Safety

Grant Agreement No. 718679
Safety – Sentinel for geohazard prevention and forecasting

Deliverable C2.6 Southern Tuscany (Volterra area) deformation activity map V2

A deliverable of

Task C: Sentinel-1 software development and data processing

Due date of deliverable: 30/06/2017
Actual submission date: 17/07/2017

Lead contractor for this deliverable: CTTC
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 map (V2) over the municipality of Volterra (Italy): the Deformation Activity Map, including the Time Series information for each measured Persistent Scatterer, and the Hotspots Activity 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.C2.4 (V0)	Southern Tuscany (Volterra area) deformation activity map V0
D.C2.5 (V1)	Southern Tuscany (Volterra area) deformation activity map V1

CONTRIBUTORS

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REVIEW: CORE TEAM

Reviewed by	Company	Date	Signature
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1 INTRODUCTION

The aim of this document is to discuss the technical aspects of the two final delivered deformation activity maps (DAM) of the Volterra municipality test site: The Deformation Activity Map, with the estimated velocity for each PS (Persistent Scatterer), and the derived HotSpots Activity Map or here below referred as Active Deformation Areas (ADA) map. Compared with the previous deliverables (D.C2.4 and D.C2.5), we have reprocessed the data by using only two periods with longer temporal windows. This has allowed us to improve the quality of the results but without improving the spatial sampling density. Moreover, we have decided not to include the deformation time series in the final DAM. The main reason is that the monitored periods for both iterations (around 1.5 year) are too short taking into account the deformation magnitudes. The deformation time series sensitivity is below the deformation magnitude and thus they are not informative.

It is worth to underline that at this step the DAM includes all the typologies of surface deformation. This includes the anthropic ones, like for example those caused by construction or mining, which are usually not included in a Geohazard Activity Map.

The data processing to obtain the Deformation Activity Map has been done by using the software tools developed and owned by the CTTC. The applied approach is different than the used in Canary Island. The main reason is the coherence that is significantly lower. The used procedure includes two main steps. The first one consists in the calculation of the stack of interferogram and coherences, and the second one consists in the generation of the DAM. The procedure has been applied to two independent datasets acquired in ascending and descending trajectory. This allowed to provide more reliable results in the intersection areas and to improve the coverage. The Figure 1-1, show an example of the obtained results: it corresponds to the deformation velocities obtained with the descending dataset in both the first and the second iteration.

The final delivery consists in the two following products: (i) first and second iteration of the DAM without time series for both ascending and descending datasets; and (ii) first and second iteration of the ADA maps also for both ascending and descending datasets. A total of 8 shapefiles (4 punctual of DAM and 4 polygonal of ADA) and 4 pdf maps of the ADA are delivered. It is worth noting that the Quality Index has not been calculated due to the lack of time series information. The ADA maps will be the main input, in terms of radar information, for the generation of the Geohazard Activity Maps.

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 maps; section 5 describes the delivered maps and Section 6 underlines particular aspects of the results.

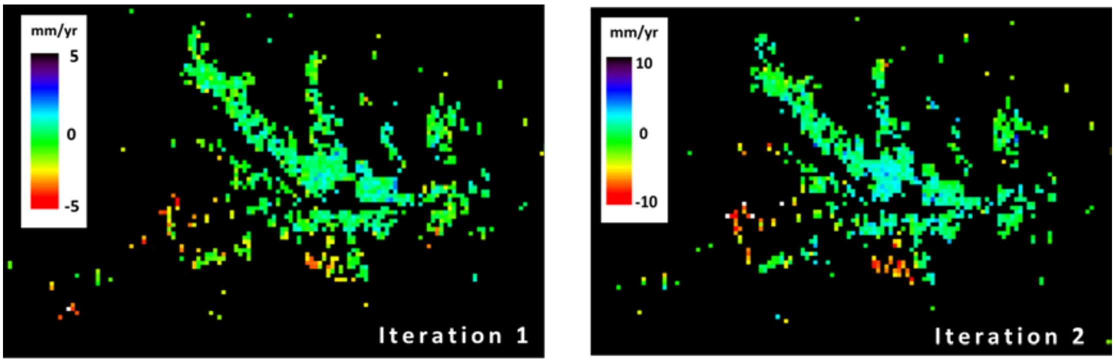

Figure 1-1: Overview of the measured points in both iterations of the descending dataset.

