2D SNOWDRIFT MODELING AND VALIDATION

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ABSTRACT: One of the objectives of the Centre d'Etudes de la Neige (Snow Study Centre of Météo-France) is to improve the modeling of snow cover evolution and avalanche risk forecasting. A numerical simulation of snow transport, related mechanical effects and snow distribution has been developed over the last years. The objective is to incorporate the wind effects in the Météo-France operational chain Safran-Crocus-Mepra (SCM) for avalanche risk forecasting. At present, an evaluation version of the model is applied to a well instrumented site (Col du Lac Blanc 2700m, French Alps) in order to assess its performance and to validate its applicability. At this place, in addition to automatic weather stations, several specific snowdrift sensors and a range of snow poles, a novel remote sensing technique based on land-based photography is being applied. This paper describes the current state of snowdrift modeling and the new technique of result validation.

Keywords: snowdrift modeling, land-based photography, geo-referencing, wind effects on snow distribution, albedo.

1. INTRODUCTION

The effects of wind on snow morphology and spatial snow redistribution play an important role in the increasing of avalanche risk. For this reason, in order to improve the existing operational forecasting chain, the Centre d'Études de la Neige (CEN – Snow Study Centre, Météo-France), has developed, during the last years, a numerical simulation of snow transport and related mechanical effects on snow particle morphology. The last version of this model, Sytron2 is described in detail in Durand et al. (2003), it results in an increasing degree of complexity in the development of snow wind transport modeling.

At present, an evaluation version is applied to a well instrumented site (Col du Lac Blanc 2700m, French Alps), in order to assess its performance and validate its applicability. At this experimental site, lots of measurements aiming at a better knowledge of the snowdrift effects on snow pack stability have been made over the last 12 years.

In addition to nivo-meteorological stations, several specific sensors and a range of snow poles, an original remote sensing technique based on terrestrial photography is being applied (Corripio et al., 2004). The choice of this technique is a compromise between feasibility, efficiency and the cost of its implementation. The idea is to measure indirectly the snow surface changes by taking digital photographs periodically and after snowdrift events from an elevated viewpoint. Firstly, the photo is geo-referenced to a digital elevation model. Then, after several radiometric corrections depending on topography and atmospheric conditions, the pixels are derived in relative albedo. In parallel, the effects of wind transport, erosion, accumulation and snow grain characteristic described by the model can be deduced to the associated values of albedo. This new tool seems to be an appropriate technique for spatial validation of snowdrift modeling in the absence of more precise technique like radar or 3D laser. The results for the last 2003-2004 winter campaign will be presented.

2. EXPERIMENTAL SITE OF STUDY

A large pass (Col du Lac Blanc – 2700m) situated between the Pic Blanc (Grandes Rousses – 3323m) and the Dôme des Petites Rousses (2810m) in the French Alps has been chosen and lots of specific sensors have been set up there. This pass is a relatively flat area and forms a natural wind tunnel between the two summits oriented roughly North-South (Figure 1).

The experimental site is equipped with 2 automatic weather stations and an horizontal profile of snow poles along a north-south transect (according to the prevailing wind) where snow depth can be measured with a precision of +/- 10cm (Figure 2). All sensor data are recorded in a small cabin on the site and transmitted to Grenoble on request (Guyomarc'h et al., 2002).. The data of this site have been very useful firstly for the wind threshold determination according to snow features and for the in-situ observations of snow grain characteristics before and after snowdrift periods and recently for the tuning of the model operators.

Figure 1 : the experimental site situated in the "Grandes Rousses" massif (2720 m).

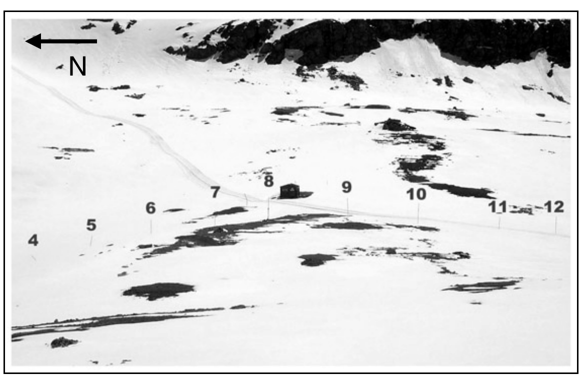

Figure 2 : a part of the horizontal profile of snow poles along a north-south axis at the experimental site.

3. SNOWDRIFT MODELING

Snowdrift modeling is a difficult task due to different factors such as the large range of the working scales (from the synoptic to the micro-topographical scale) and the permanent interaction between local topography, meteorological conditions and the snow. Nevertheless, these phenomena cannot be neglected in the framework of an automatic system of snow modeling and avalanche hazard forecasting.

