USE OF GROUND BASED INSAR RADAR TO MONITOR GLIDE AVALANCHES

Ingrid Skrede[1]*, Lene Kristensen[1] and Carlo Rivolta[2]

[1]Norwegian Water Resources and Energy Directorate, Stranda, Norway
[2]Ellegi srl, Milano, Italy

ABSTRACT: Ground based InSAR radars are commonly used to monitor deformations on rock slopes, using acceleration to predict the risk of failure. During the spring of 2015 and 2016 this method has been tested for glide avalanches at Stavbrekkfonna in Western Norway. The investigations have been part of a research project, and the aim for this particular case study has been to see if ground based InSAR radars can measure displacement on snow surfaces, and if so, to improve the knowledge of the dynamics of glide avalanches in addition to investigate the possibility to predict the time of failure. The preliminary results show that ground based InSAR radars accurately measures displacements and velocity on snow surfaces. Acceleration has been measured before each failure, implying that prediction of such avalanches might be possible. The actual avalanches can also be seen in the radar images, giving the time and duration of the avalanches, in addition to showing the avalanche path. However, more research and experience is needed to provide a reliable warning system.

KEYWORDS: Glide avalanche, InSAR, radar, monitoring, Stavbrekkfonna

1. INTRODUCTION

In the spring of 2015 and 2016 the potential of measuring movement of glide avalanches with ground based InSAR radar has been tested. This is interesting for two reasons. Firstly, ground based InSAR radars have mainly been used on rock slopes and constructions, such as dams and bridges, and been considered as unsuitable for snow surfaces. Secondly, the dynamics of glide avalanches is poorly understood, and it differs from other kinds of snow avalanches since the entire snowpack glide along the ground before the avalanche is triggered (In der Gand and Zupančič 1966; Mitterer and Schweizer 2012). This behavior is more similar to other types of avalanche, such as rock slides and landslides. Studies have shown that the latter types of avalanches have an acceleration phase prior to failure, and monitoring of the velocity is therefore used to predict the time of failure (Crosta and Agliardi 2003; Voight 1989). Since glide avalanches appears to have similar dynamics, the same methodology could possibly be applied.

A case study has therefor been performed. This has been part of a Norwegian interdepartmental research project on natural hazards (NIFS) in 2015 and part of a research project within the Norwegian Water Resources and Energy Directorate in 2016. The aim of the study has been to see if ground based radars can be used to measure deformation on snow surfaces, to get better knowledge of the dynamics of glide avalanches and to see if it is possible to predict the time of failure of glide avalanches. The use of ground based radars on glide avalanches has not been tested in Norway earlier, but a few similar studies from the alps are known (Caduff et al. 2015; Meier et al. 2016).

The Stavbrekka glide avalanche at Strynefjellet, western Norway, has been used as a test site (Fig. 1). This is a glide avalanche that occurs almost every spring, but the date of failure can be highly variable. The popular tourist road, FV 63, between Breidalen and Geiranger is in the runout area. This road is closed during the winter and is not opened until after the failure of the Stavbrekka glide avalanche. The Norwegian Public Road Administration (NPRA), have done several efforts in order to open the road earlier, trying different methods both to trigger the avalanche and to prevent it from failing (Humstad et al. 2016). So far it has been without a successful outcome. The focus has now shifted over to monitoring to get a better understanding of the mechanism of the avalanche and to be able to predict it.

The release area of the avalanche is situated on a south facing slope, with a gradient of 29-37°. It is located between 1100 masl and 1300 masl,

---

* *Corresponding author address:*
Ingrid Skrede, Norwegian Water Resources and Energy Directorate, Ødegårdvegen 176, 6200 Stranda, Norway
tel: (+47) 47642861
email: ins@nve.no

