The European Ground Motion Service For Cultural Heritage Monitoring

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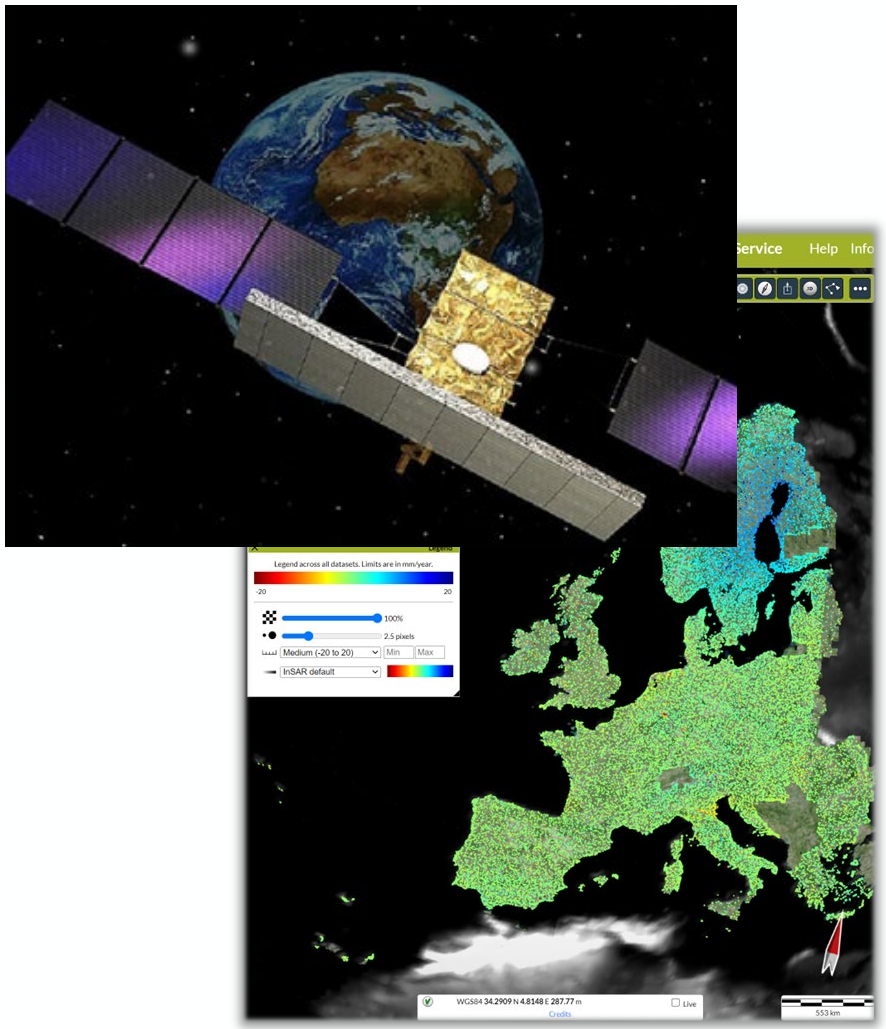
Our team

ISPRA
Istituto Superiore per la Protezione
e la Ricerca Ambientale

Sistema Nazionale
per la Protezione
dell'Ambiente

Introduction



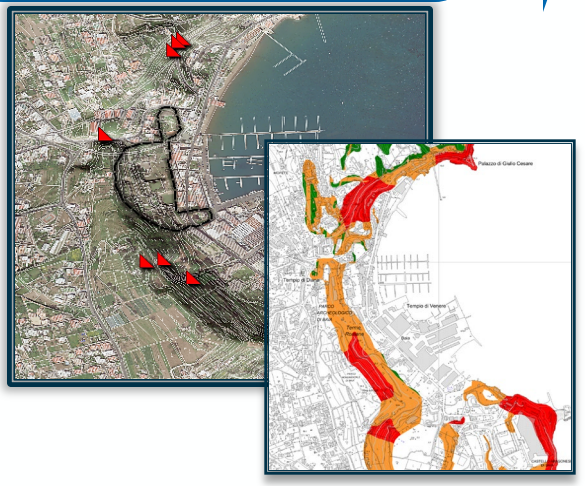
★ Archaeological area of the Phlegrean Fields

★ Ancient port of Classe in Ravenna city

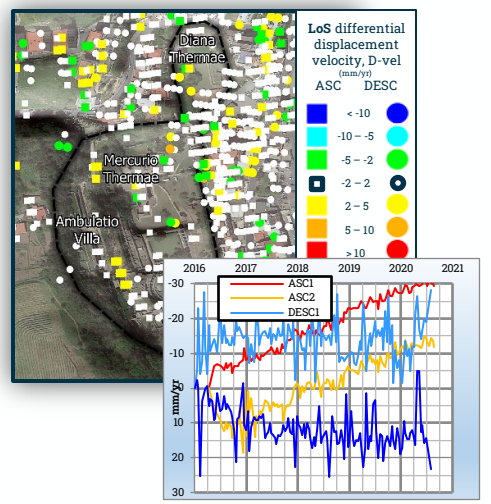
Methodology

CH Background (desk and field study):
investigating the origin, typology, construction techniques, restoration history, evolution in time, etc.

Geohazard assessment
Hazard and risk map analysis



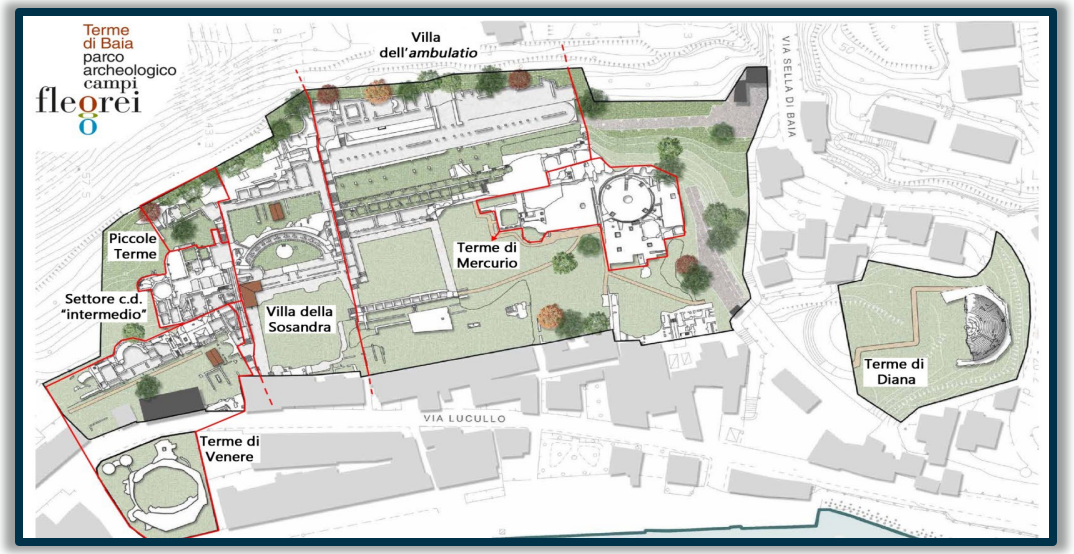
SAR Interferometry
Data integration and services



Ground motion monitoring
Field survey and risk mitigation plan

Phlegrean Fields Archaeological Park: general setting

The Roman Thermae of Baia: site map



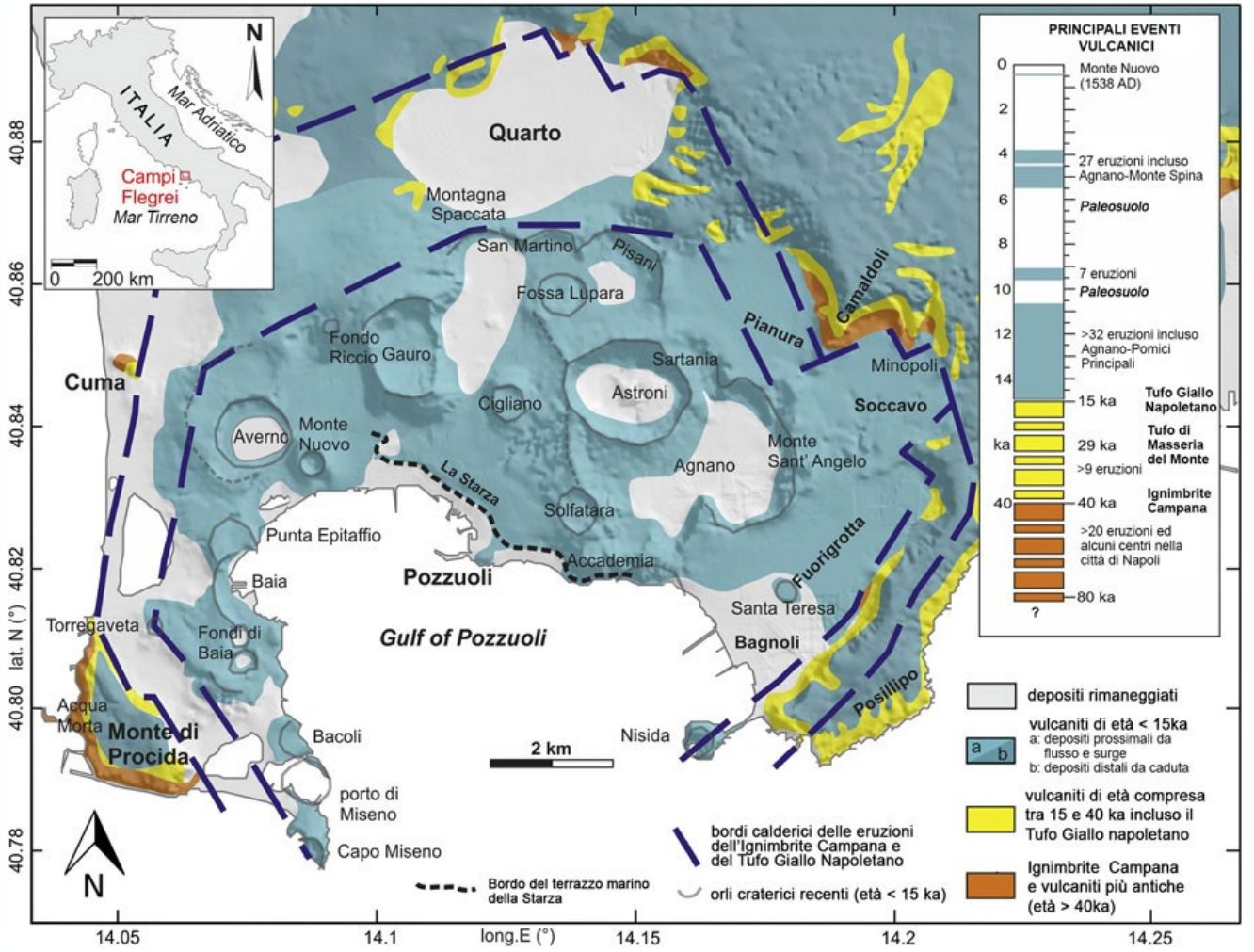
Geohazard assesment: geological and geomorphological setting

- volcanic-related subsidence with unrest cycles characterised by intense ground uplift and lowering

Surge deposists

Piroclastic deposists

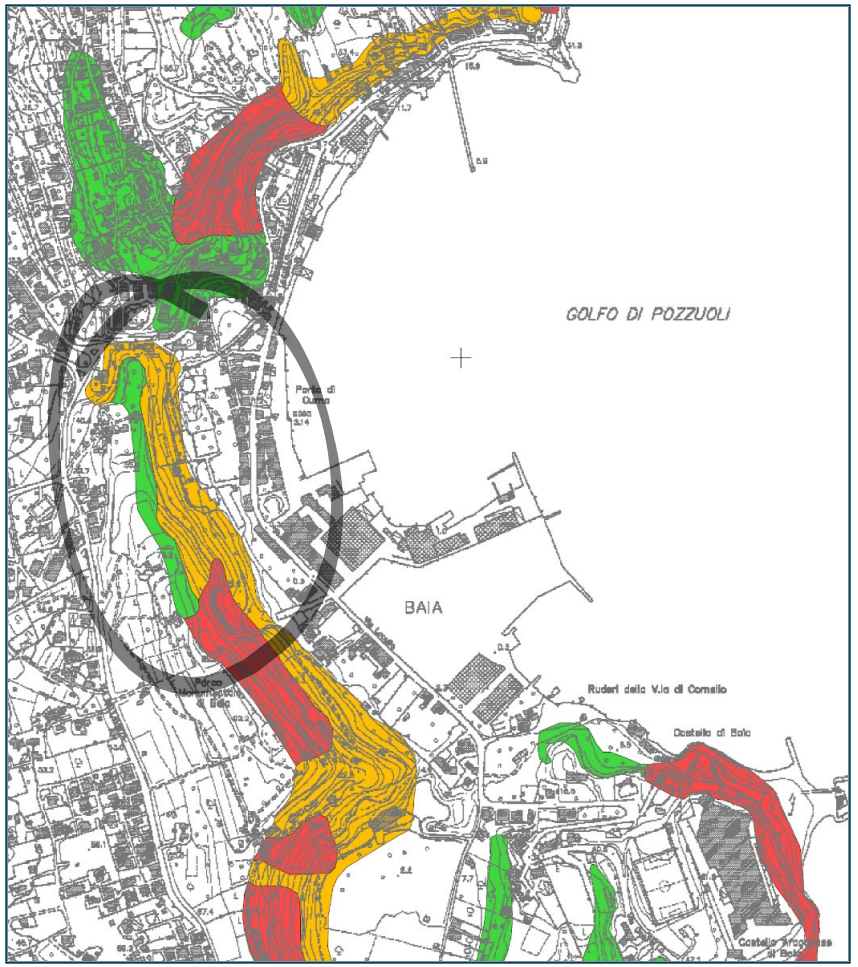
Volcanic breccia



Geohazard assesment: ground instability

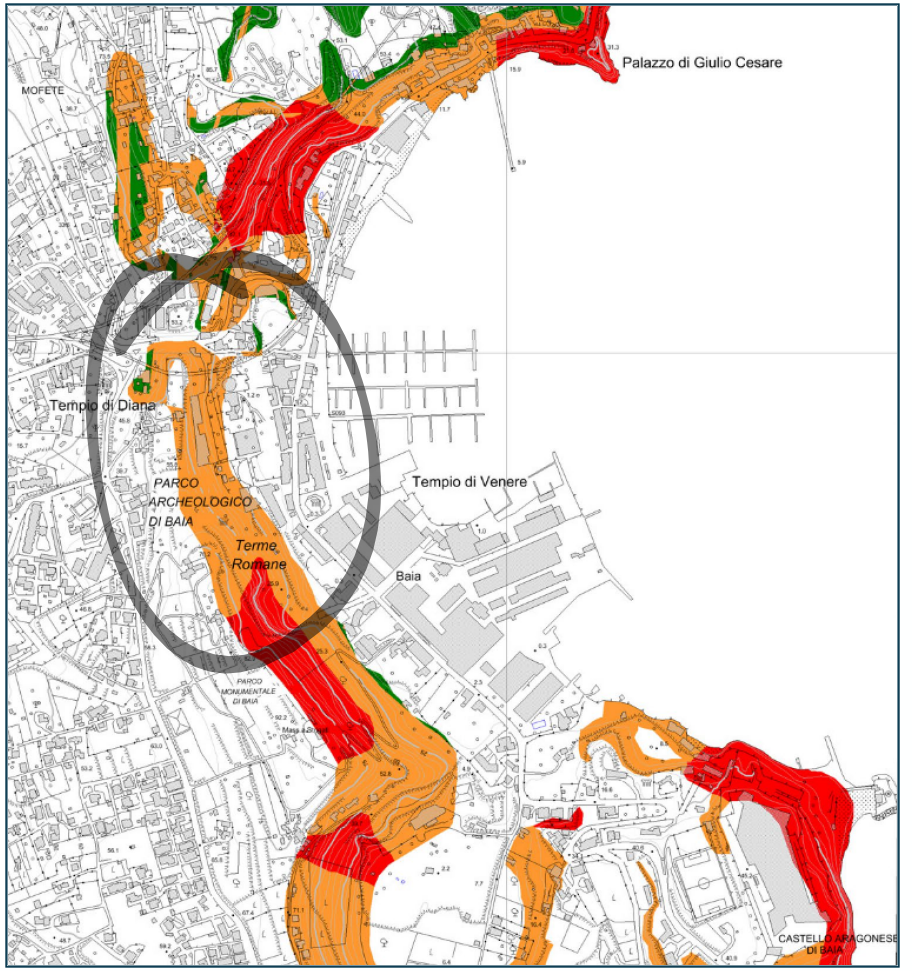
Local planning authority hazard and risk assessment

