## Seminario CNR ISAC

29 Maggio 2024

# A risk assessment tool for the protection of cultural heritage exposed to extreme climate events

Protezione del patrimonio culturale dagli impatti di eventi climatici estremi: uno strumento per la valutazione e la gestione del rischio

Alessandro Sardella

CNR – ISAC Bologna
University of Ferrara
Department of Environmental and Prevention Sciences

# Cultural Heritage at Risk

The risk to cultural and natural heritage as a consequence of natural hazards and impact of climate change is globally recognized.

**Cultural heritage at risk as a consequence of the impacts of climate induced slow and extreme changes**

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**.

- *Heavy precipitation*
- *Flooding*
- *Drought*
- *Extreme heating*

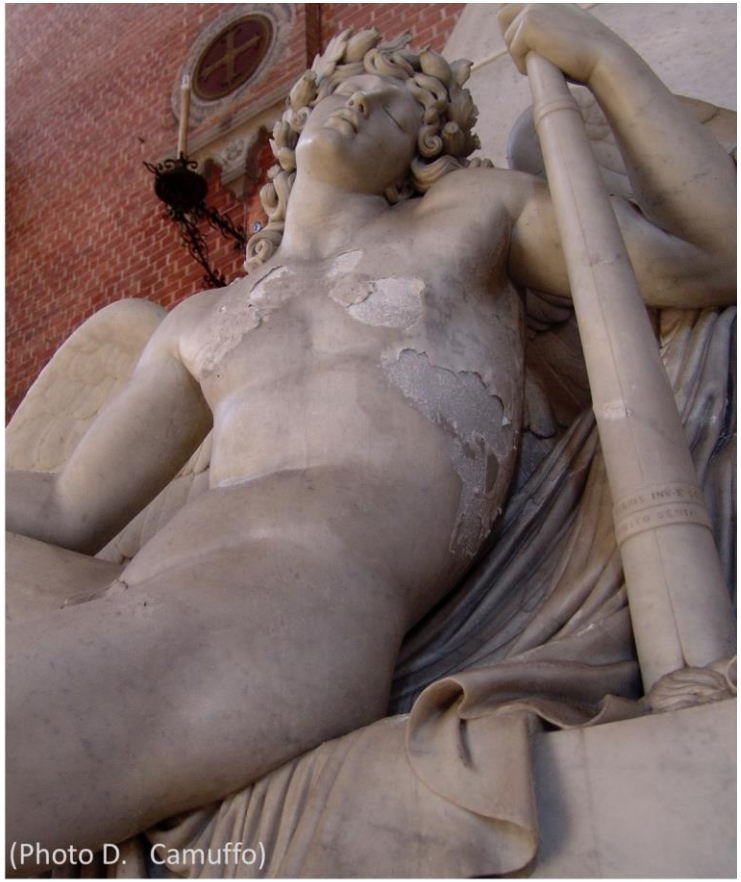
Flooding due to heavy rain
Ferrara Cathedral (IT)

Flood – Troja (CZ)

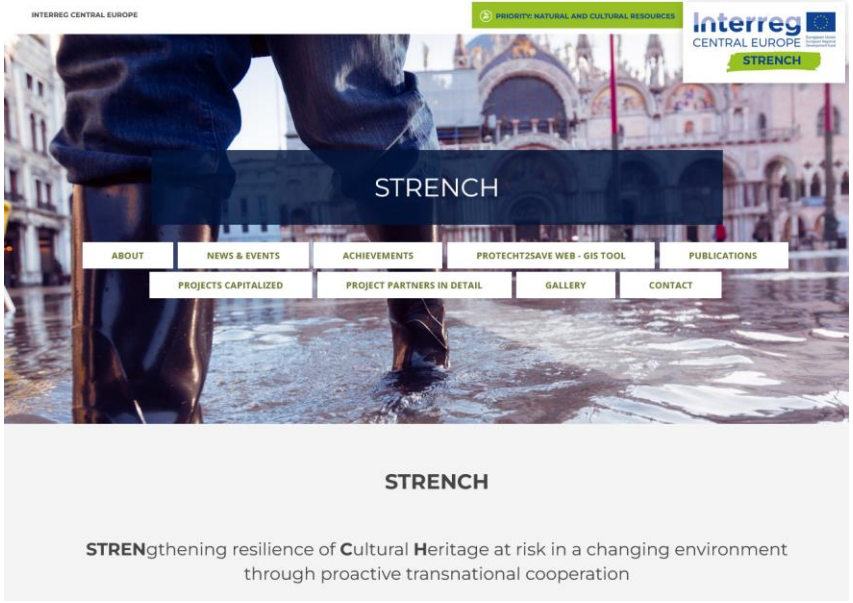
Megalithic Temples
Malta (MT)

# Cultural Heritage at Risk


Capillary rise transports sea water also in monuments located indoors. The marine salt has started to destroy them. An example from the Basilica S. Maria Gloriosa dei Frari, Venice



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

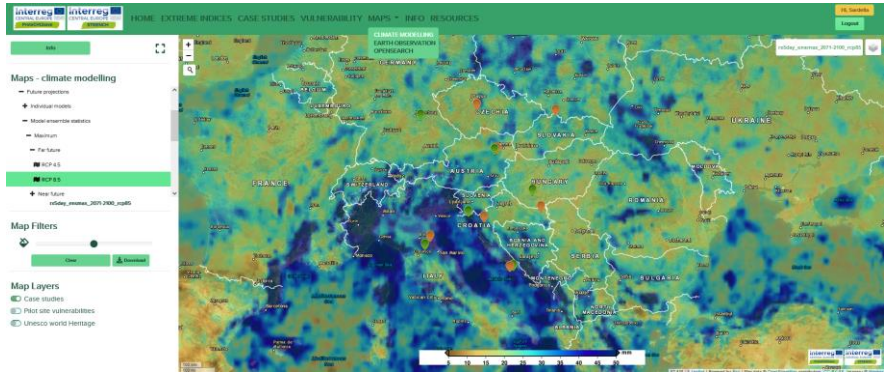




https://programme2014-20.interreg-central.eu/Content.Node/STRENCH.html

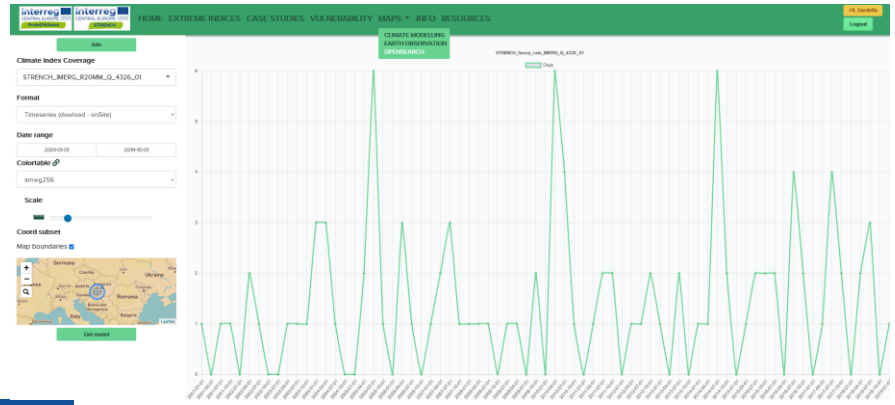
https://programme2014-20.interreg-central.eu/Content.Node/ProteCHt2save.html

