

OPERATIONAL MODEL-BASED FORECAST OF WET SNOW AVALANCHE ACTIVITY: EXPERIENCES FROM TWO SEASONS

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ABSTRACT: The avalanche warning service of Styria (Austria) developed a model-based prototype warning system for the onset of wet snow avalanche activity and operates this system since winter 2016/2017. The system is based on the SNOWPACK model to describe the liquid water content in the snow cover, combined with an ensemble of high resolution numerical weather prediction models. This ensemble-approach takes into account the uncertainty in weather forecasts. To achieve a realistic initial state of the snow cover, the model system is constrained by observations as far as possible. After initialization, the system provides forecasts for up to three days. As indicator for instability, the liquid water content index by Mitterer et al. (2013) is used. This study describes recent advances in the implementation of the warning system and experiences from two years of operation. The results demonstrate that this model system can be a valuable tool in operational avalanche warning but still needs to be completed with additional information. Familiarity with the local conditions (i.e. the experience of the avalanche forecaster) and local snow height measurements are important sources of supplementary information.

KEYWORDS: avalanche forecast, wet snow avalanches, LWC_{index} , SNOWPACK

1. INTRODUCTION

Physical modeling still plays a surprisingly minor role in the operational assessment and forecast of avalanche danger (e.g., compared to weather forecast) and only few avalanche services intensively use physical based snowpack models for avalanche danger assessment. The avalanche warning service of Styria, Austria (<http://www.lawine-steiermark.at/>) started to develop a model-based forecasting system for the onset of wet snow avalanche activity in 2015 (Gobiet et al., 2016) and operates this system since winter 2016/2017. This paper gives an overview of the improvement of the model system since 2016 and analyzes its performance in the season 2017/2018 for a specific study region in the easternmost part of the European Alps.

2. METHODS AND STUDY REGION

2.1 Model System

The forecasting system consists of the physically based detailed 1-D snowpack model SNOWPACK in operational mode (Lehning et al., 2002a,b; Lehning and Fierz, 2008; Wever et al., 2015). It is driven by meteorological and snow

cover observations from the network of the Styrian Avalanche Service to enforce as much observational constraint on the model as possible. E.g., the snow height is kept at the observed value, which strongly reduces the long-term accumulation of errors and ensures an adequate initialization of the forecasts. Every six hours an ensemble of forecasts is started from the observationally constrained modelled snow profile with lead times up to 72 hours. Meteorological input is derived from a high resolution ensemble of numerical weather prediction (NWP) models. As indicator for wet snow avalanche activity, the LWC_{index} according to Mitterer et al. (2013) is calculated. This index is a measure of liquid water content in the snowpack and reaches the value 1, when the bulk liquid water in the snowpack exceeds 3% by volume. This threshold indicates the onset of gravitational water flow in the snowpack and observations have shown that it coincides well with the onset of wet snow avalanche activity. A more detailed description of this model system is given in Gobiet et al. (2016).

Since 2016, the model system has been extended to a rather large ensemble forecast, which aims to circumvent the numerous problems involved in deriving point-forecasts from NWP models. This approach is not focused on decreasing NWP model errors by post-processing techniques like model output statistics (MOS), but shows the entire range of possible future outcomes as far as possible by using as many different models as possible. Currently eleven different models (or members of a model ensemble) are implemented (e.g. Fig. 2). This model

