An approach to modeling interactions between extreme weather events during multi-hazard events

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ABSTRACT

The IPCC AR6 report outlined that global warming can grow the number of multi-hazards worldwide, with particular emphasis on coincident heatwaves and droughts, followed by wildfires; and floods and extreme sea level episodes leading to extensive costal floods (IPCC, 2023). To fully understand and increase preparedness against this kind of events the, a holistic multi-hazard and multi-sectoral perspective is needed (Russo et al., 2023; UNDRR, 2015). Coincident storm surges and extreme rainfall events present significant challenges for flood management as the interaction between both hazards can lead more severe scenarios: Storm surges result in temporary increase of sea level, while pluvial flooding overwhelms urban drainage systems due to excessive runoff. During storm surges, elevated sea levels can intrude into drainage systems of coastal cities through outfall pipes or block gravitational drainage. The backwater may reduce the network's capacity and potentially cause upstream flooding. This combination of factors can lead to more extensive flooding in low-lying coastal areas. However, there is limited knowledge about how to model this phenomenon.

A "one-way" coupling approach is proposed to assess this multi-hazard scenario. This method involves defining abnormal boundary conditions of model components. Outfall boundary conditions representing the extreme sea level retrieved from a hydrostatic storm surge model are used to simulate seawater intrusion into drainage network. Extreme high sea level boundary conditions are applied to account for the marine water overflow. The approach requires accurate topographic surveys of system outfalls and high-resolution digital terrain models, which can be challenging due to limited data availability. The final outputs are flood maps showing water depth and velocity in the affected areas.

Multi-hazard modelling of combined floods requires a previous joint probability assessment of occurrence of the single hazards involved. Copula's refer to a mathematical approach for the coupling/modelling the dependence between two or more random variables and have been used for this purpose as they allow to determine the complex dependency between random environmental variables. Therefore, they allow to evaluate the likelihood of coincident occurrence of multi-hazard events with specific return periods, and thus determine the intensity of the rainfall and the extreme sea level that would affect a region simultaneously. This information is essential to model scenarios of interest to understand the risk posed by these events and model the risk-reduction effect of different adaptation measures. Utilising Copulalib library in Python and inferring relationship between historic data variables based on their respective marginal distributions, synthetic data is generated.

Flood maps in liaison with sectoral impact assessment models allow to quantify the effect on a variety of risk receptors considering exposure information and vulnerability functions such as economic damage curves or vulnerability curves. In addition, the holistic framework considered in ICARIA accounts for the cascading effects that the failure of one system can have on other interconnected services.

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