

ANALYSIS OF THE PRODUCTS OF THE COPERNICUS GROUND MOTION SERVICE

M. Crosetto^{1,*}, L. Solari¹, A. Barra¹, O. Monserrat¹, M. Cuevas-González, R. Palamà¹,
Y. Wassie¹, S. Shahbazi¹, S.M. Mirmazloumi¹, B. Crippa², M. Mróz³

¹ Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Geomatics Division, Av. Gauss, 7,
E-08860 Castelldefels (Barcelona), Spain, mcrosetto@cttc.cat, lsolari@cttc.cat, abarra@cttc.cat, omonserrat@cttc.cat,
mcuevas@cttc.cat, rpalama@cttc.cat, ywassie@cttc.cat, sshahbazi@cttc.cat, sm.mirmazloumi@cttc.cat

² Dept. of Geophysics, University of Milan, Via Cicognara 7, I-20129 Milan, Italy - bruno.crippa@unimi.it

³ Institute of Geodesy and Civil Engineering, University of Warmia and Mazury in Olsztyn, 10-719 Olsztyn, Poland -
marek.mroz@uwm.edu.pl

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ABSTRACT:

Radar interferometry has progressed very much in the last two decades. It is now a powerful remote sensing techniques to monitor ground motion. The technique has undergone an important development in terms of processing and data analysis algorithms. This has been accompanied by an important increase of the Synthetic Aperture Radar (SAR) data acquisition capability by spaceborne sensors. A step forward was the launch of the Copernicus Sentinel-1 constellation. This has made the development of A-DInSAR (Advanced Differential Interferometric SAR) ground deformation services technically feasible. The paper is focused on the most important ground motion initiative ever conceived: the European Ground Motion Service (EGMS). This service is part of the Copernicus Land Monitoring Service managed by the European Environment Agency. EGMS involves the ground deformation monitoring at European scale. The service will deliver the first product in May 2022. In this paper we describe some preliminary examples of deformation products coming from the EGMS.

1. INTRODUCTION

This paper is focused on radar interferometry, a powerful active remote sensing technique to monitor ground motion. In particular, it considers Advanced Differential Interferometric Synthetic Aperture Radar (A-DInSAR), which includes a class of advanced techniques based on stacks of interferometric SAR images. A-DInSAR has undergone an important development in terms of processing and data analysis. This has been accompanied by an important increase of the SAR data acquisition capability by spaceborne sensors. This in particular concerns the Sentinel-1 constellation. Note that at the time of writing this paper, only one Sentinel-1 sensor is available: the other one is currently out of service. Another important aspect is the increase in the computational capabilities, which is key to perform A-DInSAR analyses over wide areas. Therefore, the wide-area A-DInSAR deformation monitoring is technically feasible. For a general review of A-DInSAR, see Crosetto et al. (2016). A description of the first A-DInSAR technique is provided in Ferretti et al. (2000; 2001).

In Europe, at national and regional level, the wide-area A-DInSAR deformation monitoring has been already demonstrated in several cases. The first Ground Motion Service (GMS) covered Italy using data from the sensors ERS-1/2, Envisat and CosmoSkyMed, see Costantini et al. (2017). This was followed by Norway in 2018, with a GMS based on Sentinel-1 data, see NGU (2022).

Germany launched its GMS at the end of 2019, see Kalia et al. (2020). In Italy, three regions have already implemented a GMS focused on the early detection of abrupt motion changes, see Raspini et al. (2018); Solari et al. (2019); and Del Soldato et al. (2019). Other Italian regions will follow soon, see Comerci and

Vittori (2019). GMSs are operational in Denmark and The Netherlands as well. Other countries are discussing the need for such services.

This paper is focused on deformation monitoring at European scale, and in particular the development of a new service that is part of the Copernicus Land Monitoring Service: the European Ground Motion Service (EGMS). Information on the EGMS can be found in Crosetto et al. (2020) and EGMS (2022).

The EGMS is part of Copernicus, the European Union's Earth observation programme (<https://www.copernicus.eu/en>), and is implemented by the European Environment Agency (EEA). The key characteristics of the service were defined by the EGMS Task Force and are described in the EGMS White Paper (EGMS Task Force, 2017). In 2019, a specific working group was commissioned by EEA to detail the EGMS technical specifications (Larsen et al., 2020). The EGMS production is ongoing, and it is carried out by the consortium "ORIGINAL - Operational Ground motion INsar Alliance" composed of four European companies, e-GEOS, TRE-Altamira, NORCE, GAF, and five subcontractors. The processing is split between the different companies that operate their own processing chains. The overlaps between adjacent scenes will be used to ensure seamless harmonization between production chains.

