DORIS FP7-EU PROJECT: EXPLOITATION OF 20 YEARS DINSAR DATA ARCHIVE FOR LANDSLIDE MONITORING

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ABSTRACT

Differential Synthetic Aperture Radar Interferometry (DInSAR) technique represents a valuable tool for remotely investigating ground deformation and providing more insights on their spatial and temporal patterns. In this work, developed within the framework of the DORIS FP7-EU project, we apply the advanced DInSAR approach referred to as Small BAseline Subset (SBAS) and fully exploit its capability to carry out multi-scale and multi-sensor analyses of surface deformation. In particular, we use ERS-1/2 and ENVISAT SAR data spanning the 1992-2010 time interval to detect and monitor landslides and subsidence phenomena occurring in the Umbria region, Central Italy.

1. INTRODUCTION

Understanding landslides and subsidence kinematics is crucial for defining efficient prevention and mitigation strategies, and can be effectively reached if long-term monitoring data are available. With this respect, the availability of very long displacement time series can provide the opportunity to investigate the history of areas affected by deformation.

Carrying out of traditional ground-based measurements by e.g., inclinometers, extensometers, tiltmeters, and topographic surveys, often results unsustainable on long term periods and on very large areas. Data collected by space-borne radar sensors and processed by advanced multi-pass Differential SAR Interferometry (DInSAR) techniques allow to effectively integrate such conventional investigation methods and to provide improvements in terms of temporal sampling and spatial coverage.

The DInSAR technique is a remote sensing technique that allows producing spatially dense deformation maps with centimeter to millimeter accuracy, based on the exploitation of the phase difference (i.e. the interferogram) between pairs of SAR data acquired over the same area at different times and from sufficiently close flight tracks. An effective way to detect and monitor the temporal evolution of deformation is via the generation of time series; to do this, the information available from each interferometric SAR data pair must be properly related to those included in the other ones, through the generation of an appropriate sequence of DInSAR interferograms. In this work, we apply the Small BAseline Subset (SBAS) approach for the generation of deformation time-series finalized to landslide and subsidence monitoring at two spatial scales, referred to as regional and local scale [1-2]. To this aim, we exploit almost 20 years of ERS-1/2 and ENVISAT SAR data acquired between 1992 and 2010 from both descending and ascending orbits over the Umbria region, central Italy, in order to detect, map and monitor slope movements and subsidence phenomena.

2. 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 overlaid by lake and fluvial deposits [3].

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

Figure 1. Location of the study area. Red and blue boxes show the ERS-1/2 and ENVISAT footprint for descending and ascending orbits, respectively.

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meteoric events, including intense and prolonged rainfall and snow melt, and the main types are slides, earth-flows, complex and compound movements [4-5]. 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 [4]. At the same time, subsidence phenomena occur, mainly related to man-made activities, e.g., over-exploitation of water aquifers.

3. DATA PROCESSING

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 [6], earthquakes [7], subsidence caused by mining and water exploitation [8]. As regards landslide applications, several published results [9-11] 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. Indeed, SBAS relies on the use of a large number of SAR acquisitions and implements an easy combination of small spatial and temporal separation (baseline) interferograms [1] computed from these data in order to mitigate the noise effects (referred to as decorrelation phenomena) thus maximizing the number of reliable measure pixels.

Originally designed for investigating deformation phenomena extending over very large areas, the SBAS algorithm has been subsequently modified in order to analyse also localized phenomena affecting individual man-made features and slopes. As result, the SBAS analysis can be currently carried out at two spatial scales, namely at regional and local scale [2]. At the regional scale, the technique exploits average (multi-look) interferograms to produce deformation maps of wide areas (100 km x 100 km) at low spatial resolution scale (about 100 m x 100 m in the ERS and ENVISAT case); at the local scale, single-look interferograms are exploited in order to generate deformation maps at the full spatial resolution scale (about 5 m x 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 allow to further extend such multi-scale SBAS analysis in order to deal with multi-sensor SAR data collected by different radar

