Biennial report for Permanent Supersite/Natural Laboratory

Vesuvius - Campi Flegrei Supersite

History	**http://geo-gsnl.org/supersites/permanent-supersites/vesuvius-campi-flegrei-supersite/**
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Abstract

Although the three years EC FP-7 MED-SUV project, providing both scientific and financial support to the Supersite activities, ended in May 2016, satellite data are still exploited by the members of the Supersite science teams, thus demonstrating the interest of the scientific community in this active volcanic area.
The aims of these studies by the Supersite science teams are:

- research, by taking part into international research projects/activities and
- monitoring, focused on the *near-real time* surveillance of the volcanoes belonging to the Neapolitan Volcanic District (Vesuvius, Campi Flegrei and the Island of Ischia) for benefit of the local and national Civil Protection agencies.

Such monitoring was mainly focused on Campi Flegrei (CF), currently at the *attention* (yellow) level according to the CF Emergency Plan issued by the Italian Civil Protection Department, and the Island of Ischia, where a 3.9 magnitude earthquake occurred on August 21th, 2017.
Moreover, during the 2016-2018 biennium of the Supersite initiative, the improvement and fine-tuning of the MED-SUV infrastructure (http://medsuv_portal.ct.ingv.it/) continued, conceived for data dissemination within the scientific community. The infrastructure, to be exploited in the next future in the frame of EPOS (European Plate Observing System https://www.epos-ip.org/), allows the distribution of both satellite and in-situ data from the INGV monitoring networks, according to the Space Agencies and the INGV data policies, although in the latter case still to be formalized.
Similarly, in these years support activities to facilitate scientists involved in this Supersite were also implemented, like the release of high resolution DEMs (Digital Elevation Models, 12 m + 30 m pixel posting) in response to the DLR *Announcement of Opportunity* for TDX DEM product requests
(http://www.earthobservations.org/documents/gsnl/201701_tdx_dem_campi_flegrei_vesuvius_mt_etna.pdf).
The exploited satellite data were mainly from the SAR sensors on board the CSK constellation, TSX/TDX (monostatic) and S1-A/B. For particular research activities from some members of the science teams also RS-2 and ALOS-2 data were exploited.

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Science teams issues

Scientists and science teams from leading research and monitoring Institution in the field of geophysics, volcanology and earth observation take part in the activities of the Vesuvius-Campi Flegrei Supersite, namely:

- INGV (Istituto Nazionale di Geofisica e Vulcanologia, the Italian Institute of Geophysics and Volcanology) with the *Osservatorio Vesuviano* (INGV-OV), the *Osservatorio Etneo* (INGV-OE) and the *Osservatorio Nazionale Terremoti* (INGV-ONT) branches;
- IREA-CNR (Istituto per il Rilevamento Elettromagnetico dell'Ambiente, the Italian Institute for the Electromagnetic Sensing of the Environment from the National Research Council);
- Canada Centre for Mapping and Earth Observation, Ottawa (Canada);
- University of Naples *Federico II*, Department of Earth Sciences, of the Environment and Resources (Italy);
- University of Rome 3, Sciences Department (Italy);
- Instituto de Geociencias, Universidad Complutense, Madrid (Spain);
- University of Colorado, Boulder (USA).

With respect to the international participation in this Supersite, some variations were made in the last two years, including also scientists from outside Europe, actively involved in different research activities on the Neapolitan Volcanic District (e.g. Tiampo et al., 2017). This was a precise choice from the Supersite coordinator, in order to improve the results not only in terms of InSAR studies but also to include new outcomes from modelling of the deformation source in the area of interest. Some preliminary results of this activity are reported in the following as well.

Another issue to be faced in a recent past was data distribution between the Supersite coordinator and the members of the science teams, sometimes through dedicated FTPs or, in worst cases, by hand exchanging data through appropriate devices.

Apart from the Sentinel data hub, the set-up of web platforms by some Space Agencies, e.g. the ESA GEP (Geohazards Exploitation Platform, https://geohazards-tep.eo.esa.int/#!) the ESA VA4 (Virtual Archive, vers.4, http://eo-virtual-archive4.esa.int/) and the DLR *Download services for Geohazard Supersites* (https://supersites.eoc.dlr.de/) is now overcoming this problem, allowing near real time data dissemination within the science teams.

Definitely, the Supersite coordinator finds no particular obstacles for the next biennial activities of this Supersite pointing out, on the contrary, the improvement due to the above-mentioned support provided by Space Agencies.

In situ data

A general overview of the monitoring networks in the Neapolitan volcanic area is presented (see figure 1 in the Annex):

INGV-OV monitoring networks (Vesuvius)

Seismic	Permanent:	19 stations	Mobile:	9 stations
GPS	Permanent:	9 3D vertices		
Levelling	Discrete:	325 benchmarks		
Tide gauge	Permanent:	2 stations		
Tiltmetric (permanent)	Surface:	3 stations	Borehole:	5 stations
Gravimetric	Discrete:	35 benchmarks	Permanent:	1 station
Geochemical	Permanent:	4 stations		
Thermal Infrared Imagery	Discrete:	3 stations	Permanent:	1 station

INGV-OV monitoring networks (CF)

Seismic	Permanent:	26 stations	Mobile:	19 stations
GPS	Permanent:	26 3D vertices		
Levelling	Discrete:	370 benchmarks		
Tide gauge	Permanent:	4 stations		
Tiltmetric (permanent)	Surface:	4 stations	Borehole:	6 stations
Gravimetric	Discrete:	37 benchmarks	Permanent:	1 station
Dilatometric	Permanent:	4 stations		
Geochemical	Permanent:	3 stations		
Thermal Infrared Imagery	Discrete:	11 stations	Permanent:	4 stations

Type of data	Data provider	How to access	Type of access
e.g. seismic waveforms, GPS time series, gas measurements, etc.	……	*Link to data repository or description of procedure for data access*	*E.g. unregistered public, registered public, limited to GSNL scientists, etc.*
Seismic waveform	*INGV*	*Link to Network Italian Seismic Network Web Service*	*Limited to MED-SUV Consortium - Registered*
Seismic events	*INGV*	*Link to Network Italian Seismic Network Web Service*	*Limited to MED-SUV Consortium - Registered*
GPS data	*INGV*	*Link to MED-SUV GSAC server*	*Limited to MED-SUV Consortium - Registered*

In situ data issues

As already reported in the previous biennial report, the in-situ data provided by INGV are discoverable and accessible through the e-Infrastructure implemented in the frame of the EC FP-7 MED-SUV project.

Improvements of the infrastructure continued, in the perspective of its exploitation in EPOS (Freda et al., 2017).

Anyhow, some criticisms can be envisaged in a possible misalignment between the overall good availability of satellite data provided by Space Agencies and the incomplete data availability from the in-situ data provider, not yet ensuring a full open access to data and research products, mainly due to a lack of an official data policy, already established but still to be formalized.

Satellite data

Type of data	Data provider	How to access	Type of access
ERS-1/ERS-2	ESA	http://eo-virtual-archive4.esa.int/?q=Vesuvius	Registered public
ENVISAT	ESA	http://eo-virtual-archive4.esa.int/?q=Vesuvius	Registered public
Sentinel	ESA	https://scihub.copernicus.eu	Registered public
TerraSAR-X	DLR	https://supersites.eoc.dlr.de	Registered public
COSMO-SkyMed	ASI	Coordinator requests access to ASI for individual users	Authorized GSNL scientists
RADARSAT-2	CSA	Coordinator requests access to CSA for individual users	Authorized GSNL scientists
Landsat 8	USGS	http://earthexplorer.usgs.gov	Registered public
AVHRR	NOAA	http://earthexplorer.usgs.gov	Registered public
MODIS	NASA	http://modis.gsfc.nasa.gov/data/	Open

Current availability of InSAR data provided through the Vesuvius-Campi Flegrei Supersite initiative:

X-band data:

- COSMO-SkyMed (CSK, StripMap, SLC: SCS_B)
  Ascending: 368 scenes in the time span 2012.03.31 to 2018.06.11;
  Descending: 10 scenes in the time span 2011.11.25 to 2013.05.13.

- TerraSAR-X & TanDEM-X - monostatic (TSX/TDX, StripMap, SLC: SSC)
  Ascending (Vesuvius): **91** scenes in the time span 2008.02.15 to 2018.04.10;
  Descending (Vesuvius): **129** scenes in the time span 2008.02.13 to 2018.04.13;
  Ascending (CF): **129** scenes in the time span 2009.03.11 to 2018.04.04;
  Descending (CF): **7** scenes in the time span 2010.07.12 to 2015.03.13.

C-band data:

- RADARSAT-2 (RS-2, StripMap, SLC, Fine-Beam)
  Ascending: **14** scenes in the time span 2013.06.18 to 2014.05.20.
- ERS1/2 & ENVISAT archive data available from the ESA Virtual Archive.
- Sentinel archive and current data available from the Sentinels Scientific Data Hub.

Currently, no L-Band data available for the Vesuvius-Campi Flegrei Supersite.

