IMPROVEMENT OF SNOW GRAIN SIMULATIONS FROM THE MULTI-LAYERED THERMODYNAMIC SNOW MODEL SNOWPACK: IMPLICATIONS TO AVALANCHE RISK ASSESSMENT

Jean-Benoit Madore, Kevin Coté and Alexandre Langlois

Université de Sherbrooke, Sherbrooke, Qc, Canada

ABSTRACT: The snow thermodynamic multi-layers model SNOWPACK was developed by the Swiss Federal Research Institute (WSL/SLF) in Switzerland in order to address the risk of avalanches by simulating the vertical geophysical and thermophysical properties of snow. SNOWPACK risk assessments are based on the simulation of snow microstructure (i.e. grain size, sphericity, dendricity and bond size). Previous research has shown a systematic bias in the grain size simulations (equivalent optical grain size) over several areas in northern Canada. Snow specific surface area (SSA), a grain size metric, was measured using a laser-based system measuring snow albedo through an integrating sphere (InfraRed Integrating Sphere, IRIS) at 1310 nm. Optical grain size was retrieved from the SSA measurements in order to be compared with the optical equivalent snow grain radius from SNOWPACK outputs. A field campaign was conducted during the 2014 winter in the Canadian Rockies to validate the bias and. Three study plots were selected, each with its own climate particularities. The first site was located at Mt. Fidelity in Glacier National Park, BC. The second site was located within the Marmot Basin ski resort in Jasper National Park, AB and finally, the third site is located in Réserve naturelle des Chic-Chocs, QC. Profiles of snow temperature, density, grain size (IRIS) were conducted, and stratigraphic analysis completed using visual interpretation, combine with a snow micropenetrometer (SMP). The measurements are expected to provide detailed information on snow microstructure, leading to a snow grain correction coefficient for SNOWPACK for the improvement of snow stability predictions.

KEYWORDS: SNOWPACK, grain size, avalanche risk assessment, snow stability index, snow micropenetromer

1. INTRODUCTION

Avalanches are important and recurrent phenomena in many regions in the Canadian mountains. They pose a direct threat for the persons that travel in high risk areas and also for infrastructure that crosses their path. Since 1999-2000, the Canadian Avalanche Center reported 589 incidents with 197 casualties and 135 wounded. Many tools have been developed to help decision makers addressing the risk of avalanches in those regions. The snow thermodynamic multi-layer model SNOWPACK (Bartelt & Lehning, 2002; Lehning et al, 2002a, 2002b.)was developed by the Swiss Federal Research Institute (WSL/SLF) in Switzerland in order to address those risks by simulating the vertical snow cover and its thermophysical properties.

SNOWPACK is currently used operationally in Switzerland. Although it has been tested in Canada (Bellaire et al, 2011; Smith et al, 2008), it hasn't been applied in an operational mode due to sparse meteorological station network and uncertainties behind simulated geophysical variables (lack of field data with adequate instrumentation). Although Bellaire et al., (2011) identified precipitation as a critical parameter for avalanche forecasting using SNOWPACK, they highlighted the need to improve microstructure (i.e. snow grains) simulations in order to validate the overall performance of the model chain. Schweizer et al., (2006) recommended reviewing and adjusting the microstructure simulations for a Canadian implementation of the model that has yet to be done.

At the microstructure level, grain size prediction accuracy is related to one of SNOWPACK stability index, the 'skier stability index, SSI' (Schirmer et al, 2010; Schweizer et al., 2006). SSI is an adjusted version of the SK38 (Jamieson et Johnston, 1998) that did not initially considered grain size. One of the possible problems lies in the assignment of the initial grain size of new snow, which is set constant (i.e. standard value). Since the model

* *Corresponding author address:*
Jean-Benoit Madore, Université de Sherbrooke, Sherbrooke, Qc, Canada;
tel: 819-821-8000 poste 62506
email: jean-benoit.madore@usherbrooke.ca

only allows grain growth, no grain sizes less than this initial value are ever predicted which leads to systematic overestimation of grain size (Langlois et al., 2012).

Because of its variability in size and shapes, snow grain size has been difficult to measure with good accuracy (Taillandier et al, 2007) and on a regular basis (Domine et al., 2006). However, new measurement methods have been developed over the past decade. As the spectral reflectance (or its hemispherical component: spectral albedo, hereafter referred as albedo) of snow is very sensitive to grain size and shape (Picard et al., 2009). Specifically, it was shown in several studies that optical grain size is strongly related to near infrared reflectance (Kokhanovsky and Zege, 2004; Matzl and Scneebeli, 2006; Langlois et al., 2010), but at this wavelength the sensitivity to grain size is limited leaving little room for SNOWPACK validation/improvement. Recent methods using reflectance at 1300 nm using laser-mounted devices with integrating spheres (Domine et al., 2006) provided better results though an increased sensitivity of albedo to grain size at this wavelength. The Université de Sherbrooke developed its own system, the IRIS (InfraRed Integrated Sphere) (Montpetit et al, 2012), a device that measure the albedo of snow at 1310 nm from which can be derived the equivalent optical snow grain size diameter.

