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Spaceborne InSAR monitoring of terrain instabilities in Apulia, Italy: outcomes of a National project

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Carlantino

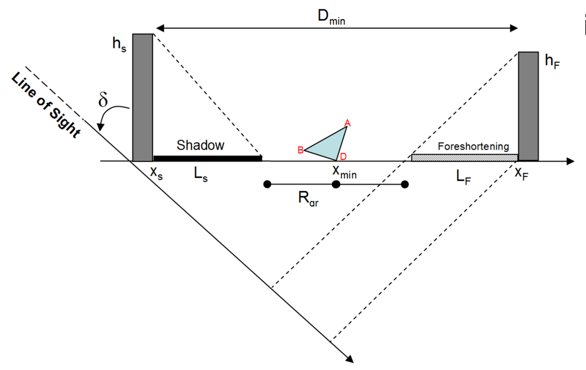
PS targets detected by both C- and X-band data correspond to urban structures or peri-urban walls and guard rails, while the landslide body is almost completely devoid of stable targets, due to the vegetation cover. In order to allow stability monitoring through spaceborne SAR interferometry, a network of passive reflectors was designed and deployed on the area of interest.

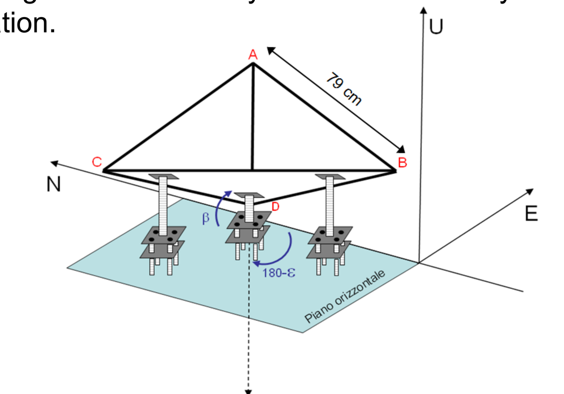
To design the corner reflector (CR) network, different factors were taken into account: the visibility of the CR by the satellite in terms of geometry and radiometry, the accessibility of the location on the ground, and the relative distance between CR.

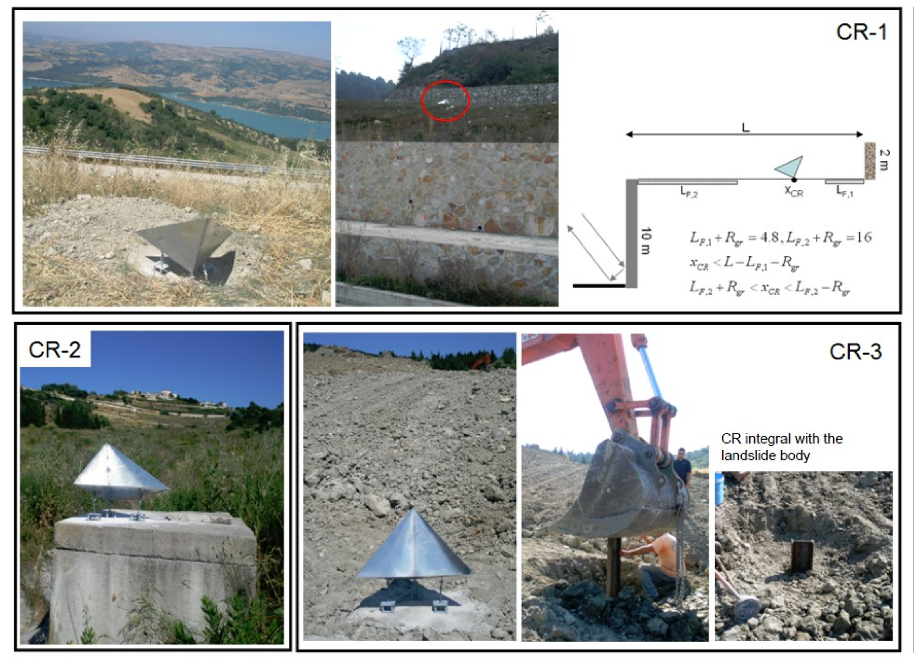
A small size (thanks to X-band & high res.) is preferred to minimize:

- ✓ curvature of the side panels
- ✓ effects of wind
- ✓ exposition to vandalism
- ✓ easier transportation/deployment in realistic harsh terrain

CR design was driven by the need of easy and cheap installation.







