Abstract Code: EP8

Differential SAR interferometry for slow-moving landslide monitoring in Crotone Province (Italy)

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Keywords
SAR interferometry – Landslides – Coherent Pixels Technique – State of activity

INTRODUCTION

The Italian territory is strongly affected by ground instability phenomena. Recent estimates made by the Ministry of the Environment and Protection of Land and Sea affirm that about 70% of Italian towns are located in landslide hazardous areas. The main reasons are due to the geological and geomorphological settings, as well as to the poor physical-mechanical properties of the involved materials. Landslide phenomena characterized by slow to moderate kinematic, are among the most widespread in Central and Southern Italy: some examples can be found at Agnone (Berti et al., 2003; Fortuna, 2006; Calcaterra et al., 2008), Calitri (Hutchinson & Del Prete, 1985; Parise & Wasowski, 1996; Calò et al., 2009, 2012), Montaguto (Guerriero et al., 2013), Moio della Civitella (Calcaterra et al., 2008; Calò et al., 2009; Di Martire et al., 2014), Maierato (Gattinoni et al., 2011). These slope movements are characterized by a long evolutionary history, involving several reactivations of the already deformed mass, due to rain, seismic events or to human activities. Unfortunately, nowadays severe damage due to this kind of disasters are still recorded, which makes their monitoring an issue of paramount importance. One of the most important innovations in monitoring is surely represented by the remote sensing. Among the recent techniques the Differential Interferometry SAR (DInSAR) is an useful tool for mapping ground movements, as landslides (Colesanti & Wasowski, 2006; Cascini et al., 2010; Di Martire et al., 2011; Calò et al., 2012; Herrera et al., 2013; Ciampalini et al., 2014; Wasowski & Bovenga, 2014). For this paper, a dataset of Very High Resolution (VHR) images, deriving from TerraSAR-X satellite constellation has been used, which cover almost the whole Crotone Province (Southern Italy). Crotone province has been strongly affected by landslides during the last years: many cases are reported, as Cirò, Papanice, Cutro, San Mauro Marchesato, Santa Severina, among which Cirò was the focus of this paper. Aim of this work is to verify the value of SAR techniques as effective tools for landslide monitoring, also thanks to a comparison with case-studies examined in the past and still under investigation in Campania region by this research team (i.e. Calcaterra et al., 2008; Calò et al., 2009; Di Martire et al., 2014).

SETTING OF THE STUDY AREA

Crotone province is located in the south of the Italian peninsula (Fig. 1). This area is part of a sedimentary basin (Crotone Basin) characterized by a complex evolution (Zecchin et al., 2012). The Crotone Basin is bounded by two major shear-zones, NW-trending, the Rossano-San Nicola shear zone in the northern part and the Petilia Sosti shear zone in the southern one (Meulenkamp et al., 1986; Van Dijk, 1990, 1991; Van Dijk & Okkes, 1990, 1991), which controlled the basin evolution. Cirò town area is located in the northern sector of the Crotone Basin (Fig.1). The base of the stratigraphic series is made up of the Varicoloured Clays, Sandstones of Monte Caciocavallo and Sandstones of Crucoli, all dating to the timespan Eocene-Miocene, meanwhile an angular unconformity separates them from the Ponda Clays formation (Serravallian-Tortonian in age). At the top of the series the Scandale Sandstone formation can be found, of Pliocenic age. Cirò settlement extends on an elongated-shaped hill, NE-SW oriented.

