mAVALANCHE – SMART AVALANCHE FORECASTING WITH SMARTPHONES

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ABSTRACT: The common information channels through which the avalanche warning service in Switzerland acquires information include a network of automated weather and snow measurement stations and stationary observers. In the winter of 2008/09, an additional mobile observation network, called mAvalanche, was initiated. mAvalanche provides software for advanced mobile phones which allows sending georeferenced on-site observations directly from the field to the avalanche warning service. Here we present data from a two-year pilot phase during which a group of about 20 mountain guides used mAvalanche. The spatial and temporal distribution of the totally 928 observations showed a significant increase in the mean altitude of the observations after mid-March, which reflects the preferences of backcountry skiers who aim at high-altitude regions in spring. In 73% of all mAvalanche observations, the estimations for the current avalanche danger were in accordance with the danger level forecasted by the avalanche warning service. In 21% of the observations, the mAvalanche observers considered the avalanche danger to be lower than the forecasted level, in 6% higher. The types and frequencies of deviations from the forecasted danger level did not differ significantly between the two winters, indicating that the number and quality of observations is sufficient to provide reliable and consistent information. Conclusively, mAvalanche proved to be a valuable tool for providing additional information to the avalanche warning service.

1. INTRODUCTION

Avalanche forecasting in Switzerland is based on a variety of resources to acquire information about snow conditions. A major part of the information is provided by high-alpine automated weather and snow measurement stations. Since 1996, the WSL Institute for Snow and Avalanche Research SLF together with the cantons of Switzerland established a network of more than 100 of these stations to enhance the existing network of measurement stations of the national weather service (MeteoSwiss). The hourly and half-hourly measurements of the stations have proven highly useful in avalanche forecasting (Russi et al. 1998, Rhyner 2002). While the automated weather stations are perfectly suited for measuring parameters like the amount of new snow or air temperature, they are not able to provide information about more complex parameters like recent avalanche activity. Hence, man-made field observations are still an essential source of information for the avalanche forecasters. For this reason, the SLF employs around 150 part time observers who perform various measurement programs each morning during wintertime. Besides measuring key weather and snow characteristics, the observers report on released avalanches, alarm signals and their assessment of the current avalanche danger. Most of the observers are stationary, which means that their observations are done each day at the same location. This guarantees continuity and comparability of the data over the years, which is important for climatologic research and other scientific topics. Despite this fine-meshed network of observers and weather stations, there is a lack of information for several high-elevation regions. Most of the stationary observers are located in the lower parts of mountain regions. As soon as these locations become snow-free in spring, the observation reports are ceased even though there might still be substantial amounts of snow in the higher parts of the corresponding areas. This problem increases in late spring when backcountry skiers aim at exactly these higher parts of the mountains and expect detailed forecasts from the avalanche warning service.

To cover this gap of information for high-elevation regions, the SLF offers online feedback forms through which people can report their on-site observations from the field, including characterizations of snow conditions, avalanche observations and estimations of the avalanche danger. These questionnaires are public and are thus used by individuals with different backgrounds, experience and knowledge. This makes it difficult to assess the quality of information in the feedback forms. Therefore, the avalanche forecasters prefer feedback from people of which they know that they have a sound background in avalanche topics, e.g. mountain guides. Due to their professional education and

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experience in avalanche terrain, mountain guides are able to collect particularly high-quality information. However, since they cannot fill out the online questionnaire until they have returned to the valley with their clients, their feedback often arrives too late in the day at the avalanche warning service (Suter 2010). The avalanche forecasters need the information before 2 pm in order to include it in the decision process for the avalanche bulletin of the next day.

