Technical note

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Monitoring snow avalanches in Grasdalen using an infrasound array

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Review and reference page

1 Introduction

The absence of near real-time information about the avalanche activity is a significant challenge for local avalanche forecasting (Schweizer and van Herwijnen 2013). Information about avalanche activity in neighboring paths (“indicator avalanches”) can be critical in understanding the current snow-stability conditions and for evaluating past bulletins (Kristensen 2016). Reliable systems for automatic monitoring of avalanche activity that can supplement visual observations are desirable for event verification and as input for operational forecasting.

An infrasound detection of avalanches (IDA) array was maintained in Grasdalen between October 2014 and spring 2019 (Humstad et al. 2016). IDA system is based on technology developed by iTem and Laboratorio di Geofisica Sperimentale of the University of Florence, Italy (Ulivieri et al. 2012). The system is commercialized in Norway by Wyssen Norge AS, which is a subsidiary of Wyssen Avalanche Control AG in Switzerland. The project has been run as a collaboration between the Norwegian Public Roads Administration (NPRA), Wyssen, and NGI.

The IDA array was positioned in Grasdalen (Location 1, 61.9792 °N, 7.2902 °E) between autumn 2014 and spring 2017. From autumn 2017 to spring 2019, the IDA system was repositioned near to Oppljostunnelen (Location 2, 61.9925 °N, 7.3146 °E). The system was moved to a location further up the valley because of better relevance to the forecasting operation and easier visual observations and maintenance during the winter season. Following relocation to location 2, the detection array was modified by Wyssen with five new sensors, better sound isolation and improved GPS equipment. The array locations are marked in Figure 1.

The objectives of this study are: (1) to evaluate the application of the IDA system in Grasdalen, (2) relate infrasound observations to local weather condition, and (3) to evaluate the use of the infrasound monitoring system in the operational avalanche forecasting conducted by NGI.

2 Partnership background & rationale

The infrasound avalanche detection system was first installed in Grasdalen in October 2014 by the Norwegian Public Roads Administration (NPRA) to test the feasibility of continuous avalanche monitoring. The NPRA had initially decided to discontinue the monitoring program in Grasdalen after the 2015–2016 season and to remove the infrasound detection system. Following a partnership proposal from NGI, it was decided to continue the research program for two more seasons.

During fall 2017, the system was moved to a location further up the valley because of better relevance to the forecasting operation and easier visual observations. The detection system was modified by Wyssen with five new sensors, better sound isolation and improved GPS equipment. During the winter 2017/2018, technical problems led to long periods of downtime. To make up for this, Wyssen offered to leave the system operational in Grasdalen also in the winter 2018/2019 at no additional cost.

According to a preliminary summary of the experiences during the winter 2018 by SVV and Wyssen (Minutes of meeting on 2018-10-23, by T. Humstad, NPRA), the main problems encountered in Grasdalen were the following:

- One of the sensors was mounted too close to the road, so that it was repeatedly covered with snow from the snow ploughs, which then turned into ice. During the summer 2018, the sensor was moved 10 m away from the road.

- It appears that the lid on one of the sensors was too tight, providing insufficient contact with the atmosphere.

During the winter 2018/2019, the measurements were continued with these two problems eliminated. Whenever the system detects an avalanche, it will alert all subscribed users by SMS within two minutes after detection. The data processing routines are improved to provide better insight about the quality and reliability of automated avalanche detection. At the same time, NGI's crew providing local avalanche forecasting for this area will be able to assess the utility of this extra information.

3 Infrasound results

Filtering of infrasound data and classification of avalanche events has been the subject of several publications, including Bedard (1994), Ulivieri et al. (2011), Schimmel et al. (2017), and Mayer et al. (2019). Typically, the criteria used to identify avalanche events includes the signal duration, peak amplitude, and thresholds related to the kinematics defining the degree of migration of the signal source (i.e. the avalanche). The infrasound waves produced by snow avalanches typically persist for 15 seconds or more and migrate over time. Avalanches can thereby be distinguished from explosions or background events – which are typically of shorter duration or originate from a static point. In this case, processing of the infrasound data (filtering and classification) was done by Wyssen. Events were classified into three types – high reliability, low reliability, or explosions – based on the degree to which the criteria were met (see Marchetti et al. 2015 for threshold criteria).

