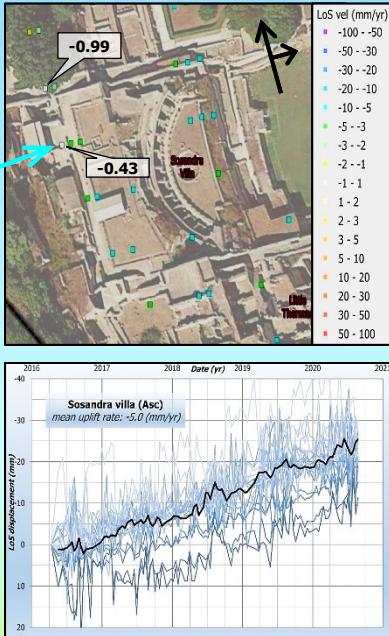
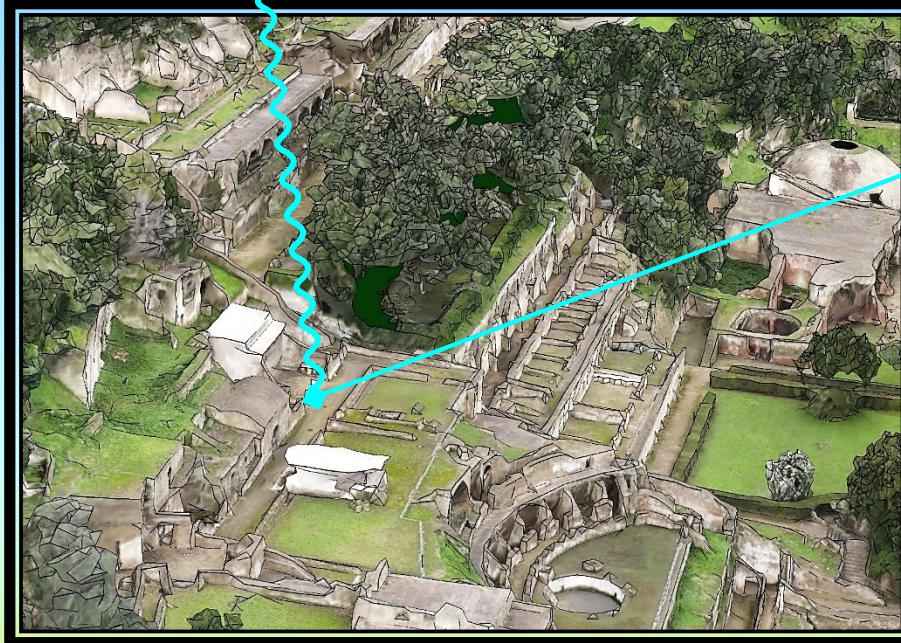


## Landslide affecting Cultural Heritage sites: Roman Thermae of Baia



# INTEGRATED APPLICATION

- methodology & application
- lessons learnt
- more info

*Original contributions from:*

**ISPRRA, Geological Survey of Italy:**

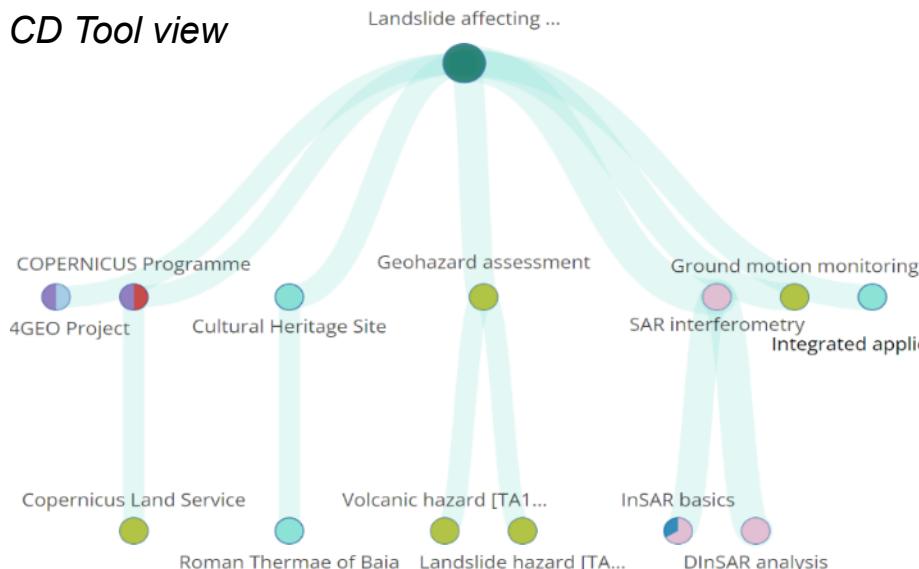
G. Leoni, F. Ferrigno, P.M. Guarino,  
L. Guerrieri, F. Menniti, D. Spizzichino

**Parco Archeologico dei Campi Flegrei:**

F. Pagano, E. Galloccchio, M. Salvatori


**INGV, Osservatorio Vesuviano:**

M.A. Di Vito, P. De Martino

*CD Tool view*


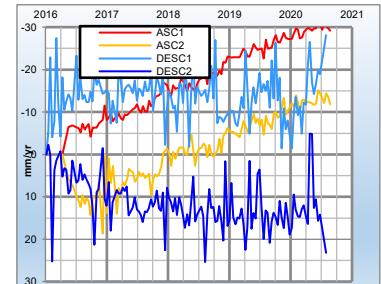
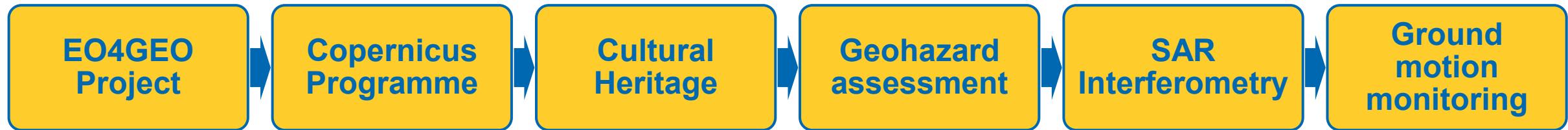
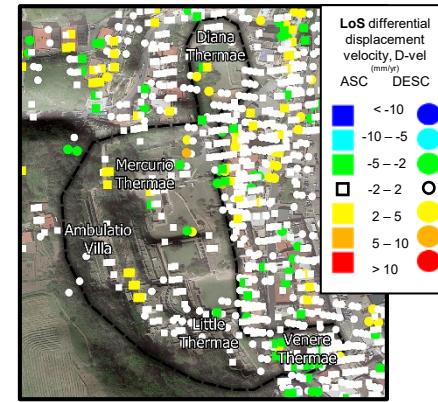
# MOOC structure

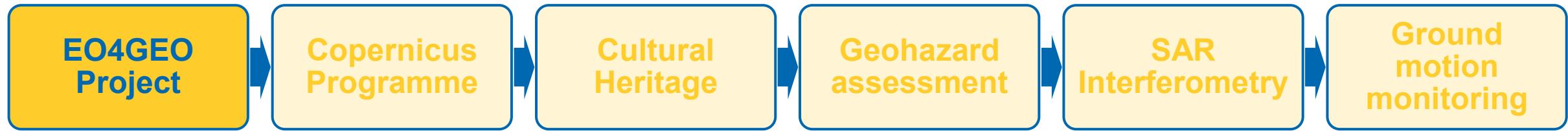
[Course >](#)
[Lecture](#)

#	Title	Description	Source
1	EO4GEO Project	EO4GEO Project overview	EO4GEO
2	COPERNICUS	COPERNICUS Programme data and services	Copernicus
2.1	Copernicus Land Monitoring Service	CLMS components and applications	EO4GEO, GEOF
3	Cultural Heritage	Phlegrean Fields Archaeological Park	PAFleg
3.1	Roman Thermae of Baia	Roman Thermae of Baia: history and monuments	PAFleg
4	Geohazard assessment	Background knowledge on natural risk management and assessment	ISPRRA
4.1	Volcanic hazard	Geological, geomorphological and volcanic overview, volcanic and bradyseism hazard	INGV, OV
4.2	Landslide hazard	Landslides hazard affecting Baia site	ISPRRA
5	SAR Interferometry	<ul style="list-style-type: none"> <li>Introduction to Remote Sensing</li> <li>EO Data Sources</li> </ul>	EO4GEO, IGIK EO4GEO, GEOF
5.1	InSAR fundamentals	<ul style="list-style-type: none"> <li>Introduction to Radar Remote Sensing</li> <li>SAR Imaging</li> <li>InSAR Basics</li> <li>introduction to SAR interferometry</li> </ul>	EO College
5.2	InSAR analysis	<ul style="list-style-type: none"> <li>PS and SBAS techniques</li> <li>SNAP+StaMPS applications</li> <li>InSAR calibration</li> </ul>	ISPRRA
6	Ground motion monitoring	InSAR & in-situ data interpretation	ISPRRA
7	Integrated application	methodology and application, lessons learnt, more info	ISPRRA



# OUTLINE





## The VISION

To foster the growth of the European Earth Observation / Geographic Information (EO/GI) sector ensuring a workforce with the **right skills, in the right place, at the right time.**

## The MISSION

To ensure the strategic cooperation among stakeholders on skills development in the EO/GI sector.

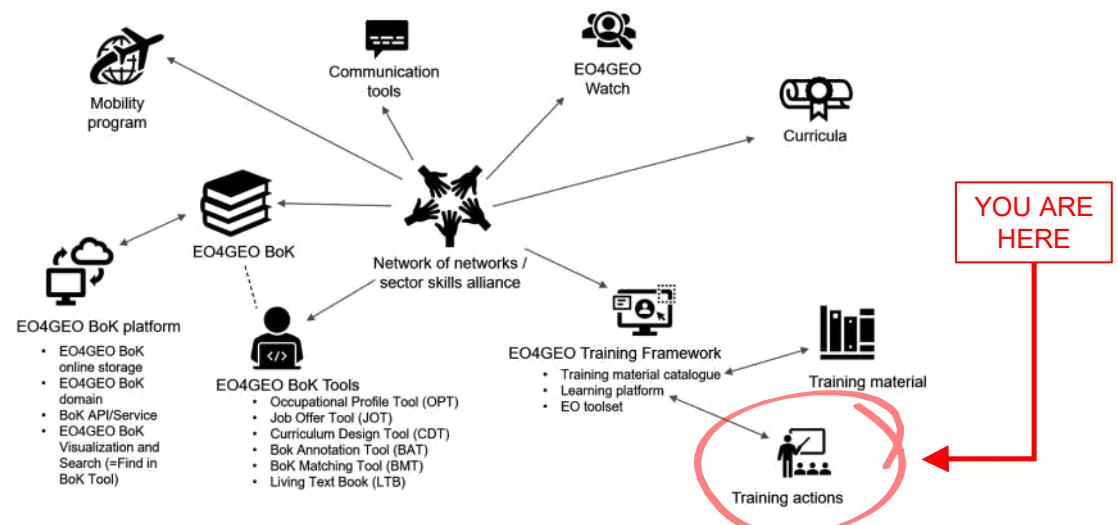
## STRATEGIC IMPORTANCE

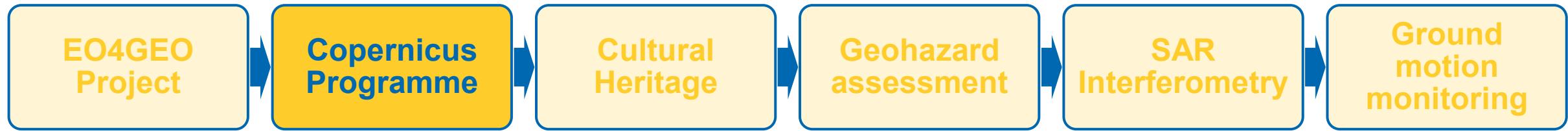
EO4GEO aims at implementing a new approach ("Blueprint") in the Space/Geospatial Sector:

- To improve the quality and relevance of training and other ways of acquiring skills
- To make skills more visible and comparable
- To enable people make better career choices, find quality jobs and improve their life chances