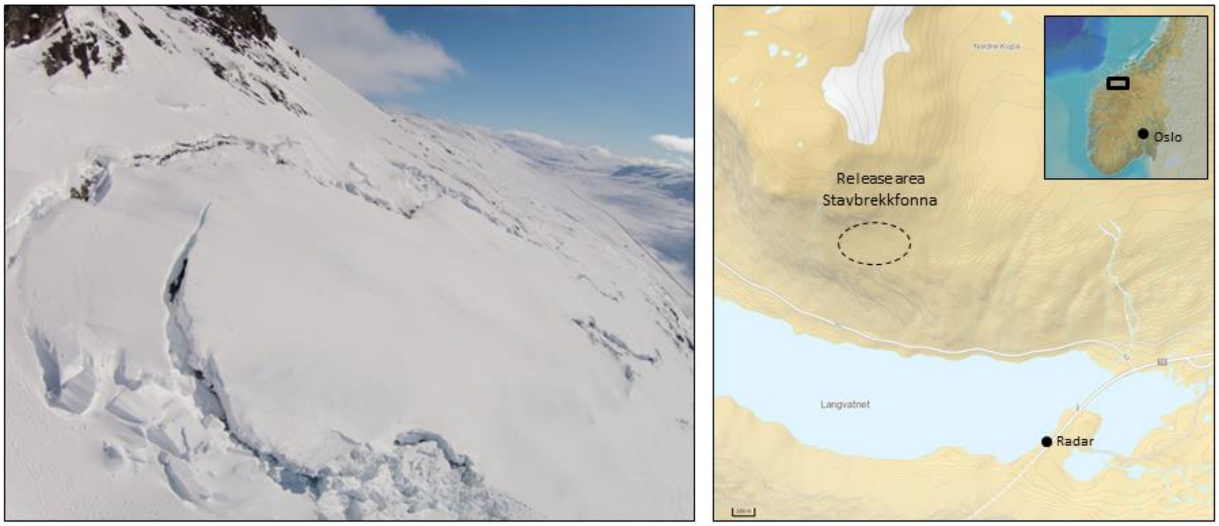

Fig. 1: The picture to the left show a picture, taken by a drone by the NPRA the 17th of April 2015, of the release area of Stavbrekkfonna. The map at the right shows the location of Stavbrekka and the location of the radar.

and the snow is deposited on glacial polished bedrock. The first visible sign of gliding is the opening of a glide crack. As the gliding continues, two lobes are developed, which later splits into two flanks as the movement proceeds. These will be referred to as the western and eastern flank in the rest of the paper. These can fail simultaneously, at different times, or only one or none of the flanks can fail. The avalanche mass contain a lot of water and crosses the road before it is deposited in the slope or on the ice covered lake, Langevatnet, below.

2. METHODS

Fig. 2: The radar on a movable fundament, measuring at Stavbrekka.

A LiSAmobile GB InSAR system (Ground-Based Interferometric Synthetic Aperature Radar) from Ellegi srl has been used (Fig. 2), and data has been processed with the Lisalab software.

Ground based radars (InSAR) measure surface displacement over time of reflecting objects in the range of the radar. This is done by emitting electromagnetic waves from an antenna, which hits the targeted object, and the backscatter signal is registered with a receiving antenna. By focusing the received signal, a bidimensional radar image can be obtained, giving information of the distance. By comparing changes in radar phases of images taken at different times in the form of interferograms, the surface deformation along the Line of Sight (LOS) can be displayed. Most often several bidimensional radar images are averaged to reduce the noise, and get more accurate results. By using a series of interferograms, the displacement and velocity through the measured time period can be derived. One of the advantages of the method is that it is independent of visibility, and it can give reliable results in darkness and in fog. It is placed outside the moving area, so no exposure of the potential dangerous objects is needed. It gives an overview of surface displacement and velocities in a large area and time series from all pixels can be extracted. By measuring the exact position and direction of the radar with a GPS-antenna, the images can be georeferenced. The precision is usually less than 1 mm, depending on the settings and the noise. It does however appear to be larger when measuring on snow rather than rock surfaces. The result can be affected by atmospheric noise and changes on the surface, such as snow and ice, which can be reviewed by means of correction algorithms.

An interferogram can show displacement of 4.4 mm towards and away from the radar in the LOS. If the displacements are greater, the next phase of the wave will be registered, giving wrong results. To avoid this, the revisiting time between two subsequent images is adjusted to the displacement rate, either by changing the interval between the images e.g. by using fewer images for the averaging process, or changing the speed of the radar. Unwrapping of the signal is possible if the phase is known, either by other monitoring equipment or if the movement is so gradual that it's possible to determine the phase by close study of the series of interferograms. The latter option requires interpretation, and the following calculations put constraints on the data. This makes the data less reliable. In 2015 phase jumps occurred after only 19 hours of measurements, so unwrapping had to be done. At that time the whole linear positioner (3 m) was used and average displacement rates of 4.7 m/day could be measured. In 2016 the radar system was improved, and only 1.5 m of the linear positioner with other settings was used, making it possible to measure maximum velocity of 14 m/day. The internet reception was also better this year, making it possible to view the data in real-time, and adjust the speed and settings remotely. Phase jumps occurred at 4 AM the day of failure.