The number of detections and back azimuth directions are indicated in Figure 1. The temporal distribution of infrasound detections for four winter seasons (2015-2019) is presented in Figure 2. Snow depth is measured near the Fonnbu station ca. 1 km north of Location 2.

57 high-reliability events and 55 low-reliability events were recorded while the station was positioned at location 1. High-reliability events originated mostly from Grasdal Vest. High- and low-reliability detections are from this direction are likely to be

avalanches given the topography in the sector. It is less certain what factors are registering as low-reliability events along the valley axis. Possible agents may include distant avalanches or traffic noise. In addition, 13 explosions (avalanche control) were recorded on three separate days in the direction of the Ryggfonn test site.

Following the repositioning of the array to location 2, the IDA system registered 11 high-reliability events (Fall 2017 – Spring 2019). The back-azimuth values from these events point to infrequent avalanches in the following areas: Grasdal aust, Oppljostunnelen vest, and Kvitenova. Low reliability (n = 29) events commonly point towards the southwest and may be caused by smaller avalanches or traffic noise near the entrance to the Grasdal tunnel. 21 detonations were recorded. Detonations were avalanche control conducted by the NPRA. Avalanches triggered by detonations were commonly confirmed by observations from NGI's automatic camera located near Fonnbu. Natural avalanches detected by the array frequently occurred during periods of low visibility either due to heavy snow fall, drift, or darkness. It was therefore not possible to confirm the high reliability detections using this camera.

The infrasound array was not operational for a portion of the avalanche seasons between 2014 and 2016 (Humstad et al. 2016). It is unclear when the station was operational in the 2016-2019 period. This information should be included in an updated evaluation.