Landslide susceptibility



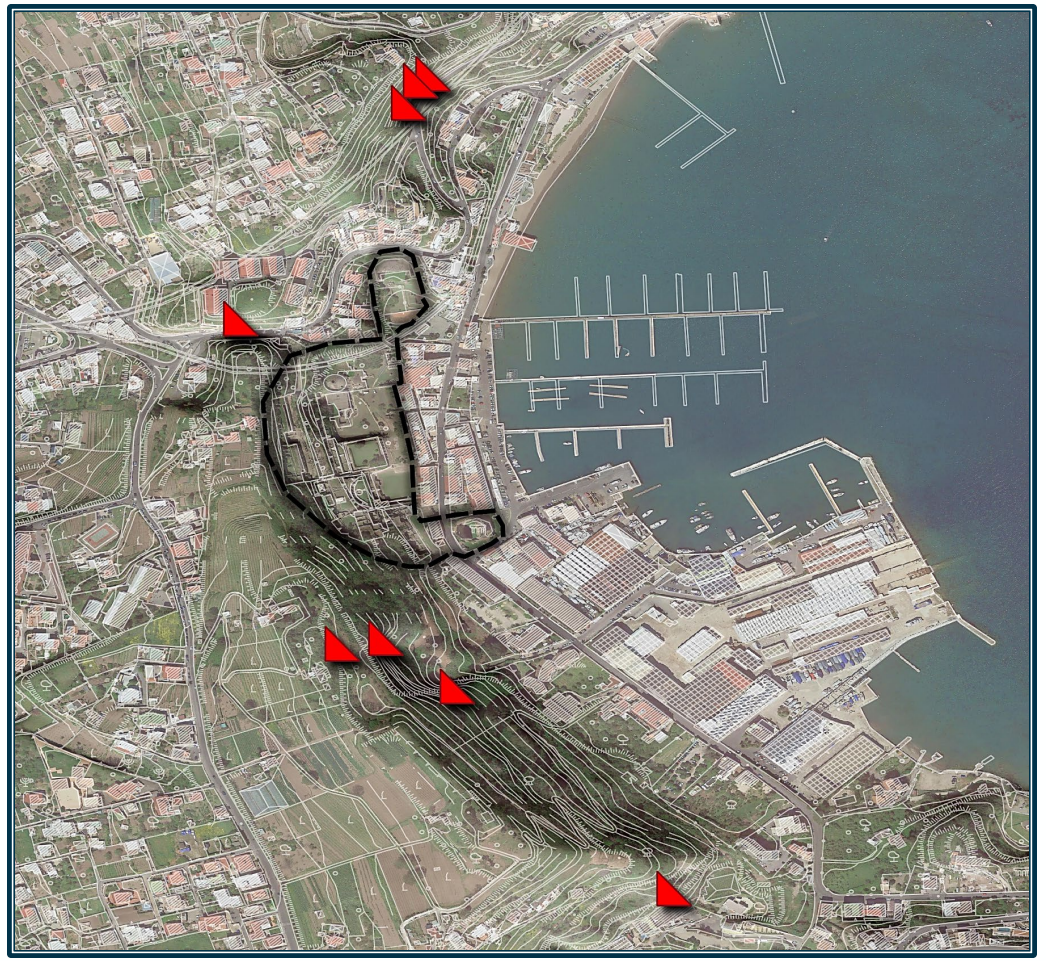
Very high
High
Medium
Low

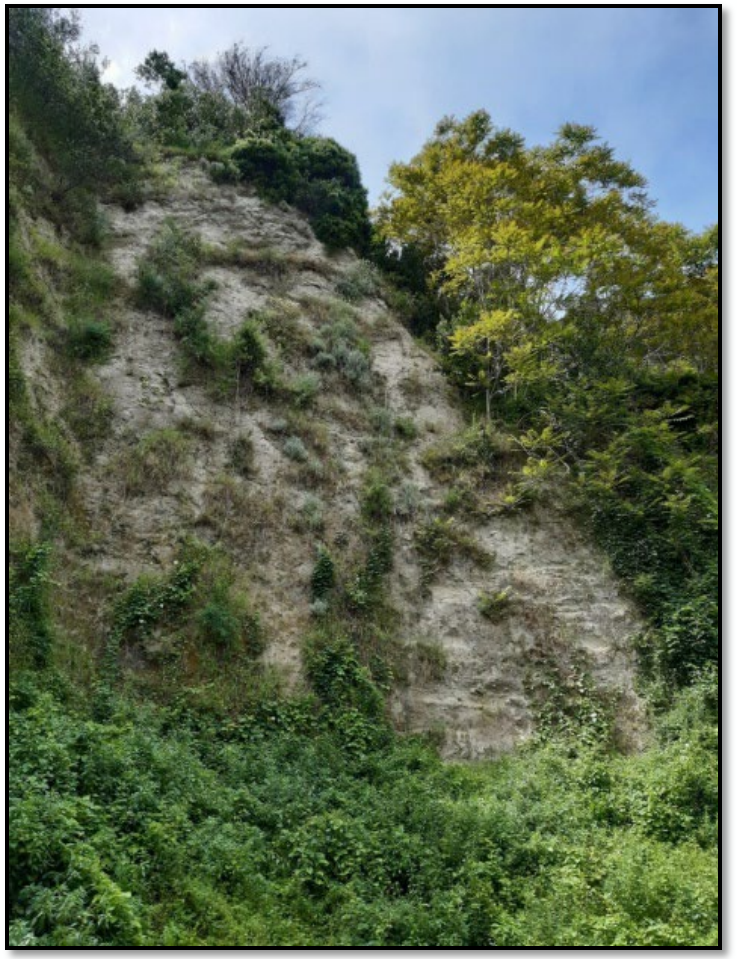
Landslide risk



Geohazard assesment: ground instability

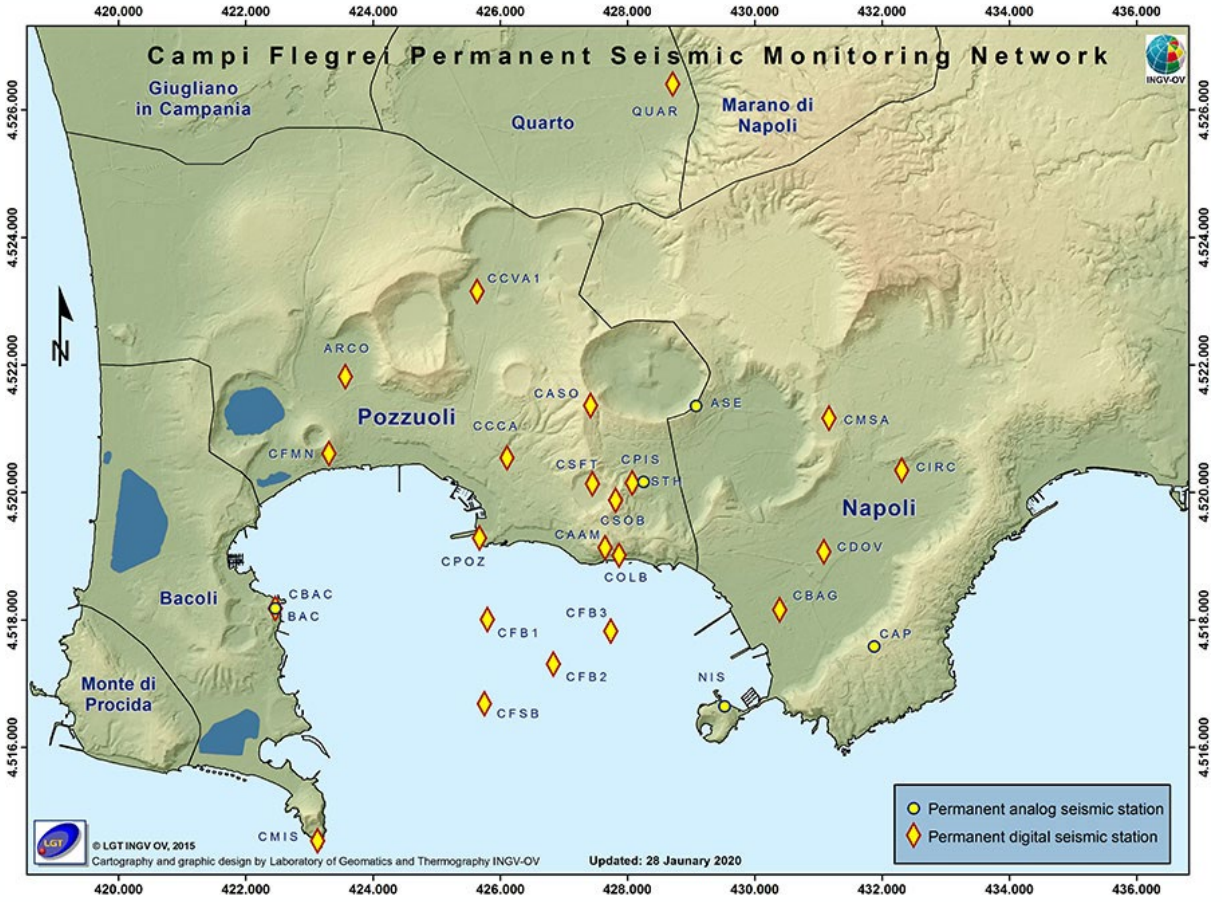
Landslide inventory



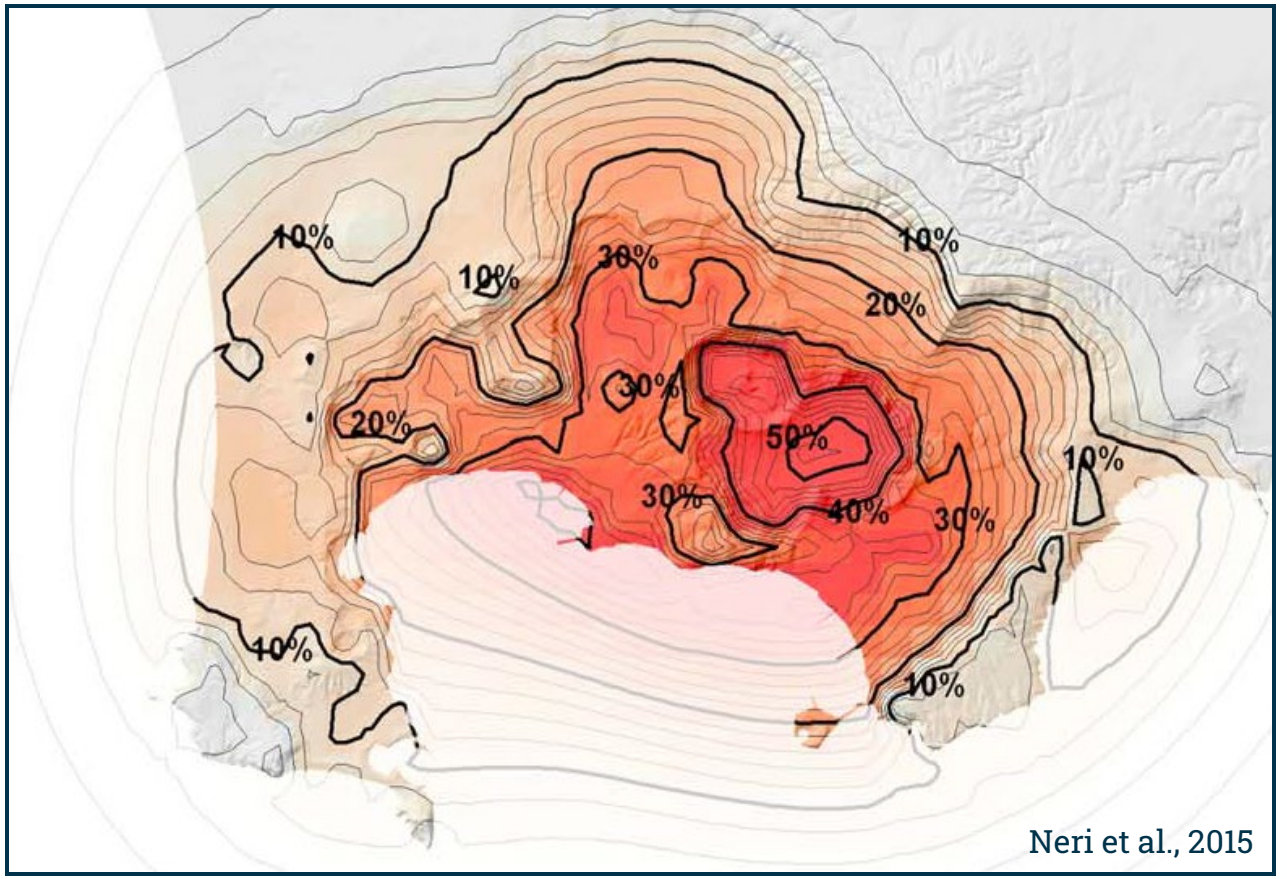


Geohazard assesment: volcanic and seismic risk

Permanent Seismic Monitoring Network



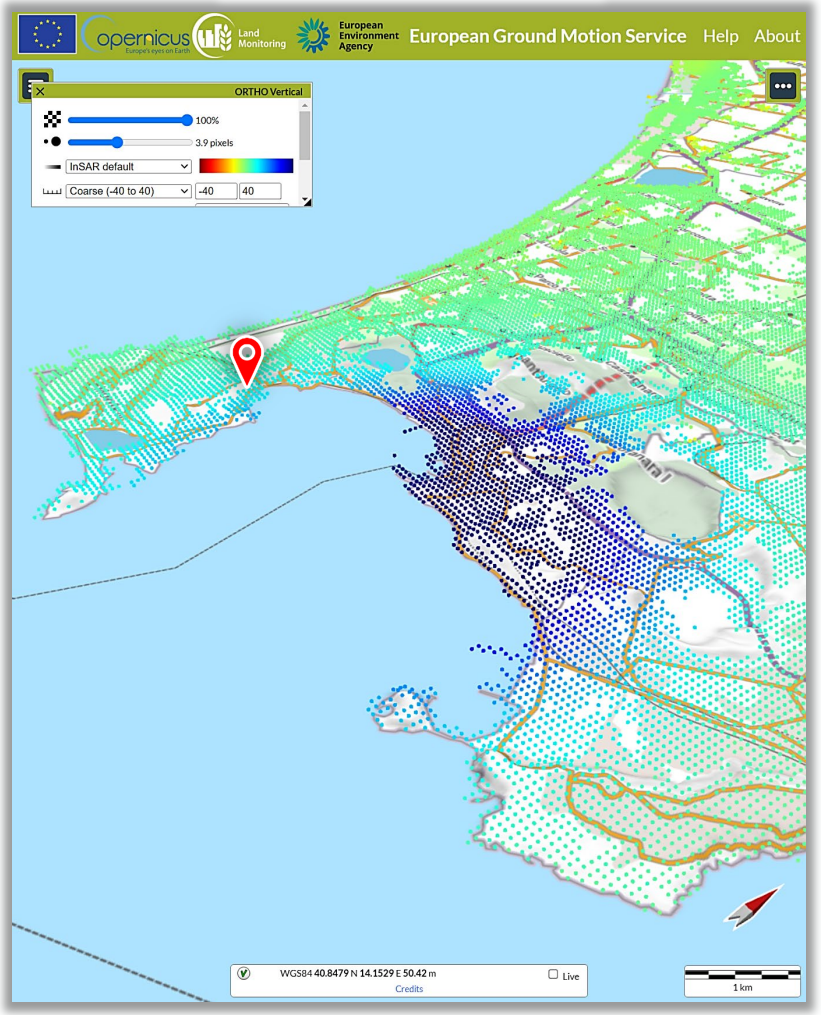
Pyroclastic Density Currents (PDC) invasion probability maps