# 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


https://www.protecht2save-wgt.eu



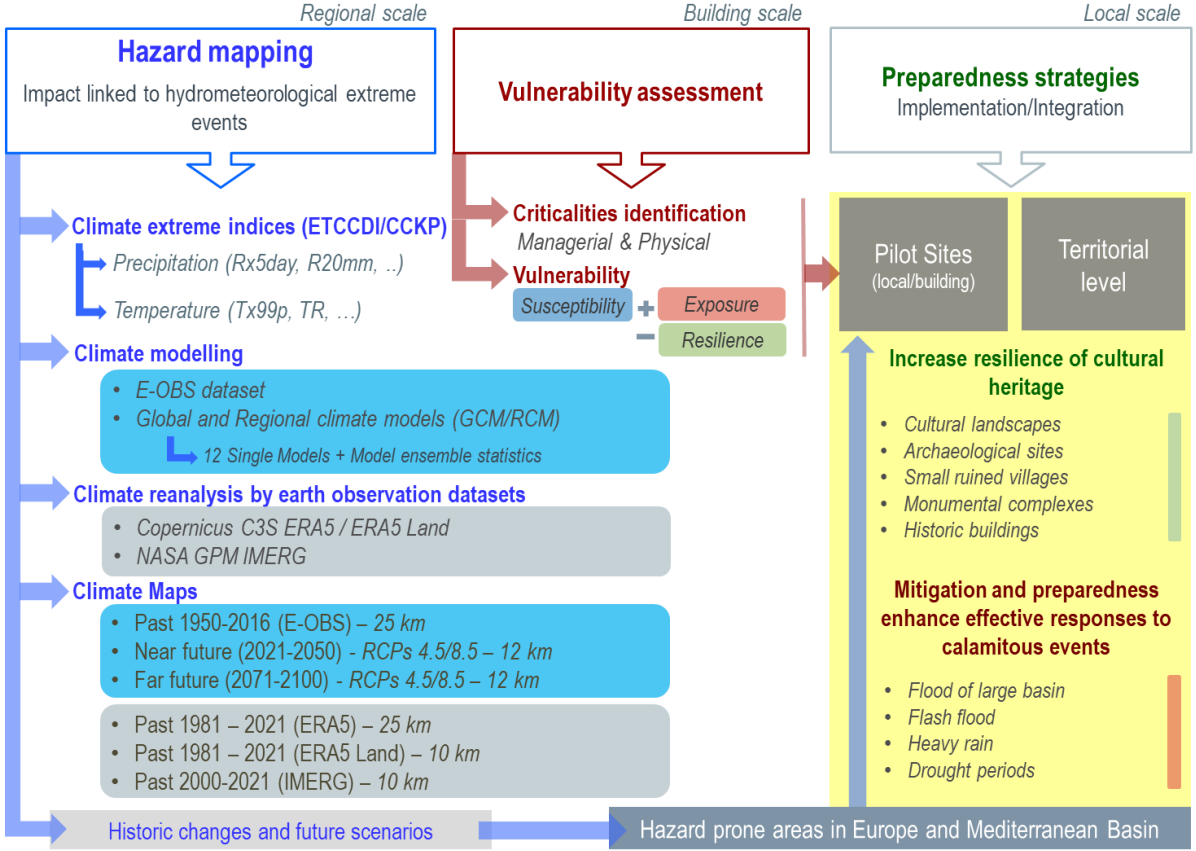

*User-friendly graphical interfaces to meet and satisfy the needs of a large number of users and visualize in an interactive way the climate risk maps produced*

# 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 by 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) – *10 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

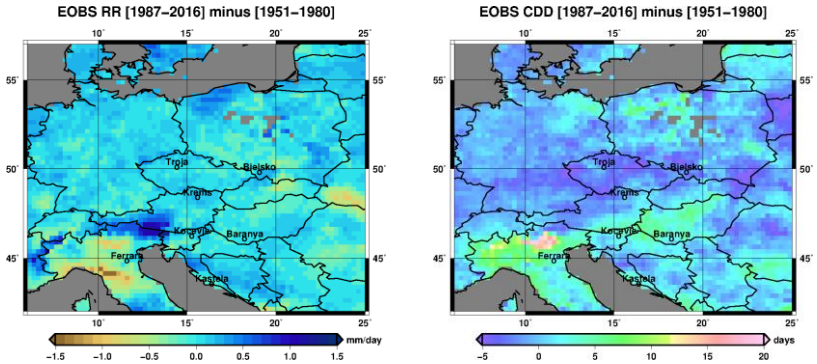
https://www.climdex.org/learn/indices

*Bonazza and Sardella, Heritage 2023*

ecosister

# Map Tools – Climate modelling

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



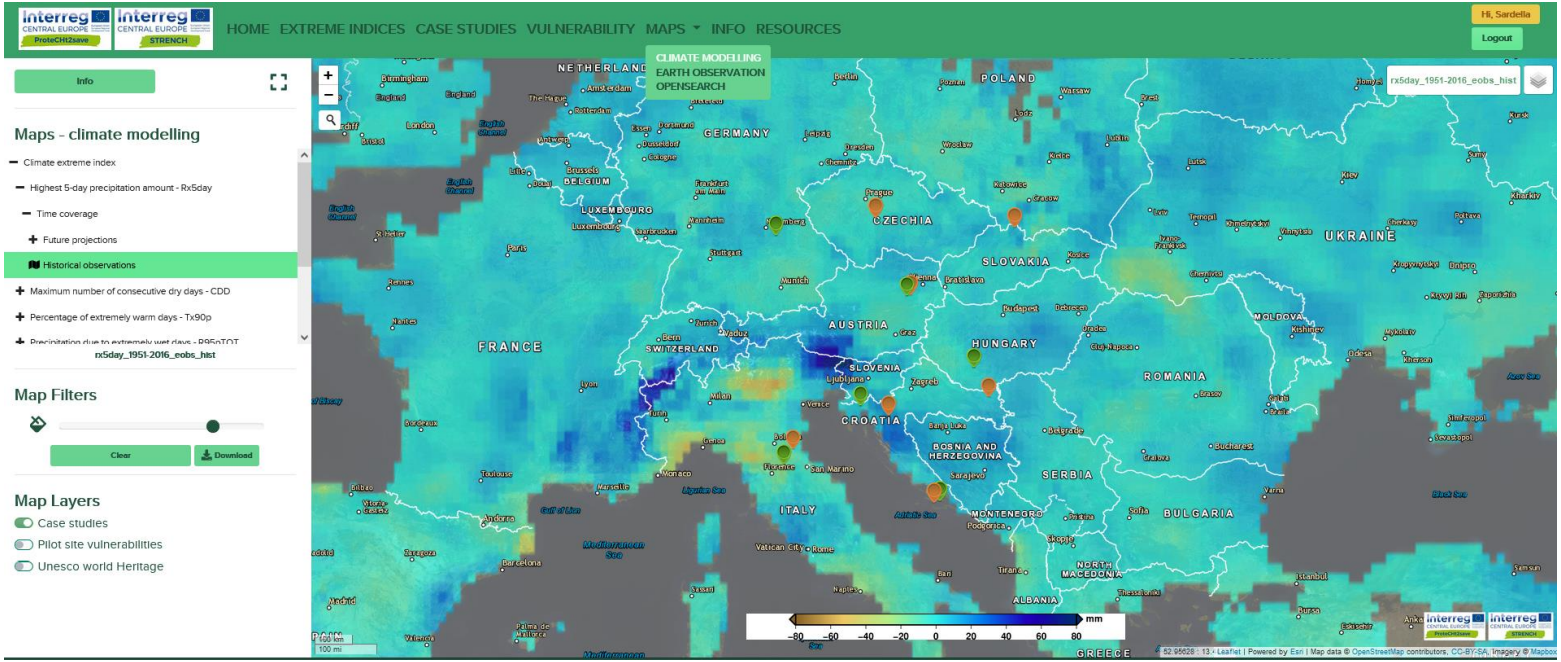

**Past changes** are calculated as the difference between the period 1987-2016 and the period 1951-1980, using **E-OBS** (spatial resolution 25x25 Km)

*Changes in (1987-2016) wrt (1951-1980) of precipitation and precipitation-related extremes (CDD, R20mm, R99pTOT, Rx5day) in Central Europe*

# 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)



# Maps Tools – Climate modelling

Elaboration of maps with hot spots of extreme potential impacts on Cultural Heritage
**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 **RCPs scenarios 4.5** and **8.5** (spatial resolution 12x12 Km)*

***RCPs***

*EURO-CORDEX scenario simulations use the new Representative Concentration Pathways (RCPs) defined for the Fifth Assessment Report of the IPCC (Moss et al. 2010).*
*RCP scenarios assume pathways to different target radiative forcing at the end of the twenty-first century. For instance, scenario RCP8.5 assumes an increase in radiative forcing of 8.5 W/m2 by the end of the century relative to pre-industrial conditions.*

12 different combinations of 6 forcing global models (**GCM**), driving 5 regional models (**RCM**), have been taken into account for the elaboration of the maps related to the future projections

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)

ecosister

# Maps Tools – Climate modelling

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

| Combination | GS | GCM | RS | RCM |
|---|---|---|---|---|
| 1 | CNRM-CERFACS | CNRM-CM5 | CLMcom | CCLM4-8-17 |
| 2 | CNRM-CERFACS | CNRM-CM5 | SMHI | RCA4 |
| 3 | ICHEC | EC-EARTH | CLMcom | CCLM4-8-17 |
| 4 | ICHEC | EC-EARTH | DMI | HIRHAM5 |
| 5 | ICHEC | EC-EARTH | KNMI | RACMO22E |
| 6 | ICHEC | EC-EARTH | SMHI | RCA4 |
| 7 | MOHC | HadGEM2-ES | KNMI | RACMO22E |
| 8 | MOHC | HadGEM2-ES | SMHI | RCA4 |
| 9 | IPSL | CM5A-MR | SMHI | RCA4 |
| 10 | MPI-M | MPI-ESM-LR | CLMcom | CCLM4-8-17 |
| 11 | MPI-M | MPI-ESM-LR | MPI-CSC | REMO2009 |
| 12 | NCC | NorESM1-M | DMI | HIRHAM5 |

