Snow profile visualisations to highlight structural instability conditions

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ABSTRACT: Interpreting snow profiles is a fairly subjective process, especially when snow stratigraphy was recorded without performing a stability test at the same time. We suggest new ways to visualize snow stratigraphy to facilitate a fast and intuitive interpretation of a snow profile in regard to stability. Whereas hand hardness is related to snow stability, it is not sufficient to detect potential weak layers by itself. If hand hardness is combined with other snowpack properties (e.g. grain size and type, differences in grain size, failure layer depth) it is possible to identify structural discontinuities related to mechanical instability. The most known method allowing a semi-quantitative stability analysis of snow profiles is the threshold sum approach (TSA). Two of the proposed methods to visualize snow stratigraphy in regard to stability are based on the TSA. In addition, we refined the TSA, so that it is no longer based on absolute threshold values but relative ones; this method is called relative threshold sum approach (RTA). The latter two methods allow displaying a profile similar to the classic representation but assigning TSA or RTA scores to snow layers instead of hardness. These visualizations sum up, in a single graph, information on six structural variables; they help to not only highlight the characteristics of the weak layer, but also the structural properties of the potential slab. In addition, the visualisation can as well be applied without any refinement to simulated snow stratigraphy profiles.

KEYWORDS: snow stratigraphy, snow profile, snow stability evaluation

1 INTRODUCTION

Assessing the avalanche danger for a given region is still a difficult process – despite the wealth of data that are usually available today. It is therefore crucial to display the data in a way that the relevant information can easily be assessed. This is of particular importance for non-numerical data such as snow stratigraphy information, which represents relevant Class II information (McClung and Schaerer, 2006). Interpreting snow profiles is a time consuming and, especially when a stability test is missing, fairly subjective process (Schweizer and Wiesinger, 2001).

Several methods were developed in the last years that aim at more objectively deriving snow instability information from snow stratigraphy. One of these methods is the threshold sum approach (TSA) presented by Schweizer and Jamieson and Schweizer (2007) based on the studies of McCammon and Schweizer (2002) and Schweizer and Jamieson (2002).

The TSA is based on the analysis of six structural variables shown to be indicative of structural instabilities within a snow profile (Schweizer and Jamieson, 2003); three of them refer to interface properties (difference in grain size and difference in hardness between two adjacent layers, and layer depth), three represent properties of the specific layer (grain size, hardness, and grain type). If the value of a variable reaches a given threshold it is considered as an indicator of potential instability.

Our aim is to present methods to visualise structural instabilities in snow profiles. The visualisations shall facilitate a fast and intuitive interpretation of a snow profile – manually observed or simulated.

2 METHODS

TSA assesses the structural instability for each layer and for each pair of layers in a snow profile by counting the variables with values in the critical range. The final score is the sum of the interface score and the score of either the layer above or below whichever is larger. If the total score is five or six, that interface is considered as potentially weak (Schweizer et al., 2008). All six variables were assigned to the relative interface because in most cases fracture will occur near a layer interface and not within a snow layer.

Monti and Schweizer (2013) refined the TSA for snow profile interpretation so that it is no longer based on absolute threshold values but relative ones. For example, it was not considered how soft a snow layer is, but rather how soft it was compared to the weighted average value of the profile. This method, called relative threshold sum approach (RTA), allows detecting

