# THE *SBAS-DINSAR* APPROACH FOR THE SPATIAL AND TEMPORAL ANALYSIS OF SINKHOLE PHENOMENA

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## ABSTRACT

Sinkholes represent the main hazards in karst areas, and are related to presence of natural and anthropogenic cavities. In order to mitigate the risk related to sinkholes, identification of likely premonitory signs preceding the catastrophic phase of collapse may be extremely important. Remote sensing and surface monitoring can be used at this aim: multi-pass space-borne Differential Synthetic Aperture Radar Interferometry (DInSAR) techniques, in particular, provide a valid support to remotely investigate the sinkhole susceptibility over large areas and long time intervals.
In this work, we analyze surface deformation occurring in Apulia region, Southern Italy, at two spatial scales. In particular, we apply the advanced DInSAR approach referred to as Small BAseline Subset (SBAS) for carrying out regional scale analysis and the 4-D (space velocity) imaging technique for investigating deformation phenomena at local scale. We exploit ascending ENVISAT images spanning the 2003-2010 period and analyze subsidence phenomena induced by both natural and anthropogenic factors.

## 1. INTRODUCTION

Sinkholes are a very subtle hazard typical of karst areas, and related to presence of soluble rocks (carbonates, evaporites) affected by dissolution processes [1,2]. Development of sinkholes is generally catastrophic in its final stage, posing severe risks to the anthropogenic environment [3, 4, 5]. In addition to those produced by natural processes, sinkholes related to man-made cavities are occurring at increasing rate, especially in areas characterized by soft, easy to be worked, rocks such as volcanic tuffs and calcarenites.
Sinkholes are widespread all over the world, and the likely damage to built-up areas and human infrastructures may result very severe, causing heavy losses to the society [6]. In many countries, sinkholes have been for a long time underestimated, when compared to other, more common, natural hazards such as slope movements and earthquakes. Nevertheless, in recent years they are occurring in Italy at an increasing rate, so that the interest of both the scientific community and the mass media has strongly raised.
Satellite Differential SAR Interferometry (DInSAR) represents a useful tool for detecting and monitoring surface deformation at different spatial scales. In the last years, the interferometric techniques have been applied to the analysis of several types of hazards (i.e., slope movements, earthquakes, volcanoes, etc.), but very few applications regarding karst collapses are present in the scientific literature. This paper describes the preliminary outcomes of an application of advanced DInSAR techniques to karst areas in Apulia region, Southern Italy (Fig. 1), aimed at understanding the potentiality of such remote sensing techniques in identifying precursory movements in the final stage of sinkhole development.

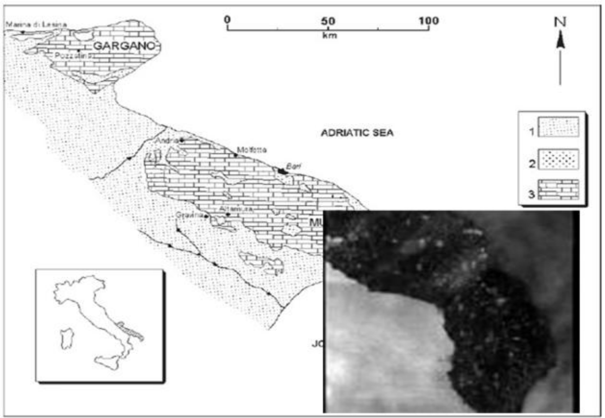


*Figure 1. Geological setting of Apulia region. Legend: 1) recent clastic cover (Pliocene-Pleistocene); 2) bioclastic carbonate rocks (Paleogene) and calcarenites (Miocene); 3) platform carbonate rocks (Cretaceous). In the inset, the SAR amplitude image of the study area is reported.*

## 2. NATURAL AND ANTHROPOGENIC SINKHOLES IN APULIA, SOUTHERN ITALY

Sinkholes occur as sudden collapses of the ground, related to natural cavities produced by karst processes in soluble rocks, or to man-made cavities deriving from different types of human activities in different historical ages (ancient aqueducts, underground mines and quarries, cisterns, human settlements, etc.). Loss of memory of these underground cavities often results in building above voids, which extension and stability conditions are not known. As a consequence, the upward evolution of instabilities phenomena occurring underground may reach the ground surface, thus creating sinkhole events.

