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Simulations of Precipitation Fields Using Stochastic Gaussian Process and Deep Learning in Urban Areas

Tinghui Li[1,2], Shuiqing Yin[1], and Nadav Peleg[2]
[1]State Key Laboratory of Earth Surface Processes and Resource Ecology, Faculty of Geographical Science, Beijing Normal University, Beijing, China
[2]Institute of Earth Surface Dynamics, University of Lausanne, Lausanne, Switzerland

Extreme precipitation events can lead to urban flooding, resulting in significant casualties and economic losses, especially in highly urbanized regions. Precipitation fields exhibit pronounced spatiotemporal heterogeneity, influenced by factors such as atmospheric circulation patterns, topography, and urbanization. This complexity brings great challenges when simulating precipitation fields but recent advancements in remote sensing technology have facilitated the analysis of high-resolution precipitation fields that can be used to parameterize such models. In this study, we analyzed the spatial patterns of precipitation fields using gridded precipitation data from the CMPAS (China Multisource Precipitation Analysis System) product from 2015 to 2020, which offers a spatial resolution of 0.01° × 0.01° and a temporal resolution of one hour. Using Beijing as a case study, we analyze frequency and duration, the temporal autocorrelation, spatial correlation, and variability of the precipitation fields. Building on these analyses, we conducted stochastic simulations using a spatiotemporal Gaussian field process and deep learning methods. Specifically, we employed the AWE-GEN-2d weather generator and deep generative diffusion model to simulate precipitation fields. The results indicate that AWE-GEN-2d effectively reproduces the evolution process of storm events, while the diffusion model excels in capturing detailed spatial patterns. These findings highlight the complementary strengths of the two methods and provide valuable insights for improving precipitation modeling, flood risk management, and climate resilience planning.