TerraSAR-X Dataset		
Sensor Mode: Stripmap		
Polarization Mode: Single Polarization		
Pass Direction: Ascending Path		
Looking Direction: Right Looking		
Incidence Angle Minimum: 34.04		
Incidence Angle Maximum: 36.57		
Phase: -1		
Orbit: 55		
Beam: strip_009R		
Polarization Channels: VV		
Azimuth resolution: 3.3 m		
Ground Range resolution: 2 m		

ID	Date	Diff Phase
1	TSX_20110712	
2	TSX_20110825	Φ_1
3	TSX_20110927	Φ_2
4	TSX_20111030	Φ_3
5	TSX_20111213	Φ_4
6	TSX_20120115	Φ_5
7	TSX_20120321	Φ_6

We computed 6 differential interferograms by coupling adjacent acquisitions, with the aim of reducing the negative impact of the temporal decorrelation. The phase coherence appears generally poor, except over the urban area. DInSAR phase appears correlated to atmospheric artifacts. This suggests the presence, of possible strong atmospheric artifacts, probably due to convective motions induced by the sun heating of the reservoir water.

Having available a network of CRs, instead of performing standard DInSAR analysis, we computed the differential phase for each CR by using precise geographical coordinates, precise orbital data (TSX acc. < 4 cm) and inverse geocoding. Then, in order to infer relative displacements, the difference between the DInSAR phase of neighbouring CRs were computed.

$$\forall\{i,j\} \qquad \Delta\Phi_{ij}(t)=\frac{4\pi}{\lambda}B_t(t)\cdot\left(v_{CRi}-v_{CRj}\right)+\left(\frac{4\pi}{\lambda}\frac{B_n(t)}{r_0\sin\theta}\right)\cdot\left(dH_{CRi}-dH_{CRj}\right)+\cancel{\Delta\Phi_{atm}(t)}+n(t)$$

The result shows a clear trend along B_n, indicating a residual differential height between CR-1 and CR-2 of 21 m (see A). The behavior of $\Delta\Phi_{12}$ along B_t does not show any clear trend (see B). Since the two CRs are located in areas where consolidation works were realized in the past, displacements are not expected to occur. The residual DInSAR phase obtained after removing from $\Delta\Phi_{12}$ the linear trend estimated along B_n shows a standard deviation of 0.8 rad and a maximum variation between phase values corresponding to a LOS path delay difference of 0.5 cm (see C).

In order to verify whether this residual phase can be explained in term of intrinsic CR phase noise or atmospheric signal, we computed the expected difference of DInSAR phase STD, $\sigma_{\Delta\Phi}$, in the case of an ideal CR of the same shape and size of those used for the experiment.

$$\sigma_{\Delta\Phi}=2\cdot\sqrt{-2\ln\left(\frac{\mathrm{SCR}}{\mathrm{SCR}+1}\right)}$$

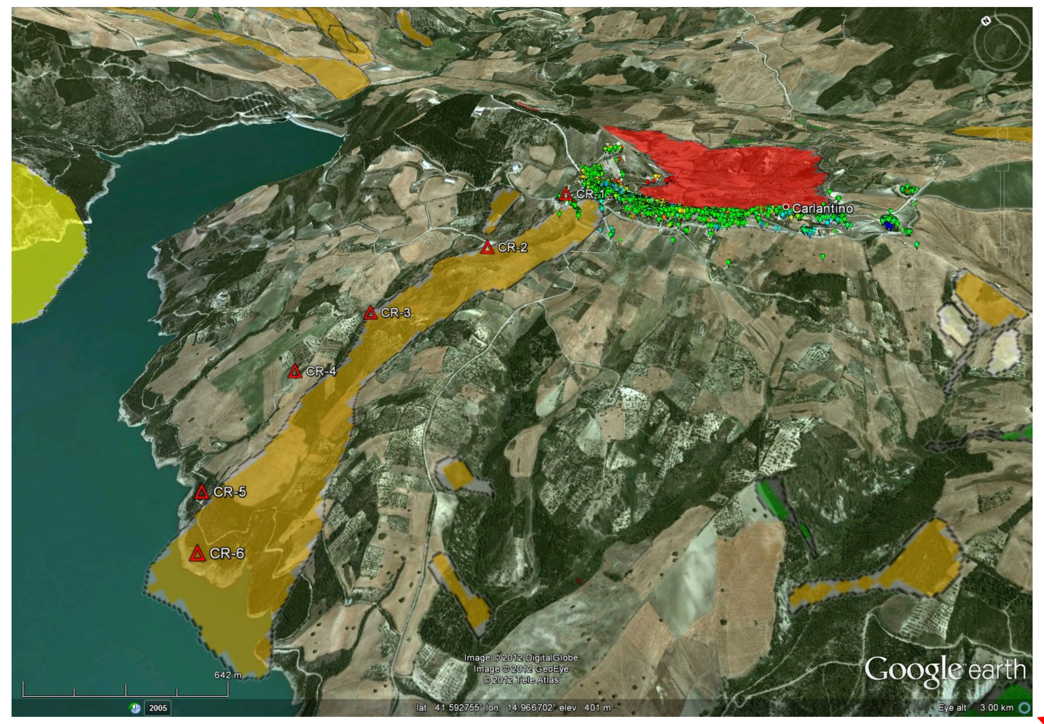
$$\text{where}\quad \mathrm{SCR}=\frac{4\pi}{\lambda^2}\frac{a^4}{3}\frac{1}{R_{az}R_{gr}\sigma_0^C}$$

