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**Deliverable DE3.2: Periodically upgraded geohazard activity maps over the two test sites of the project (V0)**

**A deliverable of**  
**Task E: Geohazard impact assessment**

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PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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TN	Technical Note, not a deliverable, only internal for members of the Consortium	



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## **EXECUTIVE SUMMARY**

SAFETY is a two-year research project funded under the ECHO (European Commission's Humanitarian aid and Civil Protection department) call "Prevention and preparedness projects in Civil Protection and marine pollution", which started the 1<sup>st</sup> January 2016. The mission of the project is to improve the efforts in detecting and mapping geohazards (i.e. landslides and subsidence), by assessing their activity and evaluating their impact on built-up areas and infrastructures' networks. SAFETY will enhance ground deformation risk prevention and mitigation efforts in highly vulnerable geographic and geologic regions. The outcomes of the project will provide Civil Protection Authorities (CPA) with the capability of periodically evaluating and assessing the potential impact of geohazards on the selected sites.

The Geohazard activity maps are one of the four deliverables foreseen in Task E "Geohazard impact assessment". This deliverable, which will be updated three times throughout the project, aims at developing and testing a methodology capable of generating geohazard activity maps. These maps will detect active and significant ground surface areas, identifying their plausible cause. The final goal is to provide an operable methodology, a protocol, which can be integrated into the Civil Protection prevention activities.


**REFERENCE DOCUMENTS**

<b>N°</b>	<b>Title</b>
RD1	DoW, Part B
RD2	D.D1: Test site selection
RD3	D.B1: User Requirements
RD4	D.C2.1 Deformation activity maps

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## INTRODUCTION

The Geohazard activity maps are one of the four deliverables foreseen in Task E “Geohazard impact assessment”. This deliverable, which will be updated three times throughout the project, aims at developing and testing a methodology capable of generating geohazard activity maps. These maps will detect active and significant ground surface areas, identifying their plausible cause. The final goal is to provide an operable methodology, a protocol, which can be integrated into Civil Protection prevention activities.

In this first version of the Geohazard activity map deliverable, only the hotspots, i.e. the active areas (Figure 1) will be delivered. In the subsequent updates at months 14 and 20 the geohazard activity maps will be completed including:

- Quality index: the standard deviation of the difference of the time series of all the PS included within every hotspot area.
- The integration of the hotspots with the geohazard inventories, field surveys and ground truth in situ data for validation.

## 1 METHODOLOGY

### 1.1 State of the art

Differential Synthetic Aperture Radar Interferometry (DInSAR) is a microwave remote sensing technique that enables the measurement of surface displacement with a centimeter to millimeter accuracy and with a large spatial coverage capability (Rosen et al., 2000). It exploits the phase difference between two SAR images acquired over the same area in different epochs providing measurements of the ground displacement component along the radar line of sight (LOS). Advanced DInSAR techniques or multi-temporal interferometric techniques, compute displacement time series from multi-image analysis, typically few tens of SAR images. A comprehensive review of these techniques and their application to monitor geohazards can be found in Crosetto et al. (2016) and Tomás et al. (2015). Previous works revealed limitations related to the acquisition geometry of the satellite systems or the land use cover (Notti et al. 2010), being evident when an integrated multi-sensor approach is considered (Herrera et al. 2013). Notti et al. (2014, 2015) presented a review on how to consider these issues for an adequate interpretation of InSAR based ground surface displacements. Therefore, based on the methodology proposed by Herrera et al. (2013), Notti et al. (2014) and Bianchini et al. (2014), which was funded by FP7 DORIS project, we present an adapted methodology to generate Geohazard activity maps based on Sentinel InSAR deformation activity maps with the target of Civil Protection prevention services.

