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Mass balance modelling of a debris cover glacier: the case study of Miage Glacier, Italy

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The growing interest in the response of glaciers to a changing climate has put large attention on the development of models of glaciers response, and mass balance models in particular, and efforts are been made to improve their accuracy and predictive skills. A key component that is receiving increasing attention is the role played by debris cover on the response of glaciers. Thin layers of debris enhance melt by increasing absorption of shortwave radiation, while thicker covers reduce melt by insulating it. This has an effect on the surface energy balance, melt rates under debris, runoff production, mass balance and ultimately glacier flow. An accurate representation of the effect of debris seems therefore important, also in view of the significant increase of the debris cover extent over glaciers associated to a warming climate. Distributed debris energy-balance (EB) models have been recently developed to account for the melt rate enhancing/reduction due to a thin/thick debris layer, respectively. Application of EB models at the glacier and regional scale however is associated with an increase of computational efforts and large uncertainties related to the spatial changes in the debris cover properties (thickness and conductivity) as well as extrapolation of the input meteorological data such as wind, temperature and radiative fluxes.

In this paper we present a model for simulations of past and future mass balance of debris covered glaciers that relies on more limited input data than required by a full EB model. The model is tested against simulations from an EB model. The new debris enhanced temperature-index model (DETI) accounts for the debris thickness feedback (Ostrem curve) through a parameterisation that includes variable debris thickness. The model is developed and then used for continuous simulations on the extensively debris-covered Miage Glacier, Italy.

First, we run the distributed debris energy balance model for the ablation season 2005, when all the meteorological variables required as input to the physically based approach are available. To evaluate the performance of the empirical approach, we then compare the energy balance model outputs against the simulations of the new DETI model. The model outputs are also validated against ablation stake readings at 22 locations. Second, the empirical approach is run for the period 2005-2011 and continuous time series of glacier mass balance are compared to those obtained with the same empirical approach with simple reduction coefficients. Accumulation is modelled by spatially distributing precipitation with a gradient and accounting for redistribution of snow by gravity.

Our main result is that an empirical approach accounting for the warming/insulating effect as a function of the debris thickness, as the DETI model, is able to simulate the glacier melt rate similarly to the more complex energy-balance model. We also show a clear difference with respect to the model with simple reduction parameters that does not take into account the variable effect of debris thickness.