The use of a numerical snow-drift model as a decision making tool in the planning of avalanche protection measures

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Abstract

Blowing and drifting snow is not only a major factor in the assessment of the acute avalanche danger, its contribution to the snow distribution also influences land-use planning. In many parts of alpine terrain endangered areas are secured by expensive avalanche protection measures. The efficiency of these measures can be affected by the redistribution of snow due to wind. Numerical snow-drift simulation could provide useful information at the planning state of protection measure to increase their efficiency and so to reduce costs.

Keywords snow-drift, numerical modeling, meso-scale weather model, nesting, planning tool

1 Intruduction

In alpine terrain, snow and wind go together. Everyone concerned with avalanche warning knows the influence of recent snow-drift on the acute avalanche danger. Hence, it is no wonder that some effort is made to incorporate snow-drift models as part of avalanche forecast systems, at least on basis of parametrization, e.g., (Doorschot, 2002; Durand et al., 2001; Lehning et al., 2000).

On the other hand, snow-drift is also a concern for land-use planning. For example, buildings or roads can be affected by drifting snow, but also the effectiveness of permanent avalanche defense structures can be reduced due to snow-drift. There are some examples in which numerical snow-drift models are used in those kind of tasks, e.g., (Jaedicke, 2001; Kawakami et al., 1997; Sundsbø, 1997), who tried to simulate the snow distribution around buildings.

Snow-drift models for each of the above mentioned tasks may differ conceptually from each other. Models used in the avalanche warning should indicate the occurrence and give an estimate of the amount of snow redistribution. The models should be cable to work at least on a regional scale, and for operational use the allowable execution time of the model is a limiting factor.

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The requirements for models used in land-use planning are different. In this case, one wants to know the deposition pattern as exact as possible. For that, it is necessary:

- to resolve a 3-dimensional wind-field;
- to be able to include buildings and/or different kind of obstacles;
- to have a high spatial resolution;
- to adapt the changing surface topography;
- to describe snow-drift in a reasonable manner;
- etc.

Although the time restriction for the execution time is not as strict as for a forecast model it is still a factor which has to be considered.

The following shows an example of snow-drift simulation for the purpose of land-use planning and how one of the major problems in those kind of simulation might be overcome, i.e., the setting of the boundary conditions for the wind-field simulation in rather complex topographies.

2 Model

A full description of the used blowing and drifting snow model can be found in (Gauer, 1999, 2001). Here, only a summary of the main features is given. The model is implemented in the commercial flow solver CFX4 from AEA (1995, present version 4.4).

This is a multi-purpose flow-solver based on a finite-volume approach. The snow-drift model is incorporate in this code by means of user defined Fortran routines. The main features of snow-drift model are:

- a fully 3-dimensional non-steady-state modeling;
- Eulerian-Eulerian approach;
- modeling of the two main transport modes:
  - saltation (founded on a height-averaged dynamical description); (slight modifications of the saltation layer parametrization was done since (Gauer, 1999, 2001), e.g., the influence of the slope angle is now better accounted for);
  - suspension;
- dynamical modeling of deposition and erosion, distinguishing between aerodynamic entrainment and ejects due to particle impacts;
- back-reaction of the particles in the saltation on the flow (two-way coupling);
- periodical grid adaptation to the new snow depth.
- possibility of externally-forced boundary conditions.

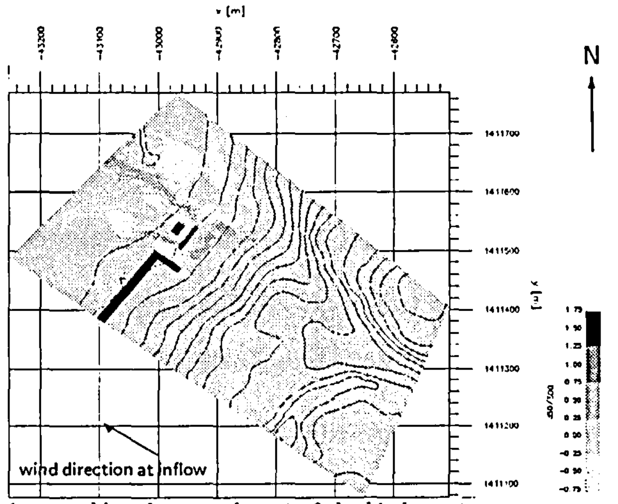
3 Case study

The purpose of the snow-drift simulation was to provide a case study of the effect of drifting snow for different scenarios of avalanche protection measures for a kindergarten. The following scenarios were considered:

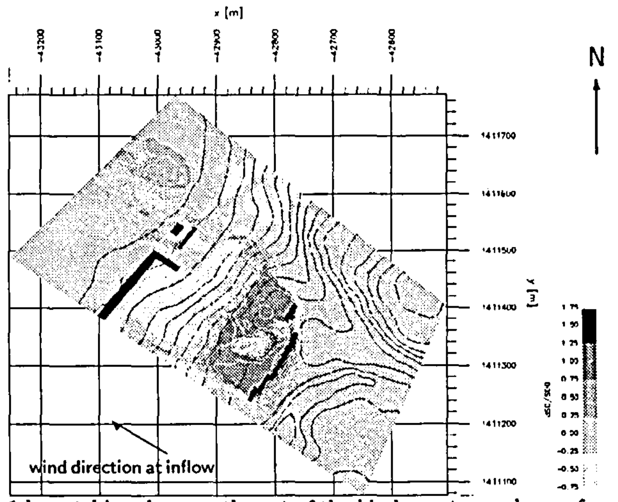
- catching dam south-east of the kindergarten;
- combination of snow fences and catching dam.
- combination of snow fences and avalanche defense structures;

Figure 1 shows a comparison between the different scenarios. All snow depths are normalized following the equation:

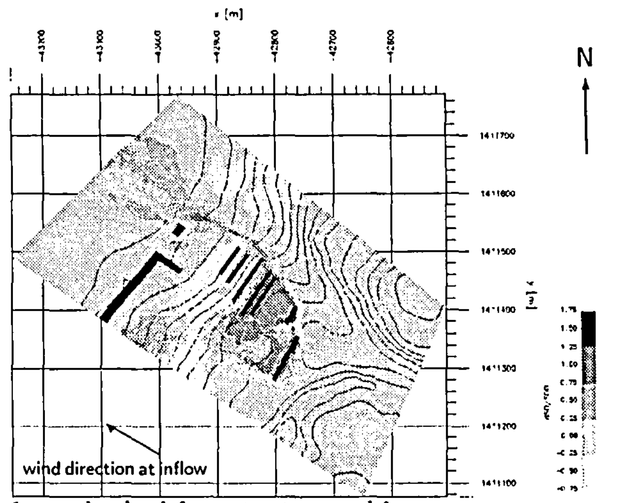
$$\frac{dSD}{SD_e} = \frac{SD - SD_0}{SD_e} \qquad (1)$$



1.a: catching dam south-east of the kindergarten



1.b: catching dam south-east of the kindergarten and snow fences



1.c: avalanche defense structures and fences

Figure 1: Snow-drift simulation around two buildings and three variants for avalanche protection measures; 10 m contour lines in black, west end side is approximately at sea level; 0.125 m isolines of the normalized snow depth in withe.

where SD is the simulated snow depth, SD_0 is the simulated snow depth for the status quo, and SD_e in the initial erodible snow depth. This normalization means: zero values indicate no difference, negative values indicate areas of depleted snow depth and positive values show areas of enhanced snow depth compared to the status quo, i.e., a simulation only including the two buildings.

The simulation considers only the redistribution of snow, no additional precipitation is included. At the south-east boundary, the reference wind speed at 10 m is set to $12.5\,\mathrm{m\,s^{-1}}$ and the critical shear stress, τ_c, for erosion to start is assumed to be 0.15 Pa.

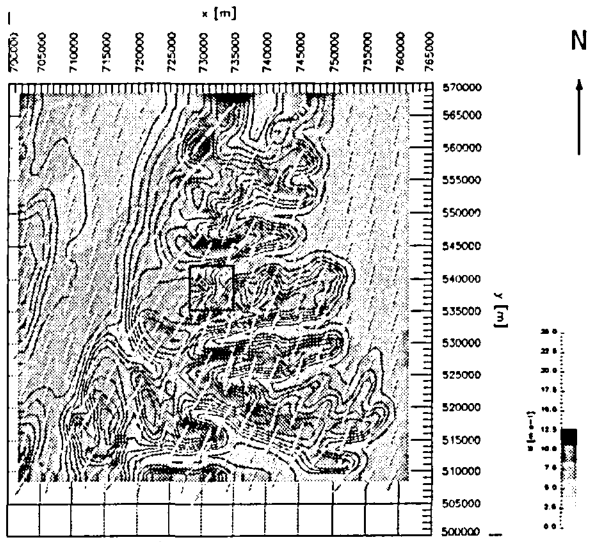
As might be expected, the influence of the sole dam is rather small, which can be seen in Fig. 1.a. Due to its larger cross section and in combination with a jet effect, the formation of the typical horseshoe pattern is more promote. The effect of additional snow fences is shown in Fig. 1.b. Most of the snow is already caught on the plateau up-slope. Similar in Fig. 1.c, the combination of snow fences and avalanche defense structures keeps most of the snow uphill. However, it can also be seen that the influence of these structures is still noticeable further down.

