LOOKING TO THE '20S: COMPUTER-ASSISTED AVALANCHE FORECASTING IN CANADA

James Floyer[1,2]*, Karl Klassen[1], Simon Horton[3], and Pascal Haegeli[2]

[1]Avalanche Canada, Revelstoke, BC, Canada
[2]Simon Fraser University, Burnaby, BC, Canada
[3]University of Calgary, Calgary, AB, Canada

ABSTRACT: In contrast to weather forecasting, where public and professional adoption of computer-based numerical weather prediction systems has been dramatic, avalanche forecasting in Canada still relies heavily on human expertise. Successful integration of computer systems has been largely limited to those that facilitate the collection, sharing and visualization of data, such as InfoEx (Canadian Avalanche Association), SnowBase (Canadian Mountain Holidays) and AvalX (Parks Canada and Avalanche Canada).

While a few attempts have been made to create automated avalanche prediction systems (e.g. the MoTI avalanche prediction system in Kootenay Pass, British Columbia), such systems have so far not extended to the domain of regional avalanche forecasting, nor have they been made available to recreational users.

This paper conceptualizes and describes a series of modules that address different components of the avalanche forecasting problem at the regional and sub-regional scale. Taken together, they form a preliminary roadmap that may eventually lead to automated avalanche forecasts, which would have a significant impact on the delivery of public avalanche information, particularly in data sparse areas such as the North Rockies region of Canada.

KEYWORDS: Avalanche Forecasting; Computer Modelling; Computer-assisted Forecasting

1. INTRODUCTION

Canada needs a suite of computer-assisted forecasting tools to be able to provide high quality, competitive avalanche forecasting into the 2020's. Correctly conceived computer-assisted forecasting tools may provide benefits in one or more of the following areas: 1. improved forecast efficiency; 2. improved forecast accuracy; 3. improved forecast consistency; 4. an ability to forecast in data sparse areas.

For the most part, current use of computer-based analysis in contemporary Canadian avalanche forecasting is limited to weather analysis, and the collection, storage, and basic visualization of data through shared databases such as InfoEx (Canadian Avalanche Association), SnowBase (Canadian Mountain Holidays) and AvalX (Parks Canada and Avalanche Canada). There are some exceptions. There is currently an experimental surface hoar model (Horton & Jamieson, 2016) hosted on the InfoEx platform that predicts areas of surface hoar growth. This model is currently available to professional InfoEx subscribers. A version of the Swiss SNOWPACK model (Barteld & Lehning, 2002) is implemented for approximately 30 point locations in western Canada. The model generates snowpack profiles using high resolution modelled weather data (GEM HRDPS) as input (Bellaire, et al., 2011). The output of this model is currently only available to Avalanche Canada forecasters. British Columbia's Ministry of Transportation and Infrastructure (MoTI) implemented an operational nearest neighbours model for Kootenay Pass, BC (Cordy, et al., 2009). However, in recent years forecasters have not tended to use it (Andersen, personal communication).

In contrast, the use of computer-based analysis for avalanche forecasting is well established in some European countries, most notably France and Switzerland. The model chain SAFRAN-Crocus-MÉPRA (Durand, et al., 1999) has predicted regional avalanche danger in France operationally for almost two decades using a combination of observed and modelled weather data. It's successor, SAFRAN–SURFEX/ISBA-Crocus–MEPRA (Vernay, et al., 2015), makes use of ensemble weather forecasts to improve predictions. The Swiss physical snow cover model SNOWPACK (Barteld and Lehning 2002, Lehning, et al., 2002a, Lehning, et al., 2002b) has been widely adopted in

* *Corresponding author address:*
James Floyer, Avalanche Canada, 1596 Illecillewaet Rd, Revelstoke, BC, V0E 2S0, Canada. 250-837-8760; jfloyer@avalanche.ca

Switzerland and elsewhere. Schweizer, et al. (2006) extended SNOWPACK to be able to make point predictions of snow instability.

