EO for Cultural and Natural Heritage
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EARSeL EUROPEAN ASSOCIATION OF REMOTE SENSING LABORATORIES
esa

# Innovative strategies to enhance the resilience of sensitive cultural and natural heritage objectives against climate hazards

*Alessandro Sardella[1], Ramiro Marco Figuera[2], Stefano Natali[2], Claudia Roberta Calidonna[3], Alessandra Bonazza[1,4]*

Presenter: Alessandro Sardella, CNR-ISAC

[1] *National Research Council of Italy, Institute of Atmospheric Sciences and Climate, Bologna, Italy*
[2] *SISTEMA GmbH, Vienna, Austria*
[3] *National Research Council of Italy, Institute of Atmospheric Sciences and Climate, Lamezia Terme, Italy*
[4] *Italian Institute for Environmental Protection and Research, Rome, Italy*

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Istituto di Scienze dell'Atmosfera e del Clima CNR ISAC
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# Cultural Heritage at Risk

The **risk to cultural and natural heritage** as a consequence of the **impact of climate change** (slow and extreme variations) **and pollution** is globally recognized


*Emilia Romagna, flooding, 2023*

***Extreme events*** *(Heavy precipitation, Flooding, Drought, Extreme heating) are likely to occur more frequently and with greater intensity across most land regions in Europe and the Mediterranean region is highlighted to be one of the most significant and vulnerable hotspots for climate change*


The **assessment** and **monitoring** of these effects impose new and continuously changing **protection actions** and urgently needs for innovative preservation and **safeguarding approach**, particularly during **extreme climate conditions**.

European Commission, Directorate-General for Education, Youth, Sport and Culture, *Strengthening cultural heritage resilience for climate change: where the European Green Deal meets cultural heritage*, 2022

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# Increasing the resilience of heritage sites in river basins

## COUNTRIES & REGIONS

| | |
|---|---|
| AUSTRIA | Niederösterreich \| Wien |
| CROATIA | Jadranska Hrvatska |
| CZECHIA | Praha |
| GERMANY | Bayern |
| HUNGARY | Dél-Dunántúl |
| ITALY | Emilia-Romagna |
| POLAND | Dolnośląskie |
| SLOVAKIA | Východné Slovensko |

Climate change increases the intensity and frequency of hydrometeorological events, including landslides, flash floods, storms, heat waves or prolonged drought periods. Amongst other negative consequences, this endangers natural and cultural heritage sites close to river basins. The INACO project strengthens the resilience of these by deploying joint adaptation strategies. The partners also design and test new WebGIS-based solutions for heritage sites and tools for them to self-assess their vulnerability. Last but not least, specially trained risk managers are introduced in selected pilot regions.

