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Exploring flooding mechanisms and their trends in Europe through explainable AI

Shijie Jiang[1], Yi Zheng[2], and Jakob Zscheischler[1]
[1]Department of Computational Hydrosystems, Helmholtz Centre for Environmental Research, Leipzig, Germany
[2]School of Environmental Science and Engineering, Southern University of Science and Technology, Shenzhen, China

Understanding the mechanisms causing river flooding and their trends is important to interpret past flood changes and make better predictions of future flood conditions. However, there is still a lack of quantitative assessment of trends in flooding mechanisms based on observations. Recent years have witnessed the increasing prevalence of machine learning in hydrological modeling and its predictive power has been demonstrated in numerous studies. Machine learning makes hydrological predictions by recognizing generalizable relationships between inputs and outputs, which, if properly interpreted, may provide us further scientific insights into hydrological processes. In this study, we propose a new method using interpretive machine learning to identify flooding mechanisms based on the predictive relationship between precipitation and temperature and flow peaks. Applying this method to more than a thousand catchments in Europe reveals three primary input-output patterns within flow predictions, which can be associated with three catchment-wide flooding mechanisms: extreme precipitation, soil moisture excess, and snowmelt. The results indicate that approximately one-third of the studied catchments are controlled by a combination of the above mechanisms, while others are mostly dominated by one single mechanism. Although no significant shifts from one dominant mechanism to another are observed for the catchments over the past seven decades overall, some catchments with single mechanisms have become dominated by mixed mechanisms and vice versa. In particular, snowmelt-induced floods have decreased significantly in general, whereas rainfall has become more dominant in causing floods, and their effects on flooding seasonality and magnitude are crucial. Overall, this study provides a new perspective for understanding climatic extremes and demonstrates the prospect of artificial intelligence(AI)-assisted scientific discovery in the future.