Towards a new chain of models for avalanche hazard forecasting in French mountain ranges, including low altitude mountains

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ABSTRACT: Operational avalanche hazard warning carried out by Météo-France for the three main mountain ranges (Alps, Pyrenees, Corsica) have used snow simulations based on the SAFRAN-Crocus-MEPRA (SCM) model chain, for over a decade. Mid-altitude mountain ranges (Massif-Central, Vosges, Jura), culminating below 2000 meters, were until now not considered. Crocus has recently been incorporated in the Earth surface platform "SURFEX" as one of the snowpack schemes of the land surface model ISBA. This allows in particular to explicitly represent interactions between snow and the underlying soil. Such an improvement makes possible to use Crocus under conditions where the state of the soil may have a significant impact on the properties of snow, which is particularly true for low altitude regions, where the snowpack is shallower and more ephemeral. A new version of the SCM model chain, renamed SAFRAN-SURFEX-MEPRA should replace SCM for all operational applications in the near future. Here we present a comprehensive evaluation of the performance of this new model chain, not only for Alps, Pyrenees and Corsica, but also for mid-altitude mountain ranges. Models are evaluated against ground-based measurements of snow depth gathered at over 150 locations in all considered mountain ranges.

KEYWORDS: snow modelling, operational, ground, mid-altitude.

1 INTRODUCTION

Operational avalanche hazard warning carried out by Météo-France for the three main mountain ranges (Alps, Pyrenees and Corsica) uses numerical simulations of the physical properties of snow on the ground and an assessment of its mechanical stability. Run both in analysis and forecast mode, the meteorological downscaling and analysis tool SAFRAN provides estimates of the atmospheric conditions by elevation steps of 300 m in meteorological homogenous areas referred to as "massifs". Crocus computes the time evolution of the physical properties of snow using SAFRAN input, for a variety of slope and aspect situations within each massif and altitude band. MEPRA is then used to diagnose whether simulated snow conditions are conducive to significant avalanche hazard. The so-called SAFRAN-Crocus-MEPRA (SCM) model chain (figure 1) has now been used operationally for over a decade.

Mid-altitude mountain ranges, Massif Central, Vosges and Jura, generally culminating below 2000 m altitude, were until now not considered. Although the latter rarely experience strong avalanche crises, in such cases until now the meteorological forecasters in charge of issuing avalanche hazard bulletins were left with almost no operational tool to assist them in analyzing and forecasting snow conditions in such areas. In these regions, forecasting snowmelt or rain-on-snow floods is also an episodically strong concern.

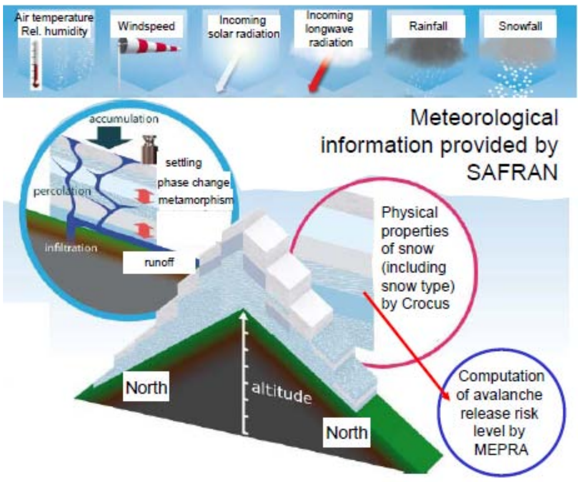


Figure 1: Overview of the model chain. Simulations are carried out for each massifs by steps of 300 m altitude for a variety of slopes (generally 0, 20 and 40°) and aspects (8 main directions)

Crocus is now one of the snowpack schemes of the land surface model ISBA (Vionnet et al, 2012, figure 2). This allows to explicitly represent interactions between snow and the underlying soil., and extends the use of Crocus to conditions where the thermal state of the underlying soil may have a significant impact on snow, which is particularly true for low-altitude regions, where the snowpack is shallower and may be more ephemeral.

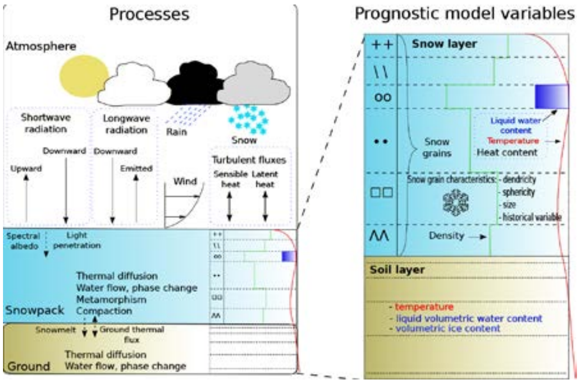


Figure 2: Overview of SURFEX/ISBA-Crocus model structure. The main novelty with respect to the stand-alone Crocus version is the explicit coupling with the ISBA multi-layer ground scheme.