The EGMS aims to provide consistent, updated, standardized, harmonized across national borders and reliable information regarding ground motion phenomena of natural and anthropogenic origins, over Europe. The ground motion will be estimated using A-DInSAR techniques and full resolution Sentinel-1 SAR data. The service will use all the available acquisitions, from both ascending and descending passes.

* Corresponding author

The Service will cover the 30 Copernicus Participating States, see Figure 1. The EGMS production will include a baseline product, which will be based on archive data, covering the period from 2015 up to the end of 2020. This will be followed by updates, delivered every 12 months.

The processing will involve about 750 Sentinel-1 SAR scenes. The baseline product will make use of about 260 SAR scenes for each processed stack. The number of SAR scenes will be reduced for the regions systematically affected by seasonal snow cover. In fact, the processing will be limited to the snow-free scenes.

The Service will include three types of products. The relation between these products is illustrated in Figure 1.

The simplest product is the so-called Basic Product. It is derived by processing independently the SAR frames, where each frame has an independent reference for the deformation measurements. Therefore, it will be delivered by frames of the original 750 scenes. This product will be generated using the Sentinel-1 imagery processed at full resolution. The Basic Product will include the deformation velocity and deformation time series measured in the Line-Of-Sight (LOS) direction. This product is similar to the A-DInSAR products that are usually generated by the different A-DInSAR techniques. It will be suitable to study local deformation phenomena.

The second product is the so-called Calibrated Product. With respect to the previous one, it represents a more elaborated product. In fact, in EGMS Calibrated, the A-DInSAR results of EGMS Basic are mosaicked and fused with data coming from an extensive network of global navigation satellite system (GNSS) stations. In this product the deformation measurements will still be in the LOS direction. This product is more complex because it relies on two types of information: A-DInSAR and GNSS. In particular, the production will have to manage an inhomogeneous density of available GNSS stations over

Europe. A 50-km GNSS velocity model is used for calibration purpose.

The third product is the so-called Ortho Product. This product is further elaborated starting from the previous Calibrated Product. In this product the two LOS (mono-dimensional) deformation products coming from ascending and descending passes are fused to derive a 2D information. This includes the horizontal East-West component and the Up-Down vertical component. The main disadvantage of this product is that the fusion of ascending and descending data requires to work at a lower spatial resolution. For this reason, the Ortho Product will be generated over a 100 by 100 m grid.

Particular attention will be devoted to quality control. Several internal verification procedures will be implemented during the production. Most of them involve automatic procedures. An external team, which is independent of the production team, will perform a comprehensive validation of the Service products.

Concerning the dissemination, following the Copernicus data policy, the EGMS products will be free and open. It will be disseminated using a dedicated webGIS, which will provide visualization tools, and allow an interactive data exploration and a preliminary analysis of the products to be performed. A download will allow users to access the deformation maps in CSV format.

The user uptake will be based on the publication of guidelines, and the organization of workshops and training sessions. The Service will presumably have a wide range of users, including research centres and universities; geological, geophysical, geodetic and topographic surveys; civil protection authorities; public authorities; road and railway administrations; water management authorities; cultural heritage institutions; mining industry; oil and gas industry; engineering companies; insurance industry; and the citizens.