The radar was covered by a tent and placed on a truck the first year and on a trailer the second year. In 2016 melting of snow and ice underneath the trailer caused problems making the radar itself move at times. Usually the radar is placed on a stable surface, but this was not possible during the test.

To check the snow thickness in the source area and the snow redistribution in general, terrestrial LiDAR scans were taken of the slope before and after the avalanche, as well as in August when all snow had disappeared from the site. A Riegl VZ®-6000 scanner was used, which is particularly well suited for snow and ice surfaces. Three scans from different positions at each selected day were registered and georeferenced in the software RiSCAN Pro, using a differential GPS and inbuilt inclinometer and compass.

3. RESULTS

The measurements were performed between the 16th and 23rd of April in 2015, and from the 1st of April to the 7th of May in 2016. There were some breaks due to rough weather conditions, and in 2016 additional measurements were made for some hours the 7th and the 30th of March. Snow and air temperatures have been measured by the NPRA. In 2015 the snowpack was generally close to 0°C after the 8th of March, but it was not fully isothermal until the 19th of April (Venås 2015). In 2016 the transition from a cold to isothermal snowpack took place around the 14th to 16th of March (Humstad et al. 2016). That was at the same time as the glide crack was observed. Due to colder air temperatures at, the upper parts of the snowpack did however refreeze for periods in April, and the snowpack became isothermal again the 5th of May.

Already from the first radar images it was clear that it was possible to measure deformation on snow surfaces (Skrede and Kristensen 2016). Both years, snow was gliding in several areas in the measured mountain side, and it was possible to see the displacement over time. Four avalanches were measured during the two campaigns, one in 2015 and three in 2016. All, except one, was in the release area of the "Stavbrekkafonna"

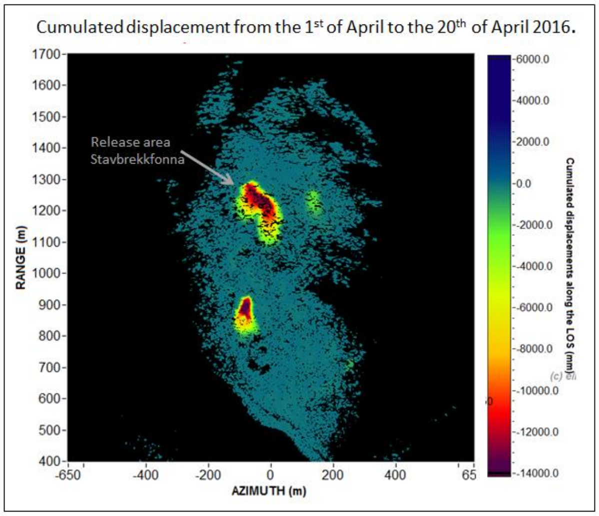

Fig. 3: Cumulated displacement from the 1st to the 20th of April 2016 showing three moving areas. Negative values show movement downhill, towards the radar, positive values movement away from the radar.

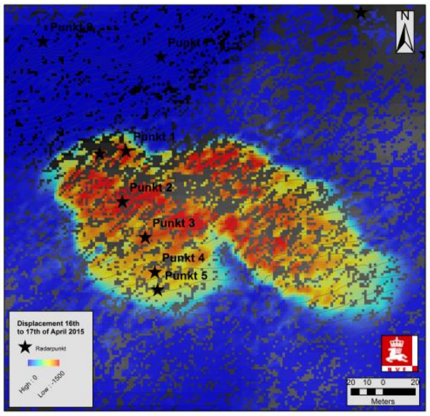

Fig. 4: Total displacement from the 16th to the 17th of April (19 hours) 2015. The positions of points for the time series are indicated.

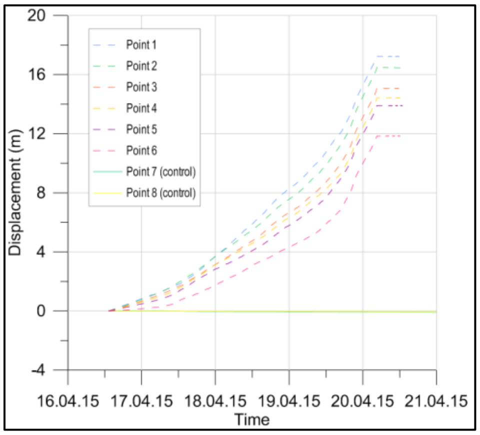

Fig. 5: Displacement during the radar campaign in 2015, after unwrapping. The location of the points can be seen in Fig. 4.