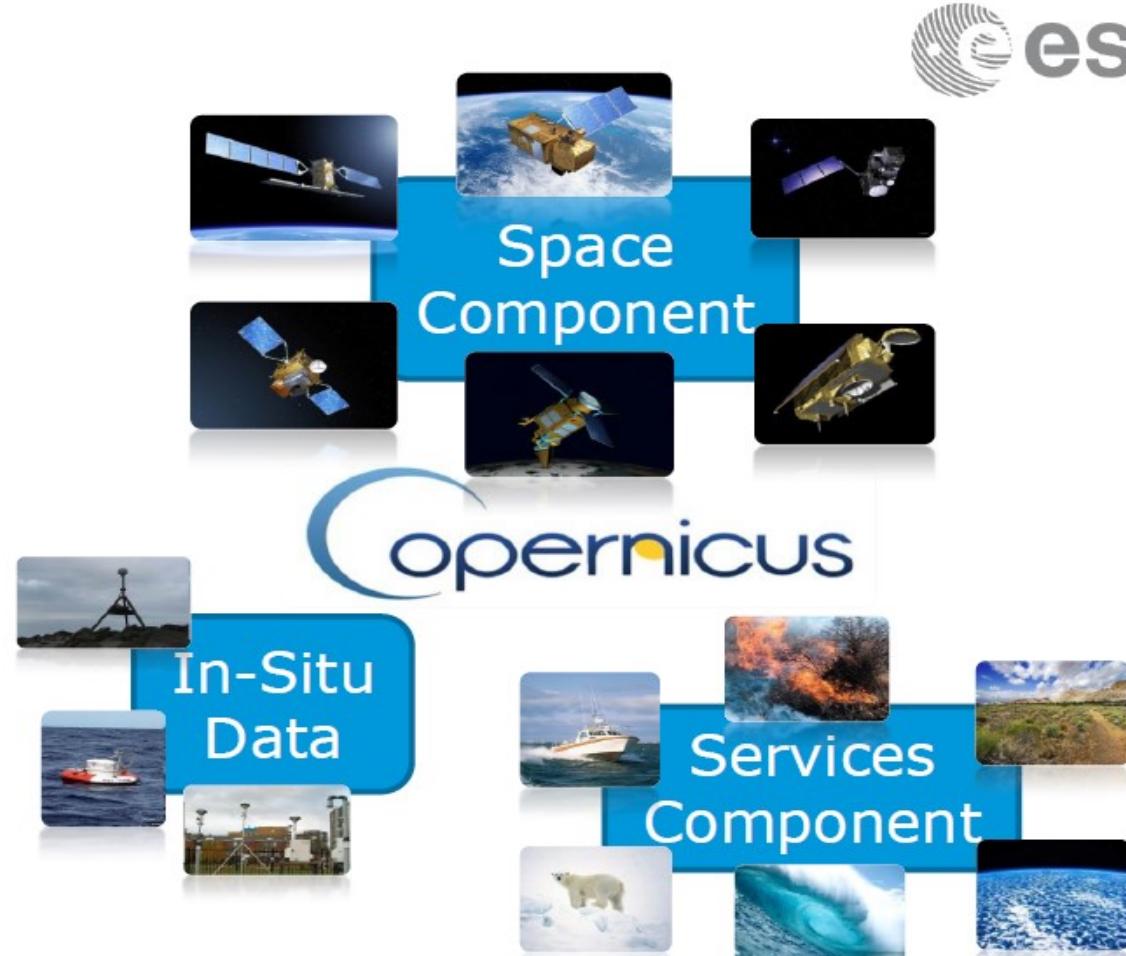
## THE INSTRUMENTS

- An ontology-based **Body of Knowledge** (BoK) for the space/geospatial sector (extending the existing GI BoK with EO/Copernicus concepts).
- A set of BoK-based **innovative tools**.
- A series of **curricula and a portfolio of training modules** directly usable in the context of Copernicus and other relevant programs.
- A series of **learning actions** for a selected set of strategic scenario's in three sub-sectors to test the approach.
- A **Long-term Action Plan** to be endorsed to roll-out and sustain the proposed solutions.
- The support of a strong group of **Associated Partners** mostly consisting of associations or networks active in space/geospatial domain.



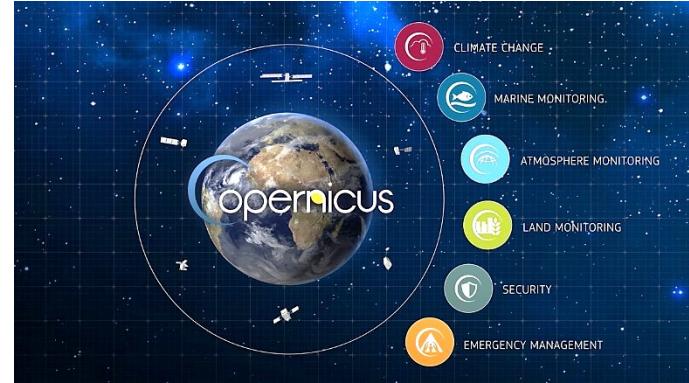


## What is Copernicus?



## Copernicus in Brief

- ★ **The Copernicus programme** is a cornerstone of the European Union's efforts to monitor **the Earth** and its many ecosystems, whilst ensuring that its citizens are prepared and protected in the face of **crises** and **natural or man-made disasters**.
- ★ The Copernicus Programme is a tool for **economic development** and a driver for **digital economy**.
- ★ The Copernicus programme places a world of insight about our planet at the disposal of citizens, public authorities and policy makers, scientists, entrepreneurs and businesses **on a full, free and open basis**.



## Introduction

- ★ The Copernicus programme entered its **operational phase** with the launch of Sentinel-1A in 2014 and its governance is based on the **Copernicus Regulation** adopted the same year which establishes the Commission as the Programme manager owning the infrastructure and data rights on behalf of the Union;
- ★ Copernicus services are based on information from a dedicated constellation of satellites, known as "**Sentinels**", as well as tens of third-party satellites known as "**contributing space missions**", complemented by "**in situ**" (meaning local or on-site) measurement data;
- ★ By making the vast majority of its **data, analyses, forecasts and maps freely available and accessible**, Copernicus contributes towards the development of new innovative applications and services, tailored to the needs of specific groups of users, which touch on a variety of economic and cultural or recreational activities, from urban planning, sailing and insurance to archaeology.

## Copernicus Components & Competences

**Overall  
Programme  
Coordination:**



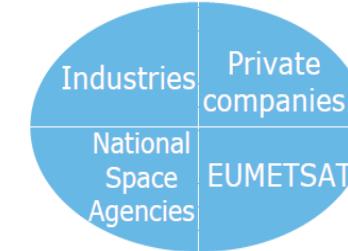
Space  
Component

Services  
Component

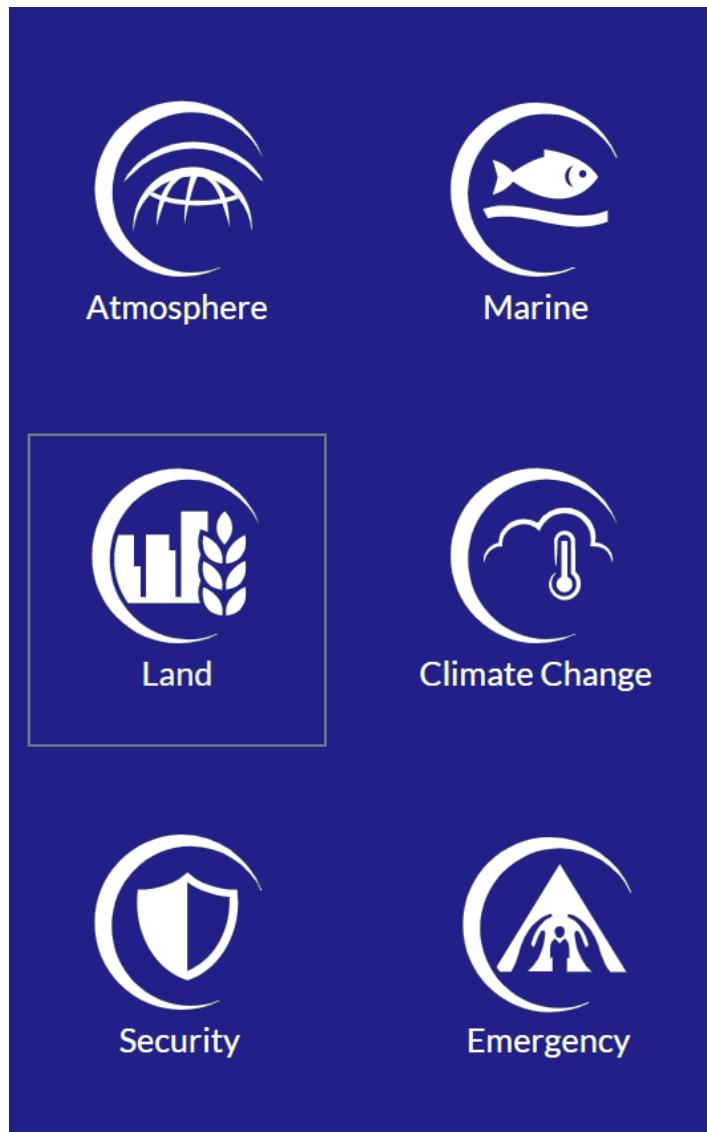
Coordinators:



Partners:



**In-situ data are supporting the Space and Services Components**



## 6 operational Services



Monitoring the State of  
the Earth System  
Environment ...



... cross-cutting Thematic Services

**Copernicus**  
Europe's eyes on Earth

1 - EO4GEO Project

2 - COPERNICUS Programme

3 - Cultural Heritage

4 - Geohazard assessment

5 - SAR Interferometry

6 - Ground motion monitoring



# Copernicus Land Monitoring Service

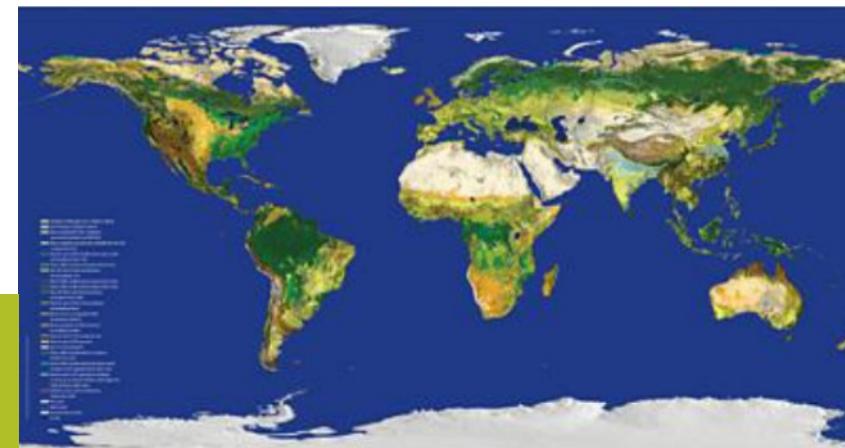
Implemented by:



&



DG JRC



From global...

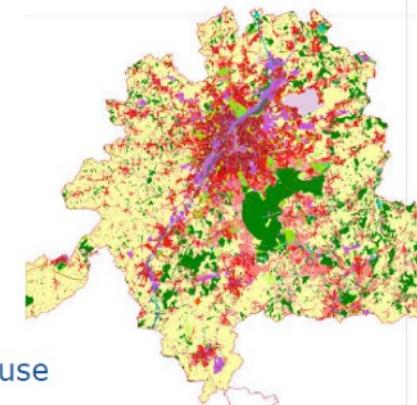
e.g. Vegetation dynamics, Bio-physical parameters, energy balance

...to pan-European...

e.g. bio-diversity, water bodies, land-use, land change



...to local  
e.g. urban land-use



1 - EO4GEO Project

2 - COPERNICUS Programme

3 - Cultural Heritage

4 - Geohazard assessment

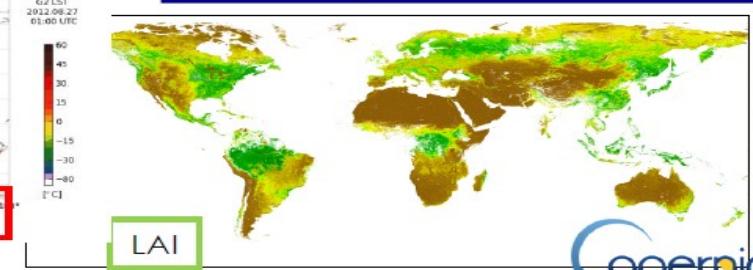
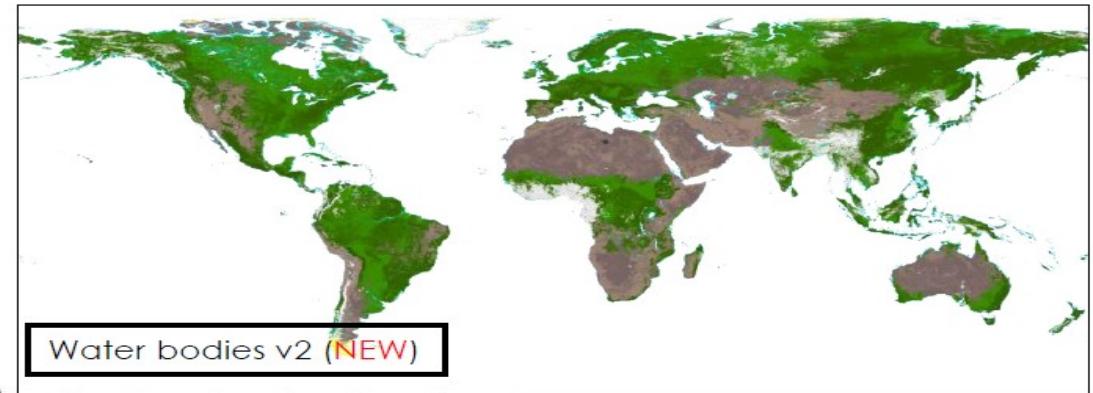
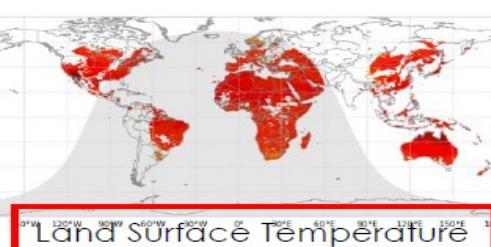
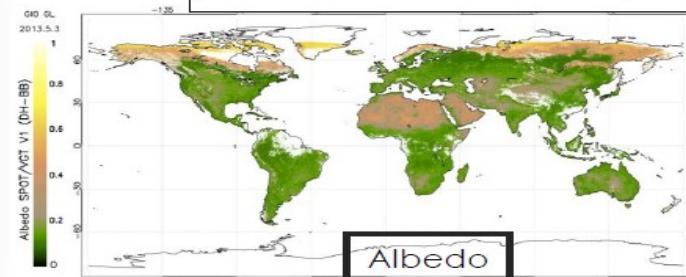
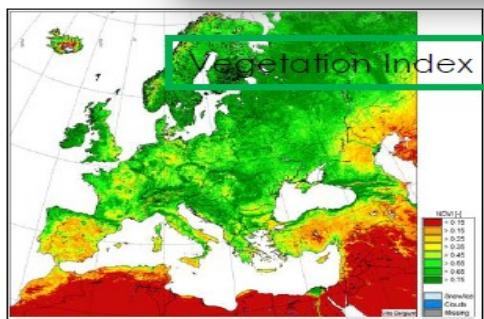
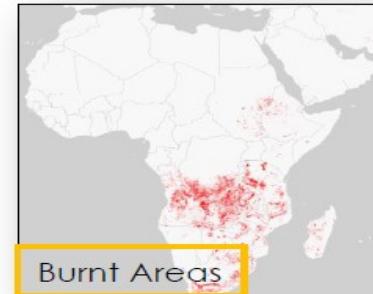
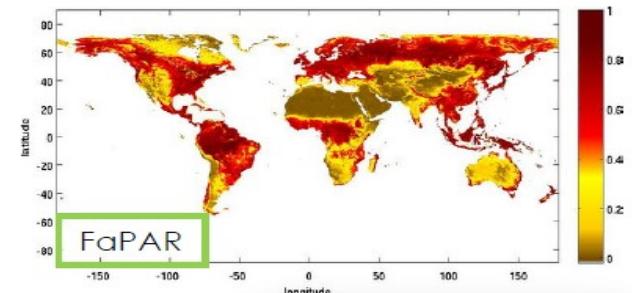
5 - SAR Interferometry

