COMBINING SNOWPACK MODELS AND OBSERVATIONS FOR BETTER AVALANCHE DANGER ASSESSMENTS

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ABSTRACT: Now-casting of avalanche danger is mainly based on direct snow stability observations (e.g. recent avalanches), snow stability tests combined with stratigraphic analyses and snowpack simulations. All these data, however, have limitations related to their temporal and spatial validity. Manual snow profiles are at most useful for days, while simulated profiles are generally available for fixed locations only. In this work we present an approach for increasing the strength of the available data in terms of both, temporal and spatial representativeness. We used a network of automatic weather stations for computing spatial 2-D interpolations of weather parameters to simulate virtual weather stations at different locations. Then, we combined the synthetic data with manual snow profiles and simulated their evolutions depending to the local weather conditions using the 1-D snow cover model SNOWPACK. We tested this approach in the Livigno municipality, Italy. The simulated evolution after re-initializing with the manual snow profile was generally in good agreement with field observations. Moreover, by simulating the snow cover for different virtual weather stations within the study area we increased the available information, which was particularly helpful for the avalanche forecasters for better evaluating the variability of the local snow stability conditions. The presented approach was particularly efficient since it increases the exploitation of already available information and will help both, the forecasters for the avalanche danger assessment and the professionals for better managing the avalanche risk.

KEYWORDS: avalanche forecasting, manual observations, snow cover modeling, snow and weather data.

1. INTRODUCTION

Assessing the avalanche danger for a given region or area is a complex process which requires different approaches and methods to cover different scales and settings (e.g. regional avalanche danger estimation, road risk management, snow stability assessment for backcountry skiing). Fundamentally, observations form the field provide the starting point for each stability evaluation process.

Field data can be divided into categories according to their relevance. The most important data are those defined as low-entropy data, e.g. observations of avalanches or in-situ stability tests (Class I). If such data is not available or in case low-entropy data has to be proved, medium-entropy data have to be used (e.g. snow stratigraphy) (Class II). Lastly, meteorological data are considered (Class III) (LaChapelle, 1980; McClung and Schaerer, 2006).

Manual snow profiles combined with stability tests are the crucial information in the absence of avalanche occurrence data to derive snow stability (Schweizer et al., 2003; Schweizer and Jamieson, 2007). Generally, for being representative of a given area, a manual snow stratigraphy needs to be collected at least every two weeks if no significant weather event (e.g. snow fall) is recorded (Schweizer and Wiesinger, 2001).

Unfortunately, direct field observations may not always be available due to time constraints (i.e. start of the operations in the early in the morning) or avalanche danger. To compensate this lack of information, data supplied by automatic weather station (AWS) networks started playing a fundamental role for the avalanche forecasting process. Evolution went on within the last 15 years and using the AWS data snow cover modeling proofed to

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have large potential to increase the spatial and temporal resolutions of snow stratigraphy (Monti et al., 2012) and stability information (Monti et al., 2014; Monti and Schweizer, 2013; Schweizer et al., 2006; Schirmer et al., 2009).

One of these snow cover models is the 1-D snow cover model SNOWPACK (Lehning et al., 2002a; Lehning et al., 2002b), which simulates the snow cover characteristics, layer by layer using both measured (Lehning et al., 1999) or simulated (Bellaire et al., 2011; Bellaire and Jamieson, 2012) weather parameters. For importing and exporting meteorological and snow data, SNOWPACK uses MeteoIO, a meteorological and snow data processing library retrieving, filtering and resampling the data if necessary, as well as providing spatial interpolations and parameterizations (Bavay and Egger, 2014). The combination of these two tools has the potential to significantly improve the availability of data for practitioners in terms of its i) processing,ii) interpretation, iii) spatial distribution, and iv) visualization.

In this work we present an approach to better exploit the generally available data for avalanche forecasters (e.g. weather data, manual snow profiles, simulated profiles). The methods were tested for one winter season in Livigno (Italy) (Fig. 1) by the local avalanche forecasting service. The avalanche forecasting service is in charge of issuing a daily regional avalanche danger bulletin and provides the risk management solution for i) the roads within the municipality of Livigno, ii) the ski resort “Carosello 3000”, iii) the cross country skiing track, vi) the safety of skitouring and snowshoeing trails, and v) the heli-skiing activity. The goals we wanted to achieve were: i) accelerate the daily data interpretation, ii) improve the exploitation of already available data, and iii) increase the information entropy from the data

2. DATA

The Livigno municipality located in the middle of the Italian alpine range, at the boarder to Switzerland and South Tyrol has a covers an area of about 200 km^2, and has an elevation ranging from 1806 m to 3302 m a.s.l. The prevailing climate is Continental-Alpine.