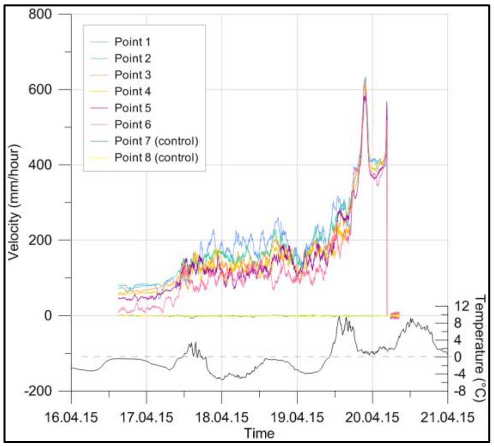

Fig. 6: Velocity during the radar campaign in 2015, after unwrapping. The location of the points can be seen in Fig. 4. The temperatures are provided by the NPRA.

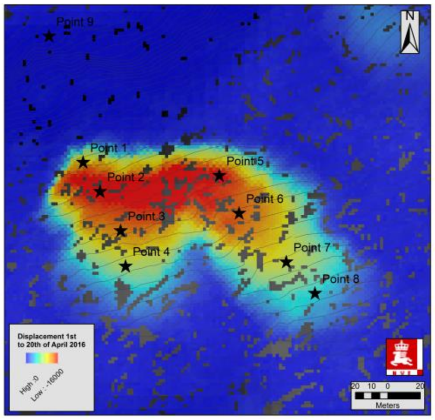

Fig. 7: Total displacement from the 1st to the 20th of April 2016. The positions of points for the time series are indicated.

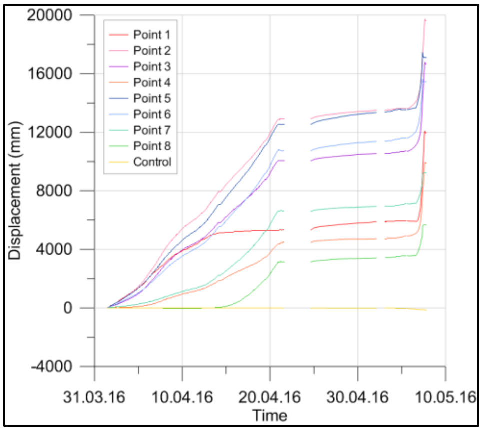

Fig. 8: Displacement during the radar campaign in 2016, after unwrapping. The location of the points can be seen in Fig. 7.

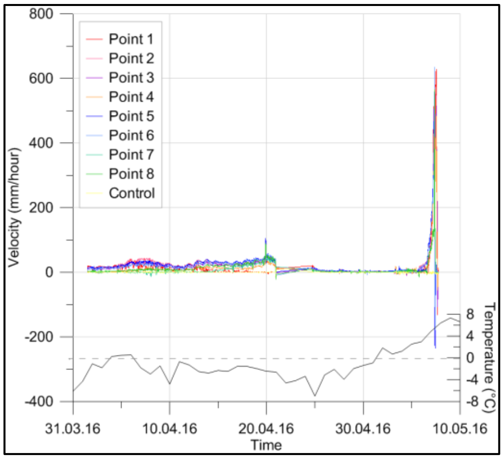

Fig. 9: Velocity during the radar campaign in 2016, after unwrapping. The location of the points can be seen in Fig. 7. The temperatures are provided by the NPRA.

The release area of Stavbrekkfonna was about 20 000 m^2 both years, and the two lobes was easily distinguished in the radar images, the eastern flank being slightly bigger than the western flank (Fig. 3). In all the moving areas the displacement was greatest in the upper and central parts and decreases downwards and to the sides.

In some areas, the snow glide started even before the snowpack was isotherm, as could be seen in the measurements from the 7th of March 2016, where movement in the east flank and the lower area was evident in the radar images. The velocity was about 2 mm/hour, and it was easy to distinguish from snow creep of the entire snowpack since it was constrained to certain areas.