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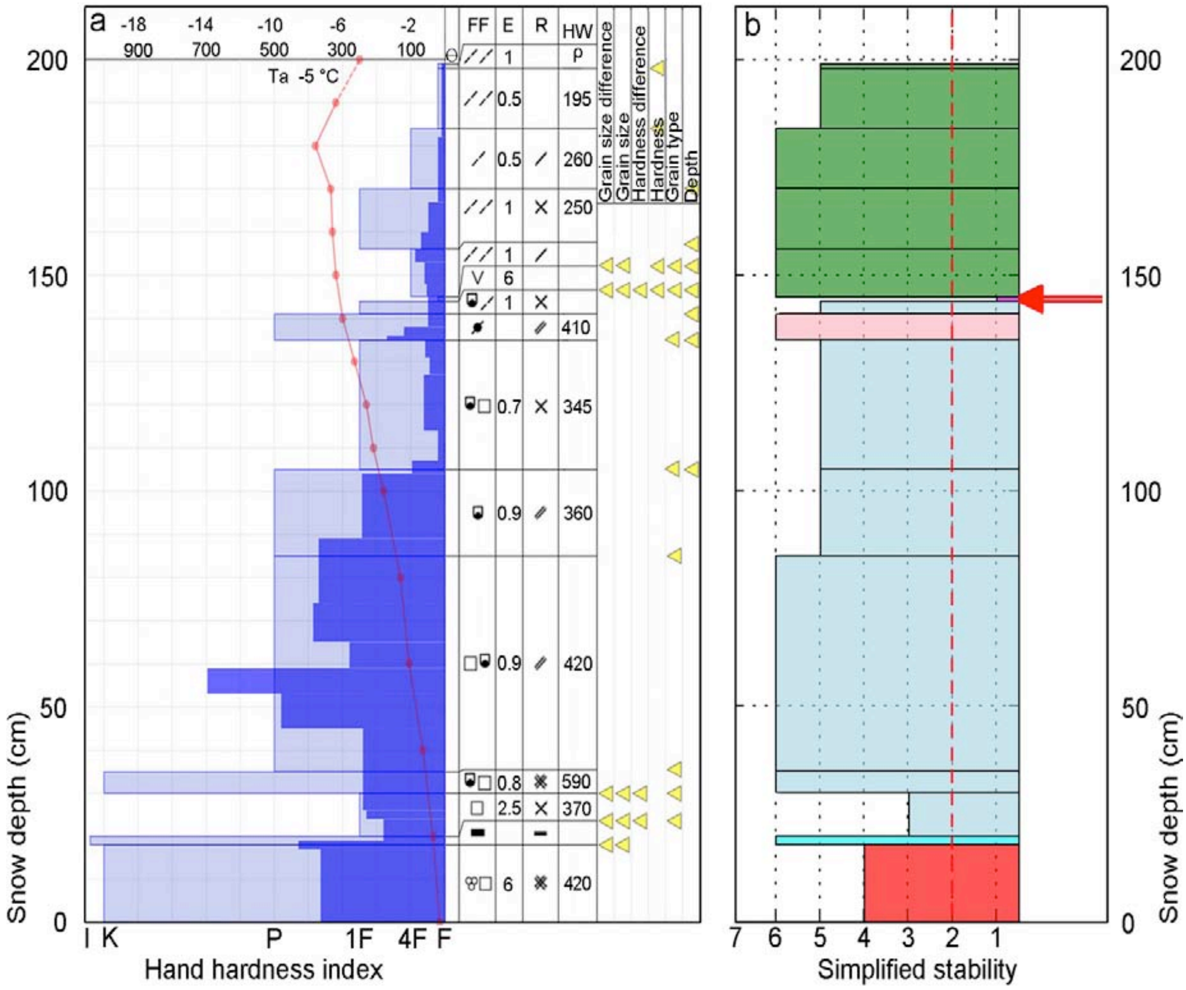

Figure 1: (a) Snow profile manually observed at the study plot Monti Alti di Ornella on 28 January 2009 with profiles of hand hardness index (light blue) and ram hardness (dark blue) given on the left, and the layer characteristics (grain type, grain size, hardness and density) given on the right. The yellow triangles indicate the critical values assigned to the interfaces as used today in snow profile viewers. (b) Simplified stability profile. The critical variables are assigned to the layers. For each layer, the principal grain type is indicated by the corresponding colour according to Fierz et al. (2009). The red arrows point to the interfaces with more than 5 critical variables (Monti et al. (2012).

potential weak layers within a snow profile but does not provide an absolute estimate of their weakness.

3 RESULTS

We first present the graphical representation suggested by Monti et al. (2012). They used a slightly different approach and assigned all the six structural variables to one of the two adjacent layers based on the following rules: (i) the variables that refer to layer properties were assigned to that layer; (ii) the variables referring to the interface between two adjacent layers were assigned to the softer one of the two layers (based on the hand hardness index); if two adjacent layers had the same hardness value, the interface variables were assigned to the upper layer since the stress induced by a skier decreases with increasing depth and hence is larger in the upper than in the lower layer; (iii) the variable for critical depth was assigned to all the layers that were found within the critical range for weak layer depth.

