Cold Regions Science and Technology 59 (2009) 103–105

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Editorial

An update on applied snow and avalanche science: Selected papers from the 2008 International Snow Science Workshop

The 2008 International Snow Science Workshop (ISSW) was held in Whistler, Canada from 21 to 27 September 2008. These workshops aim to attract practitioners and researchers, bringing them together to share their experiences, ideas, and research. The 2008 ISSW attracted over 800 people from 18 countries. The two-volume proceedings (Campbell et al., 2008) contain 179 papers. Authors had the option of revising their papers for more scientific readers, adding new material, and submitting to this special issue of Cold Regions Science and Technology. After the scientific reviews, 19 papers on a range of topics were accepted. The papers apply science to a wide range of snow and avalanche problems. Our editorial begins with recent avalanche climate work before discussing snowpack structure, stratigraphy, and new tools for investigating that stratigraphy. Then we summarize papers on field tests, avalanche forecasting and avalanche dynamics before finishing with avalanche rescue.

Garcia et al. (2009) build on a growing body of research exploring relationships between avalanches and broader climate patterns by analyzing the patterns leading to major avalanche events in the Pyrenees. Similar to a work in North America, they document a great deal of regional variability. They also tie their findings to the North Atlantic Oscillation Index (NAO), which could potentially allow for longer range forecasts of general avalanche conditions expected for upcoming winters. Ikeda et al. (2009) also investigate avalanche climate relationships, but their study area is Japan. Utilizing a classification scheme developed in the western United States (Mock and Birkeland, 2000), they show similarities and differences between the snow climates in the two countries and propose a unique classification for the Japanese Alps on the Pacific side of the island, an area characterized by the unusual combination of both rain and depth hoar.

When looking at snow stratigraphy, an increasing amount of research in the last decade has examined near-surface faceted layers. Slaughter et al. (2009) conducted a novel study exploring the process of radiation recrystallization by integrating field observations and lab work. They demonstrated that such layers could be reliably replicated in the lab. Further, they observed this process in the relatively lower elevations and higher latitudes of Montana rather than Colorado's San Juan Mountains where it was first observed. Changes in subsurface temperatures can drive diurnal recrystallization, which is another near-surface faceting process (Birkeland, 1998). In addition, subsurface temperatures can affect the mechanical properties of slabs, thereby changing the potential to release avalanches (McClung and Schweizer, 1999). Bakermans and Jamieson (2009) present a unique and simple method for tracking these important changes in subsurface snow temperature. Their empirical model is designed to give avalanche forecasters useful information about the magnitude of warming they can expect using simple and readily available inputs.

A particularly difficult stratigraphic problem is the movement of water (from melt or rain) through the snowpack. This movement often occurs along vertical flow channels. Katsushima et al. (2009) advance our knowledge in this area by developing a model that could simulate field observations of water flow movement through a cold snowpack in Japan.

New tools are becoming available for objectively assessing snowpack stratigraphy. One promising tool is radar. While Marshall and Koh (2008) recently reviewed the use of high frequency FMCW radars, Heilig et al. (2009) utilize lower frequency ground penetrating radar (GPR) in an upward configuration to identify snow stratigraphy. In addition to quantifying layer boundaries, objective and quantifiable methods are needed for classifying the snow crystals in those layers. Arakawa et al. (2009) utilize both specific surface area and intrinsic permeability to objectively discriminate between different crystal types. A method for objectively simulating snowpack conditions is the use of models such as SNOWPACK (Lehning et al., 1999). Such models are being constantly updated, and Hirashima et al. (2009) enhance the usefulness of SNOWPACK by developing a method to improve the model's shear strength parameterization.

In situ tests of snowpack instability, typically involving a column of the snowpack with a cross sectional area between 0.09 and 3 m^2, require at least 10 min for digging, testing the column, and recording results. Hence a team of two people can only perform a limited number of tests per day. However, the natural variability of key snowpack properties requires that many tests and/or observations be done to assess the stability. To address this need for many quick profiles, digital snowpack penetrometers were developed. A team of two people can do up to 200 high resolution penetrometer profiles in a field day.