$\sigma_{\Delta\Phi}$ was computed for different clutter levels, from bare soil to urban (see D).

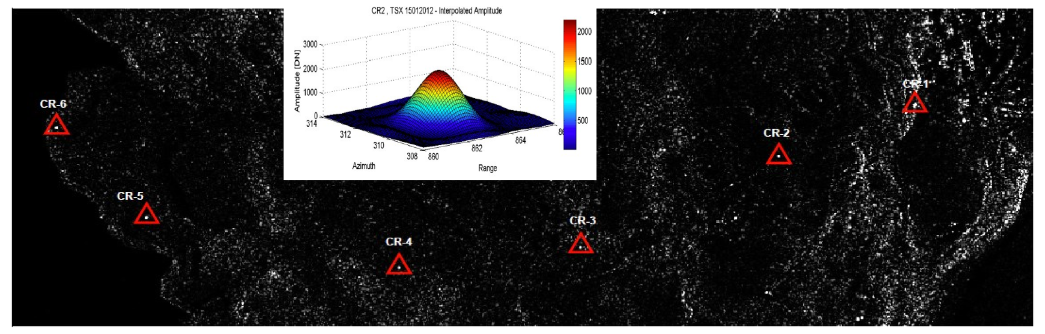
The maximum value for $\sigma_{\Delta\Phi}$ is below 0.2 rad. This confirms that the measured 0.8 rad for the $\Delta\Phi_{12}$ standard deviation has to be also related to atmospheric artifacts.

Although this residual noise hinders precise displacement measurements, we can exclude the presence of strong relative movements during the eight months analyzed.

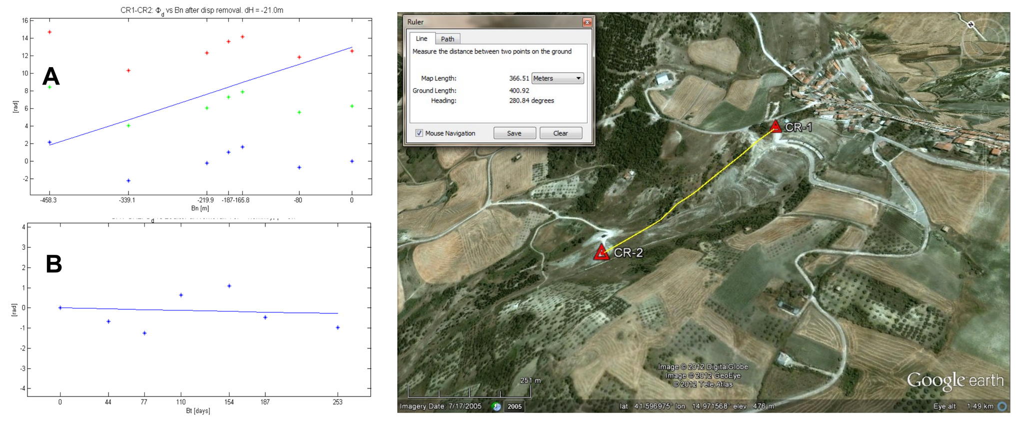
Similar results come from $\Delta\Phi_{23}$ and $\Delta\Phi_{34}$: the main body does not show strong relative movements (this suggests that consolidation works were effective).

