Can near real-time avalanche occurrence data improve avalanche forecasting?

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ABSTRACT: Avalanche forecasting is by large data driven – and experience-based. Snow instability data, which are of crucial importance, are scarce and often not available in time, i.e. when the forecast is established. Besides signs of instability, such as whumpfs, that can easily be observed and transmitted by backcountry recreationists via smart phones, avalanche occurrences are generally reported inconsistently and too late to be considered for the forecast. However, information on avalanche activity provides unambiguous evidence of unstable snow conditions. In addition, these data are essential for developing statistical relations between meteorological data and avalanche formation. Whereas meteorological data are readily available with high temporal resolution – measured and modelled – the corresponding avalanche occurrence data are lacking. Based on two winters of seismic data from the Steintälli field site above Davos (Switzerland), we studied whether seismic monitoring provides precursory data for avalanche forecasting. Before periods of high wet-snow avalanche activity the waiting time between avalanches clearly decreased towards peak avalanche activity, suggesting that an early warning based on accurate and near real-time avalanche activity is possible. However, the same feature was not observed for periods when dry snow avalanches occurred – though they were generally less frequent. Of course, prerequisites for applying the waiting time approach as an operational early warning tool are near real-time data transmission and automatic signal detection.

KEYWORDS: snow avalanche, avalanche forecasting, avalanche occurrence

1 INTRODUCTION

Reliable forecasts require reliable precursors, i.e. data that indicate imminent danger (e.g. Schweizer, 2008). For predicting the release of snow avalanches, one often relies on the observed or forecasted amount of new snow. The success rate is rather limited, especially for local forecasts (e.g. Schweizer et al., 2009). In other materials, acoustic emissions (AE) have successfully been used as predictors of imminent failure (e.g. Michlmayr et al., 2012). However, the acoustic properties of snow complicate the applicability of AE for forecasting avalanches due to the strong attenuation of high frequency waves – despite encouraging exploratory results (Reiweger and Schweizer, 2013). So far, reliable precursors to avalanche release have not been observed (van Herwijnen and Schweizer, 2011a) even though previous studies indicated the potential of the method (Gubler, 1979).

In the absence of reliable, non-invasive, in-situ mechanical precursors from the snowpack associated with imminent slope instability, avalanche occurrence might offer an alternative means. Avalanches are commonly considered as the best predictor of avalanches – though one might obviously miss the first few avalanches. However, during periods of high natural avalanche activity, for example, during storms or melt periods, near real-time avalanche occurrence data would be invaluable. While the likelihood of increased avalanching is often obvious, for instance once about 50 cm of new snow have fallen, in most cases it remains uncertain whether many natural (spontaneously releasing) avalanches will occur. Due to limited visibility during the storm, the answer can usually only be given after the storm, when the danger has already decreased and the peak activity might have been missed. Similarly, during periods of increased meltwater production, it is often difficult to forecast the exact timing of a period of high wet-snow avalanche activity, although recent work now allows much better prediction of at least the onset (Mitterer et al., 2013).

Since visibility during periods of high wet-snow avalanche activity is generally good, time-lapse photography can be used to monitor wet-snow avalanche occurrences (van Herwijnen et al., 2013a). Alternatively, seismic or acoustic methods have been used to monitor avalanche activity (e.g. Lacroix et al., 2012; Navarre et al., 2009; Ulivieri et al., 2011). van Herwijnen and Schweizer (2011a) showed that many more avalanches can be detected by seismic monitoring than with visual observation and indicated the potential of the seismic method for avalanche monitoring.

Our aim is therefore to explore the potential of seismic monitoring to provide precursory data for avalanche forecasting. We focus in particular

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on whether avalanche activity increases slowly towards peak activity so that, given near-real time data transmission and analysis, the first few avalanches might serve as precursors for a period of high natural avalanche activity.

2 DATA AND METHODS

For two winter seasons (2009-2010 and 2010-2011), we collected seismic data with a string of geophones deployed in an avalanche starting zone above Davos, Switzerland (van Herwijnen and Schweizer, 2011b). As described by van Herwijnen and Schweizer (2011a), we manually identified avalanche signals in the seismic data (of one geophone only). During the winter 2009-2010 we detected 385 avalanches over a period of 108 days, while over a period of 138 days during the winter 2010-2011 we detected only 154 avalanches. Hence, avalanche activity was substantially lower during the second winter, which had below average snow depth. Overall, most recorded avalanches were small and occurred towards spring, suggesting that many were probably wet loose snow avalanches.

