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The impact of radiatively active water-ice clouds on Martian mesoscale atmospheric circulations

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Background and Goals Water ice clouds are a key component of the Martian climate [1]. Understanding the properties of the Martian water ice clouds is crucial to constrain the Red Planet's climate and hydrological cycle both in the present and in the past [2]. In recent years, this statement have become all the more true as it was shown that the radiative effects of water ice clouds is far from being as negligible as hitherto believed; water ice clouds plays instead a key role in the large-scale thermal structure and dynamics of the Martian atmosphere [3, 4, 5]. Nevertheless, the radiative effect of water ice clouds at lower scales than the large synoptic scale (the so-called meso-scales) is still left to be explored. Here we use for the first time mesoscale modeling with radiatively active water ice clouds to address this open question.

Mesoscale simulations This study is the result of our ongoing effort to keep up with the principle that the LMD physical parameterizations coupled with an adapted WRF dynamical core [what we name the LMD Mars Mesoscale Model, LMD-MMM, see 6] shall follow closely the ones developed for the LMD Global Climate Model [LMD-GCM]. Following the development of an upgraded version of the LMD-GCM with interactive dust scheme [7], radiatively active water-ice clouds [5], and a scavenging+microphysics scheme to couple dust and water cycles [8], we were able to run mesoscale simulations in the Tharsis region with all those new developments included, and study at a fine resolution (about $5 - 10$ km horizontal resolution) the structure of the aphelion cloud belt in the volcano region, to revisit previous studies about a decade ago [9].

Nighttime mixed layers A particular emphasis in analyzing our simulations was put into studying the nighttime mixed (i.e. adiabatic) layers unveiled by radio-occultations on board Mars Reconnaissance Orbiter [Hinson et al. submitted to Icarus 2014]. Those surprising observations arose from data obtained by

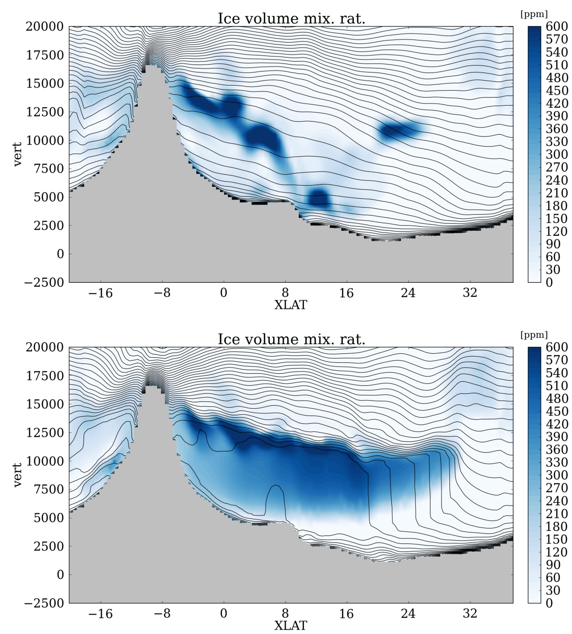

Figure 1: Latitude/altitude cross-section of water ice volumetric mixing ratio (shaded) and potential temperature (contours) at the longitude of Arsia Mons, the season of the aphelion cloud belt, and the local of performed radio-occultations (5AM). Top plot is without radiatively active water-ice clouds; bottom plot includes this effect. Our mesoscale simulations show that radiative cooling at cloud top could destabilize the atmosphere and give rise to the mixed layers (quasi-vertical contours of potential temperature, meaning heat mixing within those layers), similar to the signature evidenced by Mars Global Surveyor and Mars Reconnaissance Orbiter [Hinson et al. submitted to Icarus 2014].

a recent mission orbiting around Mars, but those features were actually present in earlier Mars Global Surveyor occultations – they simply went unnoticed in a dataset more than ten years old because the existing temperature data were never displayed as potential temperature which clearly emphasizes the presence of mixed layers as zero-slope signatures along the vertical axis. Further analysis of the spatial variability of those nighttime mixed layers shows the aphelion cloud belt correlates nicely with the detected mixed layers in the nighttime Martian atmosphere. This makes the radiative effect of water-ice clouds a plausible cause for the presence of those mixed layers. Nevertheless, the locations where nighttime mixed layers are found (Tharsis, Elysium, Meridiani) also correlates with high topography, deep daytime boundary layer [10, 11], significant gravity wave activity [12], which might produce mixed layers when breaking occur, and large tidal perturbations [3]. Further analysis is thus needed before a clear conclusion could be drawn.

Preliminary results and Perspectives Our mesoscale simulations show that the temperature structure is significantly different with and without the radiative effects of clouds, and that those differences can be very strong locally. Moreover, Figure 1 shows that our simulations reproduce nighttime mixed layers in agreement with the radio-occultations of Hinson et al. [submitted to Icarus, 2014]. Both the extent and the altitude of the mixed layers can be reproduced. The mixed layers appears below the cloud: enhanced radiative cooling by water-ice particles at the top of the cloud (our simulations indicate a rate of -4 K per hour approximately) is able to destabilize the temperature profile and possibly give rise to convective motions able to mix heat to form an adiabatic layer. This mechanism of radiative destabilization is also well-known on Earth e.g. in marine boundary layer clouds. To further demonstrate that the radiative effect of clouds is the main cause for the nighttime mixed layers, we run simulations without the radiative effect of clouds : those do not show mixed layers at the altitudes suggested by observations. Gravity waves resolved by our mesoscale simulations do produce mixed layers, but their vertical extent is much thinner, their altitude of occurrence is higher, and their region of occurrence is mostly above volcanoes, making the gravity waves source less likely to produce the nighttime miwed layers. Those first results warrant further investigation : validation of the cloud structure predicted by our model, sensitivity to dust scavenging, use of a cloud-resolving model to infer what could be the strength of the putative convective motions within the water-ice cloud. The implications of nighttime mixed layers associated to water-ice clouds on Mars are numerous : mechanisms for snow precipitation, understanding of the past and present water cycles on Mars, impact of mesoscale motions on the exploration of Mars and the large-scale climate, comparisons with clouds in other planets in the solar system, ... The impact of the radiatively active water-ice clouds on mesoscale circulations in the daytime also needs to be explored. Those perspectives will be detailed and discussed at the conference.

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