In weather forecasting, meteorologists have long been able to select charts and other visual products generated from a wide array of computer models. Although scale issues and data scarcity make this a more challenging prospect in avalanche forecasting, there is nonetheless significant scope to improve the availability of computer-based modelling products. Recent communication with snow model users in Europe and North America found many were interested in integrating computer models into their operational workflows. This paper lays out a vision for what a useful collection of such models might look like. The models considered are realistic, build on an array of recent conceptual and technical advances, and in some cases simply require reconfiguration of existing models for their implementation.

2. CONCEPTUAL AND TECHNICAL BASIS

Many of the models conceptualized here rely on the Swiss snow cover model SNOWPACK. This model has been preferred in Canada on account of historical legacy and a close association with the model's developers. There is nothing to preclude the future use of the French Crocus (Durand, et al., 1999) or SURFEX models (Lafaysse, et al., 2013).

To address problems of low weather station density and a lack of instrumentation monitoring radiation (pyranometers), Bellaire, et al. (2011) forced the SNOWPACK model using weather forecast data, initially from the GEM Regional (15 km) model, and subsequently the GEM HRDPS (2.5 km) model (Bellaire & Jamieson, 2013). In the latter study, they concluded the higher resolution model outperformed the lower in "all analyzed aspects of quality".

The recent development of the Conceptual Model of Avalanche Hazard (CMAH; Statham, et al., 2010, Canadian Avalanche Association, 2016) created a robust framework for avalanche hazard determination and communication by explicitly articulating a pathway between raw observations (i.e., weather, snowpack and avalanche observations) and hazard assessments. One of the central contributions of the CMAH is the definition of nine quasi-independent avalanche problem types (also referred to as avalanche characters) which are used to describe the primary character of a specific avalanche concern (e.g., storm slab, persistent slab, loose dry). An avalanche problem is fully described when information on the terrain where the problem is most likely located, likelihood of triggering, and potential destructive avalanche size is bound to the avalanche problem type. Multiple avalanche problems can exist at the same time and the resulting avalanche hazard is related to the sum of all avalanche problems present in a given space and time. The concept of *avalanche problems* has been widely adopted in North America as an effective way to dissect avalanche conditions into manageable units. It is used in public avalanche forecasts and taught as part of the Avalanche Skills Training (AST) course curriculum in Canada.

The stochastic models conceptualized here are based on previous ideas integrating non-linear prediction methods with rule-based systems (Schweizer, et al. 1994), but using avalanche problems as the target variable instead of avalanche hazard ratings. We believe this approach will make the modelling output more relevant for forecasters making hazard determinations, as well as recreational end users, since the output is directly useable and in an already familiar language.

3. CANADIAN AVALANCHE MODEL SUITE

We distinguish between three basic categories of computer-assisted analysis tools that can be combined into a suite of models (Table 1).

3.1 *Tools that help forecasters aggregate, assimilate and analyze complicated data sets.*

This first category of tools addresses the automation of common data aggregation and interpolation tasks that are still largely manual tasks in the avalanche domain. Contrast this to meteorology, where tasks such as contouring isobars (cf. contouring height of snow), identifying fronts (cf. mapping zones of buried surface hoar), and determining areas where significant precipitation is occurring (cf. determining areas of significant avalanche activity) have long been computerized, and it is clear that even a basic application of computer automation could have a significant impact in improving forecasting efficiency and consistency.

3.2 *Tools that model physical parameters of the natural environment.*

The second category makes use of existing physical snow cover models, but reformulated and enhanced to address specific needs of regional

Table 1: Components of the conceptual Canadian Avalanche Model Suite.