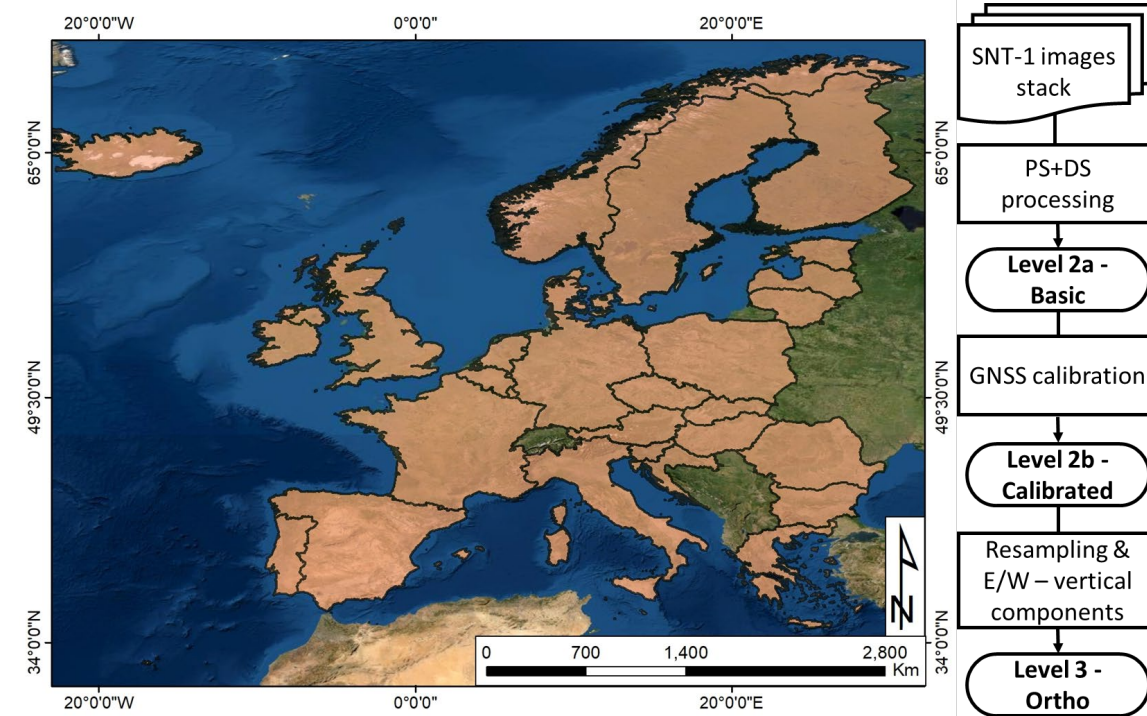


Figure 1: Left – EGMS coverage; the Azores and Madeira archipelagos, the Canary and Balears islands, the French Overseas Departments and Regions are included. Right – Simplified flowchart of the EGMS production.

2. EGMS RESULTS: LANDSLIDES

This section describes some preliminary results of the EGMS. The first one concern landslides, which are, together with subsidence, a common target for EGMS.

The first result concern a landslide in Norway. Figure 2 shows an example of slope deformation from the Høyfjorden in the Vestland County in Norway. This fjord is located approximately 230 km north of Bergen, the second main city of Norway. The fjord is characterised by steep slopes, which are commonly affected by landslides of various types and by snow avalanches (Hermanns et al., 2021).

The EGMS Basic Product, which was derived using the descending SAR passes, captures well the deformation occurring in the eastern flank of the fjord. The same cannot be said for the opposite flank, where foreshortening and layover occur (Hanssen, 2001). The deformation map was derived using 178 Sentinel-1. It is worth observing that the available data stack includes much more images: the images acquired during the winter period (approximately from end of October to early March) were discarded because the snow cover impedes to derive useful deformation measurements.

In Figure 2, the EGMS data identify the upper portion of a large slope deformation on the eastern flank of the fjord, at an elevation between 800-1000 m above sea level. The potential crown area of the landslide has an extension of about 2.5 km. The 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 will include the use of the EGMS Ortho product to estimate the magnitude of the horizontal and vertical components of motion.

3. EGMS RESULTS: SUBSIDENCE

This section concern examples of subsidence. Figure 3 illustrates an example of EGMS Basic product, which covers the southern part of the Groningen gas field (the Netherlands). This is the largest gas field in Europe. 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 consequences of the gas extraction.

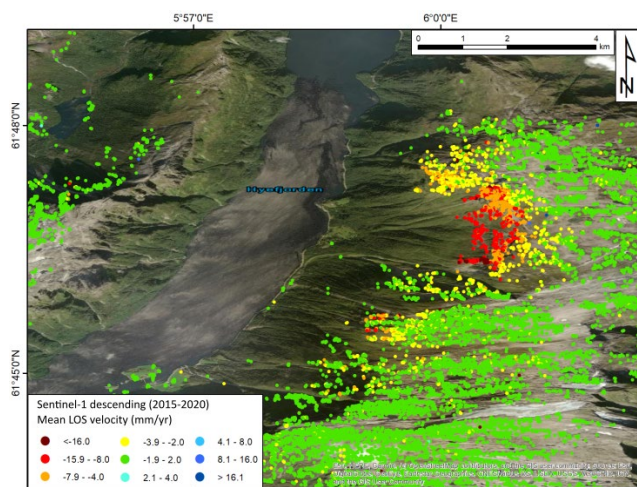


Figure 2 – Ground motion along the eastern flank of the Høyfjorden (Norway). EGMS Basic Product.

