INTEGRATION OF THE SNOWDRIFT MODELING INTO THE FRENCH OPERATIONAL CHAIN FOR AVALANCHE HAZARD FORECASTING.

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ABSTRACT : Over the last years, the Snow Study Centre of Météo-France (CEN) has developed several versions of a model called Sytron for the assessment of the snowdrift events and their consequences on the snow pack stability and the avalanche hazard estimation. These models are based on in-situ measurements and observations:

- Sytron1 simulates the erosion and accumulation of two modelled snow profiles on the opposite slopes of a virtual crest undergoing wind effects. This model takes into account the modifications of snow morphology, the amount of snow moved by the wind, the densification of the accumulated snow, …
- Sytron2/3 (based on the previous one) has been designed to simulate the snow distribution on a limited domain by taken into account an estimated wind field.

The both versions of Sytron have been validated by using the data of an experimental site. In order to improve the operational forecasting for avalanche hazard, a new version of Safran-Crocus-Mepra (SCM) including Sytron1 was developed and first tested over 3 years on the Vanoise Massif. Then, this new version of SCM has been evaluated over 3 massifs of the Isere department during the last winter season with the collaboration of the local forecaster team.
We will show the principle of the integration of snowdrift modelling into the operational chain. We will also show preliminary results of the comparison with the current chain by using the Mepra snow pack stability analysis and the evaluation of avalanche hazard made by the forecaster, so as 2D simulations on limited areas.
KEYWORDS : blowing snow modeling, operational avalanche forecasting.

1 – INTRODUCTION

The snow transported by the wind induces generally the increase of avalanche hazard, notably the accidental releases. That is why the CEN (snow research laboratory of Météo-France) has started experiments and studies on a high altitude site in the French Alps for 15 years in order to improve the knowledge of this phenomena. One of the aim of this work is to introduce in the operational tools for the forecasting of avalanche hazard the results of the drifting snow models (Durand and others, 2004).

The CEN is in charge of the improving of avalanche hazard forecasting. For this reason, some modeling tools have been developed by using the results of these studies (Durand and others, 2005). In this paper, we describe the integration of the first version of this drifting snow modeling in an operational context.

2 – DEVELOPMENT OF THE SNOWDRIFT EFFECT MODELING

2.1 – Experimental site

The first step to develop tools for taking into account snowdrift was to design and equip a high altitude site for observation and measurements related to this phenomena. So all events directly linked with the moving of snow by the wind are observed and measured on this experimental site :

- wind velocity thresholds according to snow particle types at the snow surface that are at the origin of snow erosion,
- physical parameters of the re-deposited snow (size of snow particles, density, shear strength, ..)
- snow morphological transformation during a blown snow event,
- snow distribution along a 500 m pole profile on both faces of the pass.

2.2 - 1D modeling of blowing snow events

After some winter seasons of intensive observations and measurements during and after blowing snow events, the CEN has developed some modeling tools by using the results of these measurements, observations and field experiments.

The snow redistribution is modelled by using classical physical equations. The first development of drifting snow modeling (**Sytron1**) has been based on two numerical snow profiles on both sides of the experimental site. It determines the snow redistribution depending on wind velocity and direction. The model simulates the occurrence of blowing snow events and estimates the total snow mass transport. The losses due to sublimation, as well as the modifications of density and crystal morphology, are also considered. **Sytron1** has been verified by using the field data and has proven to give reliable results at the massif scale (figure 1). This model can be now fully integrated into the operational automatic chain.

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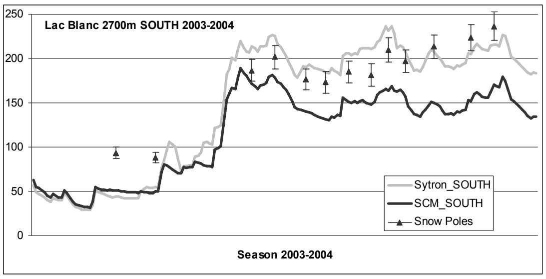


Figure 1: An example of the comparison between the operational chain (SCM) without effects of wind and **Sytron1**. The dots correspond to field measurements.

