



# Using SAR Observation Data to Support the Spatial Planning in Areas Affected by Landslide Phenomena

Alberico Sonnessa<sup>(✉)</sup> 

Department of Civil, Environmental, Land, Construction and Chemistry (DICATECh),  
Polytechnic University of Bari, Via Orabona 4, 70125 Bari, Italy  
alberico.sonnessa@poiba.it

**Abstract.** Due to the hydro geological instability involving our territories, soil ecosystems and built areas are increasingly threatened by potentially catastrophic phenomena, such as subsidence or landslides, which can also pose a danger to people safety. In the light of this, a comprehensive characterization of the instability, in terms of spatial extent and evolution over time, is needed for managing the related risk, take the proper mitigation actions and drive the spatial planning activities. Geospatial data, such as Copernicus Sentinel-1 Synthetic Aperture Radar (SAR) observations, processed using Multi-Temporal Interferometric (MTInSAR) techniques, represent a well-established and reliable tool for controlling large areas interested by ground motion events. Open and free SAR data, provided by the European Space Agency through the European Ground Motion Service, constitute an additional support. The proposed research shows the results of an application of SAR geospatial observations in the monitoring of an anthropic area affected by a landslide. To this aim, satellite acquisitions have been utilized to thoroughly describe the instability occurrence, by retrieving its main kinematic parameters and quantifying its extent. The outcomes of the analysis addressed the design of the mitigation measures to be taken for securing the study area and helped the regional Government Commissioner for the environmental risk in the planning of the future use of the space involved in the landslide phenomenon.

**Keywords:** Land management · Land monitoring · Copernicus · MTInSAR · EGMS

## 1 Introduction

Due to its peculiar morphological and geological features, the Italian territory is increasingly prone to hydro geological instabilities [1] involving soil ecosystems and built areas, which are always more frequently threatened by potentially catastrophic phenomena, such as subsidence or landslides, posing a danger to people safety.

Therefore, spatial planning and land management actions must consider the influence of these critical events on the territory and the urban centers, to properly address

the design of all the relevant activities related to the land transformations, in the most sustainable way possible [2, 3].

As well known, slow ground instability may impact the safety of structures and people [4]. The detection and the control of the associated kinematic parameters (i.e. displacements and displacement velocities) can encompass different methodologies, such as ground [5, 6] and/or satellite-based (e.g. SAR [7, 8], Global Navigation Satellite Systems – GNSS [9]) geomatic techniques. Radar images acquired by means of spaceborne SAR sensors and analyzed using the MTInSAR techniques (briefly described in par. 2) can effectively foster the understanding of ground deformation phenomena involving infrastructures and buildings [10, 11].

The capability of inspecting large portions of territory with a high-frequency temporal sampling allows to analyze diffuse instability through Persistent Scatterer Interferometry (PSI) [12], which provide information about motion/motion rates along the line-of-sight (LoS) of scatterers belonging to the investigated area. In the context of land monitoring, the European Space Agency (ESA) plays a key role through the Copernicus Programme which includes the Sentinel-1 (S1) mission, consisting of two quasi-polar-orbiting satellites, equipped with SAR devices operating in C-band [13].

Since 2022, ESA also provides free displacement SAR data through the Copernicus European Ground Motion Service (EGMS) [14]. Currently, displacement time series are available between February 2015 and December 2021, while additional data concerning the year 2002 will be available since October 2023 [15].

The presented study is aimed at bringing out the effectiveness of spatial techniques in the land management, where the prompt identification and the thorough analysis of the displacement field generated by the progression of an instability process is crucial to correctly implement the most effective strategies supporting the decision managers [16, 17]. Displacement maps derived from satellite SAR data have been used to characterize an anthropic area, affected by a slow landslide phenomenon, under the attention of the Government Commissioner for the environmental risk of the Apulia region, which is in charge for the implementations of proper interventions for mitigating the effects of the instability process. The presented outcomes are part of the results of a broader project, within which the geomatic analyses permitted to retrieve the main kinematic parameters characterizing the displacement field and highlight the presence of differential movements. These findings are supporting the geo-hydro-mechanical modelling of the landslide mechanism and the design of the mitigation actions.

