Long-Term Analysis of Landslides Via SBAS-DInSAR Technique

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Abstract

Advanced techniques of multi-pass space-borne Differential Synthetic Aperture Radar (SAR) Interferometry (DInSAR) represent a valuable tool in landslide studies allowing to remotely investigate the behavior of mass movements on long time intervals by benefiting of large datasets of SAR images covering the same area and acquired at different epochs. Among these techniques, we apply the Small BAseline Subset (SBAS) approach for analyzing surface deformation at two spatial scales, i.e., regional and local scale.

In this work, developed within the framework of the DORIS FP7-EU project, we investigate mass movements occurred in the Umbria region (central Italy) during the last 20 years, by exploiting ERS-1/2 and ENVISAT SAR images spanning the 1992–2010 time interval. Our two-scale SBAS analysis allowed detecting active landslides over all the study area, and further giving more insights on the spatial and temporal pattern of localized phenomena.

Keywords

Differential SAR Interferometry (DInSAR) • SBAS technique • Umbria region • Italy

Introduction

Landslides threaten many regions in both developed and developing countries, often resulting in high socio-economic impacts on the affected communities. In such a context, the risk management plays a significant role, and focuses on defining appropriate prevention and mitigation strategies. To this aim, a deep understanding of the landslide kinematics is needed and can be effectively reached if long-term monitoring data are available.

Ground-monitoring networks require high management costs especially over large areas and their maintenance over time can result in a difficult task, often hampered by lack of economic resources as well as by technical problems. Space-borne radar sensors provide valuable data that, opportunely processed, can effectively integrate traditional methods of landslide investigation since their capability to "observe" wide areas with high spatial resolution.

In such context, Differential Synthetic Aperture Radar (SAR) Interferometry (DInSAR) is able to retrieve surface displacements with centimeter to millimeter accuracy, by exploiting the phase difference (i.e., the interferogram) between two SAR images acquired over the same area at different times. From the produced interferograms, DInSAR allows computing the projection of the displacements along the satellite Line of Sight (LOS).

More recently, multi-pass DInSAR techniques focusing on processing stacks of SAR data collected over the same scene during repeated passes of the satellite have been developed. They allow generating deformation maps and

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C. Margottini et al. (eds.), *Landslide Science and Practice*, Vol. 2,
DOI 10.1007/978-3-642-31445-2_18, © Springer-Verlag Berlin Heidelberg 2013

Fig. 1 Location of the study area. *Red box* shows the footprint of descending ERS-1/2 and ENVISAT SAR data used in this study

furthermore associated time-series showing the temporal behavior of the investigated phenomena. Among these advanced DInSAR techniques, we apply the Small BAseline Subset (SBAS) approach for investigating landslide deformation at two spatial scales, i.e., regional and local scale (Berardino et al. 2002; Lanari et al. 2004a), in Umbria region, central Italy (Fig. 1). In particular, sets of ERS-1/2 and ENVISAT SAR data acquired from descending satellite orbits in the period 1992–2010 were exploited in order to map and monitor slope movements.

The Study Area

The study area, extending for more than 7,000 km^2 in Umbria, central Italy (Fig. 1), is geologically characterized by the presence of sedimentary rocks pertaining to the Umbria-Marche stratigraphic sequence, Lias to Eocene in age, overlaid by lake deposits, lower Pliocene to Quaternary in age, and by fluvial deposits of recent age (Cardinali et al. 2001).

The landscape shows a hilly or mountainous morphology, with open valleys and large intra mountain basins. The area is widely affected by slope instability phenomena, with relevant impacts on urban areas and infrastructures. Landslides are mainly triggered by meteoric events, including intense and prolonged rainfall and snow melt, and the main types are slides, earth-flows, complex and compound movements (Cruden and Varnes 1996; Guzzetti et al. 2008). As regards the state of activity, most of the landslides are dormant, while the active ones move with displacement rates ranging from slowly to very slowly (Cruden and Varnes 1996).

The SBAS-DInSAR Analysis

The SBAS-DInSAR approach (Berardino et al. 2002) has been successfully applied to the analysis of different geological hazards and human induced processes, such as volcanic activity (Tizzani et al. 2007), earthquakes (Lanari et al. 2010), subsidence caused by mining and water exploitation (Lanari et al. 2004b). As regards landslide applications, several published results (Berardino et al. 2003; Manzo et al. 2006; Lanari et al. 2007) pointed out the high potentiality of the SBAS technique in detecting and monitoring slow-moving phenomena.

