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Safety – Sentinel for geohazard prevention and forecasting

Deliverable C2.3: Canary Islands deformation activity map V2

A deliverable of

Task C: Sentinel-1 software development and data processing

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Partners: CTTC

Dissemination Level		
PU	Public	
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the Consortium (including the Commission Services)	
CO	Confidential, only for members of the Consortium (including the Commission Services)	
TN	Technical Note	X

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EXECUTIVE SUMMARY

This document describes the technical aspects of the delivered deformation activity maps (V2) over the Canary island site: The Deformation Activity Map, including the Time Series information for each measured Persistent Scatterer, and the Active Deformation Areas Map.

REFERENCE DOCUMENTS

N°	Title
RD1	DoW Part C
D.E3.2	Periodically upgraded geohazard activity maps over the two test sites of the project (V0)
D.C2.1 (V0)	Deliverable C2.1: Canary Islands area deformation activity map V0
D.C2.2 (V1)	Deliverable C2.2: Canary Islands area deformation activity map V1

CONTRIBUTORS

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REVIEW: CORE TEAM

Reviewed by	Company	Date	Signature
Anna Barra	CTTC	14/07/2017	

1 INTRODUCTION

In this document are discussed the results obtained in the last iteration of the task D.C2 (data processing for Canary Island test site). In this iteration are delivered the following products:

- A new processing of the first iteration (V1) of the Deformation Activity Maps (DAM) and Active Deformation Areas Maps (ADA map, i.e. HotSpots Activity Map). In this new processing (iteration V1b) we have used a slightly different dataset but composed of the same number of images (51) and covering almost the same period of time.
- The second iteration (V2) of the DAM and ADA.

The new version of the first iteration (V1b) have been generated in order to have the two DAMs (first and second iteration) derived from exactly the same processing steps and thresholds. This allowed to provide a reliable example of the map updating. For what concerns the first delivery (iteration V0), we have discarded it because of the low image availability at the beginning of the project, which caused a very noisy result. Moreover, we have implemented the Quality Index parameters (QI) in the ADA maps. These QI are used to provide, for each ADA, a measurement of the reliability of the measurements.

The data processing to obtain the DAM and ADA has been performed by using the software tools developed and owned by the CTTC. The used procedure includes three main steps. The first one consists in the calculation of the stack of interferograms and coherences, the second one consists in the generation of the DAM and the third step consists in the generation of the ADA map. The Canary Island site has a very high coherence for temporal baselines up to 150 days, in most of the covered area. This allowed to use the PS approach described in Devanthéry et al. 2014[1]. Compared with previous deliveries, there is an improvement in the robustness of the results and also in the control of the results thanks to the use of QI.

The final results (DAM and ADA) contain information of all the typologies of surface deformation, including anthropic ones. The ADA is used as an input in the Geohazard activity map generation.

The document consists of 6 sections: after the introduction, section 2 describes the Sentinel-1 dataset at hand; section 3 explains the processing and the technical aspects of the Deformation Activity Map; section 4 explains the processing to obtain the ADA map; section 5 describes the delivered maps and Section 6 underlines particular aspects of the results.

2 DATASET DESCRIPTION

The processed dataset consists of 64 Sentinel-1 Wide Swath images acquired during the period spanning from 5th November 2014 to 18th March 2017 (see Table 2-1). Table 2-1 shows the acquisition dates of the images: it can be observed that the maximum time interval of consecutive images is 48 days. The super master image is the first image. The images in green correspond to the dataset used for the iteration 1 (images from 1 to 51). The images used in the second iteration starts in the image number 23. The main characteristics of the used images are summarized in Table 2-2. Figure 2-1 shows the footprint of the processed datasets consisting in 18 bursts divided in 3 swaths.

To process the interferometric products, we have used the SRTM Digital Elevation Model provided by NASA, and the precise orbits.

To derive the deformation map, we have generated a network of 398 and 481 interferograms corresponding to the first and the second iteration respectively. The maximum temporal baseline used is 156 days. This threshold has been derived by a statistical analysis of the decrease of the coherence with respect the temporal baseline.

