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On the Pollutant Plume Dispersion in the Urban Canopy Layer over 2D Idealized Street Canyons: A Large-Eddy Simulation Approach

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Anthropogenic emissions are the major sources of air pollutants in urban areas. To improve the air quality in dense and mega cities, a simple but reliable prediction method is necessary. In the last five decades, the Gaussian pollutant plume model has been widely used for the estimation of air pollutant distribution in the atmospheric boundary layer (ABL) in an operational manner. Whereas, it was originally designed for rural areas with rather open and flat terrain. The recirculating flows below the urban canopy layer substantially modify the near-ground urban wind environment and so does the pollutant distribution. Though the plume height and dispersion are often adjusted empirically, the accuracy of applying the Gaussian pollutant plume model in urban areas, of which the bottom of the flow domain consists of numerous inhomogeneous buildings, is unclear.

To elucidate the flow and pollutant transport, as well as to demystify the uncertainty of employing the Gaussian pollutant plume model over urban roughness, this study was performed to examine how the Gaussian-shape pollutant plume in the urban canopy layer is modified by the idealized two-dimensional (2D) street canyons at the bottom of the ABL. The specific objective is to develop a parameterization so that the geometric effects of urban morphology on the operational pollutant plume dispersion models could be taken into account. Because atmospheric turbulence is the major means of pollutant removal from street canyons to the ABL, the large-eddy simulation (LES) was adopted to calculate explicitly the flows and pollutant transport in the urban canopy layer. The subgrid-scale (SGS) turbulent kinetic energy (TKE) conservation was used to model the SGS processes in the incompressible, isothermal conditions. The computational domain consists of 12 identical idealized street canyons of unity aspect ratio which were placed evenly in the streamwise direction. Periodic boundary conditions (BCs) for the flow were applied in the horizontal and the spanwise directions. The prevalent wind was driven by a background pressure gradient in the roughness sublayer only, no background force was prescribed inside the street canyons. While the periodic BC of pollutant was used in the spanwise direction, zero pollutant and an open BC were applied, respectively, at the inflow and outflow of the streamwise extent to avoid pollutant being reflected back into the computational domain. The ground of the first street canyon was assigned as the pollutant source on which a BC of constant pollutant concentration was prescribed.

The LES results showed that, in the neutrally stratified ABL, the pollutant distribution in the urban canopy layer resembled the Gaussian plume shape in general even recirculating flows were observed in the street canyons. The roof-level horizontal profile of pollutant concentration in the streamwise direction showed that the sharp drop on the leeward side of each street canyon was likely caused by the air and pollutant entrainments. On the windward side of each street canyon, a mild increase in pollutant concentration was observed that did not follow the Gaussian plume closely. Those deviations extended to a certain height over the roof level of the street canyons. It in turn suggests that the Gaussian pollutant plume model should be applied with caution in the urban canopy layer in the vicinity over urban roughness. To further analyze the effects of urban roughness on the plume dispersion in detail, a few LES calculations with different aspect ratios are currently being undertaken so as to compare with the current LES results.