Use of the models Safran-Crocus-Mepra in operational avalanche forecasting

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ABSTRACT: Avalanche forecast is based on the observation of weather conditions and follow-up snow cover. The workstation “Poste_Nivologie”, operational software developed by the CEN, is daily used by French avalanche forecasters to process observed data from the snow observation network. All observed data (snow and weather observations, snow profiles) can be displayed in various screens. Since 2006, a new functionality has been put into service. It consists in the access to the results of the chain of models Safran, Crocus and Mepra.
Daily runs of the models provide results for each massif at several altitudes (each 300m), on flat terrain and 2 slopes (20° and 40°) of 6 orientations. Analysed and forecasted results (meteorological input data, snow profiles, snow stability analysis) are available from Day-1 6H to Day+2 6H. The forecaster may visualize graphical representations (maps, pies, snow profiles, historical display) of all the simulated parameters.
One of the interest of Safran, Crocus, Mepra models for avalanche forecasters is the help to the spacialisation of the information provided by local observations. “Poste_Nivologie” integrates into the same application observed and simulated snow information that makes easier their necessary comparison.
We will present how the forecasters can select amongst the high number of views the most relevant ones according to the day situation. We will also describe the main contributions and limits of the models for different typical situations.

KEYWORDS: Avalanche forecast, modelling, avalanche hazard

1 INTRODUCTION

Avalanche forecast is based on the observation of weather conditions and the follow-up of the snow cover. The high spatial variability of the snow cover, mainly influenced by the local topography (few ten meters) and wind drift, induces a variability of the snow pack stability at a local scale. However, avalanche forecasting is possible at a larger scale because the snowpacks of a given region at similar elevation on slopes on similar aspect present similar features, for instance regarding the presence of weak layers or melt-freeze crusts.

The chain of models Safran/Crocus/Mepra (SCM chain), based on this assumption, simulates the evolution of the main characteristics of the snowpack in a massif for different elevations and aspects from the “average” meteorological conditions prevailing in that massif. One of the main limit of the SCM modelling is therefore when the weather conditions are quite different on part of the massif.

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For more than twenty years, the Centre d’Etudes de la Neige has been developing operational software for the use of avalanche forecasters. Since 2006, the direct access to the results of SCM chain (Durand, 1999) has been implemented in the operational tool “Poste Nivologie”, dedicated to avalanche forecast.

2 “POSTE NIVOLOGIE” :THE FRENCH NIVOLOGICAL WORKSTATION

“Poste Nivologie” is the daily workstation of the French avalanche forecasters (Dumas, 2006). Each workstation is adapted to the geographical area of responsibility, i.e. a French “department” consisted of 2 to 7 massifs. This software is divided in functions that fit the different tasks of the forecaster. The first one is the data entry that includes measured data from the snow-weather network (daily observations and snowpits)and also produced data at the massif scale such as mean snow depth and estimated avalanche hazard. All the data are stored in a local database and automatically transmitted over the transmission network of Meteo-France. Various utilities are also available; configuration of the application, data accounts, printing, SCM chain process control, data export functions. However visualisation functions are the most useful functions for the assessment work of stability analysis by the avalanche forecaster. In the following is a quick outline of the many visualisation possibilities of observed and simulated data.

2.1 Visualisation of observed data

Each forecaster can visualise data of his own department and the neighbour massifs. Visualisation of recent data (fig. 1) is the frequent practice but all past data can be acceded on line (since 1970 for the oldest stations).

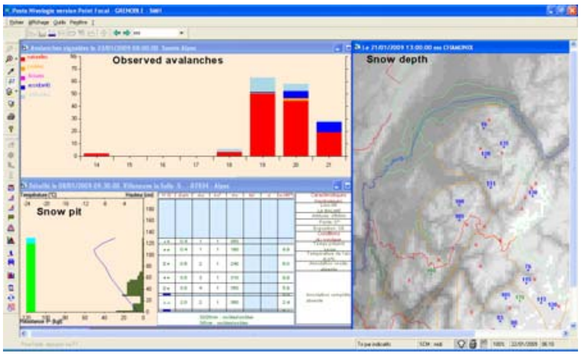

Figure 1: Examples of different representations of observed data: histogram of a week of observed avalanches, classical snow pit graph, map. A choice in a list allows updating another parameter of the map.

Temporal graph (fig 2) in a given observation site gives an interesting overview of the weather during the previous weeks. It is useful to memorise the chronology of snowfalls, warming or windy periods and snow settlement.

