Safran/Crocus/Mepra models as an helping tool for avalanche forecasters

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ABSTRACT

To describe the great variability of the snow pack and to predict the avalanche risk in the French Alps and Pyrenees massifs, the « Centre d'Etudes de la Neige » (C.E.N.) of METEO-FRANCE has developed an automatic chain of three models :

SAFRAN : a meteorological system, using the results of the "ARPEGE" French meteorological model and all the available observed weather data (automatic or manmade networks, radio soundings..) that estimates relevant input data for snow models

CROCUS : A numerical model that simulates the evolution of temperature, density, liquid water content, stratigraphy of snow cover as a function of weather conditions

MEPRA : An expert system of avalanche risk forecasting that analyses the mechanical stability of the CROCUS snow packs and deduces an avalanche risk.

These three tools operate automatically in quasi real time at numerous locations under different orientations, slopes and altitudes with a vertical discretisation of 300 meters.

According to past and forecast weather conditions, this automatic chain brings temporal and spatial information on the snow pack stability and the associated avalanche risks to the avalanche forecasters. The contribution of the Safran/Crocus/Mepra to the avalanche forecasting are shown in three avalanche situations :

⇒ winter situation with heavy snow falls and associated risks depending on the snow rain limit and air temperature.

⇒ spring situation with snow melting and snow pack wetting depending on the orientation slope.

⇒ « accidental » situation (avalanche due to skier overloading) depending on the snow pack structure with slab and weak layer.

Validations were also carried out by comparing various simulated parameters with measurements and observed avalanche activity with MEPRA avalanche risk during the 10 last winters.

INTRODUCTION

With increasing people in mountain environment, the avalanche hazard has appeared as a serious problem in alpine countries. People get killed every year in avalanches, mostly mountaineering skiers or alpine off-track skiers. Moreover, severe material damage may occur and some trouble is sometime caused to road traffic. As in our society, the need for security is growing with the need for adventure, collective prevention has thus to be organised in order to minimise avalanche casualties. Following the Swiss example of Weissfluhjoch Institute, the French Snow Research Centre (CEN) was extended since 1970, belonging to the French meteorological office with the assignment of setting up an avalanche forecasting system and of conducting research and development in that field. Before 1984, avalanche reports were produced by CEN. After 1984-1985, this daily avalanche report has been elaborated by each meteorological centre localised in the French Alps and Pyrenees (Pahaut et al., 1991). This organisation, based on the French departmental administration, aims at providing more detailed information about the snow and avalanche situation. CEN devotes then most of its activity to the development of methods and helping tools for avalanche forecasters. One of its greatest success is the development of an automatic chain to simulate snow cover stratigraphy and the corresponding avalanche risk for operational avalanche forecasting.

SAFRAN/CROCUS/MEPRA models

On the field, local snow pack stability is strongly influenced by the micro topography, especially because of the high spatial variability of snow cover due to the drift. However, avalanche forecasting is possible at a larger scale because the snow packs of a given region present similar features at similar elevations and on slopes of similar aspects. It is particularly the case for the presence of weak layers and for the occurrence of processes like melting and refreezing. For these reasons and according to the density of the snow weather network, we have developed a suite of models aiming at simulating the snow cover evolution and its stability on typical slopes. These simulated points are located in the different massifs of the Alps and Pyrenees

and they are characterised by different orientations (North, East, South East, South, South West, West and flat), slopes and altitudes with a variable vertical discretisation of 300 meters. The mean size of our massifs is about 400-600 km^2 with altitudes varying between 600 and 3600m asl.
In fact, three complementary models (figure 1) run automatically in quasi real time :

Safran (Durand et al., 1993) is a meteorological application of objective analysis using the results of the "ARPEGE" French meteorological model (Courtier, 1991) and all the available observed weather data (automatic network, French snow weather network, atmospheric radio sounding). It estimates relevant parameters affecting snow pack evolution : air temperature, wind speed, air humidity, cloudiness, snow and rain precipitation, long wave radiation, direct and scattered solar radiation. The analyses are carried out on the 23 French Alps and 15 Pyrenees massifs at hourly time steps. The main assumption is the homogeneity of each massif which allows spatial interpolations inside every massif for both altitude and aspect. This application provides all along the year series of relevant meteorological parameters at locations where no human or automatic observation is available.

Crocus (Brun et al., 1989, Brun et al., 1992*)* is a numerical snow model calculating the energy and mass evolution of snow cover. It uses the meteorological data calculated by the SAFRAN model and simulates the evolution of temperature, density, liquid water content and layering of the snow pack. The originality of this snow model comes from its ability in simulating snow metamorphism. Snow albedo and extinction coefficient depend on the wavelength and the surface snow type and age. Every year, we consider that each simulated slope is snow free on August the first. The simulated snow pack evolves day by day from the first snow fall until the complete melting without re initialisation.

