

# Remote Sensing Techniques in a Multidisciplinary Approach for the Preservation of Cultural Heritage Sites from Natural Hazard: The Case of Valmarecchia Rock Slabs (RN, Italy)

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## Abstract

The Valmarecchia area (RN, Italy), located between the Emilia-Romagna and Marche regions, displays peculiar geological features, being characterized by rocky slabs lying on gentle slopes. The main fortified villages of the area, remarkable for historical and artistic assets, were built in the medieval period on these slabs for defense purposes. The area is affected by widespread landslide phenomena, involving both the rocky slabs and the underlying clayey shales. The main phenomena acting on the slabs are lateral spreading, with associated rock falls and topples. In this area, a multidisciplinary project, involving different expertise, like geology, geodesy, geomorphology, hydrogeology, soil and rocks mechanics is ongoing. In this particular context, in order to achieve a clear recognition of the instability phenomena, it is necessary to understand the movement patterns and the eventual differential displacement occurring in the slabs. Monitoring activities, joined with geological and geomorphological interpretation, are one of the fundamental step for a deep understanding of the movements and for the risk management purposes. In many cases, the monitoring system is missing or only poor data are available, therefore an approach for the Permanent Scatterers (PS) data analysis has been used, combining analysis on the PS velocity, on the direction of the movement and statistical consideration on the time series trend. Some preliminary results regarding the rock slab on which the town of Verucchio (RN, Italy) is located are here presented.

## Keywords

Satellite interferometry • Monitoring • Cultural heritage • Valmarecchia • Italy

## 55.1 Introduction

In Italy slope instability phenomena affecting natural and cultural heritage sites are very common: some of these affect historical towns built on the top of rock slabs, like Pitigliano in Tuscany (Fanti et al. 2012), Orvieto in Umbria (Tommasi et al. 2004), and many others.

The area between the Emilia-Romagna and Marche regions, called Valmarecchia, is characterized by a typical landscape, spotted with high grounds carved in Epiligurian rock slabs. These slabs developed during the Pleistocene and Holocene, especially in the latest glacial phase; their limits are usually marked by steep cliffs or rock walls, thus offering ideal locations to build fortresses or military settlements; for this reason, in the Medieval period, villages were usually built on the top of them. Widespread instability phenomena

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affect these slabs and the clayey substratum on which they rest. The evolution of these instability phenomena can pose a severe risk to the fortified villages.

In these cases a deep knowledge of slope instability processes, taking into account the different factors that influence the evolution of the movements, is fundamental. In the context of endangered historical and environmental assets, different approaches and multidisciplinary works are needed to lead to the definition of adequate low-visual impact countermeasures and eventual monitoring systems. For example, regarding the San Leo rock slab, located in the middle part of Valmarecchia, a Terrestrial Laser Scanner survey was performed all around the cliffs, with the aim to describe the 3D geometry and the structural features of the slab. Moreover, studies about the material properties, the hydrologic system and the ongoing displacements are in progress. In this framework, geomatic and monitoring techniques can result very useful for an in-depth understanding of the rate, type and evolution of instability phenomena, but sometimes available data are not enough for the selected area or period. The PSInSAR technique has proved to be applicable in different contexts to analyze ground displacements, from land subsidence to landslides. The Permanent Scatterers (PS) analysis, due to its characteristics of precision, to the availability of quite long historical data set and wide area coverage can support the conventional in situ monitoring methods.

## 55.2 Methodology

In this work different interferometric analysis techniques were integrated to enhance the knowledge of the instability phenomena acting on the slabs. The contribution of the radar interferometric analysis for the Valmarecchia area permits to provide information on the state of activity, on the direction and on the movement pattern of different types of slope instability phenomena. These information will be integrated with geological, structural and geomorphological data to achieve a better comprehension of the acting phenomena.

The Permanent Scatterers analysis was performed using different dataset acquired in the frame of the PST-A (Piano Straordinario di Telerilevamento Ambientale/Extraordinary Plan of Environmental Remote Sensing) project: San Marino, Marecchia and Urbino datasets were collected between 1992 and 2000 and they are originated from the ERS images processing; Arezzo and Rimini datasets were collected between 2003 and 2008 and they are the results of the interferometric analysis of ENVISAT images. The images were processed by the companies T.R.E. S.r.l. and e-GEOS with the PS InSAR technique. The PS time series were analyzed with a tool developed by T.R.E.