6 - Ground motion monitoring



## GLOBAL LAND APPLICATIONS

### Global Land





## GLOBAL LAND PORTFOLIO

9 groups of products (vegetation-energy-water) providing a picture of the world every ten days

<i>Variable</i>	<i>Temporal Coverage</i>	<i>Temporal resolution</i>	<i>Spatial coverage</i>	<i>Spatial resolution</i>	<i>Sensor</i>
<i>LAI/FAPAR/FCover</i>	<i>1999 – present</i>	<i>10 days</i>	<i>Global</i>	<i>1km</i>	<i>SPOT/PROBA V</i>
<i>NDVI/VCI/VPI</i>	<i>1999 – present</i>	<i>10 days</i>	<i>Global</i>	<i>1km</i>	<i>SPOT/PROBA V</i>
<i>Dry Matter Productivity</i>	<i>2009 – present</i>	<i>10 days</i>	<i>Global</i>	<i>1km</i>	<i>SPOT/PROBA V</i>
<i>Burnt Area</i>	<i>1998 – present</i>	<i>1 day</i>	<i>Global</i>	<i>1km</i>	<i>SPOT/PROBA V</i>
<i>TOC Reflectance</i>	<i>2013 – present</i>	<i>10 days</i>	<i>Global</i>	<i>1km</i>	<i>SPOT/PROBA V</i>
<i>Surface Albedo</i>	<i>1999 – present</i>	<i>10 days</i>	<i>Global</i>	<i>1km</i>	<i>SPOT/PROBA V</i>
<i>Land Surface Temperature</i>	<i>2009 – present</i>	<i>1 hour</i>	<i>Global</i>	<i>0.05 °</i>	<i>Σ Geo</i>
<i>Soil Water Index</i>	<i>2007 – present</i>	<i>1 day</i>	<i>Global</i>	<i>0.1 °</i>	<i>Metop / ASCAT</i>
<i>Water bodies</i>	<i>1999 – present</i>	<i>10 days</i>	<i>Global*</i>	<i>1km</i>	<i>SPOT/PROBA V</i>

Current service evolution : move from 1 km resolution to 300 m (EU)





**EARTHQUAKE  
HAZARD  
ASSESSMENT**

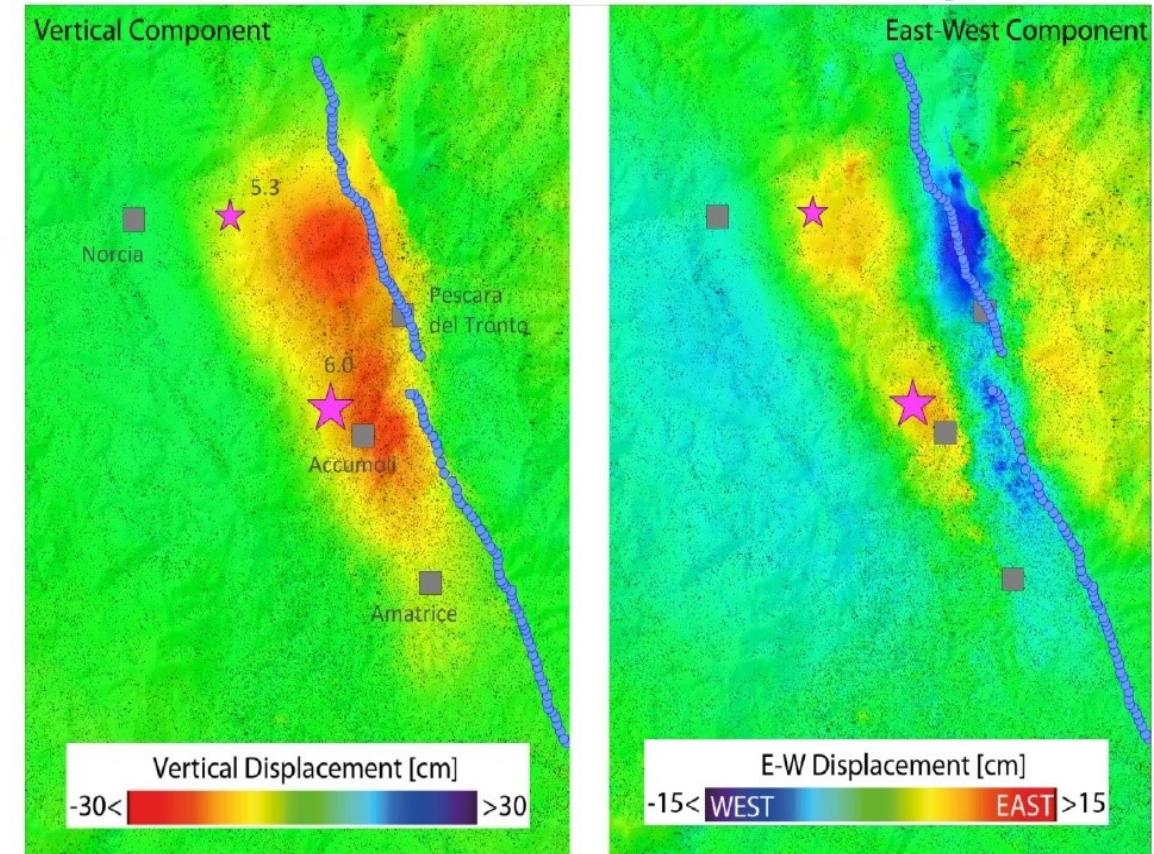
## Example of Land Monitoring

**Devastating earthquake**  
in central Italy on 24<sup>th</sup> August 2016  
(Magnitude: 6.2)



Credits: Panorama & AP Images

ESA UNCLASSIFIED - For Official Use



Vertical ground subsidence (~20 cm) and lateral movement (~16 cm) around Accumoli

1 - EO4GEO Project

2 - COPERNICUS Programme

3 - Cultural Heritage

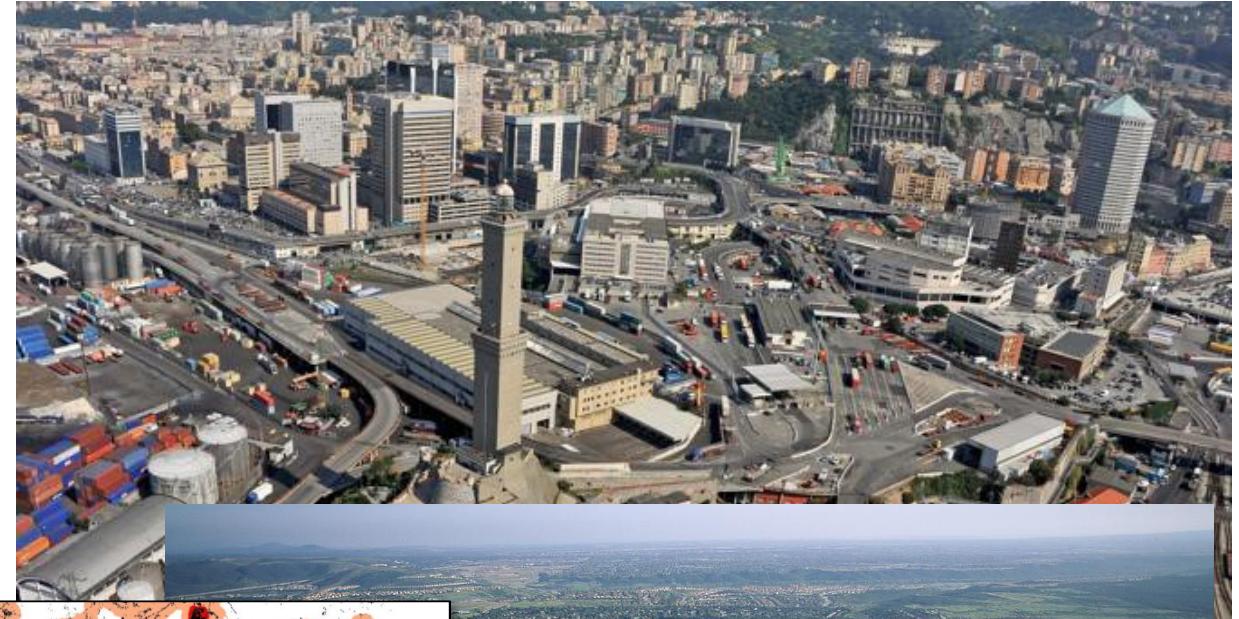
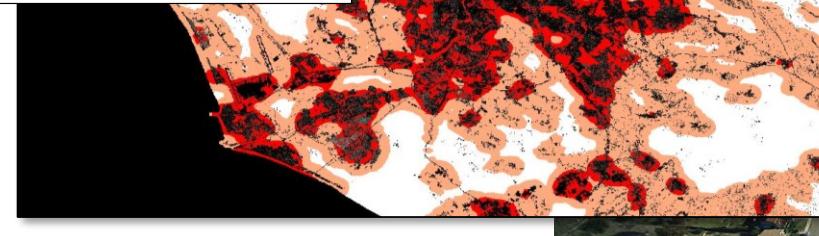
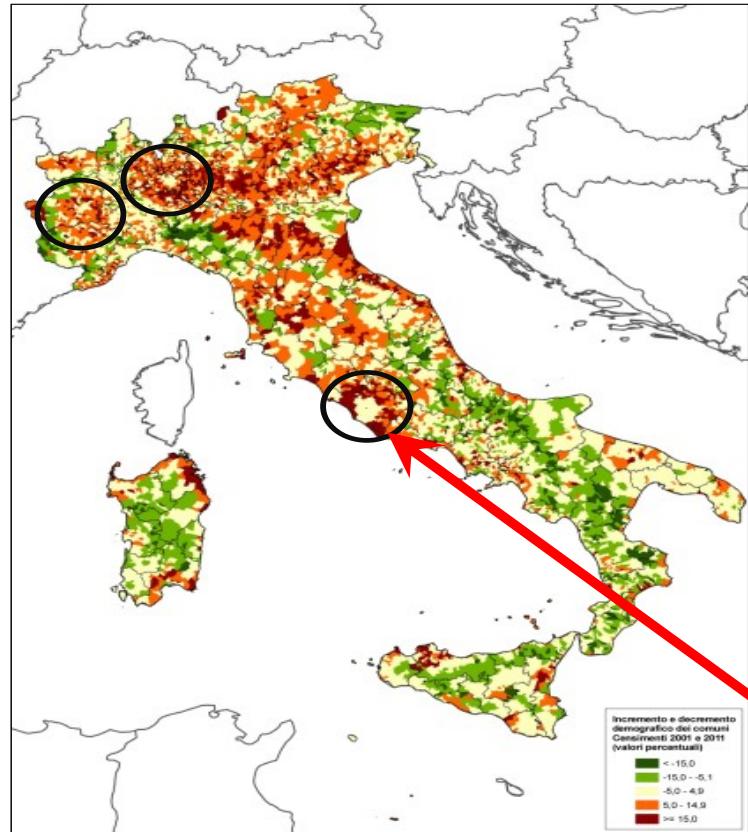
4 - Geohazard assessment

5 - SAR Interferometry

6 - Ground motion monitoring



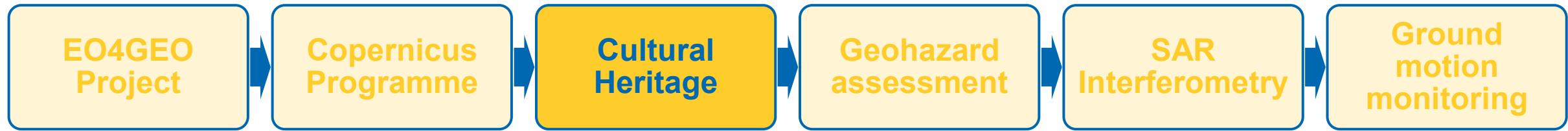
## URBAN GROWTH, URBAN SPRAWL AND SOIL SEALING IN ITALY





# SUMMARY

- COPERNICUS Programme offers a wide set of EO data and services.
- The common access point and the interoperability of formats allows an interdisciplinary approach to case studies.
- The fully, free and open availability of data and services enables the opportunity to develop applications to monitor and protect Cultural Heritage.
- The long-term availability of data makes it possible to project effective monitoring systems.





