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REPORT

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Title:

Preliminary analysis of InSAR data over Trondheim with respect to future road development

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Summary:

Timely identification of subsidence is important in order to ensure that remediation efforts are successful. Even if subsidence cannot be prevented or stopped, it must be accounted for in new construction planning. Identification and monitoring of ground deformation can be accomplished using a number of surveying techniques. Levelling and GPS are both expensive and the number of benchmarks that can be controlled is limited.

Since the early 1990's satellite-based radar interferometry has been used to identify large ground movements due to earthquakes and volcanic activity. Data stacking methods that take advantage of a growing archive of radar images, as well as increasing computing power, have led to a large increase in the precision of the technique. Both linear trends and seasonal fluctuations can be identified using the Permanent Scatterers technique.

In the current project, standard processing was performed on two independent series of radar images covering the Trondheim region. By processing two sets of images, we obtained two independent datasets that could be compared at a regional and local scale. The pattern of subsidence is identical where the datasets overlap.

It is proposed that a more detailed processing be carried out over a smaller area of interest. This will result in an increased data density as well as a more accurate velocity field. Future monitoring will be possible with the use of images from the Radarsat 1 and 2 satellites.

Keywords:	Subsidence	Interferometry
Urban geology	Fjernanalyse	Fagrapport

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1. INTRODUCTION

Timely identification of subsidence is important in order to ensure that remediation efforts are successful. Even if subsidence cannot be prevented or stopped, it must be accounted for in new construction planning. Identification and monitoring of ground deformation can be accomplished using a number of surveying techniques. Levelling and GPS are the most common. Both are expensive and the number of benchmarks that can be controlled is limited.

Since the early 1990's satellite-based radar interferometry has been used to identify large ground movements due to earthquakes and volcanic activity. Data stacking methods that take advantage of a growing archive of radar images, as well as increasing computing power, have led to a large increase in the precision of the technique. Numerous studies of urban subsidence using radar interferometry have been published (Amelung et al., 1999; Fruneau and Sarti, 2000; Galloway et al., 1998). Both linear trends and seasonal fluctuations can be identified (Colesanti et al., 2003a; Colesanti et al., 2003b).

NGU has successfully used radar interferometry to detect fault movements, landslides and subsidence (Dehls et al., 2002; Dehls and Nordgulen, 2003a, b). In this report, we present preliminary results from the Trondheim region and discuss the potential for more detailed measurements and future monitoring relative to the construction of the Nordre avlastningsveg and E6 øst.

2. DIFFERENTIAL SAR INTERFEROMETRY (DINSAR)

Differential SAR Interferometry (DInSAR) is a technique that compares the phases of multiple radar images of an area to measure surface change. It first became well known after an image of the Landers Earthquake deformation field was published in the journal Nature in 1993 (Massonnett et al., 1993). The method has the potential to detect millimetric surface deformation along the sensor – target line-of-sight.

A radar satellite emits pulses of radar energy, which are scattered by the Earth's surface. When such a pulse of radar energy is reflected back to the satellite, two types of information are recorded. The first information recorded is the amplitude of the signal. This is the information displayed in typical SAR images (Figure 1). The amplitude is influenced by factors such as the surface material, the slope of the surface and surface moisture content.

Figure 1. SAR image showing Ranafjorden and Svartisen glacier, July 1995.

The second information recorded is the phase of the wave. ERS satellites have a radar wavelength of 5.66 cm. The phase of the wave upon return depends primarily on the distance between the satellite and the surface. It is also affected by changes in the atmosphere, but this is a very small effect.

Differences in phase between two images are easily viewed by combining, or interfering, the two phase-images. In the resulting image, the waves will either reinforce or cancel one another, depending upon the relative phases. The resulting image is called an interferogram and contains concentric bands of colour, or fringes, that are related to topography and/or surface deformation.

If two images are acquired from different positions within a small period of time, the difference in phase can be used to determine the surface topography (Figure 2). If two images are acquired of the same area from the exact same position, any difference in phase is due to movements of the ground surface toward or away from the satellite during the time between the two images.

