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The role of sublimation and condensation on the development of ice sedimentation waves on the North Polar Cap of Mars

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Abstract

Mass and energy balance of ice sheets are driven by complex interactions between the atmosphere and the cryosphere. For instance, it has been demonstrated that feedbacks between katabatic winds and the cryosphere lead to the formation of sedimentation waves at the surface of Martian and terrestrial ice sheets [1, 2, 3 and 4]. Here we explore the role of sublimation and condensation of water vapor in the development of these sedimentation waves. We conduct this study by complementary observational and numerical investigations on the North Polar Cap of Mars.

1. Ice sedimentation waves on Mars

Spectacular fields of ice sedimentation waves occur on the Gemina Lingula lobe of the North Polar Cap of Mars. These waves are 10 km in wavelength and about 20 m in amplitude. Their downwind slopes are generally steeper than their upwind slopes and their crests develop at high angles to the katabatic wind streamlines. Investigations of complementary data sets reveal that these sedimentation waves grow and migrate upwind in response to the development of an asymmetric ice accumulation pattern [1 and 4]. Their shallow-dipping upwind sides, their tops and the intervening troughs are covered by young fine-grained ice and occasional longitudinal ridges, indicative of net accumulation. On the other hand, their steep-dipping downwind sides expose smooth surfaces of coarse-grained ice, indicative of reduced net accumulation associated with metamorphism.

2. Physical processes at the surface of the North Polar Cap of Mars

The Martian atmosphere is thin (7 mbar), cold (220 K) and dry (< 80 μm-pr) [5]. These extreme climatic conditions set up a water cycle that is controlled by change of state between ice and water vapor. The North Polar Cap of Mars experiences a permanent katabatic wind regime [6] and periods of accumulation by condensation (autumn and winter) alternate with periods of ablation by sublimation (spring and summer). Ice redistribution at the surface of the North Polar Cap is therefore driven by the interaction of winds and sublimation/condensation of water vapor [2, 3 and 4].

3. Model of mass transfer on a wavy surface

We designed a numerical model to explore the coupled interaction between the mass transfer of water vapor and a steady unidirectional flow on a wavy surface. The mass transfer of water vapor is computed by an equation of transport-diffusion and the flow by Navier-Stokes equations [7]. The model solves the water vapor content as a function of the Martian solar longitude and therefore as a function of surface and atmosphere temperatures. We set as input data a logarithmic boundary layer profile tuned with atmospheric models [6]. We impose at the ice surface the saturation pressure of water vapor and let evolve the water vapor profile in the resolution domain. The model was validated with different benchmarks and applied to flat and wavy surfaces on Mars.

4. Results

At the North Polar Cap temperatures, the rate of water vapor mass transfer increases with the wind speed. Above wavy surfaces, the maximum of water vapor flux coincides with the maximum shear stress, located on the upwind sides of the waves. On the downwind sides, mass transfer rates are smaller. These results are the same for sublimation (ablation) and condensation (accumulation). During a given simulation, the ice waves do not experience simultaneous accumulation and ablation as it would be the case, for instance, for aeolian sand dunes. These results mean that if the accumulation rate is greater than the ablation rate the waves will migrate upwind by redistribution of ice by sublimation and condensation of water vapor.

5. Conclusion

Our observations and simulations are in accordance with the hypothesis that the sedimentation waves could migrate upwind due to enhanced accumulation on their upwind sides and reduced accumulation on their downwind sides over a Martian year (Figure 1). Our model shows that the dynamics of these patterns result from the interaction between the fluid flow and the wavy icy surface trough mass transfer. The initiation of the sedimentation waves is probably due to oscillations in the lower atmosphere.

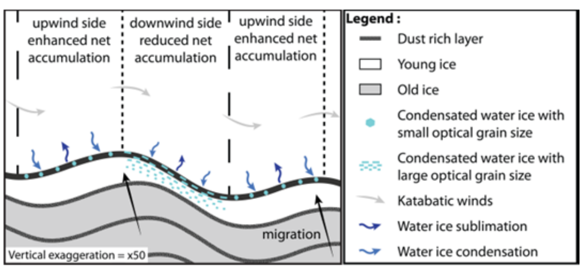

Figure 1: Interpretative cross-section of a part of Gemina Lingula, illustrating the surface topography, the internal stratigraphy and the physical processes involved in the dynamics of the ice sedimentation waves over a year.

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