Simultaneous observations of Martian clouds by the three instruments of the Emirates Mars Mission over one Martian Year

A. Stcherbinine[1], J. Deighan[2], Z. Hallemeyer[3], C. S. Edwards[3], M. J. Wolff[4], S. A. Atwood[5], M. D. Smith[5], M. M. Osterloo[4], N. R. Alsaeed[6]

[1]*Institut de Rercherche en Astrophysique et Planétologie, CNES, Univ. Toulouse III Paul Sabatier, CNRS, Toulouse, France*

[2]*Laboratory for Atmospheric and Space Physics, University of Colorado, Boulder, USA*

[3]*Department of Astronomy and Planetary Science, Northern Arizona University, Flagstaff, USA*

[4]*Space Science Institute, Boulder, USA*

[5]*NASA Goddard Space Flight Center, Greenbelt, USA*

[6]*United Arab Emirates Space Agency, Abu Dhabi, UAE*

Introduction. Clouds play an important role in the current Martian climate and water cycle. They affect the thermal structure of the atmosphere by absorbing and scattering the incoming Solar radiation, and are a major actor in the inter-hemispheric water exchange [1, 2, and references contained within]. Constraining the properties and evolution of the water ice clouds on Mars is thus of importance to better understand the climate of the planet.
The Emirates Mars Mission (EMM) "Hope" probe has been carrying three instruments to observe the Martian surface and atmosphere since May 2021 [3]. Its observation strategy focuses on the coordination of the observations by the three instruments, which provides quasi-simultaneous measurements of the same location on the planet by all of them.

Data. All three EMM instruments have the ability to observe Martian clouds in disk-viewing geometry, covering wavelength ranges from the ultraviolet (UV) to the thermal infrared (IR).

EXI. The Emirates eXploration Imager (EXI) is a UV-visible framing camera which is observing the full Martian disk in 6 bandpasses [4]. Observations at 320 nm are used to perform water ice clouds optical depth retrievals for incidence and emergence angles $\leq 75°$ [5]. It provides high-resolution spatial distribution of the water ice clouds optical depth, vertically integrated and regardless of the altitude of the clouds.

EMIRS. The Emirates Mars InfraRed Spectrometer (EMIRS) is a Fourier Transform Infrared Spectrometer which is observing the Martian disk between 5 and 100 μm [6]. Water ice clouds' optical depth retrievals are performed by fitting simultaneously the 12 μm and 40 μm water ice spectral features, then column-integrated optical depth values are provided, referenced to 12 μm (825 cm^{-1}) [7, 8].

EMUS. The Emirates Mars Ultraviolet Spectrometer (EMUS) is a UV spectrometer designed to image the Martian high atmosphere and corona from 100 to $\sim$ 185 nm [9]. Even though this instrument has not been primarily designed to study Martian clouds, mesospheric ice particles can show up in the data around 180 nm [10]. Indeed, the airglow emission is low at these wavelengths and the lower layers of the atmosphere are hidden by the CO_2 absorption, but the instrument can detect the sunlight scattered by particles at high altitudes.

Methods. Following the first identification of mesospheric clouds in EMUS data by [10], we perform a semi-automated search on the appropriate EMUS dataset, with a visual validation of the candidates to generate a catalog of 167 confirmed clouds detections by EMUS from $L_s = 49°$ (MY 36) to $L_s = 112°$ (MY 37). Then we crossed this catalog with EXI and EMIRS ephemerids data to identify the detections with data from all three instruments available, which ended up to 87 observations spanning over more than one Martian year.
To estimate the minimum altitude of the mesospheric clouds detected by EMUS, we use the DISORT radiative transfer code [11] through the *pyRT_DISORT* Python module [12] to simulate an atmospheric column of CO_2 and we add cloud layers at different altitudes to see from which altitude the presence of clouds is detectable from the orbit.

Results. Figure 1 shows an example of a large cloud system of the early Aphelion Cloud Belt (ACB) observed by the three instruments of EMM at $L_s = 144.6°$ on MY 36. We can see on the EXI image (panel a) that water ice clouds are present at all latitudes between 15°S and 30°N, with clear spatial structures, and thicker clouds close to the terminator, i.e., on the center of the image. EMIRS retrievals (panel c), with their coarser spatial resolution, are in good agreement with the spatial distribution of the clouds' optical depth as seen by EXI. Indeed, both EXI and EMIRS are sensitive to the full vertical column of atmospheric water ice crystals. But EMUS observation on panel b provides a different view of this cloud system, with only a small area showing up in the center of the image, between 2°S and 13°N. Compared to EXI and EMIRS data which show all clouds regardless of their altitude, EMUS highlights the regions where the clouds extend up to mesospheric altitudes (higher than $\sim$ 50 km here). We can see that the region highlighted by EMUS also corresponds to an area with higher optical depths in the EXI data, which suggest that it corresponds to a small water ice cloud located above the main ACB layer.

Thus, each instrument of EMM provides complementary information on the same Martian cloud that can be combined to obtain a complete view, as summarized below:

- EXI: Water ice clouds optical depth retrievals at high spatial resolution, but no information on the cloud's altitude.
- EMUS: Highlight the presence of mesospheric clouds at high spatial resolution.
- EMIRS: Water ice clouds optical depth retrievals at a coarse spatial resolution, but along with information on the size of the crystals, the presence of dust, and atmospheric temperature profiles.