2.3 – Others versions of blowing snow models

These studies have also led to more sophisticated models always under development at present time:

- 2D evolution of a set of grid-point snow packs using a digital elevation model centered on the experimental location (**Sytron2**).
- A 3D approach: this model simulates the evolution of a set of vertical snow profiles taken into account the precipitation, the effects of wind on the snow distribution, as well as the changes in snow particles and the different modes of drifting snow over a limited area. This version is very useful to simulate afterwards some typical drifting snow events in order to better understand the re-distribution of snow according to the wind velocity field and the topography. The last developments of this model, **Sytron3** are described in detail in Durand and others (2004. 2005).

Another development way is an insertion of a snow transport scheme in finer scale meteorological model. This study is under work at present time (Vionnet, 2008).

3 – INTEGRATION IN THE OPERATIONAL CHAIN

3.1 – SCM operational chain

The chain **Safran-Crocus-Mepra** (SCM) is used operationally by the French avalanche forecasters. This software suite is composed of:

- **Safran** (Durand and others, 1993): A meteorological application that performs an objective analysis of weather data available from various observation networks (including radar and satellite data) over the considered elevations (separated from 300 m between the lower and the higher altitudes) and aspects (N, E, S, W) of the different massifs of the French Alps.
- **Crocus** (Brun and others, 1992): A numerical snow model used to calculate changes in energy, mass and stratigraphy in the snow cover. It uses the weather data provided by **Safran** and simulates the evolution of temperature, density, liquid water content and layering of the snow pack at different elevations, slopes and aspects. Original features of the model include the simulation of snow metamorphisms and the representation of each snow type in an evolutionary shape.
- **Mepra** (Giraud, 1993): An expert system diagnosing stability index (RM) and avalanche hazard for the Crocus output profiles mainly based on the Rankin equilibrium between the shear strength (C) of each layer and its applied shear stress (τ): RM = C/τ.

This operational chain is called “SCM” in this paper.

3.2 – New operational chain

A correct avalanche risk estimation requires accurate knowledge of the snow and temperature profile evolution as well as the type of snow grain, the density, strength and cohesion. However, a modeling tool for the estimation of these parameters have to incorporate not only the snow from direct precipitation but also that being added by wind transport. In addition we have to take in consideration the morphological transformation of the snow particles due to the wind (Gauer, 2001).

In order to improve the current operational suite SCM (Safran-Crocus-Mepra), we are attempting to introduce the 1D version of **Sytron** between **Safran** and **Crocus** in a new version (figure 2) of the operational chain by using a simple estimation of the wind velocity and direction at each point of the SCM simulations.

For each elevation level, an amount of snow is eroded and moved by **Sytron1** from the windward to the leeward slope, according to the wind direction and velocity. In order to simplify the computer scheme, we assume that there is an imaginary crest between each aspect.

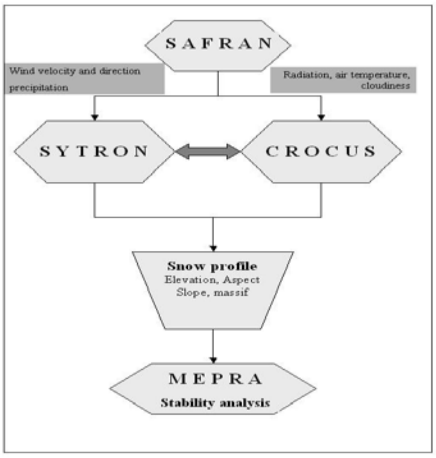


Figure 2: Flow chart of the integration of **Sytron** for hourly simulations.

By taking into account the effects of wind transport of snow which occurs at lower spatial scale but interact at our massif scale, different steps were defined: the assessment of an appropriate friction wind, the determination of the snow characteristics (size, cohesion, density, shear strength, …) in the near surface layers, the occurrence of blowing snow event as a relationship between these characteristics and the local wind velocity.

