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Editorial

Applied snow and avalanche research

1. Introduction

This special issue compiles 15 papers that illustrate very well the range of problems posed by snow in mountain areas with a seasonal snow cover. On steep slopes avalanches may form and threaten residential areas, transportation lines and people pursuing snow sport activities. Traditionally, the topic of avalanche protection in a broad sense has engendered the most research in countries where the mountain areas are relatively densely populated, such as the European Alps. However, in addition to natural hazard protection, the economic and hydrological value of the snow cover has become similarly important — and in particular the question as to how the snow cover might change under a changing climate. Conversely, newest generations of meteorological and climatological models have reached a state, in which a correct representation of snow on the earth's surface is necessary.

All these questions were addressed during the first International Snow Science Workshop (ISSW) in Europe that was held in Davos, Switzerland, 27 September–2 October 2009. The ISSW has a long tradition in North America since 1982 — where it is held bi-annually in even years. The major objective of the conference is to provide a forum for researchers and practitioners as well as to promote knowledge transfer from scientists to practitioners and administrative authorities — and vice versa. It is this “Merging of theory and practice” – the motto of all past ISSWs – that is reflected in most of these papers.

2. Snow properties

Remarkable progress has recently been made in the quantification of key snow properties and processes. Most of today's challenges require modelling the processes in the snow cover — an undertaking which is only feasible if comprehensive quantitative relations for the relevant processes such as heat conduction, radiation interaction and snow metamorphism exist. Complex feedback mechanisms exist between many of these processes, for example between heat conduction and snow metamorphism.

Morin et al. (2010-this issue) present the first in-situ measurements of the development of the effective thermal conductivity within the snow cover. During a period of three months they measured the thermal conductivity every second day at six different depths using heated needle-probes and recorded an increase of the effective thermal conductivity over time, reflecting the ongoing changes in microstructure. The rate of increase depended – among other things – on the initial microstructure of the layer. This kind of experiment complements laboratory experiments (e.g. Satyawali et al., 2008) and will lead to an advanced understanding of the complex interaction of heat flow and metamorphism in the seasonal snowpack.

As modelling techniques advance, objective verification methods are required. Recently, several optical methods have been presented to determine the optical equivalent of snow grain size from reflectance measurements at near-infrared (NIR) wavelengths (e.g. Matzl and Schneebeli, 2006). The diffuse reflectance is determined by the specific surface area (SSA), the inverse of the ratio of ice volume to ice surface area. On the other hand, Gergely et al. (2010-this issue) have shown that, if SSA is known, snow density can be determined from near-infrared transmittance measurements. SSA was calculated independently from micro-tomography measurements. For the breakthrough of this promising optical method for determining snow density, it will be essential that SSA can readily be determined, also in the field.

The examples of quantitative methods shown above refer to dry snow. In contrast, studies on wet snow are rare and similarly our understanding of wet-snow avalanche formation is qualitative at best. The problem of complex feedback mechanisms burdens wet snow research even more. With increasing liquid water content, for example due to infiltration of melt water, rapid structural changes occur due to wet-snow metamorphism, which in turn control the rate of infiltration. Nevertheless, a research group at Nagaoka (Japan) has extensively studied wet snow properties and processes. Yamaguchi et al. (2010-this issue) present unique measurements of the water retention curve as a function of grain size under unsaturated conditions. Results indicate that suction decreases with increasing grain size — in accordance with results for sand, or soil in general. Accordingly, infiltration models for soil can be applied for snow and based on their colleagues' measurements Hirashima et al. (2010-this issue) improved the water transport model in the numerical snow cover model SNOWPACK (Bartelt and Lehning, 2002). The model correctly reproduces water storage at capillary barriers, i.e. boundaries between layers of different grain size (fine over coarse). This type of snow stratigraphy was found to favour wet-snow avalanche formation (Baggi and Schweizer, 2009).

3. Snow stability and avalanche forecasting

Snow properties do not only change over time but within the seasonal snow cover they also vary spatially. Just as slab and weak layer properties vary over terrain, so does snow stability. This makes the application of point observations or simulations to avalanche forecasting challenging. When assessing snow stability in the field, site selection and extrapolation become crucial. Snow stability needs to be estimated from few observations – ideally from one or two on a given slope – to the surrounding terrain. Schweizer and Bellaire (2010-this issue) studied how well a single test is representative on a given slope by comparing the results from pairs of compression tests

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that were ~10–15 m apart. The fracture character (van Herwijnen and Jamieson, 2007) was consistent between sites in 75% of the cases. Rather stable slopes tended to have more small scale (~1 m) variation than rather unstable slopes. They suggested that a second investigation on a slope (~10–15 m from the first) would only be necessary if at the first location the test results did not indicate instability. In all other cases, a second investigation would reduce the number of false-stable predictions — which can result from poor site selection and/or large slope scale variations.