For the avalanche forecasting activity, data from several AWS within and in the surroundings of the Livigno municipality are available thanks to the municipality and the collaborations with the nearby Regional Avalanche Centers, ARPA of Bormio (Italy) and the WSL Institute for Snow and Avalanche Research SLF, Davos (Switzerland). For this work we combined the AWS from both networks including four wind stations situated ridge line locations, and eleven snow stations on rather wind sheltered flat sites (Fig. 1).

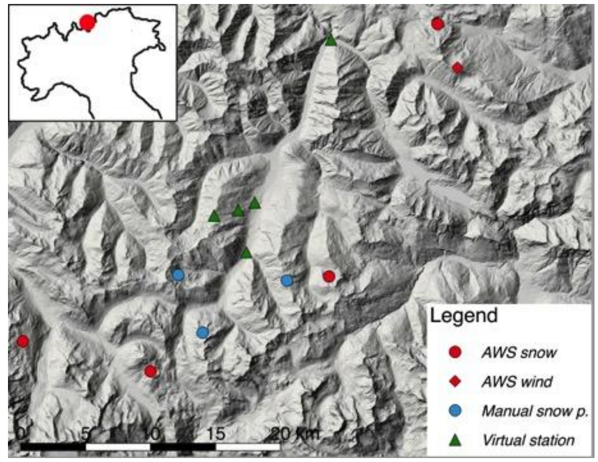

Fig. 1: The Livigno municipality is located in the middle of the Italian alpine range, at the boarder to Switzerland and South Tyrol at 1816 m a.s.l.. Map shows the locations of 5 of the 11 used snow and wind stations, the location of the manual snow profiles and the virtual stations.

During the winter season, manual snow pits combined with stability tests (i.e. rutschblock and compression test) and direct snow stability observations were systematically collected.

3. METHODS

First of all, we wanted to obtain useful information based on manual snow profiles, which assured useful information for a longer period than a couple of weeks. To achieve this goal we used the MeteoIO library to spatially interpolate the weather data of the AWS and extrapolating their values for the location of the collected manual profiles. We then initialized SNOWPACK with the manual profile and forced it with the interpolated weather data. In this way we could follow the evolution of the measured snow stratigraphy depending on the weather conditions.

Second, as Livigno is characterized by a North-South oriented main valley and is located along the main divide of the Alps, a strong gradient of precipitation might be recorded between the two main valley sides. These differences can be significant and strongly affect the snow cover characteristics. Thus, in order to highlight potential differences in snow stability between the two valley side of the municipality, it would be important to compare stratigraphies resulting from these dif-

