GROUND DISPLACEMENTS EVALUATION OF AREAS AFFECTED BY SLOPE DEFORMATIONS THROUGH SAR INTERFEROMETRIC INSPECTION: EVIDENCE IN CENTRAL – SOUTHERN ITALY

L. Beccaro[1], G. Dixit Dominus[1], M. Albano[1], M. Moro[1], C. Tolomei[1], M. Saroli[1,2]

[1]Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
[2]Università degli Studi di Cassino e del Lazio Meridionale, Cassino, Italy

Introduction

The activities of the FRASI project (*Integrated and multi-scale approach for the definition of seismic-induced landslide hazard in the Italian territory*) are developed in three Lines of Activities carried out at national, regional and local scale. The main purpose of the project is to define a methodological procedure that addresses the problems related to the mapping of areas potentially susceptible to earthquake-induced landslides. Such procedure is applied to local-scale phenomena to be extended on regional to national scale. The test areas have been selected on the base of the landslide type, the lithology and the morphostructural context. Particular attention is devoted to the analysis of Deep-seated Gravitational Slope Deformations (DGSD), whose movement can significantly affect the stability of infrastructures and the safety of people. To this aim, Synthetic Aperture Radar Interferometry, combined with analytical and numerical modelling, proved to be an accurate support for the monitoring and modelling of different types of landslides (e.g. rotational/translational slides and rock avalanches) [Frattini et al., 2018]. Understanding the factors (e.g. seismicity, geomechanical properties, interaction with underground aquifers) [Moro et al., 2012] that regulate the triggering and the extent of landslide displacements could allow to define the complex dynamics of several types of landslides. In this project, we investigate three different slope movements located in the Italian territory characterized by moderate-to-high seismic hazard (Fig. 1), exploiting the integration of geological and geotechnical data with the satellite SAR data processing. Specifically, the preliminary outcomes resulting from interferometric processing of SAR data are presented in terms of ground displacements. The first case study is represented by a DGSD located approximately 5 km West of Paternò village (Sicilia Region, Southern Italy). Such unknown paleo-landslide was recognized during the studies accomplished on the Etna Volcano eruption in December 2018 [Bignami et al., 2019]. The investigated area is part of the Gela fold and represents the most external sector of the Apennines-Magrebides chain. The site is composed of proximal molassic deposits belonging to the Terravecchia Formation (upper Miocene) consisting of grey-blue and brown marly clays with brown brecciated clays on the top of the formation [Carbone et al., 2010]. The second DGSD is sited approximately 3 km North-West of Pescosolido municipality (Lazio Region, Central Italy), in the southern sector of the Roveto Valley. Structural analysis indicates that the study area experienced a multi-stage tectonic activity, which involved the Latium-Abruzzi carbonate platform sequence and Plio-Quaternary continental deposits [Saroli et al., 2003]. The last results presented are referred to the Pisciotta landslide (Campania Region, Southern Italy), a DGSD situated in the Rizzico locality. The landslide develops in an exceptionally deformed turbidite series composed of intercalated calcarenites, marls and mudrocks [De Vita et al., 2017]. It produced several damages to the surrounding provincial road in the last decades and currently poses an hazard to the national railway that intersects the toe of the landslide.

