



Quantifying compound hydro-climatological extremes in coastal and deltaic regions

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Coastal and deltaic regions are increasingly exposed to compound hydro-climatological extremes, particularly the interaction of coastal and riverine flooding with extreme temperature events such as heatwaves and heat stress. These hazards interact across spatial and temporal scales, generating complex multi-hazard events that challenge conventional single-hazard risk-reduction and adaptation strategies. Despite growing attention in recent years, quantifying such multi-hazard interactions remains challenging due to limited long-term extreme-event data and incomplete understanding of the physical processes linking different hazards. This study addresses these gaps by quantifying and characterising compound and consecutive flood-temperature extremes across five coastal or deltaic regions in Bangladesh, India, Ghana, the United Kingdom, and the Netherlands. These case study regions are subject to multiple hydro-climatological extreme events. Long-term observational time series of tidal level, river water level, air temperature, and relative humidity were analysed for each case study. Coastal and riverine flood events were identified using the 90th percentile of tidal and river water levels, respectively, while extreme heat and heat stress events were defined using the 95th percentile of air temperature and wet bulb globe temperature. Interactions among hazards were examined using Kendall's tau correlation to assess dependency structures, cross-correlation functions to identify precursor relationships and optimal time lags, and a non-parametric copula framework to estimate joint probabilities of hazards occurring in close succession. Results reveal distinct multi-hazard profiles for each region, including characteristic time lags between interacting hazards on an annual timescale. Coastal and riverine flooding exhibited strong multivariate dependence in most of the deltaic regions studied, with optimal time lags generally shorter than three days, indicating a high susceptibility to compound flooding. Similarly, all regions showed strong co-occurrence of extreme heat and heat stress events. Notably, heterogeneous temporally compounding events were observed between Global North and Global South regions. Temporally

compounding events involving mixed combinations of flooding and temperature extremes (e.g., river flooding followed by extreme heat or coastal flooding followed by heat stress) were evident in coastal Bangladesh, whereas the United Kingdom and the Netherlands were primarily affected by compound flooding and compound heat events separately. The findings of this study advance the understanding of complex multi-hazard dynamics in vulnerable coastal and deltaic environments and provides evidence to support climate-resilient and adaptive management strategies.