*Sardella et al. Atmosphere, 2020*

12 different combinations of 6 forcing global models (**GCM**), driving 5 regional models (**RCM**), have been taken into account for the elaboration of the maps related to the future projections

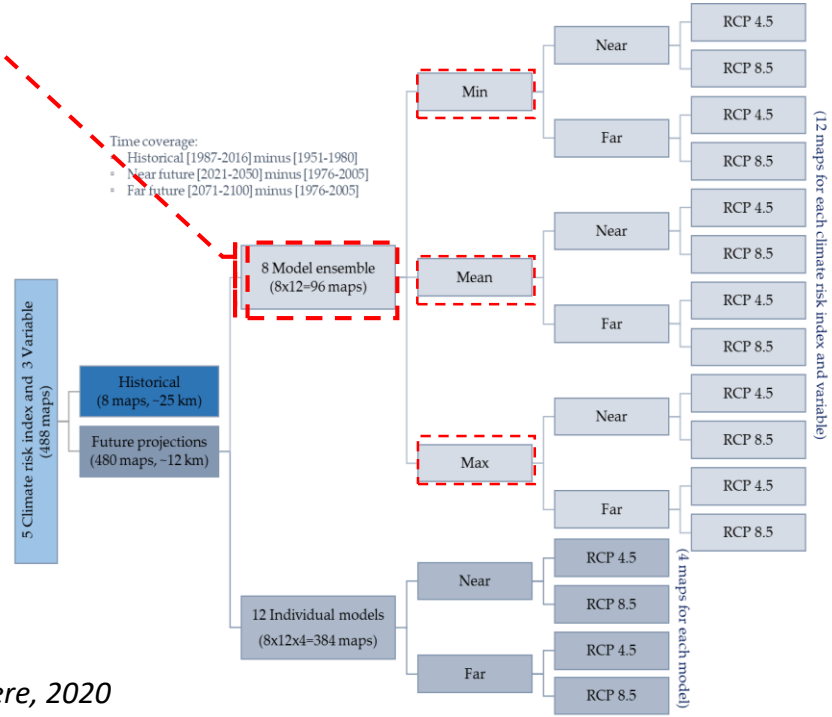
Multi-models ensembles of regional climate projection have been based on the **EURO-CORDEX*** initiative, which provides regional climate projections for Europe at two different spatial resolutions:
- "standard" 0.44 degrees (EUR-44, ~50 km)
- "finer" 0.11 degrees (EUR-11, ~12 km)

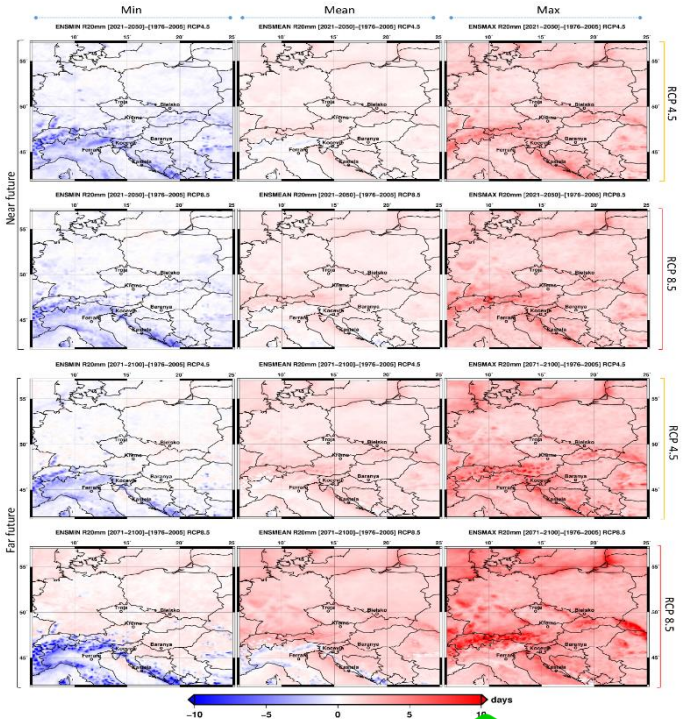
Interreg CENTRAL EUROPE ProteCHt2save
Interreg CENTRAL EUROPE STRENCH
ecosister

# Maps Tools – Climate modelling

Elaboration of maps with hot spots of extreme potential impacts on Cultural Heritage
**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

