Operational Use of the Model Crocus by French Avalanche Forecast Services

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Introduction

Since 1971, the operational avalanche forecasting is operated by the french national meteorological service in the Alpes and in the Pyrenees. In the Alps, about 100 snow weather stations provide twice a day with informations on weather and on snow surface state and once a week with snow pit informations to describe the internal state of the snow cover. These informations are at the basis of snowcover stability analysis.

Even over a small mountain area, snowcover is characterized by a great variability due to different altitudes, slopes and orientation and 100 snow pits in the french Alps are not enough to describe the whole natural diversity. Furthermore, snowcover state may vary significantly during a week and, sometimes, the avalanche forecaster waits impatiently for the next snow profiles.

That is to solve this lack of informations that we have developed a numerical model of snow cover which simulates snow profiles from the observed or forecasted weather conditions.

Rapid description of the model

The numerical model, named Crocus, computes the internal and external heat and mass exchanges in order to simulate snow temperature, density and liquid water content profiles and also snow cover stratigraphy. It uses unidimentional layers of variable thickness. Heat conduction is solved by a Cranck and Nicholson scheme. Phase changes due to melting or freezing are directly computed though phase changes between the solid or liquid and the gazeous phases are taken into account through an effective thermal conductivty coefficient. Water transmission is derived using free water content as a maximum value. Snow settlement of each numerical layer is derived according to its grains type and size.

At the snow atmosphere interface, radiative heat exchanges, sensible and latent heat fluxes and precipitations are computed using a time centered scheme which avoids large errors in heat exchanges involving snow surface temperature (i.e sensible and latent heat exchanges and also longwave radiative output).

The original feature of this model is to simulate snow metamorphism of each layer and so building up the snow cover stratigraphy. It allows to let match the natural and numerical layers of the snowpack and also to simulate with accuracy snow cover albedo according to snow surface grains size and shape. Metamorphism is derived using laws that were determined experimentally in cold lab. Experiments were conducted on the all known metamorphism on varoius snow types.

Model validation

The model Crocus was tested on the measurements field of Le Col de Porte located in the north french Alps (Massif de la Chartreuse, 1320m a.s.l) in a lightly windy glade.

During the winter 88/89, the parameters necessary as input data for the model were measured automatically once an hour: air temperature and humidity, wind velocity, snow and rain precipitations, incoming long wave and short wave radiation. To control the model results, snow depth, snow surface temperature and bottom water run-off were measured automatically and once an hour too. Once a week a snow pit provided with temperature, liquid water content and density profiles. Snow grains were taken out from each snow layer and put in sub-freezing iso-octane to stop for a long time all metatmorphism. They were later observed under a microcscope to get a perfect description of them.

Crocus validation was conducted comparing snow internal and surface observations with the results of the simulation. No reinitialization appeared to be necessary during the whole winter. A first profile was deduced from a pit at december the 17th. and the simulation stopped at snow melting, at may the 7th. Snow depth, snow surface temperature and bottom water run-off are compared on figure 1 to 3. After this test, the model was considered efficient enough to be used by the french operational avalanche forecast services. The original feature of this model comes from its ability to simulate snowpack stratigraphy with accuracy.

Operational use of the model Crocus

In the Alps, 5 weather stations operate avalanche forecast on the different mountainous massifs located in their region. These weather stations get meteorological models outputs,

satellite Meteosat and AVHRR pictures, precipitation radars pictures and all other stuff necessary for weather forecast.

For avalanche forecast, they use a software on a PC to store and display snow and weather informations they collect from about 20 snow-weather stations in each region. These snow-weather stations are mainly hold by patrol services of ski resorts. The software on their PC enables to display snow profiles, the evolution of snow surface and of weather since the last three weeks, maps of observed parameters, etc..

The model Crocus was adapted to run on their PC and to use as input data the meteorological data measured by the different snow-weather stations.A run session is organized according to the following scheme:

- the forecaster chooses a geographical location and the simulation period (usually the last 24 hours). He chooses it from a file that stores up to 15 predetermined locations defined by their altitude, latitude, slope, orientation, longitude and sometimes their masks related to solar radiation.
- he chooses an initial snow profile that can be a new profile deduced from a snow pit or a profile derived by a previous simulation.
- he chooses to use recorded weather data if he wants to update the derived snow cover or he introduces forecasted weather data if he wants to simulate snow cover evolution within the next 24 hours.
- the model Crocus is automatically activated
- the forecaster may look at the hourly simulated profiles, the simulated snow surface temperature and the simulated bottom water run-off. He may store on the computer some of these profiles to use them after as initial profiles for a next run which is usually the next day.