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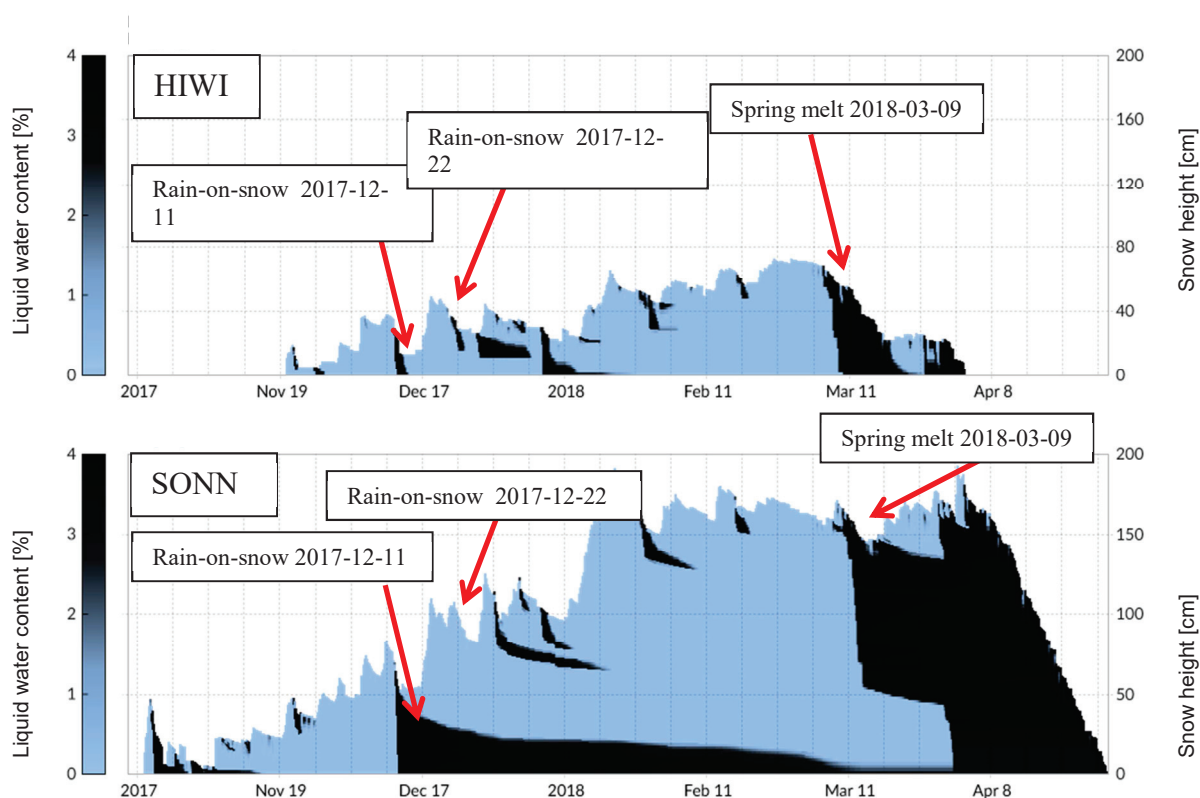


Fig. 1: Evolution of snow height (shaded, blue) and liquid water content (gray to black) during winter season 2017/18 at HIWI (upper panel) and SONN (lower panel).

system is currently operated at five stations in Styria. The number of Stations will be continuously increased in the coming seasons.

2.2 Study region

The study region is located along a road north of the Hochschwab Massive, following the Salza valley and adjacent side valleys. The road is affected by multiple avalanche tracks, especially in wet snow situations. Typical avalanche starting zones in the area range between 1000 – 1900 m a.s.l. Forecasts in this region are generated for two different automatic weather stations, one being located on a plateau of the Hochschwab Massive, named Sonnschienenalm (SONN, 1523 m a.s.l., 47.587 deg. N, 15.040 deg. E), the other in the valley bottom of Hinterwildalpen, a side valley of the Salza valley (HIWI, 802m a.s.l., 47.6414 deg.N, 14.9315 deg. E).

3. RESULTS AND DISCUSSION

3.1 Season 2017/2018 overview

A persistent snow cover in higher elevations (above 1500 m) of the study area developed from the beginning of November, in lower elevations and valleys from mid-November. Within the upper layers of the snowpack liquid water content > 3% occurred multiple times throughout the

winter season (Fig.1). Various rain events combined with mild temperatures occurred in December and January. Depending on the snow line, these events either led to increasing liquid water content within the snowpack or increasing snow height at higher elevations. In places with smaller snow height (Fig. 1, upper panel) the snowpack was able to recover from liquid water penetrations and refreeze (Fig.1, Rain-on-snow event 2017-12-11). In locations with more snow the snow water at the bottom of the snowpack remained liquid for the rest of the season, due to better insulation from the atmosphere (Fig.1, lower panel). The onset of spring in mid-March brought substantial melting within the entire snowpack (Fig.1, Spring melt 2018-03-09).