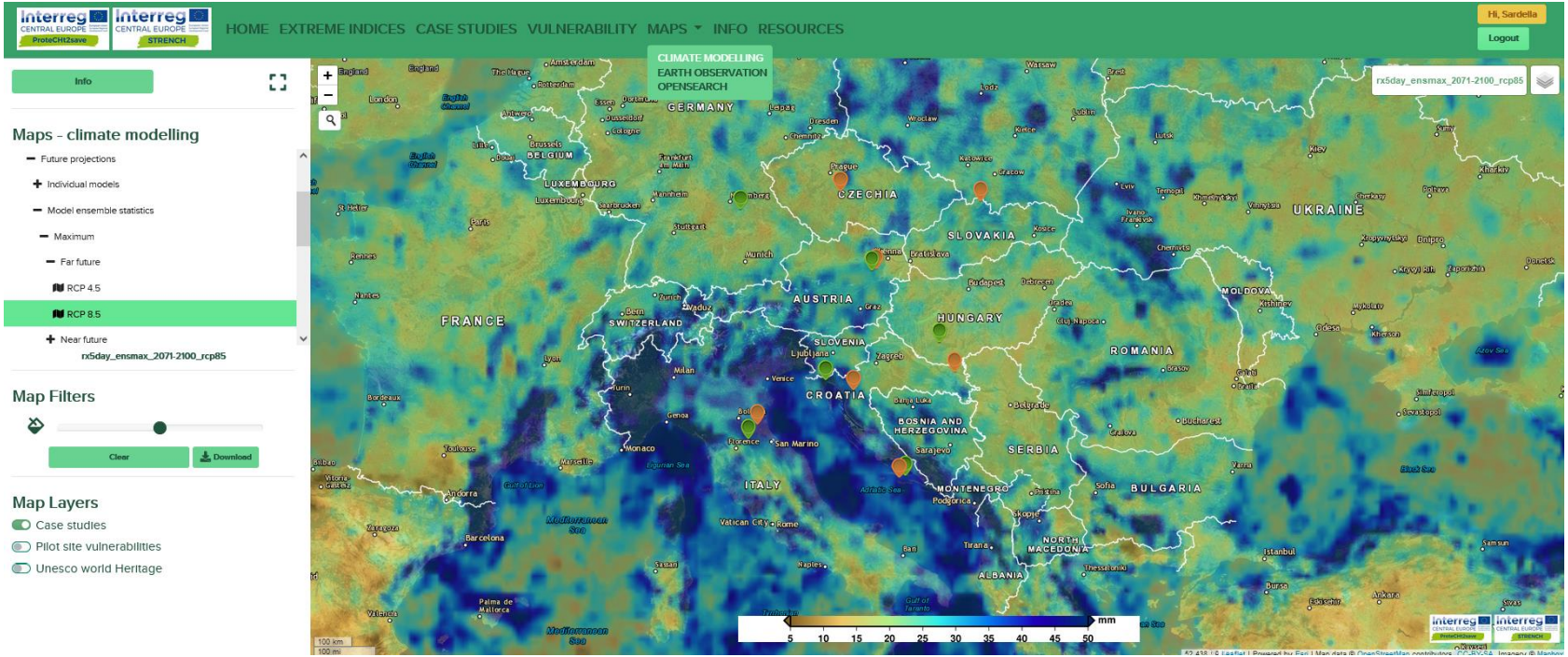



*Sardella et al. Atmosphere, 2020*

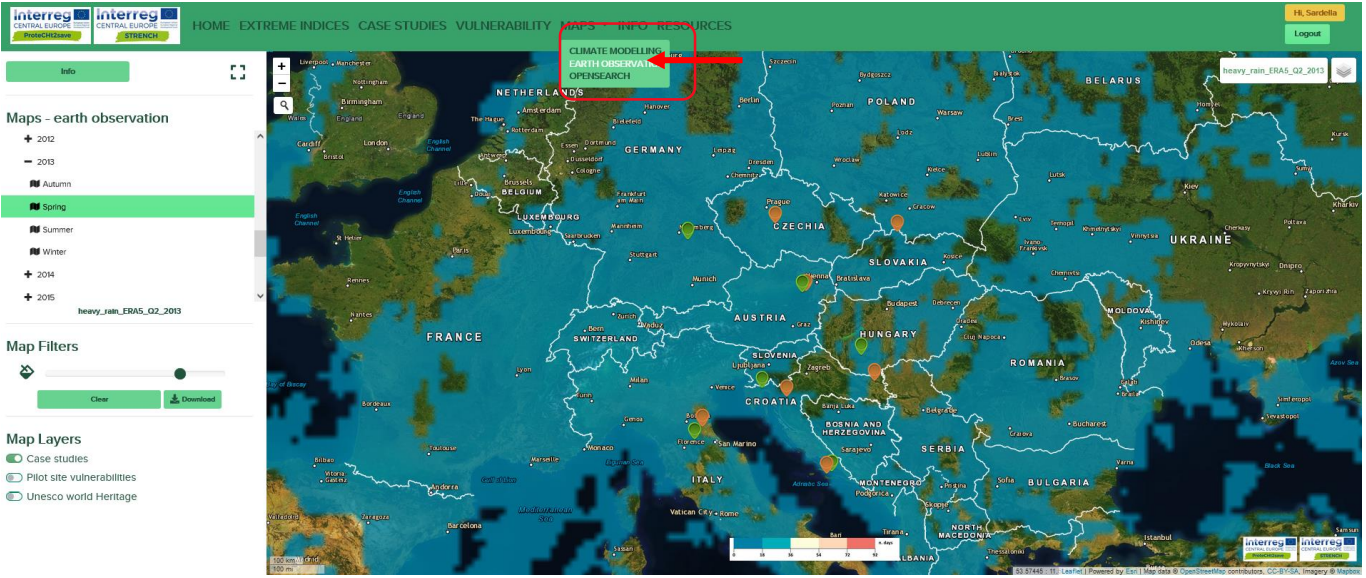
# Maps Tools – Climate modelling

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



# Maps Tools – Exploring EO datasets

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




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

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

- Copernicus ERA5(Land) dataset
- Both GPM IMERG and Copernicus ERA5(land) datasets

**Precipitation extreme indices**

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

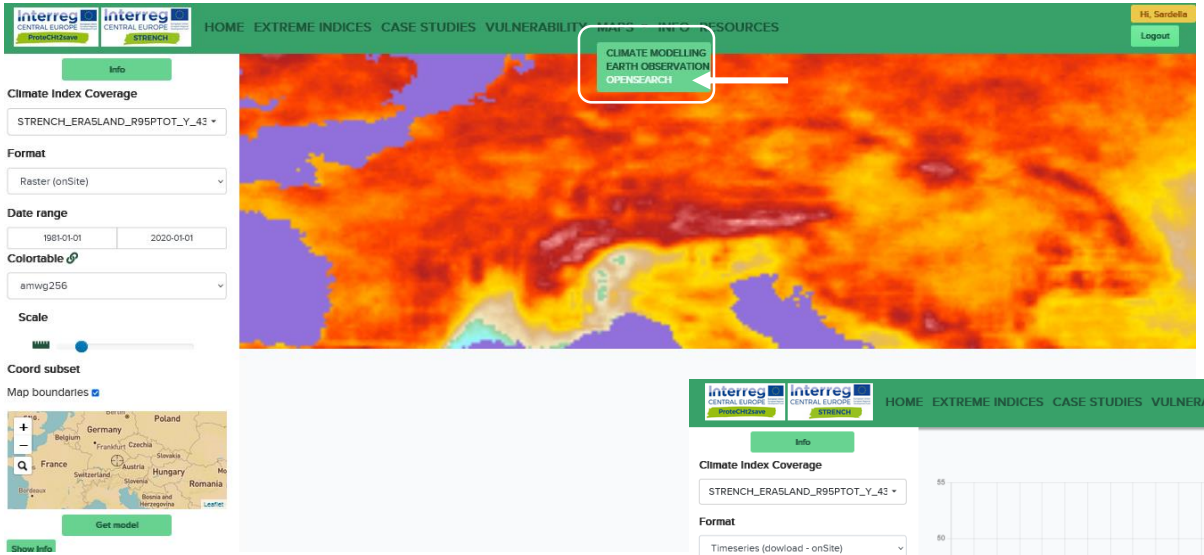
**Temperature extreme indices**

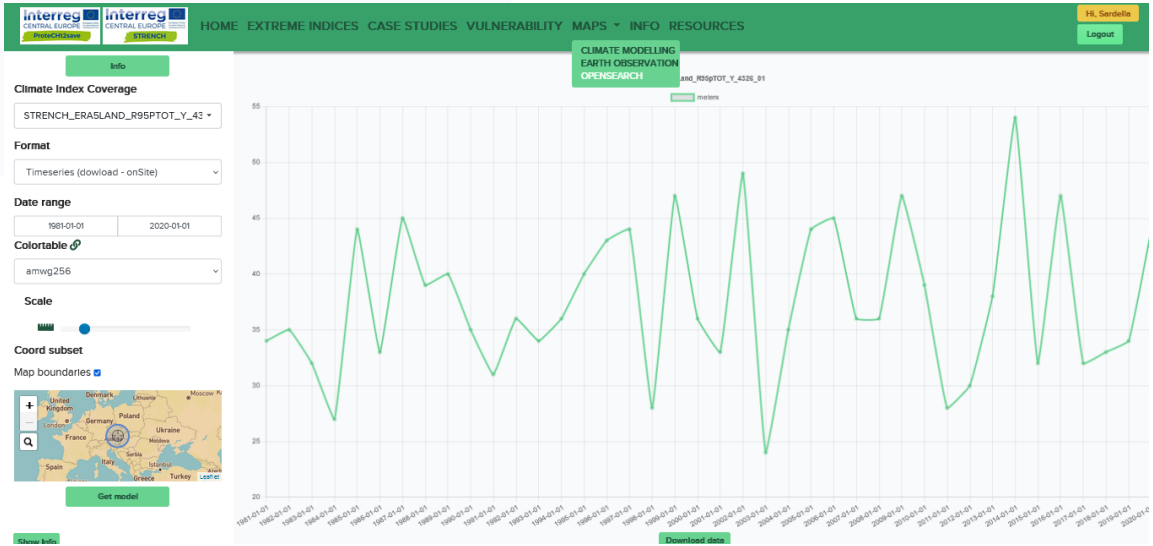
- HWI
- Tx99p
- TR
- Su30

**Climate variable**

- RR

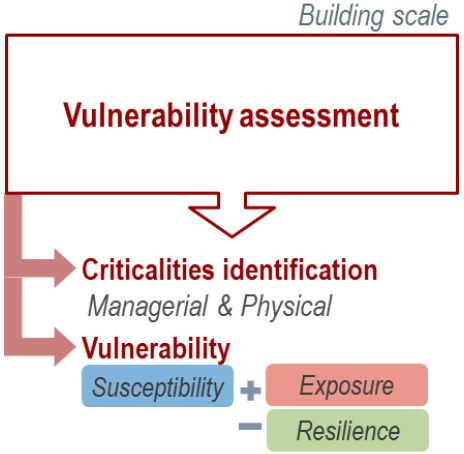
# Maps Tools – Exploring EO datasets




- **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).

# Methodology for the Vulnerability assessment





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

- Survey
- Local working tables
- Awareness raising events

Fragility, deficiency, predisposition to be adversely affected

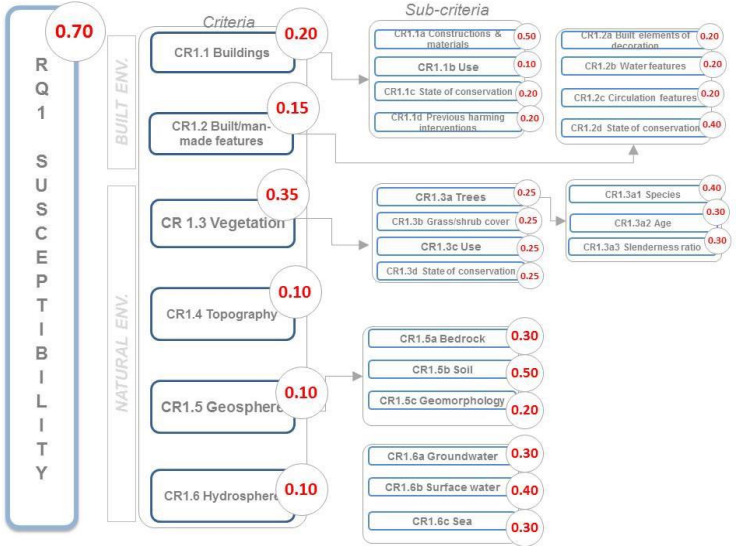
Extent of exposure to a selected hazard, to the climatic condition that can negatively impact on the cultural assets or values