2. mAVALANCHE

The SLF addresses this problem with the project mAvalanche. mAvalanche provides software for advanced mobile phones (e.g. iPhone or Windows mobile smartphones) which allows mountain guides to send georeferenced on-site observations directly from the field to the avalanche warning service. The integrated GPS automatically detects the current position and provides the avalanche forecasters with the exact coordinates of the observation. Mountain guides benefit from mAvalanche by getting access to local weather forecasts, data from automated weather stations and the avalanche bulletin. Additionally, mAvalanche offers access to the 1:25'000 map of Switzerland which allows the guides to check their current position. Furthermore, the mountain guides get paid for each observation.
During the last two winters, mAvalanche was tested extensively by a group of mountain guides and the avalanche warning service, resulting in approximately 1000 feedback messages. In the first winter (2008/09), ten mountain guides participated. In the second winter (2009/10), the number increased to fifteen. At the end of both test phases, mAvalanche was evaluated with a questionnaire. The strongest point of criticism after the first test phase related to the cell phone which was a Windows mobile based phone. Both the battery capacity and the usability of the operating system were not satisfactory to the users. Therefore, mAvalanche was ported to the iPhone system for the winter 2009/10 which improved its usability substantially. Furthermore, the input form of mAvalanche was revised for the second test phase to better balance the needs of detailed data acquisition and user friendly data input. The actual version of the input forms is classified into four characteristic avalanche patterns: i.) new snow, ii.) drifting snow, iii.) wet snow, and iv.) snowpack. In a first step, the mountain guides specify the most dominant pattern. In a next step, they are guided through a set of detailed questions that relate specifically to the pattern they have selected before. In a last step, the mountain guides enter their estimation of the current danger level and the trend for the next day, including the corresponding exposition and altitude. This new approach of structuring the input forms based on characteristic avalanche patterns proved very useful. It reduces the time and effort to complete the form but still guarantees that all relevant information is collected. Since it is not possible to cover all possible circumstances with a standardized set of questions, mAvalanche contains an input field for additional comments.

2.1 Use of mAvalanche

During the last two years, mAvalanche proved to be a valuable tool for providing additional information to the avalanche warning service. Both the avalanche forecasters and mountain guides appreciate the bidirectional exchange of information through mAvalanche. Thus, the SLF decided to use mAvalanche as a productive system in order to complement the existing data channels through which the avalanche forecasters receive information on snow conditions.
A particular advantage of mAvalanche is that most of the observations refer to areas, which are frequently visited by backcountry skiers. Furthermore, the observations often relate to the decrease from the danger level 3 (considerable) to the level 2 (moderate), which covers the typical range of conditions for backcountry and off-piste skiing.
In order to make optimal use of the mAvalanche observation network and to further improve its performance, it is necessary to critically assess the content and quality of the observations. In the present study, we analyzed the spatial and temporal distribution of the observations from the two-year test phase and compared the mAvalanche observations with the forecasted avalanche danger of the bulletin and the observations of the regular stationary observers. In particular, we addressed the following questions:

a) Does the spatial and temporal distribution of the mAvalanche observations reflect the characteristic patterns of backcountry skiing activity?

b) To what extent do the mAvalanche observations agree or disagree with the forecasted avalanche danger level of the bulletin?

c) Are mAvalanche observations consistent over the two winters of the test phase?

3. RESULTS

Since the first mAvalanche observation in mid-December 2008, a total of 928 observations were made over the two winters of the test phase. Among the 32 different mAvalanche observers, the number of people making more than 15 observations per winter increased from 9 in the winter 2008/09 to 15 in the winter 2009/10. The most active observer made 148 observations over the whole test phase.

3.1 Spatial and temporal distribution of observations

The mAvalanche observation network covers all the main regions of the Swiss Alps. Figure 1 shows the locations of all observations that were made over the two-year test phase. Based on the numbers of observations per unit area, we calculated the density of observations, as represented by the colour density in the map. A particularly high density of observations was found in the region of St. Antönien and Davos, a region in the eastern part of Switzerland which is very famous for backcountry skiing and freeride activities. Other typical ski touring areas are covered (e.g. Furka, Sustenpass and Wallis). However, a rather low density of observations was found in the Bernese Alps, especially in the higher parts around Finsteraarhorn.

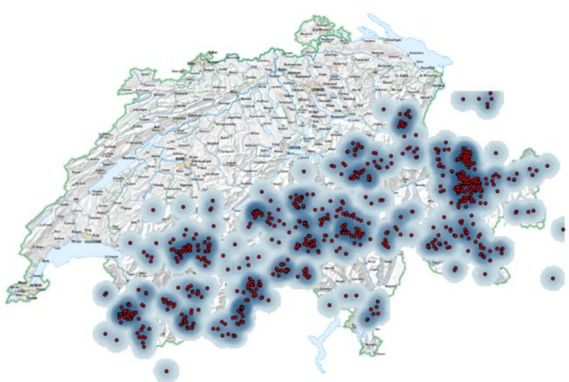

Figure 1: The locations of all observations that were made over the two-year test phase.