As these snowpack investigations are time-consuming and sometimes dangerous for the field crew, they are often scarce in space and time — despite their vital importance for avalanche forecasting. Numerical modelling of snow stratigraphy offers the possibility to overcome this data sparseness by using simulated snowpack properties as a proxy for snow stability. Schirmer et al. (2010-this issue) related numerical model outputs from SNOWPACK to observed stability and constructed two classification trees to predict stable and unstable conditions, respectively. They obtained a classification accuracy comparable to that of classification models entirely based on observed snowpack and stability variables. This model performance was achieved with modelled snow stratigraphy rather than measured meteorological data, suggesting that snowpack modelling can deliver an additional benefit to standard measured input variables when snow stability needs to be estimated. Accordingly, it seems promising to complement the data in the avalanche forecasting process with modelled snow stratigraphy data.

During extraordinary snow storms, meteorological data, in particular precipitation is often the most important single predictor for extreme avalanche activity (e.g. Schweizer et al., 2009). This finding has been confirmed by Eckert et al. (2010-this issue) who compared meteorological and avalanche data for the exceptional avalanche cycle of December 2008 in the eastern part of the French Alps. They found that the predictive power of the instability index provided by the French model chain Safran-Crocus-Mépra (Durand et al., 1999) was limited and that cumulated snowfall over three days was a better predictor. They introduced a simple relative threshold to define an avalanche cycle: the number of avalanches recorded during a cycle should on average not occur more often than once every 2 years. The exceptional cycle in December 2008 had a return period of about 50 years and was caused by an extreme snowfall event with a return period of about 10 years. The difference in return periods is typical and has also been observed for other severe cycles such as the February 1999 cycle which affected large parts of the European Alps. The February 1999 cycle was caused by a strong north-westerly current bringing moisture from the Atlantic ocean, whereas during the December 2008 cycle a generally southerly current from the Mediterranean prevailed.

These two sources of moisture also affect avalanche activity in the Pyrenees. Garcia-Selles et al. (2010-this issue) related the atmospheric circulation patterns to major avalanche activity in the eastern Pyrenees. Major avalanche cycles were correlated with the North Atlantic Oscillation (NAO) as well as the Western Mediterranean Oscillation (WeMO). Whereas the avalanche activity in the eastern parts of the study area was mostly negatively correlated with the WeMO index, cycles in the western areas were negatively correlated with the NAO index. About two thirds of the major avalanche cycles since 1970–1971 occurred during month with a negative NAO index. Linking avalanche activity to climate variability in the past may shed light on the question as to whether avalanche cycles will still occur under future climate scenarios — or even increase in number.

4. Climate variability and snow chemistry

In view of climate variability, long term data series on snow depth in mountain areas are essential to understand extreme events (Blanchet et al., 2009), and to detect past changes and predict future ones in snow cover duration and extent (Bavay et al., 2009). As a resource snow has a high economic value in the European Alps, in particular for the tourism industry and for hydro-power production. Valt and Cianfarra (2010-this issue) analysed the historical records of snow depth for the Italian Alps. Snowfall and snow cover duration at stations located between 800 and 1500 m a.s.l. generally decreased during the last 40 years, most strongly during the 1990s. Above 2000 m a.s.l. the snow duration did not change much. These findings agree with results from other Alpine areas. The snow duration in the Italian Alps strongly correlated with the Northern Hemispheric snow extension, indicating that long term snow records are useful to monitor climate variability — even at the global scale.

Atmospheric circulation patterns are also responsible for the snow quality in terms of its chemical deposition. Significant amounts of particulates and solutes can accumulate in the mountain snowpack and are only released during snowmelt. Filippa et al. (2010-this issue) investigated major element chemistry in the Aosta valley in the north-western Italian Alps and found a unique ion distribution compared to other regions in the Alps. The pattern might be representative for inner alpine valleys in the absence of strong anthropogenic pollution and dust deposition — and worth considering while modelling ion deposition at the global scale.

5. Avalanche characteristics

The same study area, the Aosta Valley, was considered by Viglietti et al. (2010-this issue) who investigated the characteristics of snow avalanches that started in forests. A dense forest is among the best and most traditional ways of protecting villages and infrastructure in mountain areas. Releases from forested terrain are relatively rare. In the case of the Aosta valley, about 5% of the avalanches recorded released from forested slopes. Comparing characteristics of the forest in the starting zones to those in adjacent forested areas revealed that stem density was the most important factor for snowpack stabilization in agreement with previous findings obtained with much larger data sets (Schneebeli and Bebi, 2004).

