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

Deliverable C2.4 Southern Tuscany (Volterra area) deformation activity map V1

A deliverable of

Task C: Sentinel-1 software development and data processing

Due date of deliverable: 31/12/2016
Actual submission date: 10/01/2017

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

Table of Content

EXECUTIVE SUMMARY

This document describes the technical aspects of the delivered deformation activity map (V1) 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

CONTRIBUTORS

Contributor(s)	Company	Contributor(s)	Company
Anna Barra	CTTC		
Oriol Monserrat	CTTC		

REVIEW: CORE TEAM

Reviewed by	Company	Date	Signature
Michele Crosetto	CTTC	03/01/2017	

1 INTRODUCTION

The aim of this document is discussing the technical aspects of the two delivered deformation activity maps (version 1) of the Volterra municipality test site: the Deformation Activity Map, including the Time Series (TS) information for each PS (Persistent Scatterer), and the derived HotSpots Activity Map. Compared with the first iteration (version 0), we have used a different approach that has allowed us to improve the quality of the results, at the expense of losing spatial sampling density.

It is worth to underline that at this step the deformation activity map 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 used procedure includes two main steps. The first one consists in the calculation of the stack of interferograms and coherences, and the second one consists in the generation of the deformation maps. The above mentioned change of the type of analysis has been decided in base of the non-positive results obtained for the first version of this delivery. As shown in Figure 1-1, the new procedure results in a rather low spatial density of PSs, but it ensures a more reliable and robust result.

In this iteration, we deliver two different levels of deformation activity maps: (i) a Deformation Activity Map containing all the measured points; and (ii) the HotSpots Activity Map derived by analyzing the velocity data in a Geographic Information System (GIS) environment as described in D.3.2[1]. The HotSpot activity map will be the main input, in terms of radar information, for the generation of the Geohazard Activity Maps.

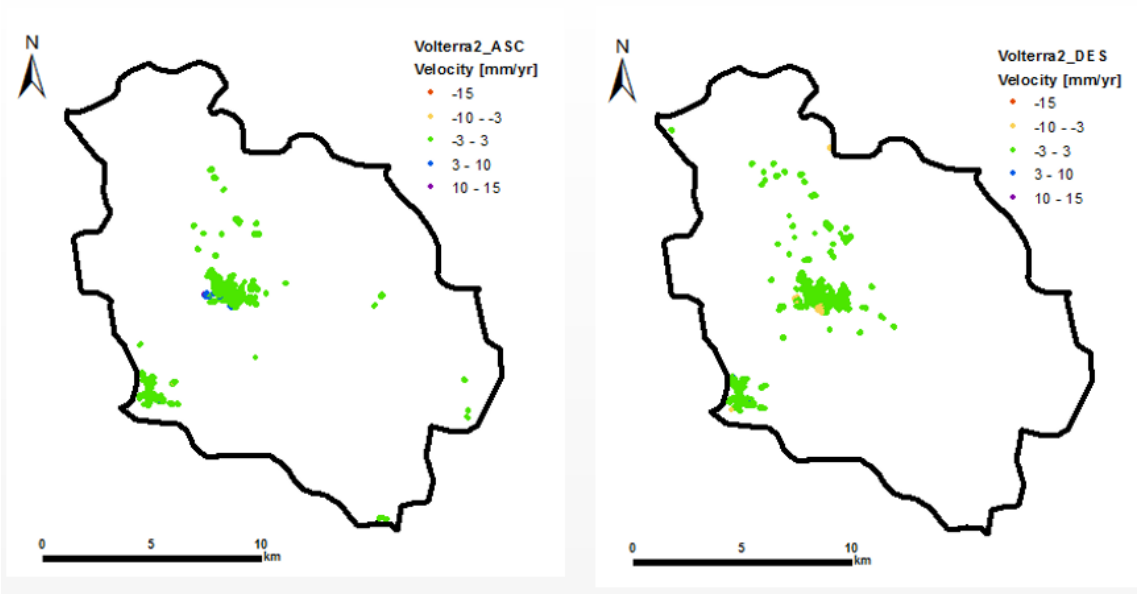

Figure 1-1: Overview of the measured points in both ascending and descending trajectories.

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

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

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 50 images spanning from 3rd February 2015 to 7th October 2016 (See Table 2-1); the descending dataset consists of 51 images spanning from 12th October 2014 to 01st October 2016 (Table 2-2). The ascending dataset includes only one image from Sentinel-1B satellite, while in the descending dataset there are 2 images from Sentinel-1B. Thus, the shorter temporal baseline is 6 days, but most of the temporal baselines are of 12 days.

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[2]) of the National Institute of Geophysics and Volcanology (INGV).

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

Table 2-1 Dates of the 49 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.

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

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 - October 2016
Minimum revisit period [days]	6
Wavelength (□) [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 DEFORMATION ACTIVITY MAP

As shown in the previous delivery (V0[3]), the obtained results over the Volterra test site were not satisfactory. The main reasons for this were the lack of coherence and the short analyzed period. For this delivery (V1) the period of the V0 has been extended, covering a period of 20 months. Moreover, also the descending trajectory has been processed covering a period of two years.