The key point at the base of the SBAS technique is the selection of the SAR data pairs used for generating the interferograms. In order to mitigate the noise (i.e., the decorrelation phenomena) affecting interferograms, and to maximize the reliable measure points, only SAR data pairs characterized by small spatial and temporal separation (baseline) between the satellite orbits are considered for the processing (Berardino et al. 2002).

Originally designed for investigating deformation phenomena extending over very large areas, the SBAS algorithm has been subsequently modified in order to analyze also localized phenomena affecting individual man-made features. As result, the SBAS analysis can be currently carried out at two spatial scales, namely at regional and local scale (Lanari et al. 2004a).

At regional scale, the technique exploits average (multi-look) interferograms to produce deformation maps of wide areas (100 km $\times$ 100 km) at low spatial resolution (about 100 m $\times$ 100 m in the ERS and ENVISAT case); at local scale, single-look interferograms are exploited in order to generate maps at full spatial resolution (about 5 m $\times$ 20 m in the ERS and ENVISAT case), thus allowing to focus on local deformation affecting single elements at risk. At both scales, time-series showing the temporal evolution of surface displacements are generated.

Recent algorithm developments allowed to further extend the multi-scale SBAS analysis to the multi-sensor processing of SAR data collected by different radar systems acquiring with the same illumination geometry (ERS-1/2 and ENVISAT satellites), in order to fully exploit the large SAR data archive for the production of very long-term deformation time-series spanning a time period of almost 20 years (Bonano et al. 2012).