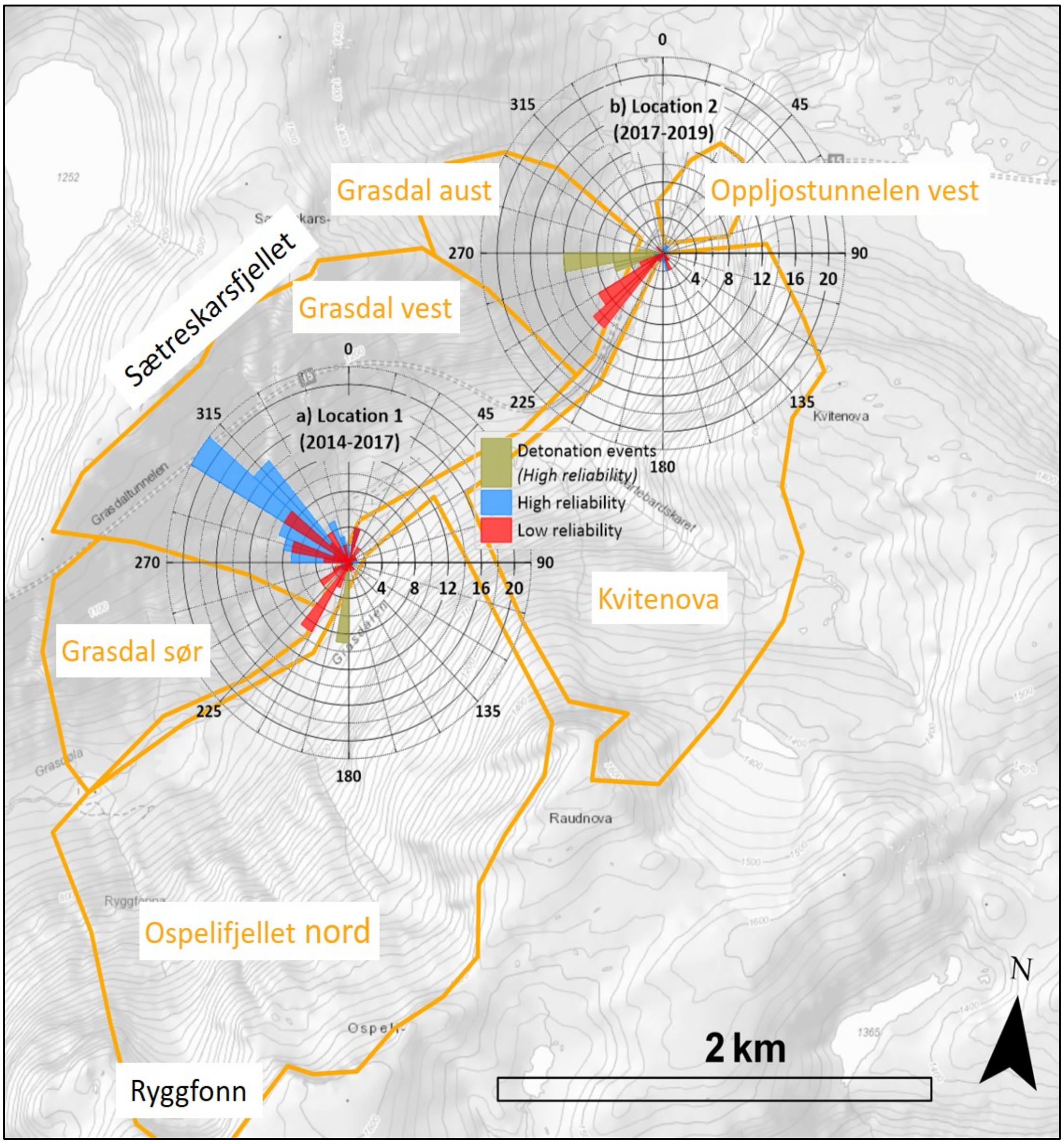

Figure 1 Infrasound monitoring locations and back-azimuth directions for reported events.

