Analysis of the Lisbon metropolitan area using the P-SBAS service of the Geohazards Exploitation Platform

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ABSTRACT

Web platforms and cloud computing are revolutionizing the remote sensing methodologies and improve significantly the capacity to analyze the Earth surface. Here, we present the Geohazard Exploitation Platform (GEP) of the European Space Agency (ESA) and, particularly, an application of the P-SBAS service of this platform on the Lisbon metropolitan area. The analysis was developed as part of the project RISKCOAST that deals with coastal hazards, seeking to test diverse methodologies to monitor them. The region of Lisbon is a pilot area of this project because different surficial and coastal processes impact it. To analyze this region, we generated through GEP a deformation map over 3,000 km^2 of the Portuguese coast where 2.8 million people live. Thanks to GEP we generated the map in only 24h. This deformation map serves us to recognize several places with ground instability problems. The main processes identified associated to those unstable terrains were landfill and sediment consolidation, active landslides and local subsidence most probably related to groundwater withdrawal. As far as we know, most of the detected deformations were not registered so far. We also detected deformations of unknown origin. Furthermore, we determined that an area previously affected by ground subsidence in the 90's appears to be currently stable. The mentioned findings show how different processes due to the interaction of human activities and infrastructures with the ground can affect metropolitan areas. In the case of Lisbon metropolitan area, the municipalities can use the obtained information to know and to anticipate future issues regarding building and infrastructure damage. In this sense, this research is an example of how new InSAR technologies such as the modern cloud analytic platforms can serve to identify and monitor surficial processes in an easy way to prevent problems associated to unstable ground.

I. INTRODUCTION

Some tools based on web platforms for cloud computing were applied to several coastal areas of the southwestern Europe in the framework of the RISKCOAST project (the Interreg SUDOE Programme; https://riskcoast.eu/). These tools are revolutionizing the remote sensing methodologies and improve significantly the capacity to analyze the Earth surface. The mentioned project aims to use tools for processing satellite radar images and deriving Earth surface displacement maps in supporting disaster risk reduction in coastal areas. This objective is focused on the technique of satellite interferometry with the aim of generating maps to detect, characterize and monitor surface movements associated with coastal hazards.

Satellite interferometry, or more specifically, Differential Interferometric SAR (DInSAR) is a powerful tool for the detection and monitoring of ground movements associated with different geological phenomena (Crosetto *et al.*, 2016). Despite being a relatively young technique, its consolidation came at the beginning of this century (Ferretti *et al.*, 2001; Crosetto *et al.*, 2005), it is a versatile, reliable and inexpensive technique for mapping and monitoring subsidence, landslides, infrastructure control and urban areas (Crosetto *et al.*, 2016). Here, we evaluate the operability of a platform that allows this type of analysis to be carried out quickly in the cloud, the platform developed by the European Space Agency (ESA) called Geohazard Exploitation Platform (GEP). At the time of writing (April-2022), this platform has already been put into service after several years of development and testing, a phase in which several authors of this paper have participated as part of an "Early Adopters" Programme. During this period, we have learned how the platform has been developed and identified its limitations and advantages for supporting decision-making in disaster prevention and management. A first study of the platform's capabilities was described in the article by Galve *et al*. (2017) in the specialized journal "Remote Sensing". This paper adds additional and novel information to that work by including descriptions of new services of the GEP platform, as well as focusing on its benefits for coastal risk analysis.

II. The Geohazard Exploitation Platform

Web platforms and related collaborative projects are revolutionizing the way remote sensing data is analyzed. On the other hand, the launch of new radar missions by ESA that offer open-access information allows these platforms to be fed with large amounts of information ready to be analyzed by them. Among the web-based platforms being developed for radar image analysis, the Geohazard Exploitation Platform (GEP) (https://geohazards-tep.eo.esa.int/#!) stands out. This platform makes it possible to perform various interferometric analyses with satellite SAR images in the cloud. This platform is a major step towards the widespread use of this technology by a wider community than has developed it so far. Until now, this technology was only applied by a few research teams or specialized companies in the world, and the areas studied in depth were limited to areas of interest for scientist or large companies, especially in the energy sector. With the emergence of platforms such as GEP, it will be easier to extend the users of the technology to members of public institutions, medium-sized or small companies in business sectors where its potential use is not yet known. In this way, land and disaster managers would be one of the target groups of the platform who could develop their own analyses without knowing in depth the mathematics and physics behind the application of this technique. In the GEP platform these analyses are performed through what are called "services". The platform hosts several "services" to identify, monitor and evaluate hazardous processes associated with seismic and volcanic activity, subsidence and landslides, among others.

