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What if you know what's next? On snow cover simulation in data sparse areas

by Sascha Bellaire

Canada is huge, and so are some of the forecasting regions of the Canadian Avalanche Center. Assessing the snow cover stability is mainly based on snow cover information and recent avalanche activity. Combining this now-cast with the weather forecast for the next few days allows one to estimate the evolution of the snow cover stability and hence to forecast the avalanche danger. This concept sounds easy and straightforward; however, it strongly relies on two things. First, you need the information on snow cover stability for different regions, aspects and elevation bands and second, you have to rely on the weather forecast.

This fact is where the challenge begins. The 20 Canadian avalanche-forecasting regions range from 200 km^2 to over 50 000 km^2 covering a total area of 345 000 km^2. In some of these regions information is available on a regular basis provided by experienced persons and automatic weather stations making them data rich areas. However, in some of the forecasting regions for example the North Rockies, almost no information on weather and snow cover conditions is available on a regular basis, making the now-cast and forecast impossible. Nevertheless, these so called data-sparse areas and their avalanche terrain are frequent by winter backcountry recreationists exposing themselves to a potential avalanche hazard.

When I started this project during the summer of 2010 I had to answer one simple question. How do we get more snow cover information in data sparse areas? Lucky me Bruce already thought about the basic idea during the renewal of his NSERC Research Chair in Snow and Avalanche Risk Control and came up with a project called "Coupled meteorological and stochastic snowpack models for avalanche forecasting in data sparse areas." The following will explain the idea and first results of this project.

Beside the fact that we do not fully understand the snow cover yet the basic processes of the formation and evolution of the snow cover are fairly well understood. Specifically, during and after a storm the atmospheric conditions in combination with the terrain determine the formation and evolution of the snow cover, i.e. snow metamorphism and weak layer formation. Because we understand the fundamental processes acting within and above a seasonal snow cover, researchers developed physically-based snow cover models in order to simulate the snow cover using meteorological parameters as input data. One of the more advanced models is the Swiss snow cover model SNOWPACK. This model was developed about ten years ago to

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simulate the snow cover at the location of automatic weather stations.

It would be great if we could send experienced people out to bring back information about the snow cover. However, this is time consuming, costs a lot of money and is often not possible due to weather conditions and finally the local avalanche danger. In other words, when it is really interesting out there it is also often very dangerous.

Using snow cover models sounds like the solution for the problem of providing additional snow cover information. In fact this is how SNOWPACK is used for example in Switzerland. However, the standard setup of running SNOWPACK requires a weather station measuring at least radiation, air temperature, relative humidity, wind speed, wind direction as well as a snow height measurement or precipitation amounts. This is where we run into a problem. A network of these full weather stations simply doesn't exist in Canada. In most cases the radiation measurements are missing and even more important, weather stations are not available in data sparse areas, otherwise it wouldn't be a data sparse area.

The solution to this problem lies in numerical weather prediction models. These models – nothing more than the weather forecast – run a couple of times daily providing all required information to force the snow cover model SNOWPACK. The Canadian regional weather prediction model is called GEM (Global Environmental Multiscale) and provides meteorological parameter on a 15 km grid, i.e. weather data is available over North America every 15 km in each direction. That means if we couple the snow cover model SNOWPACK with the numerical weather prediction model GEM we would be able to not only simulate the snow cover, i.e. get a full depth profile, every 15 km we would also be able to predict the evolution of the snow cover using the weather forecast.

Simply spoken I basically did that, I took SNOWPACK and used the forecasted meteorological data from GEM to run it. This has never been done before so nobody knew if this would even work. In addition, we all know how good the weather forecast works for the mountains. That means verification of such a model chain in a non data-sparse area with weather and snow cover information was necessary. Therefore, I analyzed weather and snow cover data from the winter 2009-2010 for a GEM grid point close to Mt. Fidelity Study plot at Rogers Pass, BC. It turned out that most meteorological parameters were reasonably forecasted by GEM, except for the precipitation amounts, which the model tends to over-estimate, i.e. GEM forecasted too much precipitation. However, this can be filtered and the simulated snow depth showed a fair agreement – considering the source of the input data, i.e. the weather forecast - compared to the measured snow depth at Mt. Fidelity study plot (Figure 1). The snow depth is of secondary interest for an avalanche forecaster. However, the new snow amounts and consequently the snow depth must be modeled with some confidence since it is relevant for the snow cover stability, i.e. how much snow is above a weak layer.

We all probably remember the winter of 2009-2010 as a very touchy winter with many surface hoar layers within the first meter of the snow cover. So what if you would have known in advance that these layers are out there?

The model chain SNOWPACK-GEM allows exactly this, knowing in advance what might be out there. As shown in Figure 2 most of the surface hoar layers were modeled and a comparison with a manual observed profile from Mt. Fidelity Study Plot showed a reasonable agreement of the general snow cover structure including potential weak layers.