Mepra (Giraud, 1992) is an expert system for avalanche risk forecasting. This expert system deduces from the Crocus snow pack simulations additional mechanical characteristics (shear strength, ram resistance and grain types...). After classifying the ram and stratigraphical profile, this model studies in a first step the natural mechanical stability of the snow pack and then deduces a natural avalanche risk on a 6 levels scale (very low, low, moderate increasing, moderate decreasing, high and very high) completed with the avalanche types (fresh dry, fresh wet, fresh mixed, surface slab, surface wet, bottom wet). In a second step, the expert system interprets the snow pack structure to detect the possible release of a dry slab avalanche by a skier and then deduces an accidental avalanche risk on a 4 levels scale for each simulated point (very low, low, moderate, high).

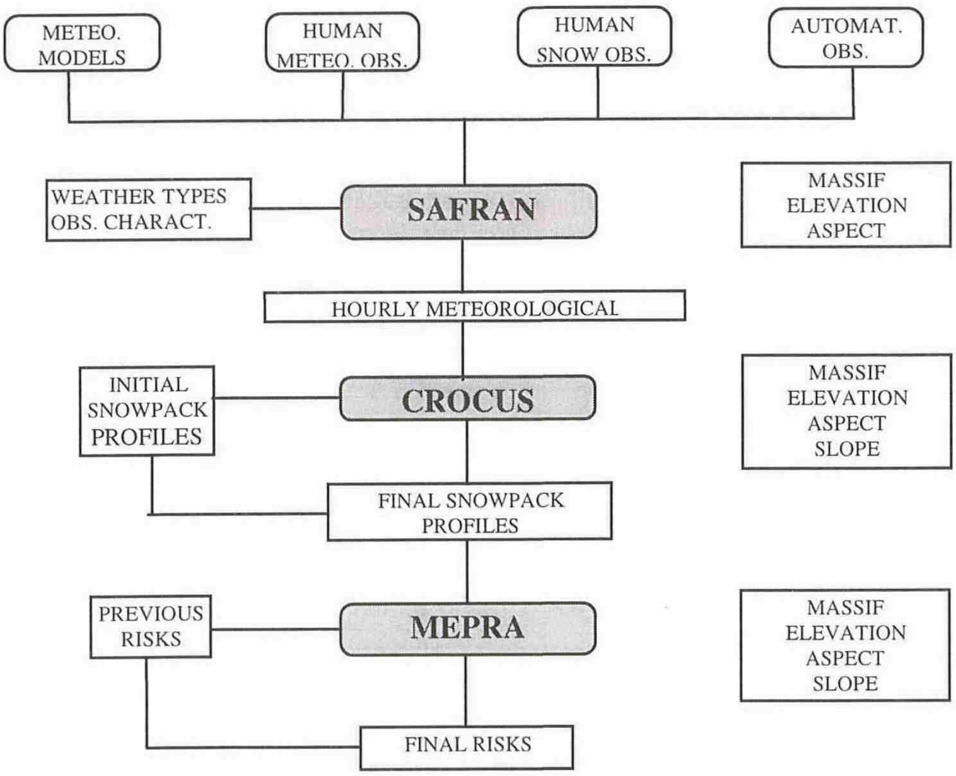

Fig 1 : Architecture of Safran/Crocus/Mepra models

OPERATIONAL RUN AND DISPLAY

In the mid-morning of each D day, this chain calculates automatically the snow profile evolution between D-1 day to D Day at 6 UTC in all the French Alps and Pyrenees massifs. In France, the daily avalanche report emitted by each mountain meteorological center describes the present state of the snow cover but also its evolution for the next 24 hours in connection with the weather forecast. Therefore, SCM has been upgraded in order to provide a 24 hours and 48 hours forecast of the snow cover evolution (Durand, 1995).

To help the avalanche forecaster in the interpretation of the SAFRAN/CROCUS/MEPRA (SCM) results, a specific software was developed. It allows him to look at the meteorological analysis outputs and simulated snow packs in the different aspects and elevations of the different massifs by :

- displays of SAFRAN meteorological parameters averaged at the massif scale : air temperature, wind speed, humidity, solar radiation.... on Alps or Pyrenees maps
- symbolic representations i.e. concentric circles by elevation steps (300 meters) with expositions (pie charts) or projections on a ground digital model (75 m mesh) of some elaborated parameters : surface snow temperature, snow depth, avalanche risk, avalanche type, wet snow depth or refreezing snow depth
- complete and detailed graphics of stratigraphic and ram profiles
- continuous evolution of stratigraphy and snow pack temperature (figure 4) from the beginning of the winter season

As the expert system must justify its reasoning, the avalanche forecaster can also visualise complete and detailed graphics of stratigraphics and ram profiles with instability levels and MEPRA information like avalanche risks and type, snow pack profile.

