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Physical state and temporal evolution of icy surfaces in the Mars South Pole

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Abstract On Mars H_2O and CO_2 ices can be found as seasonal or perennial deposits notably in the polar regions. Their bidirectional reflectance factor (BRF) is a tracer of their evolution which is still not completely understood. It is a key parameter for characterizing the composition and the physical state, as well as for calculating the bolometric albedo, the energy balance of the icy surfaces, and thus their impact on the martian climate. The BRF is potentially accessible thanks to the near-simultaneous multi-angle, hyperspectral observations of the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) implying 11 viewing angles in visible and infrared ranges. In previous research [1, 2] we put forward the Multi-angle Approach for Retrieval of Surface Reflectance from CRISM Observations (MARS-ReCO), an algorithm that characterizes and corrects the aerosol scattering effects. The aerosol optical depth (AOD) and the BRF of surface materials are retrieved conjointly and coherently as a function of wavelength. In this work, we apply MARS-ReCO on time series of CRISM sequences over different regions of interest in the outskirts of the south permanent polar cap. The time series span from mid-spring to late summer (L_s=210-320°) during which the CO_2 ice sublimates sometimes revealing H_2O frost and defrosted terrains. Thanks to the atmospheric correction, we are able to identify various classes of spectrophotometric behavior. We also note a regular increase of the directional-hemispherical surface albedo during the period of the time.

Data In this paper we restrict the analysis to the visible channel (VIS) of the CRISM instrument (0.4-1.0 μm). The minimum solar incidence is 64° and the maximum is 75° implying varied but large ranges of phase angles (typically 40-115°) suitable for the use of MARS-ReCO and for the physical characterization of the icy materials. No ground truth is available for the region implying the calculation of quality criteria by the algorithm itself and a procedure of cross-validation.

Methods In order to facilitate the simultaneous processing of the multi-angle Top Of the Atmosphere (TOA) reflectance factor of one CRISM observation, the spectra corresponding to the eleven scans are rearranged in a common geographical grid of super-pixels (i.e., terrain units sensed at more than one geometry) to create a single data set which facilitates the access to photometric curves. Each spatial bin is ≈ 200 meters in size. Independently for each wavelength MARS-ReCO performs the processing of TOA photometric curves $\mathbf{R}^C = \{R_1^C, \ldots, R_{Ng}^C\}$ where Ng is the number of available angular measurements. MARS-ReCO retrieves conjointly the AOD and the BRF of surface materials. The inversion procedure exploits the spatial homogeneity of the atmosphere opacity relative to the surface. See [1] and [2] for a complete description of the processing. A first analysis of the retrieved surface BRF values consists of performing a non-supervised k-means classification of the phase curves extracted at a wavelength of 750 nm for each CRISM observation. Maps of the quasi nadir BRF and directional-hemispherical albedo are also computed and co-registered between observations allowing to extract the temporal evolution of these physical quantities at different locations.

Results MARS-ReCO gives results with good accuracy comparable to what is achieved for the processing of controlled synthetic data or real data acquired for moderately anisotropic mineral surfaces under usual incidence (40-60°). Even though the atmospheric conditions vary largely during the period of the time series we note a continuous increase of the directional hemispheric albedo of the icy surface (≈ 20-50%) until $L_s \approx 270°$, followed by a decrease during the summer season (Fig. 1). Furthermore we note three to five classes of phase curves showing a good coherency between observations. The most prevalent class is dominantly forward scattering CO_2 ice but with a backscattering secondary lobe. When the defrosting is well advanced, as for observation FRT144E9 (Fig. 2), very distinct photometric behaviors become apparent. The "blue" class corresponds to parts of the CO_2 ice unit that have a high concentration of sub-pixel topography (CO_2 type1). The phase curve presents a moderate and monotonic decrease of reflectance from the low to the high phase angles. It is likely controlled by the presence of extended shadows (sun low on the horizon) that are differently visible depending on the viewing geometry. The "magenta" class corresponds to parts of the CO_2 ice unit that is generally smoother (CO_2 type 2). The phase curve has a forward scattering lobe (large phase angles) and a backward scattering lobe (low phase angles). They are both modest, the former being linked with volume scattering and the latter being due to shadows. The "red" class is the unit of dust mixed with minute amount of water ice (mostly defrosted terrains). It is backscattering with a relatively strong monotonic decrease in reflectance from the low to the high phase angles (the dominant role of shadows). The "green" class corresponds to compositional transition zones with a high concentration of H_2O frost. It is the most anisotropic with two prominent diffusion lobes, a forward (volume scattering) and a backward (surface scattering), the latter being predominant.

Conclusions: In this study we recognize different classes of icy surface phase curves likely determined by their composition, grain micro-texture, and surface roughness that we will determine by modeling. Prior to sublimation, CO_2 ice shows a continuous increase of the nadir reflectance factor (≈20-50%) until $L_s \approx 270^o$, followed by a decrease during the summer season. Based on the mapping of the ice physical properties along with the examination of high resolution images, we will recognize in the near future the most relevant controlling processes: sublimation, structural modifications of perennial ice (e.g. cracks), dust settling and removal linked with atmospheric activity, etc.

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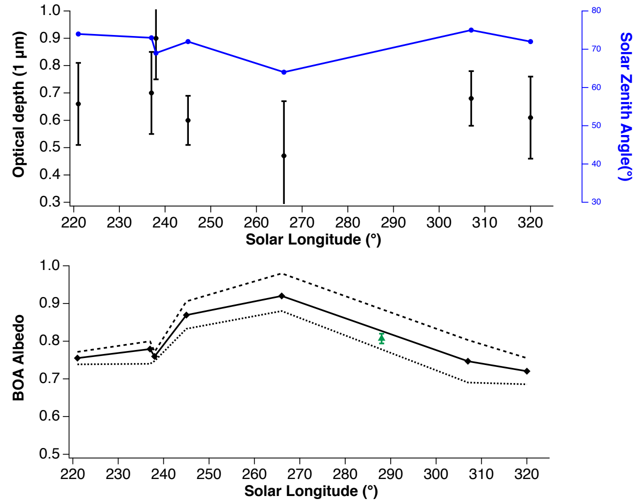

Figure 1: Time evolution for one of the sites. Top: incidence angle and AOD. Bottom: directional hemispheric albedo (mean behavior and standard deviation).

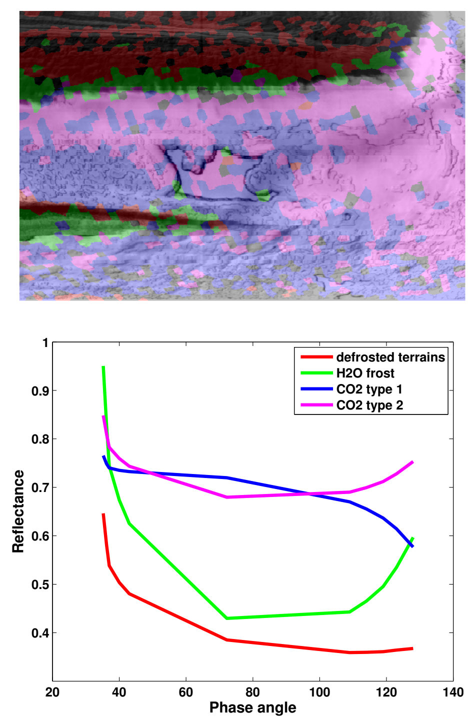

Figure 2: Classifying the phase curves at 750 nm for observation FRT144E9. Top: distribution of the color-coded photometric classes over the nadir full resolution CRISM scan. Bottom: mean phase curve of the classes.

References

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