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

**Vulnerability= 0.70xSusceptibility + 0.30xExposure - 0.30xResilience** from 0 (low v) to 1 (high v)

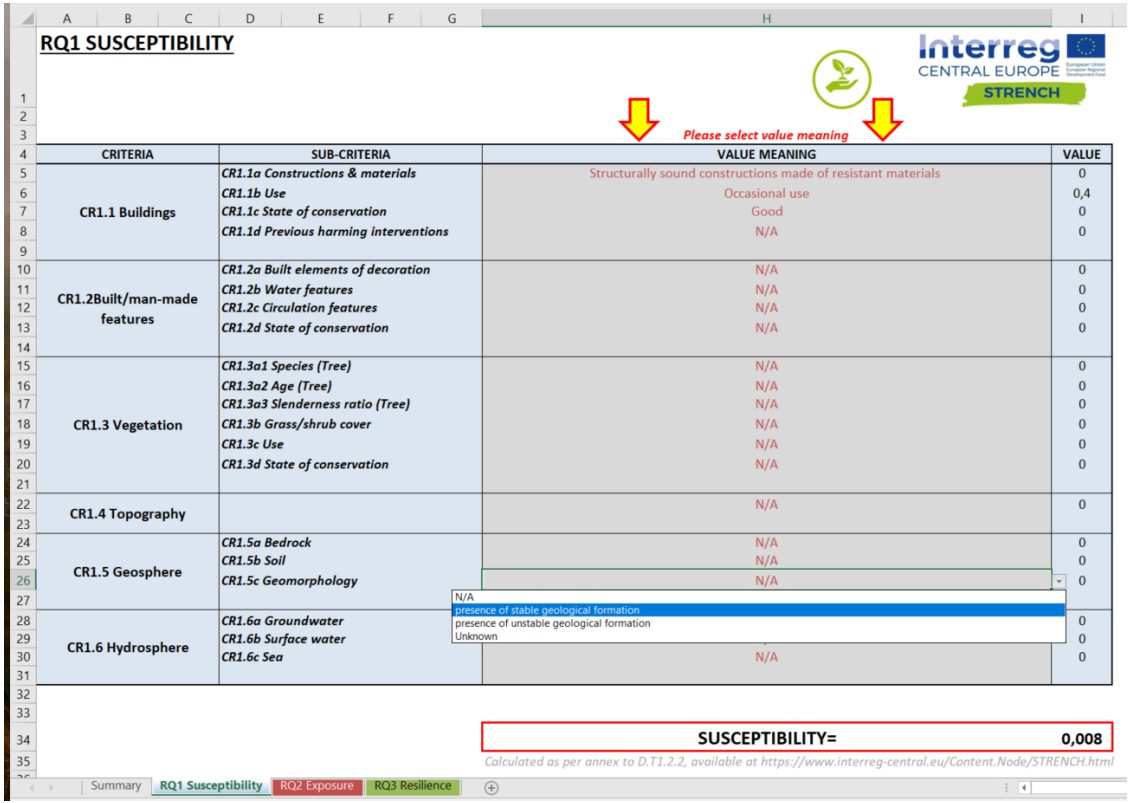
# Methodology for the Vulnerability assessment

A hierarchy tree with criteria and sub-criteria composed of Multiple choice like questions
Each choice is given a certain value which is then used to compute the Requirement for the case study




*Susceptibility = (0.20 x Building) + (0.15 x Built/man-made features) + (0.35 x Vegetation) + (0.10 x Topography) + (0.10 x Geosphere) + (0.10 x Hydrosphere)*

**Tested at the Site with local stakeholders**



**RQ1 SUSCEPTIBILITY**

Please select value meaning

| CRITERIA | SUB-CRITERIA | VALUE MEANING | VALUE |
|---|---|---|---|
| CR1.1 Buildings | CR1.1a Constructions & materials | Structurally sound constructions made of resistant materials | 0 |
| | CR1.1b Use | Occasional use | 0,4 |
| | CR1.1c State of conservation | Good | 0 |
| | CR1.1d Previous harming interventions | N/A | 0 |
| CR1.2Built/man-made features | CR1.2a Built elements of decoration | N/A | 0 |
| | CR1.2b Water features | N/A | 0 |
| | CR1.2c Circulation features | N/A | 0 |
| | CR1.2d State of conservation | N/A | 0 |
| CR1.3 Vegetation | CR1.3a1 Species (Tree) | N/A | 0 |
| | CR1.3a2 Age (Tree) | N/A | 0 |
| | CR1.3a3 Slenderness ratio (Tree) | N/A | 0 |
| | CR1.3b Grass/shrub cover | N/A | 0 |
| | CR1.3c Use | N/A | 0 |
| | CR1.3d State of conservation | N/A | 0 |
| CR1.4 Topography | | N/A | 0 |
| CR1.5 Geosphere | CR1.5a Bedrock | N/A | 0 |
| | CR1.5b Soil | N/A | 0 |
| | CR1.5c Geomorphology | N/A | 0 |
| CR1.6 Hydrosphere | CR1.6a Groundwater | N/A | 0 |
| | CR1.6b Surface water | N/A | 0 |
| | CR1.6c Sea | N/A | 0 |

N/A
presence of stable geological formation
presence of unstable geological formation
Unknown

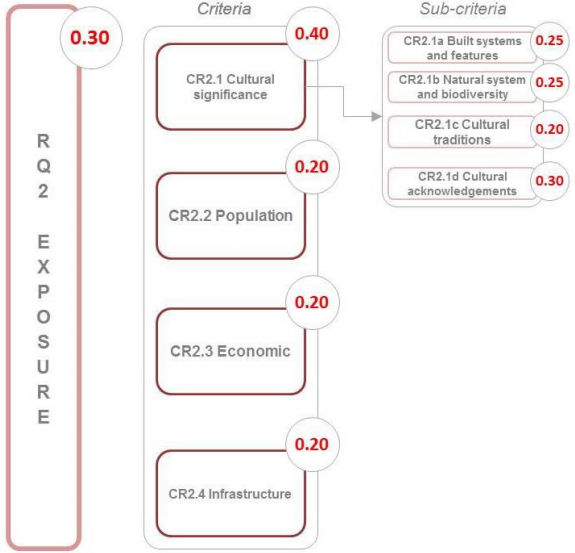
SUSCEPTIBILITY= 0,008

Calculated as per annex to D.T1.2.2, available at https://www.interreg-central.eu/Content.Node/STRENCH.html

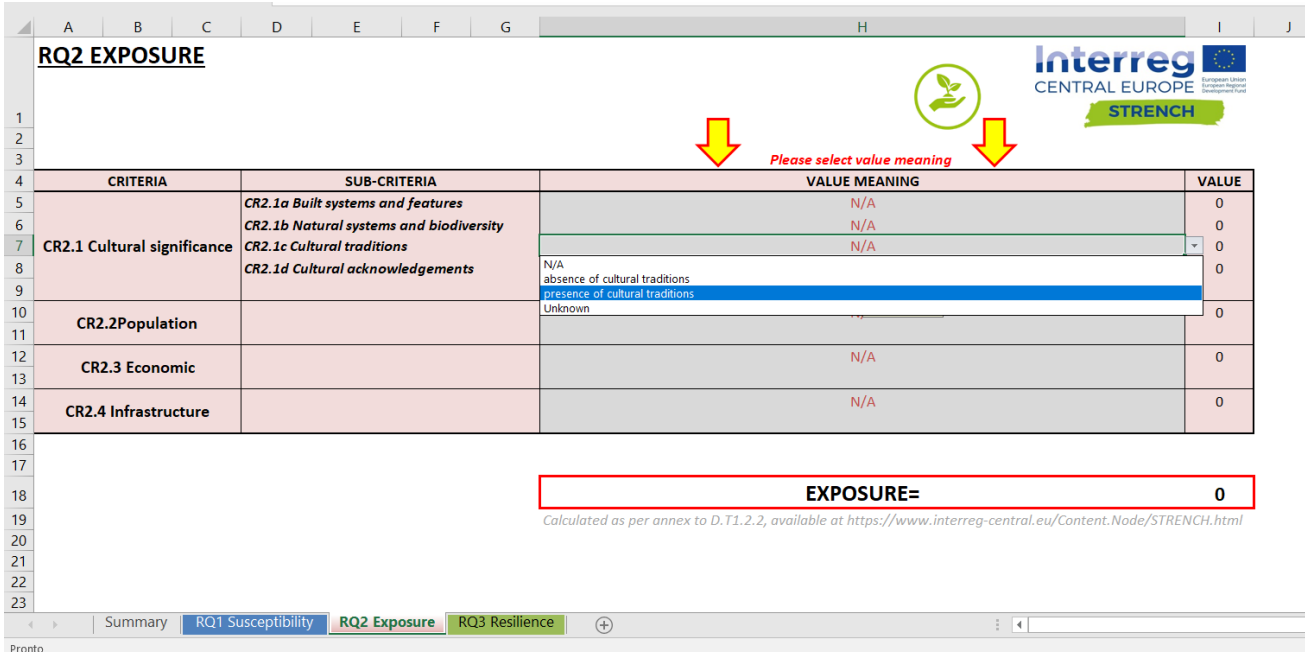
Summary | RQ1 Susceptibility | RQ2 Exposure | RQ3 Resilience