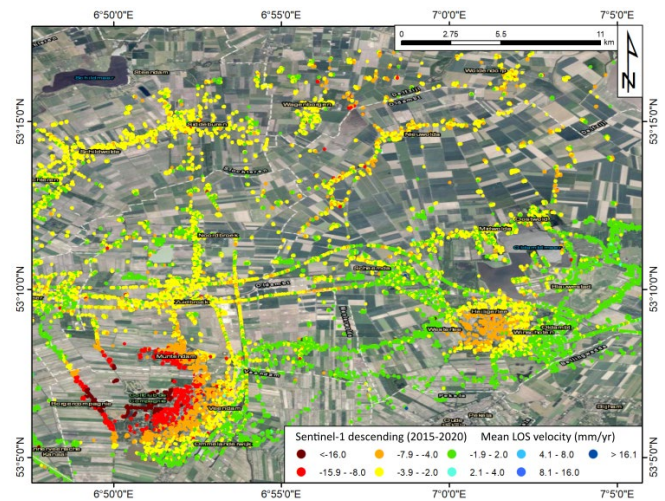


Figure 3 – Ground motion related to gas extraction in the Groningen gas field (the Netherlands). EGMS Basic Product.

The area was previously studied using A-DInSAR. From these studies, average subsidence rates were estimated to be approximately between -7 and -4 mm/yr in the period 1992-2007 (covered by SAR data from the ERS and Envisat sensors), and -5 mm/yr for the period 2015-2017 (using Sentinel-1 data) (Gee et al., 2019).

The deformation map presented in Figure 3 results from the analysis of 295 Sentinel-1 images that span the period from February 2015 to December 2020. The images were acquired in descending geometry. The subsidence rates reach a maximum of 25 mm/yr in the centre of the subsidence bowl located in the southwestern corner of Figure 3. However, excluding high local deformation rates, subsidence is estimated at an average value of 4 mm/yr. This is in line with the estimations published by Gee et al. (2019).

We describe a second important example of subsidence, which is related to the exploitation of geothermal reservoirs. The exploration and exploitation of geothermal reservoirs for power production have an important environmental impact, which includes air and water pollution, induced seismicity, and ground subsidence. The latter can be often detected by using A-DInSAR.

Figure 4 shows the EGMS Basic Product over the Larderello geothermal field (Tuscany, Italy). Larderello is the oldest geothermal power plant in the world; the activity started in early 1900s. Nowadays, 34 power production plants produce approximately 30% of the electricity demand of the Tuscany region. The geothermal reservoir reaches temperatures between 200°C and 350°C at a depth between 400 and 3500 m and it is hosted by carbonate and metamorphic formations (Bertini et al., 2005).

There are previous investigations, which were based on ERS 1/2 and Envisat data, that revealed the presence of a large subsidence bowl with maximum subsidence rates of ~-30 mm/yr (Solari et al., 2018). This is confirmed by the EGMS data in Figure 4. The results were derived using 295 images acquired in ascending geometry. The results allow us to draw the contour of a subsidence area, which extends for roughly 12 km in the NE-SW direction (Larderello-Lagoni Rossi axis) and for 10 km in the SE-NW direction (Sasso Pisano-Serrazzano axis). Subsidence rates are on average equal to 8 mm/yr with a maximum of 25 mm/yr in the centre of the valley.

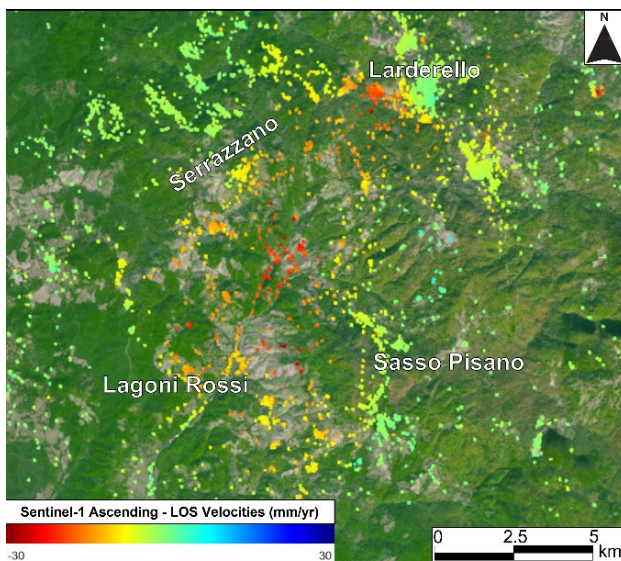


Figure 4. Ground motion in the Larderello geothermal field (Tuscany, Italy). EGMS Basic Product.

