Principal Investigator

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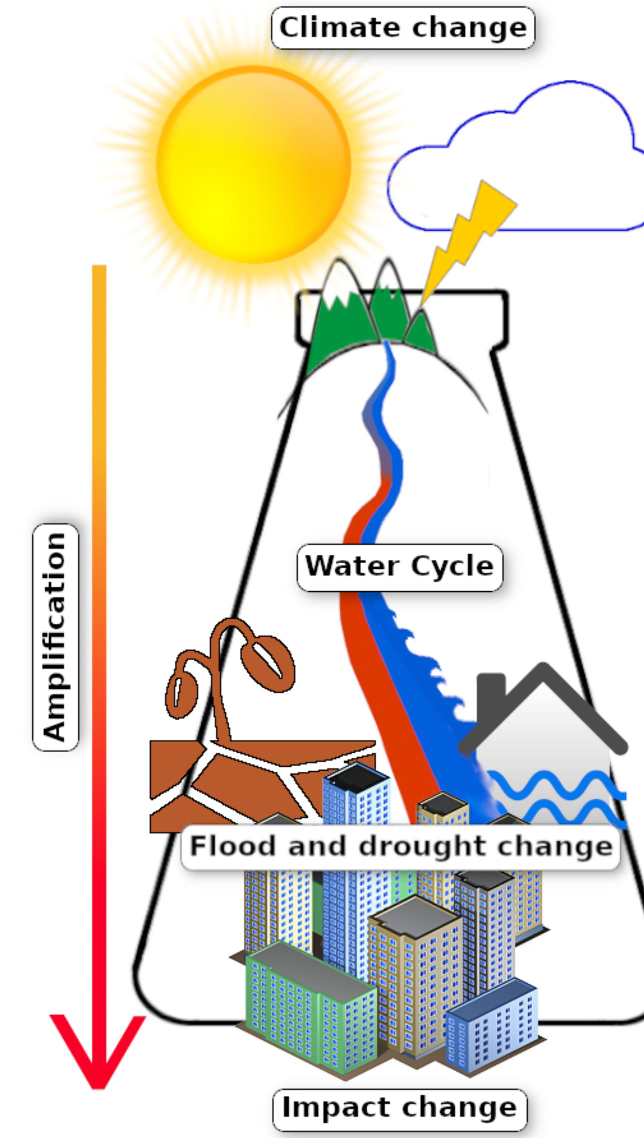
Scientific proposal submitted to the Competitive Procedure Supporting Fundamental Research Activities financed by the Italian Science Fund

$CO_2$2Water

Stochastic amplification of climate change into floods and droughts change



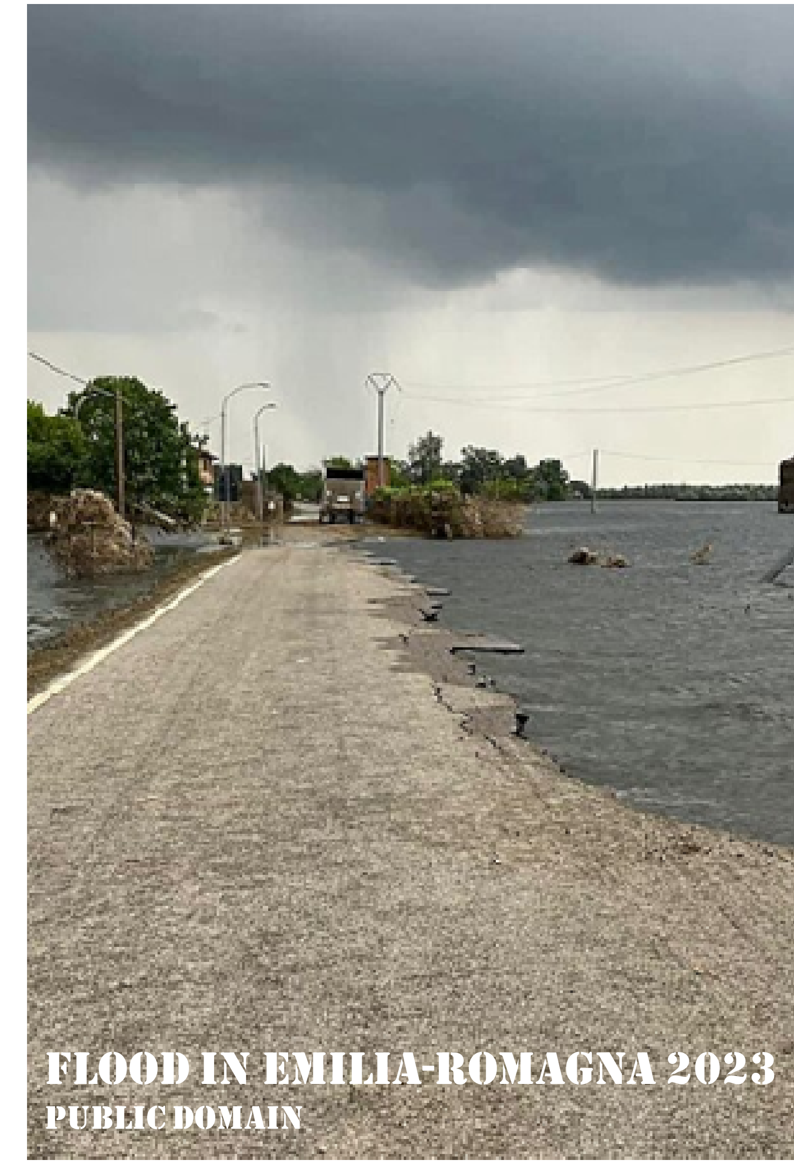
Research question: What drives the amplification of climate change into droughts and floods impact change?