Today, GEP is a commercial platform that offers a sponsorship programme to develop research projects. Many of the platform's "Early Adopters" maintain their access to the platform free of charge under ESA sponsorship. The access policy and pricing depending on public or commercial use is being defined in a new phase. More information on the platform and its services can be found at the following web address: http://terradue.github.io/doc-tep-geohazards/overview/index.html#

III. Study area

One of the study areas of the RISKCOAST project is the entire coastline of the Lisbon metropolitan area including the Tagus River estuary and the river basins that flow into this coastline. This area is characterized by some stretches of coast with cliffs and beaches but also show wide sand dune deposits and tidal flats. In this diverse coastal context, it is expected to find different active surface processes also affected by anthropic activities. There were three previous studies using InSAR in the area developed by Catalão *et al*. (2011; 2015) and Oliveira *et al*. (2015). The studies of Catalão *et al*. (2011; 2015) were focused in the subsidence due to the construction of a subway line detected in the Lisbon urban area. These authors processed images from ERS and ENVISAT satellites. For their part, Oliveira *et al*. (2015) analyzed images of the TerraSAR X satellite to monitor the activity of landslides in the surroundings of Lisbon.

IV. Methodology

The GEP platform presents a simple interface where algorithms can be run to process satellite radar images and obtain maps of movements on the Earth's surface. The algorithms are implemented in so-called "Services" which can be accessed directly from the main analysis web page. These "Services" containing the acronym "SBAS" have implemented programs to apply the "P-SBAS" algorithm developed by Casu *et al*. (2014) and De Luca *et al*. (2015). These algorithms are widely proven techniques for performing what are known as multi-temporal DInSAR analyses (MTA), *i.e*. analyses over a period of time where a large number of radar images are compared to obtain the time series of movements at each point measured on the Earth's surface. The input data for these algorithms are as follows:

- Set of radar satellite images acquired with the same geometry in the area of interest during the analyzed period.
- Data on the satellite position at the time of acquisition of each image.
- Digital elevation model of the area of interest.

The GEP platform provides access to all available radar images in ESA's archives and processes them directly on ESA's servers using very high-performance computing installations. As a result, users do not need to download all the necessary information, nor do they need to purchase and maintain high-capacity computing power or expensive specialized analysis software.

The DInSAR analysis is performed from the web interface of GEP's so-called "Thematic Apps". These "Thematic Apps" are pages divided into several windows where images, services and parameters for analysis are selected. The steps to follow are simple and can be summarized as follows:

1. Selection of the "Service" in the "Services Window". Once the service has been selected, the window displays a form to be filled in with the necessary parameters to perform the analysis.
2. Selection of the Area of Interest (AOI) in the "Map Window". Using the visualization tools in this window, we can move around the map and draw a rectangle with the area we wish to analyze.
3. Once the rectangle has been drawn, the types of images to be analyzed are selected. This selection is made by dragging the selected images from the "Selection Window" to the "Services Window". The "Services" evaluated can analyze images from the ERS 1/2, ENVISAT and Sentinel-1A/B satellites covering various time periods from the 1990s to the present day.
4. Finally, in the "Services Window", the analysis parameters must be completed and, above all, the stable reference point must be defined, which serves as a basis for determining the unstable areas and for carrying out the displacement measurements based on it. This reference point can also be defined using the "Map Window".

Once the study area, the images to be processed and the analysis parameters have been defined, the service is executed, generating a "Job" which will provide a result in the form of a digital displacement map after 24-48 hours.

The processing is sometimes unsuccessful because of technical errors such as low overlapping of images, wrong choice of reference point or deficiencies in the processing chain. The latter can be corrected by the GEP technical team who identify the problem and reconfigure the service to correct the error. In the case of the first two, a review of the input data can correct the error and result in successful processing.

The results presented in this paper have been developed using images acquired by the Envisat and Sentinel-1A/B satellites. The Envisat data are archived images from that mission from 2003 to 2008. Their images cover areas of approximately 100 x 100 km and have a spatial resolution of 30 x 30 m and a temporal resolution of 35 days, *i.e*. ideally one image of the same location is acquired approximately every month. These images are analyzed from the SBAS Stripmap service. Sentinel-1 data cover areas of 250 x 250 km, acquire an image every 6 days, have a nominal resolution of 4 x 14 m and are completely free of charge. These images are processed by the SBAS-InSAR S-1 TOPS service. Regarding the results provided by GEP, the "SBAS Stripmap" and "SBAS-InSAR S-1 TOPS" services provide displacement rate maps with a spatial resolution of approximately one point every 40-80 m together with the time series of the displacements at each point.

