Climate change and droughts: uncovering the drivers for drought impact amplification

(Or: Impact prediction without accounting for uncertainty is like climbing free solo)

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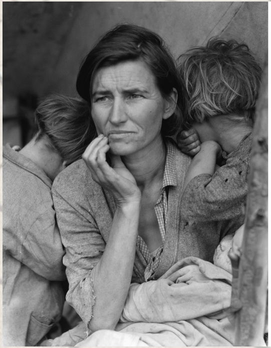
Emphasis is also on a basic element of uncertainty which seems to pervade nature and our knowledge of it. It is expressed by Gödel's incompleteness theorem, by fuzzy logic, by Heisenberg's uncertainty relation, by other random fluctuations and random measuring errors etc, which have fascinated the imagination of mathematicians, physicists, astronomers and geodesists since C.F. Gauss.
H. Moritz in Science, Mind and the Universe

The focus of this talk: droughts with unexpected impact

Dust bowl (US prairies, 1930s, see also https://www.albertomontanari.it/ebookdroughts)

The Dust Bowl was a prolonged drought that affected the prairies of the United States during the 1930s. It is one of the most relevant ecological disasters that ever affected the US, as wind storms hit the dry land and provoked extended dust storms. The causes of the Dust Bowl can be resumed in the following points:

- The Geography of the region, which is uniformly flat or uniformly sloping, with no protection against blowing wind.
- The Homestead Act of 1862, by which an applicant could acquire ownership of government land or the public domain, typically called a homestead. Nearly 10 percent of the total area of the United States was given away free to 1.6 million homesteaders.
- An unusually long wet period during the 1860s and 1870s. The increased amount of rain encouraged people to take advantage from the Homestead Act and move in the region, under the illusion that climate had changed permanently.
- The use of farming methods that opposed reduced resistance to wind erosion. In particular farmers switched to massive crop cultivation with extended use of plowing.
- The occurrence of a long drought after a period of rainfall abundance.



Drought impact is dictated by an intersection of systems: climate, hydrological, socio-economic. The co-occurrence of critical conditions in different systems may determine (abrupt) amplification of impact. Co-occurrence is regulated by potentially random processes.

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Research question

- Major droughts occurring with increasing frequency have raised the concern that changes in climate may lead to a disproportionate and unexpected increase in drought risk.
- Such amplification has the potential of producing drought impacts whose magnitude is underestimated by current models, so that communities are taken by surprise.
- The reasons for the amplifications of impact are currently not completely understood.

Research question: why, where and when changes in climate may lead to unexpected increases in drought risk?

We would like to stimulate a collective effort to make a synthesis of knowledge on climate impact amplification to elaborate a predictive approach to mitigate drought risk.
We propose to rely on the hypothesis that the above amplification is controlled by the co-occurrence of critical patterns and states of climate, water cycle, ecological and societal dynamics, and that the local conditions play a key role.

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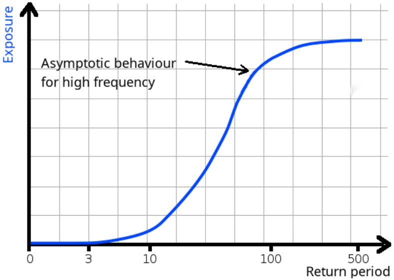
Climate impact amplification

Hydrology is not subjected to chaotic expansion, but hydrological risk is, through exposure that may evolve with a markedly non linear pattern dictated by hazard, vulnerability and socio-economic conditions. The presence of thresholds and marked step changes in risk pattern is one of the causes of an "impossible event" (Montanari, Merz and Bloeschl, 2024), namely, the "surprise" effect (Merz et al., 2015).



"Climate impact amplification" is defined as a step change in the impact of floods and droughts – impossible drought – after a relatively minor change in climate. We assume it is given by the concurrency of critical conditions in the climate, hydrologic and socio-economic systems.

