GROUND MOTION EXAMPLES FROM THE EUROPEAN GROUND MOTION SERVICE

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ABSTRACT

The Copernicus European Ground Motion Service (EGMS) provides consistent, regular, standardised, harmonised and reliable information regarding natural and anthropogenic ground motion phenomena over the Copernicus Participating States and across national borders, with millimetre accuracy. The EGMS is based on the multi-temporal interferometric analysis of Sentinel-1 radar images at full resolution. Global navigation satellite systems (GNSS) data are used to calibrate the interferometric measurements.

EGMS provides an unprecedent opportunity to study geohazards and human-induced deformation over Europe, such as slow-moving landslides, natural subsidence or due to groundwater exploitation or underground mining activities, volcanic unrests and many other phenomena. This paper offers a first look at the products distributed by EGMS through relevant case studies in different environmental contexts of Europe.

Index Terms— ground motion, multi-temporal satellite interferometry, geohazards, Europe, Copernicus

1. INTRODUCTION

The European Ground Motion Service (EGMS) is the most recent addition to the product portfolio of the Copernicus Land Monitoring Service. The Service is funded by the European Commission in the frame of the Copernicus Programme. It is implemented under the responsibility of the European Environment Agency [1].

The EGMS will distribute ground motion information through a dedicated viewer and download interface; the data will be available and accessible to all and free of charge.

The EGMS was born and requested by users. Starting from November 2016, a group of 75 InSAR (Interferometric Synthetic Aperture Radar) data experts from many diverse European institutions and entities started developing the concept behind EGMS. The efforts of the task force resulted in the EGMS White Paper, which constitutes the conceptual framework for the current EGMS implementation [1].

The EGMS is also a natural consequence of the growing interest in interferometric data at European (and global) scale. The reliability of algorithms, the improvement of computational capacity and the launch of science-oriented radar satellite constellations allowed many different users to have access to precise ground motion information. The development and launch of national ground motion services greatly contributes to this [2]. The EGMS is intended to respond to the growing user need at European level.

This short paper provides a first overview of EGMS products and proposes some case studies to demonstrate the added value of EGMS for geohazards-related studies. The following sections will present various examples of representative types of ground motion, such as landslides and human-induced subsidence. Each case study is accompanied by a very brief interpretation of the results under geoscientific aspects.

2. WIDE AREA PROCESSING APPROACH

The EGMS is produced by means of multi-temporal satellite interferometry (MTInSAR) techniques. In brief, MTInSAR relies on the analysis of a long stack of radar images and interferograms to identify reliable measurement points for which time series are derived. These measurement points can be PS, persistent scatterers, or DS, distributed scatterers. The first correspond to point-like targets such as buildings, rocks, and infrastructures in general; the latter are relative to small areas with similar radar response such as open spaces with no vegetation. Both types of targets are considered in EGMS to provide the optimal measurement point density.

MTInSAR is already a complex and computational demanding technique. The EGMS offers another level of challenge because of the area to cover and the volume of input

and processed data. Because of this, the parallelization of processes is mandatory; only hundreds of central processing units can speed up the computational burden.
More information on the processing approach adopted to produce EGMS can be found in Costantini et al. [3].

3. EGMS PRODUCTS

The EGMS distributes three levels of products:

- Basic. Line of sight (LOS) velocity maps in ascending and descending orbits referred to a local reference point.
- Calibrated. The main product of EGMS. It is fundamentally the same as the Basic product, but the measures of ground deformation are referenced to a model derived from GNSS time-series data. Therefore, the measurements are no longer relative to a local reference point but are considered absolute.
- Ortho. This product exploits the discrete look-angles provided by the Calibrated product to derive two layers: one containing the vertical component of motion and the other with the east-west displacements.

Both Basic and Calibrated products are derived from full resolution (~4 by 14 m) Sentinel-1 radar images. Ortho product is resampled on a regular grid with 100 by 100 m cells.
The EGMS GNSS model used to calibrate the Basic product will also be available to users. The model is a 50 km gridded velocity model obtained from the analysis of ~3900 GNSS stations mainly part of the EUREF Densification network [4].

