Mapping building differential deformations over wide areas

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Abstract

SAR interferometry is an active remote sensing technique for measuring and monitoring land deformation. The European Ground Motion Service (EGMS), which is part of the Copernicus Land Monitoring Service, makes use of SAR interferometry to derive consistent and annually updated information about ground displacements related to both natural and anthropogenic phenomena. The EGMS policy is providing its products free of charge. This open new prospectives to fully exploit SAR interferometry data at continental European scale. We propose in this paper a procedure that exploits the EGMS products to derive the differential displacements of buildings and urban structures. The proposed procedure facilitates the generation of a differential deformation map for individual buildings by computing spatial gradient of deformation for each building and then classify them into distinct classes according to their gradient values. The procedure has been illustrated considering the town of Torremolino (Spain). In this case study, using the Basic product of EGMS, a differential deformation map has been generated. In addition, three additional maps have been produced by considering this multisource data: deformation velocity, age of buildings and population density of the study area. These three maps, called ground deformation intensity map, potential damage intensity map and potential impact map, can provide useful information related to the health of buildings, structures and infrastructures and, supporting the associated decision-making.

Keywords: EGMS, deformation, differential deformation, spatial gradient, building damage.

1. Introduction

Interferometric SAR is an active remote sensing technique to measure and monitor ground deformation. Persistent Scatterer Interferometry represents an advanced class of InSAR techniques based on large stacks of Synthetic Aperture Radar (SAR) imagery (Crosetto et al., 20216). PSI is well-suited for structures and infrastructure analysis and monitoring. PSI offers the advantage of high sensitivity to small deformations, with a typical velocity precision of approximately 1 mm/yr.

The objective of the European Ground Motion Service (EGMS), part of the Copernicus Land Monitoring Service, is to provide homogeneous and consistent information about ground motion related to both natural and human-induced phenomena. This service is based on Sentinel-1 data processed at full resolution and it consists of a baseline product, which ranges from 2015 to the end of 2021, and annual updates (Crosetto et al., 2000; Crosetto and Solari, 2023). EGMS data have a policy of free and open access. They are available at https://egms.land.copernicus.eu/.

The EGMS includes three types of products. The Basic product is made up of geocoded line of sight (LOS) deformation velocity maps in ascending (ASC) and descending (DES) orbits, with measurements referred to a local reference point. The second product, the Calibrated Product, builds on the Basic Product by combining PSI results with data from a network of global navigation satellite system (GNSS) stations. The deformation measurements remain in the LOS direction, incorporating both PSI and GNSS data. This product considers the varying density of GNSS stations across Europe and uses a 50-km GNSS velocity model for calibration. The third product, the Ortho Product, refines the Calibrated Product by fusing the mono-dimensional LOS deformation data from both ascending and descending passes to derive 2D information, including the horizontal

East-West and vertical Up-Down components. This fusion requires a lower spatial resolution, resulting in an Ortho Product generated on a coarse 100 by 100 m grid.

This work is focused on spatial differential deformations or spatial deformation gradients. Such deformations can cause cracks and structural damage to buildings, structures and infrastructures (Peduto et al., 2017; Barra et al., 2022). The main goal of this work is to generate differential deformation maps for buildings and structure using the products from EGMS. Other interesting works related to the automatic analysis of EGMS data include Mele et al. (2023), Navarro et al. (2020), Palamà et al. (2024), López-Vinielles et al. (2024), etc. The paper is organized as follows. Section 2 provides an overview of the proposed procedure. Section 3 describe a case study, where the differential deformation maps are analysed and combined with data coming from multiple sources. Section 4 contains the conclusions of this work.

2. Methodology

We focus the analysis on spatial differential deformations, which is directly related to damages to structures and infrastructures. In fact, such damages depend on the deformation pattern: the most significant ones are associated with high spatial differential deformations, i.e. high spatial deformation gradient values. The procedure requires as inputs the EGMS Basic product and a vector map of buildings and infrastructures, see for details Shahbazi et al. (2024). For all buildings covered by enough EGMS Measurement Points (MPs), it computes the slope (gradient) and aspect of the deformation field, highlighting the local maximum deformation slopes. For this reason, the procedure involves selecting MPs that belong to buildings, while ignoring data from other objects. A buffer is set around the polygon perimeters of buildings to account for errors in MPs positioning. The height of MPs is also checked to ensure that the chosen MPs belong to the building. Furthermore, MPs are filtered to detect and delete isolated and noise-affected points.