The studies by Pielmeier and Marshall (2009), Floyer and Jamieson (2009) and van Herwijnen et al. (2009) identified characteristics of the penetrometer signal that were associated with instability in adjacent snowpack tests. Although spatial variability of stability is ultimately required by avalanche forecasting programs, these field studies minimize spatial variability by profiling the snowpack with the penetrometer within a few metres of the stability test. Pielmeier and Marshall (2009) used the SnowMicroPen (Schneebeli and Johnson, 1998) and found weak layer micro-scale strength in combination with the SMP-estimated slab density to be the best predictors of stability classes as predicted by the rutschblock test (Föhn, 1987).

doi:10.1016/j.coldregions.2009.09.003

van Herwijnen et al. (2009) also used the SMP penetrometer but sought characteristics of its signal that were associated with observed fracture characters in adjacent compression tests. They developed an autocorrelation method to identify the failure layers in adjacent compression tests which, however, required manual picking of a reference layer. Sudden collapse fractures, which are associated with instability on adjacent slopes (van Herwijnen and Jamieson, 2007), were associated with large differences in penetration resistance between the failure layer and the adjacent layer.

Floyer and Jamieson (2009) used sudden and not-sudden fractures in compression tests to select key characteristics of the penetrometer signal. Instead of the SMP, they used a modified Sabre penetrometer (Mackenzie and Payten, 2002; Floyer, 2008). The force resistance in the failure layer and transition between the failure layer and adjacent layers correctly classified 80% of the failures as sudden or not. However, their algorithm required that failure layers be manually pre-identified in the penetrometer signal. When randomly selected layers were considered, the classification rate dropped to 67%.

In contrast to the studies which sought signal characteristic associated with instability, Lutz et al. (2009) used the SMP to detect the effect of artificial overburden changes on weak layers. The overburden was changed by adding blocks of snow to the top of a column and then penetrating a pre-identified weak layer and adjacent layers with the SMP. They found the micro-scale strength of the weak layer decreased significantly when the overburden was artificially increased by adding blocks of snow to the top of the column. Artificial removal of slab stress resulted in greater rupture forces and larger microstructures, likely due to elastic rebound.

Simenhois and Birkeland (2009) report on the development of a new snowpack test called the Extended Column Test (ECT), which is intended to indicate (1) whether localized dynamic surface loads (triggers), such as skiers, are likely to initiate a fracture in a weak snowpack layer and then (2) whether the fracture will propagate beyond the influence of the trigger. While small-column tests for fracture initiation such as the Compression Test (Greene et al., 2004, p. 45–47) are well established, the ECT also indicates the propensity for fracture propagation, which has been missing from small-column stability tests. By comparing test results with ratings of local stability, Simenhois and Birkeland (2009) showed the ECT has a false stable ratio generally lower than those of the Compression Test and the Propagation Saw Test (PST) (Gauthier and Jamieson, 2008). Also using a rating of local stability, Winkler and Schweizer (2009) showed that the ECT's unweighted average accuracy was comparable to the rutschblock test and higher than that of the CT.

In numerical avalanche forecasting the following developments can be seen: (a) using input from weather stations and thereby increasing the temporal resolution (e.g. Cordy et al., 2009), (b) using forecasted weather data to provide an avalanche forecast rather than a nowcast, and (c) complementing weather data with modeled snow cover data (e.g. Schirmer et al., 2009). Furthermore, new statistical methods have been explored (e.g. Pozdnoukhov et al., 2008). Cordy et al. (2009) used hourly interval electronic weather sensor inputs to a nearest neighbour model to predict the avalanches in the coming 12 h in two highway corridors in British Columbia Canada. The models were applied operationally and model performance (unweighted average accuracy) was about 75%.

Whereas numerical forecasting systems are usually developed and applied for areas including numerous avalanche paths, it remains to be seen whether forecasting tools can be developed for predicting large and infrequent (naturally released) avalanches in a specific path. These tools would be particularly useful for local avalanche services responsible for avalanche safety in mountain villages. Schweizer et al. (2009) utilized a well documented avalanche path near Davos (Switzerland) to investigate whether avalanche occurrence during major storms can be reliably predicted based on precipitation data. Avalanche occurrence was correlated to new snow depth, total snow depth, air temperature and type of snow stratigraphy. However, predicting single events still involved a great deal of uncertainty, particularly since the new snow amounts assumed to be critical had a significantly lower return period than the avalanche events.