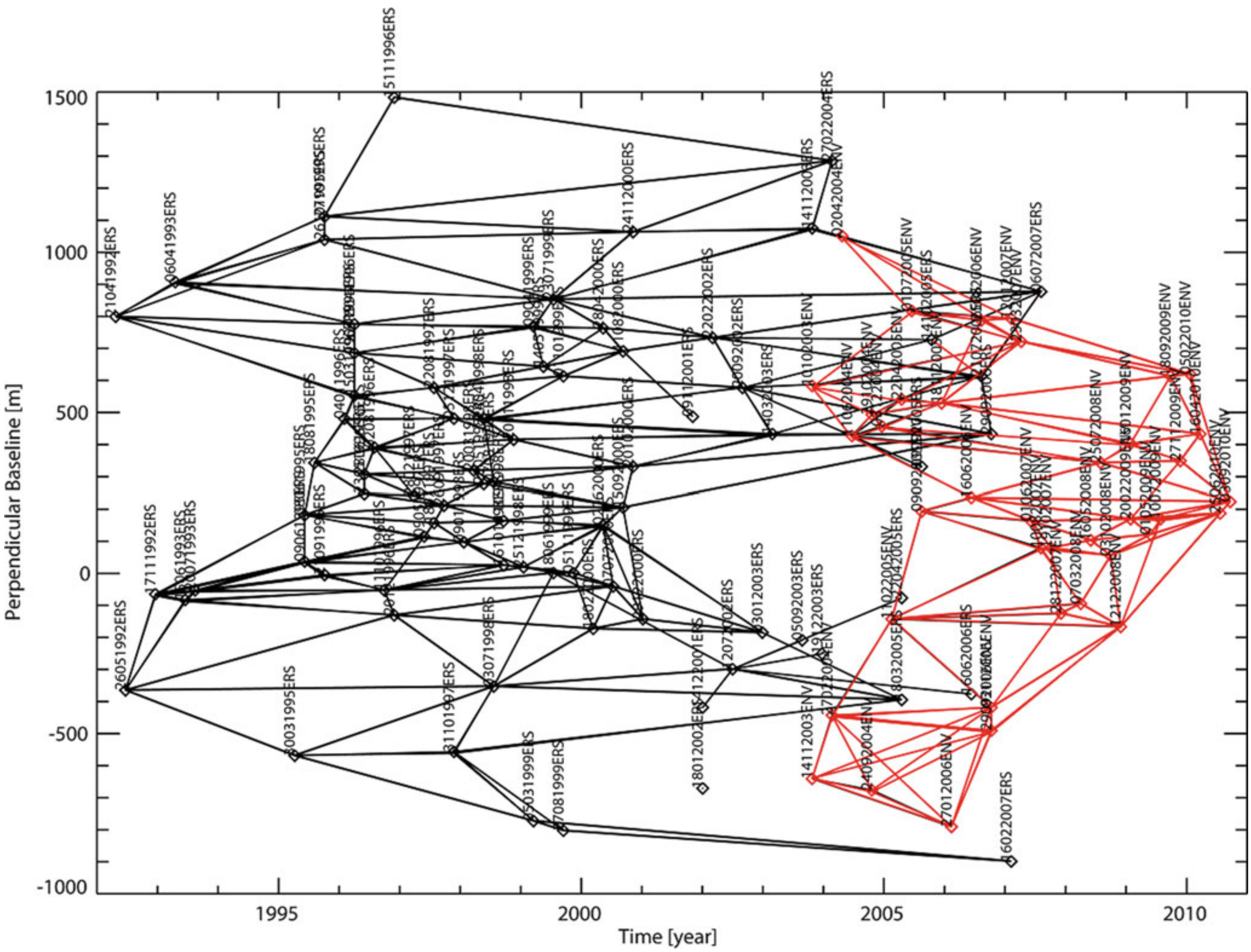

Fig. 2 Sketch of the SAR data distribution in the temporal/perpendicular baseline plane. The *black and red diamonds* represent the ERS and ENVISAT acquisitions, respectively; each arc of the graph corresponds to a generated interferogram

Results

Our two-scale SBAS-DInSAR analysis has been performed by processing a dataset of 116 SAR data acquired along descending satellite orbits (Fig. 2). In particular, the dataset is composed by 77 ERS-1/2 and 39 ENVISAT images, spanning the period between April 1992 and September 2010, from which 312 interferograms have been computed. The constraints imposed on the interferograms are 400 m and 1,500 days on the spatial and temporal baseline, respectively.

Figure 3 shows the low resolution deformation velocity map, obtained by processing the descending dataset, superimposed on an amplitude SAR image of the analyzed area. The deformation velocity map reveals an overall stability of the study area in the analyzed time interval. However, significant deformation patterns are present in the Valle Umbra, where a subsidence induced by water exploitation occurs, and in the area around Perugia. It is worth to point out that while the portion of Valle Umbra between Assisi and Foligno was affected by subsidence since 1992 (Fig. 3c), as already shown from the SBAS analysis conducted on the Umbria region by Guzzetti et al.

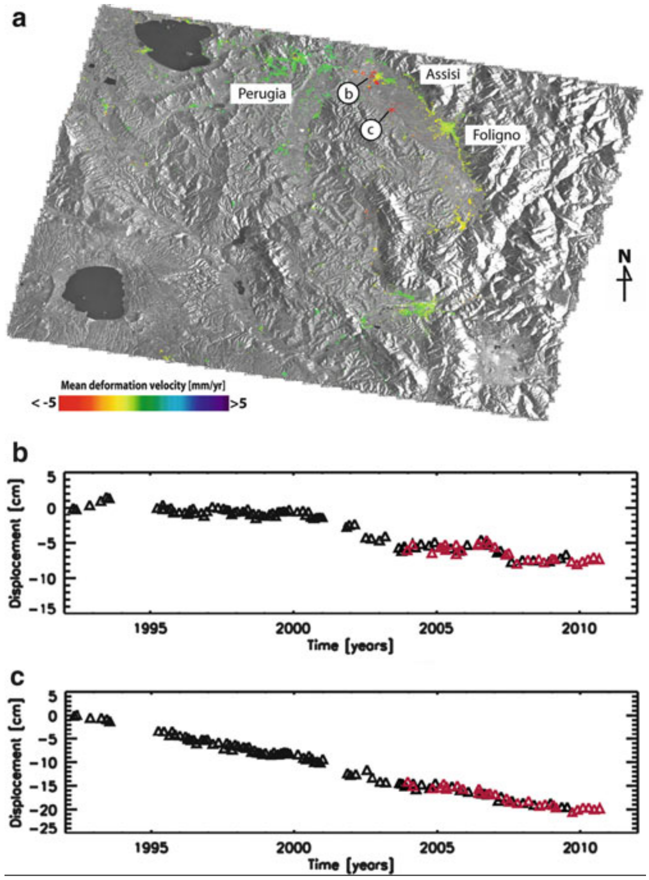

Fig. 3 (**a**) Geocoded mean deformation velocity map at low spatial resolution scale (pixel size ≈100 m × 100 m) of the whole study area, obtained from descending SAR data, and superimposed on the amplitude SAR image. Deformation values are measured along the satellite Line of Sight (LOS). (**b**) Deformation time-series relevant to the pixel labelled as (**b**) in Fig. 3a is shown. *Black and red triangles* represent ERS and ENVISAT acquisitions, respectively. (**c**) Same as (**b**) but referred to the pixel labelled as (**c**) in Fig. 3a

(2009), the Perugia area exhibits ground deformation since 2000, as clearly highlighted in the plot of Fig. 3b.

