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Radar-based remote sensing monitoring of roads

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ABSTRACT

This paper provides a brief description of two powerful radar-based remote sensing techniques to monitor the deformations of roads, their associated infrastructures and, more in general, their surroundings. The first technique is the satellite radar interferometric technique. In this work a specific technique, named Persistent Scatterer Interferometry (PSI), is considered. This technique has wide-area coverage capability (e.g. covering thousands of square kilometres at the time) and, at the same time, is sensitive to very subtle displacements. The second technique, named ground-based radar interferometry is based on a terrestrial instrument. From the viewpoint of the deformation measurement principle this second technique is very similar to the first one. However, it can be used to cover much smaller areas but offering a very dense temporal sampling capability (e.g. one measurement every a few minutes). This is typically used to monitor critical deformation phenomena, e.g. very active landslides that may represent a high risk for a given road, etc. This work provides, for both techniques, a concise description with several references to major works related to them. In addition, it illustrates some examples of the results that can be achieved with both techniques.

Keywords: Deformation, vibration, Synthetic Aperture Radar, Real Aperture Radar, satellite.

1 INTRODUCTION

This paper describes two powerful radar-based remote sensing techniques that can be used to monitor the deformations associated with roads, infrastructures and, more in general, their surroundings. The two techniques are briefly introduced below:

- Satellite radar interferometry and, in particular, the Persistent Scatterer Interferometry (PSI) technique are deformation monitoring techniques, which are sensitive to millimetric displacements. PSI can be used to monitor deformation of roads, bridges other infrastructures and, more importantly, the surroundings of roads, getting an overview of the phenomena (e.g. landslides) that might influence a give road network. This technique has wide-area coverage capability (up to 1'000 km^2 for X-band high-resolution data and up to 10'000 km^2 for C-band medium-resolution data), which makes it suitable to monitor very wide regions.
- Ground-based radar interferometry, also known as Ground-based Synthetic Aperture Radar (GBSAR) is a terrestrial deformation monitoring technique which is very similar to the previous one: it uses the same measurement principle. It can be used to monitor parts of roads that are particular critical, e.g. a road infrastructure affected by a very active landslide. The main advantage of this technique is its capability to monitor continuously a given deformation over time with a dense sampling: this make is suitable to support decision-making during emergencies.

The paper is organized as follows. Section 2 briefly describes satellite radar interferometry and, in particular, the PSI technique. The same section illustrates some deformation monitoring examples related to roads. Section 3 introduces the GBSAR technique, illustrating an example of GBSAR monitoring result. Section 4 contains the conclusions of this work.

2 SATELLITE RADAR INTEFEROMETRY: PSI

PSI is a radar-based remote-sensing technique to measure and monitor land deformation [1,2]. The deformation over time is estimated by exploiting the phase of Synthetic Aperture Radar (SAR) imagery and by using the interferometric technique. This technique requires the acquisition of at least two SAR images over the same area. In order to use the PSI technique the minimum number of required images is typically between 15 to 20 images. PSI represents the most advanced category of satellite radar interferometry techniques. Different PSI approaches have been proposed in the last decade [2-7]. The availability of SAR data acquired by space-borne sensors represents a key issue for the successful use of PSI. In particular, image acquisition continuity over large periods of time plays a fundamental role in PSI. The first satellite that allowed demonstrating the potentialities of the PSI technique was ERS-1. This satellite has been operative for 10 years and, more importantly, together with ERS-2, has provided a valuable historical archive of interferometric SAR data. ERS satellites have provided global spatial coverage over a time period of 19 years, with the first images dating back to 1991. There are hundreds of high level scientific publications that demonstrate the success of the ERS mission. Radarsat-1 and ASAR-Envisat have also been particularly important PSI data sources.

