8th IAHR EUROPE CONGRESS
LISBON - PORTUGAL
4-7 JUNE 2024

Multivariate Models for Flood Prediction: A Glimpse into the Future

Diego URREA Méndez[1], Dina GOMEZ RAVE[1], Salvador NAVAS[1], Manuel DEL JESUS[1]

[1] IHCantabria - Instituto de Hidráulica Ambiental de la Universidad de Cantabria, Santander, Spain
dum834@alumnos.unican.es
dinavanesa.gomez@unican.es
Salvador.navas@unican.es
manuel.deljesus@unican.es

ABSTRACT

The integration of multivariate analysis into the study of compound hydrological events reveals its potential to better understand the complexity of extreme events and generate likely scenarios. Our methodology, divided into two parts, focuses on comparing different multivariate models that capture all the uncertainty and implementing machine learning techniques that enable the simulation of floods considering multivariate scenarios. The analysis underscores the importance of carefully selecting the appropriate multivariate model, as Gaussian models underestimated extreme events, while extreme vine copula models provided more accurate results. This approach contributes to the understanding and effective management of compound hydrological events, benefiting critical infrastructure planning and flood prediction, and opening new perspectives in climate risk management.

1. Introduction

As we delve further into the analysis of compound hydrological events, it has become evident that the integration of multivariate analyses, which consider the interaction among a greater number of variables, can optimally capture, and characterize uncertainty compared to conventional analyses. Multivariate approaches, especially when the study variables are correlated, not only provide a deeper understanding of extreme event complexity but also enable the generation of a wide range of probable scenarios. Studies such as those by Salvadori et al. (2011) and Tosunoglu et al. (2020) have demonstrated the applicability of multivariate models in the study of compound events.

In multivariate analysis of the frequency of compound extreme events, it is essential to consider the dependency structure in the tails of the variables of interest. If the selected copula fails to accurately capture this extreme dependence, the estimation of extreme values can be significantly affected by uncertainty (Hangshing et al., 2018). Therefore, it is crucial to conduct a comprehensive evaluation of the copula model fit to the data, including tail dependency (Serinaldi et al., 2015). This process guides us in selecting the most suitable copula family to model these extreme compound events.

Modeling compound events using multivariate approaches can provide a more precise measure of the return period, benefiting critical infrastructure design, flood prediction, risk management, and more. However, performing simulations considering many multivariate scenarios requires substantial computational resources. In recent years, hybrid downscaling techniques (as demonstrated in previous works such as Camus et al., 2011; Lin et al., 2016; Navas et al., 2017) have been developed to mitigate this challenge by reducing computational time. These techniques rely on machine learning methods that simplify conventional computationally expensive models. Despite advancements in hybrid downscaling, further research and development are still needed in this area.

2. Methodology

We propose a two-part methodology: (I) This phase focuses on the comparison of various multivariate models that capture all the uncertainty. It involves researching different models and copula structures. The main objective here is to assess the goodness of fit and tail dependence of these copula models. Additionally, it integrates synthetic data generation with the selection of representative events through the analysis of design storms. This strategy has the potential to further simplify the number of scenarios that need to be modeled using hybrid downscaling techniques. The inclusion and selection of representative events enable the study of the joint behavior of multiple variables, even surpassing the common dimensionality limitations in many studies. A concrete example would be evaluating the behavior of events measured at multiple rain gauges within a watershed to adequately capture spatial structure.

(II) In this second stage, we create a more robust methodology that includes the study, evaluation, and implementation of multiple statistical and machine learning techniques. The focus is on using the results obtained in the first stage to develop flood models. These models allow us to compare multivariate models in terms of their performance in flood prediction and other related impacts.

3. Results

The results of this research offer valuable insights into the significance of selecting different approaches in the hydrological analysis of precipitation-linked design events. Our findings indicate that using a multivariate approach leads to significantly more accurate precipitation estimations compared to the univariate approach. The analysis underscores the importance of carefully choosing the appropriate multivariate model, as Gaussian models underestimated extreme events, while extreme vine copula models provided more precise results.

The underestimation by Gaussian models also manifested in flood predictions. We observed that floods generated by extreme vine copula models exceeded the predictions of Gaussian copula models significantly. This discovery suggests that tail-dependent vine copula structures outperform Gaussian structures in modeling extreme events. This development has a positive impact on the field of engineering, reducing uncertainty in engineering design processes and providing a more precise approximation of climate-related impacts. Additionally, the proposed methods have the potential to offer crucial climatic information applicable to planning, infrastructure design, adaptation proposals, and managerial decision-making, ultimately leading to more effective territorial management.

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