Conclusion & Perspectives. By having all three of its instruments observing together the Martian clouds, the EMM mission offers a unique capability to study the properties and evolution of the Martian clouds, and their role in the current climate and water cycle of the planet. Ongoing work includes a classification of the EMUS clouds to discuss their climatology, and investigations on their potential link with CO_2 clouds when detections by EXI and EMUS are not fully spatially correlated.

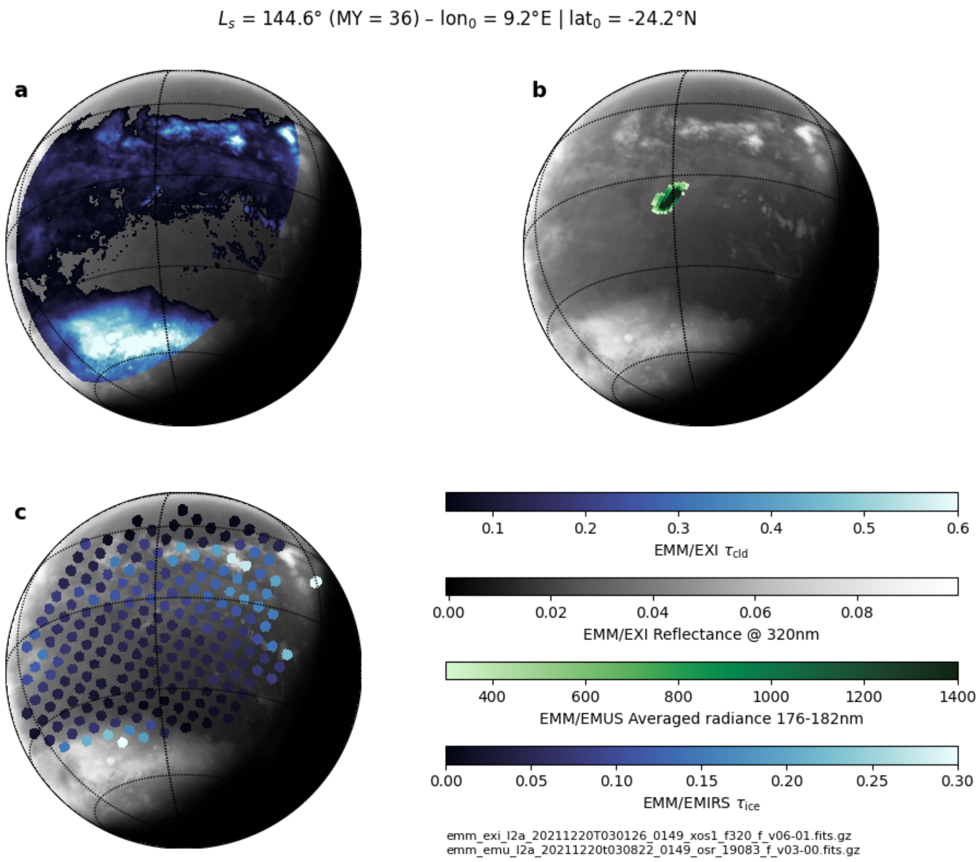

Figure 1 *– Equatorial Martian clouds as seen by the three instruments of the Emirates Mars Mission at* $L_s = 144.6°$ *(MY 36). Early Aphelion Cloud Belt (ACB).* ***a.*** *EXI water ice clouds optical depth at 320 nm.* ***b.*** *EMUS averaged radiance from 176 nm to 182 nm.* ***c.*** *EMIRS water ice clouds optical depth at 12 μm. The background image is the EXI reflectance at 320 nm.*

Acknowledgments. A. S. acknowledges funding by CNES. This work was funded by the Emirates Mars Mission project under the Emirates Mars Infrared Spectrometer and the Emirates eXploration Images instruments via The United Arab Emirates Space Agency (UAESA) and the Mohammed bin Rashid Space Centre (MBRSC).

References. [1] Clancy R. T. et al. (2017) *The Atmosphere and Climate of Mars*, 76–105. [2] Montmessin F. et al. (2017) *The Atmosphere and Climate of Mars*, 338–373. [3] Amiri H. E. S. et al. (2022) *Space Science Reviews*, 218(1):4. [4] Jones A. R. et al. (2021) *Space Science Reviews*, 217(8):81. [5] Wolff M. J. et al. (2022) *Geophysical Research Letters*, 49(18):e2022GL100477. [6] Edwards C. S. et al. (2021) *Space Science Reviews*, 217(7):77. [7] Smith M. D. et al. (2022) *Geophysical Research Letters*, 49(15):e2022GL099636. [8] Atwood S. A. et al. (2024) *Icarus*, 418:116148. [9] Holsclaw G. M. et al. (2021) *Space Science Reviews*, 217(8):79. [10] Deighan J. et al. (2022) *AGU Fall Meeting 2022.* [11] Stamnes K. et al. (2017) *Astrophysics Source Code Library*, ascl:1708.006. [12] Connour K. and Wolff M., pyRT_DISORT (2024).