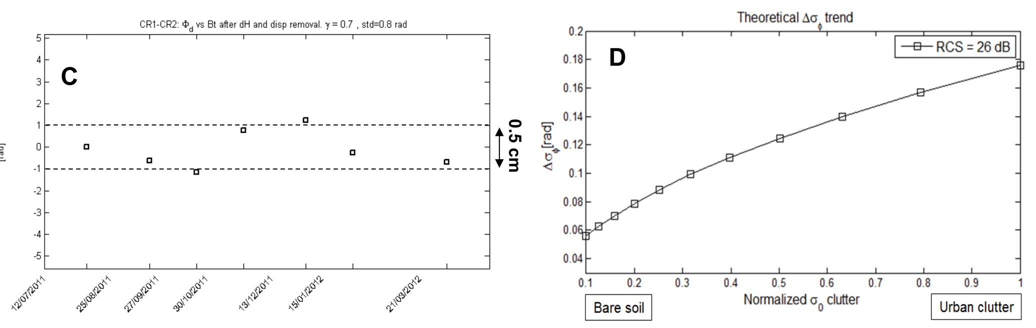


The CR locations were planned through a compromise between the constraints for designing an ideal geodetic network and those of CR visibility and ground accessibility. The harsh in situ conditions hindered ideal settings for the network, as only 6 CRs could be installed: the minimum distance condition between CRs, needed for a reliable atmospheric signal suppression, is not completely fulfilled.



The resultant Sigma Naught, σ^0, was computed for each CR at different acquisition times,and used to investigate the CRs amplitude stability. The trends of σ^0 for each CR: except for CR-5, which suffered of vandalism, the σ^0 values are quite stable in time, ranging between 14.7 dB and 17.2 dB, and with standard deviations between 03 dB and 0.8 dB. These RCS values are slightly lower than those theoretically predicted, probably due to both the cheap manufacturing and the interaction with the clutter.





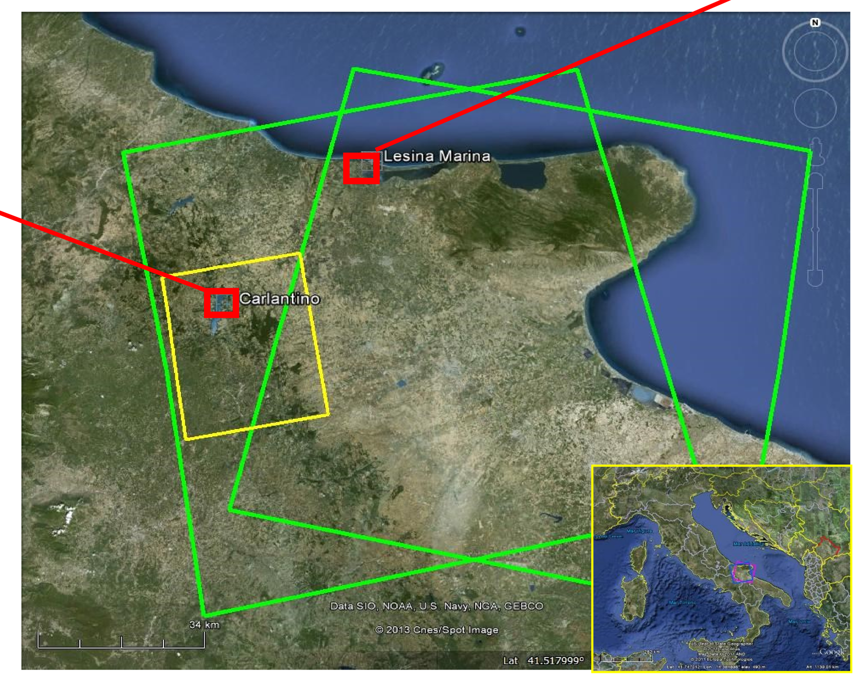
Final comments

- Networks of passive reflectors were used to monitor slope stability through space-borne DInSAR techniques.
- New generation of SAR sensors allow to design small and cheap CR thanks to short wavelength and high resolution.
- Although reflectors allow to provide the advantages of geodetic networks (natural reflectors → network of opportunity), realistic in situ conditions hinder ideal setting.
- A preliminary analysis on Carlantino test case performed with a limited dataset pointed out the possible impact of atmospheric artifacts due to sub-optimal network geometry: **only strong relative movements can be detected**.
- Preliminary outcome: the slope area subject to consolidation works does not show strong relative movements.
- Ongoing work: ad hoc processing strategies and more acquisitions.

