A COMPARATIVE ANALYSIS OF DINSAR RESULTS ACHIEVED BY THE SBAS AND SPINUA TECHNIQUES: THE MARATEA VALLEY CASE STUDY, ITALY

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ABSTRACT

We compare the results of two independent synthetic aperture radar differential interferometry (DInSAR) approaches to slope instability investigations in the Maratea valley (Southern Italy), based on different processing methods and software. The area selected for the comparison is well ground truthed and provides suitable examples of movements ranging from mm to cm per year. The DInSAR analyses are based on the Small Baseline Subset (SBAS) and Stable Point INterferometry over Unurbanised Areas (SPINUA) techniques. Both methods are applied to SAR images acquired by the ERS-1/2 satellites in the period 1992-2000. Despite the differences in the data processing and minor discrepancies between the displacement maps, mainly due to differences in data classification and thresholding, the results obtained from the two techniques are largely comparable and provide very similar ground surface motion information that leads to a clear distinction between stable and unstable areas and between the zones with different velocity of movement.

Figure 1. Location map of the study area in Southern Italy. The inset shows a shaded relief DEM of the Maratea valley (in the centre) affected by slope movements.

1. INTRODUCTION

In the past few years, several interferometric differential processing methodologies have been introduced and experimented on multi-temporal interferometric data with the aim of detecting long-term deformation. In particular, two main strategies can be distinguished:

- the Persistent Scatterers Interferometry (PSI) approach [1], which studies the phase information over single isolated objects characterised by a high temporal phase stability; this approach is usually implemented by computing differential interferograms of all the acquisitions with respect to the same reference master image, then performing advanced phase analyses on the pixels exhibiting stable SAR response throughout the stack;
- other methods that exploit more spatially distributed information in differential interferograms obtained from pairs of images with the best values of spatial baseline (e.g. below a certain threshold) and then infer, through various procedures (Least Mean Squares, Singular Value Decomposition), the connected time series of phase values due to deformation [2]-[5]

We compare the results of the application of two independent approaches to slope instability investigations, representative of the above strategies. One approach relies on the SBAS (Small Baseline Subset) technique [2] and the other on the SPINUA (Stable Point INterferometry over Un-Urbanised Areas) technique [6], [7].

The Maratea valley area (Southern Italy, Figure 1), selected for the comparison, is well ground truthed and provides suitable examples of movements ranging from mm to cm per year (Figure 2). In particular, the in situ monitoring data acquired periodically since 1983 indicate the presence of apparently continuous, very slow landslide displacements (up to several cm/yr). The movements are of deep-seated nature and involve the central portion of the Maratea Valley characterised by the presence of clay-rich sedimentary rocks (flysch). The surrounding slopes made of carbonate rocks result relatively stable or in part involved in extremely slow gravity tectonics deformations.

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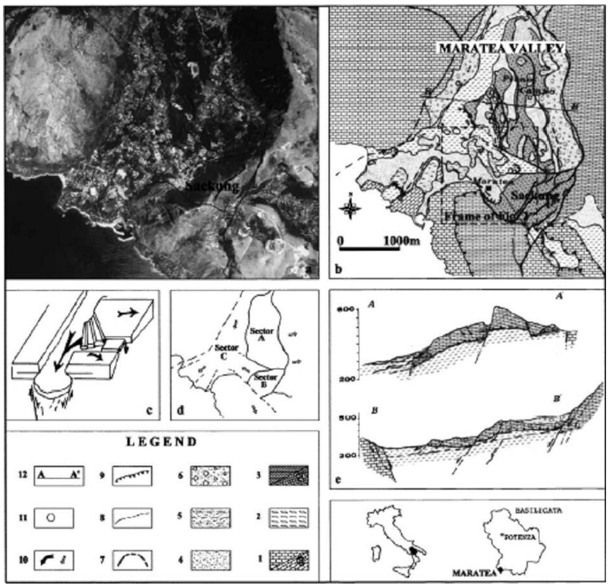