interreg-central.eu/projects/inaco

**1,99** million €
Project budget

**80%**
ERDF co-financing

**11**
Partners

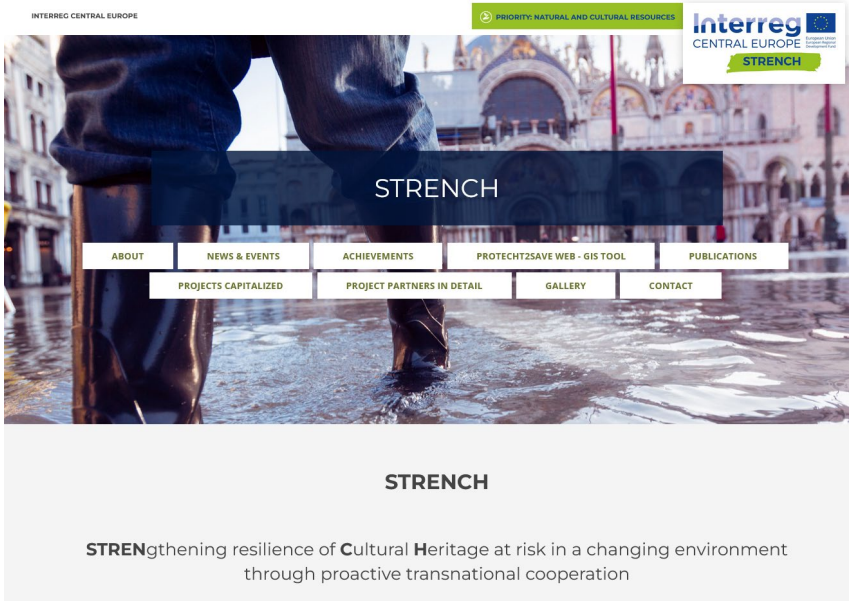
**8**
Pilots

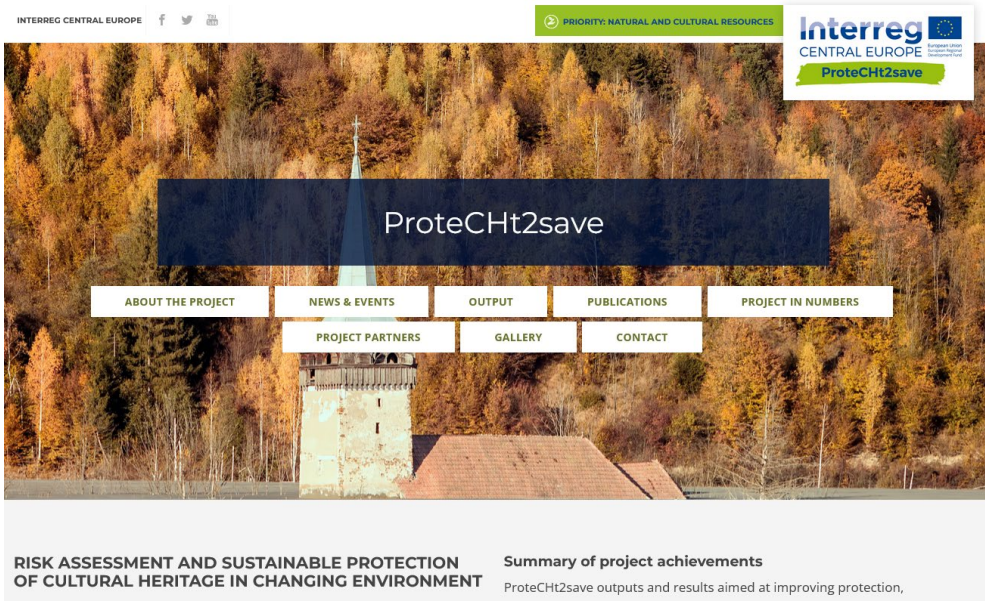
**06.2024**
Start date

**11.2026**
End date

Information based on application form | February 2024

# Interreg CE Projects ProteCHt2save and STRENCH: Scientific research vs End-users requirements

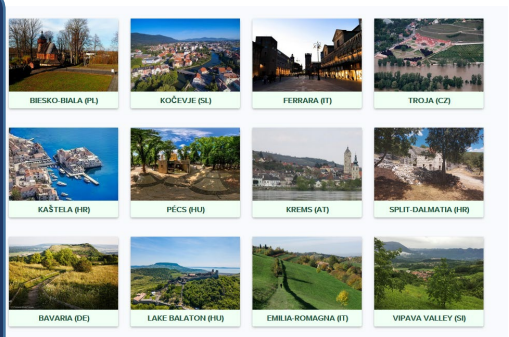


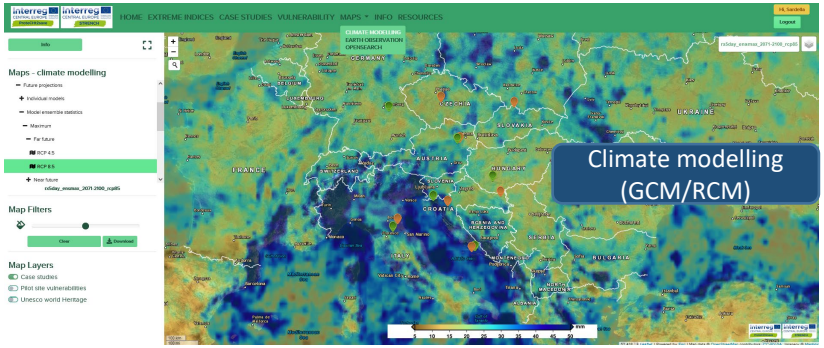

https://programme2014-20.interreg-central.eu/Content.Node/STRENCH.html

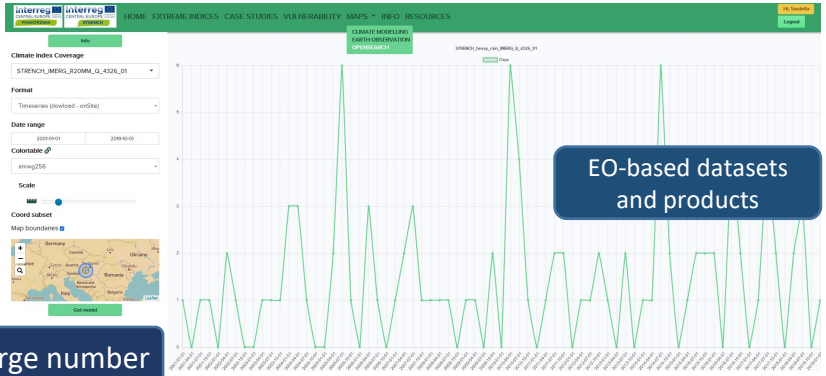
https://programme2014-20.interreg-central.eu/Content.Node/ProteCHt2save.html

# The Risk mapping tool for cultural heritage protection


Tools for supporting policy and decision makers in the identification of risk areas and vulnerabilities for cultural heritage in Europe and in the Mediterranean Basin exposed to extreme events linked to climate change