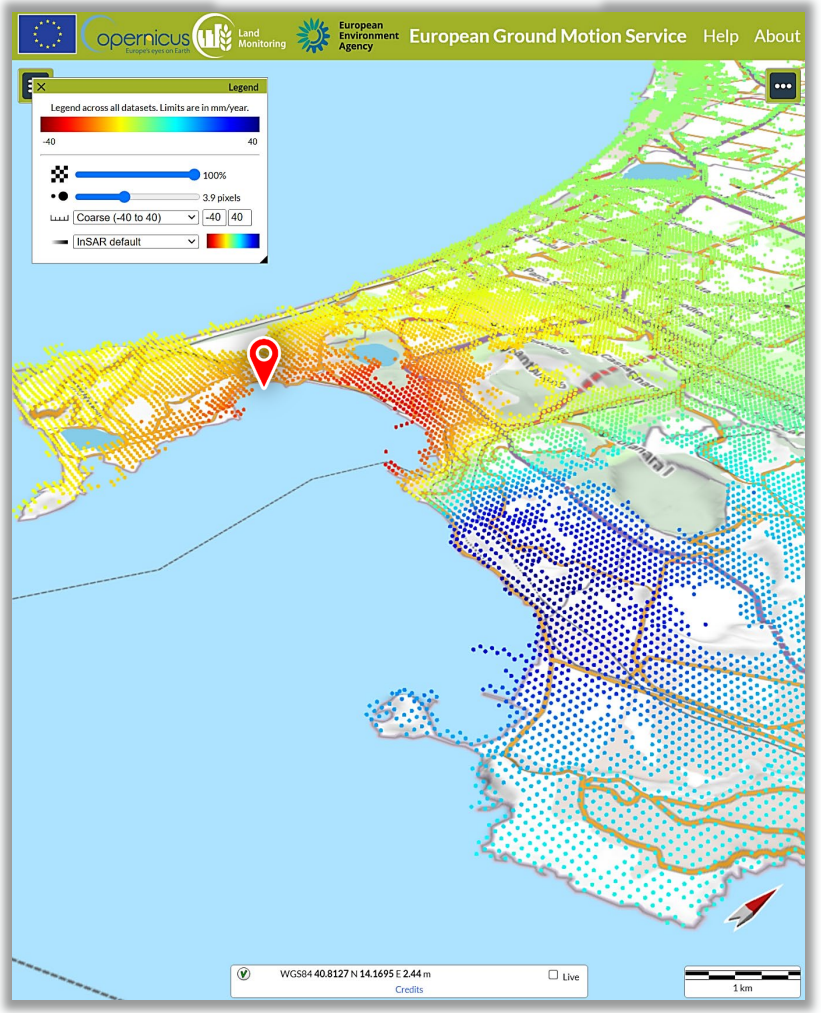
Neri et al., 2015

PS InSAR analisys - EGMS (ORTHO level) 2015-2020

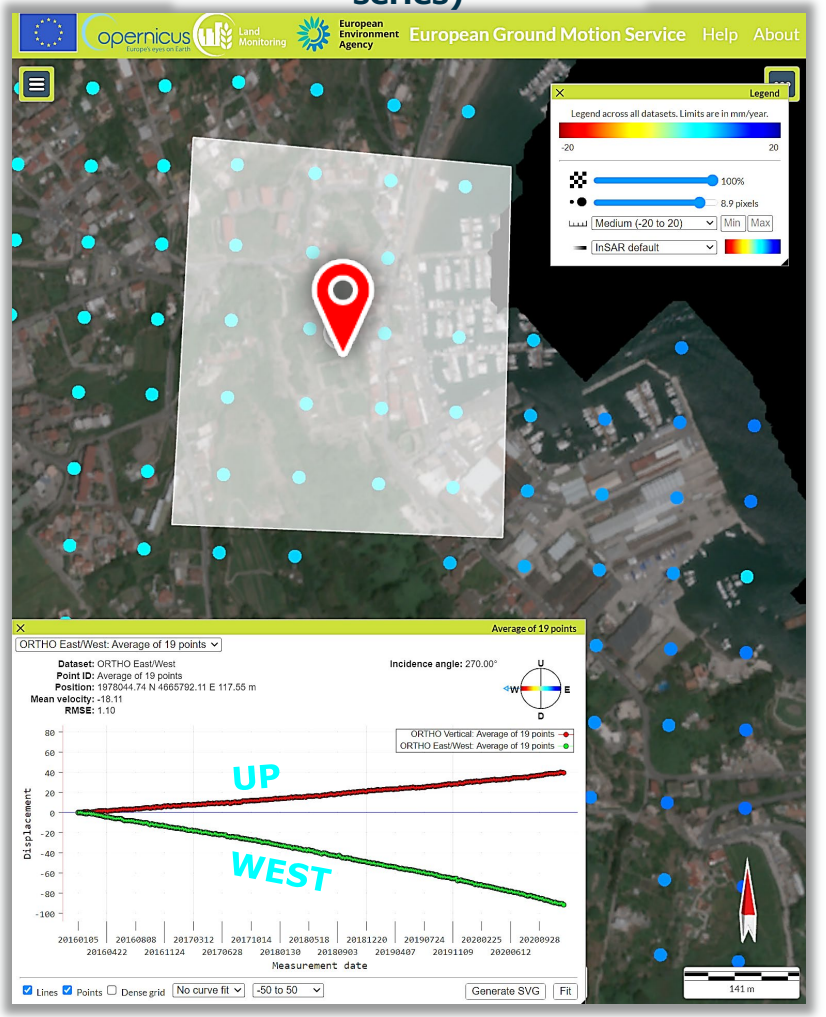
vertical (up)



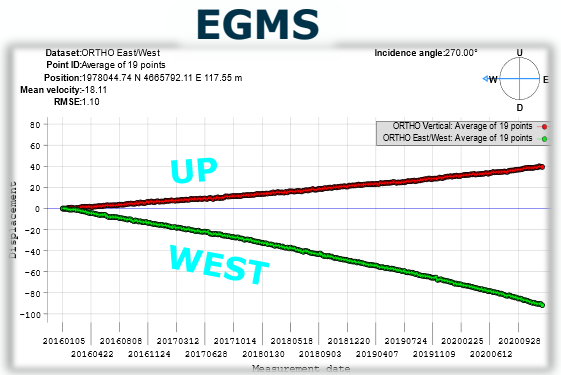
horizontal (E-W)

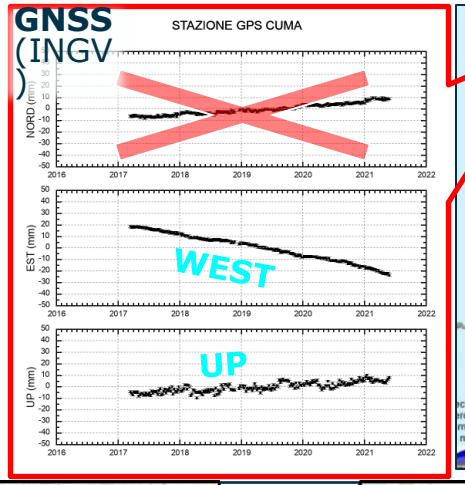


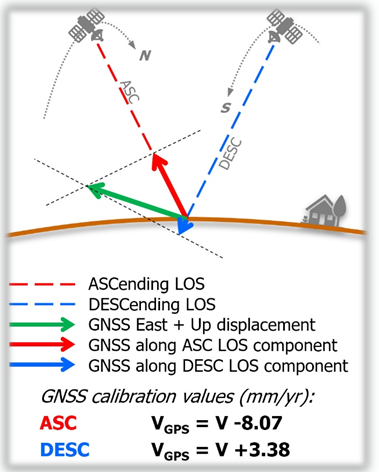
site analysis, 19 PS (time series)

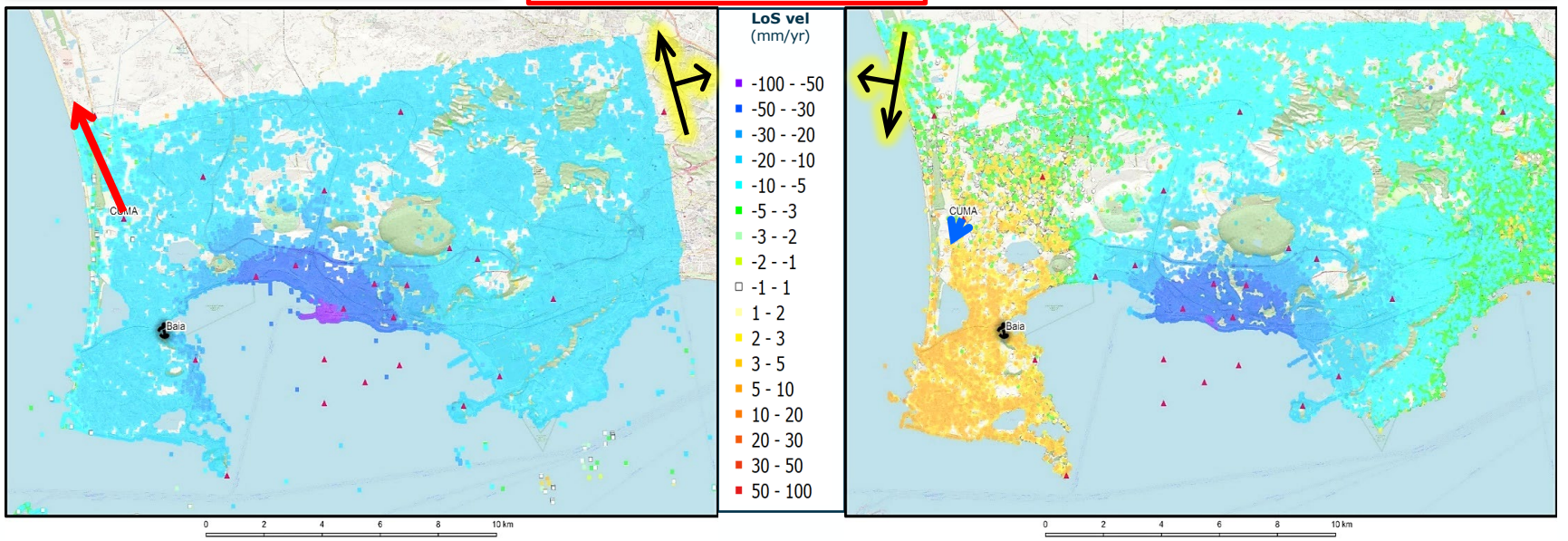


PS InSAR analisys- ISPRA Campi Flegrei









The Cuma GPS station, belonging to the GNSS monitoring network of the Vesuvius Observatory (INGV), is the nearest of those outside the Campi Flegrei volcanic area.

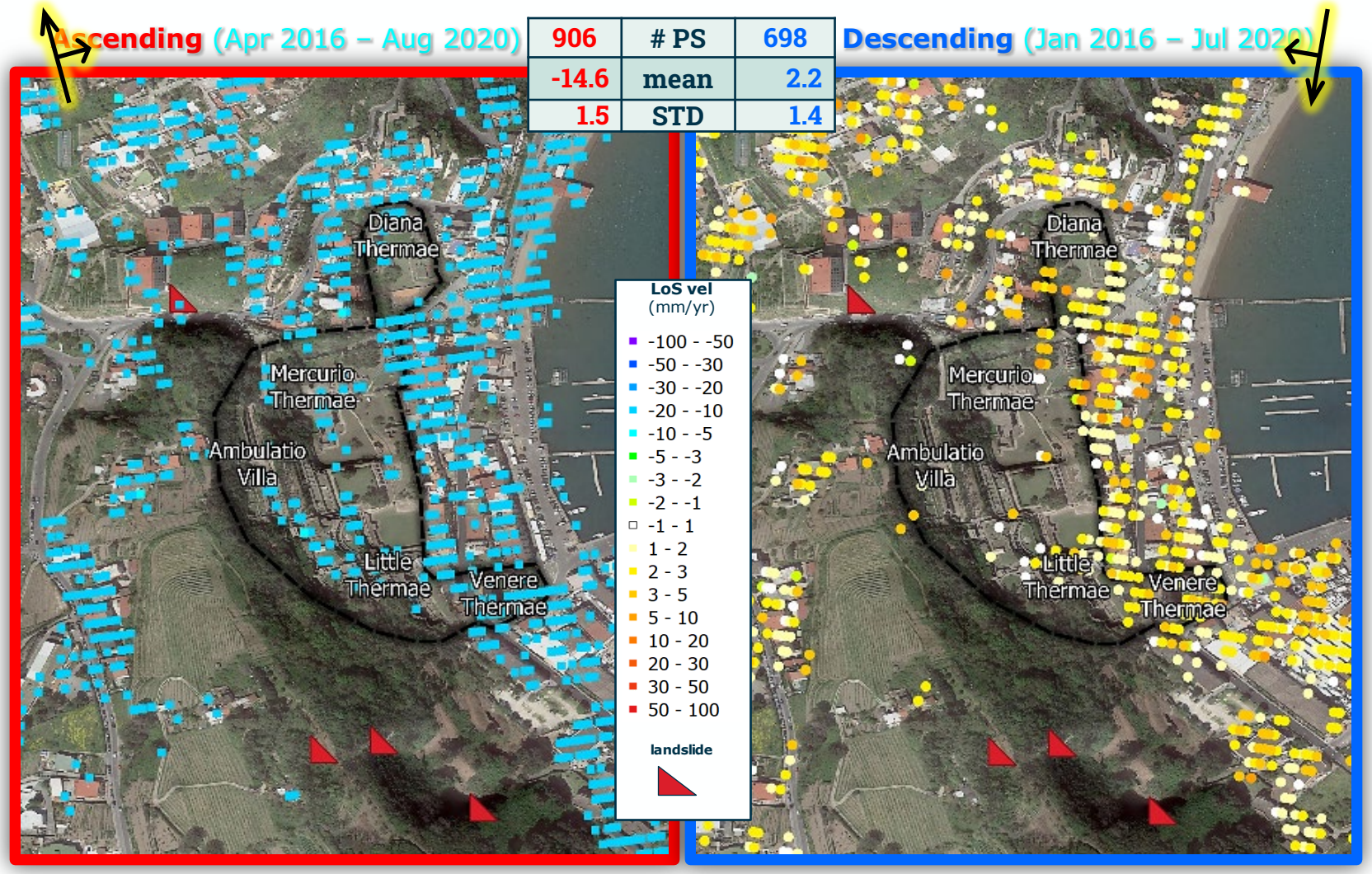
The N-S component of the displacement is not detected by the InSAR technique.

The LoS displacement is calibrated with respect to the regional displacement trend.

ISPRA and INGV have developed a PS InSAR product calibrated with the GNSS data, in ascending and descending geometry, showing displacements along the respective LoS.

This product is an equivalent of the EGMS Level 2b.

Ground Motion: PS InSAR data interpretation



Due to the PS coverage, for each acquisition geometry, the interpretation of PS InSAR data at the site scale requires the highest resolution available.

The horizontal displacements component is highlighted through the comparison between PS measured from two opposite viewpoints, as is the case for slope movements.

In this case, the ascending geometry is more affected by the northwestward displacement of the area, with average "uplift" values of about 15 mm/year.

On the other hand, localized differential displacements are more evident with descending geometry.

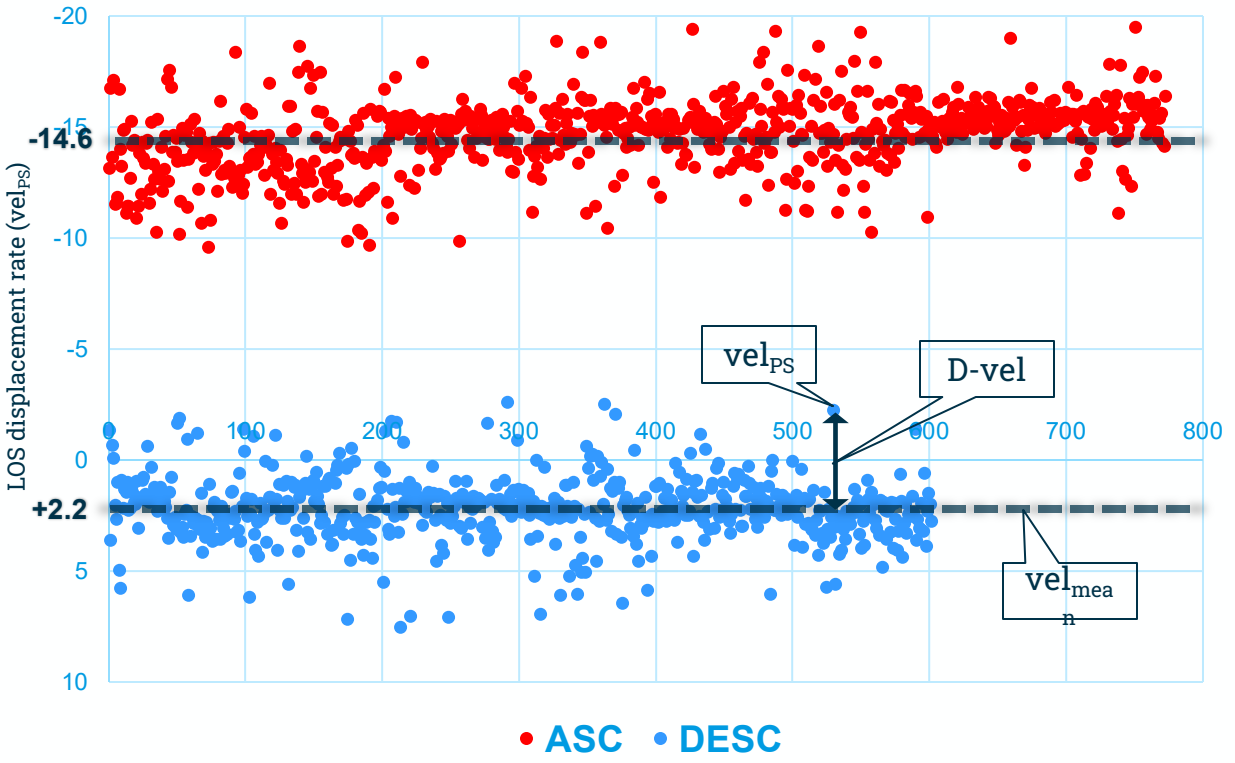
Differential displacement

The area is subject to high rates, more evident with the ASCending geometry.

Therefore, to highlight differential ground motions at the site scale, the difference between the displacement velocity of each measurement point (PS) and the site mean value was calculated.

