Regional landslide mapping and detailed site characterization using InSAR

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ABSTRACT
After several years of testing on known landslides, InSAR is currently being used in an operational basis for regional landslide mapping in Norway. An area of approximately 150,000 km^2 is currently being mapped using data from the ERS and ENVISAT archives. The results enable more efficient field activities during the summer. The millimetric precision obtained in velocity measurement allows us to map variations in deformation within individual landslides. Historical scenes dating back to 1992 allow us to study past behaviour of slopes. Regular acquisition of new satellite scenes, combined with the use of artificial corner reflectors, enables year-round monitoring of active slopes.

RÉSUMÉ
Après plusieurs années de tests sur des glissements de terrain bien connus, InSAR est actuellement utilisé comme standard pour la cartographie régionale des instabilités gravitaires en Norvège. Une zone d'environ 150,000 km^2 est actuellement cartographiée à partir d´archives ERS et ENVISAT. Les résultats permettent une meilleure appréhension des travaux de terrain effectués pendant les périodes d´été. La précision millimétrique des vitesses estimées permet de cartographier les variations de la déformation de chaque instabilité. L'enregistrement historique depuis 1992 permet d'étudier l´évolution du comportement des pentes. Les acquisitions régulières de nouvelles données satellitaires, combinées avec l´utilisation de réflecteurs angulaires artificiels permettent une surveillance accrue de ces zones actives.

1 INTRODUCTION

Being a mountainous country, with long steep fjords and valley sides, Norway is particularly susceptible to large rock avalanches. In the last 100 years, over 170 people have been killed by tsunamis in fjords caused by large rock avalanches. In each case, the rock avalanche was preceded by many years of slow movement, with acceleration prior to slope failure.

The Geological Survey of Norway is responsible for landslide mapping throughout the country. With several thousand kilometres of inhabited coastline and valleys, it is a challenge to identify similar hazards in an efficient manner. Once we suspect an area to be sliding, it may take several years of measurements to confirm it and extensive ground instrumentation to characterize the type of motion. We have begun to use interferometric synthetic aperture radar (InSAR) to help with both of these problems. InSAR analysis of the almost two decades long time series available in the ERS and ENVISAT archives enables rapid identification of landslides within a large region, allowing us to focus field mapping in areas with known hazards. In the case of known active landslides, new scenes are regularly acquired for continued monitoring.

Since 2005, we have been cooperating with Norut Northern Research Institute to establish a Norwegian facility for InSAR processing. We are currently processing over 1100 ERS and ENVISAT SAR scenes covering three counties in northern and western Norway. This project has allowed us to identify numerous new landsides. Field investigations have also confirmed the accuracy of InSAR in quantifying differential movement within individual landslides, thus extending our knowledge of the processes of fault scarp development and slide evolution.

2 INSAR METHODOLOGY

An excellent overview of InSAR methods and applications can be found in Rocca, et al. (2000). In the last few years, a number of Persistent Scatterers Interferometry (PSI) algorithms have been developed, starting with the Permanent Scatterers technique (PSInSAR™; Ferretti et al., 2000). These algorithms utilize a long time series of SAR images to estimate movement of discrete, stable natural or artificial reflectors, with millimetric precision.

Our analysis is based upon using all available European Remote Sensing Satellite (ERS-1 and ERS-2) SAR images from 1992 through 2000, with the exception of snow-covered winter scenes. Once our initial survey is completed, we will reprocess areas of interest using ENVISAT scenes in addition. We compute all interferograms with a maximum baseline of 300 m and a maximum temporal separation of 4 years. The topographic contribution is removed using an existing digital elevation model. For each interferogram, an orbital phase ramp as well as phase delay due to tropospheric stratification are estimated and removed. Based on the resulting InSAR pairs, we carry out the small-baseline subset (SBAS) processing steps as outlined in Figure 1, (Berardino et al., 2002). We apply a complex multi-look operation using two and eight looks in range and azimuth, respectively. The ground range pixel dimensions are therefore about 40 × 34 m in the range and azimuth directions, respectively. In order to exclude decorrelated

