Rebuttal of Review CC1

Dear authors and colleagues of the scientific community,

Fist, I would like to thank the authors for the valuable response to my comment concerning Part I and I am pleased to add a second comment for Return period of high-dimensional compound events. Part II: Analysis of spatially-variable precipitation.

For this, four questions seems to me interesting to be asked if possible. My first question concerns the RP. It changes in space and time and its occurrence is not necessarily of the same intensity. How can you differentiate short return periods from long-term ones?

In our approach, the RP is addressed using the *Joint Return Period* (JRP) concept, which considers the simultaneous occurrence of extreme events across multiple locations and various temporal scales. The differentiation between short and long return periods is achieved through the analysis of the joint distribution of extreme events in space and time, utilizing multivariate copulas and Kendall's method to evaluate the critical probability level (t). This procedure enables the identification of events with varying frequencies of occurrence, adjusting the results to the spatial and temporal characteristics of the phenomenon.

It is important to highlight that the critical probability level (t) depends on the selected return period. In our study, we used a 100-year return period as a reference, but this threshold can be adapted to other values, whether lower or higher, depending on the specific needs of the analysis. The choice of the return period directly influences the value of t, which in turn defines the critical hypersurface in the multidimensional space. This hypersurface contains the values of the analyzed variable —in our case, precipitation measured across multiple locations— that are associated with the selected *Joint Return Period* (JRP). Events located on this hypersurface meet the conditions established by the defined return period, allowing their identification and analysis within the applied multivariate framework.

My second question, in addition to the hydraulic and hydrological study, is it possible to introduce anthropogenic variables, for example, the existence of dams, sewage networks, treatment plants, which can by incidence or overload amplify the risk of flooding?

We acknowledge the relevance of anthropogenic factors in influencing hydrological processes, particularly in the context of compound events and their potential amplification due to human interventions. While the current study focuses on the statistical modeling of precipitation and its spatial variability, the proposed methodological framework is flexible and allows for the integration of additional variables, such as the presence of dams, sewage networks, and treatment plants, which can significantly alter hydrological responses during compounding events.

The importance of considering such variables has been highlighted in previous studies, notably by Salvadori et al. (2011), who emphasized the necessity of incorporating system-specific characteristics when defining multivariate return periods and identifying critical design events. In their case study of the Ceppo Morelli dam, the authors modeled key hydrological variables—flood peak discharge, flood volume, and the initial water level in the reservoir—using a trivariate copula-based framework. While the study focused primarily on these hydrological variables, it also recognized the role of structural features, such as storage capacity and spillway levels, in influencing flood behavior.

In this approach, anthropogenic variables can be integrated either directly into the multivariate modeling framework or indirectly by modifying boundary conditions that influence the hydrological response. For example, dam regulation policies, operational constraints, and sedimentation effects can alter flow dynamics, while urban infrastructures, such as drainage networks and treatment plants, can affect the timing and magnitude of runoff. Incorporating these variables would require adjusting the dependency structures within the copula framework or redefining the critical hypersurface associated with specific joint return periods to reflect altered system behaviors.

Although this study primarily focuses on hydroclimatological variables, future research could expand the framework to systematically include anthropogenic elements. Such an extension would enhance the capacity to simulate complex hydrological systems and improve the characterization of compound events, especially in highly managed or urbanized watersheds.

My third question concerns the implications of geomorphology and the terrigenous material transported and deposited during the flood. For this, I would like to invite you to read my discussion concerning the Evaluation the Effectiveness Of The Existing Flood Risk Protection Measures Along Wadi Deffa In El-Bayadh City, Algeria By Ben Said M., Hafnaoui M.A., Hachemi A., Madi M., Benmalek A. In this discussion, I highlighted the implications of geomorphology and the sedimentary material transported and then deposited during the flood. These are two related factors that change over time where we can follow the evolution of the morphology of the river and quantify the terrigenous material. Using your approach, can you combine runoff morphology and sediment supply in a flood scenario?

Indeed, fluvial dynamics and sediment transport are fundamental processes that shape river basins and influence the behavior and impacts of compound flood events. The redistribution of terrigenous material during floods alters channel morphology, affects flow patterns, and changes floodplain connectivity, all of which can significantly influence the evolution of future flood events.

While our current study focuses on the statistical modeling of compound precipitation events, the proposed methodological framework—based on multivariate copulas and the identification of critical hypersurfaces—offers the flexibility to incorporate additional variables, such as those related to runoff morphology and sediment transport. This integration could enable the simulation of more comprehensive scenarios that account not only for precipitation magnitude but also for geomorphological processes that affect flood dynamics.

We recognize, however, that incorporating sediment dynamics into a multivariate return period framework presents certain challenges. Key limitations include the scarcity and irregularity of sediment transport data, the complex and often nonlinear relationships between hydrological variables and sediment dynamics, and the difficulty in defining extreme geomorphological events in a way that aligns with hydrological thresholds. Additionally, the dynamic nature of sediment transport and channel morphology, which evolves during flood events, complicates the use of traditional copula models that typically assume static dependencies.

Despite these challenges, the inclusion of geomorphological variables is both feasible and valuable. Future research could explore the use of dynamic copula models or vine copulas to better capture evolving dependencies during flood events. Additionally, coupling the copula-based statistical framework with geomorphological models—such as sediment transport or erosion-deposition models—could provide a more holistic understanding of compound flood events.

Such an integrated approach would offer a more realistic representation of flood scenarios, particularly in regions where sediment dynamics significantly influence flood hazards. It would also enhance the capacity to evaluate the effectiveness of flood risk mitigation measures, especially in sediment-sensitive environments, as highlighted in your discussion on the Evaluation of the Effectiveness of the Existing Flood Risk Protection Measures Along Wadi Deffa in El-Bayadh City, Algeria.

A final question concerns the lithological vulnerability, particularly erosion and the implication of flooding on urban areas. Is it possible to add variables indicating the lithological vulnerability in the modelling, or should the modelling in your approach be limited to hydroclimatological data?

Here attached, my discussion Of Evaluating The Effectiveness Of The Existing Flood Risk Protection Measures Along Wadi Deffa In El-Bayadh City, Algeria By Ben Said M., Hafnaoui M.A., Hachemi A., Madi M., Benmalek A.

While our current approach focuses on hydroclimatological data, the framework can be adapted to include variables such as soil type, rock composition, and erosion susceptibility to better capture the interactions between geology and flood dynamics.

We acknowledge that integrating lithological data presents challenges due to spatial variability and data availability. However, exploring this integration could provide valuable insights, especially in regions where erosion significantly amplifies flood risks.

Future research could focus on combining statistical models with geotechnical and geomorphological analyses to assess how lithological factors influence flood behavior and urban vulnerability. Your reference to the study on Wadi Deffa in El-Bayadh City, Algeria highlights the relevance of this approach and the potential for more comprehensive flood risk assessments.