The longer dataset has allowed us applying a different processing approach (Crosetto et al. 2011[4]), in order to get more robust results. However, this approach presents two main constrains: (i) the deformation model is linear and (ii) the sampling density is drastically reduced with respect the approach used in V0. In the final delivery (D.C2.4 V2) is planned to test a new approach in order to improve the sampling density and to include the strong non-linear deformation processes.

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 0.5. 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. However, as shown in Fig. 1-1, the sampling density has reduced drastically. The main reason of this reduction is that we have used longer temporal baselines and thus the number of non-coherent observations increases drastically.

The total number of points for the ascending trajectory is 1309. 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 1837 and the estimated noise level is 3 mm/yr. 3 mm/yr is the threshold to discriminate between active and stable areas.

The main active areas are located in the west and south parts of Volterra town. Figure 3-1 and Figure 3-2 show the deformation velocity maps of this area in ascending and descending acquisition geometry. One may observe 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.

[3] D.C2.4 Southern Tuscany (Volterra area) deformation activity map V0, 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.

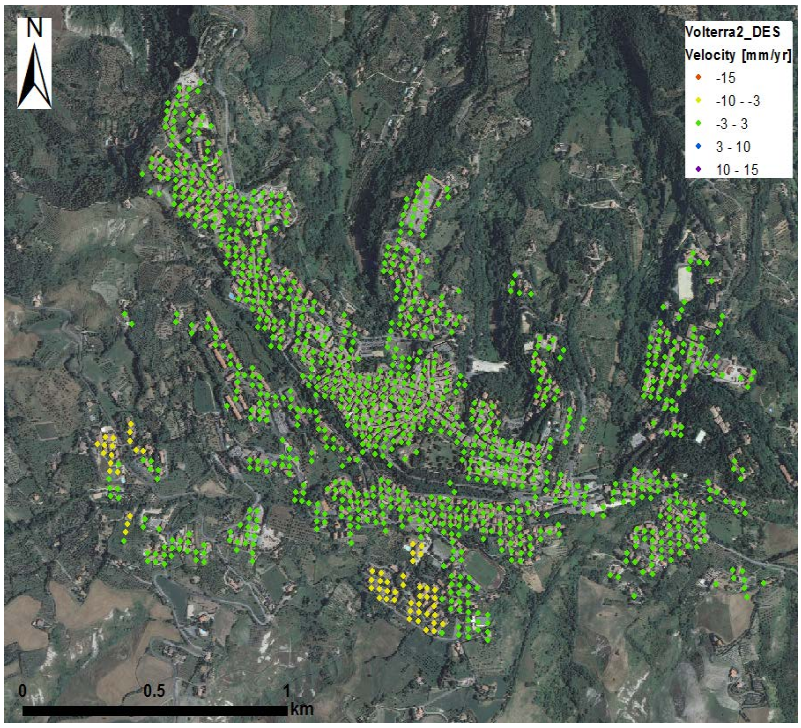

Figure 3-1: Deformation velocity of the Volterra town obtained from the descending dataset.

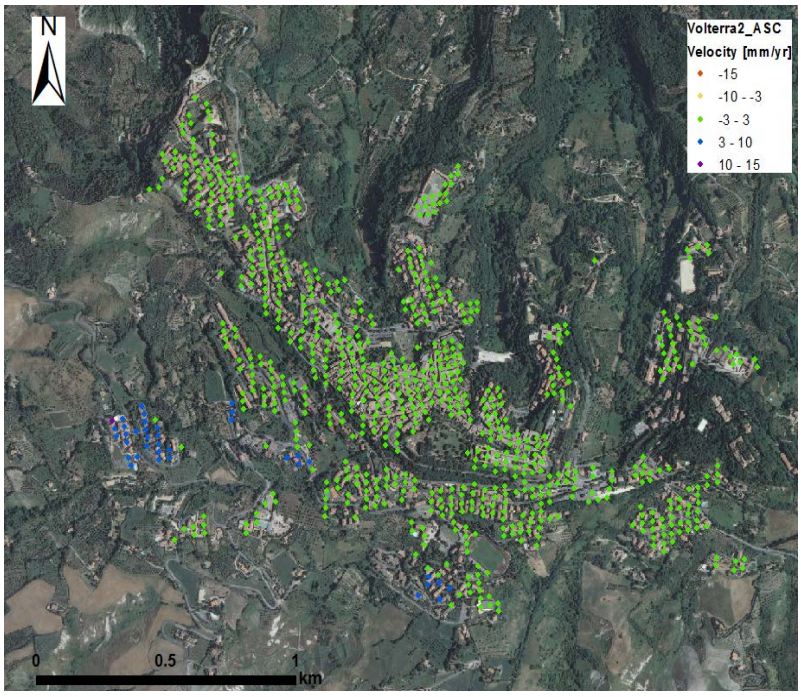

Figure 3-2: Deformation velocity of the Volterra town obtained from the ascending dataset.