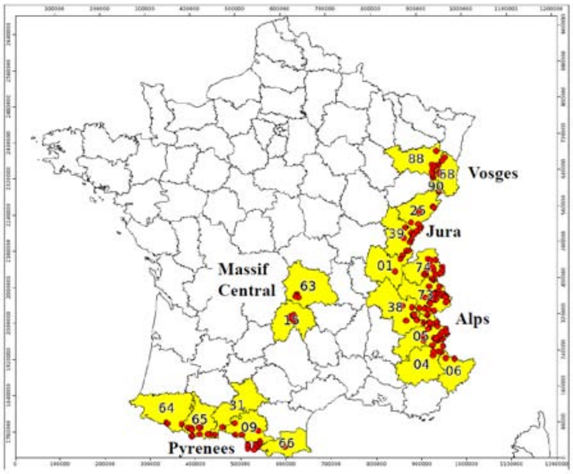
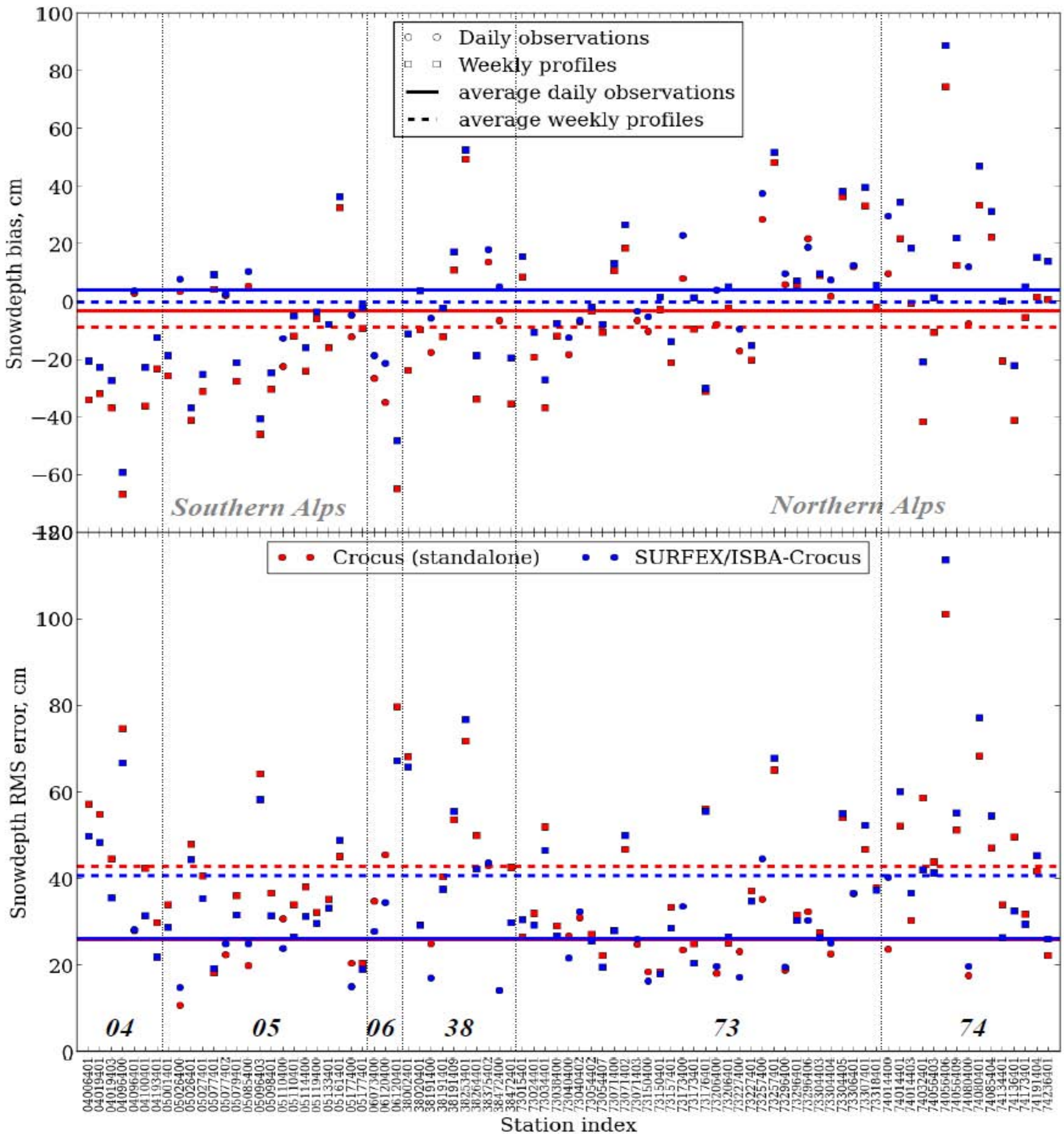


Figure 3: Map of French departments and of snowdepth measurements stations used for evaluation (red circles)

Figure 4: Snowdepth bias (top) and RMS error (bottom) for the 83 alpine stations sorted by department.



