Corso di Laurea Magistrale in Fisica del Sistema Terra
Ciclo di Seminari ISAC-CNR & INGV

Viale Berti-Pichat 6/2, Bologna
Aula 4, ore 16:00

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

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Cultural Heritage at Risk

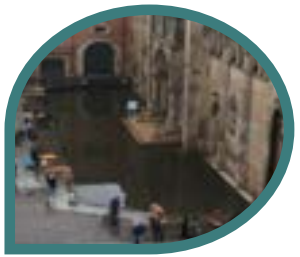
The risk to cultural and natural heritage as a consequence of natural hazards and impact of climate change is globally recognized.

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)

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

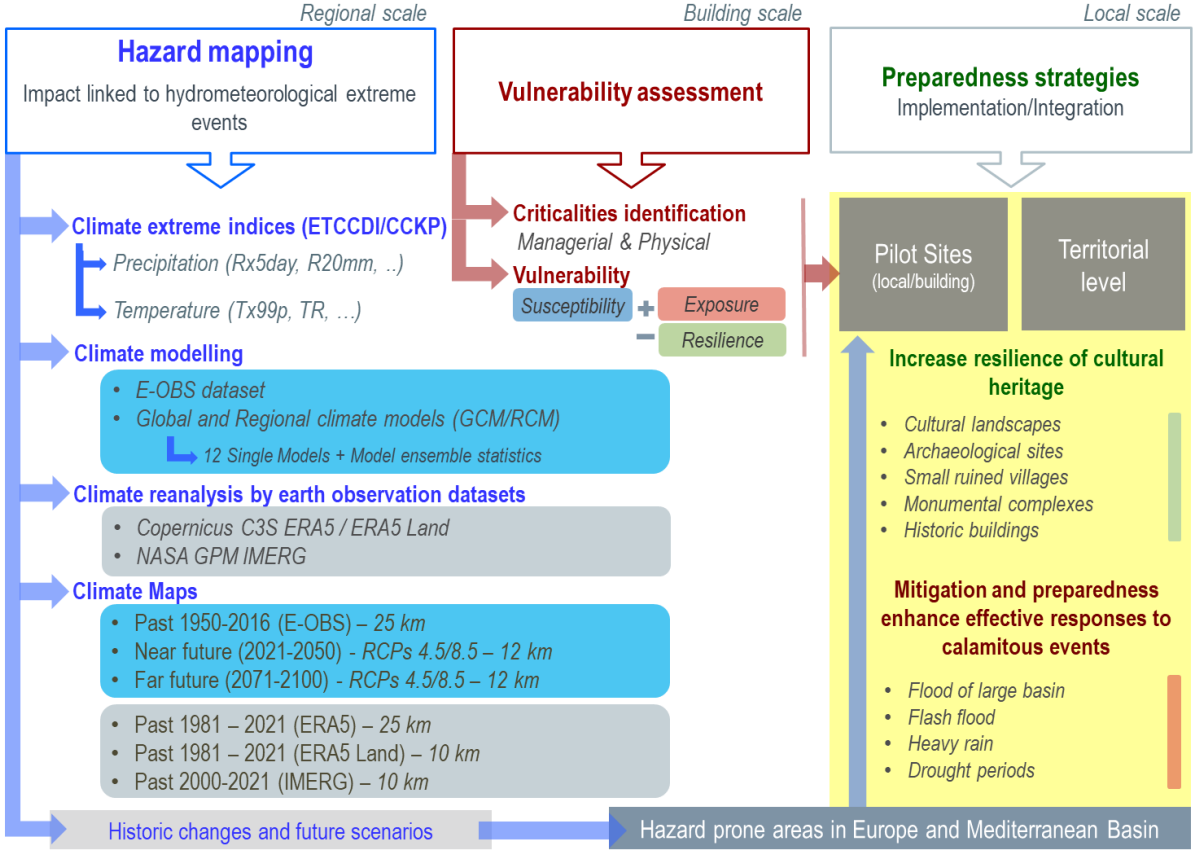
https://www.protecht2save-wgt.eu/

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

Methodology for mapping climate extremes

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

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