Satellite data issues

As already outlined in the first report, some satellite data issues still remain.
Shortly summarizing, they are:

- no way to trace scientists downloading ERS/ENVISAT and Sentinel data for the area of interest, potentially interested to interact with the Supersite science teams;
- same for TSX/TDX;
- RS-2 data ordering, only from Windows through the APT tool, still remains a not user-friendly step: a web-based ordering solution would represent an improvement, allowing a smoother way to get data;
- no ALOS-2 data available for this Supersite: these data would successfully complement the huge X- and C-band database for the area;
- no high/very high resolution data (spotlight/staring spotlight) available for this Supersite, apart from TSX spot data acquired after the 2017 Ischia earthquake; the integration with ground-based geodetic data would result in a better knowledge of the deformation pattern for some critical areas.

On the other hand data download/distribution, as said before, was recently marked by a great improvement carried out by Space Agencies through their own web portals. In particular the Geohazards Exploitation Platform, providing data from both the ESA sensors and SAR systems from other Space Agencies, by linking the platform to their repositories.

Research results

Scientific achievements (figures in the Annex)

InSAR data processing for ground deformation studies and source modelling in the Neapolitan Volcanic District

Ground deformation studies
(P. Prats-Iraola, M. Nannini, M. Pinheiro - DLR-HR)
(M. Costantini, F. Vecchioli, F. Minati - e-GEOS)
(S. Borgstrom, P. De Martino, V. Siniscalchi - INGV-OV)
One of the main activities during the last biennial period includes the studies carried out in the frame of the ESA-SEOM (Scientific Exploitation of Operational Missions) project *INSARAP Sentinel-1 Constellation Study*, performed for the European Space Agency by the Consortium formed by the Microwaves and Radar Institute of the German Aerospace Center (DLR-HR), e-GEOS and INGV, the *Osservatorio Vesuviano* Naples branch. This study, started in 2016, is an extension of the study *INSARAP Sentinel-1 InSAR Performance Study with TOPS Data (2014-2015)* (http://seom.esa.int/page_project006.php). The main goal of the *INSARAP Sentinel-1 Constellation Study* was the assessment of the interferometric performance when combining images from S1-A and S1-B, be it by exploiting single interferograms or by processing time series with combined S1-A and S1-B acquisitions.
In the following, the main results of these studies over CF area are shown, jointly with relevant comparisons with continuous GPS (cGPS) data from the INGV-OV monitoring networks in the area in the time interval 04.2015-11.2017 (figures 2, 3, 4, 5).
An excellent agreement was found between S1 and cGPS time series not only on the InSAR ascending and descending Line of Sight (LoS) data (figures 2, 3), but also on the vertical/east-west inversion (figures 4, 5). As we would expect, almost no deformation was pointed out for the cGPS stations at the borders of the caldera, outside the red ellipsoid shown in the figures.
Noteworthy is the fact that the maximum vertical displacement, recorded close to the coast at RITE (RIone TErra) cGPS station (fig.4), is exactly located in between the two areas characterized by an opposite horizontal displacement (fig.5), i.e. east deformation about zero.
Accordingly, besides the clear uplift signal outlined in the vertical inversion by the e-GEOS team exploiting the PSP-IFSAR analysis (fig.6), also the above mentioned horizontal deformation appears in the east-west inversion (fig.7), with an eastward displacement on the east side of the CF caldera, towards the city of Naples (east positive values), whereas a westward displacement appears on the opposite side (east negative values).

Modelling results
(J. Fernandez, A. Camacho - CSIC-UCM)
A preliminary modelling of the deformation source in CF area (Fernandez and Camacho, 2017, personal communication) takes into account only S1-A data acquired in the time span 10.2014-02.2016 (fig.8) without cGPS data, to be considered in the next future, also with the GPS north component and S1 up and easting components.

Preliminary results pointed out that the observed deformation is strongly determined by a dominant pressure body - as the modelling approach accepts different kinds of sources: pressure source and arbitrary dislocation - at a mean depth of about 2 km, with a rather cup shape. In this dataset it is possible to detect also the presence of a very weak deeper source (about 12 km depth), although the effect of the main shallow body is so dominant that it is difficult to obtain further information about the deeper source, like its geometry and exact nature.
In general, the modelling results are in a good agreement with the achievements from other researchers in the scientific literature (e.g. Trasatti et al., 2015, Borgstrom et al., 2015).
Inclusion of a longer dataset considering both S1 units, besides the available in-situ data from the INGV-OV geodetical networks, will contribute in the next future to provide a more robust modelling of the deformation source.

InSAR data processing and modelling of the August 21th, 2017 Ischia earthquake
(A. Montuori, M. Albano, M. Polcari, S. Atzori, C. Bignami, C. Tolomei, G. Pezzo, M. Moro, M. Saroli, S. Stramondo, S. Salvi - INGV-ONT)
Ischia is a volcanic island belonging to the Phlegrean Volcanic District. On August 21th, 2017 an earthquake occurred in the northern part of the island (Casamicciola Terme) (Nappi et al., 2018), with an estimated moment magnitude Mw = 3.9. Immediately after the earthquake, several activities begun following the emergency plan of the National Civil Protection Department. Within such a framework, multi-platforms and multi-frequency satellite InSAR data were collected and processed (Montuori et al., 2018) to retrieve the surface displacement field occurred in the interested area. In detail, X- and C-band InSAR acquisitions were provided by SAR sensors on board the Italian CSK constellation and the European S1 mission, respectively. The analysis of InSAR data allowed providing a complete overview of surface displacements due to the mainshock, thus identifying the areas affected by significant deformations. Such information were exploited to identify the possible sources by means of analytical and numerical models. Both models allowed inferring useful information about the source parameters and mechanism responsible for the observed ground displacements.
The dataset used for the InSAR analysis and modelling of the coseismic crustal deformations, consists of X- and C-band SLC SAR images, collected before and after the earthquake. Moreover, the availability of both ascending and descending acquisitions allowed evaluating the vertical (Up) and horizontal (East) components of surface deformation, retrieved along the satellite LoS. Both S1 and CSK acquisitions were processed with the classical InSAR approach, with the 30 m Shuttle Radar Topography Mission (SRTM) DEM used to remove the topography. Data were multi-looked to have the same pixel posting of the SRTM product; hence, the Goldstein filtering was adopted to reduce phase noise of InSAR data, setting the exponent parameter and the windows size values to 0.8 and 16, respectively. Finally, both S1 and CSK interferograms were unwrapped by using the Minimum Cost Flow (MCF) phase unwrapping algorithm. As a final step, the coseismic InSAR deformation maps were investigated with both analytical and numerical models to infer the source mechanism responsible for the observed deformations. In figure 9 the CSK interferogram (2017.08.19-2017.08.23, descending orbit) is shown, where each phase cycle represents a LoS displacement of 1.55 cm.

Figure 10 shows the LoS coseismic deformation map from CSK data: the result shows a displacement pattern in the epicentral area (yellow star) with values of about -2.5/-5 cm (i.e., away from the satellite) in the north-western sector of the island.
Depending on the availability of both ascending and descending S1 data, the Up and East components of ground deformation were computed as well, indicating a dominant vertical component in the earthquake area with values up to -3.6 cm; conversely, the horizontal east-west component is negligible.
To better understand the displacement occurred in the island during the event, also some terrain profiles are shown (fig.11), indicating a ground subsidence peaking at about 3.8 cm, located on the NW flank of Mt. Epomeo.
The analysis of modelling solutions lets supposing the combination of different mechanisms as responsible for the observed deformations, i.e., the tectonic dislocation caused by the earthquake slip and the dynamic triggering of shallow landslides. However, the high seismic susceptibility of the areas affected by the greater InSAR displacements suggests that most of the ground displacements are caused by shallow surficial landslides.

The August 21th, 2017 Ischia earthquake (2)

(M. Pinheiro, M. Nannini, P. Prats-Iraola - DLR-HR)

Ground deformation studies on the Ischia earthquake exploiting S1 data, were carried out by the DLR-HR team as well (fig.12, Pinheiro et al., 2017, personal communication).
In the following, the east-west/vertical inversion computed from ascending and descending data is shown (fig.13): in particular, from the vertical component of ground displacement, a subsidence signal recorded after the earthquake is visible (see the blue ellipsoid), pointing out a deformation less than 5 cm in the north-western part of the island, in a good agreement with the results from the INGV-ONT team.
In fig.12 the results of a time series processing (2015.04.12-2017.11.09) are also shown, for two pixels located in the earthquake area indicating the subsidence after the event. In order to improve these results, another reference point in a more stable area was chosen afterwards: after that figure 14 shows the times series of two pixels in the epicentral area, more clearly indicating the post-event subsidence.

IREA-CNR activities on the Naples Bay area

(F. Casu, M. Manzo, R. Castaldo, C. De Luca, V. De Novellis, M. Manunta, S. Pepe, G. Solaro, P. Tizzani, I. Zinno - IREA-CNR)

Some of the IREA-CNR activities on the Naples Bay area, carried out during the last years by exploiting DInSAR techniques, are presented. In particular, the ground displacements induced by both the August 2017 Ischia earthquake and the volcanism of CF caldera, were studied. The presented results were obtained as part of the IREA-CNR monitoring activities to support the Italian Civil Protection Department.

