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Stability information supplied by the snow cover model SNOWPACK

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The one-dimensional snow cover model SNOWPACK (Lehning et al., 1999) simulates snow stratigraphy using input data from automatic weather stations. The model provides information on the snow conditions reproducing most of the physical processes affecting the snow cover. For avalanche forecasting direct information on snow stability is most wanted. Lehning et al. (2004) introduced three stability indices, namely the natural stability index (S_N), the skier's stability index (S_{K38}) and the deformation index (S_d). They are mostly based on the shear strength of snow. Schweizer et al. (2006) modified the S_{K38} by introducing two parameters (difference in grain size and in hardness) which are related to snow stratigraphy (SSI). Further, they developed a classification, based on the SSI and S_{K38} that assigns a stability class (poor, fair, good) to simulated snow profiles (stability class index).

Schirmer et al. (2010) compared the characteristics of simulated and observed weak layers with observed stability conditions using the SSI to select the potentially most critical weak layer within a simulated snow profile. Based on their statistical analyses they concluded that SNOWPACK is useful to estimate snow stability. However, they noted that the relation of some weak layer properties to snow stability was counterintuitive and contrary to previous results derived from analysing manually observed profiles. Other analyses (e.g. Monti et al., 2009) did not find this discrepancy. The objective of the present work is therefore to solve the problem of these contradicting findings.

Picking the weak layer with the help of the SSI proved to be the most crucial step in estimating snow stability. We compared various versions of SNOWPACK and the corresponding implementation of SSI. In fact, with the presently implemented version, the SSI has in about 40% of the cases difficulties in finding the potentially most critical weak layer (Figure 1). Using the same data as Schirmer et al. (2010), but excluding all cases where we were sure that the weak layer was not detected correctly, we found that most weak layer parameters were either not related with stability, or the relation was not statistically significant. Integrating the simulated shear strength instead of the hand hardness index improved the discrimination power of the SSI. Based on our analyses, we suggest to recalibrate the SSI and/or to introduce a new method for assessing snow stability from simulated snow stratigraphy. The process of weak layer picking and the evaluation of its strength have to be separated. In any case, the new method must be robust against changes with in the modelling framework – otherwise repeated recalibration is needed.

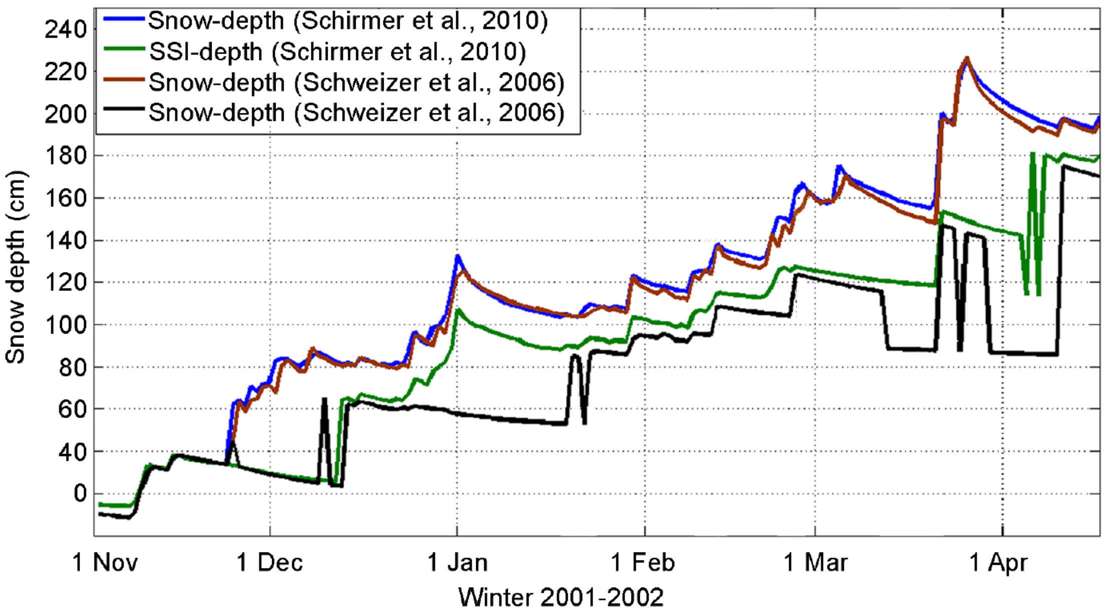

Figure 1: Comparison of the SNOWPACK simulations (winter 2001-2002) for the Weissfluhjoch study plot, used by Schweizer et al. (2006) and Schirmer et al. (2010). In the case of Schirmer et al. (2010), the SSI (green line) identifies the weak interface just below the depth of ski penetration from about the mid of December 2001 to the mid February 2002. Throughout this period, the depth indicated by the SSI is most probably not the depth of a truly critical weak layer. Therefore, these layer properties should not be used for the statistical analyses.

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Thermal changes in ventilated overcooled talus slope: a mutli-methodological approach

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Overcooled talus slopes are porous debris accumulations located in mid-latitude areas far below the regional mountain permafrost limit. These landforms are characterized by the occurrence of a negative thermal anomaly compared to the mean annual air temperature (MAAT) in the lower part of the slope, the preservation of ground ice during summertime and often by the existence of boreo-alpine species at elevation where MAAT is definitively positive. The main process leading to these cold environments is an internal and reversible mechanism of air circulation, the so-called "chimney effect" (Morard et al. 2010).

Since 2004, temperatures at the ground surface and in boreholes were recorded continuously in several sites in western Switzerland to better understand the ventilation process. In addition, the use of time-lapse electrical resistivity tomography (ERT) was used to document indirectly more precisely the 2D spatial pattern of temperature changes at depth (Hilbich et al. 2008).

The main results of this multi-methodological approach are:

- Despite differences in elevation, orientation, vegetation cover and material properties, the same seasonal thermal regime was observed in all the investigated sites. In the lower part of the talus slopes, a negative annual thermal anomaly reaching 3 to 7°C compared with MAAT is observed. This anomaly tends to increase at lower elevation. In contrast the upper part of the slope is characterized by a positive annual thermal anomaly.
- During wintertime, resistivity increases strongly (about 4 to 20 times) at the ground surface in the lower part of the talus slope, as at depth in the lower half of the debris accumulation. These modifications fit well with temperature records in borehole (figure 1). They illustrate both the deep penetration of freezing and the (re)filling of a cold reservoir inside the porous talus slope.
- The thermal conditions observed at the ground surface and in the shallow sub-surface in the blocky layer are mainly influenced by the intensity of winter cooling. The size of the cold reservoir is for instance more important during winters with cold atmospheric conditions. Winter air temperature is thus the main controlling factor for the evolution of the thermal regime of ventilated talus slope. However snowcover and summer temperatures play a less significant role.
- According to the observations of two boreholes in Dreveneuse d'en Bas (Valais Prealps, 1590m a.s.l., MAAT +4°C), a thin talus permafrost forms just a few meters below the surface in the lower part of the slope. This frozen ground extends to greater depth until the middle part of the slope, where it is found at 11.5m depth directly beneath the blocky material in finer sediments (till). This advective-induced permafrost is mainly temperate and its geometry and occurrence have suffered very rapid changes since November 2004: responding directly to contrasted interannual winter air temperature conditions, its growth has been reported between 2004 and 2006 and its thaw consecutive to the exceptional mild winter 2007. Only seasonal freezing was observed in 2008 and 2009. The little snowy but cold winter 2009-2010 led to the rebuilding of this particular extra-zonal permafrost.