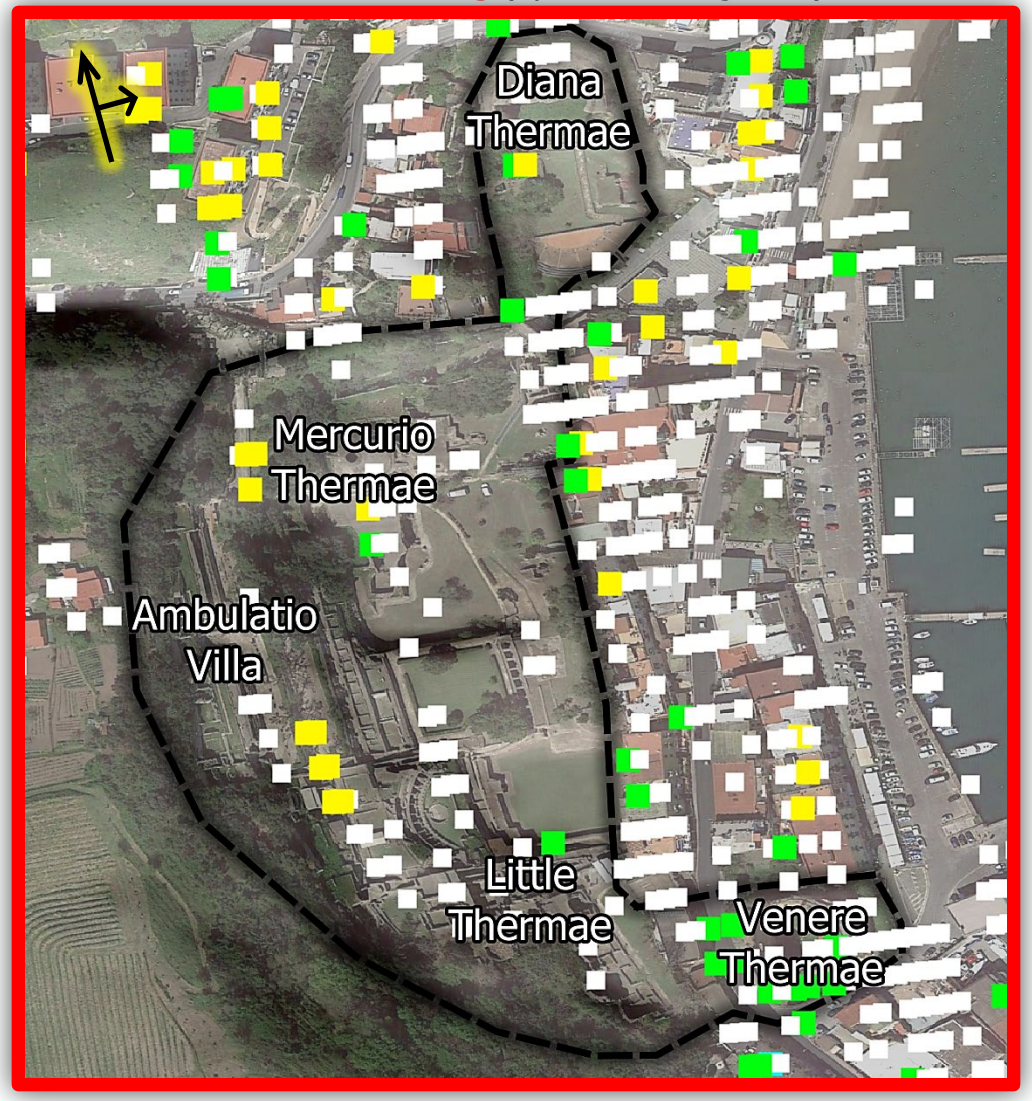
$$D\text{-}vel = vel_{PS} - vel_{mean}$$

ASC	mean D-vel	DESC
-14.6	mm/yr	2.2



Differential displacement (D-vel)

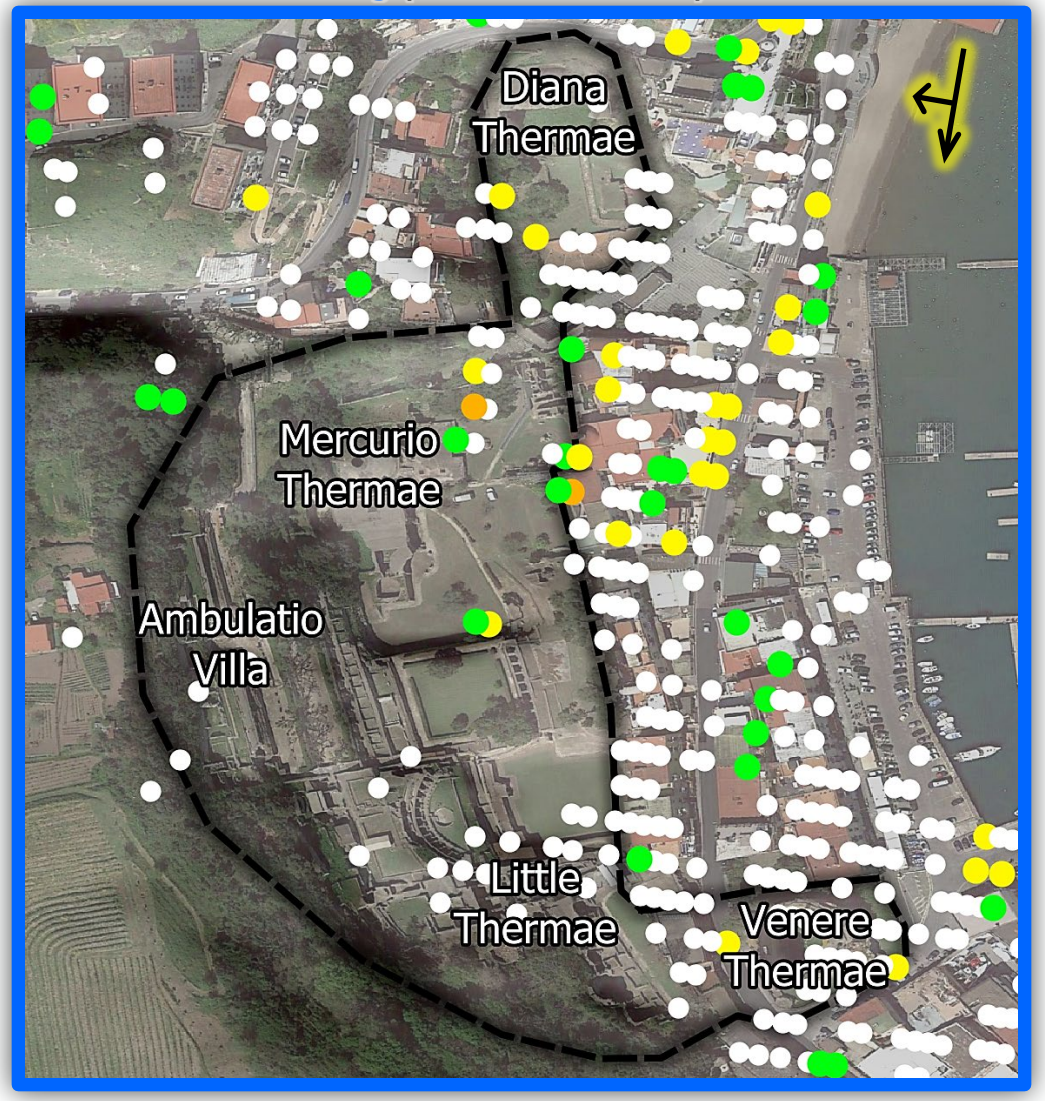
Ascending (Apr 2016 – Aug 2020)



LoS differential displacement velocity, D-vel (mm/yr)

ASC		DESC
	< -10	
	-10 – -5	
	-5 – -2	
	-2 – 2	
	2 – 5	
	5 – 10	
	> 10	

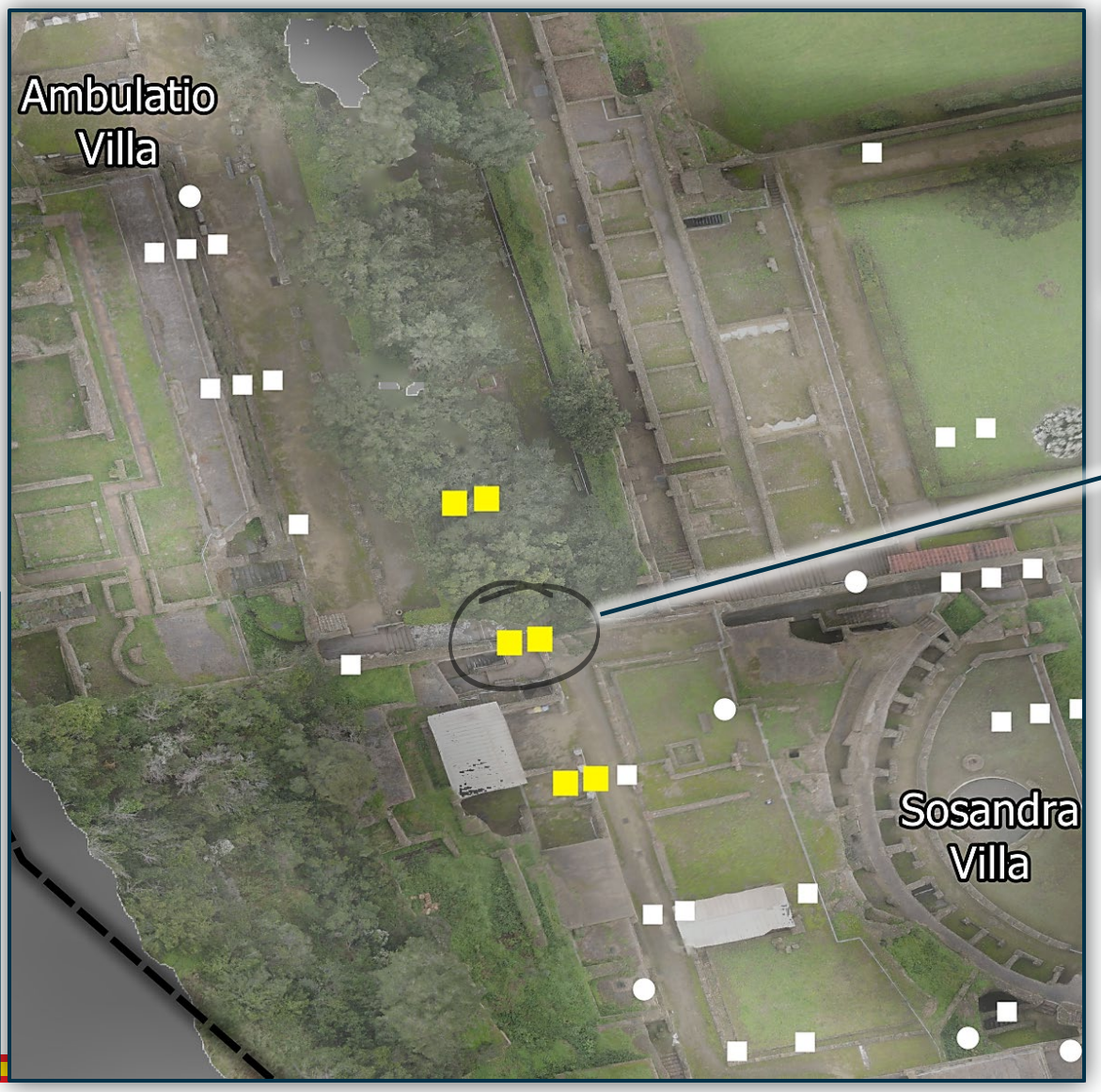
Descending (Jan 2016 – Jul 2020)



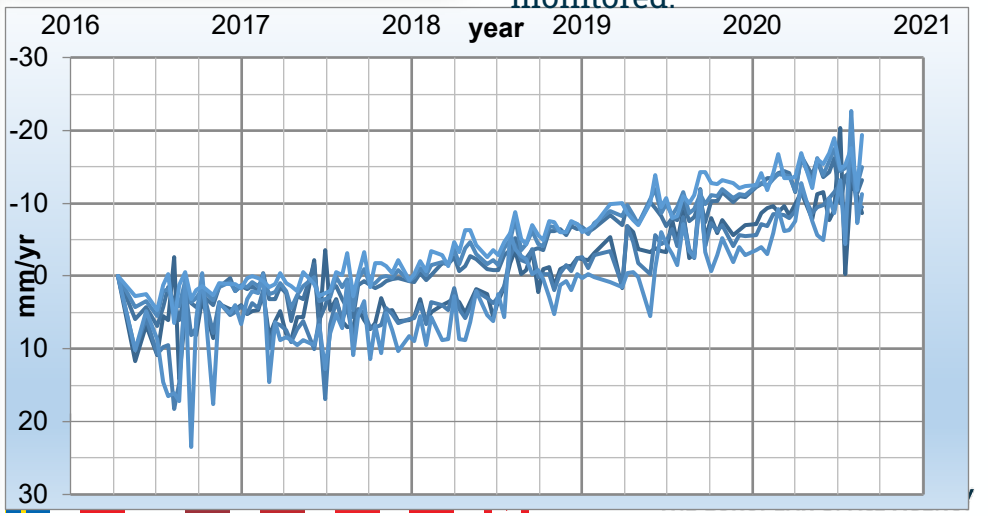
PSI data interpretation: upper terrace example

LoS differential displacement velocity, D-vel (mm/yr)

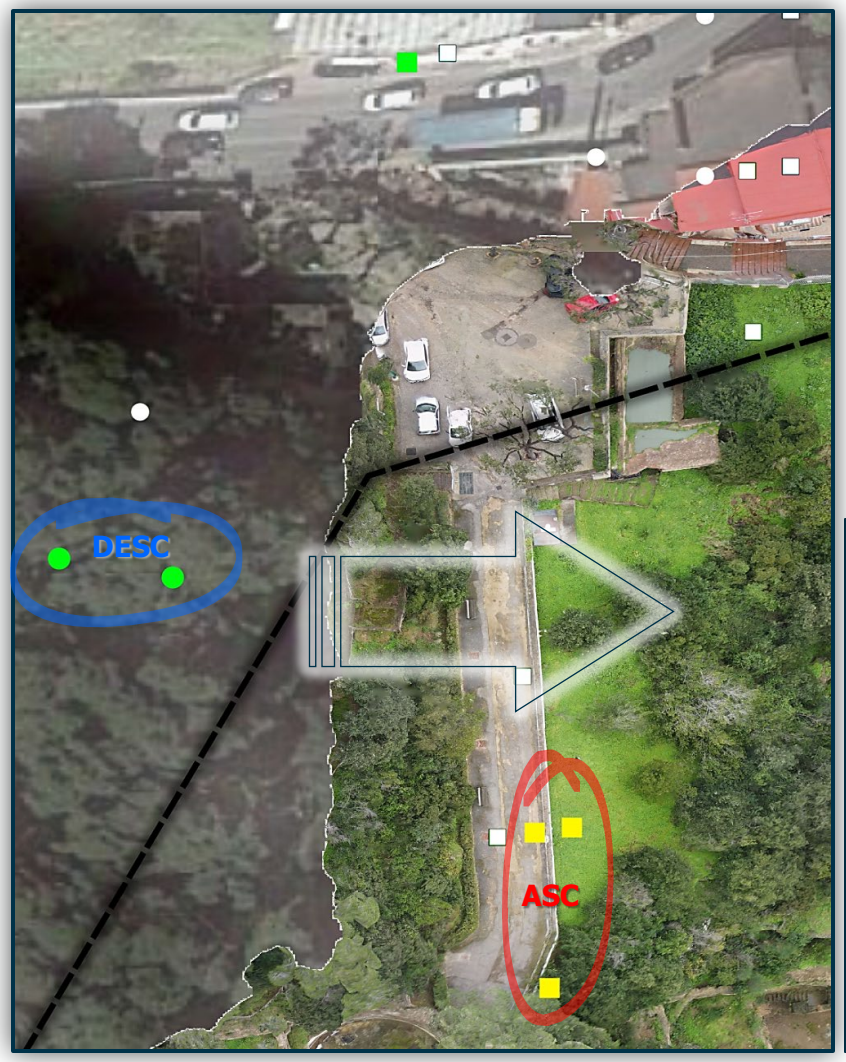
ASC		DESC
	< -10	
	-10 – -5	
	-5 – -2	
	-2 – 2	
	2 – 5	
	5 – 10	
	> 10	



Ascending geometry seems to be more sensitive to radar targets in the site area; this is due mainly to "noise effect", then to East facing geometry of the slope too. At the edge between *Ambulatio* and *Sosandra* villas a cluster of 6 PSs indicates, consistently, a relatively subsiding area. The crack along the sidewall may indicate this masonry weakness, thus needs to be properly monitored.



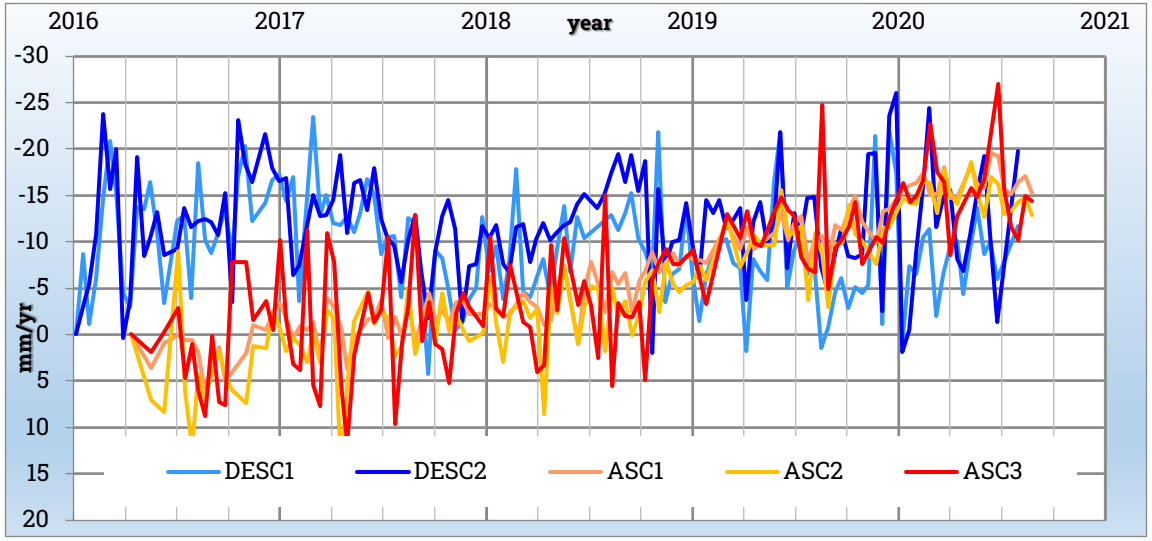
Slope stability: PS InSAR analysis



The combined interpretation of the PS, moving away from the ASC satellite and approaching the DESC satellite, shows the prevalence of the horizontal movement of slow slope sliding eastward, i.e., seaward.