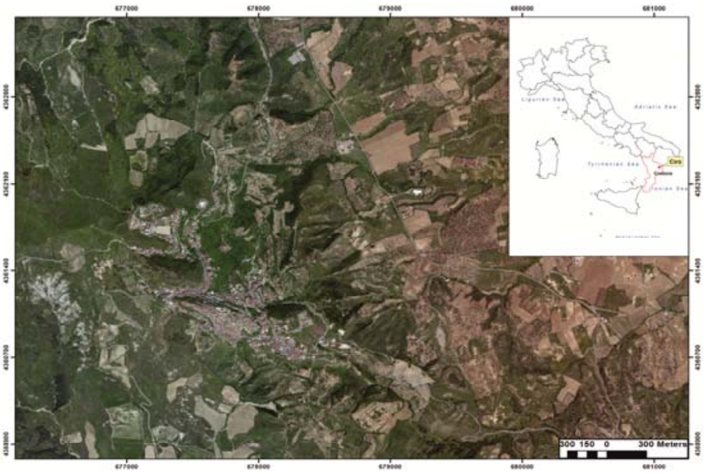

Fig. 1 *Location of Cirò.*

The historic centre was established on sandstones, belonging to the Scandale Formation. The latter is lithologically composed of shallow-marine, medium-to fine-grained deposits, characterized also by sub vertical and intensively jointed cliffs. The landslide-prone condition, especially in the SW facing slope, is due to the geological setting, where the relationship between sandstones and the underlying clayey Argille del Ponda formation, characterized by different permeability, strongly conditioned the water circulation.
Here, in fact, in the night of 1st/2nd February 2011, a landslide occurred in one of the main access road to town centre, causing severe damage and also forcing people to abandon five houses. According to the Cruden and Varnes classification (1996) the movement can be defined as a rotational slide evolving in a earth flow. The landslide crown (Fig.2) is almost vertical, about 5 m deep, causing the excavation of the foundation system of three houses, meanwhile the landslide body is characterized by an extension of about 250 m downslope, and 120 m of width. It is a reactivation of a well-known phenomenon, included in the entirely unstable SW-facing slope, as reported by the Calabria Basin's Authority in the Hydrogeomorphological Setting-Plan (HSP), realized in 2001. One of the most important instability factors is surely represented by the copious rainfalls occurred in this area. In fact, in the days immediately preceding the triggering phase, a cumulated value of rainfall equal to 287 mm has been recorded, with a daily maximum of 125 mm (see Fig.3). These data comes from Crucoli rain gauge, the nearest one (about 7 Km) and the most similar for geomorphological context to Cirò town (Cirò rain gauge has been installed after the landslide).

***Fig. 2** Cirò landslide crown*

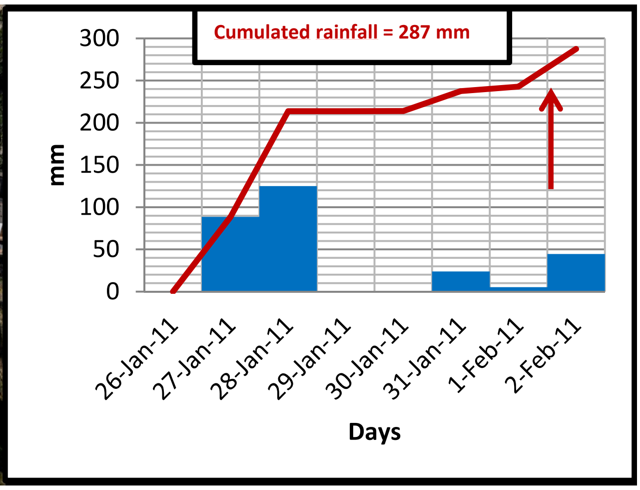

***Fig. 3** Daily rainfall related to the $1^{st}/2^{nd}$ February 2011 Cirò landslide. In red arrow the date of the event.*

MATERIALS AND METHODS

The dataset available for this paper is composed of 35 TerraSAR-X images acquired over descending orbits, covering almost the whole Crotone Province territory, meanwhile the time interval goes from April 2008 to June 2010. The available satellite images have been processed through the SUBSOFT processor, developed at the Universitat Politecnica de Catalunya of Barcelona. Such software is implemented with Coherence Pixels Technique (CPT) (Blanco et al., 2005). The latter, based on Small Baseline Subset (SBAS – Berardino et al., 2002, Lanari et al., 2004) approach, allows to obtain the displacement rate map along the Line of Sight (LOS), focusing on the so-called Coherent Points, (CPs: targets characterized by a stable phase quality in time) and the deformation time series of the reliable selected pixels; more details on this issue can be found in Mora et al., (2003).

RESULTS

Interferometric results have shown several CPs located on the top of the landslide body, thanks to the presence of buildings and roads (targets highly recognizable by this technique). Such CPs indicate displacement rates up to 2cm/year, thus confirming the active state of the landslide, as reported in the 2001 HSP (Fig. 4). Moreover, DInSAR processing, jointly used with a geological-geomorphological survey, made possible to redraw the landslide boundary, which now delimits and area of about 24500 $m^{2,}$ a figure almost twice as large as previously known (Fig. 4c) By comparing the 2001 landslide body and that resulting from this study, a retrogressive and a widening trend can be recognized. Another noticeable result is represented by the comparison between time series, derived from the DInSAR processing, and the precipitations occurred in this area, in the same time-span. It is, in fact, possible to realize that the acceleration phase of the movement corresponds to intense and long rainfall events, unlike during periods with scarce rainfall, when a slowdown of the movement can be noticed (Fig. 5). This remark is in agreement with the general behaviour of slow and intermittent landslides, where there is a strong cause-and-effect relationship between rainfalls and velocity of the instability phenomena. It is also worth to underline that, being the TerraSAR-X database antecedent to the landslide's reactivation, the SAR results are able to recognize precursor stages of a future slope failure. This achievement confirms the ability of SAR techniques to represent powerful monitoring and prediction tools.

