TOWARD AN INTEGRATION OF A SNOWDRIFT MODELING IN THE OPERATIONAL AVALANCHE FORECAST.

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ABSTRACT : For several years the CEN has measured, studied and developed specific tools concerning drifting snow effects. The final objective of this work is to improve the operational models dedicated to the avalanche risk forecast in France. To reach this aim, numerous sensors adapted to the research subject were carried out in an experimental site of high altitude. In addition, specific measurement campaigns were organised to complete the knowledge on the wind speed thresholds associated with snow particles of the surface.
All these works allowed to develop two versions of a snowdrift model:

- 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 simulated the snow distribution on a limited domain (DEM with a mesh of 45 m) by taken into account an estimated wind field.

The both versions of Sytron have been validated by using the data of the experimental site.
The subject of this paper is to estimate the contribution of these models, at spatial various running scales:

- on extreme avalanche situations of the past (eg Chamonix - France, February 1999)
- in the framework of the operational models for the avalanche risk forecast in France.

KEYWORDS : blowing snow, modeling, operational avalanche forecasting.

1 – INTRODUCTION

The snow transported by the wind induces generally the increase of avalanche risk, 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 on this phenomena.

All events directly linked with the moving of snow by the wind are observed and measured in this experimental site :

- wind velocity thresholds according to snow particle type 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.

Lots of specific sensors dedicated to this study are carried out in order to follow precisely the evolution of the snow distribution on a site which undergoes snow transport by wind. Then, by using the results of measurements, observations and field experiments, the snow redistribution is modelled by using classical physical equations.

The CEN is in charge of the improving of operational forecasting of avalanche hazard. For this reason, some modeling tools have been developed by using the results of these studies (Durand and others, 2005)

After the first developments of the modeling software (named **Sytron** for : System for Aeolian Transport of Snow), the results are validated by using the observations of snow

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distribution on the site, which are not included in the simulation. These studies have then led to two models: 1D simulation of the snow pack on both sides of an imaginary crest which undergoes drifting snow (**Sytron1**), 2D/3D evolution of a set of grid-point snow packs using a Digital Elevation Model centered on the experimental location (**Sytron2**). The last developments of this model, **Sytron3** are described in detail in Durand and others (2004. 2005).

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 of the operational chain by using a simple estimation of the wind velocity and direction at each point of the SCM simulations.

This paper presents the contribution of these models, at spatial various running scales:

- firstly, on extreme avalanche situation of the past (Chamonix - Mont Blanc, February 1999) on a restricted area,
- on the other hand on seasonal assessments on the massif of Vanoise (the Alps French).

2 – **MODELING OF SNOW EVOLUTION AND WIND EFFECTS.**

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).

After some winter seasons of intensive observations and measurements during snowdrift events, the CEN has developed some modeling tools by using the results of these studies.

2.1 - 1D modeling

In order to improve the current operational avalanche risk model, the first development of drifting snow modeling (**Sytron1**) has been based on two numerical snow profiles on both sides (South and North) 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.

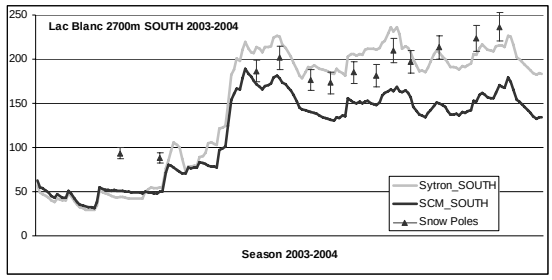


Figure 1: An example of the comparison between the operational chain (SCM) without effects of wind and **Sytron1**. The dots correspond to field measurements.

2.2 – SCM operational chain

For now 15 years, the chain **Safran-Crocus-Mepra** (SCM) is used operationally by the French avalanche forecasters. This software suite is composed of:

- **Safran** (Durand et al., 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 et Al., 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 “ref” in the rest of this paper.

2.3 – New operational chain

In order to introduce **Sytron1** in the operational tools for avalanche forecasting, a new operational chain (figure 2) has been developed. 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 “sytron” in the rest of the paper.