Once in motion, avalanches develop large destructive power. Structures in the avalanche path or runout need to be designed to withstand the pressure and/or should be located such that the risk is reduced. To determine the extent of the hazard, dynamics models are used typically in combination with e.g. a study of terrain, vegetation and historical records of weather and avalanche occurrence. In recent years, the development of avalanche dynamics models has much been fostered by experimental results from full-scale test sites (e.g. Sovilla et al., 2008). Measurements from sensors mounted on structures located in the avalanche path have provided new insight into the flow behavior of snow avalanches. Nevertheless, these punctual measurements do not accurately describe the complex dynamical interaction between the avalanche and the structure itself. For this reason, Baroudi and Thibert (2009) applied inverse analysis techniques. They report on pressure measurements at the Lautaret full-scale avalanche test site in the French Alps. Using advanced sensitivity and error analyses they identified two main sources of error and quantified the uncertainty of the reconstructed peak pressure (21 ± 2 kPa). This suggests that this complementary method is well suited to determine not only impact pressures, but also to understand the complex interaction between avalanche and structure.

At the full-scale avalanche test site in Ryggfonn (Norway), for about 30 avalanches which occurred during the last 30 years, the front velocities and run-distances were recorded.

Gauer et al. (2009) use a set of 20 of these avalanches to evaluate the performance of mass block models — a class of simple avalanche dynamics models. They not only use the runout distance but also front velocity measurements to optimize the model parameters for individual avalanches. This yields probability distribution functions of the model parameters that may be used in probabilistic avalanche modeling. Additionally, they observed that retarding accelerations on average seem to be rather constant during the avalanche descent and hence suggested that feedback mechanisms in avalanche flows tend to counterbalance velocity dependencies of the retarding accelerations. This implies that the avalanche rheology would depend on the flow state itself — a concept which clearly cannot be captured by simple block models.

If people are caught and buried by a snow avalanche the only device that allows rescuers to quickly search for the victims are avalanche rescue transceivers or beacons. The search strategy depends – among other things – on the signal search strip width which influences the search time. The search strip width is not a given value as often has been assumed in the past, but depends on technical characteristics, in particular on the range of the specific device (Schweizer and Krüsi, 2003). So far range (and search strip width) has been determined with field tests that are time consuming and prone to errors. Genswein et al. (2009) present a novel simulation approach to determine a survival change optimized search strip width. Their results suggest that most presently used values of search strip width are too low.

Of the many important topics yet to be addressed by applied snow and avalanche science, a few stand out. One topic is assessing the potential of radar for detecting the stratigraphy that is critical for snow slope stability, perhaps using the signals from stable and unstable slopes as has been done for stability tests. Another topic is researching and developing issues such as cost, ease of use, and reliability of penetrometers. While these instruments are providing extremely useful information for assessing snowpack stability in research, their use in forecasting operations remains limited due to some of those issues. Finally, spatial modeling of the snowpack and especially the formative processes for critical weak layers is required, and may require a stochastic approach since we do not yet know all the causes of spatial variations at the slope scale.

Acknowledgements

The International Snow Science Workshop (ISSW) in Whistler, Canada was a remarkably successful merging of theory and practice. We wish to thank the conveners, Helene Steiner and Brian Gould, as well as the chairs of the ISSW papers committee, Cam Campbell and Steve Conger, and chair of the poster session, Pascal Haegeli. For prompt, constructive reviews we are grateful to the many reviewers. We extend our thanks to our colleagues, the other Guest Editors of this special issue, Ed Adams, Peter Gauer, Ethan Greene, Pascal Haegeli and Stefan Margreth, as well as to Editor-in-Chief, Garry Timco, for his guidance with the reviewing and editing.

References

Arakawa, H., Izumi, K., Kawashima, K., Kawamura, T., 2009. Study on quantitative classification of seasonal snow using specific surface area and intrinsic permeability. Cold Reg. Sci. Technol. 59 (2-3), 163–168.