V. Results

The area covered by the displacement maps obtained with GEP provided a lot of information about imperceptible movement processes occurring around the city of Lisbon. The most recurrent process detected in these maps is the compaction of material extracted in the numerous quarries distributed throughout the region (Figure 1). Compaction or accommodation of near-shore sand dune deposits (Figure 2) and tidal flat deposits (Figure 3) is also common.

Figure 1. Quarry located in the east of the Lisbon metropolitan area (top) where ground movement velocities in LOS direction of more than 2 cm/year are observed moving away from the satellite (yellow, orange and red pixels in the image on the bottom) linked to the consolidation of fill materials (dumps). The data were obtained through the "SBAS-InSAR S-1 TOPS" service by processing Sentinel-1 ascending orbit images. This applies to the rest of the figures presented in this section from this point onwards.

From the point of view of processes that could generate risk situations or damage to buildings or infrastructures, movements linked to subsidence have been detected in alluvial materials of the Tagus River (Figure 4) and slope instabilities in the relief of hills surrounding the city, which have been the subject of a large number of studies (e.g. Zêzere *et al*., 2017).

Only one of the sites where ground displacements are detected had clearly evidenced the movement of a landslide already identified (Figure 5), but the rest the instabilities of the area were not known (Figure 6 and 7).

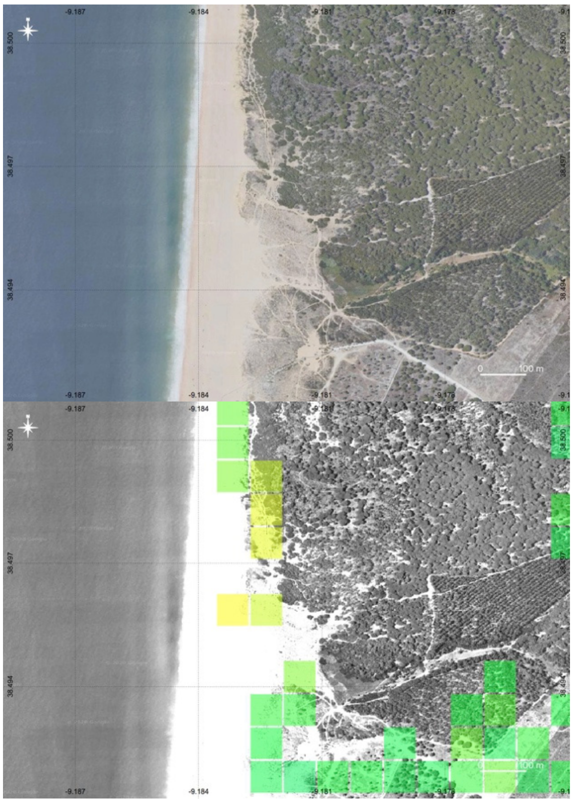

Figure 2. Beach south of Lisbon (top) showing movements with very slow speeds (yellow pixels: 1-1.5 cm/year) possibly linked to the movement of the sand of a coastal dune belt (bottom).

Figure 3. Coastal area on the eastern bank of the Tagus estuary showing a tidal plain occupied by cultivated land (top) A deformation of the terrain in the LOS direction away from the satellite is most likely associated with a subsidence of this terrain (orange pixels: 2-2.5 cm/year) (bottom) linked to the consolidation of the sediment.

Figure 4. Castanheira do Ribarejo area (Lisbon) along the Tagus river shortly before it flows into the estuary (top). The observed LOS ground velocities are in the range between 1 and 3 cm/year in the direction away from the satellite. It is interpreted as a subsidence zone of unknown origin that coincides with an urbanised area (bottom).

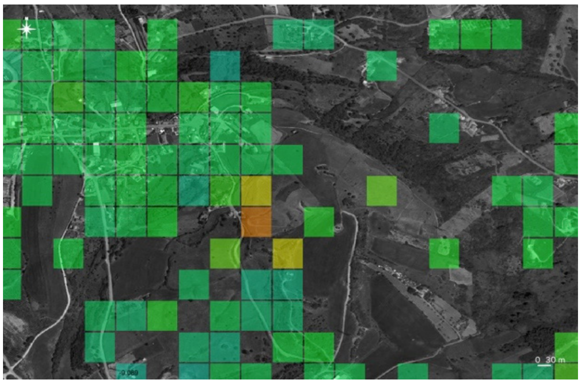

Figure 5. Monte Mourão area (358 m). Ground movement velocities in LOS direction of more than 1.5-2 cm/year (yellow and orange pixels) are observed linked to a known active landslide.

