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Temporal Information Partitioning Networks (TIPNets): Characterizing emergent behavior in complex ecohydrologic systems

Allison Goodwell and Praveen Kumar
University of Illinois, Civil and Environmental Engineering, Urbana, Illinois, United States (kumar1@illinois.edu)

Within an ecosystem, components of the atmosphere, vegetation, and the root-soil system participate in forcing and feedback reactions at varying time scales and intensities. These interactions constitute a complex network that exhibits behavioral shifts due to perturbations ranging from weather events to long-term drought or land use change. However, it is challenging to characterize this shifting network due to multiple drivers, non-linear interactions, and synchronization due to feedback. To overcome these issues, we implement a process network approach where eco-hydrologic time-series variables are nodes and information measures are links. We introduce a Temporal Information Partition Network (TIPNet) framework in which multivariate lagged mutual information between source and target nodes is decomposed into synergistic, redundant, and unique components, each of which reveals different aspects of interactions within the network. We use methods to compute information measures given as few as 200 data points to construct TIPNets based on 1-minute weather station data (radiation Rg, air temperature Ta, wind speed WS, relative humidity RH, precipitation PPT, and leaf wetness LWet) from Central Illinois during the growing season of 2015. We assess temporal shifts in network behavior for various weather conditions and over the growing season. We find that wet time periods are associated with complex and synergistic network structures compared to dry conditions, and that seasonal network patterns reveal responses to vegetation growth and rainfall trends. This framework is applicable to study a broad range of complex systems composed of multiple interacting components, and may aid process understanding, model improvement, and resilience and vulnerability assessments.