Summary

We report on the InSAR-related results of the National Research Project (PRIN) entitled "Advanced techniques in the assessment and mitigation of the landslide risk: precursors detection, previsional models and thematic mapping", funded by the Italian Ministry for Scientific Research.

In the framework of the project, multi-temporal interferometric techniques were applied to time series of SAR data, from legacy ERS and ENVISAT, as well as high-resolution TerraSAR-X sensors. We report on the final outcomes of the project, which concentrate on two sites of the Apulia Region, representative of terrain instability problems widespread in the area.



The first test site is the coastal area near the Lesina Marina tourist village, at the north of the Apulia Region, close to the Gargano promontory, where the excavation of a canal exposed grey micro- and meso-crystalline gypsum which is now showing a high density of cavities and sinkholes due to gravitational collapse processes.

The second site is an inland landslide area close to the municipality of Carlantino, in the Daunia mountains. Here, a relatively large landslide affects the slopes spreading from the town outskirts to the banks of the Occhito lake, an artificial basin formed by a dam on the Fortore river.

Acknowledgements

Research funded through the Italian Ministry of Research – PRIN 2008 research grant "Advanced techniques in the assessment and mitigation of the landslide risk: precursors detection, previsional models and tematic mapping".

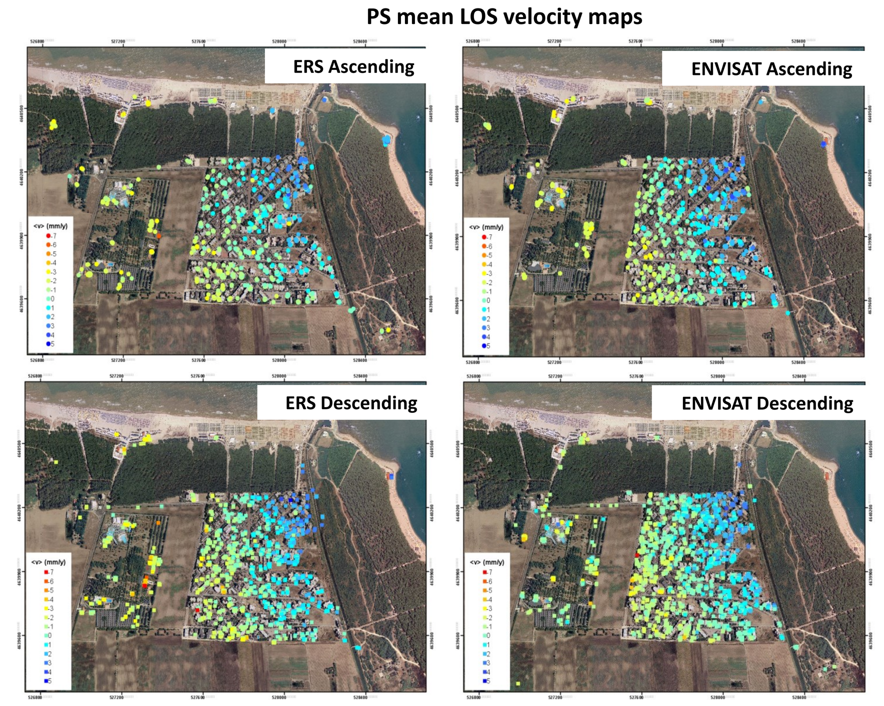
ENVISAT data provided by European Space Agency – Category-1 project N. 5367, 2Subsidence monitoring in Daunia and Capitanata (Puglia Region, Italy) through multi-temporal point-target DInSAR techniques"

