Interpretation of archived measurements within “PROION” project.

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ABSTRACT

Earth’s surface is constantly changing due to either natural processes or human activities. The systematic monitoring of surface deformation is an essential task to mitigate infrastructure risk and to ensure human safety. It is widely known that Persistent Scatterer Interferometry (PSI) constitutes an effective remote sensing technique for the measurement and monitoring of the Earth’s surface over time. The aim of the current work is to underline the capabilities of PSI technique for the monitoring of high-priority infrastructure in the framework of “PROION” project. The project is co-financed by the European Union and the Hellenic government and its main objective is the systematic monitoring of national infrastructure in Western Greece using remote sensing data, in situ measurements and advanced soft computing methods. In light of SAR interferometry, an innovative type of corner reflector was designed and manufactured. These newly-developed corner reflectors are described in details along with their installation in the specified observation sites. Since PSI technique requires the generation of large time-series datasets, along with the need of a better understanding of the possible infrastructure motion, we obtained archived PSI measurements derived from the European Ground Motion Service. The specific data are offered free of charge through the Copernicus Land Monitoring Service. At this point, archived PSI measurements over the observation sites of PROION project, covering a time span of five years, were analyzed and interpret in order to understand the ongoing deformation processes.

Keywords: radar, PSI, infrastructure, monitoring

1. INTRODUCTION

Earth’s surface is constantly affected by natural processes or human activities. In recent years, these alterations have accelerated due to rising temperatures and weather extremes (drought, floods, etc.), threatening both living organisms as well as the inanimate environment. In this framework, infrastructure is at an increased risk and thus the scientific community should provide reliable and cost-effective monitoring solutions in order to mitigate the effects and ensure human safety.

It is widely known that Persistent Scattering Interferometry (PSI) has proven to be an effective remote sensing technique for measuring and monitoring the Earth for more than two decades. Large-scale monitoring, regular surface measurements and cost efficiency are among the main advantages of the technique. At the same time, it has been demonstrated that Synthetic Aperture Radar (SAR) imagery and interferometric techniques are able to identify the deformation in multiple parts of a given infrastructure with sub-centimeter accuracy.

In particular, the first studies of infrastructure deformation were implemented using ERS-1/2 and ENVISAT imagery [1, 2]. Several interferograms were created and subsequently processed via Small BAseline Subset (SBAS) InSAR technique in order to analyze the deformation occurred on either dam or railway network. In corresponding studies, the aforementioned C-band data were utilized in conjunction with high-resolution radar imagery (COSMO-SkyMed, TerraSAR-X) to identify the deformation mechanism on dams as well as to evaluate the structural health of bridges [3, 4]. The recently launched Sentinel-1 constellation allows the generation of denser time series, contributing to the near real time measurement of infrastructure deformation. With regard to this, numerous researchers have dealt with the monitoring of infrastructure health using Sentinel-1 imagery [5-10]. In fact, the extracted outcomes are highly consistent with the in-situ measurements, while the root mean square error was estimated at 2 mm/year [11]. Moreover, Sentinel-1 imagery along with Persistent Scatterer Interferometry (PSI) were used to determine the soil behavior changes beneath road and rail networks in six different urban areas in UK [12]. In other efforts, space-borne SAR measurements and GNSS data were combined to monitor displacements on dam crest and determine the triggering factors [13].

Despite the provision of freely available and timely data of C-band sensors, X-band missions are still widely used due to their advantage of higher spatial resolution. Hence, COSMO-SkyMed and TerraSAR-X/TanDEM-X data have been used efficiently on dam monitoring concepts [14, 15]. Moreover, large-scale surface measurements resulted from the processing of high-resolution radar data via interferometric techniques have been effectively exploited to the analysis of long-term deformation of transportation infrastructure (highways, railways, bridges) [16-21]. In lights of this, an approach for quantifying and characterizing the seasonal surface deformation of highways was developed [22]. The approach focused on estimating surface deformation and calculating seasonal indices such as degree and period of deformation concentration [22].