Objectives:

1. Developing a new and unified stochastic theory of climate change amplification along eco-hydrological and human systems.
2. Providing new knowledge and tools to identify critical situations and states leading to amplification of climate change impact.

Why this project

- Floods and droughts increasingly take us by surprise;
- Examples: Emilia-Romagna 2023; Marche 2022; Germany 2021; Emilia-Romagna 2014 and 2017; Australia 2001-2009 (Van Dijk et al., 2013); Austria 2002;
- In a hindsight, it looks hazards could have anticipated but we could not foresee the amplification of the social and environmental impact of disasters (Merz et al., 2015);
- Evidence shows that the impact of climate change is diversified depending on land and socio-economic conditions (Pörtner et al., IPCC, 2022; Sivapalan & Bloeschl, 2015);
- **Research question: What drives the amplification of climate change into droughts and floods impact change?**



Objectives

1. Developing a unified stochastic theory of climate change amplification along eco-hydrological and human systems.
   The scientific impact will be granted by new knowledge and new research avenues on climate change effects on society.

2. Providing new knowledge and tools to identify critical situations and states leading to amplification of climate change impact, to avoid that citizens and administrations are taken by surprise.
   $CO_2$2Water knowledge will deliver indications to policy makers to recognize the situations where climate change is threatening human communities in terms of flood and drought risk.

