Monitoring Ground Instability in Wide Areas and Single-building Cases by Means of Satellite A-DInSAR

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ABSTRACT

Satellite Differential SAR Interferometry (DInSAR) represents one of most innovative ground and structures displacement monitoring solutions in urban areas. At present several Advanced DInSAR techniques (A-DInSAR) based on multi-image data processing are available to achieve information about trends and time series of displacement through the analysed period with high accuracy.

In the context of geotechnical issues, A-DInSAR can be a useful tool in several situations, both for diagnostic and monitoring purposes. As a matter of fact, A-DInSAR is one of the few techniques available for detection and measurement of ground displacements occurred in the past, thanks to satellite SAR data archived by several Space Agencies starting from 1992. Hence, it is possible to obtain information on ground stability conditions (e.g. landslides, subsidence) when no preliminary monitoring activities had been performed before on specific areas. Moreover, A-DInSAR is a valuable tool for monitoring of ground deformation during construction (*post-operam),* thanks to new satellite images acquisitions planning.

Given its features and new high-resolution SAR satellites, A-DInSAR represents a powerful solution for investigation of ground and structures displacements both for large areas and defined buildings or structures.

1 INTRODUCTION

Monitoring of displacement is today a well-accepted control tool, nevertheless, it can be very often considered as a source of information for investigation and diagnostic purposes (Mazzanti 2012). In particular, when no information about past displacements are available for some areas or when very large areas have to be monitored, satellite SAR interferometry (DInSAR), especially with new Advanced DInSAR (A-DInSAR) techniques, can represent a unique resource (Bozzano & Rocca 2012). Other techniques, in fact, (e.g. aerial photos records) may provide such information, but generally, accuracy of detected displacements is much reduced when compared with the results of A-DInSAR.

In what follows, this paper presents some results of A-DInSAR applications to detect and quantitatively derive past or unknown deformation processes caused by several phenomena in various contexts. In the first one, a 20 square kilometres river basin in central Italy, severely affected by landslides, has been analysed by detecting and evaluating displacements occurred on the slopes during the period 1992-2010. Thanks to A-DInSAR results, the state of activity of many landslides, has been evaluated and mapping of landslide areas has been refined. Displacements in terms of time series and dynamics have been properly defined. A-DInSAR data have been merged with more traditional methods (aerial photos, field surveys, geotechnical monitoring) to find a useful integration of information both in spatial and temporal terms (Rocca et al. 2013).

Furthermore some details about A-DInSAR applied to some single buildings are discussed to show the great opportunity to analyse displacement distribution at different portions of the structures.

A-DInSAR could become a new standard in monitoring and geological survey for both the site planning and natural terrain hazards comprehension and design of mitigation measures. Several sensors and satellites with various characteristics can be used in terms of resolutions (both spatial and temporal), accuracy, sensitivity and frame dimensions, making A-DInSAR able to afford several situations with different characteristics (Bozzano & Rocca 2012).

2 MONITORING OF DISPLACEMENT BY A-DINSAR

Starting from the first 1990s, satellite DInSAR has gradually become a common tool used to detect and measure ground displacements, especially for the scientific community dealing with geology, geophysics and geomatics. (Massonnet et al. 1993; Peltzer & Rosen, 1995; Rott et al. 1999). Today, thanks to the developments of new data processing approaches (Ferretti et al. 2001; Berardino et al. 2002; Kampes 2006; Perissin & Wang 2012), Advanced DInSAR can be considered as a well-established technique able to provide information of ground displacements with high accuracy.

The basic principles of the technique are the following: SAR satellites fly along predetermined orbits paths acquiring radar images of earth's surface. They review the same area with a frequency that depends on the satellite itself (once every 35 days for older satellites and with higher frequencies for new generation satellites). The analysis of images stacks acquired is performed comparing the phase of the microwave signal sent to the ground and backscattered to the sensor. The signal phase differences, specifically processed, are related with displacements occurred during the time interval between images acquisition. In this way it is possible to derive the velocity trends of objects with millimetre accuracy.