Figure 2. Geology and interpretative scheme of the slope instability at Maratea valley [3]: (a) and (b) show large scale mass movement phenomena; (c) and (d) indicate the inferred complex pattern of movements affecting the study area. In particular, the lower part of the Maratea valley (sector C) is subject to a deep and slow landslide movements occurring at a "constant rate" (2-3 cm/yr). Legend explanation: 1 – carbonate rocks; 1a – as before, but dislocated by gravity and perhaps tectonic processes; clay flysch; 3 – carbonate rocks; 3a – as before, but dislocated by gravity and perhaps tectonic processes; 4 – Pleistocene dbris and breccias; 5 – elluvuim; 6 – Holocene alluvial fan; 7 – boundaries between masses having different velocity and mechanism of rupture; 8 – main morphostructural dislocations; 9 – thrust; 10 – direction of slope movement; 11 – spring; 12 – geological section or seismic line.

Finally, a previous DInSAR study of the Maratea valley [3] revealed the occurrence of slow, spatially variable slope movements. Thus, the main question here is not how well the SAR data reflect the reality. Rather, by using the average annual displacement estimates we illustrate to what extent the SBAS and SPINUA results match.

2. COMPARISON OF THE RESULTS

The results of the two independent DInSAR analyses rely on images acquired by ESA's ERS-1 and ERS-2 radar sensors (descending geometry). Both analyses cover the same 1992-2000 time interval, but different subsets of available images were used (60 for SBAS and 27 for SPINUA). The reader is referred to the literature [2], [6] for details about the two processing techniques.

Although the final spatial distributions of coherent pixels with displacement information are somewhat different in the two cases, due to different processing parameters and thresholds, and their dimensions vary from about 100×100 m^2 for SBAS to 20×5 m^2 for SPINUA, the resulting average annual displacement maps compare quite well (see Figure 3). It should be noted that the estimated precision of average annual velocity measurements for both techniques are on the order of 1 mm/yr, and all the measurements are referred to a common reference point situated on the stable carbonate range in the NW part of the study area.

In an attempt to provide a quantitative comparison of the results, we took the following steps:

- introduction of a 50 m buffer around the centres of coherent pixels of both original SBAS and SPINUA datasets;
- intersection of the buffered areas of the two datasets;
- generation of two regular grids of average annual velocities by interpolating the original SBAS and SPINUA coherent pixels data through an inverse-distance weighted average, with final grid cells of 50×50 m^2;
- selection of the grid cells included in the intersection of the buffered areas, i.e. definition of the useful cells for velocity data comparison; on these, the original data points closest to the cells' centres were considered.

The results of the quantitative comparison are illustrated as velocity maps in Figure 4. To facilitate the visual comparison the number of velocity classes has been reduced to 7. The results including a larger number of classes are shown in Figure 5 as average velocity frequency distribution histograms; the associated scatter plot and relevant correlation coefficient are given in Figure 6.

A simple visual examination of the velocity maps indicates a good match between the SBAS and SPINUA displacement estimates. Furthermore, even at the level of single pixels, in most cases the agreement appears to be good. At some points minor discrepancies exist regarding the velocity magnitudes. These, however, do not exceed a few mm per year. Importantly, a distinction between stable and unstable areas can readily be made on both datasets.

The above evaluation is confirmed by considering the displacement results arranged in velocity classes at 2 mm/yr intervals (Figure 5). Despite the overall very good agreement (consistent also with the correlation coefficient R^2 exceeding 0.95 – Figure 6), the velocity histograms reveal slight differences for the lowest-magnitude velocity classes. In particular, for SBAS and SPINUA the most populated average velocity classes correspond, respectively, to –6 - –4 and –4 - –2 mm/yr. Regarding the linear regression, the dispersion of the measurements, evaluated as standard deviation of the residues with respect to the linear fit, does not exceed 2 mm/yr for both datasets.