Bakermans, L., Jamieson, B., 2009. Swarm: A simple regression model to estimate near-surface warming for back-country avalanche forecasting. Cold Reg. Sci. Technol. 59 (2-3), 133–142.

Baroudi, D., Thibert, E., 2009. An instrumented structure to measure avalanche impact pressure: error analysis from Monte Carlo simulations. Cold Reg. Sci. Technol. 59 (2-3), 242–250.

Birkeland, K.W., 1998. Terminology and predominant processes associated with the formation of weak layers of near-surface faceted crystals in the mountain snowpack. Arct. Alp. Res. 30 (2), 193–199.

Campbell, C., Conger, S., Haegeli, P. (Eds.), 2008. Proceedings of the International Snow Science Workshop in Whistler, Canada.

Cordy, P., McClung, D.M., Hawkins, C.J., Tweedy, J., Weick, T., 2009. Computer assisted avalanche prediction using electronic weather sensor data. Cold Reg. Sci. Technol. 59 (2-3), 227–233.

Floyer, J.A., 2008. Layer detection and snowpack stratigraphy characterisation from digital penetrometer signals. PhD Thesis, University of Calgary, Calgary, Canada.

Floyer, J., Jamieson, B., 2009. Predicting the fracture character of weak layers from snowpack penetrometer signals. Cold Reg. Sci. Technol. 59 (2-3), 185–192.

Föhn, P.M.B., 1987. In: Salm, B., Gubler, H. (Eds.), The Rutschblock as a practical tool for slope stability evaluation. Symposium at Davos 1986 — Avalanche Formation, Movement and Effects, IAHS Publ., vol. 162. International Association of Hydrological Sciences, Wallingford, Oxfordshire, U.K, pp. 223–228.

Gauer, P., Medina-Cetina, Z., Lied, K., Kristensen, K., 2009. Optimization and probabilistic calibration of avalanche block models. Cold Reg. Sci. Technol. 59 (2-3), 251–258.

Garcia, C., Martí, G., Oller, P., Moner, I., Gavaldà, G., Martinez, P., Peña, J.C., 2009. Major avalanche occurrence at regional scale and related atmospheric circulation patterns in the eastern Pyrenees. Cold Reg. Sci. Technol. 59 (2-3), 106–118.

Gauthier, D., Jamieson, B., 2008. Fracture propagation propensity in relation to snow slab avalanche release: validating the Propagation Saw Test. Geophys. Res. Lett. 35 (13), L13501.

Genswein, M., Reiweger, I., Schweizer, J., 2009. Survival chance optimized search strip width in avalanche rescue. Cold Reg. Sci. Technol. 59 (2-3), 259–266.

Greene, E., Birkeland, K.W., Elder, K., Johnson, G., Landry, C., McCammon, I., Moore, M., Sharaf, D., Sterbenz, C., Tremper, B., Williams, K., 2004. Snow, Weather and Avalanches: Observational Guidelines for Avalanche Programs in the United States. American Avalanche Association and USDA Forest Service National Avalanche Center.

Heilig, V., Schneebeli, M., Eisen, O., 2009. Upward-looking ground-penetrating radar for monitoring snowpack stratigraphy. Cold Reg. Sci. Technol. 59 (2-3), 152–162.

Hirashima, H., Osamu, A., Atsushi, S., Lehning, M., 2009. An adjustment for kinetic growth metamorphism to improve shear strength parameterization in the SNOWPACK model. Cold Reg. Sci. Technol. 59 (2-3), 169–177.

Ikeda, S., Wakabayashi, R., Izumi, K., Kawashima, K., 2009. Study of snow climate in the Japanese Alps. Cold Reg. Sci. Technol. 59 (2-3), 119–125.

Katsushima, T., Kumakura, T., Takeuchi, Y., 2009. A multiple snow layer model including a parameterization of vertical water channel process in Snowpack. Cold Reg. Sci. Technol. 59 (2-3), 143–151.