When analysing time series of extreme events, it is common practice to consider the waiting time (or return period), i.e. the time interval between recurrent events (von Storch and Zwiers, 1999). Faillettaz et al. (2011) studied the waiting time distribution of ice-quakes to predict glacier break-off. Our data obviously do not satisfy the standard assumption of a random variable. Observations are correlated and hence clustered. Depending on the type of clustering, the avalanche occurrence data might be suited as basis for an early warning system. We will therefore explore whether during periods of high avalanche activity, the waiting time between avalanches decreases. If a decreasing trend can be observed before the peak in avalanche activity, prediction might be possible. In other words, decreases in the temporal evolution of the waiting time indicate periods with several avalanches occurring within a relatively short time span. If for the calculation of the waiting time we consider the last 5, 10 or 20 avalanches, trends become more evident and the lead time increases, i.e. the time to peak avalanche activity once the decrease in waiting time reaches a critical value. A considerable lead time is crucial for the applicability as early warning method.

Besides the timing of the avalanches, we also recorded seismic signal duration. Signal duration is expected to be related to avalanche length. In fact, van Herwijnen et al. (2013b) showed that avalanche length is proportional to the square of seismic signal duration. Considering the Canadian size classes (McClung and Schaerer, 2006), avalanche length can be related to avalanche size. If avalanche size is known, the avalanche activity index (AAI) can be calculated as suggested by Schweizer et al. (1998). The index assigns a weight depending on size; the weights are 0.01, 0.1, 1 and 10 for the sizes 1 to 4, respectively. If to each avalanche size a typical length is assigned, the weights and hence the AAI can be calculated from avalanche length. We assumed for the size classes 1, 2, 3, and 4, typical length of 50 m, 250 m, 500 m and 2000 m, respectively. This implies that avalanche size is roughly proportional to the square of avalanche length. Combining the two relations, we calculated the avalanche activity index for each single avalanche from seismic signal duration t: AAI = $4 \times 10^{-8}\, t^{3.8}$. For the region of Davos we calculated the avalanche activity index based on visual observations according to Schweizer et al. (2003).

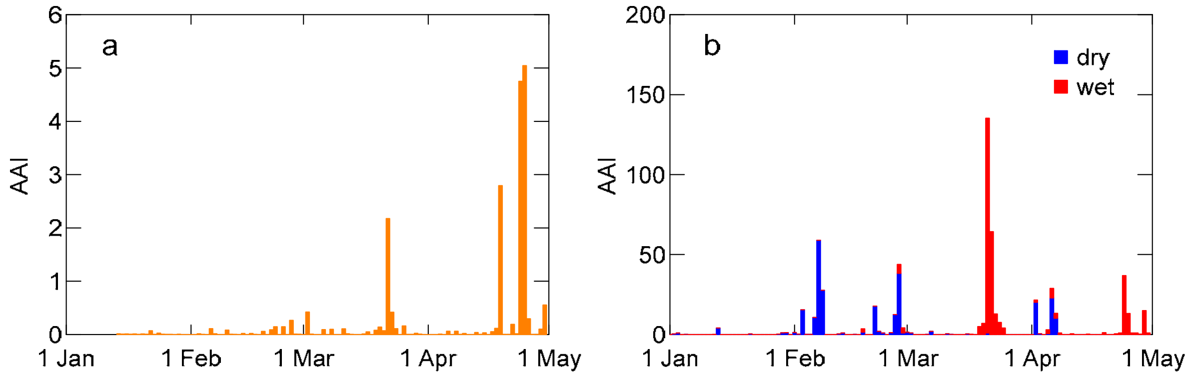

Figure 1. Avalanche activity index (AAI) for (a) the Steintälli basin (seismic monitoring) and (b) the region of Davos (conventional visual observation) for the winter 2009-2010; for the visually observed avalanches the avalanche type (dry or wet) was recorded and the AAI was calculated separately for dry and wet snow avalanche activity.