A-DInSAR is characterized by many advantages: for example, it operate in a full remote way (no artificial reflectors need to be installed); it is possible to perform analyses at different scales, in wide areas (more than thousand square kilometres) as well as at single-building scale (the latter, in particular, thanks to new high-resolution sensors); widespread results over analysed areas can overcome the problem of limited information, punctually distributed, often achievable using standard geotechnical monitoring methods. Moreover, probably the most important feature of A-DInSAR is its capability to investigate in quantitative way displacements occurred in the past, analysing SAR data archived from 1992 by Space Agencies in charge of satellites management.

On the other hand, some limitations must be considered: only some pixels of the images are characterized by stable and strong enough signal to be processed. Commonly, they are called “Persistent Scatterers” (PS) (Ferretti et al. 2001) and they are related to highly reflective objects on the scene (e.g. buildings, concrete or metal structures, exposed rocks etc.). For this reason, areas totally covered with vegetation are not analysable. Moreover, the amount of detectable displacement is related to a portion of the microwave signal wavelength, which is commonly in the order of few millimetres. For this reason, very fast displacements are not detectable.

Finally, as for other remote sensing monitoring technique, displacements are detectable only along the satellite ‘Line of Sight’ (LOS). Nevertheless, because the same area can be observed from different points of view, while the satellite flies along different orbit paths (the so-called ascending path, when the orbit is from South to North and descending when it is from North to South), it is possible, combining these different information, to decompose displacement direction in vertical and W-E component, while the N-S is in any case, not detectable.

3 INVESTIGATION BY A-DINSAR

3.1 Landslides

This section presents a study on a small basin (about 20 km^2), crossed by a stream, located in a low-hilly area in the central Italy. By field surveys and multi-temporal analysis of aerial photos from 1954 to 2002 more than 90 landslides were identified and mapped. The landslides affect more than 75% of this portion of the basin and were classified in translational sliding (38%), earth-flows (31%) and complex mass movements (31%). Landslides areas are found to be ranging from very few hundreds m^2 to some km^2. Landslide deposits are related to the mobilization of pelitic and psammitic lithologies, especially in the middle and lower portions of the slopes. In the mainly pelitic areas, geomorphological elements related to the largest landslide phenomena, such as niches, scarps and counterslopes, are highly altered and degraded, and often modified by the strong anthropic activity in the area.