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[1] Devanthéry, M. Crosetto, O. Monserrat, M. Cuevas-González, B. Crippa. An approach to persistent scatterer interferometry. Remote Sens., 6 (7) (2014), pp. 6662–6679.

Nº image	Date	Nº image	Date	Nº image	Date	Nº image	Date
1	05/11/2014	18	08/08/2015	35	28/02/2016	52	13/10/2016
2	17/11/2014	19	20/08/2015	36	11/03/2016	53	25/10/2016
3	29/11/2014	20	01/09/2015	37	23/03/2016	54	06/11/2016
4	11/12/2014	21	13/09/2015	38	04/04/2016	55	18/11/2016
5	23/12/2014	22	25/09/2015	39	16/04/2016	56	30/11/2016
6	04/01/2015	23	07/10/2015	40	28/04/2016	57	12/12/2016
7	16/01/2015	24	19/10/2015	41	10/05/2016	58	24/12/2016
8	28/01/2015	25	31/10/2015	42	22/05/2016	59	05/01/2017
9	09/02/2015	26	12/11/2015	43	03/06/2016	60	17/01/2017
10	21/02/2015	27	24/11/2015	44	15/06/2016	61	29/01/2017
11	05/03/2015	28	06/12/2015	45	09/07/2016	62	22/02/2017
12	17/03/2015	29	18/12/2015	46	21/07/2016	63	06/03/2017
13	29/03/2015	30	30/12/2015	47	02/08/2016	64	18/03/2017
14	09/06/2015	31	11/01/2016	48	14/08/2016		
15	03/07/2015	32	23/01/2016	49	07/09/2016		
16	15/07/2015	33	04/02/2016	50	19/09/2016		
17	27/07/2015	34	16/02/2016	51	01/10/2016		

Table 2-1 Dates of the 51 processed Sentinel-1 images. In red is highlighted the date of the super-master image, while in green are indicated the images used in v0.

Satellite	Sentinel-1
Acquisition mode	Wide Swath
Period	Nov 2014 - September 2016
Minimum revisit period [days]	12
Wavelength (λ) [cm]	5.55
Polarization	VV
Full resolution (azimuth/range) [m]	14/4
Multi-look 1x5 resolution (azimuth/range) [m]	14/20
Multi-look 2x10 resolution (azimuth/range) [m]	28/40
Orbit	Descending
Incidence angle of the area of interest	36.47º - 41.85º

Table 2-2 Main characteristics of the processed data.

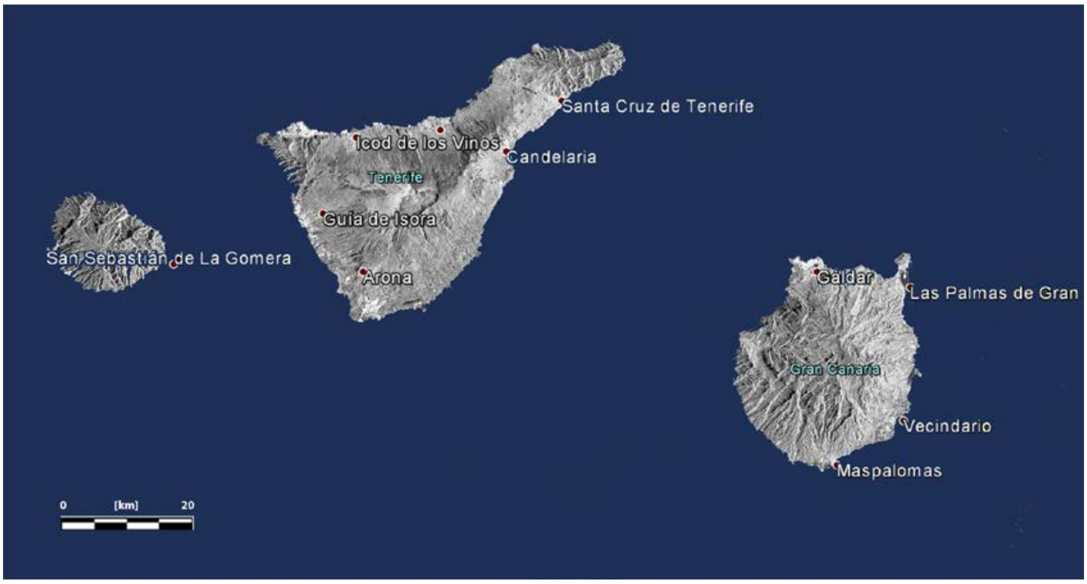

Figure 2-1 Mean amplitude image, geocoded and superimposed to a Google Earth image.