Precipitation

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

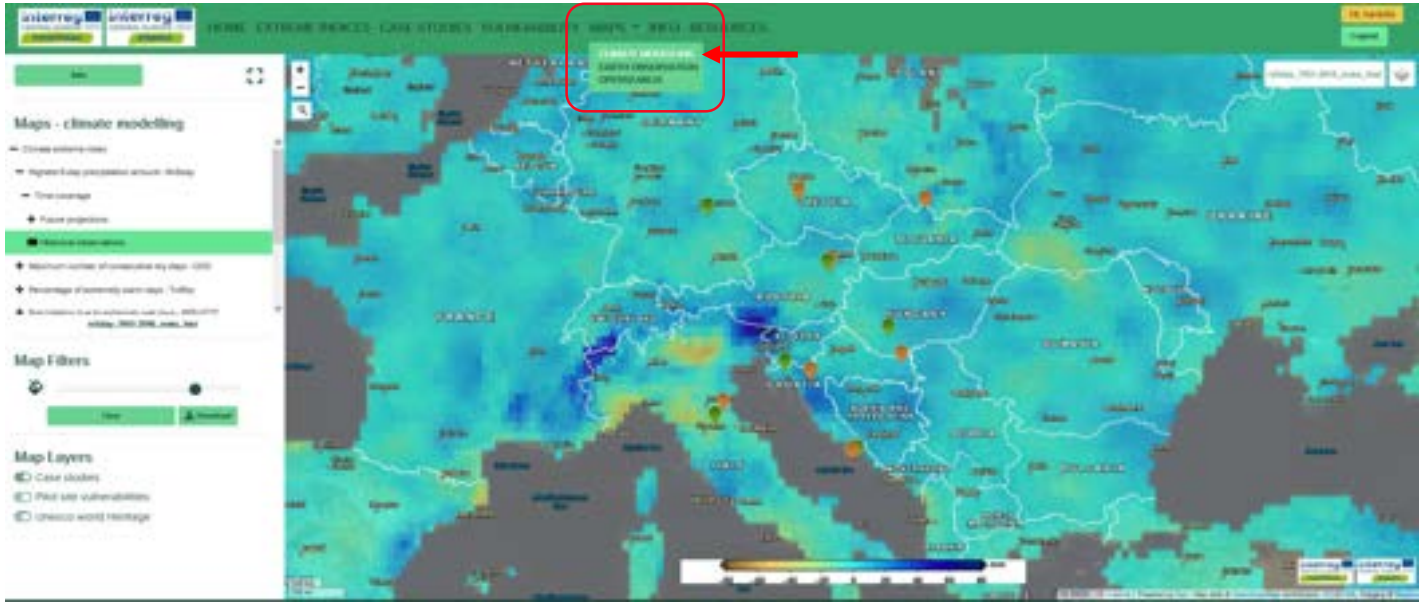
Temperature

- Heat waves index
- Tx99p
- TR
- Su30
- Tx
- Tn

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)*

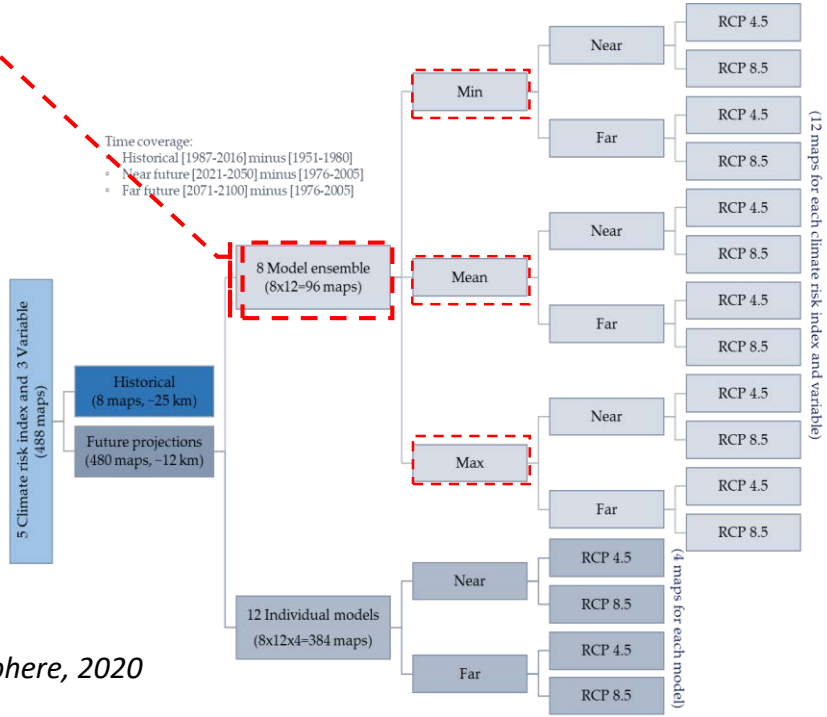
12 different combinations of 6 forcing global models (**GCM**), driving 5 regional models (**RCM**), have been taken into account for the elaboration of the maps related to the future projections

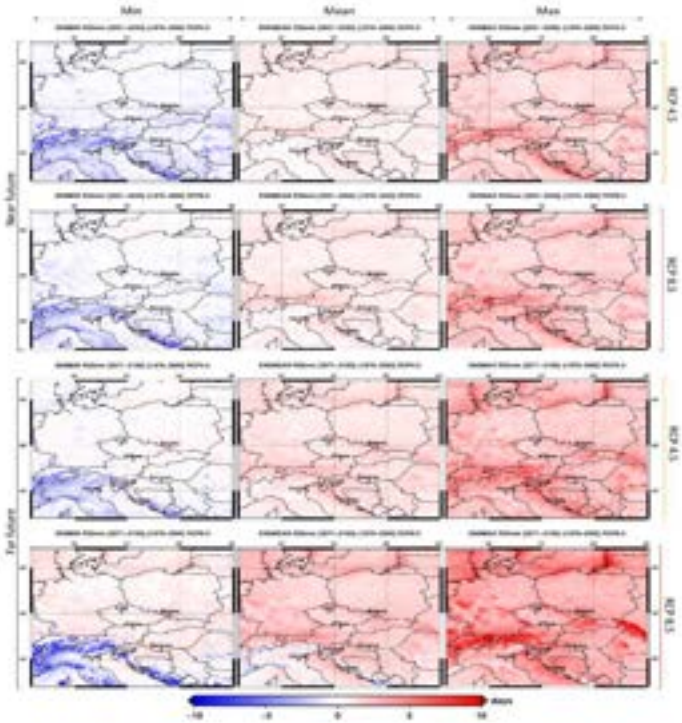
Multi-models ensembles of regional climate projection have been based on the **EURO-CORDEX*** initiative, which provides regional climate projections for Europe at two different spatial resolutions:
- "standard" 0.44 degrees (EUR-44, ~50 km)
- "finer" 0.11 degrees (EUR-11, ~12 km)