We discuss below a third example of subsidence. It belongs to an important class of deformation phenomena, where the ground motion is induced by underground or surface mining. This is a type of application where the multi-temporal satellite interferometry of A-DInSAR offers a useful deformation measurement and monitoring tool.

Figure 5 presents the EMGS Basic Product in the surroundings of the Hambach open pit mine (North Rhine-Westphalia, Germany). In this site, the lignite extraction begun in 1978 and created a depression of about 50 km², and almost 500-m deep. The mine has an important environmental impact, which is especially related to deforestation and destruction of biodiversity. In addition, the mine altered the groundwater circulation. In fact, the water level must be maintained low enough to guarantee the excavation and extraction operations. Due to changes in the groundwater, subsidence is triggered in the surroundings of the mine.

The EGMS results shown in Figure 5 allow us delimitating the extension of the subsidence area, which has a surface of approximately 600 km². This is clearly a very important surface, which includes urban and peri-urban areas, and important infrastructures. Two cities, Düren and Kerpen, few kilometres south of the mine, are located in the moving area. The deformation map was derived using a stack of 286 Sentinel-1 images covering the period 2015-2020. The results shown in Figure 5 were derived using the descending geometry.

The subsidence rates reach 60 to 70 mm/yr in the proximity of the mine. The first 10 km around the mine record an average subsidence rate of approximately 20 mm/yr. Time series of the area show a linear deformation without big seasonal variations. Such important deformation rates are often associated with horizontal displacements. This aspect can be studied using the Ortho Product.

Looking at the Figure 5, one may notice that the measurement point density in the mining area is strongly reduced. This can be due to decorrelation due to the frequent surface changes induced by the excavation of new coal levels. In addition, this can be due to a loss of measurement points due to fast and non-linear deformation. For this aspect, refer to Crosetto et al. (2020).

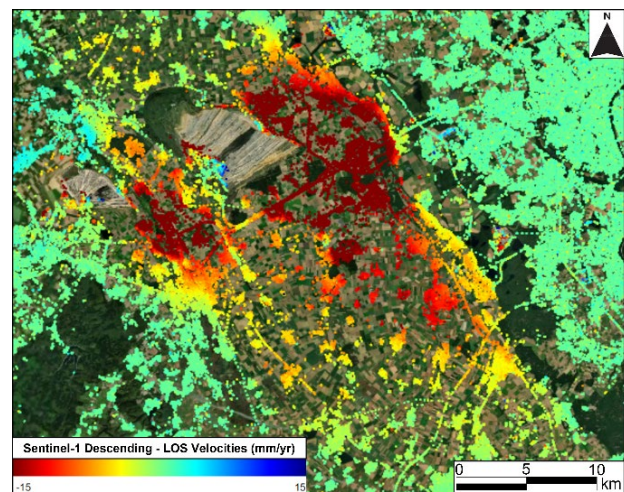


Figure 5. Subsidence in the surroundings of the Hambach mine (North Rhine-Westphalia, Germany). EGMS Basic Product.

4. EGMS RESULTS: INFRASTRUCTURES

The deformation monitoring of infrastructures represents an important component of the EGMS. This Service will allow users to monitor critical infrastructures like railways, highways, etc.

The Figure 5 presents the EGMS Basic Product along a portion 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. The focus of Figure 6 is a portion of A-48, which links the town 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 6).

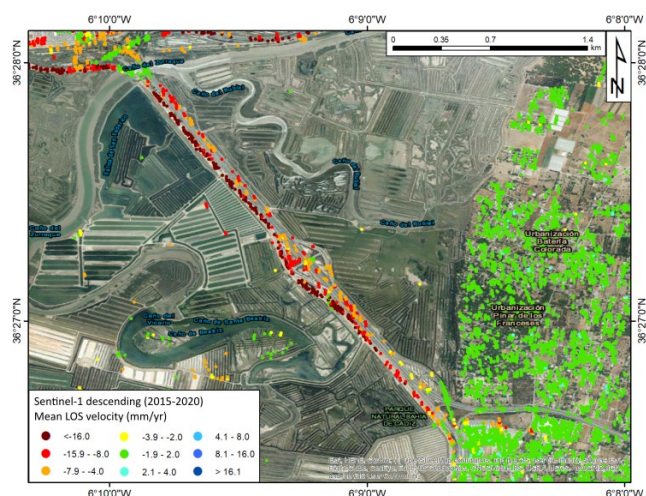


Figure 6. Ground motion along the A-48 highway (Spain). EGMS Basic Product.

