VERIFICATION OF SNOW-COVER MODELING ON SLOPES

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ABSTRACT: A correct representation of snow-cover evolution on slopes is crucial to enable the use of snow-cover models as a valuable tool for avalanche forecasting. Though important verification work has been done to assess the models' ability on flat terrain, less is known on their reliability on slopes as this implies to compare model output to field measurements in steep alpine terrain. This contribution presents simulations obtained by running SNOWPACK, the Swiss snow-cover model, with forcing data measured either in situ on slopes or at a nearby flat-field automatic weather station and projecting the shortwave radiation onto slopes of given exposition and inclination but neglecting any effects by the surroundings. The newly established, objective profile comparison method is used to evaluate the quality of simulations as compared with pit profiles observed either in situ on adjacent northerly and southerly slopes or on the flat field. In general, flat field simulations show most weak layers of interest. However, simulations on slopes are necessary to get a better representation of the actual situation on different aspects. Finally, case studies of stability evaluation show promising results.

Keywords: snow-cover modeling, snow stratigraphy, snow stability

1 INTRODUCTION

Model verification is the last but not the easiest step in model development. Up to now, most verification work was done for level, well instrumented study sites. However, for avalanche work, snow-cover evolution on slopes is required and in particular information on snow-cover stability.

Using a chain of three models, the French approach is to model avalanche danger on idealized mountain ranges (Durand et al., 1999) for up to 6 aspects on 40 ° steep slopes in steps of 300 m. Unfortunately, this approach is quite inadequate for model verification.

With forcing data calculated by a distributed energy balance model, Fierz and Gauer (1998) modeled snow-cover evolution on slopes including blowing snow effects. However, verification relied solely on visual comparison of modeled with observed snow profiles.

In this study, modeled profiles obtained using either projected forcing data or data measured in situ are objectively compared with observed snow profiles. In addition, calculated skier stability index is compared with recorded rutschblock score. The analysis focuses on how much information is already contained in simulations for level fields as compared to model results for slopes.

2 METHODS

2.1 Field Measurements

The field measurements analyzed here are three sets of snow pit profiles taken during the winter 1996/1997. The first is the set of bi-weekly pit profiles from the level SLF study site located at Weissfluhjoch/Davos, 2540 m a.s.l.. The second and third set were taken on adjacent, about 35 ° steep East and North slopes located 2 km north of the Weissfluhjoch study site on Gaudergrat ridge, 2280 m a.s.l. Pit profiles including Rutschblock tests were taken about every ten days, but the on the same day on both slopes.

2.2 Meteorological Input and Model Set-up

A full description of SNOWPACK is beyond the scope of this paper and the reader is referred to the publications by Bartelt and Lehning (2002) and Lehning et al. (2002a, b). For this study, SNOWPACK was run using either meteorological forcing data collected at the SLF study site Weissfluhjoch and projecting the incoming solar radiation onto slopes or data measured in situ on the slopes of Gaudergrat ridge. Note that the Weissfluhjoch site is about

2km south of Gaudergrat on the other side of the Weissfluh ridge and approximately 250 m higher. At Gaudergrat, no incoming longwave radiation was measured. Therefore the in situ simulations at Gaudergrat were run using the measured snow surface temperature as Dirichlet boundary condition (Lehning et al., 2002b). For the projections however, Neumann boundary conditions must be used because the flat field surface temperature cannot be projected into the slope. Thus, in this case, the full surface energy balance is calculated. Furthermore, as no independent estimation of precipitation was available for the Gaudergrat site, the simulations for both sites have been driven with measured Weissfluhjoch precipitation data. Simulations for the study site were run over the season with no snow on the ground at the beginning whilst on Gaudergrat Ridge, a profile observed on January 10, 1997 was provided as initial condition to SNOWPACK.

2.3 Objective comparison

Since the aim of this study is to compare snow cover simulations from projected flat field input data with simulations from in situ slope input with the respective observed profiles, three comparison methods are pursued. In addition to the qualitative visual comparison of the simulated grain types with profile records, two objective measures are used: The calculated skier stability index (Lehning et al., in press) and the objective snow profile comparison method proposed by Lehning et al. (2001). For the latter, agreement scores between observed and simulated snow profiles are calculated for various snowpack properties such as texture (grain shape and size) or temperature and averaged over the profile's depth. For the method to be valid, total snow water equivalent of both observed and simulated profiles must agree