Component Name	Description	Relies On…	Benefits
Tools that help forecasters aggregate, assimilate and analyze complicated data sets			
Forecaster Dashboard	Interpolation, extrapolation and gridding of basic variables. Options to merge observations (where available) with model output (where observations unavailable)	• Weather station data • Field observations • GEM HRDPS weather model output • SNOWPACK forced with GEM HRDPS data	• Rapid assimilation of data—Forecasters do not need to visit multiple sources • Data gaps are filled • Geographic uncertainty reduced
Tools that model physical parameters of the natural environment			
Enhanced Surface Hoar Model	Similar to existing surface hoar model, with improved visualization and a MOS or manual override layer to modify coverage based on burial conditions. Extension to evolve weak layer parameters over time.	• SNOWPACK forced with GEM HRDPS data	• Forecasters able to keep more accurate track of where critical surface hoar layers exists • Improved consistency between forecasters
Representative Regional Profiles	Modelled snowpack profiles that combine critical elements from an aerial aggregation of individual snow profiles over a large region.	• SNOWPACK forced with GEM HRDPS data • Module to highlight critical profile components and merge non-critical components	• Profiles generated at a scale appropriate for regional avalanche forecasting • Small-scale uncertainties eliminated by regional aggregation
Evolving Snowpack Profiles	Manual snowpack profiles that are kept current through modelled updates	• SNOWPACK initialized with manual data and subsequently forced with GEM HRDPS data	• Effectively increases data flow, particularly valuable in data sparse area
Tools that aid avalanche hazard determination			
Regional Avalanche Problem Prediction	Stochastic model to predict avalanche character, likelihood and expected size from avalanche, snowpack, and weather inputs.	• Conceptual model of avalanche hazard • Non-linear stochastic model (as yet undeveloped)	• Enhance forecast consistency • Validate personal assessment of forecast • Provide output for data sparse areas
Regional Avalanche Danger Prediction	Stochastic model to predict avalanche hazard from a set of avalanche problems.	• Regional Avalanche Problem prediction model (above) • Non-linear stochastic model (as yet undeveloped)	Enhance forecast consistency • Validate personal assessment of forecast • Provide output for data sparse areas
Problem-based Nearest Neighbour Model	Reworking of the nearest neighbours concept to match days with similar avalanche problems	Database of professional avalanche problem designations	• Improve forecast accuracy for outlier conditions • Improve forecast consistency

avalanche forecasters. Relatively minor improvements to the surface hoar model, particularly addressing improvements in the visualization and the ability to modify the model output based on evidence of burial conditions, have the potential to further improve the value of this tool for data sparse regions.

The vision for modelled snow profiles is similarly quite pragmatic. Profiles need to be made available across the entire HRDPS Western grid, and an effort made to match the output to the expectations and needs of avalanche forecasters. In the Representative Regional Profiles model, the objective is to develop generalized regional snow profiles that highlight critical components of the snowpack (such as weak layers), while providing summarized information on general characteristics and their variability (such as slab thickness). This technique is widely used by guides and snow professionals through the use of “whiteboard profiles” in daily safety briefings, and could have significant potential to make modelled snowpack profiles relevant to regional forecasting, including for data sparse regions.

3.3 *Tools that aid avalanche hazard determination.*

The third class of tools directly address components (Avalanche Problems and Danger Ratings) that could lead to the provision of full-featured avalanche forecasts to data sparse regions. Professional data sets that include Avalanche Problem information are becoming sufficiently large to yield valuable relationships between the Problems themselves and the associated avalanche, snowpack and weather observations (Haegeli, et al., 2012, Shandro, et al., 2016).

4. DISCUSSION AND SUMMARY

Guided by Statham, et al., (2010)’s conceptual model of avalanche hazard, and underpinned by a high quality network of professional observations, Canadian avalanche forecasters issue high quality, effective, reliable forecasts on a daily basis. A major output of the forecasts is the *avalanche problem* information, which ties in directly with the curriculum of recreational avalanche safety courses, which trains people to make specific travel decisions when certain Avalanche Problems are present. This, in a nutshell, is Canada’s comprehensive avalanche safety strategy.

The strategy is extremely effective when regular, high quality avalanche, snow and weather data, are available (either collected directly or via InfoEx) to support avalanche forecasts. But it breaks down for data sparse regions (Storm & Helgeson, 2014) when regular data is not available. Public expectation is driven by the success of forecast products in data-rich areas, resulting in a continued effort to find effective methods for addressing avalanche safety in data sparse ones.

The suite of models conceptualized in the paper lays the foundation for being able to provide computer-assisted forecast products for all areas including data sparse areas that integrate with Canada’s comprehensive avalanche safety strategy. It also has the potential to improve forecast accuracy and consistency, as well as increasing forecasting efficiency. The latter will help free up forecaster time which may be used for other tasks, such as targeted social media communication.

ACKNOWLEDGEMENTS

We are very grateful for funding provided by the Avalanche Canada Foundation ISSW fund in support of this work.

