1.5 MARTIAN YEARS OF MONITORING OF THE MARTIAN WATER ICE CLOUDS WITH TGO/ACS-MIR.

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Introduction

Water ice clouds play an important role in the Martian water cycle and climate. They are a major actor in the inter-hemispheric water exchange and affect the radiative structure of the atmosphere, as their crystals absorb and scatter the incoming Solar radiation [1, 3, and references contained within]. Thus, monitoring the spatial and temporal evolution of the Martian water ice clouds, along with their physical properties (crystal effective radius, opacity) is of importance to improve our understanding and modeling of the current Martian climate.

The Atmospheric Chemistry Suite (ACS) MIR channel onboard the ESA-Roscosmos Trace Gas Orbiter (TGO) [2] probes the Martian atmosphere in the 2.3–4.2 µm spectral range using the Solar Occultation technique since April 2018. This observing geometry provided detailed vertical profiles of the atmospheric transmission, which allows us to detect and derive the physical properties of the Martian water ice clouds as a function of the altitude for more than one full Martian Year (MY) now.

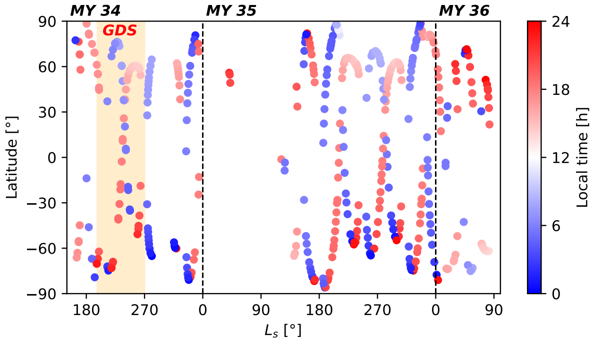

Figure 1 – Spatial (latitude) and temporal (L_s and local time) distribution of the 452 ACS-MIR position 12 observations used in this study. The orange region corresponds to the period of the 2018/MY34 Global Dust Storm.

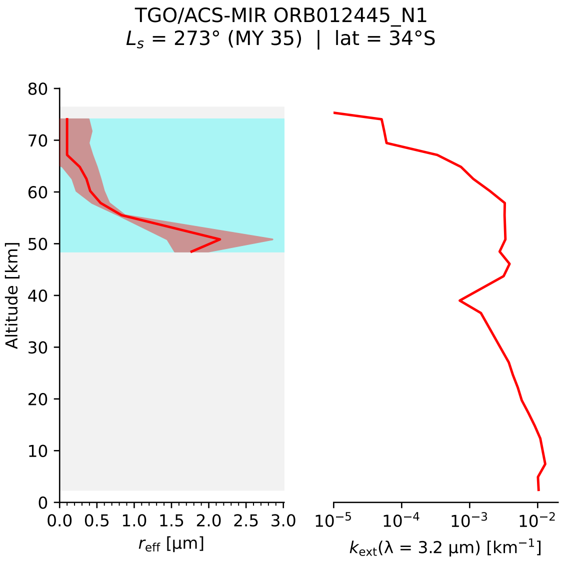

Figure 2 – Example of a vertical profile showing the water ice particle size r_{eff} (left) and the vertical variation of the extinction coefficient k_{ext} at 3.2 µm from a single ACS-MIR observation. The light blue areas represent the altitudes where water ice clouds have been identified, and the greys (and blues) regions indicated all the observed altitudes below the haze top.

Data & Methods

In this study, we use data acquired using the secondary grating position which covers the 3.1–3.4 µm spectral range (referred to as "position 12") [2] between April 2018 and August 2021. After filtering the data to remove observations in which there was no full spectral coverage ("partial frames"), the dataset analyzed consists of 452 observations ranging from L_s = 163° (MY 34) to L_s = 83° (MY 36). The spatial and temporal distribution of these observations is shown in Figure 1. This temporal coverage notably includes the MY 34 Global

Dust Storm (GDS) period and allows us to compare these observations with the ones acquired at a similar epoch during MY 35 (without GDS).

Based on the methodology described in [5], we extract the global continuum transmission spectrum for each observed altitude in ACS-MIR profiles and we convert them into extinction spectra through an onion-peeling vertical inversion algorithm. Then, we compare each ACS-MIR spectrum with theoretical modeled spectra for various sizes of water ice and dust particles. This allows us to simultaneously derive the presence of water ice crystals in each atmospheric layer, along with their effective radii. Figure 2 shows an example of the extinction profile and the water ice crystal sizes obtained from an ACS-MIR observation.

Latitudinal variations

To isolate the latitudinal variations from the seasonal ones, Figure 3 presents the ACS-MIR cloud profiles acquired between L_s = 140° and L_s = 230° (MY 35). We observe that the mean altitude of the water ice clouds follows a bell-shaped distribution as a function of latitude: moving from $\sim$ 10–40 km in the polar regions to $\sim$ 40–80 km around the equator.

We note that regardless of the latitude, there is still a vertical gradient of the particles sizes within the cloud: the size of the ice crystals decreases in the upper layers of the clouds. Larger crystals ($r_{\text{eff}} \geq 1.5$ µm) thus occupy the lower layers of the clouds and are observed up to 55 km around the equator, while the smallest particles ($r_{\text{eff}} \leq 0.1$ µm) can reach 85 km for the same profiles. Clouds are usually founded at the top of the profiles, thus capping the lower layers composed of other types of aerosols (either dust, large water ice crystals, or a mix of them) that may be present in the Martian atmosphere [4].

