CASE STUDY 3
Forecasting and warning communication
The example of Campi Flegrei, Italy

Geneva, 9 July 2025

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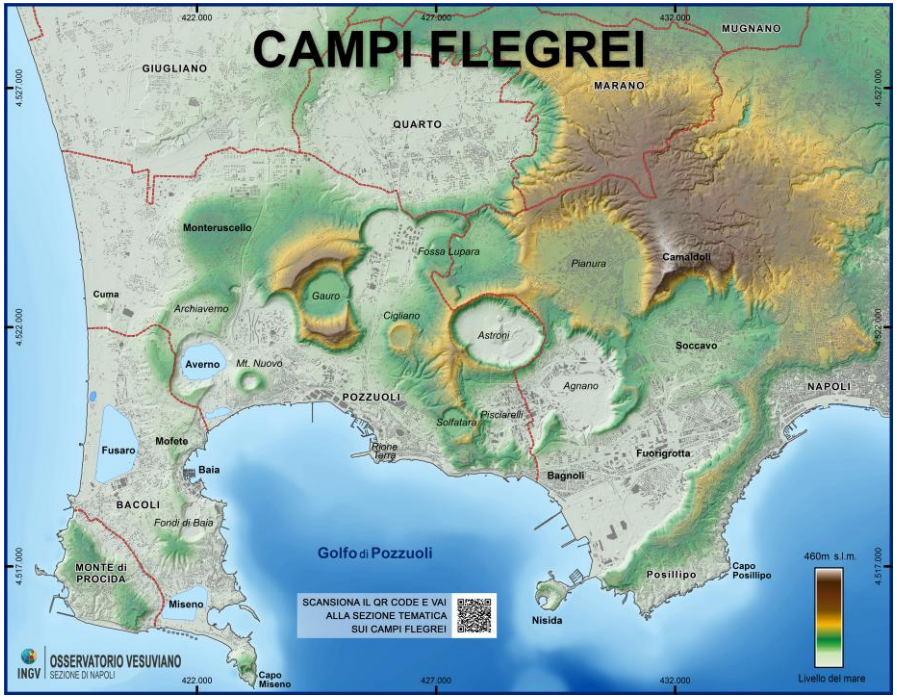
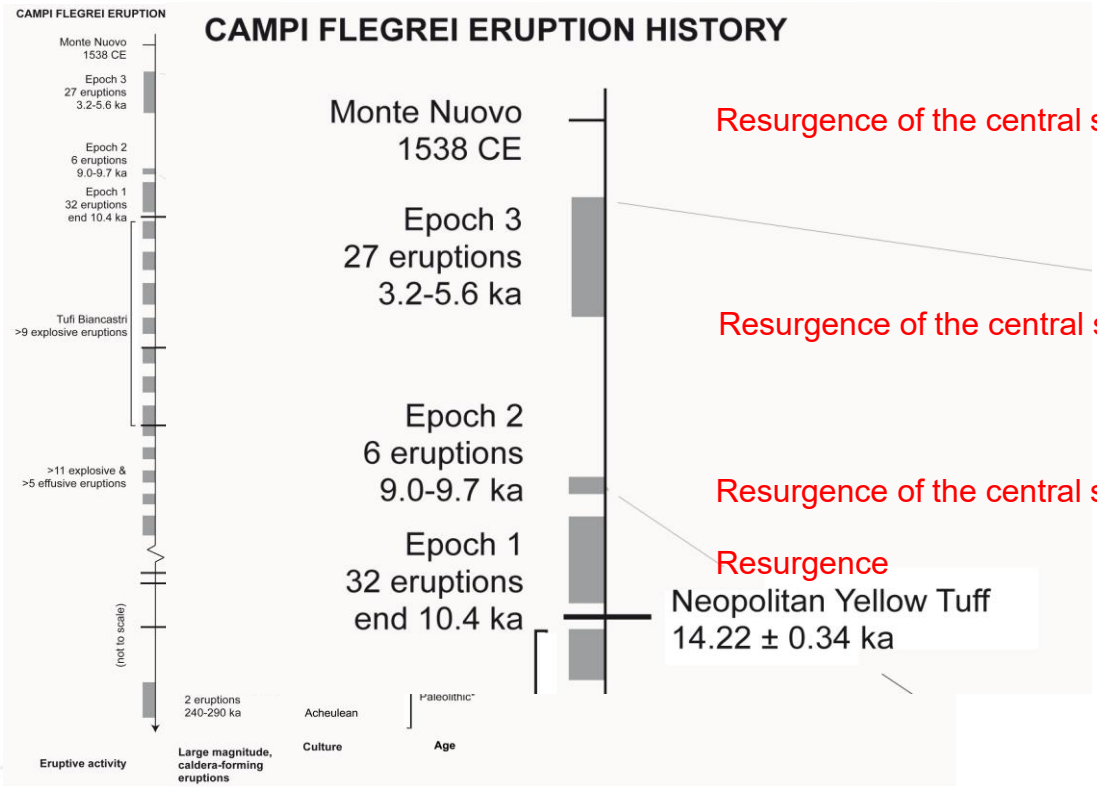
General setting, the Neapolitan area