REFERENCES

Barteld, P., & Lehning, M. (2002). A physical SNOWPACK model for the Swiss avalanche warning: Part I: numerical model. *Cold Regions Science and Technology, 35*(3), 123-145.

Bellaire, S., & Jamieson, B. (2013). Forecasting the formation of critical snow layers using a coupled snow. *Cold Regions Science and Technology, 94*, 37-44.

Bellaire, S., & Jamieson, B. (2013). On estimating avalanche danger from simulated snow profiles. *International Snow Science Workshop*, (pp. 154-161). Chamonix Mont-Blanc.

Bellaire, S., Jamieson, B., & Fierz, C. (2011). Forcing the snow-cover model SNOWPACK with forecaster weather data. *The Cryosphere, 5*(4), 1115-1125.

Canadian Avalanche Association. (2016). *Technical Aspects of Snow Avalanche Risk Management.* Revelstoke, BC, Canada: Canadian Avalanche Association.

Cordy, P., McClung, D., Hawkins, C., Tweedy, J., & Weick, T. (2009). Computer assisted avalanche prediction using electronic weather sensor data. *Cold Regions Science and Technology, 59*(2-3), 227-233.

Durand, Y., Giraud, G., Brun, E., Mérindol, L., & Martin, E. (1999). A computer-based system simulating snowpack structures as a tool for regional avalanche forecasting. *Journal of Glaciology, 45*(151), 469-484.

Haegeli, P., Falk, M., & Klassen, K. (2012). Linking avalanche problems to avalanche danger-a first statistical examination of the conceptual model of avalanche hazard. *International Snow Science Workshop*, (pp. 859-865). Anchoarge, AK, USA.

Horton, S., & Jamieson, B. (2016). Modelling hazardous surface hoar layers across western Canada with a coupled weather and snow cover model. *Cold Regions Science and Technology, 128*, 22-31.

Lafaysse, M., Morin, S., Coléou, C., Vernay, M., Serça, D., Besson, F., . . . Durand, Y. (2013). Towards a new chain of models for avalanche hazard forecasting. *International Snow Science Workshop*, (pp. 162-165). Chamonix Mont-Blanc, France.

Lehning, M., Barteld, P., Brown, B., & Fierz, C. (2002b). A physical SNOWPACK model for the Swiss avalanche warning: Part III: meteorological forcing, thin layer formation and evaluation. *Cold Regions Science and Technology, 35*(3), 169-184.

Lehning, M., Bartelt, P., Brown, B., Fierz, C., & Satawali, P. (2002a). A physical SNOWPACK model for the Swiss avalanche warning: Part II. Snow microstructure. *Cold Regions Science and Technology, 35*(3), 147-167.

Schweizer, J., Bellaire, S., Fierz, C., Lehning, M., & Pielmeier, C. (2006). Evaluating and improving the stability predictions of the snow cover model SNOWPACK. *Cold Regions Science and Technology, 45*(1), 52–59.

Schweizer, M., Fohn, M., & Schweizer, J. (1994). Integrating Neural Networks and Rule Based Systems to build an Avalanche Forecasting System. *International Association of Science and Technology for Development (IASTED)* (pp. 1-4). Zurich, Swizerland: IASTED Acta Press.

Shandro, B., Haegeli, P., Statham, G., & Floyer, J. (2016). Spatial and temporal distribution of avalanche problem types in western Canada: an analysis of the winters 2010-2016. *International Snow Science Workshop*, (p. This proceedings). Breckenridge, CO, USA.

Statham, G., Haegeli, P., Greene, E., Birkeland, K., Israelson, C., Tremper, B., . . . Kelly, J. (2010). A Conceptual Model of Avalanche Hazard. *International Snow Science Workshop*, (p. 133). Whistler.

Storm, I., & Helgeson, G. (2014). Hot-spots and hot times: exploring alternatives to public avalanche forecasts in Canada's data sparse Northern Rockies region. *International Snow Science Workshop*, (pp. 91-97). Banff, AB, Canada.

Vernay, M., Lafaysse, M., Mérindol, L., Giraud, G., & Morin, S. (2015). Ensemble forecasting of snowpack conditions and avalanche hazard. *Cold Regions Science and Technology, 120*, 251–262.