# Integrating snow management processes and practices into a detailed snowpack model
# Relevance, applications and prospects


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## *Overview*

Heavy demand exists for scientific investigation of both snow management optimization in terms of costs and energy/water consumption and assessments of the ability of snow industry to face climate change. Here we introduce new developments targeting the explicit integration of snow management into the detailed snowpack model Crocus including both physical and socio-economical considerations.

### Machine Made Snow properties

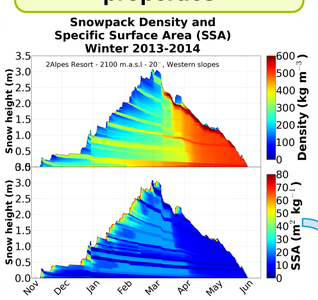


**Fig.1** At least 8 snowmaking sessions can be observed (initially higher density ≈350 kg m$^{-3}$ and lower SSA ≈22 m$^2$ kg$^{-1}$)

### Meteorological Constraints

- Wet Bulb Temperature
  $T_w$ < -5°C
- Wind Speed
  V < 15 km h$^{-1}$

### Production Timing

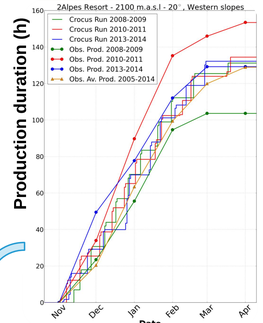


**Fig.2** Scarce (e.g. 2010-2011) or abundant natural snow conditions (e.g. 2008-2009) impact snowmakers' decisions, which is not accounted for yet

### Snowmaking

### SAFRAN-Crocus model chain

The detailed multi-layer snowpack model Crocus (Vionnet et al., 2012) is usually run in French mountain regions using outputs of the meteorological downscaling and surface analysis tool SAFRAN (Durand et al., 2009).

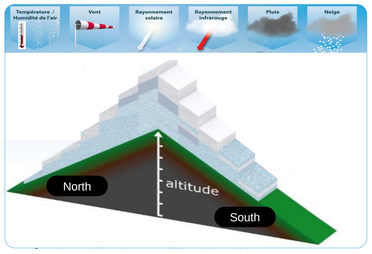


**Fig.4**: SAFRAN-Crocus principles

### Grooming

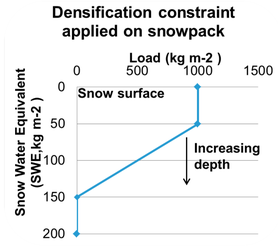


**Fig.3**

- As close as possible to usual practices
- November to April
- 6pm to midnight
- One day out of two

### Densification Load

### Timing Frame


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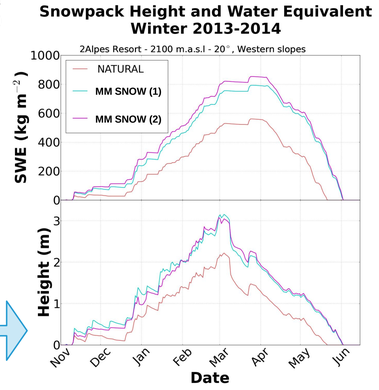
## *Results*

Crocus actually produces snow accounting for specified properties (fig.1) and in agreement with the production frame (fig.2). The energy balance of the snowpack is thus modified by this extra material as well as by densification which can be observed on Figures 5 and 6. This results in higher snowpack depth and snow water equivalent (SWE), colder ground temperature and later complete removal. This is consistent with resorts snow managers experience.

**Fig.5**: Snowpack height and SWE when forcing MM snow density and microstructure properties (SSA) in Crocus (« MM SNOW (1) ») and when these properties are determined by the model depending on current meteorological conditions (« MM SNOW (2) ») compared with natural run




Accounting for MM snow properties (fig.1) impacts the snowpack behavior (fig. 5). Higher density probably acts in the same way as densification (fig. 6) while microstructure properties (SSA) modify the snow albedo and thus the radiations absorption by the snowpack