References

- Bovenga F. et al. (2004), "SPINUA: a flexible processing chain for ERS / ENVISAT long term interferometry", Proceedings of ESA-ENVISAT Symposium, Salzburg, Austria, 6-10 September 2004.
- M.D. Fidelibus, F. Gutiérrez, G. Spilotro (2011), "Human-induced hydrogeological changes and sinkholes in the coastal gypsum karst of Lesina Marina area (Foggia Province, Italy)", Engineering Geology, 118, 1–19
- F. Bovenga, A. Refice, G. Pasquariello, "Using Corner Reflectors and X-band SAR Interferometry for Slope Instability Monitoring". Proceedings of Tyrrhenian Workshop on Advances in Radar and Remote Sensing (TyWRRS), 2012; pp. 114-120; September 12-14, 2012, Naples, Italy.
- A. Refice, F. Bovenga, G. Pasquariello, D. Fidelibus, G. Spilotro, "Uplift at Lesina Marina (southern Italy) revealed by PSI techniques". Proceedings of Fringe 2011 Workshop, SP-697 January 2012. Advances in the Science and Applications of SAR Interferometry from ESA and 3rd party missions, September 19-23, 2011, ESA/ESRIN, Frascati, Italy.
- G. Mastronuzzi and P. Sansò, "Holocene coastal dune development and environmental changes in Apulia (southern Italy)," *Sedimentary Geology*, vol. 150, no. 1–2, pp. 139–152, 2002.
- F. G. Bell, J. C. Cripps, and M. G. Culshaw, "A review of the engineering behaviour of soils and rocks with respect to groundwater," *Geological Society, London, Engineering Geology Special Publications*, vol. 3, no. 1, pp. 1–23, Jan. 1986.
- C. Lubitz, M. Motagh, H.-U. Wetzel, and J. Anderssohn, "TerraSAR-X Time series uplift monitoring in Staufen, South-West Germany," in *2012 IEEE International Geoscience and Remote Sensing Symposium*, 2012, pp. 1306–1309.