Furthermore, in the context of the Italian National Strategy for the Inland Areas [18], focused at countering the depopulation of Italian inner territories with poor and distant essential services (education, health, mobility), causing cultural, social, and economic impoverishment of these regions, this study wishes to contribute to the improvement of the resilience of the investigated areas vs. landslide, and provide elements useful for the planning of regeneration actions.

## 2 The MTInSAR Technique and the EGMS Program

MTInSAR technique is based on the coherent image principle of synthetic aperture radar (SAR), in which a sensor uses electromagnetic waves to acquire and collect information on amplitude and phase of the signal reflected/scattered back from the surface. This technique enables displacement measurements along the so-called LoS, (i.e. the direction sensor-to-target) exploiting the phase difference between the backscattered signals of two radar images acquired in different epochs, thus making possible long-term analysis of modifications in the Earth's surface with centimetric or millimetric accuracy [19]. The technique allows identifying reliable coherent measurement points (MP), i.e. Persistent Scatterers (PS) associated with a single pixel of the image and Distributed Scatterers (DS), related with a group of statistically homogeneous pixels of the same image, for which motion velocity values and time series of deformation are extracted. As well known, the main limitations of this technique are the lack of MP in vegetated areas, and the low sensitivity to the North-South component of the displacement due to the quasi-polar orbits characterizing the S1 satellite missions. However, under certain assumptions [20], the estimation of the velocity of an MP can reach an accuracy in the order of than  $1 \div 2$  mm/year.

In this context, the European Union's Earth observation space programme, named Copernicus, provides, among its Land Monitoring Services openly accessible to all users, the European Ground Motion Service (EGMS).

Based on the MTInSAR analysis of S1 radar images at full resolution, the EGMS allows the analysis of deformations phenomena, natural or triggered by the anthropic activity, such as slow-moving landslides or subsidence, also serving as a starting point for detecting and investigating ground motion affecting urban areas and infrastructures [21]. The EGMS also provide, via webgis, tools for visualization, interactive data exploration and user uptake elements for further investigations [22].

## 3 The Case Study

The analysis of the spatial dataset related to a ground instability phenomenon has been carried out on the municipality of Chieuti, located in the South of Italy. The town of Chieuti, sited in the Apulia region (Fig. 1), was founded in the 15th century by Albanian immigrants. Agriculture is the most important source of its economy income. The old town is perched on a hilltop at 221 m a.s.l., where a population of about 1600 people is currently living.

Being the municipality closest to the northern border of Apulia, Chieuti has been awarded the title of Porta della Puglia (Apulian Door) by the Ministry of Economic Development. This strategic position, along with the care in preserving its cultural identity and traditions (e.g. the use of an ancient idiom called arbëreshë, typical of the southern Albania), make Chieuti a very peculiar hamlet. The historic center is characterized by masonry buildings and alleys.

Evidence of instabilities affecting the old town has been recorded since 1800, as reported by archive documents referring to collapses of structures positioned in the north-western sector bordered by Largo Quattro Novembre, Via dei Martiri di Via Fani



**Fig. 1.** Case study. The town of Chieuti (source: Google Earth).

and part of Via Vitalia (Fig. 2). Buildings located westward the red dash-dotted line have suffered from the cumulation of mainly downward displacements, caused by a landslide. Unfortunately, all the mitigation actions, implemented in the last decades to counter the landslide phenomenon, have had a reduced effectiveness. The most recent intervention, consisting of a concrete retaining wall connected to the pre-existing structure founded on shallow footings (dated 1987–1989), has been built between 2004 and 2006 (yellow line in Fig. 2). This construction shows the effects of a still ongoing instability.