4. CASE STUDIES

This section presents some examples of EGMS data used for the detection of natural and human-induced phenomena.
Note that the interferometric data shown in this section are to be considered as demonstrational. At the moment of writing this paper, the production of the EGMS is still ongoing. For this reason, only the Basic products are shown below.

4.1. Landslides

Landslides are, along with subsidence, the main target for the EGMS.
Figure 1 shows an example of slope deformation from the Hyefjorden in the Vestland County in Norway. The fjord is located 230 km north of Bergen, the second main city of Norway. As most of all the thousand fjords in Norway, this area is characterised by steep slopes which are commonly affected by landslides of various types and snow avalanches [5].
The EGMS Basic data provide an overview of ongoing deformation on the eastern flank of the fjord. Unfortunately, measurement points cannot be extracted for the opposite flank due to well-known geometrical constrains with respect to the viewing geometry. One hundred and seventy-eight images compose the Sentinel-1 descending stack that has been processed to obtain the deformation map. The image stack has a reduced size since all the images acquired during the winter period (end of October – early March) are discarded to avoid injecting noise into the system related to the snow cover.
The EGMS data identify the upper portion of a large slope deformation on the eastern flank of the fjord, at an elevation between 800 and 1000 m a.s.l. The (potential) crown area of the landslide has an extension of ~2.5 km. LOS velocities reach -30 mm/yr in the southern portion of the moving area; the average velocity value is -9 mm/yr. LOS velocities are negative indicating motion away from the sensor in the downslope direction. Further investigations would include the use of the EGMS Ortho product to estimate the magnitude of the horizontal and vertical components of motion.

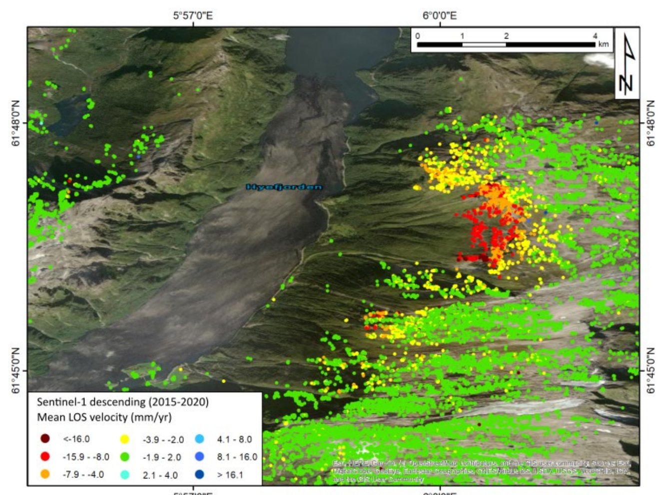

Figure 1 – Ground motion along the eastern flank of the Hyefjorden (Vestland County, Norway). Data from EGMS.

4.2. Subsidence

This section presents two examples of subsidence induced by human activities, one related to underground mining and one linked to the extraction of natural gas.
Figure 2 shows the EGMS Basic product in a mining area; part of the Upper Silesian Coal Basin (Ostrava-Karviná Coal Field). The deformation map derives from Sentinel-1 data acquired in descending orbit; 298 images from February 2015 to December 2020 compose the time series of deformation.
The Ostrava-Karviná Coal Field represents 90% of the black coal reserve of Czech Republic and it is one of the most populated areas of the Silesian Region, with Ostrava as the third biggest city in Czech Republic. Mining began in the second half of the 18th century and had the maximum expansion after the second half of the 20th century. After 1989, mining rates were reduced and now only five mining

concessions are active. Still, the annual production is ~8 million tonnes of coal [6].
The rural area east of the city of Ostrava is characterised by the presence of multiple subsidence bowls that reach maximum lowering rates up to 40 mm/yr. Such deformation affects areas occupied by small cities and infrastructures. This clearly imposes a risk for the population and damage to buildings have been reported in the past [6].