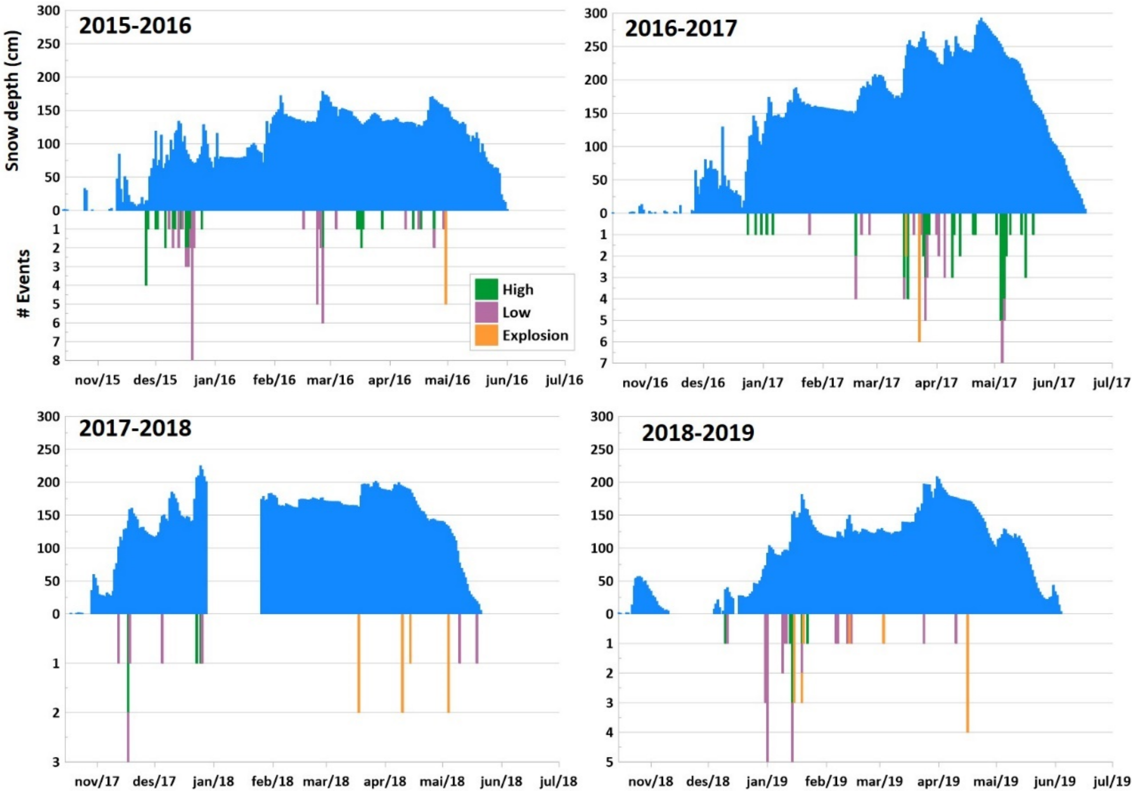

Figure 2 2015-2019 winter seasons overview. Note non-operating periods of the infrasound system are not indicated. Snow height is measured near to the Fonnbu research station. Note the infrasound station was moved to location 2 before the start of the 2017-2018 season.

4 Infrasound in applied avalanche forecasting

NGI produced daily applied avalanche forecasts for the Strynefjellet region during the period of the IDA system operation. These bulletins are applied forecasts and are primarily issued to inform the NPRA about snow avalanche hazards along the road. One of the objectives of the project was to evaluate the application of remote avalanche detection using the IDA system in an applied avalanche bulletin.

The daily avalanche bulletins are issued by NGI at 0900 each day during the snow season (November to late-April). The bulletins consist of a forecasted avalanche hazard level, likelihood estimate that an avalanche would reach the road infrastructure, and summary of weather, snow, and avalanche conditions and prognoses – forming the basis for the assessment. Wind, precipitation, and air temperature are major factors influencing the hazard assessments, in addition to other available information on snow stability conditions.

A summary of the frequency of the forecasted avalanche danger and avalanche danger on days with infrasound events at location 1 is presented in Figure 3. During the period when the sensor was positioned at location 1, avalanche danger level 2 was forecasted for 59% of the days (267/454) while level 3 was forecasted on 27% of the days (123/454). Most infrasound events were recorded on days with danger level 2 or 3.

The frequency of the dominant wind direction and wind direction during high-reliability events for the location 1 period is illustrated in Figure 4. Wind from the SW is most commonly reported, followed by wind from the E and SE directions. A disproportionately large number of high-reliability events are recorded during periods with wind from the SW. Regionally, westerly wind directions are commonly associated with precipitation. The direction is also favourable for loading in the Grasdal Vest slopes.

A summary of the frequency of the forecasted avalanche danger and avalanche danger on days with infrasound events at location 2 is presented in Figure 5. During the period when the sensor was positioned at location 2, avalanche danger level 2 was forecasted for 63% of the days (194/306) while level 3 was forecasted on 26% of the days (81/306). Danger level 4 was forecasted on 12 occasions in this period (4%). By and large, infrasound events were recorded on days with danger level 3 or 4.

Evaluating false alarms with the automated camera at Ryggfonn was not possible as high-reliability events which were not associated with avalanche control typically occurred during periods of poor visibility. In a recent study, Mayer et al. (2019) concluded that infrasound detection systems were best suited for identifying large avalanches within a radius of ca. 3 km. Small- and medium-sized avalanches were commonly undetected.