User-friendly graphical interfaces to meet and satisfy the needs of a large number of users and visualize in an interactive way the climate risk maps produced

https://www.protecht2save-wgt.eu

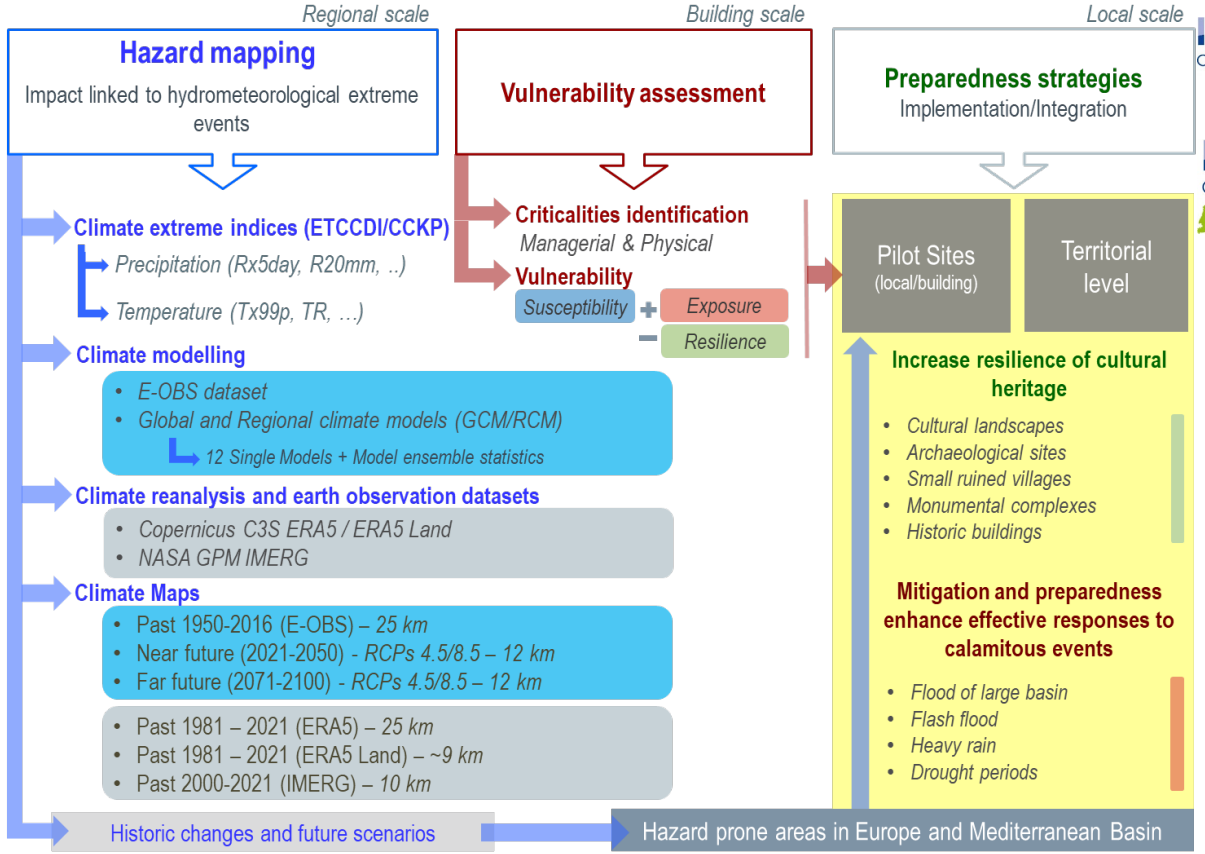
# Methodology for risk assessment

Focus on climate extreme events

Development of high resolution maps using climate models and satellite data

Hazard maps useful for Preparedness/prevention

*Bonazza and Sardella, Heritage, 2023*



# Climate hazard mapping

*Regional scale*

**Hazard mapping**

Impact linked to hydrometeorological extreme events

- **Climate extreme indices (ETCCDI/CCKP)**
  - *Precipitation (Rx5day, R20mm, ..)*
  - *Temperature (Tx99p, TR, …)*
- **Climate modelling**
  - *E-OBS dataset*
  - *Global and Regional climate models (GCM/RCM)*
    - *12 Single Models + Model ensemble statistics*
- **Climate reanalysis and earth observation datasets**
  - *Copernicus C3S ERA5 / ERA5 Land*
  - *NASA GPM IMERG*
- **Climate Maps**
  - Past 1950-2016 (E-OBS) – *25 km*
  - Near future (2021-2050) - *RCPs 4.5/8.5 – 12 km*
  - Far future (2071-2100) - *RCPs 4.5/8.5 – 12 km*
  - Past 1981 – 2021 (ERA5) – *25 km*
  - Past 1981 – 2021 (ERA5 Land) – *~9 km*
  - Past 2000-2021 (IMERG) – *10 km*

Historic changes and future scenarios → Hazard prone areas in Europe and Mediterranean Basin