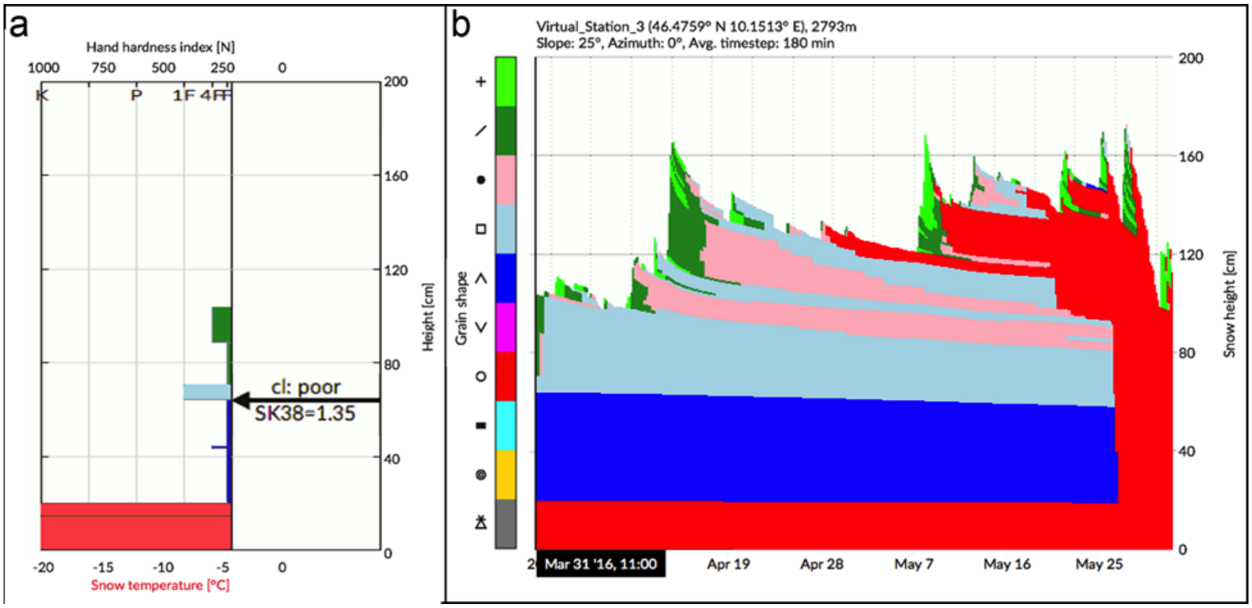

Fig. 2: a) Manual profile collected on Monte Vago on 18 March 2016. b) Manual profile evolution simulated by the snow cover model SNOWPACK forced with the weather data derived by MeteoIO for the specific location. Symbols and colors are accordingly to Fierz et al. (2009).

ferent weather conditions independently from other topographic factors (i.e. local topography, aspects, elevation). Again, we used MetelO to extrapolate weather data for virtual stations simulated on flat fields at the same elevation but at different coordinates of the area.

Finally, we used the plug-in of MeteoIO for spatially distributing the weather data on a digital terrain model (DTM) in order to obtain maps for helping understanding the different weather conditions within the area (e.g. snow surface temperature, air temperature, snow high, wind speed).

4. RESULTS

A manual profile performed on Monte Vago is shown in Fig. 2a. For collecting this profile 4 hours of ski touring were needed but, still, having information from that specific area was interesting since it is heavily skied especially during the second half of the winter season. In Figure 2b the evolution of that profile computed by MeteoIO coupled with the snow cover model SNOWPACK is shown.

In Fig. 3a, three simulated snow profiles are shown: they are the results for three virtual stations located on a north to south transect at the bottom of the main valley of Livigno. Whereas, an elevation transect of three simulated snow profiles in correspondence of the most skied area of the municipality is shown in Fig. 3b.

In Fig. 4 a map reporting the wind speed within the area of Livigno is shown. The results of the map are based on a fairly simple algorithm that elaborates the distributed wind speeds depending on the recorded wind at the AWS locations and the DTM, i.e. elevation, aspects, slope angles. The two highlighted areas are regularly used by the heli-skiing operation; in Fig. 4 two pictures recorded at the same day suggest that the simulated wind drifting effects are about correct.

DISCUSSION

Initializing SNOWPACK with the manual profile and forcing it with weather data allows us to have updated information on snow stratigraphy from one spot for longer period than before. This means the time spent for performing a detailed manual snow profile is a valuable investment even on a long term prospective (Fig. 2). The presented approach takes into account the different elevations (for deriving the gradients of snow surface and air temperature and the different aspects and slope angles to account changing incidence of solar radiation. The results of the simulations were in good agreement with what was observed in the field during the season.