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*Figure 2. Sinkholes related to natural (photos a and c) and man-made (photos b and d) caves in the Apulian karst: a) Spedicaturo (March 1996); b) Cutrofiano (July 15, 2008); c) Casalabate (March 2010); d) Barletta (May 3, 2010).*

Both the conditions above are widely satisfied in Apulia, south-east Italy (Fig. 2), a region almost entirely characterized by presence of carbonates, and by a very high number of man-made cavities as well. Sinkholes of different types (according to the classification in [3]) represent one of the most common karst landforms in the region, often being the access to the underground network of karst caves [7]. At the same time, Apulia has also a long history of anthropogenic sinkholes, that is events directly related to presence of underground voids. In the last years an impressive number of sinkholes (both natural and anthropogenic in origin) have been recorded and surveyed in the region [8], and the issue has become of greater attention. This was in particular due to the event occurred in the town of Gallipoli where on March 29, 2007, a sinkhole opened as a consequence of the collapse of the vault in an underground quarry; the sinkhole margins touched two buildings and three cars were engulfed in it (Fig. 3), but likely no casualty was registered.

*Figure 3. The sinkhole in the town of Gallipoli (March 29, 2007), formed because of the collapse of the vault in an ancient underground quarry.*

In such a context, research activities have been started, integrated by speleological exploration and surveys, in the attempt to gain a better comprehension of the mechanisms leading to underground failures, and their upward propagation to the ground surface, with sinkhole formation.

In particular, as regards mitigation of the risk related to sinkholes, it is of interest to explore the feasibility in identifying and measuring premonitory signs in the final stage of sinkhole evolution, which may precede the collapse [9, 10]. At this aim, the application of DInSAR techniques to remotely analyze and monitor these phenomena may result very useful and productive, even more than for many other natural hazards. Differently from landslides, in fact, which are generally characterized by features that make often difficult the application of interferometric techniques (presence of vegetation, steep slopes, geomorphological complexity), sinkholes occur in flat areas, often on bare ground or in built-up areas. This should at least reduce some of the problems encountered when applying DInSAR to investigation and monitoring of landslides and may, at the same time, greatly contributing to demonstrate its applicability to the evaluation of the sinkhole hazard.

## 3. DInSAR PROCESSING AND RESULTS

Multi-pass DInSAR techniques use stacks of SAR images in order to overcome the problems associated with atmospheric propagation delay variation and, at the same time, to monitor, with high accuracy, natural phenomena and achieve accurate localization of the monitored points. Particularly, the SBAS (Small BAseline Subsets) technique [11], focuses on the use of appropriate combinations of interferograms, characterized by small baseline, in order to mitigate the decorrelation errors and to obtain very accurate deformation measurements. The SBAS technique has been successfully applied to medium resolution SAR sensors (i.e. ERS and ENVISAT) [12, 13], allowing to produce deformation maps at regional scale (typically with spatial resolution of the order of tens of meters) and time series of displacements. The extension of the technique to full resolution data (spatial resolution of 5-10 meters) has been also exploited [14], thus allowing the monitoring of deformation phenomena at local scale, even affecting single buildings and man-made structures.

However, in this work we apply the SBAS technique for performing analysis at regional scale by exploiting averaged (multi-look) interferograms and the technique known as 4-D (space velocity) imaging for carrying out the full resolution analysis [15]. Such a technique, to achieve high accuracy on the localization of targets at large scale, uses also large baselines. Moreover by exploiting the amplitude and phase information, it allows a robust identification of persistent scatterers.

Our DInSAR analysis has been carried out by processing a dataset of 41 SAR images acquired along the ascending orbit (Track 272, Frame 801) and spanning the time interval between March 2003 and May 2010.
As result, a low resolution deformation velocity map has been produced (Fig. 4) pointing out that the study area is not affected by regional patterns of surface deformation. Subsequently, the full resolution processing has been performed on selected active areas in order to gain insights on the spatial and temporal behavior of very localized deformation phenomena.
In particular, we focused on areas characterized by high sinkhole susceptibility localized in the Salento peninsula, the southernmost part of Apulia, both being interested in the last 15-20 years by sinkhole events. They include the town of Gallipoli, where the March 2007 event occurred, and the area around Cutrofiano, highly affected by sinkhole phenomena because of the presence of extensive, several tens of km-long, systems of underground quarries.
In Fig. 5 the full resolution deformation velocity map relevant to the Gallipoli area is reported. Visual inspection of the map reveals the presence of very localized deformation phenomena occurring in the south of urban centre whose temporal trends have been analyzed by generating displacement time-series (Fig. 6).
These preliminary results demonstrate the effectiveness of multi-scale interferometric techniques in analyzing both spatial and temporal patterns of surface deformation. Furthermore, the availability of data archives (ERS and ENVISAT) and the high accuracy of the measurements make advanced DInSAR techniques suitable for the analysis and monitoring of sinkholes. Despite the suddenness of the final catastrophic collapse, in fact, sinkhole occurrence is preceded by slow movements, which could be surveyed by generating long deformation time-series.