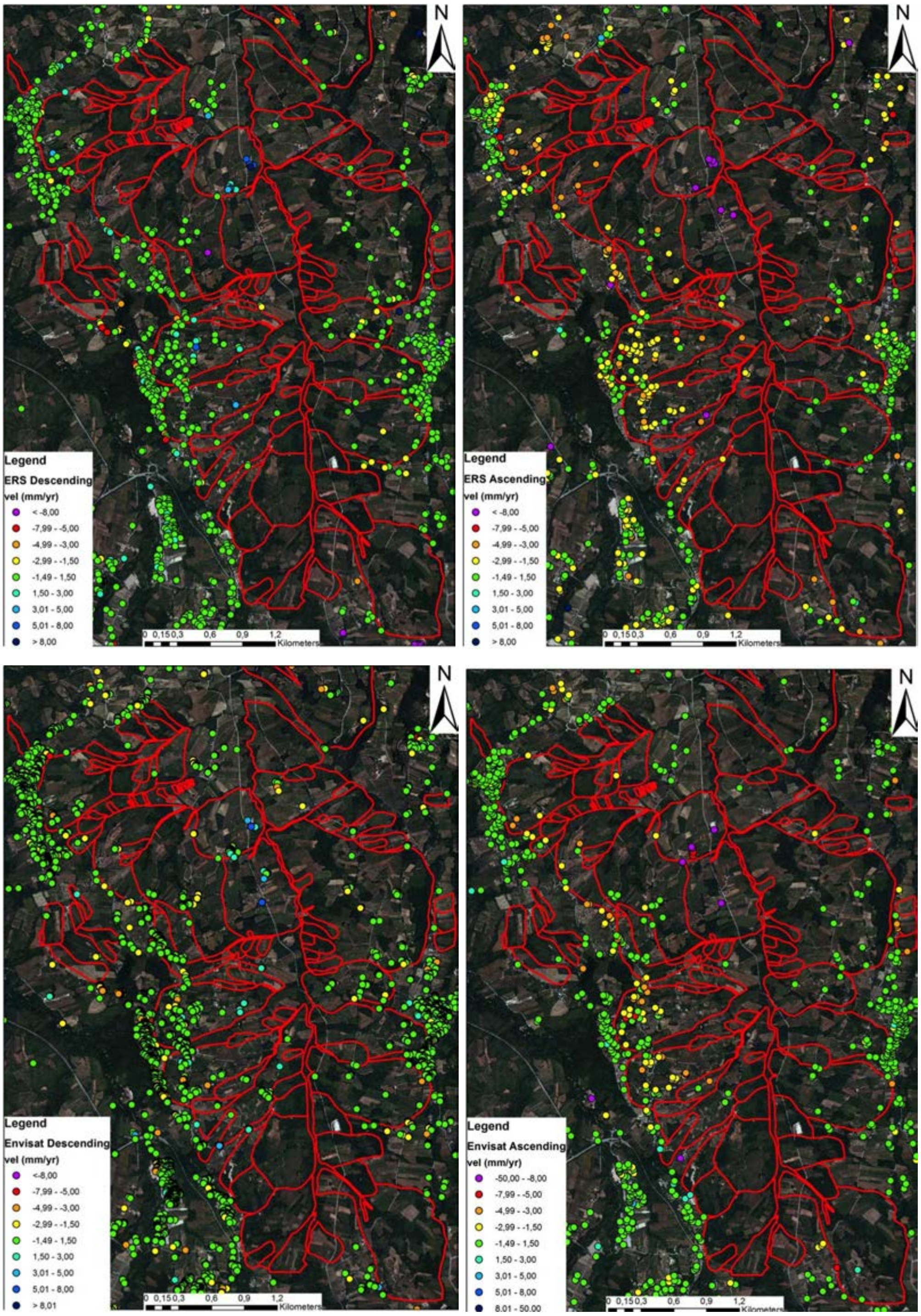

Figure 1. – ADInSAR results: red polygons identify the mapped landslides; PS are represented as coloured points. It is clear the evidence of instability processes during the analysed period (ERS: 1992-2001; Envisat: 2003-2010)

In order to refine landslide mapping and to derive state of activity and the evolution rate, A-DInSAR investigation have been performed. This study have been carried out, by using images derived from the European Space Agency (ESA) archives, available in the frame of the CAT-1 project "Landslides forecasting analysis by displacements time series derived from Satellite and Terrestrial InSAR data" (ID: 9099). Four different datasets have been used to characterize the landslides historical displacements; specifically, ERS1-

ERS2 and Envisat satellite data both in ascending and descending orbit acquisition geometry have been selected for the period 1992-2010 (Rocca et al. 2013).

The SAR data have been processed through SARPROZ, a software tool specifically developed for multi-image InSAR analyses such as PS (Ferretti et al, 2001) and QuasiPS (QPS) (Perissin & Wang, 2012). For this case study, two different approaches have been used: i) standard PS analysis where velocities are evaluated applying a linear trend model (Ferretti et al, 2001); ii) local analysis of small areas, performed for most interesting zones, which allows to achieve higher accuracy in displacements estimation, and, especially, to detect non liner trends. It is worth noting that non-linear movements are considered crucial for a suitable investigation of landslide processes affecting the investigated area.

A-DInSAR results (Fig. 1) allowed the investigators to derive useful information for more than 30% of the mapped landslides affecting the basin (more than 55% in terms of area), especially for largest ones and those affecting urbanized areas.

Thanks to the availability of the long-term data record (1992-2010), the displacement information allowed the refinement of landsides mapping and in deriving the state of activity. Furthermore, some coalescent landslides previously mapped were recognized as a unique event and some landslides were internally distinguished thanks to the identification of differential deformations. Furthermore, some areas of particular interest have been analysed by a local analysis, with *ad hoc* data processing performed to investigate localized processes.

