Use of Satellite and Ground Based InSAR in Hazard Classification of Unstable Rock Slopes

John F. Dehls, Tom Rune Lauknes, Reginald L. Hermanns, Halvor Bunkholt, Tom Grydeland, Yngvar Larsen, Harald Ø. Eriksen, and Trond Eiken

Abstract

A newly developed hazard classification system for large unstable rock slopes depends on the evaluation of a number of criteria. These criteria include both displacement rates and the structural development of the unstable slope. Satellite and ground-based interferometric radars have the potential to measure the displacement of active rockslides. By using several complimentary InSAR datasets, with different viewing geometries, we are able to assess both movement criteria and a number of criteria related to structural development of the bounding surfaces.

We have collected five years of high resolution satellite imagery using several viewing geometries for the Gamanjunni 3 rockslide in northern Norway. In addition, we have collected radar using a ground-based radar. The results show a clearly defined block moving as a wedge. However, the decrease in movement velocity and steepness towards the lower part of the slope, along with the lack of visible basal structures, indicates that rock creep acts at the base of the slide body.

Keywords

InSAR • Hazard • Satellite

Introduction

Catastrophic failure of large rock slopes in Norway has occurred several times in the last century, leading to large loss of life. The Geological Survey of Norway (NGU), under the direction of the Norwegian Water and Energy Directorate (NVE), carries out systematic geological mapping of potentially unstable rock slopes that may fail catastrophically. The large mountainous land area of Norway necessitates a systematic mapping approach. Once a potential unstable slope is identified, a hazard and risk classification is performed in order to prioritize potential mitigation measures, such as periodic or permanent monitoring.

NGU, together with a group of international experts, has developed a systematic hazard classification system for large unstable rock slopes for use in Norway (Hermanns et al. 2012). The hazard analysis is based upon two sets of criteria. The first set involves site investigations, including structural mapping and kinematic analysis. These criteria include the development of bounding surfaces. The second set involves assessment of the current activity level of the slope. This includes evidence of historic or prehistoric events in the area, observations of current rockfall activity, and measurements of current velocity and possible acceleration. These last parameters have historically been provided by periodic GNSS surveys. However, this

---

J.F. Dehls (✉) • R.L. Hermanns • H. Bunkholt
Geological Survey of Norway, P.O. Box 6315,
Sluppen 7491 Trondheim, Norway
e-mail: john.dehls@ngu.no; reginald.hermanns@ngu.no; halvor.bunkholt@ngu.no

T.R. Lauknes • T. Grydeland • Y. Larsen • H.Ø. Eriksen
Norut, Postboks 6434, Forskningsparken 9294 Tromsø, Norway
e-mail: tom.rune.lauknes@norut.no; tom.grydeland@norut.no; yngvar.larsen@norut.no; harald.overli.eriksen@norut.no

T. Eiken
Department of Geosciences, University of Oslo, Postboks 107,
Blindern 0316 Oslo, Norway
e-mail: trond.eiken@geo.uio.no

K. Sassa et al. (eds.), *Landslide Science for a Safer Geoenvironment*, Vol. 2,
DOI 10.1007/978-3-319-05050-8_60, © Springer International Publishing Switzerland 2014

is a very resource intensive method that provides at most one measurement per year on a sparse network of observation points. Increasingly, we have been using first satellite based, and now ground based InSAR measurements to determine deformation rates on a dense network of points.

Study Area

The Lyngen region in Troms County has an unusually high density of large unstable rock slopes (Henderson et al. 2011; Osmundsen et al. 2009). These unstable rock slopes are located in glacially steepened or over-steepened valleys and fjord sides. In this study, we take the example of an unstable rock slope referred to as "Gamanjunni 3".

The Gamanjunni 3 unstable area consists of a large block, approximately 150 by 160 m, that has been displaced approximately 100 m towards the valley floor. Despite considerable internal fracturing, the upper part has moved together as a cohesive volume. The lower part of the unstable block is highly fractured.

Methods

In 2011, two GNSS benchmarks were installed on the upper block as well as another benchmark in the stable area above. This network was connected to another network on a nearby unstable slope to increase accuracy on both networks. Repeat surveys were carried out in 2012 and 2013. A robust linear regression is usually applied to a time series of dGNSS data to determine yearly average displacement rates (Böhme et al. 2013). Since we only have three measurements so far, this is not yet possible. However the displacements in the two periods are very similar, with both vertical and horizontal velocities of 3–4 cm/year.