3.2 Melt event

A typical spring wet snow cycle took place between March 09th and March 11th, 2018 in the region around station SONN and HIWI in the Hochschwab Massive. Following some days with repeated precipitation and slowly rising temperatures, a low-pressure system south-west of the British Islands led warm and moist air masses into the region. The daily maximum temperatures at 1500 m increased from about 3°C to over 10°C. A step-wise increase of liquid water content during daytime was supported by partly cloudy or overcast conditions during the night, which prevented the snow surface from substan-

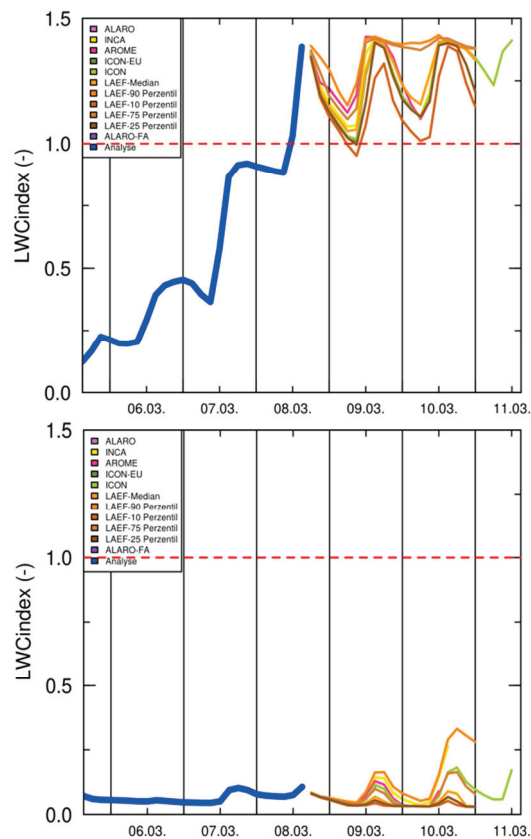


Fig. 2: Retrospective (blue) and prognostic (different forecasts colored) LWC_{index} at HIWI (upper panel) and SONN (lower panel) for a flat area.

tial cooling. Avalanche activity in the area was recorded from March 09th to March 11th.

Fig. 2 shows the retrospective and prognostic LWC_{index} at HIWI and SONN. The calculations were performed for a flat terrain. The LWC_{index} at HIWI (Fig.2, upper panel) rose to critical levels already on March 08th and was predicted to stay above 1 during the following avalanche cycle. Instead, at SONN (Fig.2, lower panel) the LWC_{index} only started to react to the rising temperatures on March 7th and should not reach values above 0.5 until the end of the period.

Divergent model output at the two stations is a result of the different local conditions at the station locations (altitude, shading). It nicely shows that the question of representativeness of the station for the local conditions at the avalanche paths is crucial and needs to be considered by the forecaster. Familiarity with the local conditions (i.e. the experience of the avalanche forecaster) and local snow height measurements are important sources of supplementary information. E.g. SONN recorded about 160 cm of snow before the melt event (Fig.1, lower panel). This is more than twice as much as measured at

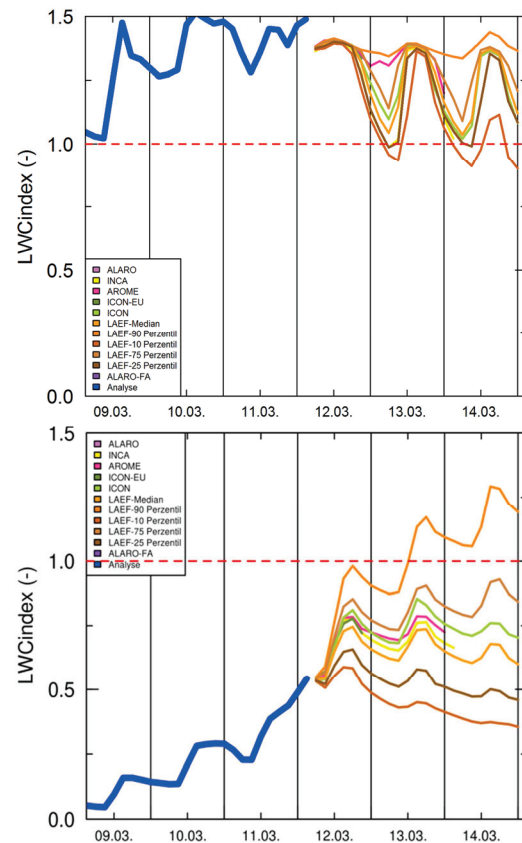


Fig. 3: Retrospective (blue) and prognostic (different forecasts colored) LWC_{index} at HIWI (upper panel) and SONN (lower panel) for a flat area.

HIWI (Fig.1, upper panel). As bulk liquid water content depends on the snow height, the LWC_{index} reaches higher values sooner, the smaller the local snow height (Fig.2).