In Figure 2 the frequency of mAvalanche observations over the two winters is shown. In the winter 2008/09, the frequency was highest in January. Between February and March, there was no considerable difference in the observation frequency. In mid-April, the observation frequency started to decrease with time. The last mAvalanche observation was made on May 29. In the winter 2009/10, the observation frequency strongly increased from mid-January to mid-March. Here it is important to note that at the end of January, an iPhone version of the mAvalanche application was released and therefore mountain guides with iPhones could not send any observation data until end of January. The maximum of observations at one day was reached on March 10 with 13 different observations.

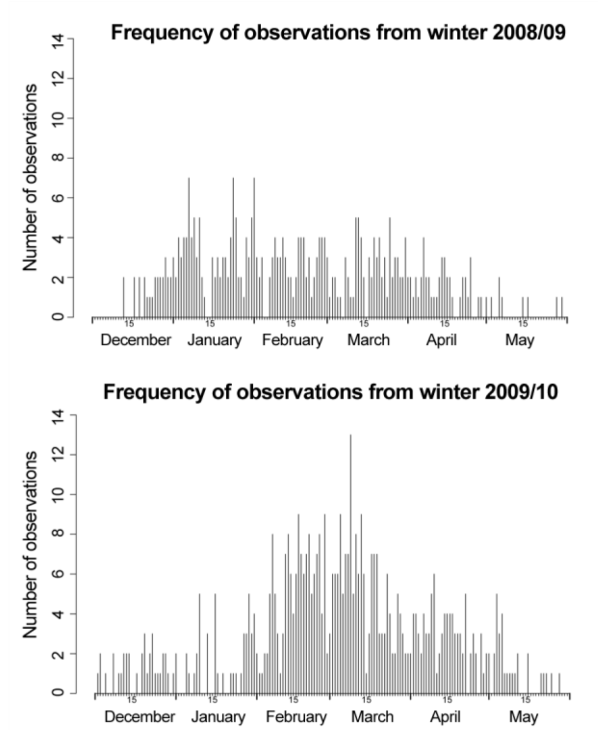

Figure 2: The frequency of mAvalanche observations over the two winters.

To detect seasonal trends in the altitude of

Table 1: Number of mAvalanche observations and of the corresponding observations from stationary observers for the 4 combinations of danger level 2 and 3 (sum of winter 2008/09 and 2009/10) .

Danger Level Bulletin	Danger Level mAvalanche resp. observers	Frequency mAvalanche both winters	Frequency observers both winters	p-Value of proportional-test
3	2	100	81	0.002
2	3	28	42	0.528
2	2	211	281	0.457
3	3	237	363	0.003
Total of all observations		689	864	

mAvalanche observations, we fitted a loess model to the average altitude of the observations per day (Figure 3). This analysis was restricted to observations that were made at the highest point of the corresponding backcountry tour. In the first months of the winter, there was no significant trend in the altitudinal distribution of the observations. After mid-March, however, a significant increase in altitude was detected. The highest observation was made at an altitude of 4430 m a.s.l. near the highest point of Switzerland.

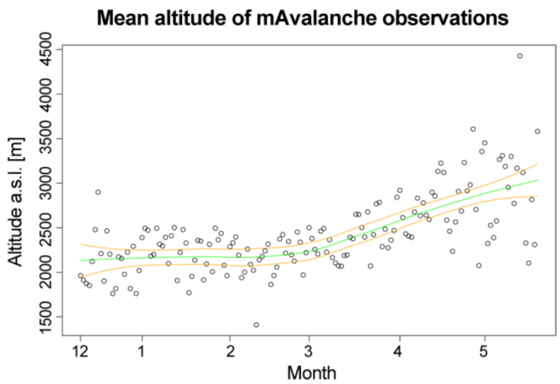

Figure 3: Loess curve fitted to the daily mean altitude of mAvalanche observations (highest point of the corresponding backcountry tour). Green line: fitted loess curve. Orange line: upper and lower 95% confidence interval of the loess fit. From mid March onward the fitted altitude is significant higher than in the months from December to February.

3.2 *Comparison with avalanche bulletin and stationary observers*

An essential task of mAvalanche observers is to make an estimation of the current avalanche danger according to the five levels of the European danger scale. The forecasting area of the Swiss Alps is split into 120 small areas. For each of these areas the SLF forecasts a danger level. This danger level was compared with mAvalanche observations and stationary observations only on days where both kinds of observations were available. During the two winters of the test phase, there were no mAvalanche observers reporting estimations above danger level 3.