A new generation of sensors has been launched in the last years, including the C-band Radarsat-2 (launched in December 2007 by the Canadian Space Agency), the X-band TerraSAR-X (launched in June 2007 by the German Aerospace Centre, DLR, and EADS Astrium GmbH), and the X-band COSMO-SkyMed (Constellation

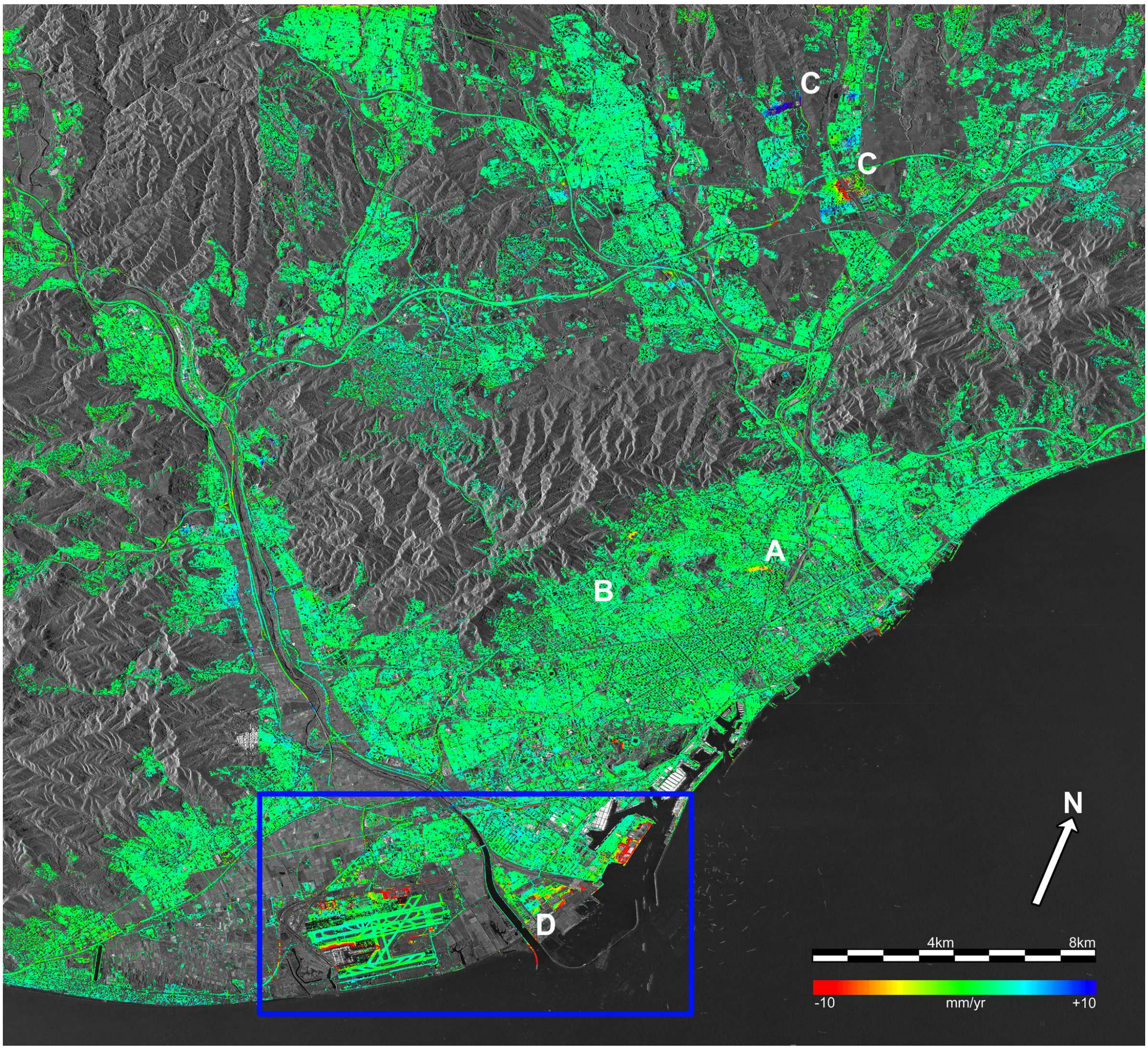

Figure 1. Deformation velocity map over the metropolitan area of Barcelona. The blue frame highlights the area affected by most of the deformation phenomena: the airport and the port of Barcelona.