# Methodology for the Vulnerability assessment

A hierarchy tree with criteria and sub-criteria composed of Multiple choice like questions
Each choice is given a certain value which is then used to compute the Requirement for the case study



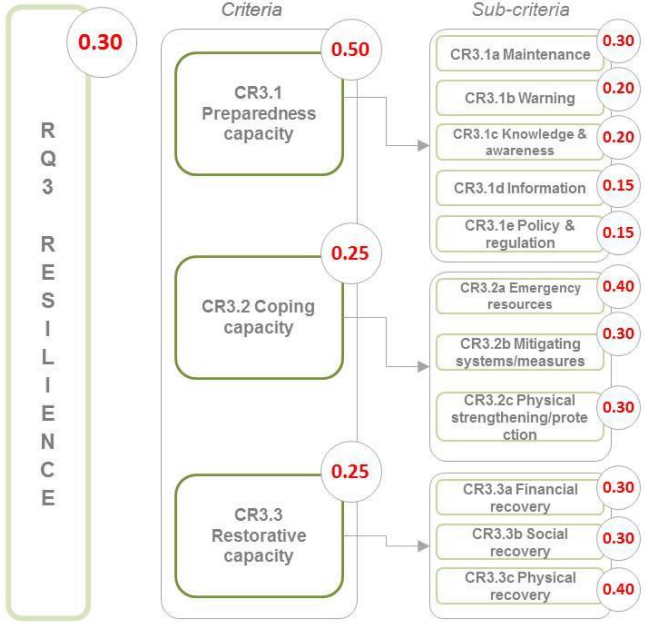

*Exposure = (0.40 x Cultural significance) + (0.20 x Population) + (0.20 x Economic) + (0.20 x Infrastructure)*

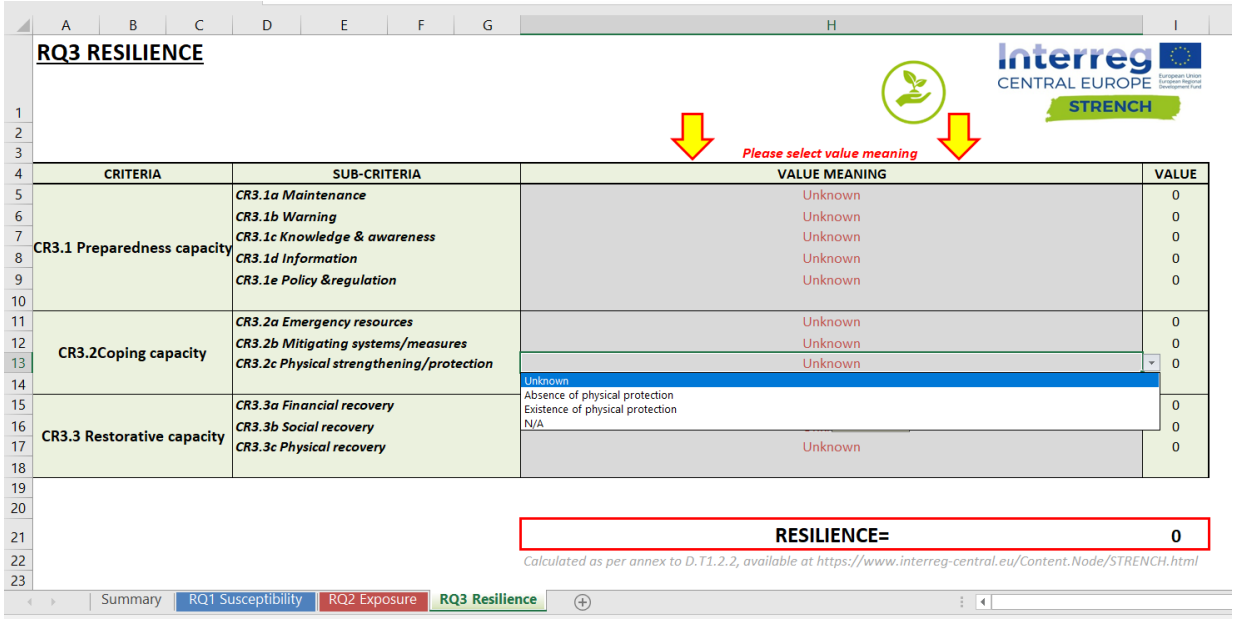



**Tested at the Site with local stakeholders**

# Methodology for the Vulnerability assessment

A hierarchy tree with criteria and sub-criteria composed of Multiple choice like questions
Each choice is given a certain value which is then used to compute the Requirement for the case study