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

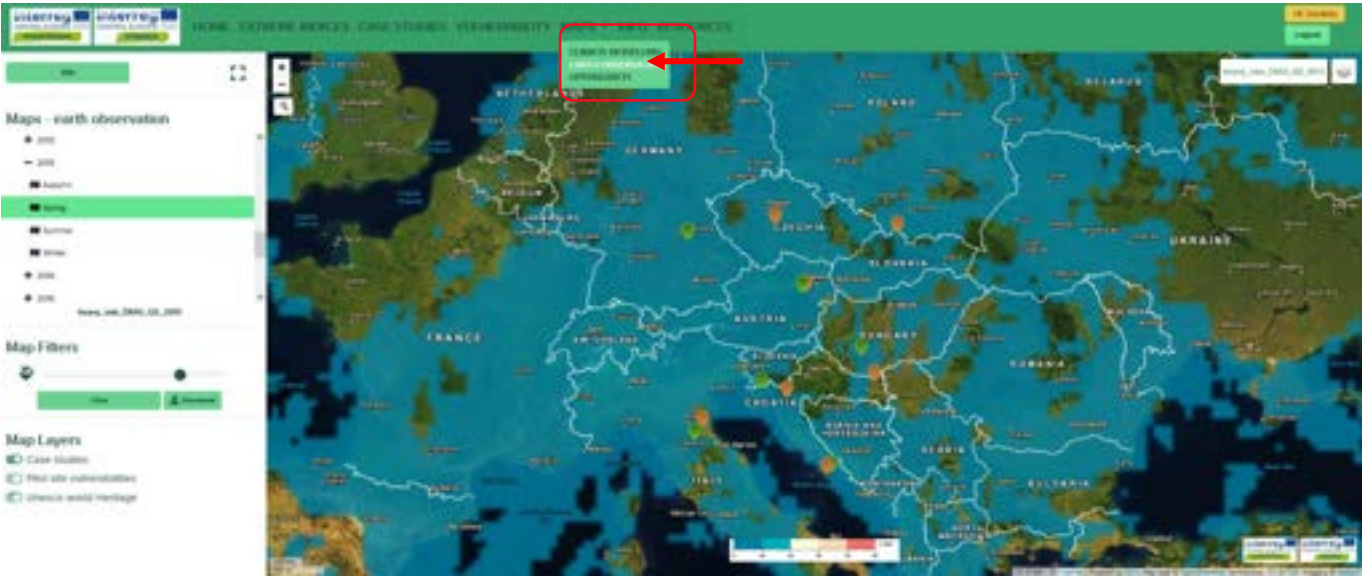




Sardella et al. Atmosphere, 2020

Maps Tools – Exploring EO datasets

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



- 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

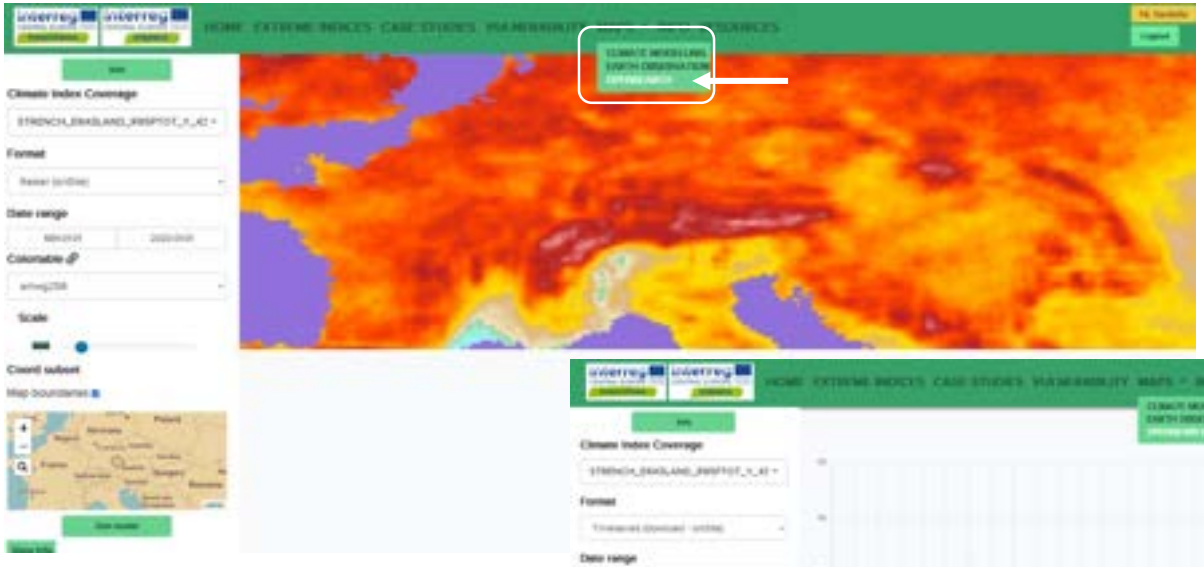
Temperature extreme indices

- HWI
- Tx99p
- TR
- Su30

Climate variable