The August 21th, 2017 Ischia earthquake (3)

On August 21th, 2017 (18:57 UTC) a M_w 3.9 (M_d 4.0) earthquake stroke the northern sector of the active volcanic Island of Ischia, causing two casualties and extensive damage to the Casamicciola Terme city center, along the northern structural rim of Mt. Epomeo; the main

shock was followed by a seismic sequence of almost 20 earthquakes with significantly lower magnitude.
The coseismic ground displacements were detected via DInSAR measurements (De Novellis et al., 2018, De Novellis et al., 2018b). Several ascending and descending cross-event interferograms were generated by exploiting both S1 and CSK data. Among them, the authors selected four interferometric pairs (see table below), three from S1 data (fig.15) and one from CSK ones (fig.16), showing the best interferometric coherence characteristics.

Co-seismic interferometric pairs used for monitoring the Ischia earthquake

Sensore	Modalità	inteferomtric pair	wavelength [cm]	perpendicular baseline [m]	Orbit	Track	Average incidence angle [deg]
S1	IWS*	16082017 – 22082017	5.5	7	DESC	22	39
S1	IWS*	16082017 – 22082017	5.5	55	ASC	117	39
S1	IWS*	17082017 – 23082017	5.5	65	DESC	124	39
CSK	StripMap	19082017 – 23082017	3.1	66	DESC	--	24

* IWS = Interferometric Wide Swath

Accordingly, the maximum temporal baseline is of six days for the selected S1 interferograms and four days for the CSK one. All the generated displacement maps present a consistent range increase pattern localized in an area south of Casamicciola Terme, independently from the orbit pass, look angle and interferometric pair. This implies that the detected displacements are mainly vertical (i.e. subsidence). The maximum range change is of about 4 cm in LoS and the shape of the displacement pattern shows an E-W alignment, which is in good agreement with the epicentre distribution of the aftershocks.
In order to identify the main shock causative source, the authors performed an inversion of the DInSAR coseismic measurements, which allowed them to estimate the fault plane parameters and retrieve the associated slip distribution. A main patch of slip (with values up to 14 cm) was found, located at the centre of the fault plane at a depth of 800 m (fig.17). This result provides a picture of the seismogenic mechanism of the earthquake, dominated by a normal fault where the hanging block (located in the northern part of Mt. Epomeo) moves downwards.
In particular, the retrieved seismogenic fault, responsible for the main shock, is characterized by (i) an E-W striking fault (86°), (ii) a south-dipping high-angle plane (70°) and (iii) a rake value close to -90°. These findings are in rather good agreement with the recorded aftershocks alignment along the E-W direction and with the computed focal mechanism calculated by INGV.

Campi Flegrei caldera ground deformation monitoring
The deformation of the CF caldera was constantly monitored via both CSK and S1 data and the relevant DInSAR measurements are provided to the Italian Civil Protection Department on a monthly basis. Moreover, since January 2017 the IREA-CNR displacement results are included in the surveillance reports released every 6 months by INGV. In the following the DInSAR results obtained up to 2017 are presented.

COSMO-SkyMed DInSAR results

CSK data processing was carried out exploiting the Small BAseline Subset (SBAS) DInSAR algorithm on the data acquired from ascending orbits in the time interval 2009.07.12-2017.04.05. The table below shows the main characteristics of the data used for the CSK interferometric analysis.

CSK data set used for the SBAS DInSAR analysis of Campi Flegrei

Sensor	COSMO-SkyMed
Wavelength [cm]	3.1 cm
Orbit	Ascending
Average incidence angle [deg]	44
Spatial Coverage [km]	40x40
Time Interval	12 July 2009 – 5 April 2017
SLC Images	476
Interferograms considered	1417
DEM	SRTM (30 m)

In figure 18, the map of the mean deformation velocity in the sensor LoS relevant to the analysed area, which includes the CF caldera (on the west) and the city of Naples (on the east), is presented. The information of average deformation velocity (in false colours) has been geocoded and superimposed to an optical image of the area (in grey); the areas where the deformation measurement is affected by decorrelation noise are excluded from false colour map; the spatial reference with respect to which the deformation measurements were calculated is located near the Naples harbour.

Figure 18 shows a radial deformation pattern (the surface is moving towards the sensor) of the caldera, whose centre can be identified within the city of Pozzuoli (i.e. Rione Terra area). In particular, a maximum LoS displacement of about 28 cm in the whole analysed period (2009.07.12-2017.04.05) was measured. Accordingly, figure 19 shows the temporal evolution of the LoS displacement for a point located within the maximum deformation area of the caldera (Rione Terra, Pozzuoli). Assuming that in this area the displacement is purely vertical, the measured entity corresponds to about 40 cm of uplift.

From the analysis of figure 19, it is evident that since 2011 the caldera was interested by a positive deformation rate, which is characterized by an alternation of accelerations and slowdowns. In particular, during the 2012.04-2013.01 time interval, the caldera has shown a rapid uplift of about 11 cm, with a peak rate of about 3 cm/month during December 2012.

This uplift period was extensively studied in D'auria et al., 2015, whose main outcome is the evidence that the recent dynamics of CF can be explained as the emplacement of a magma batch within a flat, sill-shaped, magmatic reservoir.

Sentinel-1 DInSAR results

The surface deformation of CF is also constantly analysed since October 2014 by using the SAR data acquired by the Copernicus S1 constellation. Both units (S1-A/B) have operated almost continuously during the study period (2014.10-2017.12). In order to generate the interferometric results presented below, 125 and 121 SAR images were acquired from ascending (Track 44) and descending (Track 22) orbits, respectively. The table below summarizes the main characteristics of the S1 data used.

Sentinel-1 data set used for the SBAS DInSAR analysis of Campi Flegrei

	ASCENDING	**DESCENDING**
Wavelength [cm]	5.5	
Average incidence angle [deg]	39	
Acquisition Mode	Terrain Observation by Progressive Scans	
Spatial resolution [m]	80x80	
Time Interval	20/10/2014 – 03/12/2017	07/10/2014 – 02/12/2017
SLC Images	125	121
Track	44	22

From these data, the displacement time series and the relevant mean deformation velocity maps were generated by using the SBAS DInSAR technique. For the Interferometric processing, an SRTM DEM of the area with a spatial resolution of 30 m has been used. Both the differential interferograms and the subsequent deformation maps and time series present a spatial resolution of about 80 m, which was obtained via a multilooking operation. All measurements are spatially referred to a point located in the city of Naples.
The availability of SAR data acquired from both ascending and descending orbits makes it possible to retrieve the vertical and east-west components of the ground deformation.
Accordingly, the mean velocity maps related to the vertical and east-west displacement components are reported in figures 20a-b. These maps reveal a radial spatial distribution of the vertical displacement whose centre, corresponding to the maximum deformation area, is approximately located in the Rione Terra neighborhood (P2 in fig. 20a). The measured vertical displacement rates are of about 6 cm/year throughout the analysed period (2014.10-2017.12). The east-west component has a maximum westward displacement in the Arco Felice area (P3 in fig.20b) and a maximum eastward displacement in the area between the *Accademia Aeronautica* and Bagnoli (P1 in fig.20b): in both cases, the measured displacements are about 2.5-2.7 cm/year. This horizontal spatial distribution is consistent with the vertical maximum displacement measured at Rione Terra, where indeed the east-west component is negligible (P2 in fig.20b).
Being the time difference between ascending and descending passages of about one day, and assuming that the variation of deformation is negligible at a distance of one day, it is possible to combine the single ascending and descending acquisitions to generate the time series of the vertical and east-west deformation components. This assumption is valid in case no sudden and large deformation (for example high magnitude earthquakes) occur in the analysed period, as in this case.
Figure 20 also shows the plot of the time series of the vertical and east-west components of the deformation for the points indicated as P1, P2 and P3 in figure 20a-b. In particular, the graphs of figure 20c-20e-20g show how the vertical displacement has reached a maximum uplift (fig.20e) of about 18 cm, in the analysed time frame (2014.10-2017.12). Similarly a deceleration

of the deformation starting from the end of August 2016 is also visible. Nevertheless, the measured displacement of the period 2016.09-2017.12, although at a lower rate, is still positive.
The behaviour of the horizontal component of the displacement is consistent with the vertical one, as shown by the plots of figure 20d-20f-20h, relative to the previously identified points P1, P2 and P3 (fig.20b). In particular, during the period under study, positive (eastward, fig.20d) and negative (westward, fig.20h) displacement values of approximately 8 cm were measured, while no significant horizontal deformation was registered in the centre of the caldera (fig.20f).