On the contrary, other researchers have adopted more synergistic approaches regarding the data used. In particular, C-band imagery was combined with high resolution X-band imagery for the long-term monitoring of displacement patterns over viaducts, highways or bridges [23-25]. The main idea was based on exploiting the advantages of both sensors, i.e. the improved accuracy of high resolution SAR data and the short temporal resolution of the C-band missions. While in other cases, a synergistic use of PSI and: a) Light Detection And Ranging (LiDAR), b) Terrestrial Laser Scanning (TLS) or c) Unmanned Aerial Vehicle (UAV) measurements led to the optimization of the deformation monitoring procedure [26-28].

The most updated works are focusing on developing sophisticated infrastructure monitoring approaches using interferometric measurements along with GIS and/or machine learning algorithms such as regression tree, support vector machine, boosted regression trees, random forest, etc. [29, 30]. These newly developed methods are able to provide: a) full automation of deformation detection and/or the extraction of possible warnings and b) effective decision-making tools.

In this framework, the current work aims to highlight the effectiveness of PSI technique in the monitoring of high-priority infrastructure, as a supplementary component of “PROION” project. The project is co-funded by the European Union and Greek national funds and its main goal is the systematic monitoring of national infrastructure located in the Region of Western Greece using instrumental, remote sensing and soft computing methods. In light of SAR interferometry, an innovative type of corner reflector was designed and manufactured. These newly-developed corner reflectors are described in details along with their installation in the specified observation sites. Since PSI technique requires the generation of large time-series datasets, along with the need of a better understanding of the possible infrastructure motion, we obtained archived PSI measurements derived from the European Ground Motion Service. At this point, archived PSI measurements over the observation sites of PROION project, covering a time span of five years, were analyzed and interpret in order to understand the ongoing deformation processes.

2. CORNER REFLECTOR CONSTRUCTION AND INSTALLATION

2.1 Corner reflector construction

The design of this new corner reflector (CR) was carried out taking into account respective infrastructure monitoring studies of the international literature. To design and construct a CR, parameters such as the reflector type, construction material, material strength and low cost are considered [31-36]. Some of the most common reflector types are: the monohedral square (flat plate), dihedral, and trihedral reflector. The trihedral is classified into four subcategories based on its shape: square, cubic, circular and triangular. It has been proven that the triangular trihedral type was used in the majority of case studies, due to its structural stability, ease of installation, and lower manufacturing costs [31-36].

In this framework, four triangular trihedral reflectors with dimensions of 1.47m X 1.04m X 0.74m were manufactured at the Mechanical Engineering Workshop of the University of Patras. They are made of 6 mm thick aluminum. The main features of the newly developed CRs are the following:

1. Adjustment mechanism for easy re-orientation

The CR has a re-orientation adjustment mechanism to modify it according to the imaging geometry of the different SAR sensors (Figure 1). It can be rotated 360 degrees in azimuth.

Figure 1. a) Initial base orientation (0 degrees). b) 30-degree base re-orientation, counterclockwise.

2. Adjustable baseplate with respect to the horizontal surface

The CR has an adjustable baseplate with an angle opening greater than 30° with respect to the horizontal surface to modify it appropriately (Figure 2).

Figure 2. a) Initial position of the baseplate (5 degrees angle opening), b) Position of the baseplate (angle opening at 80 degrees).

3. Adjustable 5/8" pole for the performance of GNSS measurements

The corner reflector has an adjustable 5/8" pole for the leveling of GNSS sensors (Figure 3).

Figure 3.a) Mounted GNSS antenna in a horizontal position with the baseplate of the reflector at 80 degrees, b) Leveling of the GNSS antenna in three axes.

4. Thermal sensor

The corner reflector has a 6 mm diameter and 30 mm deep socket for the integration of a thermal sensor with a data logger (Figure 4).

Figure 4. Socket of the thermal sensor.

5. Modular structure

The corner reflector is modular which allows easy transport, assembly and installation in the areas under investigation (Figure 5).

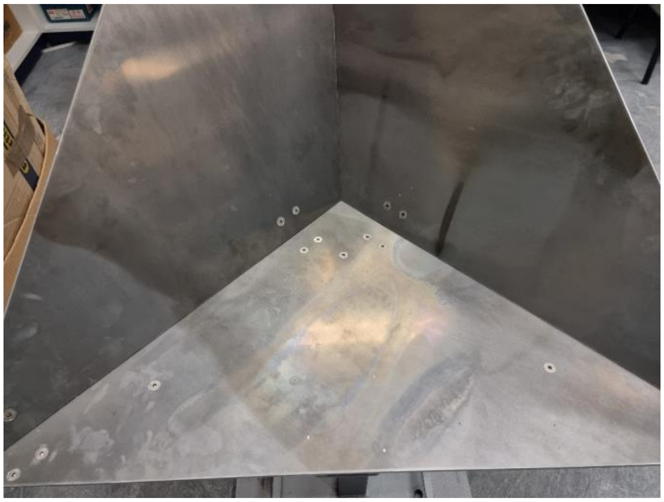


Figure 5. Modular structure of the reflector.