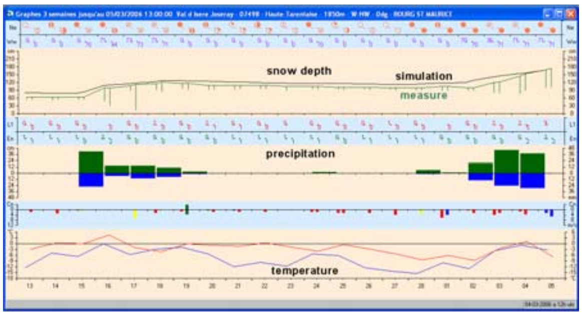

Figure 2: Three weeks weather conditions in a station. Moving of the mouse displays the value of the measurement.

2.2 Safran/Crocus/Mepra models

SCM chain has been developed at Meteo-France, Centre d'Etudes de la Neige. It is composed of three individual models; Safran, Crocus and Mepra that run one after the other.

Safran is a meteorological analysis model which computes meteorological variables at the massif scale from all meteorological data available. Results from the French meteorological models Arpège and Aladin are the base of the inputs of Safran. In analyse mode, there are combined with observations from different sources; the French snow-weather network, the automatic weather stations and atmospheric upper-level sounding available in and around the massif. Safran provides hourly atmospheric parameters (temperature, wind, clouds, humidity, snow and rain precipitation, long wave radiation, solar radiation) for each of the 36 French massifs.

Crocus is a physically based model that simulates the evolution of a snow profile using the weather conditions calculated by Safran. It simulates the evolution of the temperature, density, liquid water content and the grain type in each layer of the snow pack. The originality of this snow model lies in its ability to simulate snow metamorphism in near-surface and buried layers. However few problems remain for the simulation of the evolution of deep buried weak layers. Another limitation concerns the lack of detailed description of the fresh snow type.

Mepra is an expert system. It adds new information, mainly mechanical characteristics, deduced from a Crocus simulated profile. Then the model analyses the mechanical stability of the profile and provides a diagnostic in term of "natural" and "accidental" risk.

For operational purpose, Safran has been implemented on the central computer of Météo-France in Toulouse. Four daily runs provide results that are transmitted to each departmental avalanche warning centre of Alps, Pyrenees and Corse where Crocus and Mepra run over a geographical area limited to the department and neighbour massifs. All the results are stored one year in a local database from August 1st, when the run of Crocus began with snow-free slopes, to July 31st. The simulated snow profiles are daily available every 3 hours for the analysed day and up to 48 hours in forecast, only twice profiles a day (6h and 12h) are stored in the past days.

2.3 Visualisation of the results from the chain of models

Since 2006 the access of all results of the chain have been integrated in "Poste Nivologie". Many graphical representations are available : map, pie, snow profile, historical display. From a selected view an adapted toolbar allows changing date, parameter, massif, altitude, slope angle or aspect. A direct access to a detailed snow profile, as well as risk chronology, is also available from synthetic views as a pie or a multiple profiles screen.

The most synthetic information from the models is the spontaneous avalanche release index (Martin, 2001) which gives one value per day and massif. Its display on a mosaic of map (fig. 3) offers a quick view of the natural instability and its evolution for the next 48 hours. A similar representation is also available for the daily amount of precipitation.

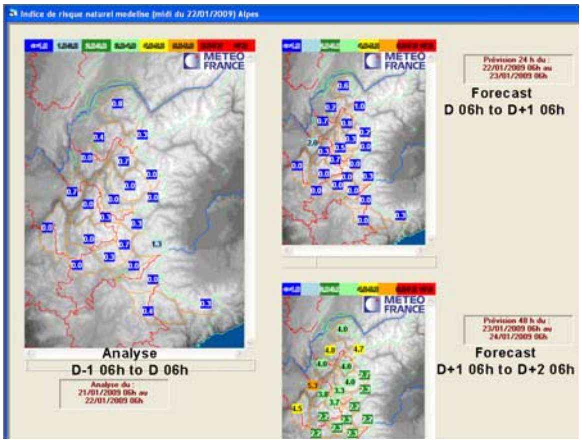

Figure 3: Mosaic of maps with the analysed and forecasted values of the spontaneous avalanche release index calculated from Mepra results.

Snow evolution highly depends on meteorological conditions. The knowledge of the input data of Crocus model is therefore essential for a good analysis of the resulting snow profiles. For a given elevation of a massif, the outputs of Safran model are displayed on a temporal graph.

