SIMULATION OF THE ALPINE SNOWPACK USING METEOROLOGICAL FIELDS FROM A NON-HYDROSTATIC WEATHER FORECAST MODEL

V. Vionnet¹, I. Etchevers¹, L. Auger², A. Colomb³, L. Pfützner³, M. Lafaysse¹ and S. Morin¹

¹Météo-France - CNRS, CNRM-GAME UMR3589, Centre d'Etudes de la Neige, Grenoble, France,
²Météo-France - CNRS, CNRM-GAME UMR3589, Toulouse, France,
³Météo-France, Ecole Nationale de la Météorologie, Toulouse, France.

ABSTRACT:

In the Alps, the snowpack is very variable at all scales and depends in particular on the climatological area and local orography represented by altitude, slope and aspect. To represent this variability, Météo-France has used for 20 years the meteorological analysis system SAFRAN to produce atmospheric forcing for the snowpack model Crocus. SAFRAN outputs are provided at various elevations, aspects, and slopes for geographical areas assumed to be meteorologically homogeneous (massifs). Using this assumption, the system cannot capture the whole variability of weather and snowpack conditions within each massif with a potential impact on the quality of avalanche forecasting. An alternative to SAFRAN is offered by the non-hydrostatic meteorological model AROME which provides operational numerical forecasts at 2.5-km grid spacing over France since December 2008. In this study, we used AROME forecasts to force Crocus and simulate the evolution of the snowpack at 2.5-km grid spacing over the French Alps during five winters (2009-2014). Results are evaluated against ground-based measurements of snow depth and snow water equivalent. They are also compared with outputs from a simulation where AROME meteorological forcing is replaced by SAFRAN meteorological forcing distributed over the 2.5 km grid. In addition, simulations for winter 2012-2013 were carried out at 500-m grid spacing over the Mont Blanc massif using a novel, high-resolution implementation of AROME.

KEYWORDS: Snowpack modelling, numerical weather prediction, French Alps

1. INTRODUCTION

Snowpack modeling in mountainous terrain has been used over the last 20 years to support avalanche hazard forecasts. In the French mountains, snowpack forecasts are currently provided at various elevations, aspects and slopes for geographical areas assumed to be meteorologically homogeneous (“massif”, typical size 800 km²). Under this assumption, this system cannot capture the variability of snowpack conditions within each massif which limits the spatial resolution of avalanche hazard forecasts. This contribution presents on-going work to study the potential of high-resolution meteorological forecasts to improve snowpack forecasts in the French Alps.

2. MATERIAL AND METHODS

2.1 Modelling tools

Numerical simulations supporting avalanche hazard forecast activities are currently carried out using the SAFRAN – SURFEX/ISBA-Crocus – MEPRA model chain (S2M ; Lafaysse et al., 2013). The detailed snowpack model SURFEX/ISBA-Crocus (hereafter referred to as Crocus ; Vionnet et al, 2012) computes the evolutions of the physical properties of the snowpack and the underlying ground under given meteorological forcing data (air temperature, relative humidity, incoming short-wave and long-wave radiation, wind speed and solid/liquid precipitation rate). The mechanical stability of the snowpack simulated by Crocus is estimated by the model MEPRA (Giraud, 1992) which diagnoses the avalanche hazard level for each simulated snowpack profile and provides an integrated natural avalanche hazard index at the massif scale.

The generation of consistent meteorological variables used to perform numerical simulations of the
snowpack is operationally carried out by the meteorological downscaling and surface analysis tool SAFRAN (Durand et al., 1993). The main original feature of SAFRAN is that it operates at the geographical scale of meteorologically homogeneous mountain ranges (referred to as « massifs ») within which meteorological conditions are assumed to depend only on altitude and aspect. Based on a robust data assimilation scheme combining large-scale output from NWP models, ground-based and radiosonde observations and remotely-sensed cloudiness, SAFRAN provides hourly meteorological conditions for each massif for 300m-spaced altitude bands. Variables dealt with by SAFRAN include not only precipitation (rainfall and snowfall rate) and air temperature but also relative humidity, wind speed, incoming long-wave and shortwave radiation. SAFRAN also operates in forecast mode, solely using NWP output. In this case, SAFRAN is a downscaling tool from the NWP model grid to the massifs/altitude bands geometry. However, this mode was not used in the present study, where SAFRAN is used as reference analysis system and the performance of SAFRAN as downscaling tool from the NWP model grid to the massifs/altitude bands geometry is not assessed.

An alternative to SAFRAN is offered by the non-hydrostatic meteorological model AROME which provides operational numerical forecasts at 2.5-km grid spacing over France since December 2008 (Seity et al., 2011). Here we used two versions of AROME, referred to as AROME-2.5km and AROME-500m. AROME-2.5km is the operational version of AROME, which covers all the French territory (including the Alps) and for which data are available from August 2009 to July 2013. In this case, we use meteorological data at the surface diagnostic level for 2m high temperature and relative humidity, and 10 m wind speed. AROME-500m is a research implementation of AROME at 500 m horizontal resolution. In this case, data are available only the Northern French Alps domain (200 x 200 km domain), from November 2011 to July 2012. In this case, we use temperature, relative humidity and wind-speed from the first prognostic level of the atmospheric model (roughly 5.5 m above ground). In both cases, continuous meteorological driving data are generated from the succession of AROME forecasts (initialized each day at 0:00 UTC, data are used only from 6:00 UTC to 0:00 UTC the next day).