Following these rules it is possible to establish a simplified stability profile (Fig. 1b). In order to look like a classic hand hardness profile (Fig. 1a), the simplified stability profile highlights the number of structural variables for a given layer that are not in the critical range. For example, if for a given layer the number of structural variables in the critical range is 4, the instability score assigned to the layer is 7 - 4 = 3. In order for the minimum stability value to be 1 rather than 0, the number of variables is subtracted from 7 instead of 6, the maximum number of variables in the critical range. Consequently, according to Schweizer and Jamieson (2007), the “simplified stability" (SSD) varies from 1, for the potentially most unstable layers, to 7 for the most stable ones. In addition, on the side, arrows indicate the potential failure interfaces. The colours of the bars refer to the primary grain type of the layer according to the colour scheme proposed by Fierz et al. (2009).

RTA can be similarly represented. The RTA index goes from 0 to 1; values close to 0 indicate that a layer is rather strong, whereas a value close to 1 points to a potential weak layer (Fig. 2). Again, the colours of the bars refer to the primary grain type of the layer according to the colour scheme proposed by Fierz et al. (2009).

4 CONCLUSIONS

We have shown how to visualise snow profiles in regard to structural instability. The two suggested representations allow a fast and intuitive interpretation of a snow profile. For both methods, a dimensionless index derived from absolute (TSA) or relative (RTA) snow cover characteristics was used. The visualisations not only help to identify the potential weak layers, but also indicate the properties of the potential slab. They can be applied both to manually observed and simulated snow profiles allowing easier comparisons between the two.

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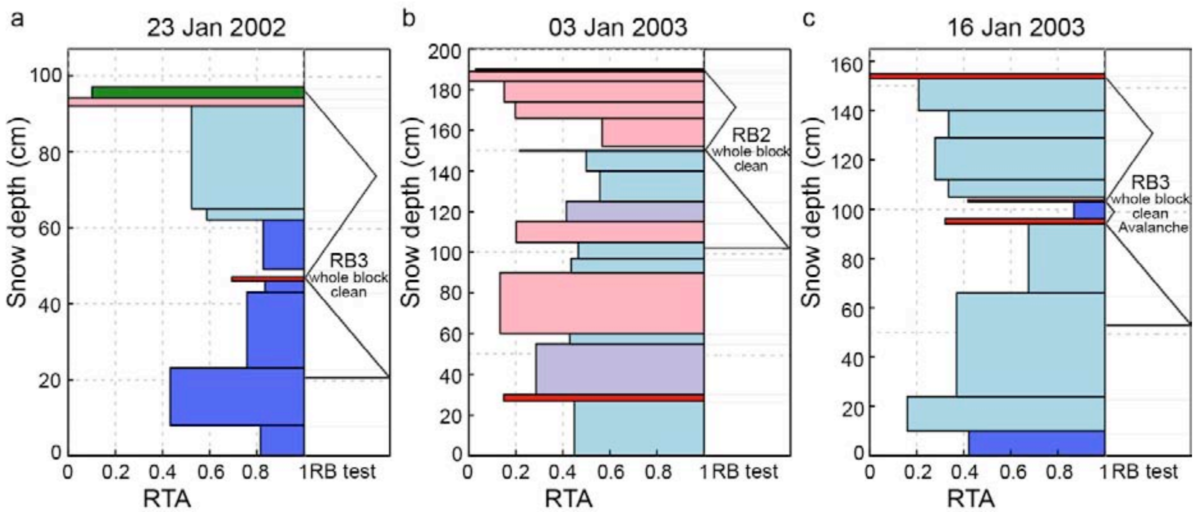

Figure 2: Manual snow profiles (a, b, c) combined with rutschblock test (RB test). For each profile, the relative threshold sum approach (RTA) index is shown. A layer is considered as potentially unstable with RTA values close to 1. The RTA index detected potential weak layers both in generally well (b, c) as well as poorly (c) consolidated snowpacks.