### 1.2 Description of the methodology

In this section we describe the methodology to generate the Geohazard activity map based on the deformation activity maps derived by Sentinel-1 InSAR (Figure 1.1). The methodology consists in three main steps:

Step 1:

In the first part radar deformation data are processed in order to identify “hotspots” or active ground deformation areas where further analysis should be made. In order to apply this methodology, the estimated linear Velocity (Vlos) or the total Deformation (Dlos), cumulated during the analysed period, will be used depending upon the characteristics of every dataset. A stability threshold is set based on the statistical analysis of the InSAR processing of Sentinel SAR images. The results, obtained by using the PSIG software (Devanthéry et al., 2014, Crosetto et al., 2011) in Canary Islands and in Volterra municipality, show similar statistical characteristics and permit to set a stability threshold of 10 mm/yr (Vlos) for Canary Islands and of 10 mm (Dlos)

for Volterra municipality. These thresholds are set to distinguish active from stable Persistent Scatterers (PS). Then, in order to generate the hotspots (deformation areas), we aggregate groups of four or more active PS located within the area of influence of every PS. The result of this step is the generation of the hot spots, i.e. the ground motion active areas with an average velocity  $V_{los}$  or a cumulative displacement  $D_{los}$  greater than the stability thresholds.

Step 2:

In order to provide a quality index of the deformation areas estimated in the previous step, for each hot spot the standard deviation ( $\sigma_{ts}$ ) of the differences between the deformation time series (TS) of all the aggregated PS is calculated. Then, the reliability of the estimations is evaluated by comparing the standard deviation of each hot spot ( $\sigma_{ts}$ ) with the general standard deviation ( $\sigma_{tot}$ ) of all the PS  $V_{los}$  or all the PS  $D_{los}$  values of the areas:

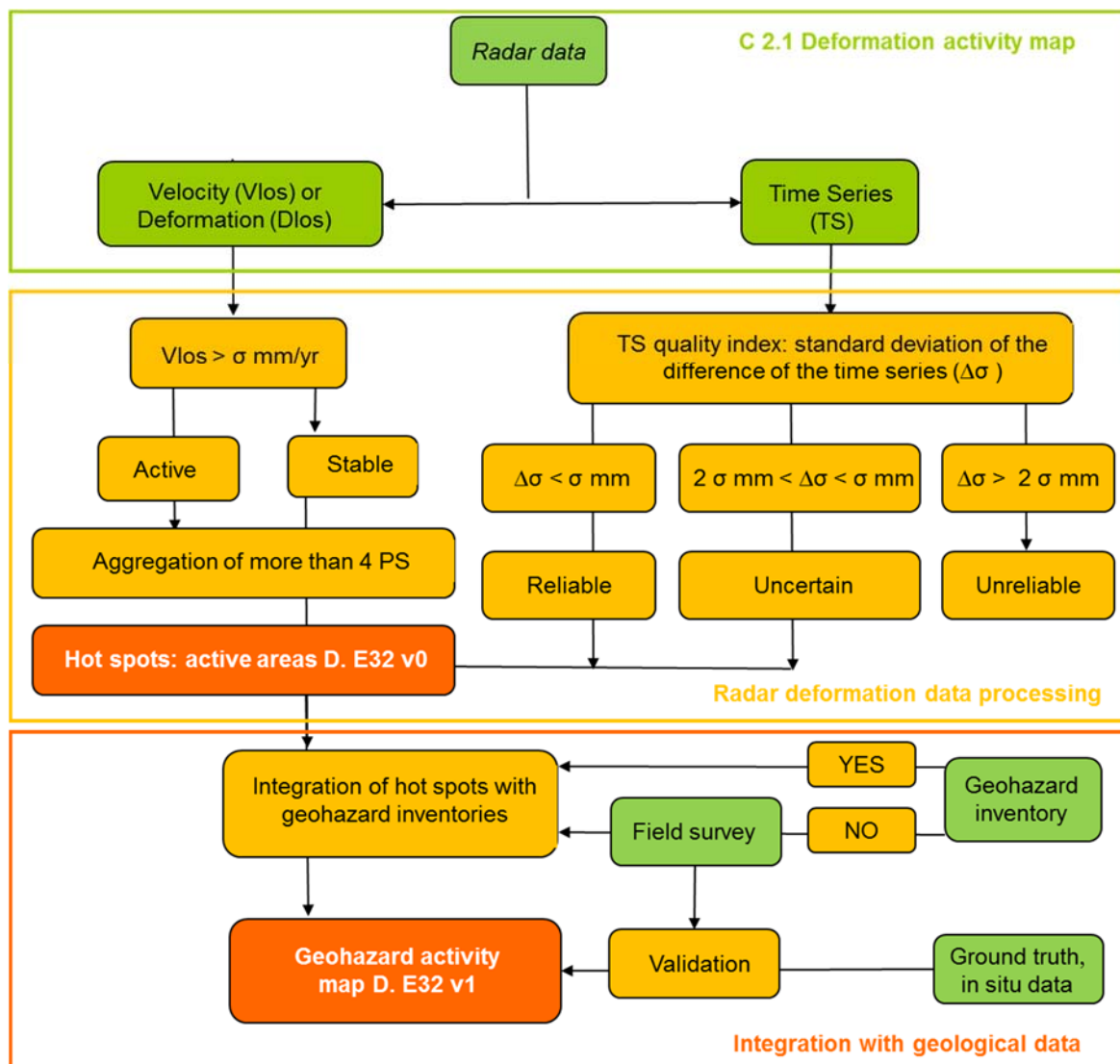


Figure 1.1. Flow chart of the methodology to improve landslide and subsidence PSI analysis. Green cells represent necessary input data. Light orange is procedure steps and dark orange the output of the methodology.

$\sigma_{ts} < \sigma_{tot}$	Reliable estimation
$\sigma_{tot} < \sigma_{ts} < 2 \sigma_{tot}$	Uncertain estimation
$\sigma_{ts} > 2 \sigma_{tot}$	Unreliable estimation

For the Canary Island the standard deviation ( $\sigma_{tot}$ ) of all the Vlos is 10 mm/yr, for the Volterra municipality the standard deviation ( $\sigma_{tot}$ ) of all the Dlos is 10 mm. Therefore, taking as an example the area of Volterra municipality, in the case that the  $\sigma_{ts}$  is smaller than 10 mm, the deformation estimated is considered reliable; in the case that the  $\sigma_{ts}$  is between 10 and 20 mm, the calculated deformation is considered uncertain; in the case that the  $\sigma_{ts}$  is greater than 20 mm ( $2 \sigma_{tot}$ ) the estimated deformation is unreliable.

### Step 3:

The integration of the hotspots with the geohazard inventories (e.g. landslide or subsidence) consist of determining the average velocity for every geohazard polygon taking into account the displacement measured by the PS inscribed within the area of every landslide or subsidence area. In the case that in situ ground truth information is available (e.g. differential GPS, inclinometers, extensometers or damage inventories) the geohazard activity map can be evaluated providing an estimation of the confidence degree (Bianchini et al. 2013).

In the case that previous geohazard inventories are not available, a combination of photo-interpretation and field work from a trained geologist is necessary for every detected hotspot. In order to be efficient hotspots should be ranked in terms of vulnerable elements where hotspots have been detected.

## 2 GEOHAZARD ACTIVITY MAP

### 2.1 Volterra test site

#### 2.1.1 *Input data: deformation activity maps*

In the Volterra municipality, 19 Sentinel-1 wide swath images spanning from the 15<sup>th</sup> June 2015 to the 29<sup>th</sup> January 2016 have been processed with the PSIG processing chain to generate the deformation activity maps (D.C2.4).

Deformation measurements are available for 11064 PS (measurement points). According to the processing characteristics, the error of the deformation measurements is  $\pm 10$  mm. Due to the short analysed period (only 6 months), the threshold for selecting stable points will be set on the total displacement and not on the velocity value. Hence, this value is equal to the error of the deformation measurements (10 mm).