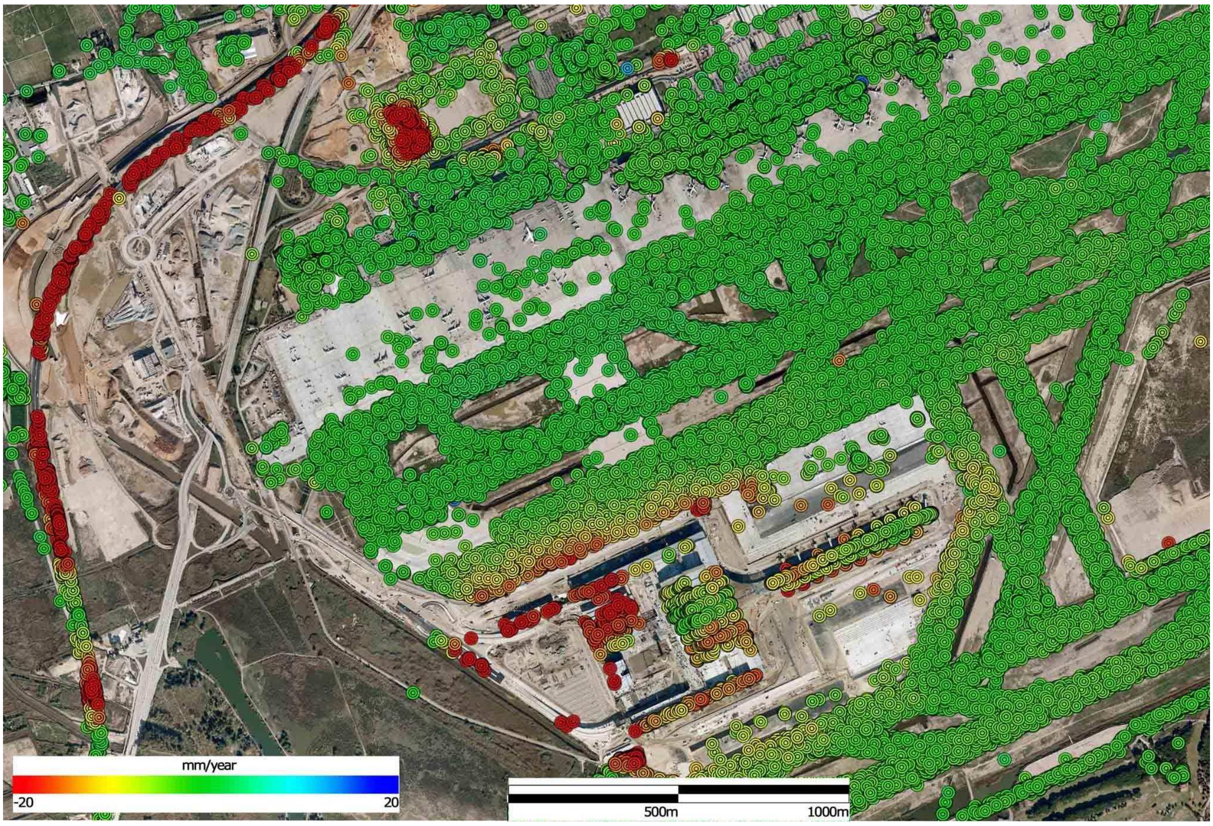

Figure 2. Deformation velocity map over the airport of Barcelona (centre-left) and over the C-31 highway (right).

of small Satellites for the Mediterranean basin Observation) by the Italian Space Agency, ASI. The last two systems, TerraSAR-X and COSMO-SkyMed are particularly promising due to their very high spatial resolution imaging capabilities and the use of the X-band. The following section describes some examples of PSI results based on a rich set of TerraSAR-X images. These images were processed using the PSI in-house experimental software chain of CTTC (former Institute of Geomatics).

2.1 Examples of PSI monitoring of roads

The PSI results shown in this section cover the metropolitan area of Barcelona. They were derived using a very high resolution X-band SAR dataset composed by 28 StripMap images acquired by the sensor onboard the satellite TerraSAR-X. The dataset covers a time period that starts in December 2007 and ends in November 2009. The images used in this work cover approximately 30 by 50 km, with a pixel footprint of about 1.9 by 1.6 m; they were acquired with an off-nadir angle of 35.5º. The perpendicular baselines of the interferograms based on these images (i.e. the component of the vector that connects the two satellite positions during image acquisition, measured in the direction perpendicular to the SAR line-of-sight) are in the range of -275 m to 500 m.