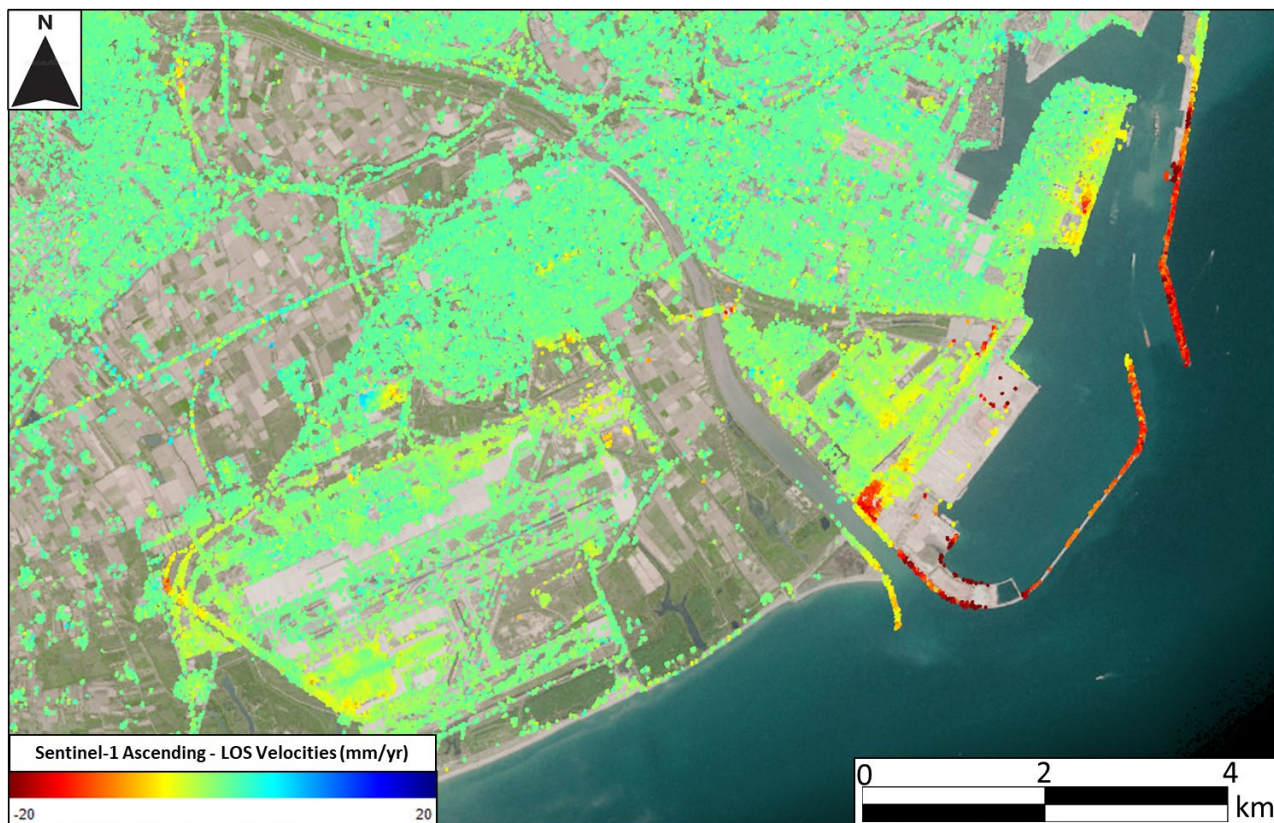


Figure 7. Deformation velocity map that concerns the ground motion along over the airport and port of Barcelona (Spain). EGMS Basic Product.

The last example concerns two important types of infrastructures: the airport and port of Barcelona (Spain). The deformation of both infrastructures is well sampled. Over the airport there are a lot of measurement points both in the runways and the terminals. The airport includes several deformation areas. Some of them are caused by water pumping, while others are due to construction works.

The port area includes the most important deformations. They concern reclaimed land and key infrastructures like the dikes that protect the port. In the dykes deformation well below -20 mm/yr occur.

These results are similar to those published in previous works, e.g. see Devan  ry et al. (2014)

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