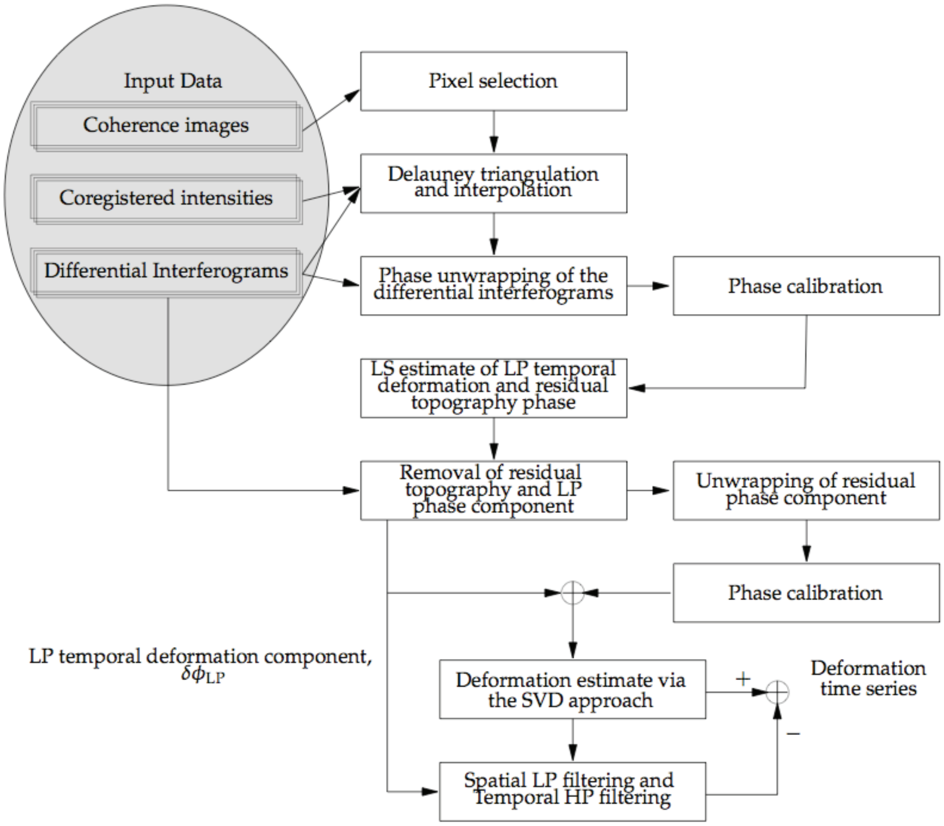

Figure 1. Flow chart showing the implementation of the small-baseline subset (SBAS) algorithm used in this study (Lauknes et al., 2005).

areas from the study, we select only the common coherent pixels in all interferograms. Atmospheric contributions are estimated and filtered out before estimating a mean displacement velocity.

3 REGIONAL MAPPING

Two large areas were chosen for initial mapping. These were chosen because of their steep topography and history of landslide activity. Figure 2 shows the location of these areas; one in western Norway and one in northern Norway.

3.1 Western Norway

This area encompasses the counties of Møre og Romsdal and Sogn og Fjordane. These counties are the site of many historical landslides (Blikra et al., 2006). A number of these have resulted in devastating tsunamis and large loss of life. Two unstable rock slopes are currently being monitored using ground instrumentation (Blikra et al., 2008), as well as InSAR.

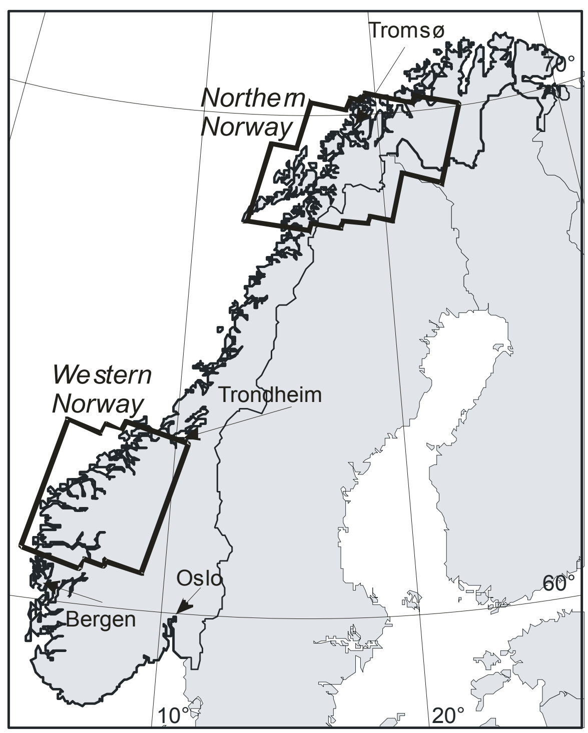

Figure 2. Location of the two study areas.