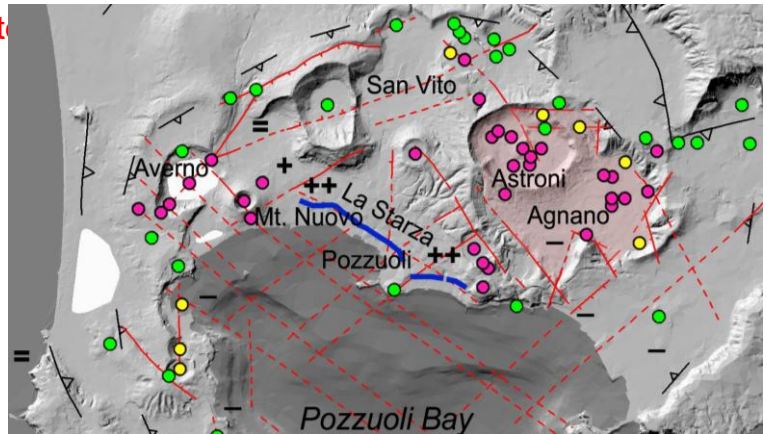


The three Neapolitan volcanoes and dense urbanization

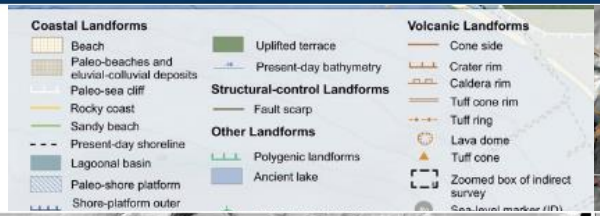
General setting, Campi Flegrei volcanism

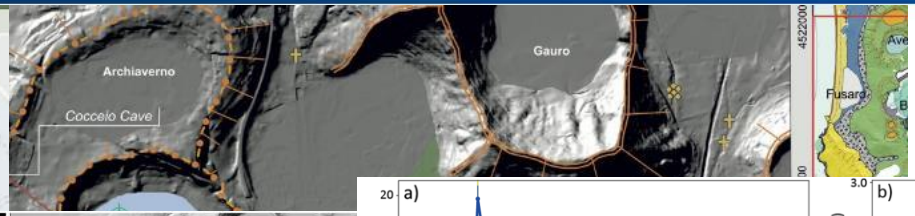


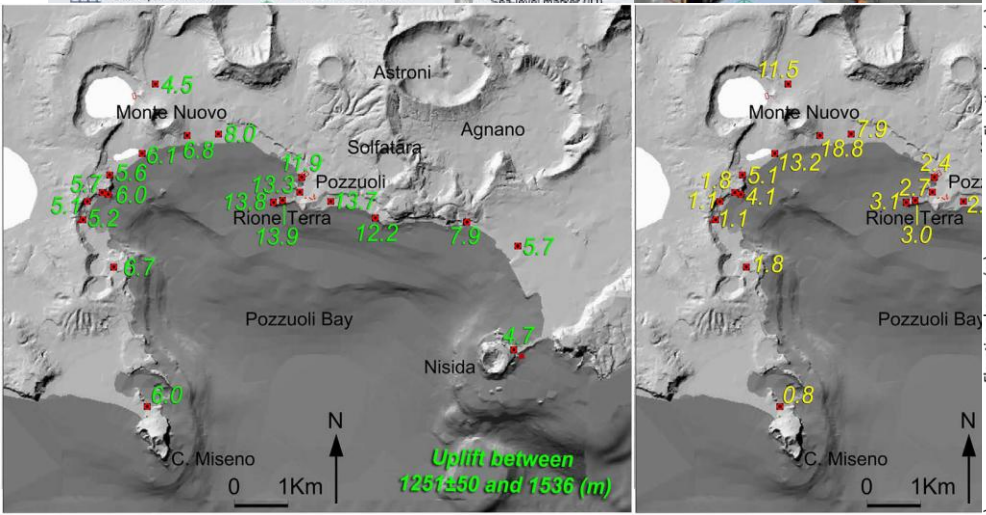
Volcanism and deformation of Campi Flegrei caldera. Relationships between ground deformation and vents distribution

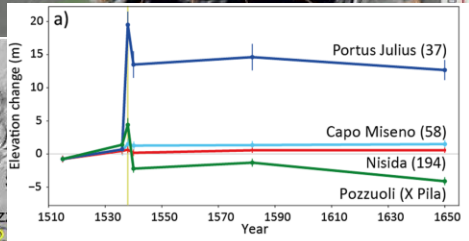


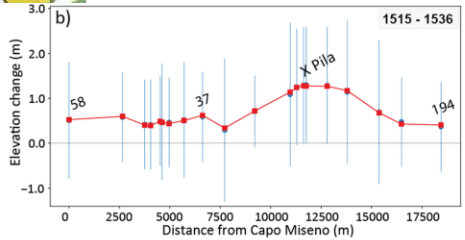
General setting, Campi Flegrei, dynamics befere the last eruption