Another noteworthy point is that this bell-shaped latitudinal distribution noted for the general distribution of the clouds is also observed if we only consider a fixed size of ice crystals. Thus, there is no bijective relation between the altitude and the size of the crystals, other parameters such as the latitude have to be taken into account. This is coherent with the decrease of the scale height of the atmosphere in the higher altitudes.

Seasonal variations

As noted above, the latitude across the planet affects the vertical distribution of the water ice clouds within the atmosphere. Thus, to decorrelate the seasonal variations from the latitudinal trends, Figure 4 presents the evolution of the vertical clouds profiles from mid-MY 35 to the beginning of MY 36 for the equatorial latitudes (between 45°S and 45°N).

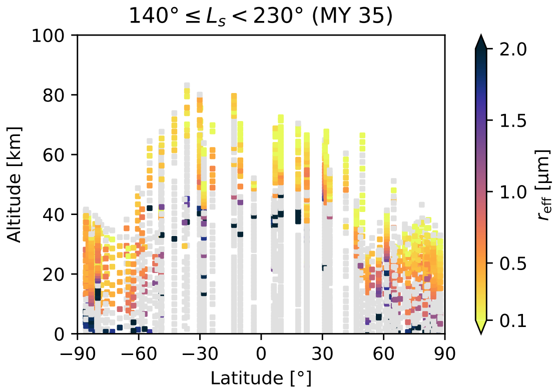

Figure 3 – Vertical profiles of water ice cloud crystal sizes in the Martian atmosphere as observed by ACS-MIR between L_s = 140° and L_s = 230° (MY 35) as a function of the latitude of observation.

We observe that the maximal altitude of the clouds goes from 60 km around L_s = 150° to 85 km around the perihelion (L_s= 270°) and then starts decreasing after L_s = 300° to reach 50 km at L_s = 50° (MY 36). Similarly to the latitudinal effect, we also observe that these seasonal variations of the cloud's altitude affect all the ice particles, regardless of their size. If the proportion of small crystals increases for the high-altitude clouds, at first order the entire size vertical distribution is shifted towards higher altitudes when the average altitude of the clouds increases. I.e., for a fixed value of r_{eff} water ice particles are observed at higher altitudes around the perihelion than at the aphelion.

Conclusion

To conclude, we present here the results of the monitoring of the distribution and characteristics of the Martian water ice clouds with ACS-MIR since the beginning of TGO's science phase in April 2018. This new dataset allows us to derive the vertical profiles of the clouds' extinction and crystals sizes over all latitudes for 1.5 MY now, including the MY 34 GDS followed by one classic year.

For a given L_s range, we observe that clouds are detected about 40 km higher in the equatorial regions than under polar latitudes. And, regarding the equatorial latitudes, we also observe a seasonal evolution of the main cloud's altitude, with water ice crystals detected about 30 km higher around the perihelion than at the aphelion. We also note that water ice crystals larger than 1.5 µm can be observed up to 50 km under equatorial latitudes around the aphelion during a classic (i.e., GDS-free) year.

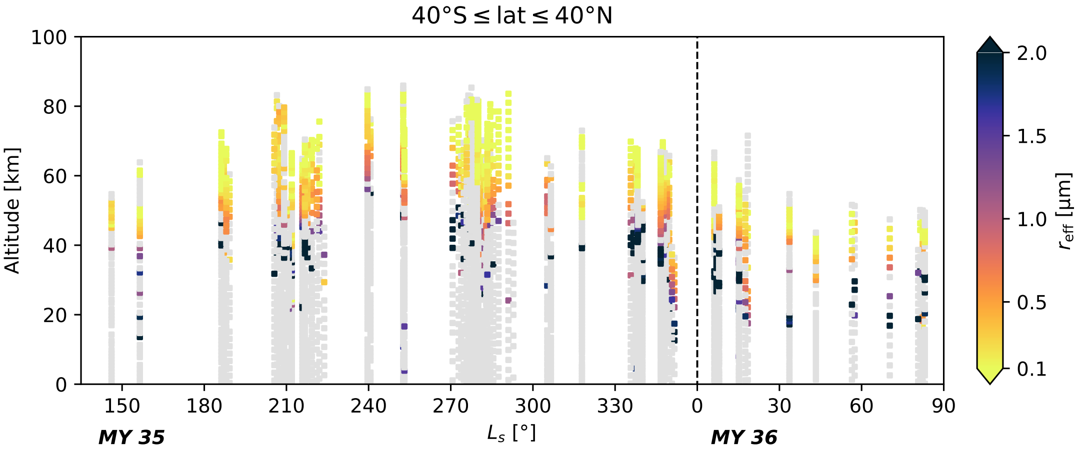

Figure 4 – Vertical profiles of water ice clouds crystals sizes in the Martian atmosphere as observed by ACS-MIR between $L_s = 140°$ (MY 35) and $L_s = 90°$ (MY 36) over the equatorial latitudes.

Acknowledgments

ExoMars is a space mission of ESA and Roscosmos. The ACS experiment is led by IKI Space Research Institute in Moscow. The project acknowledges funding by Roscosmos and CNES. Science operations of ACS are funded by Roscosmos and ESA. Science support in IKI is funded by Federal agency of science organization (FANO). Raw ACS data are available on the ESA PSA at `https://archives.esac.esa.int/psa/#!Table%20View/ACS=instrument`.

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