In order to be able to compare the outputs of the various simulations considered, meteorological forcing data from SAFRAN were projected on the same simulation grid as AROME-2.5km and AROME-500m : in this case, each point was associated with a given SAFRAN massif (the French Alps consist of 23 such massifs), and the meteorological driving data were interpolated from the underlying and overlying nearest 300m altitude band for each point of the grid. The AROME-2.5 km forcing was also horizontally interpolated to the AROME-500m grid (not accounting for altitude differences between the two grids at this stage). In all cases, effects of aspect and slope on incoming solar radiation were not included since simulation outputs are compared with measurements collected on flat terrain.

2.2 Evaluation of numerical simulations

The numerical simulations were evaluated in two ways. First of all, differences between simulated snow depth using either SAFRAN or one AROME-based forcing were computed. In this case, SAFRAN is considered the reference, because it consists of a meteorological forcing which incorporates an analysis of observations and should thus account better than purely forecast-based datasets for the actual unfolding of the time series of meteorological conditions. In addition, simulation results were compared to in-situ snow depth observations from a large number of stations covering the entire French Alps. Basic statistics (mean and standard deviation of difference between observations and simulation results) were computed. Observation stations were only considered if their altitude was less than 150 m different from one of the 4 nearest grid points, so that the total number of stations is different for the two domains and the two horizontal resolutions considered (80 in the whole French Alps domain at 2.5 km resolution, 83 in the Northern French Alps domain at 500 m resolution).

3. RESULTS

3.1 Four years of simulations using AROME-2.5km – Crocus

Figure 1 shows an example of the numerical simulation of snow depth at col de Porte (1325 m altitude) for the 4 snow seasons from 2009 to 2013, driven by SAFRAN reanalysis and AROME-2.5 km. Both model results show a generally consistent time series of snow depth through the season,
Although discrepancies can be found. It is observed that, due to the long term memory of the snowpack for the unfolding of meteorological conditions since the beginning of the snow season, a single failure in predicting the correct amount or phase of precipitation and/or error due to snowpack model imperfection can cause detrimental effects for the remainder of the snow season (see e.g. late season 2009-2010, where the last large precipitation event was almost not captured by AROME-2.5km).

Statistics from the ensemble of the 80 stations considered for the 4 seasons were computed. Overall, the mean bias for the simulations driven by SAFRAN and AROME-2.5 km are 17.3 and 32.2 cm, respectively, while in terms of standard deviation of the difference the corresponding values are 35.0 and 49.7 cm, respectively. This indicates that both simulations generally overestimate snow depth, and that the AROME-2.5km driving data leads to higher mean and standard deviation of the difference with observations. In addition, results appear geographically variable, with a N-S gradient of statistical scores (better scores to the South in both cases), potentially due to lower average snow depth in the Southern French Alps (data not shown). Similar to what can be observed on Figure 1, it is generally found out that the simulation performance at the point scale varies greatly from year to year and from one station to another (data not shown).

Figure 2 shows the difference of snow depth between AROME-2.5km – Crocus and SAFRAN – Crocus on 1 March of each of the four seasons. It reveals that the snow depth difference follows a pattern which appears persistent at the interannual time scale.
3.2 Results from the AROME-500m – Crocus simulations

Figure 3 shows an example of the snow depth from the Crocus simulation driven by AROME-500m forcing on 1 February 2012, and the difference between AROME-500m – Crocus and SAFRAN – Crocus in terms of snow depth for the same date. It illustrates that high resolution driving data lead to highly heterogeneous snow depth spatial distributions, and that in terms of difference with SAFRAN driving data, a realistic spatial variability of snow conditions within SAFRAN massifs can be found. Based on a network of 83 stations from this domain, using only data from the 2011-2012 winter, it is found that the simulation driven by AROME-500m performs better than the simulation driven by AROME-2.5 km (bias of 6.8 cm against 24.3 cm, standard deviation of difference of 46.4 cm against 66.6). The simulation driven by SAFRAN exhibits a negative bias in this case (-9.3 cm) and a lower standard deviation than for the two simulations driven by AROME meteorological forcings (35.0 cm). Simulations driven by AROME-500m tend to provide higher snow depth than SAFRAN at high altitude, and at low altitude simulations driven by AROME-500m provide lower snow depth than SAFRAN. In short, AROME-500m provides meteorological forcing (in particular, precipitation) with more pronounced altitude variations than SAFRAN.
4. CONCLUSIONS AND PERSPECTIVES

This preliminary study illustrates the large potential interest of high-resolution (2.5 and 0.5 km) meteorological forecasts to improve snowpack forecasts in mountainous terrain in the French Alps. Given that the AROME operational domain extends well beyond the French border, the developed framework could be useful for neighboring countries (Spain, Northern Italy, Switzerland, parts of Austria etc.). Furthermore, AROME is shared with partner national weather services so that the results and framework presented here could be used in other contexts as well (Scandinavia, Austria etc.).

Several aspects of the presented work require further inquiry and improvements. The evaluation of the numerical simulations of snow depth was performed against in-situ snow depth observations, which poses several issues due to (i) their questionable representativeness due to high spatial variability of snow depth at the m scale and (ii) the low number of such observations when the goal is to evaluate 500m resolution numerical simulations. A fully fair comparison between the simulations using the 500m and 2.5 km resolution AROME driving data could not be achieved due to the lack of a dedicated downsampling tool from the 2.5 km to 500m resolution, which could help disentangle the added-value of performing full model runs of AROME at the resolution of 500 m vs. a posteriori downsampling of 2.5 km resolution model runs (which are already performed operationally to assist weather prediction in France). Last, one key feature of SAFRAN not covered by AROME is the ability to integrate meteorological observations including precipitation data in its analysis system. Currently, precipitation data are not used in any known NWP assimilation system, although this would be critical to avoid the accumulation of forecast errors in the analysis of snow conditions, and would allow better snow forecasts. Addressing all these limits form the body of planned future works to advance the status of this work beyond its current status.

REFERENCES