This study area is covered by six satellite tracks. All together, 538 ERS and ENVISAT scenes acquired during the months from May to October were purchased. At this relatively high latitude, there is a large overlap between neighbouring tracks. We could have purchased only every second or third track, but by processing all available data we have at least two completely independent result sets for any given area. This allows us to check for processing errors and uncorrected atmospheric effects.

3.2 Northern Norway

This area encompasses Troms County as well as the Lofoten and Vesterålen island chains in northern Nordland County.

This study area is covered by eight satellite tracks. A total of 590 scenes were purchased. As for western Norway, only May to October scenes were purchased, but overlapping tracks are being processed to provide independent results for each area.

Figure 3 illustrates an example of the results from around the Lyngen peninsula and Kåfjord. This is an area with a number of previously identified unstable mountainsides. The results of the InSAR processing were used to direct field activities in the summer of 2007. In all cases where significant movement was identified using InSAR, field observations confirmed active movement.

Not all known landslides, however, were identified using the InSAR results. Vegetation at lower altitudes results in incoherence between successive SAR images. In addition, since the ERS satellite is a side-looking instrument, and only descending scenes were used, resulting in no coverage of the eastward facing steep slopes. It is unfortunate that very few ascending scenes are available in the ERS archive for Norway.

4 DETAILED SITE CHARACTERIZATION

The Gamanjunni rockslide (Figure 4) is located on a west-facing mountain at 1200 metres elevation and is bounded by two back-scarps. This block volume is estimated at