The avalanche fracture depth is one of the key parameters observed when recording avalanche events. Usually, a few measurements are taken and minimum, maximum and average values are estimated. Fracture depth is also one of the main inputs for avalanche dynamics calculations which are increasingly able to consider terrain in 3D (Christen et al., 2010). Accordingly, fracture depth should be treated as a distributed value rather than a single average value. Bair et al. (2010-this issue) collected and analysed fracture depth along crown transects of 10 dry-snow slab avalanches. Crown heights were equally well fitted by the normal and the Weibull distributions and were spatially correlated. The authors suggest that the normally distributed transects result from a spatially correlated Gaussian process, i.e. new snow deposition, with wind loading being the primary driver of the transect geometry. In the future, the application of terrestrial laser scanning can provide more detailed measurements of slab geometry, as well as snow depth and its relation to snow drift — possibly allowing the above hypothesis to be checked.

6. Avalanche dynamics and protection measures

Once the slab is detached, the avalanche flow is mainly determined by frictional processes originating from the interaction with the underlying snow cover or the ground. Schaefer et al. (2010-this issue) analysed high-speed video images taken during snow chute experiments at the bottom of small scale avalanches. The derived velocity profiles for dry-snow flows exhibited very high shear rates near the ground. Such high shear rates have not been observed in full-scale experiments (Kern et al., 2009) either because in the full-scale experiments the basal layer cannot be resolved, or because in the chute experiments the friction is higher as the sliding surface is not snow. In any case, measurements of velocity profiles are essential to gain insight in the flow behaviour and eventually improve the flow rheology in numerical models.

These avalanche dynamics models are applied for avalanche hazard mapping in land-use planning. For a given release scenario, they calculate the run-out distance and provide estimates of the impact pressure along the track. Most dynamics models used in practice presently use a simple flow rheology with two friction parameters. Reasonable values for the parameters are determined by back-calculating historical events with known run-out distance. For various conditions parameter sets are recommended depending on avalanche size, elevation of the path, channelization and return period (Gauer et al., 2010). These parameter sets are not universal but depend on the characteristics of the avalanches used for back-calculation. Oller et al. (2010-this issue) assessed whether the friction parameters recommended to be used in the Swiss Alps for numerical modelling with AVAL-1D (Christen et al., 2002) are appropriate for the conditions in the Pyrenees. They found a good fit between recorded and simulated run-out distances using the friction parameters originally calibrated for the Swiss Alps — despite the difference in snow climate between the two mountain ranges. This finding indicates that extreme avalanches releasing during or shortly after heavy snowfalls may well have similar characteristics. This seems obvious as the conditions for avalanche formation depend on the mechanical properties of snow which in turn do not depend on either latitude or longitude but mainly on snow temperature.

In hazard mapping, existing mitigation measures (such as supporting structures, forests or dams) have to be considered for risk assessment. On the other hand, if new protection is put in place the existing hazard map might need to be adapted. Until the present, changes were decided *ad hoc* without being based on a sound concept. Margreth and Romang (2010-this issue) present a new procedure to assess the effectiveness of protection measures so that changes to hazard maps can be carried out on a common basis with a well defined terminology. The procedure is presented for snow avalanches but can be applied to any of the following natural hazards: rockfall, landslides, debris flows and floods.

7. Concluding remarks

Although the papers in this Special Issue have not been selected with the aim to provide a comprehensive overview, they reflect many of the important developments in applied snow and avalanche research over the last years. These clearly include an improvement in our ability to quantify the relevant processes based on sophisticated experimental procedures in the lab as well as advanced modelling of snow cover processes, avalanche release and avalanche dynamics. In the field, on the other hand, manual observations are still important but increasingly complemented with modern quantitative methods. Terrestrial laser scanning, in particular, allows us for the first time to gain detailed insight into the spatial variability of the snow cover at some of the most relevant scales (Grünewald et al., 2010). While much progress has been made with respect to measuring and modelling (Mott and Lehning, 2010) snow depth variability, the effect of variations on snow stability (e.g. Bellaire and Schweizer, in press) and avalanche size remains a future challenge. If during storms the release conditions can be estimated the formidable task of dynamical avalanche forecasting, i.e. real-time prediction of avalanche run-out and impact can be tackled. Finally, also in the future, snow research will likely be driven by people's needs and problems in snow covered mountain areas and by the curiosity and talent of enthusiastic researchers who are keen to provide useful solutions — a combination that seems most promising.

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