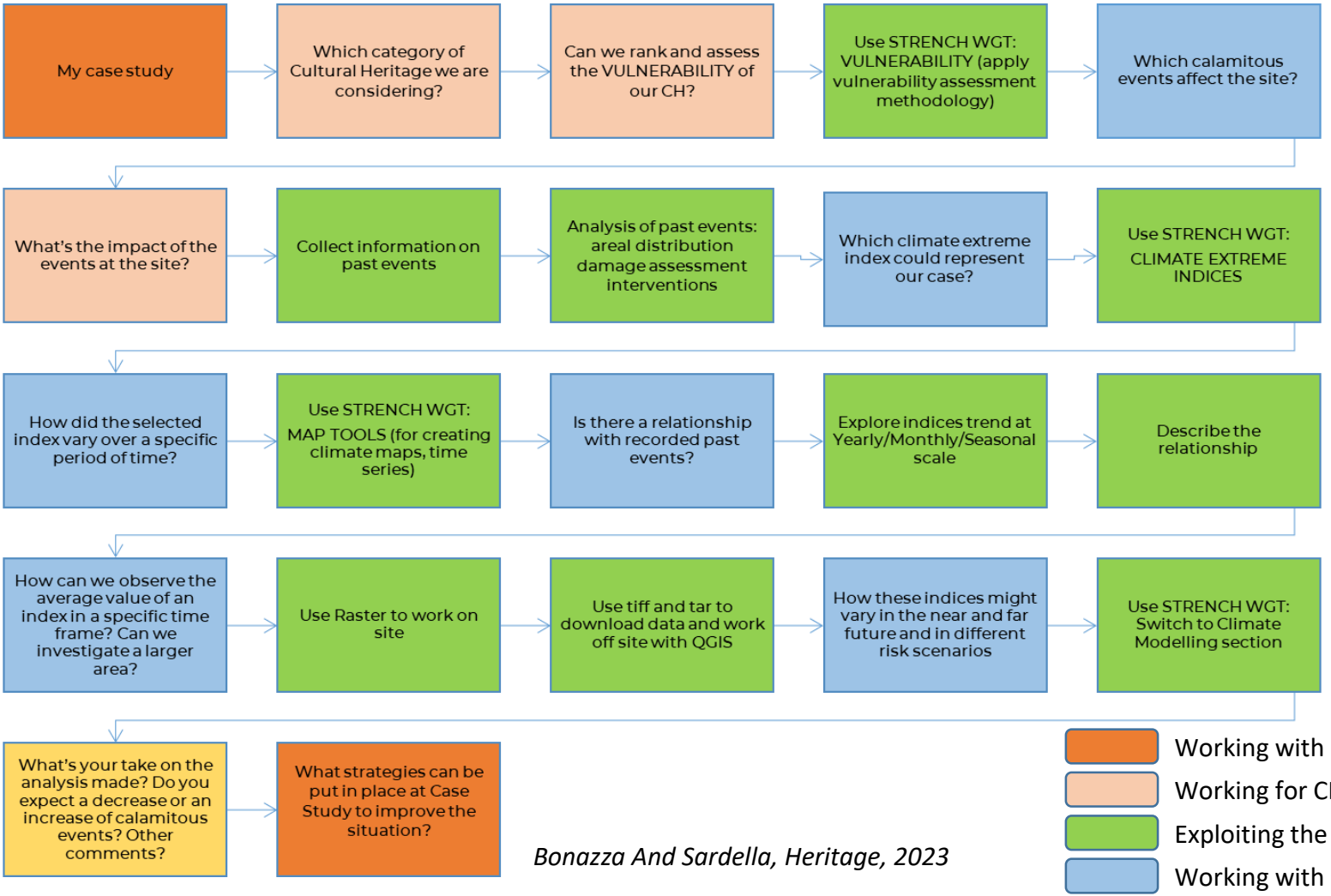



*Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)*

**Tested at the Site with local stakeholders**

# An example of methodological approach for working with the Web GIS Tool




*Bonazza And Sardella, Heritage, 2023*

Working with case study

Working for CH vulnerability

Exploiting the Risk Mapping Tool

Working with climate extreme events

# Application at Case studies


| Place | Assessed site | CNH | Cultural relevance | Elements under threat | Impacting hazards |
|---|---|---|---|---|---|
| Wachau Valley<br><br>Krems, Stein, Melk (AT) | • Melk Abbey landscape<br>• Dürnstein<br>• Krems Stejn | CL<br><br>H<br><br>R | Multitude of CNH: historic city centres, monasteries, ruins, hamlets, terraced vineyards, apricot trees | Landscape, Dry stone walls<br><br>Building materials<br><br>Fruit growing | Heavy rain<br><br>River Flood<br><br>Flash flood<br><br>Landslide<br><br>Fire |
| Troja Hamlet<br><br>Troja-Praha<br><br>(CZ) | • Troja Château | H<br><br>HPG | Historic landscape<br><br>Historic buildings<br><br>Architectural heritage | Landscape<br><br>Building materials<br><br>Flora&Fauna | Flood, windstorm, Fire |

Legend: CL, Cultural landscape; CNH, Cultural and Natural Heritage; H, Hamlets; HPG, Historic parks & gardens; R, Ruins.

*Cacciotti R., Sardella A.*, Drdacky M., Bonazza A. 2024. A methodology for vulnerability assessment of cultural heritage at risk due to extreme changes in climate. International Journal of Disaster risk Science*

# Preliminary results at selected case studies

## VULNERABILITY ASSESSMENT

| Sub-criteria | Troja Château (CZ) | Wachau Valley (AT) | | |
|---|---|---|---|---|
| | *Troja Château* | *Melk Abbey landscape* | *Dürnstein* | *Krems Stejn* |
| CR1.1a | 0,50 | 0,00 | 0,00 | 0,00 |
| CR1.1b | 0,10 | 0,10 | 0,10 | 0,10 |
| CR1.1c | 0,00 | 0,00 | 0,00 | 0,18 |
| CR1.1d | 1,00 | 0,00 | 0,00 | 0,00 |
| CR1.2a | 1,00 | 1,00 | 1,00 | 1,00 |
| CR1.2b | 1,00 | 1,00 | 1,00 | 1,00 |
| CR1.2c | 1,00 | 1,00 | 1,00 | 1,00 |
| CR1.2d | 0.18 | 0,00 | 0,00 | 0.18 |
| CR1.3a1 | 0,00 | 0,00 | 0,30 | 0,00 |
| CR1.3a2 | 0,00 | 0,30 | 0,30 | 0,30 |
| CR1.3a3 | 0,00 | 0,30 | 0,30 | 0,30 |
| CR1.3b | 0,30 | 0,00 | 0,00 | 0,00 |
| CR 1.3c | 0,30 | 0,30 | 0,30 | 0,30 |
| CR1.3d | 0,00 | 0,00 | 0,00 | 0,18 |
| CR1.4 | 0,15 | 0,30 | 0,30 | 0,15 |
| CR1.5a | 0,00 | 0,00 | 0,00 | 0,00 |
| CR1.5b | 0,00 | 0,30 | 0,30 | 0,00 |
| CR1.5c | 0,00 | 0,00 | 0,00 | 0,00 |
| CR1.6a | 1,00 | 0,00 | 0,00 | 0,00 |
| CR1.6b | 1,00 | 1,00 | 1,00 | 1,00 |
| CR1.6c | 0,00 | 0,00 | 0,00 | 0,00 |
| **RQ1** | **0,33** | **0,22** | **0,23** | **0,22** |

| Sub-criteria | Troja Château (CZ) | Wachau Valley (AT) | | |
|---|---|---|---|---|
| | *Troja Château* | *Melk Abbey landscape* | *Dürnstein* | *Krems Stejn* |
| CR2.1a | 1,00 | 1,00 | 1,00 | 1,00 |
| CR2.1b | 0,50 | 1,00 | 1,00 | 1,00 |
| CR2.1c | 1,00 | 1,00 | 1,00 | 1,00 |
| CR2.1d | 0,86 | 1,00 | 0,86 | 0,61 |
| CR2.2 | 0,30 | 0,30 | 1,00 | 0,30 |
| CR2.3 | 0,50 | 1,00 | 0,50 | 0,50 |
| CR2.4 | 1,00 | 1,00 | 1,00 | 1,00 |
| **RQ2** | **0,69** | **0,86** | **0,83** | **0,71** |

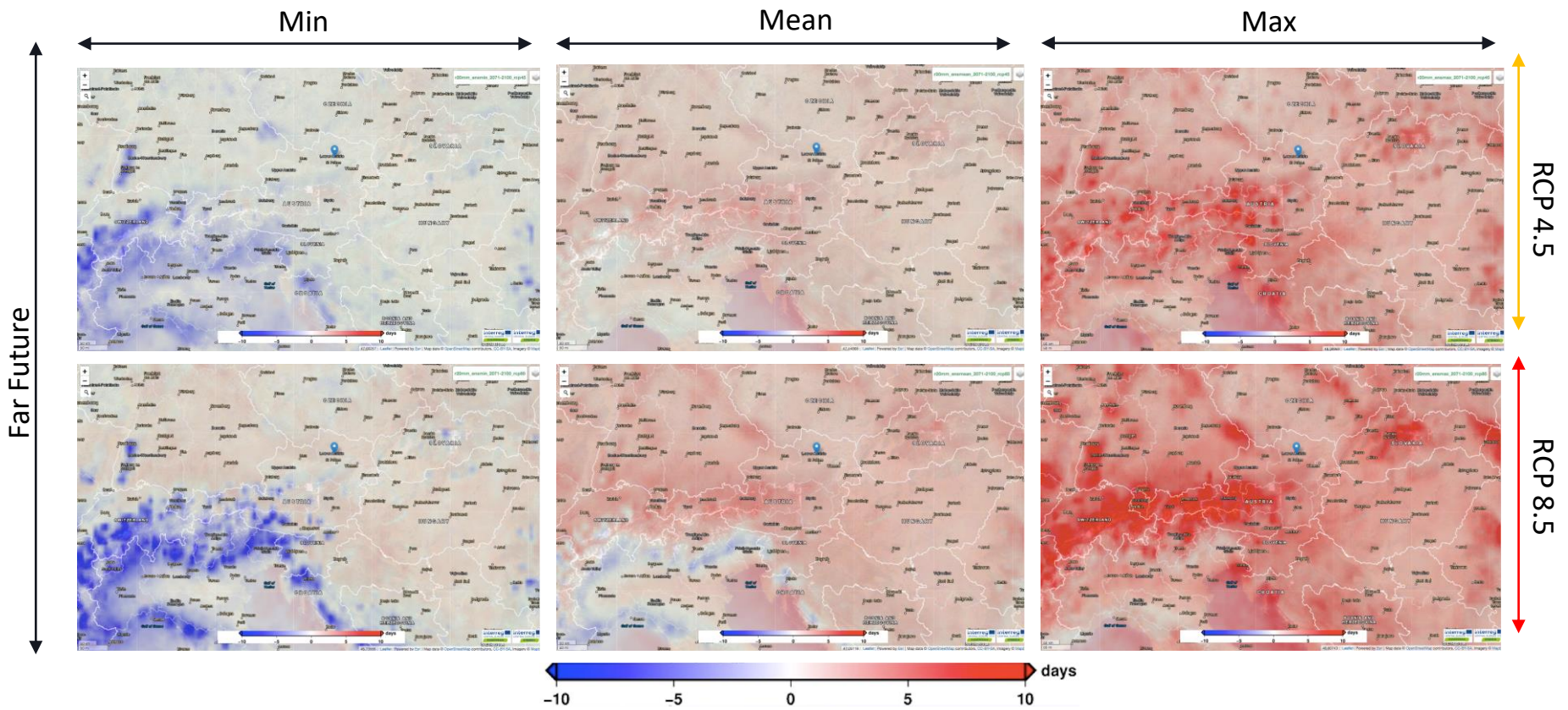
| Sub-criteria | Troja Château (CZ) | Wachau Valley (AT) | | |
|---|---|---|---|---|
| | *Troja Château* | *Melk Abbey landscape* | *Dürnstein* | *Krems Stejn* |
| CR3.1a | 0,50 | 1,00 | 1,00 | 1,00 |
| CR3.1b | 1,00 | 0,00 | 0,00 | 1,00 |
| CR3.1c | 1,00 | 1,00 | 1,00 | 1,00 |
| CR3.1d | 0,50 | 1,00 | 1,00 | 1,00 |
| CR3.1e | 1,00 | 1,00 | 0,00 | 1,00 |
| CR3.2a | 1,00 | 1,00 | 0,00 | 1,00 |
| CR3.2b | 1,00 | 1,00 | 1,00 | 1,00 |
| CR3.2c | 1,00 | 1,00 | 0,00 | 1,00 |
| CR3.3a | 0,30 | 1,00 | 1,00 | 0,30 |
| CR3.3b | 0,00 | 0,00 | 0,00 | 0,00 |
| CR3.3c | 1,00 | 1,00 | 0,00 | 1,00 |
| **RQ3** | **0,76** | **0,83** | **0,48** | **0,87** |