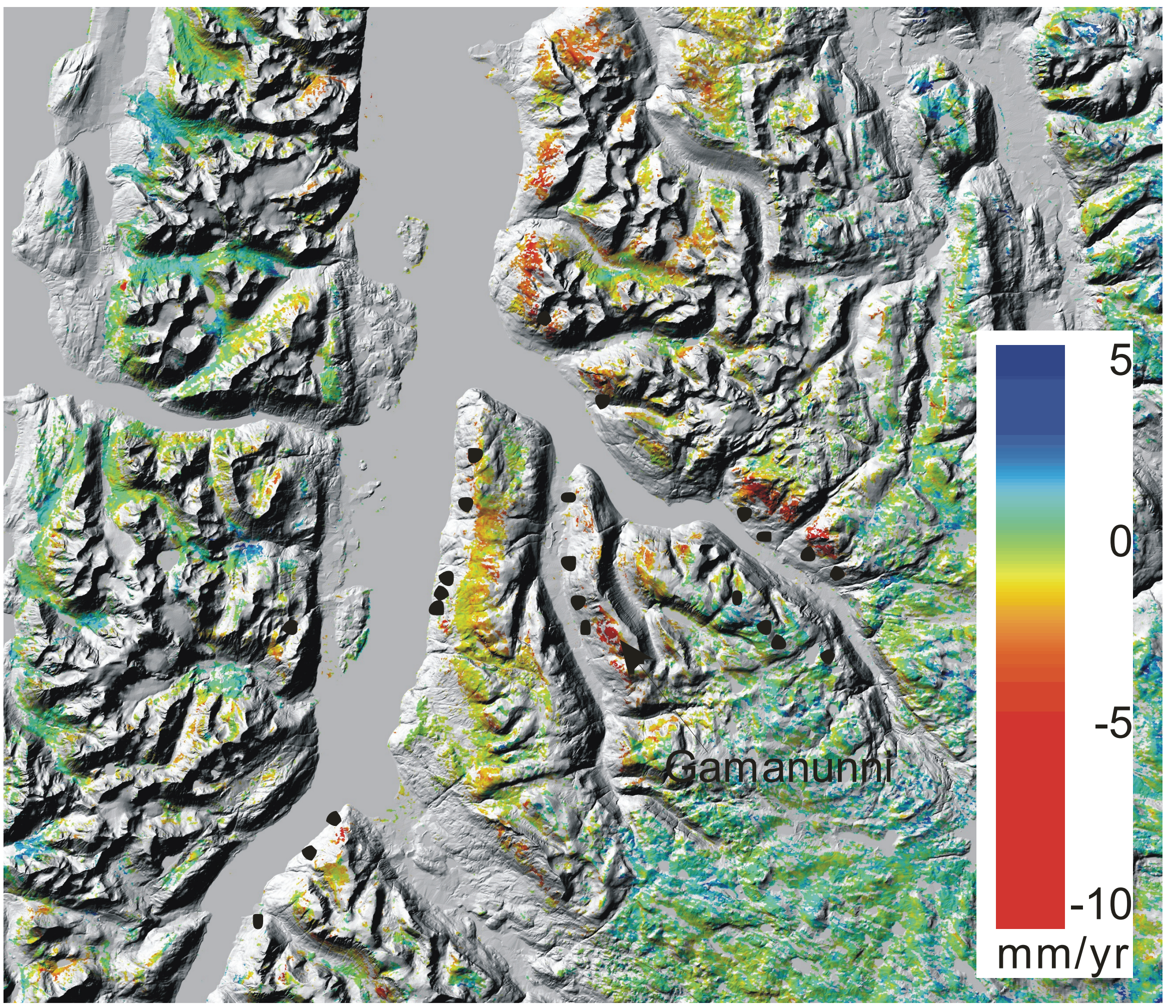

Figure 3. InSAR results from the Lyngen peninsula and Kåfjord. The area shown is 65 x 55 kilometres. Black dots represent areas visited in the field during 2007. The average velocity from 1992 to 2000 is shown in mm/yr. Details of the Gamanjunni rockslide are shown in Figure 4.

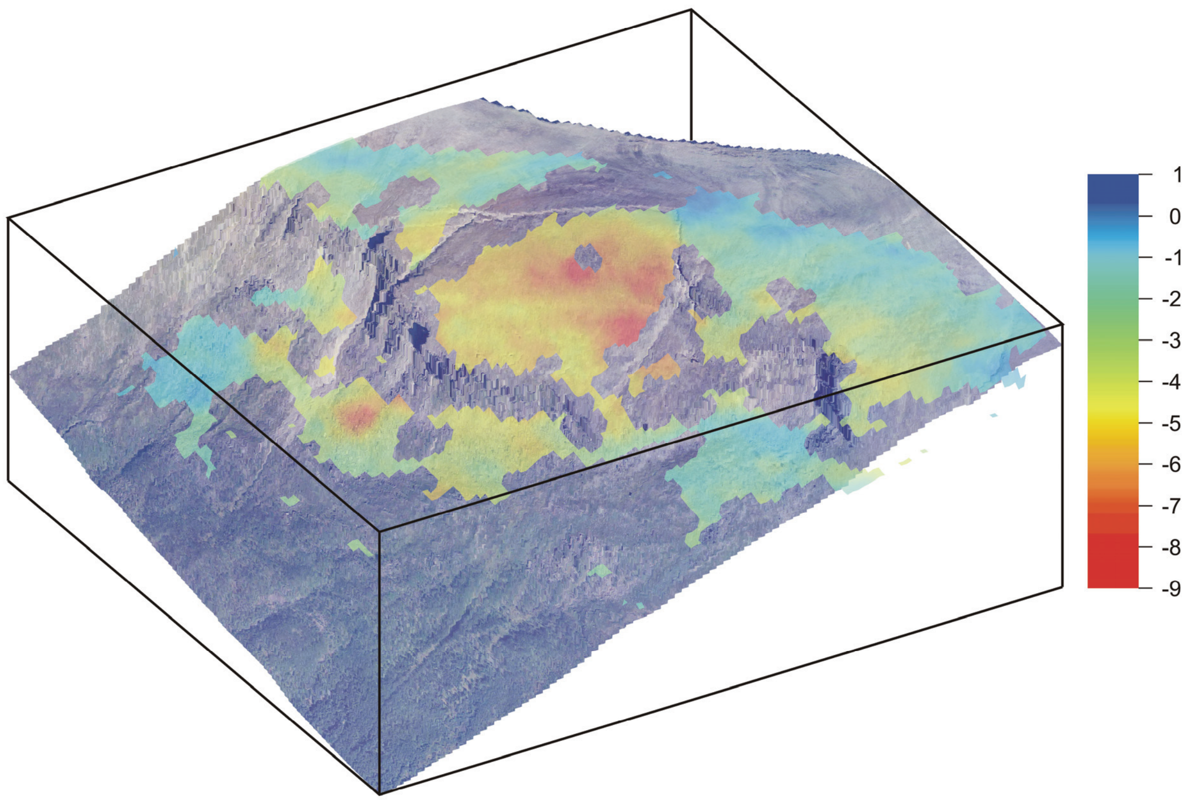

Figure 4. Gammanjunni rockslide is located in Troms County. The area shown in the figure is just over 2 kilometres on each side. The average velocity from 1992 to 2000 is shown in mm/yr.

approximately $17 Mm^3$, and is therefore among the biggest potential landslides in Norway.