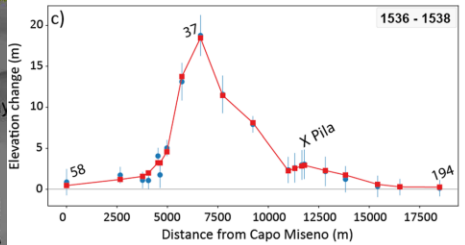


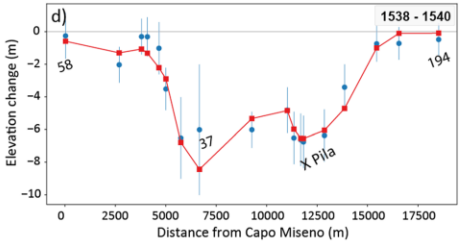


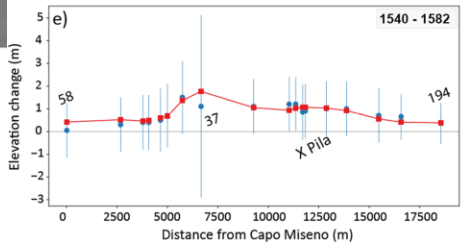


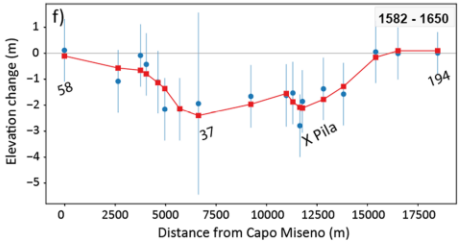












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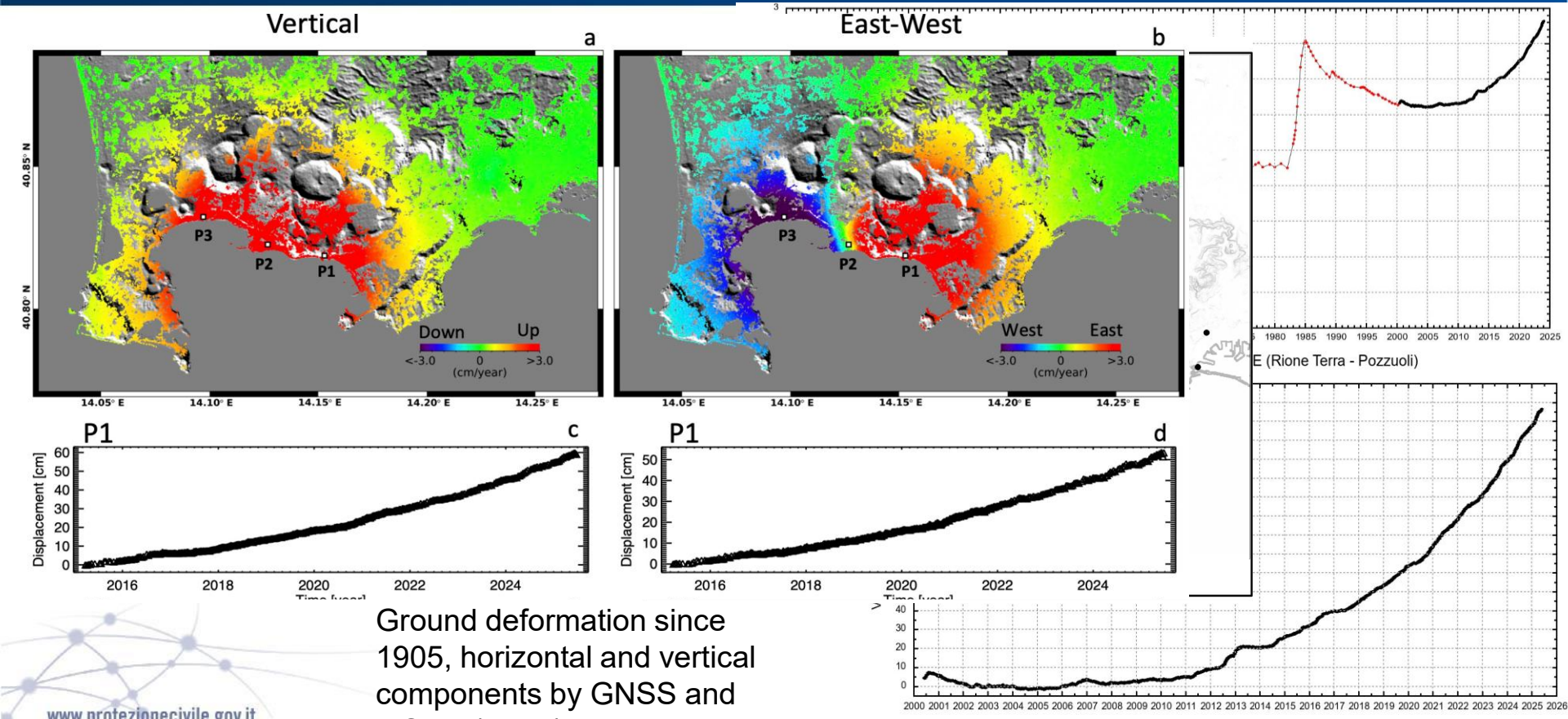
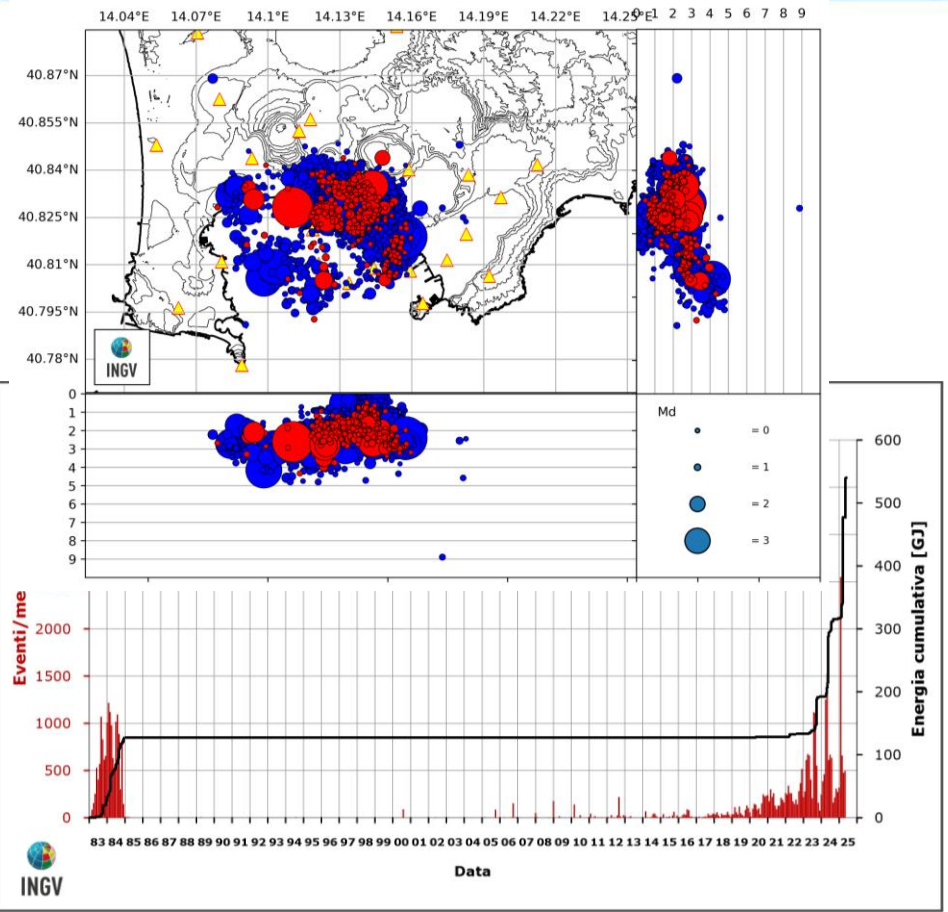
Multi-source data integration for the reconstruction of the ground deformation before and after the AD 1538 eruption