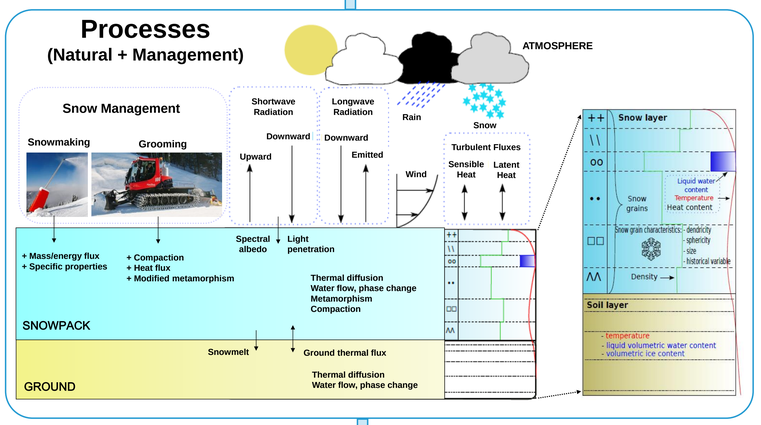
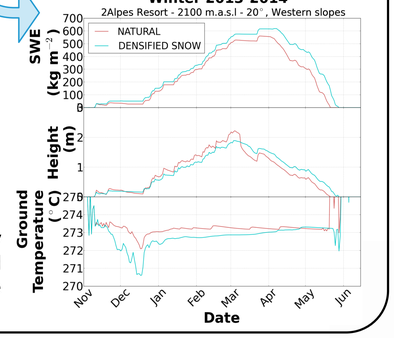



**Fig.7:** Modified Crocus scheme

The densification mostly impacts the snowpack thermal conductivity which leads to a gradual relative cooling of the densified vs. the natural snowpack and makes it more "resistant" against ablation processes

**Fig.6:** Effect of densification as simulated by Crocus on snow depth, SWE and ground temperature




## Outlooks

Following Francois et al. (2014), we crossed SAFRAN-Crocus and "BD Stations": snowpack simulations can be applied on the geographical database "BD Stations" (fig.8) to assess snow conditions in French Alps ski resorts (fig. 9 and 10). Further analysis of snow management in ski resorts should be possible thanks to this new model chain. We particularly look forward assessing the resorts ability to face climate change thanks to potential climate scenarii.

### Test site : *Les 2 Alpes* ski resort

*Les 2 Alpes* (fig.8) ski resort (Oisans, French Alps) is the twelfth most visited resort in France. It is equipped with approximately 200 snowguns below an altitude of 2100m.a.s.l. Above that line, only densification is applied. Fig. 9 and 10 show results according to that configuration.

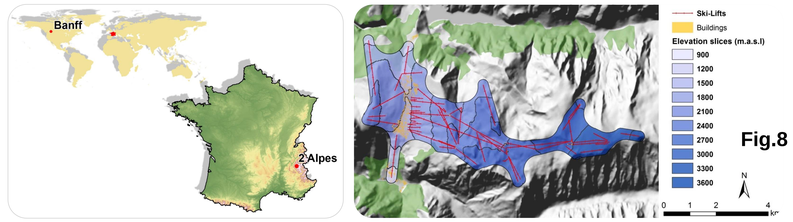
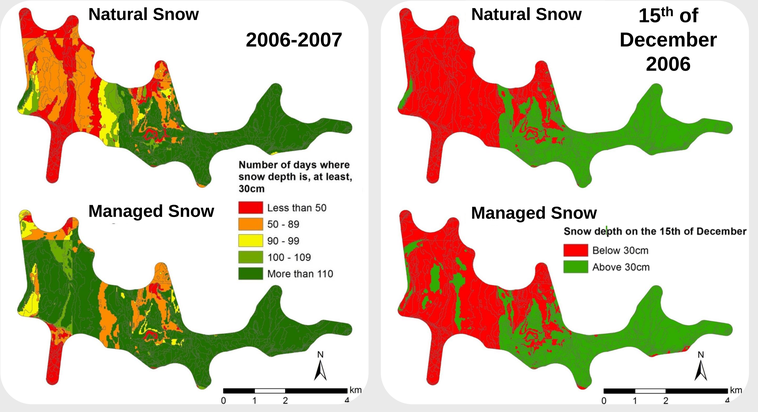



**Fig.8**

**Fig.9:** Under scarce natural snow conditions, snow management highly improves the snowpack conditions over the season.

**Fig.10:** Before 2006 Christmas holidays. Snowmaking can not always compensate the lack of natural snow when meteorological conditions do not allow it.




**2006-2007: "Dry and warm!"** one of the worst winter seasons over the last two decades in Europe with low precipitations and relatively warm conditions.

### Main references


Durand, Y., Laternser, M., Giraud, G., Etchevers, P., Lesaffre, B., and Mérindol, L.: Reanalysis of 44 years of climate in the French Alps (1958–2002): Methodology, model validation, climatology and trends for air temperature and precipitation, *J. Appl. Meteorol. Climatol.*, 48, 429–449

François, H., Morin, S., Lafaysse, M., George-Marcelpoil, E., Crossing numerical simulations of snow conditions with a spatially-resolved socioeconomic database of ski resorts: A proof of concept in the French Alps, *Cold Regions Science and Technology* (2014)

Vionnet, V., Brun, E., Morin, S., Boone, A., Faroux, S., Le Moigne, P., Martin, E., and Willemet, J.-M. : The detailed snowpack scheme Crocus and its implementation in SURFEX v7.2, *Geosci. Model Dev.*, 5, 2012