2.2 Corner reflector installation

These newly developed corner reflectors were installed on the observation sites of the project, i.e. a) Asteri dam, b) Department of Geology, University of Patras and c) Krini village. To verify their visibility, Sentinel-1 images before and after the installation were obtained. Post-installation Sentinel-1 images display a strong backscatter (white shades) at the location where the corner reflector has been set (Figure 6).

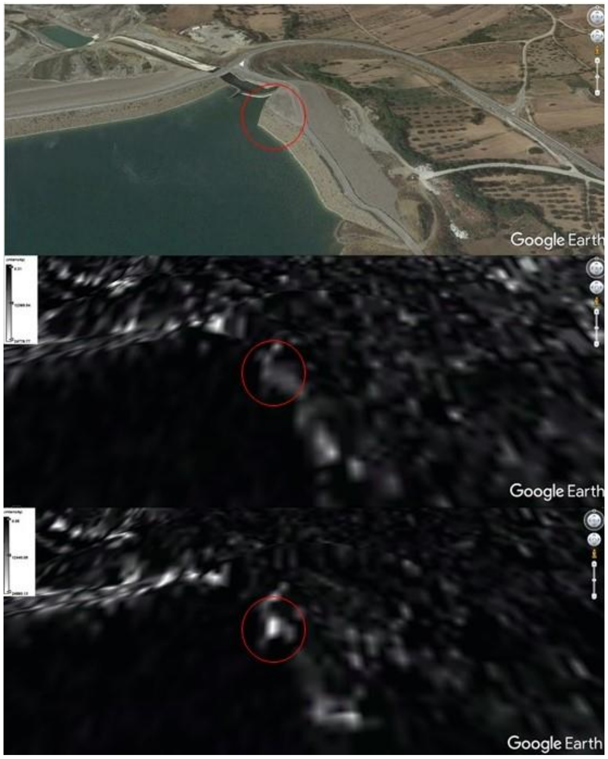
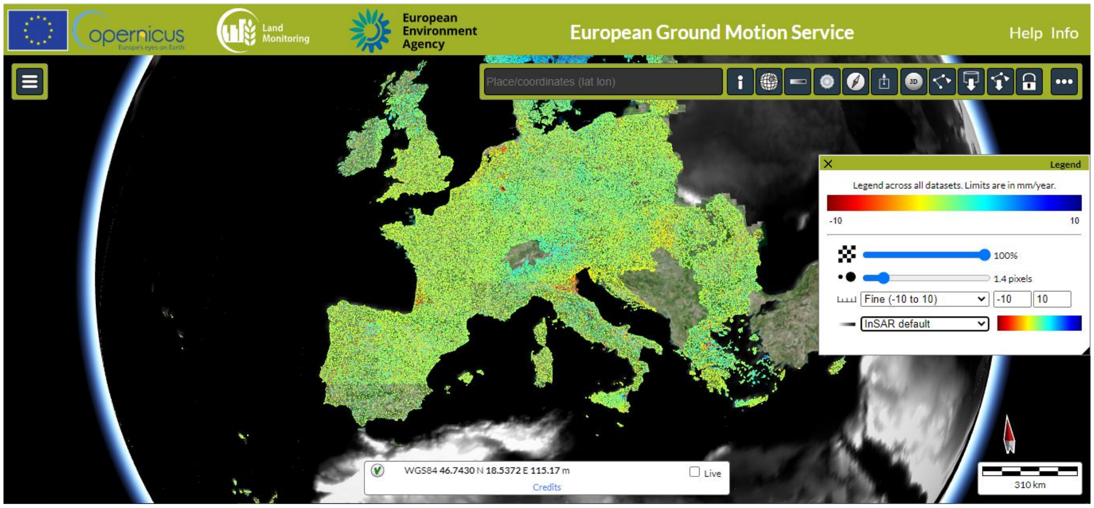


Figure 6. Identification of the corner reflector installed on Asteri dam in Sentinel-1 imagery.