Interreg CENTRAL EUROPE ProteCHt2save | Interreg CENTRAL EUROPE STRENCH

HOME | EXTREME INDICES | CASE STUDIES | VULNERABILITY | MAPS | INFO | RESOURCES

The analysis of changes in climate extremes can be done using indices to evaluate statistics of extreme events for precipitation and temperature and to compare them with observed extremes

| | E-OBS | C3S ERA5 | C3S ERA5Land | NASA GPM IMERG | GCM/RCM future projection |
|---|---|---|---|---|---|
| R20mm | ✓ | ✓ | ✓ | ✓ | ✓ |
| R95pTOT | ✓ | ✓ | ✓ | ✓ | ✓ |
| Rx5day | ✓ | ✓ | ✓ | ✓ | ✓ |
| CWD | | ✓ | ✓ | ✓ | |
| CDD | ✓ | ✓ | ✓ | ✓ | ✓ |
| CDD5 | | ✓ | ✓ | ✓ | |
| Tx90p | ✓ | | | | ✓ |
| su30 | | | ✓ | | |
| HWI | | ✓ | ✓ | | |
| Tx99p | | ✓ | ✓ | | |
| TR | | | ✓ | | |

https://www.wcrp-climate.org/etccdi

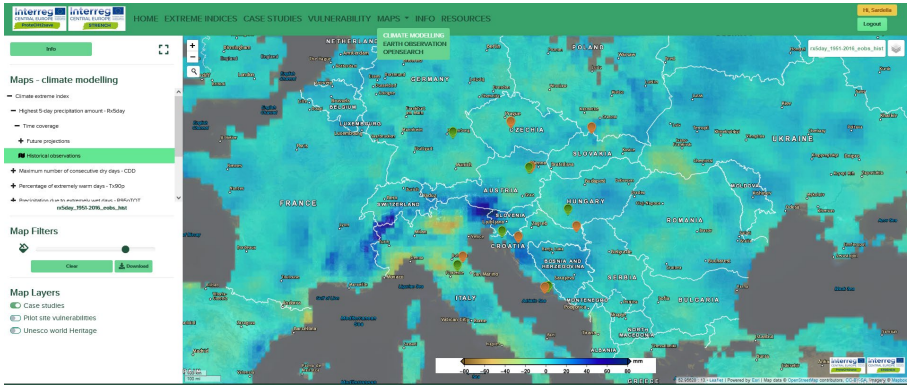
https://www.climdex.org/learn/indices

*Bonazza and Sardella, Heritage 2023*

# Map Tools – Climate modelling

Elaboration of maps of historical changes by using **E-OBS**

**Past changes** are calculated as the difference between the period 1987-2016 and the period 1951-1980, using **E-OBS** (spatial resolution 25x25 Km)

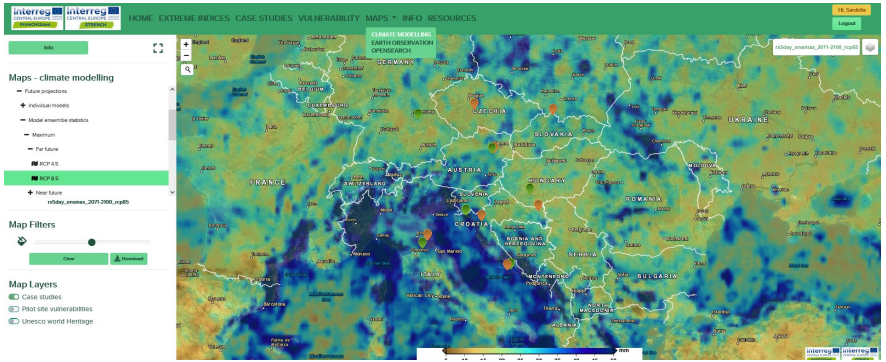



Elaboration of maps with hot spots of extreme potential impacts on CNH by using **CLIMATE MODELLING**

**Future changes** are calculated as the difference between:

- 2021-2050 and 1976-2005 (near future projection)
- 2071-2100 and 1976-2005 (far future projection)