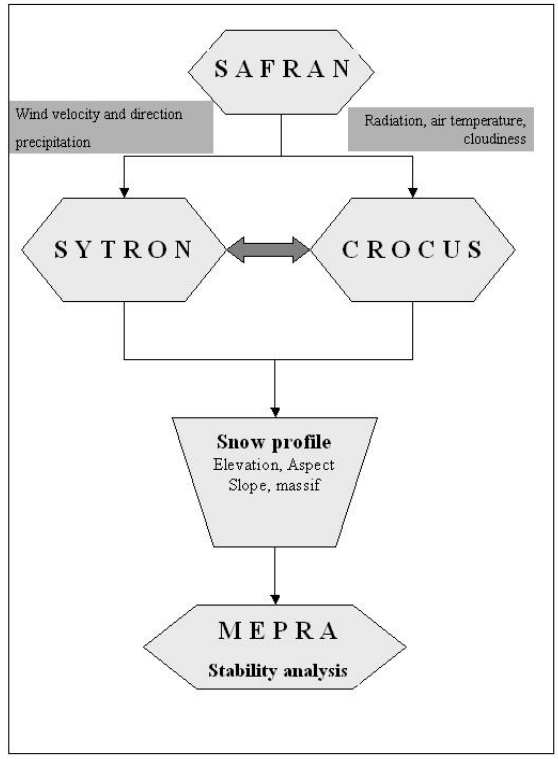


figure 2: Flow chart of the integration of Sytron for hourly simulations.

3 – RESULTS FOR CHAMONIX AVALANCHE EVENT (1999)

3.1 - Study background

The framework of this study are the dramatically avalanche events which occurred in the Alps in February 1999. We focus particularly on the Chamonix events (February 9th) where a lot of information is now available. This study has been funded in the framework of the EC project IRASMOS. The Chamonix valley is situated in the “Mont Blanc” massif in the northern part of the French Alps.

3.2 – The avalanche index

In order to evaluate and compare the different results and to make easier the quantification of the **Mepra** risks and their temporal evolution, two indices were defined (among others working indices):

- the first one is an instability index, it is called IG and is based on the operational **Mepra** diagnosis of natural hazard, it is computed every 3 hours. It consists of a weighted average value of the **Mepra** elaborated diagnosis for all aspects between 1,500 and 3,000 m a.s.l. (Martin and others, 2001). The

final "IG" index is the daily maximum value and varies between 0 and 8.

- The second synthesis index, called IL can be hourly computed. It is the massif maximum value of the potential local instability of a profile. In addition, it gives an indication of the avalanche magnitude by taking into account the depth of snow that can be moved by the avalanche. This index is computed with the upper layer of the snow pack where the **Mepra** index (RM) is lower than 2 (stability criterion). We keep the maximum of this index for 3 adjoining elevation levels. This index aims at simulating the capacity of snow capture by the erosion of avalanche flow.

3.3 Results and comments

The figure 3 illustrates the difference between "ref" and "sytron" through the global index IG. Both curves are globally very close and the two avalanche events of February are well identified. However, it is clear that the "Sytron" index anticipates better the event with increased values compared to "ref". The "sytron" index is saturated (value 8) during 3 days (February 9 to 11) and exhibits a quite higher value on the 8th of February (6.7 instead of 6). We can also see that the "ref" index value decreases a little quicker after the 9th of February event when the last main avalanche was observed in Taconnaz (on February 11, morning) in spite of the significant snow pack settling under 2,000 m together with a limited wetting in southern aspects under 2,000 m due to the prevailing sunny conditions. Concerning the last avalanche flood (February 17 to 24) the lower "sytron" value is probably due to the wet characteristic of the snow: the consequences are first to reduce snowdrift phenomena, and secondly a weaker ability for this wet snow to play the role of weak layer.