The results of GEP have made it possible to locate new areas in the metropolitan region of Lisbon linked to active slope movements.

In the Lisbon urban area, two cases are noteworthy, the instability observed in the area of the "Pedro Arrupe" School located in the north of Lisbon (Figure 8) and the movement of the ground away from the satellite (interpreted as a subsidence) observed in the area where the "Parque das Artes e do desporto" would be located, the high area of a slope facing the IC-16 motorway entering the city (Figure 9).

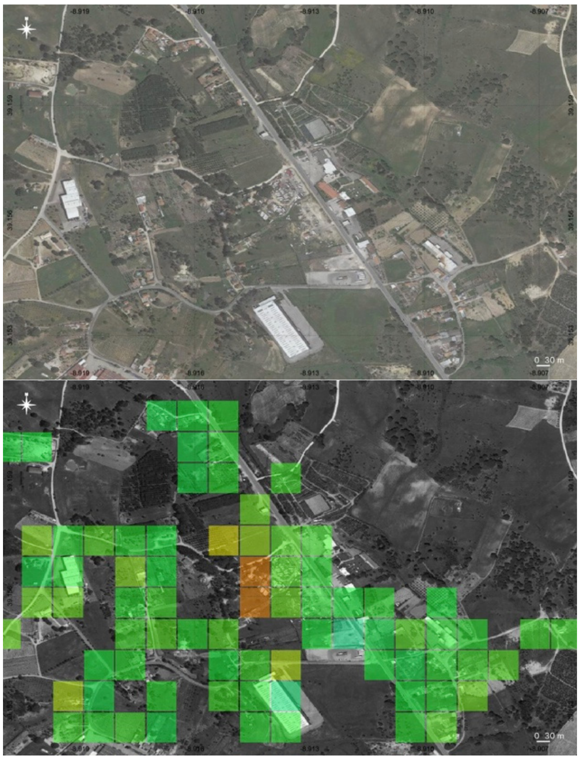

Figure 6. Aveiras de Cima area (top). Ground movement velocities in LOS direction of more than 2 cm/year of unknown origin are observed (bottom).

Figure 7. Cotovios area (top). Ground movement velocities in the LOS direction of more than 2 cm/year are observed, possibly linked to a slope movement (bottom).

A remarkable feature of the new analyses with Sentinel-1 images performed in GEP has been to verify that the subsidence zone detected in previous analyses with ERS 1/2 and ENVISAT images at the University of Lisbon Campus (Catalão *et al*., 2011; 2015) is no longer active (Figure 10). This subsidence was interpreted by Catalão *et al*. (2015) as a subsidence associated with the extraction of groundwater for the construction of a metro line right in an area where there were layers of fine-grained sands that were consolidated by this cause, added to the urbanisation of the area and the sealing of the soil by this cause. These phenomena may occur again in the future in the city or its metropolitan area, which makes the GEP platform very useful to have a first-order idea of the evaluation of the process.

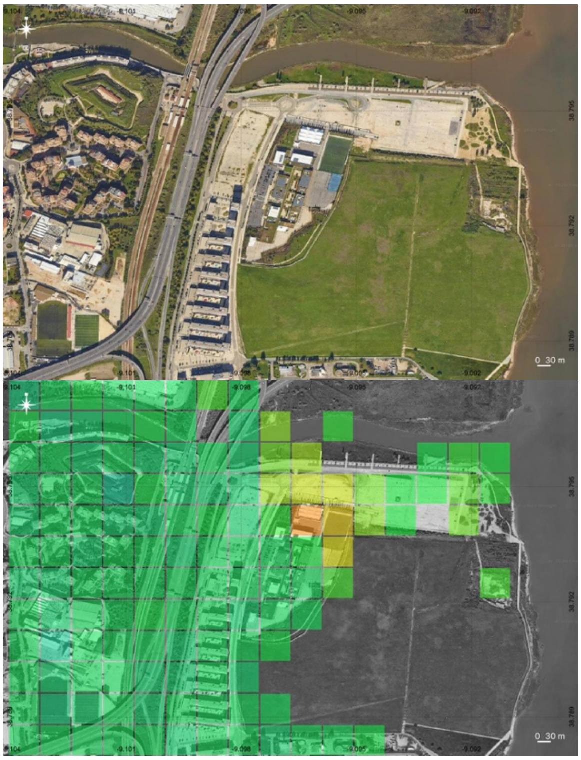

Figure 8. “Pedro Arrupe” School area (Lisbon) (top). Slight ground movements away from the satellite have been detected, possibly associated with a subsidence of unknown origin (bottom).

