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Explicit urban canopy and landscape parameterisations in a high spatial and temporal resolution hydrometeorological cascade

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Flash floods are one of the greatest and costliest natural hazards but remain a simulation challenge due to highly non-linear processes that take place, such as saturation excess as function of hydraulic conductivity and moisture deficit that occur over small spatial and temporal scales. The appropriate implementation of numerical models to assimilate high accurate input data is crucial to identify and characterise these short-lived events reliably. To address this challenge, the present work proposes a hydro-meteorological cascade where meso-scale atmospheric conditions generate dynamically-downscaled rainfall for hydrological modelling at catchment scale. This case study focuses on the June 2012 flash flood in the city of Newcastle, United Kingdom, where already saturated soils and significantly higher than normal river levels contributed to flash flooding just two hours after the arrival of severe thunderstorms. Although the event was not historically unique, it resulted in more than 1200 flooded homes and nearly £ million of direct damage to road network.

Rainfall scenarios were obtained using the Weather and Research Forecasting (WRF) model. This meso-scale, non-hydrostatic meteorological tool allows the explicit treatment of convection within its multiple nesting capabilities. Although the model includes urban canopy (UC) parameterisations, they are mostly applied to analyse changes in temperature, wind speed profiles and air quality so their influence in storm cells origin and evolution is often overlooked. In the present study, three UC schemes and the most extensively used microphysics and cumulus parameterisations are implemented in a downscaling modelling framework to analyse their impact on intense, localised rainfall processes. Ten scenarios were evaluated using three different thresholds and six score metrics to assess if prediction skill increases with rainfall intensity, and if increasing complexity in urban processes reduces model errors. Results show that the need for a comprehensive characterisation of evaporation rates due to urban heat islands is determined by the presence of heat, moisture and momentum vertical fluxes, and that the choice of UC scheme has a direct impact on model efficiency.

The WRF outputs were then used as inputs for a flexible and computationally efficient hydrological model, DECIPHeR, that enables incorporating heterogenous landscapes and different model parameterisations and structures to account for the spatial variability of urban hydrological processes. High spatial-resolution (25 m) land cover information was used to discretise the catchment in urban and non-urban areas which were assigned different parameter sets. The Generalised Likelihood Uncertainty Estimation was used for model calibration and propagation of uncertainty. Estimated parameter ranges exhibit the impervious behaviour of the urban land cover (for example, the reduced storage capacity compared to non-urban areas) and demonstrates the model capability to capture the rapid response of the urban catchment. Moreover, simulated flows suggest a strong impact of the choice of meteorological physics schemes, showing how uncertainties propagate at different spatial and temporal scales.