2 DATASET DESCRIPTION

Two datasets, from both ascending and descending orbits, of Sentinel-1 (A and B) Wide Swath images have been processed. The ascending dataset consists of 70 images spanning from 3rd February 2015 to 10th February 2017 (See Table 2-1); the descending dataset consists of 71 images spanning from 12th October 2014 to 10th February 2017 (Table 2-2).

The main characteristics of the used images are summarized in Table 2-3. To process the interferometric products, we have used the 10-m cell resolution Digital Elevation Model (DEM) provided by the cartographic database (TINITALY/01, Tarquini et al., 2007, 2012[1]) of the National Institute of Geophysics and Volcanology (INGV).

Nº image	Date	Nº image	Date	Nº image	Date
1	03/02/2015	25	18/11/2015	49	07/10/2016
2	15/02/2015	26	30/11/2015	50	13/10/2016
3	27/02/2015	27	12/12/2015	51	19/10/2016
4	11/03/2015	28	24/12/2015	52	25/10/2016
5	23/03/2015	29	17/01/2016	53	31/10/2016
6	04/04/2015	30	29/01/2016	54	06/11/2016
7	16/04/2015	31	10/02/2016	55	12/11/2016
8	28/04/2015	32	05/03/2016	56	18/11/2016
9	10/05/2015	33	17/03/2016	57	24/11/2016
10	22/05/2015	34	29/03/2016	58	30/11/2016
11	03/06/2015	35	10/04/2016	59	06/12/2016
12	15/06/2015	36	22/04/2016	60	12/12/2016
13	27/06/2015	37	04/05/2016	61	18/12/2016
14	09/07/2015	38	16/05/2016	62	24/12/2016
15	21/07/2015	39	28/05/2016	63	30/12/2016
16	02/08/2015	40	09/06/2016	64	05/01/2017
17	14/08/2015	41	03/07/2016	65	11/01/2017
18	26/08/2015	42	15/07/2016	66	17/01/2017
19	07/09/2015	43	27/07/2016	67	23/01/2017
20	19/09/2015	44	08/08/2016	68	29/01/2017
21	01/10/2015	45	20/08/2016	69	04/02/2017
22	13/10/2015	46	01/09/2016	70	10/02/2017
23	25/10/2015	47	13/09/2016		
24	06/11/2015	48	25/09/2016		

Table 2-1 Dates of the 70 processed Sentinel-1 ascending geometry images. In red is highlighted the date of the super-master image. In green the images used for the first delivery.

[1] Tarquini, S., Vinci, S., Favalli, M., Doumaz, F., Fornaciai, A., Nannipieri, L. (2012). Release of a 10-m-resolution DEM for the Italian territory: Comparison with global-coverage DEMs and anaglyph-mode exploration via the web. Computers & Geosciences, 38(1), 168-170.

Nº image	Date	Nº image	Date	Nº image	Date
1	12/10/2014	25	24/11/2015	49	19/09/2016
2	24/10/2014	26	06/12/2015	50	01/10/2016
3	17/11/2014	27	18/12/2015	51	13/10/2016
4	29/11/2014	28	30/12/2015	52	20/08/2016
5	23/12/2014	29	11/01/2016	53	07/10/2016
6	04/01/2015	30	23/01/2016	54	19/10/2016
7	28/01/2015	31	04/02/2016	55	25/10/2016
8	09/02/2015	32	16/02/2016	56	31/10/2016
9	21/02/2015	33	28/02/2016	57	06/11/2016
10	05/03/2015	34	11/03/2016	58	12/11/2016
11	17/03/2015	35	23/03/2016	59	18/11/2016
12	29/03/2015	36	04/04/2016	60	24/11/2016
13	10/04/2015	37	16/04/2016	61	30/11/2016
14	22/04/2015	38	28/04/2016	62	06/12/2016
15	04/05/2015	39	10/05/2016	63	18/12/2016
16	16/05/2015	40	22/05/2016	64	24/12/2016
17	09/06/2015	41	03/06/2016	65	30/12/2016
18	03/07/2015	42	15/06/2016	66	05/01/2017
19	15/07/2015	43	09/07/2016	67	11/01/2017
20	08/08/2015	44	21/07/2016	68	23/01/2017
21	20/08/2015	45	02/08/2016	69	29/01/2017
22	01/09/2015	46	14/08/2016	70	04/02/2017
23	13/09/2015	47	26/08/2016	71	10/02/2017
24	12/11/2015	48	07/09/2016		

Table 2-2 Dates of the 51 processed Sentinel-1 descending geometry images. In red is highlighted the date of the super-master image. This dataset was not used in the first delivery.

