SAFRAN/CROCUS : meteorological analysis and snow monitoring in mountain region

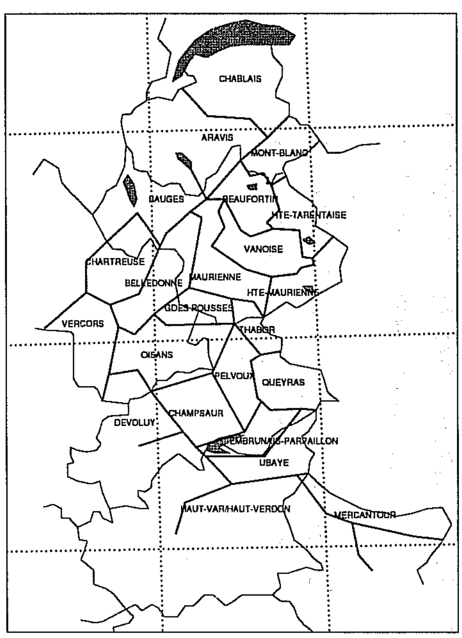
Eric Martin
Météo-France, Centre national de recherches météorologiques, Centre d'études de la neige
1441 rue de la piscine, 38406 St Martin d'Hères

Introduction

In the framework of avalanche forecasting research, several tools were developed for snow monitoring in mountain regions. The first tool is a meteorological analysis system, called SAFRAN, the second tool is a detailed snow model (CROCUS) which simulate the internal state of the snow cover. MEPRA is an expert model which analyses the snow profiles in terms of mechanical stability. The purpose of this paper is to describe SFRAN and CROCUS and their operational implementation.

1. The SAFRAN analysis system

The aim of the SAFRAN system (Durand et al, 1993) is to estimate, at an hourly time step the meteorological data necessary to force the snow model CROCUS. These data are air temperature, air humidity, wind speed, cloudiness, incoming solar and longwave radiation, amount and phase of precipitation. The analysis is made for each massif of the Alps and Pyrenees (the surface of these massifs varies between 500 and 1000 km²). Figure 1 shows a schematic representation of the French Alps and the 23 massifs considered.



RESEAU NIVOMETEOROLOGIQUE ALPES

Massifs

Fig. 1 Schematic map of the French Alps with the 23 massifs used in this study

The massifs are considered as homogeneous from a meteorological point of. view. This hypothesis allows interpolations within the massif. The data sources are the outputs of the ARPEGE model (operational mode) or the ECMWF model (long term runs), ground and upper-air meteorological observations. During winter more than 100 meteorological observations from an adapted network (snow network) are available. These data are very informative as they are situated mainly at high elevations (in ski resorts). SAFRAN uses also satellite products for the cloudiness analysis. The analysis is done at a daily time step, beginning at 06UTC. It can be divided into three major phases :

- *Analysis of the main meteorological variables (temperature, humidity and cloudiness).* This analysis is done at 6, 12, 18, 00 and 6 UTC. Free atmosphere variables are analysed first. An optimal interpolation scheme is used. The guess is the output of the meteorological model (extended below the model orography to the minimal elevation of the massif if necessary). The informativity of all analysis points were estimated by the local forecasters. For cloudiness, the guess (three layers of clouds) is deduced from the humidity profile. For the surface variable, the guess is the result of the free atmosphere analysis plus the boundary layer effect given by the meteorological model. This latter analysis is cruder and uses a successive corrections method.

- *Daily precipitation amounts.* This analysis is performed at a daily time step because of the availability of the observation. The guess is the result of a climatological study done with the AURELHY method (Bénichou and Le Breton, 1987), which takes into account the local orography. The analysis uses also an optimal interpolation scheme but an additional constraint is imposed : the analysed vertical gradient must be consistent with the climatological gradient.

- *Hourly interpolations.* All variables are interpolated linearly at an hourly time step, except for air temperature and precipitation. A radiation scheme (Ritter and Geleyn, 1992) is used to estimate the radiation terms. The air surface temperature is adjusted hourly by taking into account a forcing based on solar radiation and a relaxation to an equilibrium temperature. The determination of the phase and hourly distribution of precipitation is treated in three steps. 1) determination of the zero isotherm in the air profiles. 2) Correction of this isotherm with observations and vertical temperature gradient. 3) estimation of a daily ratio between liquid and solid precipitation. With observations and the results of previous steps. Finally, the 24 values of precipitation are adjusted using a variational method.

A forecast version of SAFRAN has been developed recently (Durand et al, 1997). It is based on models outputs. Precipitation is estimated from the model forecast and the results of an estimation based on a research of analogues in the past.

2. The snow model CROCUS

The snow model CROCUS (Brun et al, 1989, 1992) is a one-dimensional snow model. The input data of the model include air temperature, humidity, wind velocity, short wave and long wave incoming radiation, amount and phase of the precipitation at an hourly time step. The model calculates the internal state of the snow cover : temperature, liquid water content, density and snow types. To calculate the different variables, the snow cover is divided into layers parallels to the slope. Energy transfers are projected perpendicular to the slope. The thickness of the different layers is variable versus depth and time. Since the greatest variations in amplitude occur near the surface, the thickness of the upper layers are smaller than that of the bottom layers. The phenomena taken into account by the model are the energy exchange inside the snowpack and at the snow-soil and snow-atmosphere interfaces, the absorption of solar radiation with depth, the phase changes between solid and liquid water, the water transmission through the snowpack, the mass exchanges due to precipitation and water runoff, the settlement and the metamorphism of the snow. The originality of this model is that it describes the snow grain characteristics (shape and size) with a specific formalism.