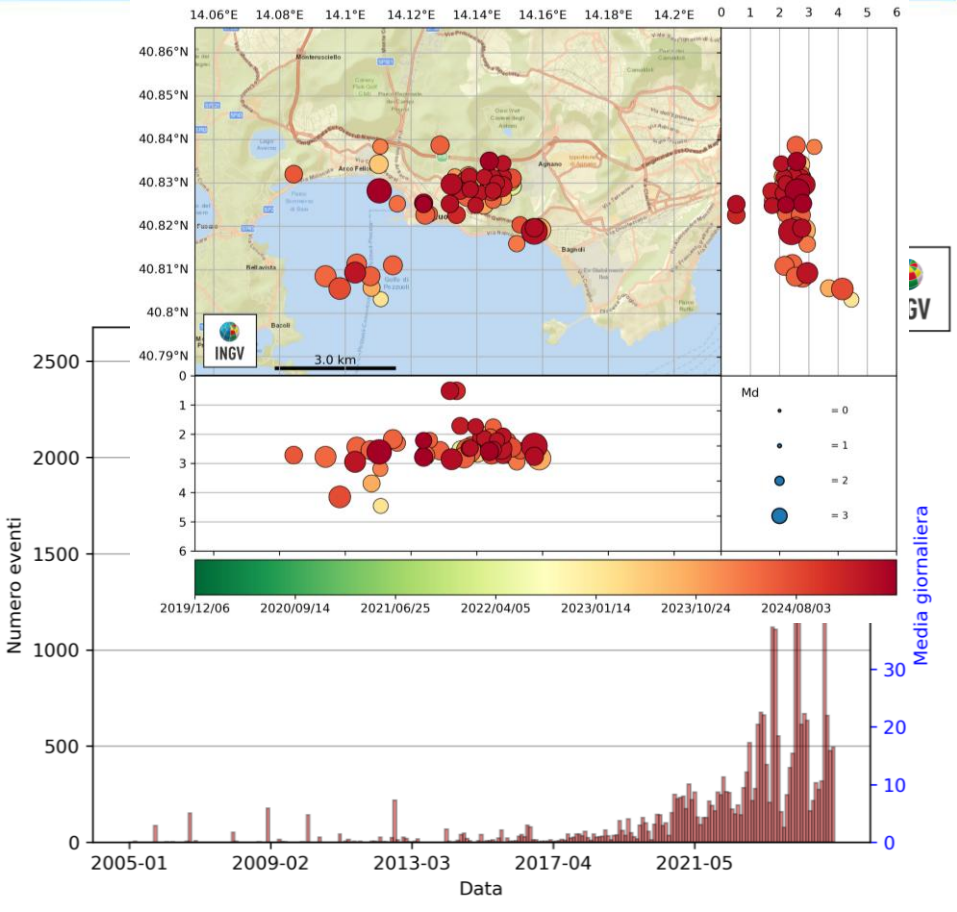
General setting, ground deformation



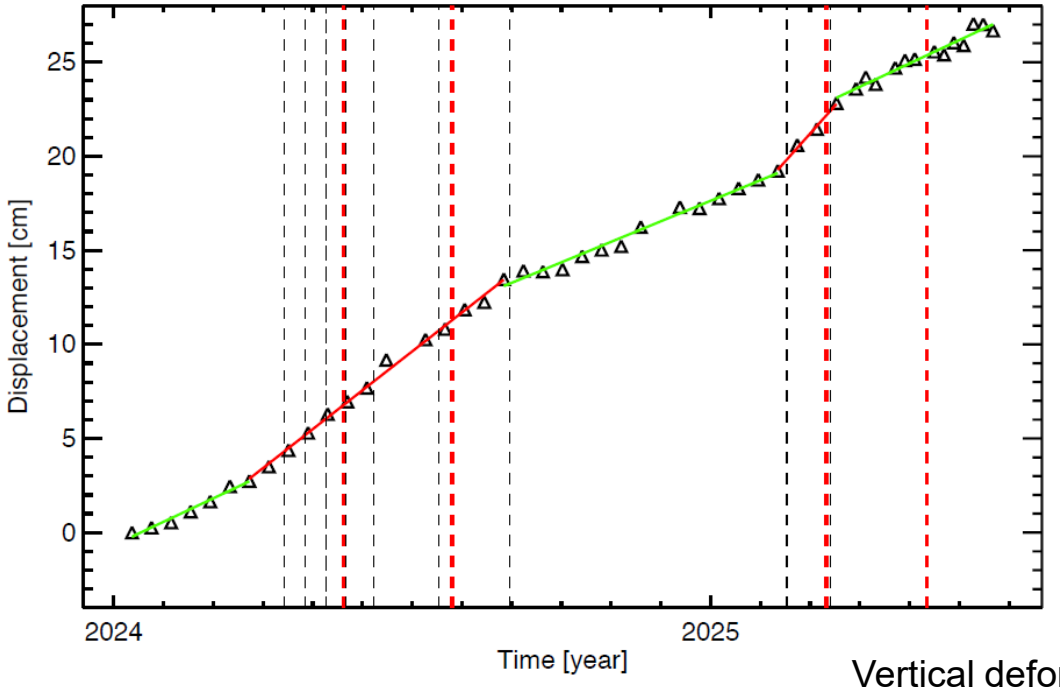
Ground deformation since 1905, horizontal and vertical components by GNSS and InSAR (IREA)