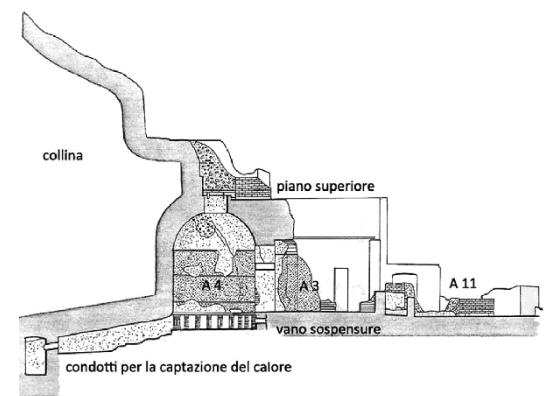
parco  
archeologico  
campi  
**fleorei**  
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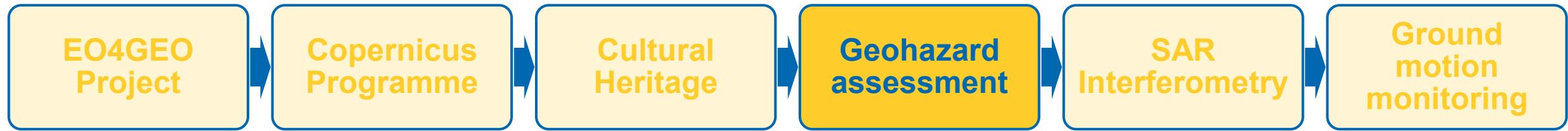
# ARCHAEOLOGICAL SETTING

- Phlegrean Fields Archaeological Park includes many different sites, spread over a wide territory and spanning over a long period: since early Greek colonies until late Roman Age, with evidences also for the Middle Age.
- The human settlements adapted to an unstable land, characterized by the unrest ground motion of bradyseism, but also rich of fertile soils and thermal resources.

## ROMAN THERMAE OF BAIA

- The complex was originally built to exploit the natural thermal spring at the foothill of the volcano.
- The wealth of thermal resource led to the rise of majestic villas and thermal complexes, dominated by large domed halls.
- Villas were also built around the *Lacus Baianus*, but all this area is nowadays submerged, due to the bradyseism.
- The site is still active during the Middle Age.
- The buildings on the slope were largely abandoned, then buried by earth flows and rock falls, and partially excavated only during last century.
- The long human presence caused the reuse of ancient walls without a proper knowledge of the foundation's bearing capacity.

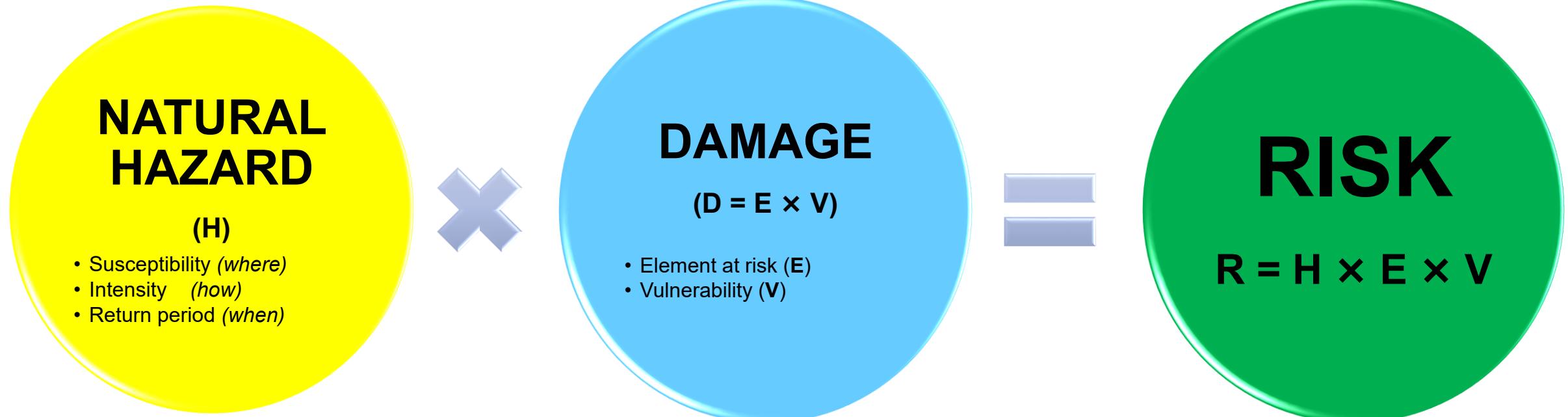




## Natural Risk:

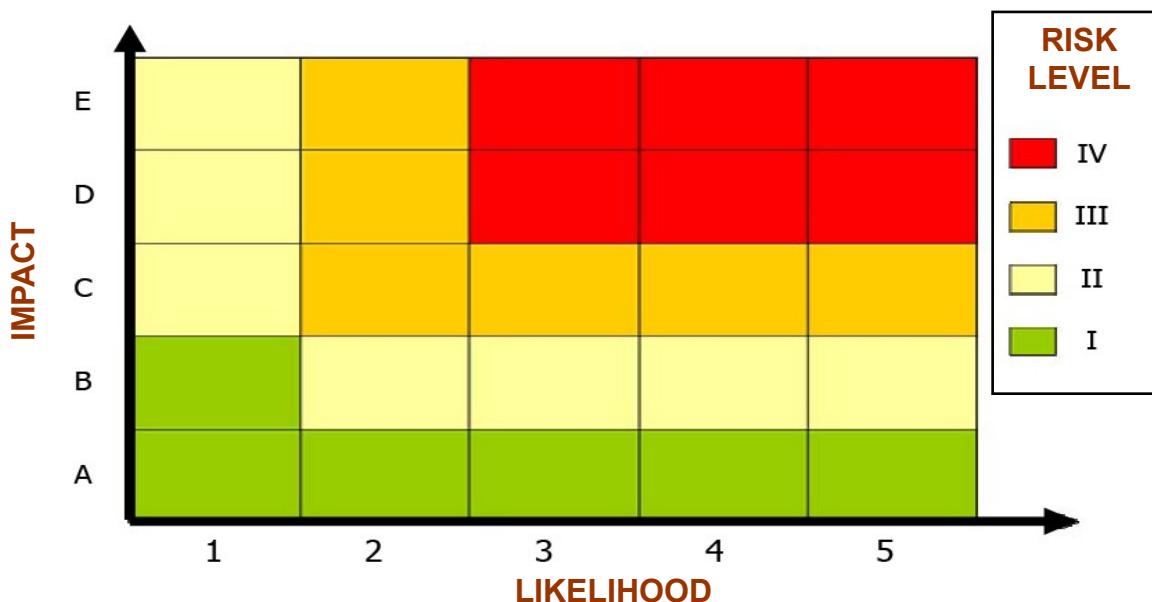
$$R = H \times E \times V$$

“Natural Risk is the combination of the probability or frequency of occurrence of a defined natural disaster and the magnitude of the consequences of its occurrence.”

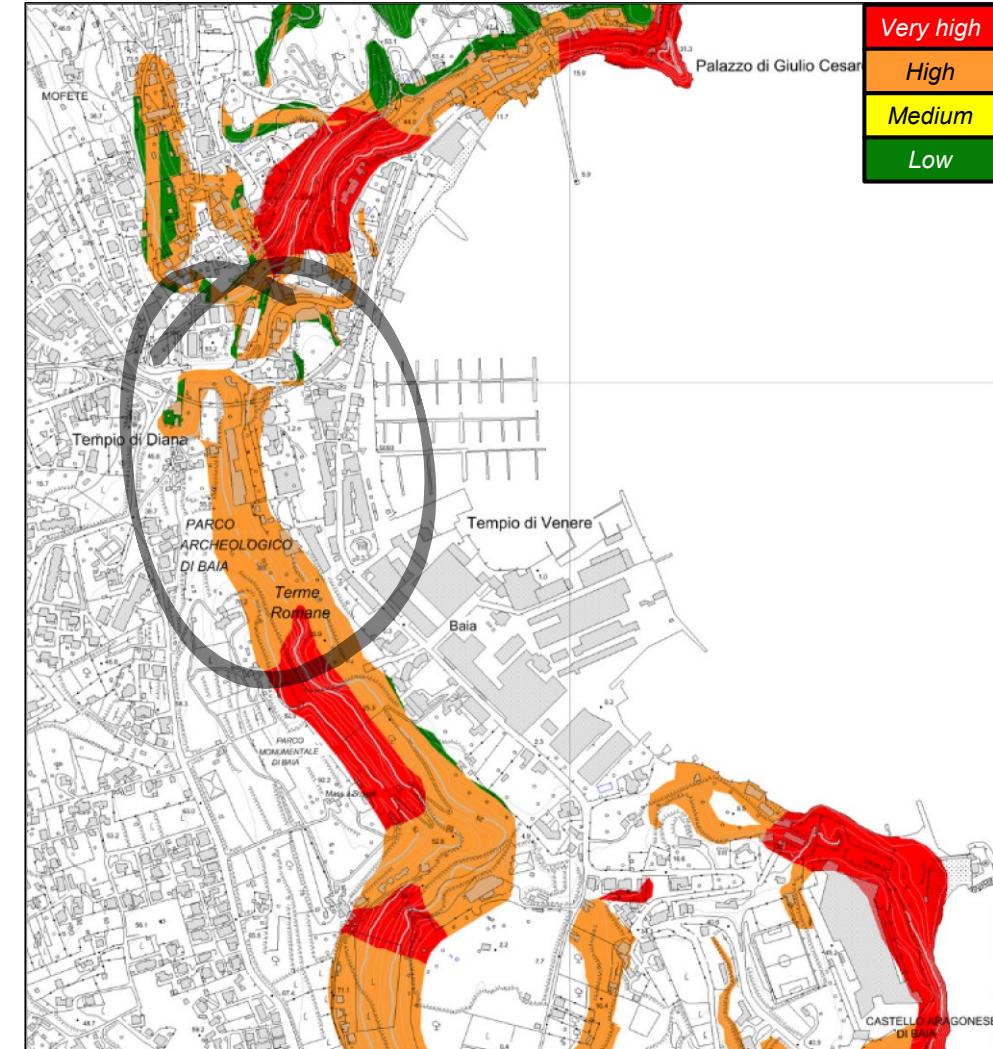


## QUALITATIVE RISK ASSESSMENT

- A risk matrix relates the two dimensions likelihood and impact. It is a graphical representation of **risk level** in a comparative way.
- The matrix is used as a visualization tool when multiple risks have been identified to facilitate comparing the different risks.