Subsequently, the full resolution SBAS processing allowed performing a detailed analysis of ground deformation and giving more insights on the behaviour of localized phenomena. Full resolution deformation velocity maps, and associated time-series, have been produced for selected hazardous areas. Figure 4 reports the results related to the active, slow-moving, deep-seated landslide affecting the Ivancich area, in the Assisi municipality, causing severe damage to buildings and urban roads. In particular, in Fig. 4a the full resolution velocity map superimposed on an optical image relevant to the city of Assisi is shown and a zoomed view of the area affected by the above mentioned landslide is pictured in Fig. 4b. The effectiveness of the two-scale SBAS approach to generate very long-term deformation time-series in order to analyze and monitor deformation phenomena affecting localized areas is clear.

This case study further confirms the relevance of such DInSAR analyses for the investigation of complex scenarios involving surface deformation, with the relevant impact on the definition of risk prevention and post-crisis management strategies.

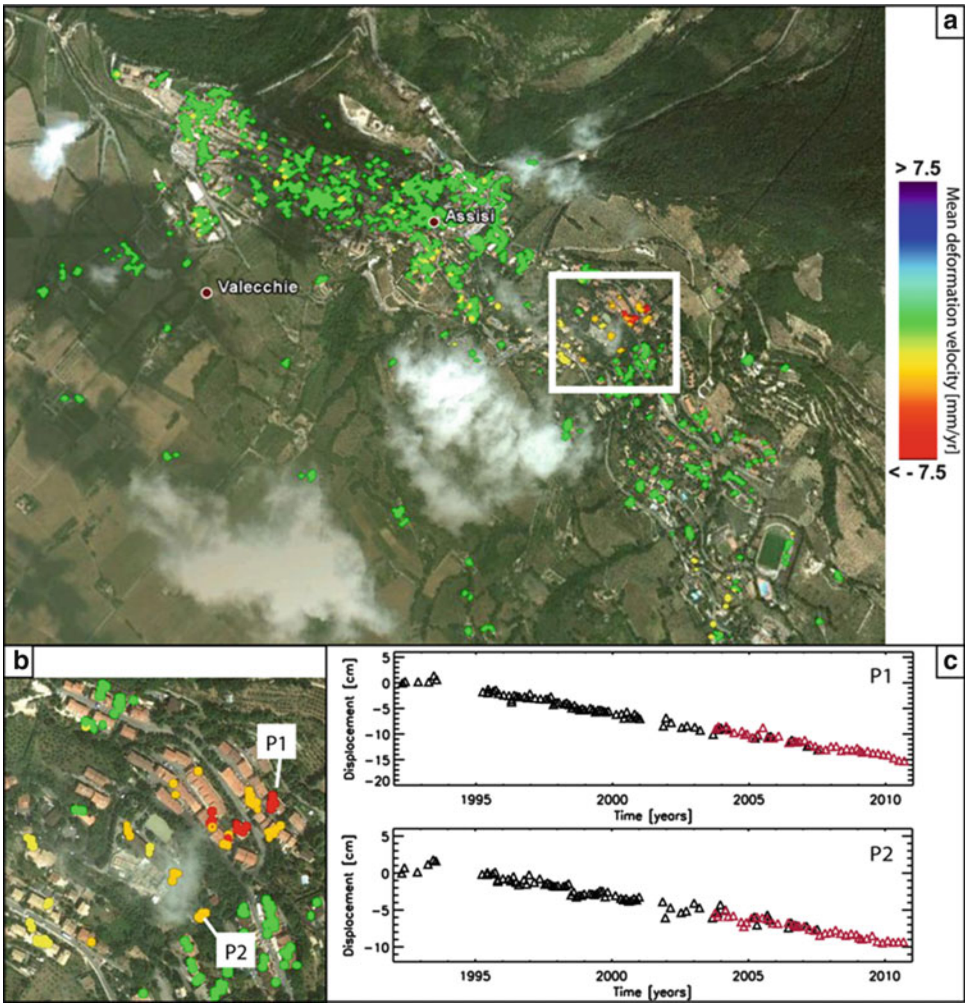

Fig. 4 (**a**) Geocoded mean deformation velocity map at full spatial resolution scale (pixel size ≈5 m × 20 m) relevant to the Assisi municipality and superimposed on an optical image of the analyzed area. Deformation values are measured along the satellite Line of Sight (LOS). (**b**) Zoomed view of the mean deformation velocity map of the area, highlighted by the *white box* in Fig. 4a, relevant to the Ivancich area affected by an active, slow-moving, deep-seated landslide. (**c**) Deformation time series relevant to the pixels labelled as *P1* and *P2* in Fig. 4b, respectively. *Black and red triangles* represent ERS and ENVISAT acquisitions, respectively