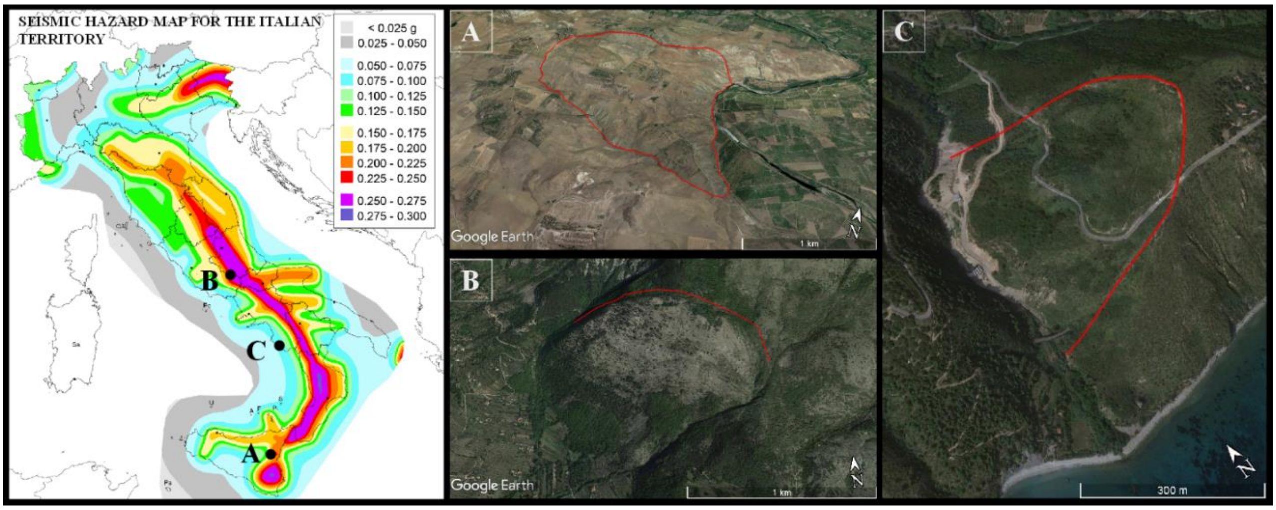

Figure 1 - Seismic hazard map expressed in terms of peak ground acceleration (PGA) for the Italian territory, with a 10% probability of exceedance in 50 years, together with the location of the investigated DGSDs. A) Paternò landside within Sicilia Region, B) Pescosolido DGSD inside Lazio Region, and C) Pisciotta landslide within Campania Region. The red curves identify the approximate boundary of the landslides.

Methods

All the presented products have been obtained by processing satellite SAR data through the SARscape software (sarmap SA, Caslano, CH - https://www.sarmap.ch/), integrated into the ENVI environment (https://www.l3harrisgeospatial.com/Software-Technology/ENVI-SARscape). To investigate the behaviour of the Paternò landslide, two pairs of TOPSAR Sentinel-1 data (C-Band) were used, acquired on 22nd and 28th December 2018, both along the ascending (track 44) and descending (track 124) orbit. DInSAR technique [Massonnet and Feigl, 1998] was applied to generate the interferograms with 15 m ground resolution, allowing to obtain the Line of Sight (LoS) cumulated displacements in the six days timespan.

Regarding the analysis of Pescosolido and Pisciotta DGSDs displacements, a large dataset of SAR images acquired during Sentinel-1 satellite mission has been processed applying the Small Baseline Subset (SBAS) technique [Berardino et al., 2002], one of the most adopted algorithms proposed in the context of multi-temporal methods of Differential SAR Interferometry. We exploited SAR images acquired in descending mode in the 11/01/2015 - 26/02/2020 time interval to determine the movements over time in the Pescosolido area. Instead, the surface displacement recorded at the Pisciotta landslide refers to an ascending dataset encompassing the 12/01/2015 - 23/12/2020 temporal interval. These elaborations are able to reproduce the displacement time series along the satellite LoS in the investigated periods. Therfore, it is possible to understand the displacement evolution over time and eventually detect displacement rate changes related to seismicity or the occurrence of significant damage to roads and human-made infrastructures.

Preliminary results and Discussion

The results of the SAR data processing are shown in Figure 2, by applying simple and advanced interferometry techniques.