2 DATA

Total snowdepth simulated by the SAFRAN-Crocus model chain was compared to local measurements over all French massifs. The simulated snowpack is expected to represent the average conditions at the massif scale (typically 200 km²) for a given altitude, whereas point scale measurements describe a snowpack affected by numerous local effects (spatial heterogeneity of precipitation, snow drift, modification of incoming radiation by the local topography, etc.). This can be somewhat circumvented by performing evaluations on a large number of stations and seasons. For this, 83 stations have been selected in the Alps, 30 stations in the Pyrenees, and 47 stations in the mid-altitude mountains (figure 3). Altitudes range from 800 to 3000 meters. The maximum evaluation period is 1980-2012 (between October and June), but most stations have only a limited availability of data over this period.

3 RESULTS IN THE ALPS

As illustrated by figure 4, the old standalone version of Crocus (red), and the new version implemented in SURFEX (blue) present a similar average performance over the Alps. In most cases, both simulations are very close (example figure 5) and in the general case, the very high spatial variability of scores does not allow to conclude for a better model than another. However, for some seasons and stations, particulary with relatively thin snowpacks, some significant differences occur at the beginning of the season and can be explained by the different ground heat fluxes (example figure 6).

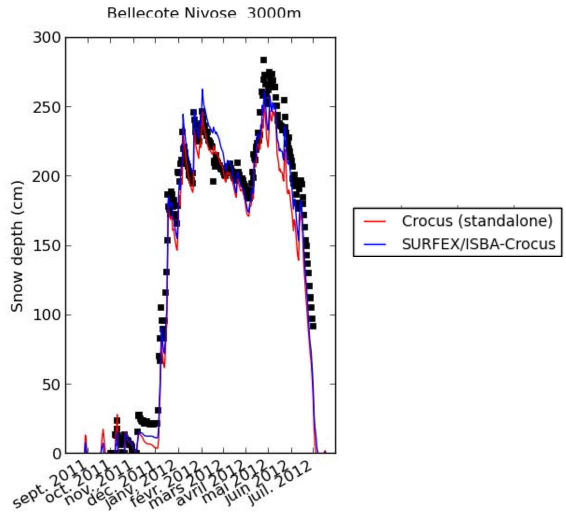


Figure 5: Simulated and observed snowdepth at Bellecote (73)

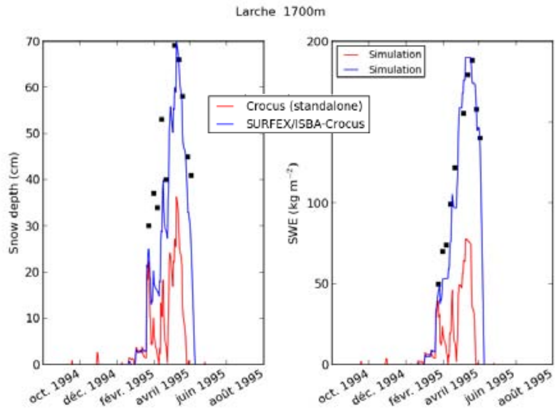


Figure 6: Simulated and observed snowdepth and snow water equivalent at Larche (04)

The bias exhibits a geographical pattern with an underestimation of snow depth in Southern Alps and an overestimation in Northern Alps. This might be linked with the very different climate of these regions (much drier and warmer in the South), but also with the different number of meteorological stations used in SAFRAN analysis.

The RMS error is much lower over the daily regular stations network (circles, solid line for average) than over the occasional sites of snow profiles (squares, dash line for average).

4 RESULTS IN MID-ALTITUDE MASSIFS

Results in mid-altitude massifs do not exhibit a systematic bias. The RMS error is low (less than 10 cm for 28 stations). It is of course influenced by lower average snowdepths than in the Alps. However, the Nash-Sutcliffe-Efficiency for all the data is also very satisfactory (0.67) compared to the value for the Alps (0.77). In these regions with thinner and transient snow covers, it probably means than the simulated heat flux at the soil-snow interface is realistic.