Based on the maximum slopes, it performs a slope classification. The classes range from “Low” to “Very High”, see Figure 2. Considering the gradient uncertainty, a “Not reliable” class is defined. This was set by estimating the gradient standard deviation using a Monte Carlo simulation. The estimated gradient standard deviation is 0.05 $mm*yr^{-1}*m^{-1}$.

The procedure can be a useful screening tool to analyse large PSI datasets. The reliability of the procedure depends on the number of MPs falling inside a given building (Shahbazi et al., 2024). Figure 1 illustrates the main steps of the proposed procedure.

Figure 2 shows the estimation of the deformation gradient class of a building, starting from the input EGMS MPs. The first step is the interpolation of the deformation velocity of MPs that fall within polygon (in Figure 2 the velocities are shown using grey values). The second step involves calculating the spatial gradient. Finally, the third step involves the classifications of the gradients, assigning a class to each processed building.

As a resulting output, this tool generates a shapefile containing the identification and coordinates of buildings, as well as the maximum, mean, standard deviation, and orientation of the gradient. To visualize them, a Geographic Information System (GIS) tools can be used.

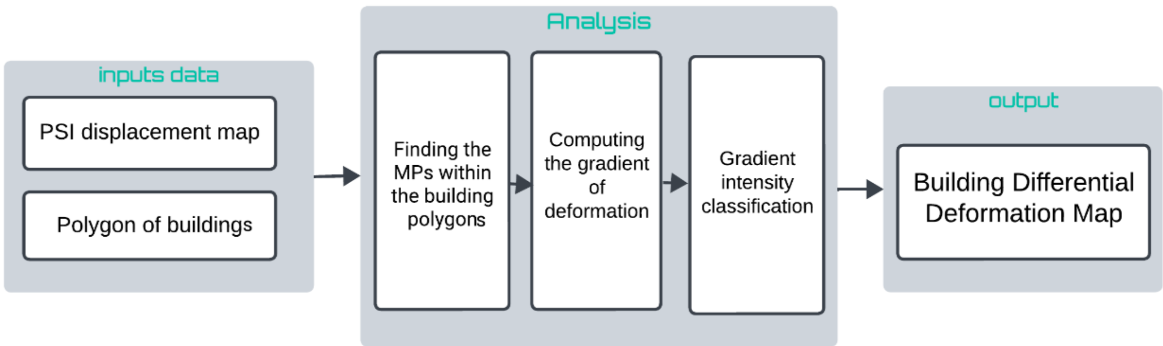

Figure 1: Scheme of the proposed procedure.

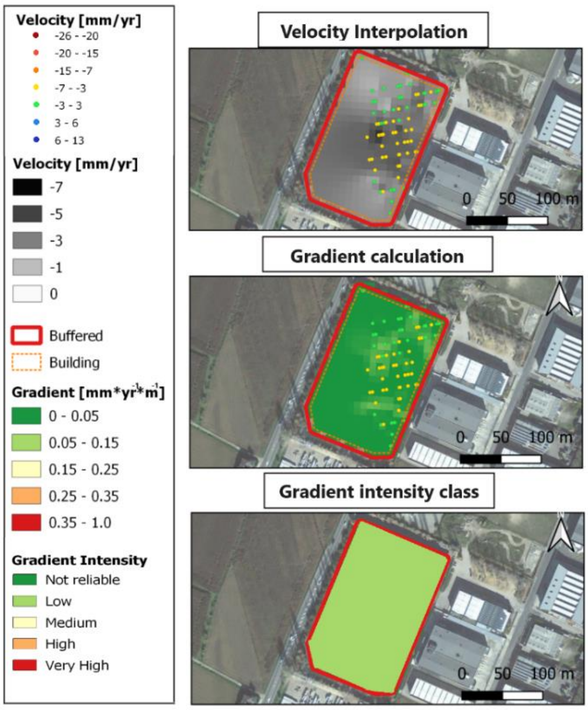

Figure 2: Deformation gradient classification starting from the EGMS MPs.

3. Discussion of a case study

We illustrate our procedure considering the city of Torremolinos, Málaga, located in southern Spain, a tourist destination which is experiencing subsidence due to excessive underground water extraction.

Figure 3 illustrates the generation of the Differential Deformation map. The process begins with the selecting of MPs for each building, followed by velocity interpolation, gradient computation, and classification. Figure 3(e) shows that among all identified at-risk buildings, the most common gradient intensity is in the "Low/Very Low" range, while some bigger industrial buildings have a "Medium" gradient intensity. There are relatively few buildings with a "High" gradient intensity.

