Dear Hafidha Khebizi,

Thank you very much for your comment and for sharing your interest in our work. We are pleased to know that you find our approach valuable for your research in the Algerian Sahara.

We would like to inform you that we have already published a second part of this study, which is currently under review and available as a preprint, titled *Return period of high-dimensional compound events. Part II: Analysis of spatially-variable precipitation*. You may consult it at the following link: https://hess.copernicus.org/preprints/hess-2024-335/.

In this work, we present a comprehensive framework for modeling compound precipitation events, including a practical application that addresses spatial dependence in precipitation across multiple sites and the estimation of multivariate return periods in five dimensions. We encourage you to review this second part, as it may provide useful insights into the questions you raise. Additionally, we are currently evaluating the methodology in combination with other multivariate approaches and continuous hydrological-hydraulic models, which we hope to share in future publications.

Question 1 and 2

To specifically address the questions, you posed—namely, **(1)** *how to integrate the floods in the province of Valencia into a risk scenario*, and **(2)** *how to incorporate the cold drop into the analysis of multivariate return periods according to our six-step approach*—we have developed a hypothetical case study that examines these issues and offers insights into both inquiries.

The flood event in the province of Valencia in October 2024 can be analyzed using the proposed methodological framework, structured into six key steps. In the ***initial diagnostic*** phase, this event can be classified as a spatially and temporally compound event. The main modulators were the Mediterranean Sea surface temperature and the presence of an isolated cut-off low, known in Spanish as “Depresión Aislada en Niveles Altos” (DANA). The interaction between these factors created the necessary conditions for extraordinary rainfall exceeding 200 mm in 24 hours, thereby amplifying extreme surface runoff. In terms of temporal resolution, sub-daily data are particularly relevant to capture the intensity of the rainfall, while spatially, it is crucial to include both urban areas and the affected river basin in the analysis.

Subsequently, an ***exploratory dependence analysis*** could be conducted using coefficients such as Kendall or Spearman to quantify the relationships among the key variables involved in the event, such as the elevated Mediterranean Sea surface temperature and the influence of the DANA (reflected in parameters like rainfall, wind, and atmospheric pressure). This analysis would, on the one hand, allow for the assessment of dependencies among multiple variables to identify the joint return period of the conditions that triggered the event. On the other hand, it could incorporate the factors driving the flooding, for example by considering precipitation dependencies measured at different locations. This approach would be especially useful for examining how the intensity and spatial distribution of rainfall contributed to the floods in Valencia, providing a more comprehensive understanding of the interactions that led to this extreme event.

The next step would involve ***identifying the most suitable multivariate structure*** to represent the behavior of the variables. To achieve this, it would be crucial to consider metrics such as upper- and lower-tail dependencies, along with other tools that ensure an excellent goodness of fit. This approach guarantees that the selected model accurately captures the relationships between variables, providing a robust and realistic representation of the phenomenon under analysis.

The fourth step would consist of calculating a variety of ***hazard scenarios*** using "AND" and "OR" approaches, complemented by analyses based on "KENDALL" and "KENDALL SURVIVAL" scenarios. These proposed scenarios would offer a more detailed understanding of the interactions among the main variables. Based on this foundation, for instance, one could explore an "AND"-type scenario in which elevated Mediterranean temperatures and the presence of a DANA (represented by multiple variables such as rainfall, wind, and atmospheric pressure) are necessary conditions for generating the compound event. Moreover, these approaches could be integrated into a spatial analysis, estimating the joint return period of rainfall across different locations. This would help identify the multivariate return period of the rainfall produced by the DANA, taking its spatial dependency into account.

Once the compound event and its genesis conditions are defined, it becomes important to distinguish it from its impacts, especially the potential flooding it could cause. To this end, a broader, multidimensional, and multivariable scenario could be evaluated—one that not only includes the initial meteorological variables but also those that capture the hydrological response and the formation of the flood itself, such as peak flow, total accumulated water volume, and event duration. Integrating these approaches with a spatial analysis that estimates the joint return period of rainfall at various locations not only provides information about the multivariate frequency of the conditions that triggered the event, but also helps anticipate how the spatial distribution of water contributes to the formation and extent of flooding.

Finally, by applying the framework proposed in Figure 4, we could ***define the critical layer*** for each of the proposed scenarios. From this critical layer, it would be possible to identify the compound event with the greatest probability density or to conduct a comprehensive analysis of joint events for the studied return period. For the scenario that considers elevated Mediterranean temperatures and the presence of a DANA, we could examine the period or frequency at which such a large-scale combined event might occur. If we consider the spatial dependency of rainfall, it would be possible to extract spatial rainfall events associated with the event's return period and, using rainfall-runoff models, simulate the basin's hydrological response and the resultant flooding. Finally, by considering a multidimensional and multivariable scenario, we could evaluate the joint behavior of all the described variables to assess compound events such as those that occurred on October 29 and 30 in terms of risk.

This framework would provide a broader range of potential events, useful not only for establishing response and mitigation protocols but also for guiding the redesign of hydraulic infrastructure and the development of early warning systems to address similar scenarios in the future. This comprehensive approach combines scientific understanding of the phenomenon with practical applications, ultimately improving resilience against extreme hydrometeorological risks.

Question 3

Regarding your third question—how to select the variables and temporal/spatial scales to define compound extremes and present a risk scenario for a cold drop (DANA)—it is important to consider both meteorological and hydrological factors, as well as the appropriate resolution and coverage in time and space. In the following explanation, we outline the key considerations that ensure a comprehensive and reliable assessment of such extreme events.

To define compound extremes associated with the spatial evolution of a "cold drop"—a colloquial term historically used in Spain to describe episodes of intense rainfall, but which today is generally associated with the meteorological phenomenon known as an isolated cut-off low (DANA)—it is necessary to draw on variables that capture both its meteorological and hydrological characteristics. Meteorologically, it is common to include factors such as precipitation intensity and duration, Mediterranean Sea surface temperature, atmospheric pressure, as well as wind direction and speed; all of these influence the formation and persistence of the phenomenon. From a hydrological perspective, variables such as peak river discharge, total accumulated rainfall volume, surface runoff, and soil drainage capacity are fundamental for understanding the event's territorial impact and the potential flood risk.

The selection of temporal and spatial scales must be adapted to the dynamics of the DANA and the objectives of the risk analysis. Temporally, sub-daily resolutions (e.g., hourly) allow for capturing the event's peak intensity and rapid evolution, which is essential for identifying precipitation peaks or critical moments in flood formation. At the same time, supplementing these data with daily or weekly information makes it possible to assess longer-term trends and recurrences over extended return periods. Furthermore, analyzing long-term time series encompassing multiple DANA events over several decades can provide a more robust statistical foundation, improving the understanding of long-term variability and the reliability of return-period estimates across different temporal scales.

From a spatial standpoint, it is important to consider various levels of detail: local scales to understand immediate hydrological responses in urban areas or small watersheds, and regional scales to evaluate the extent, displacement, and interaction of the DANA with surrounding atmospheric conditions, as well as its impact on multiple river basins.

In short, carefully selecting variables, as well as temporal and spatial scales, contributes to more accurate risk scenarios. These scenarios integrate not only the identification of the extreme event and its atmospheric origin, but also the spatial distribution of its effects, the temporal dimension of its evolution, and the inclusion of extensive historical records. Altogether, this provides an effective tool for designing mitigation strategies and improving risk management in the face of extreme hydrometeorological phenomena.

Please, do not hesitate to contact us if you need any additional clarification

Best regards