3. DATA COLLECTION AND PROCESSING METHODOLOGY

It is widely known that PSI analysis requires the creation of large time series. To overcome this limitation and to better understand the potential ground deformation on the observation sites, we obtained archived PSI measurements acquired from the European Ground Motion Service (EGMS) [37]. The service provides systematic and accurate (millimeter-scale) ground deformation measurements over the Copernicus participating countries. An overview of the EGMS Explorer is depicted in Figure 7. Applications such as infrastructure monitoring or geohazard analysis are viable through the service. EGMS measurements are based on the processing of Sentinel-1 imagery using PSI. Buildings, man-made structures and areas without vegetation are used as permanent scatterers among the multi-temporal Sentinel-1 datasets. The calibration of PSI measurements is performed through data acquired by Global Navigation Satellite Systems (GNSS). The service distributes three types of products, namely Basic, Calibrated and Ortho. The Basic level includes ascending and descending Line of sight velocity maps with annotated geolocalisation and quality measures for each point. Calibrated data consist of ascending and descending Line of sight velocity maps, which are referenced to a model created by GNSS data. Finally, Ortho products provide motion components (horizontal and vertical), which are anchored to a reference geodetic model. In the current research we collected Ortho products for each observation site of PROION project.



Legend across all datasets. Limits are in mm/year.

Figure 7. Overview of the EGMS Explorer.

4. PSI ANALYSIS AND INTERPRETATION

The archived PSI measurements over each observation site were analyzed to determine the on-going ground deformation. In particular, vertical displacement over the wider area of Asteri dam is displayed in Figure 8. As it can be observed, the scatterers located at the crest of the dam present higher velocities that the corresponding ones in the surrounding. A similar pattern is illustrated in the multi-temporal analysis of the vertical velocities between a point on the crest (Figure 10) and a respective on the abutment (Figure 9). The point on the abutment has a vertical velocity equal to -5.80 mm/year (Figure 9), while the point on the crest seems to move approximately -21.10mm/year (Figure 10). Although the discrepancy between the two points looks irrelevant, the deformation occurred on the crest results from the construction works that were completed in 2019. Hence, the recorded vertical motion is strongly related to the human activities for the dam completion. Regarding the second observation site i.e., the Department of Geology at the University of Patras, the vertical motion is minor (Figure 11) and it is calculated at -4.20 mm/year (Figure 12). The motion is associated with tectonics, taking place in the northwestern Peloponnese. Finally, the analysis of archived PSI measurements wasn't efficient, due to the dense vegetation contributing to the absence of enough scatterers (Figure 13). However, selecting the closest point to the village demonstrated that the wider area moves slowly and systematically over time (Figure 14). In fact, the village is located upon an active landslide, which has been verified by GNSS measurements [38].