LoS differential displacement (mm/yr)

	< -10
	-10 – -5
	-5 – -2
	-2 – 2
	2 – 5
	5 – 10
	> 10



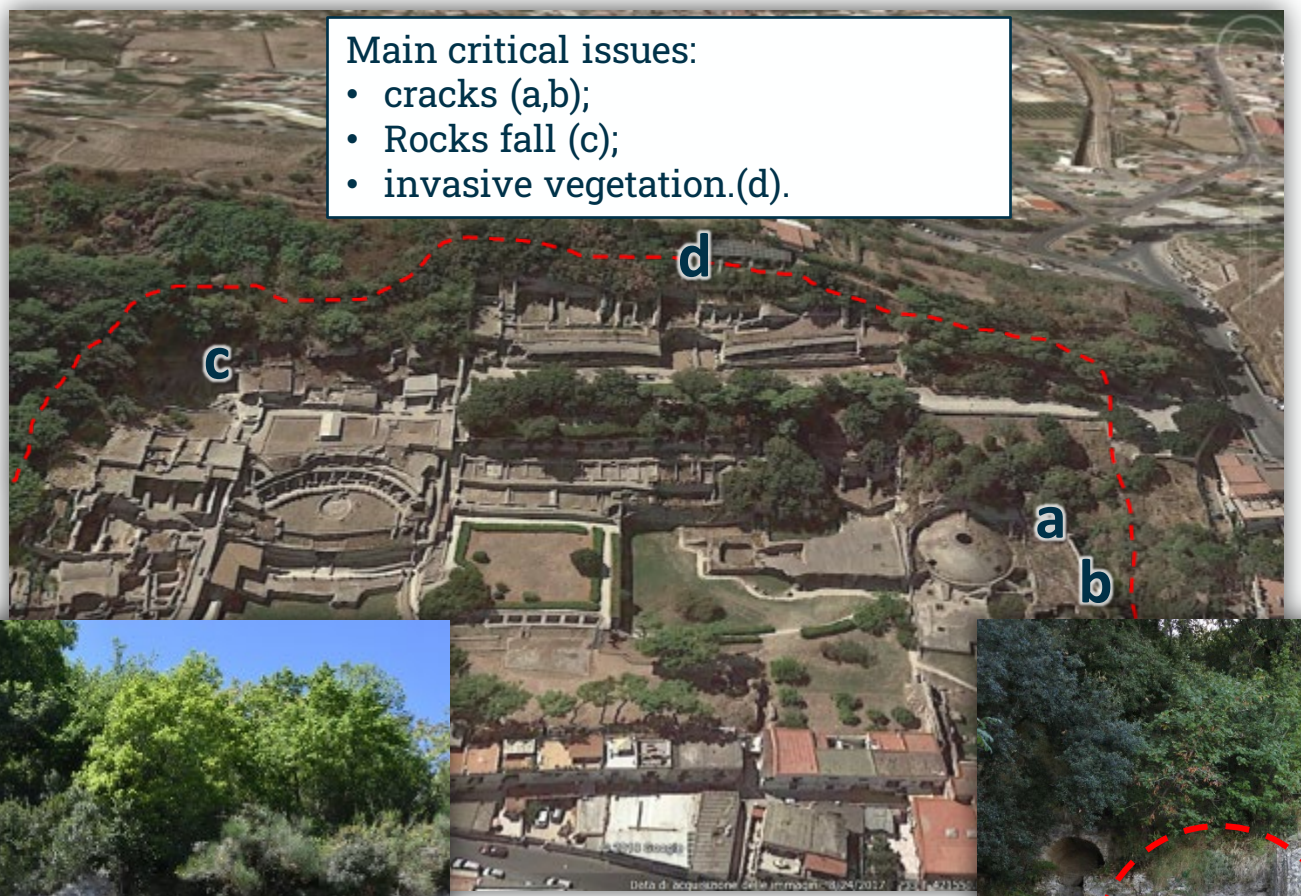
Field survey

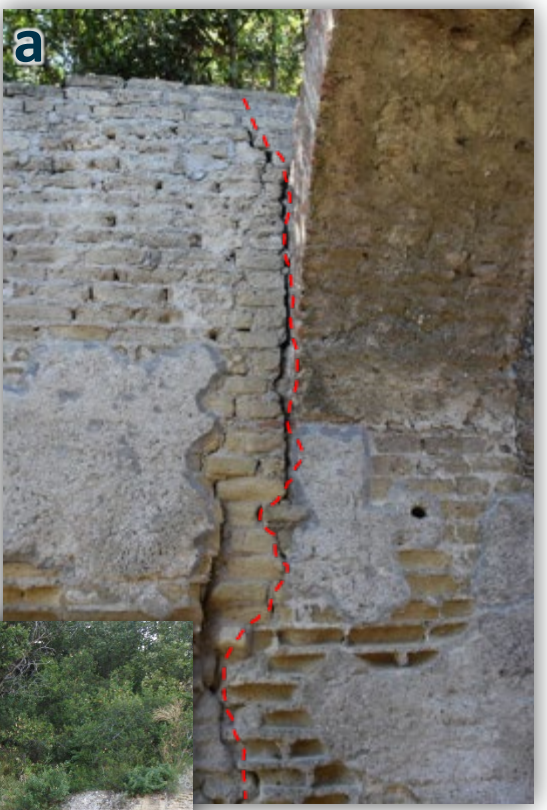
The analysis of the area and of the type of buildings helps in classifying main ruptures:

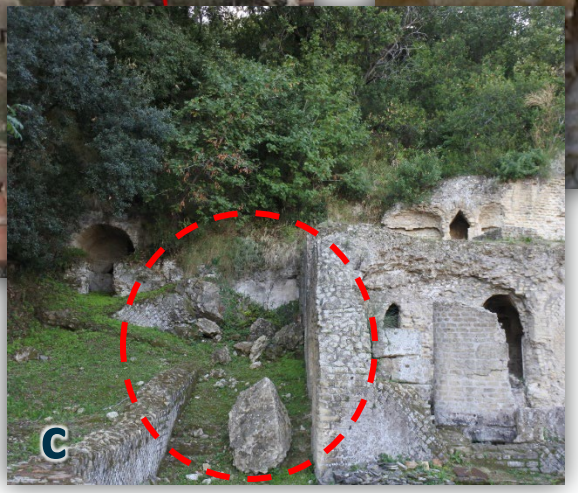
- cover detachment (1);
- wall cracks (2, 4);
- block fall (3);
- leaning walls, that need shoring (5).

Demage overview

Main critical issues:
- cracks (a,b);
- Rocks fall (c);
- invasive vegetation.(d).

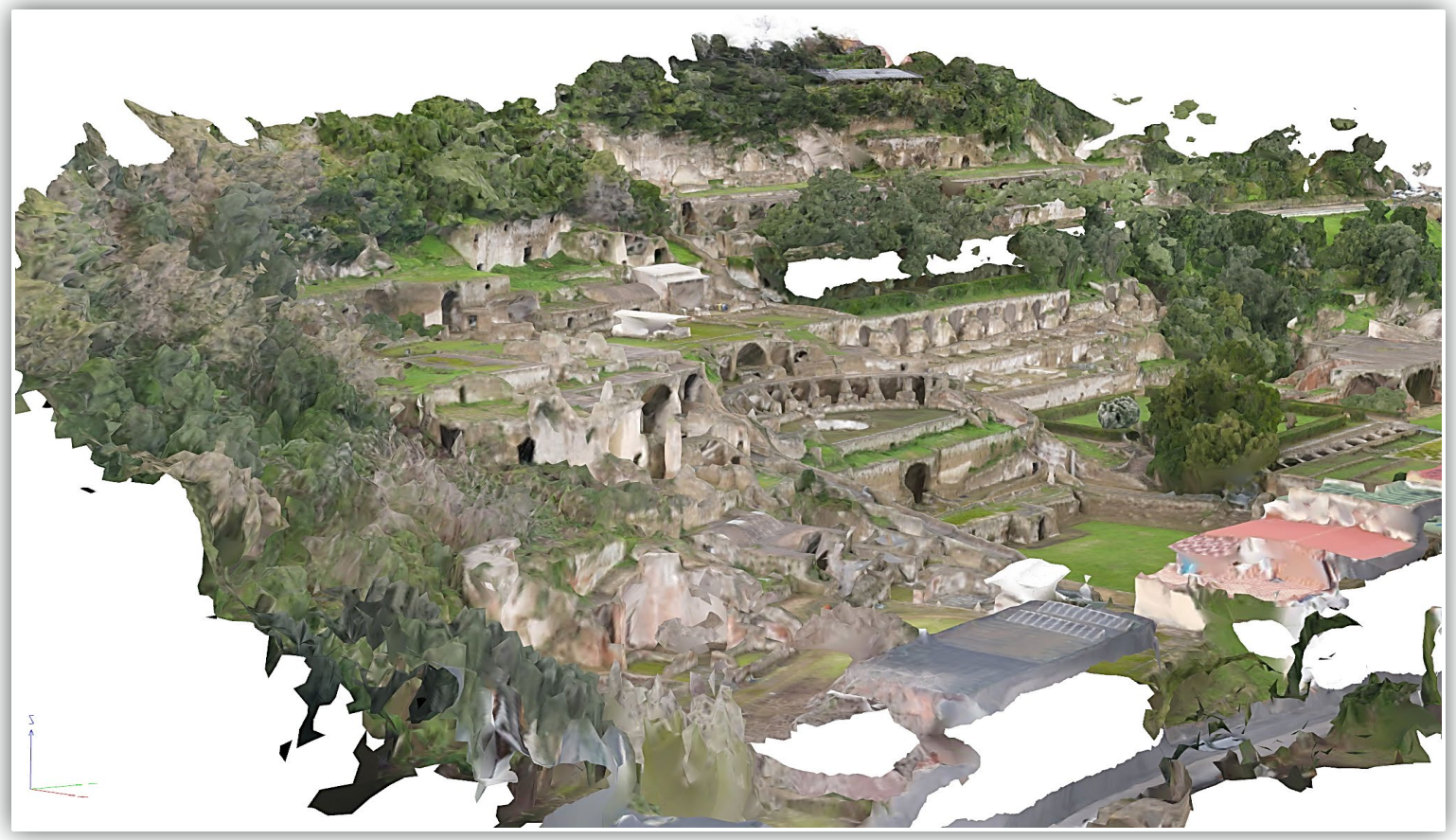






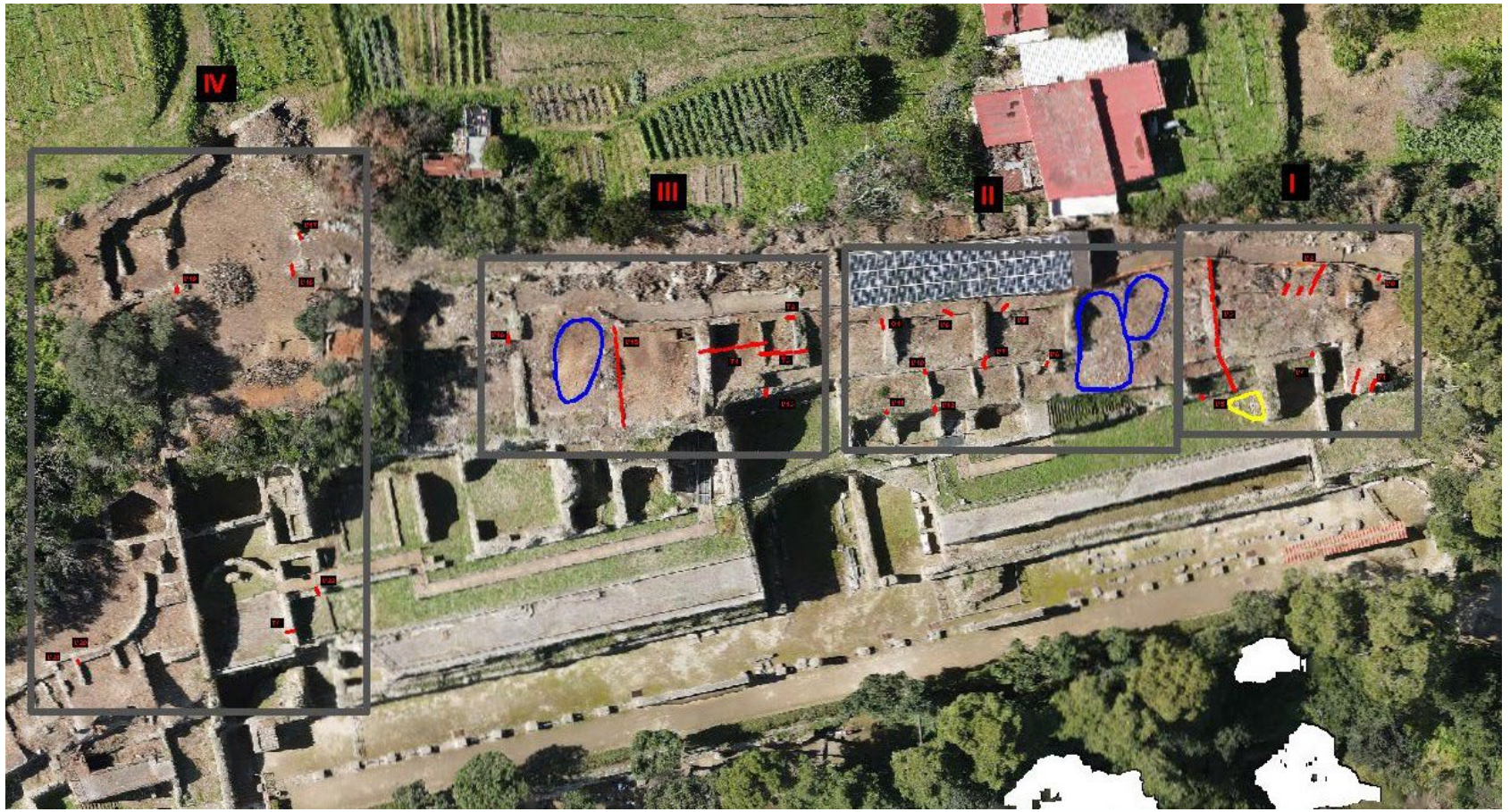
CH management

3D survey



CH management

Image interpretation



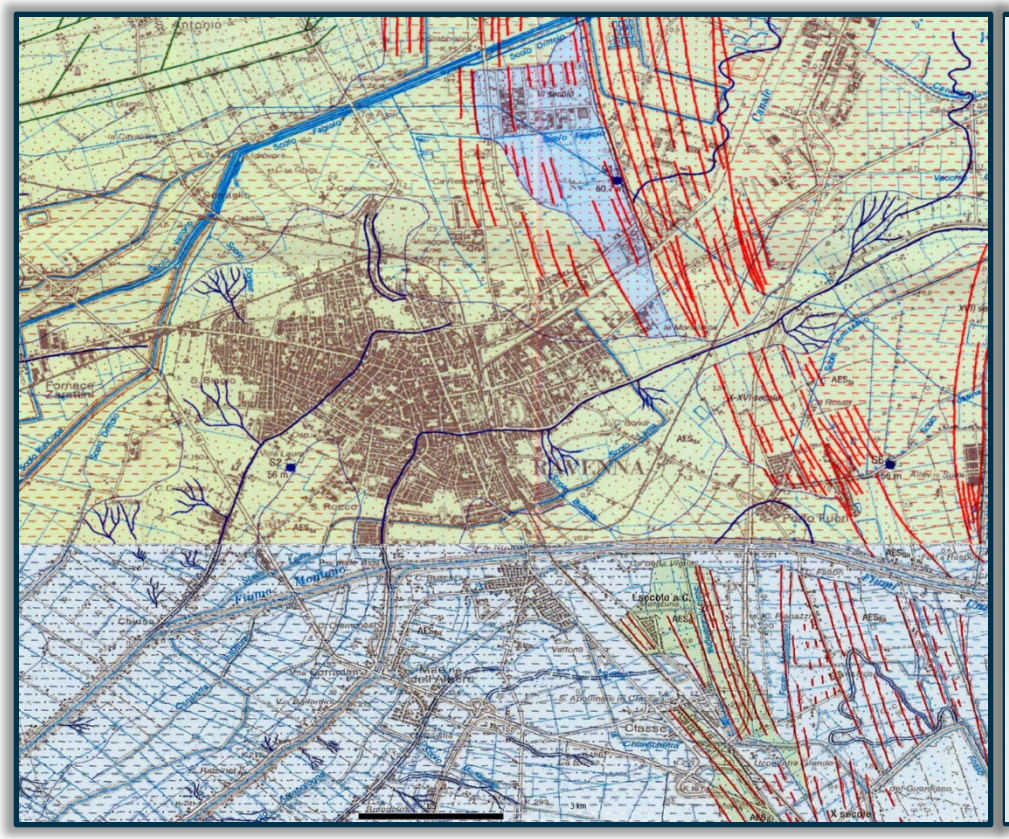
cracks V= vertical development; T= transversal to the slope ; O= subhorizontal