4 HOTSPOTS ACTIVITY MAP

The aim of the HotSpot Map generation is to perform a rapid identification (and monitoring, after a first validation) of the more probable “true deformation zones” (the HotSpots) 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 HotSpot 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 implementation. 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 HotSpots.

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). Hence, the threshold value of 3 mm/yr is set to distinguish active from stable PS (stability threshold) for the Volterra Municipality.

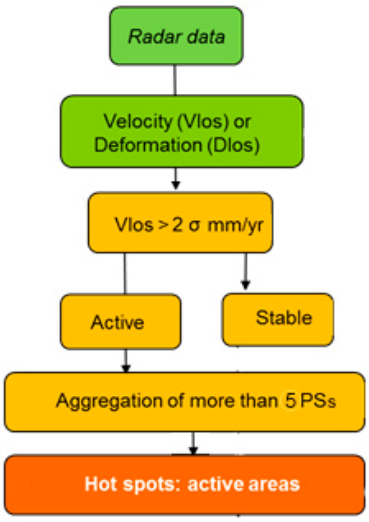

Figure 4-1: Flow chart of the methodology to identify the HotSpots. The green indicates the input data, the light orange indicates the procedure steps, while the dark orange the output of the methodology.

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 inscribing a 40 by 40 m area where the PS is located 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 HotSpots are classified by the maximum velocity (V_m) as follow:

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

In the Volterra municipality test-site, 5 hotspots with the descending processing and 2 hotspots with the ascending one have been identified (Figure 4-2).

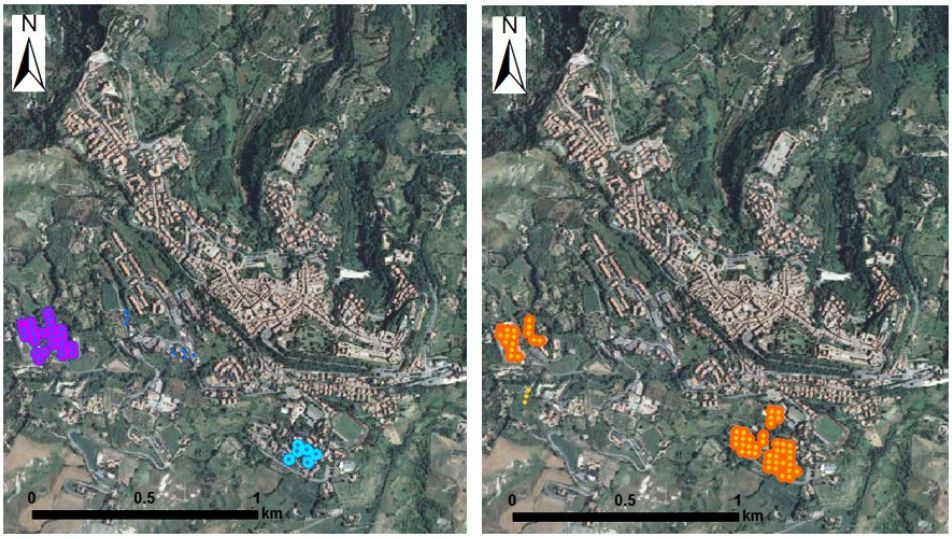

Figure 4-2: Identified HotSpots in the Volterra municipality for the Ascending datase (left) and the descending dataset (right).

5 MAP DESCRIPTION

The delivered Deformation Activity Map consists in a shapefile of points with the following attribute fields:

Field	Description	Units
ID	Name of the point	-
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]
Velocity	Point displacement velocity	[mm/yr]
S0	Sigma zero of the residuals of the velocity estimation	[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.

The delivered HotSpots Activity Maps consist in two shapefiles of polygons:

- D.C2.4_Southern_Tuscany(Volterra area)_HotSpots_ASC_GT3mmyr: it contains the HotSpots with a velocity greater than 3 mm/yr
- D.C2.4_Southern_Tuscany(Volterra area)_HotSpots_DESC_LT-3mmyr: it contains the HotSpots with a velocity lower than -3 mm/yr

The attribute fields of the shapefiles are:

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]
Velocity_mean	Mean velocity of the hotspot (average of displacement velocities of the grouped PSs)	[mm/yr]
Sigma0_mean	Mean sigma zero of the residuals of velocity estimation of the hotspot (average of the Sigma0s of the grouped PSs)	[mm]
Daaaa/mm/dd	Mean cumulated deformation of the hotspot at the last date of the dataset (aaaa/mm/dd)	[mm]
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]
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 HotSpot Activity map shape file.

6 OBSERVATIONS

- The total number of points is 1837 for the descending dataset and 1309 for the ascending one.
- 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.
- Compared with the first delivery we have an improvement on the deformation measurements, but a critical reduction of the sampling density. For the last delivery of the project is expected to reprocess the three iterations by improving this aspect.

- We still have a lack of a quality index for each hotspot. We plan to implement it during the last period of the project and provide it in the last deliverable.