EVALUATING THE POTENTIAL OF USING SNOWPACK AND ALPINE3D SIMULATIONS IN THREE CANADIAN MOUNTAIN CLIMATES

Côté K., Madore, J-B. and Langlois, A.
Université de Sherbrooke, Sherbrooke, QC, Canada

ABSTRACT: Each year, approximately 1.5 million avalanches potentially dangerous to humans occur in Canada; of which about 5% in areas accessible by mountain users (Stethem, 2003). As the interest for outdoor activities in remote areas such as hiking, sledding and ski touring is increasing, there is a strong need for improved avalanche forecasting at the regional scale. Therefore the project aims at improving the large-scale predictions of snow stability and avalanches by using the Swiss snow thermodynamic multi-layer model SNOWPACK. Driving meteorological data are acquired by weather stations in three national parks in Canada: Gaspésie National Park (QC), Jasper National Park (AB) and Glacier National Park (BC). Reanalysis meteorological data are also used to run simulations at larger scale (i.e. remote areas). The data is then used to simulate snow geophysical properties using a combination of SNOWPACK and Alpine3D (SLF), a spatialized version of SNOWPACK. We will use the DNEC digital elevation model (~30m resolution in mountainous terrain with an altimetry precision of ± 10m at 90% confidence) to run the Alpine3D model. Fieldwork has been conducted at each site to validate the simulated profiles with in-situ measurements and will continue in 2014-2015.

KEYWORDS: Avalanches, simulation, hazard, SNOWPACK, Alpine3D, Canada

1. INTRODUCTION

Each year, approximately 1.5 million avalanches potentially dangerous to humans occur in Canada; of which about 5% in areas accessible by mountain users (Stethem, 2003). Since the 1990s, 12 people per year are killed on average by avalanches, so that it now represents the primary cause of death related to winter disasters in Canada (Stethem, 2003). Analysis of snow conditions on a large scale basis for avalanche forecasting is a critical study subject and increasingly relevant since many years (Schweizer, 2008; Stethem, 2003, Jamieson et al, 2002. Jamieson et al, 1992). Currently, prediction of avalanche risk is mainly accomplished by doing field observations and measurements combined with visual observations of avalanches tracks and available meteorological data. However, terrain of Canadian mountains is highly variable (elevation, aspect and land type) and drives the accuracy of the observations. This method is then effective mainly at the local level. The hazardous nature of the realization of these observations, the lack of weather station data in alpine regions and the time required to travel to sites of interest limit the assessment of snow cover stability at the regional level and in remote areas (Schirmer et al, 2010).

It has been shown that using snow cover simulation models and in-situ meteorological data could be an effective way of to assess stability of the snowpack (Bellaire, 2006). Swiss model SNOWPACK (Bartelt & Lehning, 2002; Lehning et al, 2002a, 2002b.) is among the models developed and used for snow cover stability and avalanches prediction by avalanches experts. The model simulates snow cover at a weather station location and characterizes the strength and resistance of each layer according to its physical properties (Schweizer et al., 2006). SNOWPACK is used operationally since 1997 in the Swiss alpine regions on a network of weather stations (Lehning, 1999).

* Corresponding author address:
Depthina A. Hoar, Institute of Hoarticulture, Walla Walla, WA 98523-1234;
tel: 509-555-1234; fax: 509-555-1235;
email: dhoar@depth.snow
Such models are gaining popularity from avalanche experts because of the possibility to overcome the logistical limitations of manual measurements, even if they remain essential for validation. However, the punctual aspect of simulations with SNOWPACK still poses a major limitation for assessing the stability of snow cover over large areas in highly heterogeneous terrain. A model derived from SNOWPACK, Alpine3D (Lehning et al., 2006) has been developed to include the surface hydrological processes related to snow and investigate these dynamics at the regional level. This model could be a useful asset for regional simulations by avalanche experts of the Canadians mountains. However, there is only few studies using this model in this context (Steinkogler, 2014; Mitterer, 2009; Mott, 2008) and these are not applied to the Canadian mountains.

The accuracy of the simulations with Alpine3D is strongly related to the amount and quality of the meteorological data used. Since it is difficult to have access to a weather stations network with good spatial resolution in remote areas, an alternative would be to use data from meteorological reanalysis models that are available for all of the Canada geographical extent at spatial resolutions of up to 2.5 km (Côté et al., 1998).

2. OBJECTIVES

The primary objective of this project is to assess the potential of simulating snow cover with SNOWPACK and Alpine3D models using in-situ and reanalysis meteorological data in an avalanches prevision context. To achieve this goal, three secondary objectives are defined:

- Simulate snow cover with SNOWPACK and Alpine3D with validated in-situ and reanalysis data for all the project sites;
- Validate simulations with in-situ measurements and propose an adequate parameterization of the models;
- Create spatiotemporal maps of the biases and precision of the simulated and measured parameters.

3. METHODS

3.1 Study sites

Three study sites are visited for this project:

- Mount Fidelity, Glacier National Park, British Columbia, Canada (Fig. 1);
- Marmot Basin, Jasper National Park, Alberta, Canada (Fig. 2);
- Chic-Chocs Mountains, Gaspésie National Park, Québec, Canada (Fig.3).