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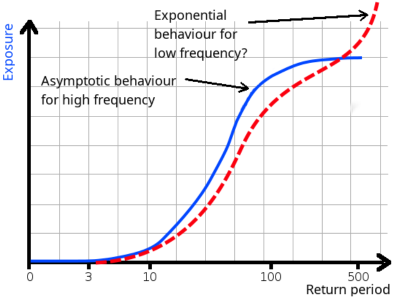

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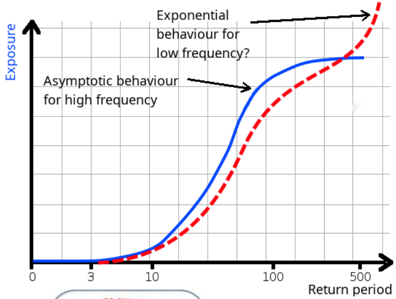

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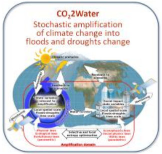
Italian Science Fund
www.albertomontanari.it/co22water



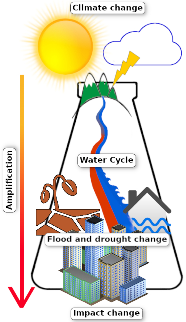
Ministero dell'Università e della Ricerca
FIS
Fondo Italiano per la Scienza

There is often more than one driver for extreme impact

Some of the co-occurrences causing impact amplification are well known. For example:

- Meteorological drought co-occurring with limited diversity of water sources (remember: lack of diversity weakens the resilience of a system setting);
- Hydrological drought co-occurring with poor water quality;
- Surface water drought co-occurring with a groundwater drought;
- Drought co-occurring with a critical public debt of a country and geopolitical tensions.

However, our knowledge of the causes of impact amplification is still fragmented. This is why some droughts call us by surprise.



The idea: To make a global inventory of extreme events (droughts and floods) that took communities by surprise, along with available data for event investigation and modeling.

The purpose: To assemble a global database of critical system interactions that may amplify the impact of extreme hydrological events. No limitation to spatial and temporal scale.

The workflow: A call for interest and proofs of concept (amplification cases) addressed to the community to make a compilation to be presented in a review paper.

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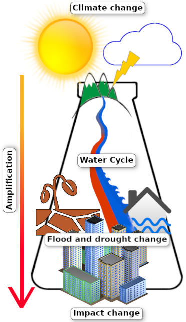

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Database construction

Description of events (droughts and floods) should be provided through storylines, possibly quantitative:

- Narrative description of the event;
- Identified causes;
- Data (climate, seasonality, societal asset, description of any available observation);
- Description and quantitative assessment of impact.

Data collected through a webform available at
www.albertomontanari.it/co22water
Stay tuned! This is an **open** research initiative!

In a first step only preliminary information and metadata will be collected. Quantitative description will take place through direct interaction with the research team.

Any information and data will be made available in the public domain.

First step: expected outcome

Basing on the collected inventory of events we will build a knowledge base of critical co-occurrences, in turn leading to the compilation of a **first checklist**, addressed to:

- Researchers;
- Policy makers;
- Responsible institutions for risk mitigation.

The purpose of the checklist is to provide a scientifically based operational tool to quickly recognize potential drivers for impact and risk amplification.

A second checklist will guide the users to assessing the likelihood of each driver of amplification affecting the considered situation.

When possible, likelihood will be translated into probabilities.

These probabilities will set the basis for the second step, leading to a quantitative and process based estimation of the probability and magnitude of amplification.

Remember: the stochastic approach includes the deterministic solution. The outcome from a deterministic model is certain and therefore occurring with probability 1.

