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A one-dimensional urban flow model with an Eddy-diffusivity Mass-flux (EDMF) scheme and refined turbulent transport (MLUCM v3.0)

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In recent years, urban canopy models (UCMs) have been used as fully coupled components of mesoscale atmospheric models as well as offline tools to estimate temperature and surface fluxes using atmospheric forcings. Examples include multi-layer urban canopy models (MLUCMs), where the vertical variability of turbulent fluxes is calculated by solving prognostic momentum and turbulent kinetic energy (TKE, k) equations using length scale (l) and drag parameterizations. These parameterizations are based on the well-established 1.5-order $k-l$ turbulence closure theory and are often informed by microscale fluid dynamics simulations. However, this approach can include simplifications such as the assumption of the same diffusion coefficient for momentum, TKE, and scalars. In addition, the dispersive stresses arising from spatially-averaged flow properties have been parameterized together with the turbulent fluxes while being controlled by different mechanisms. Both of these assumptions impact the quantification of turbulent exchange of flow properties and subsequent air temperature prediction in urban canopies. To assess these assumptions and improve corresponding parameterization, we conducted 49 large-eddy simulations (LES) for idealized urban arrays, encompassing variable building height distributions and a comprehensive range of urban densities ($\lambda_p\in[0.0625,0.64]$) seen in global cities. We find that the efficiency of turbulent transport (numerically described via diffusion coefficients) is similar for scalars and momentum but 3.5 times higher for TKE. Additionally, the parameterization of the dispersive momentum flux using the $k-l$ closure was a source of error, while scaling with the pressure gradient and urban morphological parameters appears more appropriate. In response to these findings, we propose two changes to MLUCM v2.0: (a) separate characterization for turbulent diffusion coefficient for momentum and TKE; and (b) introduction of an explicit physics-based "mass flux" term to represent the non-Gaussian component of the dispersive momentum transport as an amendment to the existing "eddy diffusivity" framework. The updated one-dimensional model, after being tuned for building height variability, is further compared against the original LES results and demonstrates improved performance in predicting vertical turbulent exchange in urban canopies.