Taking into account this stability threshold ( $\pm 10$  mm), the number of active deformation measurement points is 3398, equal to the 30.7% of the total amount of detected measurement points (Figure 2.1).

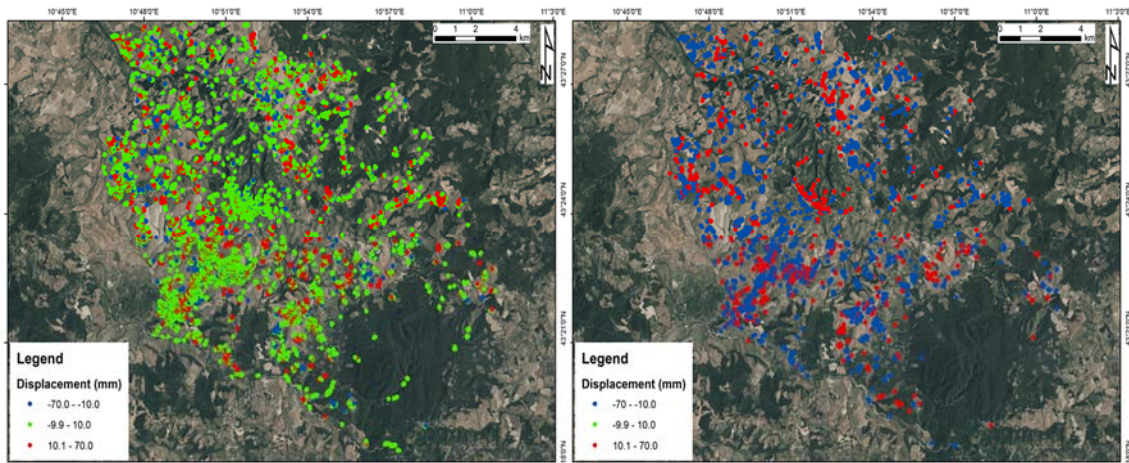


Figure 2.1. Left: Deformation velocity in the line of sight (Vlos) in Volterra municipality. Right: measurement points with a deformation velocity greater than  $\pm 10$  mm/yr.

### 2.1.2 Hotspot generation

Following the methodology presented in Figure 1.1, we first selected the PS with a cumulated displacement greater than 10 mm. Then we aggregated more than 4 neighbour PS sharing their influence area. In order to define the influence area of every PS we considered the multi-look used in the processing to select the most probable area of the PS. The original resolution of the PS is 14 m x 4 m. In the Volterra test site the applied multi-look was 1 x 5 (azimuth and range, respectively), which yielded an approximate PS area of 14 m x 20 m. We calculated the radius of the circle inscribing a 20 m x 20 m area where the PS is located and we multiplied it by a factor of 1.3 to ensure that neighbouring pixels will be selected. In the Volterra municipality a total number of 89 hotspots with total displacement higher than 10 mm were selected with the proposed methodology.

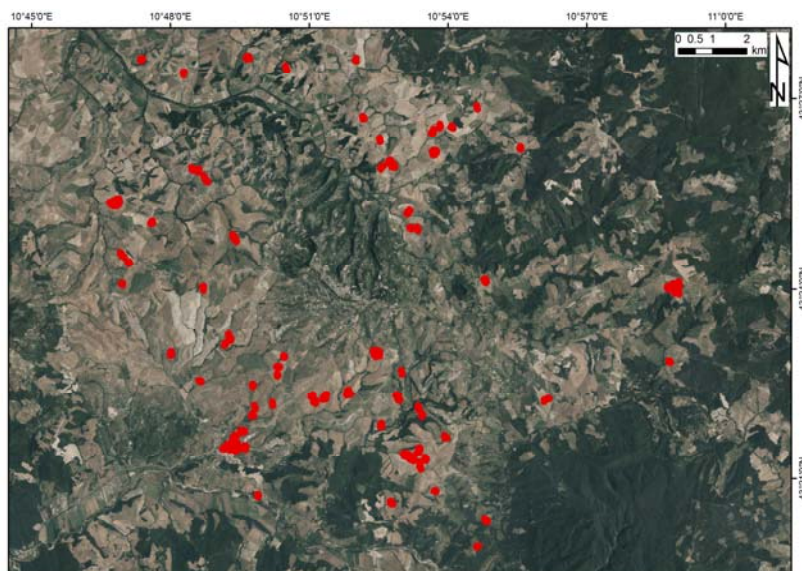


Figure 2.2 Hotspots detected in the Volterra municipality, with an average cumulated displacement greater than  $\pm 10$  mm.