The selected resolution has been the multi-look 2 by 10 that corresponds to a footprint of approximately 28 by 40 m. This resolution is a compromise between the density of measureable points, due to coherence, and a resolution high enough to detect small deformation phenomena.

3 DAM GENERATION

Figure 2-2 shows the flow chart of the procedure used to generate the DAM. First, it is generated the deformation map (velocities and time series) using an approach based in Devanthery et al. 2014[2]. Then, in a second step, the obtained map is filtered in order to remove isolated and noisy points to produce the DAM. A detailed description of the used approach can be found in Barra et al. 2017[3].

The final point selection has been based in two different criteria: (i) the standard deviation (σ) of the residues between the estimated deformation phases and the original interferometric phases, and (ii) a spatial criterion based on the variability of a point with respect its neighbors. The first one has been useful to remove the noisier points in terms of temporal behavior, while the second one has filtered the isolated points. The used threshold for the σ has been ±10 mm. We have selected this relatively high threshold in order to keep the maximum number of measurements. However, as a general statistic, the noise level (σ) of the estimated velocities has been evaluated to be ± 2.3 mm/yr. The number of measured points is 1060750 for the first iteration and 1036328 for the second iteration.

The identification of the active phenomena is done in base of the deformation velocity. The threshold to discriminate between stable or moving point is ±4.7 mm/y (2σ) in both iterations. The total number of points identified as non-stable are 2358 and 1859 for the first and the second iteration respectively. This is less than 1% of the total number of measured points. Figure 2-3 shows an identified active area in Tenerife Island. It is located in the South-East of the island and is a subsidence phenomenon related to the activities of a landfill industry. This area is active in both iterations. The mean velocity of the subsidence in the second iteration is -40.4 mm/yr (red area), while in the first delivery the mean velocity was -41.4 mm/yr. In this sense, there are not significant changes between both iterations.

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2 Devanthéry, M. Crosetto, O. Monserrat, M. Cuevas-González, B. Crippa. An approach to persistent scatterer interferometry. Remote Sens., 6 (7) (2014), pp. 6662–6679.