*under **4.5** and **8.5 RCPs scenarios** (spatial resolution 12x12 Km)*



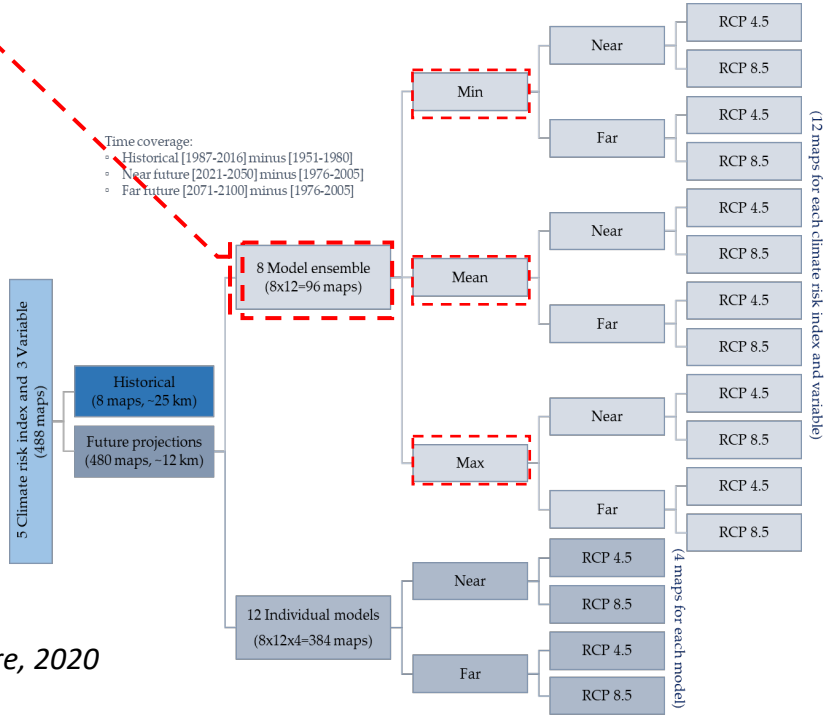

Application of 12 different combinations of 6 forcing global models (**GCM**) driving 5 regional models (**RCM**)

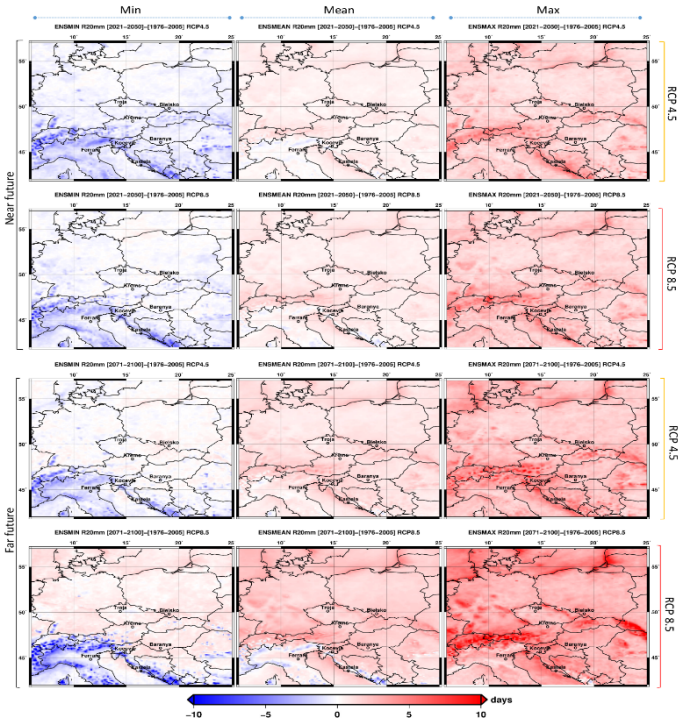
Multi-models ensembles of regional climate projection have been based on the **EURO-CORDEX** initiative, which provides regional climate projections for Europe at two different spatial resolutions: “standard” 0.44 degrees (EUR-44, ~50 km) - “finer” 0.11 degrees (EUR-11, ~12 km)

# Maps Tools – Climate modelling

Elaboration of maps with hot spots of extreme potential impacts on Cultural Heritage by using **CLIMATE MODELLING**

Being aware that each individual GCM/RCM model has its own uncertainties, we kept the entire ensemble and considered all members and their statistics, in particular calculating the minimum, mean and maximum values of the model ensemble

