DEFORMATION ANALYSIS OF THE TRONDHEIM CITY FROM SAR INTERFEROMETRY

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ABSTRACT

Trondheim is a coastal city in central Norway, which lies on the south shore of the Trondheim Fjord. Because of the river Nidelva, which runs through the city, floods, erosion and landslides, are occurring in and along the river. Therefore, displacement monitoring of the city is important. In this study, 31 SAR images acquired in a descending track from TerraSAR-X are used to assess ground deformation in Trondheim during 2012–2014. The data is processed using InSAR time-series technique of Small BAseline Subset (SBAS) approach. The results show displacement with peak value of approx. -10 mm/yr on the coastal area and more than -5 mm/yr in the clayey areas along the river. We found that the spatial pattern of the displacement field is correlated with the deposit thickness.

1. INTRODUCTION

Floods, erosion and landslides naturally occur in and along Norwegian rivers. Trondheim city is located in central Norway. It is a coastal city, lying on the south shore of the Trondheim Fjord (see Fig. 1). There are some areas with deposit thickness of more than 100 m, especially besides the river Nidelva, which runs through the city. Flood, erosion and landslide may cause considerable damage to houses, roads and other infrastructure situated along the river.

In January 2012, a massive landslide took place just south of Trondheim leading to evacuation order of people from a rural area. Unusual warm winter weather as well as violent storm across Scandinavia, which dumped massive amounts of rain on Trondheim, may have contributed to the landslide.

Trondheim is the third largest city in Norway. Because of its special location, climate change and rapid urbanization, assessment and characterization of ground deformation in Trondheim is important. Ground deformation is the most evident expression of geological and natural hazards. In regions like Trondheim, risk managers and local administrations need this information to plan effective prevention measures and implement warning systems. Even if ground deformation 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. These techniques have been evolved using Global Navigation Satellite Systems (GNSS) [1-3], but for large areas, the use of GNSS and leveling are time consuming, expensive and laborious.

In contrast to the surveying techniques that rely on point measurements at the Earth surface, Interferometric Synthetic Aperture Radar (InSAR) overcomes many practical limitations and readily provides high-resolution measurements of at sub-cm accuracy over relatively large areas [4-6]. Advanced time-series techniques of Persistent Scatterer (PS) and small baseline methods [7-9], enable the retrieval of deformation time-series and velocity maps from SAR data [10-14].

In this study, we use 31 SAR images from TerraSAR-X to assess deformation during 2012–2014. The data is processed using InSAR time-series technique of small baseline approach, implemented in StaMPS software (http://radar.tudelft.nl/~ahooper/stamps).

At a subsequent step, we investigate the correlation between InSAR-derived results and surficial deposit thickness, which has been observed in several boreholes by the Norwegian geological survey (NGU) organization (red colored circles in Fig. 1).

In addition, the correlation of the displacement time-series with the meteorological information, temperature, precipitation, water level, and groundwater will be investigated. The locations of the meteorological stations are shown in Fig. 1. The temperature and groundwater data have been provided by the Norwegian Water Resources and Energy Directorate (NVE), the precipitation data by the Norwegian Meteorological Institute, and the water level by the Norwegian Mapping Authority.

2. DATA AND METHODOLOGY

31 SAR images acquired in a descending track from TerraSAR-X in stripmap mode are used to assess

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deformations during 2012–2014. The interferometric processing was achieved using the repeat-pass technique implemented in DORIS software [15]. The Digital Terrain Model was provided by the Norwegian Mapping Authority with a resolution of 10 m for topography phase correction and geocoding. The interferometric dataset includes 86 differential interferograms with minimal spatial, temporal and Doppler baselines, which are processed using InSAR time series technique of small baseline approach [9], implemented in StaMPS software. The processing in StaMPS is done in three main steps. They are (1) generation of small baseline interferograms, (2) selection of coherent pixels, and (3) phase unwrapping and least squares inversion. One of the main challenges in InSAR processing is related to atmospheric delays. We have considered atmospheric delays in our computations. Different correction methods exist. Complexity of our study area requires further investigation of atmospheric effects.