3 Barra, A., et al. (2017). Geohazard activity map generation based on Sentinel -1 images. Submitted to Remote Sensing.

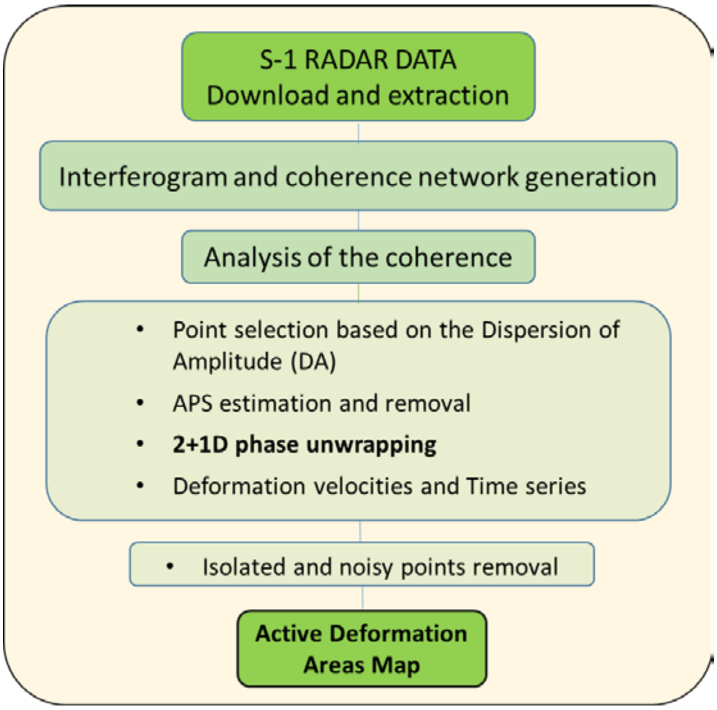

Figure 2-2: flow chart of the approach used to generate the DAM in canary island

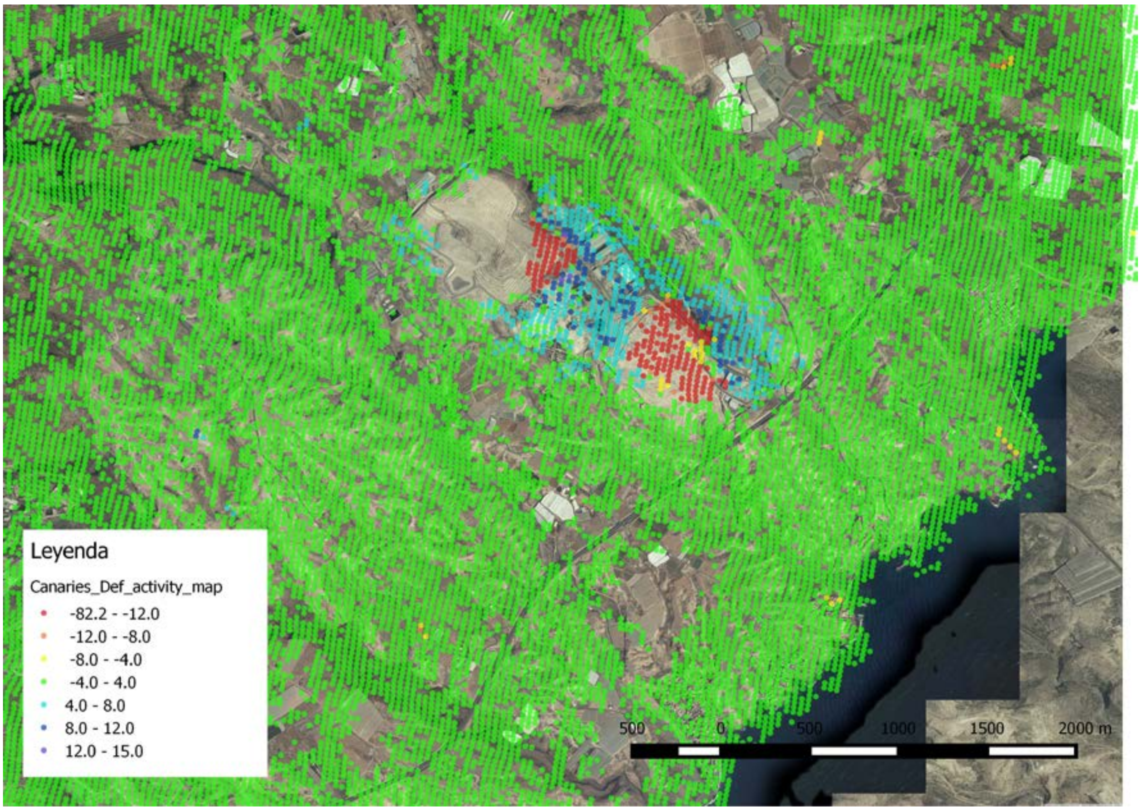

Figure 2-3 Active deformation area located in the South-East of Tenerife.

4 ADA MAP GENERATION

The aim of the Active Deformation Areas (ADA) Map generation is to perform a rapid identification (and monitoring, after the first validation) of the more probable "true deformation zones" (the Active Deformation Areas) over the spatial noise of the velocity data. The final map has to be a clear input to be validated and integrated with other data (e.g. geohazard inventories, ground truth information, etc.) in order to determine the nature of the deformation and thus to generate a Geohazard Activity Map.

The ADA Map has been generated by following a partial implementation of the procedure described in the deliverable D.E3.2[(4)]. Figure 4.1 shows the flow chart of the used implementation. The main input is the DAM map derived from radar data. The PS with absolute velocity (|v|) higher than a stability threshold (2σ) are selected. This threshold is a value representing the general noise of the data. Finally, from this subset of points (PS_m), only those areas with at least 5 PS_m within a fixed distance between themselves are considered ADA.