General setting, seismicity since ‘82



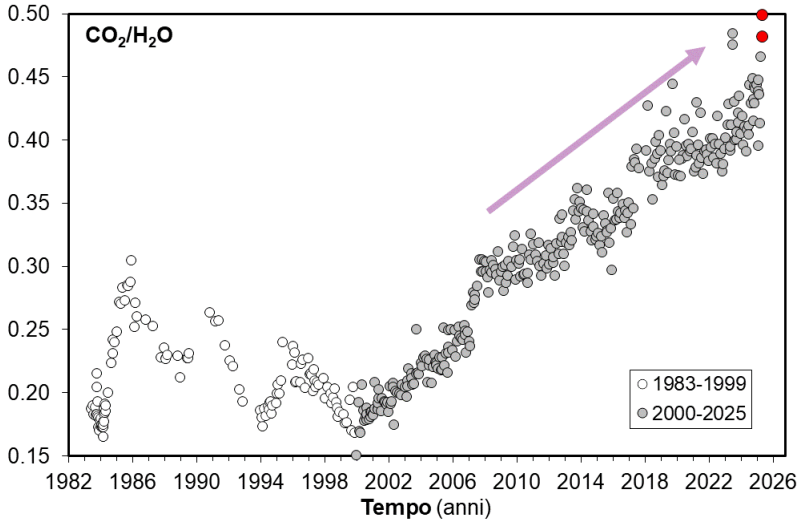


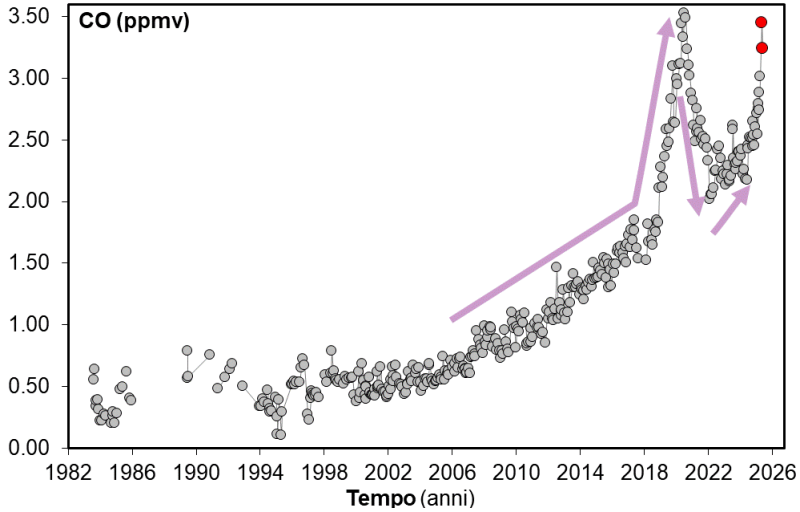
General setting, ground deformation and seismicity



Vertical deformation at the RITE GPS station (January 2024 – June 2025). The dashed lines indicate the the main earthquakes (Md > 3.6) and in red the events with Md ≥4 (courtesy of CNR-IREA).