(TRECcustomerToolbar, T.R.E. s.r.l.) and using a method for automated classification (Berti et al. 2013).

Moreover, the data of average velocity provided by the 2 geometries, ascending and descending, were combined to obtain the orientation of the velocity vector on the horizontal plane (EW) and vertical axis. Analyzing the time series, it is possible to identify and map homogeneous areas with respect to the deformation processes. Differences in average velocity of deformation may be useful for the identification of areas with distinct evolution and for the discrimination of different deformation behavior within the same landslide area, i.e., of rock blocks affected by differential subsidence due to deep-seated lateral spreading phenomena.

### 55.2.1 Time Series Analysis

In order to provide a general overview of the time series and to investigate the spatial distribution of different time series trends with respect to topographic and geologic features, the PS data were processed with PS Time software (Berti et al. 2013), which allowed the automated classification of the PS movement based on their time series trends. In particular, the datasets were subjected to a conditional sequence of statistical tests to classify each time series into one of the six predefined target trends: uncorrelated, linear, quadratic, bilinear, discontinuous with constant velocity and discontinuous with variable velocity. These trends describe different modes of ground deformation (Berti et al. 2013); uncorrelated time series represent random fluctuations of displacements around zero, and therefore PS with no significant movements during the observation period; linear trends indicate ground displacements with constant velocity and deformation phenomena acting over long time scales like creep, natural subsidence and slow and steady motion of so-called “dormant” landslides. Non-linear trends, quadratic, bilinear and discontinuous, denote the displacement rate variation during the analyzed period: velocity varies continuously in time for the PS with quadratic trends; for the PS characterized by a bilinear trend, the time series is segmented in two linear tracts of different velocity separated by a breakpoint in which the function is continuous; for the PS with a discontinuous trend, the time series is segmented in two linear tracts of similar or different velocity separated by a breakpoint in which the function is discontinuous.

### 55.2.2 Displacements Direction Analysis

The possibility to combine the velocity of PS data processed in ascending and descending orbit improves the amount and quality of information obtainable on the analyzed phenomena. The analysis procedures described in PST-A Guidelines

(MATTM 2009) were followed. In areas where both acquisition geometries for the same satellite are available, velocity measurements along the two different Line Of Sight (LOS) can be combined. It is almost never verified that a PS is considered as a target in both acquisition geometries, it is therefore necessary to proceed with a re-sampling of the ascending and descending datasets on a square grid mesh in order to make them comparable. The average velocity value of the Permanent Scatterers (PS) located inside each grid cell can be assigned to the cell center. The velocity values recorded along the ascending and descending orbits are then geometrically combined to obtain the velocities along the vertical and E-W horizontal direction. Estimation of the N-S horizontal velocity of deformation is not feasible, as one of the main limitations of the PS technique is the difficulty in recording horizontal movements along the North-South direction since the sensors operating orbits are oriented approximately along the meridians.