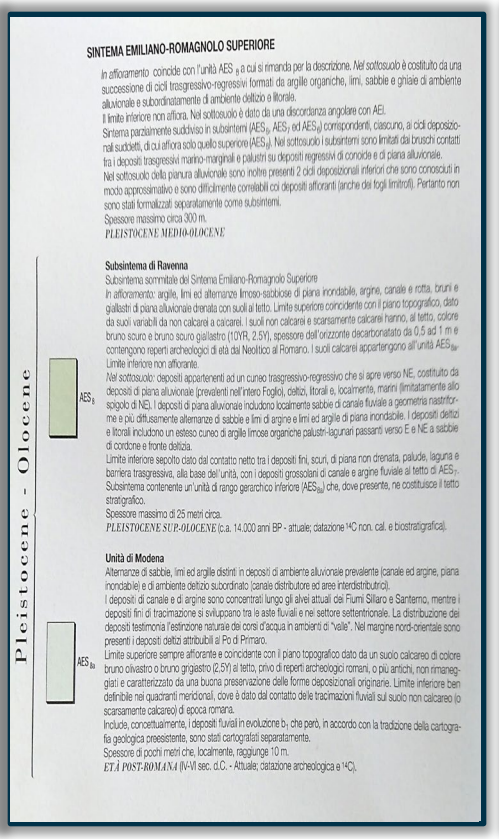
Wall structure blocks (recent collapse)

Soil creep

Classe Port, Classe Archaeological Park: general setting

Geohazard assesment: geological and geomorphological setting





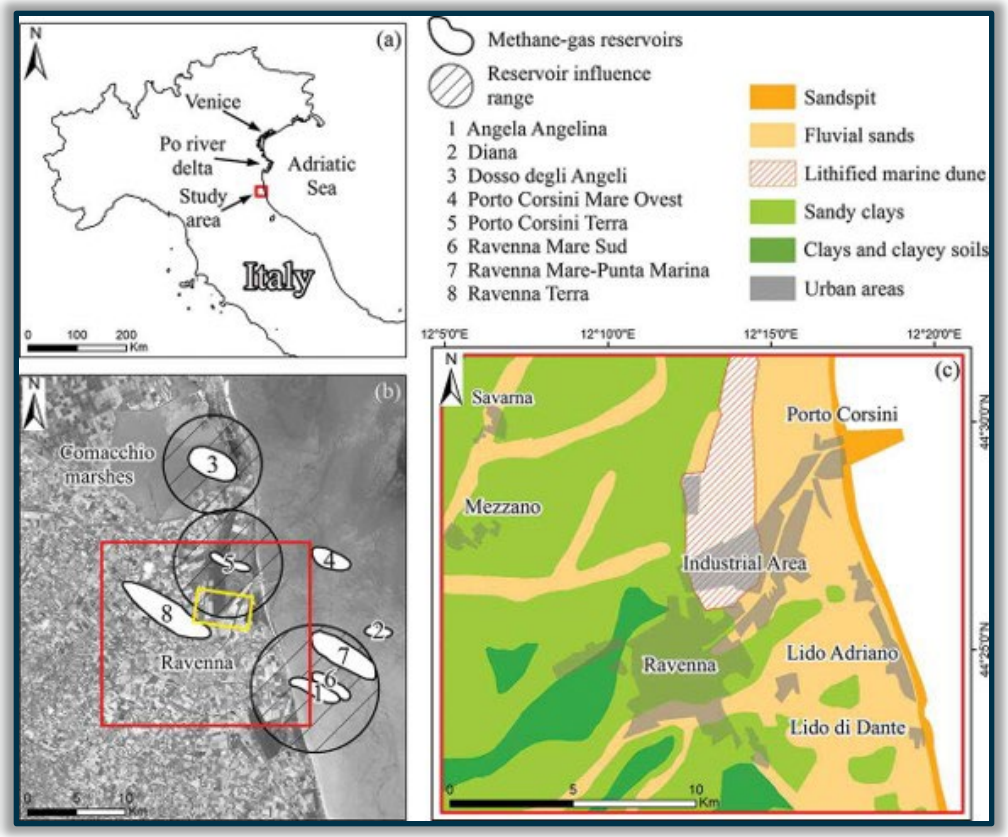
SINTEMA EMILIANO-ROMAGNOLO SUPERIORE

In affioramento coincide con l'unità AES 8 a cui si rimanda per la descrizione. Nel sottosuolo è costituito da una successione di cicli trasgressivo-regressivi formati da argille organiche, limi, sabbie e ghiaie di ambiente alluvionale e subordinatamente di ambiente deltizio e litorale.
Il limite inferiore non affiora. Nel sottosuolo è dato da una discordanza angolare con AEI.
Sintema parzialmente suddiviso in subsintemi (AES_{8c}, AES_7 ed AES_{8a}) corrispondenti, ciascuno, ai cicli deposizionali suddetti, di cui affiora solo quello superiore (AES_{8a}). Nel sottosuolo i subsintemi sono limitati da bruschi contatti tra i depositi trasgressivi marino-marginali e palustri su depositi regressivi di conoide e di piana alluvionale.
Nel sottosuolo della pianura alluvionale sono inoltre presenti 2 cicli deposizionali inferiori che sono conosciuti in modo approssimativo e sono difficilmente correlabili coi depositi affioranti (anche dei fogli limitrofi). Pertanto non sono stati formalizzati separatamente come subsintemi.
Spessore massimo circa 300 m.
PLEISTOCENE MEDIO-OLOCENE

Subsintema di Ravenna
Subsintema sommitale del Sintema Emiliano-Romagnolo Superiore
In affioramento: argille, limi ed alternanze limoso-sabbiose di piana inondabile, argine, canale e rotta, bruni e grigiastri di piana alluvionale drenata con suoli al tetto. Limite superiore coincidente con il piano topografico, dato da suoli variabili da non calcarei a calcarei. I suoli non calcarei e scarsamente calcarei hanno, al tetto, colore bruno scuro e bruno scuro giallastro (10YR, 2.5Y), spessore dall'orizzonte decarbonatato da 0,5 ad 1 m e contengono reperti archeologici di età del Neolitico al Romano. I suoli calcarei appartengono all'unità AES_{8a}.
Limite inferiore non affiorante.
Nel sottosuolo: depositi appartenenti ad un cuneo trasgressivo-regressivo che si apre verso NE, costituito da depositi di piana alluvionale (prevalenti nell'intero Foglio), deltizi, litorali e, localmente, marini (limitatamente allo spigolo di NE). I depositi di piana alluvionale includono localmente sabbie di canale fluviale a geometria nastriforme e più diffusamente alternanze di sabbie e limi di argine e limi ed argille di piana inondabile. I depositi deltizi e litorali includono un esteso cuneo di argille limose organiche palustri-lagunari passanti verso E e NE a sabbie di cordone e fronte deltizia.
Limite inferiore sepolto dato dal contatto netto tra i depositi fini, scuri, di piana non drenata, palude, laguna e barriera trasgressiva, alla base dell'unità, con i depositi grossolani di canale e argine fluviale al tetto di AES_7.
Subsintema contenente un'unità di rango gerarchico inferiore (AES_{8b}) che, dove presente, ne costituisce il tetto stratigrafico.
Spessore massimo di 25 metri circa.
PLEISTOCENE SUP.-OLOCENE (c.a. 14.000 anni BP - attuale; datazione ^{14}C non. cal. e biostratigrafica).

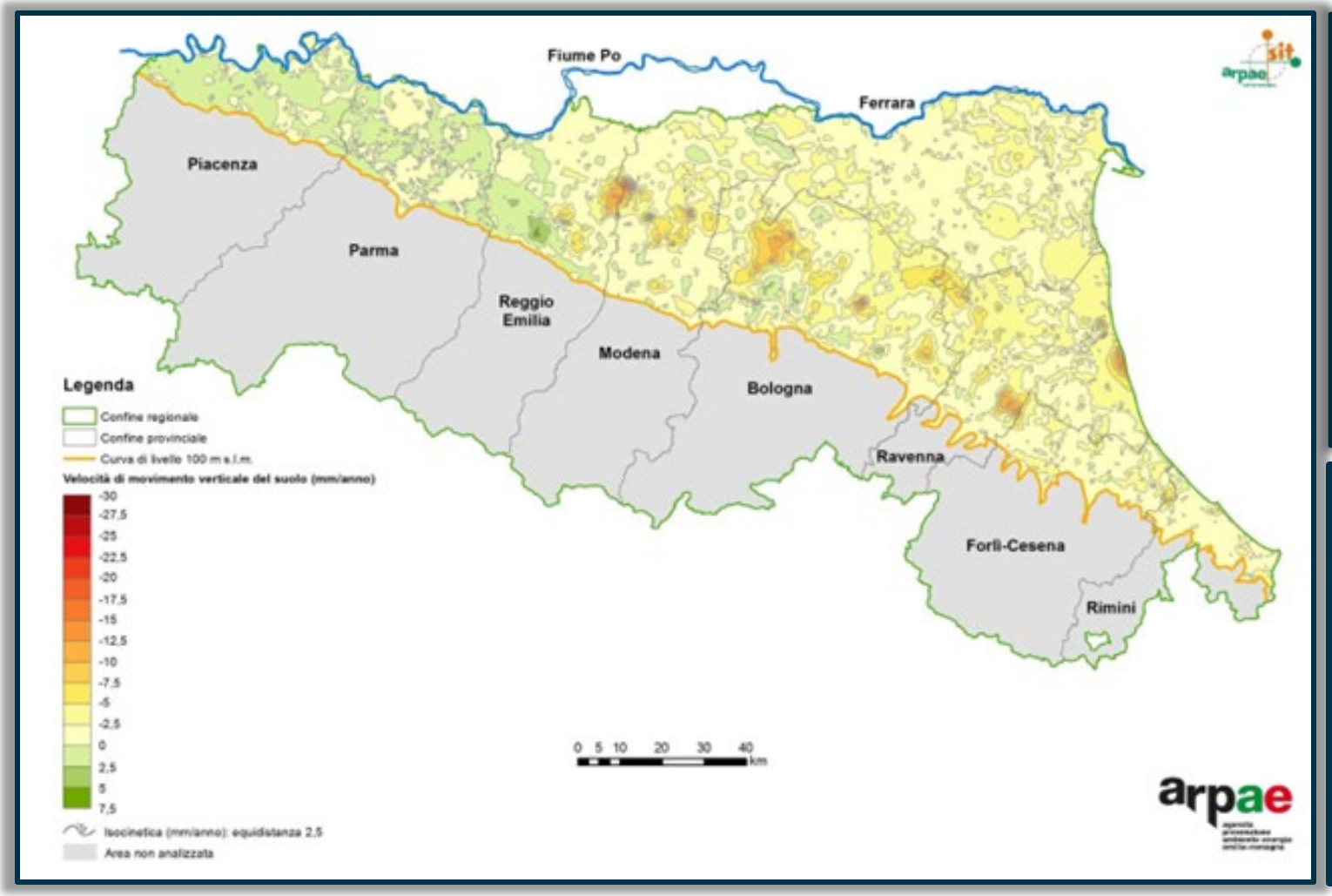
Unità di Modena
Alternanze di sabbie, limi ed argille distinti in depositi di ambiente alluvionale prevalente (canale ed argine, piana inondabile) e di ambiente deltizio subordinato (canale distributore ed aree interdistributrici).
I depositi di canale e di argine sono concentrati lungo gli alvei attuali dei Fiumi Sillaro e Santerno, mentre i depositi fini di tracimazione si sviluppano tra le aste fluviali e nel settore settentrionale. La distribuzione dei depositi testimonia l'estinzione naturale dei corsi d'acqua in ambienti di "valle". Nel margine nord-orientale sono presenti i depositi deltizi attribuibili al Po di Primaro.
Limite superiore sempre affiorante e coincidente con il piano topografico dato da un suolo calcareo di colore bruno olivastro o bruno grigiastro (2.5Y) al tetto, privo di reperti archeologici romani, o più antichi, non rimaneggiati e caratterizzato da una buona preservazione delle forme deposizionali originarie. Limite inferiore ben definibile nei quadranti meridionali, dove è dato dal contatto delle tracimazioni fluviali sul suolo non calcareo (o scarsamente calcareo) di epoca romana.
Include, concettualmente, i depositi fluviali in evoluzione b_1 che però, in accordo con la tradizione della cartografia geologica preesistente, sono stati cartografati separatamente.
Spessore di pochi metri che, localmente, raggiunge 10 m.
ETÀ POST-ROMANA (IV-VI sec. d.C. - Attuale; datazione archeologica e ^{14}C).

Pleistocene - Olocene



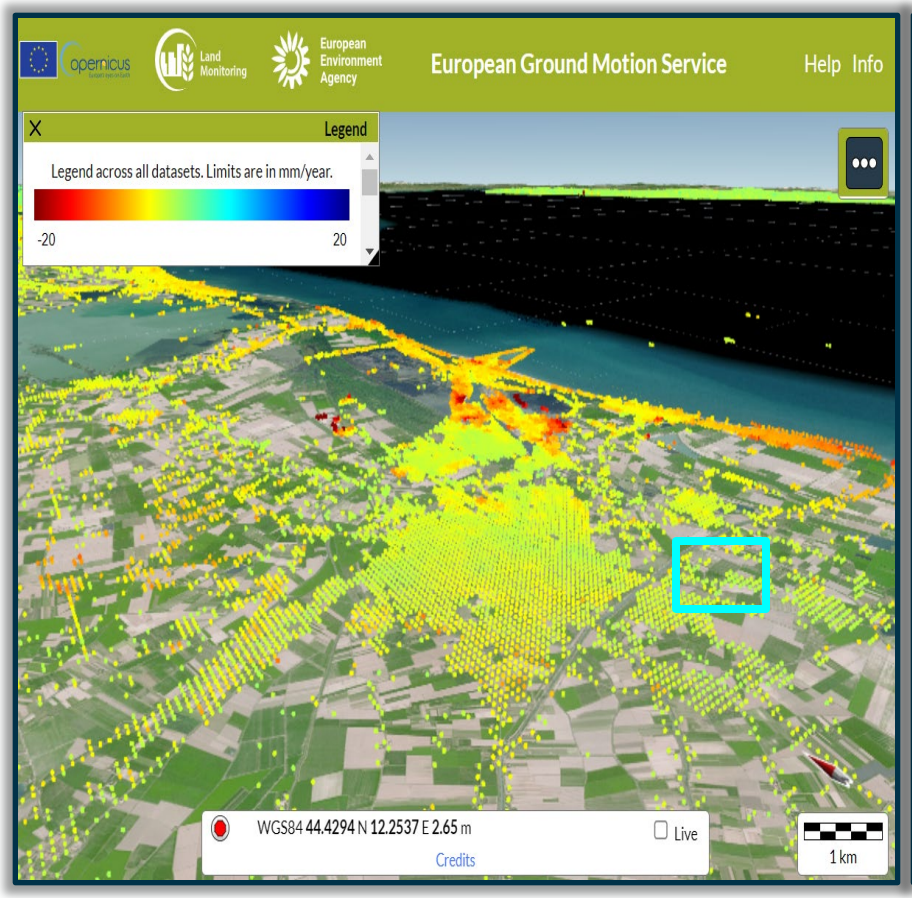
Litology: sequence of marine, delta, lagoon, marsh and alluvial deposits of Pliocene-Quaternary age;
Bedrock: complex fold structure;
Tectonic: Adriatic folds with axis parallel to the main Apennine structural lines (NW-SE).