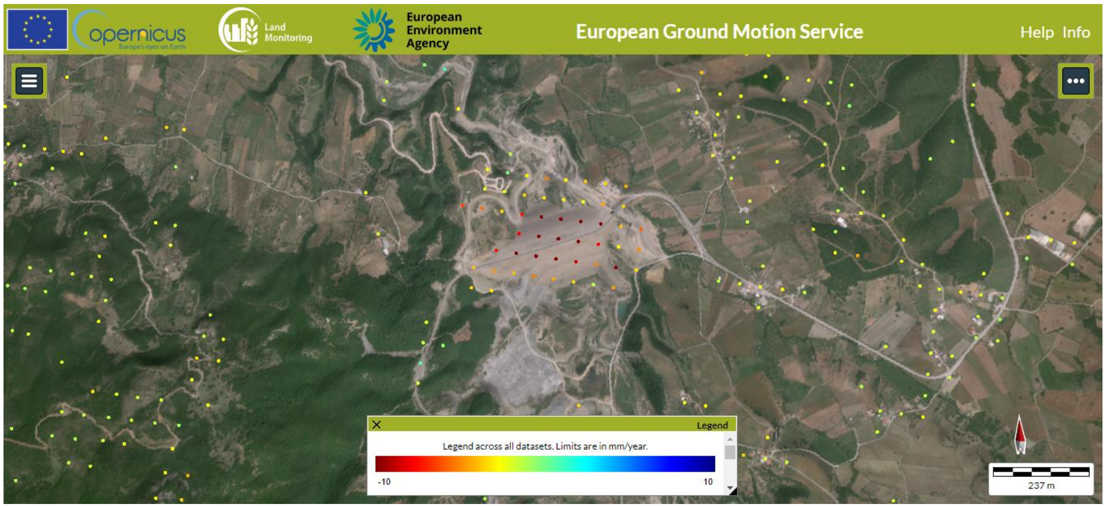
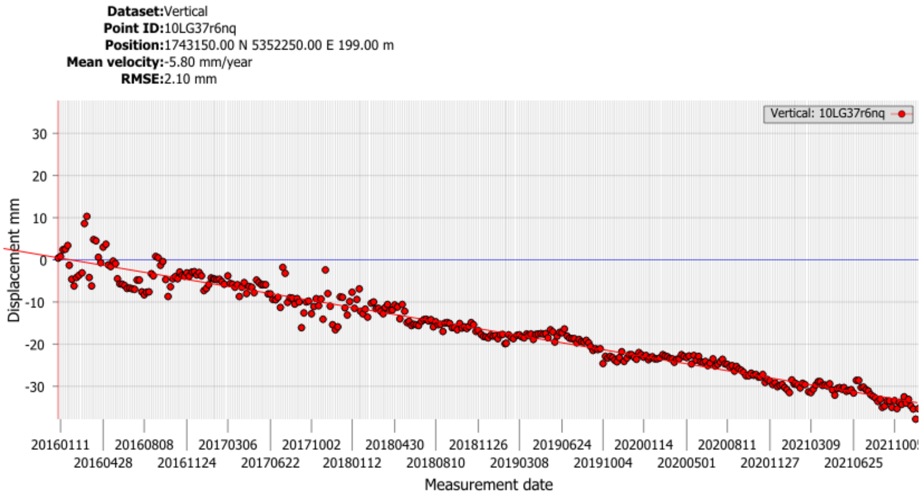


Figure 8. Vertical displacement over the wider area of Asteri dam.



Dataset: Vertical
Point ID:10LG37r6nq
Position:1743150.00 N 5352250.00 E 199.00 m
Mean velocity:-5.80 mm/year
RMSE:2.10 mm

Figure 9. Multitemporal vertical displacement of a point at the abutment of Asteri dam.

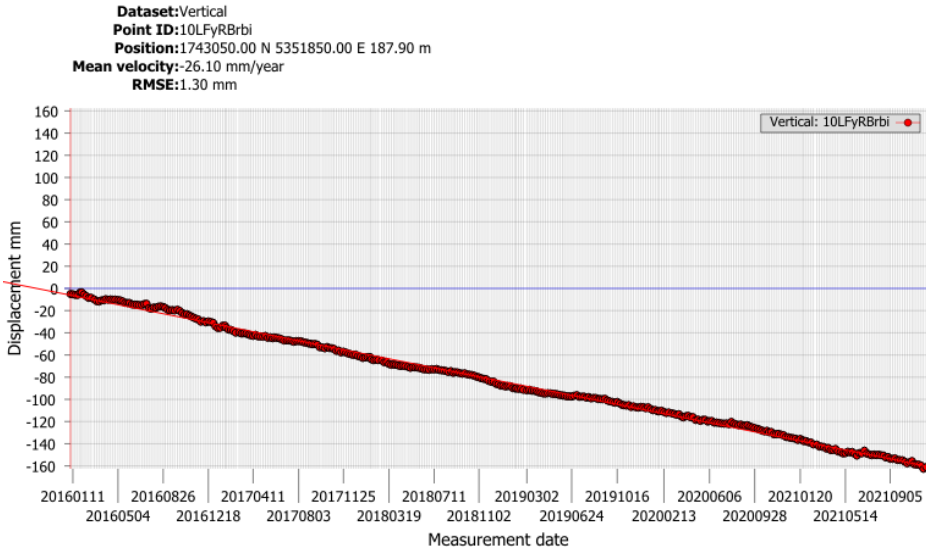


Figure 10. Multitemporal vertical displacement of a point on the crest of Asteri dam.