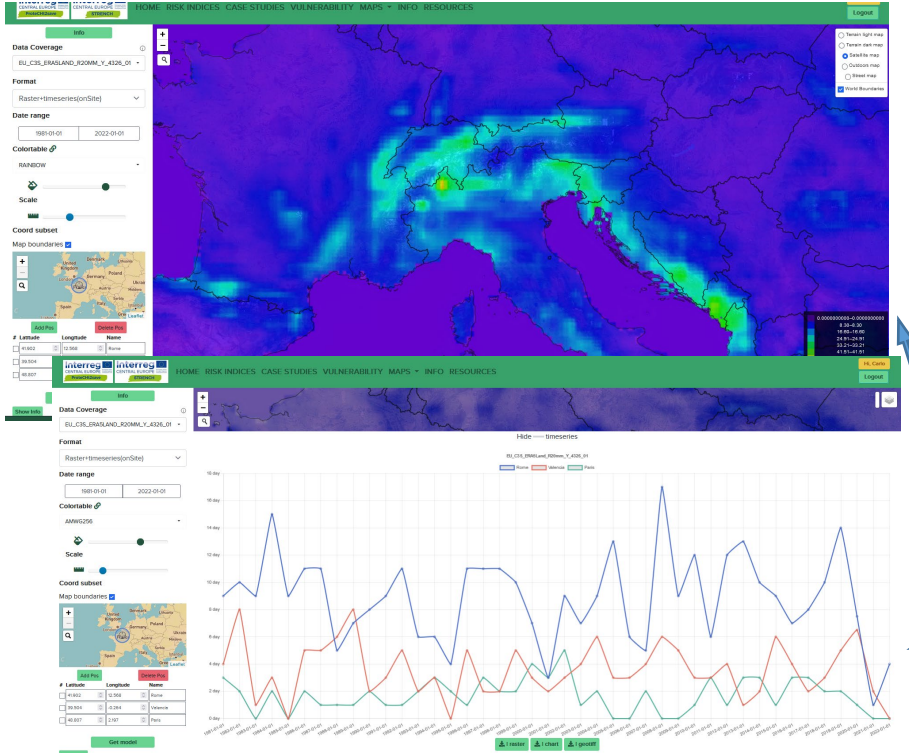



*Sardella et al. Atmosphere, 2020*

# Maps Tools – Exploring EO-based dataset/products

Elaboration of maps with hot spots of extreme potential impacts on Cultural Heritage using EO products from **NASA and COPERNICUS**




**Precipitation extreme indices**

- R20mm
- R95pTOT
- Rx5day
- CWD
- 1-in-50 return level
- CDD
- >5 days consecutive dry days

**Temperature extreme indices**

- HWI
- Tx99p
- TR
- Su30

**Climate variable**

- RR

***Copernicus C3S ERA5 Land** products** (~9 km resolution, from 1981).

***Copernicus C3S ERA5** products** (~31 km – 0.25° resolution, from 1981)

***NASA GPM IMERG** products*** (10 Km resolution, from 2000)

**https://climate.copernicus.eu/*

***https://gpm.nasa.gov/data/imerg/*

Map and timeseries of R20mm extreme index at 3 different location created by using the Open Search Tool Box which exploits EO-based products

# Vulnerability assessment of CNH at risk due to extreme changes in climate

*Vulnerability evaluation plays a key role in risk assessment and reduction and it is essential for the definition of strategies for climate change adaptation and mitigation*

1) Three main requirements

2) Integrated value model for sustainability assessment (MIVES)

3) Consultation with stakeholders *(authorities, rescue bodies from local to national level)*:

- Survey
- Local working tables
- Awareness raising events

4) Testing at the Site with local stakeholders


**RQ1** - Fragility, deficiency, predisposition to be adversely affected

**RQ2** - Extent of exposure to a selected hazard, to the climate condition that can negatively impact on the cultural assets or values

**RQ3** - Ability of a system to cope with the potential damage arising from climate change

**Vulnerability= 0.70xSusceptibility + 0.30xExposure - 0.30xResilience**

ranges between 0.00 and 1.00 and can be ranked in five different categories form very low to very high

Very low: $0.0 \leq V < 0.2$
Low: $0.2 \leq V < 0.4$
Moderate: $0.4 \leq V < 0.6$
High: $0.6 \leq V < 0.8$
Very high: $0.8 \leq V < 1.0$

*Starting from these requirements, a hierarchy tree is introduced including various branches (referred to as criteria or sub-criteria) which help conceptualizing the evaluation.*

*Cacciotti et al., 2024, International Journal of Disaster Risk Science*

# Methodology for the Vulnerability assessment

The proposed methodology (hazard oriented) for the vulnerability assessment has been applied at 15 specific case studies located in seven different countries in Central Europe (Italy, Austria, Hungary, Slovenian, Czech Republic and German)


*Cacciotti et al., 2024, IJDRS*

## Villa Ghigi, Bologna, Italy

**Hazards types**

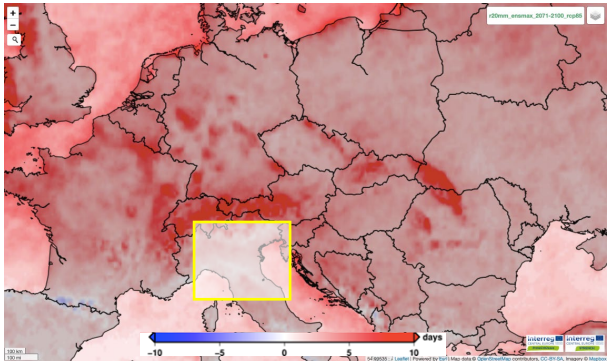
- **Flash floods** (R20mm, R95pTOT)
- **Erosion** (R95pTOT, Rx5day)
- **Landslides** (R95pTOT, Rx5day)
- **Vegetation damage** (Rx5day, CDD, Tx90p)

As part of the Park Management Plan, the area of the Villa Ghigi Park pilot site was zoned according to the main vulnerabilities identified in order to improve management and set up pre- and post-event contingency plans.

