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Editorial

Snow and avalanche research: A journey across scales

1. Introduction

The 2013 International Snow Science Workshop (ISSW) was held in Grenoble, France on 7–11 October 2013. For the second time, after Davos in 2009 (Schweizer, 2010), the traditional bi-annual meeting usually taking place in North America, was hosted in Europe. The meeting gathered almost 750 snow and avalanche practitioners and scientists from 34 countries under the traditional theme of "*A Merging of Theory and Practice*".

This Special Issue compiles nine papers that very well illustrate the range of studies in snow and avalanche research from investigating the effect of the snow microstructure on the mechanical properties of snow to assessing the vulnerability of buildings and people — a common problem in avalanche engineering.

2. Snow and snow cover properties

The bulk physical and mechanical properties of snow depend not only on density but also on the three-dimensional arrangement of the ice matrix, i.e. the snow microstructure. Finding relevant microstructural parameters beyond density is a longstanding problem that hinders the formulation of accurate parameterizations of snow properties needed for diverse applications such as avalanche forecasting or calculating the surface energy-balance of snow-covered areas (Löwe et al., 2013). Whereas in recent years it has been shown that the specific surface area (SSA) can be used as a microstructural parameter in a wide range of application (e.g. Dominé et al., 2007), properties such as strength and thermal conductivity seem to be controlled by the bonds between the grains.

Hence, Hagenmuller et al. (2014–in this issue) characterize the microstructural bonding system of snow in order to formulate a parameterization of snow properties controlled by fluxes internal to the ice matrix. They described the reduced thickness of the ice matrix at bonds by a new microstructural indicator, the minimum cut density, and found good correlation between this measure and the thermal and elastic properties of snow. Their low values of the minimum cut density illustrate the weak connectivity in snow. Microstructures resulting from temperature gradient metamorphism exhibited a minimum cut density larger in the vertical direction than in the horizontal plane. The anisotropy has obvious consequences on strength as has been shown by Reiweger and Schweizer (2010).

Whereas in dry snow the physical and mechanical properties are controlled by the microstructure only, in wet snow the presence of water largely complicates the description of snow properties and changes of the ice matrix occur much faster (e.g. Mitterer et al., 2011). Water transport in a porous medium such as snow can either be classified as matrix flow or preferential flow. Most studies in the past have studied water transport through the snowpack via matrix flow (e.g. Hirashima et al., 2010; Wever et al., 2014), but for realistic simulation of water transport in a snowpack, in particular in view of wet-snow avalanche formation (e.g. Baggi and Schweizer, 2009), both preferential and lateral flow need to be considered (e.g. Gustafsson et al., 2004). Hirashima et al. (2014–in this issue) developed a first multi-dimensional water transport model to reproduce preferential flow in a snowpack. Preferential flow crucially depended on heterogeneities in snow density and grain size as well as water entry suction. Comparison with laboratory experiments (Katsushima et al., 2013) showed good qualitative agreement of flow behavior.

Ikeda et al. (2014–in this issue) as well focused on water transport and compared the effects of water infiltration into a snowpack on flat land and on a slope. They observed the snow stratigraphy evolution repeatedly in classical snow pits and found that the proportion of melt forms was higher in the sloping snowpack than in the snowpack on level ground. They attributed the observed differences to differences in the amount of water flowing in vertical channels, i.e. to preferential flow — hypothesizing that preferential flow is more prominent in the snowpack on flat ground than on the slope. The fact that water quickly drains through vertical channels in the snowpack on flat ground, prevented that large parts of the snowpack developed into melt forms as observed in the sloping snowpack. They tested this hypothesis with a numerical model that included a parameterization of the vertical water-channel process. Results indicated that to reproduce the observed proportion of melt forms less water was flowing in vertical channels in the sloping snowpack than in the snowpack of level ground.

3. Snow as a resource

Snow can cause damage to buildings by overloading roofs or impacting as flowing avalanche, but is also an important resource for winter tourism, irrigation and hydro-power production. In particular, the ski tourism industry requires reliably snow conditions and has therefore made large investments into snow making facilities to counterbalance the impact of the typically strong interannual variability of snow conditions and the emerging trends of climate change on snow cover depth and extent, in particular at lower elevations in the European Alps (e.g. Abegg et al., 2007; Steger et al., 2013).

François et al. (2014–in this issue) crossed detailed snowpack simulation results with a resort-level geographical and socio-economic database for 142 ski resorts in the French Alps to study the viability of the resorts expressed as the weighted fraction of the ski resort surface areas meeting the 100-day rule. Results were compared to economically relevant data such as skier days and indicated a complex relationship

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between ski resort operation and natural snow conditions. The model did only consider natural snow conditions which are not particularly representative of the snow conditions in ski resorts. Snow making and grooming may substantially modify the natural snow conditions. Nevertheless, the presented approach has strong potential for the integrated assessment of the socio-economic and physical understanding of the functioning of ski resorts, in particular in view of climate change projections.

Snowmaking is considered as the number one adaptation measure to climate change impacts on the mountain snow cover and today, almost half of the surface area in the ski resorts in the Alps is equipped with snowmaking systems according to Hanzer et al. (2014). They present a model that explicitly quantifies technical snow production in a physically-based, spatially distributed simulation of the mountain snow cover. The model considers the snow production by individual snow making systems and distributes the snow along the slopes. This allows optimizing the snow management — saving energy as well as water. The model was applied to the ski resort Schladming in the Austrian Alps. Results indicate that the model well reproduced the total snow making time, water and energy consumption.