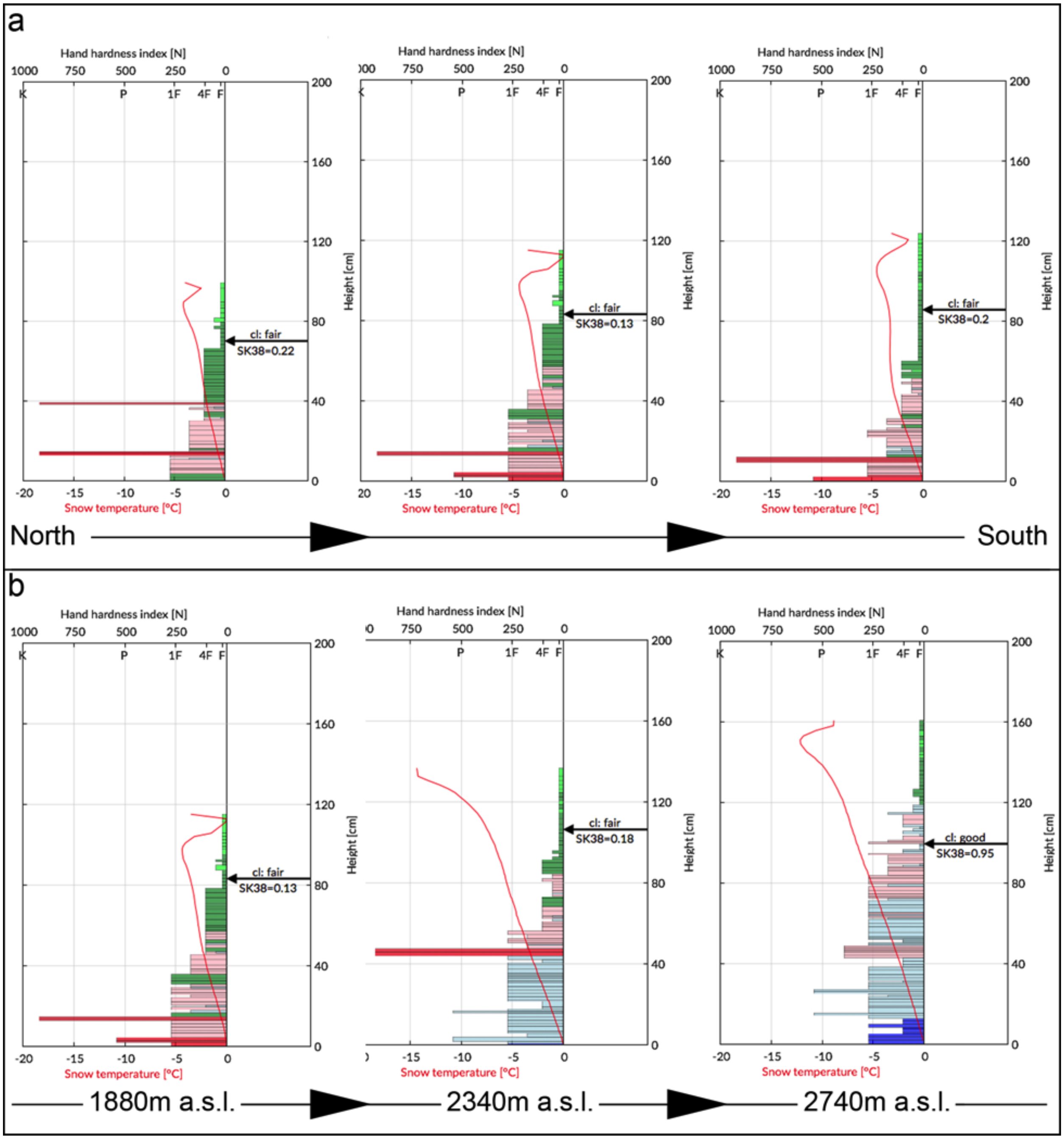

Fig. 3: a) Simulated snow profiles for three virtual stations located on the North-South axis on the bottom of the main valley of Livigno. The difference in elevation is below 40m. b) Simulated snow profiles for three virtual stations located on an elevation transect in correspondence of the most skied area of the municipality.

The SNOWPACK simulations performed on virtual stations allowed us to better compare the snowpack differences between adjacent areas. In fact, virtual stations can be chosen avoiding differences generally existing between classical AWS (e.g. different elevations or expositions): if, for example, only the elevation is changing, the effects on the snow cover due to different temperatures and winds can now be easily shown and evaluated more quantitatively (Fig. 3b). Moreover, this approach could be used to solve the temporary lack of data due to the malfunctioning of an AWS and overcome possible information gaps.

Finally, we have shown the possibility to spatially interpolate the weather data and report them on a map. In Fig. 4 it is possible to notice how the wind speeds varying depending on the orientation of the valleys and thus it is possible to forecast were the snow drifting activity was strongest which in term may be a very useful information for e.g. planning the heli-skiing activity. The same technic may be accomplished with other weather parameters (e.g. air temperature, snow surface temperature or simulated values such 24h sum of new snow (not shown).

The proposed approach has the potential to improve the information needed by the avalanche forecasters for evaluating the different conditions ascribable to one of the four main avalanche problems: i) new snow (e.g. by mapping the new snow amount, or by adding the new snow on manually recorded snow profile); ii) drifting snow (e.g. by mapping the wind speed and direction); iii) wet snow (e.g. by mapping the simulating the liquid water content of snow in a specific point of a slope); iv) old snow problems (e.g. tracking the evolution of persistent weak layers within manually recorded profiles). This kind of information can also be useful to professionals for moving safer on avalanche terrain.

We decided to use this approach and not more complex ones and potentially more precise like the 3D snow model ALPINE3D, because we wanted a tool applicable for operational use: i) it can be run without significant investments; ii) it does not require large calculation resources; iii) results could be produced fast and more times a day.

Limitations of this approach are related to the quality of the AWS network: i) The higher the density of AWS is the higher the resolution of the results, ii) it is paramount to know the quality of the input data in order to exclude potential sources of error (e.g. data from an AWS with too much drifting snow or exposed to winds influenced by local topography).

This approach can be easily performed forcing it with data obtained by weather prediction models, with the potential of forecasting the snow and weather evolutions as well.