VALIDATIONS

Operational validation

The SCM results have been used and verified by the Grenoble avalanche forecasters since the winter 92/93. This operational validation allowed us to correct some preliminary errors and to implement or modify reasoning such as the determination of the snow /rain limit. For the French avalanche forecasters, this automatic chain is considered as the first objective and physically based tool in avalanche forecasting. It helps them in analysing the spatial variability of the snow pack structure (weak layer, ram resistance, shear strength...) connected to variation in elevation and in aspects.

Along the whole year, the avalanche forecaster can use realistic simulation of snow cover limits, snow depths, high temperature gradient metamorphism, wetting or refreezing depth, natural or accidental avalanche risks. At the beginning or at the end of the winter season, snow and avalanche observations are rare and the SCM chain has proved itself a very interesting source of indication by its optimal use of the sparse available information.

The biggest problem with this automatic chain comes from the present difficulties and even the impossibility to reinitialise the simulated snow profiles with measured data during the season. Snow pits, in the French snow weather network, are carried out only once a week, at elevations typically ranging from 1800m to 2400m asl and mainly on north and flat slopes. It happened in rare cases that SCM profiles too much differed from local observations. In this case, only one possibility exists to change the results : modifying wrong input meteorological data and running again the models since the date of the mistake. But all the problems are not always directly connected with wrong data and they may come from the limits of these models. Then to help the avalanche forecasters in the comparison between simulated and measured snow packs, SCM simulations are also carried out in quasi real time on real snow pit sites characterised by its massif, elevation, slope and aspect. Hopefully, such cases are rare and limited to a few range of elevations. Most problems come from a poor estimation of the snow rain limit when observations are rare before or after the avalanche forecast period.

Objective validation

An objective validation is also necessary to determine the quality of these models. This validation concerns mainly some simulated variables. It has been done over a ten years period (August 1981 to July 1991) and the concerned parameters are selected in order to integrate different possible sources of errors. The diagnostics are so representative of meteorological errors coming from SAFRAN and of associated mismatches in the simulated snow packs evolution and their stability.

In a first time, we compared simulated snow depths, direct outputs of SAFRAN/CROCUS model, with measurements (Martin et al., 1994) on thirty seven locations of the French snow weather station network. Except at locations where snowdrift is very frequent or where the local meteorology differs from the regional one, the quality of the simulations is quite satisfactory. Results are better in the northern Alps than in the southern Alps due to a higher density of the snow weather network. The errors of the 37 sites are usually less than 20 cm for test sites below 1500 m or 30 cm for other sites.

The second comparisons concerned the natural observed avalanche activity with SCM natural avalanche risk on "Vanoise" massif. Spring situations have been well estimated with a good spatial and temporal correlation between activity and risk. Wrong forecast (low risk with observed avalanche) are essentially due to very small spring avalanches which are notified as avalanche instead of snow flow. On the contrary, winter avalanche situations with high snow precipitation do not seem to have been so well estimated. In fact, in these situations, avalanche observations are very difficult and even impossible when weather conditions are extreme. Wrong warning (high risk without observed avalanche) are essentially due to these avalanche situations.

TYPICAL SIMULATED SITUATIONS

For illustrating the SCM avalanche forecasting processes, three examples of classical situations are described.

The first example is a winter situation with heavy snow falls in Grandes-Rousses massif near Grenoble the 16 February 1995. The automatic suite gives essential information about snow rain limit, snow pack accumulation or settlement and natural avalanche risks which depend on the fresh snow depth and vertical distribution of its density. A high risk is indicated at low elevation due to the destabilisation by rain (first wetting of dry weak layer). When all the weak layers have been wetted, the MEPRA avalanche risks immediately decrease with a return to stability. Just above the snow rain limit, a low avalanche risk is estimated because fresh snow density calculated by CROCUS is high enough. At higher elevation, natural avalanche risk is more important with fresh snow becoming lighter according to elevation. At the present, this numerical chain can not take into account spatial redistribution of snow transported by wind. But, initial density and grain morphology of new layers depend on the analysed wind speed during the precipitation. It makes possible to simulate the formation of fresh snow layers likely to be release as a slab avalanche but the role of snow drift has still to be better taken into account. To illustrate this first example, a graphical comparison between Mepra natural avalanche risks at 2100m, 2400m and 3000m elevation (north aspect, 40 deg. slope) for a week around the 16th February (figure 2).