## Landslide risk of the Baia area



1 - EO4GEO Project

2 - COPERNICUS Programme

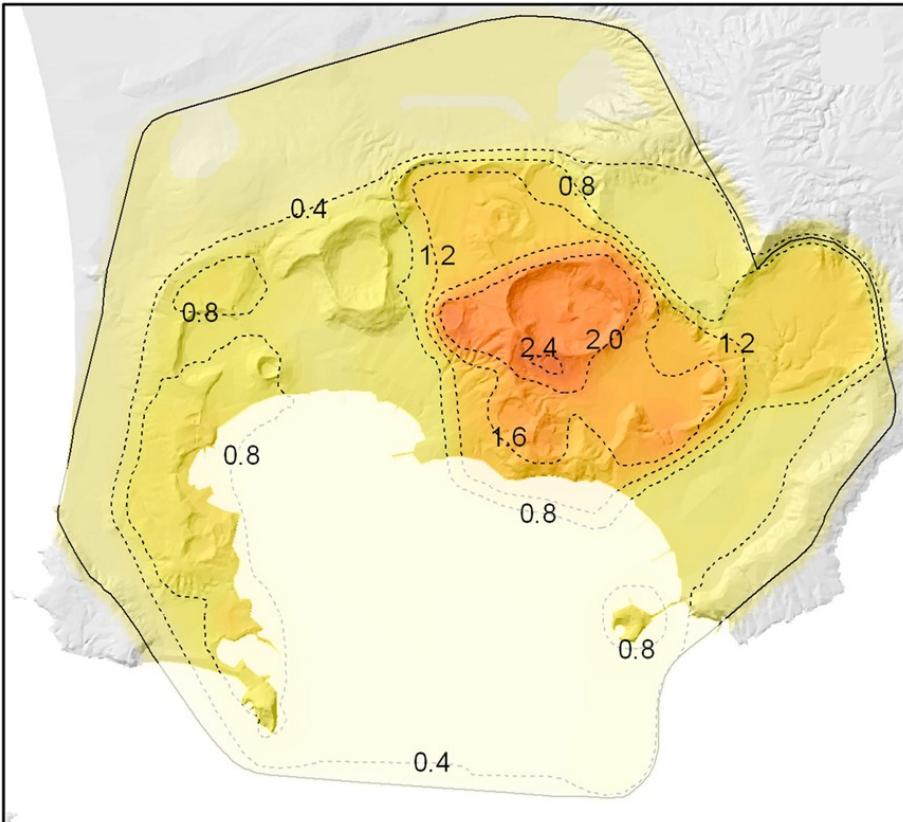
3 - Cultural Heritage

4 - Geohazard assessment

5 - SAR Interferometry

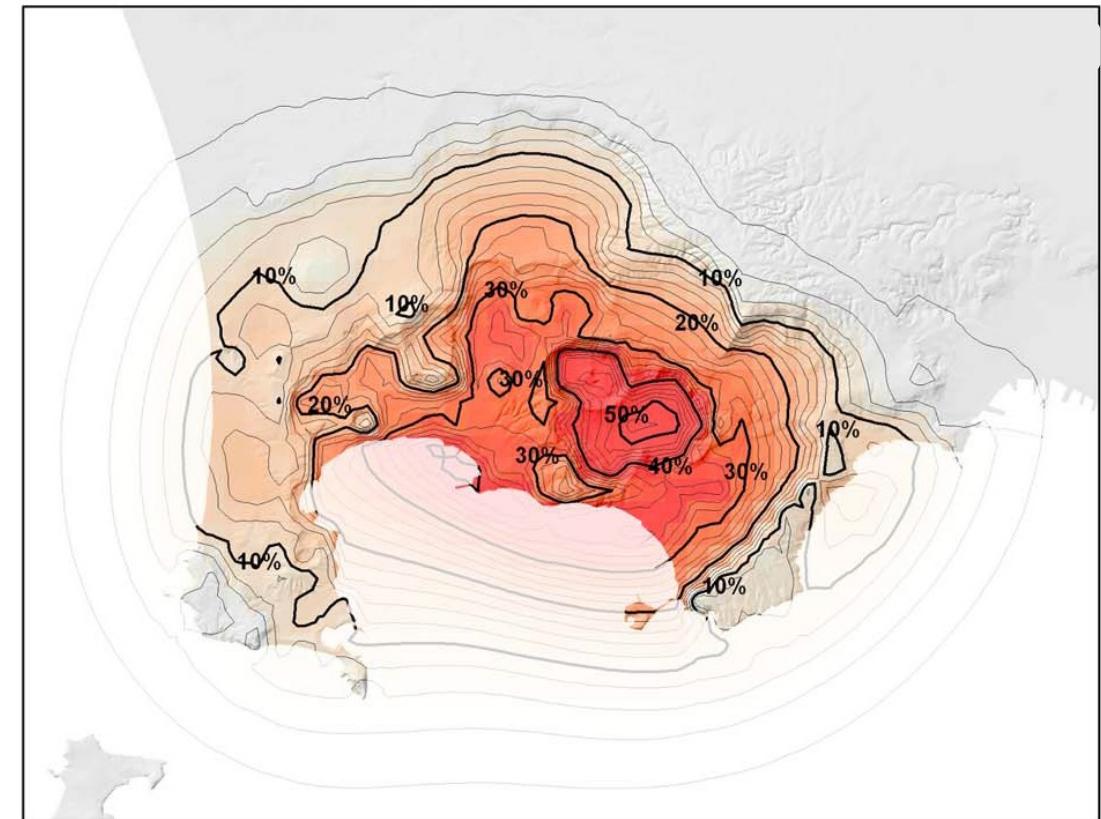
6 - Ground motion monitoring

## Volcanic hazard



Map of background probability of future vent opening produced by incorporating the information on the distributions of past vents in the last 15 ka, fault displacement and surface fracture density (Bevilacqua et al., 2015).

## Pyroclastic Density Currents (PDC) invasion probability maps



PDC invasion probability maps computed by assuming the vent opening distribution described in Bevilacqua et al., 2015 and the spatial density distribution of invasion areas of the last 5 ka. Single vent located on-land. Contours and colors indicate the percentage probability of invasion conditional on the occurrence of an explosive eruption (Neri et al., 2015).

## Volcanic surveillance at Phlegrean Field

October 2021:

- 212 Earthquakes
- $M_{dmax} = 1.5 \pm 0.3$

Cumulative displacement at Rione Terra since Jan2016:

53 cm

Alert level:

2, advisory

## CAMPI FLEGREI - Italia ottobre 2021

### Comunicazione sullo stato attuale della caldera dei Campi Flegrei

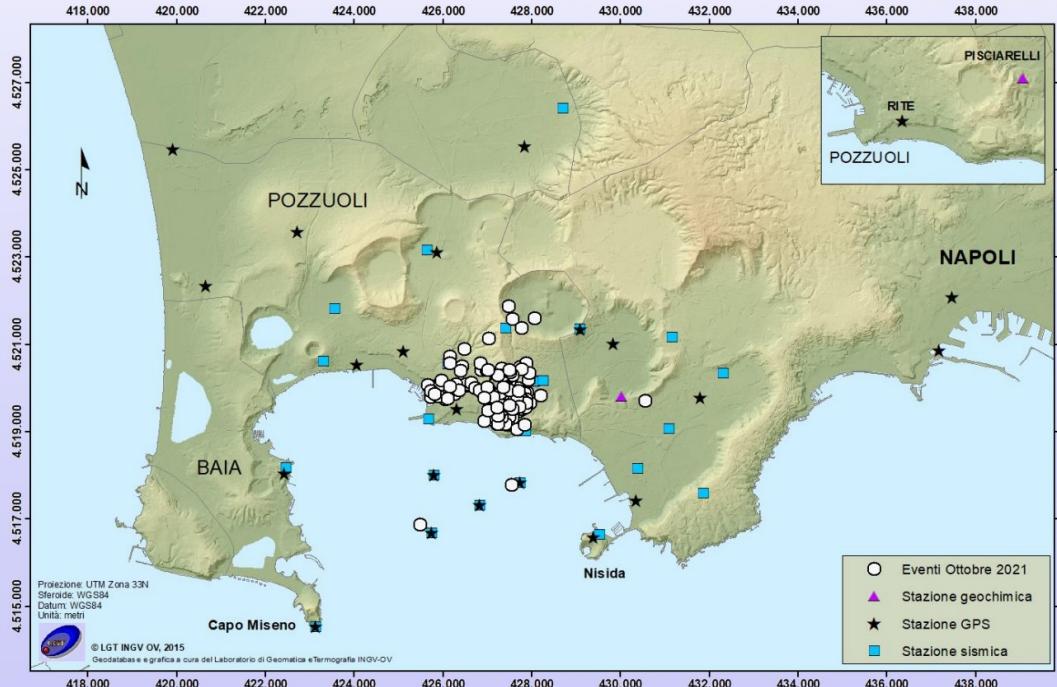
Nel corso del mese di ottobre 2021 sono stati registrati 212 terremoti ( $M_{dmax}=1.5\pm0.3$ ).

Il sollevamento registrato alla stazione GPS di RITE è di circa 53 cm a partire da gennaio 2016.

I parametri geochimici indicano il perdurare dei trend già identificati in precedenza.

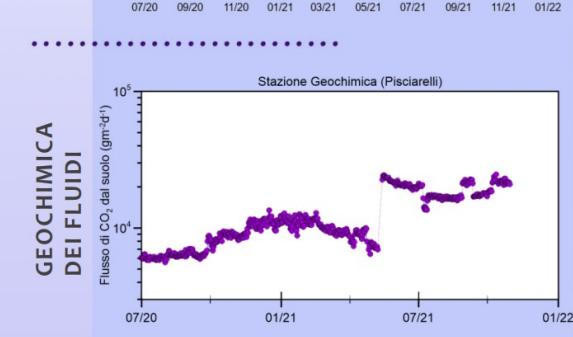


Per approfondimenti: [www.ov.ingv.it/ov/it/bollettini.html](http://www.ov.ingv.it/ov/it/bollettini.html)



**ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA OSSERVATORIO VESUVIANO**

[www.ov.ingv.it](http://www.ov.ingv.it)