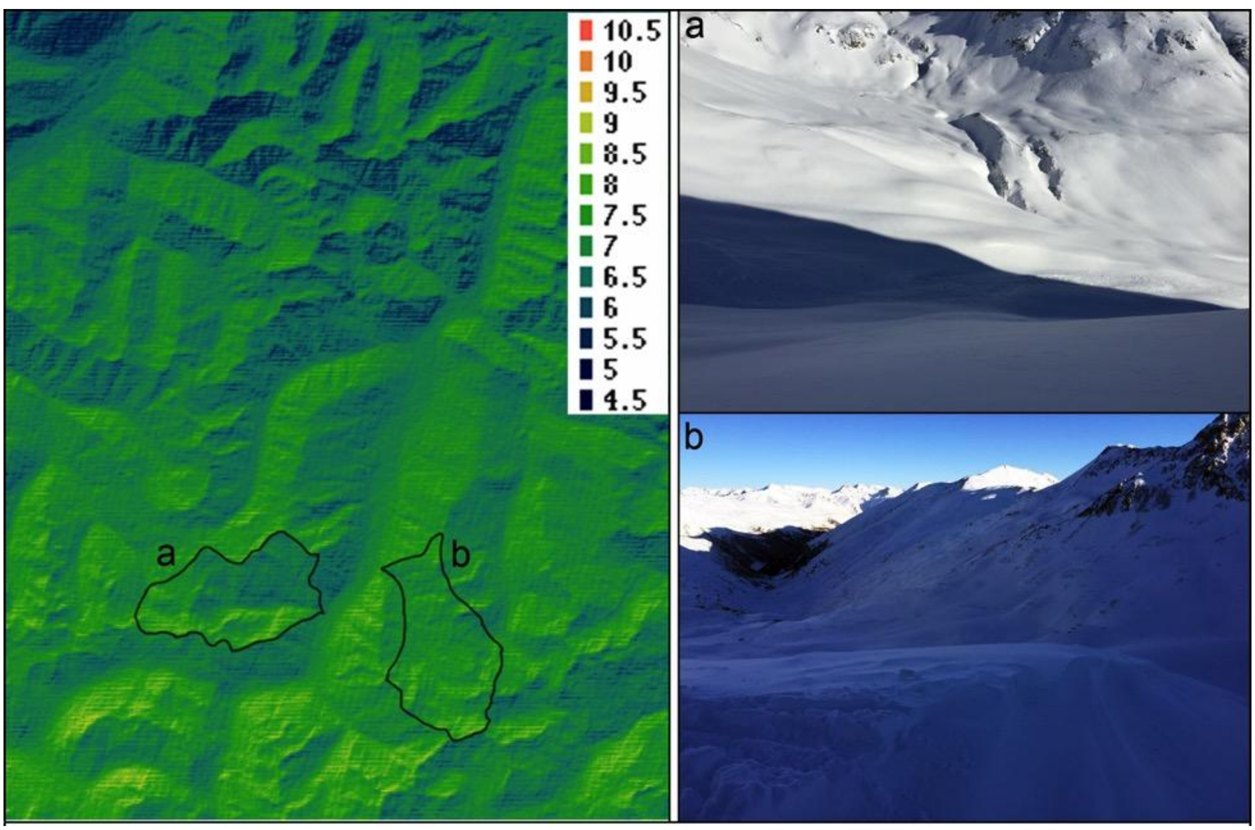

Fig. 4: Map showing the wind speed within the area of Livigno (expressed in m/s) for the 11 February 2016. The two highlighted areas (a,b) are normally used for heli-skiing activity. The picture of Valle del Monte (a) shows that snow drifting was not as high as in Valle delle Mine (b).

5. CONCLUSIONS

By combining manual and simulated data, the proposed approach increases the exploitation of already available information and helps both managing avalanche problems and understanding the local snow conditions.

We experimented it operationally for one winter season in Livigno (ITALY) for avalanche forecasting and risk management purposes. Its evaluation is only qualitative and requires more in depth analysis; however, its quality is strongly related to the quality of the input data and the capability to choose representative data only.

Coupling manual profiles with simulations turn them into a long-term source of information and reduce the subjectivity related to the forecast of their stability evolution.

Simulating the snow cover characteristics for virtual stations helps for better understanding differences within the area by neglecting effects related to other variables (e.g difference in elevation). This approach could even been used to fill gaps of data for AWS solving problems of possible lack of information.

Finally, spatially distributing weather data helps the practitioners for better evaluating the local conditions and can help professionals (e.g. mountain guides) not only for their safety management, but also for understanding where to find the best snow conditions.

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