We have been acquiring TerraSAR-X stripmap data in both ascending and descending geometries over the Lyngen area since 2009. This radar operates at X-band (9.6 GHz). The satellite has a repeat cycle of 11 days. In addition, we have been acquiring Radarsat-2 data in both Fine mode and Ultrafine mode during the same period. This radar operates at C-band (5.4 GHz), and has a repeat cycle of 24 days. For both satellites, we collected images during each snow-free season. We have process each dataset using both short baseline (SBAS) and persistent scatterer (PSI) algorithms, implemented in the GSAR software package developed by Norut (Larsen et al. 2006).

During six weeks in July and August 2012, we observed the Gamanjunni 3 rockslide using the GPRI radar developed by Gamma Remote Sensing AG. This instrument operates at Ku-band (17.2 GHz) and has measurement sensitivity better than 1 mm. The radar data were acquired with a temporal sampling as often as every three minutes. Since the instrument was mounted in the valley below the unstable slope, it has a different field of view than the satellites. The shorter wavelength provides a higher sensitivity to motion than the X- and C-band satellites, and the frequent observation interval allows us to measure changes in the velocity during the campaign.

InSAR only provides a measurement of the deformation along the line-of-sight (LOS) between the satellite and the ground, so it cannot measure the absolute deformation magnitude or direction from a single dataset. By using InSAR data from both ascending and descending orbits, as well as the ground based system, we can calculate the horizontal and vertical components and measure changes in the movement direction within the moving area. This is important in assessing the likelihood of proposed deformation mechanisms.

Results

Results from all satellite datasets show a clearly defined area of movement (Fig. 1), constrained by a back scarp, side fractures and a toe area. The average velocity is on the order of 5 cm/year. This is consistent with the results from the dGNSS measurements, that show that the upper block has a horizontal component of movement of about 4 cm/year. The lower part of the slide contains a fast moving lobate shaped landform, visible in the high velocity area in (Fig. 1b). It has the characteristics of a rock glacier with steep front and a rough surface with large blocks floating on top.

The most obvious hazard criteria that the InSAR results can be used in defining are the displacement rate and possible changes in displacement rate over time. We have now establish the average velocity over the last 5 years. Satellite InSAR measurements will be continued long into the future, allowing us to recognise any future acceleration. In addition to displacement, however, there are a number of other criteria that are also much easier to define with the help of InSAR. The presence of both a back scarp and lateral release surfaces are clearly indicated in the velocity maps. While these structures can usually be identified in the field, it is not always clear whether or not such planar surfaces are fully developed, allowing movement.

The presence of a basal rupture surface is a necessary criterion for eventual failure. In this case, there is no morphological expression of a rupture surface in the field. The InSAR data clearly defines an area that is moving and a stable area, but the lower boundary is not as clear as for the lateral surfaces.

By combining InSAR data from three different orientations, we can determine the direction of movement and variations in the direction of movement throughout the surface of the sliding mass. This in turn allows us to infer something about the