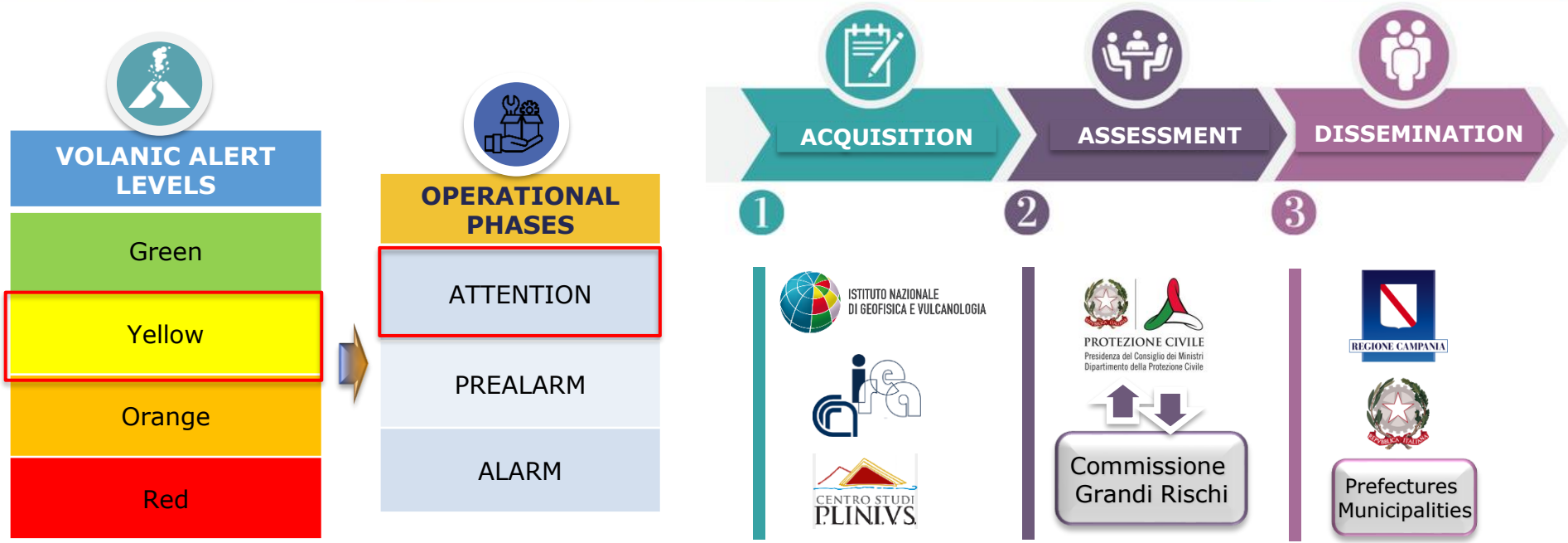
General setting, geochemical parameters





The chemical composition of fumaroles suggests an increase of the magmatic component in the fumarolic fluids through time. Furthermore, their analysis confirms a pluriannual trend of heating and pressurization of the hydrothermal system.

National volcanic early-warning system



- **Fully automated** early-warning systems for **paroxysmal explosions** and **volcanic tsunamis at Stromboli** activating **sirens**
- **Fully automated** early-warning system for **"lava fountains"** and **magmatic intrusions**

National volcanic early-warning system

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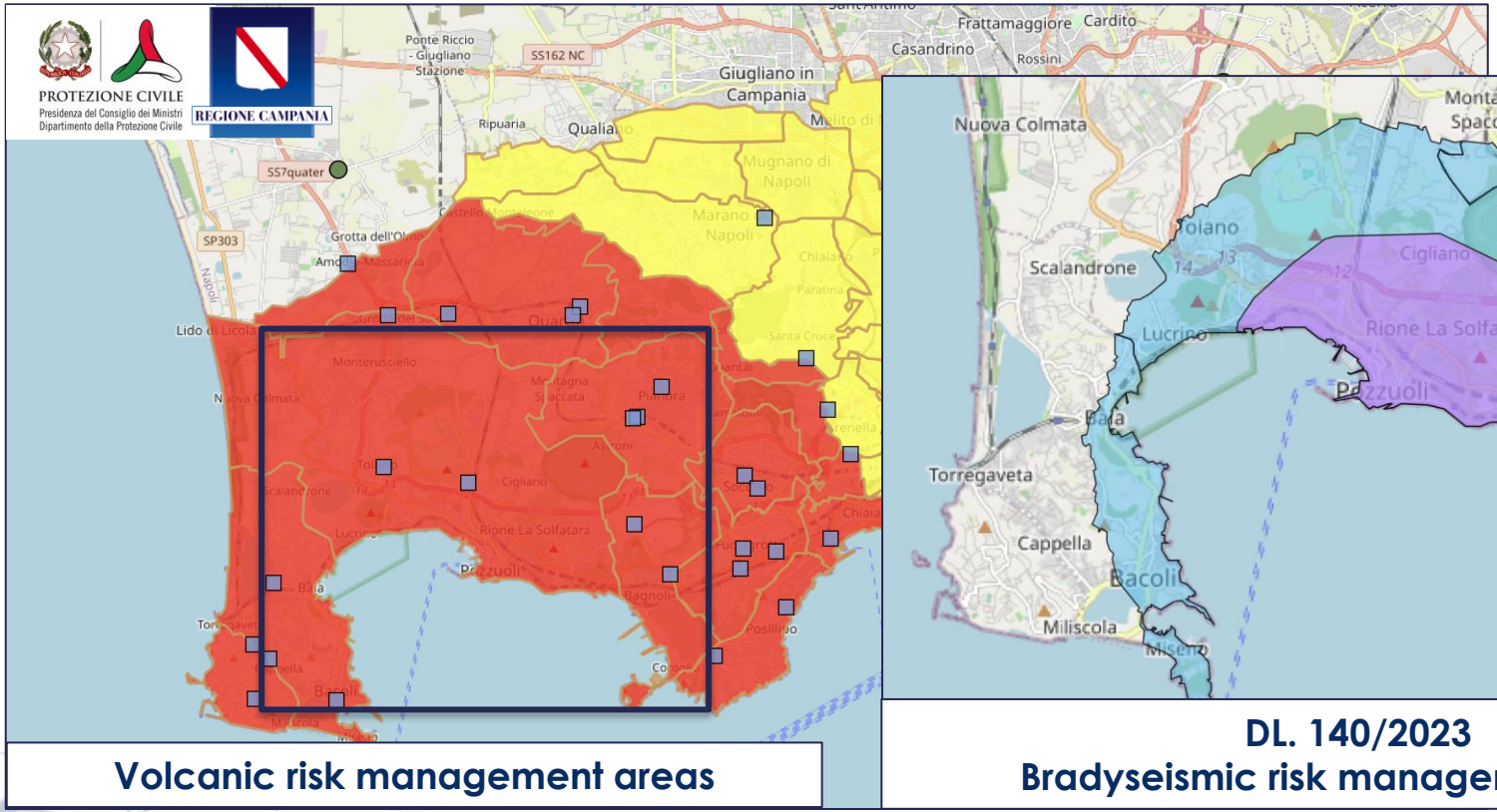
COMMUNICATION PROTOCOLS

1. **ACTIVITY NOTICE** — Volcanic activity; Seismic activity in volcanic areas
2. **EXTRAORDINARY NOTICE** — Ongoing volcanic activity which causes significant changes in the expected hazard scenarios
3. **EARLY-WARNING MESSAGES** — Sudden or fast evolving volcano related events
4. **BULLETINS** — Multi-disciplinary analysis; Overview of the activity and parameters
5. **REPORTS** — Released on annual base; In case of particular monitoring campaigns or updates on hazard scenarios

Risk management in Campi Flegrei



Volcanic risk management areas

DL. 140/2023
Bradyseismic risk management areas

Enhancing preparedness and alert dissemination




2 exercises on volcanic scenarios (2019 e 2024)

2 exercises on bradyseismic scenarios (2024)

IT-alert
National public warning system

Role and activity of the National scientific advisory board (CGR)

WHAT

Highest scientific advisory board of the Italian National Civil protection department (NCPD)

WHO

Professors/scientists from Universities and research institutions nominated by a Decree of Ministry of Civil protection and sea policies.