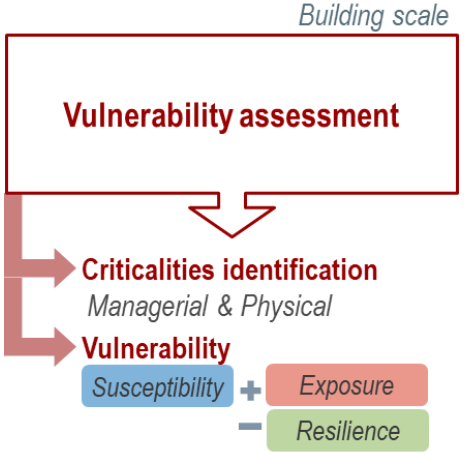
- RR

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

Methodology for the Vulnerability assessment

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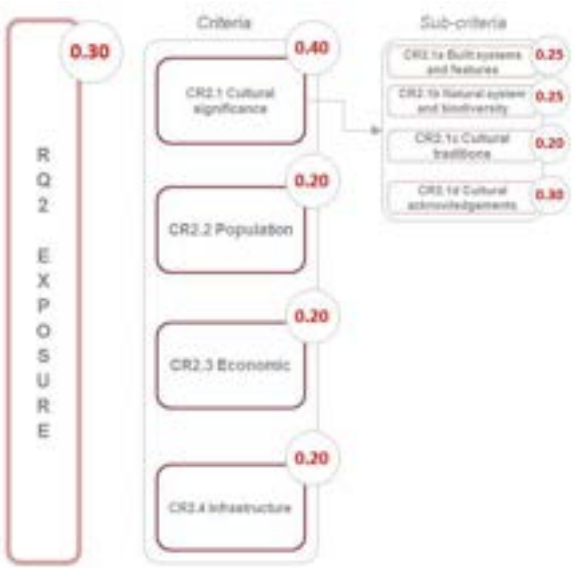
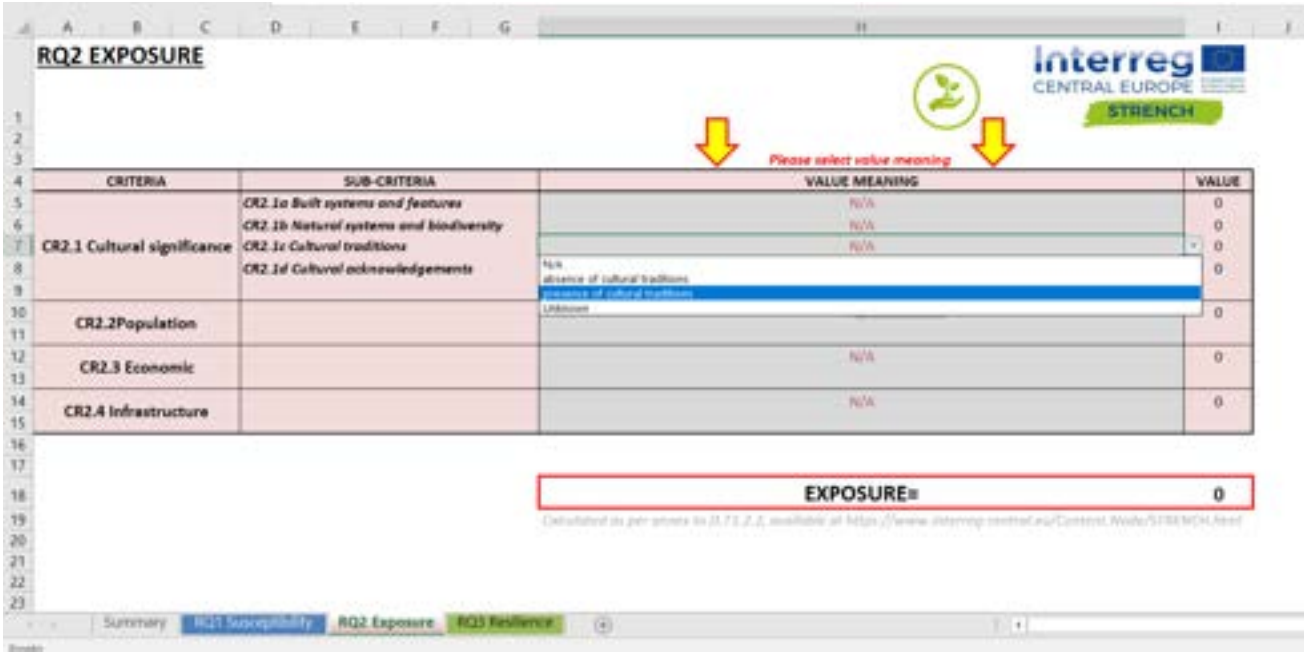


Exposure = (0.40 x Cultural significance) + (0.20 x Population) + (0.20 x Economic) + (0.20 x Infrastructure)