CONCLUSIONS

In this work it has been possible to notice how SAR methods represent a powerful tool for landslide prevision and monitoring, especially when coupled with geological and geomorphological field surveys The availability of conventional ground-based monitoring instruments (inclinometers, topographic total stations, etc.) notoriously can further improve the reliability of the satellite observations, which are being considered as an useful supporting tool for urban planning and landslide hazard assessment on behalf of public agencies and administrations. In the ongoing research the results so far obtained will be reconsidered through the implementation of different DInSAR techniques (i.e. SBAS, PS), as to evaluate the related reliability. In the near future these results will also be compared with other case studies in the Crotone province, as well as with some cases located in Campania region, under investigation by this research team.

ACKNOWLEDGEMENTS

TSX data have been provided by the German Aerospace Center (DLR) through the GEO1589 project (P.I. Davide Notti - University of Pavia, Italy). Authors would like to thank Prof. J.J. Mallorquì (Remote Sensing Laboratory of the UPC of Barcelona for the SUBSOFT processor. Thanks are also due to ARPACAL (Regional Agency for Environmental Protection of Calabria Region) for providing rainfall and geological data.

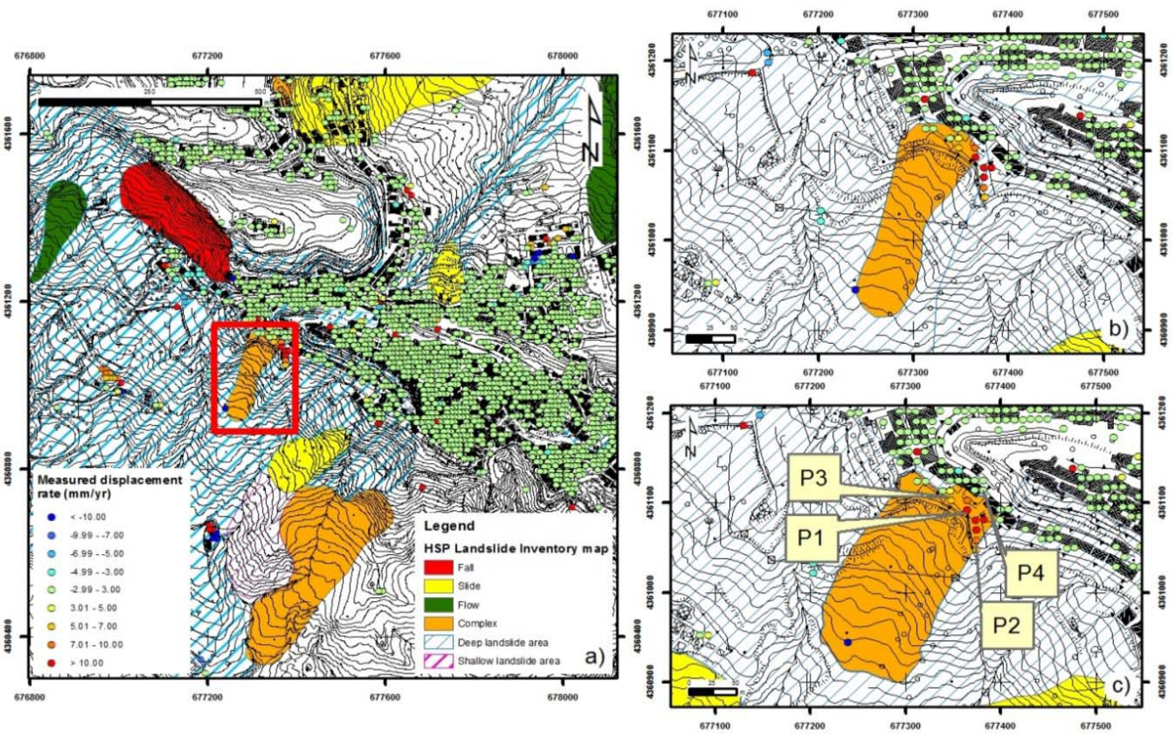

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Fig. 4 *a) Measured displacement rate map of the area of Cirò town; b) Shape of the main active landslide in SW slope, according to the HSP; c) Scarp of the main active landslide along the SW slope, according to field survey and interferometric results. P1, P2, P3, P4= significant selected CPs for time series analysis.*