1 - EO4GEO Project

2 - COPERNICUS Programme

3 - Cultural Heritage

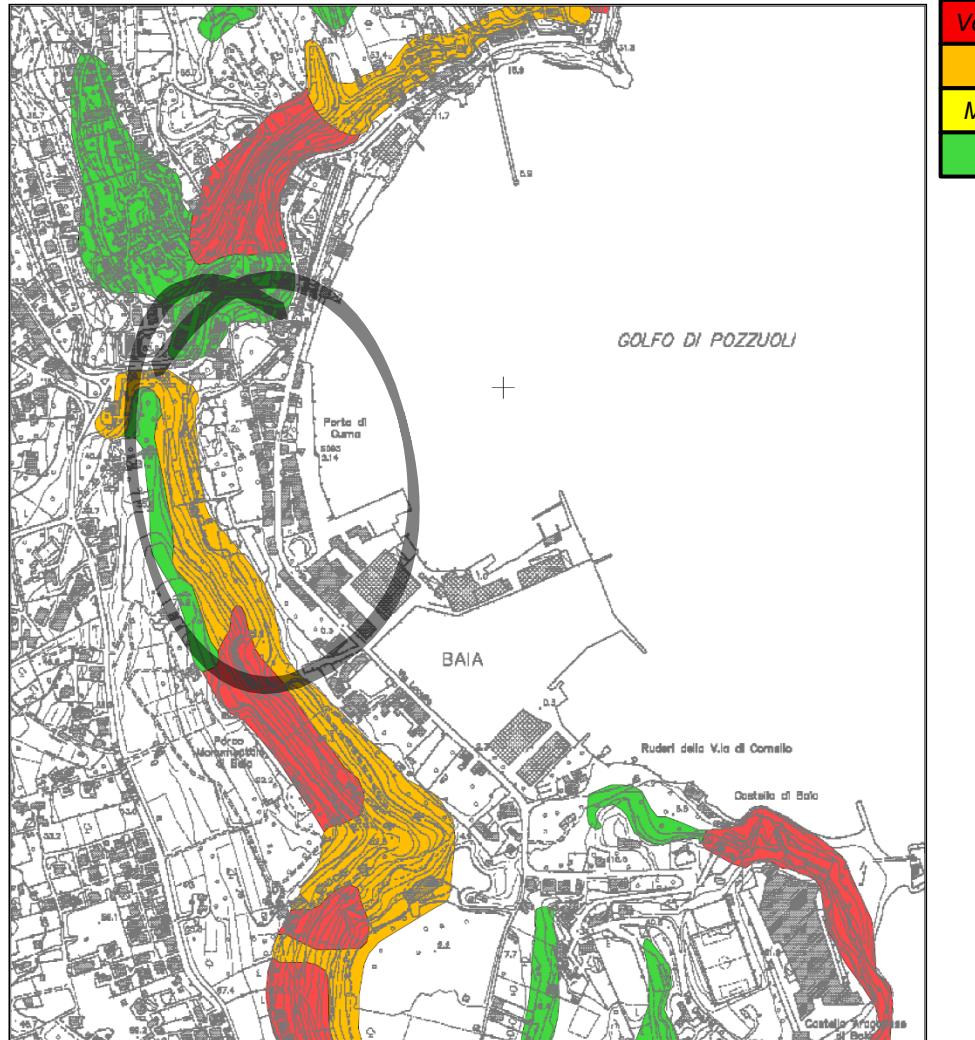
4 - Geohazard assessment

5 - SAR Interferometry

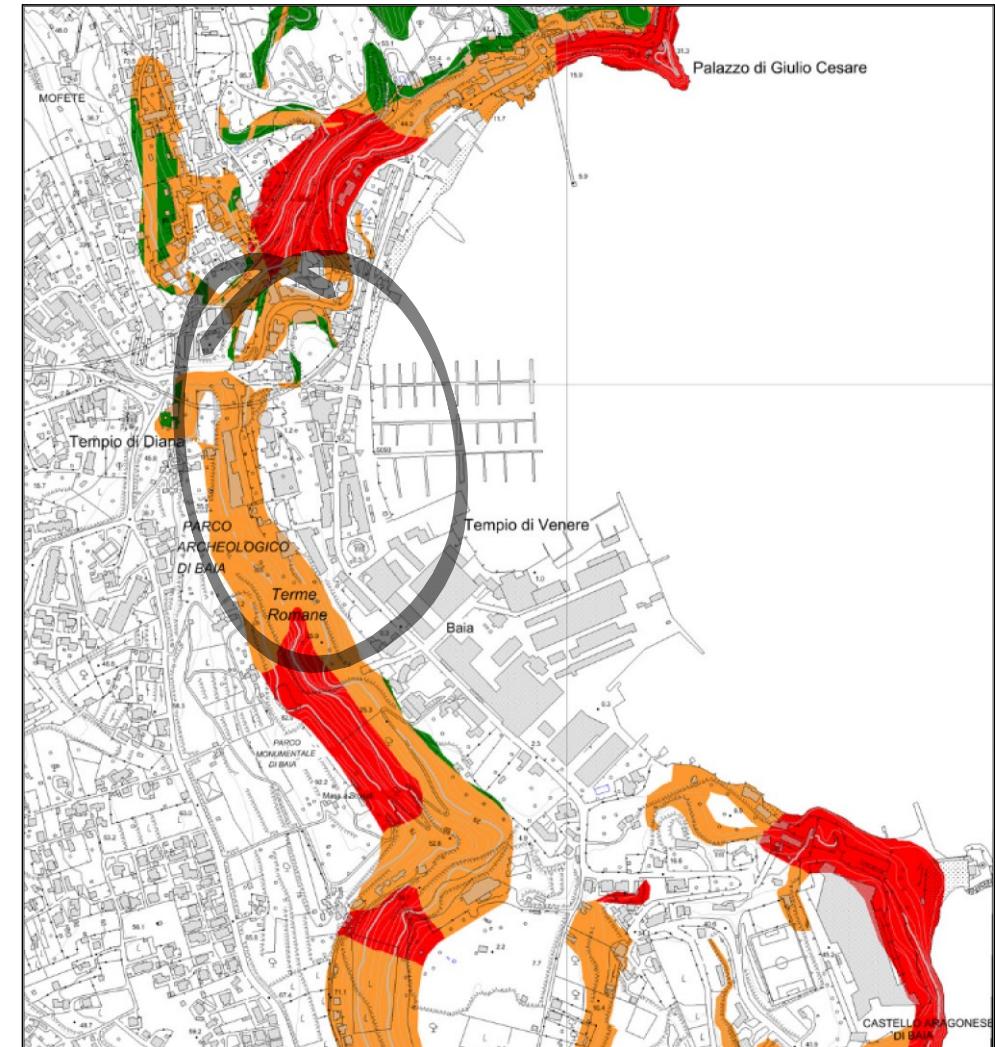
6 - Ground motion monitoring

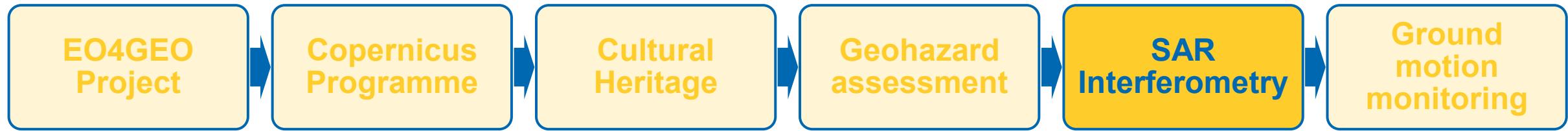
Local planning  
authority  
hazard and risk  
assessment

## Landslide susceptibility



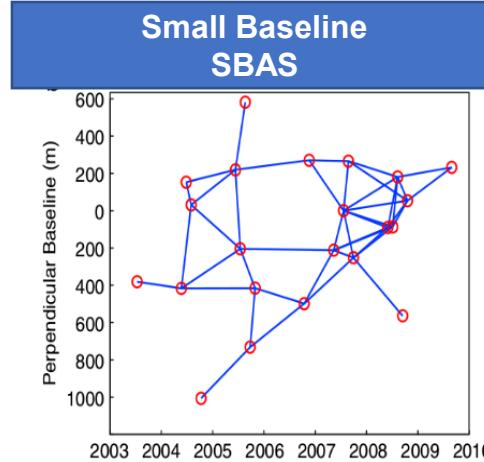
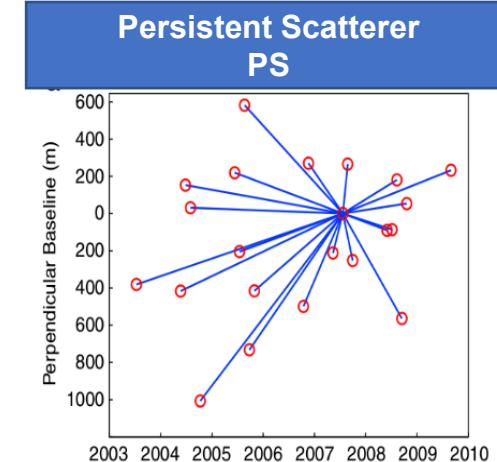
## Landslide risk





## Training objectives:

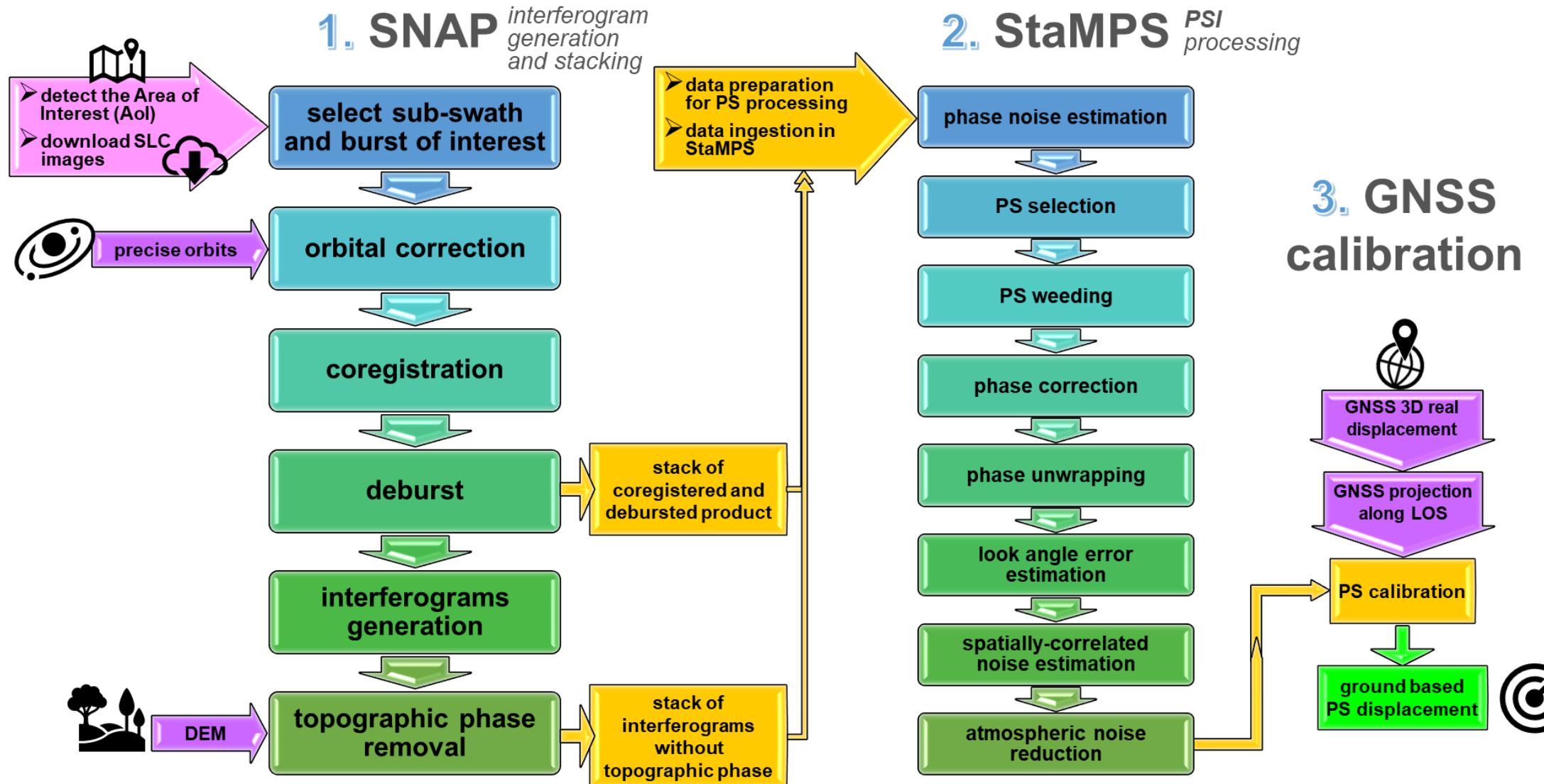
- Understand main features of InSAR techniques.
- Compare each techniques' pros and cons.
- PSI processing guidance.
- PSI data GNSS calibration.

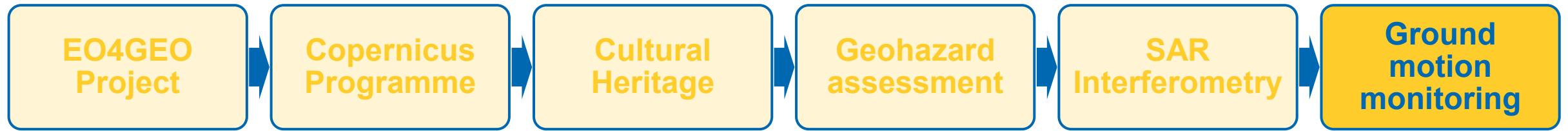


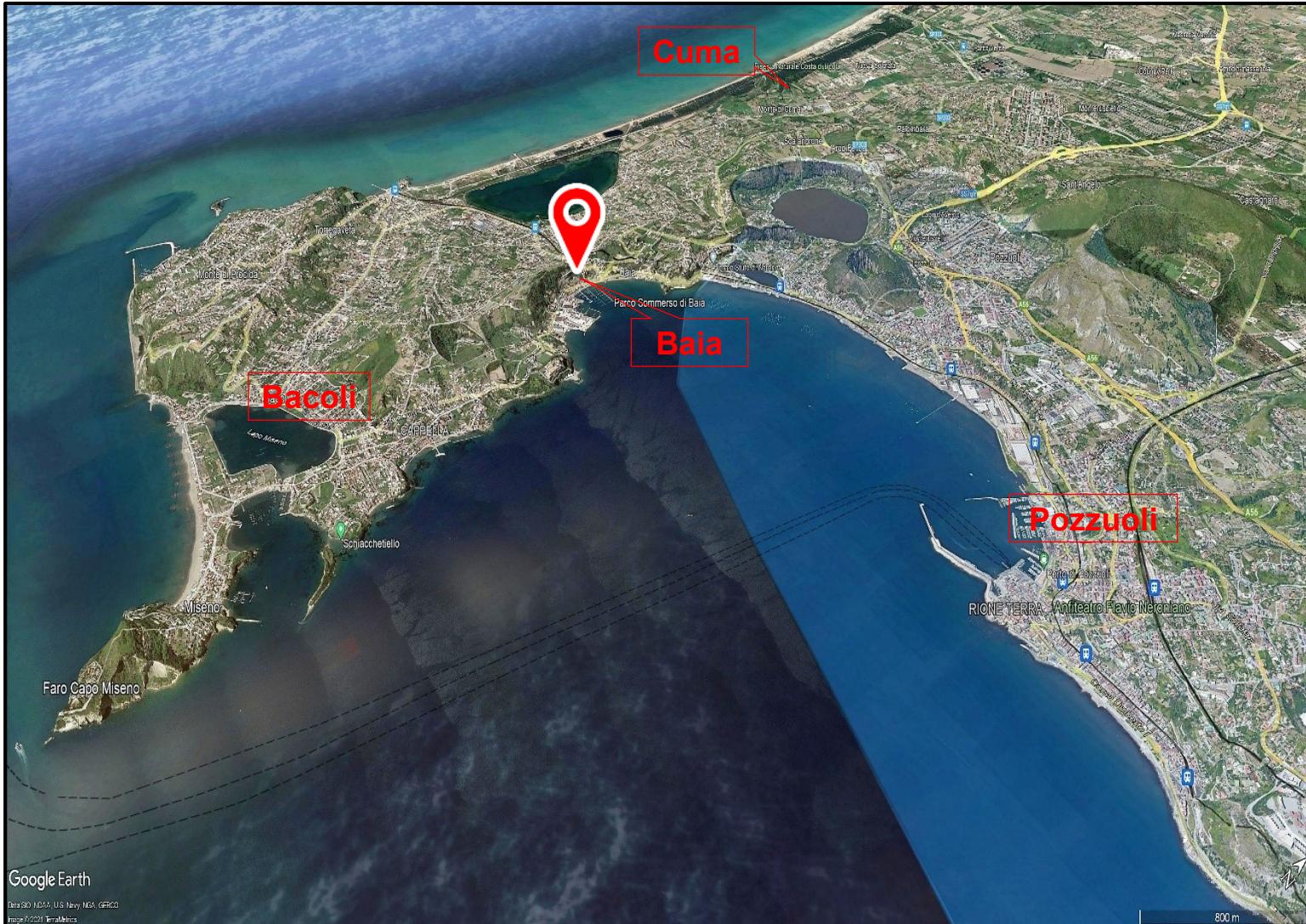
## Summary:

- Persistent Scatterer (PS) approach relies on pixels that exhibit low decorrelation over whole time series.
- Small Baselines (SB) approach relies on pixels that exhibit low decorrelation with short times and small perpendicular baselines.
- Non-deformation signals are reduced by modelling and filtering in both cases.
- PS techniques work best in urban environments, but can also be applied in rural environments.
- SB approach works more generally.
- Combined approach is possible.
- To ensure a proper interpretation, PSI data need to be **calibrated** with absolute control point, such as GNSS stations, thus obtaining a quasi continuous distribution of absolute ground displacements measures.