Satellites	Sentinel-1A, Sentinel-1B
Acquisition mode	Wide Swath
Period	October 2014 - February 2017
Minimum revisit period [days]	6
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
Relative orbits	Ascending: 15, Descending: 95
Incidence angle of the area of interest	36.47º - 41.85º

Table 2-3 Main characteristics of the processed data.

3 DAM : DEFORMATION ACTIVITY MAP

As shown in the previous deliveries (V0[2] and V1[3]), the obtained results over the Volterra test site have a significant lower sampling density compared to the Canary Island dataset. The main reasons for this is the land cover. For this delivery we have processed two iterations for each trajectory in order to derive the final maps and to simulate the map updating with a sufficiently good datasets (tables 2-1 and 2-2). The first iteration of the ascending dataset starts the 3rd of February 2015 and ends the 20th of August 2016. The second iteration covers from the 2nd of August 2015 to the 10th of February 2017. For the descending dataset, the first iteration starts the 12th of October of 2014 and ends the 16th of April 2016 while the second iteration ranges from the 8th of August 2015 to the 10th of February 2017. In particular, the descending dataset is longer and allowed both to use only six months of intersection between the two iterations and to keep good temporal windows.

The applied processing approach is based in Crosetto et al. 2011[4]. This approach has been used to get more robust results compared to V0. However, this approach presents two main constrains: (i) the deformation model is linear and (ii) the sampling density is drastically reduced with respect to the approach used in V0. As planned, we have also calculated the deformation time series. However, they have not been delivered because the magnitude of the accumulated deformation during the monitored periods are below the sensitivity of the technique.

The ascending and descending datasets have been processed independently. For each dataset, the final selection of the points consisted in selecting only those with temporal coherence higher than 0.6. With this threshold, the estimated standard deviation (σ) of the velocities is approximately 1.5 mm/yr, which is sensibly lower than the one obtained in the first delivery (V0). The final result has not improved the sampling density with respect the V1 version. The main reason is that the land cover of the area results in a very low coherence from the interferometric point of view.

The total number of points for the ascending trajectory is 788 and 1266 for the first and the second iteration respectively. Most of them are located in urban areas. The noise level of the deformation measurements has been estimated to be ±3 mm/yr (2σ). Regarding the descending dataset, the total number of point is 1492 and 1154 respectively for the first and the second iteration. The estimated noise level is also 3 mm/yr. Thus, 3 mm/yr is the threshold to discriminate between active and stable points (PS).

The main active areas are located in the south- west border of the Volterra town. Figure 3-1 and Figure 3-2 show the first iteration of the deformation velocity maps of this area in ascending and descending acquisition geometry. It can be observed that the measured line-of-sight deformation presents opposite sign for the ascending and the descending results. This suggests that the observed phenomena are landslide processes. Moreover, it can be observed that the deformation shape and magnitude differs from both results. This fact can be explained by two main reasons. The monitored periods are different (more or less 5 months of shift) and the geometry is also different.

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[2] D.C2.4 Southern Tuscany (Volterra area) deformation activity map V0, Deliverable of the SAFETY Project.

[3] D.C2.5 Southern Tuscany (Volterra area) deformation activity map V1, Deliverable of the SAFETY Project.

[4] Crosetto, M., Monserrat, O., Cuevas, M., & Crippa, B. (2011). Spaceborne differential SAR interferometry: Data analysis tools for deformation measurement. Remote Sensing, 3(2), 305-318.