Fig. 3 shows the retrospective calculation for the presented avalanche cycle together with further prognostic values. The ensemble predictions (Fig.2) for the avalanche cycle correspond well with the retrospective simulation (Fig.3) and predicted the main features of LWC_{index} evolution in both locations correctly. For this specific case ensemble members with higher prognostic LWC_{index} correspond best with the retrospective simulation. A closer investigation of specific ensemble members was not part of this study and could be included in future work.

However, simulations at both locations missed to predict the right day for the onset of the avalanche cycle. The spatial variability of local snowpack conditions is large. To obtain better results in future it is necessary to determine and investigate key parameters for the simulation of the LWC_{index} and to design strategies to adjust model input to the location of the avalanche paths of interest.

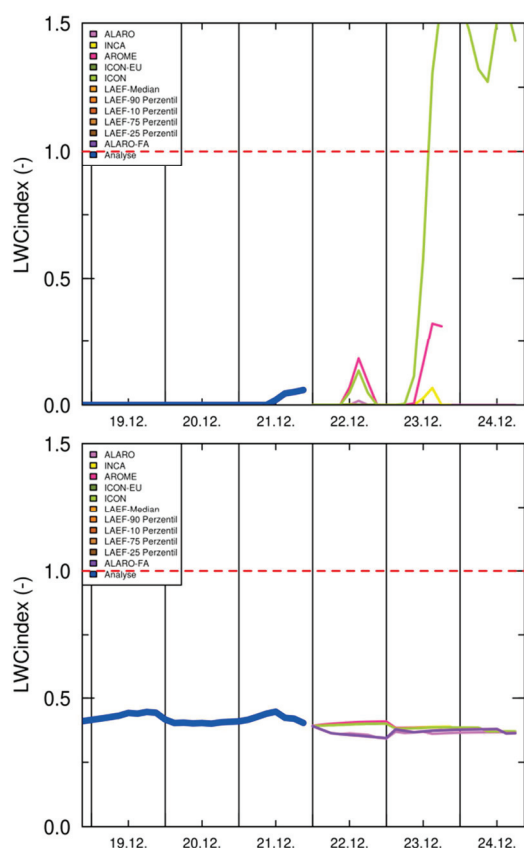


Fig. 4: Retrospective (blue) and prognostic (different forecasts colored) LWC_{index} at HIWI (upper panel) and SONN (lower panel) for a flat area.

3.3 Rain-on-snow event

A rain-on-snow event was observed on December 22nd, 2017 in the same region. After two overcast days with repeated, small snowfall events a warm front followed by strong winds from NW brought moist, atlantic air into the study region. Light precipitation lasted the entire day. The snowline was located between 800 to 1500 m. A couple of small wet snow avalanches were observed during afternoon of December 22nd.

The prognostic LWC_{index} at HIWI (Fig.4, upper panel) indicated a slight increase to approx. 0.2 in the early afternoon of December 22nd, just when the avalanches were observed. At SONN (Fig. 4 lower panel) the LWC_{index} was predicted to keep its level or even decrease in the course of the day.

The retrospective LWC_{index} for this day (Fig.5) corresponds well with the prognostic values in Fig.4. Measurements of snow height, temperature and precipitation (Fig.1) confirm snowfall at SONN while they indicate rain or at least wet snowfall at HIWI.

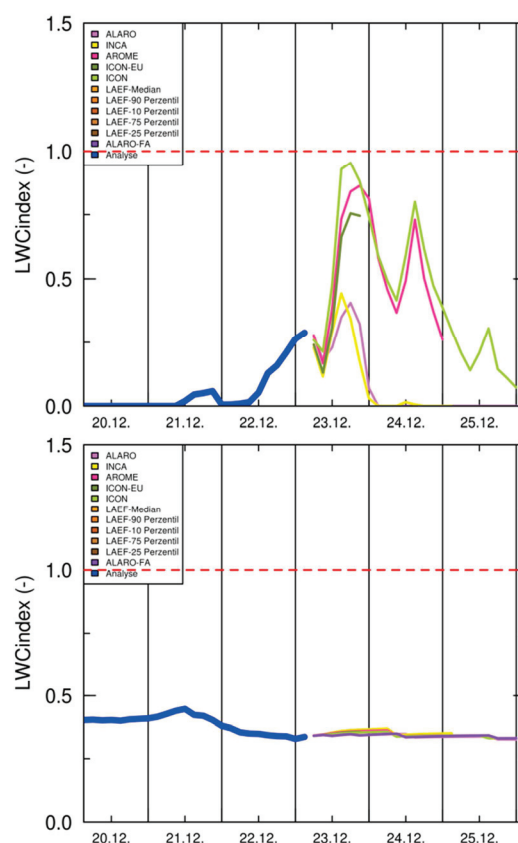


Fig. 5: Retrospective (blue) and prognostic (different forecasts colored) LWC_{index} at HIWI (upper panel) and SONN (lower panel) for a flat area.