Several valuable attempts have been successfully done by several authors (Gauer 1998, Liston and Sturm 1998, Lehning et al. 2002). Our present operational version runs at a scale of about 400 km and provides only the large scale conditions for wind and snow (Durand et al. 1999). Current research work aims at the operational incorporation of a high resolution model at a fine mesh size of about 45 m. To allow the realistic modeling of the snowdrift effects, this finer model is coupled with that of less resolution, but getting from a greater extent. At this moment, this last model, called Sytron2, is at the testing and validation stage.

Sytron2 is initialized with a realistic snow pack information derived from the Météo France operational chain for avalanche hazard estimation (SAFRAN-CROCUS-MEPRA), and coupled to a wind field computed by the new Samver model. This last model is a downscaling process from the massif scale, calculated by SAFRAN (Durand et al. 1999), to the range of 45 m. Once initialized with realistic wind and snow conditions from the model Samver, the 2D drifting model Sytron2 aims to simulate the occurrence of blowing snow and to estimate the bulk snow mass exchanges due to creep, saltation and suspension. The losses by sublimation as well as the modifications of density and crystal morphology are also treated (Durand et al. 2003, Figure 3).

During transport, the characteristics of the snow crystals are modified both by mechanical interaction between them and by partial sublimation. Sytron2 algorithms tend to make the new drifted crystals closer to small rounded grains, a realistic situation as observed during snowdrift events. These transformations are a multi-step process. The snow crystal characteristics are described using the parameters of the model Crocus (Brun et al. 1992). A fresh snow crystal is thus defined in terms of dendricity (ranging from 1 to 0) and sphericity (0 to 1). When drifted, a snow crystal dendricity is made to decrease and its sphericity to increase according to the wind velocity. The operators governing crystal change are based on the laws of snow metamorphism used by Crocus and additional observation of the drifted snow crystals, done at the instrumented site for many years (Guyomarc'h and Mérindol, 1998). At each grid point and time step, the deposited snow is then added to the snow surface by aggregation to the first layer or through a new layer if the amount is deep enough. A new snow profile is then made at each grid point, where density and snow grain characteristics (dendricity and sphericity) are recalculated. At this stage Sytron2 uses the original Crocus temperature profile but does not recalculate it. A more complete thermodynamic treatment of the new snow profile will be incorporated in future versions of Sytron2. Fresh snow, in case of snow fall, is simply added to the snow mass in movement and treated as it was eroded snow. This allows a deposition of the fresh snow suited to the wind and topographic conditions. All these formulations have an implicit self limitation: the transported snow is less subject to a new drifting effect during the following hours because it underwent some crystal changes which decrease the corresponding snow-driftability index and thus the transportability.

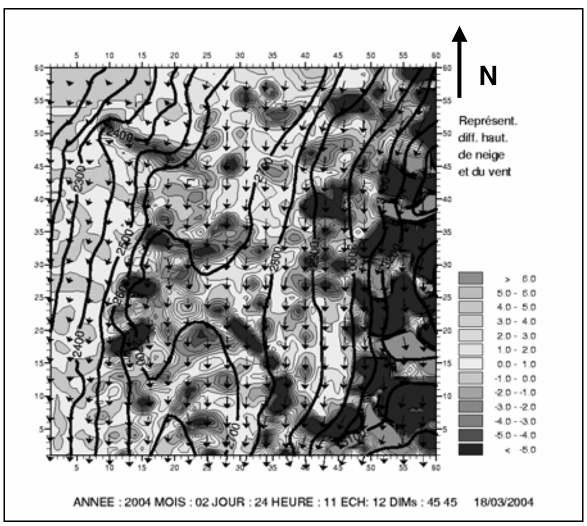

Figure 3: an example of Sytron2 outputs displaying snow-depth differences and wind speed field after a simulated snowdrift event on 24th February 2004.

4. VALIDATION OF THE RESULTS

A realistic validation of Sytron2 model requires a step forward from the previous methods of snow pole measurements towards a as fully as possible spatial evaluation of the results. Nevertheless that poses additional problems to define the adapted tools which are practical in terms of cost and implementation.

Measuring directly the variations of snow depth over large areas is not an trivial task. The choice is an indirect measurement of snow surface changes. Oblique digital photographs of the experimental site are taken periodically and after snowdrift events from an elevated point. These photographs are then geo-referenced to a digital elevation model (DEM) and compared to ground control points (see Figure 4). Further radiometric corrections depending on topography and atmospheric conditions are applied to the geo-referenced pixels to derive relative albedo of the snow surface. Spectral filtering (in order to obtain near IR photography) applied to the digital camera permits detecting small variations in the associated snow grain characteristics.