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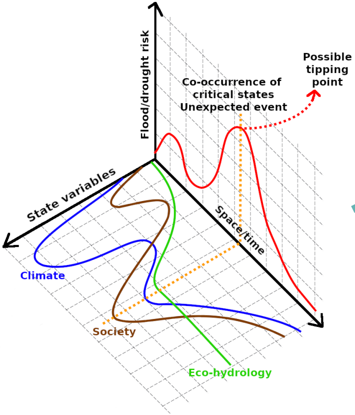
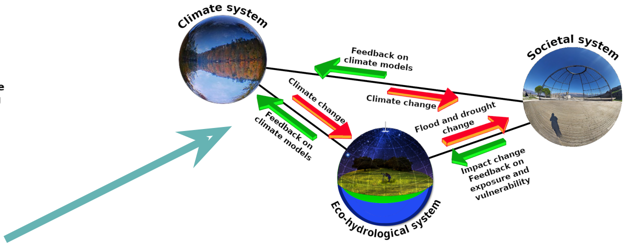
Second step: modeling co-occurrence and impact amplification

Co-occurrences are governed by stochastic development and interactions of climate, hydrologic and socio-economic systems:





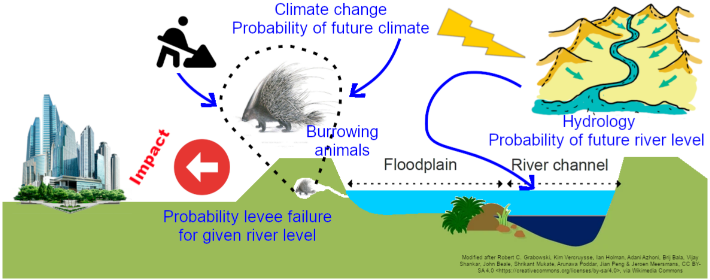
Stochastic systems, stochastic links and associated probabilistic structures are defined basing on physical considerations, elaborated on the collected events, as these extreme surprises are too rare to allow a purely frequentist analysis

Note: define spatial and temporal scale of modeling.

An example of modeling

Co-occurrence of climate change **(climate sytem)**, critical hydrologic conditions **(hydrologic system)**, presence of burrowing animals **(ecologic and societal system)**, exposure **(socio-economic system)**

Spatial scale: local context. **Temporal scale**: annual (maxima of rainfall and river flow). **Probabilities of**: future rainfall, river flow and level, presence of burrowing animals for given river level.



Results: probability of levee failure in one year, return level of a levee failure.
Note: Climate change estimated with climate scenarios (WU). Hydrology estimated through socioeconomic and catchment scenarios (WU). Burrowing animals estimated with surveys, climate scenarios, scenarios of river maintenance (WU). Exposure estimated with socio-economic scenarios (WU). **WU means**: With Uncertainty

Modeling: the essential role of uncertainty

Probabilities of future climate, hydrology and socio-economic state variables imply uncertainty

Climate uncertainty: Estimated with climate scenarios.
Hydrologic uncertainty: Estimated with frequentist or Bayesian techniques (Blue-cat, GLUE, ...).
Other uncertainties: for example burrowing animals. Estimated basing on local information and/or expert knowledge.

- Uncertainty derives from the composition of different contributions to randomness and therefore it is expected to be large.
- Large uncertainty is not a concern: it does not imply a weakness of the prediction.
- The identification of possible scenarios for risk amplification and their likelihood is precisely the target of the analysis.
- The proposed approach allows to attribute uncertainty, identify possible scenarios with related probabilities and support the collection of additional information.

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Take home messages

- **"Open research initiative to get information on climate impact amplification".** Take a picture of the QR code, monitor the call for interest and participation.
- We are looking for **surprise events** whose impact whose unexpected to understand their causes.
- We assume that unexpected impact is given by the **co-occurrence of critical conditions of climate, hydrologic and socio-economic systems**. We want to describe these systems and the above co-occurrence with probabilities.
- Depending on spatial and temporal scale and data availablity, probabilities will be estimated by a **frequentist analysis or through Bayesian inference**.
- First step: **a review paper of unexpected events and their causes at global scale.** Get on board!

2025 EGU Leonardo Conference
Third Bologna Meeting from Science to Engineering

From Science to People:
Expecting the unexpected in flood and drought risk management

Thursday June 19, 2025 - Friday June 20, 2025

A focus on surprise in risk assessment and management
(Website to be activated in January 2025 - Information on www.albertomontanari.it)

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- Surprise in floods and droughts
- Amplification of climate signal
- Hydrological change and non-stationarity

First flyer to come soon!