On the outcrop scale, the InSAR results are in close agreement with field observations. The spatial extent of the InSAR movement area fits extremely well with the area delimited by the active structures. The block is subsiding at approximately 5-10 mm per year relative to the surrounding mountainside. Field evidence suggests that some fault segments have been active at different times and that previously active fault segments, which are now extinct, have been superseded by younger, more active faults, which are accommodating movement at the present day. This is also reflected in the details of the InSAR data.

5 CONTINUED MONITORING AND USE OF ARTIFICIAL REFLECTORS

In addition to identification and characterization of landslides, we are using InSAR for monitoring of a number of known landslides, as well as subsidence in the urban areas of Norway. Regular acquisitions of Radarsat and ENVISAT images in both ascending and descending modes are scheduled, and images are delivered by ftp within hours of acquisition.

At some sites, steep topography and vegetation limit the number of natural reflectors identified. In these cases, we have installed artificial corner reflectors (Figure 5). The reflectors are covered to prevent snow accumulation, thus allowing new data to be collected throughout the year. Reference reflectors are installed on the moving blocks, as well as on presumed stable areas above the slides. PSI processing is done on just the reflectors, as the surrounding terrain is incoherent all winter due to snow cover. The limited number of coherent points makes atmospheric correction difficult. Nonetheless, clear displacement trends are measurable.

Figure 5. Artificial corner reflector installed on a moving block on the north side of Tafjord. After installation, the reflectors are covered to prevent snow accumulation.

At the Åknes landslide, in western Norway, we also have seven permanent GPS stations collecting data. Two of these stations are collocated with reflectors. A third reflector is approximately 200 metres from the nearest GPS station, but is believed to be on the same moving block. The two datasets are compared in Figure 6.

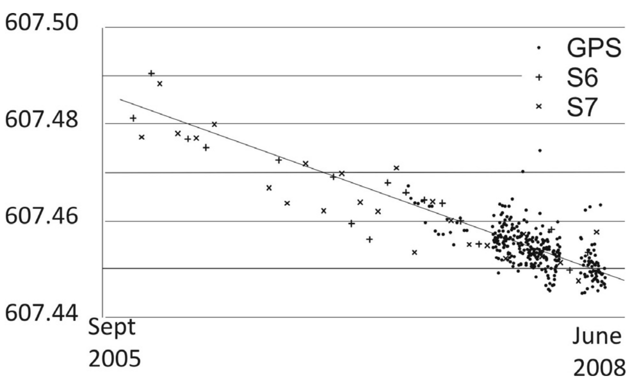

Figure 6. Elevation (metres) vs time as derived from permanent GPS and InSAR for the centre of the Åknes landslide. ENVISAT data from S7 and S6 image modes were processed independently. Both GPS and InSAR datasets are affected by changing atmospheric conditions, but show an average vertical displacement of 13 mm/yr.

The large elevation difference between the base station and the rest of the GPS network leads to difficulties in correcting for atmospheric effects. The same is true for the InSAR data. Nonetheless, a clear downwards displacement is evident and the velocities derived from the InSAR processing and the GPS match very closely.

6 CONCLUSIONS

Persistent Scatterers Interferometry has proven to be an invaluable tool for regional scale landslide mapping. The SBAS algorithm provides good coverage, even in non-urban areas. An area of 10,000 km^2 can be processed in about a week or less, allowing rapid screening for significant movements. Not all landslides can be identified, but large areas can be determined to be stable, allowing field activities to be focussed on areas with detected movement.

The millimetric precision of velocity determination, combined with the relatively high spatial resolution, allows detailed site characterization of many large landslides. In addition to determining if a block is moving, we can discern subtleties such as differential velocities along a fault scarp.

Although InSAR cannot be considered a replacement for ground based monitoring of active landslides, it provides an important complementary dataset, even in winter when other survey methods may not be possible.

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