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Operational implementation and evaluation of a blowing snow scheme for avalanche hazard forecasting

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ABSTRACT

In alpine terrain, blowing snow events strongly affect the local evolution of the avalanche danger and must be taken into account by avalanche hazard forecasters. This study presents the implementation and the evaluation of the blowing snow scheme Sytron into the operational chain for avalanche hazard forecasting (named S2M) used in the main French mountain ranges. S2M-Sytron provides information on blowing snow occurrence and intensity per 300-m elevation bands and aspects for several regions of the French mountains. The wind forcing is provided by the meteorological analysis system SAFRAN. S2M-Sytron was evaluated for winter 2015/16 at 11 automatic stations measuring wind speed and blowing snow fluxes in the French Alps. The system detects 55% of blowing snow days with less than 10% of false alarms. S2M-Sytron captures the occurrence of blowing snow events with and without concurrent snowfall. Improvements are obtained when considering an updated parameterization for the properties of falling snow which reduces the threshold velocity for freshly fallen snow. Using observed wind speed instead of SAFRAN wind speed to drive Sytron shows further improvements at stations where SAFRAN wind speed differs from the observations due to local topographic features. Overall, S2M-Sytron provides a regional blowing snow assessment but cannot fully reproduce the local intensity of blowing snow events.

1. Introduction

In mountainous terrain wind plays a determinant role in shaping the small-scale distribution of snow and strongly influences the evolution of avalanche danger (Schweizer et al., 2003). Wind-induced snow transport can create large, local accumulations of snow that increase the loading of exposed slopes and can trigger natural avalanches. Deposited snow is made of fine grains due to sublimation and rebounds on the snow surface during the transport (Clifton et al., 2006; Comola et al., 2017). These fine grains present a high cohesion due to sintering and a layer of deposited snow may act as a slab if deposited on a weak layer made of faceted crystals, depth or surface hoar or fresh snow. Local overload such as a skier, a snowmobile or a cornice fall can trigger the release of a slab avalanche. Therefore, blowing snow events in alpine terrain are recognized as one of the major avalanche problems that need to be taken into account by avalanche forecasters (Mair and Nairz, 2010).

When reporting on blowing snow conditions in their bulletin, avalanche forecasters can rely on several sources of data. For the past and present conditions, they can use blowing snow information from local observers and/or blowing snow fluxes measured at automatic weather stations using specific devices. For example, in the Alps and the Pyrenees, governmental and private organizations have deployed stations equipped with FlowCapt acoustic sensors (Chritin et al., 1999), mainly for the avalanche protection of exposed roads and tunnels. However, these types of networks are generally scarce and therefore provide only limited information on blowing snow conditions. A supplementary approach has been proposed by Lehning and Fierz (2008) to increase the number of stations with blowing snow information. Wind measurements at automatic weather stations (AWS) deployed across the Swiss Alps are combined with outputs from the detailed snow model SNOWPACK (Bartelt and Lehning, 2002) running at the location of each AWS to determine the occurrence of blowing snow and estimate loading of lee slopes by wind-transported snow. In this approach, SNOWPACK provides an estimation of the threshold wind speed for snow transport that depends on the simulated microstructure properties of surface

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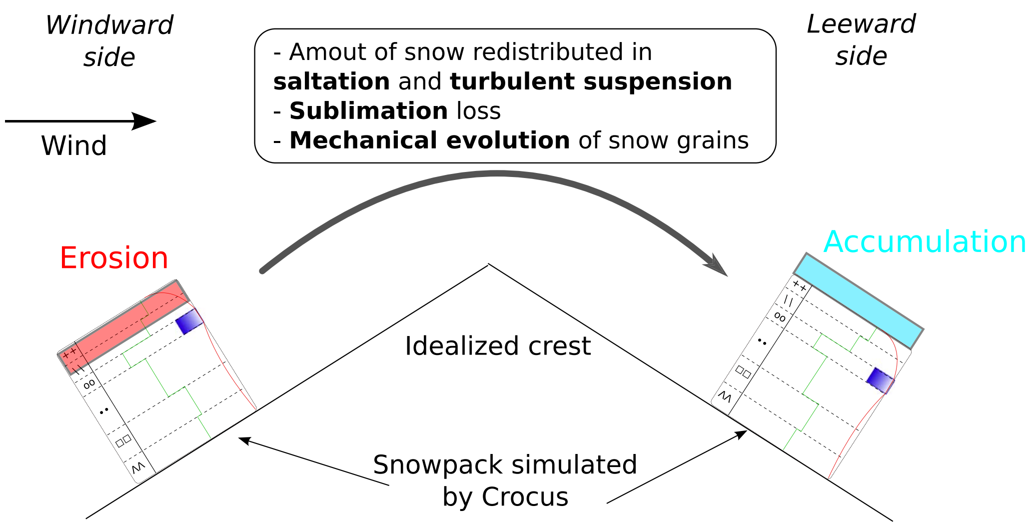

Fig. 1. Sytron conceptual scheme. Sytron simulates wind-induced snow redistribution between the windward and the leeward side of a virtual crest where the snowpack is simulated with the snowpack model Crocus. Sytron computes the amount of snow transported in saltation and turbulent suspension and accounts for mass loss due to blowing snow sublimation.

snow (sphericity, coordination number, bond radius) (Schmidt, 1980; Lehning et al., 2000).