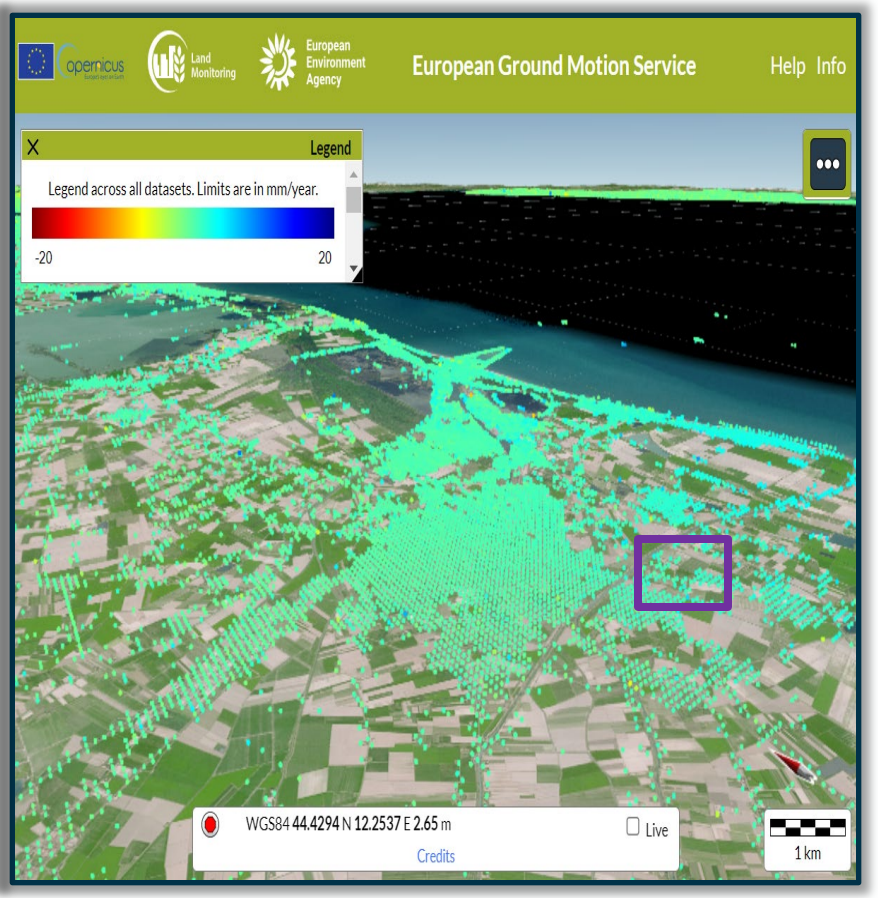
Geohazard assesment: ground instability

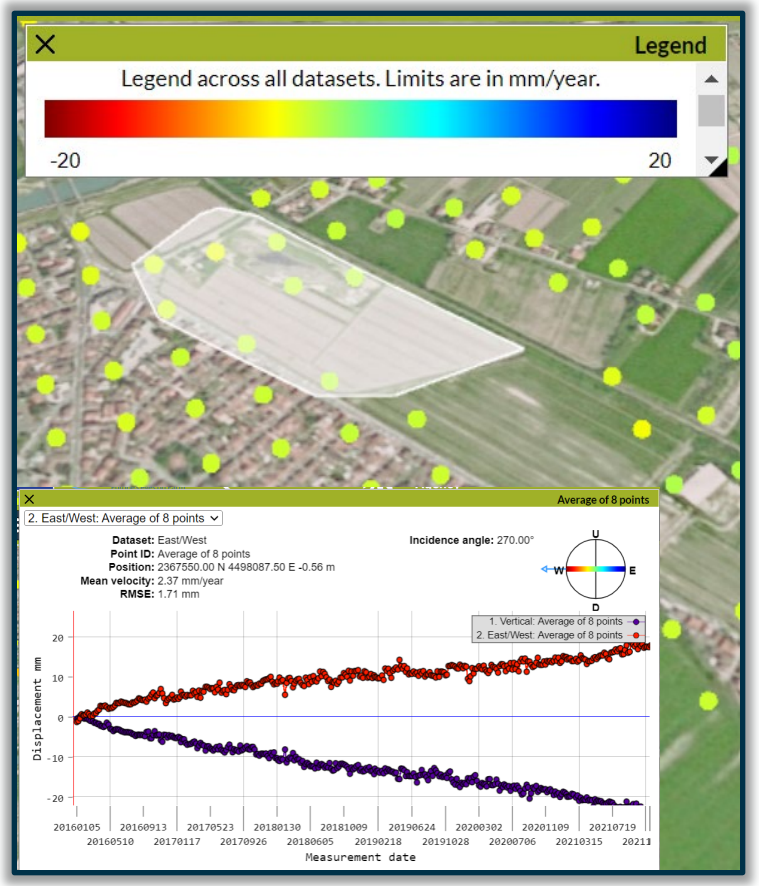


- The Regional Agency for the Environmental Protection (ARPA) of Emilia-Romagna Region and the Emilia-Romagna Region (2010) estimate the overall contribution of the natural subsidence in −1.4 mm/year at Ravenna, −2.5 mm/year at Po river delta, and −1 mm/year at Venice.
- The present-day subsidence in the Po Plain is also given by the effects of the last deglaciation period that contributes with increasing values going from Venice (−1.1 mm/year) to Ravenna (−3.5 mm/year) (Carminati, Martinelli, and Severi 2003).

PS InSAR analisys - EGMS (ORTHO level) 2015-2021







PS InSAR analisys : FIASCHI et al 2017

Figure 5. Vertical displacement maps obtained from the processing of (a) ERS-1/2 (1992–2000), (b) ENVISAT 2003–2010, (c) TerraSAR-X (2012–2014), and (d) Sentinel-1A (2014–2016) . The black dots, from P1 to P8, are the locations of the points considered for the time series analysis.

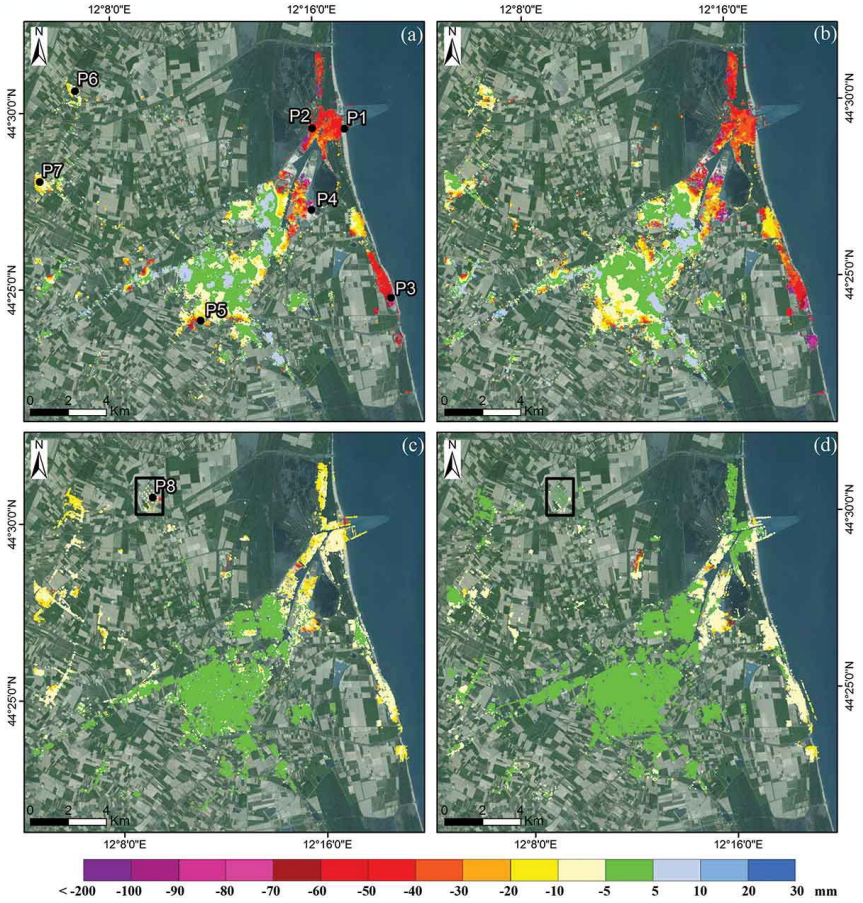
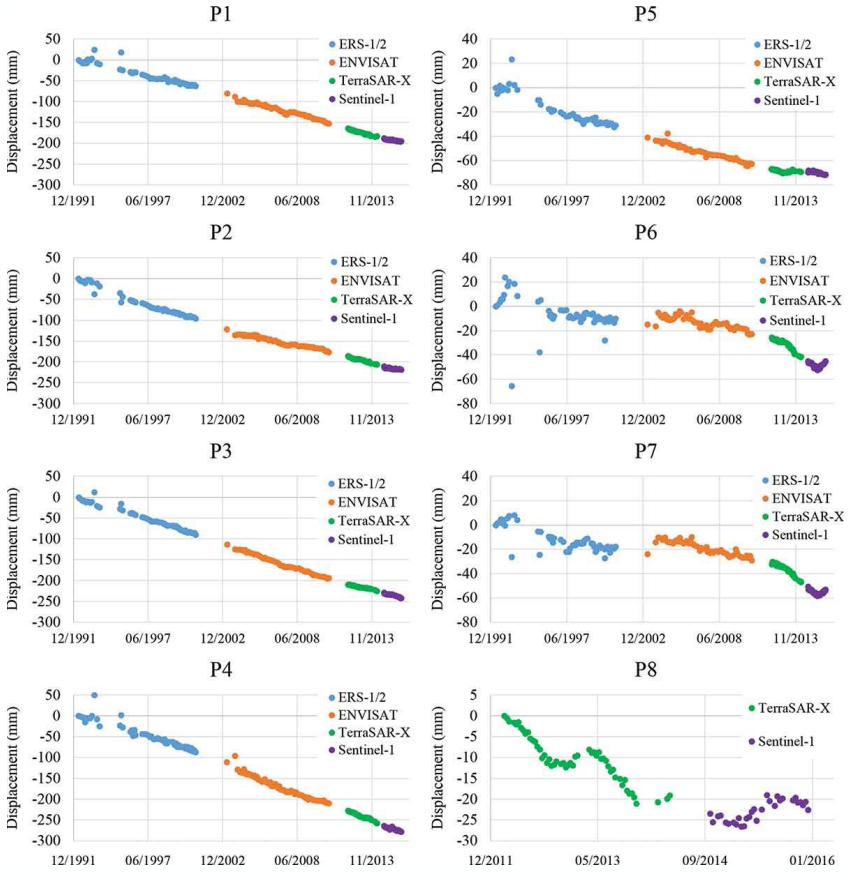


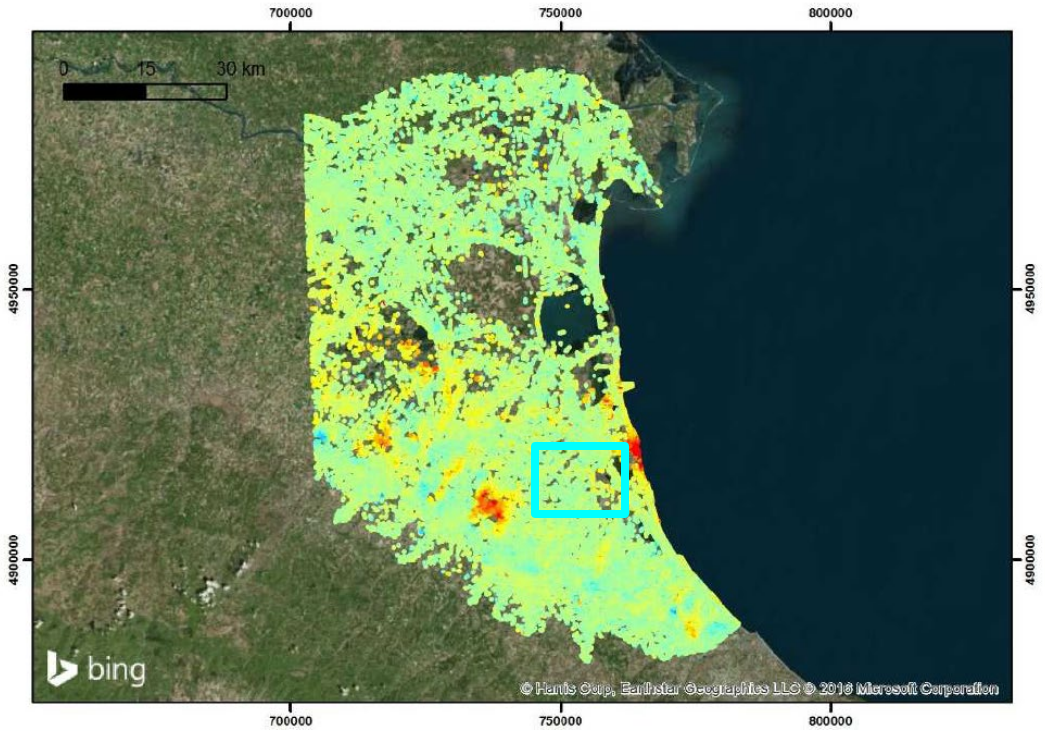
Figure 6. Cumulated displacement time series for the eight selected points reported in Figure 5 (a,c).

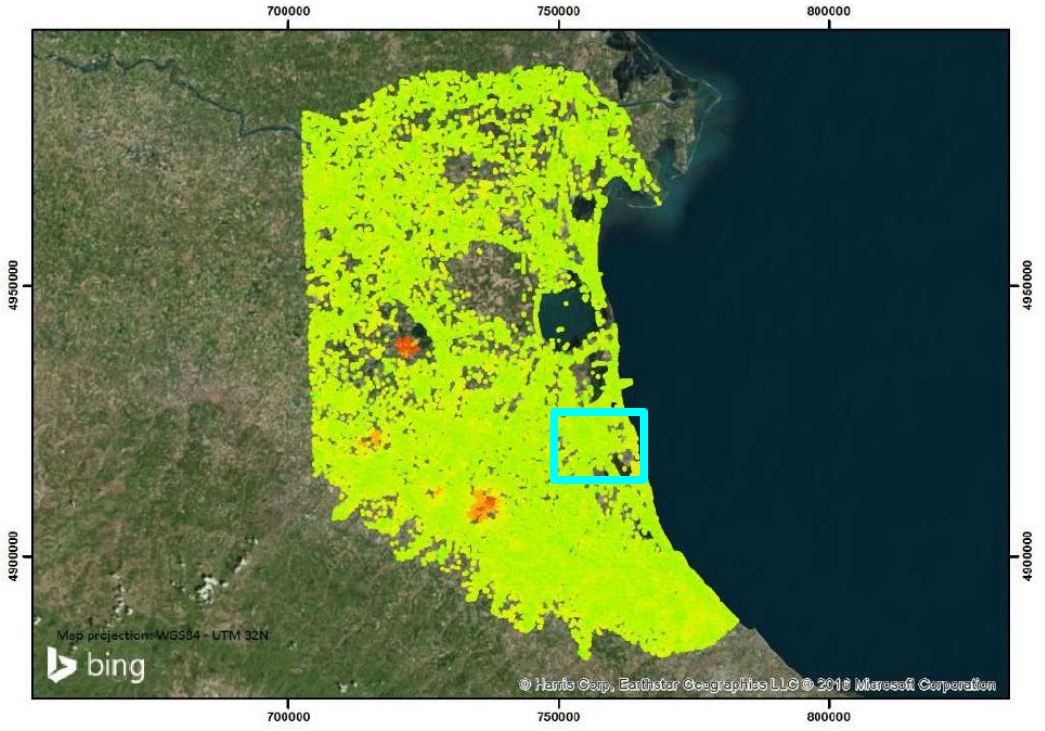


PS InSAR analisys : TRE PSInSAR + SqueeSAR

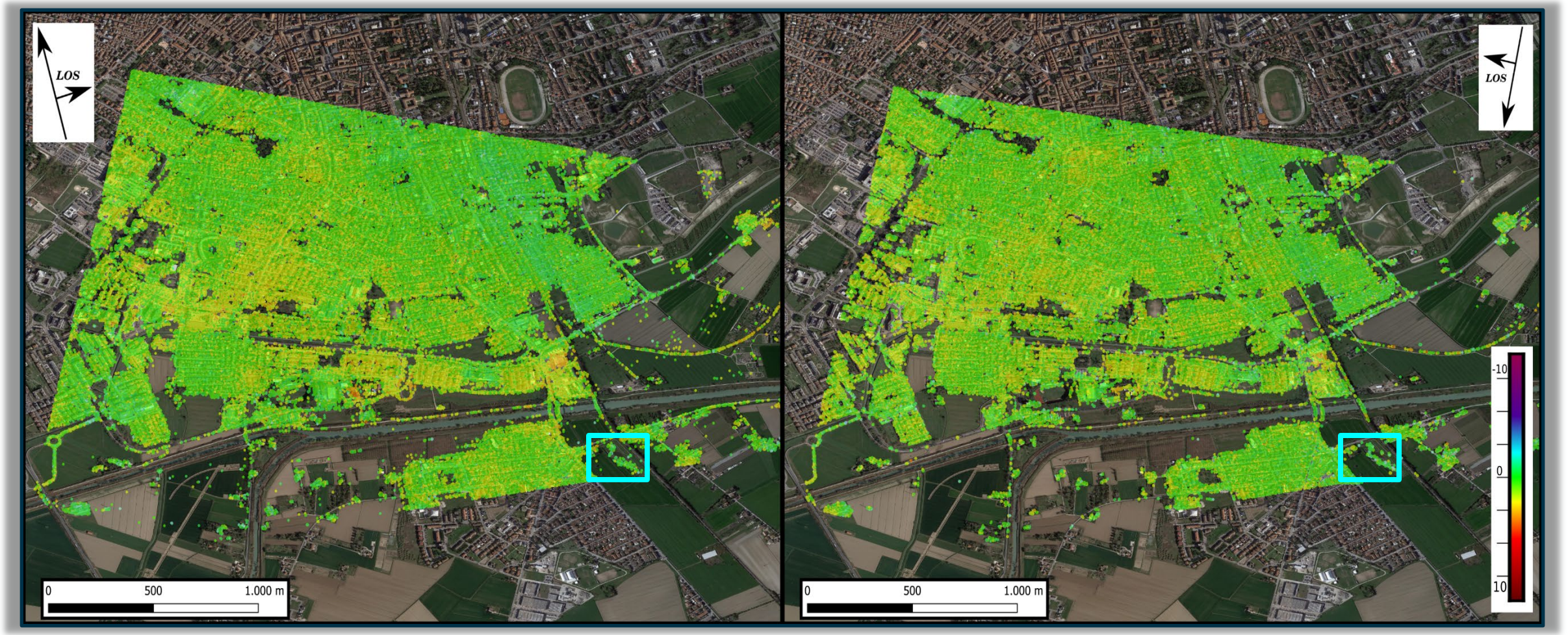
- Analisys: TRE PSInSAR+SqueeSAR
- SAR Images : RADARSAT1 e RADARSAT2 (SqueeSAR)
- Band: C
- Resolution: 5x20 m
- Time period: 05/2011 – 05/2016

RAVENNA
In the Ravenna site, 325,871 measurement points were identified, with an average density of 56 MP/Km2.