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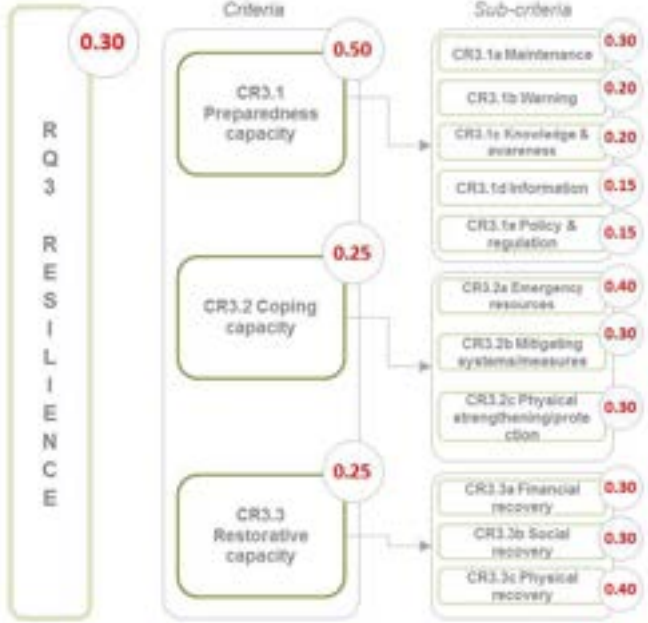
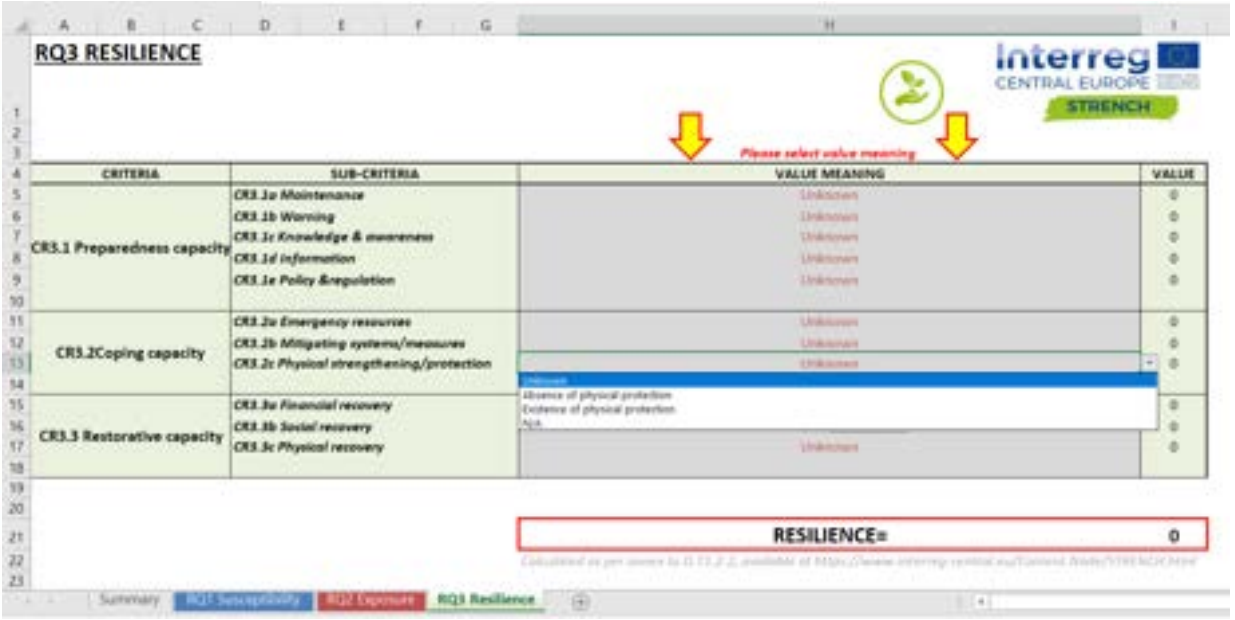
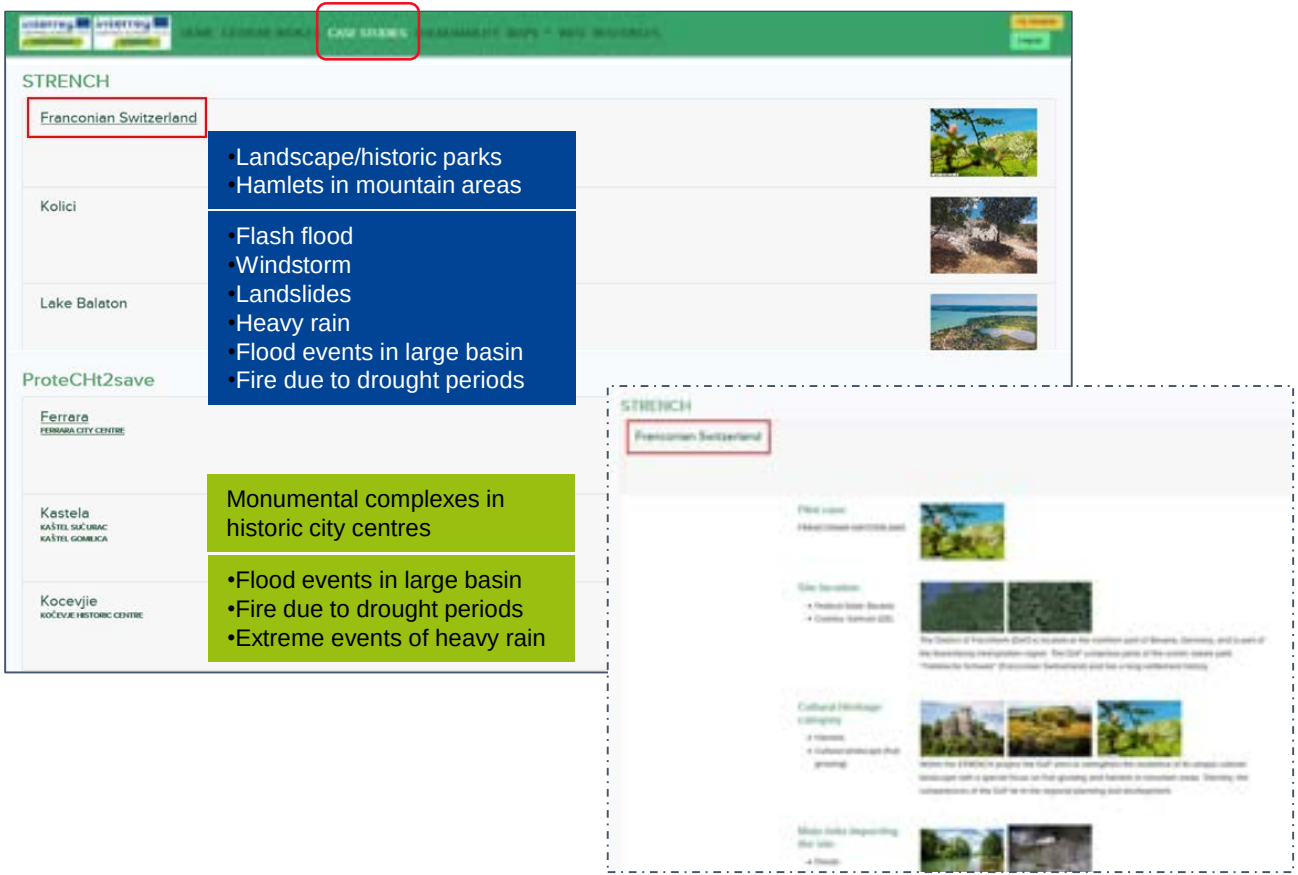




Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)

Tested at the Site with local stakeholders

Case studies

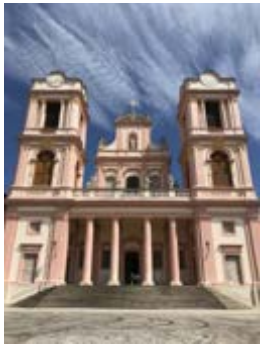


Methodology for VULNERABILITY assessment

Case study: Wachau Valley, Austria

Flood event

Heavy rain



- Cultural Landscape
- 36 km in lenght
- Stretch of the Danube river valley located between the cities of Melk and Krems
- December 2000: inscribed in the UNESCO List of World Heritage Sites

- Architecture (monasteries, castles, ruins)
- Urban design (town and villages dating back to 11th and 12th centuries)

Methodology for VULNERABILITY assessment

Case study: Troja Valley (AT)

Flood event

Heavy rain

The Troja hamlet is located in Prague's north-west borough and it lies in the proximity of the Vltava river

The Troja Valley features important natural and cultural heritage assets with millions of visitors yearly

Frequent high water level situations with major flooding are the main natural hazard threatening the cultural heritage of the site along with the large numbers of visitors

Structures susceptible to partial damage due to flooding

Minor risks include local flash floods intensified with insufficient capacity of the rain drainage system, harsh weather situations with drought, strong winds and temperature fluctuations

Methodology for vulnerability assessment

Susceptibility= (0.20xBuildings) + (0.15x Built/manmade features) + (0.35 x Vegetation) + (0.10x Topography) + (0.10x Geosphere) + (0.10 x Hydrosphere)	=0.33
Exposure= (0.40xCultural significance) + (0.20x Population) + (0.20x Economic) + (0.20x Infrastructure)	=0.69
Resilience= (0.50xPreparedness capacity) + (0.25xCoping capacity) + (0.25xRestorative capacity)	=0.76
Vulnerability= 0.70xSusceptibility + 0.30xExposure -0.30xResilience	**=0.21**

Case study		Ranking of vulnerability			
		RQ1	RQ2	RQ3	Vulnerability
WACHAU (AT)	Melk Abbey	0,22	0,86	0,83	0,16
	Dürnstein	0,23	0,83	0,48	0,28
	Krems-Stein	0,23	0,71	0,87	0,11
PRAJA-TROJA (CZ)	Troja Château	0,33	0,69	0,76	0,21

The overall vulnerability scores in the low to medium range.

Methodology for risk assessment: analysis of calamitous events

Case study: Wachau Valley, Austria

Flood event

Heavy rain

Aug. 1501

The biggest flood in recent history. Peak flow of water in Danube at arounf 12000 m^3/s.

1787

Partly caused by ice jams. Danube regulated: side brances cut off, banks secured with big rocks.

Sept. 1899

100-years flood. Danube regulated at Stein. Flood protection dam enlarged.

Jul. 1954

30-years flood. Settlement and agricultural areas flooded. Ten hydroelectric power dams built.

Aug. 2002

100-years flood. Heavy rainfall. Severe damage to dry-stone wall wine terraces Mobile flood barriers installed.

Jun. 2009

Different rockslides. Projects for mobile flood protection continued.

Jun. 2010

10-years flood. No damage in Stein. Flood protection in operation in Krems.

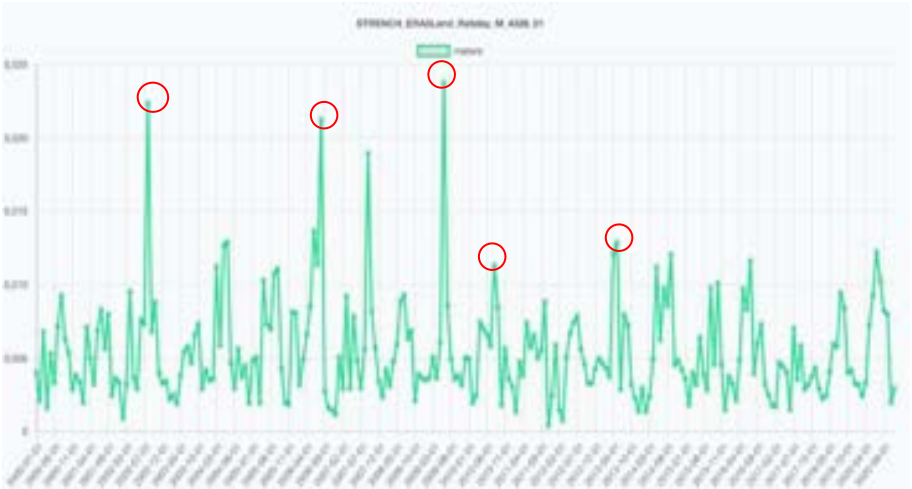
Jun. 2013

100-years flood. High amount of precipitation, intially as snow in Alpine regions. Implementati o of protection systems.