### 55.3 Valmarecchia Geology and Geomorphology

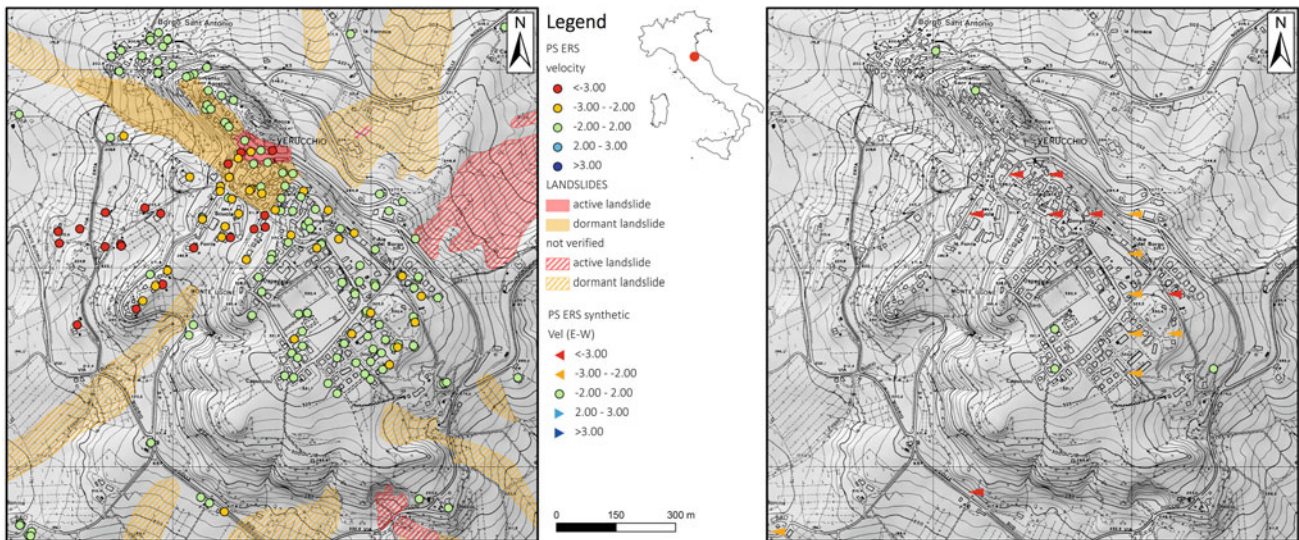
From a geological point of view, the study area is marked by a unique geodynamical phenomenon, known as Valmarecchia thrust sheet. In the sheet, the most ancient Ligurian Units and the younger Epiligurian Units, which are related to different depositional cycles, overthrust autochthonous Units of the Umbro-marchean-romagnan domain sedimented on the Adria continental microplate. The Epiligurian Units (hard rocks) rest unconformably on the Ligurian Units (varicoloured clays, marly and limestones) creating high grounds named Epiligurian plates or slabs. The slabs are often tectonized and crossed by several joint sets and faults, often interested by lateral spreading phenomena and associated rock falls, topples and tilting. Moreover, the underlying clayey substratum is involved in plastic movements, like earth flows and slides (Casagli 1994). The main cause of instability, which brings about these widespread movements, is the high deformability contrast between the plates and the underlying clays (D'Ambra et al. 2004). Other factors that predispose the instability are the structural setting of these slabs, the groundwater flow inside the plates and the consequent destabilization of the basal clays, which, together with creep and flows in the underlying clay, undermines the foot of the rock plates and causes the opening and widening of vertical fractures in the limestone rock masses. Therefore, the understanding of the movement patterns and of the differential displacement occurring in the slab is fundamental in order to achieve a clear description of the phenomena.

### 55.4 Discussion

Some preliminary results regarding Verucchio site are here described. The town of Verucchio is located on a rock slab, in Valmarecchia area, about 20 km SW of Rimini, at an average altitude of about 300 m a.s.l. The slab, formed by the so-called San Marino and Monte Morello geological units (limestones and sandstones) and crossed by several small faults or joints, lies on a clay substratum. Finally it is worth to emphasize the presence of a vast overthrust on the east side of the slab having a roughly North-South direction, that testifies the movement of the plate on the older Ligurian units occurred in the past. ERS dataset, acquired between 1992 and 2000, was analyzed to infer the behavior of the rock slab. Three areas with different trends of movements were identified from the study of the PS data, even if an higher density dataset would be certainly useful for a better characterization of the phenomenon. The presence of an area located in the central part of the slab, showing higher velocities can be observed from the PS velocity map (Fig. 55.1); in the eastern sector of this area the landslide inventory map reports an active landslide, classified as rock fall or toppling. In this area damages to buildings were reported but the definition of the landslide type and evolution is not clear, since no in situ geotechnical instruments are available at present. Interferometric results can confirm the existence of an unstable area and suggest some features, i.e. the rate, the direction and the pattern of the movement; this can be the starting point on which further specific investigation and monitoring activities can be proposed.

Moreover, in the western sector of the central area, where no landslides were previously mapped, some clusters of point with a mean velocity reaching values of  $-12$  mm/year along the LOS in the descending geometry, are detectable; these points are located on the San Marino geological unit. The PS velocities suggest the presence of unstable areas, requiring specific investigations. The northern area appears to be more stable, while in the south one velocity between 2 and 3 mm/year, along descending LOS, were registered.