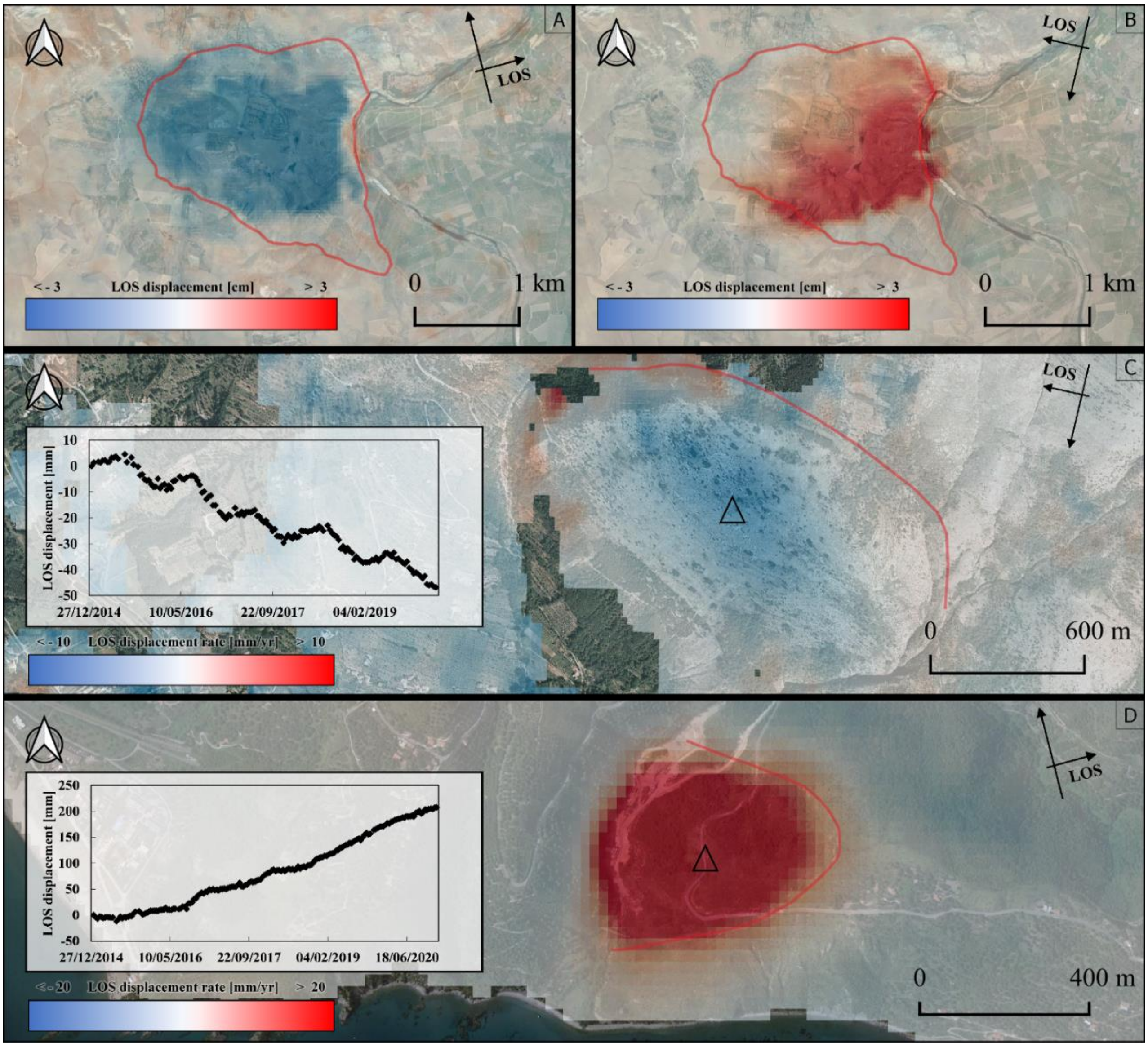

Figure 2 – Results of the interferometric processing: A) Ascending and B) Descending LoS displacement maps obtained for the Paternò landslide. C) Descending displacement map obtained for Pescosolido DGSD and D) Ascending displacement map related to Pisciotta landslide and respective displacement time series plotted at the centre of the landslide area (black triangles).

Figures 2A and 2B show the Paternò landslide displacements evaluated from 22nd to 28th December 2018 along the ascending and descending satellite orbit. The highest displacements, around 6 cm, are reached at the foot of the hill along both orbits and gradually decrease moving towards the DGSD boundaries. The similarity of displacement amplitudes and spatial extents along both satellite trajectories with different signs (negative and positive displacements indicate movements away from and towards the satellite sensor, respectively) suggest that horizontal displacements dominate the actual movement.
Figures 2C and 2D show the displacement rate in millimetres per year for Pescosolido and Pisciotta DGSDs, respectively. Negative LoS velocities, indicating ground movements away from the satellite sensor, were recorded for Pescosolido landslide, while positive LoS velocities, implying ground movements approaching the satellite sensor, were observed for the Pisciotta DGSD. Both the outcomes are consistent with the expected landslides kinematic. The deformation evolution over time is also shown for Pescosolido and Pisciotta landslides thanks to the detailed investigation carried out at the centre of both landslide masses (black triangle in Fig. 2C and 2D). In these areas the average velocities measured along the corresponding LoS can be quantified as about 9 mm/year for the Pescosolido landslide and approximately 35 mm/year for the Pisciotta landslide. Moreover, the deformation time history in the Pescosolido area shows a seasonal behaviour, with an increase in the displacement rate in winter, i.e. from December to January, following the seasonal rainy period. Instead, the Ascea landslide shows an almost linear trend, with a slight increase in displacement rate over time from the end of 2014, suggesting a probable ongoing creep process.

Concluding remarks

In this work, the preliminary results obtained by processing Sentinel-1 SAR data were presented to monitor the ground displacement in specific time intervals. In particular, three slope movements were studied. Regarding the Paternò landslide case study, the outcomes suggest that the DGSD, was reactivated during the seismic swarm that occurred in conjunction with the eruption of Etna at the end of December 2018. The multitemporal processing performed on Pescosolido and Pisciotta landslides revealed clear movements measured along the satellite LoS that agree with the general kinematics of the investigated phenomena. The displacements time series allowed us to evaluate the DGSDs evolution over the considered time span. The results will be used to evaluate possible correlations with external factors such as earthquake and heavy rains. Next analysis will consist on the analytical inversion of the InSAR results to identify the geometry and kinematics of the potential sliding surfaces. The latter should be in accordance with the geological and geomorphological findings that will be observed during the in-situ measurement campaign.
It is believed that such a multidisciplinary approach, including the processing of remote sensing data together with geological, geomorphological, seismological data and modelling procedure, could allow a proper characterization of the DGSDs dynamic, allowing to assess the related hazard.

Acknowledgements

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The Sentinel-1 data are distributed by the European Space Agency free of charge.

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Corresponding author: Lisa Beccaro – lisa.beccaro@ingv.it