Even though an LWC_{index} of 0.25 is far from critical, the simulation correctly predicted the increase in liquid water content at HIWI. An LWC_{index} of 1 was probably reached within the uppermost layer of fresh snow. For future applications a layer-by-layer calculation of the LWC_{index} would improve the performance of the warning system.

The high level of LWC_{index} at SONN even before the precipitation event (Fig 4, lower panel) is another interesting feature to point out. Investigations suggest that this is a relic of an earlier precipitation period, penetrating the entire snowpack (Fig.1, Rain-on-snow event 2017-12-11). During the following cold period the shallow snowpack at HIWI refroze while at SONN the temperatures could not penetrate through the entire snowpack and a moist bottom layer was conserved. The remaining liquid water in the bottom layer leads to higher LWC_{index} values.

This shows that the model successfully captures the different evolution of the snowpack at the two measurement locations and nicely exemplifies the importance of local snowpack and weather information as an ingredient for a successful simulation of the wet snow avalanche activity onset.

3.4 *Further events*

Another wet snow avalanche event (Fig 1. Rain-on-snow event 2017-12-11) showed a steep increase of the prognostic and retrospective LWC_{index} to values well above 1 due to warming and in a later phase of rain (not shown). Precipitation intensities were higher and liquid water penetrated deeper into the snowpack than in the event described in section 3.3. The LWC_{index} nicely indicated this event, but it was unclear, whether the avalanches were triggered due to rain or the preceding warming.

4. CONCLUSIONS AND OUTLOOK

The study demonstrated that observational constraints have a big influence on the model output. This demands strategies to adjust local measurements and NWP predictions to the exact location of interest. The investigation of key parameters that determine model simulation of liquid water penetration is a necessary next working step that provides a foundation for the adaption of model input to specific avalanche paths. Still, familiarity with the local conditions (i.e. the experience of the avalanche forecaster) will be necessary to interpret and utilize model outputs operationally.

Furthermore, forecasts of LWC_{index} based on this constrained modelling setup are a good indicator of liquid water content increase. Still, they are not yet reliable enough to use them as a single warning tool for wet-snow avalanches without considering additional factors. A calculation of the LWC_{index} layer-by-layer would provide valuable additional information about the structure and the conditions within the snowpack.

ACKNOWLEDGMENTS

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REFERENCES

- Gobiet A., Mitterer C., Jöbstl L., Steinkogler W., Rieder H., Olefs M., Studerregger A., Monti F., Bellaire S., 2016: Operational forecasting of wet snow avalanche activity: A case study for the eastern European Alps. Proceedings of the International Snow Science Workshop, Breckenridge, Colorado, 2016
- Lehning, M., Bartelt, P., Brown, R.L. and Fierz, C., 2002a: A physical SNOWPACK model for the Swiss avalanche warning; Part III: meteorological forcing, thin layer formation and evaluation. Cold Regions Science and Technology, 35(3): 169-184.
- Lehning, M., Bartelt, P., Brown, R.L., Fierz, C. and Satyawalli, P.K., 2002b: A physical SNOWPACK model for the Swiss avalanche warning; Part II. Snow microstructure. Cold Regions Science and Technology, 35(3): 147-167.
- Lehning, M. and Fierz, C., 2008: Assessment of snow transport in avalanche terrain. Cold Regions Science and Technology, 51(2-3): 240-252.
- Mitterer, C., Techel, F., Fierz, C. and Schweizer, J., 2013: An operational supporting tool for assessing wet-snow avalanche danger. In: F. Naaim-Bouvet, Y. Durand and R. Lambert (Editors), International Snow Science Workshop, Grenoble, France, 7-11 October 2013. ANENA, IRSTEA, Météo-France, Grenoble, France, pp. 334-338.
- Wever, N., Schmid, L., Heilig, A., Eisen, O., Fierz, C. and Lehning, M., 2015: Verification of the multi-layer SNOWPACK model with different water transport schemes. The Cryosphere, 9: 2271-2293.