ADVANCED ANALYSIS TOOLS FOR THE EUROPEAN GROUND MOTION SERVICE DATA

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ABSTRACT:

This paper is focused on Advanced Differential Interferometric SAR (A-DInSAR). In the first part, the paper describes the European Ground Motion Service (EGMS), a new service of the Copernicus Land Monitoring Service. The EGMS provides consistent, regular, standardized, harmonized and reliable information regarding natural and anthropogenic ground motion over Europe. It is derived from A-DInSAR analysis of Copernicus Sentinel-1 data. The EGMS includes three main products: Basic, i.e. basic deformation maps delivered for individual and consistent frames of image stacks; Calibrated, i.e. deformation map integrated into a reference Global Navigation Satellite System network; and Ortho, which includes the East-West and Up-Down deformation, obtained by combining the ascending and descending results. The second part of the paper describes examples of data analysis. The first one is a clustering of PSI results, which highlights the so-called Active Deformation Areas (ADAs). The second one is an automatic classification of the ADAs. The third analysis concerns the differential deformation maps, which are useful to highlight areas where high deformation gradients occur. Such gradients are often associated to damages in buildings and infrastructures.

1. INTRODUCTION

In this paper, the focus is on radar interferometry, specifically Advanced Differential Interferometric Synthetic Aperture Radar (A-DInSAR), which is a powerful remote sensing technique for monitoring ground motion. A-DInSAR has undergone an important development in terms of processing and data analysis. This has been accompanied by remarkable increase of the SAR data acquisition capability by spaceborne sensors. Another important aspect is the increase in the computational capabilities, which is key to perform massive A-DInSAR analyses over wide areas. These advancements make wide-area A-DInSAR deformation monitoring technically feasible.

Wide-area A-DInSAR deformation monitoring has already been demonstrated in several cases at the national and regional levels in Europe. For instance, Italy, Norway, and Germany have implemented national Ground Motion Services. The main focus of the paper is the development of a new A-DInSAR service, called European Ground Motion Service (EGMS), which is part of the Copernicus Land Monitoring Service. The EGMS is implemented by the European Environment Agency (EEA) as part of the Copernicus program, the European Union's Earth observation program.

The EGMS aims to provide consistent, updated, standardized, and reliable information about ground motion phenomena across European countries. It utilizes A-DInSAR techniques and full-resolution Sentinel-1 SAR data, incorporating both ascending and descending passes. The service covers the 30 Copernicus Participating States and delivers a baseline product based on archive data from 2015 to the end of 2020, followed by annual updates. At the time of writing this paper, the first update, covering 2021, has been published.

The processing for the baseline EGMS involves approximately 750 Sentinel-1 SAR frames, with 260 SAR scenes for each processed stack. The EGMS production is carried out by the consortium "ORIGINAL - OpeRatIonal Ground motion INsar Alliance," consisting of four companies (e-GEOS, TRE-Altamira, NORCE, GAF) and five subcontractors. Each company operates its own processing chain, and the overlaps between adjacent scenes are utilized to ensure seamless harmonization between chains. For more information on A-DInSAR and the EGMS, refer to additional references such as Rosen et al. (2000), Ferretti et al. (2000 and 2001), Hanssen (2001), Crosetto et al. (2016), Crosetto et al. (2020), Costantini et al. (2017), Raspini et al. (2018), Solari et al. (2018), NGU (2022), Kalia et al. (2020), EGMS Task Force (2017), Larsen et al. (2020), and Crosetto and Solari (2023).

The European Ground Motion Service (EGMS) will offer three types of products, as illustrated in Figure 1. The first product is the Basic Product, which is generated by independently processing each SAR frame. Each frame has its own reference for deformation measurements, and the product includes deformation velocity and time series in the Line-Of-Sight (LOS) direction. This product is suitable for studying local deformation phenomena and will be delivered for the original 750 scenes at full resolution.

The second product is the Calibrated Product, which builds upon the Basic Product. It combines the A-DInSAR results from the EGMS Basic with data from a network of global navigation satellite system (GNSS) stations. The deformation measurements in this product are still in the LOS direction, and it utilizes both A-DInSAR and GNSS data. The production of this product takes into account the varying density of available GNSS stations across Europe and uses a 50-km GNSS velocity model for calibration.

