Geophysical Research Abstracts
Vol. 15, EGU2013-10987, 2013
EGU General Assembly 2013

On the influence of debris in glacier melt modelling: a new temperature-index model accounting for the debris thickness feedback

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The increase of rockfalls from the surrounding slopes and of englacial melt-out material has led to an increase of the debris cover extent on Alpine glaciers. In recent years, distributed debris energy-balance models have been developed to account for the melt rate enhancing/reduction due to a thin/thick debris layer, respectively. However, such models require a large amount of input data that are not often available, especially in remote mountain areas such as the Himalaya. Some of the input data such as wind or temperature are also of difficult extrapolation from station measurements. Due to their lower data requirement, empirical models have been used in glacier melt modelling. However, they generally simplify the debris effect by using a single melt-reduction factor which does not account for the influence of debris thickness on melt.

In this paper, we present a new temperature–index model accounting for the debris thickness feedback in the computation of melt rates at the debris-ice interface. The empirical parameters (temperature factor, shortwave radiation factor, and lag factor accounting for the energy transfer through the debris layer) are optimized at the point scale for several debris thicknesses against melt rates simulated by a physically-based debris energy balance model. The latter has been validated against ablation stake readings and surface temperature measurements. Each parameter is then related to a plausible set of debris thickness values to provide a general and transferable parameterization.

The new model is developed on Miage Glacier, Italy, a debris cover glacier in which the ablation area is mantled in near-continuous layer of rock. Subsequently, its transferability is tested on Haut Glacier d'Arolla, Switzerland, where debris is thinner and its extension has been seen to expand in the last decades.

The results show that the performance of the new debris temperature-index model (DETI) in simulating the glacier melt rate at the point scale is comparable to the one of the physically based approach. The definition of model parameters as a function of debris thickness allows the simulation of the warming/insulating effect suggested by the Ostrem curve. We show that it is important indeed to take into account the effect of debris thickness also in empirical approaches, especially for thin debris mantles. The new DETI model is an innovative approach that can be included in continuous mass balance models of debris-covered glaciers, because of its limited data requirements. As such, we expect its application to lead to an improvement in simulations of the debris covered glacier response to climate.