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Defrosting processes on the Russell crater megadune of Mars: quantitative analysis and interpretation

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Introduction and summary

The megadune located in the Russell Crater of Mars is the siege of a complex defrosting sequence implying seasonal CO2 and a small amount of water ice in each spring [3]. Besides on its pole facing slope, the dune displays gullies thought to have been carved by liquid water although they could also be related to dry avalanches triggered by the defrosting activity. In order to improve our understanding of seasonal versus secular phenomena, we conducted a quantitative analysis of a time series of joint image pairs : hyperspectral (CRISM) and high-resolution panchromatic (HiRISE), both sensors operating on board MRO. Automatic extraction and characterization of sublimation structures (e.g. dark spots) in the HiRISE images is performed on the basis of their geometry or their texture with image processing methods. The different conditions of CO2 ice are mapped by applying unsupervised linear spectral unmixing methods on the CRISM images. Modeling the spectral signatures with a radiative transfer model reveals the structural organization of the ice and its level of dust contamination. Finally we propose a joint interpretation of all the resulting products for understanding the defrosting processes and their role in shaping the dune.

1. Methods

A key preliminary step to achieve is the fine co-registration of both type of imagery. The processing of one given HiRISE image is performed with a multi-scale method in several stages : Pixel Shape Index classification [4], geometric filtering and regularization. The extraction of the endmembers - spectra deconvolved of effects related to the limited spatial resolution of the CRISM sensor and interpreted as different physical conditions of CO2 - is achieved using unsupervised linear spectral unmixing methods VCA and MVC-NMF [2]. The spatial distribution of the endmembers is computed in the form of maps giving their respective surface fraction in each pixel. Modeling of the spectra is performed with a semi-analytical model aimed at simulating the reflectance of a rough slab layer containing impurities [1]. The temporal dimension of observations allows us to locate and quantify the changes.

2. Interpretation

We perform the joint interpretation of the different products derived from the analysis of the CRISM and HiRISE data : (i) the dark spot distribution maps derived from the morphological analysis (ii) the corresponding estimation of the growth (shrinking) rate of the spots as a function of the position on the dune (iii) the distribution of the surface fractions occupied by the different physical conditions recognized by spectral unmixing.

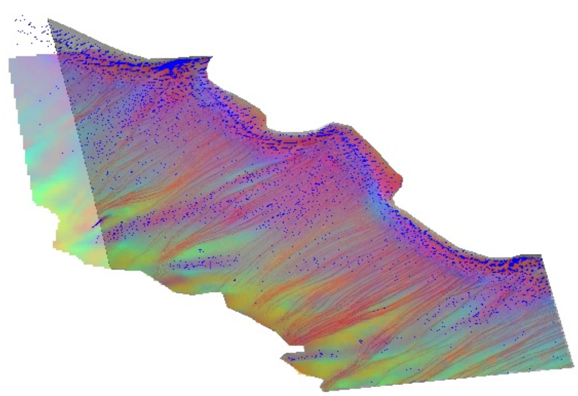

Figure 1: stacking of two products characterizing the Russell dune at a given date: (i) detection mask of the active areas in blue (ii) color composite showing the spatial distribution of the different CO2 ice conditions (structure and dust contamination).

At Ls=158° we note a very intense activity close to the crest of the dune with the growing of numerous individual spots. Conjointly the abundance maps show a high superficial contamination of the ice by the dust. On the main slope numerous small spots are appearing where granular ice is abundant. At the contrary, area dominated by a slab of compact ice on top of granular ice are devoid of spots. In a time span of 14°Ls the superficial contamination shows a dramatic spatial expansion on the slope of the dune. The spot growth rate is substantial in 4 topographical controlled regions located on the dune slope and separated by gaps of no activity. We also note flow like features associated with the deepest gullies with very high level of dust contamination. However they do not show substantial spot growth except in their upper part. Consequently we can infer that the dust contamination on the slope of the dune has two distinct origins: the activity of the neighboring spots (local source) one the one hand and the avalanches of dust coming from the crest ("distant" source) on the other hand. At Ls=172° limited area of granular weakly contaminated CO2 ice appear on the crest. We interpret the latter phenomena as re-condensing CO2 gas. Between Ls=172° and Ls=179° a slab of compact ice on top of granular ice is detected in some area. We observe the migration of this physical condition from the bottom part of the dune to the upper part. At Ls=179° we note the appearance of a new spectral endmember interpreted as the complete metamorphosis of the CO2 ice into a compact slab directly in contact with the sandy substratum of the dune. Between Ls=179° and Ls=181° the abundance of granular weakly contaminated CO2 ice builds up in some places along with an increased apparent reflectance factor. Once again we interpret the latter phenomena as freshly condensed CO2 gas in the granular form. During the same period the upward migration on the slope of the dune of the slab of compact ice on top of granular ice also continues. At Ls=181° the activity of the spots is much reduced compared to earlier times both in the slope and along the crest of the dune. The completely metamorphosed ice is mostly abundant in discontinuous area along the crest of the dune where are situated the most extended, sometimes coalescent spots. In addition this condition is also widespread in the western part of the slope. At contrary it has been replaced by an optically thick layer of dust - likely the completely defrosted sandy substratum- in the flow like features and in the large dark area all in the lower half part of the slope.

3. Conclusions

Our study documents in great details the evolution of the CO2 ice physical condition and degree of contamination by dust as well as the associated phenomena prior to the complete sublimation of these seasonal deposits. The main conclusion of our study is that intense ejection of dust occurs in multiple places on the crest of the dune Russell because of the CO2 sublimation. This phenomenon leads to the accumulation of a thick dust layer on the ice that causes dust avalanches channeled in the gullies. Thus it is now established that the gullies are currently not active by the flow of water but by the flow of dust. In addition we note two remarkable observations: (i) the evolutionary path of CO2 ice implies a top-down metamorphosis associated to sublimation leading to a slab of decreasing thickness (iii) the condensation of CO2 gas back to the ground in the form of granular weakly contaminated CO2 ice occurs in some places.

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