Lesina Marina

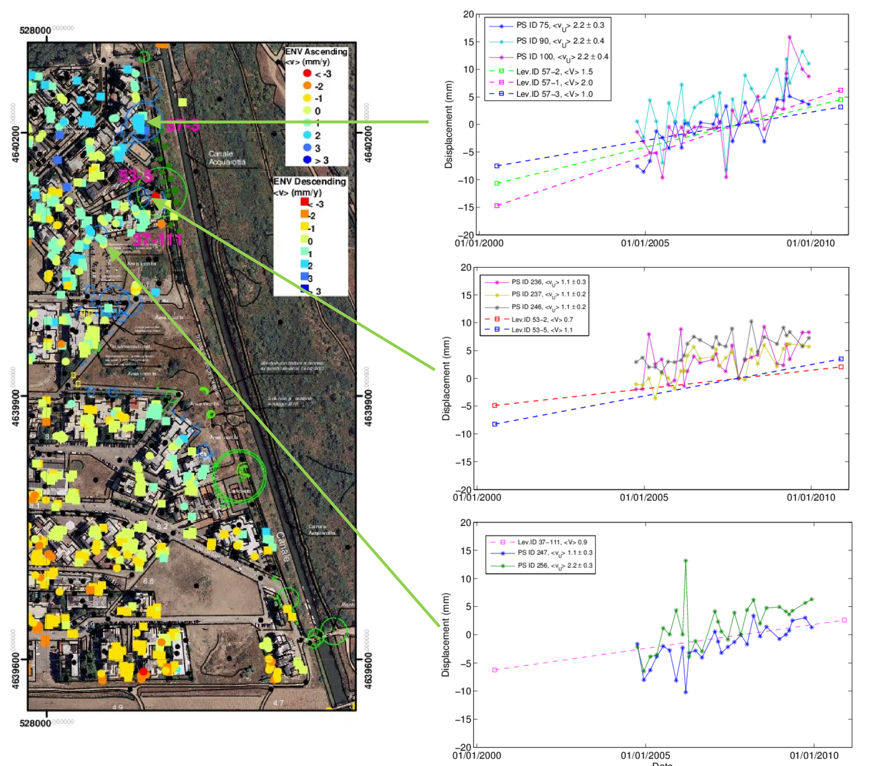
PS mean LOS velocity maps

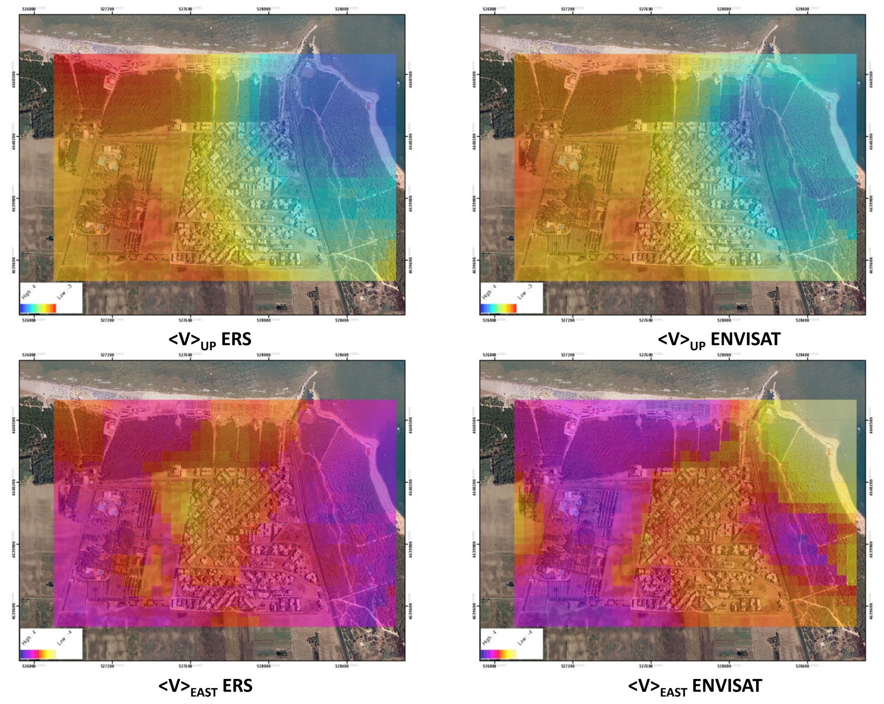


In order to extract relevant information about mean velocities of stable points located on the Lesina Marina area, we processed, through persistent scatterers interferometry (PSI) methodologies (SPINUA algorithm), ERS and ENVISAT SAR data, acquired in both ascending and descending geometries, and spanning a total time interval from 1995 to 2010. By combining asc. and desc. displacements we derived vertical and horizontal displacement maps:

$$\langle v_U\rangle=\frac{\langle v_A\rangle+\langle v_D\rangle}{2\cos\theta}$$

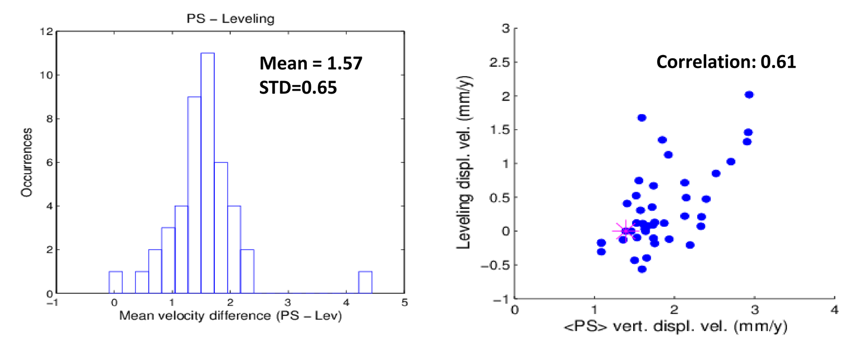
$$\langle v_E\rangle=\frac{\langle v_A\rangle-\langle v_D\rangle}{2\sin\theta}$$





A slow but steady uplift phenomenon has been detected. Derived vertical displacement rates exceed 4 mm/y on locations adjacent to the canal, decreasing to zero towards the western end of the built up area (about 600 m width).

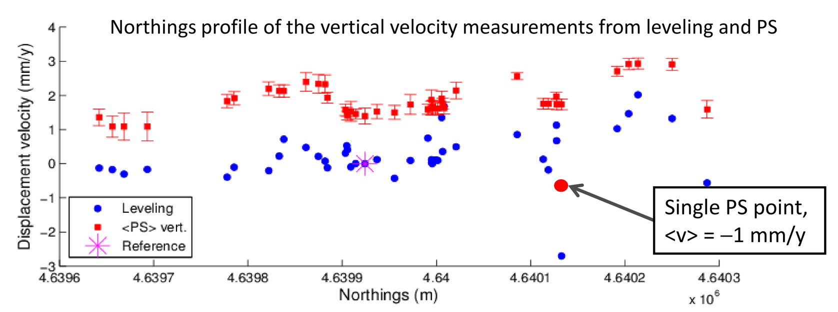
The east-west velocity component shows an apparent W-SW trend with maximum rates of about 2 mm/y.

