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On the air pollutant removal mechanism from 2D urban street canyons

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Urban development influences the micro-climate, and heat and mass transport in urban atmospheric boundary layer (UABL). The flow, energy transfer, and pollutant transport in urban areas closely affect the daily lives of urban inhabitants. Because the large length scales and uncontrollable atmospheric turbulence impose technical difficulties on field measurements, computer models are alternative solutions to shade some light on the problems.

In this paper, we employ the computational fluid dynamics (CFD) techniques to elucidate the transport process of atmospheric constituents in UABL. Our CFD model, differing from the conventional approaches, explicitly resolves the built structures instead of using empirical parameterizations handling the bottom UABL. Moreover, it probes the spatial behaviors of flow quantities in a transient manner that facilitates our fundamental understanding of individual spatio-temporal scales in the atmospheric turbulent transport processes.

As a pilot trial, idealized two-dimensional (2D) street canyons, which are the basic unit constructing a city, are employed as urban structures in our CFD. The more sophisticated large-eddy simulation (LES) is used as the turbulence model instead of the conventional Reynolds-average Navier-Stokes (RANS) approach. It calculates explicitly the large significant energy-carrying scales and models only the small isotropic turbulence that unveils the detailed transport processes in a transient manner. It is found that flow reattachment and separation promote and suppress, respectively, the local ground-level heat and mass removal. Right over the buildings, sweeps and ejections are the major turbulence events governing the removal from street level through the roof-level shear layer to the urban canopy layer (UCL) aloft. Obviously, buildings and streets, in the form of urban roughness elements, tremendously modify the heat and mass transfer in the UCL. Hence, the conventional Gaussian pollutant plume models should be applied with caution.

Partitioning the vertical pollutant flux normal to the roof of the street canyon into its mean and turbulent components, it is found that in the street canyon with pollutant sources, turbulent flux is the key component removing pollutant out of the street canyon. On the contrary, the mean flux removes ground-level pollutant from the street canyon but it subsequently entrains the roof-level pollutant back into the ground level that ends up with negligible net pollutant removal. In the street canyons without ground-level pollutant source, the mean and turbulent pollutant fluxes are about the same in which pollutant is recirculating between the UCL and the street canyons.