In 73% of all mAvalanche observations, the estimations for the current avalanche danger were in accordance with the danger level forecasted by the avalanche warning service. In 21% of the observations, the mAvalanche observers considered the avalanche danger to be lower than the forecasted level. In 6% of the cases, they considered it to be higher than the forecasted level. The most frequent type of deviation was that the mAvalanche observers estimated the avalanche danger to level 2 when the forecasted danger was on level 3. This situation occurred in 29% of the observations made on days with the forecasted danger being on level 3 (Figure 4). The strongest deviation of a single observation was found on a day when the forecasted avalanche danger was on level 4 (high) and a mAvalanche observer estimated level 2 (moderate). It has to be considered, that the danger level 4 was a forecast made on the day before. In the bulletin issued on the day of the mAvalanche observation, the danger level has been downgraded to level 3, which reduces this deviation. However, avalanche danger seems to have decreased faster than forecasted in the bulletin.

When comparing the mAvalanche observations with the observations of the regular stationary observers, we found several differences and similarities with regard to the types and absolute frequencies of deviations from the forecasted avalanche danger. On days with the forecasted avalanche danger being on level 3, the proportion of observations estimating level 2 to the total frequency of observations was significantly higher for the mAvalanche observers than for the regular stationary observers (p-value of the proportional test is 0.002, Table 1). The proportion of higher estimations than the forecasted danger was the same for mAvalanche observers and for stationary

Table 2: Frequencies of mAvalanche observations of forecasted and assessed danger levels 2 and 3. The p-values result from tests of equal proportions between the number of observations for a given danger level combination and the total amount of observations per year.

Danger Level mAvalanche	Danger Level Bulletin	Frequency 2008/09	Frequency 2009/10	p-Value of proportional-test
2	2	88	123	0.72
2	3	38	62	0.33
3	2	8	20	0.16
3	3	96	141	0.39
Total of all mAvalanche observations		296	393	

observers (p-value = 0.528, Table 1). The proportion of frequencies of observations that accorded to the forecasted avalanche danger did not differ significantly between mAvalanche observers and stationary observers at danger level 2 (p-value of 0.457, Table 1), whereas for danger level 3 it did (p-value of 0.003, Table 1).
The relative frequency of mAvalanche observations that deviate from the forecasted avalanche danger did not differ significantly between the two winters of the test phase. Tab. 2 shows the results from tests of equal proportions between the number of observations for a given danger level combination and the total amount of observations per year.

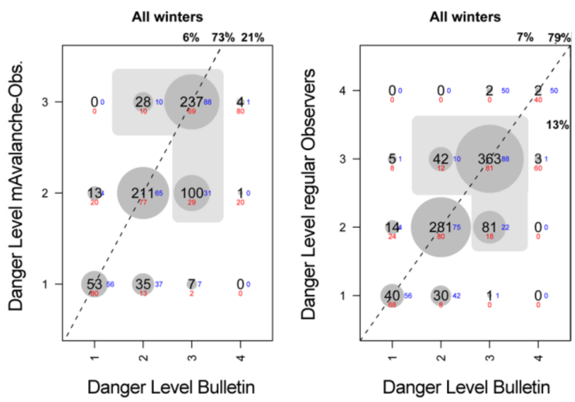

Figure 4: Frequencies of forecasted and assessed danger levels for winter 2008/09 and winter 2009/10. Left graph: mAvalanche oberservers and bulletin. Right graph: stationary observers and bulletin. The size of the circles is proportional to the frequency. The dotted line shows the diagonal of equal danger levels. Red numbers: Conditional frequencies of assessed danger levels in percent given a forecasted danger level by the bulletin. Blue numbers: Conditional frequencies of forecasted danger levels from the bulletin in percent given an assessed danger level from the observers.

