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Event-type-based Multi-dimensional Diagnostics of Process Limitations in Hydrological Models

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Shifts in generation processes of streamflow events driven by advancing climate change are raising concerns about the adaptability of conceptual hydrological models to changing hydrological systems. Using 30-year streamflow data across 395 German catchments, we evaluate the performance of a conceptual rainfall-runoff model for three distinct streamflow event types: events associated with snow and icy conditions (Snow-or-Ice), rainfall on dry soils (Rain-on-Dry), or wet soils (Rain-on-Wet). We focus on a two-dimensional evaluation of the timing and magnitude of streamflow events using the Series-Distance approach (Seibert et al., 2016) while also diagnosing the impact of inherent process limitations on model performance using random forest. The results reveal that the modelled streamflow consistently exhibits time delays and underestimations of magnitude for all types of events. Specifically, the Rain-on-Dry are associated with the most considerable delays, while underestimation of streamflow is the largest for Snow-or-Ice events. Given the statistically significant increasing trends in the occurrence of Rain-on-Dry events across 78.8% of catchments (Mann-Kendall test, $p < 0.05$), it can be assumed that the timing errors might further deteriorate in the future, compromising the reliability of the model-based early-warning systems for future flood events. Additionally, the errors vary across different hydrograph components (rising limbs, peaks, and recessions) for each type of streamflow event. Peaks are the most underestimated component in all events. Further diagnostics of the links between errors and drivers identifies the pre-event errors are the most important factors of timing and magnitude errors during the events. The process limitation in the model (e.g., groundwater recharge and fast runoff process) and properties of the events themselves (e.g., duration and peak discharge of events) cause the error heterogeneity among the events and exacerbate the errors in peaks of the events. Therefore, our study highlights the critical need for further improvement of process representation in hydrological models and more accurate simulation of pre-event conditions in order to address emerging challenges posed by changing hydrological systems.

Seibert, S. P., Ehret, U., & Zehe, E. (2016). Disentangling timing and amplitude errors in streamflow simulations. *Hydrology and Earth System Sciences*, *20*(9), 3745-3763.