Monitoring activities at INGV-OV (Conventional DInSAR processing, comparison with cGPS data)
(S. Borgstrom, P. De Martino, V. Siniscalchi - INGV-OV)
The results of monitoring activities in the Neapolitan volcanic area, in the form of simple interferograms and deformation maps from TSX/TDX (monostatic) data, were provided on a six months basis to the Italian Civil Protection Department, for inclusion into the surveillance reports. These results were presented jointly with a full SAR data processing provided by the IREA-CNR team, the latter appointed by the Civil Protection Department as a *Centre of Expertise* (Centro di Competenza).
In the following, a deformation map (fig.21, 1cm/color cycle) from TSX ascending data is shown, for the time span 2017.01.19-2018.04.04. For comparison, the height variations of a cGPS station are reported (fig.22), located in the maximum deformation area close to the coast. The dashed red line refers to the same time span of the deformation map: a good agreement can be pointed out (> 5cm), although the InSAR deformation signal is not clear enough in the inland due to the strong decorrelation.
Though the deformation map derives from a simple interferogram, potentially affected by atmospheric residuals, the strong deformation signal on the coast still remains clearly visible/uncorrupted.
In the figure, the centre of deformation is shifted westward with respect to the real one, due to the ascending pass in presence of an horizontal displacement as in CF.
Nowadays, jointly with the codes routinely used, also the data processing tools available on the ESA GEP platform are exploited for fast and (extremely) user-friendly processing. Just as an example, in the figures 23a), 23b) and 23c) the results from a S1 data processing (2017.06.29-2018.01.01) are shown, exploiting the DIAPASON InSAR S1 TOPSAR code implemented within the GEP Processing Services.
Figure 23c), the interferometric phase, although dominated by large incoherent areas (the sea and vegetation in the inland) shows a clear phase signal due to the deformation occurring in CF area (blue circle).

InSAR data exploitation for geotechnical applications
(D. Calcaterra, D. Di Martire - University of Naples, DISTAR)
In the frame of this activity started some years ago by the University of Naples team, the geotechnical monitoring of a reinforced ground work, by means of SAR imagery (Tessitore et al., 2017), has been carried out by experimentally exploiting a Persistent Scatterers technique. In detail, the aim of the current work is to determine the validity of such technique, usually

implemented for the geotechnical monitoring of wide areas, in the observation of engineering works.
The study area is located in the Caravaggio Sport Center, in the city of Naples, Fuorigrotta neighborhood, in Via Terracina (fig.24). Following the realization of the work, a first plano-altimetric monitoring plan was identified. Such topographic measurement station consisted in setting up several optical sights, with three reference points located on fixed structures (buildings and retaining walls) and six optical sights (fig.25) made by catadioptric prisms, sited along the walkways on the armed land front, with three along the ridge line of the scarp and three along the ridge line of the reinforced ground embankment. The algorithm used for the interferometric analyses is the Coherent Pixel Technique (CPT, Mora et al., 2003), implemented in the SUBSOFT software, developed by the *Remote Sensing Laboratory* of the *Universitat Politecnica de Catalunya (UPC)*. Both PSs (fig.26) and optical prisms show a coherent displacement trend (figures 27a), b), c), d)).

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Research products

The main research products of this Supersite are the scientific publications (e.g. see list above) and the surveillance reports to the national civil protection authorities.

Type of product	Product provider	How to access	Type of access
e.g. ground deformation time series, source model, etc.	*Name of scientist(s)*	*Link to publication, research product repository or description of procedure for access*	*E.g. public, registered, limited to GSNL scientists, etc.*
Research	*Supersite science teams*	*Scientific literature (national/international)*	*Public*
Surveillance	*Mainly INGV-OV, IREA-CNR*	*Surveillance reports*	*Restricted (Civil Protection Department)*

Research product issues

Access rules outlined above. New research products are expected within the new H2020 EUROVOLC (2018-2021) (EUROpean Network of Observatories and Research Infrastructures for VOLCanology) infrastructure project (Vogfjörd et al., 2018).

Dissemination and outreach

Dissemination and outreach activities started during the first biennial period went on, with publications and workshop presentations addressed to the scientific community, besides reporting relevant results from the Supersite activities to the main stakeholder, the Italian Civil Protection Department in the form of surveillance reports.
These reports are mainly focused on regular updates of the ongoing ground deformation in CF, currently at the *attention* (yellow) level according to the Emergency Plan issued by the Civil Protection Department. Indeed, the area underwent an overall inflation, in the maximum deformation area close to the coast, of more than 43 cm from 2011 to date (see http://www.ov.ingv.it/ov/it/bollettini/272-campi-flegrei-bollettini-settimanali.html)
Relevant results are also shown during conferences and public meetings with local authorities/citizens.

Funding

Right now no funding resources are officially available for the Vesuvius-Campi Flegrei Supersite after the end of MED-SUV (Pepe et al., 2016), therefore any new funding opportunities must be investigated, with the submission of new project proposals to both European and national funding bodies.
Currently, almost only in-kind contributions by the science teams are provided to support the Supersite activities, besides institutional funding resources.
For instance, a relevant financial support to INGV come from the Italian Civil Protection Department for set-up and maintenance of the monitoring networks, whose data can be exploited for integration with satellite data from Supersite.
A limited amount of funding is now guaranteed by ongoing projects, like EVER-EST (European Virtual Environment for Research-Earth Science Themes) Virtual Research Environment, funded by the EC H2020 program and managed by ESA (Trasatti et al., 2017). The Virtual Research Environment is being designed to suit the needs of Supersites scientists and provides a variety of services for improving the collaboration in the Supersites framework.
Further scientific and financial support to the Supersite activities is foreseen in the near future from the aforesaid EC H2020 EUROVOLC project, lasting the next three years.

Societal benefits

The main stakeholders benefiting from the Vesuvius-Campi Flegrei Supersite activities are the Italian Civil Protection Department and, on a local scale, the Regional Civil Protection of the *Campania* Region, besides the different interested Municipalities.
In this regard, all the results from InSAR studies (conventional DInSAR processing, ground deformation velocity maps, time series generation), besides other geophysical and geochemical studies, are reported on a regular basis to the Civil Protection Department for surveillance purposes and support to decision makers.

On a mid-term scale, the societal benefits to be achieved through the outcomes of this Supersite can be summarized in a technical support to Civil Protection authorities in setting up the updates of the National Emergency Plan for Vesuvius and CF areas.
These plans are continuously evolving, depending on the contributions from the reference scientific community, in terms of new scientific knowledge of both areas.
A recent example of a fruitful interaction between Supersite, providing satellite data and other institutional activities, was a dedicated regional project (SISTEMA Project: *Sistema Integrato di Sorveglianza del TErritorio con Metodologie Aero-spaziali*) (Vilardo et al., 2017) funded by the EC and allowing instrumental acquisitions, with a focus on ground deformation studies in CF area exploiting different geodetic techniques, mainly InSAR and cGPS.
Ultimately, the chance from remotely sensed data to extend investigations on large/wide areas, far beyond the measurements on single ground-based stations, is an added value in this case, where ground deformation patterns on large areas have to be considered for surveillance and civil protection purposes.

Conclusive remarks and suggestions for improvement

As already highlighted in the first biennial report, the Supersites initiative fits into a particularly favorable period for the scientific and the stakeholders communities. The availability of free-of-charge satellite data from some Space Agencies represents a big step forward in supporting research and surveillance in some areas in the World, prone to natural hazards.
A significant effort in this direction was carried out by ESA for data dissemination not only from currently operated missions like the Sentinel constellation, but from previous missions as well, e.g. ERS/ENVISAT, available through the ESA Virtual Archive (VA4).
The same for DLR, whose TSX/TDX data for Supersite users are available from the *Download services for Geohazard Supersites* after registration.
ASI is also sharing this data dissemination philosophy, making the CSK constellation data available through the ESA GEP platform for authorized users.
Anyhow, the ESA GEP represents not only an opportunity for satellite data sharing, by linking to web portals from other Space Agencies, but also for data processing by means of cloud-based processing services implemented in the platform. These extremely user-friendly services result in a valuable tool for both scientific users and experienced stakeholders involved in land management issues.
But also other ongoing projects, like EVER-EST (European Virtual Environment for Research-Earth Science Themes) lead by ESA, will offer the partners, during its lifetime, the chance to exploit virtual machines for SAR data processing by means of high level codes.
In addition to cloud-based processing services, a further support to the activities by the scientific users and the stakeholders is also provided by the availability on the web of stand-alone and user-friendly softwares, like the ESA SNAP (the SeNtinel Application Platform http://step.esa.int/main/toolboxes/snap/), for an easy and well explained data processing.
As already mentioned, an official data policy from the in-situ data provider, still to be released, is needed for the provision of ground-based data to supplement satellite data.

Also the access to the aforesaid web services should be monitored, with a particular focus on the ESA GEP, not only to avoid the indiscriminate use/download of satellite data by unauthorized users, but also (to avoid) the exploitation of the processing services by not expert stakeholders (e.g. not governmental), especially when they have no knowledge/experience to properly handle the processing results.
As regard to the continuation of future activities, the provision of adequate funding resources is a key point, especially if mid-long term activities are foreseen.
High/very high resolution data provision by Space Agencies would result in a strong improvement in the knowledge of the areas of interest, especially in combination with in-situ data from monitoring networks, but the Supersite coordinator understands that Space Agencies could have sometimes some tasking priorities with regard to particular acquisition modes.
Definitely, the Supersite coordinator finds no particular obstacles for the next biennial activities of the Vesuvius-Campi Flegrei Supersite, although some issues mentioned before still need to be fixed. Anyhow, the high quality of the scientific results achieved so far must be taken into account, thus demonstrating the interest of the scientific community in this active volcanic area.

Annex with dissemination material

Figures remain in the ownership of their authors (see Credits). Any use must be previously authorized.