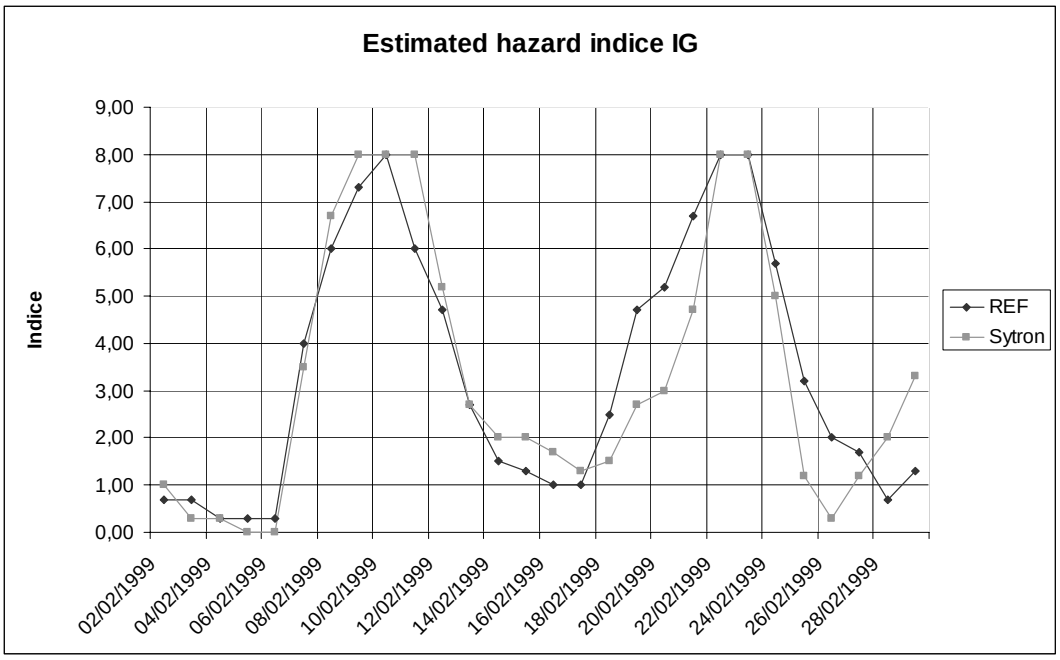


Figure 3: temporal evolution (from February 2 to 26) of the integrated risk index IG over "Mont Blanc" massif for the "Ref" experiment compared to the "Sytron" experiment.

The figure 4 shows the averaged IL index over a larger period (mid January-February). The three main avalanche floods are well visible. During the first event, the "sytron" index is rightly lower (as shown by the low number of observed damages). Both experiments focus well on the February 9th. The "sytron" experiment illustrates the importance of the snowdrift effects on the events of that day. More than previously seen in the IG index, the exceptional characteristic of the

avalanche event is there better illustrated. Due to the northwestern strong wind, a great amount of accumulated snow has been performed by the model. That leads to this great increase of the index value. However, even if it is difficult to precise the impact at local scale, the graph shows that the snowdrift had a great influence in increasing the quantity of snow which can feed the avalanche and this impact is well temporal positioned.

