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Causal Relationships in Sequential Drought–Flood Events Across Multiple Catchments

Hossein Abbasizadeh, Oldrich Rakovec, and Petr Maca
Czech University of life sciences Prague, Faculty of Environmental Sciences, Water Resources and Environmental Modelling, Prague, Czechia (abbasizadeh@fzp.czu.cz)

Understanding hydrological sequential extremes is a major contemporary challenge, particularly when droughts and floods increasingly occur in close succession. Recent studies have primarily focused on identifying consecutive and compound drought-flood events and their characteristics; however, the causal mechanisms linking these events remain largely unexplored. In this study, we investigate the causal relationships between hydrological droughts and subsequent floods, as well as their antecedent conditions, at the catchment scale. Building on established approaches for identifying drought–flood events, we extend the analysis by using the PC (Peter–Clark) algorithm to uncover causal dependencies between the characteristics of pre-event, streamflow drought, transition, and flood phases (Abbasizadeh et. al., 2025). To apply causal discovery, we first identify drought–flood events from 30 years of observed streamflow records across a large sample of catchments in the United States (Rakovec et. al., 2019). We characterize streamflow droughts by their duration and deficit, and floods by their volume, peak discharge, and duration. Using flux variables, namely precipitation, actual and potential evapotranspiration, and baseflow, as well as the state variable terrestrial water storage, we then identify anomalies during the pre-event, drought, and transition phases that lead to flooding. Actual and potential evapotranspiration, baseflow, and terrestrial water storage are derived from the mesoscale Hydrologic Model (mHM) simulation. The catchment characteristics are also included as the potential time-independent drivers of drought-flood events during different phases. Then the causal discovery method is applied to the pool of drought-flood events derived from all catchments to identify the causal links and their strength between variables. Our results reveal distinct causal links across the different phases, clarifying the conditions under which droughts either amplify or suppress the flood characteristics. These findings advance the understanding of compound and consecutive hydrological drought-flood extremes.

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