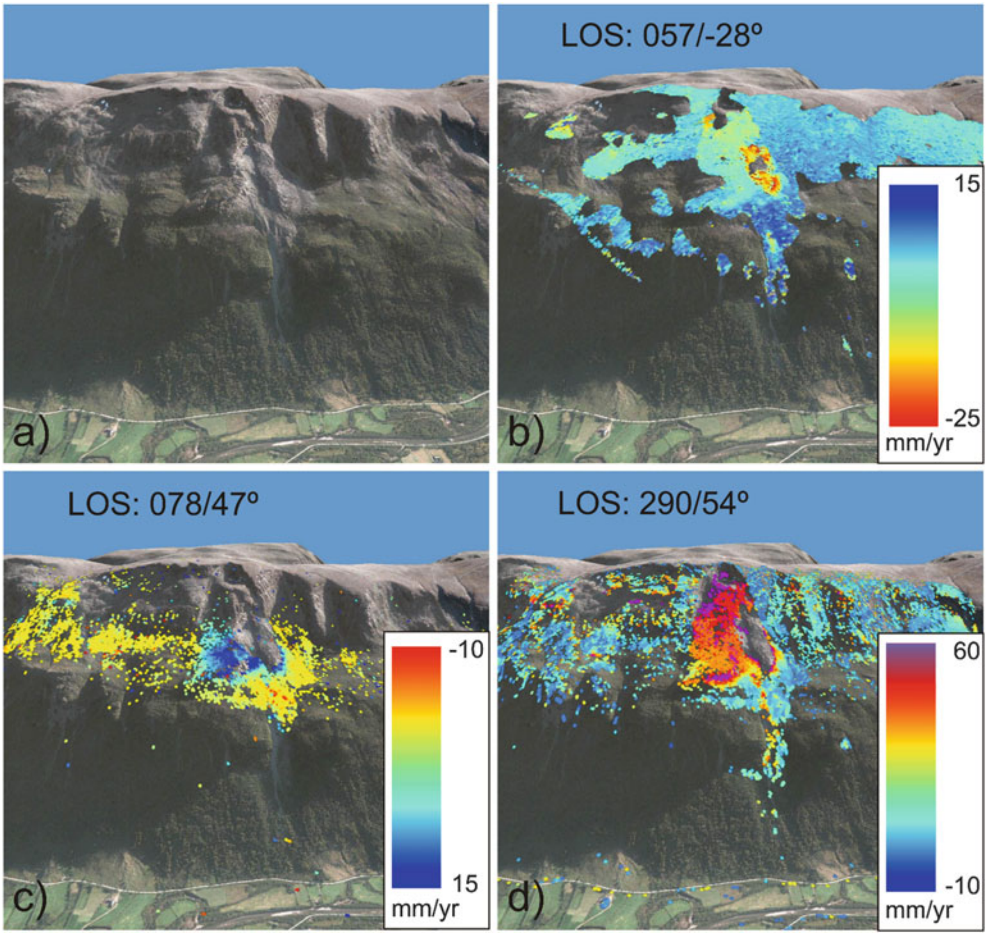

Fig. 1 Gamanjunni 3 rockslide. (**a**) Area of the rockslide; (**b**) GPRI data from 21-day interferogram. *Red* is towards radar. *Blue* is away from radar; (**c**) Mean descending TerraSAR-X data (2009–2012). *Red* is away from radar. *Blue* is towards radar; (**d**) Mean descending TerraSAR-X data (2009–2012) *Purple* is away from radar. *Blue* is towards radar

sliding mechanism. We have determined that the velocity decreases from the upper block through the fractured area in the toe. In addition, the movement direction becomes shallower near the toe. These observations indicate that we have a clear block slide that develops on an underlying sliding surface and lateral release surfaces, forming a wedge. None of those structures daylights at the slope, and neither does the intersection line. This structural condition makes it necessary that rock creep acts at the base of the slide body. A steady decrease of the velocity from about 5 cm/year to about 2 cm/year in the lower part of the instability supports this interpretation.

Discussion

Satellite-based InSAR has proven invaluable for regional landslide mapping and has led to the discovery of numerous large unstable rock slopes in Norway. In this study, we show how high resolution ground-based and satellite-based InSAR can also play an important role in hazard classification. Although field mapping of structures still remains a very important part of the process, it is not always possible to determine whether or not structures that are identified actually allow movement. dGNSS surveys allow us to determine whether or not a potentially unstable slope is actually moving. However, it is an expensive and time consuming technique that only provides information on a limited number of points. By using InSAR we are able to obtain tens of thousands of measurements, and delineate areas of movement. This in turn gives us more information about the structures bounding the unstable area. The combination of several look directions gives us the added benefit of being able to determine the actual movement direction for many of these points, potentially giving us further insight into the kinematics. In the case of the Gamanjunni 3 rockslide, it is clear that although there is significant annual displacement, the basal rupture surface necessary for catastrophic failure has not yet developed.

Acknowledgments The first 3 years of TerraSAR-X data were provided through the German Aerospace Centre (DLR) TerraSAR-X AO projects #GEO0565 and GEO0764.

The use of the ground based radar within this project has been financed by the regional research funds North-Norway.

References

Böhme M, Hermanns RL, Oppikofer T, Fischer L, Bunkholt H, Eiken T, Pedrazzini A, Derron M-H, Jaboyedoff M, Blikra LH, Nilsen B (2013) Analyzing complex rock slope deformation at Stampa, western Norway, by integrating geomorphology, kinematics and numerical modelling. Eng Geol 154:116–130

Henderson IHC, Lauknes TR, Osmundsen PT, Dehls J, Larsen Y, Redfield TF (2011) A structural, geomorphological and InSAR study of an active rock slope failure development. In: Jaboyedoff M (ed) Slope tectonics, vol 351. Geological Society, London, pp 185–199, Special Publications

Hermanns RL, Oppikofer T, Anda E, Blikra LH, Böhme M, Bunkholt H, Crosta GB, Dahle H, Devoli G, Fischer L, Jaboyedoff M, Loew S, Sætre S, Yugsi Molina F (2012) Recommended hazard and risk classification system for large unstable rock slopes in Norway. NGU-Rapport 2012.029, 53 p

Larsen Y, Engen G, Lauknes TR, Malnes E, Høgda KA (2006) A generic differential interferometric SAR processing system, with applications to land subsidence and snow-water equivalent retrieval. In: Fringe 2005 Workshop, ESA SP-610. Frascati, Italy, p 56

Osmundsen PT, Henderson IHC, Lauknes TR, Larsen Y, Redfield TF, Dehls J (2009) Active normal fault control on landscape and rock-slope failure in northern Norway. Geology 37:135–138