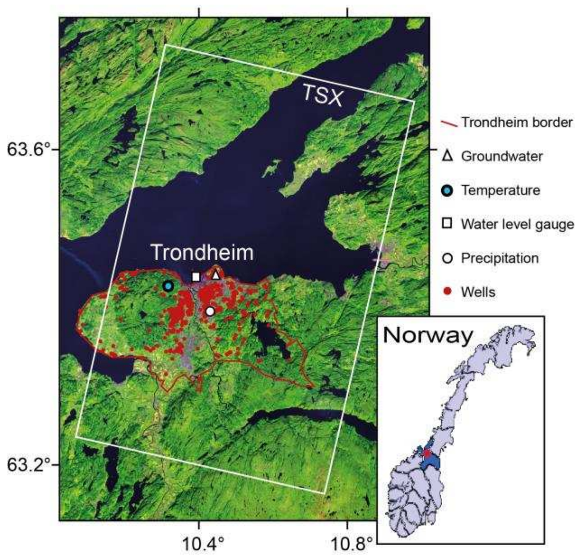

Figure 1: Landsat-8 image of the study area. Inset at the bottom right indicates the location of Trondheim city in Norway. Rectangle shows the frame of TerraSAR-X used in this study.

3. RESULTS

Fig. 2 (a) shows the preliminary displacement velocity map along the line-of-sight (LOS) direction in the year 2012-2014 derived from TSX data, and overlaid on Google Earth image. The map shows that the displacement is occurred in the area ranging from more than -10 mm/year to approx. 10 mm/yr in the LOS direction. We can identify 3-4 important deformation areas.

Displacement time series relevant to the points labelled A, B, and C in Fig. 2 (a) have been illustrated in Fig. 2 (b, c, d). The time series of the point A, located in coastline depicts the cumulative displacement of approx. 25 mm in two years (Fig. 2b). The point B, which is located in the clayey area (the white polygons in the map), shows the displacement of approx. -15 mm in this time-period with some fluctuations (Fig. 2c). For the point C that is located in the rocky area with positive deformation rate, the cumulative LOS motion reaches to about 15 mm (Fig. 2c). It should be mentioned, since the velocity map is a function of fluctuations in time-series data, it requires long period and dense satellite data in different imaging geometries and sensors.

With the average look angle of 26 degrees and the heading of 193.79 degrees, the unit vector of the LOS direction in the coordinate system (east, north, up) is approximately (0.42, -0.10, 0.89). Therefore, the sensor is most sensitive to vertical deformation, but east-west displacement will also appear in the result.

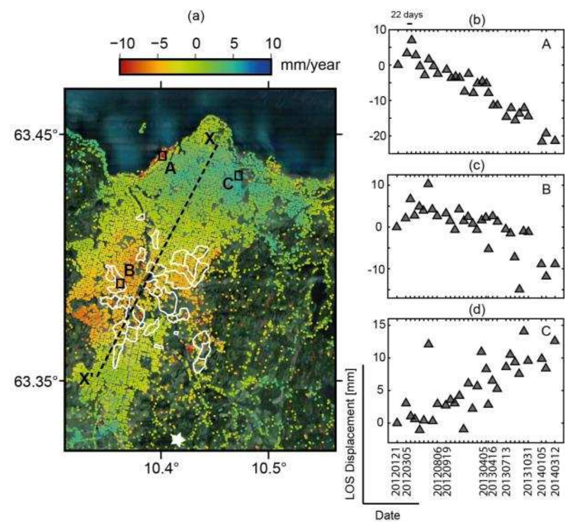

Figure 2: (a) Displacement velocity map along the LOS direction in the year 2012-2014 derived from TSX data, and overlaid on Google Earth image. The white polygons in the map show the areas with clayey layers. The white star depicts the reference area. (b, c, d) displacement time series in points A, B, and C (in Fig. 2 a).