2. OBJECTIVES

The main objective of this research is improve snow grain simulations form SNOWPACK in order to improve the snow stability predictions in a Canadian weather context. . Specific objectives are to:

- Calculate and analyze the snow grain simulation biases by comparing in-situ measurements of IRIS with the SNOWPAKC simulations;
- Identify the different processes (i.e. temperature gradient, snow thickness, meteorological variation, etc.) governing the simulated grain size bias,
- Develop a correction factor (empirically-based) to reduce the observed bias, either by a correction coefficient applied directly on the simulated grain size or by a modification of the model metamorphism algorithms;
- Integrate the correction into the model operationally and validate the 'corrected' simulation with an independent dataset.

3. METHODS

3.1 Study sites

The climate and terrain variability has a major impact on snow cover physical attributes. McClung and Schaerer (2006) identified three major climates that have a significant impact on the risk assessment and evaluation of avalanches, and therefore the risk will be different from a climate to another. To evaluate this variability, three different sites have been chosen throughout Canada (Fig.1), each of which has avalanches problems of their own. Two of the sites are located in western Canada in the Rockies mountain.

The first site is situated in Glacier National Park at Mount Fidelity, west of Roger's Pass. This site is characterized by a transitional mountain climate and is known to have the largest amount of precipitation in Canada. An annual maximum height of 3.5m of snow has been reported at this location.

The second study site is located in Jasper National Park around Marmot Basin ski resort. This site is characterized by a continental mountain climate. With less precipitation than Glacier Park, cold temperatures is the main characteristic of this climate, thus metamorphism processe are expected to be different.

The third site is located in the Chic-Choc park, Québec. It is one of the only eastern site where avalanches are observed. It is also one of the few areas in eastern Canada that has alpine areas within avalanche terrain so that terrain variability is fully represented in this area.

3.2 Meteorological data

The SNOWPACK model requires specific input meteorological data to be able to perform a simulation. The minimum requirements are air temperature, relative humidity, wind speed, incoming longwave, incoming shortwave and precipitations. It can also be forced on observed snow depth for more accurate simulations. The