A first example of deformation monitoring over a wide area is shown in Figure 1. This deformation velocity map covers the entire metropolitan area of Barcelona: more than 1000 km^2 are monitored at the time, using a single technique. This allows us getting a global overview of the deformation phenomena occurring in the entire area, including several cities, industrial areas, valuable infrastructures (e.g. the airport and the port of Barcelona) and, more importantly, a big network of roads.

The second example, shown in Figure 2, is focused on the airport area, which is subjected to different types of deformation phenomena. On the left side of this figure there is an interesting deformation result that concerns a new part of the C-31 highway: most parts of this road undergo subsidence, which is probably due to recent construction of this part of the highway.

The third example concerns a road of the municipality of Barcelona, which gives access the Montjuïc area. The two blue circles shown in Figure 3 highlight two deformation areas that affect the road and that are probably associated with landslide phenomena.

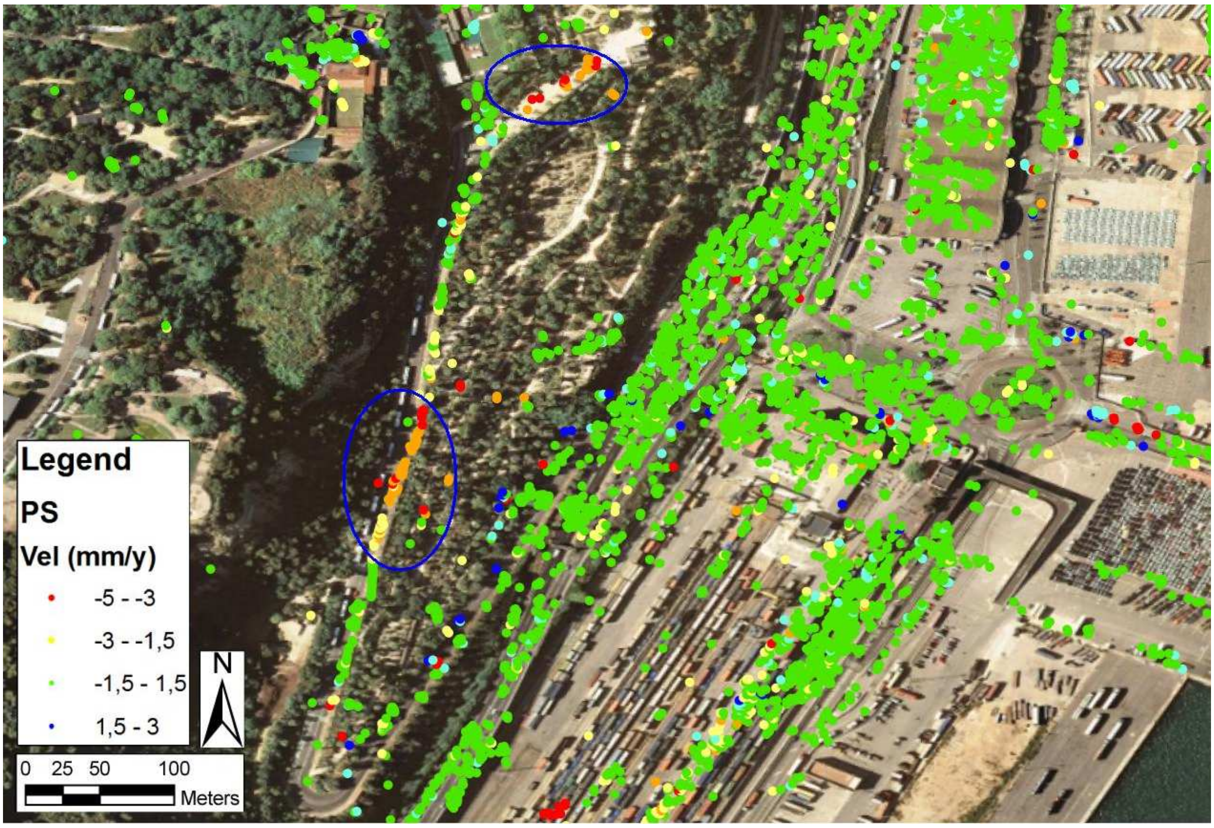

Figure 3. Example of deformation in one of the roads to access the Montjuïc area in Barcelona.