The $CO_2$2Water assumption

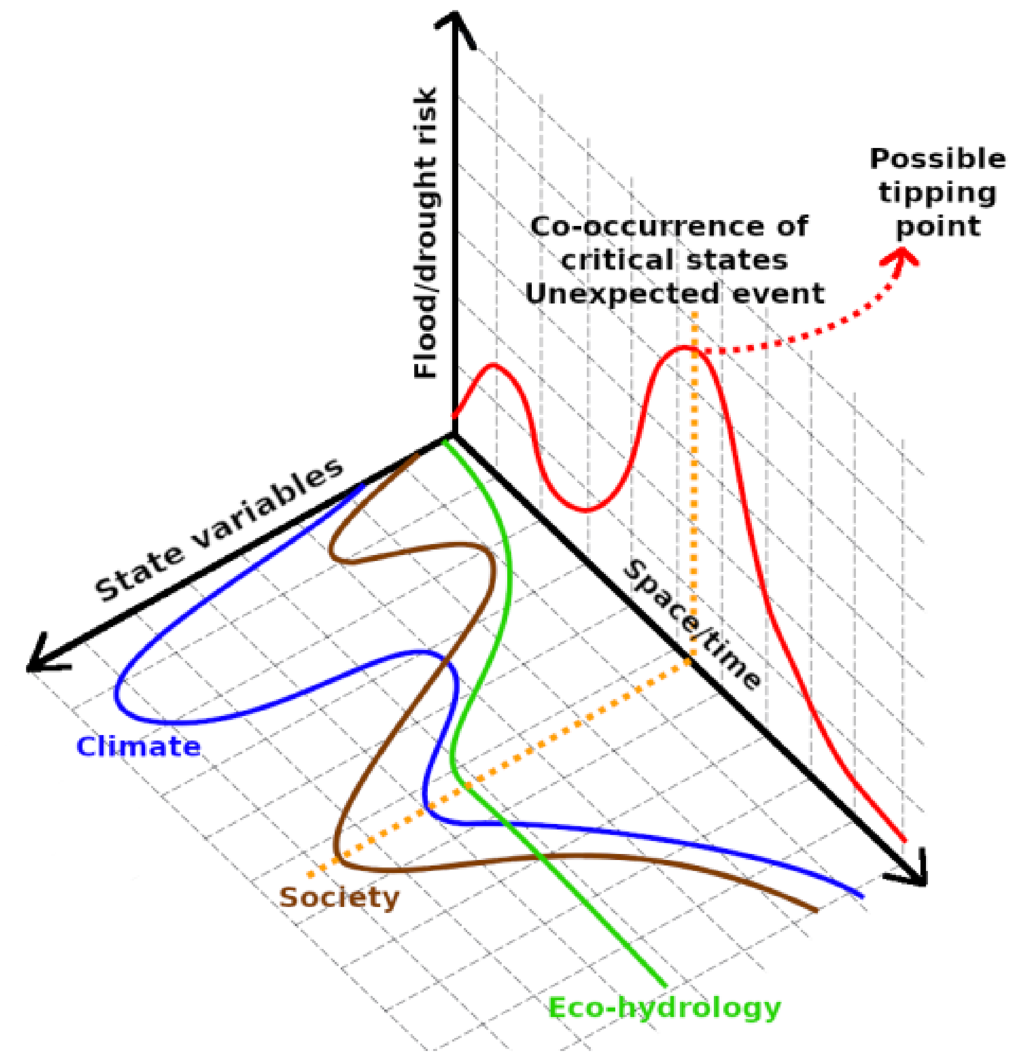
Flood and drought impact amplification is controlled by the co-occurrence of critical patterns and states of climate, water cycle, ecological and human dynamics. Local conditions play a key role.

For example drought risk may be exacerbated by unsuitable crop choice and increased irrigation, and flood risk may be exacerbated by lack of preparedness of communities.

The idea

To describe and predict the probability of co-occurrence of critical states of the considered triangle of systems (climate, eco-hydrological and societal systems) with a **stochastic physically based approach** (Montanari and Koutsoyiannis, 2012; Koutsoyiannis and Montanari, 2022).

The stochastic physically based approach describes each system and the interactions between systems with a deterministic model (causal, process based) which is then converted to a stochastic form (casual, statistically based) by including bias correction and statistical representation of errors.



Example of co-occurrence of critical states and probability estimation

Emilia-Romagna Case Study: Co-occurrence of (a) extreme drought, (b) shortage of water resources and (c) high vulnerability and exposure of agricultural production.

- **Defining probabilities of extreme droughts** through climate models and stochastic replication of historical series for the region (Guo & Montanari, 2023).

  Innovation: merging stochastic and deterministic models for climate change prediction.

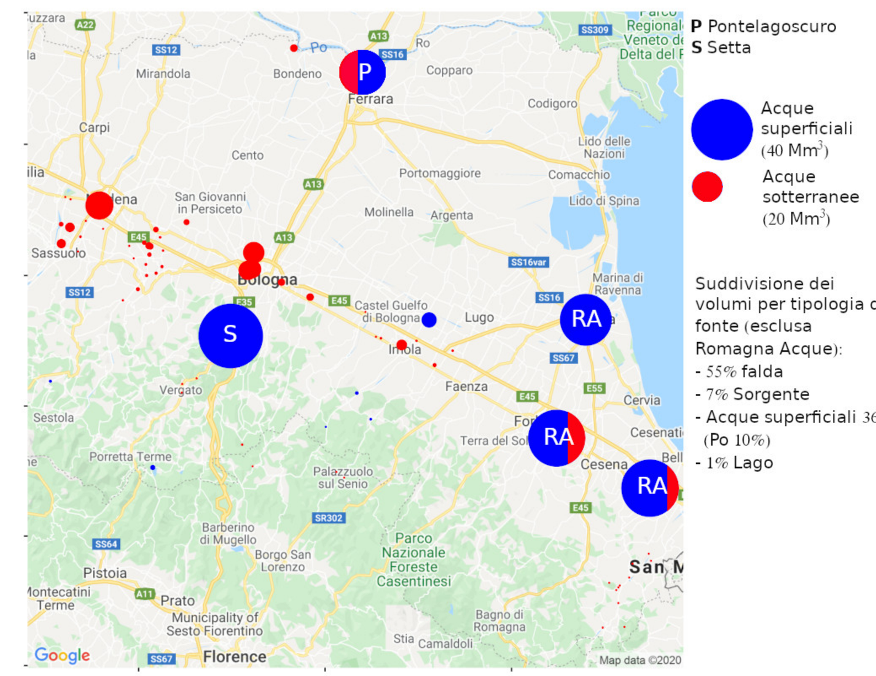
- **Defining probability of shortage of water resources**, conditioned to drought occurrence and duration with a physically based model.