4 Difficulties

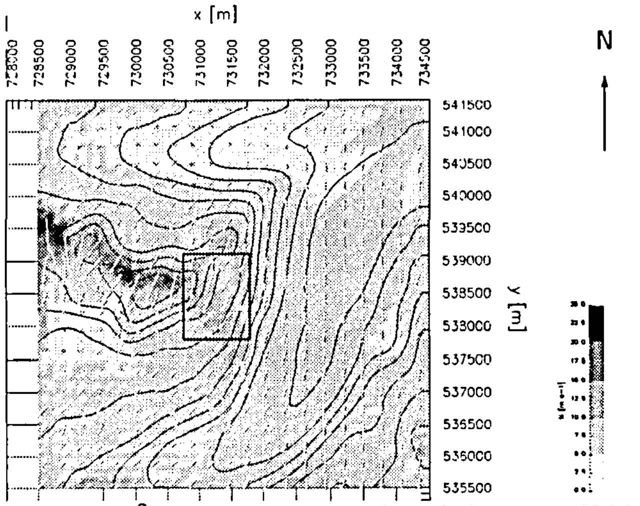
One of the major difficulties in this kind of simulation is it to provide reasonable boundary conditions for the wind field. In the example above, rather crude estimates were used in setting symmetry planes at the north-east and south-west side of the considered domain and a logarithmic wind-profile at the inflow. No wind measurements were available for the area interest. That is a common case and one can be lucky to have information about the wind conditions at least at one point nearby. This causes also difficulties to verify simulations.

One way in dealing with know boundary conditions is to bring them as far away as possible from the area of interest. Thus their influences become weaker–hopefully. The disadvantage of this procedure is that a larger domain has to be consider in the snow-drift simulation, which increases the computational effort.

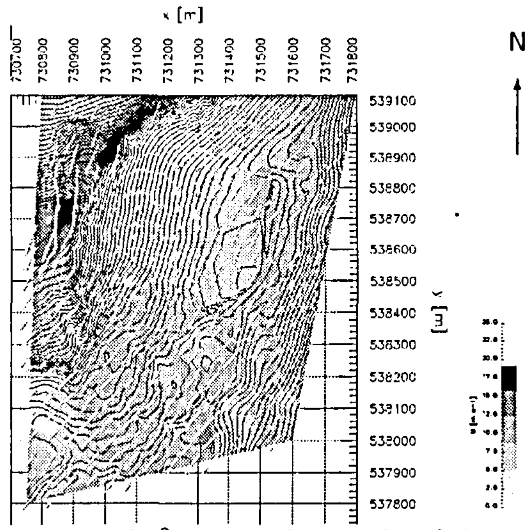
Figure 2: Modeled surface wind-field; rectangles mark the areas which are used in the different nesting steps; notice the different color coding for the wind speed



2.a: $60 \times 60\,\mathrm{km}^2$ with 1 km horizontal resolution using ARPS; 100 m contour lines



2.b: $6 \times 6\,\mathrm{km}^2$ with 100 m horizontal resolution using ARPS; 100 m contour lines



2.c: $\approx 1 \times 1\,\mathrm{km}^2$ with 10 m horizontal resolution using CFX; 10 m contour lines

One way to overcome this problem is to use a meso-scale weather model and to use a common technic from the numerical weather forecast: nesting. That means in this case, first, the wind field is calculated for a larger area with low spatial resolution and than these results are used as initial and boundary conditions for a smaller area with a higher resolution. In this way it is possible to place the initial boundaries far away from the area of interest and be still able to resolve the area of interest with the demanded high spatial resolution and reasonable computational effort.

Figure 2 shows an example were this technic was used to get the boundary conditions for a snow-drift simulation around a mountain top. The first two steps were carried out using the meso-scale weather model ARPS from the Center of Analysis and Prediction of Storms (Xue et al., 1995). The final wind field was than calculate with CFX. At that point, CFX is used because off its capability to include obstacles and to deal with a time-dependent topography.

5 Summary

These examples show how numerical snow-drift simulation can further develop into a tool for land-use planning. However, there is still work to be done. One should remember, using a nesting technic for the wind field simulation only transfers a problem and meso-scale models have still some problems in mountainous terrain. There is also the question: What are reasonable scenarios for those kind snow-drift simulations. This question is not limited to the meteorological conditions for which simulations should be done. There is also the part of the snow and its mechanical properties, e.g., the erodibility, which effect snow-drift rates. Thus, there are still topics for development and research left. And one should keep in mind: numerical models are only models with a need of verification. Hence, there is also room left for experienced judgement.

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