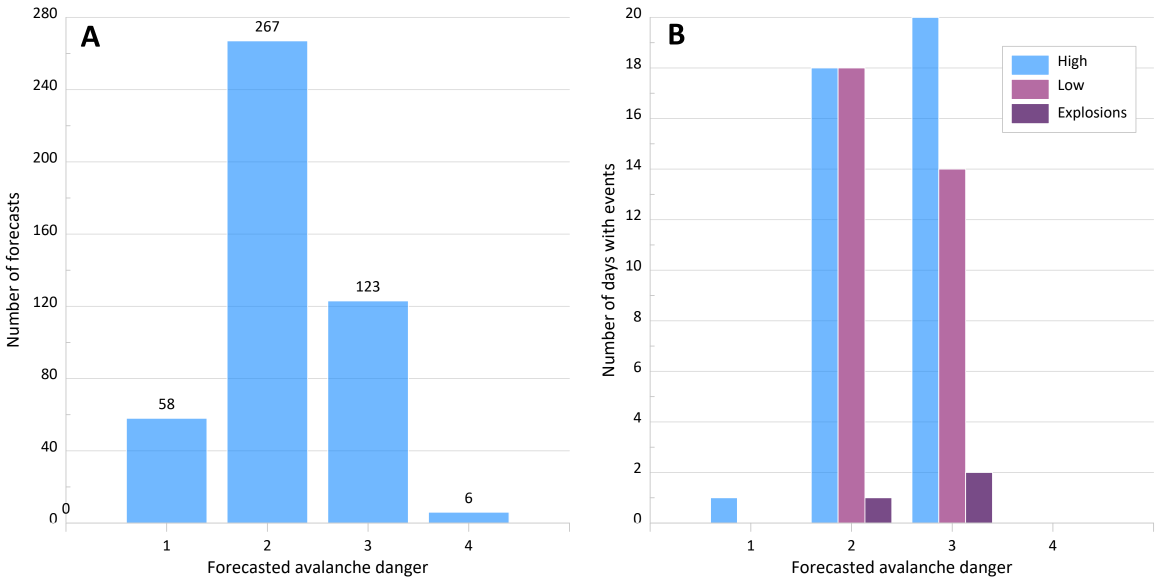

Figure 3 (A) Frequency of forecasted avalanche danger between autumn 2014 and spring 2017. (B) Number of days with events at Location 1 (high- and low-reliability avalanches and explosions) for different levels of avalanche danger. Note values will need to be corrected for periods when the infrasound array was not operating.

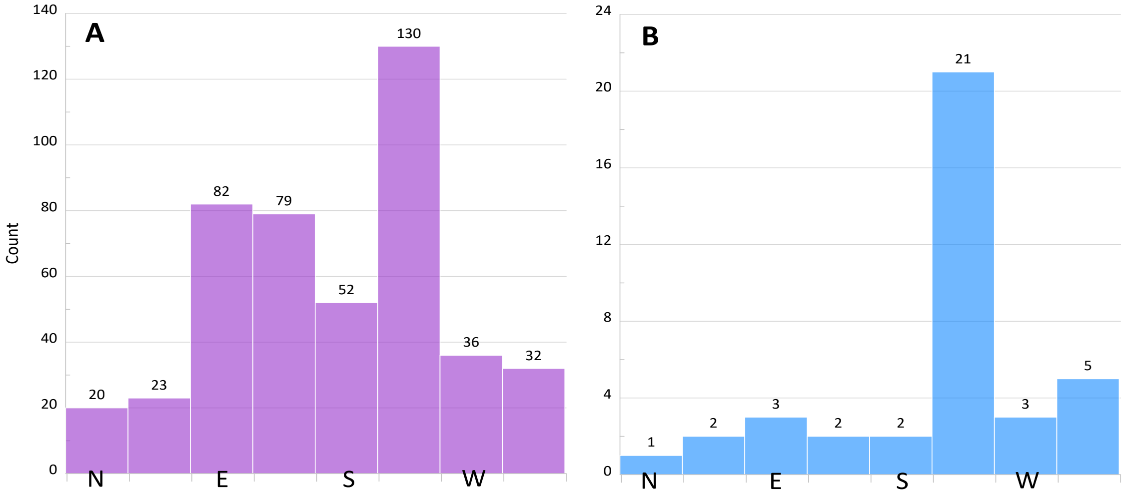

Figure 4 (A) Wind direction in the forecast region (NGI varsling). (B) wind direction on days with high-reliability events registered at Location 1 between autumn 2014 and spring 2017. Note values will need to be corrected for periods when the infrasound array was not operating.