3. CONCLUDING REMARKS

Despite the differences in data processing methods and software, the results obtained from the SBAS and SPINUA techniques are largely comparable and provide very similar ground surface motion information that leads to a clear distinction between stable and unstable areas and between the zones with different velocity of movement.

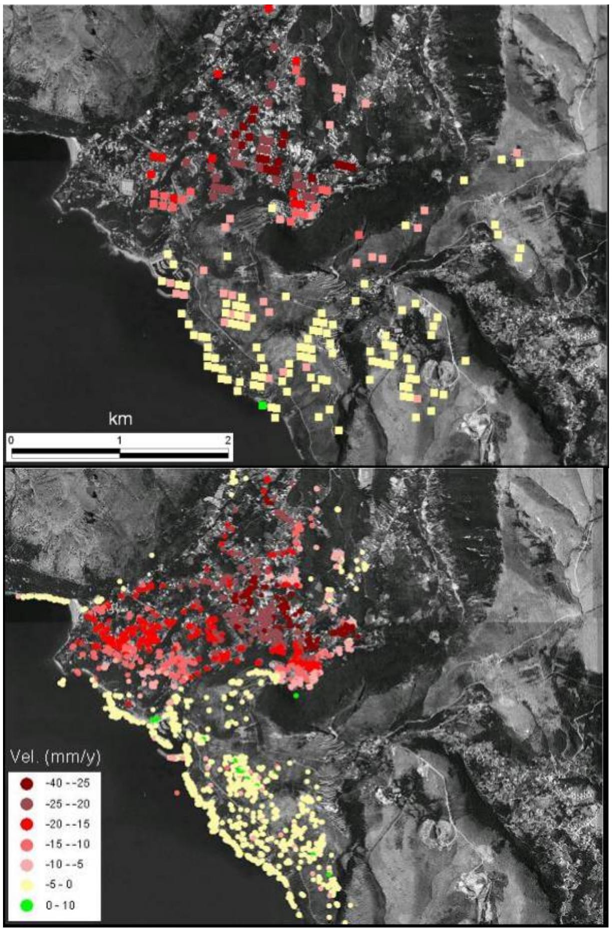

Figure 3. SBAS (top) and SPINUA (bottom) displacement estimates (coloured squares for SBAS and coloured dots for SPINUA indicate coherent pixel centres) plotted over an orthophoto of the Maratea valley. Vel. stands for the average Line Of Sight (LOS) velocity of displacement. Despite some differences in the distribution of satellite radar targets the overall SBAS and SPINUA results are largely comparable.

Furthermore, a quantitative comparison of the two velocity datasets reveals a very close match with correlation coefficient R^2 around 0.95.

Although the spatial resolution of the SBAS interferometric product (coherent pixels with displacement information) is on the order of 100×100 m^2, given the large extent of the unstable area, the results are adequate for a preliminary investigation of slope instability.

Clearly, the better spatial resolution of the SPINUA output product (on the order of 20×5 m^2) offers a possibility to refine the transitions between the unstable zones characterised by different velocities. This is important in the Maratea valley case study, where the occurrence of internal differential deformations could potentially lead to local failures and thus constitute a significant hazard to houses and other infrastructures located on the landslide. Nevertheless, a good resolution of transition zones characterised by significant velocity gradients can also be obtained by applying a full resolution version of SBAS technique [8].

