MICROPHYSICAL CYCLE OF EVOLUTION OF THE NORTHERN MARTIAN SEASONAL CONDENSATES

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Introduction: The detailed CO_2 and water cycles on Mars are strongly determined by both the local thermal balance of the surface and the availability of the volatiles in the atmosphere and at the surface. The composition and physical state (mixing modes, temperature, …) of the ices at the surface and in the top layers of soil can determine the exchange fluxes with the atmosphere. It is thus necessary to understand the spatial and temporal evolution of these parameters in the condensate deposits to constrain the sources and sink of volatiles during a seasonal cycle. This may lead to improve the Martian climatic models by taking into account new volatile sources/sinks or processes influencing the thermal and volatile balances.

Overview of the northern condensates cycle: The northern Martian condensate cycle has been only poorly monitored from ground based observations due to unfavorable observation geometry during northern spring. The orbital observations of the past decade have accumulated a large amount of data pertaining to different aspects of the condensation/sublimation cycles both in the southern and northern hemispheres [1,2]. The OMEGA/Mars Express spectroscopic observations are especially well adapted to directly monitor the temporal evolution of the abundance, physical state and distribution of the CO_2, water and dust components of the condensates through their visible and near-infrared spectral signatures [3].

Condensation observations: Water frost condensation and sublimation cycle has been observed around 45° latitude by Viking 2 lander [4] but it has been only poorly monitored at the global scale. Condensation of CO_2 is even less documented because it occurs mostly during the polar night, precluding solar reflectance measurements, down to only a few degrees below the terminator, thus under difficult illumination conditions (low flux, large atmospheric absorption and aerosol scattering).

Sublimation observations: The observation conditions of the spring sublimation of the condensates are much more favorable and a large set of data have now been accumulated over several Martian seasons [1, 2, 5]. A detailed study of the spring evolution of the northern seasonal condensates has been performed over one full Martian year using OMEGA/Mars Express data and is presented in a companion paper [6].

Possible scenarios of microphysical evolution: To understand the possible sublimation scenario, both microphysical and at the hemispheric scale, it is first necessary to infer the structure of the condensates, and thus a condensation scenario, just before the start of the sublimation stage. Then the spatio-temporal evolution of this initial layer subjected to spring sublimation can be followed using the observations.

Condensation scenario: There are typically two stages during the condensation of the frosts occurring during late autumn and winter. First a condensation of a thin layer of pure water frost and then, when the surface temperature decrease, the condensation of the meter thick CO_2-rich ice layer, including small amounts of water ice and dust. The condensation of water frost first starts during the daily night and completely sublimate during the day. The latitude-time dependence of the first frosts will depend on the partial water vapor pressure in the atmosphere. In a second step, when the sun is low enough, the frost persists all day long [4]. At this stage the accumulation rate should increase due to the positive feedback of the surface albedo on the thermal balance. This frost may also partly diffuse inside the upper layer of soil and adsorb on mineral grains or possibly form some ice-cemented crust. Vapor diffusion and condensation at some depth will occurs if a negative thermal gradient occurs at some time of the daily cycle. In a second stage, when the thermal balance allow the surface temperature to drop below the CO_2 freezing point, CO_2 frost can start condense including tiny amounts of water ice grains (< 1 %) and dust particles (< 0.1 %). This condensation should be first a daily condensation/sublimation cycle but at high latitudes, typically northern a latitude 5-10° below the mid-day terminator, condensation will occurs continuously at a rate mostly by determined by the surface CO_2 thermal emission. At lower latitudes, although the daily average balance is negative and net accumulation occurs, the daily condensation/sublimation cycle should still be effective. The thin water frost underneath should then be "frozen" at the CO_2 ice temperature and water vapor diffusion inside the regolith no more efficient. The initial H_2O frost condensation and its associated surface albedo decrease should help in lowering the surface temperature and thus may initiate CO_2 condensation earlier (or at lower latitude) than without this precursor frost. During the water frost stage and roughly the first half of the CO_2 frost condensation stage the thermal inertia of the first decimeters of the surface should play a major role on the surface temperature and thus in determining whether H_2O ice and then CO_2 ice can condense at the surface. It should also affect the condensation rate [7]. Local and general slope orientations and surface albedos may also play a role on determining the sign of the thermal balance but only up to shortly after the first CO_2 condensations. After this point CO_2 condensation mostly occurs in the polar night at high latitudes where slopes and albedo will have no more effect on the thermal balance. The result should be a layer of CO_2-rich ice, with thickness globally increasing from about 50° latitude to the pole, on top of a millimeter-thick layer of H_2O frost, and possibly a few millimeters or centimeters of icy soil. To which extent microphysical evolutions of these frosted soil, H_2O frost and CO_2 ice layers occurred during these condensation stages is still an open question. The occurrence of condensation/sublimation cycles at the beginning of each of these stages should have at least modified the bottom part of these layers, especially at low latitudes.

Sublimation scenario: Our microphysical scenario of sublimation is mostly based on the results obtained from the spatio-temporal mapping of the CO_2 and H_2O ices during northern spring [6] completed with global statistical analysis [8] and local radiative transfer modelling of the layered condensates [9] using optical constants of CO_2 and H_2O [10, 11]. The major results are:

- A CO_2-free water ice annulus is present around the CO_2 ice rich deposits. Before the beginning of the recession it likely corresponds to the daily water frost cycle stage and is extended (8°). During the CO_2 ice sublimation stage the narrower dusty water ice annulus (2°-3° wide) correspond to the ice released by the CO_2 ice layer (bottom icy soil and water frost layers + ice and dust grains trapped inside the CO_2 layer). Diffusion of water vapour from this ice layer through the underlying soil may be boosted due to strong negative ice-soil thermal gradient probably present at that stage.
- Water ice detected southern of the albedo limit. It probably corresponds to dusty water ice or icy soil segregated with defrosted soil. Progressive de-icing and water desorption of the soil occurs at this stage.
- CO_2 ice is systematically detected southern its thermal stability limit as determined by TES [12]. A spatial segregation occurs between the dusty water ice lag and the CO_2-rich ice layer.
- CO_2 ice reappear at the surface in late spring (Ls=50-70°) at several locations where it had disappeared. This peculiar behavior may be explained by recondensation at higher latitudes of water vapor sublimated from the ice annulus and cold trapped at the surface of the CO_2 ice rich deposits [6, 8]. A millimetres thick layer of H_2O ice may form, hiding the CO_2 ice, until strong sublimation of CO_2 ice occurs in late spring disrupting the H_2O ice layer.

Difference with the southern volatile cycle: The main differences of the southern condensates are the much lower water vapor amount in the atmosphere. Thus the initial frost condensation should be very limited before CO_2 condensation occurs and the amount accumulated within the CO_2 frost is about an order of magnitude lower [3]. Water ice segregated at the edge of the CO_2 condensates during recession is almost nonexistent or should be probably limited to less than a few tenth of a degree. Thus water recondensation on top of the CO_2 condensate should be far less efficient than in the north and certainly not enough to create an optically thick water ice layer that can hidden the infrared CO_2 signatures.

Conclusion: The knowledge of the structure and composition of the condensates and their spatial and temporal evolutions should help to understand the various microphysical processes occurring during their deposition and condensation stages. These processes should strongly constrain the fluxes of volatiles between the atmosphere and the surface. The future climatic Martian models should include the effective locations of the different sources and sinks of water vapour evidenced by these studies.

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