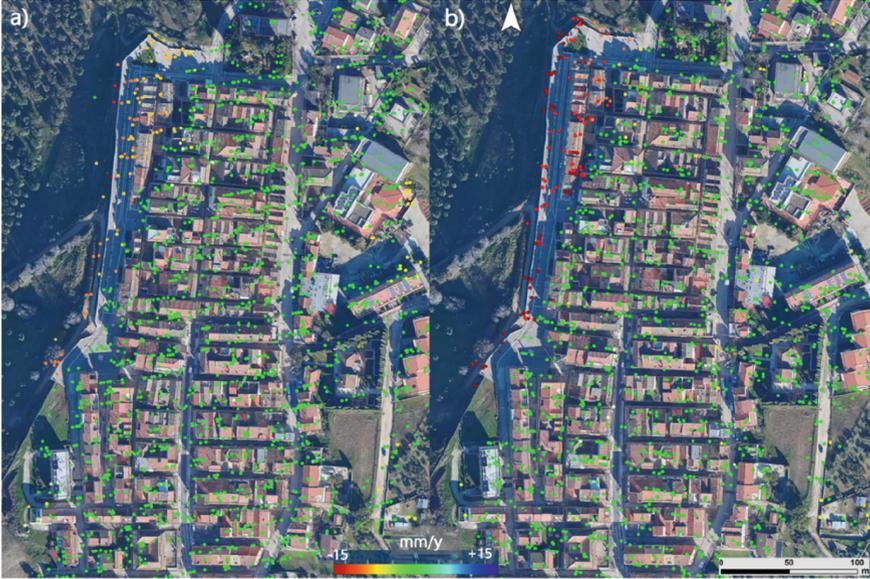
**Fig. 2.** The old town affected by the instability. Number 1,2,3, indicate the location of some of the damages clearly detectable on the field.

#### 4 Analysis of the SAR Dataset

The analysis of the MTInSAR measurements has been focused on the estimation of the distribution and magnitude of the displacement rates over the investigated area, by using an S1 interferometric dataset and made available by the Government Commissioner. Under the hypothesis of absence of deformation of the structures, the results can be considered indicative of the ground morphology evolution.

Hereafter, the results refer to an image processing whose acquisition spans from 12 April 2015 to 30 November 2021. Their reliability takes advantage from the large image stack available, including 352 and 349 acquisitions along the ascending orbit and over the descending track respectively, and covering six years with an average revisit time of the area equal to six days after the introduction of the Sentinel-1 B satellite in September 2016.

Mean displacement velocity maps estimated along the satellite LoS are shown in Fig. 3, where the sections a and b correspond to the results retrieved along the ascending and descending orbits, respectively. Both maps provide clear evidence of the location and extent of the settling area, confirming that it is mainly confined in the north-western sector of the old town, limited by Via dei Martiri di via Fani, Largo Quattro Novembre and the north part of Via Vitalia. The landslide involves an area of about 9000 m<sup>2</sup>. Mean



**Fig. 3.** PS obtained on the Chieuti area (both ascending (a) and descending (b) orbits) by the S1 satellites between April 2015 and November 2021

displacement rates away from the sensor, estimated along the LoS, range from millimeter to centimeter per year, with a maximum of  $-13$  mm/year along the ascending orbit, and  $-15$  mm/year along the descending orbit.

Differential movements potentially harmful for the structures have been detected by setting a threshold on the coherence and velocity values on the PS map obtained along the descending track. A first classification allowed to highlight the areas characterized by the higher motion rates by selecting the PS according to the parameters listed below:

- coherence  $\geq 0.8$
- velocity along the LoS ( $V$  LoS)  $\leq -9$  mm/year

A close inspection of the velocity map in Fig. 4 reveals sectors characterized by different displacement velocities (A, B and C, D, emphasized in the red and orange squares). The A and B areas (dots located on the southern and northern part of Via dei Martiri di Via Fani respectively) are location of the highest mean displacement rate ( $-13 \div -14$  mm/y). A lower speed was detected for C and D sectors, underlining the presence of differential movements along the Martiri di via Fani axis (Table 1).

With the aim of confirming the extent and the magnitude of the instability, a very preliminary analysis of the dataset available via EGMS has been performed. The displacement map displayed in Fig. 5, even referring to a slightly different time span (February 2015 to December 2021), completely agree with the results obtained from the independent processing. The presence of differential motions is also confirmed, as evidenced by PS evidenced in the white squares in Fig. 4.