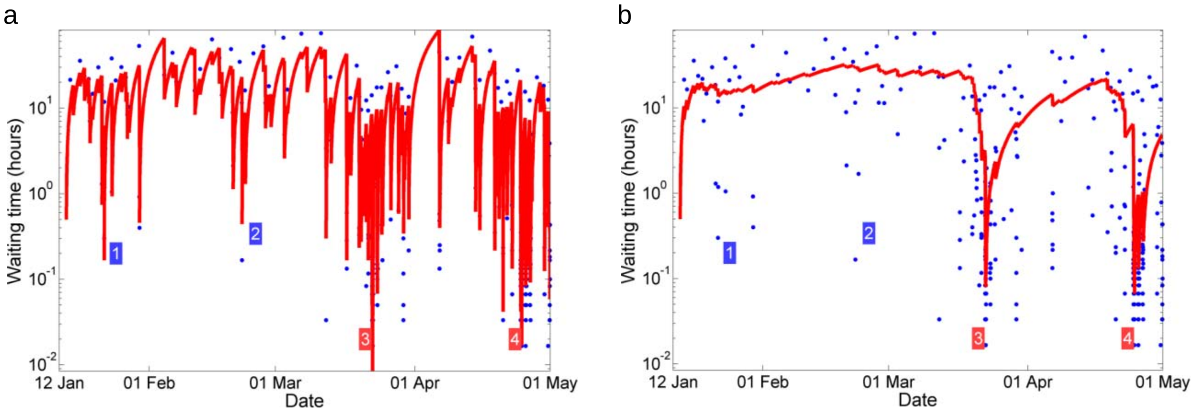

Figure 2. Waiting time (blue dots) and average waiting time (red line) for avalanche occurrence data of winter 2009-2010, (a) if only the previous two events are considered; (b) averaging over the last 20 waiting times; numbers (1 to 4) indicate avalanche periods (see text).

3 RESULTS

Not only were there fewer avalanches in the winter 2009-2010 than in 2010-2001, the avalanche activity index was also substantially lower. Avalanche activity observed in the small study basin compared well with avalanche activity in the entire region of Davos observed through conventional visual observations (Figure 1). Despite the small area covered by the seismic monitoring system, about 2 km^2 (compared to about 50 km^2 for the region of Davos), many of the major avalanche periods were detected, in particular the periods of wet snow avalanche activity in the second half of March and April 2010. The seismic system did hardly record any avalanches during the dry snow avalanche period of 6-7 February 2010. Interestingly, the peak in activity for the visually observed avalanches was recorded on 7 February, whereas the seismic system indicated the peak on 6 February 2010. The storm arrived on 5 February in the evening and lasted until about 7 February at noon. Most of the snow fell until 6 February at noon – suggesting that some of the avalanches observed at 7 February when visibility improved might have occurred the day before.

Avalanche occurrence data can serve as precursor if the time between two subsequent avalanches decreases towards peak activity. On average, the waiting time was about 7 hours. However, the waiting time strongly varied and the distribution was strongly not normal, but bimodal, with a peak at about 10 minutes and a secondary peak at about 20 hours. In other words, the time between two events was 10-20 hours during ‘quiet periods’, but often considerably less than 1 hour in ‘active’ periods (Fig. 2). During the dry-snow season up to mid March, there were periods of increased activity in the second half of January and near the end of February 2010 (1 and 2 in Fig. 2). However, avalanche activity was not high enough and the waiting time did not sufficiently decrease towards a peak (Fig. 2b) in order to be useful for forecasting. In contrast, there were two periods of high wet-snow avalanche activity (3 and 4 in Fig. 2). Both could have been well predicted by the consistent decrease in waiting time that started several days before the peak activity.

During winter 2011-2012 less avalanches occurred, but essentially the same features as in the previous winter were observed. Only periods of high wet-snow avalanche activity existed. Dry-snow avalanches were relatively rare and not sufficiently concentrated within a short period of time. Consequently, the avalanche occurrence data was not suited as precursor information – in contrast to the periods of high activity in the spring.

4 CONCLUSIONS

For avalanche forecasting, avalanche occurrence data are highly-prized class I data (McClung and Schaerer, 2006). Besides signs of instability such as whumpfs or shooting cracks, recent avalanching provides direct evidence on the state of the snowpack: avalanches are the best indicators of avalanches. This is particularly true for periods when many natural avalanches release, for example during storms or melt events.

We therefore explored two winters of avalanche occurrence data collected with a seismic sensor in a small basin above Davos Switzerland in view of its suitability as precursor – in the realm that avalanches are the best predictors of avalanches. Before periods of high wet-snow avalanche activity the waiting time between avalanches clearly decreased towards peak avalanche activity, suggesting that an early warning based on accurate and near real-time avalanche activity is possible. However, the same feature was not observed for periods when dry snow avalanches occurred – though they were generally less frequent.

The waiting time approach can only be used as an operational early warning tool, if the data can be transferred in real-time and the signal detection can be automated (Rubin et al., 2012), i.e. that avalanche signals can reliably be distinguished from other source that generate seismic signals.

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