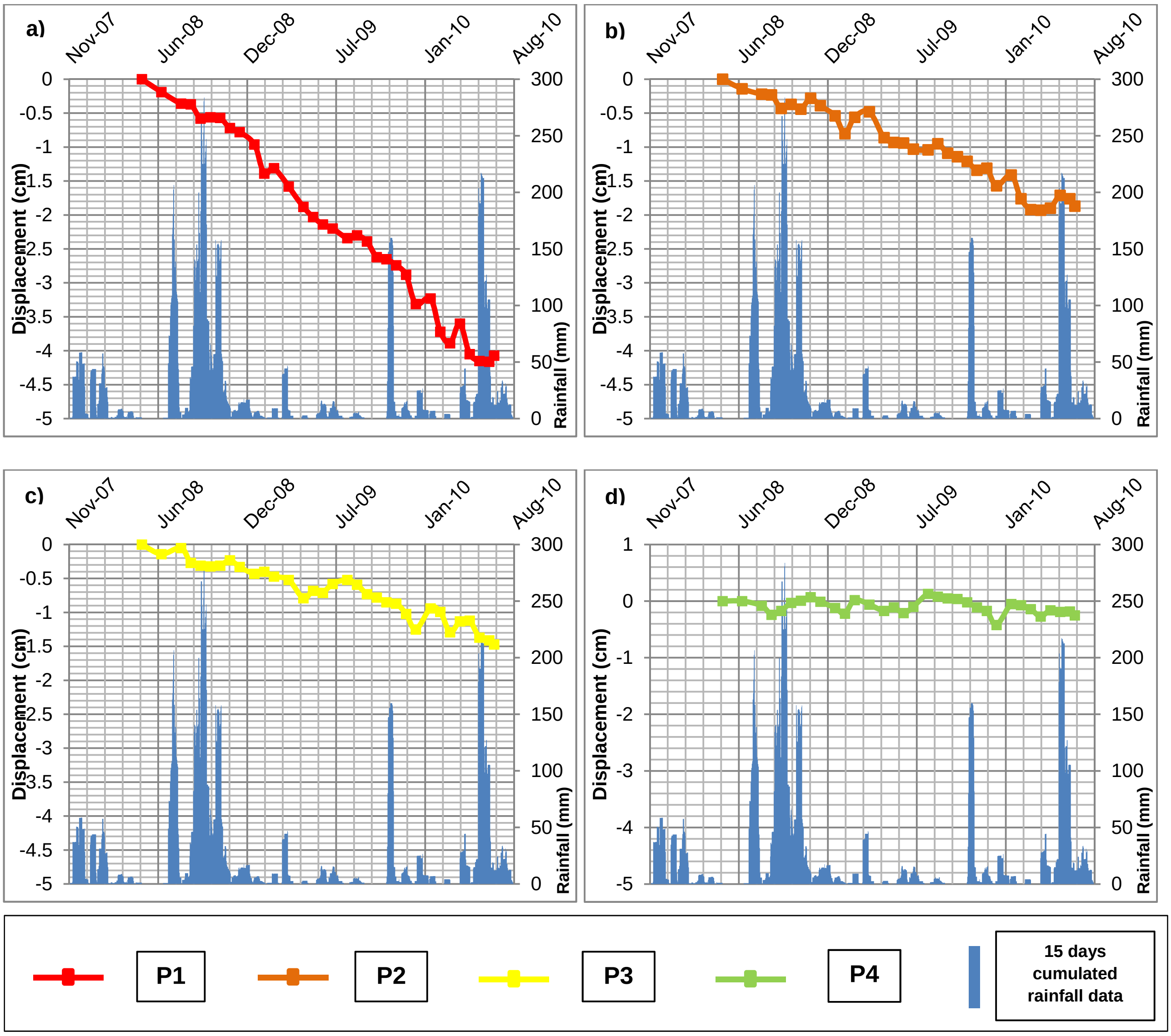

Fig. 5 *Comparison P1 (more than 10mm/yr) - Rainfall data (a). Comparison P2 (between 5 and 7 mm/yr) - Rainfall data (b). Comparison P3 (between 3 and 5 mm/yr) – Rainfall data (c). Comparison P4 (stable point) – Rainfall data (d.)*

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