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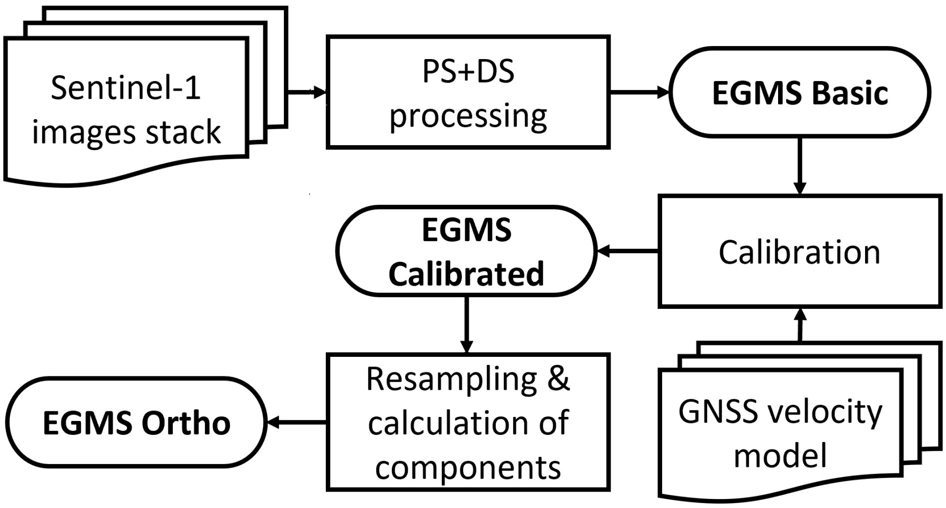

Figure 1. Flow chart of the EGMS.

The third product is the Ortho Product, which further refines the Calibrated Product. It fuses the mono-dimensional LOS deformation products coming from both ascending and descending passes to derive 2D information, including the horizontal East-West component and the vertical Up-Down component. However, the fusion of ascending and descending data requires to work at a lower spatial resolution. For this reason, the Ortho Product is generated on a coarse 100 by 100 m grid.

Quality control is an important aspect of the EGMS. The production incorporates various internal verification procedures, mostly automated. Additionally, an independent external team is performing a comprehensive validation of the Service products.

In terms of dissemination, the EGMS products adheres to the Copernicus data policy and is freely and openly available. The Calibrated and Ortho products are accessible through a dedicated WebGIS (https://egms.land.copernicus.eu/, see Figure 2), offering visualization tools for interactive data exploration and preliminary analysis. Users have the option to download the products (including the Basic product) in CSV format to analyse the data locally, e.g. using GIS tools.

To promote user uptake, guidelines are published, and workshops and training sessions are organized, see the main page of the Service: https://land.copernicus.eu/pan-european/european-ground-motion-service.

The EGMS is expected to attract a wide range of users, including research centres, universities, geological and geophysical surveys, civil protection authorities, public authorities, infrastructure administrations, water management authorities, cultural heritage institutions, mining industry, oil and gas industry, engineering companies, insurance industry, and citizens.