Considering the size of the studied area, a detailed presentation of the results on observed landslides is not possible for this paper. By way of example, results and interpretations related to one of the most interesting processes are shown. In this specific area (Fig. 2), located at the foot of a wide complex landslide with many coalescent bodies, displacements during the overall period 1992–2010 were detected. Thanks to the ascending and descending geometry combination it was possible to infer the movement direction that is mainly horizontal. This particular dynamics produces, in fact a singular result of PSs, which show opposite direction of displacement (positive in descending geometry and negative in the ascending one; see blue circle in Fig. 2). If only one image stack related to a single orbital geometry had been used, the comprehension of the process would be strongly compromised. The upper part shows lower displacements starting from 2003, while in the lower part displacements are evident since 1992, with a higher rate and a more horizontal component. Furthermore, the overall movement trend is strongly not linear with several acceleration stages recognized. Displacement rates are high (>15 mm/yr) (Fig. 3).

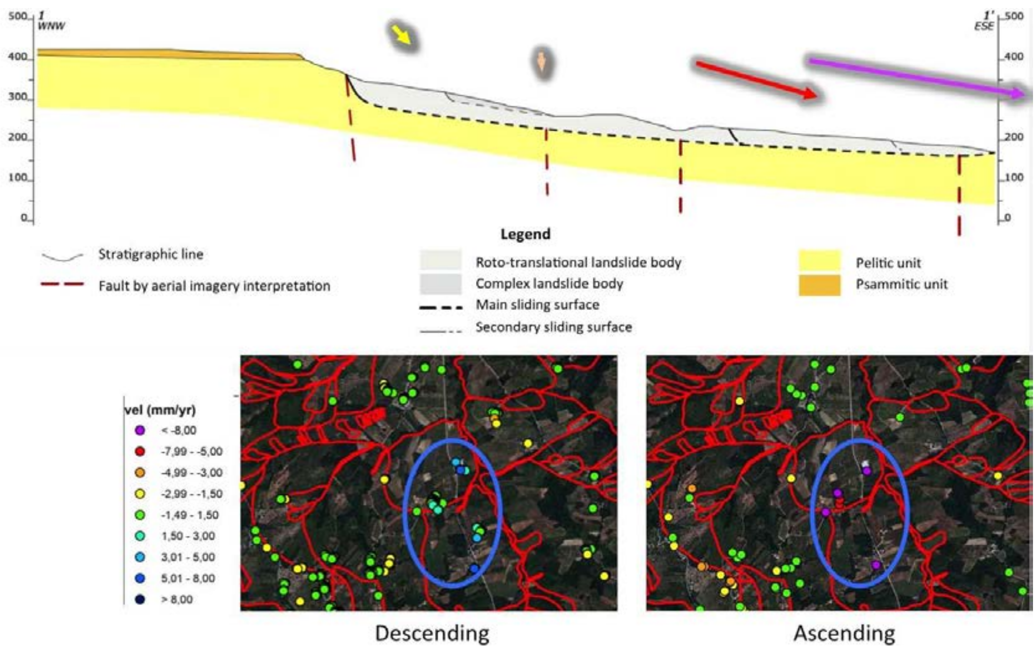

Figure 2. – Single landslide process dynamics derived combining ascending and descending A-DInSAR information. Vertical and horizontal displacement components have been inferred, so deriving the real displacement direction for all the landslide body portions.

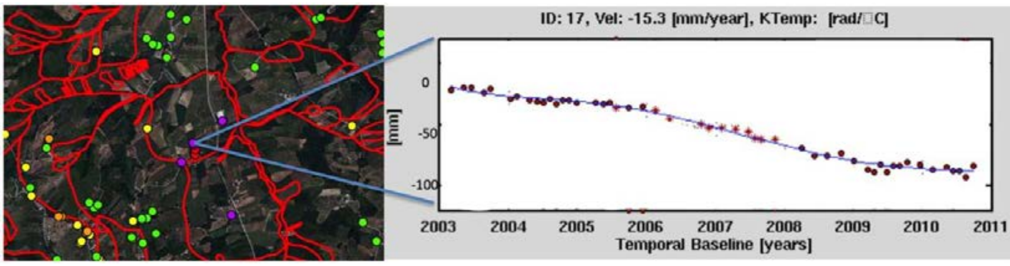

Figure 3. – Time series of displacement related to a PS detected on the discussed landslide

