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On the importance of including the heat conduction into the snow and icepack in glacier energy-balance modelling

M. Carenzo (1), F. Pellicciotti (1), S. Rimkus (1), J. Helbing (2) and P. Burlando (1)

(1) Institute of Environmental Engineering ETH Zurich, (2) Swiss Federal Institute of Aquatic Science & Technology EAWAG

Understanding the energy-balance at the glacier-atmosphere interface is essential to model the interaction between glaciers and climate and a key step to study the mass balance of glaciers. Heat conduction into the snow and icepack (also referred to as subsurface flux) is a component of the surface energy-balance, which is often neglected in numerical studies and commonly assumed to be small during the ablation season when melting takes place. In these conditions, many models assume the snowpack to be at melting point (zero-degree assumption). This is not the case at night and for certain climatic conditions, for instance when a strong radiative cooling occurs (as in the dry climatic settings of the dry Andes of Chile), and can lead to a significant overestimation of computed ablation, because part of the energy that in reality heats up the snowpack to melting point is used instead for melt.

Various studies used and validated energy-balance models that do not include the subsurface heat flux, also showing that they can be successfully used for simulation of melt. Conversely, other works demonstrated that neglecting internal heat conduction leads to a considerable overestimation of ablation. Evidence on the applicability of the zero-degree assumption and the magnitude of the fluxes is thus not conclusive. This analysis aims at contributing to the ongoing debate.

Using meteorological measurements from automatic weather stations the zero-degree assumption is tested, and the error that is made by neglecting subsurface fluxes is quantified. We present the results obtained by running an energy-balance model with

and without inclusion of the internal heat flux and by testing the model performance against measurements at both ablation stakes and ultrasonic depth gauges. The subsurface fluxes are calculated by means of a two-layer model, and assuming that 36 % of the total incoming shortwave radiation is absorbed by the surface layer, while the rest penetrates into the snowpack. Meteorological and ablation data from Gornergletscher and Haut Glacier d'Arolla in the Swiss Alps collected over several ablation seasons provide the field observations to test the zero-degree assumption over seasons characterised by different climatic conditions. Moreover, the study also includes data from Juncal Norte glacier in the dry Andes of central Chile, where climatic conditions can be expected to favour strong radiative cooling at night and the related cooling of the snowpack, thus showing that under these conditions, the zero-degree assumption most likely does not hold.