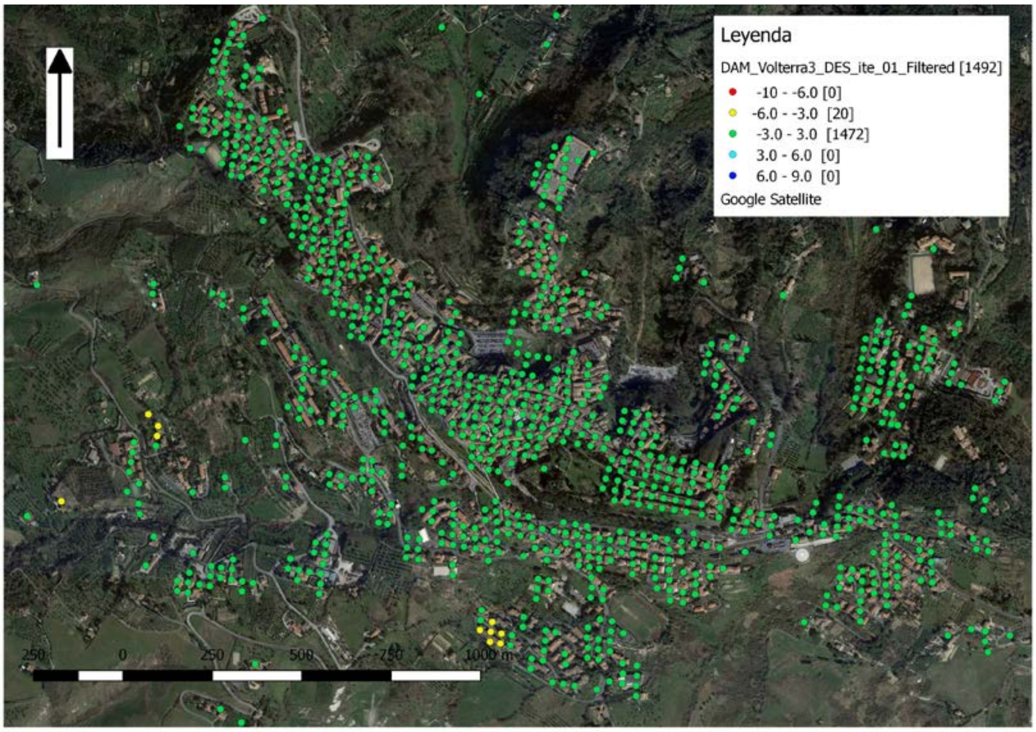

Figure 3-1: Deformation velocities of the Volterra town obtained from the descending dataset.

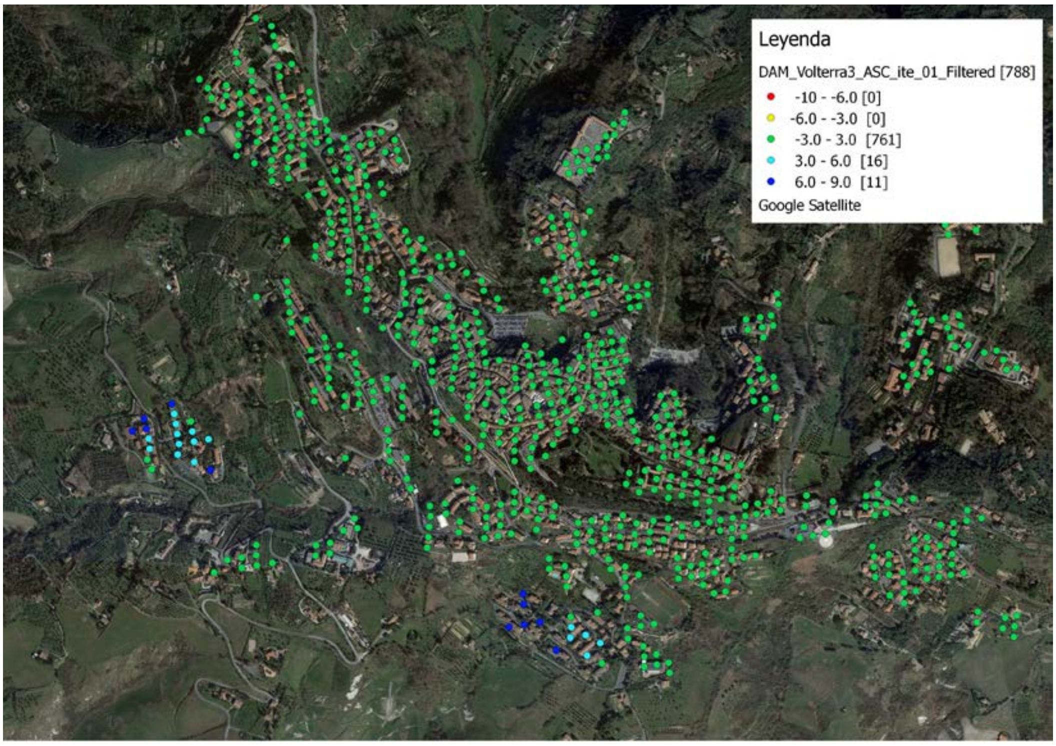

Figure 3-2: Deformation velocities of the Volterra town obtained from the ascending dataset.