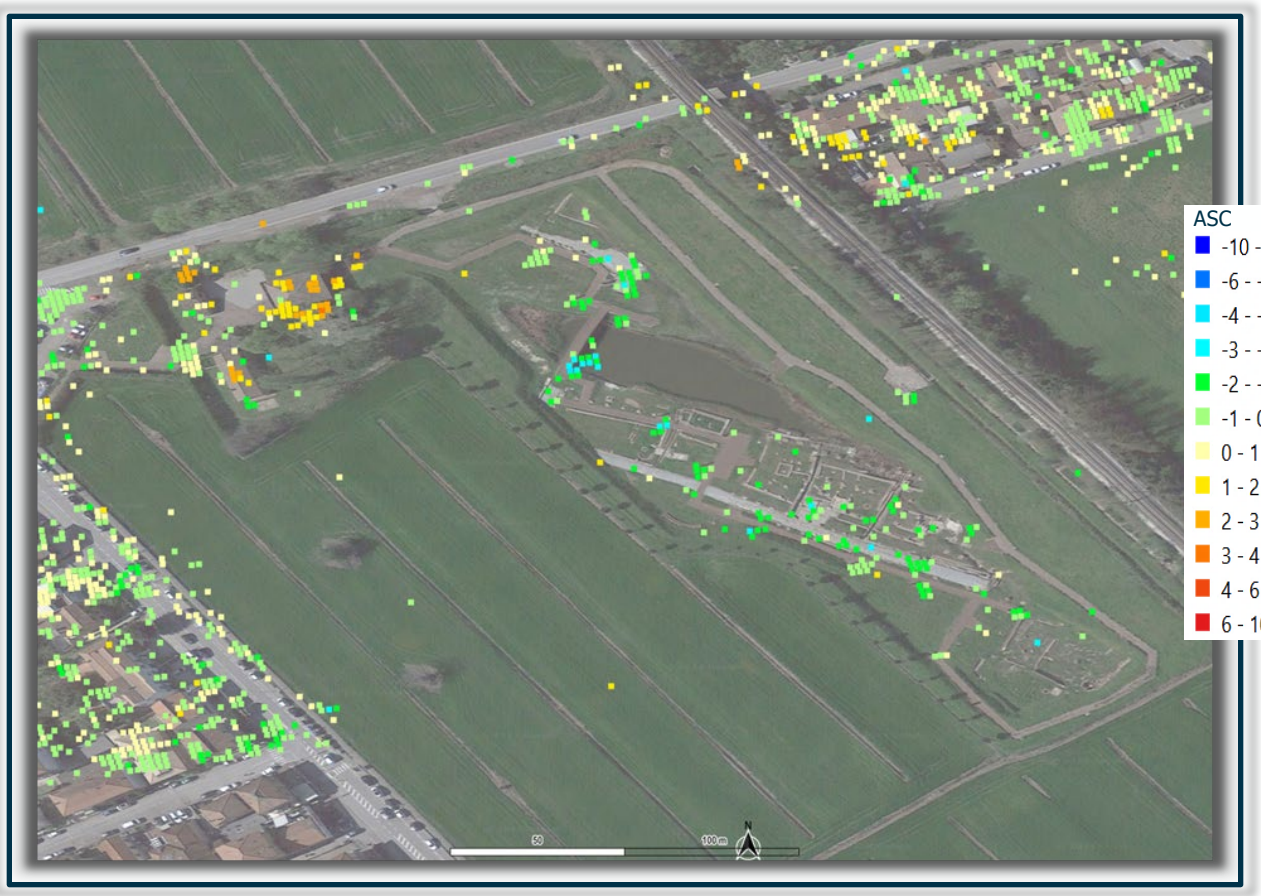


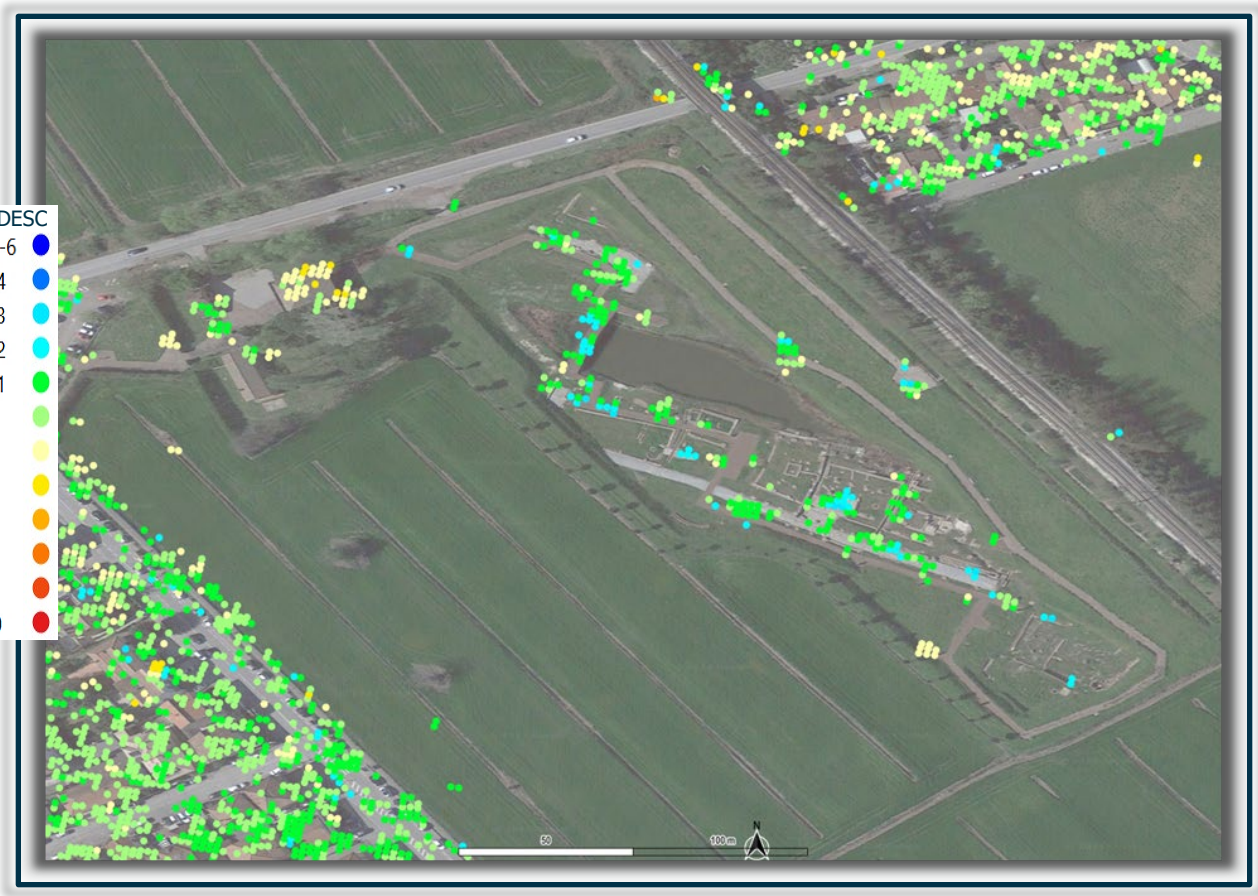


ISPRA InSAR analysis – StaMPS/MTI - CSK 2018-2022

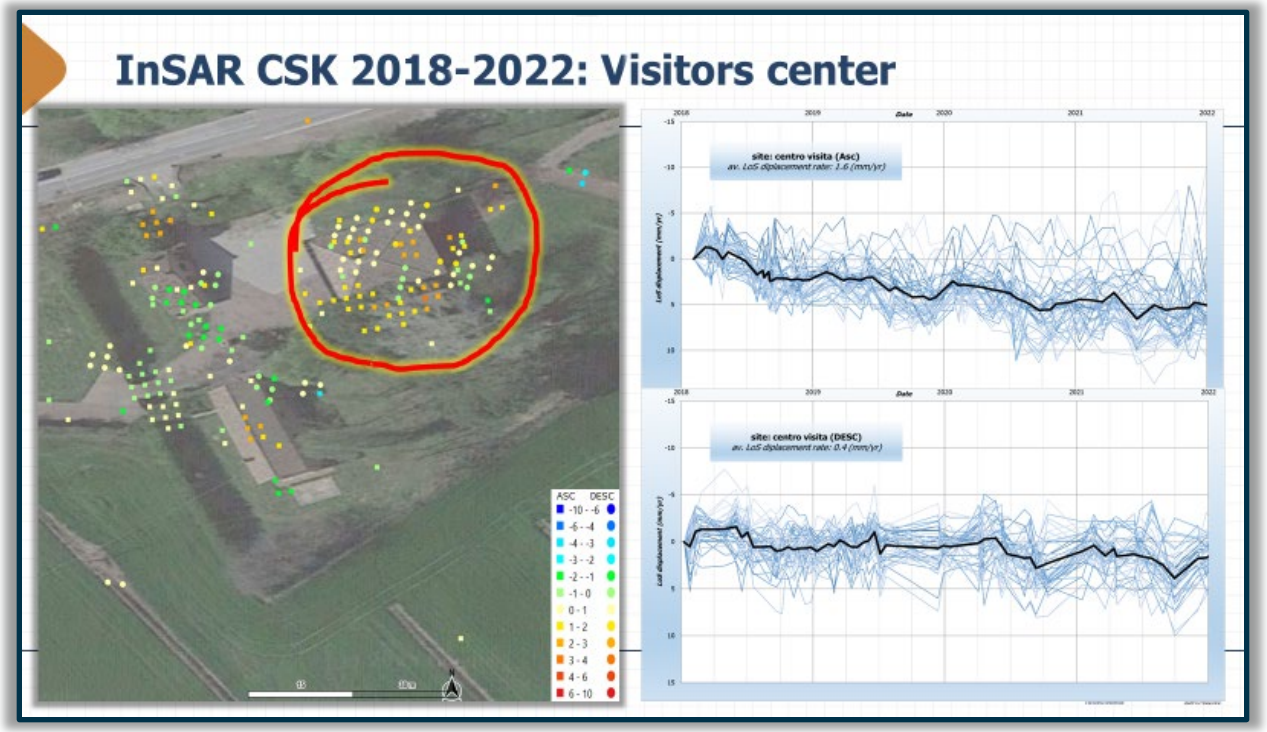


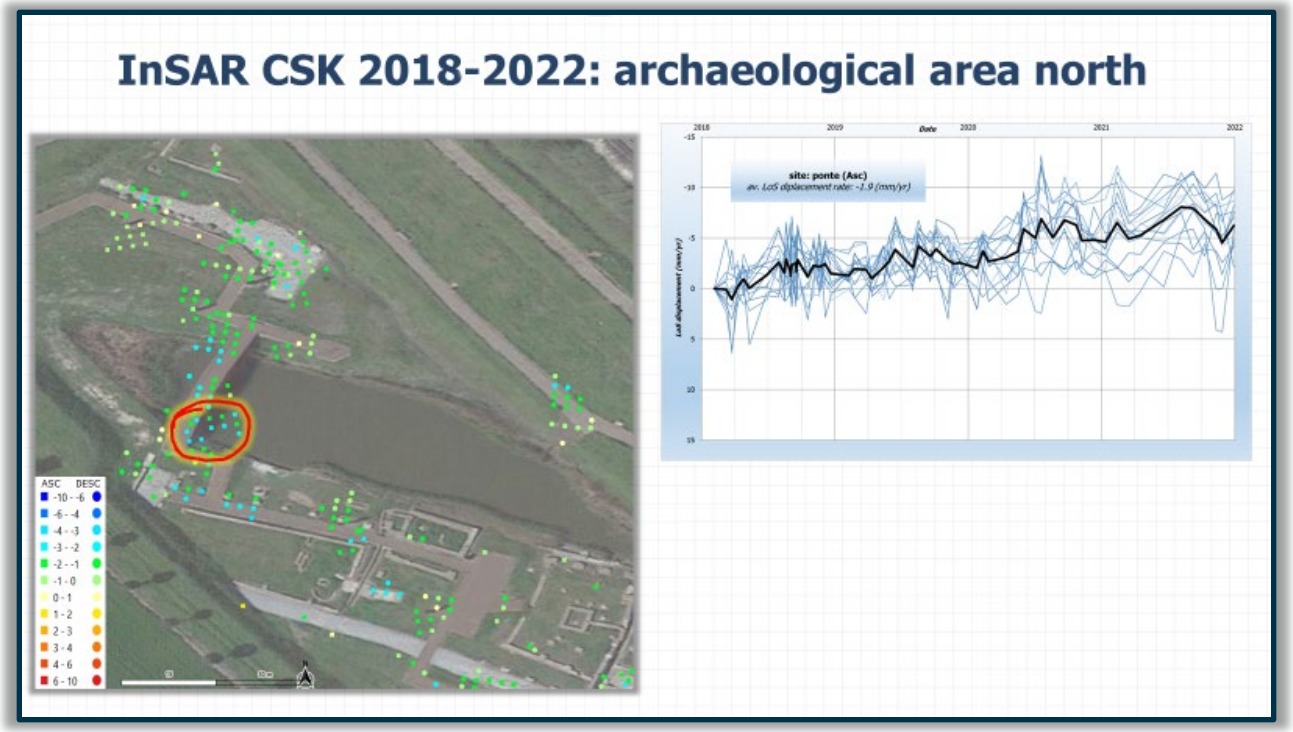
ISPRA InSAR analysis – StaMPS/MTI - CSK 2018-2022



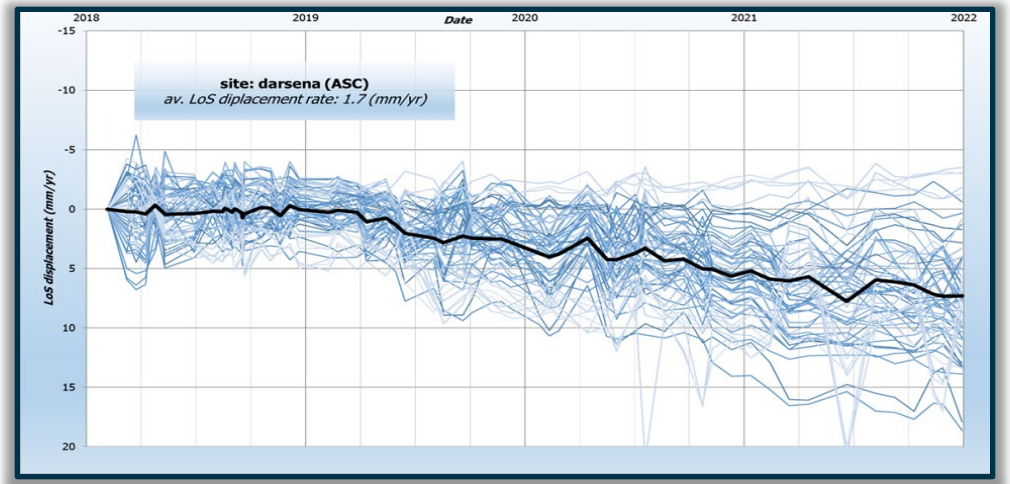


ISPRA InSAR analysis – StaMPS/MTI - CSK 2018-2021





ISPRA InSAR analysis – StaMPS/MTI - CSK 2018-2021



Final remarks

CH Background
investigating the origin, typology, construction techniques, restoration history, evolution in time,

Geohazard assessment
Hazard and risk map analysis

SAR Interferometry
Data integration and services

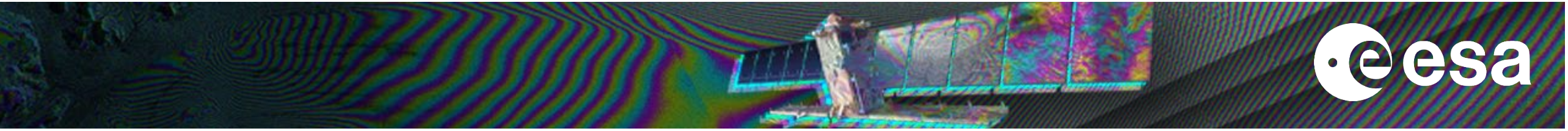
Ground motion monitoring
Field survey and risk mitigation plan

The main results of this study have highlighted the importance of the EGMS service for preliminary studies at medium resolution. The anomalies highlighted at the sub-regional and municipal scale must then be detailed in both spatial and temporal resolution in order to be correctly interpreted, validated and calibrated directly in situ.

- understanding the framing of actual **natural hazard** conditions.
- real knowledge of the site, to be acquired by **field survey** and **EO monitoring**, involving experts, managers and stakeholders too.
- **InSAR dataset is analysis** and eventually correct, to highlight the site-scale pattern of ground motion.
- **PSI data interpretation** of local events pointed out by previous steps, in order to understand the interaction between structure damage and ground motion. The actual relation reveals if and how building's damages are caused by structural weakness or by ground motion.

The final goal is to set up:

- integrated monitoring system
- mitigation and conservation plan



Thank you

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