Lehning, M., Bartelt, P., Brown, R.L., Russi, T., Stöckli, U., Zimmerli, M., 1999. SNOWPACK model calculations for avalanche warning based upon a network of weather and snow stations. Cold Reg. Sci. Technol. 30 (1–3), 145–157.

Lutz, E., Birkeland, K., Marshall, H.P., 2009. Quantifying changes in weak layer microstructure associated with artificial load changes. Cold Reg. Sci. Technol. 59 (2-3), 202–209.

Mackenzie, R., Payten, W., 2002. A portable, variable-speed, penetrometer for snow pit evaluation. Proceedings of the 2002 International Snow Science Workshop, Penticton BC, Canada, 29 September–4 October 2002, pp. 294–300.

Marshall, H.P., Koh, G., 2008. FMCW radars for snow research. Cold Reg. Sci. Technol. 52 (2), 118–131.

Mock, C.J., Birkeland, K.W., 2000. Snow avalanche climatology of the western United States mountain ranges. Bull. Am. Meteorol. Soc. 81 (10), 2367–2392.

McClung, D.M., Schweizer, J., 1999. Skier triggering, snow temperatures and the stability index for dry slab avalanche initiation. J. Glaciol. 45 (150), 190–200.

Pielmeier, C., Marshall, H.P., 2009. Rutschblock-scale snowpack stability derived from multiple quality-controlled SnowMicroPen measurements. Cold Reg. Sci. Technol. 59 (2-3), 178–184.

Pozdnoukhov, A., Purves, R.S., Kanevski, M., 2008. Applying machine learning methods to avalanche forecasting. Ann. Glaciol. 49, 107–113.

Schirmer, M., Lehning, M., Schweizer, J., 2009. Statistical forecasting of regional avalanche danger using simulated snow cover data. J. Glaciol. 55 (193), 761–768.

Schneebeli, M., Johnson, J.B., 1998. A constant-speed penetrometer for high-resolution snow stratigraphy. Ann. Glaciol. 26, 107–111.

Schweizer, J., Krüsi, G., 2003. Testing the performance of avalanche transceivers. Cold Reg. Sci. Technol. 37 (3), 427–436.

Schweizer, J., Stoffel, L., Mitterer, C., 2009. On forecasting large and infrequent snow avalanches. Cold Reg. Sci. Technol. 59 (2-3), 234–241.

Simenhois, R., Birkeland, K.W., 2009. The Extended Column Test: test effectiveness, spatial variability, and comparison with the Propagation Saw Test. Cold Reg. Sci. Technol. 59 (2-3), 210–216.

Slaughter, A., McCabe, D., Munter, H., Staron, P.J., Staron, D., Adams, E.E., Catherine, D., Henninger, I., Cooperstein, M., Leonard, T., 2009. An investigation of radiation–recrystallization coupling laboratory and field studies. Cold Reg. Sci. Technol. 59 (2-3), 126–132.

Sovilla, B., Schaer, M., Kern, M., Bartelt, P., 2008. Impact pressures and flow regimes in dense snow avalanches observed at the Vallée de la Sionne test site. J. Geophys. Res.-Earth Surf. 113 (F1), F01010. doi:10.1029/2006JF000688.

van Herwijnen, A., Bellaire, S., Schweizer, J., 2009. Comparison of micro-structural snowpack parameters derived from penetration resistance measurements with fracture character observations from compression tests. Cold Reg. Sci. Technol. 59 (2-3), 193–201.

van Herwijnen, A., Jamieson, B., 2007. Fracture character in compression tests. Cold Reg. Sci. Technol. 47 (1–2), 60–68.

Winkler, K., Schweizer, J., 2009. Comparison of snow stability tests: extended column test, rutschblock test and compression test. Cold Reg. Sci. Technol. 59 (2-3), 217–226.

Bruce Jamieson
Department of Civil Engineering, University of Calgary, Calgary, Canada
Department of Geoscience, University of Calgary, Calgary, Canada
Corresponding author.
E-mail address: bruce.jamieson@ucalgary.ca(B. Jamieson).

Jürg Schweizer
WSL Institute for Snow and Avalanche Research SLF, Davos, Switzerland

Karl W. Birkeland
National Avalanche Center, USDA Forest Service, Bozeman, USA