So what's next? It seems to work! No digging anymore? Unfortunately, it is not that easy. The model chain seems to do a reasonable job for one point in the Columbia Mountains. However, as I wrote in my first sentence Canada is huge and has therefore many different snow climates from wet to dry, from sheltered to wind hammered. Furthermore, the showed simulation is only for a level site, which is useful, but we are usually not skiing or sledding there. Therefore simulations on different aspects and elevation bands in different sow climates are required to assess the difference, for example, between a north and a south-facing slope. Long story short - a lot of work!

Nevertheless, I'll keep going and working on this together with the CAC forecasters this winter. The model chain will run on selected locations from the Yukon, over the Columbia's to the South Rockies as well as along and from the west coast over the North Rockies to the Haute Gaspesie. This setup will cover most snow climates and areas of interest. CAC field crews in the Yukon and South Rockies will provide snow cover information and of course ASARC will be out there as well to gather the data for a detailed verification. This effort will hopefully result in a forecasting tool for data sparse areas.

Sascha studied meteorology at the University of Hamburg, Germany. He worked on the stability formulation implemented into the current version of the snow cover model SNOWPACK for his M.Sc. thesis at the WSL Institute for Snow and Avalanche Research SLF in Davos, Switzerland. Sascha continued working at the SLF in Davos for his Ph.D. thesis for which he studied the effect of spatial variability on avalanche formation on the slope scale. He is a certified mountain instructor and works since January 2010 as a post-doctoral fellow with ASARC at the University of Calgary.

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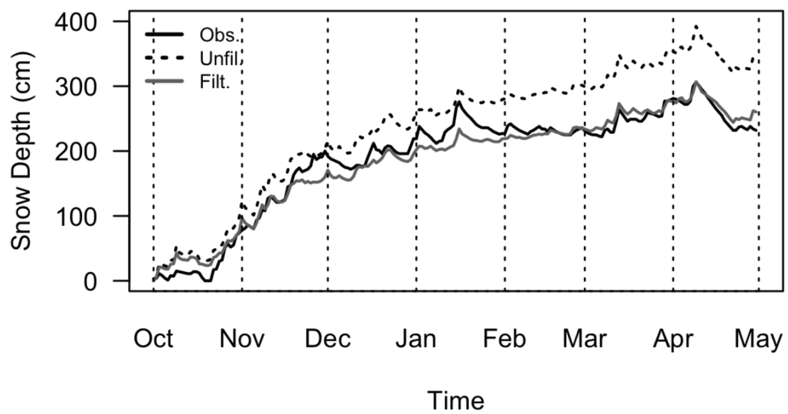

Figure 1: Comparison of observed and simulated snow depth at Mt. Fidelity Study plot. Solid black line shows the measured snow depth (Obs.) and the dashed line a simulation with SNOWPACK-GEM using the unfiltered precipitation forecast as input data (Unfil.). The solid grey line shows the result of a simulation after applying a constant factor to each forecasted precipitation amount (Filt.).

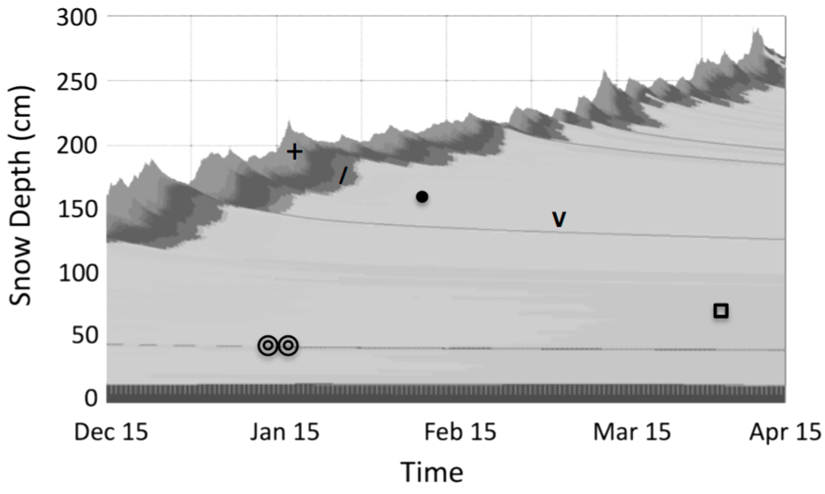

Figure 2: Snow cover simulation with the snow cover model SNOWPACK using forecasted GEM data as input. Shown is a simulation for the winter 2009-2010 for Mt. Fidelity Study Plot. Different grey scales indicate different grain types starting with precipitation particles over decomposed fragmented particles to small rounds and facets. The three grey lines above 100 cm indicate surface hoar layers and the thin line around 50 cm corresponds to a melt-freeze crust.