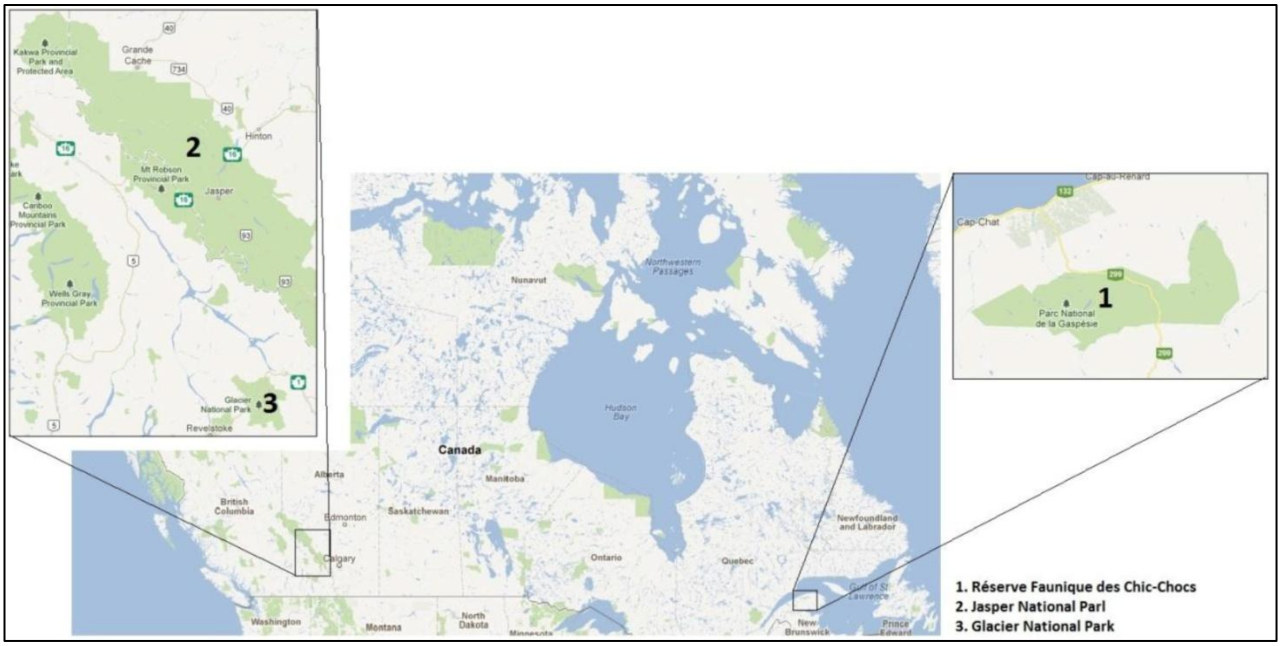

Fig.1: Location map of the three study site 1) Réserve Faunique des Chic-Chocs, 2) Jasper National Park and 3) Glacier National Park.

other meteorological variables that can be incorporated into the simulation are wind direction, outgoing longwave and shortwave, surface temperature and soil temperature. All those data are mainly available across the different weather stations on the study sites.

Reanalysis data are also used to drive SNOWPACK when station data are not available (e.g. remote areas). For the western sites (Glacier Park and Jasper Park), GEMLam (Global Environnemental Multiscale Model – Limited Area Model) by the Canada government weather service data is used. This data as a 2.5km resolution and all necessary variables are available to run SNOWPACK. This dataset isn't available for the moment for the Chic-Choc study site but is in experimental mode. For this site, GEM10 (10km resolution) or GEM15 (15km resolution) is used to complete the dataset of the weather stations. Those data are to be validated and adjusted with the weather stations on each sites.

3.3 Field data

A field campaign occurred in the 2014 winter at the different study sites. Snow grain size profiles have been measured using IRIS. Stratigraphy and stability analysis, followingthe Canadian Avalanche Association standards, has been performed on each site to characterize snow cover physical properties and stability. Those measurements included temperature, density and resistance profiles, grain type and grain size measure with a snow ruler. Measurements were made near the weather stations but also in different types of terrain in order to obtain various aspects and terrain characteristics. A Snow Ram was also used to obtain snow hardness profiles along with the SMP. A 270cm deep profile was conducted at Mt Fidelity weather station plot (Fig. 2). A second winter of field measurement is to be performed in the winter of 2014-2015.

3.4 Grain size validation

Simulated snow grain size is to be compared with the grain size derived from the IRIS measurement. The simulated snow grain size from the same hour as the field measurement will be extracted. Since the model is not forced with a measured snow height, a snow depth bias is expected. Simulated snow depth will be adjusted to match the observed height (only if bias is small). The main goal of this observation is to compare the bias on each metamorphism algorithms.

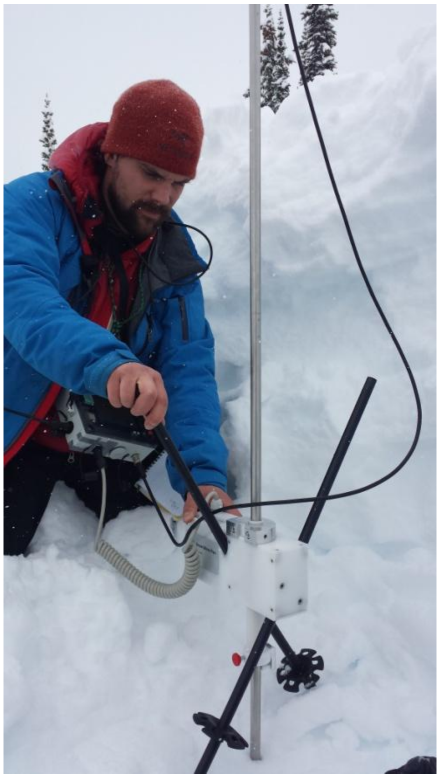

Fig. 2: The author performing a 270cm SMP profile at Mt Fidelity study plot.

3.5 New metamorphism parameterization

Once the biaswill identified and documented, an adjustment will be tested on the model. Since the code of SNOWPACK is open, it is possible to implement a correction directly in the model suing published methods (Montpetit et al., 2013; Langlois et al., 2012).

The new parameterisation will be tested in the 2014-2015 field campaign on the different study sites. The snow temperature, density, grain type will also be evaluated to test the global performance of the model. These measurements will be performed on different altitudes and aspects to test the robustness of the simulations. Finally, the stability index of SNOWPACK (SK38, SSI) will also be evaluated to see if an improvement is observed.

4. EXPECTED RESULTS

It is expected that the identification and the analysis of the snow grain size bias by the SNOWPACK model will lead to an improved understanding of SNOWPACK limitations in predicting snow stability. Identifying the controlling factors leading to snow grain bias will obviously benefit the avalanche community, but also remote sensing applications using snow models to derive surface state variables.

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