# PSI – processing workflow







## OUTLINE:

Methodology

Geohazard assessment

EO & in-situ monitoring

PS InSAR analysis

PSI data interpretation

## METHODOLOGY

similarity and differences in different monuments and sites, timeline approach



### Background

### Diagnosis of Current conditions

### Monitoring Processes

### Conservation policies and management

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

**Diagnosis of current conditions**  
**field study**): Non-invasive and non-destructive investigations.

**Monitoring processes**  
**(field study)**: Remote and in situ monitoring with low environmental impact.

**Conservation policies and management**  
**(desk and field study)**: An Eco-friendly strategy to enhance sustainability and local conservation practices

1 - EO4GEO Project

2 - COPERNICUS Programme

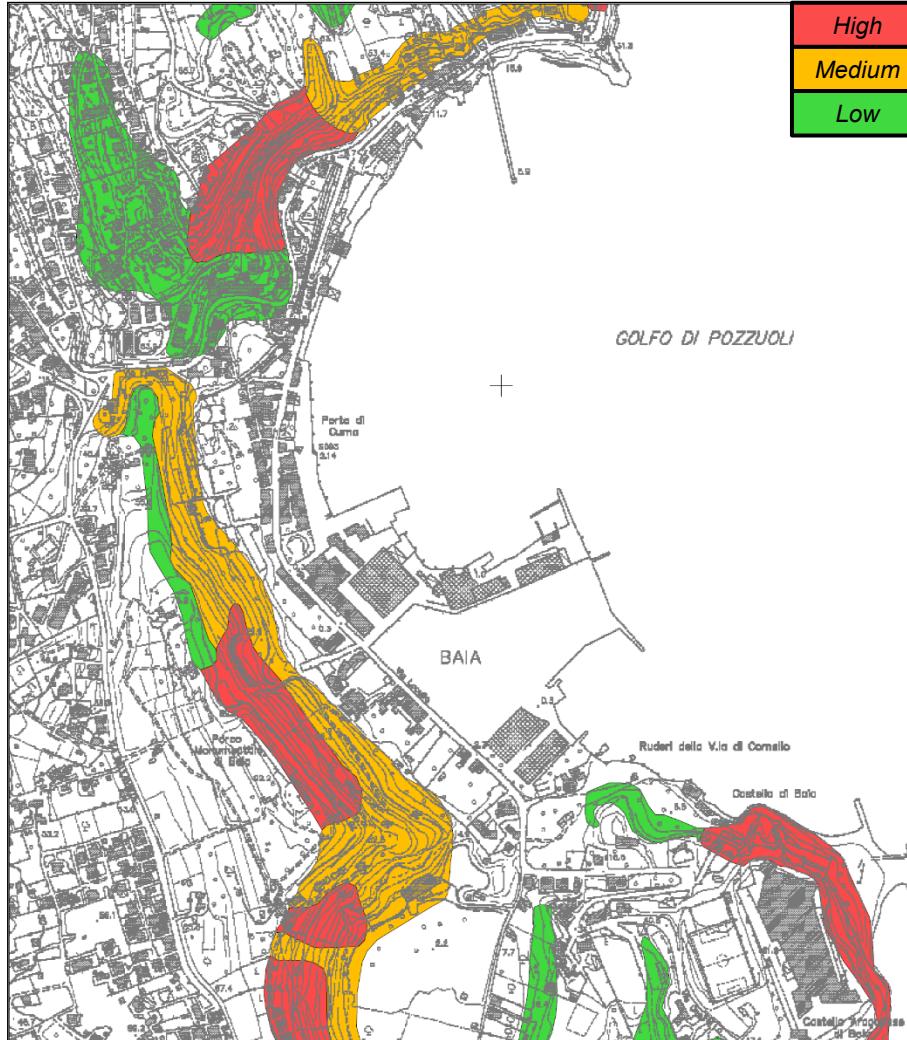
3 - Cultural Heritage

4 - Geohazard assessment

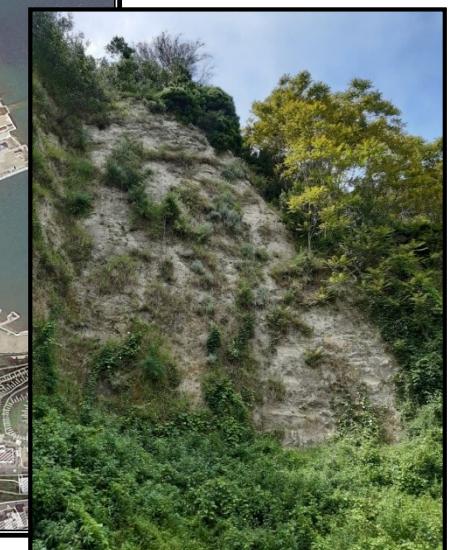
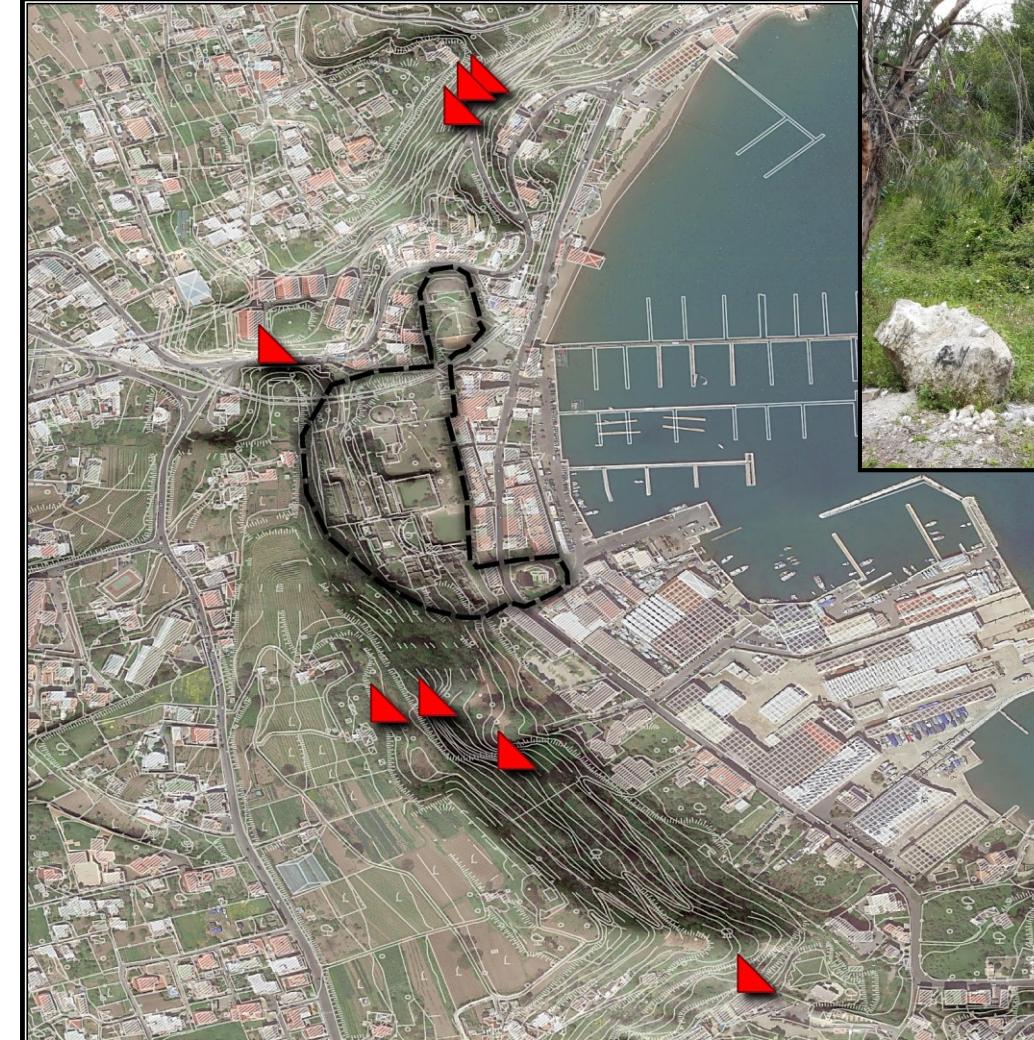
5 - SAR Interferometry

6 - Ground motion monitoring

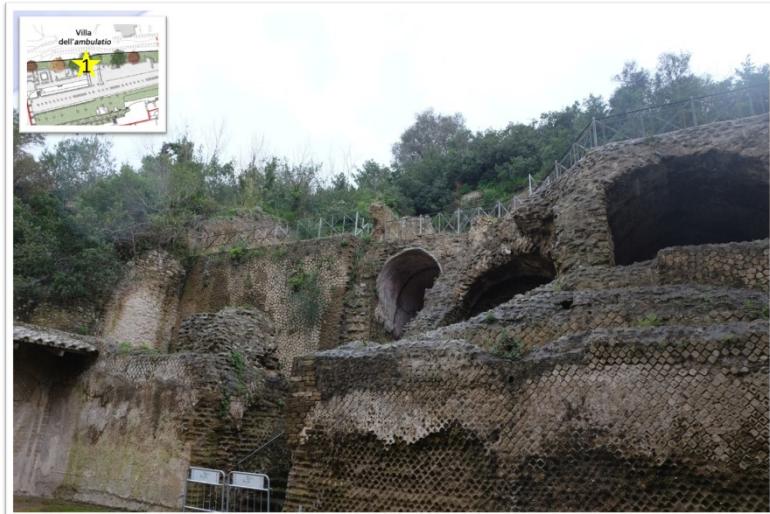
## Landslide susceptibility



## Landslide inventory

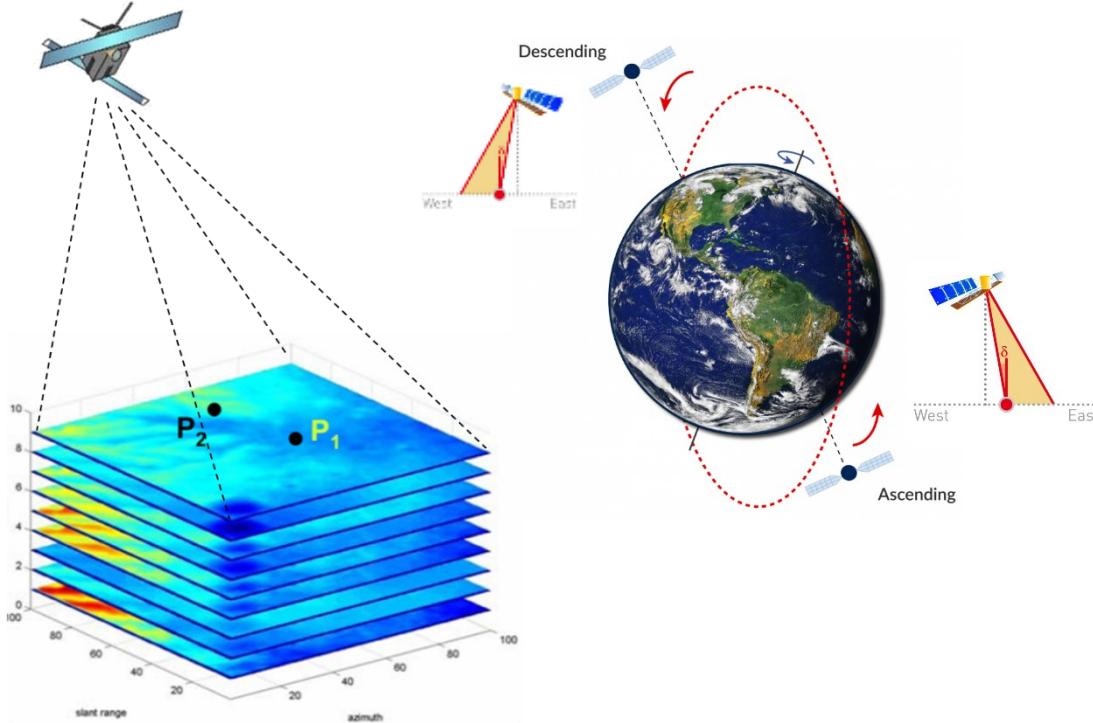


## Field survey

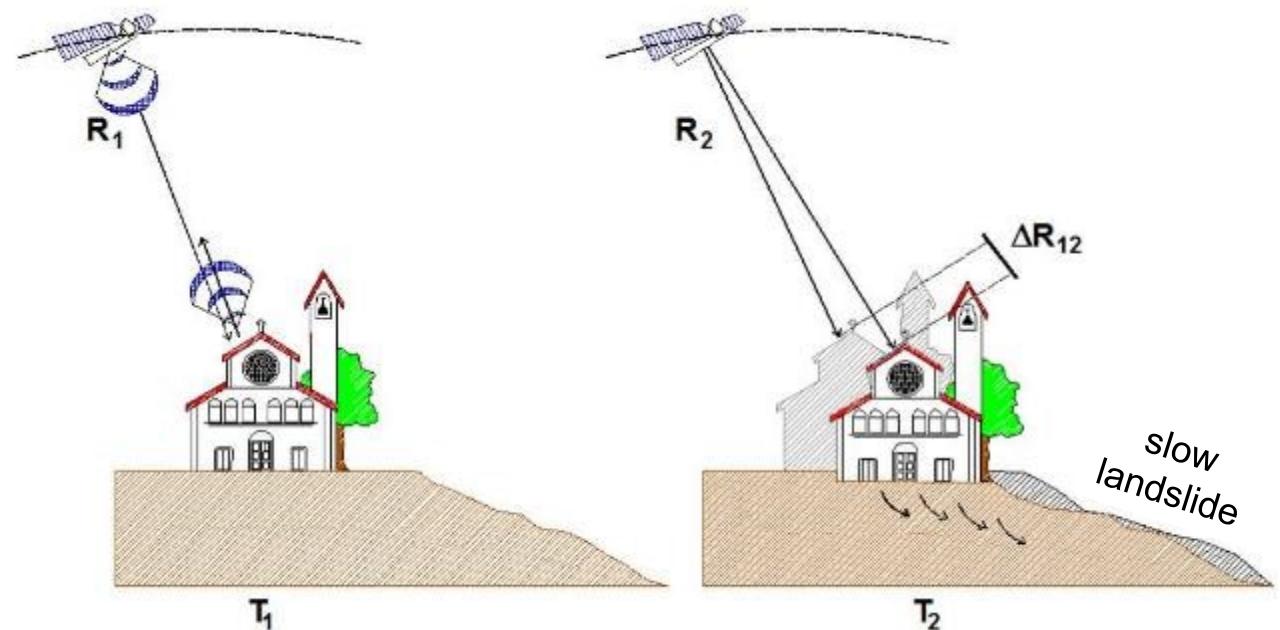


The analysis of the area and of the type of buildings helps in classifying main ruptures:

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



# InSAR for CH monitoring



Through many radar images acquisition and processing it is possible to obtain:

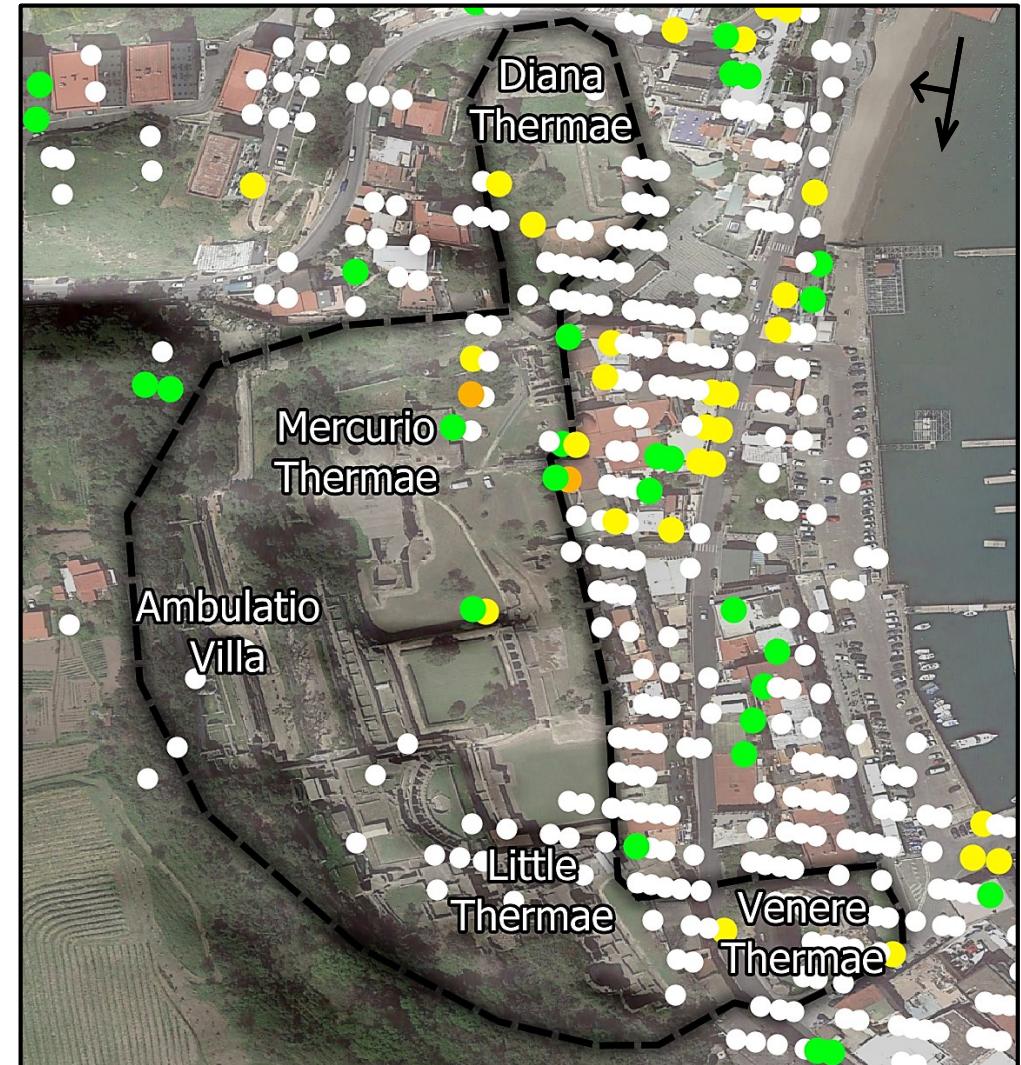
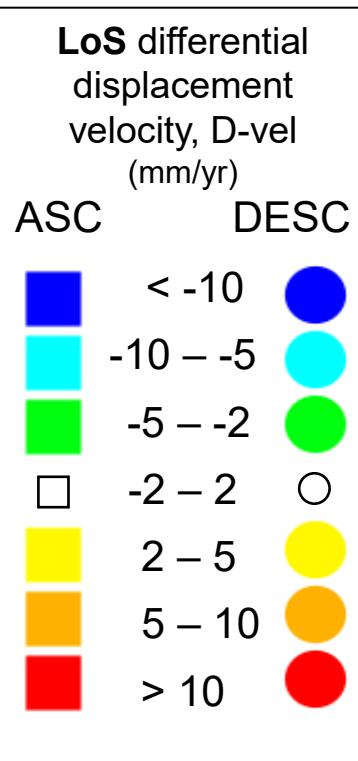
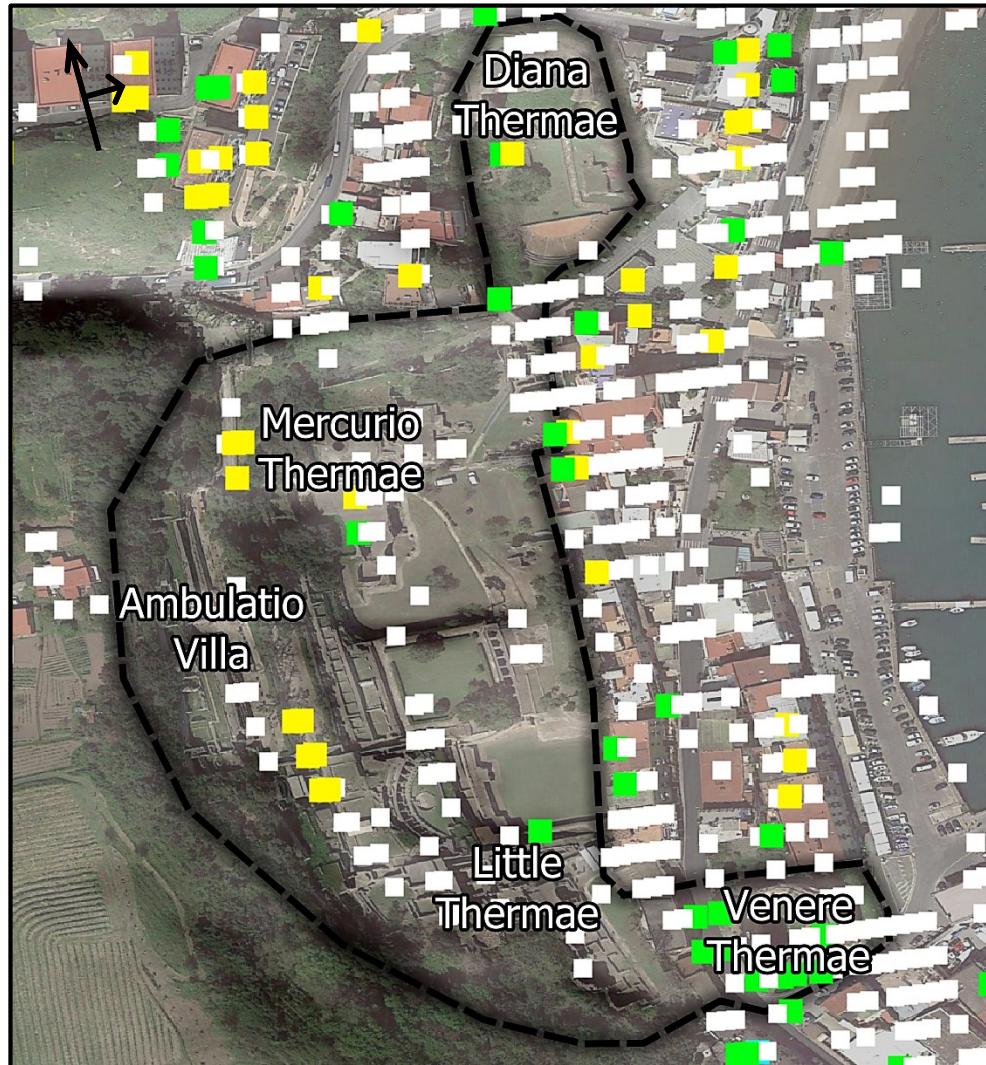
- time series displacement (millimeters precision),  
&
- average year velocity along the LOS (millimeters precision),

in order to detect ground deformation (e.g. slow landslide, subsidence).

Ascending (Apr 2016 – Aug 2020)

## Sentinel-1 PS: differential displacement velocity (D-vel)

Descending (Jan 2016 – Jul 2020)

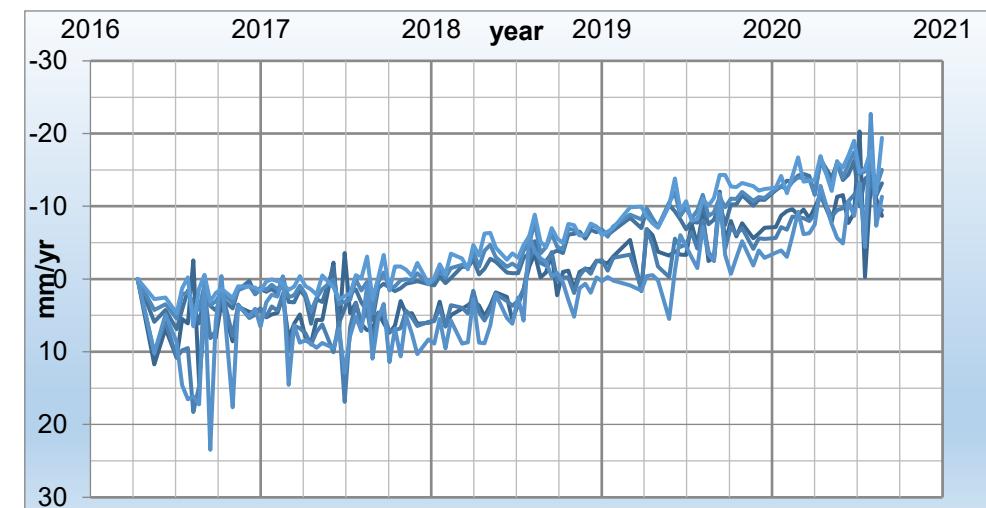


## PSI data interpretation: upper terrace example

LoS differential displacement velocity, D-vel (mm/yr)	
ASC	DESC
< -10	●
-10 – -5	●
-5 – -2	●
□	○
2 – 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.



[1 - EO4GEO Project](#)[2 - COPERNICUS Programme](#)[3 - Cultural Heritage](#)[4 - Geohazard assessment](#)[5 - SAR Interferometry](#)[6 - Ground motion monitoring](#)

## SUMMARY

The proposed methodology drives the analysis through an integrated assessment of different elements that contribute to define the exposure level of Cultural Heritage sites to actual local natural hazard.

- The first step is the understanding and correct framing of actual **natural hazard** conditions.
- The second step is the real knowledge of the site, to be acquired by **field survey** and **EO monitoring**, involving experts, managers and stakeholders too.
- Then, **the InSAR dataset is analyzed** and eventually corrected, to highlight the site-scale pattern of ground motion.
- Last comes the **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 a proper mitigation and conservation plan and to implement an integrated monitoring system.

more info (1/2)

1 - EO4GEO Project

[EO4GEO Project](#)

2 - COPERNICUS Programme

[COPERNICUS Programme](#)

3 - Cultural Heritage

[International COuncil on MOuments and Sites \(ICOMOS\)](#)

[Phlegrean Fields Archaeological Park](#)

[Roman Thermae of Baia](#)

[Speleological path at Roman Thermae of Baia](#)

[Underground Thermae of Baia restoration](#)

[Mercurio Temple restoration](#)

### more info (2/2)

4 - Geohazard assessment

[United Nations Office for Disaster Risk Reduction](#)

[UNESCO - International Programme on Landslides](#)

[UNESCO CHAIR - Prevention and Sustainable Management of Geo-Hydrological Hazards](#)

5 - SAR Interferometry

[ESA - InSAR Principles: Guidelines for SAR Interferometry Processing and Interpretation](#)

[European Ground Motion Service - White Paper](#)

[EGMS - Service Implementation Plan and Product Specification Document](#)

[Ground Motion Services for Geohazard Monitoring](#)

6 - Ground motion monitoring

[EU - European Ground Motion Service](#)

[Norway InSAR Visualization Tool](#)

[Tuscany InSAR Visualization Tool](#)