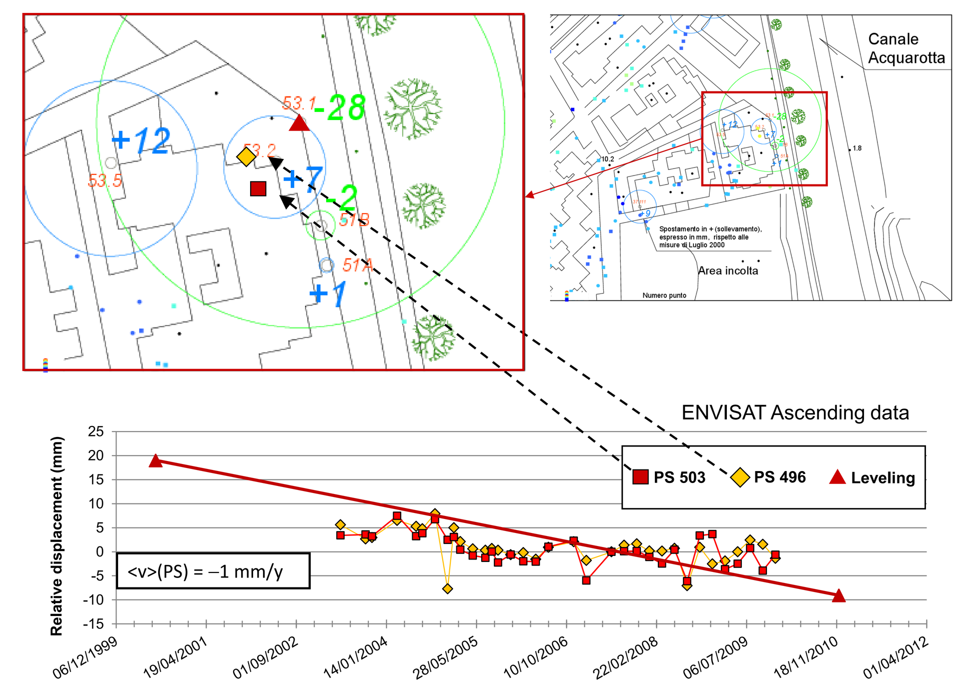


The displacement data were validated by comparison with leveling measurements performed in 2000 and 2010. Mean displacement velocities derived from each leveling data point were compared with the nearest PSI measurements within a fixed search radius. Differences appear Gaussian-distributed, with a mean of about 1.6 and a dispersion (st.dev.) of about 0.65 mm/y. Statistical correlation between the two datasets is reasonable, in spite of the limited span of the measured velocities.

A pair of PS were detected close to a sinkhole site, indicated by leveling measurements which reported a decreasing height of up to 28 mm in 10 years. The two PS points closest to these subsiding leveling benchmarks exhibit a slow downward movement, of about −1 mm/y. Compared to the surrounding, positive uplift velocity values, around 2-3 mm/y, this means a relative subsidence (negative) rate of about 3-4 mm/y.

The time series seem to indicate a relatively fast subsidence during the years 2005 and 2006, followed by a more stable behaviour. This seems compatible with the total displacement measured by the leveling.





Final Comments

The area affected by the vertical displacements coincides with the higher part of the salt dome, which was pushed out by several magmatic dikes (Punta delle Pietre Nere formation), 60 My aged. Therefore a residual diapirism, although rather unlikely, cannot be excluded in principle (Mastronuzzi and Sansò, 2002). Another phenomenon is the hydration of the residual anhydrite, in the core of the gypsum mass residing beneath the surface. Gypsum hydration, which involves a volume increase of up to 63% (Bell et al., 1986) of the hydrating mass, has been observed to cause consistent and sudden uplift phenomena on other sites, such as the city of Staufen, Germany (Lubitz et al, 2012), causing serious infrastructure damages. In the present case, the uplift phenomenon is much less intense, but the uplift intensity is apparently increasing towards the canal; this could be compatible with a smaller mass of anhydride, not directly exposed, or with other processes, characterized by a slower hydration rate.

Other factors which could be taken into account include the following:

- ✓ Stratigraphy of the area (sand vs. sediment layers)
- ✓ Geochemistry of the underground
- ✓ Seismicity of the area