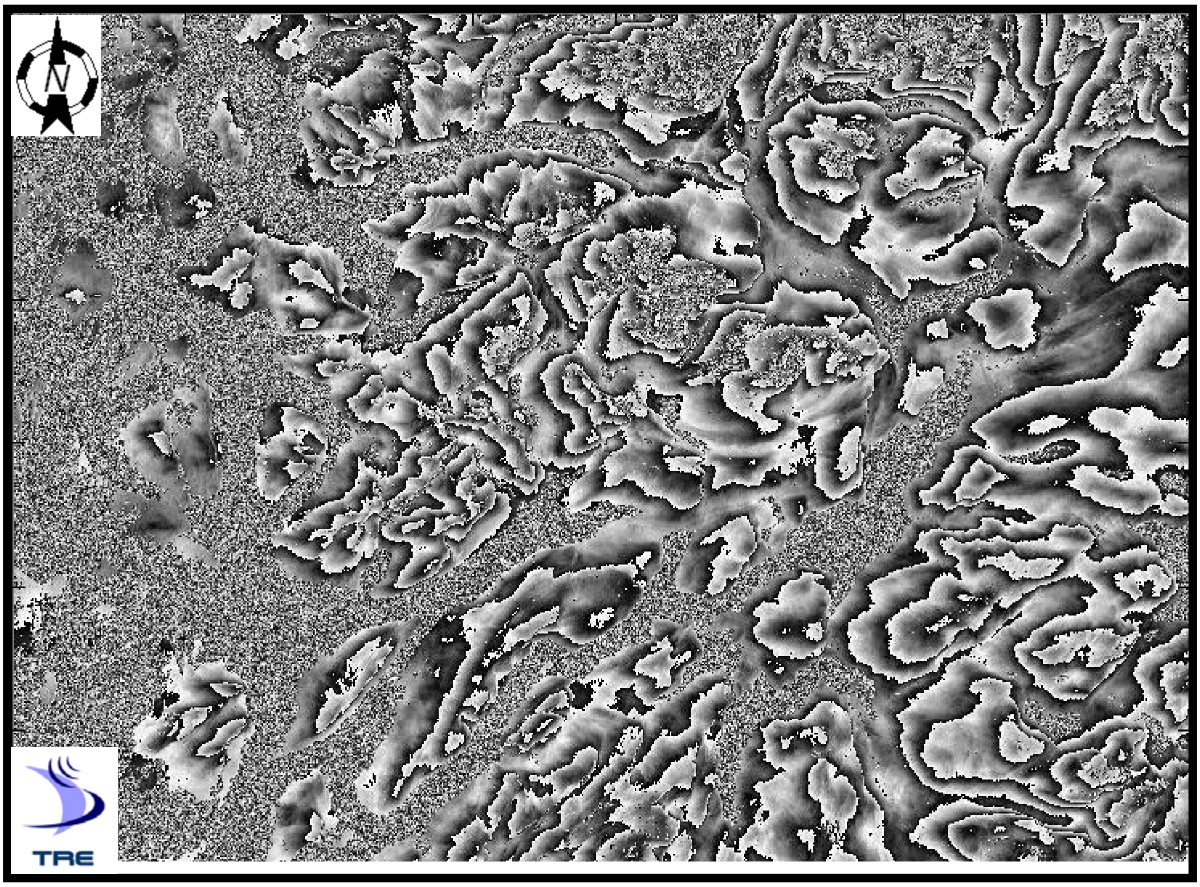

Figure 2. SAR interferograms obtained from a pair of images acquired July 15 and 16, 1995, by the ERS-1 and ERS-2 satellites. The area is the same as Figure 1. Fringes are related to topography.

Since it is nearly impossible to obtain two images of the same area from exactly the same point at two different times, three images are typically used to analyse surface change. First, an image pair taken during a short interval is used to determine the topography. Second, an interferogram is created using two images with a longer time interval. The effects of topography are removed using the results of the first interferogram, and the resulting image contains fringes due to surface deformation. Each fringe represents one-half wavelength of surface movement. In the case of the ERS satellites, this is less than 3 cm.

Radar interferometry has one stringent condition that must be met in order for it to work. The many small reflective objects contributing to each pixel must remain unchanged, or *coherent*, between images. Decorrelation may occur due to variations in the complex reflectivity of individual sampling cells as a function of the acquisition geometry (geometric decorrelation) and/or time (temporal decorrelation). In addition, atmospheric phase screen, mainly due to the effect of the local water vapour content, can be difficult to discriminate from ground deformation.