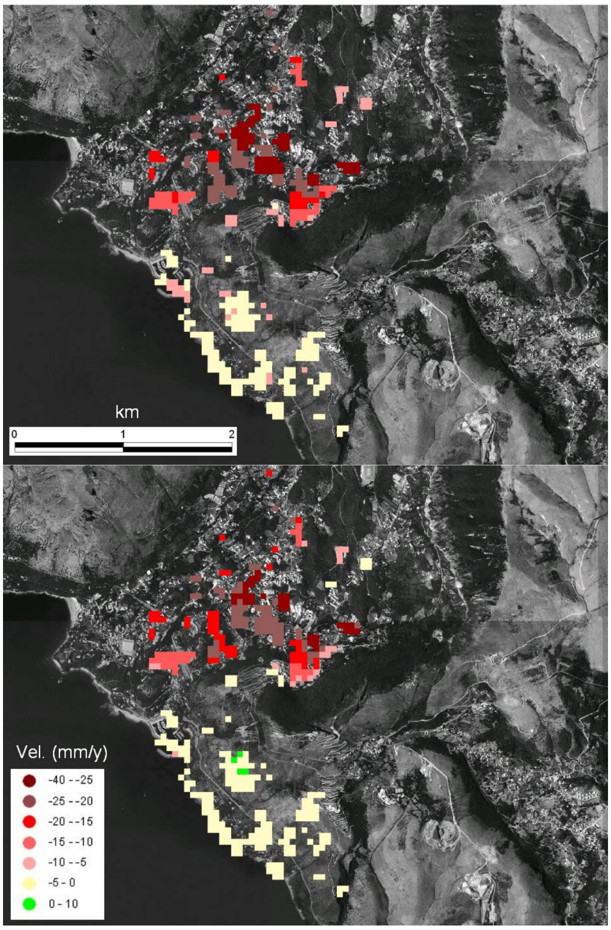

Figure 4. Interpolated average annual displacement velocity results from SBAS (top) and SPINUA (bottom): cells of 50 m where both approaches provide measurements are plotted over an orthophoto of the Maratea valley.

Thus in the future we plan to extend our preliminary comparisons presented here to higher resolution SBAS data as well as to single point displacement time series.

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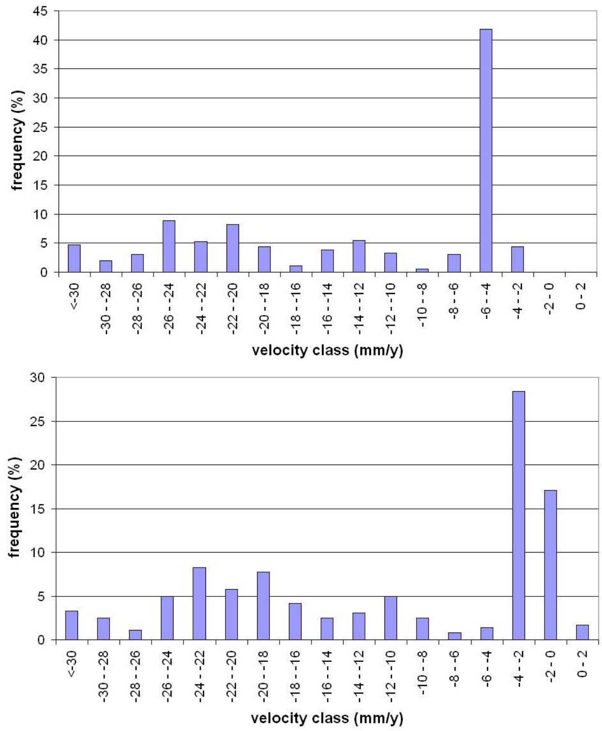

Figure 5. Average annual velocity frequency distribution histograms. Top: SBAS, bottom: SPINUA.

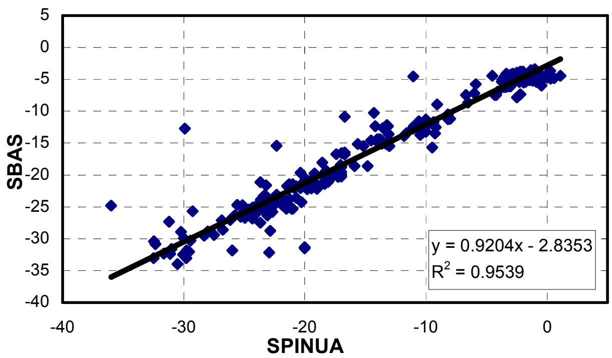

Figure 6. Scatter plot of average annual velocity (mm/yr): SBAS versus SPINUA data; linear regression parameters are also reported.