The corresponding snow transport rates for creep, saltation, suspension and sublimation have also been considered, as well as a shear wind estimation and the corresponding velocity thresholds. This new operational chain does not use any observation from the snow pack, the snow cover being hourly simulated by using the meteorological conditions calculated by **Safran**. The numerical results are complete and detailed snow profiles at different elevations (by steps of 300m), aspects and slopes (0, 20 and 40 °).

This new chain is called "SSCM" in this paper.

3.3 – Tests on "Vanoise" massif over 3 winter seasons

In order to quantify the contribution of **Sytron** to the operational avalanche forecasting, we have perform two runs ("SCM" and "SSCM") over three winter seasons (from November 1st to April 30th) for one mountainous region. The "Vanoise" massif is located in the Northern French Alps and has been chosen because of the great number of observation locations.

The figure 3 shows, for the 3 seasons, the difference of snow depth for North and South aspects at an elevation of 3,000 m.

For the two first winter seasons, we can see the great influence of the prevailing northwest winds which lead to erosion at the North slopes and the contrary on the opposite slope. It is less obvious on the last season.

In this first phase, one of our goals was to verify the compatibility of **Sytron1** with current operational chain SCM. The snow depth for example are equivalent and the modeled wind effects does not result in excessive differences.

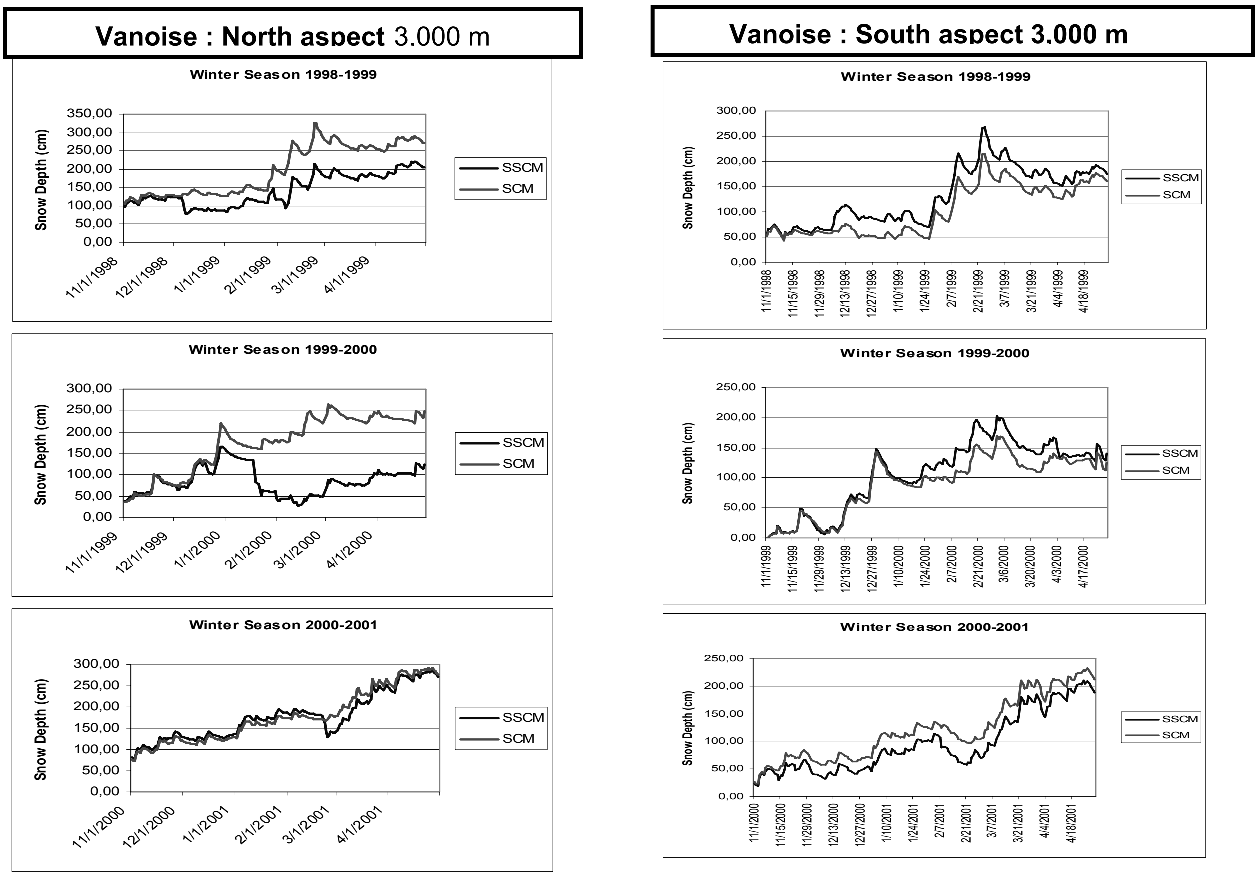


Figure 3: comparison of snow depth for the 3 winter seasons (SCM = Ref, SSCM=Sytron).

4 – TESTS IN AN OPERATIONAL ENVIRONMENT

The new version integrating wind effects for avalanche hazard forecasting was evaluated during the winter season by the avalanche hazard forecasters of the Isère department in parallel with the operational chain. For this experiment, the "SSCM" chain were used on 3 alpine massifs near Grenoble: Belledonne, Grandes Rousses and Oisans. The aim of this experiment was to compare "SCM" and "SSCM" results among themselves, and also with the analysis of the local forecaster day after day. This analysis is based on the French nivo-meteorological network and could be considered as an expert validation of this test.

5 – FIRST RESULTS

5.1 – Comparison with reference observation sites.

The figure 4 shows a set of comparisons between the snow depth daily measured at some reference observation stations considered by the avalanche forecaster as representative of each massif and an interpolation of the two modeling results at the same aspect and altitude level. Although local effects are not taken into account by the modeling, in the presented examples, we can see a better agreement with "SSCM" simulations. But some cases of strong wind velocity have to be examined more precisely: for example at "Vaujany" (Grandes Rousses) on the 23rd of January, the "SSCM" model has underestimated the wind velocity, it is why we can observe this difference with the observation which is probably due to a snow accumulation at the observation point.

