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Large-eddy simulation of flow past urban-like surfaces: A model validation study

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Accurate prediction of atmospheric boundary layer (ABL) flow and its interaction with urban surfaces is critical for understanding the transport of momentum and scalars within and above cities. This, in turn, is essential for predicting the local climate and pollutant dispersion patterns in urban areas. Large-eddy simulation (LES) explicitly resolves the large-scale turbulent eddy motions and, therefore, can potentially provide improved understanding and prediction of flows inside and above urban canopies. This study focuses on developing and validating an LES framework to simulate flow past urban-like surfaces. In particular, large-eddy simulations were performed of flow past an infinite long two-dimensional (2D) building and an array of 3D cubic buildings. An immersed boundary (IB) method was employed to simulate both 2D and 3D buildings. Four subgrid-scale (SGS) models, including (i) the traditional Smagorinsky model, (ii) the Lagrangian dynamic model, (iii) the Lagrangian scale-dependent dynamic model, and (iv) the modulated gradient model, were evaluated using the 2D building case. The simulated velocity streamlines and the vertical profiles of the mean velocities and variances were compared with experimental results. The modulated gradient model shows the best overall agreement with the experimental results among the four SGS models. In particular, the flow recirculation, the reattachment position and the vertical profiles are accurately reproduced with a grid resolution of (Nx)x(Ny)x(Nz) =160x40x160 ((nx)x(nz) =13x16 covering the block). After validating the LES framework with the 2D building case, it was further applied to simulate a boundary-layer flow past a 3D building array. A regular aligned building array with seven rows of cubic buildings was simulated. The building spacings in the streamwise and spanwise directions were both equal to the building height. A developed turbulent boundary-layer flow was used as the incoming flow. The results were compared with wind tunnel experimental data. Good agreement was observed between the LES results and experimental data in the vertical profiles of the mean velocities and velocity variances at different positions within the building array.