2.1 Permanent Scatterers Technique (PSInSAR)

The SAR processing group at Politecnico di Milano has developed a new method based upon the identification of stable natural reflectors (called permanent scatterers) that are coherent over a long period of time (Ferretti et al., 2001). These permanent scatters (PS) can be identified and used in many images over a long period of time.

The PS approach is a two-step processing technique aimed at isolating the different phase terms (atmospheric phase screen, deformation and residual topography) on a sparse grid of phase stable, point-wise radar targets. The PS approach is based on the exploitation of long time-series of interferometric SAR data (at least 25-30 images). The technique is able to overcome both main limiting factors: PS are only slightly affected by decorrelation and can be used to estimate and remove the atmospheric phase screen.

The sparse PS grid can be thought of as a high spatial density (up to 400 PS/km2, in highly urbanized areas) geodetic network allowing ground deformation measurements (along the line-of-sight direction) with millimetric accuracy (0.1-1 mm/yr on the average line-of-sight deformation rate and 1-3.5 mm on single measures).

Since Permanent Scatterers mainly correspond to portions of man-made structures, and a minimum PS density is required to guarantee the measurements reliability, most significant PS results have been obtained analyzing urban areas and their immediate neighbourhood. The PS approach allows the identification of isolated phase-stable targets in low coherence areas. These provide precise surface deformation data in areas where a conventional DInSAR approach fails due to decorrelation noise.

3. OVERVIEW OF RESULTS

In the current project, standard processing was performed on two independent series of radar images. This was possible due to the large overlap between images from neighbouring orbits at this high latitude. 40 images from track 423 and 38 images from track 151 were processed, covering the time period 1992 to 2001. One of the gyroscopes onboard the ERS-2 satellite failed on January 7, 2001, and very few images acquired since then have been of sufficient quality to use for interferometry.

By processing two sets of images, we obtained two independent datasets that could be compared at a regional and local scale. In addition, since the acquisition geometry was slightly different, only a subset of the PS in the two dataset corresponds to the same objects. Thus we obtained a higher total density of measurements.

Figures 3 and 4 show the two velocity fields. The PS density is clearly related to the density of man-made structures. The highest density, in the city center, is over 500 PS/km^2 in track 423 and over 700 PS/km^2 in track 151.

Since the two datasets were processed independently, each has its own arbitrarily chosen reference point, which is considered stable. For this reason, the velocity values vary slightly from one dataset to the other. Nonetheless, the pattern of subsidence is identical where the datasets overlap.