Beyond the spatial gradient, we considered additional factors. By incorporating the velocity into the Differential Deformation map, we generated the Ground Deformation Intensity map. Then we took into account the age of buildings and population density, to produce the Potential Damage Intensity map and the Potential Impact map, respectively. Figure 4 shows a construction age map from the Spanish Inspire Cadastral database. In addition, the same figure shows the population map of the area.

The Potential Damage Intensity map mix the information of the Ground Deformation Intensity map with the age of buildings, while the Potential Impact map mix Potential Damage Intensity map with population density.

Figure 5 illustrates the generation of the above maps. Figure 5(a) represents the Differential Deformation Map of Torrremolino. By incorporating the velocity into this map, we obtained the Ground Deformation Intensity map (Figure 5(b)). In these two maps most buildings maintain their original categories; however, a few buildings are reclassified into higher categories due to the velocity information. By combining the building construction age with the Ground Deformation Intensity map, we generated a Potential Damage Intensity map (Figure 5(c)). This map considers the higher concentration of old buildings, which are supposed to be more prone to damage. Finally, by combining the Potential Damage Intensity map with the population data, we obtained the Potential Impact map.

The area from Figure 5 includes residential neighbourhoods and accommodations, with most buildings dating back to 1980. The gradient and velocity for these buildings range from 0.03 to 0.15 (mm×yr^{-1}×m^{-1}) and -3 to -12 (mm/yr), respectively. A medium level of Gradient Intensity is indicated for most of these buildings. After incorporating construction age, the Potential Damage Intensity map reveals that nearly all buildings retained their original classification, with only minor reclassifications observed among mid-age buildings. The Potential Impact map highlights three buildings with a high density of residents and potential damage intensity.

4. Conclusions

The availability of large InSAR datasets, like those coming from the EGMS, opens new horizons to analyse, in a systematic and automatic way, new parameters over wide areas.

We have proposed in this paper a procedure to analyse the differential displacements of buildings and urban structures. The proposed tool facilitates the generation of a differential deformation map for individual buildings by computing spatial gradient of deformation for each building and then classify them into distinct classes according to their gradient values.