According to the statistical characteristics of the results, the error (σ) of the velocity measurements is around ±2.3/2.4 mm/yr in both iterations. Hence, the threshold value (2σ) of 4.7 mm/yr is set to distinguish active from stable PS (stability threshold).

Once selected the PS with a deformation velocity greater than 4.7 mm/yr (absolute value), groups of at least 5 neighbour PSs, sharing their influence area, have been aggregated (ADAs). In order to define the influence area of every PS, we consider the multilook used in the processing to select the approximated footprint of a PS. The original resolution of the PS is 14 by 4 m. The applied multilook is 2 by 10 and yields an approximate PS area of 28 by 40 m. We calculate the radius of the circle inscribing a 40 by 40 m area where the PS is located and we multiply it by a factor of 1.5 to ensure that neighbouring pixels are selected.

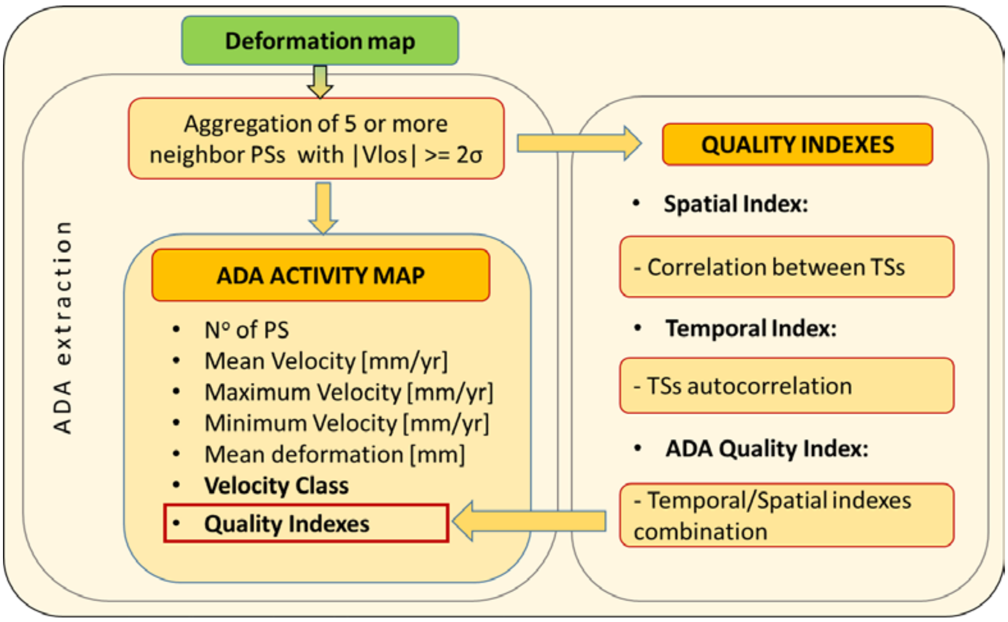

Figure 4-1: Flow chart of the methodology to identify the ADA. The green indicates the input data, the light orange indicates the procedure steps, while the dark orange the outputs of the methodology.

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

If the grouped PS are less than 5, they are considered to be a not significant deformation for a regional scale analysis. Then, the ADA are classified using the maximum velocity (V_m) as follow:

- *Class 1*: $| V_m | > 1$ cm/yr.
- *Class 2*: $2\sigma < | V_m | \leq 1$ cm/yr

Finally, for each ADA we have implemented a Quality index in order to evaluate its reliability. This QI is based on the temporal and spatial consistency of the PSs included in the ADA. The QI is a four classes index where: class 4 is a not reliable ADA; class 3 is a reliable ADA but TS cannot be exploited, class 2 is a reliable ADA but each TS need analysis and class 1 is reliable ADA and TS. A detailed description of the algorithm is found in Barra et al. 2017[(5)]. The figure 4-2 shows a zoom of the derived deformation activity map (a) and ADA map (b) on the area of Teide peak. Figure 4-2 (c) shows three examples of time series corresponding to different ADAs and to a stable point. Finally, figure 4-2 (d) shows the used color scale in (a) and (b).