Methodology for risk assessment: Representative climate extreme indices

Index	Definition and description	Related extreme event	Unit
R20mm	**Very heavy precipitation days** Number of days in a year with precipitation greater than or equal to 20 mm/day	Heavy rain	days
R95pTOT	**Precipitation due to extremely wet days** The total precipitation in a year cumulated over all days when daily precipitation is larger than the 95th percentile of daily precipitation on wet days. A wet day is defined as having daily precipitation ≥ 1 mm/day. A threshold based on the 95th percentile selects only 5% of the most extreme wet days over a 30 year-long reference period.	Heavy rain	mm
Rx5day	**Highest 5-day precipitation amount** Yearly maximum of cumulated precipitation over consecutive 5-day periods.	Flooding	mm

Application of Risk Mapping Tool: climate indices time series



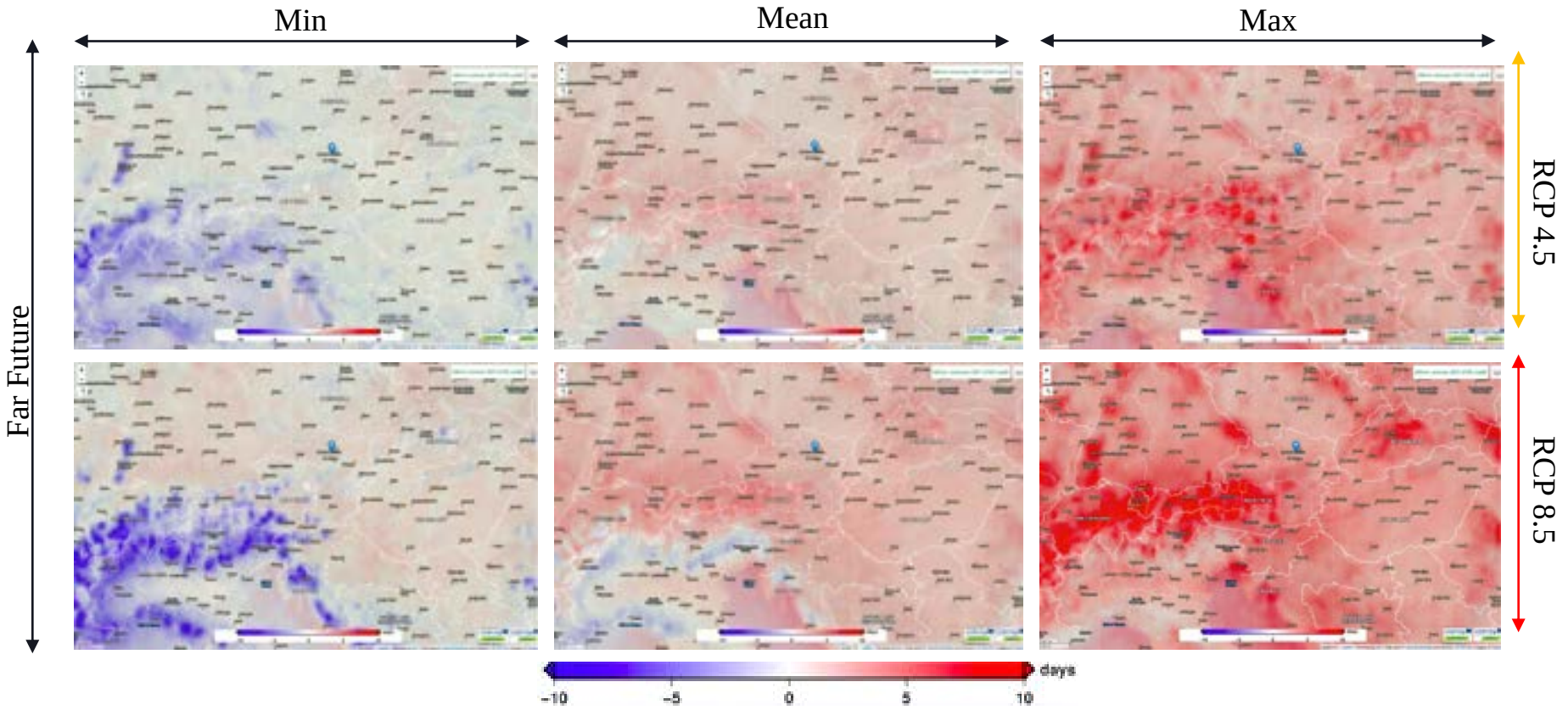
Time series

- R20mm values at seasonal scale derived from IMERG products

- Rx5day at monthly scale derived from ERA5Land products

Peaks of R20mm and Rx5day clearly visible in sorrispondence of recorded catastrophic heavy rainfall and floods