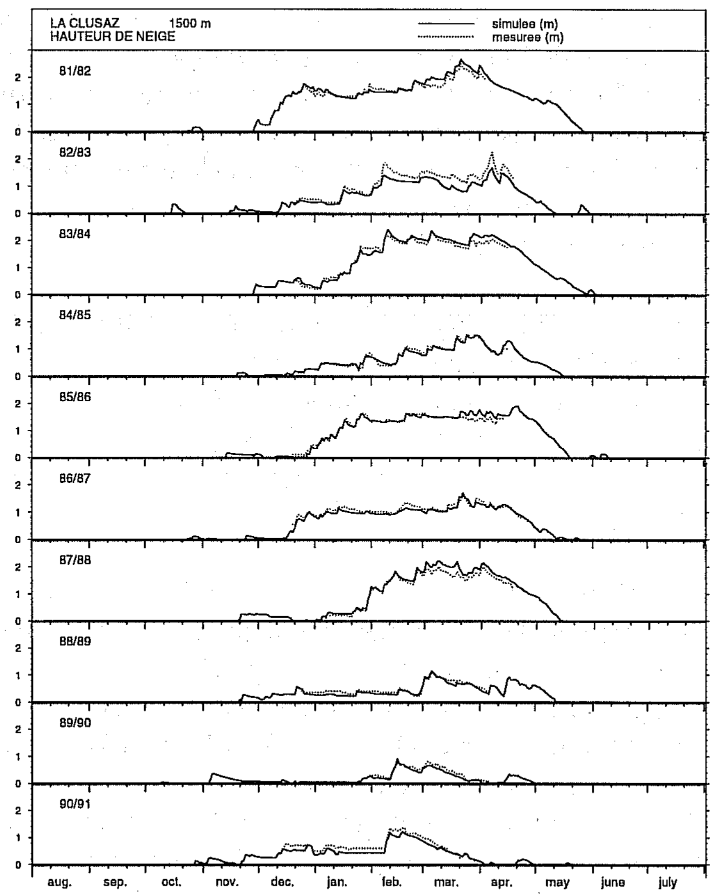


Figure 2 : comparison between observed (continued) and simulated (dashed line) snow depth

3. Validation and operational use

SAFRAN was validated during several periods using meteorological data measured at two sites (1320 and 2800m). CROCUS was validated using data from a well-instrumented site during several winters. In order to validate the coupling between SAFRAN and CROCUS, the snow depth was simulated from August 1981 to July 1991 at 37 locations where measurements were available (Martin et al, 1994). The 37 points covered the whole French Alps and their altitude was in the range of 900 to 3000m. At most of the locations, the comparison with observed and simulated snow depth has shown a good agreement. In a few cases, however, agreement was poor. This occurs at places where snow drift plays a major role, or where local precipitation is systematically larger or smaller than the mean precipitation analysed at the corresponding altitude of the massif. Despite these few cases, the coupling of SAFRAN with CROCUS has proven itself to be very efficient to reproduce the snow depth evolution over a long period.

Since the winter 1991/1992, the chain SAFRAN/CROCUS/MEPRA is used on a pre-operational mode at The Centre d'études de la neige. The operational implementation is as indicated in table 1. The crucial point is the transfer of local observations in remote areas to CEN (twice a day). This is the responsibility of the meteorological stations who collect the data (mainly by phone). After several years of operational use, the chain appears to be very robust. It must be noted that each year the chain begin in summer with no snow on the ground and no re-initialisation is done in winter.

UTC	Operational centre (Toulouse)	Meteorological. Stations	CEN	production	Remarks
04→ ?	ARPEGE outputs transfered				
06			SAFRAN	24H Forecast, 48H Forecast	used by meteorological forecasters
08→ ?		Obs from snow network transfered			
09H30			SAFRAN CROCUS MEPRA	Analysis, J-1(06H)-J(06H) *(Isère only)*	run for local forecasters
10H50			SAFRAN CROCUS MEPRA	Analysis, 24H and 48H Forecast Specific messages to stations *(All massifs)*	Main run for all meteorological stations
21H00			SAFRAN CROCUS MEPRA	Analysis *(All massifs)*	accounts for late observations

Table 1 : operational timetable used during the winter 97/98

4. Meteorological analysis in the Rhone Basin

In the framework of the French Project GEWEX-Rhone, which aims at the simulation of the hydrological cycle of this basin, the SAFRAN system is now implemented in this area (Etchevers et al, 1998). Instead of the massifs used for operational avalanche forecasting, pre-existing zones (also defined by local forecasters and used for short term forecasts) has been used. The observations come from synoptic (60) and climatological (1600) stations ; The ECMWF is used, as the study covers 15 years (81/95). A validation of the system has been made at 33 sites, which were not used by the analysis system. The temperature is quite well analysed (mean error usually lower than 0.5°C). Cloudiness is underestimated (-5%). Humidity is also underestimated (-10%). Wind speed is slightly underestimated, but the rms is high as this variable is subject to very local effects. At this stage, the extension of SAFRAN to the Rhone basin seems promising. The 15 years of meteorological data are currently used to force a hydrological model of the basin. The land surface is simulated using both ISBA (Noilhan and Planton, 1989) and CROCUS.

Conclusion

The various validations of SAFRAN and CROCUS proved the ability of these models to simulate meteorological and snow conditions in mountainous areas. The system now can be considered as stable ; Further activities will include the improvement of each tool and application to other domains (e.g. Hydrology).

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