At a given location, the interest of simulating the snow cover evolution depends naturally on the situation. The model Crocus is very useful to get informations on the following events that affect significantly snow cover stability:

- liquid water appearing at snow surface
- wetting of internal deep layers
- depth of refreezing during the night
- occurence of temperature gradient metamorphism
- fresh snow settlement

- crust formation.

Future developements

After using the model Crocus during a first winter season, the avalanche forecasters of the different weather stations judged the model very useful but they have regretted to have no time enough to let run the model more than over one or two locations a day, especially under worrying avalanche situations when they had much work.

To progress in the way to use the model, we have begun an important application to provide automatically the model with input meteorological data. It will use meteorological models outputs, automatic and human snow weather observations, satellite and radar pictures. A meteorological model of limited area has been developed to determine the wind and the air temperature at an horizontal step of 1 km on a real relief of the french Alps. Optimal analysis methods will provide with cloudiness and precipitations.

Once meteorological parameters are determined by this application, Crocus will run on a central computer to simulate the snow cover evolution on a great number of geographical locations. The forecasters of the different weather stations will get directly Crocus outputs (snow profiles) without to spend any time to let it run. Such a development will enable the expert system MEPRA (presented during ISSW88) to extract simulation results for an automatic analysis of snowpack stability.

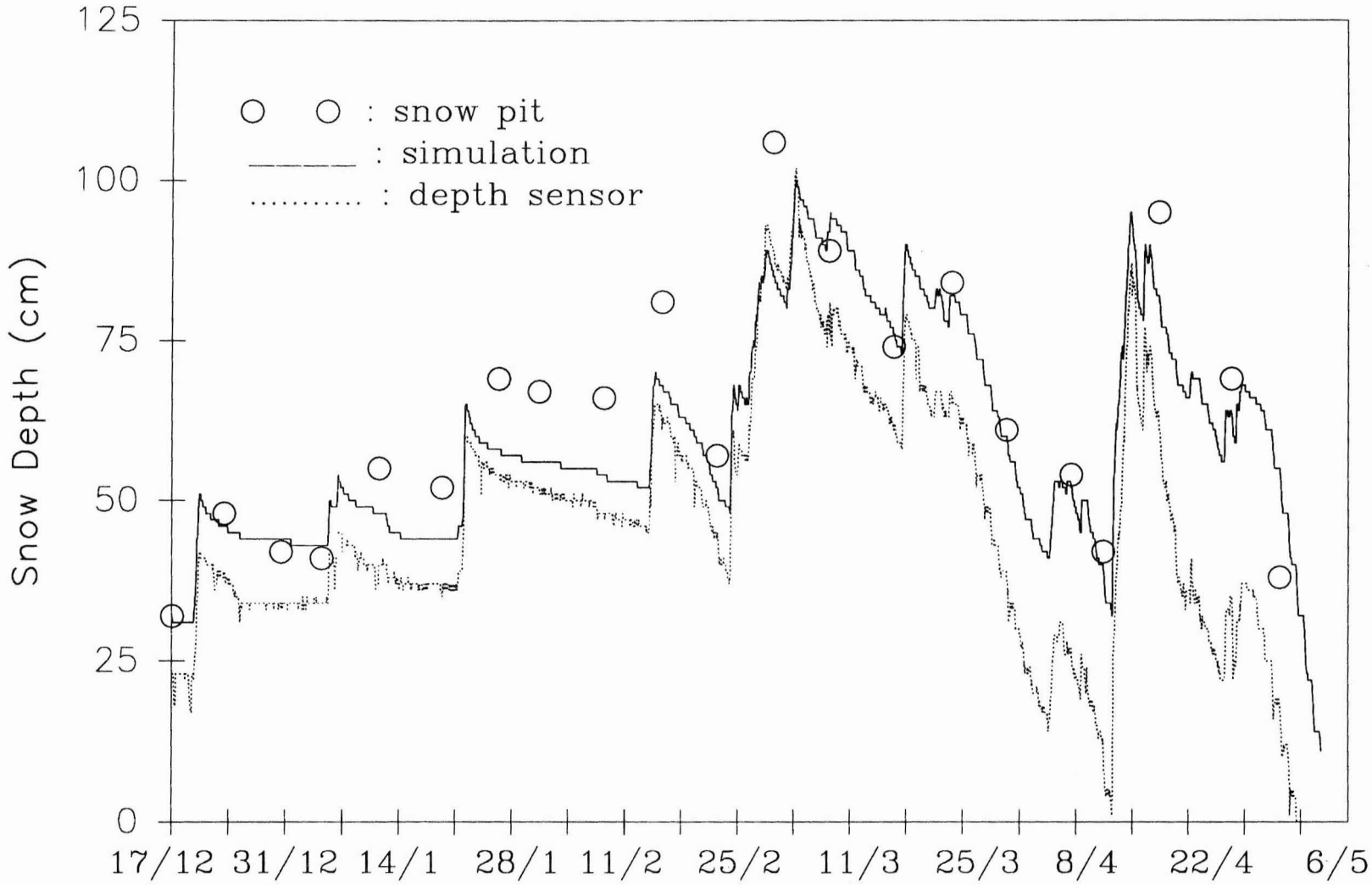
Snow Depth Comparison
125
100
75
50
25
0
Snow Depth (cm)
○ ○ : snow pit
_____ : simulation
..... : depth sensor
17/12
31/12
14/1
28/1
11/2
25/2
11/3
25/3
8/4
22/4
6/5
Date