Application of Risk Mapping Tool: Investigation of future projection



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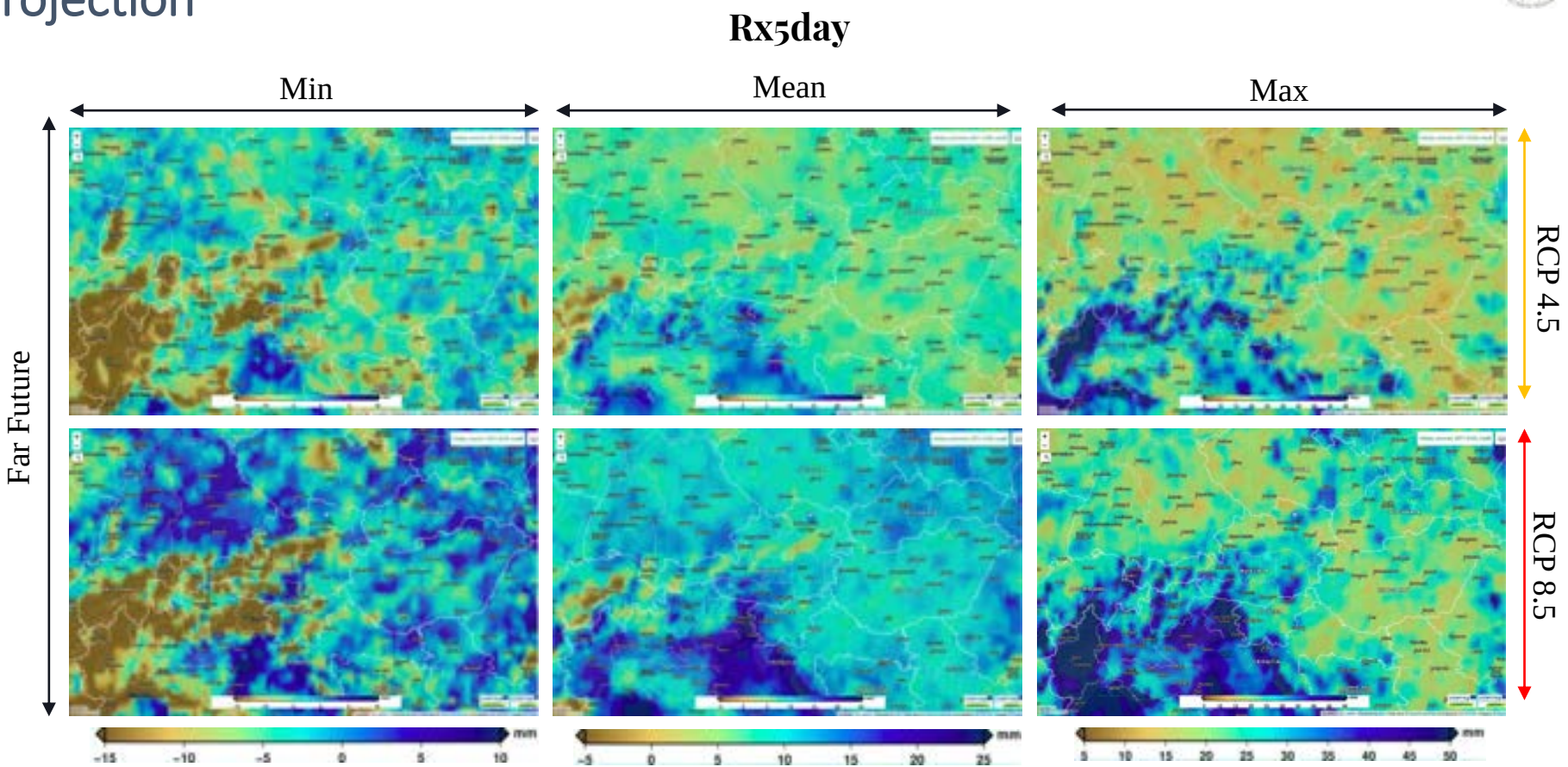
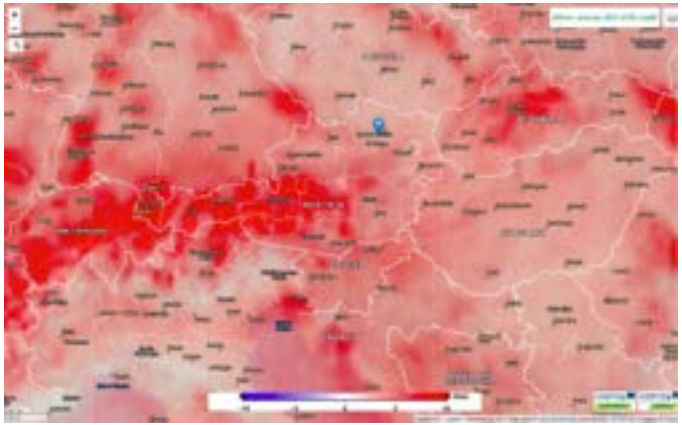
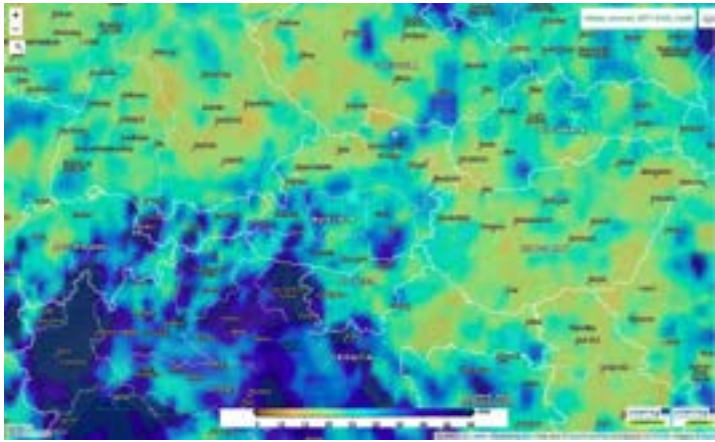


Results at case studies



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 are elaborated covering the European and Mediterranean areas calculating climate extreme precipitation and temperature indices using data from the selected combination of models.
- 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.
- Possible to obtain a numerical quantification of the vulnerability at local and building scale
- Helpful decision support tools for different stakeholders involved in the management of Cultural Heritage
- Future work: further developing and testing the validity of the tools, particularly in preparedness and emergency situations
- Elaboration of standardized approaches at European level for CH safeguarding

Thesis proposals

Impact assessment of climate-induced extreme events at case studies:

1) historic Centre of Verona (Italy)
2) historic centre and bell towers Venice lagoon (Italy)
3) Aeolian islands landscape and historic centre (Italy)

Additional research theme for the proposed case studies:

- Vulnerability assessment at case studies using STRENCH Methodology
- Impact of slow cumulative damage due to main deterioration parameters linked to air pollution

Methodology: acquisition, processing and analysis of climate and environmental data.

- exploitation of products and datasets of C3S and CAMS services with the realization of maps at Regional/National level, with specific focus on the entire historical center object of study
- Census of weather-climate monitoring and pollution stations at the scale of the historic center/ area under study. Verification, collection, analysis and processing of available useful data
- Comparison of the elaborations carried out on the scale of the historical centre/territorial area under study with the results of the elaborations produced using Copernicus C3S and CAMS products

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/

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