The behavior prior to failure has been different during the two years of measurements. In 2015 the velocity increased gradually, although diurnal fluctuations were observed. The velocities were greatest at daytime and lowest around midnight. The two lobes moved as one object until 9 PM the 19th of April. At that time the eastern flank slowed down, while the western flank continued accelerating up to failure, which occurred at 05:13 the 20th of April. The avalanche lasted for five minutes and crossed the road. At this time, the total measured displacement in the campaign was up to 18 m in the LOS of the radar, which is about 22 meters in reality (Fig. 5). The velocity was over 600 mm/hour prior to failure (Fig. 6). The east flank had a greater displacement during the radar campaign, being up to 30 m. It failed the 6th of May, after the radar was moved. The data was corrected for phase jumps most of the time, but the result corresponded well with displacement measurements acquired by the NPRA (Venås 2015). Analyses of the lidar scans show that the thickness of the snowpack was about 2 m in the release area at the day of failure (Fig. 10).

In 2016 the velocities were quite steady in the beginning of the campaign, but slowed down between the 20th of April and the 5th of May (Fig. 9). This coincided with a colder period, when the upper layers of the snowpack refroze (Humstad et al. 2016). From there on the acceleration was quite rapid as the temperature rose and the snowpack became isothermal again. Both flanks moved together until one and a half hour before the failure of the eastern flank. This occurred at 11:00 the 7th of May, and the avalanche lasted for two minutes. The west flank failed that same afternoon at 16:25, and lasted for two minutes. At this stage the total measured displacement was up to 20 meters in the LOS of the radar (Fig. 8). The highest velocity measured before failure was over 600 mm/hour (Fig. 9), similar to the year before.

The smaller moving area underneath Stavbrekka failed the 12th of April at 22:34, lasting for one minute. Also this had an accelerating period prior to failure. The release area was about 5000 m^2, and it moved over 20 m in the 12 days of measurements. The recorded velocity was smaller in this area than on Stavbrekkfonna, but it exceeded 150 mm/hour. This avalanche also crossed the road.

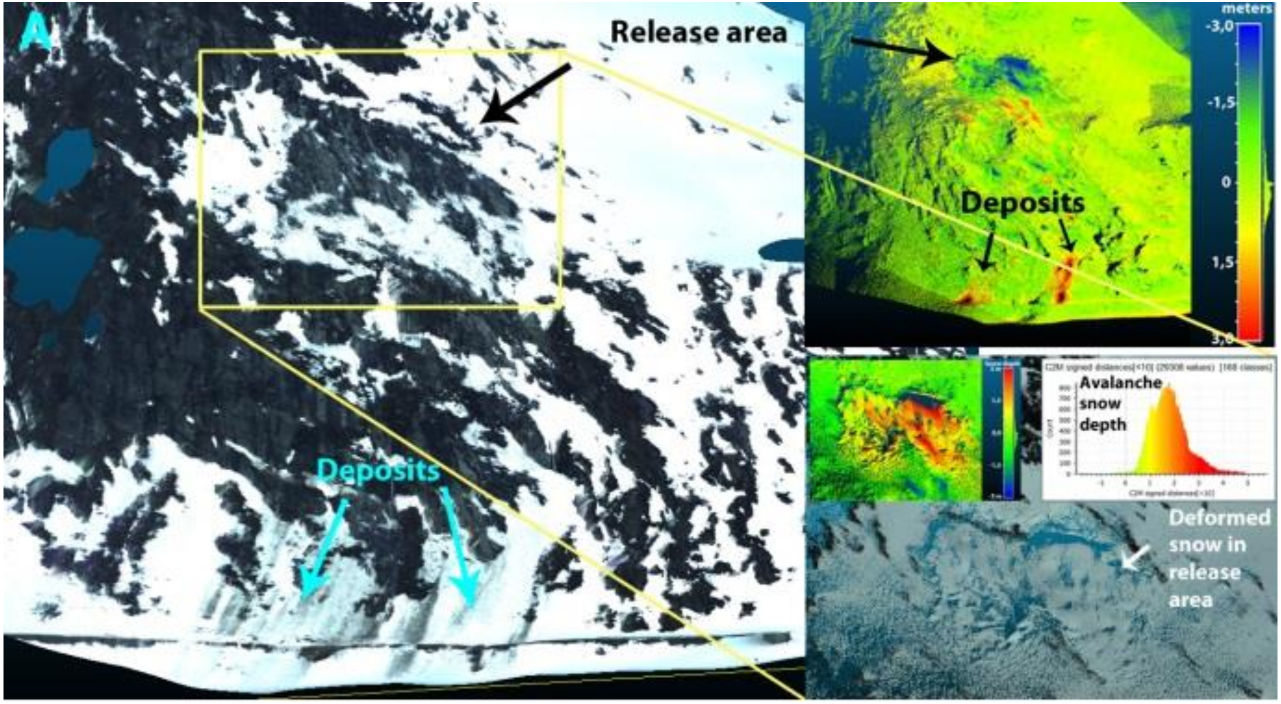

Fig. 10: Lidar analyses showing the difference in snow cover before and after the avalanche.