## 2.2 Canary Island test site

### 2.2.1 Input data: deformation activity maps

In Gran Canaria, Tenerife and La Gomera islands, 34 Sentinel-1 Wide Swath images acquired during the period spanning from 5<sup>th</sup> November 2014 to 4<sup>th</sup> February 2016 were processed with the PSIG software chain to generate the deformation activity maps (D.C24).

Deformation measurements are available for 1082727 PS (measurement points): 618412 in Tenerife, 399739 in Gran Canaria and 64576 in La Gomera. In this case the threshold for selecting stable points was set on the velocity values. The stability threshold of the velocity dataset was set to  $\pm 10$  mm/yr.

Taking into account this stability threshold ( $\pm 10$  mm/yr), the number of active deformation measurement points is:

- Gran Canaria: 3975 PS, which represents 1% of the total amount of detected measurement points (399739 PS).
- La Gomera: 425 PS, which represents 0.6% of the total amount of detected measurement points (64576 PS).
- Tenerife: 7574 PS, which represents 1.2% of the total amount of detected measurement points (618412 PS).

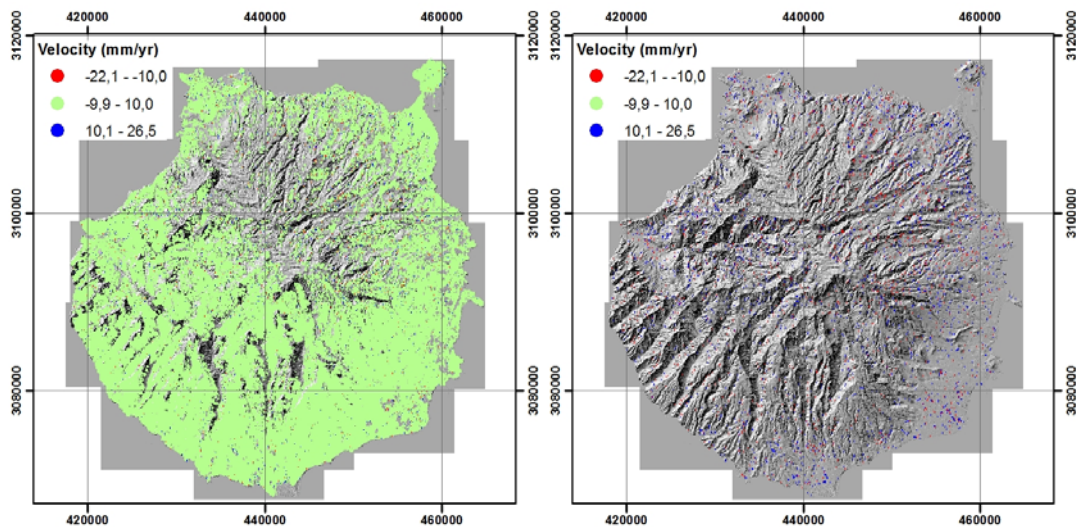


Figure 2.3. Left: Deformation velocity in the line of sight (Vlos) in Gran Canaria Island. Right: measurement points with a deformation velocity greater than  $\pm 10$  mm/yr.