The number of detected ADAs are 72 and 120 for the first and the second iterations respectively. Regarding the distribution of the ADAs, for the first iteration, 69 of 72 are in Tenerife Island and the other 3 in Gran Canaria. For the second iteration, 112 are in Tenerife, 7 in Gran Canaria and 1 in Gomera. Table 4-1 summarizes the comparison between the two iterations. The total number of detected ADAs is 192: 68 of them have QI 1 from which 43 are present in both iterations and 25 only in one of them. Looking at the opposite, the total number of ADA with QI equal to 4 are 69, but in this case, 62 of them have no intersection between first and second iteration. This fact can be considered as an indicator of the significance of the QI information.

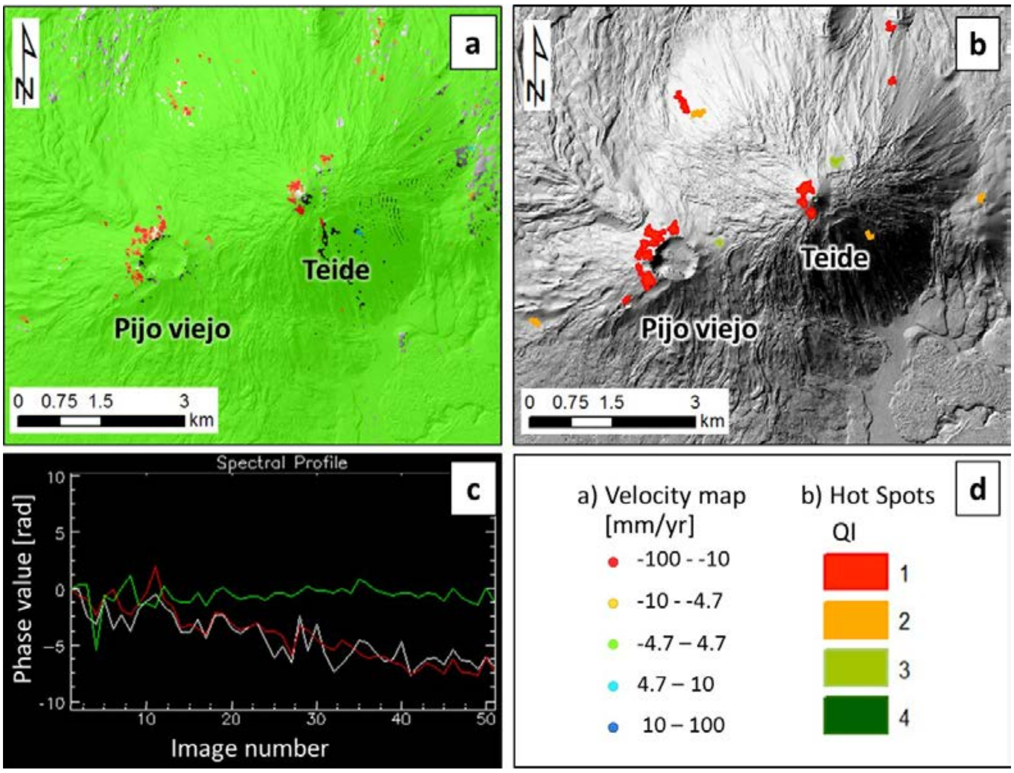

Figure 4-2: (a) deformation velocity of the first iteration in the Teide caldera area. (b) ADAs detected in the Teide caldera in the first iteration. (c) Examples of deformation time series (TS) of 3 PS located in the same area: 2 PS follow in an active area (active PS) while 1 (the green TS) in a stable area (stable PS). (d) Colour scales for (a) and (b) maps.

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5 Barra, A., et al. (2017). Geohazard activity map generation based on Sentinel -1 images. Submitted to Remote Sensing.

	No.			% OF THE TOTAL AREAS			QI RELATIVE %	
QI CLASS	TOT	INTERS	NO INTERS	TOT	INTERS	NO INTERS	INTERS	NO INTERS
1	68	43	25	35%	22%	13%	63%	37%
2	32	10	22	17%	5%	11%	31%	69%
3	23	6	17	12%	3%	9%	26%	74%
4	69	7	62	36%	4%	32%	10%	90%
TOT	**192**	66	126	100%	34%	66%	34%	66%

Table 4-1: Results of the comparison between first and second iteration.