The proposed methodology 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)

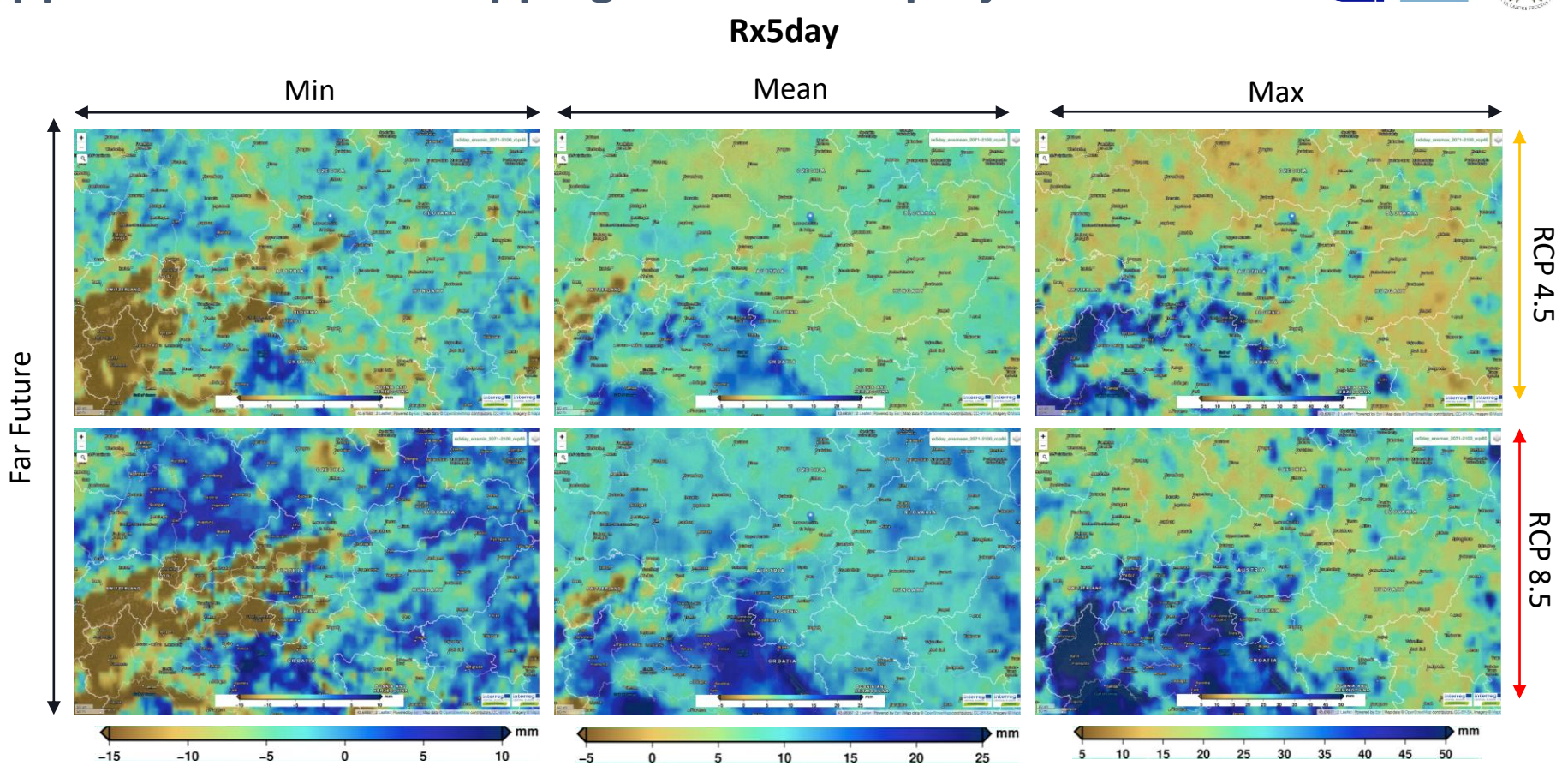
*Cacciotti R., Sardella A.*, Drdacky M., Bonazza A. 2024. A methodology for vulnerability assessment of cultural heritage at risk due to extreme changes in climate. International Journal of Disaster risk Science*

# Application of Risk Mapping Tool: future projection

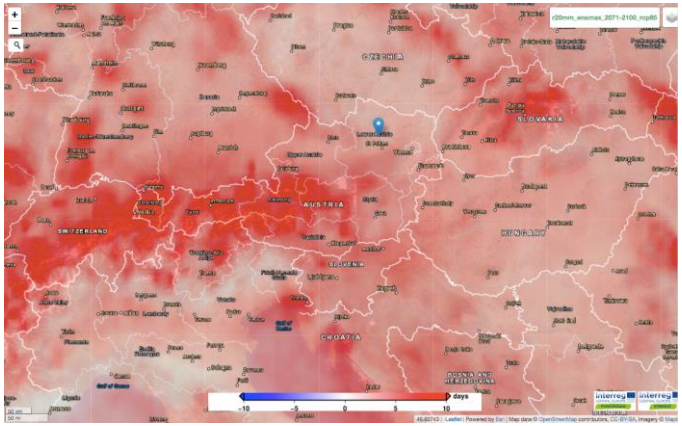
**R20mm**



# Application of Risk Mapping Tool: future projection

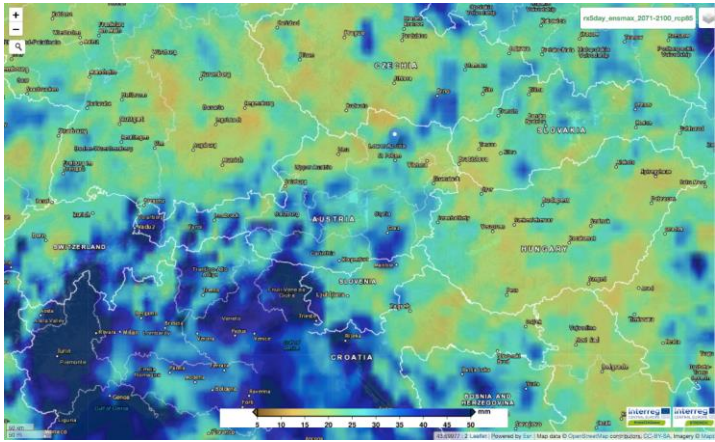


# Application of Risk Mapping Tool: future projection




From the climate hazard mapping, it is evidenced that both Troja hamlet and built CH in Wachau Valley will experience with time increasing rainfall as well as dry spells. This will impact the site possibly triggering soil erosion, speeding up the degradation of materials and influencing the conservation of the vegetation and other natural systems present on-site

Remarkable climate changes are instead observed under the pessimistic scenario (8.5 RCP). The far future projection, predicting strong changes in precipitation and temperature at the site, is of particular concern. This scenario would lead to a remarkable risk situation for flood and flash flood



# Final remarks

- The Risk Mapping Tool provides insights on the hazard maps referring to heavy rain, flooding, drought, and extreme heat. The maps covers 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.
- Assessment of the vulnerability at local and building scale
- Helpful decision support tools for different stakeholders involved in the management of Cultural Heritage

# Gaps and future developments

Climate maps: integration with values of extreme indices of the reference period in addition to the anomalies

Downscaling: hazard mapping at higher spatial resolution

Future projections under Socioeconomic pathway scenarios (SSPs)

Develop and integrate tools for coastal and underwater cultural and natural heritage protection (H2020 TECTONIC, Interreg CE INACO, PNRR ECOSISTER)

Integrate with additional hazards and case studies (H2020 TECTONIC, Interreg CE INACO, Piano di Monitoraggio MIC, PNRR ECOSISTER, PNRR CHANGES )

Tavolo di valorizzazione beni culturali Copernicus (Applicazione C3S, CAMS, CMEMS per il patrimonio culturale)

# A risk assessment tool for the protection of cultural heritage exposed to extreme climate events

# 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