  Innovation: identification of causes of hydrological amplification.

- **Defining probability of failure of agricultural production** conditioned to drought behaviour and state of water resources.

  Innovation: identification of causes of socio-economic amplification.

- **Defining spatio-temporal joint probability of co-occurrence of critical states** through multivariate process based probability distributions.



Water sources for the HERA water supply system

Stochastic physically based representation

Deterministic (process-based) model of a given system (Montanari and Koutsoyiannis, 2012):

$Q = S(\boldsymbol{\Theta}, \mathbf{X})$ where Q is a variable which may reach a critical value, **X** is input data vector and Θ is parameter vector.

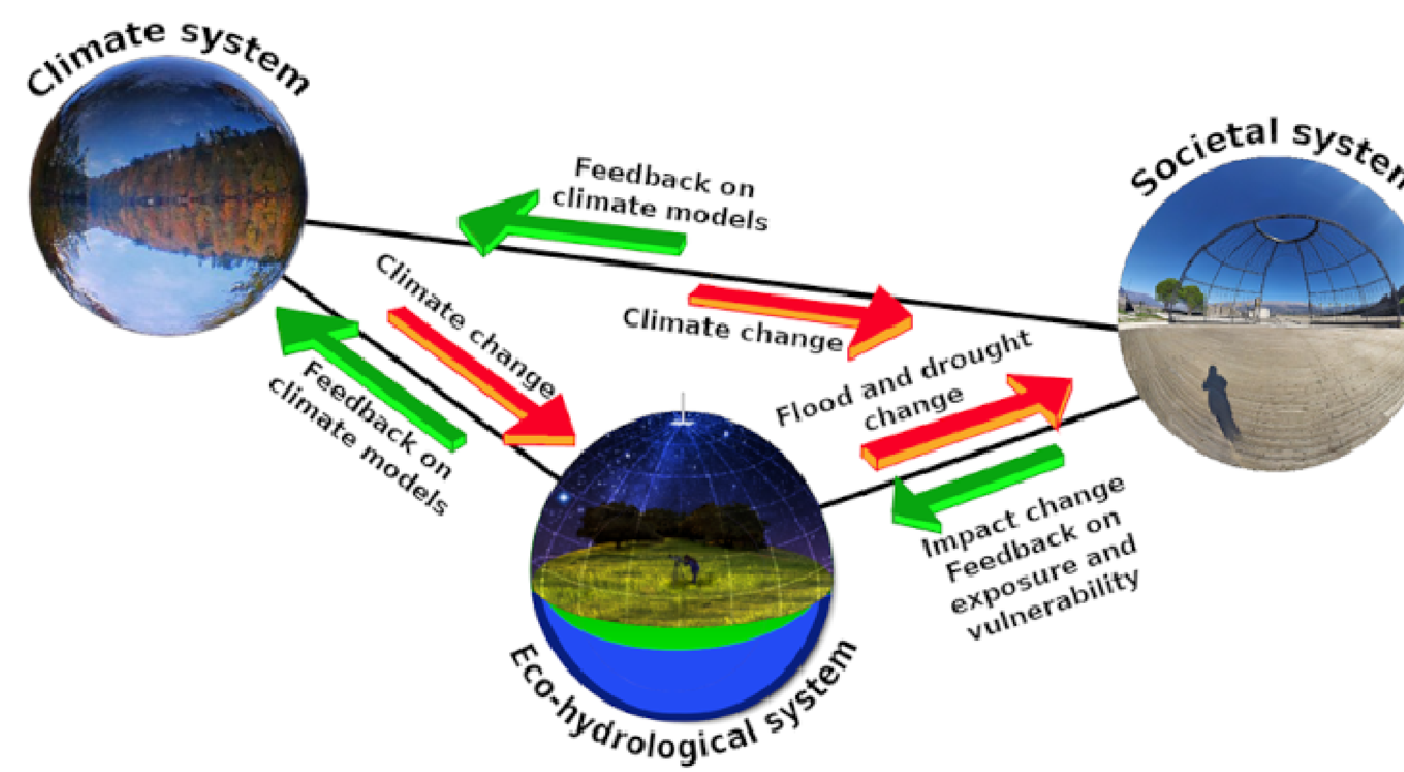
Stochastic physically based representation:

$$f_Q(Q) = \int_{\boldsymbol{\Theta}} \int_{\mathbf{X}} f_e(Q - S(\boldsymbol{\Theta}, \mathbf{X}) | \boldsymbol{\Theta}, \mathbf{X}) \, f_{\boldsymbol{\Theta}}(\boldsymbol{\Theta}) f_{\mathbf{X}}(\mathbf{X}) \, d\boldsymbol{\Theta} d\mathbf{X}$$

where $f_Q(Q)$ is the probability density function of Q and $f_e(Q - S(\boldsymbol{\Theta}, \mathbf{X}) | \boldsymbol{\Theta}, \mathbf{X})$ is the conditional probability density function of the model error. It is estimated by using observations or other information. $f_{\boldsymbol{\Theta}}$ and $f_{\mathbf{X}}$ are probability density distributions of input and parameters.

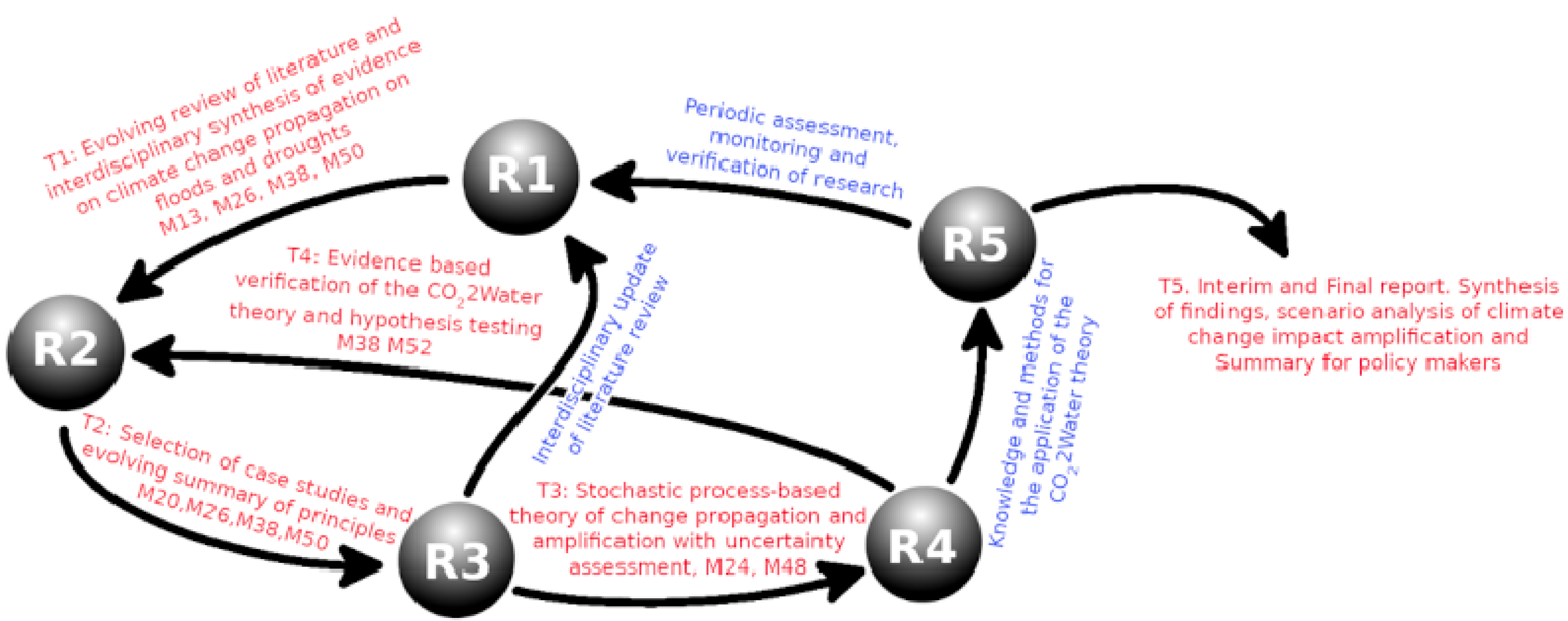
The above equation provides the **marginal probability distribution of the critical state for one system**.
In $CO_2$2Water we will derive the **joint probability distribution** (process based) of the **co-occurrence of critical states** for the triangle of systems, by also deciphering their interaction.