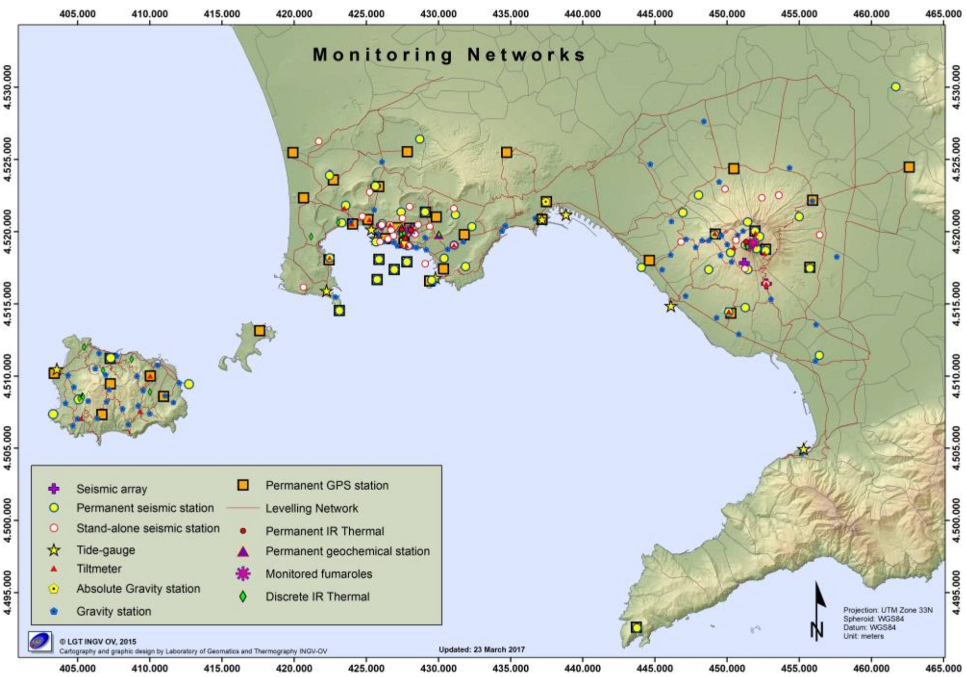
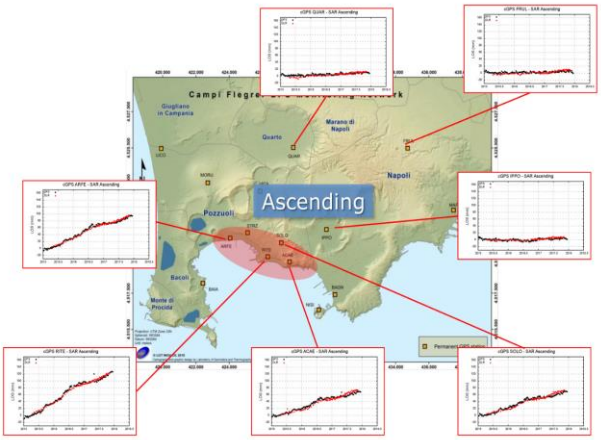
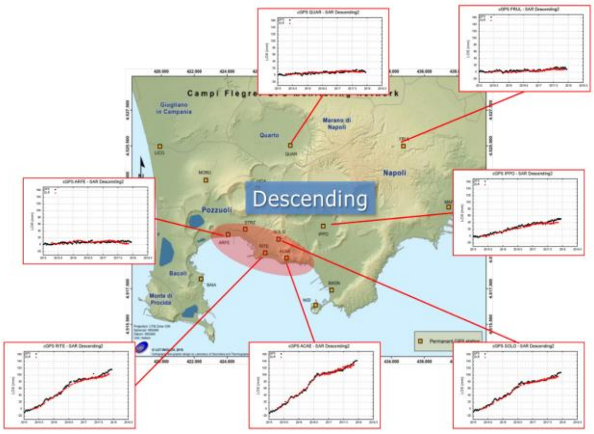
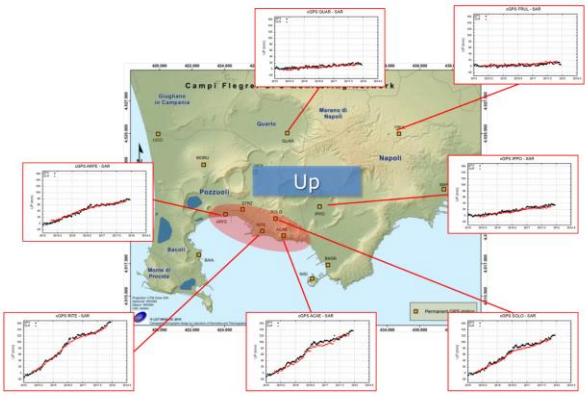


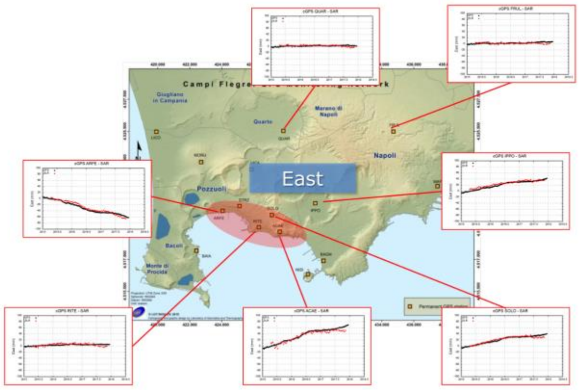
Figure 1 - INGV-Osservatorio Vesuviano monitoring networks in the Neapolitan Volcanic District (Credits INGV-OV)



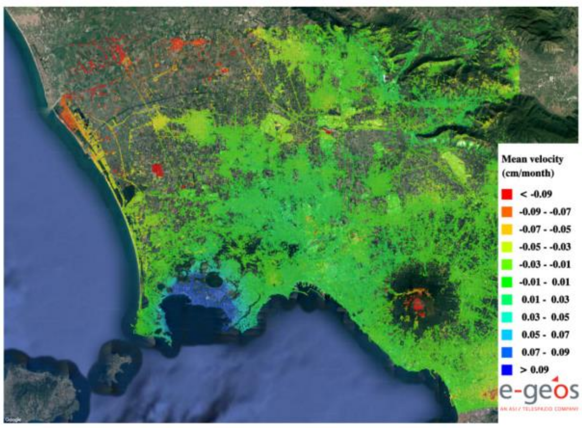


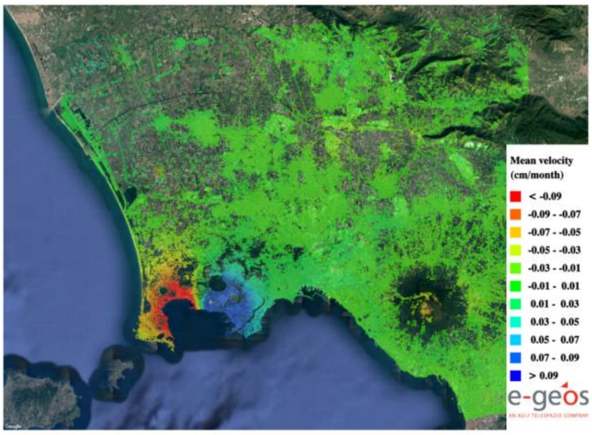
Figures 2, 3 - Sentinel-1-cGPS LoS comparison (04.2015-11.2017) for ascending (left) and descending (right) orbits (Credits **ESA-SEOM INSARAP**: DLR-HR/INGV-OV)





Figures 4, 5 - Sentinel-1-cGPS comparison (04.2015-11.2017) for vertical (left) and east-west (right) components (Credits **ESA-SEOM INSARAP**: DLR-HR/INGV-OV)





Figures 6, 7 - Sentinel-1 mean velocity maps (04.2015-11.2017) - vertical (left) and east-west (right) components from the PSP IFSAR analysis (Credits **ESA-SEOM INSARAP**: e-GEOS)

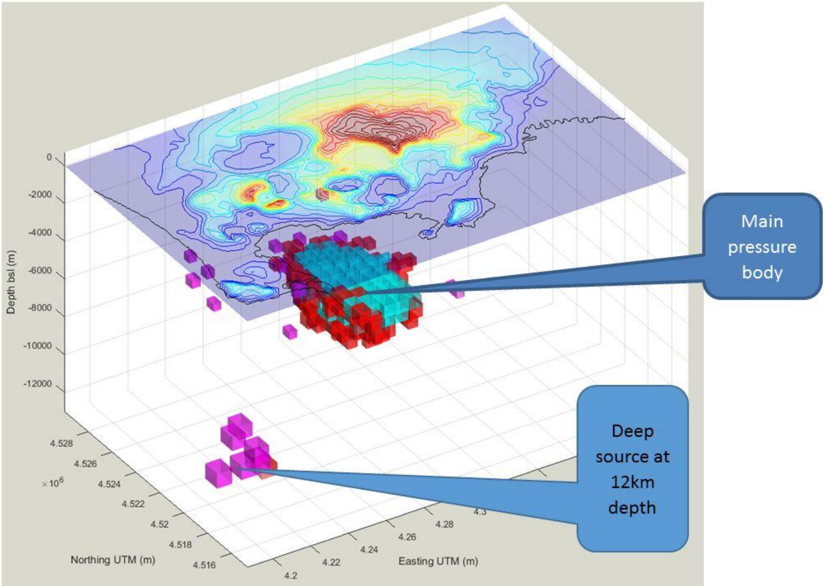


Figure 8 - Adjusted 3D model for extended sources from Sentinel-1A data (10.2014-02.2016) (Credits CSIC-UCM)