3.2 Buildings

In addition to landslides, A-DInSAR is a valuable tool for investigation of other deformation processes that induce displacements of terrain or structures. For example, the following results are relative to an A-DInSAR analysis performed over an area near the city of Rome, Italy. This area, during the past decades, was affected by ground subsidence caused by dewatering linked to quarrying activities (Brunetti et al. 2013). The process affected a wide area (several sq. km), but in this work the authors wish to focus on some details. Because of a pronounced geological heterogeneity, the effect of subsidence depends on the thickness of the compressible layers and is more evident exactly where these are thicker. As a consequence, some large buildings with foundations built partially on thick compressible layers and partially on less thick compressible layers were affected by differential settlement processes. This effect was well recognized also by A-DInSAR results. In this case, the combination of descending and ascending data has been very useful to detect this dynamics thanks to the difference between the two LOS displacement magnitudes (Fig. 4).

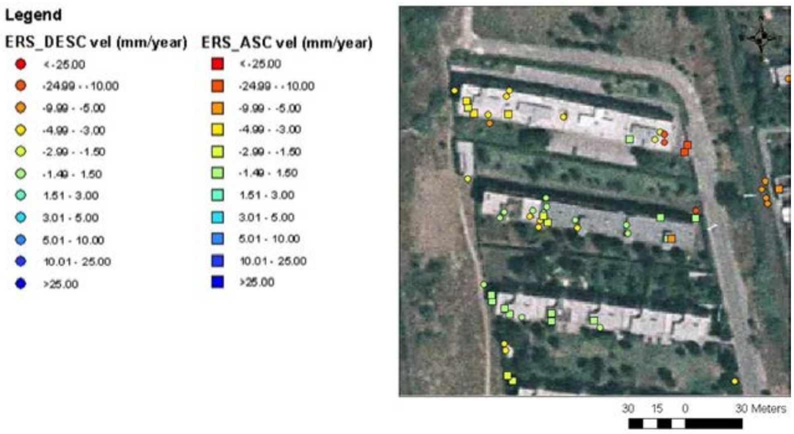

Figure 4. – Ascending and descending PS related to a couple of buildings (higher part of the picture) affected by differential settlement process (period: 1992-2001).

Another brief example, useful to understand A-DInSAR potential in building investigation, is relative to a high rise building in Hong Kong. In this case, thanks to the building height (more than 90 m) and the high-resolution data available, a single orbital geometry is enough to detect a hypothetical and very small tilting process possibly affecting the building. This hypothesis is related to a sort of gradient of displacement, which increases with increasing height (Fig. 5). To perform the analysis TerraSAR-X data relative to a four years period (2008-2012) have been used.

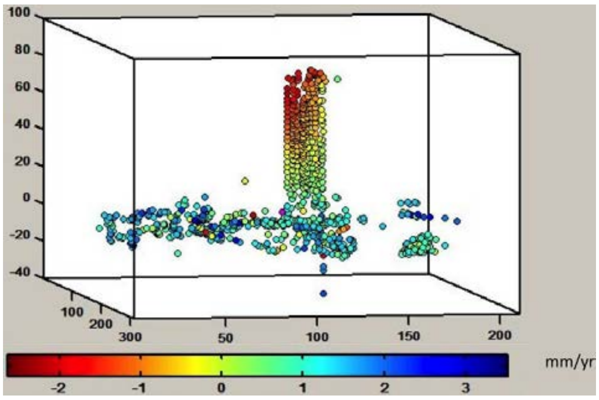

Figure 4. PS related to a high-rise building with a clear gradient of displacement along the structure.

4 CONCLUSIONS

In this paper, we have showed some results related to A-DInSAR analyses performed in different contexts for investigation of different deformational processes. Large area analyses as well as local area investigations are achievable in order to improve knowledge about the observed processes. Both landslides and subsidence and local deformation processes have been observed and described with very good detail concerning the dynamics. In this perspective, A-DInSAR can represent a diagnostic tool especially for investigation of past events when no other monitoring data are available. This solution can substantially change the approach related to projects and building works in areas with unknown ground instability problems. On the other hand, it can also be an effective tool for planned monitoring of large areas (e.g. during building activities in urban areas) if new satellite images acquisition is expressly planned.

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