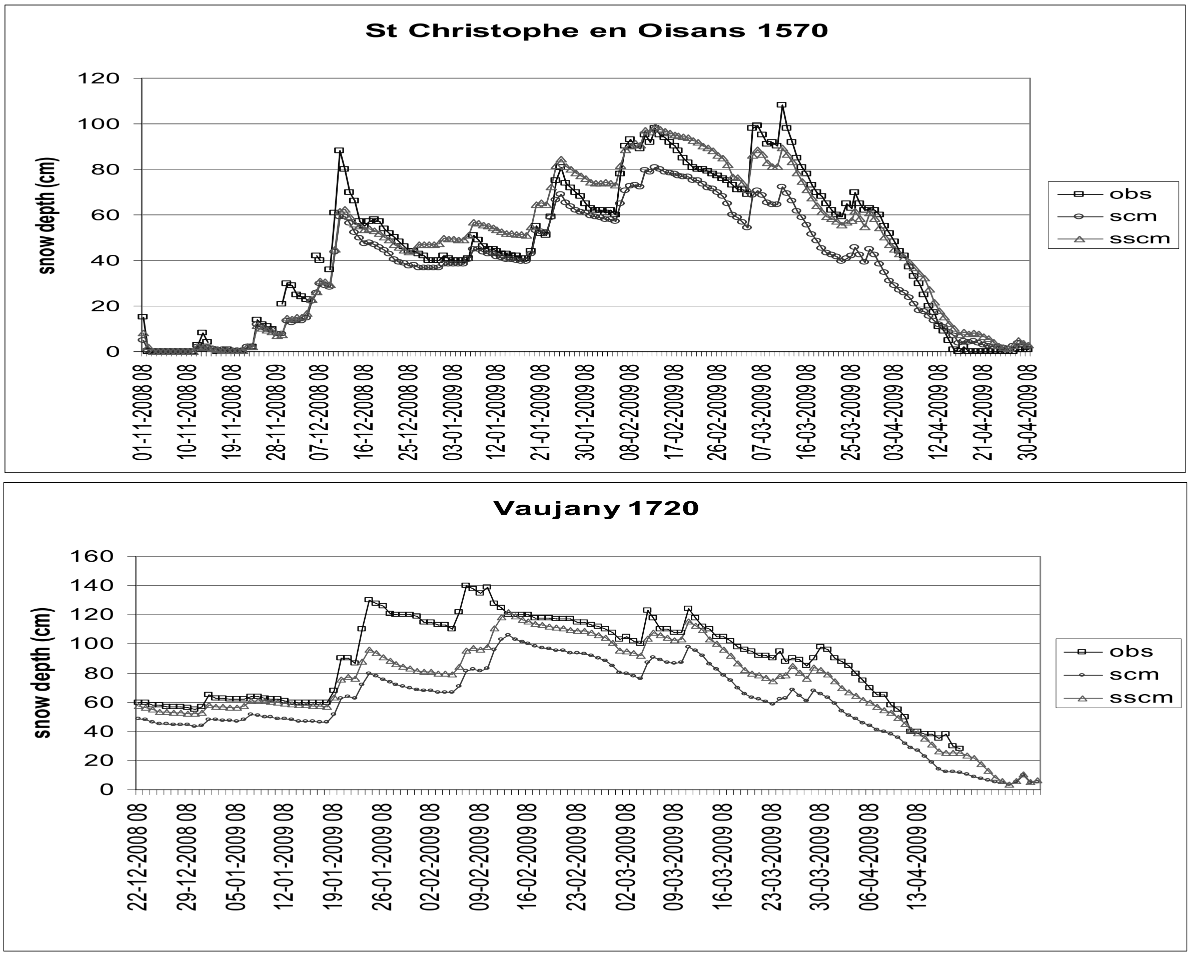


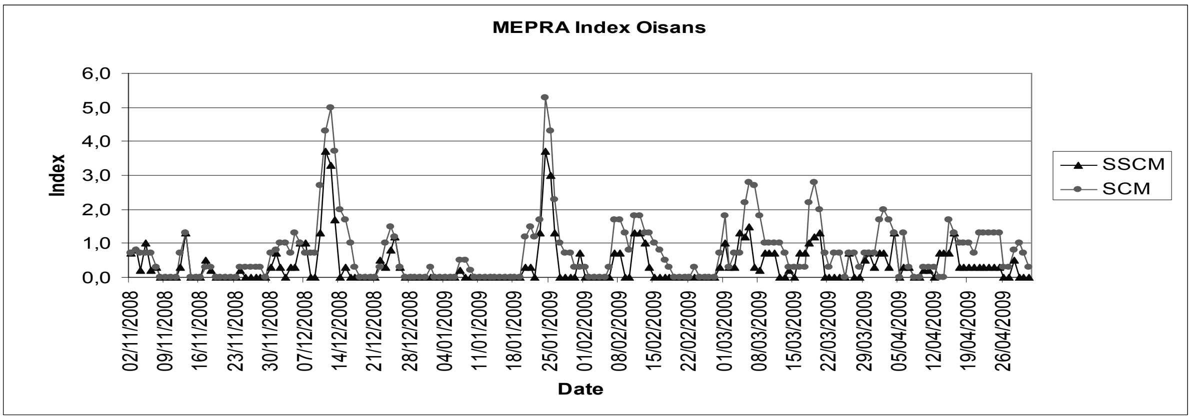
Figure 4 : comparison between modeling results and observations

5.2 – Indices of avalanche activity

Another way to appreciate the contributions of **Sytron** in the operational chain for the forecasting of the avalanche hazard is to take into account the final analysis performed by **Mepra**. An index, based on the usual stability diagnosis of natural hazard, is calculated by using a weighted average value for all aspects between 1,500 and 3,000m (Martin and others, 2001).

The figure 5 shows a comparison between this **Mepra** natural index for each model. In average, the "SCM" hazard evaluation is often higher than for "SSCM". This is probably due to an increasing of snow density caused by the wind effects, in this case the natural avalanche hazard is less high.

The next step of this work is an investigation on some periods. It will be interesting to detail, in terms of aspect and altitude, the difference of avalanche hazard evaluations. For that, each period of interest will be documented and as often as possible, we will perform additional measurements at special location which undergoes wind effects.