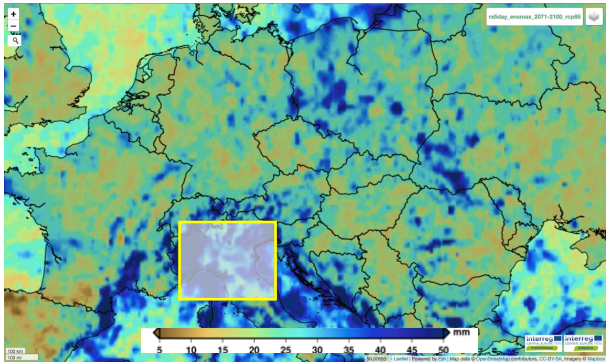
More attention has been paid to areas that may be subject to flash floods (top map), those at risk of landslides (side map) and areas of the park that may be subject to damage in the event of high winds or snowstorms (bottom map).

# Climate Hazard Mapping

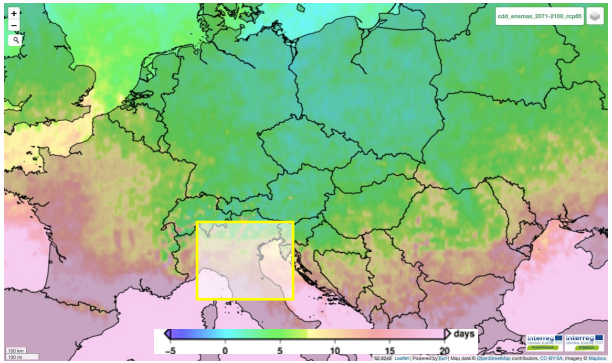
## Focus on Emilia-Romagna Region




R20mm (very heavy precipitation days)




Rx5day (highest 5-day precipitation amount)




CDD (consecutive dry days)

Projection: Ensemble max, far future (2071-2100), pessimistic scenario (RCP8.5)

Climate hazard maps elaborated by applying “Climate modelling” tool of the “Risk Mapping Tool for Cultural Heritage Protection” (https://www.protecht2save-wgt.eu)

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# INACO Pilot sites

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**GROUP A SEA/RIVER SHORE.**

Natural reserve, historic villages and gardens in transitional river/sea shore environment:

- Valli di Comacchio, Po Delta River – IT (PDPO)
- Dubrovnik River – HR (IRD)

**GROUP B LAKE SHORE.**

Natural reserve, historic buildings and archaeological sites in a lakeshore environment:

- Lake Neusiedl – AT (UWK, BAW)
- Fonyód town – HU (LBDCA)

**GROUP C INLAND.**

Monumental complexes, historic parks and gardens in inland river basin:

- Valley of Wiesent and Rednitz – DE (FO)
- Jelenia Gorà Valley – PL (FOK)
- Kosice Region - SK (TUKE)
- Central Bohemia Vltava River Valley –CZ (ITAM CAS)

# Next steps – ongoing projects

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***Extraordinary National plan for monitoring and conservation of Italian cultural heritage***

*The Risk Mapping Tool for Cultural Heritage Protection provides insights on the hazard maps referring to heavy rain, flooding, drought, and extreme heat. The maps are elaborated covering the European and Mediterranean areas.*

*The application of Copernicus C3S and other Earth Observation-based products and their integration with climate projections from regional climate models constitutes a notable innovation that will deliver a direct impact to the management of Cultural and Natural Heritage, with high potentiality to be scalable to new sectors under threat by climate change.*

- Setup of Vulnerability Web/Mobile Apps for professionals and citizens
- C3S and CAMS data processing and exploitation
- Upgrading and Testing of the tools, particularly in preparedness and emergency situations (INACO pilot sites).
- Integration of the WebGIS Tool with results obtained by application of CAMS (impact due to slow on ongoing climate/pollution)
- Definition of vulnerability/risk indicators for the protection and fruition of natural and cultural sites under threat
- Implementing risk management plans based on the application of INACO solutions at CE River Basin Districts

CNR ISAC

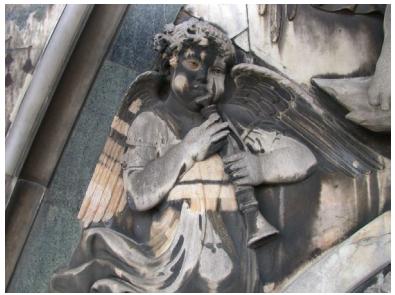
# Application of Damage Functions: EO-based products/datasets