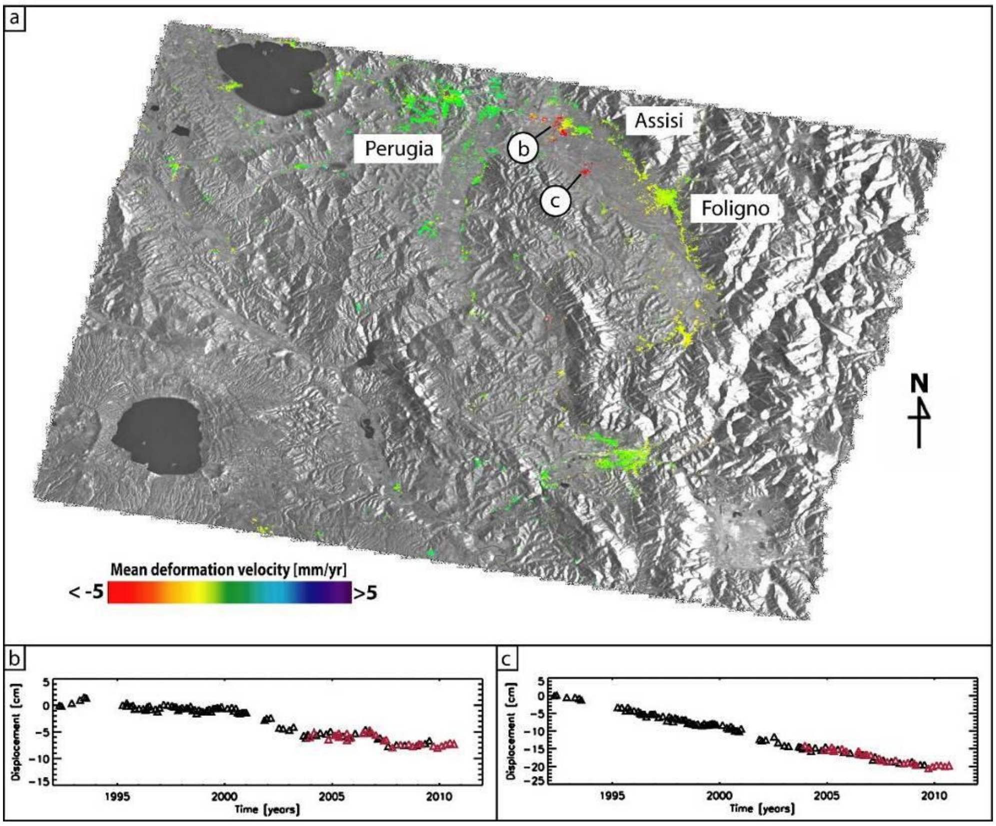

Figure 2. (a) LOS Mean deformation velocity map at low spatial resolution scale (pixel size ≈ 100 m x 100 m) of the study area, obtained from descending SAR data, and superimposed on the amplitude SAR image. (b) Deformation time series relevant to the pixel labelled as (b) in figure 2(a) is shown. Black and red triangles represent ERS and ENVISAT acquisitions, respectively. (c) Same as (b) but referred to the pixel labelled as (c) in figure 2(a).

