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Periodic bedforms generated by sublimation on terrestrial and martian ice sheets under the influence of the turbulent atmospheric boundary layer

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The redistribution of surface ice induced the wind flow may lead to the development and migration of periodic bedforms, or “ice ripples”, at the surface of ice sheets. In certain cold and dry environments, this redistribution need not involve solid particle transport but may be dominated by sublimation and condensation, inducing mass transfers between the ice surface and the overlying steady boundary layer turbulent flow. These mass transfers diffuse the water vapour sublimated from the ice into the atmosphere and become responsible for the amplification and propagation of ripples in a direction perpendicular to their crests. Such ice ripples, 24 cm in wavelength, have been described in the so-called Blue Ice Areas of Antarctica. In order to understand the mechanisms that generate and develop these periodic bedforms on terrestrial glaciers and to evaluate the plausibility that similar bedforms may develop on Mars, we performed a linear stability analysis applied to a turbulent boundary layer flow perturbed by a wavy ice surface. The model is developed as follow. We first solve the flow dynamics using numerical methods analogous to those used in sand wave models assuming that the airflow is similar in both problems. We then add the transport/diffusion equation of water vapour following the same scheme. We use the Reynolds-averaged description of the equation with a Prandtl-like closure. We insert a damping term in the exponential formula of the Van Driest mixing length, depending on the pressure gradient felt by the flow and related to the thickness of the viscous sublayer at the ice-atmosphere interface. This formulation is an efficient way to properly represent the transitional regime under which the ripples grow. Once the mass flux of water vapour is solved, the phase shift between the ripples crests and the maximum of the flux can be deduced for different environments. The temporal evolution of the ice surface can be expressed from these quantities to infer the growth rate, migration direction and velocity of the ripples.

The present approach has been first used to model the atmospheric flow developing over wavy terrestrial ice bedforms in the Blue Ice Areas of Antarctica. Both the predicted preferential wavelength and propagation direction of the ice ripple have been found to be in agreement with the observations. The present model has subsequently been applied to the same flow configuration but on Mars. Ice ripples are indeed likely to exist there, given that temperature and pressure conditions in the martian atmosphere favors sublimation/condensation as the dominant mass-transport process. The model has proved able to predict not only the development of ice-ripple on Mars (i.e it showed that some most amplified wavelength also exist under Martian atmospheric conditions) but also both their wavelength and propagation direction. The preferential wavelength of ices-ripples on the Martian polar caps appears to be much larger than on the Earth. Finally, a good match between the most likely ice-ripple wavelength predicted by the model and those deduced from recent available observations of the surface of Martian polar caps is shown.