Figure 1

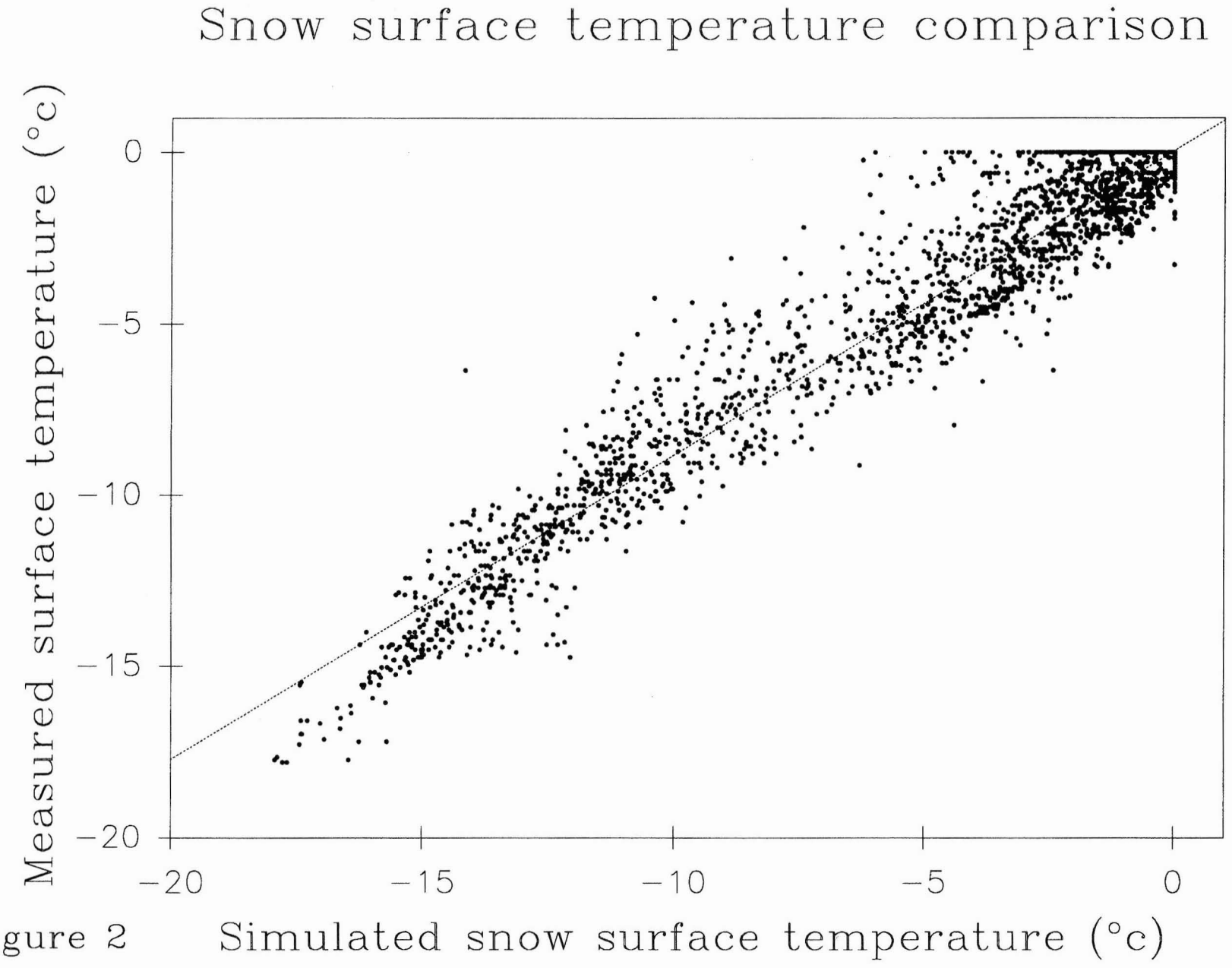
Snow surface temperature comparison
Measured surface temperature (°c)
0
-5
-10
-15
-20
-20
-15
-10
-5
0
Simulated snow surface temperature (°c)