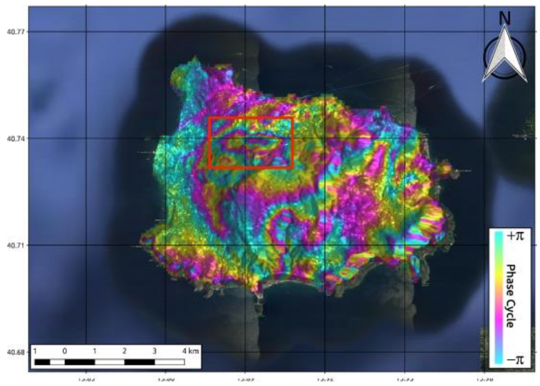


Figure 9 - COSMO-SkyMed interferogram (2017.08.19-2017.08.23), descending orbit (Credits INGV-ONT)

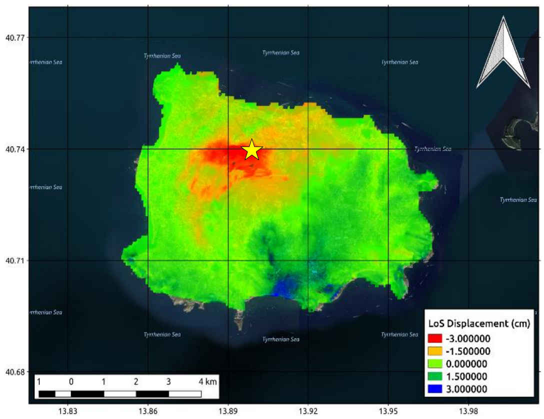


Figure 10 - The Ischia earthquake LoS displacement map from COSMO-SkyMed data (Credits INGV-ONT)

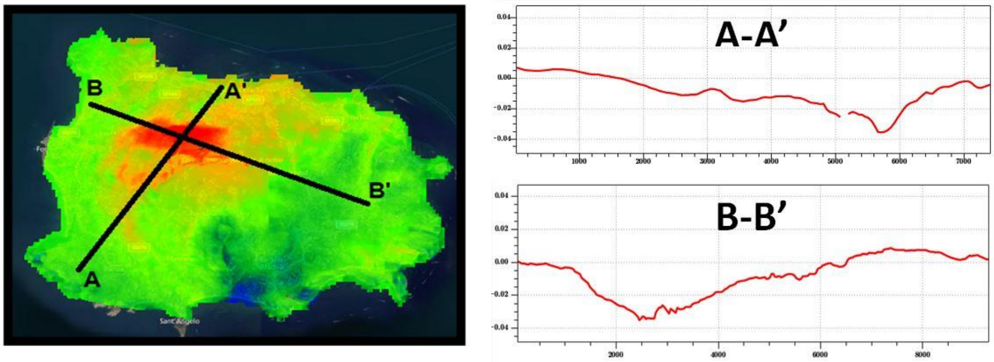


Figure 11 - Terrain profiles (A-A' and B-B') over the displacement map: subsidence is shown on the NW flank of Mt. Epomeo (Credits INGV-ONT)

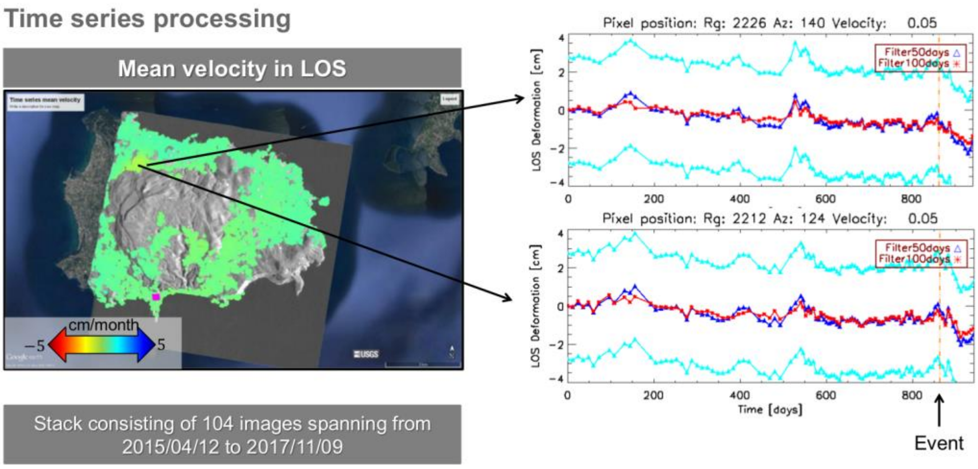


Figure 12 - Sentinel-1 mean velocity map, descending orbit (2015.04.12-2017.11.09), with time series processing for two pixels located in the earthquake area (black arrows) (Credits DLR-HR)

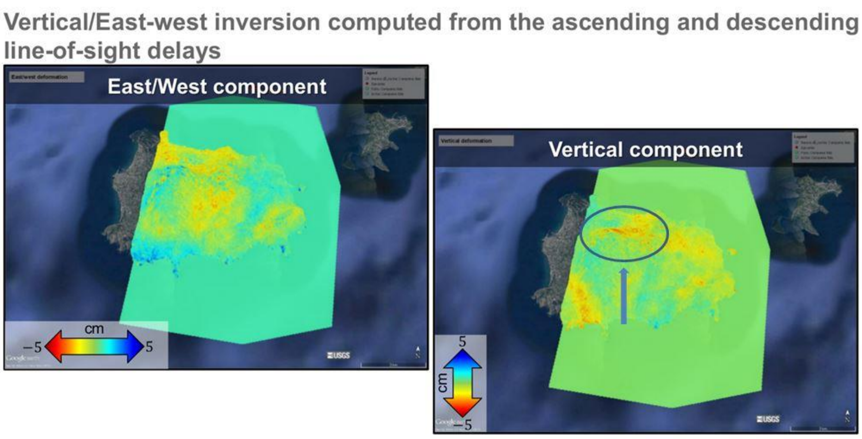


Figure 13 - East-west and vertical inversion from Sentinel-1 ascending and descending data: the post-event subsidence is visible inside the blue ellipsoid from the vertical component (Credits DLR-HR)

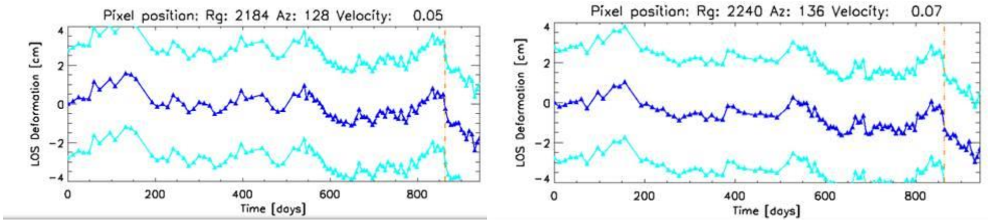


Figure 14 - Time series processing for two pixels in the earthquake area, after choosing a more stable reference point (refers to fig.12; dashed line is the event date) (Credits DLR-HR)

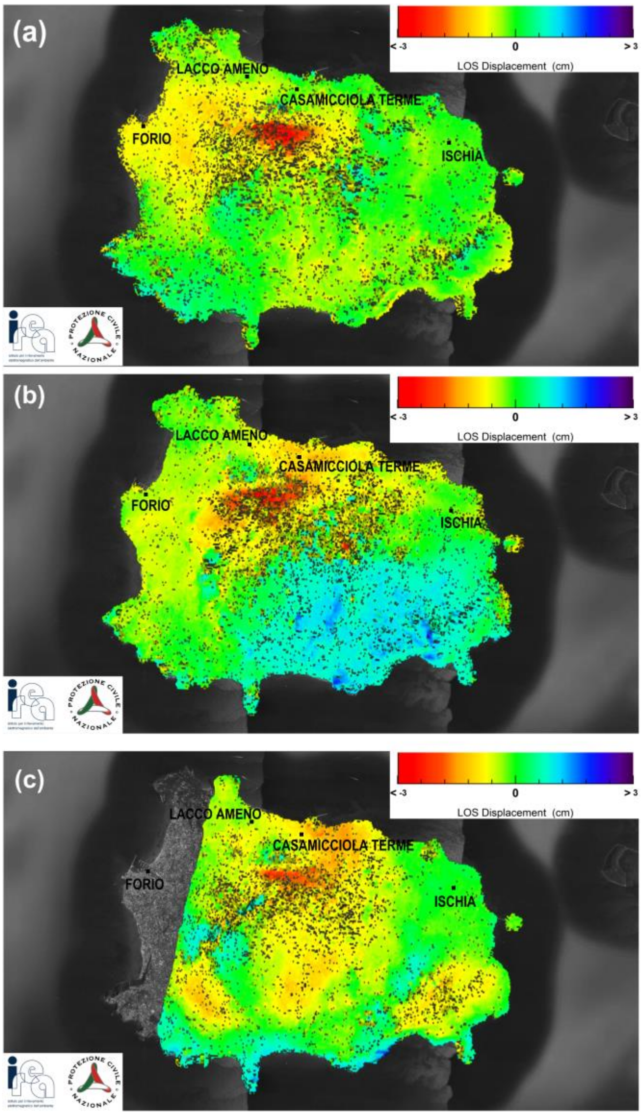


Figure 15 - DInSAR (LoS) displacement maps computed by using Sentinel-1 images acquired from (a) descending orbits on 16-22/08/2017, (b) ascending orbits on 16-22/08/2017 and (c) descending orbits on 17-23/08/2017. Contains modified Copernicus products ©2017 (Credits IREA-CNR)