$CO_2$2Water will develop a spatio-temporal representation of the probability of climate change impact amplification.



$CO_2$2Water research tasks

- R1: Periodic interdisciplinary review of the literature on climate change propagation.
- R2: Evidence based conceptualization of amplification in the triangle of systems.
- R3: Development of a unified theory of change propagation along the triangle of systems (climatic, eco-hydrological and socio-economic systems).
- R4: Validation of the proposed framework on selected case studies.
- R5: Synthesis of findings and dissemination.



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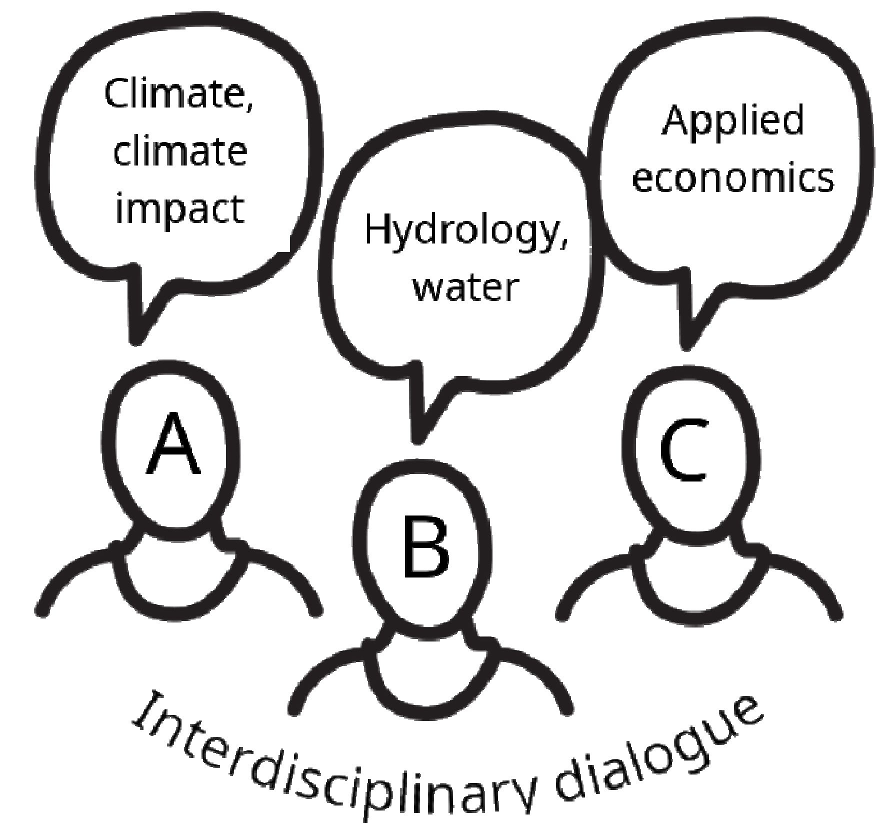
Case Studies

- Floods and droughts in the Emilia-Romagna region;
- Drought in the Po River in 2022;
- Drought in the Urmia Lake region;
- Flood in Germany in 2021;
- Other cases to be identified during the course of the project.

Project interdisciplinary team

Interdiscipinary faculty members at the University of Bologna

- Principal investigator: **Alberto Montanari**, full professor of water engineering, 5 PM/year.
- Staff member: full professor of hydrology and water resources, 1 PM/year.
- Staff member: full professor of geophysics and climate dynamics, 1 PM/year.
- Staff member: full professor of applied economics, 1 PM/year.



Interdisciplinary personnel to be hired with the project's funding

- 3 PhD students (36 PM each);
- 3 post-doctoral researchers with a position of fixed time researchers (36 PM each);
- 6 post-doctoral researchers with a position of temporary research fellow (21 PM each).

Positions to be recruited will be uniformly distributed over the disciplines of (A) climate dynamics and prediction, climate impact, (B) hydrology, water resources and risk assessment, (C) applied economics. Recruitment will be managed according to principles of **equity, diversity and inclusivity**.