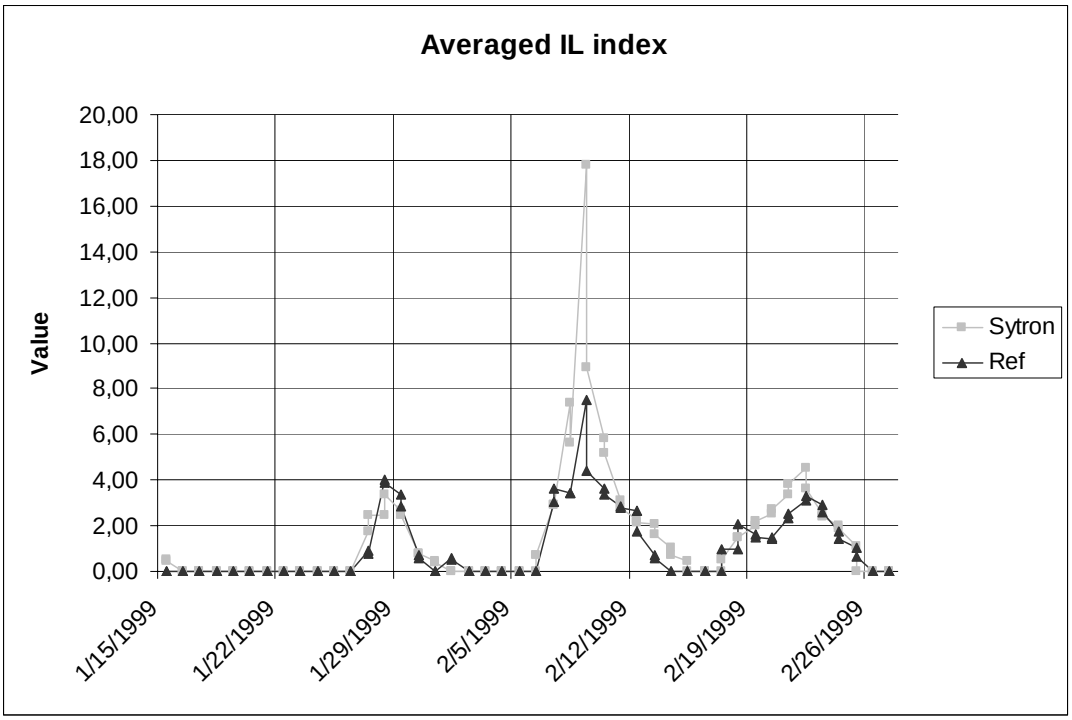


Figure 4: comparison of the "IL" index for "ref" and "Sytron" experiments between January 1st and February 26th.

4 – ATTEMPTS ON "VANOISE" MASSIF OVER 3 WINTER SEASONS

4.1 – Study background

Another way to quantify the contribution of **Sytron** to the operational avalanche forecasting is to perform the two runs ("ref" and "sytron") over three seasons (from November 1st to April 30th) for one massif. The "Vanoise" massif is located in the Northern French Alps and has been chosen because of the great number of observation locations.

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

4.1 – Results and comments

The table below (figure 5) shows the difference of snow water equivalent in average along the winter season between "ref" and "sytron" simulations. It appears that for the two first seasons, the prevailing wind has blown from North-West and consequently the corresponding slopes were eroded.

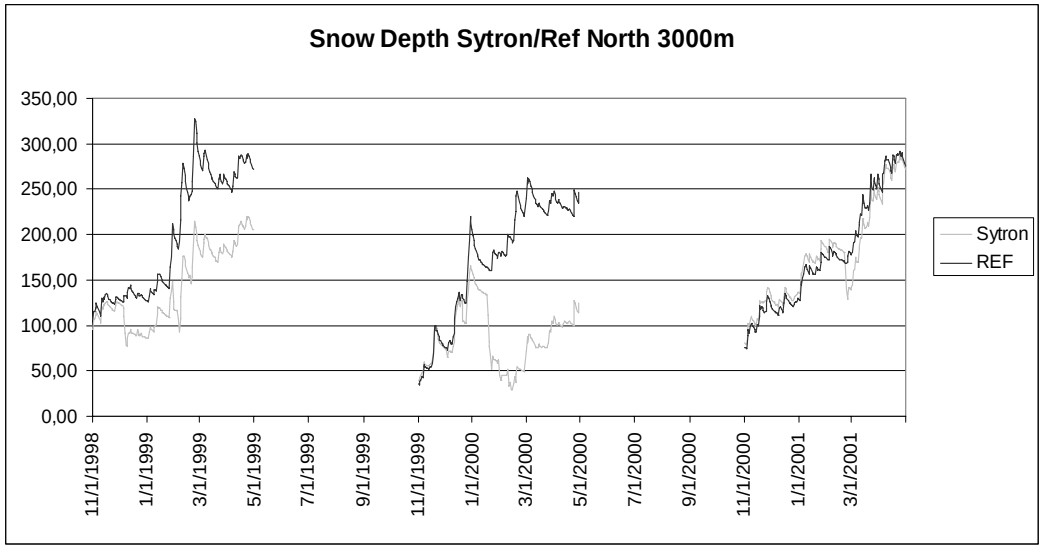
	North	East	South	West
98/99	-55,76	21,87	27,38	-59,54
99/00	-86,81	14,32	14,71	-61,57
00/01	-0,71	25,25	-25,18	-56,18

Figure 5: Difference of average snow water equivalent (mm) for each winter season.