4. DISCUSSION

4.1. Coastal displacement

Fig. 3 depicts the LOS displacement rate profile along the coastline (in the range of the frame in Fig. 2a). The profile shows that the displacement along the coastline is mainly between -4 mm/yr to 5 mm/yr. However, two parts of the coast in 4-6 km and 12-14 km have been affected by the deformation of more than -12 mm/yr and -4 mm/yr, respectively.

The area in 4-6 km in Fig. 3 is the river delta and has been filled by different kinds of building materials up to 5-10 m depth, while the area in 12-14 km is located in rocky layers and filled up recently. Therefore, these areas are in the preliminary consolidation phenomenon, and according the Fig. 2b are subsiding steadily.

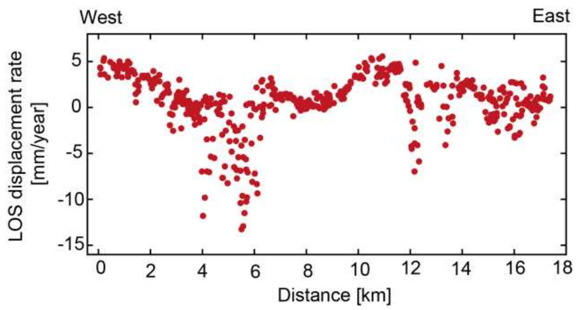

Figure 3: LOS displacement rate profile along the coast

4.2. Spatial correlation

The white polygons in the Fig. 2a show the areas with clayey layers. It can be seen that these regions are adversely affected by the displacement rate of more than ~-5 mm/yr.

To investigate further the deformation pattern in the area we extracted a profile along XX' (In Fig. 2a). Fig. 4 (a) shows the profile. As it can be seen, the displacement rate has been increased in both sides of the Nidelva River in the regions having clayey layers. We also plotted the thickness of the surficial deposit along XX' (the wells have been shown in Fig. 1 with red circles). We find that greater displacement rate occurs close to the clayey areas with a major deposit thickness. The consolidation of the layer will be more due to self-overloading pressure if the thickness is more.

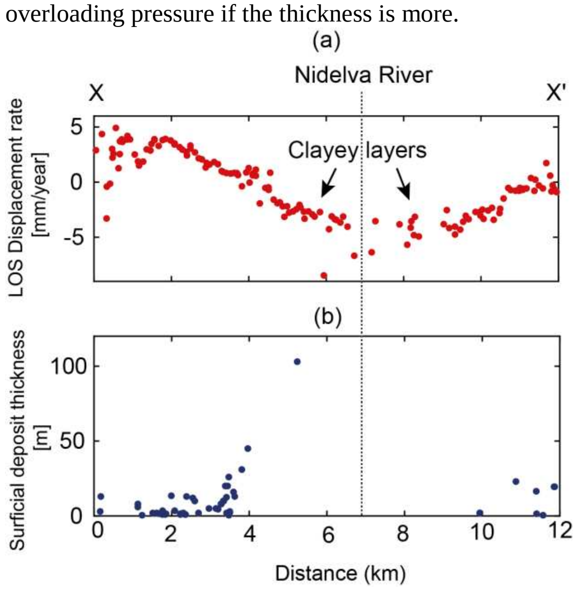

Figure 4: (a) LOS displacement rate, and (b) the thickness of the surficial deposit along XX'. The dotted line shows the location of the Nidelva River.

4.3. Temporal correlation

We have also shown the temporal variation of de-trended temperature, de-trended water level, precipitation, and groundwater with the average LOS displacement of the clayey areas in Fig. 5. Although we can see some relations between the meteorological data and the LOS displacements, we do not consider these meteorological data as the main triggering cause of displacement. The study region is located in an area marked by geodynamic and geological complexity, and finding out the reason of displacement is a challenging task. Several hydrogeological factors, climate, surface roughness, vegetation, and many other factors should be investigated to obtain a comprehensive conclusion [16]. We need longer and denser SAR data to draw a better conclusion.