Conclusions

The SBAS-DInSAR technique can assume a key role in monitoring landslide-prone areas, thus preventing and mitigating the landslide risk, since the possibility to fully exploit very large archive of SAR data (over 20 years of SAR acquisitions). The results presented in this work show the effectiveness of such SBAS analyses in landslide applications, and suggest as the development of integrated monitoring systems, based on the joint use of ground measurements and DInSAR data, can significantly improve the landslide risk management; this latter can further benefit from the availability of improved temporal and spatial resolution SAR systems, as the Italian COSMO-SkyMed constellation.

References

Berardino P, Fornaro G, Lanari R, Sansosti E (2002) A new algorithm for surface deformation monitoring based on small baseline differential SAR interferograms. IEEE Trans Geosci Remote Sens 40(11):2375–2383

Berardino P, Costantini M, Franceschetti G, Iodice A, Pietranera L, Rizzo V (2003) Use of differential SAR interferometry in monitoring and modeling large slope instability at Maratea (Basilicata, Italy). Eng Geol 68:31–51

Bonano M, Manunta M, Marsella M, Lanari R (2012) Long-term ERS/ENVISAT deformation time-series generation at full spatial resolution via the extended SBAS technique. Int J Remote Sens 33 (15):4756–4783. doi:10.1080/01431161.2011.638340

Cardinali M, Antonini G, Reichenbach P, Guzzetti F (2001) Photogeological and landslide inventory map for the Upper Tiber River basin. CNR, Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche, Publication no. 2154, scale 1:100,000

Cruden DM, Varnes DJ (1996) Landslide types and processes. In: Turner AK, Schuster RL (eds) Landslides, investigation and mitigation, vol 247, Transportation Research Board Special Report. National Academy Press, Washington, DC, pp 36–75

Guzzetti F, Ardizzone F, Cardinali M, Galli M, Reichenbach P, Rossi M (2008) Distribution of landslides in the upper Tiber River basin, central Italy. Geomorphology 46:105–122

Guzzetti F, Manunta M, Ardizzone F, Pepe A, Cardinali M, Zeni G, Reichenbach P, Lanari R (2009) Analysis of ground deformation detected using the SBAS-DInSAR technique in Umbria, Central Italy. Pure Appl Geophys. doi:10.1007/s00024-009-0491-4

Lanari R, Mora O, Manunta M, Mallorquí J, Berardino P, Sansosti E (2004a) A small baseline approach for investigating deformations on full resolution differential SAR interferograms. IEEE Trans Geosci Remote Sens 42:1377–1386

Lanari R, Lundgren P, Manzo M, Casu F (2004b) Satellite radar interferometry time series analysis of surface deformation for Los Angeles, California. Geophys Res Lett 31:L23613. doi:10.1029/2004GL021294

Lanari R, Casu F, Manzo M, Zeni G, Berardino P, Manunta M, Pepe A (2007) An overview of the small baseline subset algorithm: a DInSAR technique for surface deformation analysis. Pure Appl Geophys 164:637–661

Lanari R, Berardino P, Bonano M, Casu F, Manconi A, Manunta M, Manzo M, Pepe A, Pepe S, Sansosti E, Solaro G, Tizzani P, Zeni G (2010) Surface displacements associated with the L'Aquila 2009 Mw 6.3 earthquake (central Italy): new evidence from SBAS-DInSAR time series analysis. Geophys Res Lett 37:L20309. doi:10.1029/2010GL044780

Manzo M, Ricciardi GP, Casu F, Ventura G, Zeni G, Borgstrom S, Berardino P, Del Gaudio C, Lanari R (2006) Surface deformation analysis in the Ischia Island (Italy) based on spaceborne radar interferometry. J Volcanol Geotherm Res 151:399–416

Tizzani P, Berardino P, Casu F, Euillades P, Manzo M, Ricciardi GP, Zeni G, Lanari R (2007) Surface deformation of Long Valley Caldera and Mono Basin, California, investigated with the SBAS-InSAR approach. Remote Sens Environ 108(3):277–289