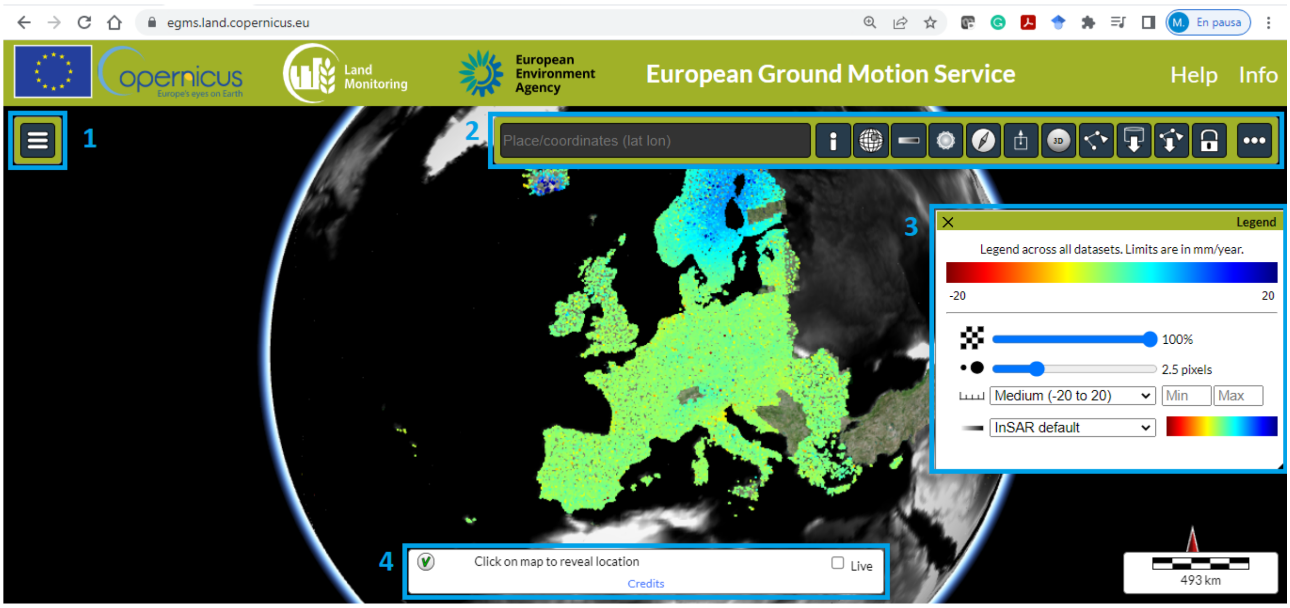

Figure 2. EGMS explorer.

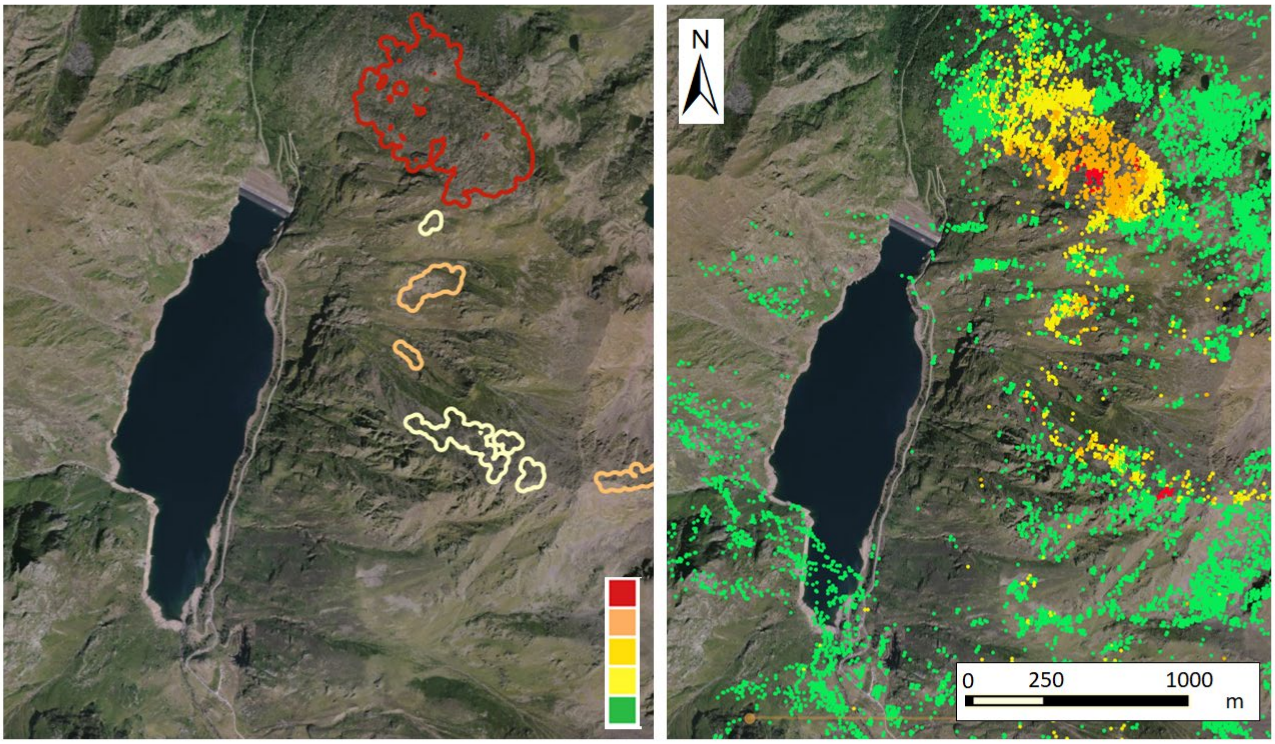

Figure 3. Deformation velocity map (right) and corresponding ADA map (left).

