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Editorial

On recent advances in applied snow and avalanche research

1. Introduction

This Special Issue compiles 11 papers that very well represent the breadth of the subject from the physical properties of snow to avalanche forecasting, the flow of avalanches and how they are best prevented. All papers were presented at the 2012 International Snow Science Workshop (ISSW) that was held in Anchorage, Alaska, USA on 16–21 September 2012. This biannual meeting gathered almost 750 snow avalanche practitioners and scientists from 15 countries around the world. The meeting has become the premier snow and avalanche conference for applied snow and avalanche research; it wants to promote knowledge transfer from scientists to practitioners and administrative authorities — and vice versa. The meeting's theme is "*A Merging of Theory and Practice*."

2. Snow and snow cover properties

Improved avalanche forecasting requires – among other things – a sound understanding of the physical processes in the mountain snow cover. Whereas many processes have been well understood in a qualitative sense, it is only with new quantitative methods employed during cold laboratory studies that these processes become amenable to modelling (Löwe et al., 2013). In addition, the new methods can also provide completely new insights into the magnitude of processes such as the mass turnover due to recrystallization during snow metamorphism under strong temperature gradient (Pinzer et al., 2012).

Staron et al. (2014-in this issue) made a series of laboratory experiments to examine the evolution of snow microstructure under non-equilibrium thermal conditions. Due to either a strong temperature gradient or fixed heat input, chains of depth hoar crystals developed. Examination of the entropy production rates showed that the microstructural changes resulted from the snow or the surroundings moving toward a stationary state under given non-equilibrium constraints imposed by the boundary conditions. The laboratory experiments suggest that the rate of metamorphism, responsible for reorganizing the microstructure and increasing the effective thermal conductivity, is driven by the mass flux at the bonds between the grains.

As chains of depth hoar crystals develop, the snow becomes largely anisotropic with prominent effects on many physical properties such as thermal conductivity but also strength (Reiweger and Schweizer, 2013). Calculating a so-called contact tensor, a specific fabric tensor derived from the orientation of grain to grain contact, Walters and Adams (2014-in this issue) described the degree of anisotropy for a layer of radiation recrystallized snow. Mechanical testing of such a layer in compression indicated that the layer became stiffer perpendicular to the snow surface, whereas shear testing suggested a decrease in the modulus parallel to the snow surface when compared to the isotropic material.

Whereas the two above mentioned studies focused on weak layer formation and properties in the lab, Horton et al. (2014-in this issue) used weather-based models to predict the formation of surface hoar and investigated how buried layers changed over time. As previously shown, variations in weather and terrain make the spatial distribution of these layers highly variable (Feick et al., 2007). Horton et al. (2014-in this issue) calculated the mass of vapour deposition from weather station data as well as forecasted data from a numerical weather prediction model and found a linear relationship between modelled vapour mass flux and observed surface hoar crystal size — suggesting that NWP data could be used for predicting surface hoar formation in remote regions. This would be very useful for avalanche forecasting in data sparse areas since layers of buried surface are often observed to be failure layers in slab avalanches and often persist in the snowpack for several weeks. In regard to temporal changes in layers of buried surface hoar, Horton et al. (2014-in this issue) reported a steady increase of shear strength with time, but little change in crack propagation propensity, as assessed with the propagation saw test (PST) for up to six weeks.

The most promising method to quantitatively assess weak layer as well as slab properties (Reuter et al., 2013) – and eventually snow instability (Schweizer et al., 2013) – is the snow micro-penetrometer (SMP) (Schneebeli and Johnson, 1998). Deriving snow properties from the SMP signal requires a sound understanding of how the SMP tip interacts with the ice–air matrix. LeBaron et al. (2014-in this issue) performed laboratory experiments with a split-axis probe simulator to measure the deformation of snow around the SMP tip. The probe was driven along a Plexiglas window which formed one side of the box containing the snow sample. The strain was derived from video images using a particle image velocimetry (PIV) algorithm. Results suggest that a substantial deformation zone exists around the tip during penetration. However, it cannot be excluded that some of the deformation is due to the special experimental set-up. It is not clear whether and if so how present algorithms to derive snow properties from the SMP signal (Löwe and van Herwijnen, 2012; Marshall and Johnson, 2009) should be improved.

3. Avalanche formation and forecasting

Particle tracking velocimetry (PTV) has largely improved our understanding of how snow fails during snow stability tests (e.g. van Herwijnen and Jamieson, 2005; van Herwijnen et al., 2010). In snow stability tests a snow column is successively loaded until it fails. The aims are to identify potential weak layers, to assess their strength (the load required to fracture them), and to evaluate whether an initial crack will propagate (Schweizer and Jamieson, 2010b). van Herwijnen and Birkeland (2014-in this issue) have studied what happens to the snow slab and the underlying weak layer during an extended column test (ECT) (Simenhois and Birkeland, 2006). They found that the load

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application by tapping on the column mainly compresses the slab and does not progressively damage the weak layer. Propagation speeds measured in ETCs were on the order of 20 to 30 ms^{-1}.