All the avalanches have been visible in the radar images giving both the time of failure, the duration of the avalanche and the avalanche path. They are visible by the total loss of coherence, which means that the paths form “holes” in the radar images, or by an area of chaotic, wrapped signals (Fig. 11), depending on settings in the software.

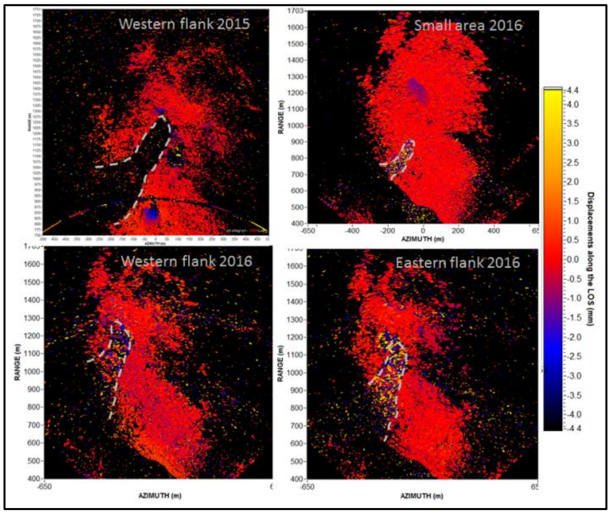

Fig. 11: Interferogram showing the four avalanches that’s measured.

4. DISCUSSION

After two seasons of measurements it is evident that ground based InSAR radars can be used to measure deformation on snow surfaces. It clearly shows the moving area, the displacement and the velocity. The radar also picks up creep before it is visible by glide cracks. One thing that can affect the result is large snow falls, snow drift and settling of the snow, which changes the surface. However, since the movement is correlated to temperature, snowfalls will come in periods of little movement, and this is also the time when the potential for snowdrift is greatest, since the snow is dry. Settling of the snow is almost negligible compared to the displacement rate when the snowpack is isothermal, although it will affect the result.

One of the biggest challenges is the very high displacement rates, which in the last phase is greater than the system can measure. With the improved system and using only 1.5 meters of the linear positioner, phase jumps only occurred a short time before failure, and this was possible to correct for. The data becomes less reliable since it is dependent of interpretation when phase jumps occur, and following calculations puts constraint on the data. The result has however corresponded well with the measurements performed by the NPRA. The unwrapping is impossible to do real-time and is time consuming. Having a functional network connection is crucial to follow the real-time movement, and gives the ability to change the settings remotely.

What is seen so far is that the movement is highly dependent on temperature, and responds quickly to changes. The movement in certain areas does however start moving even before the snowpack is isothermal. The snow masses moves relative homogenous, but the displacement rates are greatest in the upper central parts of the moving snow bodies, and decrease downwards and to the sides. For the specific glide avalanche Stavbrekkfonna, the flanks moves as one object for a long periode, before the flanks starts to moves independently. In the measurements, an acceleration phase is obvious before all the avalanches, although the movement can slow down if the external driving forces changes. Velocities up to 600 mm/hour have been measured in the Stavbrekka release area before all the avalanches. A short time before failure, a sudden drop in velocities has been observed in the western flank both years, before it again accelerates and fails (Fig. 6 and Fig. 12). This can be caused by errors in the unwrapping, but may also be the case. Possible explanations in that case can be that it is effects by the underlying topography or compression in the stauchwall.

Since the acceleration phase have been so clear for all the avalanches measured, it seems feasible to be able to predict the time of failure. However, since the snow masses responds very quickly to changing weather conditions it is probably more natural to predict the hazard level of a glide avalanche instead of the actual failure time in an early warning system.