2. ADVANCED ANALYSIS TOOLS

Through EGMS, a huge amount of data is available. The analysis of such data requires appropriate tools. In the following we mention three main tools: (i) the Active Deformation Areas (ADA) Finder; (ii) the ADA Classifier; and (iii) the computation of differential deformations.

2.1 Active Deformation Area Finder

The primary objective of the ADA Finder tool is to simplify the interpretation and utilization of large volumes of InSAR output data, particularly for non-expert users (Barra et al., 2017). It achieves this by generating a map of ADAs (Active Deformation Areas), where each ADA represents a cluster of neighbouring measurement points (MPs) with deformation velocities above a specified threshold. The number of MPs per cluster is a configurable parameter of the tool. One of the key outputs of the ADA Finder is the quality index assigned to each ADA, which indicates its reliability. This index is derived from considering factors such as the noise present in the deformation time series and the spatial homogeneity of the estimated deformations. The ADA map consists of polygons representing the clusters, with attributes such as the number of MPs, statistical information about the velocities within the ADA, quality index, etc.

It is important to note that the ADA map simplifies certain types of InSAR analyses, but for other analyses that focus on localized phenomena where even a single MP is significant, the original InSAR output dataset needs to be considered. Additionally, it is essential to understand that the ADA extraction process does not overcome the inherent limitations of InSAR, such as the absence of MPs due to unfavourable geometry or low coherence. Figure 3 provides an example of an ADA map, where the information from thousands of MPs is condensed into a limited number of polygons. The ADA Finder tool is available from CTTC (Centre Tecnològic de Telecomunicacions de Catalunya). It has been employed to filter the Basic data of the European Ground Motion Service (EGMS). The resulting ADA maps can be visualized through a webmap interface, which is freely accessible at https://groundmotionadas.com/groundmotionadas.

2.2 ADA Classifier

The goal of this analysis is to identify, through a classification based on a decision tree, the geological or anthropogenic process that causes the presence of ADAs. This is a useful tool to simplify and speed up the interpretation of ADA maps, especially over broad areas, when dealing with numerous ADAs.

In the implementation described in Navarro et al. (2020), six different phenomena are tested, i.e. landslide, sinkhole, subsidence, building settlement, expansive soil, and thermal expansion. To do so, some extra auxiliary data are required. The inputs of the ADA Classifier include: the output of the ADA Finder; a digital terrain model; the inventories for landslides, sinkholes and land subsidence; a map of infrastructures; and a geologic map.

The output of ADA Classifier is another file with ADAs, where the attribute table of each ADA is extended to include additional fields, each of them stating the probability that the ADA belonging to the corresponding deformation process, see Figure 4. The ADA Classifier is part of the ADAtools software, which is freely available from CTTC. Details about the implementation of the ADA Classifier and its use are provided in Navarro et al. (2020).