**Table 1.** Cluster of PS selected by the coherence value and displacement velocity.

|                      | A   | B   | C   | D   |
|----------------------|-----|-----|-----|-----|
| Mean coherence       | 0.8 | 0.8 | 0.9 | 0.9 |
| Mean V LoS (mm/year) | -14 | -13 | -10 | -9  |

**Fig. 4.** Areas showing differential ground motions over the 2015–2021 period.

## 5 Discussion

In this work, a C-band SAR image stack, acquired from April 2015 to November 2021 by the S1 satellite mission has been investigated to highlight the effect of the landslide phenomena affecting the western slope and part of the urban area of the town of Chieuti.

The study of the retrieved velocity displacement maps confirmed the presence of a still on-going process located in the north-western sector of the town. Although the first evidence of this critical occurrence dates to the last decades of 19th century, the back-analysis performed over the last six years of SAR acquisitions permitted to better delimit the portion of the built-up area (about 9000 m<sup>2</sup>) affected by the instability and quantify the displacements and velocities suffered by the structures in the period considered. The analyses, which mainly focused on the zone overlooking the slope and the retaining wall carrying Via dei Martiri di Via Fani, allowed the identification of sectors characterized



**Fig. 5.** Displacement map of the Chieuti area (both orbits are displayed) produced by the EGMS, between February 2015 and December 2021. White squares enclose PS characterized by higher displacement rates.

by different displacement rates, ranging from 9 to 14 mm/year along the LoS on the descending track, thus evidencing possible risk for the investigated structures.

## 6 Conclusions

European Land Monitoring Services are acquiring an always increasing importance in supporting spatial planning. EGMS, in particular, could represent a fundamental tool in areas affected by landslide phenomena, as showed by the analysis of the S1 SAR dataset, suggesting a permanent displacement rate trend. A preliminary comparison with the data provided by the EGMS, indeed, fully confirms the location and the magnitude of the instability.

As this work is framed in a broader project aimed at diagnosing the causes of the mechanism generating the instability phenomenon affecting the slope, to select the better

strategy to mitigate the instability effects, the findings will be integrated in a joint analysis of geotechnical and geological data, along with deep displacement data, acquired by means of inclinometric monitoring. Furthermore, the displacement data presented in this paper will be of reference for comparison with numerical predictions resulting from the three-dimensional modeling of the stress-strain equilibrium of the hillslope evolving with time under the external actions (e.g. climatic conditions).

Obtained outcomes will help the Government Commissioner to implement the proper mitigation actions and, hopefully, generate a territorial management prototype for tackling potentially critical occurrences. Furthermore, thanks to the future availability of a comprehensive dataset including geomatics, geotechnical and geological data and information, the Chieuti case history could be eligible to become an open-air laboratory for all the scientific community interested in studying instability phenomena.

**Acknowledgments.** This research has been conducted under the agreement between the DICATECh and Government Commissioner for the environmental risk of Apulia.

Copernicus Land Monitoring Service products and services were produced with funding by the European Union.