Figure 2

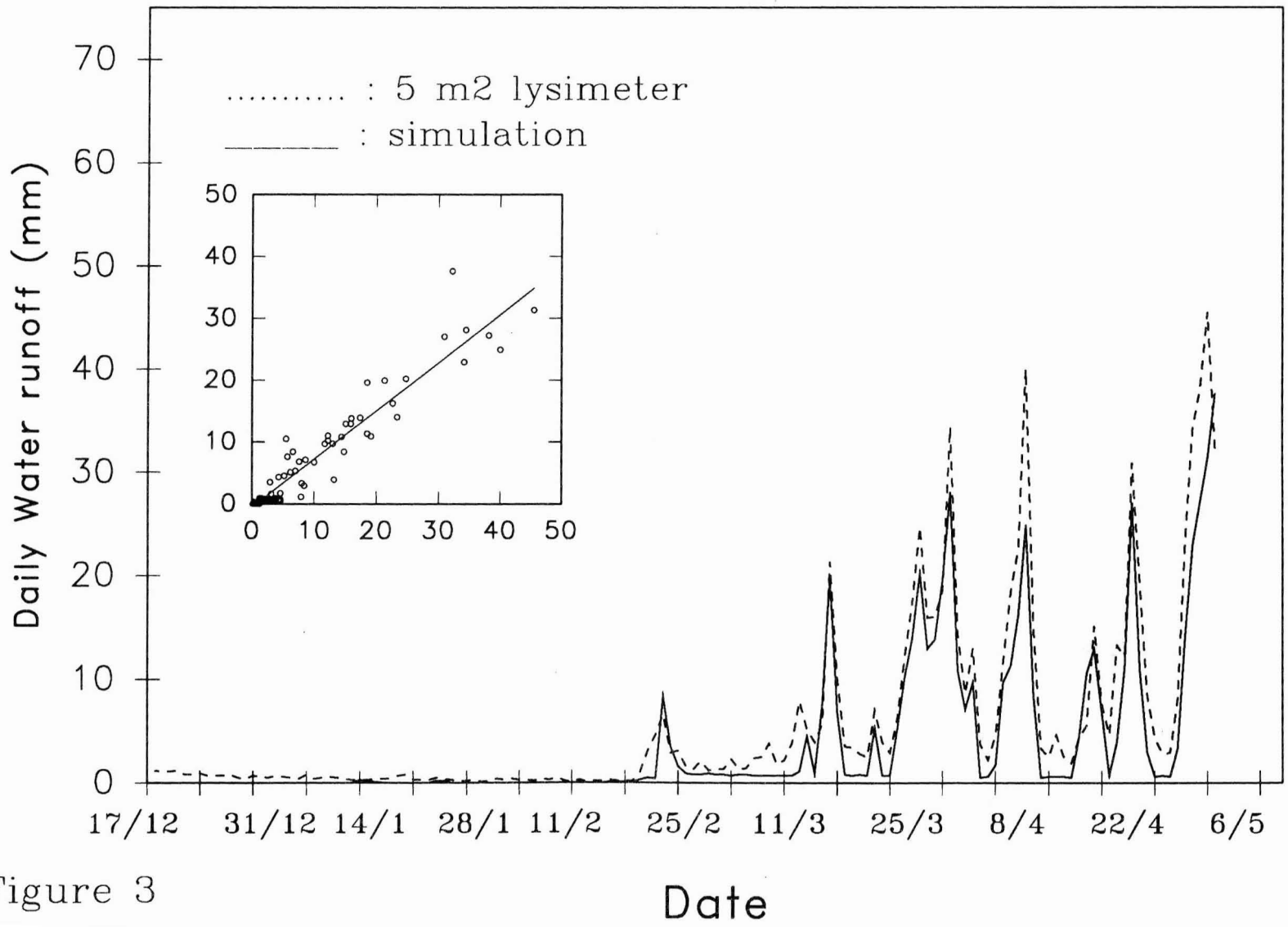
Bottom Water Run-off Comparison
..... : 5 m2 lysimeter
_____ : simulation
Daily Water runoff (mm)
0
10
20
30
40
50
60
70
17/12
31/12
14/1
28/1
11/2
25/2
11/3
25/3
8/4
22/4
6/5
Date
0
10
20
30
40
50

Figure 3