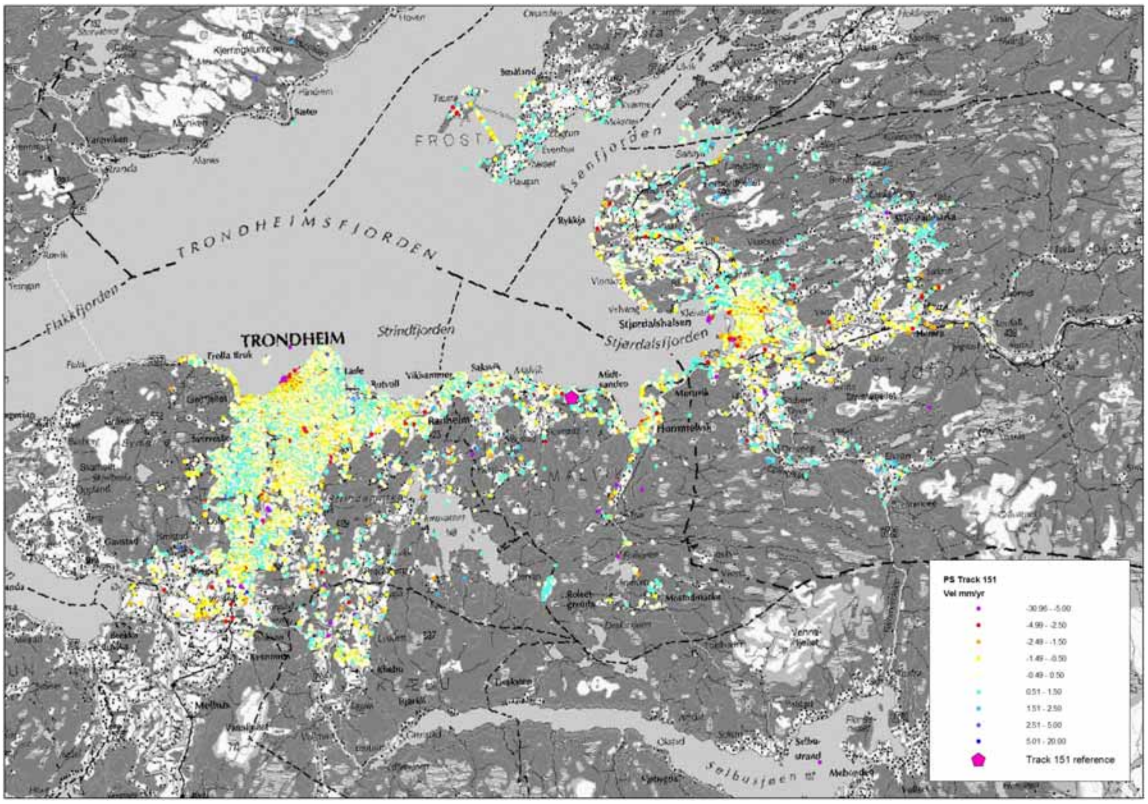

Figure 3. Average line-of-sight velocity field over the Trondheim – Stjordal region determined from SAR images along track 151. All velocities are relative to the purple reference point, which is assumed to be stable.

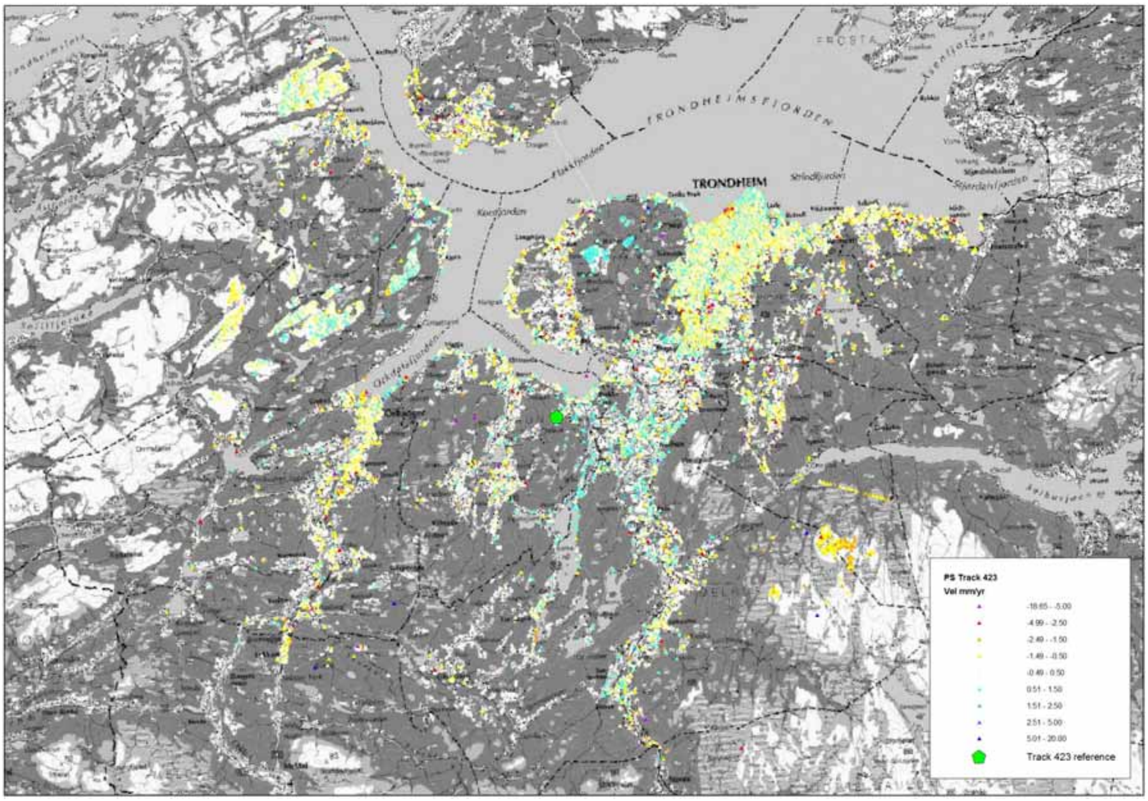

Figure 4. Average line-of-sight velocity field over the Trondheim – Orkanger region determined from SAR images along track 423. All velocities are relative to the green reference point, which is assumed to be stable.