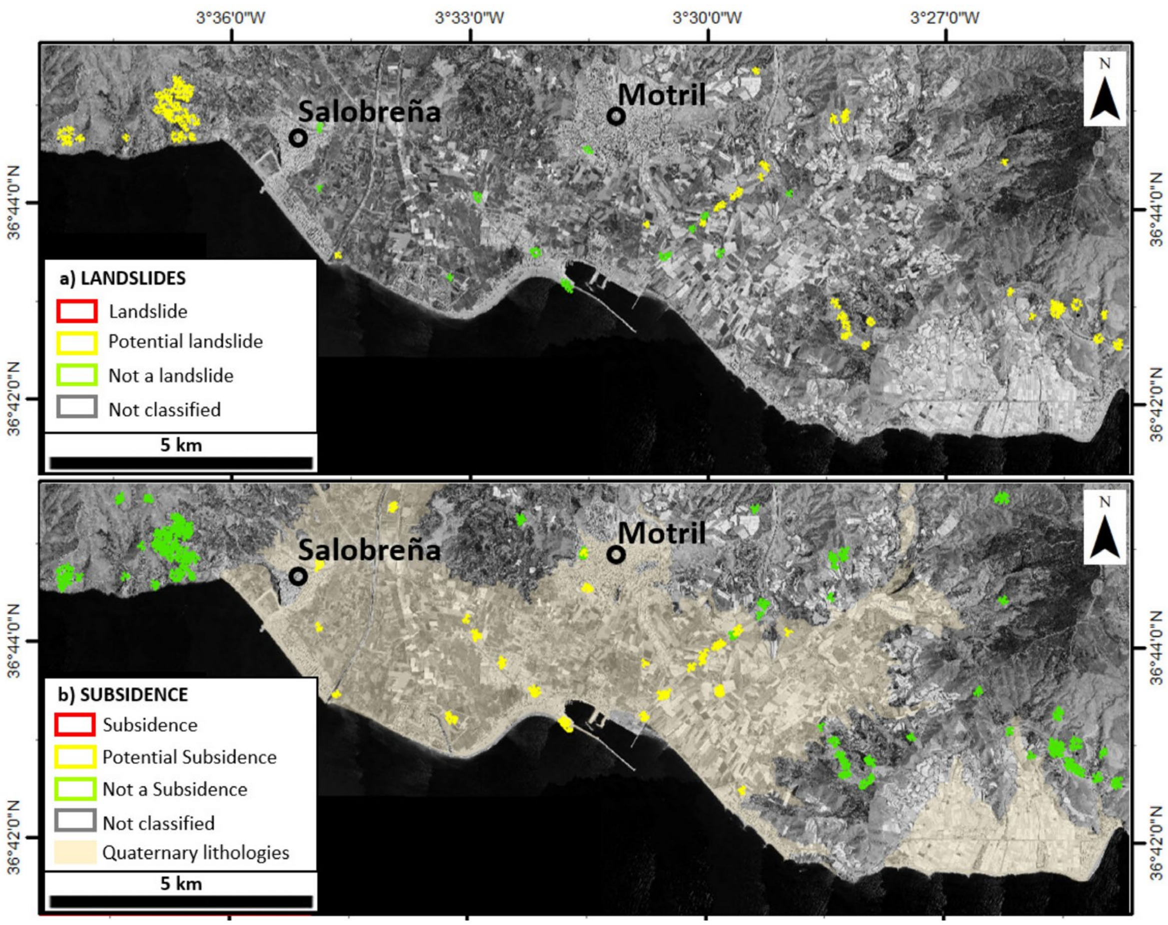

Figure 4. Example of output of the ADA Classifier. It includes two layers: one devoted to subsidence (below), and one related to landslides (above).

2.3 Differential deformations

Given a deformation field, which can be measured with A-DInSAR, the main damage to structures and infrastructures depends on the deformation pattern. In particular, the most significant damages are associated with high differential deformations, i.e. to high spatial deformation gradient values. Shahbazi et al. (2022) describe two types of differential deformations: terrain differential deformations (TDD) and building differential deformations (BDD). They compute the slope and aspect of the deformation field, focusing the attention on the local maximum deformation slopes. The TDD is computed using all available MPs that fall outside buildings, structures, or infrastructures. Examples of TDD maps can be found in Shahbazi et al. (2022).

The BDD is computed over each building, structure, or infrastructure of the area of interest, which are identified using an external building map and over which there is a minimum number of MPs.

In Fig. 4 we show an example of BDD. At the right side of the Figure there are: a deformation velocity map (above), the map of the deformation velocity gradients (middle), and the map that indicates the intensity of the gradient (below).

The BDD can be a useful screening tool to analyze large InSAR datasets. However, it is worth emphasizing that the reliability of BDD locally depends on the number of MPs that fall within a given building polygon. For large buildings, where dozens of MPs are available, the BDD information is certainly useful.