VI. Discussion

The GEP results, even with their limitations linked to the resolution of the output data, complement the abundant studies on slope movements and subsidence already carried out in the Lisbon region and provide displacement rates for some movements. This is an achievement in an area where there is a deep knowledge of unstable terrain. Thus, in the Lisbon area, GEP's ability to quickly analyze entire coastal regions and get a preliminary idea of possible unstable areas was demonstrated. In this case, in one day we obtained a displacement map covering a land area of approximately 3,000 km^2 where more than 2.8 million people live. Therefore, a preliminary idea of the general stability of hundreds of kilometers of coastline can be obtained with minimal effort compared to the use of other in-situ monitoring methods.

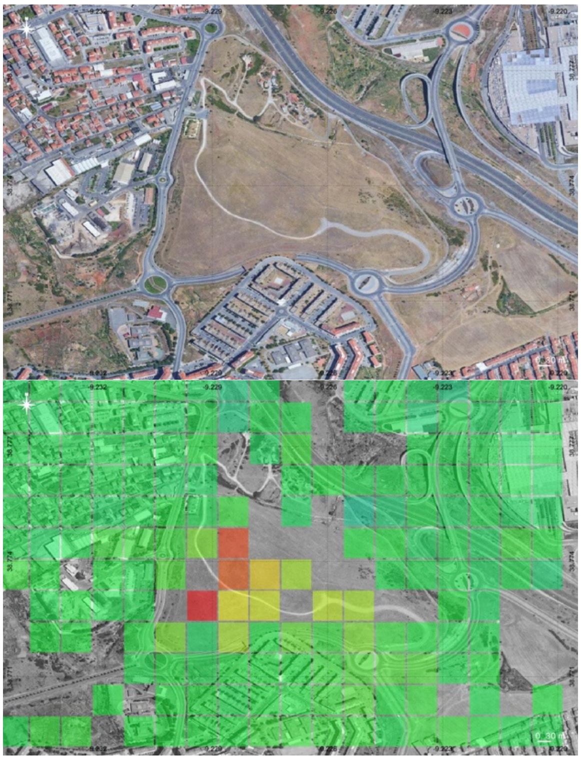

Figure 9. Area of the "Parque das Artes e do desporto" (Lisbon) (top). The area appears to be a large anthropic fill where a slope has been outlined. In the upper area, ground movements away from the satellite of more than 2 cm/year in the LOS direction are observed, possibly related to the consolidation of the fill (bottom).

Figure 10. Area of the University of Lisbon Campus with InSAR data obtained from ERS images (from Catalão *et al.*, 2015) (top). Data obtained from GEP after processing Sentinel-1 images (bottom). The green colour of the pixels indicates stability of the whole area.

From a technical point of view, GEP is a complex tool that, although user-friendly, does not allow control over almost any processing parameters, so it is necessary to contact the technical team when problems arise in the SAR image processing. Furthermore, depending on the availability of images, their quality and the area analysed, it can offer results that are difficult to interpret due to the "noise" that the data may show. In some of the cases presented here, it was necessary to carry out several processing operations with different parameters and images to obtain a reliable result. All these shortcomings are contrasted with the possibility of obtaining results in 24-48 h, which allows several tests to be carried out in a short space of time to obtain several displacement maps.

VII. Conclusions

The GEP platform developed by ESA is a useful tool for rapid analyses to locate possible unstable terrain with a continuous movement of a few mm-cm per year. The platform provides unsupervised analysis results, *i.e*. without much modification of the processing parameters to optimize the analysis, but within 24-48 h, which allows a quick and preliminary assessment of the instability situation. In addition, the services mentioned provide time series of displacement, which also helps in the interpretation of the movements and can guide in the identification of the causal factors causing the detected instability. With GEP, a user with basic training can obtain DInSAR data relatively easily, although it is always a preliminary result. At that point, applying the technique is no longer an obstacle and it is the rigorous interpretation of the data that becomes important.

The findings in the Lisbon metropolitan area show how different processes due to the interaction of human activities and infrastructures with the ground can affect urban areas. The municipalities can use the obtained information to know and to anticipate future issues regarding building and infrastructure damage. In this sense, this research is an example of how new InSAR technologies such as the modern cloud analytic platforms can serve to identify and monitor surficial processes in an easy way to prevent problems associated to unstable ground.

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