## References

1. Trigila, A., Iadanza, C., Bussetini, M., Lastoria, B.: *Dissesto idrogeologico in Italia: pericolosità e indicatori di rischio - Edizione 2018* (2018)
2. Krishnan, A., George, G.: *Spatial Planning for Flood and Landslide: A Case of Nilambur* (2021)
3. Andersson-Sköld, Y., Bergman, R., Johansson, M., Persson, E., Nyberg, L.: *Landslide risk management - A brief overview and example from Sweden of current situation and climate change*. *Int. J. Disaster Risk Reduction* **3** (2013). <https://doi.org/10.1016/j.ijdr.2012.11.002>
4. Esposito, D., Cantatore, E., Sonnessa, A.: *A Multi Risk Analysis for the Planning, Management and Retrofit of Cultural Heritage in Historic Urban Districts*. (2021). [https://doi.org/10.1007/978-3-030-68824-0\\_61](https://doi.org/10.1007/978-3-030-68824-0_61)
5. Crespi, M., Giannone, F., Marsella, M., Sonnessa, A.: *Automated geomatic system for monitoring historical buildings during tunneling in Roma, Italy*. In: *Life-Cycle and Sustainability of Civil Infrastructure Systems - Proceedings of the 3rd International Symposium on Life-Cycle Civil Engineering, IALCCE 2012* (2012)
6. de Luna, R.M.R., Garnés, S.J. dos A., Cabral, J.J. da S.P., dos Santos, S.M.: *Groundwater overexploitation and soil subsidence monitoring on Recife plain (Brazil)*. *Natural Hazards* **86** (2017). <https://doi.org/10.1007/s11069-017-2749-y>
7. Sonnessa, A., et al.: *Integration of multi-sensor MTInSAR and ground-based geomatic data for the analysis of non-linear displacements affecting the urban area of Chieuti, Italy*. *Int. J. Applied Earth Observ. Geoinfo.* **117** (2023). <https://doi.org/10.1016/j.jag.2023.103194>
8. Scifoni, S., et al.: *On the joint exploitation of long-term DInSAR time series and geological information for the investigation of ground settlements in the town of Roma (Italy)*. *Remote Sens Environ* **182** (2016). <https://doi.org/10.1016/j.rse.2016.04.017>
9. Sonnessa, A., Tarantino, E.: *Using GNSS Observation for Mitigating the Impact of SODs and RODs on the Built Environment – Introducing the New SNIK Continuously Operating Reference Station and Its Applications* (2021). [https://doi.org/10.1007/978-3-030-87007-2\\_8](https://doi.org/10.1007/978-3-030-87007-2_8)

10. Bovenga, F., et al.: Assessing the Potential of Long, Multi-Temporal SAR Interferometry Time Series for Slope Instability Monitoring: Two Case Studies in Southern Italy. *Remote Sens (Basel)* **14** (2022). <https://doi.org/10.3390/rs14071677>
11. Dong, J., et al.: Tri-decadal evolution of land subsidence in the Beijing Plain revealed by multi-epoch satellite InSAR observations. *Remote Sens Environ* **286** (2023). <https://doi.org/10.1016/j.rse.2022.113446>
12. Crosetto, M., Monserrat, O., Cuevas-González, M., Devanathéry, N., Crippa, B.: Persistent Scatterer Interferometry: A review (2016). <https://doi.org/10.1016/j.isprsjprs.2015.10.011>
13. ESA: Copernicus Programme, <https://www.copernicus.eu/en>, last accessed 21 June 2023
14. ESA: EGMS, last accessed 21 June 2023
15. Crosetto, M., et al.: The evolution of wide-area DInSAR: From regional and national services to the European ground motion service (2020). <https://doi.org/10.3390/RS12122043>
16. Festa, D., et al.: Nation-wide mapping and classification of ground deformation phenomena through the spatial clustering of P-SBAS InSAR measurements: Italy case study. *ISPRS J. Photogram. Remote Sensing* **189** (2022). <https://doi.org/10.1016/j.isprsjprs.2022.04.022>
17. Pereira, S., et al.: A landslide risk index for municipal land use planning in Portugal. *Science of the Total Environment* **735** (2020). <https://doi.org/10.1016/j.scitotenv.2020.139463>
18. Agenzia per la Coesione Territoriale: Strategia Nazionale Aree Interne, <https://www.agenziacoesione.gov.it/strategia-nazionale-aree-interne/>, last accessed 21 June 2023
19. Franceschetti, G., Lanari, R.: Synthetic aperture radar processing (2018). <https://doi.org/10.1201/9780203737484>
20. Ferretti, A., Prati, C., Rocca, F.: Permanent scatterers in SAR interferometry. *IEEE Trans. Geosci. Remote Sensing* **39** (2001). <https://doi.org/10.1109/36.898661>
21. ESA: IREA-CNR: European Ground Motion Service (EU-GMS) A proposed Copernicus service element (2017)
22. ESA: EGMS Explorer, <https://egms.land.copernicus.eu/>, last accessed 21 June 2023