3 GROUND-BASED SAR

In the last years GB-SAR, a radar-based terrestrial remote sensing imaging system [8], has gained an increasing interest as a deformation measurement and monitoring tool. The GB-SAR is a coherent system, which measures not only the amplitude but also the phase of the received radar signal. The phase measurements can be exploited, by using interferometric techniques, to derive information on the deformation and topography of the measured scene. The main GB-SAR application is deformation monitoring, where the high sensitivity to small deformations, the long range of measurements (up to several kilometres) and the imaging capability, which allows the system to perform a vast number of measurements, are interesting characteristics that make the GB-SAR system complementary to other deformation measurement techniques.

Most of the GB-SAR studies published in the literature concern landslide monitoring, where the GB-SAR can offer good performances with respect to other measurement techniques, such as total stations or terrestrial laser scanners. Several authors use a GB-SAR for slope monitoring in a continuous mode, i.e. leaving the instrument installed in situ during the whole monitoring period [9-12]. Reference [13] describes a discontinuous monitoring experiment based on artificial reflectors. This approach is usually appropriate to monitor slow or very slow displacement phenomena. The GB-SAR monitoring of manmade structures is discussed in [14-15]. GB-SAR has been used to monitor a number of natural phenomena such as urban subsidence [16], glacier displacements [17] and volcano slopes [18]. Finally, the GB-SAR has been successfully used as a tool for monitoring slopes in open pit mines [19].

3.1 GBSAR monitoring examples

The monitoring result shown in Figure 4 concerns a landslide located in the Pyrenees: the Formigal landslide. Starting from 2004, and due to the construction of a new parking area, the landslide has been reactivated, producing important damages to the international road A-136, which connects Spain to France, and to the same parking. The system used in this case was an experimental GBSAR developed by the University of Florence. It worked in the so-called C-band, with a wavelength of 5.03 cm, and a cross-range resolution of 12 mrad, i.e. with a pixel footprint of 12 m at a distance of 1 km from the radar (and 1.2 m at 100 m).