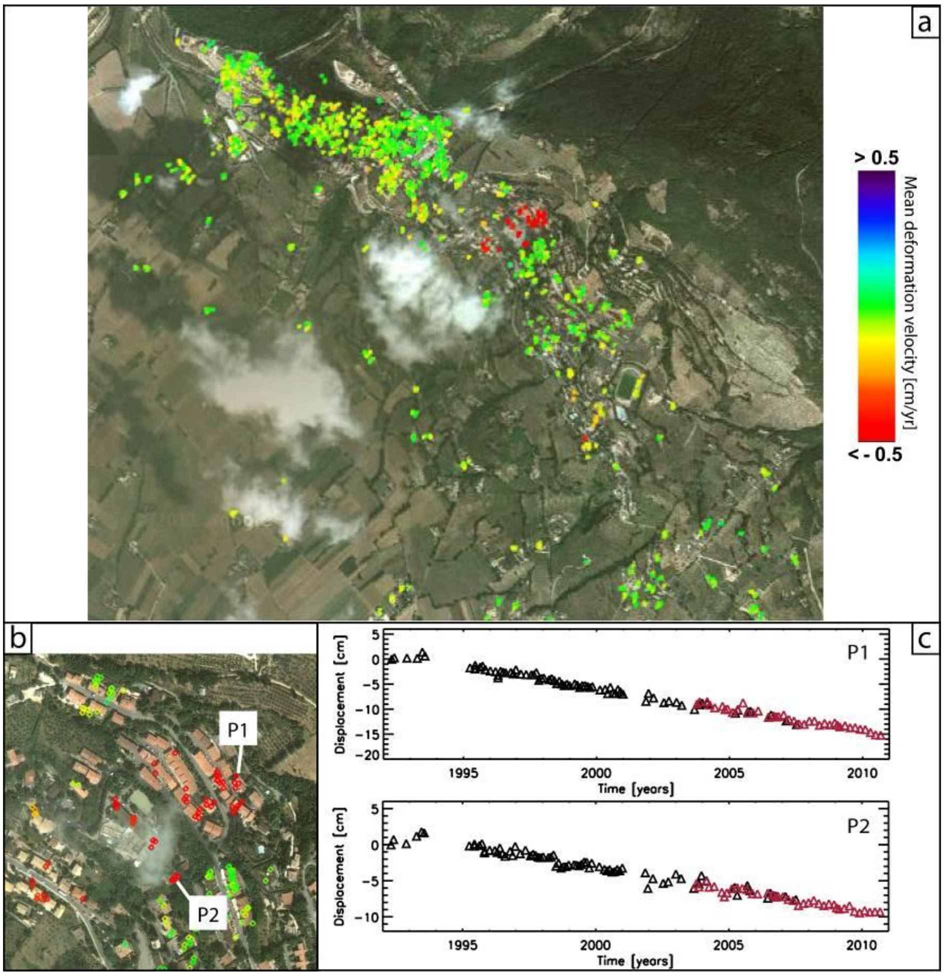

Figure 3. (a) LOS Deformation velocity map at full spatial resolution scale relevant to the Assisi municipality and superimposed on an optical image of the analyzed area. (b) Zoomed view of the velocity map of the area, highlighted by the white box in figure 3(a), relevant to the Ivancich area interested by an active, slow-moving, deep-seated landslide. (c) Deformation time series relevant to the pixels labelled as P1 and P2 in figure 3(b), respectively. Black and red triangles represent ERS and ENVISAT acquisitions, respectively.

systems acquiring with the same illumination geometry as for the case of ERS-1/2 and ENVISAT satellites [12], thus fully exploiting the large SAR data archive for the production of very long term deformation time-series of almost 20 years.

The basic issue is to consider the images acquired by the ERS and ENVISAT sensors as belonging to independent subsets; accordingly, no ERS/ENVISAT cross-interferograms, characterized by heavy decorrelation effects due to slightly different carrier frequencies of the two radar systems, are generated and the integration of ERS/ERS and ENVISAT/ENVISAT interferograms is effectively performed by applying the conventional SBAS strategy without major changes. The multi-sensor SBAS approach has been recently extended to the full spatial resolution scale, in order to produce deformation time-series from large archives of full resolution ERS-1/2 and ENVISAT SAR data [13]. In particular, the Doppler centroid variations of the post-2000 ERS-2 acquisitions and the carrier frequency difference between the ERS-1/2 and the ENVISAT systems have been exploited, thus maximizing the number of investigated SAR pixels, identifying also those exhibiting a response significantly deviating from a single scatterer backscattering, and improving their geocoding as well.

4. RESULTS

Our two-scale multi-sensor SBAS-DInSAR analysis has been performed by separately processing two datasets of SAR data acquired along the descending and ascending satellite orbits, respectively. In particular, the