To provide blowing snow information over a wide range of areas and altitudes, including regions with neither AWS nor human observations, Durand et al. (2001) have developed the conceptual scheme Sytron which simulates wind-induced snow redistribution between the windward and the leeward side of virtual crests. Similar to Lehning and Fierz (2008), Sytron uses information on surface snow conditions provided by the detailed snowpack model Crocus (Brun et al., 1992; Vionnet et al., 2012). Sytron is designed to work in the framework of the French operational system for avalanche hazard forecasting S2M (Durand et al., 1999; Lafaysse et al., 2013) and aims at providing avalanche forecasters with information on blowing snow occurrence and intensity in the past (analysis mode) but also for the next two days (forecasting mode). However, Sytron has never been deployed operationally. Other numerical models of varying complexity have been developed to simulate wind-induced snow redistribution in alpine terrain (e.g. Gauer, 2001; Liston et al., 2007; Lehning et al., 2008; MacDonald et al., 2010; Schneiderbauer and Prokop, 2011; Vionnet et al., 2014). Except for the conceptual approach followed by MacDonald et al. (2010) where the topography is represented by hydrological response units, all the other models are based on a gridded representation of the topography. These models have mainly been applied in a research perspective to better understand and quantify the complex interactions between the wind flow and the snow surface during blowing snow events in alpine terrain. They have never been used in the context of avalanche hazard forecasting.

The main objective of this paper is to describe and evaluate the operational implementation of a blowing snow scheme for avalanche hazard forecasting. Since winter 2015/2016, the conceptual scheme Sytron has been deployed in S2M. This implementation is described in Section 2 as well as the daily diagnostic available to avalanche forecasters. Section 3 presents the automatic stations measuring blowing snow fluxes deployed across the French Alps and used to evaluate S2M-Sytron in terms of simulated blowing snow occurrence for events with and without concurrent snowfall. Three configurations of the model were tested with a specific emphasis on the sensitivity of the model to wind forcing and on the importance of the properties of fresh snow influencing the threshold wind speed for snow transport (Vionnet et al., 2013). The results of the model evaluation are described in Section 4. Section 5 contains a discussion of the main results of this study and Section 6 offers several concluding remarks.

2. Analysis and forecasting of blowing snow over the French mountain ranges

2.1. Operational chain for avalanche hazard forecasting

Operational avalanche hazard forecasting carried out by Météo-France for the three main mountain ranges in France (Alps, Pyrenees and Corsica) mainly relies on an observation network of weather and snowpack conditions. Numerical simulations of the physical properties of the snowpack on the ground are also available for a more comprehensive spatial coverage, including an assessment of its mechanical stability (Durand et al., 1999; Lafaysse et al., 2013). The meteorological downscaling and analysis system SAFRAN (Durand et al., 1993, 2009) provides estimates of the atmospheric conditions in 300-m elevation steps in meteorological homogeneous areas referred to as massifs, ranging approximately between 500 and 2000 km^2. SAFRAN runs in analysis mode (the guess from the meteorological model is corrected by observations) and in forecast mode (in that case, the system only performs an altitudinal downscaling of the meteorological model). The detailed snowpack model SURFEX/Crocus (hereafter referred as Crocus, Brun et al., 1992; Vionnet et al., 2012) computes the time evolution of the physical properties of the snowpack using SAFRAN input (air temperature and humidity, wind speed, incoming longwave and shortwave radiation, rainfall and snowfall amount) for a variety of slope and aspect situations within each massif and altitude band. The expert system MEPRA (Giraud, 1992) is then used to diagnose whether simulated snow conditions are conducive to significant avalanche hazard. The so-called SAFRAN-SURFEX/Crocus-MEPRA (S2M) model chain has now been used operationally for over 15 years.

2.2. Blowing snow scheme Sytron

The blowing snow scheme Sytron (Durand et al., 2001) has been developed to simulate wind-induced snow redistribution between the windward and the leeward side of virtual crests as illustrated in Fig. 1. Sytron determines the occurrence of blowing snow using the formulation of Guyomarc'h and Mérindol (1998) which gives the threshold wind speed as a function of simulated snow properties at the surface. The presence of a wet layer or a crust at the top of the snowpack prevents blowing snow. When blowing snow occurs (wind speed higher than the threshold value), Sytron computes the amount of snow transported in saltation and turbulent suspension from the windward to