WHEN

Meetings take place when the Head of the NCPD requests a specific advice on a hazard/risk related topic.

HOW

Every meeting includes two sessions: **open session** (non-members, invited speakers) and **evaluation session** (only for CGR members) where the final report of the meeting is drafted and sent to NCPD Head.

Role and activity of the National scientific advisory board (CGR)

1. Seismic
2. Volcanic
3. Tsunami
4. Hydraulic, hydrogeological weather and climate
5. Forest fires Drought
6. Nuclear Radiological
7. Chemical, technological, industrial and transportation
8. Environment and health

Activity of the National scientific advisory board since 2023

Volcanic risk sector meetings

2025 — 6

- Volcanic alert level evaluation;
- Criteria for defining operational sub-areas within the red zone;
- Advice on the definition of operational sub-areas within the red zone.

2024 — 6

- Volcanic alert level evaluation;
- International focus on phreatic eruptions and monitoring capabilities;
- International focus on VALs and its updating at Campi Flegrei;
- Engagement in volcanic exercises.

2023 — 5

- Volcanic alert level evaluation;
- Multi-disciplinary analysis of the current monitoring system capabilities at Campi Flegrei;
- Advice on the definition of bradyseismic risk management areas together with the seismic sector.

Roadmap towards the new VAL table for Campi Flegrei

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REGIONE CAMPANIA

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January 2013
Final report from the scenario working group

February 2015
Operational guidelines for the red area

June 2016
DPCM
Update of the civil protection plan

June 2024
New working group for VAL update

January 2025
Final report of the VAL working group

March 2025
CGR-SRV meeting
Advice o the new VAL table

March 2025
VAL shared with local authorities

ALERT LEVEL	VOLCANO STATUS	EXPECTED CHANGES IN MAIN MONITORING PARAMETERS	PROBABILITY OF EVOLUTION TOWARDS AN ERUPTION	EXPECTED DURATION AT THIS LEVEL (DEGREE OF UNCERTAINTY)	POSSIBLE HAZARDS
GREEN	**QUIESCENT**	**Monitoring parameters within baseline values:** • Absence of medium-to-long term ground uplift or subsidence • Seismicity mostly absent • Fumarolic gases mainly hydrothermal in origin; hydrothermal system pressure and temperature stable over time	VERY LOW	NOT DEFINED	- CO_2 concentrations occasionally at potentially hazardous levels to human health near emission sites, in downwind sectors, morphologically depressed zones, or enclosed spaces
YELLOW	**LOW UNREST**	**One or more monitoring parameters above baseline values, slowly progressing and/or prolonged over time:** • Uplift of the caldera center at slow speed with radial geometry • Sporadic, low-energy volcano-tectonic seismicity • Slight increase in magmatic component in fumarolic gases; increase of CO_2 and degassing areas. Minor changes in the hydrothermal system equilibrium pressure and temperature	LOW	NOT DEFINED	- CO_2 concentrations occasionally at potentially hazardous levels to human health near emission sites (also diffusive), in downwind sectors, morphologically depressed zones, or enclosed spaces - Occasionally felt seismic shaking
	MEDIUM UNREST	**Monitoring parameters above baseline values, showing progression over time:** • Uplift of the caldera center at moderate speed with general radial geometry • Frequent volcano-tectonic seismicity with maximum magnitude (Md) sporadically between 4 and 4.5 • Moderate increase of the magmatic component in fumarolic gases; increase in CO_2 flux and extension of degassing areas. Further variations in the hydrothermal system equilibrium pressure and temperature	LOW-TO-MEDIUM	NOT DEFINED	- Potentially hazardous concentrations of CO_2 and H_2S to human health near emission areas (including diffusive), in downwind sectors, morphologically depressed zones or enclosed spaces - Light to occasionally strong seismic shaking near epicentral areas - Localized phreatic explosions in areas with intense hydrothermal activity - Seismic induced landslides near epicentral areas
ORANGE	**HIGH UNREST**	**Monitoring parameters significantly above baseline values, with an ongoing progression:** • Uplift of the caldera center at moderate-to-high speed with general radial geometry • Very frequent volcano-tectonic seismicity with repeated events of magnitude (Md) between 4 and 4.5 • Significant increase of the magmatic component in fumarolic gases and of the hydrothermal system equilibrium pressure and temperature values; further expansion of degassing areas	MEDIUM	WEEKS/MONTHS/YEARS (VERY HIGH)	- High concentrations of CO_2 and H_2S, potentially hazardous to human health, near emission areas (including diffusive), in downwind sectors, morphologically depressed zones or enclosed spaces - Strong seismic shaking near epicentral areas - Localized phreatic explosions in areas with intense hydrothermal activity - Seismic induced landslides near epicentral areas
	VERY HIGH UNREST	**Monitoring parameters well above baseline values, with further progression:** • High-speed ground uplift with radial geometry, eventually not centered in the caldera. Surface fractures may open. • Very frequent volcano-tectonic seismicity with general increase in maximum magnitude (eventually up to Md = 5). Possible appearance of long-period (LP) seismicity • Further geochemical variations with expansion of degassing areas and new emission points. • Sudden changes in groundwater level, temperature, and salinity. Possible appearance of SO_2 in fumarolic fluids	MEDIUM-TO-HIGH	WEEKS/MONTHS/YEARS (VERY HIGH)	- High concentrations of CO_2 and H_2S, potentially hazardous to human health, near emission areas (including diffusive), in downwind sectors, morphologically depressed zones or enclosed space - Intensification of hydrothermal activity and expansion of high-emission areas with increased likelihood of phreatic explosions - Strong and frequent seismic shaking near epicentral areas - Seismic induced landslides near epicentral areas - Surface fracturing in areas experiencing the greatest uplift
RED	**PRE-ERUPTIVE**	**Monitoring parameters at very high levels and rapidly evolving:** • Very high-speed uplift with non-radial geometry. Deformation maxima may localize in association with surface fracturing and/or faulting, sometimes associated with water or fumarolic fluid emission • Extremely frequent volcano-tectonic seismicity eventually migrating towards the surface. Possible increase of the maximum Md also over 5 and occurrence of LP seismicity. • Strong increase in gas flux, significant rise of the temperatures, rapid changes (days/hours) in gas chemistry, appearance and/or increase of SO_2, and possible presence of other acidic gases (HF, HCl) Possible identification of the area with the highest probability of eruptive vent opening.	VERY HIGH	HOURS/DAYS (LOW)	- CO_2-SO_2 gas emissions from areas of maximum uplift and surface fracturing - Further intensification of hydrothermal activity with expansion of the emission zones and higher probability of hydrothermal and/or phreatic explosions - Very frequent and intense seismic shaking - Seismic induced landslides near epicentral areas - Rapid and localized uplift with surface faulting/fracturing - Opening of new degassing areas associated with possible phreatic explosions