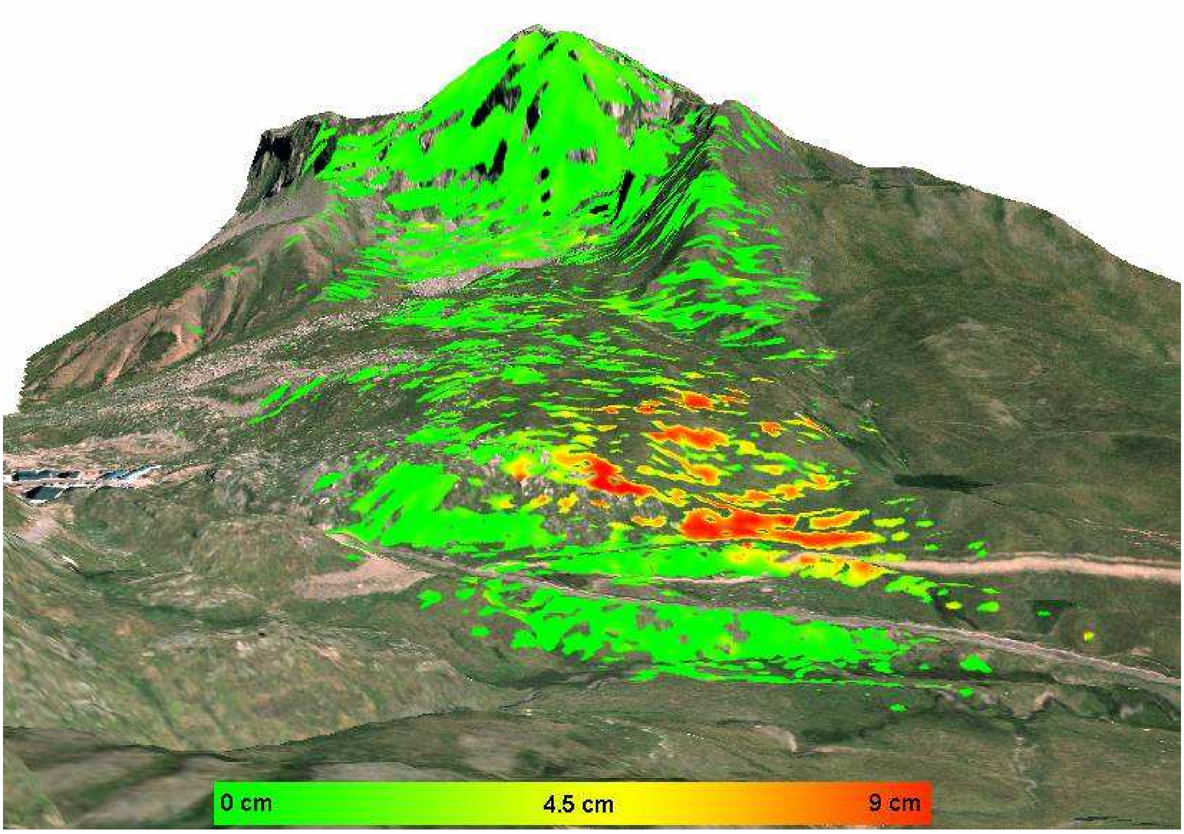

Figure 4. Deformation estimated by GBSAR during a 45-day campaign in Formigal, Spanish Pyrenees.

The campaign lasted 45 days, acquiring approximately one image per hour. Figure 4 displays the accumulated deformation over the entire period. In the deformation area the maximum displacement is 9 cm. This is an interesting result that can contribute to the characterization of this landslide: in the specific case these data were used to build a numerical landslide model.

5 CONCLUSIONS

In this paper two powerful remote sensing techniques have been described, which can be used to monitor roads, their associated infrastructures and, more in general, their surroundings. The satellite-based technique offers the unique capability of monitoring very wide areas at the time, obtaining a synoptic view of the ongoing deformation phenomena. This may represent a valuable source of information for the authorities and private companies in charge of the maintenance of roads and other assets. It is worth noting that, besides its wide area coverage, satellite interferometry can focus on relatively small or thin objects, like single buildings, thin infrastructures, etc.

GBSAR represents a versatile and complementary deformation monitoring tool. It can measure deformation with a precision that ranges from sub-millimetres to a few millimetres. It has the capability of measuring independently of the atmospheric conditions at distances up to some kilometres. This is a key advantage with respect to other techniques like terrestrial laser scanner or topographic total stations. It has a dense sampling capability, which represents an advantage with respect to point-like measurement techniques, like GPS, total stations, etc. And, finally, the whole GBSAR deformation monitoring process can be highly automated: it can be used as an operational monitoring tool, even during emergencies.

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5 REFERENCES

[1] Rosen, P.A., Hensley, S., Joughin, I., Li, F., Madsen, S., Rodríguez, E., Goldstein, R. 2000. Synthetic Aperture Radar Interferometry. *Proc. of the IEEE*, 88 (3), pp. 333-382.

[2] Crosetto, M., Crippa, B., Biescas, E., Monserrat, O., Agudo, M., Fernández, P. 2005. Land deformation monitoring using SAR interferometry: state-of-the-art. *Photogrammetr. Fernerkundung Geoinformation*, 6, pp. 497-510.

[3] Ferretti, A,, Prati, C., Rocca, F., 2001. Permanent scatterers in SAR interferometry. *IEEE Transactions on Geoscience and Remote Sensing*, 39(1), pp. 8-20.

[4] Berardino, P., Fornaro, G., Lanari, R., Sansosti, E. 2002. A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. *IEEE Transactions on Geoscience and Remote Sensing*, 40(11), pp. 2375-2383.

[5] Colesanti, C., Ferretti, A., Novali, F., Prati, C., Rocca, F. 2003a. SAR monitoring of progressive and seasonal ground deformation using the Permanent Scatterers Technique. *IEEE Transactions on Geoscience and Remote Sensing*, 41(7), pp. 1685-1701.