4. Drifting and blowing snow

Snow transport by wind is an important factor contributing to the uneven snow distribution typically found in mountain regions (e.g. Mott et al., 2010). Accumulation of snow by wind is also significant in Antarctica where it influences the surface mass balance — an important element to assess changes to the ice sheet and hence the influence of Antarctica on the global climate system (e.g. van de Berg et al., 2006). Trouvilliez et al. (2014–in this issue) report on three years of observations of aeolian snow transport in Adélie Land in Antarctica using automatic acoustic sensors. They estimated the threshold friction velocity, the transport events and a lower limit for the quantity of transported snow. Threshold values found were higher than previously reported for other locations in Antarctica. The snow transport frequency was very high and the snow quantity transported was substantial, but with the sensors used the absolute snow mass flux could not be quantified.

5. Avalanche flow and impact

Snow avalanches may while traveling downslope erode and entrain snow from the underlying snowpack. Entrainment affects avalanche motion most obviously by changing the mass balance (Sovilla et al., 2001) but also by changing the temperature and moisture content of the flowing snow so that the flow regime may change (Steinkogler et al., 2014). Eglit and Yakubenko (2014–in this issue) present a mathematical model of entrainment of material (initially at rest) by an unsteady flow down a constant slope. They consider one possible mechanism of entrainment only, which shows an asymptotic behavior. Their work is by large theoretical and application to the real world, i.e. modeling avalanche flow from top to bottom, was not intended.

Snow avalanches can be triggered by large earthquakes and can be considered a collateral hazard associated with earthquakes. However, this type of triggering is rather rare and restricted to some regions with high seismicity and steep snow-covered terrain. Podolskiy et al. (2010) have recently compiled an inventory of historic cases of earthquake-induced snow avalanches. Whether an avalanche can be triggered by an earthquake, i.e. ground motion, mainly depends on the distance from the source, the characteristics of the source, the local geological and topographical conditions, and the snow stability (Surinach et al., 2011). Pérez-Guillén et al. (2014–in this issue) report on a natural avalanche that was recorded in the Vallée de la Sionne test site in Switzerland, only seconds after an earthquake of magnitude M_L 3.1 had occurred, in a distance of about 43 km from the avalanche starting zone. As the test site is fully equipped with a suite of sensors it was possible to analyze whether the avalanche release was related to the earthquake. Furthermore, the snow stratigraphy was simulated with the numerical snow cover model SNOWPACK. The rather low stability found for the day of the avalanche occurrence suggests that the ground motion caused by the earthquake may have been sufficient for triggering the avalanche. The analysis suggests that triggering by minor earthquakes seems only possible in case of already marginal stability.

The most effective avalanche mitigation measure is hazard mapping for land-use planning, i.e. simply to avoid – whenever possible – constructing buildings and infrastructure in endangered zones. Hazard mapping involves determining the avalanche frequency and impact (or another measure of consequence) at a given location in an avalanche path. It is currently applied in many mountain communities based on assessing results of avalanche dynamics models, evaluating historical records, and studying vegetation for signs of past avalanches expert opinion — to name the most important methods (Bründl and Margreth, 2014). However, hazard mapping does typically not take into account the probable consequences for elements at risk in the hazard zones. For an integrated quantitative risk evaluation (Eckert et al., 2012), as well as for assessing the effectiveness of mitigation measures as a basis for a cost–benefit analysis (Margreth and Romang, 2010), the consequences of avalanche impact, i.e. the vulnerability of structures or the mortality of people, need to be known. Vulnerability curves have mainly been established based on the analysis of historical events by comparing the observed damage to estimated impact intensity (e.g. Cappabianca et al., 2008; Fuchs et al., 2012). In this issue, Favier et al. (2014–in this issue) provide vulnerability relations for reinforced concrete buildings and people inside them based on a comprehensive reliability analysis of various building types subjected to avalanche loads. In a case study for a site in the French Alps, they show how the individual risk estimates are highly sensitive to the choice of the vulnerability relation. For risk zoning this finding suggests that the individual risk in the blue zone, considering a 300-year event, may still be too high. However, for real risk mapping and optimal design of mitigation measures the presented approach needs to be expanded, in particular by using a more sophisticated flow model.

6. Concluding remarks

The papers compiled in this Special Issue exemplarily show the range of scales relevant in snow and avalanche research, for a definition of the relevant scales see Schweizer and Kronholm (2007). For avalanche formation the microstructural properties of individual snow layers are crucial for estimating instability — for either dry or wet snow. For dry snow, microstructural snow properties as acquired with the snow micro-penetrometer (SMP) (Schneebeli and Johnson, 1998) have recently been linked with macroscopic failure properties — and then used to describe instability patterns at the scale of a small Alpine basin (Reuter et al., 2013, 2014). This progress was only possible by combining high precision field measurements (SMP), laboratory experiments (μCT) and numerical simulations. Numerical modeling is also the key for modern engineering approaches from optimizing snow making to assessing the avalanche hazard in residential areas. Also, modern avalanche flow simulations, often spanning one or more kilometers from initiation to runout, rely on a detailed description of the properties and behavior of snow granules (Bartelt et al., 2006). Hence, linking the scales is essential in most problems of applied snow and avalanche research.

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