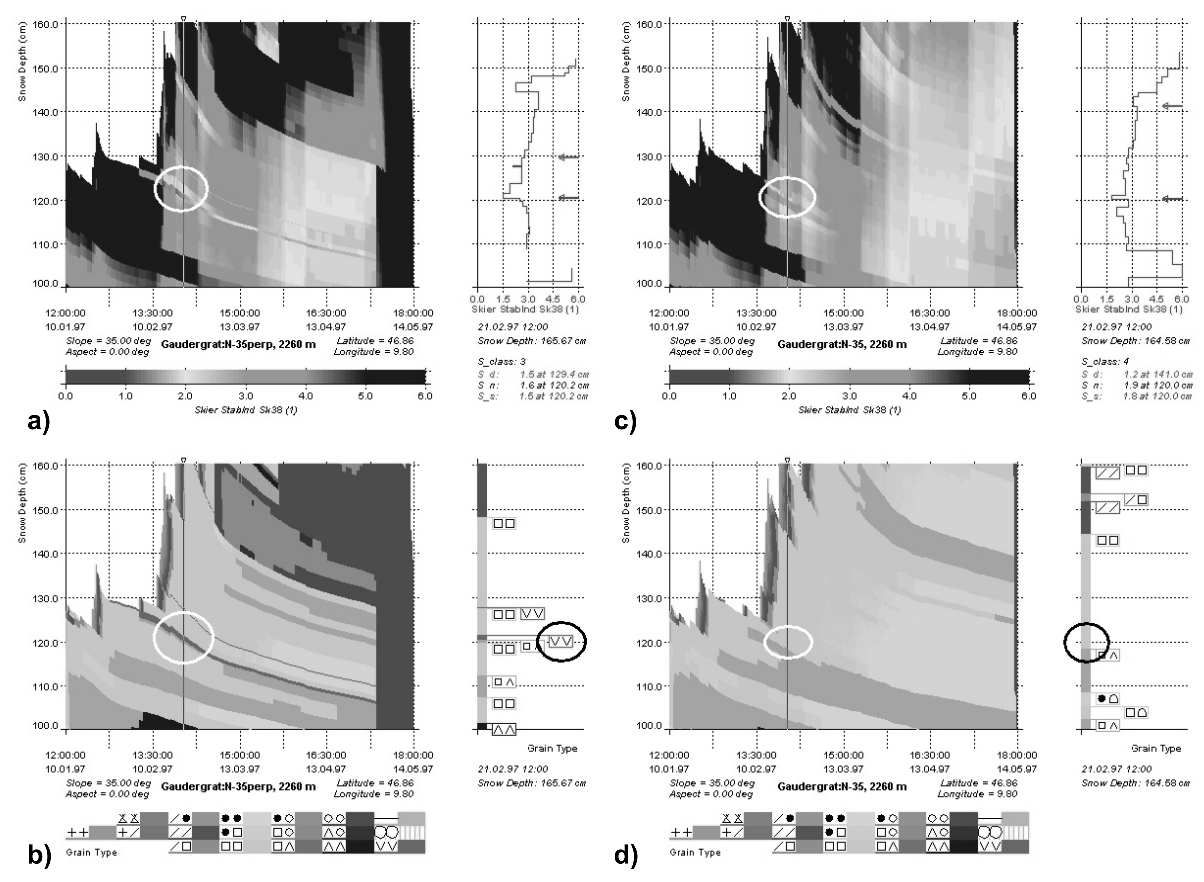

Figure 3 Skier stability index (top row) and grain shapes (bottom row) for simulations with forcing data either measured in situ (left hand side) or projected from flat field (right hand side). Marker position is set at 21 February, 1997. White circles show position of instability and black circles show grain types involved.

within ± 40%, a condition very often violated during the melt period when comparing slope to flat field simulations.

3 RESULTS AND DISCUSSION

3.1 Skier stability index

First we present the situation of February 21, 1997 as a case study. A snow pit profile taken on the north slope of Gaudergrat on that day revealed a weak surface hoar layer in approximately 0.3 m depth and an associated Rutschblock score of 4. Figure 3 shows the corresponding simulation results for both in situ forcing and projected forcing. A visual comparison reveals that both simulations reproduce the observed profile quite well, but the in situ forcing only shows the observed surface hoar layer which was buried in beginning of February 1997 (Figure 3b). Note that this simulation uses the observed surface temperature as Dirichlet boundary condition. The projected simulation, using Neumann boundary conditions, produces a small amount of surface hoar on January 25, 1997 which however disappears during the fair weather period before the next snow fall (Figure 3d). This behavior is often observed when comparing simulations with Dirichlet and Neumann boundary conditions respectively. Therefore we assume that this discrepancy can not be attributed to the difference in meteorological forcing at the two sites.

Nevertheless, both simulations show a distinct weakness at this depth as quantified by the calculated skier stability index of 1.5 and 1.8 (Figures 3a and c), respectively. For the in situ simulation, the surface hoar is responsible for this instability, while for the projected simulation a thin layer of distinctly larger faceted grains produces a weakness too. Located at the same depth as the surface hoar layer in the in situ simulation, these grains grew during the fair weather period prior to the snow fall beginning of February 1997.

Furthermore, on the same day, two weaknesses in the profile observed on the eastward slope resulted in a Rutschblock score of 2. In simulations for that slope (not shown), a weakness is present too with a calculated skier stability index of 1.6. Located at the boundary between larger and smaller faceted grains, the modeled weakness corresponds to the lower of the two layers regarding grain shape and size but is less deeply buried.