[6] Lanari, R., Mora, O., Manunta, M., Mallorquí, J.J., Berardino, P., Sansosti, E. 2004. A small-baseline approach for investigating deformations on full-resolution differential SAR interferograms. *IEEE Transactions on Geosciences and Remote Sensing*, 42(7), pp. 1377-1386.

[7] Crosetto. M., Biescas, E., Duro, J., Closa, J., Arnaud, A. 2008. Quality assessment of advanced interferometric products based on time series of ERS and Envisat SAR data. *Photogrammetric Engineering and Remote Sensing*, 74(4).

[8] Tarchi, D., Rudolf, H., Luzi, G., Chiarantini, L., Coppo, P., Sieber, A.J. 1999. SAR interferometry for structural changes detection: A demonstration test on a dam. *Proc. of IGARSS 1999*, Hamburg, Germany, pp. 1522–1524.

[9] Pieraccini, M., Casagli, N., Luzi, G., Tarchi, D., Mecatti, D., Noferini, L., Atzeni, C. 2002. Landslide Monitoring by Ground-Based Radar Interferometry: a field test in Valdarno (Italy). *International Journal of Remote Sensing*, 24, 1385–1391.

[10] Leva, D., Nico, G., Tarchi, D., Fortuny, J., Sieber, A.J. 2003. Temporal analysis of a landslide by means of a ground-based SAR interferometer. *IEEE Transactions on Geoscience and Remote Sensing*, 41, 745–752.

[11] Tarchi, D., Casagli, N., Fanti, R., Leva, D., Luzi, G., Pasuto, A., Pieraccini, M., Silvano, S. 2003. Landslide monitoring by using ground-based SAR interferometry: an example of application. *Engineering Geology*, 68 (1–2), 15–30.

[12] Herrera, G., Fernandez-Merodo, J.A., Mulas, J., Pastor, M., Luzi G., Monserrat, O. 2009. A landslide forecasting model using ground based SAR data: the Portalet case study. *Engineering Geology*, 105 (3-4), 220-230.

[13] Luzi, G., Monserrat, O., Crosetto, M., Copons, R., Altimir, J. 2010a. Ground-Based SAR interferometry applied to landslide monitoring in mountainous areas. *Proceedings of the Mountain Risks conference*, 24-26 November 2010, Florence, Italy.

[14] Tarchi, D., Rudolf, H., Pieraccini, M. Atzeni, C. 2000. Remote monitoring of buildings using a ground-based SAR: Application to cultural heritage survey. *International Journal of Remote Sensing*, 21 (18), pp. 3545–3551.

[15] Luzi, G., Crosetto, M., Monserrat, O. 2010b. Advanced Techniques for Dam Monitoring. *II International Congress on Dam Maintenance and Rehabilitation*, 23-25 November, Zaragoza, Spain.

[16] Pipia, L., Fabregas, X., Aguasca, A., Lopez-Martinez, C., Mallorqui, J., Mora, O. 2007. A Subsidence Monitoring Project using a Polarimetric GB-SAR Sensor. *Proc. of the 3rd Int. Workshop POLinSAR*, 22-26 January 2007, Frascati, Italy.

[17] Luzi, G., Pieraccini, M., Mecatti, D., Noferini, L., Macaluso, G., Tamburini, A., Atzeni, C. 2007. Monitoring of an Alpine Glacier by Means of Ground-Based SAR Interferometry. *IEEE Geoscience and Remote Sensing Letters*, 4 (3), 495-499.

[18] Casagli, N., Tibaldi, A., Merri, A., Del Ventisette, C., Apuani, C., Guerri, L., Fortuny-Guasch, J., Tarchi, D. 2009. Deformation of Stromboli Volcano (Italy) during the 2007 eruption revealed by radar interferometry, numerical modelling and structural geological field data. *J. of Volcanology and Geothermal Research*, 182 (2009), 182–200.

[19] Mecatti, D., Macaluso, G., Barucci, A., Noferini, L., Pieraccini, M., Atzeni, C. 2010. Monitoring open-pit quarries by interferometric radar for safety purposes. *Proc. of European Radar Conference (EuRAD)*, 30 September-1 October 2010, Paris, France, pp. 37-40.