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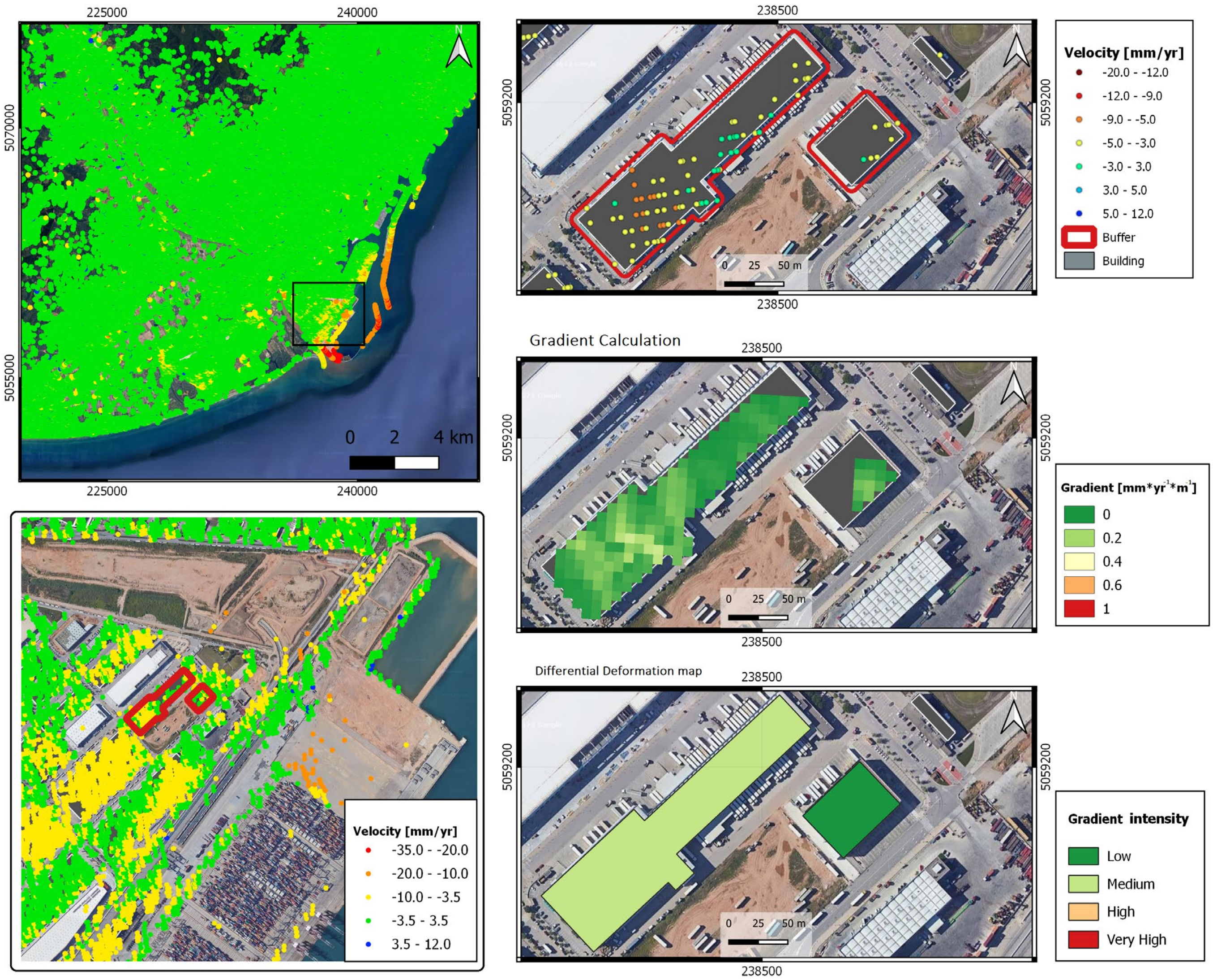

Figure 5. Deformation velocity map of the Barcelona area (upper left). The most important deformations concern the dikes of the port of Barcelona. Zoom of the deformation velocity over the black frame indicated in the previous map (bottom left). In this figure are highlighted in red the two buildings considered in the rest of this figure. Deformation velocity map over the two analysed buildings (upper right). Estimated deformation gradient over the two buildings (middle right). Gradient intensity over the two buildings (bottom right). In the gradient intensity map, one building has a low intensity, while the other one has a medium intensity. This is a useful information for urban management.

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