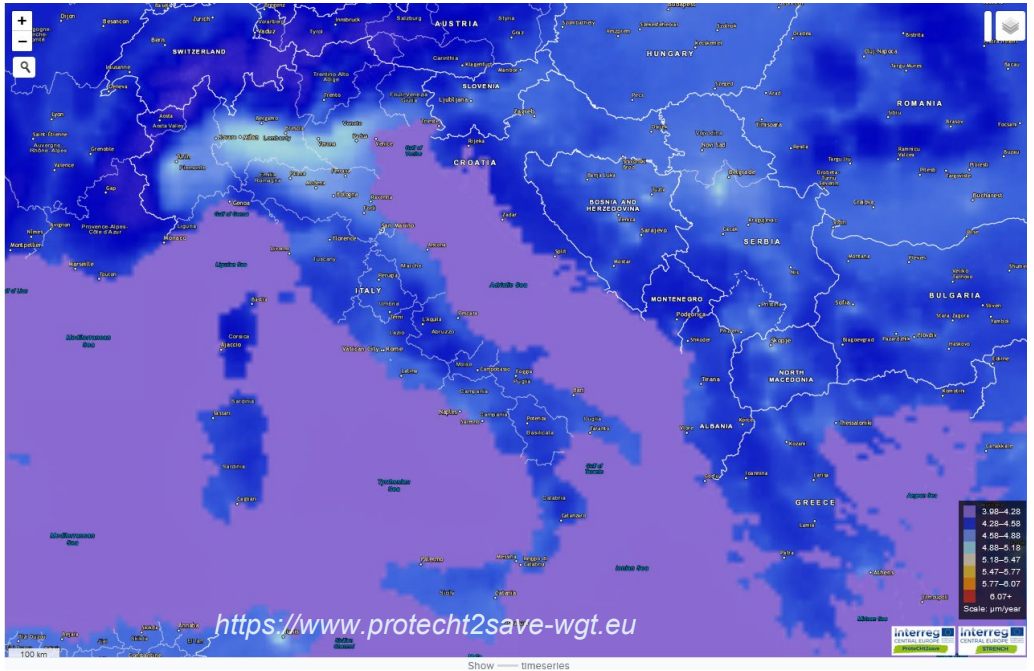
Integration with results obtained by application of CAMS (impact due to slow on ongoing climate/pollution)

**Surface Recession** $R = 3{,}95 + 0{,}0059[SO_2]RH60 + 0{,}078[HNO_3]RH60 + 0{,}0258PM_{10}$ **(Kucera et al., 2007;modified)**

Where:
R, Surface Recession per year (μm · year$^{-1}$) (yearly average)
$SO_2$, is the $SO_2$ surface concentration (μg m$^{-3}$) (yearly average)
RH60, is the elative humidity considered only when RH>60, otherwise 0 (yearly average)
Rain, is the yearly amount of rain (mm)
$HNO_3$, is the $HNO_3$ concentration (yearly average) (μg m$^{-3}$)*
$PM_{10}$ , is the concentration of PM10 (yearly average) (μg m$^{-3}$)

*$HNO_3$ = 516 * e-3400(T + 273) * ([$NO_2$ * [$O_3$] * RH)0:5






*Map of Surface recession in the Mediterranean Basin (year 2021) – Data source IMERG, CAMS e ERA5Land*

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# References 2020-2024


atmosphere

MDPI

*Article*

**Risk Mapping for the Sustainable Protection of Cultural Heritage in Extreme Changing Environments**

Alessandro Sardella [1], Elisa Palazzi [2], Jost von Hardenberg [2,3], Carlo Del Grande [4], Paola De Nuntiis [1], Cristina Sabbioni [1] and Alessandra Bonazza [1,*]

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journal homepage: www.elsevier.com/locate/ijdrr

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**Safeguarding cultural heritage from climate change related hydrometeorological hazards in Central Europe**

Alessandra Bonazza [a,*], Alessandro Sardella [a,b], Anna Kaiser [c], Riccardo Cacciotti [d], Paola De Nuntiis [a], Christian Hanus [c], Ingval Maxwell [e], Tomas Drdácký [d,f], Milos Drdácký [d]

2022 IMEKO TC-4 International Conference on Metrology for Archaeology and Cultural Heritage
University of Calabria, Italy, October 19-21, 2022

**The Risk Mapping Tool for Cultural Heritage Protection in Europe and Mediterranean Basin**

A. Sardella*[1,2], S. Natali[3], C. Del Grande[4], R. Cacciotti[5], A. Bonazza[1]

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*Review*

**Climate Change and Cultural Heritage: Methods and Approaches for Damage and Risk Assessment Addressed to a Practical Application**

Alessandra Bonazza [1,*] and Alessandro Sardella [2,3]

heritage

MDPI

*Article*

**Hazard Analysis and Vulnerability Assessment of Cultural Landscapes Exposed to Climate Change-Related Extreme Events: A Case Study of Wachau (Austria)**

Linda Canesi [1], Alessandro Sardella [1,2,*], Rainer Vogler [3], Anna Kaiser [4], Carmela Vaccaro [2] and Alessandra Bonazza [1,5]

International Journal of Disaster Risk Science
https://doi.org/10.1007/s13753-024-00564-8

ARTICLE

**A Methodology for Vulnerability Assessment of Cultural Heritage in Extreme Climate Changes**

Riccardo Cacciotti[1] · Alessandro Sardella[2,3] · Miloš Drdácký[1] · Alessandra Bonazza[2,4]

Accepted: 27 May 2024
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# Innovative strategies to enhance the resilience of sensitive cultural and natural heritage objectives against climate hazards

## Thank you for you attention!

We are waiting for you online for a fruitful navigation on the

**Risk Mapping Tool for Cultural Heritage Protection**

https://www.protecht2save-wgt.eu/

Alessandro Sardella
a.sardella@isac.cnr.it