. The probability of propagation of this GW to the mesosphere was calculated using the temperature and wind fields of the LMD MGCM. The results revealed a high correlation of the mesospheric cloud observations with the regions and seasons where the atmospheric structure is favorable to the GW propagation. This remarkable correlation points strongly to the mechanism proposed by [5] being correct.

These results paved the way for more detailed studies on cloud formation and development in the cold pockets formed as previously described. [20], after revising condensation theory to the case of a near-pure vapor [21] used the temperature profiles from [19] in their microphysical 1D model to study in detail the properties of the mesospheric clouds. They were able to form CO_2 ice clouds in the cold pockets formed by the GW and monitor their short lifespan. They showed that the vertical extent and lifetime of the clouds are closely linked to the cold pockets responsible for their formation and that the clouds sublimate rapidly once the cold pocket has disappeared. They also concluded that dust (required as condensation nuclei for cloud formation) lifted from the surface of Mars can not explain the observed cloud opacities, but an exogenic source is required, such as meteoric dust.

Conclusion: Mesospheric cloud datasets have been published from several instruments, allowing for studies on the new phenomenon and revealing the very active nature of the Martian mesosphere. In particular, the detection of these clouds by OMEGA and the very long dataset it has provided is a major source of information on the mesospheric CO_2 clouds. Overall, the mesospheric cloud datasets have revealed a plethora of new information on the Martian mesosphere. We have now access to hints on mesospheric temperature variability, wind speeds, properties of the clouds, and even on the microphysical formation mechanisms of these clouds. Mesoscale modeling of these clouds with the recently developed state-of-the-art tools will give new insight into the dynamics of the clouds.

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