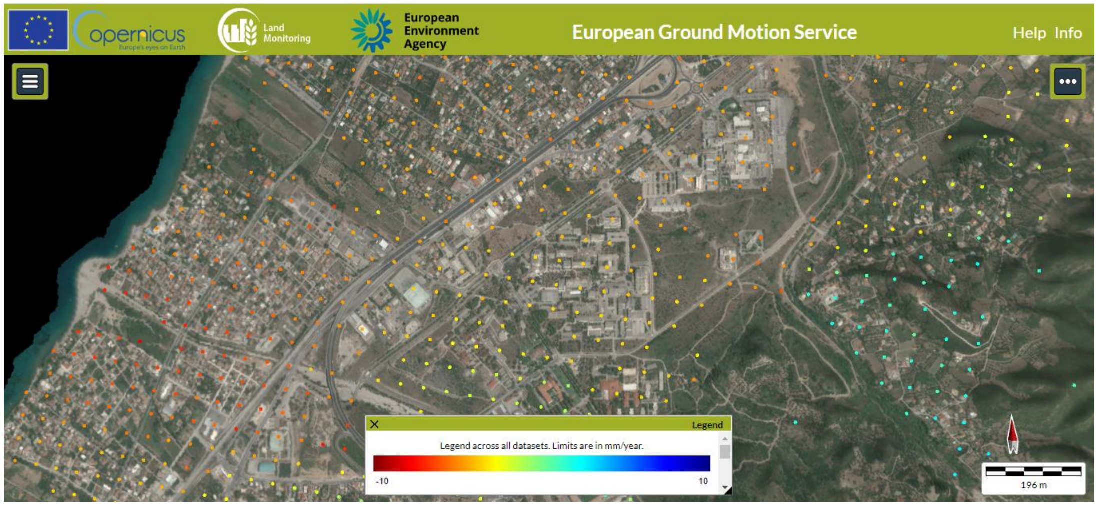


Figure 11. Vertical displacement over the campus of University of Patras.

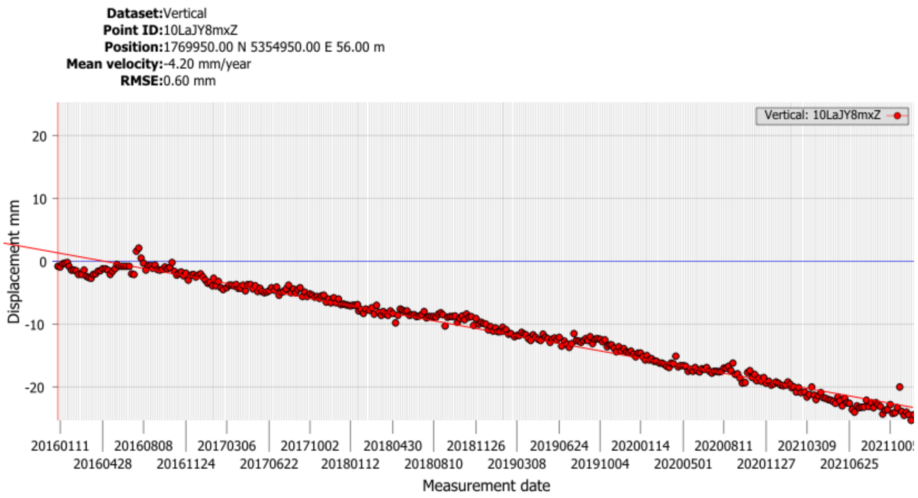


Figure 12. Multitemporal vertical displacement of a point at the Department of Geology at the University of Patras.