4. DISCUSSION

4.1 Spatial and temporal distribution of observations

An important criterion for selecting mAvalanche observers was to obtain a representative coverage of the Swiss Alps. The spatial distribution of the mAvalanche observations indicates that this goal was achieved successfully. According to Figure 1 mAvalanche observations are widely spread over the Swiss Alps. However, low mobile network coverage seems to impede mAvalanche observations in some parts of the Swiss Alps. This may explain at least partly the low density of mAvalanche observations in the higher parts of the Bernese Alps. Backcountry skiers choose their destination areas based on various criteria such as the local avalanche danger, snowpack quality, season and weather. In the course of a winter season, this results in typical spatial patterns of backcountry skiing activity. The mAvalanche observation network is expected to reflect these patterns, since the mountain guides participating in the network choose areas that are interesting for backcountry skiing and are not bound to a specific location as the stationary observers. The observations of the two-year test phase suggest that mAvalanche does indeed adaptively provide information from areas of high backcountry skiing activity. Evidence for this is found when looking at the seasonal trends in altitude distribution of observations, and the preferential occurrence of the danger levels 2 and 3, as discussed in the following two paragraphs.
From December until March, the mean altitude of observations was 2100 m a.s.l., which corresponds approximately to the mean altitude of the automated measuring stations. After mid-March, however, the mAvalanche observers moved to higher regions. Thus, the mAvalanche observations help to reduce the lack of information about high-altitude regions in late winter and spring.
The avalanche danger levels to which the observations refer to cover the typical range of conditions that are most relevant with regard to backcountry skiing. There was no mAvalanche

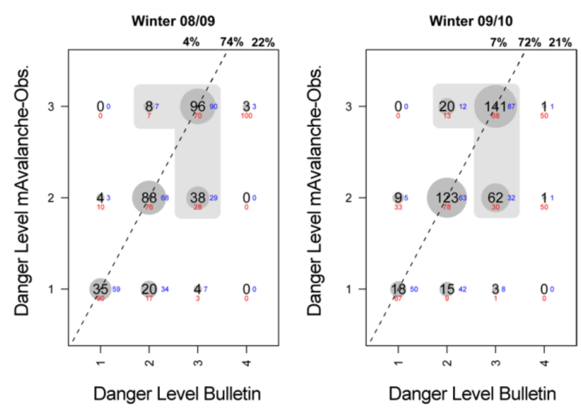

Figure 5: Frequencies of forecasted and assessed danger levels. Left graph: mAvalanche oberservers and bulletin for winter 2008/09. Right graph: mAvalanche oberservers and bulletin for winter 2009/10. The size of the circles is proportional to the frequency. The dotted line shows the diagonal of equal danger levels. Red numbers: Conditional frequencies of assessed danger levels in percent given a forecasted danger level by the bulletin. Blue numbers: Conditional frequencies of forecasted danger levels from the bulletin in percent given an assessed danger level from the mAvalanche observers.

observation with an estimated danger level higher than 3, indicating that the mountain guides choose a less dangerous region if the avalanche danger is too high.

4.2 Comparison with avalanche bulletin and stationary observers

In 21% of the mAvalanche observations, the estimated avalanche danger was lower than the forecasted danger level. Most of these deviations were found when the forecasted danger was on level 3 (considerable). In this case, 29% of the mAvalanche observers and 18% of the regular stationary observers estimated the danger level to be lower than 3. This shows that given a danger level 3 in the bulletin, mAvalanche observers assess the danger being level 2 more often then stationary observers. An unpublished SLF-survey among bulletin users also shows that alpinists with high avalanche knowledge tend to estimate the danger lower than the bulletin.

The winters 2008/09 and 2009/10 were quite different with regard to the avalanche danger patterns. In the winter of 2008/09, periods of intensive snow fall alternated with long periods of dry high-pressure weather (Stucki et al. 2010) New snow and wind-deposited snow were the main hazards. In the winter of 2009/10, however, the main problem was a weak snow pack with deep instabilities due to repeated small snowfall events (Etter et al. 2009). Despite these differences between the two winters, there were no significant differences in how the mAvalanche observations deviated from the forecasted avalanche danger levels (Table 2, Figure 5). This indicates that the number and quality of observations is sufficient to provide reliable and consistent information. However, these issues need to be further investigated in the future.

5. OUTLOOK

After a two-year test-phase, we are able to make first conclusions about the possibility of mAvalanche as an addition to the regular observation network. The system is widely accepted by the mountain guides and it delivers useful information for the avalanche forecasters. However, the daily amount of mAvalanche observations did not exceed an average of 4, and therefore, mAvalalanche has to be considered as an additional source of information for the three lower danger levels rather than a comprehensive observation network. For the upcoming winter, we further improved the input forms of the mAvalanche application, aiming at a reasonable compromise between detailed information acquisition and low effort for entering data by the observers. More than twenty mountain guides will make mAvalanche observations using iPhones. We expect to obtain even better information about the snow conditions in areas of high backcountry skiing activity. In the near future, mAvalanche will be an inherent part in the forecasting process at the SLF.

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