4 ADA MAP: ACTIVE DEFORMATION AREAS MAP

The aim of the ADA Map generation is to perform a rapid identification (and monitoring, after a first validation) of the more probable “true deformation zones” (the ADAs) over the spatial noise of the velocity data. The final map has to represent 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 the Geohazard Activity Map.

The ADA map has been generated by following a partial implementation of the procedure described in the deliverable D.E3.2[5]. Figure 4.1 shows the flow chart of the used procedure. The main input is the deformation velocity map derived from radar data. The PSs 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 radius are considered ADA.

According to the statistical characteristics of the results, the error (σ) of the velocity measurements is around ±1.5 mm/yr (note that in the first iteration the error was ±10 mm, in terms of accumulated deformation). Hence, the threshold value of 3 mm/yr is set to distinguish active from stable PS (stability threshold) for the Volterra Municipality.

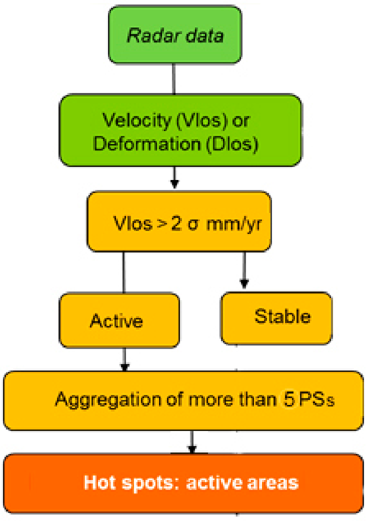

Figure 4-1: Flow chart of the methodology to identify the HotSpots. The green indicates the input data, the light orange indicates the procedure steps, while the dark orange the output of the methodology.

Once selected the PSs with a deformation velocity greater than 3 mm/yr (absolute value), groups of at least 5 neighbour PSs, sharing their influence area, have been aggregated. In order to define the influence area of every PS we consider the multilook used in the processing to select the approximated footprint of the PSs. The original resolution of the PSs 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

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

the circle inscribed in a 40m by 40 m area, around the PS is location and we multiply it by a factor of 1.3 to ensure that neighbouring pixels are selected. If the grouped PSs are less than 5 they are considered to represent a non-significant deformation for a regional scale analysis. Moreover, the isolated active PSs (groups of 1 or 2 PSs) are considered outliers (noise) and have been removed. Finally, the ADA are classified by the maximum velocity (V_{max}) as follow:

- *Class 1*: | V_{max} | > 1 cm.
- *Class 2*: 2 σ < | V_{max} | ≤ 1 cm

In Figure 4-2 are shown the identified ADA for the different dataset and periods. It may be observed that there are noticeable differences between the different iterations. This differences can be explained by the fact that the minimum number of aggregated points must be 5. Some of the areas identified as ADA in one iteration are lost by the fact that the number of aggregated points decreases from 5 to 4. Even this can be a limitation of the proposed approach, it is worth underlining that together with the ADA map is delivered the DAM map that contain all the measured points. In this context, it can be helpful to check the DAM map in the detected ADAs in order to assess the potential affected area. Moreover, taking into account the observed movement it could be useful to extend the monitoring periods of each iteration in order to exploit also the time series information. This has not been possible during the project development due to the lack of temporal period.