All these results were based on meteorological forcing from SAFRAN reanalysis. In real-time, the SAFRAN analysis does not include a number of meteorological stations from the Meteo-France climatological network. In some areas where the number of available meteorological stations is critical, the performance of the SAFRAN-Crocus chain is lower in real-time (figure 8). This problem should not affect Northern Alps where a dense observation network is available in winter thanks to collaboration with ski resorts.

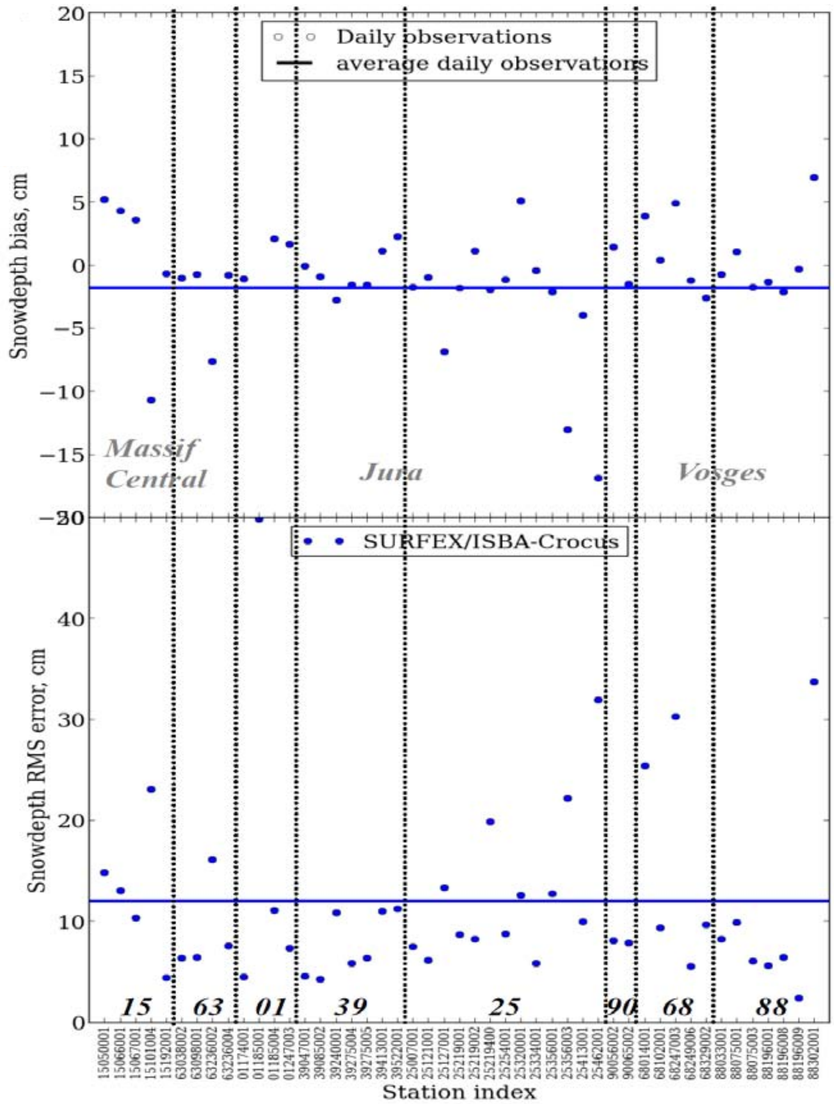


Figure 7: Snowdepth bias (top) and RMS error (bottom) for the 47 stations of Massif Central, Jura and Vosges sorted by department.

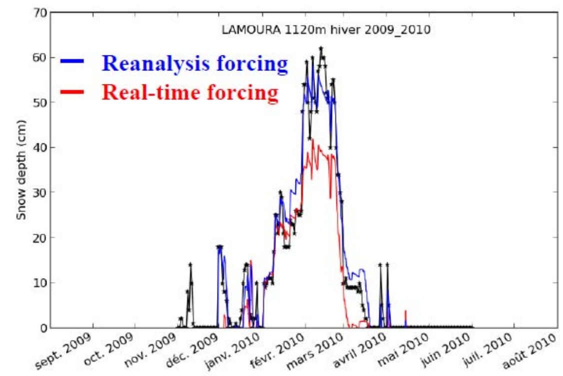


Figure 8: Simulated and observed snowdepth at Lamoura (39)

5 FUTURE WORK

The utility of this model chain for avalanche risk forecasting is conditioned by the ability of the model to reproduce the detailed stratigraphy of the snowpack and not only snowdepth. A major difficulty for an objective evaluation is the different layering between observations and simulations. As a first step, subjective comparisons of simulated and observed profiles are in progress.

6 REFERENCES

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