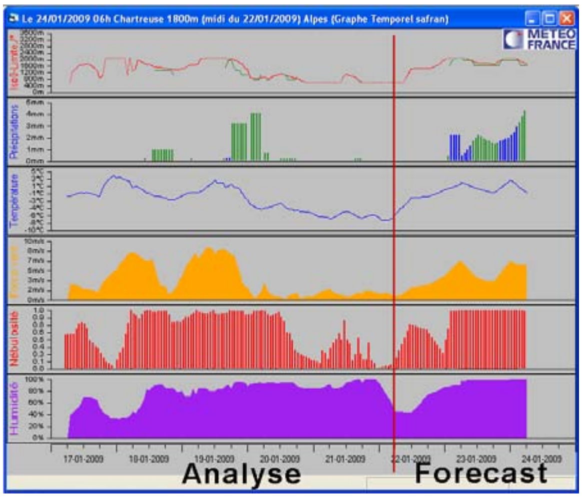

Figure 4: View of the analysed weather conditions on a massif and the forecast for the next two days.

Pie-shaped representation (fig. 5) is successful with the forecasters. Each circle represents an elevation level and the pie is shared according to the aspect. Therefore each pie shows the spatial distribution in the massif of the plotted parameter. A lot of parameters from Crocus and Mepra can de visualised; as snow depth, surface temperature, wetting or freezing depth, avalanche risk, … An interesting function is the possible display of the detailed snow profile of each sector.

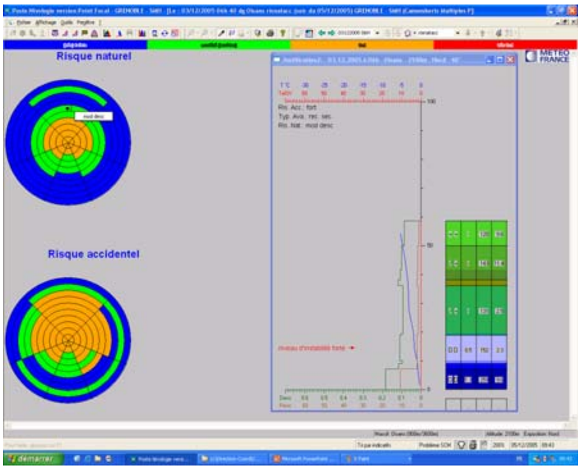

Figure 5: Accidental and natural risk level analysed by Mepra are shown on these pies.

More detailed information of the snowpacks is provided by a view of multiple profiles. Simulated profiles can be displayed by multiple altitude (fig. 6), multiple aspects or time evolution of a simulated snow profile at a given location.

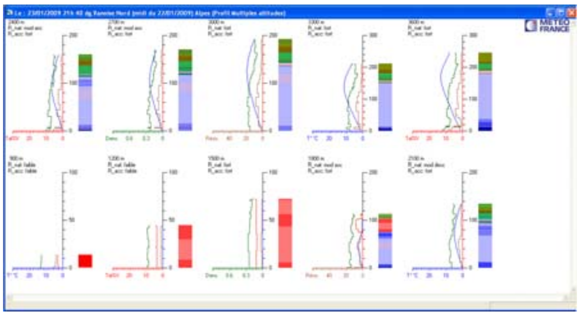

Figure 6: View of all the snow profiles at different elevations (300m step) of a given massif, date, slope angle, aspect. Red colours of the grain types show the impact of the rain/snow limit on the snow layering for the lowest elevations.

Two different functions are available for helping the comparison between simulated profiles and field measurement. The first one is shown in figure 2, the curve of a simulated snow depth can be plotted on the graph. The second is the possibility to display the closest (massif, altitude, slope, aspect) simulated snow profile of an observed snow pit (figure 7). However the main difficulty is to quantify the similarity between two profiles. Comparison is complicated by uncertainties of the observation itself and natural varibilty of the snowpack.

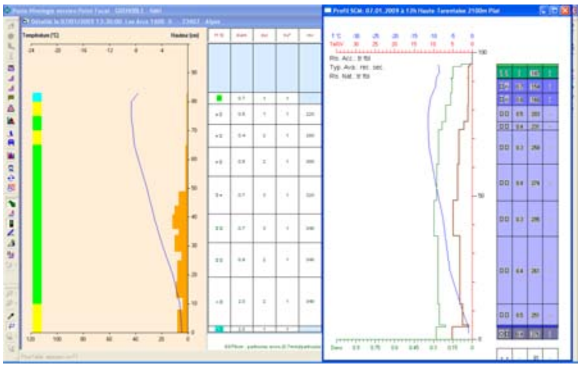

Figure 7: observed snow pit and closest simulated snow profile.

3 OPERATIONAL USE OF THE MODELS FOR SOME TYPICAL SITUATONS

Each departmental centre can visualise on its area of responsibility and its neighbourhood, measured data from the observers and automatic stations as well as analysed and forecasted data from the SCM chain. Ways of consulting the results are multiple and results from the models are so many (more than one hundred analysed and forecasted snow profiles per day for each altitude of one massif) that it is not possible to check all the results each day. Therefore it is necessary to focus on the most relevant views and parameters according to the day situation.