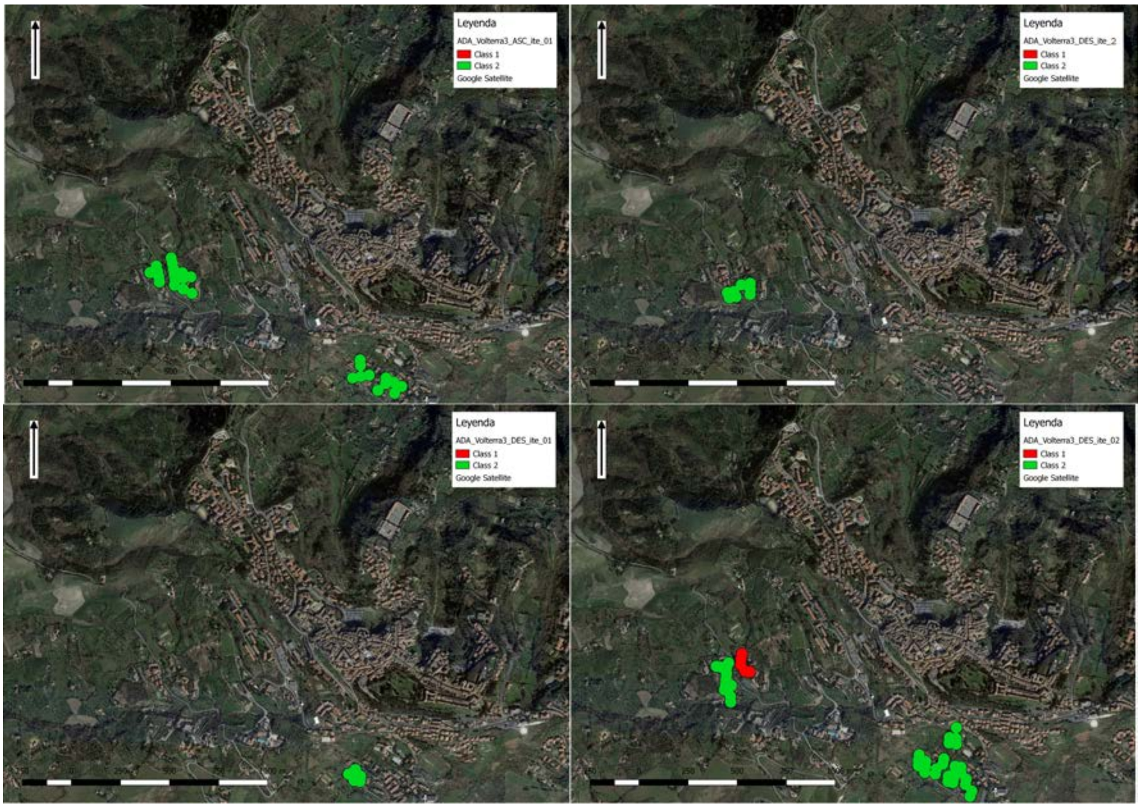

Figure 4-2: Identified ADA in the Volterra municipality for the Ascending dataset (up) and the descending dataset (down).

5 MAP DESCRIPTION

The delivered maps consist in:

- 00_DC2.6_DAM_shapefiles_Volterra: 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 3-1 and 3-2.
- 01_DC2.6_ADA_shapefiles_Volterra: 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 (Table 5-2 or Figure 4-2) in order to assess the reliability.
- Safety_deliverable_DC2.6_ADA_Volterra_ASC_ite[X].pdf: Volterra active deformation areas (first and second iteration) for the ascending dataset and following the user requirement format (see deliverable DB1[(6)] and DB2.2[(7)]).
- Safety_deliverable_DC2.6_ADA_Volterra_DESC_ite[X].pdf: Volterra active deformation areas (first and second iteration) for the descending dataset and following the user requirement format (see deliverable DB1 and DB2.2).

The delivered Deformation Activity Map consists in a shapefile 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]

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

The delivered ADA Map consists in a shapefile of polygons with the attribute fields:

Field	Description	Units
ID	Identification Number of the hotspot	-
Join_Count	Number of unstable points (velocity higher than 3 mm/yr) grouped in the hotspot	-
Row	Radar image line	-
Col	Radar image column	-
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]

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

Velo_min	Minimum velocity of the PSs grouped in the hotspot (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]
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.	-
Velocity_mean	Mean velocity of the hotspot (average of displacement velocities of the grouped PSs)	[mm/yr]

Table 5-2: Description of the fields of the final HotSpot Activity map shape file.

6 OBSERVATIONS

- The total number of points for the ascending trajectory is 788 for the first and 1266 for the second iteration. Regarding the descending dataset, the total number of point is 1492 for the first iteration and 1154 for the second iteration.
- The deformations are in **Line-of-Sight**, i.e. they represent the projection of the real 3D displacement in the “satellite-point” direction.
- 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.
- The deformation shape and magnitude is slightly different between ascending and descending processing. This fact can be explained by two main reasons. The monitored periods are different (more or less 5 months of shift) and the geometry is also different.
- It may be observed that there are noticeable differences between the different iterations. This differences can be explained by the fact that the minimum number of aggregated points must be 5. Some of the areas identified as ADAs in one iteration are lost by the fact that the number of aggregated points decreases from 5 to 4. Nevertheless, the presence/absence of an ADA can be also caused by a change of the magnitude of the estimated movements between the two temporal windows. In this case, in order to monitor a known area, it is suggested a more local study, with a case-specific procedure setting (different thresholds).