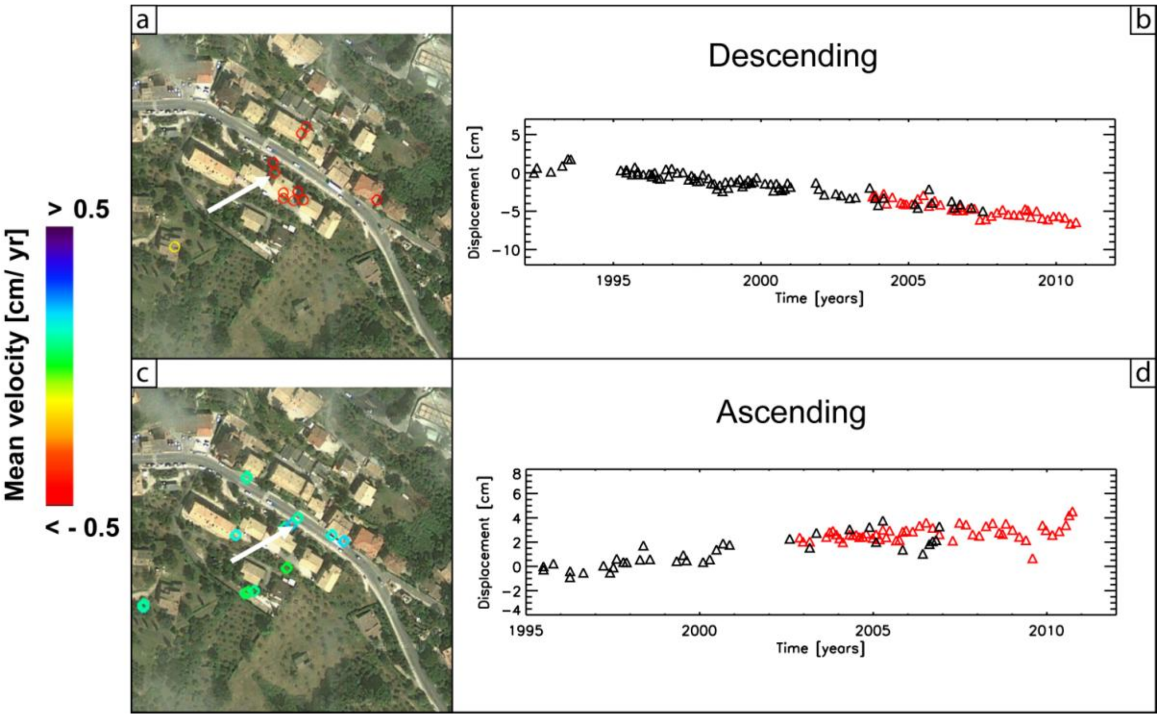

Figure 4. Comparison between descending (a-b) and ascending (c-d) results relevant to the toe of Ivancich landslide (Assisi, Italy). The two zoomed view (a-c) of the descending and ascending mean deformation velocity maps and the two plots (b-d) clearly show the presence of a strong East-West component in the detected displacements. Black and red triangles represent ERS and ENVISAT acquisitions, respectively.

descending dataset is composed by 77 ERS-1/2 and 39 ENVISAT images, spanning the time interval between April 1992 and September 2010, that have been coupled in 312 interferograms. The ascending dataset includes 36 ERS-1/2 and 51 ENVISAT acquisitions collected from June 1995 to September 2010, and 233 interferograms have been produced. For both datasets, the constraints imposed on the interferogram selection and generation have been 400 m and 1500 days on the spatial and temporal baseline, respectively.

Fig. 2 shows the low resolution mean 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 temporal spam. However, significant deformation patterns are clearly visible in the Valle Umbra, where a subsidence induced by water exploitation occurs, and in the area around the city of 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. 2(c)), as already shown from the SBAS analysis conducted on the Umbria region in [14], the Perugia area exhibits ground deformation since 2000, as clearly highlighted in the plot of fig. 2(b).

Subsequently, the full resolution SBAS processing allows 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. Fig. 3 reports the descending dataset 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. 3(a) 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 interested by the above mentioned landslide is pictured in fig. 3(b). The two plots of fig. 3c show the spatial gradient of the detected displacements, confirming the complex behaviour of the landslide body.

Further, the availability of both ascending and descending datasets permits to further investigate the direction of movements. In particular, while the landslide body is imaged only in the descending dataset, being in a layover area in the ascending one, several coherent targets have been detected in both descending and ascending datasets in correspondence of the toe of the landslide, located in an almost flat zone (fig. 4). By analyzing the achieved deformation time series (fig. 4b and fig. 4d), it is clear the presence of a strong East-West component in the detected movements [14].

The effectiveness of the two-scale multi-sensor 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.

5. 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 play a key role in the interpretation of landslide mechanisms and in the understanding of their kinematics, as well as in the landslide risk management. This latter can further benefit by the availability of improved temporal and spatial resolution SAR systems, as the Italian COSMO-SkyMed constellation.

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