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Analysis of the Momentum and Pollutant Transport at the Roof Level of 2D Idealized Street Canyons: a Large-Eddy Simulation Solution

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To investigate the detailed momentum and pollutant transports between urban street canyons and the shear layer, a large-eddy simulation (LES) model was developed to calculate the flow and pollutant dispersion in isothermal conditions. The computational domain consisted of three identical two-dimensional (2D) idealized street canyons of unity aspect ratio. The flow field was assumed to be periodic in the horizontal domain boundaries. The subgrid-scale (SGS) stress was calculated by solving the SGS turbulent kinetic energy (TKE) conservation. An area pollutant source with constant pollutant concentration was prescribed on the ground of all streets. Zero pollutant concentration and an open boundary were applied at the domain inflow and outflow, respectively. The quadrant and budget analyses were employed to examine the momentum and pollutant transports at the roof level of the street canyons.

Quadrant analyses of the resolved-scale vertical fluxes of momentum $\langle u''w''\rangle$ and pollutant $\langle w''c''\rangle$ along the roof level were performed to compare the contributions of different events/scales to the transport processes. The roof of the street canyon is divided into five segments, namely leeward side, upwind shift, center core, downwind shift and windward side in the streamwise direction. Among the four quadrants considered, the sweeps/ejections, which correspond to the downward/upward motions, dominate the momentum/pollutant transfer. The inward/outward interactions play relatively minor roles. While studying the events in detail, the contribution from the sweeps is mainly large-scale fluctuation compared with that of ejections. Moreover, most of the momentum and pollutant transports take place on the windward side. The strong shear at the roof level initiates instability that in turn promotes the increasing turbulent transport from the leeward side to the windward side. At the same time, the roof-level fluctuations grow linearly in the streamwise direction leading to the vigorous turbulent transport and mixing near the windward facade.

Budget analyses of the velocity variance, shear stress, pollutant concentration and pollutant flux were also performed. A sharp peak of TKE production is developed at the roof level. Owing to the strong gradient of streamwise velocity, the streamwise velocity fluctuation is promoted first. The TKE is then transferred from the streamwise to the spanwise and vertical velocity fluctuations via the pressure-rate-of-strain tensor. Analogous to the quadrant analyses, the TKE production grows from a sharp peak ($\sim$0.1h width, where h is the building height) on the leeward side to a broad one ($\sim$0.5h width) on the windward side. This pattern is partly attributed to the growth of the flow instability and the enhanced turbulent processes along the roof of the street canyon in the streamwise direction.

The pollutant removal mechanism is clearly illustrated by the budget analysis of the pollutant concentration. The pollutant is carried by the primary recirculation from the ground level to the roof level of the street canyon. The vertical turbulent pollutant flux $\langle w''c''\rangle$ dominates the pollutant removal in the region right below the roof level ($0.8h<z<h$) while the streamwise advection dominates the pollutant removal in the shear layer ($h<z<1.3h$). It is thus suggested that the pollutant is initially removed vertically from the street canyon to the shear layer by turbulence before being carried away by the prevalent wind. Moreover, the roof-level flow instability was found to play a major role so a more efficient pollutant removal was observed on the windward side.