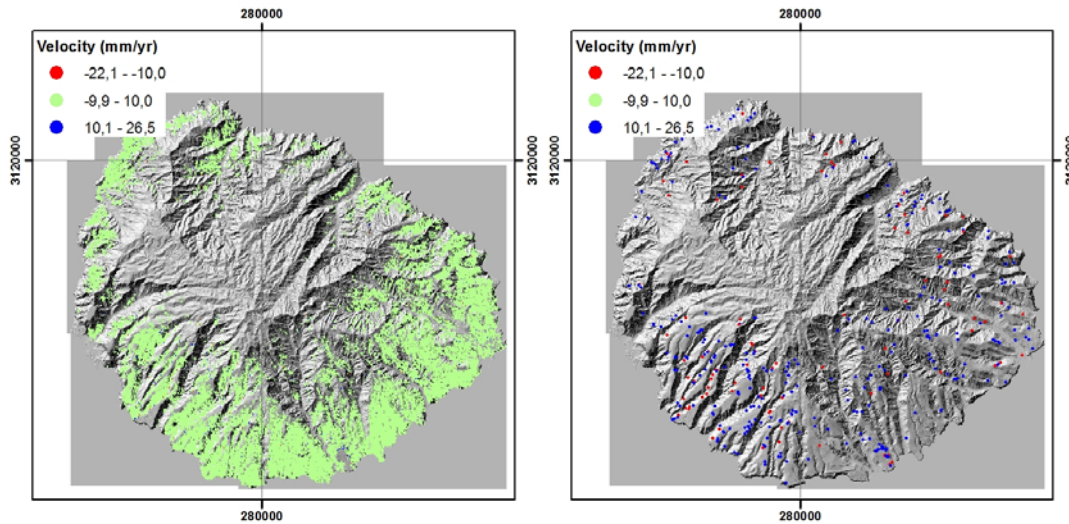


Figure 2.4 Left: Deformation velocity in the line of sight (Vlos) in La Gomera Island. Right: measurement points with a deformation velocity greater than  $\pm 10$  mm/yr.

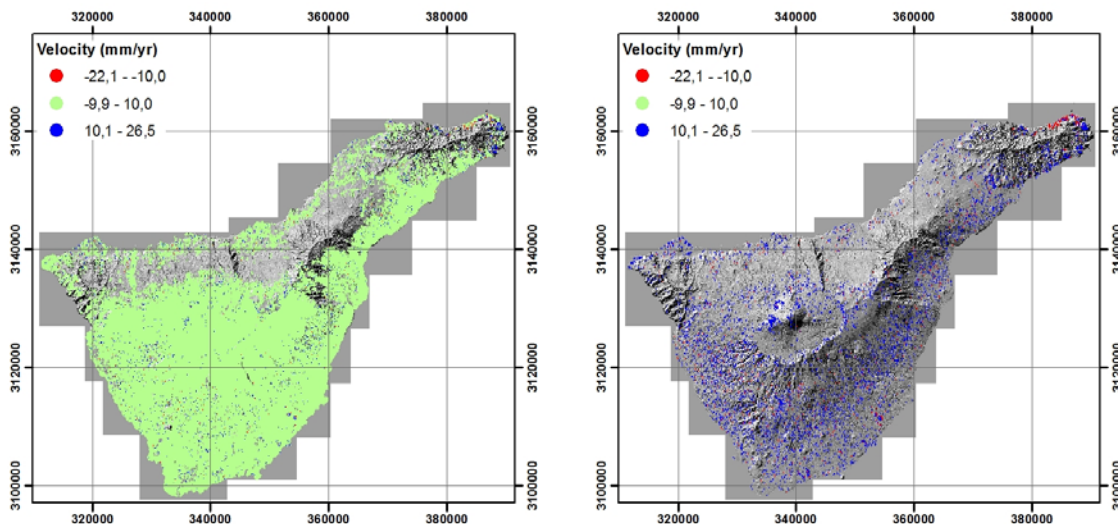


Figure 2.5 Left: Deformation velocity in the line of sight (Vlos) in Tenerife Island. Right: measurement points with a deformation velocity greater than  $\pm 10$  mm/yr.