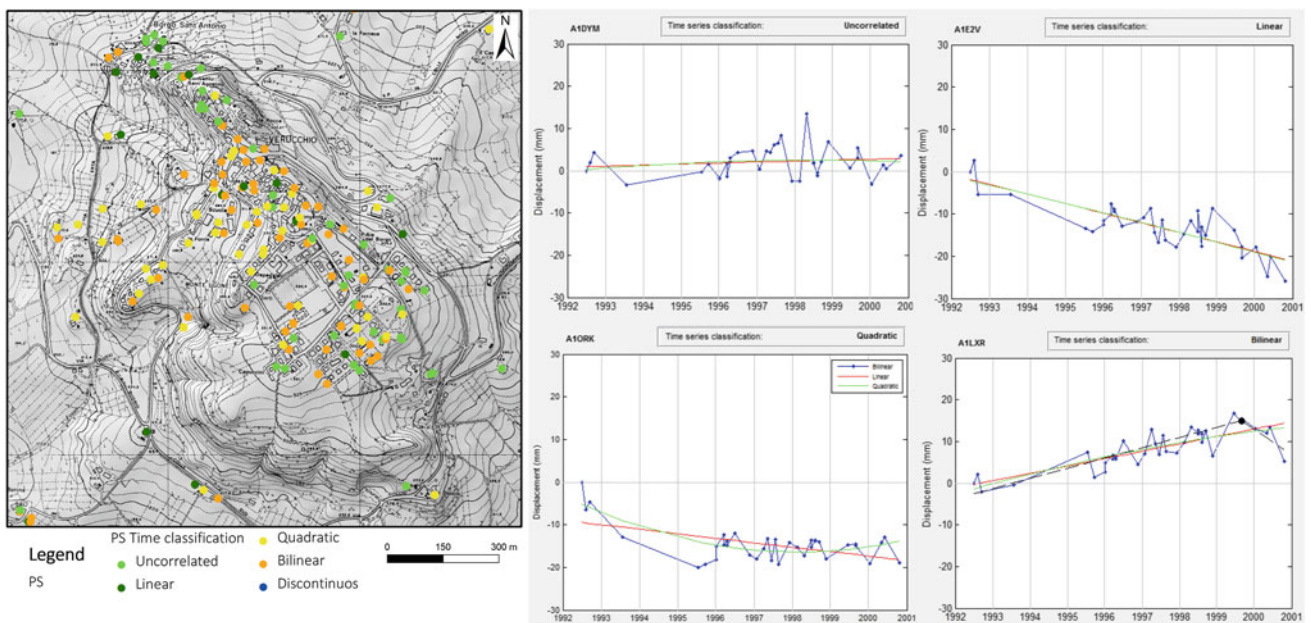
The synthetic PS obtained from Ascending and Descending geometries combination are fewer than the original points, because they can be obtained only in cells in which targets from the two geometries are present. By analyzing PS trends, part of the slab is roughly characterized by E to W displacements. PS showed velocities reaching  $-4.0$  mm/year; further investigations are required to better understand the main cause of the movement. The Vertical displacements range between  $-1.5$  and  $0.7$  mm/year, for the analyzed period. Almost the same results were obtained with a slightly different procedure. Each descending geometry PS was joined with the closest ascending geometry PS using a 50 m maximum radius distance. Different types of



**Fig. 55.1** Velocity class along LOS of ERS PS (ascending and descending geometries) and direction of the movement on E-W axis

movement patterns are identifiable analyzing the LOS velocity. Uncorrelated and linear trends, probably indicating no movements and/or dormant landslides, are predominant in the north area, where, in fact, a dormant landslide is located. Quadratic and bilinear trends are prevalent in the central part, in correspondence of the above mentioned mapped and newly detected landslides; a mix of quadratic, uncorrelated and bilinear trends characterize the south area (Fig. 55.2).

Obviously, these preliminary results need to be interpreted, validated and integrated with others techniques, but they show how the applied methodology can give an overview of the movements occurring in this particular context; these data are useful for the interpretation and the understanding of the phenomena, mostly in the cases in which others monitoring data are not available or cover only limited periods. These indications, deriving from interferometric analysis, can give a first idea of the type and of the movement rate, useful to choose



**Fig. 55.2** PS-Time classification and examples of the different movement patterns

where and how to continue or focus the monitoring activity. Another interesting issue can be the correlation between these results and the rainfall or the seismic records in a selected area, especially for points showing displacement rate variations during the analyzed period. Interferometric techniques permit also to update landslide boundaries or to highlight unstable areas where no mapped landslides were previously detected, as in the Verucchio case. This information have to be integrated with other data, like geological and geomorphological maps and on site investigations.

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