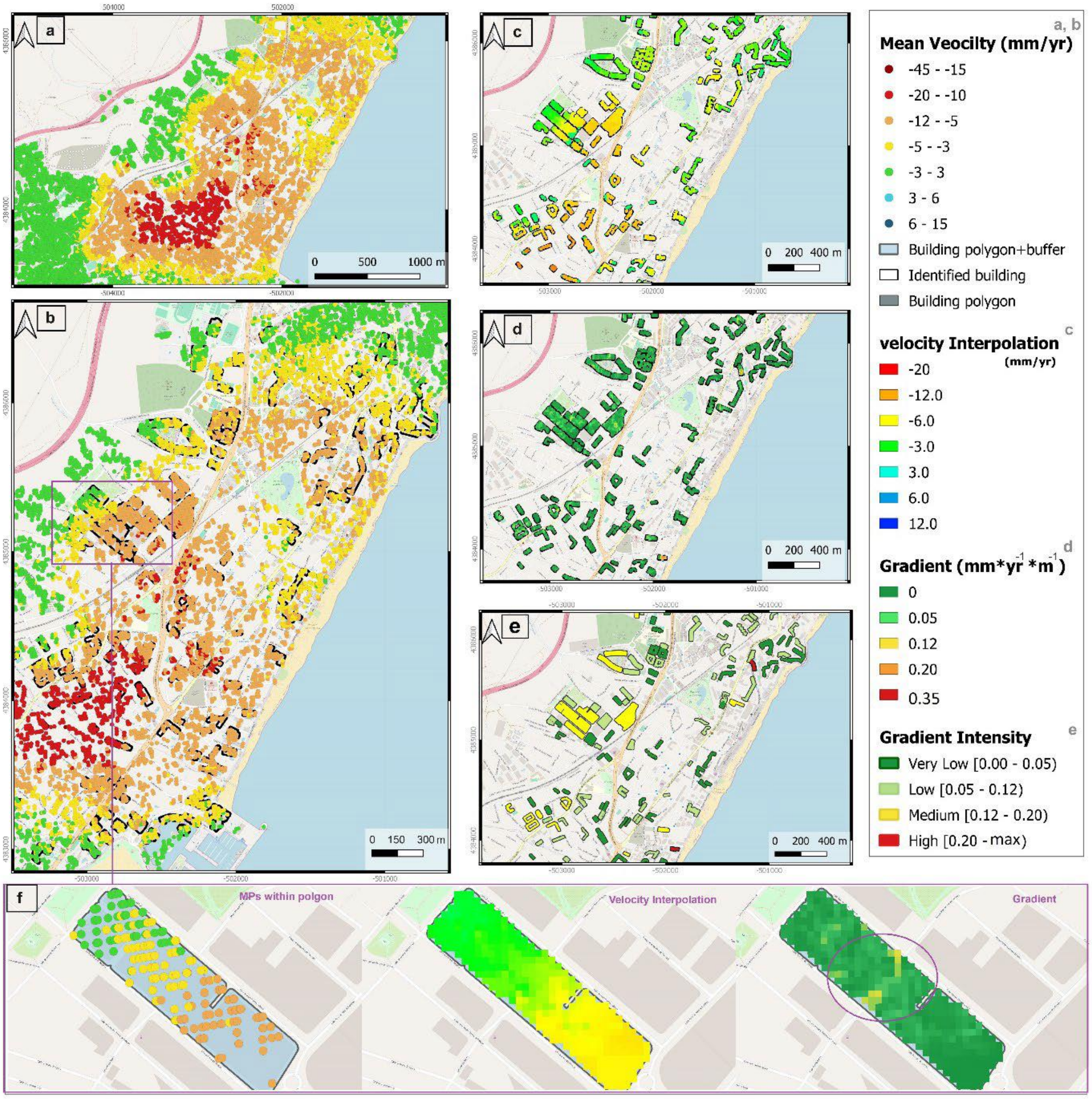

Figure 3: PSI displacement map of the town of Torremolinos (a). MPs associated with buildings (b). Velocity interpolated for each building (c). Spatial deformation gradient (d). Classification of buildings based on the deformation gradient of each building(e).

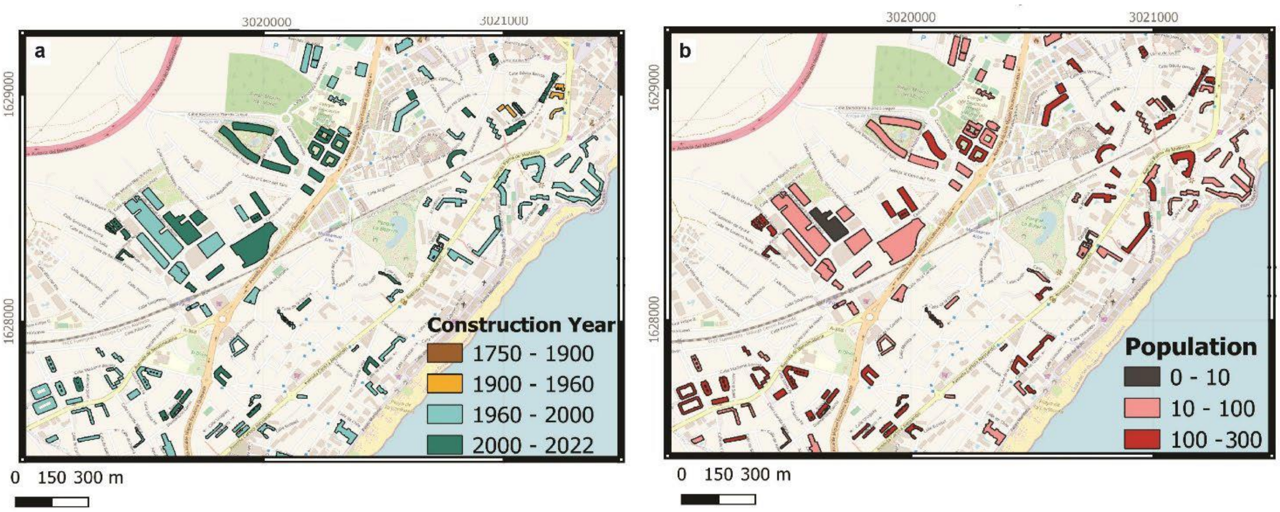

Figure 4: Additional data used in the analysis and interpretation of the results from Figure 3: construction age map, expressed in years (a) and map of population, expressed in number of people per hectare.

Figure 5 Case study of Torremolino. Original Differential Deformation map generated with the standard procedure (a). Three advanced products to improve the analysis: Ground Deformation Intensity map (b); Potential Damage Intensity map (c); and Potential Impact map (d).

The procedure has been illustrated considering the town of Torremolino (Spain). In this case study a Differential Deformation map has been generated. In addition, three additional maps have been generated considering the deformation velocity, the age of buildings and population density of the study area. These three maps, called Ground Deformation Intensity map, Potential Damage Intensity map and

Potential Impact map, can provide useful information related to the health of buildings and infrastructures and appropriately support its management and decision-making.

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