3.2 Objective profile comparison

We present agreement scores for both temperature and texture, i.e. the minimum of the agreement scores for grain shape and size. For comparisons of flat field as well as projected simulations with pit profiles taken on the level study site Weissfluhjoch, agreement scores are shown in Figure 2. The line represents the comparison for the flat field simulation and symbols stand for the comparison with projected slope simulations (N, E, S, W; 38 ° steep).

Note that little difference exists between agreement scores for either flat field or slope simulations except for temperature in spring time. This suggests that flat field simulations

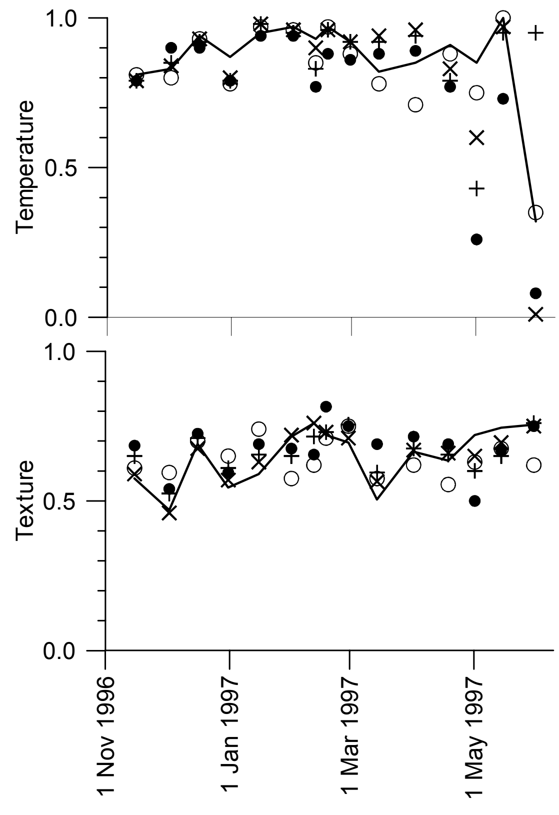

Figure 1 Agreement score for the flat field simulation on Weissfluhjoch (solid line) and projections on 38 ° steep North (●), East (+), South (o) and West (x) facing slopes.

contain most information on snowpack structure found on slopes already.

Agreement scores over a limited period starting 10 January, 1997 for simulations on slopes at Gaudergrat are shown in Figure 3. Forcing is either by data measured in situ or from projected flat field data collected at Weissfluhjoch. An simulation projected towards the east is included as the observed profiles were mostly east facing.

Note the increased scatter in the results while maximum scores are comparable to those shown in Figure 2. One reason for this scatter may be the differences in snow-cover structure due to the mismatch of profile and recording instruments locations. The second lies in erroneously large values of reflected shortwave radiation measured in both northerly and south-easterly slopes. These errors are due to either direct radiation impinging the sensor head or sensor not being correctly leveled out. Both

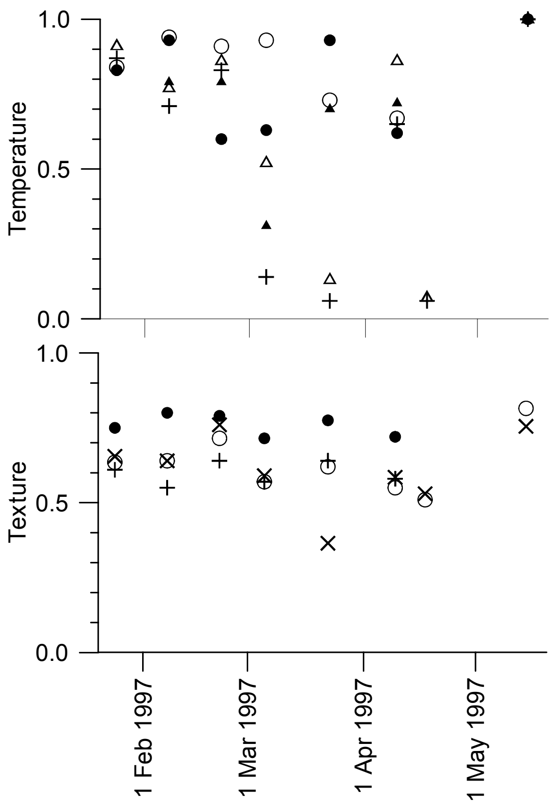

Figure 2 Agreement score for Gaudergrat simulations with forcing data either measured in situ (North: ●; South East:▲) or projected from flat field (North:o; South East: Δ; East: +).

effects are most pronounced on south-easterly slopes.

4 CONCLUSIONS

The case study presented here suggests that projected flat field simulations can capture important stability features of slope snow covers, despite the fact that not all features of the complete stratigraphy are reproduced correctly. The results also suggest that projected flat field simulations are able to give a representative picture of slope conditions even for a spatial separation of about 2 km in our case.

As site selection, installation and maintenance are much easier for flat field stations, it may be concluded that for the purpose of avalanche warning, slope stations are not mandatory. In this context we also found that radiation measurements in particular are difficult on slopes.

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