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# A new fully-coupled atmospheric-hydrological model for urban areas: development and testing

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Urban areas have distinct features (e.g. impervious surfaces) which modify the energy-water balance at the upper subsurface, lower atmosphere, and over the land surface. Moreover, the atmosphere and groundwater are strongly coupled in places with shallow groundwater. To improve the understanding of urban atmospheric-hydrological processes, their interconnections, and their impacts on other environmental processes, a new fully-coupled urban atmosphere-surface-subsurface hydrometeorological model was developed. The new model brings together WRF-PUCM (Princeton Urban Canopy Model) with ParFlow (a 3D variably saturated groundwater model with an integrated 2D overland flow component) to build WRF-PUCM-PF. The new model and the original non-coupled WRF-PUCM were both applied to a small watershed (10.64 km2) in a heavily urbanized area in the Baltimore metropolitan region as a demonstration test case. To capture atmospheric-hydrological processes at scales closer to urban heterogeneous land cover, models were run at a 90-m horizontal resolution using the LES mode in WRF. The analysis period after the two models were spun up to an identical initial condition spanned 96 hours from July 19 to July 23, 2008. The period was selected as it started with a drydown period for 40 hours followed by several intense rain events. This period allowed evaluation of both models' responses to dry-down and rain events. First the models were run with homogeneous similar hydrogelogic input to isolate the effect of terrestrial hydrology implementations in each model. In response to rain events, the homogeneous WRF-PUCM model output gained and retained a 40% greater amount of soil moisture (area-averaged) compared to the homogeneous WRF-PUCM-PF case. WRF-PUCM performed poorly in lateral distribution of water due to its 1D implementation of subsurface hydrology and lack of overland flow parameterization. The spatial distribution of soil moisture at the end of the simulation in a homogeneous WRF-PUCM model looked similar to the cumulative spatial distribution rain at the end of the simulation with no indication of surface topography impact on soil moisture distribution. On the other hand, lateral movement of water in WRF-PUCM-PF resulted in a more realistic distribution of soil moisture following topography. To further analyze the impact of urban areas, results of WRF-PUCM-PF simulations incorporating heterogeneous subsurface hydrogeology were compared with WRF-PUCM with its 2D implementation of hydrogeology units for the region. The heterogeneous WRF-PUCM model generated a 10-fold greater area-averaged soil moisture increase compared to the heterogeneous WRF-PUCM-PF case. Influenced by lateral hydrology and impervious surfaces, the heterogeneous WRF-PUCM-PF model output, generated lower latent heat flux, resulting in half of the domain

having higher land surface temperatures (2-10 °C), compared to the heterogeneous WRF-PUCM model. Overall, the new model provides a tool that can enhance simulation of urban areas by combining ParFlow's representation of terrestrial hydrology, PUCM's improved representation of the urban heterogeneous energy and water balance, and incorporation of higher-resolution urban heterogeneous microclimatic variations.