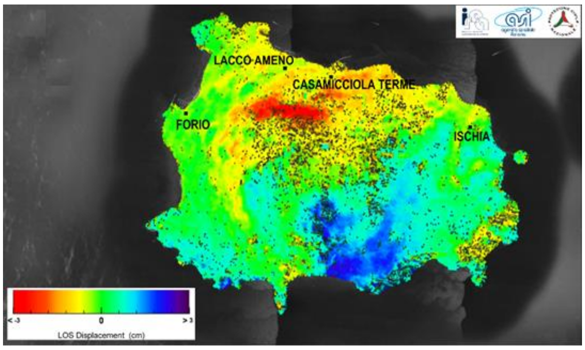


Figure 16 - DInSAR (LoS) displacement map computed by using COSMO-SkyMed images acquired from descending orbits on 19-23/08/2017 (Credits IREA-CNR)

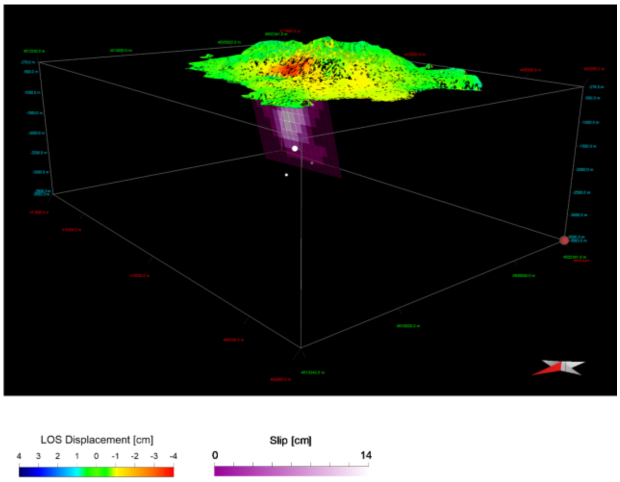


Figure 17 - DInSAR (LoS) displacement 3D map computed by using Sentinel-1 images acquired from ascending orbit on 17-23 August 2017. The causative fault (with the distributed slip over a mesh of 200 × 200 m^2) is displayed in 3D view; the main shocks (white circles) are also shown (Credits IREA-CNR)

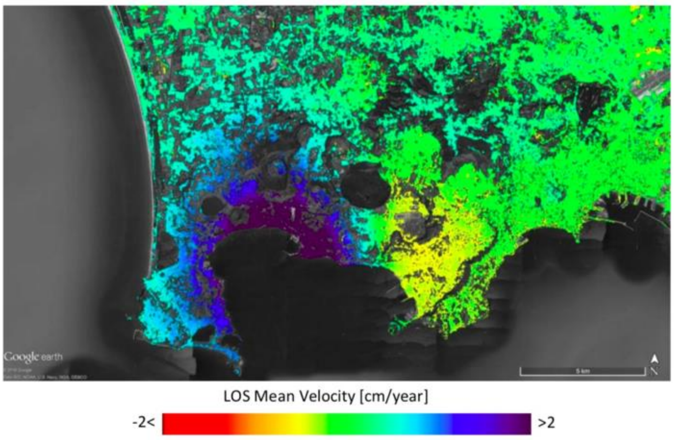


Figure 18 - Geocoded map (in false colours) of the average deformation rate in LoS for the area of Campi Flegrei. The map is superimposed to an optical image of the area (in grey) (Credits IREA-CNR)

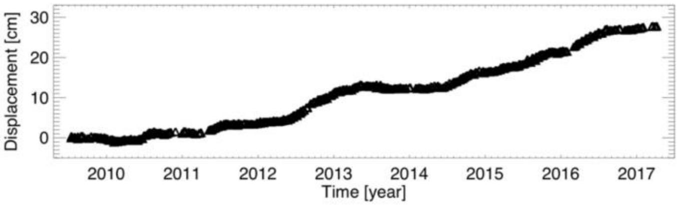


Figure 19 - LoS time series of the displacement, for a point located in the area of maximum deformation (Rione Terra, Pozzuoli) (Credits IREA-CNR)

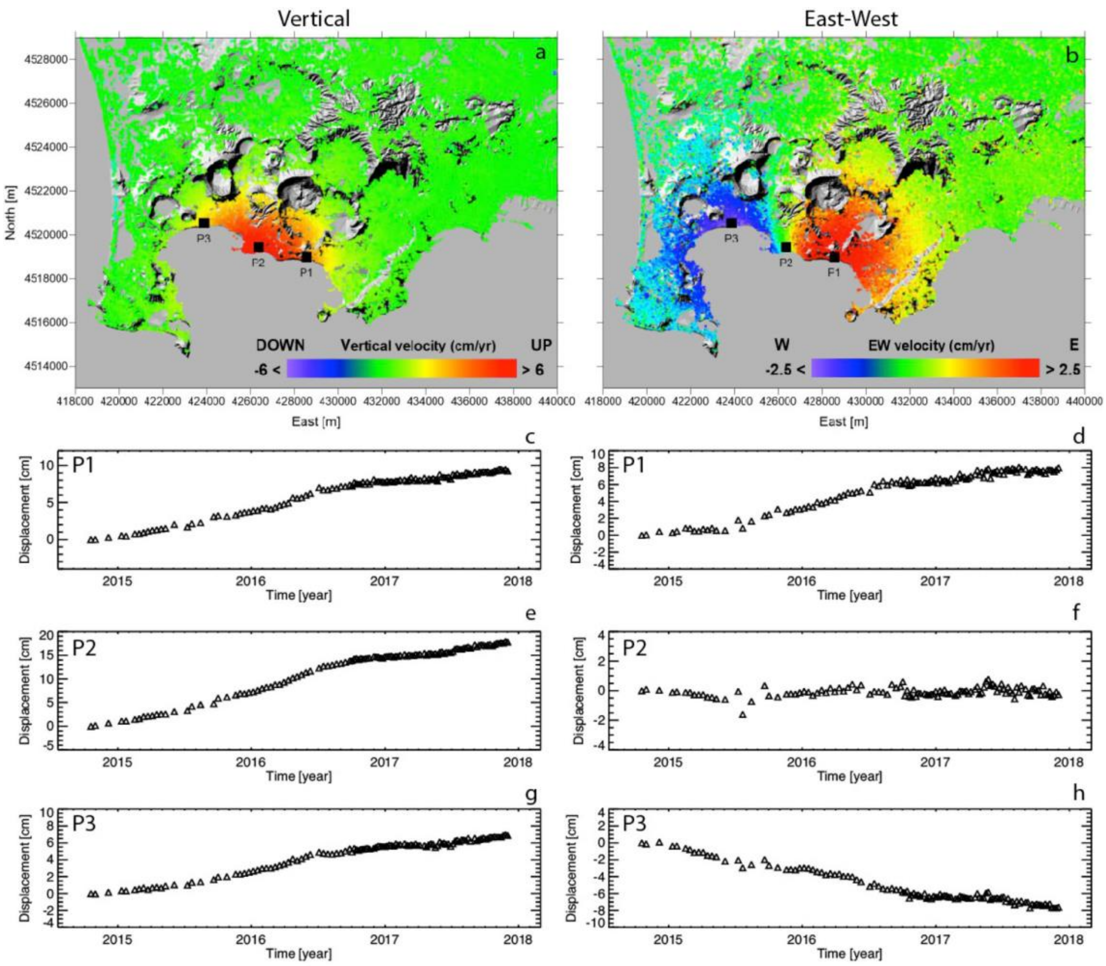


Figure 20 - Mean velocity maps of the vertical and east-west deformation components in the period 10.2014-12.2017, generated from Sentinel-1 data; a) vertical component; b) east-west component; c-h) displacement time series along the vertical (c) (e) (g) and east-west (d) (f) (h) directions of three points identified as P1, P2 and P3, respectively, in (a)-(b) (Credits IREA-CNR)