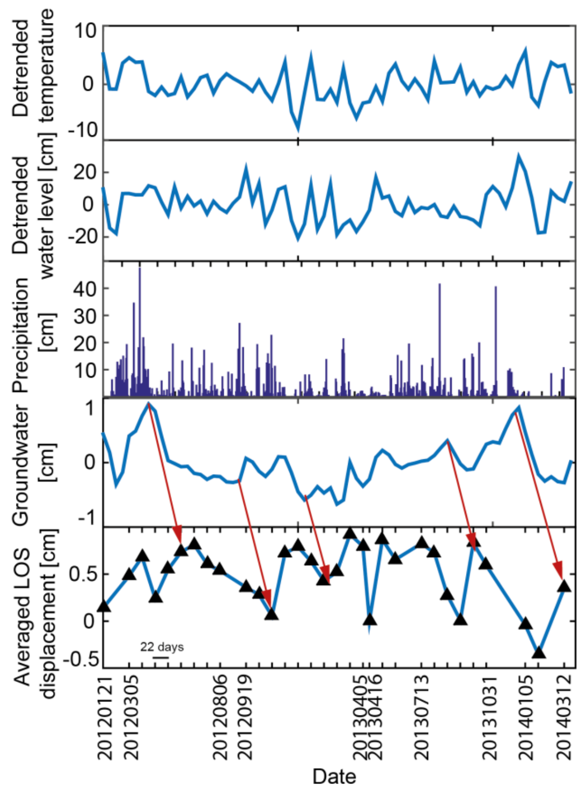

Figure 5: De-trended temperature, de-trended water level, precipitation, groundwater, and averaged LOS displacement of the clayey areas LOS displacement rate. The location of the stations have been illustrated in the Fig. 1

4.4. Post Glacial Rebound (PGR)

It is worth noting that according to the Fig. 6, the study area is affected by the PGR. This means that our results include the PGR as seen in the Fig 6.

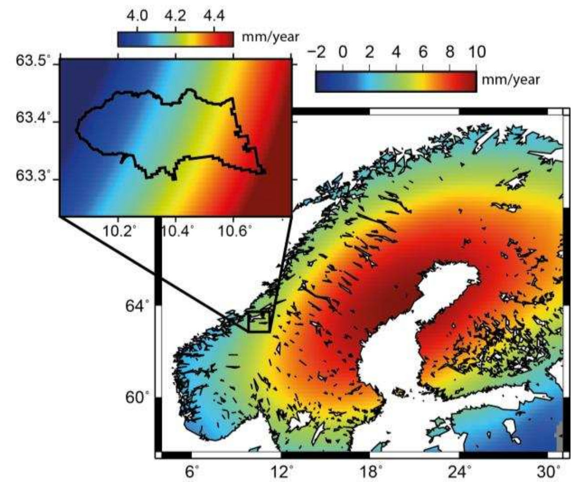

Figure 6: PGR in Norway. Inset at the top left indicates the PGR in Trondheim city (provided by the Norwegian Mapping Authority)

5. CONCLUSION

Using X-band InSAR time-series survey, we mapped the displacement in Trondheim city, Norway. The results showed a clear indication of deformations, with a peak value of more than -10 mm/yr, especially on the harbour area of the city and clayey areas during 2012-2014. We also investigated the spatial correlation between InSAR derived deformation and the thickness of deposit, and temporal correlation with metrological information. We found that there is a correlation between displacement rate and the deposit thickness. Geodynamic and geological complexity of the study area make it difficult to interpret the causes and origins of ground displacements. In addition, the study area is covered with urban and rural developments, which is located on the coast that makes the investigation even more complicated. We will utilize the C-band and L-band SAR images to be able to decompose the LOS result into three directions. In addition, increasing the time series data (Radarsat-2, Sentinel-1, and ALOS-2) will help the correlation investigations.

6. REFERENCES

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