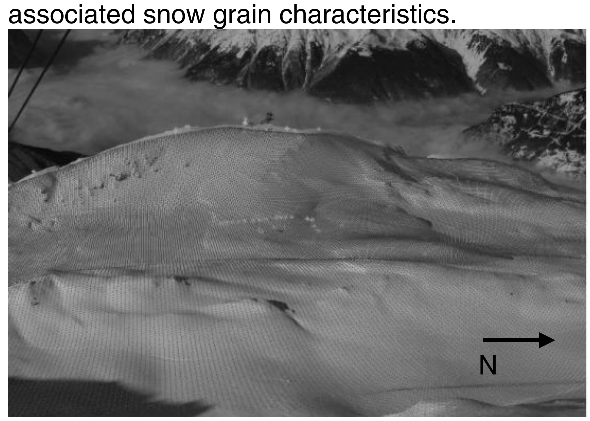

Figure 4: original photograph taken from "Pic Blanc" (3300 m) and the projection of the DEM.

The result of the processing described above is a map of reflectance values (normalized for sun radiations and topography) (Figure 5). By comparing this map to a pixel of reference, we can deduce the relative albedo of the whole visible area.

The effects of wind transport, erosion or accumulation and snow grain characteristics described by the model (Figure 6) can be then compared through the associated changes in albedo to the snow texture and feature variations recorded by the photographs.

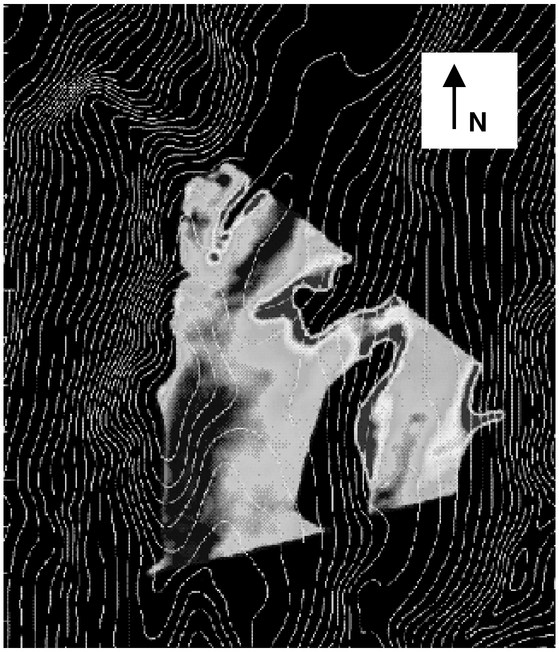

Figure 5: relative albedo derived from the digital image.

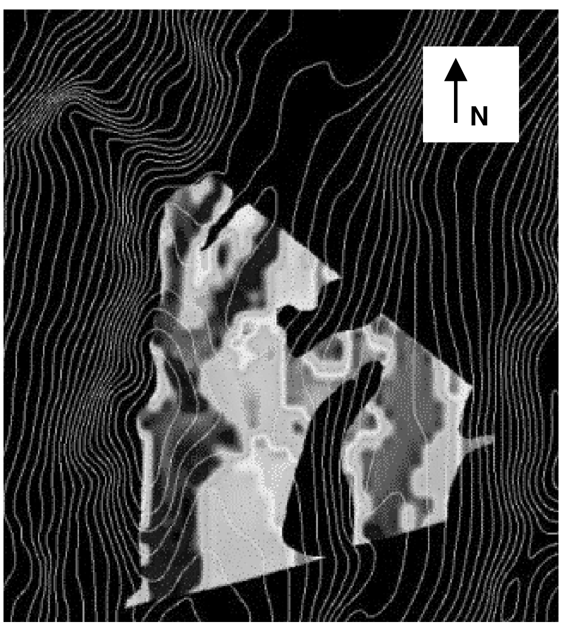

Figure 6: relative albedo derived from the results of Sytron2 modeling.

5. CONCLUSIONS

The entire tools presented here are still in development as well as the validation techniques. A lot of work is still necessary in the Sytron development, but its conception allows one to hope for a substantial increase in performance.

The new tool developed for the verification of the modeling results seems to be an appropriate technique for spatial validation of snowdrift modeling and it is useful in identifying both strengths and weaknesses of the model.

For the last winter season (2003-2004), we have used this monitoring technique in order to estimate the improvement of the second version of Sytron2 by using around 12 periods of observed snowdrift events. This new version, Sytron3, aims to take into account the vertical structure of the snow pack.

Two versions are being tested on real situations of the recent past seasons: A 1D version runs operationally for 4 years and the 2D version (Sytron 2 and 3) has been tested for 2 years.

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7. REFERENCES

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