The figure 6 shows, for the 3 seasons, the difference of snow depth for North and South aspects at an elevation of 3,000m.

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. Nevertheless, in order to go ahead in the understanding of the consequences of this new distribution of snow caused by the wind, it could be interesting to see how the snow pack stability is impacted during the whole season. This is the next step of our study, where we will compare the **Mepra** diagnosis in both cases.



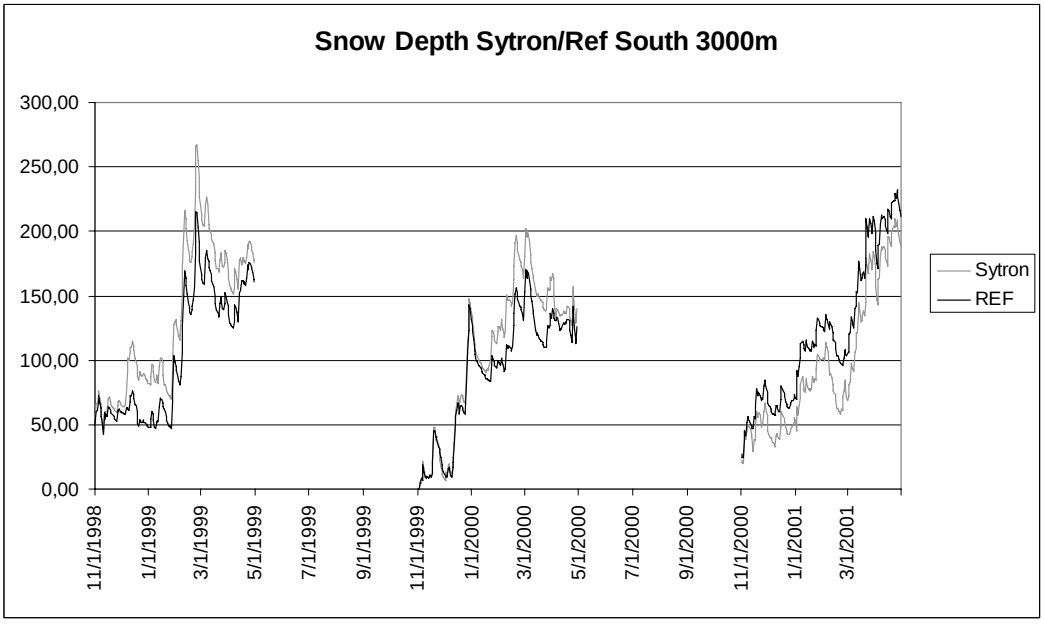


Figure 6: comparison of snow depth for the 3 winter seasons.

For a comparison as objective as possible, an index of the observed avalanche activity is here used (IAA). This index is based on the nivo-meteorological network, it combines the avalanche activity observed at each observation point by using a weighted function. For each simulation, a comparison is made with the **Mepra** index.

We have to face several difficulties, notably the definition of classes of risks and the non-exhaustiveness of the observation of avalanche generally. It is why, it is difficult to interpret the results of the table below.

Nevertheless, if we look (figure 7) at the percentage of well classified cases (weighted by the class population), the “sytron” simulation presents a slightly better result (0.45 vs 0.43).

Sytron		IG<0.4	0.4<IG<2	IG>2	
	IAA<0.8	170	63	12	245
	0.8<IAA<2.5	21	16	3	40
	IAA>2.5	12	10	8	30
		203	89	23	315
Ref		IG<0.4	0.4<IG<2	IG>2	
	IAA<0.8	193	45	7	245
	0.8<IAA<2.5	25	12	3	40
	IAA>2.5	17	7	6	30
		235	64	16	315

Figure 7: contingency table.

5 – CONCLUSION AND PERSPECTIVES

The 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. 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 will be used next winter season by the avalanche forecasters of the Isère French 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 will be performed each time that differences will be observed between the simulation with or without the snow transport modeling.

A 3D approach, using a digital elevation model, is still under development. 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.

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).

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