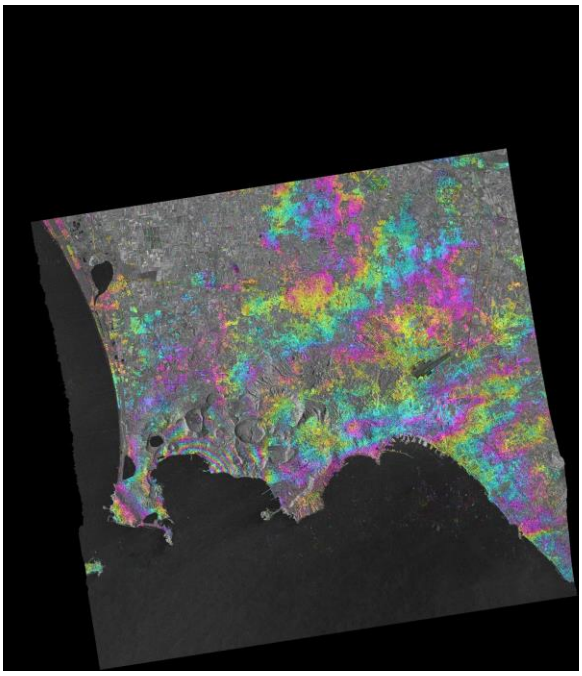


Figure 21 - TerraSAR-X displacement map (1cm/color cycle), ascending orbit (2017.01.19-2018.04.04) (Credits INGV-OV)

Figure 22 - Height variations of a cGPS station (RITE, Rione Terra) inside the maximum deformation area close to the coast; the dashed red line refers to the same time span of the TSX displacement map (Credits INGV-OV)

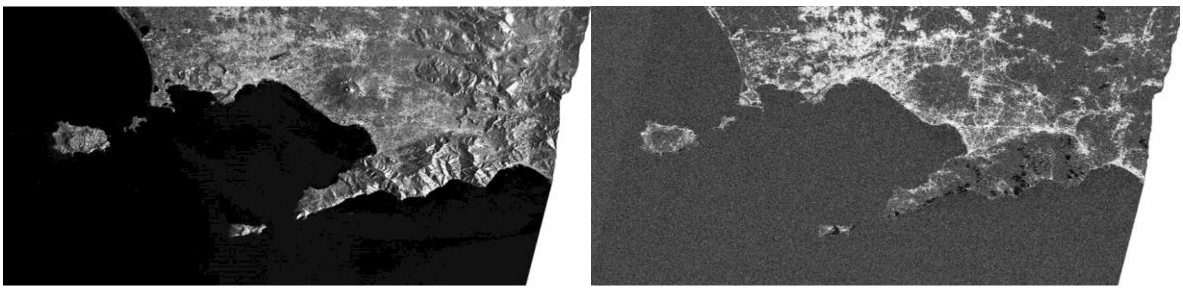


Figure 23a), b) - Sentinel-1 data processing, descending orbit (2017.06.29-2018.01.01) - amplitude (left) and coherence (right) from the DIAPASON InSAR S1 TOPSAR code implemented within the ESA GEP Processing Services

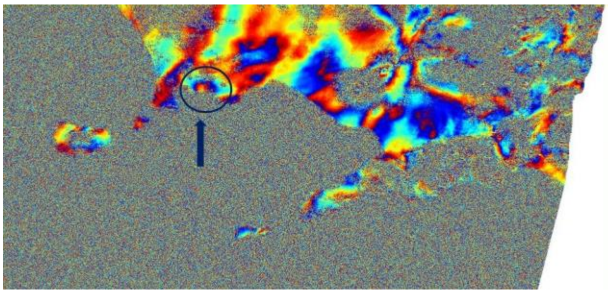


Figure 23c) - Sentinel-1 data processing, descending orbit (2017.06.29-2018.01.01) - the interferometric phase from the DIAPASON InSAR S1 TOPSAR code implemented within the ESA GEP Processing Services: a phase signal due to the deformation occurring in Campi Flegrei area (blue circle) is shown

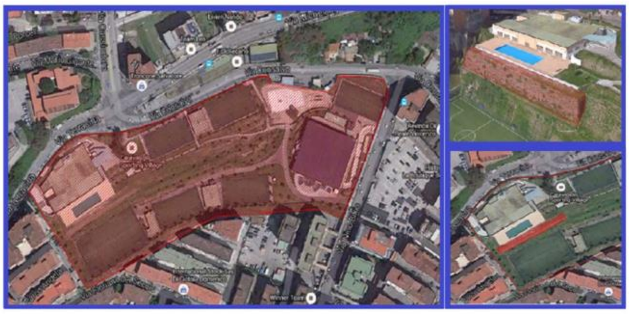


Figure 24 - On the left: Caravaggio Sport Center; on the top right the reinforced ground work, on the bottom right, its position within the sport center (Credits UniNa - DISTAR)

Figure 25 - Location of the monitored points, on the top and at the foot of the embankments (Credits UniNa - DISTAR)

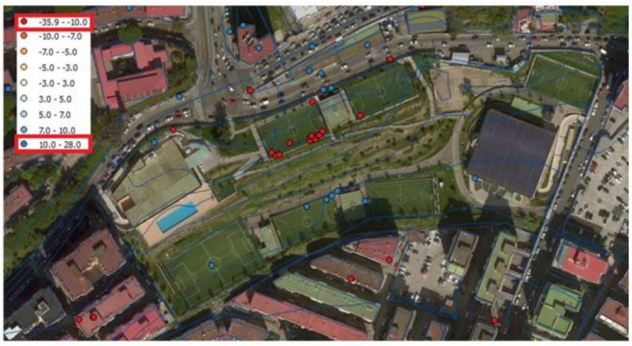
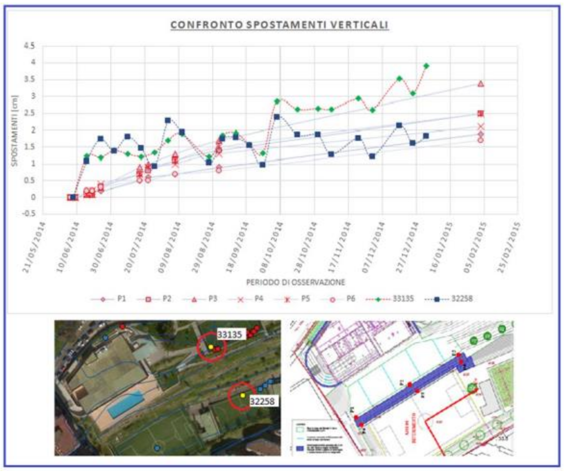
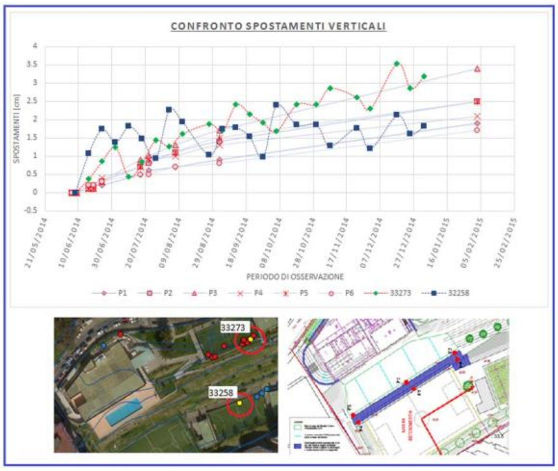


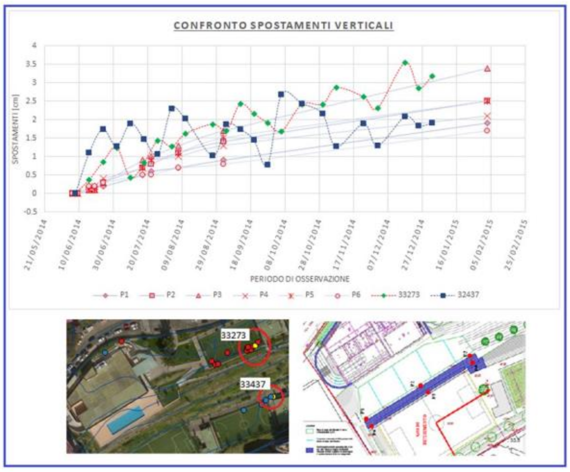
Figure 26 - COSMO-SkyMed persistent scatterers along ascending orbit acquired in the same time span of the topographic monitoring taken (mm/year) (Credits UniNa - DISTAR)



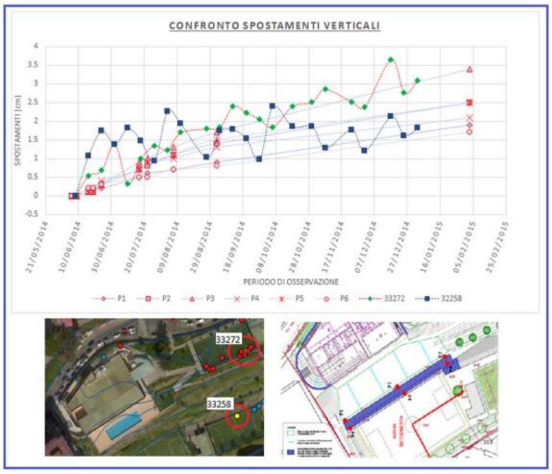
a)



b)



c)



d)

Figure 27a), b), c), d) - Time series analyses compared with the topographic measurements of the several points (Credits UniNa - DISTAR)