3.1 Nordre avlastningsveg and E6 øst

Maps 1 and 2, submitted along with this report, show the results of both datasets along the Nordre avlastningsveg and E6 øst respectively. Several points must be kept in mind when interpreting the velocity values.

- All values are relative to one of the arbitrarily chosen reference points that are assumed to be stable. Relative movement between the two reference points results in a difference in the velocity values for a given area.

- The standard deviation of velocity errors increases with distance from the reference point. For both datasets in this study, the reference point is quite distant from the area of interest.

- As stated earlier, the velocity given is the velocity along the line-of-sight to the satellite, which is on average 23° from the vertical. If the true movement direction is not along this line-of-sight, the velocity is an underestimate of the true velocity. This is especially true if there is a large horizontal component.

The density of data points along both road projects is sufficient to give a general picture of the subsidence pattern prior to construction start. Further processing can be done to increase the density and quality of the data.

4. FUTURE PROCESSING AND MONITORING POSSIBILITIES

4.1.1 Standard Processing vs. Advanced Processing

The results presented in this report are based upon standard processing of a very large area. Standard PS processing is fully automatic, with quality checks performed only on the final results. A linear rate of movement is assumed and search parameters are optimized to process areas up to several thousand square kilometres.

Advanced processing can be performed on smaller areas once ground motion is identified. The main differences with advanced processing are:

- finer sampling grid of the focused and fitted data.

- lower thresholds for atmospheric phase screen estimation and removal to obtain a higher PS density.

- ad hoc procedures are carried out for a better detection of seasonal motion or abrupt steps in rate of movement. No "a priori" models on the PS behaviour are imposed.

- manual control by the operator for a better refining and calibration of the processing parameters.

We suggest that the area of interest be reprocessed using the advanced processing chain. A reference point that is known to be stable can be chosen close to the centre. Data density is expected to increase significantly. In addition, it will be possible to extract time-displacement curves for individual data points.

4.1.2 Future monitoring

The Permanent Scatters technique is based upon the availability of a time-series of SAR images. With the failure of gyroscope 1 onboard ERS-2 on January 7, 2001, very few images have been of sufficient quality to use for interferometry. The ESA satellite ENVISAT, launched in March 2002, is in the same orbit as ERS-2 and able to obtain very similar images using it's ASAR instrument. It is possible to combine ERS and ASAR images to do PS analysis. Unfortunately, the ASAR instrument currently only acquires images upon request. A 'background mission' has begun but it is still unclear how often the database of images will be updated. If we wish to study ongoing deformation, a new and more reliable source of images must be decided upon.

The images for a given geographic area must be acquired using the same beam mode and geometry and must be acquired as regularly as possible. The Canadian Radarsat satellites offer the stability and reliability necessary to build up an archive of SAR images over Norway that can be used for current and future ground motion studies. Radarsat-1 was launched in November 1995. Radarsat-2 is expected to be launched in 2006.

In January 2003, the Norwegian Space Centre (Norsk Romsenter) signed an agreement with the Canadian Space Agency that assures access to Radarsat data to Norwegian public authorities. The agreement was based primarily on the need for scan-SAR images along the Norwegian coast to support ship detection and oil pollution applications. However, there is provision for the acquisition of a number of scan-SAR and standard mode scenes over the mainland. The main users of these data will be NVE (snow water equivalent determination) and NGU (ground motion detection and monitoring). In June 2004, Kongsberg Spacetec began to acquire images over Trondhiem and Oslo on the recommendation of NGU. It is hoped that we can sufficient scenes by mid 2005 to begin monitoring critical areas. Although the raw satellite scenes will be available for free or a nominal cost, processing costs will have to be borne by the end users.

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