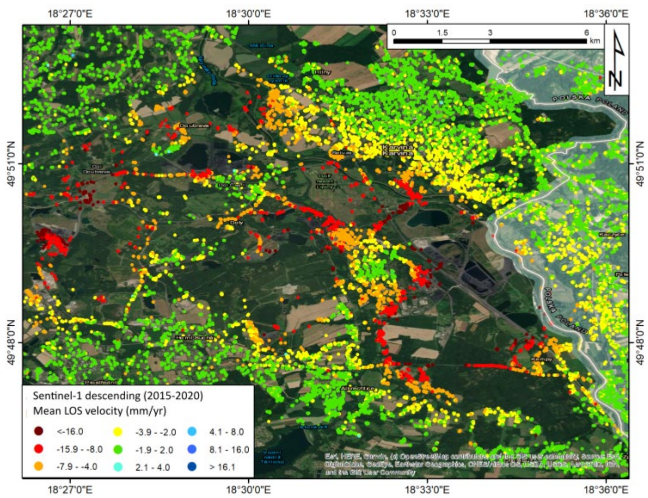

Figure 2 – Ground motion related to coal mining in the Silesian Basin, not far from the city of Ostrava (Czech Republic). Data from EGMS.

Figure 3 displays an example of EGMS Basic product from the southern part of the Groningen gas field (the Netherlands). This area hosts the largest gas field in Europe, operational since 1963, and due to its high environmental impact it is expected that the production will completely shut down between 2025 and 2028. Large-scale subsidence due to the compaction of the reservoir and increased seismicity are the most evident consequences of the gas extraction.
Satellite interferometric analyses for past periods have previously been applied in this area. Average subsidence rates were estimated to be between 4 and 7 mm/yr in the period 1992-2007 (ERS and Envisat data) and ~5 mm/yr for the period 2015-2017 (Sentinel-1 data) [7].
The deformation map presented in Figure 3 results from the analysis of 295 Sentinel-1 images in descending orbit covering the time span February 2015 – December 2020 (EGMS data). Subsidence rates reach a maximum of 25 mm/yr in the centre of the subsidence bowl in the south western corner of Figure 3. However, excluding high local deformation rates, subsidence is estimated at an average value of ~4 mm/yr. This is consistent with previous studies [7].

4.3. Infrastructures

Although the EGMS is conceived to target wide-area deformation, it can also reveal localised motion affecting single infrastructures. It is worth mentioning that the EGMS is not providing data for full structural analyses; rather, it provides a useful starting point for further studies, which can rely on e.g. X-band interferometric products or other types of in-situ data.

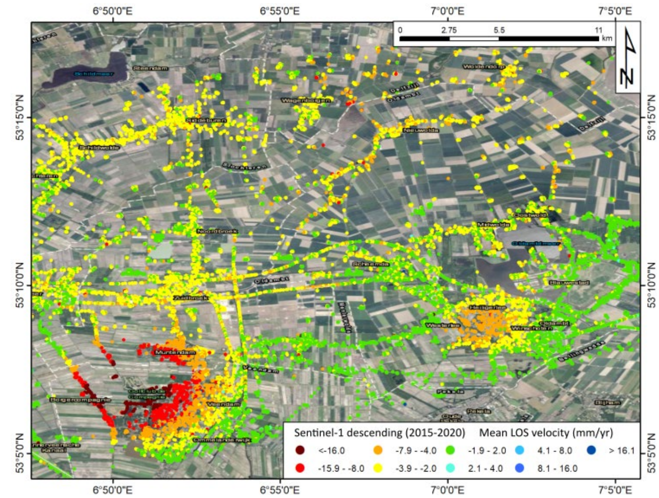

Figure 3 – Ground motion related to gas extraction in the Groningen gas field (the Netherlands). Data from EGMS.

Figure 4 shows an example of deformation involving a critical infrastructure. The infrastructure is the outer port (Puerto Exterior) of A Coruña in northern Spain (Galicia Region). This is a new port area whose construction ended between 2012 and 2016. The harbour is protected by two breakwaters, one external and one internal.
A stack of 301 Sentinel-1 images in descending orbit (EGMS data) were analysed to derive the deformation map. Both breakwater structures register high LOS velocities, up to -30 mm/yr. Velocities averaged over the entire length of the structures reach -15 mm/yr and -10 mm/yr for the external and internal breakwater, respectively. Negative velocities imply a movement away from the sensor, meaning a lowering of the ground/structure. This can be linked to the compaction of the material used to build the embarkment part of the coastal defence structures. LOS velocities up to -8/-10 mm/yr are also registered along the docks of the harbour.