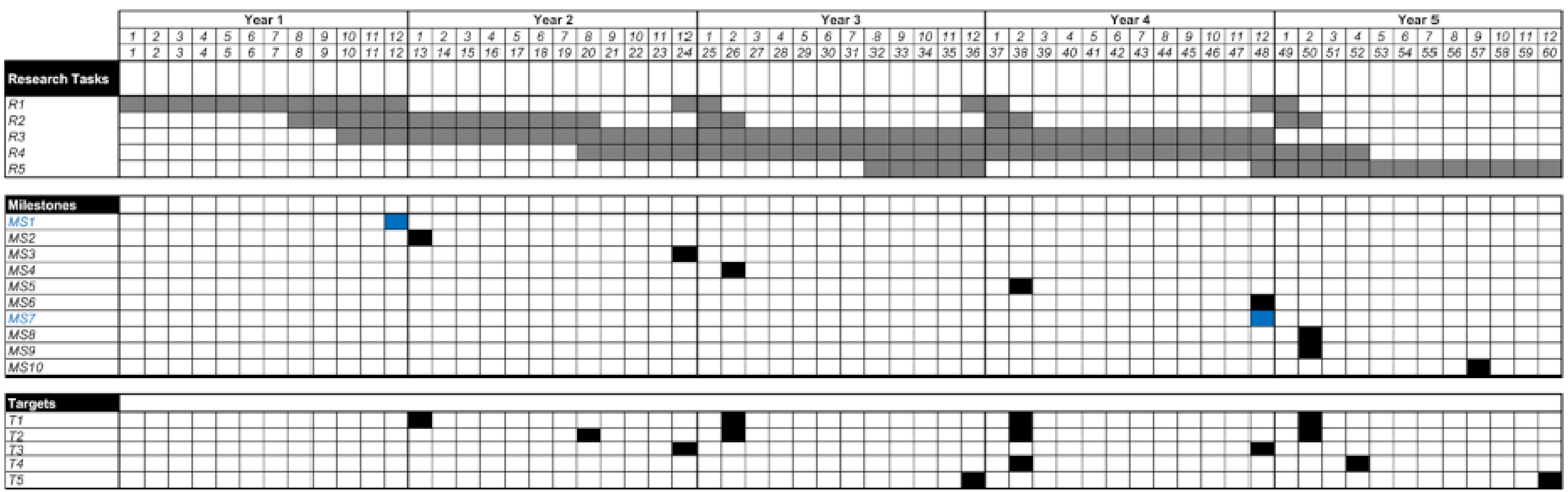
Targets/Milestones

Research Tasks
R1: Periodic interdisciplinary review of the literature on climate change propagation
R2: Evidence based conceptualization of amplification in the triangle of systems
R3: Development of a unified theory of change propagation along the triangle of systems
R4: Validation of the proposed framework on selected case studies
R5: Synthesis of findings and dissemination

Milestones
MS1: Project kick-off, opening of the web site, purchase of hardware, hiring of 6 Postdocs and 3 PhD students completed
MS2: First version of Interdisciplinary review, first selection of case studies and first analysis of principles completed
MS3: First phase of the CO22Water theory completed
MS4: First update of interdisciplinary review, selection of case studies and analysis of principles completed
MS5: Second update of interdisciplinary review, selection of case studies and analysis of principles; first phase hypothesis testing completed
MS6: Second phase of the $CO_2$2Water theory completed
MS7: Hiring of 6 postdoctoral researchers (3 with 18 PM each and 3 with 12 PM each) completed
MS8: Third update of interdisciplinary review, selection of case studies and analysis of principles completed
MS9: Second phase of hypothesis testing completed
MS10: Synthesis of findings and dissemination completed

Targets
T1: Evolving review of literature and interdisciplinary synthesis of evidence on climate change propagation on floods and droughts (3 updates)
T2: Selection of case studies and evolving summary of principles (3 updates).
T3: Stochastic process-based theory of change propagation and amplification with uncertainty assessment (2 phases).
T4: Evidence based verification of the CO22Water theory and hypothesis testing (2 phases)
T5. Interim and final report. Synthesis of findings, scenario analysis of climate change impact amplification and summary for policy makers (2 phases)

Administrative milestones are marked in blue



Duration: 5 years

Total budget: 1.383.631 €

Host institution: University of Bologna

Essential references

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