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Toward Optimal Rainfall – Hydrologic QPE Correction in Headwater Basins

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Large errors in Quantitative Precipitation Estimates (QPE) tied to remote-sensing retrieval algorithms remain a challenge especially in complex terrain with fast hydrologic response. We propose a new framework to derive dynamic hydrologic corrections of rainfall in headwater basins that constrains water budget closure at a desired time-scale and distributes transient rainfall corrections along runoff trajectories by Lagrangian backtracking constrained by realistic time-of-travel distributions. Downscaled QPE products (250 m resolution) are applied first as input to a distributed hydrologic model to predict runoff trajectories and the event hydrograph at the basin's outlet. Second, time-varying rainfall corrections are derived from the residuals between predicted and observed discharge at the outlet. Finally, the corrections are spatially distributed following the runoff trajectories backward (i.e. trajectories are used as streaklines originating at the basin's outlet). Because nonlinear interactions between rainfall, runoff and storage are transient, the corrections are applied recursively until the shape and volume of the predicted hydrograph are stable. The framework is applied to ground-based (e.g. Stage IV) and satellite-based remote-sensing QPE (e.g. IMERG) associated with the 49 largest floods 2008-2018 in the Southern Appalachian Mountains, USA. The results show improvements in hydrograph prediction efficiency skill at 15min timescale from -0.5 to 0.6 on average and up to 0.9 for warm season events, bounding event runoff volume errors with a mean of 3%, and reducing time to peak errors by half an hour on average. Corrected QPE exhibits nearly perfect correlation and no bias at high elevation gauge locations. Cumulative uncertainty in the water budget closure at event scale is less than the uncertainty in streamflow measurements. Error attribution shows strong organization of QPE corrections according to seasonal weather and rainfall regime, thus providing a path to generalization to ungauged mountain basins.