These sites have been chosen for their different mountain climates and snowpack characteristics. According to McClung and Schaerer (1993), Mount Fidelity is part of the Columbia Mountains and is located in a transitional mountain climate characterized by heavy snowfall and warm temperatures. Climate at this location is influenced by warm and wet air masses from the Pacific Ocean. Precipitations at Roger’s Pass where Mount Fidelity is located can reach as much as 15m per winter and then makes this region very prone to avalanches. At the project study plot, a snowpack of an average of 3 m is on the ground during most of the winter.

Marmot Basin is located in a continental climate characterized by cold temperatures and low snowfall. The Marmot Basin ski resort has the highest base elevation in Canada with 1697 m and with highest peak at 2612 m. Superior part of the resort has frequent avalanche activity and needs constant work to ensure security for the public. Opposite faces of the ski resort are also frequently visited by ski touring adepts because of the easy access the ski resort provides.
Chic-Chocs mountain chain is located in a coastal climate characterized by heavy snowfall (location with the most snow precipitations in Quebec). The chain is located from 20 to 40 km away from St-Lawrence River inside the gaspesian peninsula and has an extent of 95 km by 10 km.

Common thermal inversions and influence of oceanic air masses combined with orographic effect in mountainous areas lead to frequent instability developments in the snowpack (Germain, 2007).

The study sites have been visited last winter and will be visited in the next year to continue the acquisition of snow cover validation data.

### 3.2 Meteorological data

In-situ meteorological data are used to run the models and are provided by partners from the different study sites. Data acquired from the different sites are air temperature, relative humidity, incoming and outgoing radiation, snow surface and ground temperature, wind speed and direction and precipitation rate.

Meteorological reanalysis data is also used to run simulations. For this project, data from GEM10 (10 km resolution), GEM15 (15 km resolution) and GEMLAM (2.5 km resolution) models of the Canada government weather service are used. Variables used to run the simulations are air temperature, relative humidity, wind speed and direction, incoming radiation and precipitation rates.

<table>
<thead>
<tr>
<th>Model</th>
<th>Pixel resolution</th>
<th>Data time step</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEMLAM</td>
<td>2.5 km</td>
<td>1h</td>
</tr>
<tr>
<td>GEM10</td>
<td>10 km</td>
<td>3h</td>
</tr>
<tr>
<td>GEM15</td>
<td>15 km</td>
<td>3h</td>
</tr>
</tbody>
</table>

### 3.3 Validation data

To validate the simulated snow covers, field campaigns have been realized past winter and will be realized this year again at each study sites. Stratigraphy (temperature, density and resistance profiles, grain type, size and reflectance) and stability analysis are achieved according to the Canadian Avalanche Association standards and will be compared with the simulated snow profiles.

In-situ meteorological data is also used to validate the GEM10, GEM15 and GEMLAM models data for each site.

### 3.4 Methods

Meteorological reanalysis data will first be validated with in-situ data to assess the quality of modeled variables before doing snowpack simulations. Similar validation as Bellaire and al. (2011) will be realized on GEMLAM, GEM15 and GEM10 data.
for each of the study sites and if necessary, correction factors will be applied.

SNOWPACK simulations will then be realized using both types of data for each of the project study sites. The snow stratigraphy and characteristics resulting from these simulations will be compared with the stratigraphy and stability data acquired during the field campaigns. Depending on the results, specific parameterization of the model will be defined for each site and climatic context.

Finally, simulations with Swiss model Alpine3D will be realized using a network of meteorological reanalysis data pixels and compared with field campaign data to assess performance of such model with modeled data. Digital elevation model from Natural Resources Canada will be combined with land use data to drive the model.

The flow chart shown in Fig. 4 resumes these steps.

4. EXPECTED RESULTS

This project aims at assessing the potential of different meteorological data and type of snowpack simulations in the avalanche prediction context. In this context, precision of the simulations are very important and are directly related to the quality of the input data. First expected result is then a statistical analysis of the meteorological reanalysis data GEMLAM, GEM15 and GEM10 compared with in-situ data.

Second part of the project is to assess the potential of Swiss models SNOWPACK and Alpine3D to correctly simulate snow cover in different mountain climates of Canada and with different types of meteorological data. Analysis of simulated snow profiles compared to field campaign data will allow the evaluation of the models performances in different climatic contexts. Particulate attention will be given to the ice crust simulation by the models as this is one of the most important factors of instability in the snowpack.

ACKNOWLEDGEMENTS

This project is funded through SAR-NIF, CFI, NSERC, UdeS, and Parks Canada. The authors would also like to thank ASARC (B. Jamieson and M. Schirmer), Glacier National Park (J. Goodrich), Jasper National Park (S. Blake), the Centre d’avalanche de la Haute Gaspésie (D. Boucher) and Marmot ski resort (K. MacDonald) for tremendous field support.

REFERENCES


Jamieson, B., and Stethem, C., 2002: Snow Avalanche Hazards and Management in Canada: Challenges and Progress, Natural Hazards, 26, 35–53.


Fig. 4 Simplified project flow chart


