EGU24-9639, updated on 22 Mar 2025
https://doi.org/10.5194/egusphere-egu24-9639
EGU General Assembly 2024

Interpretable Machine Learning to Uncover Key Compound Drivers of Hydrological Droughts

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Hydrological drought (negative streamflow anomalies) can have significant societal and ecosystem impacts, and understanding its drivers is crucial for interpreting past and present droughts, as well as assessing future drought risk. However, despite recent research advancements, a comprehensive multivariate perspective on the drivers of hydrological drought remains elusive, particularly in the context of global warming, where distributional changes in drivers could result in an increased frequency of complex, compound events. In order to address this, quantifying the contribution of each driver is necessary. In our research, we devise an interpretable machine learning framework that can explain which hydrometeorological variables contribute to streamflow predictions. This is done by encoding a conceptual hydrological model into a neural network architecture, creating a physics-encoded hybrid model that allows us to maintain physical consistency and ensure a more causal understanding. We apply our framework to numerous North American basins across spatiotemporal scales and quantify the contribution of each potential driver to identified streamflow deficit events. We also investigate the mechanisms associated with compound drivers and assess if drought drivers are becoming increasingly complex due to climate change based on the defined compoundness index. Overall, our framework has managed to capture the contribution of diverse drought drivers to events across different hydroclimatological regimes. The results demonstrate the effectiveness of our novel method in improving hydrological drought process understanding, especially the mechanisms and severity of droughts associated with compound drivers, thereby facilitating increased preparedness for future drought risks.