Figure 5 presents the EGMS Basic product along a portion of the track of a major highway located in southern Spain.
The A-48 highway (Autovía de la Costa de la Luz) connects Cadiz to Algeciras in the Andalucía Region (southern Spain). The focus of Figure 5 is a portion of A-48, which links the cities of Chiclana de la Frontera to the east with San Fernando to the west. This area is part of the Bahía de Cádiz Natural Park, not far from the mouth of the Guadalete river. This is a marsh environment characterised by shallow channels and agricultural parcels.
The highway track is characterised by high subsidence rates up to 20 mm/yr; on average, the highway track register subsidence rates in the order of 12 mm/yr. The geological

characteristics of the area play a critical role in controlling the ground motion; in fact, high LOS velocities are recorded in the marsh area, whereas the city of Chiclana de la Frontera, located on sandy soils, is stable (see the eastern part of Figure 5).

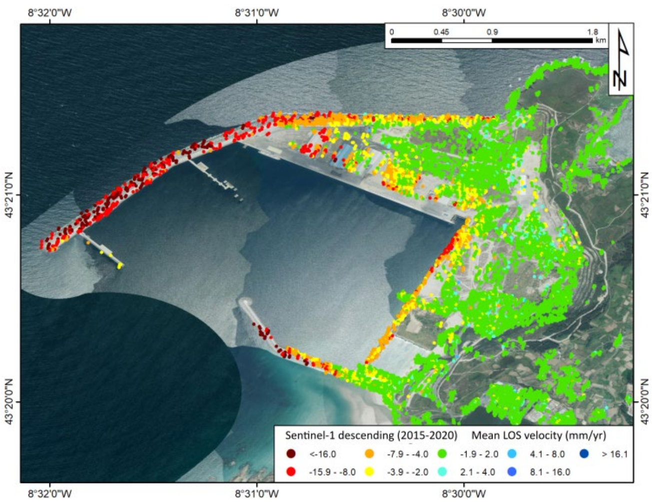

Figure 4 – Ground motion in the port area of Punta Langosteira, A Coruña Outer Port (Spain). Data from EGMS.

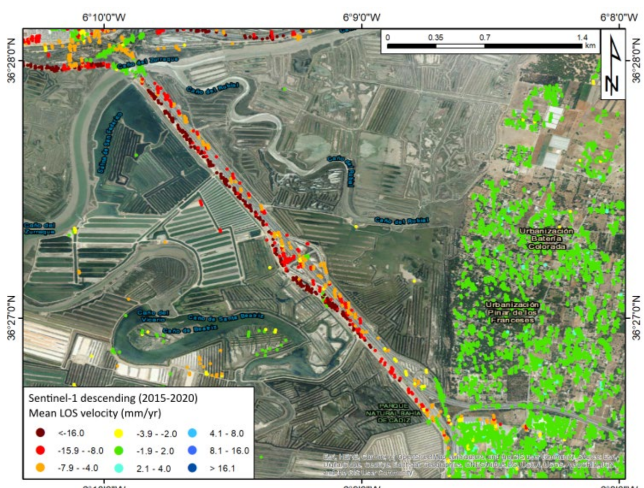

Figure 5 – Ground motion along the A-48 highway (Spain). Data from EGMS.

5. CONCLUSIONS

This paper presents some preliminary case studies extracted from the huge volume of data offered by the EGMS, the first continental-scale service of ground deformation. The analysis is a first look at the EGMS products, which are still under production. Several case studies have been described. The case studies show that the EGMS can provide quantitative and spatially dense information for geohazard management in case of landslides and subsidence. EGMS can also act as a baseline for studies on localised deformation affecting critical infrastructure.

10. AKNOWLEDGMENTS

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