Operational response to the bradyseismic unrest

D.L. n.140 del 12 October 2023

SERIE GENERALE

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Anno 164° - Numero 239

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SOMMARIO

LEGGI ED ALTRI ATTI NORMATIVI

DECRETO-LEGGE 12 ottobre 2023, n. 140.

Misure urgenti di prevenzione del rischio sismico connesso al fenomeno bradisismico nell'area dei Campi Flegrei. (23G00156) ..... *Pag.* 1

DECRETO 2 ottobre 2023.

Rinnovo e modifica del decreto 14 marzo 2018, con il quale al laboratorio Mondeco S.r.l. in Alba, è stata rinnovata la designazione al rilascio dei certificati di analisi nel settore vitivinicolo. (23A05565) *Pag.* 6

Ministero dell'economia e delle finanze

- Art. 2. Extraordinary vulnerability analysis plan for the the built environment directly impacted by the bradyseism.
- Art. 3. Communication plan
- Art. 4. Rapid civil protection plan for the area exposed to the bradyseism.
- Art. 5. Urgent civil protection measures to verify the functionality of transportation infrastructures and of other critical services.
- Art. 6. Urgent civil protection measures to strengthen the operational response capacity of the local civil protection authorities.

Recognized operational challenges and needs

1 VOLCANIC PROCESSES

Volcanic processes may evolve **faster than expected**. There is a need to better constrain and **identify precursors of magma migration**. High performance monitoring and early warning system are essential

2 RESPONSE

The **72 hours buffer could not be sufficient** in case of fast evolving volcanic dynamics. Most likely there will be a need to **compress evacuation time**, identifying a **priority area** inside the red zone where to start operations

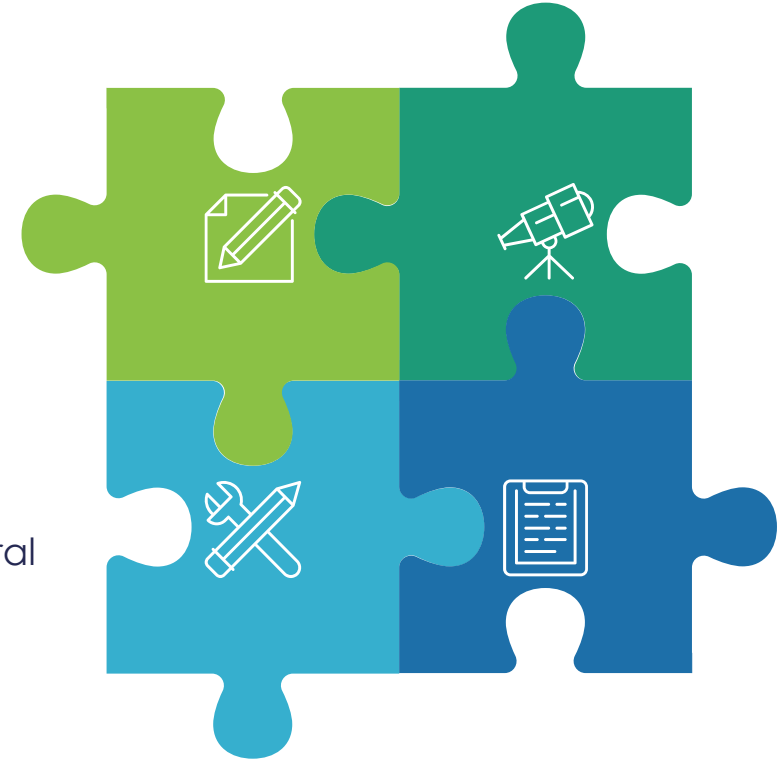
3 UPDATE OF THE PLAN

Review the National civil protection plan operational procedures connected to the new VAL table

Future perspectives

Increase preparation and risk awareness among population and stakeholders

Foster seismic vulnerability reduction (structural measures)



New operational procedures and contingency planning

Strengthen the dialog between Civil protection authorities, scientists and CGR