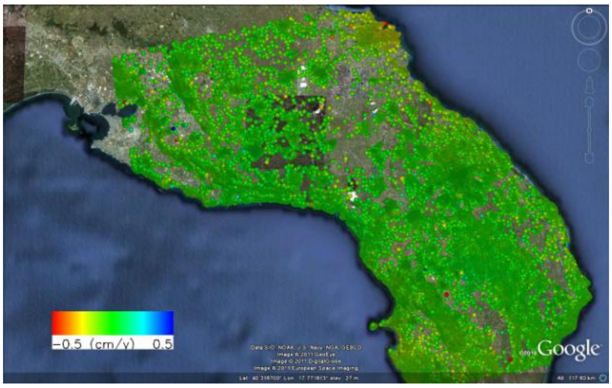


*Figure 4. Ground deformation velocity map at regional scale relevant to the Salento area, Apulia region (ENVISAT ascending dataset).*

*Figure 5. Ground deformation velocity map at local scale relevant to the urbanized area of Gallipoli (ENVISAT ascending dataset).*

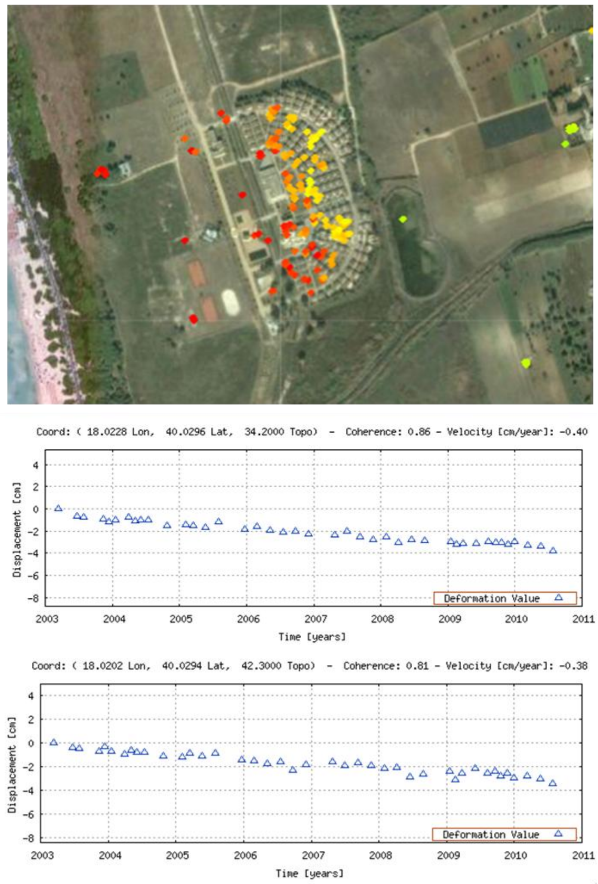


*Figure 6. Zoomed view of the ground deformation velocity map at local scale, relevant to a building located in the south of Gallipoli urban centre (on the top) and displacement time-series (on the bottom) relevant to two points significantly affected by deformation.*

## 4. DISCUSSION AND FUTURE PERSPECTIVES

The research described in this paper is part of the activities of a project addressed to evaluate the hazard related to sinkhole phenomena of natural and anthropogenic origin. Among the main goals of the project, there is the detection of premonitory signs before the occurrence of documented sinkhole events, and the comparison between the deformations (up to final collapse) registered at the ground surface and underground with those detected by satellite.

The analysis has so far consisted of the production of deformation maps of the studied areas, and time series of the surveyed points. These maps are at present being critically evaluated, based upon knowledge of the spatial distribution of underground cavities, and of dates of occurrence of sinkhole phenomena. Following this first evaluation, it will be possible to draw some conclusions about the sinkhole kinematics. At the same time, research about identification of the failure mechanisms, and their upward propagation to the surface, is going on, also by means of numerical modeling [10]. This part of the research will eventually be combined with the outcomes from the interferometric analyses, in order to understand the feasibility of advanced DInSAR techniques to predict the last catastrophic stage of sinkhole evolution, and thus to be used as Civil Protection tool, by developing integrated systems of surface, subsurface and satellite monitoring in sinkhole-prone areas.

The expected results will provide valuable suggestions for the development of procedures aiming at the exploitation of remote sensing data for natural hazards evaluation and mitigation of their risk.

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