Avalanche forecasting can be defined as predicting snowpack instability in space and time relative to a given triggering level (McClung, 2000). Particularly difficult to forecast are so-called deep slab avalanches that release due to failure of a persistent weak layer — often many weeks after burial (Jamieson et al., 2001). Conlan et al. (2014-in this issue) characterised 41 persistent deep slab avalanches in western Canada. Results indicate that these avalanches fail on weak layers that are old, relatively strong and rather hard to trigger. The reasons why they fail remains unknown and forecasting does not seem possible. Though Conlan et al. (2014-in this issue) argue that many releases were associated with warming trends, it remains questionable whether warming actually was the trigger as the effect of snow temperature changes on slab instability have been reported to be subtle and weak at depth (Reuter and Schweizer, 2012; Schweizer and Jamieson, 2010a). Deep slab avalanches may belong to the class of avalanches that even in hindsight do not always have an identifiable "trigger".

On the other hand, storm snow avalanches are by far better predictable than persistent deep slab avalanches. Hendrikx et al. (2014-in this issue) analysed meteorological variables using classification trees to determine and forecast significant avalanche activity on the Seward Highway in coastal Alaska. Precipitation, wind and temperature were the important variables to differentiate between avalanche and non-avalanche days in this type of maritime avalanche climate. Two cross-validated classification trees were trained and developed. When applied to seasons outside of their training data set (including 28 seasons), the probability of detection was substantially lower — despite the fact that cross-validation is believed to provide conservative estimates of predictive power (Breiman et al., 1998). For one season the trees were not only tested in "hindcast" but also in real-time 24-h forecast mode — without any significant reduction in model performance.

4. Avalanche dynamics and mitigation

So far snow properties have not been explicitly considered for calculating the flow behaviour of avalanches. Data from various avalanche test sites have exemplified that avalanches with similar initial mass and topography can exhibit quite different flow behaviour. Steinkogler et al. (2014-in this issue) reconstructed the snow conditions for five large avalanches from the Vallée de la Sionne using the 3-D surface process model ALPINE3D and the snow cover model SNOWPACK (Lehning et al., 2006). They showed that the total mass, mainly controlled by entrainment, defined the run-out distance but did not correlate with front velocity. Flow behaviour depended on snow temperature with a threshold of about −2 °C; above this value significant changes in flow dynamics, for example front velocity, were observed. New model developments are presently under way that take snow properties into account (Bartelt et al., 2012).

Avalanche front velocity is a common measure to estimate avalanche intensity, a key element in hazard mapping or planning of mitigation measures. Gauer (2014-in this issue) presents a series of avalanche front velocity measurements from a variety of dry-mixed avalanches (i.e. they were partially fluidized and accompanied by a power cloud). The maximum velocities scaled with the square root of the total drop height. Gauer (2014-in this issue) states that many commonly used numerical avalanche models would underestimate flow velocity, and suggests the proposed scaling behaviour to have implications for the choice of the empirical parameters in avalanche models that have a velocity dependent friction term. Furthermore, he recommends that velocity measurements should be combined with observations of run-out distances to validate numerical models for dry-mixed avalanches.

Fischer et al. (2014-in this issue) suggest a framework for improving the calibration procedure for numerical avalanche models. They present a new probabilistic method to objectively evaluate the velocity results of a numerical model with Doppler radar measurements from two European snow avalanche test sites (Ryggfonn and Vallée de la Sionne). A large number of avalanche simulations were performed and the accordance between simulations and measurements was evaluated. As indicated by Gauer (2014-in this issue) there was a tendency of velocity underestimation for the cases investigated. Furthermore, for the presented simulation approach, the release depth and certain friction coefficients proved to be the crucial parameters to obtain optimal correspondence of simulated and measured velocities.

Presently, the most common methods to retard (and eventually stop) a large avalanche in motion are breaking mounds and catching dams. Gleirscher and Fischer (2014-in this issue) suggest an alternative approach for retarding small avalanches using flexible wire rope nets. The same approach has been employed for debris flow mitigation (Wendeler et al., 2006). Margreth and Roth (2008) showed that rockfall nets were able to stop small avalanches, but that they were damaged. Gleirscher and Fischer (2014-in this issue) installed a prototype of a flexible net structure above a ski run and measured impact forces. Additional lab experiments with different mesh sizes indicated a velocity dependence of the effectiveness at a certain ratio of mesh to particle size. With limited field data and comparability between scaled lab experiments and field measurements it is not clear yet whether the proposed net barrier is suitable for retarding avalanches in motion.

5. Concluding remarks

The papers compiled in this Special Issue reflect many of the important developments in applied snow and avalanche research over the last years. Substantial progress has been made in quantifying snow properties and processes due to sophisticated instrumental setups and advanced analysis methods, in applying numerical modelling for avalanche forecasting, in particular in data sparse areas, and in developing improved models of avalanche flow mainly thanks to the field data from full-scale avalanche test sites collected over the last 10 years.

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