5 DELIVERED PRODUCTS AND PRODUCT DESCRIPTION

The delivered maps consist in:

- 00_DC2.3_DAM_shapefiles_Canary_Island: folder containing the shape files of the first and second iterations of the DAM. To visualize the DAM is recommended to use the Velocity field and the scale shown in figure 4.2(a).
- 01_DC2.3_ADA_shapefiles_Canary_Island: folder containing the shape files of the first and second iteration of the ADA maps. The ADA map can be visualized in two different ways. First, using the Class field (see Table 5-2) in order to automatically identify the most active areas and then using the QI field in order to assess the reliability.
- Safety_deliverable_DC2.3_ADA_Gran_Canaria_ite[X].pdf: Gran Canaria active deformation areas (first and second iteration) following the user requirement format (see deliverable DB1[6] and DB2.2[7]).
- Safety_deliverable_DC2.3_ADA_LaGomera_ite[X].pdf: La Gomera active deformation areas (first and second iteration) following the user requirement format (see deliverable DB1 and DB2.2).
- Safety_deliverable_DC2.3_ADA_Tenerife_ite[X].pdf: Tenerife active deformation areas (first and second iteration) following the user requirement format (see deliverable DB1 and DB2.2).

The delivered DAM consists in a shape file of points with the following attribute fields:

Field	Description	Units
Fi	WGS84 Geographic Latitude	[º]
Lambda	WGS84 Geographic Longitude	[º]
E	WGS84 UTM zone 32N - East	[m]
N	WGS84 UTM zone 32N - North	[m]
H	SRTM Height	[m]
Velocity	Point displacement velocity	[mm/yr]
Acc_defo_4	Accumulated deformation (mean of the las 4 images)	[mm]
Daaaa/mm/dd	Deformation value at the date aaaa/mm/dd	[mm]

Table 5-1 Description of the fields of the final deformation activity map shape file.

6 Deliverable DB1: User needs and requirements.
7 Deliverable DB2.2. Technical Note. User assessment – Preliminary results.

The delivered ADA Maps consist in a shape file of polygons. The attribute fields of the shape files are:

Field	Description	Units
Join_Count	Number of unstable points (velocity higher than 4.7 mm/yr) grouped in the hotspot	-
Fi	WGS84 Geographic Latitude (average of the grouped PSs)	[º]
Lambda	WGS84 Geographic Longitude (average of the grouped PSs)	[º]
E	WGS84 UTM zone 32N - East (average of the grouped PSs)	[m]
N	WGS84 UTM zone 32N - North (average of the grouped PSs)	[m]
H	SRTM Height (average of the grouped PSs)	[m]
Acc_defo_4	Accumulated deformation (mean of the last 4 images) (average of the grouped PSs)	[mm]
Velocity_mean	Mean velocity of the hotspot (average of displacement velocities of the grouped PSs, in terms of absolute value)	[mm/yr]
Velo_max	Maximum velocity of the PSs grouped in the hotspot (in terms of absolute value)	[mm/yr]
Velo_min	Minimum velocity of the PSs grouped in the hotspot (in terms of absolute value)	[mm/yr]
QI	Quality index of the ADA : Class 4 = ADA not reliable Class 3 = Reliable ADA but TS cannot be exploited Class 2 = Reliable ADA but each TS need analysis Class 1 = Reliable ADA and TS	-
Class	Classification of the hotspots based on the Velo_max: Class = 1 if Velo_max ≥10 mm/yr. Class = 2 if Velo_max < 10 mm/yr.	-

Table 5-2: Description of the fields of the final ADA maps (shape file).

6 OBSERVATIONS

- The deformations are in **Line of Sight**, i.e. they represent the projection of the real 3D displacement in the direction "satellite-point".
- The negative values represent points that are moving far from the satellite (i.e. subsidence in case of vertical displacements). The negative ones represent those that are moving towards the satellite.
- This last delivery has been useful to evaluate the performances of the proposed approach.
- For future iterations is recommended to move the temporal window of 6 months and apply again the procedure.