In the following main contributions and limits of the SCM chain for some typical cases are presented. These results are issued from the analysis of different real situations that are also used in practical courses for avalanche forecast training.

3.1 Situation with high spontaneous avalanche release hazard :

The main release factor is usually the amount of snow. Therefore, weather forecast with a detailed chronology of the snowfalls is very important and the Safran graph is well adapted (figure 4). The mosaic of the spontaneous avalanche release index gives also a synthetic information on the evolution of the situation.

Main SCM contribution are the quality of the forecasted precipitations and the pertinence of the spontaneous avalanche index. Safran performs not only an adaptation of the meteorological model at the massif scale. These results are merged with results from statistical analysis of nearest-neighbour that improves the estimated precipitation. The spontaneous avalanche index, computed from Mepra results, corresponds to a spatial and temporal synthesis. It gives a good qualification for the extreme events and is also relevant when the risk is dropping. The simulated snow profiles contribute to follow the quality of the amount of snow in the upper layers and is also an additional source of information to the missing field observations during bad weather periods.

The first weakness of the models is the analysis of the rain/snow limit. Because it is a physical threshold, when the analysis determines it is raining instead of snowing, an error in the determination of the snow layering can affect all the simulated profiles of a given altitude. The second limitation is that the SCM chain does not simulate the erosion and accumulation by the wind which may significantly modify local snowpacks. It only takes into account the destructive effect of the wind during a snowfall by changing the characterisation of the initial layer of fresh snow. Finally, in the forecasting mode, the choice of the meteorological model is fixed which can be a problem in some cases.

3.2 Situation with high probability of triggering an avalanche :

The relevant information for the avalanche forecast rests in the snow structure rather than in the weather conditions. The comparison between the measured snow profiles and the simulated ones is all the more needed in such cases. “Poste Nivologie” allows, on the graph of observed data, a superimposition of the simulated snow depth at the same altitude and aspect. It is also possible from a view of a local snow pit to display the closest (massif, altitude, slope, aspect) simulated snow profile.

Temperature profiles are well simulated, especially in winter season, that is very important for the snow metamorphism. So SCM results effectively contribute to detect the presence of weak layers and to estimate their spatial extension and localisation in terms of aspects and altitude. Details on the quality of the weak layer, its burying depth, the quality of the upper layers are given by the simulations. The evolution of the recent snow layers (densification, grain type) is also well simulated that gives relevant information on the amount of snow that can be easily eroded by wind.

The main limit of the SCM chain is once more the non simulation of snow drift both for the snow accumulated by the wind and a potential erosion of a weak layer. Furthermore, Mepra analysis of the triggered avalanche risk is sometimes inaccurate due to threshold effects and there is also a lack of a synthetic index for the triggered avalanche risk.

3.3 Springtime warming-up :

The main difficulty for the avalanche forecaster is the estimation of the depth of the wetting according the aspects and altitude. A good estimation of the penetration of the liquid water is essential to estimate the increasing instability, especially when the water reaches a previously dry buried weak layer.

Snow measurements are punctual and the liquid water content is not measured routinely in the network. The main SCM contribution is an overview of the extent of the wetting. It gives spatial information on the affected slopes and aspects, the depth of wetting and the wetting evolution during the day.

One of the limitation is due to the simple simulation of the water percolation by the one dimensional Crocus model that cannot represent water preferential paths or saturated layers. Furthermore the spontaneous avalanche release index is few representative in such cases. Finally, in some conditions SCM seems to overestimate the wetting, however field validation is not easy due to the difficulties of wet snow measurement.

3.4 Beginning of the season – few observations and measurements :

The following of the snowing up is important but difficult if early snowfalls occur due to the lack of observations and measurements.

Different validation experiments have shown that SCM is a reliable source of information on the snowpack structure in spite of sparse observations. SCM contribution depends on the prevailing weather conditions during the autumn. For instance, results from the models are very useful when disturb periods follow each other and rain/snow limit varies. SCM chain also helps the following of the evolution of the first snow falls on slopes with different aspects, that could be very important for assessing the basement stability of the future snowpacks.

The limitations are also linked to the day situation. Analysis of rain/snow limit, wind effect have been yet quoted. Moreover the melting of a thin first snow layer is sometimes underestimated. In any case the confidence attached to the results is lowered by the difficulty to check their quality.

4 CONCLUSION

Transferring snow models to operational context was a challenge both technical and human. The arrival of all the SCM results changes the work method of the avalanche forecaster. Besides the needed initial training, the forecaster had to gain experience about; the SCM results understanding, the comparison between field measurements and simulated snow profiles, the realisation of a synthesis for the snow and avalanche report and for the danger level assessment.

SCM chain of models is now part of the different tools that use the French avalanche forecasters.

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