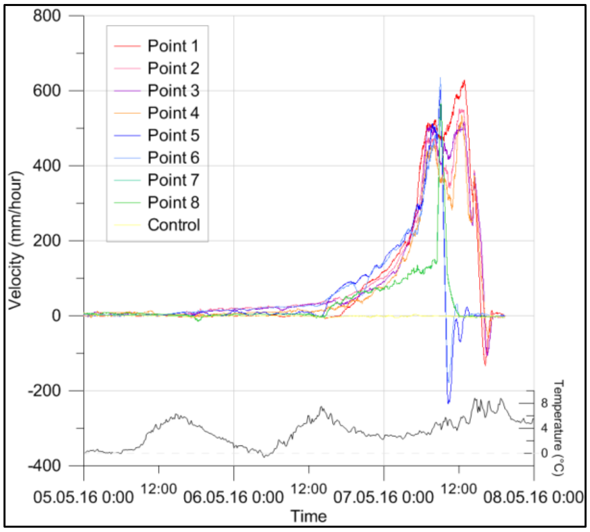

Fig. 12: Velocity in the acceleration phase and failure. The temperatures are provided by the NPRA.

Since only two avalanche seasons are measured it is too little empirical foundation to make conclusions with certainty. More data has to be collected both from this and other sites. It would be interesting to start the measurements earlier in the season to see the first sign of movement. In 2016 melting of ice and snow underneath the trailer caused some problems in the real time processing, and the radar should definitely have a permanent foundation and a house protecting it from snowdrift and snow storms. Still, many similarities and useful information about the glide avalanche is already seen, and the method seems very promising to both increase the knowledge of glide avalanches and to make an early warning system.

5. CONCLUSION

Ground based radar (InSAR) is a good tool to measure the real-time displacement and velocity of glide avalanches. It shows which areas are moving, the size of the areas and the distribution of the displacement. Time series for all pixels in the cumulated radar images can be retrieved. Avalanches are visible in the radar images giving the time of failure, the duration of the avalanche and the avalanche path. There is a clear acceleration phase before failure, which probably makes the avalanches/avalanche hazard possible to predict. The method has only been tested for two seasons so a better empirical foundation is needed to make certain conclusion. Improvements of the system have been done and further improvement such as having a solid foundation and a house to protect the system from the rough weather conditions is planned. The preliminary result is very promising for increase the understanding and prediction of glide avalanches.

CONFLICT OF INTEREST

The third author of this paper is the manufacturer and Chief executive office of Ellegi srl, which develops and sells the radar system used in this study.

AKNOWLEDGEMENTS

The authors would like to acknowledge the good cooperation with the Norwegian Public Road Administration, and the good service provided by Ellegi srl, both to improve the radar system for good assistance during measurements.

REFERENCES

Caduff, R., A. Wiesmann, Y. Bühler, and C. Pielmeier, 2015: Continuous monitoring of snowpack displacement at high spatial and temporal resolution with terrestrial radar interferometry. Geophysical Research Letters, 42, 813-820.

Crosta, G., and F. Agliardi, 2003: Failure forecast for large rock slides by surface displacement measurements. Canadian Geotechnical Journal, 40, 176-191.

Humstad, T., M. Venås, H. Dahle, K. I. Orset, and I. Skrede, 2016: Monitoring the Stavbrekka glide avalanche. International Snow Science Workshop, Breckenridge, Co, U.S.A., pp. in press (see this volume).

In der Gand, H., and M. Zupančič, 1966: Snow gliding and avalanches. Symposium at Davos 1965 - Scientific Aspects of Snow and Ice Avalanches, IAHS, 230-242.

Meier, L., M. Jacquemart, B. Blattmann, S. Wyssen, B. Arnold, and M. Funk, 2016: Radar-based Warning and Alarm Systems for Alpine Mass Movements. Interpreavent, Luzern, Switzerland, 960-968.

Mitterer, C., and J. Schweizer, 2012: Towards a better understanding of glide-snow avalanche formation. International Snow Science Workshop ISSW, Anchorage, AK, U.S.A., 610-616.

Skrede, I., and L. Kristensen, 2016: Måling med bakkebasert radar (InSAR) av Stavbrekka, Sjåk commune. NIFS-report 12.2016.

Venås, M., 2015: Overvåkning og varsling av glideskred ved Stavbrekka i Skjåk, Institutt for geologi og bergteknikk, Norges teknisk-naturvitenskapelige universitet.

Voight, B., 1989: A relation to describe rate-dependant material failure. Science, 243, 200-203.