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Formation of supraglacial channelization underlying the snowpack

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Glacier surfaces exhibit an amazing variety of meltwater-induced morphologies, ranging from small scale ripples and dunes on the bed of supraglacial channels to meandering patterns, till to large scale drainage networks. In spite of the structure and geometry of these morphologies play a key role in the glacier melting processes and climate changes make urgent their understanding, the physical-based modeling of such spatial patterns have attracted less attention than englacial and subglacial channels. In order to fill this gap, our work concerns the large scale channelization occurring on the ice slopes and focuses on the role of snow cover on the wavelength selection processes during the channelization inception.
In a recent study[1], two of us showed that the morphological instability induced by a free-surface water stream flowing over an ice bed is characterized by transversal length scales of order of centimeters. Being these scales much smaller than the spacing observed in the channelization of the drainage networks (that are of order of tens of meters), it follows that the mere meltwater film flowing on bare ice is not able to initiate the network formation. Starting from this theoretical result and by observing that network inception is likely to occur when the glacier is still covered with snow and a phreatic aquifer develops in the snowpack region close to the ice surface, we propose a fluid-dynamical theory where the free-surface flow in the porous snowpack is the key ingredient to explain the large observed wavelengths in the surface drainage networks.
We perform a linear stability analysis of the physical system made up of the snowpack portion occupied by the aquifer together with the superficial region of the ice slope. A rigid snow matrix is assumed and the flow field is modeled by Darcy's law, while the water energy balance includes viscous dissipations and convective heat transfer to snow and ice. Under the assumption of small Stefan number, the differential eigenvalue problem is solved analytically and the dispersion relation is obtained from Stefan equation.
As main outcome of such an analysis, the morphological instability of the ice-snowpack interface is detected and investigated in a wide range of the independent parameters: longitudinal and transversal wavenumbers, glacier slope, Reynolds number, free surface temperature and snow temperature. The most remarkable result is that critical transversal wavelengths of order of tens of meters are obtained, which are in general agreement with the patterns observed on glaciers during the melt season.
In conclusion, we demonstrate that snow plays a key role in the inception of channelization, and provide an analytical model able to predict the dominant channel spacing in the supraglacial networks draining meltwater.

[1] Camporeale, C. & Ridolfi, L. (2012) Ice ripple formation at large Reynolds number. J. Fluid Mech. 694, 225-251.