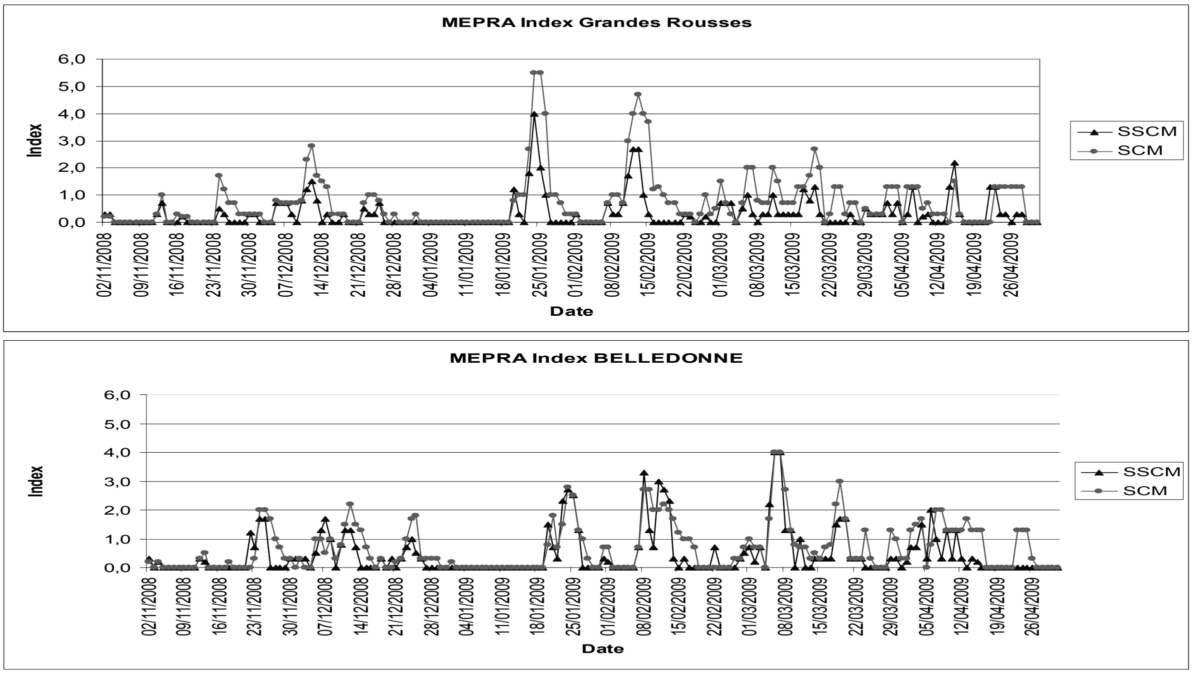


Figure 5: comparison of the Mepra index for the 3 mountainous regions of the experiment.

6 – CONCLUSION AND PERSPECTIVES

These preliminary attempts have shown that the rough modeling of drifting snow (Sytron1) can be directly used in the operational models for avalanche risk estimation and can improve the results in a first approach. This model simply simulates the changes in snow particle morphology and the distribution of snow depending on the wind exposure.

In order to go ahead in this integration, we have started to develop a real-time operational chain including the snow transport modeling. This chain has been used last winter season by the avalanche forecasters of the Isère department who are in charge of the daily report for avalanche hazard. This allows to follow day after day over the whole winter season, the difference between both simulations and to get the “experiment feedback” of the end users. Some measurements should be performed each time that differences were observed between the simulations with or without the snow transport modeling.

The work presented in this paper represents a first step of the analysis of the last winter testing. Notably, the taking into consideration of the feedback of avalanche forecasters remains to be done more completely, and the more detailed comparison of the periods when the avalanche hazard was high. It could be so interesting to compare the hazard evaluation with the observed avalanche activity.

The first comparisons with the observations are encouraging. Nevertheless, it will be interesting to see how the stability of the snow pack is impacted over the whole season and to detail several periods where we seen a noticeable difference in the avalanche hazard estimated by **Mepra**. We will focus especially on the hazard of accidental release. This is an important part of the future work to be done for this study.

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