### 2.2.2 Hotspot generation

Following the methodology presented in Figure 1, we first selected the PS with an absolute velocity greater than 10 mm/yr. Then we aggregated more than 4 neighbour PS sharing their influence area. In order to define the influence area of every PS, we considered the multi-look used in the processing to select the most probable area of the PS. The original resolution of the PS is 14 x 4. In the Canary Islands the applied multi-look is 2 x 10 and yields an approximate PS area of 28 m x 40 m. We calculated the radius of the circle inscribing a 40 m x 40 m area where the PS is located and we multiply it by a factor of 1.3 to ensure that neighbouring pixels will be selected. In Figures 2.6 to 2.8 the hotspots identified in the three islands are depicted with an estimate of the average Vlos of all the PS included within this area.

The hotspots detected in the three islands account for a number of 101 polygons with average Vlos greater than 10 mm/yr in absolute value, being:

- 12 in Gran Canaria,
- 87 in Tenerife,
- 2 in Gomera.

To conclude, it is worth emphasizing that the hot spot detected in the coastal lines must be analysed a part. This is due to that the analysed period is still short in order to discriminate in a reliable way between possible artefacts of the atmospheric filtering (border effects) and real deformations.

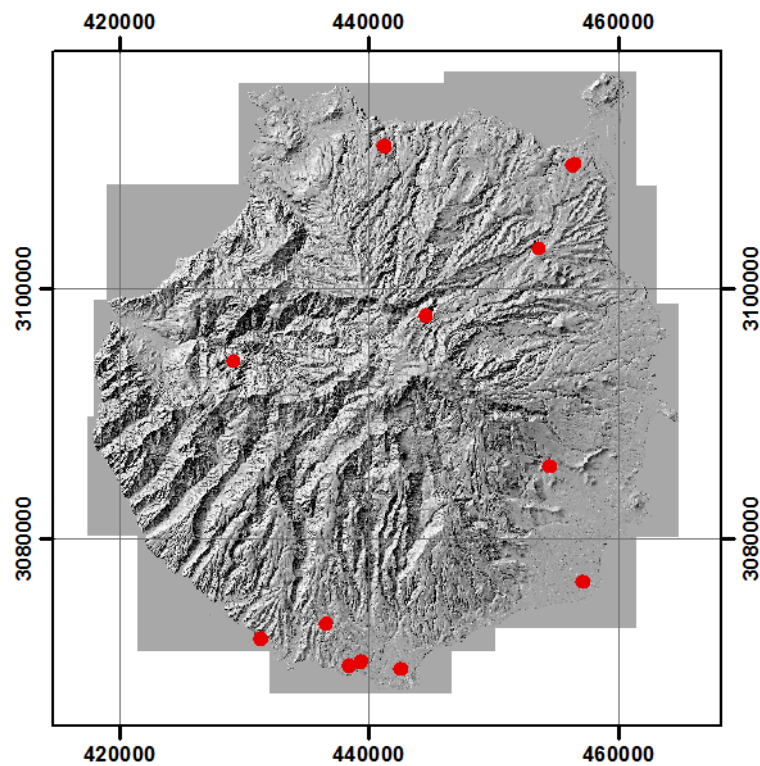


Figure 2.6. Hotspots detected in Gran Canaria Island, with an average deformation velocity greater than  $\pm 10$  mm/yr.