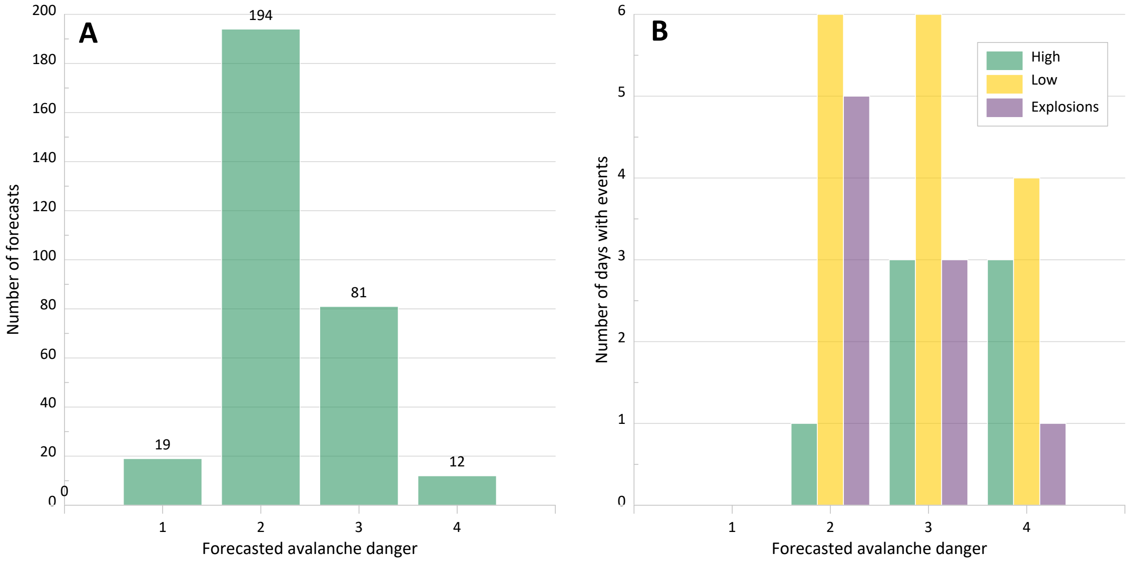

Figure 5 (A) Frequency of forecasted avalanche danger between autumn 2017 and spring 2019. (B) Number of days with events at Location 2 (high- and low-reliability avalanches and explosions) for different levels of avalanche danger. Note values will need to be corrected for periods when the infrasound array was not operating.

5 Summary

Previous studies have demonstrated the potential of infrasound technology to monitor avalanche activity within confined forecasting areas. The current investigation relates monitoring results to applied avalanche bulletins and snow and wind conditions. The results highlight some remaining uncertainties about the reliability of infrasound, its ability to detect all types of avalanches, and the relation between proximity to the IDA system and avalanche size for a successful detection. Concerns about detection performance have also been identified in recent literature (e.g. Mayer et al. 2019).

The ability of IDA systems to record events in foul weather is a considerable advantage. Future efforts should improve the verification of infrasound results by combining methods for avalanche detection, improved photo documentation, or manual surveys to confirm high-reliability events from safe areas. Reliability needs to be further demonstrated to characterize avalanches which go undetected by the array with respect to distance from the array, size, and avalanche type. The infrasound method has considerable potential to observational information to forecasters and improve regional avalanche forecasts.

6 References

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