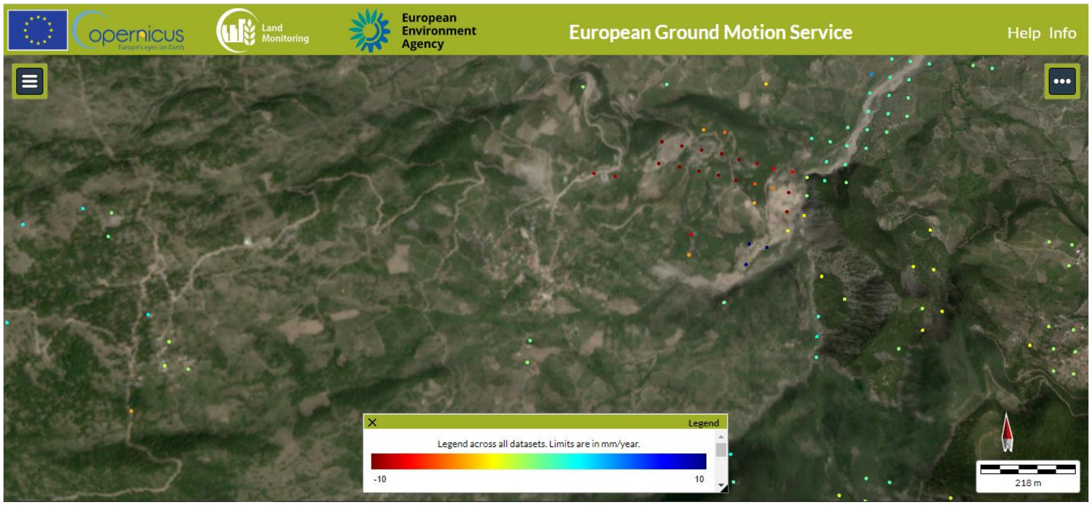


Figure 13. Vertical displacement over the wider area of Krini village.

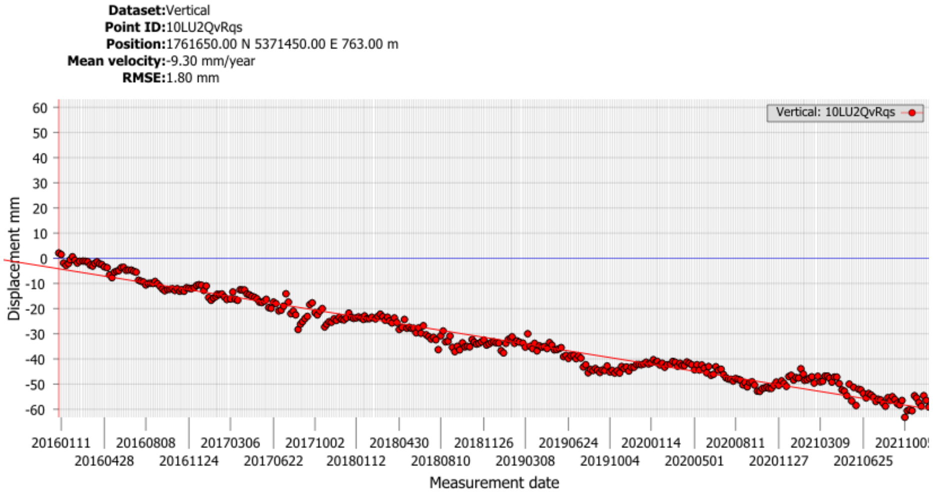


Figure 14. Multitemporal vertical displacement of the closest point to Krini village.

5. DISCUSSION AND CONCLUSIONS

The main objective of the current research is to highlight the capabilities of PSI in the monitoring of high-priority infrastructure, as a supplementary component of “PROION” project. In this framework, an innovative type of corner reflector was designed and manufactured at the University of Patras. The main features of the CR include: a) adjustment mechanism for easy re-orientation, b) adjustable baseplate with respect to the horizontal surface, c) adjustable 5/8" pole for the performance of GNSS measurements, d) thermal sensor and e) modular structure. Three newly-developed CRs were installed in the specified observation sites of PROION project in order to establish stable backscatter points for the multitemporal Sentinel-1 analysis. The underlying principle of PSI technique is that it requires the generation of large time series of data. Since the installation was performed recently, a sufficient amount of Sentinel-1 data has not yet been collected. To overcome this limitation and to fully understand the on-going ground deformation at the observation sites, we obtained archived PSI measurements acquired by the European Earth Motion Service (EGMS). The measurements over the observation sites of the PROION project, covering a time span of five years, were analyzed and interpreted. The Department of Geology and the Asteri dam exhibit small vertical displacement, while Krini village is located upon an active landslide that is moving slowly and systematically over the time.

The key points of the current work are summarized in the following:

- The innovative CR can be easily identified in Sentinel-1 imagery.
- Archived PSI can be effectively used to analyze the ground deformation of the investigated areas.
- Archived PSI measurements are able to detect ground deformation related to geotectonics, landslides and even man-made activities.
- A good knowledge of the area of interest is required for the proper interpretation of PSI results.

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