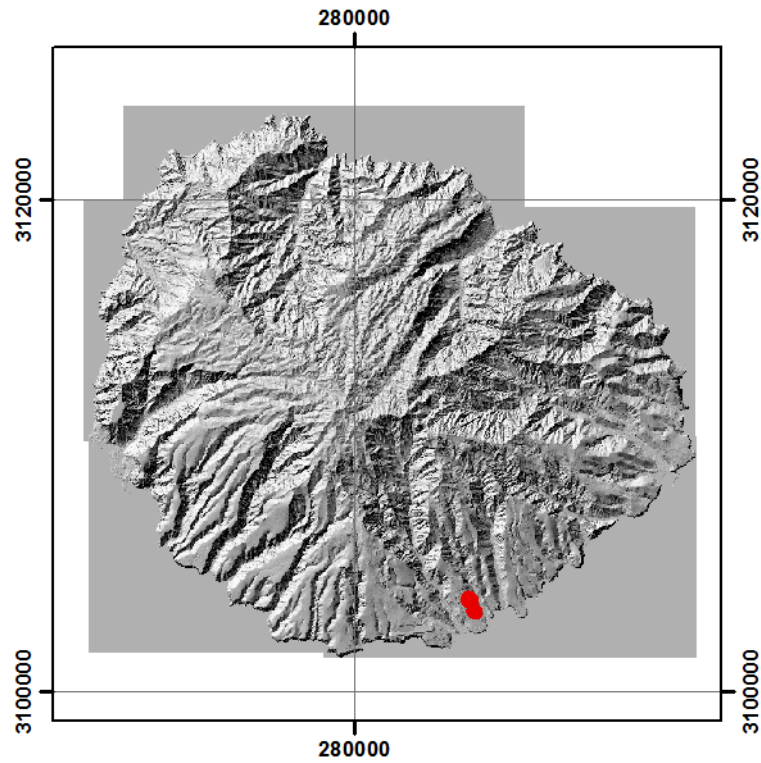


Figure 2.7. Hotspots detected in La Gomera Island, with an average deformation velocity greater than  $\pm 10$  mm/yr.

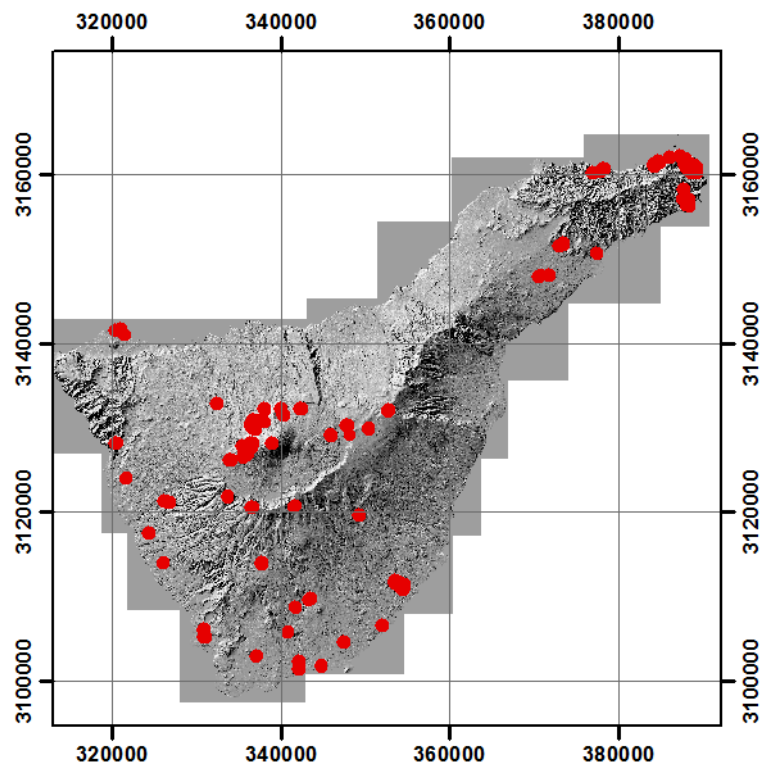


Figure 2.8. Hotspots detected in Tenerife Island, with an average deformation velocity greater than  $\pm 10$  mm/yr.

### 3 CONCLUSIONS

This deliverable describes the first delivered Geohazard Activity maps and the procedure used to derive them. In the forthcoming iteration it is expected to improve the results by means of the evaluation of the quality of deformation estimates, as well as generating the final Geohazard activity map that will integrate deformation estimates with the available geohazards inventories, field work and in situ data.

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