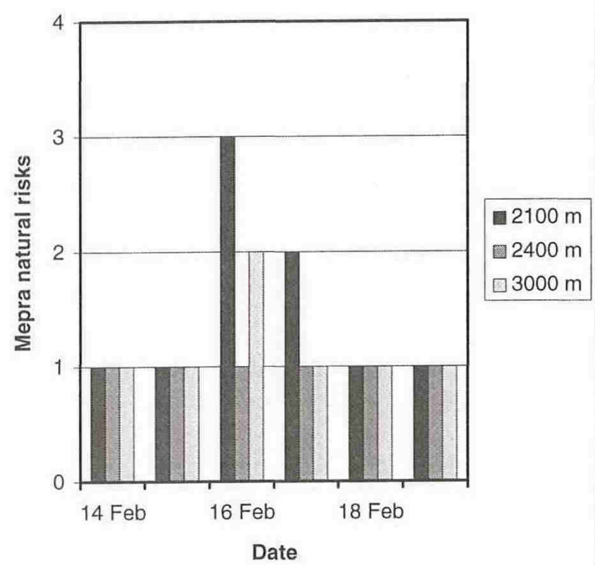

Fig 2: Mepra avalanche risks from 14 Feb 95 to 19 Feb 95

The second example is a spring situation with destabilisation by wetting due to solar radiation and water flow in Belledonne massif the 09 March 1994. In this type of avalanche situation, the most important factor is liquid water penetration in the snow pack. When a dry weak layer (fresh or recent snow, faceted crystal, depth hoar) becomes wet, its shear strength decreases and an avalanche risk is estimated as a function of wet snow depth. This process of destabilisation is depending on both aspect and elevation. The SCM chain gives main information about this geographical distribution of these parameters in order to survey day by day the snow cover wetting and the associated avalanche risk. This spring situation is illustrated by a comparison between Mepra natural avalanche risks at the elevation of 2100m for 4 aspects (north, east, south, west) and a slope of 40 degrees for a week (simulations at 6 o'clock and 12 o'clock) around the 09 March (figure 3). The Mepra avalanche risks are very low in north aspects and increasing during the sunny day in east and west aspects due to the wetting of a weak layer. In south aspects, the Mepra avalanche risks are low due to a whole wet snow pack without unstable wet layer.

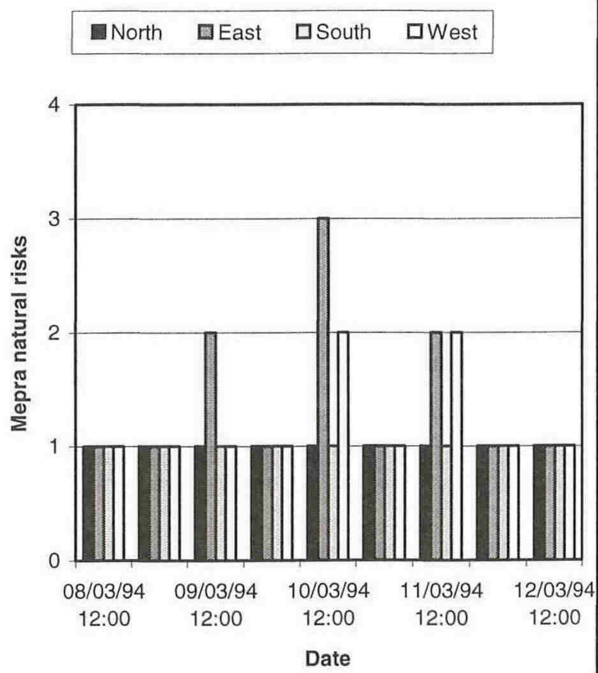

Fig 3: Mepra avalanche risks from 08/03/94 to 12/03/94

The third example is an unstable snow pack with accidental risk in Vanoise massif the 15 February 1996. After an analysis of each snow pack in term of human triggering, the SCM suite helps the avalanche forecasters in localising high risks in relation with the presence of snow slab overlying weak layers. The SCM models gives also a main information about the temporal evolution of this accidental instability.

CONCLUSION

Even if problems such as wind transported snow (Guyomarc'h and Castelle, 1992) still exist, the results of the SCM validation prove that modelling is one of the most promising approaches in avalanche forecasting. The avalanche forecaster reaction is also proof of this. At the present, all the French meteorological mountain centres receive analysed and forecast CROCUS snow depths and MEPRA avalanche risks messages once a day and could also look at some displays on Meteo-France server web. In a nearest future, a complete application will automatically run in each centre. A new integrated software will allow the avalanche forecasters to visualise and to compare all the simulated results with measured and observed data.

In another field, the SAFRAN/CROCUS/MEPRA chain has been also used as a research tool in order to :

- evaluate the sensitivity of the snow cover to different climate change (Martin et al., 1994)

- improve conceptual snow melt run off model and simulate daily discharge of a French alpine river (Braun et al., 1994)

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