Reduced-order model analysis of the pollutant dispersion on an urban street canyon

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Abstract: Pollutant dispersion within street canyons is one of the most challenging topics today. The complex flow patterns, along with turbulence effects, can be regarded as a multi-dimensional non-linear system with a huge amount of information. This paper applies spectral proper orthogonal decomposition (SPOD), one of the cutting-edge reduced-order modeling (ROM) techniques, to capture the main features of the complex non-linear phenomena and save the computational resources for data processing. The relationship between flow structures and pollutant concentration field is illustrated via SPOD cospectra, while the turbulence-induced pollutant removal mechanism is demonstrated via SPOD modes. The results show that both external large-scale coherent structures at the canyon roof level, and waves caused by the canyon vortex play a crucial role in pollutant removal within the street canyon.

Introduction

As a basic unit of urban canopy elements, the street canyon model is widely investigated to understand the interactions between the urban canopy and the atmosphere. In the current study, an idealized street canyon is modeled via computational fluid dynamics (CFD). The model is composed of two parallel buildings with width (streamwise-*z*) × height (spanwise-*y*) × length (crosswind-*x*) = $H \times H \times 10H$, with the width of the street between the two buildings set as *H*. The air pollutant sulfur hexafluoride (SF6) is emitted from four line sources situated at the bottom of the model. The flow field and pollutant concentration field are simulated by Large-Eddy Simulation (LES) method (See figure 1).

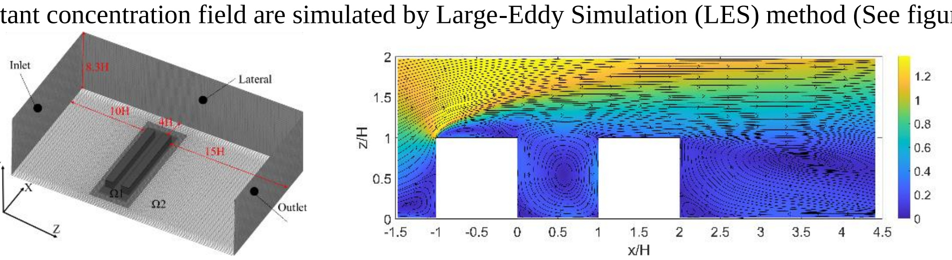

Figure 1: Schematic of the street canyon model and the mean velocity field

Results and Discussion

Compared to obtaining complete information of the system, ROM techniques can help to extract the main spatial-spectral features and dynamic properties from a complex flow field in the street canyon. This paper applies SPOD as a post-processing technique to determine the relationship between turbulent motion and pollutant removal. SPOD is a kind of cutting-edge ROM method, which has the advantages of both traditional POD (proper orthogonal decomposition) and DMD (dynamic mode decomposition)[1]. SPOD modes capture the external large-scale coherent structures and those waves caused by the canyon vortex at building roof (see figure 2). The SPOD cospectra are defined to elucidate the spatial-temporal variation of the phase relationship between the velocity components and concentrations (see figure 3). Mode f4 and f5 represent the large vortex structure in the canyon, those intermittent oblique stripes agree well with the vertical velocity distribution. Mode f1 and f2 represent the large-scale coherent structures, while f3 appears to fall between these two groups of modes. All the modes demonstrate that both external large-scale coherent structures at the canyon roof level, and waves caused by the canyon vortex play a crucial role in pollutant removal within the street canyon.

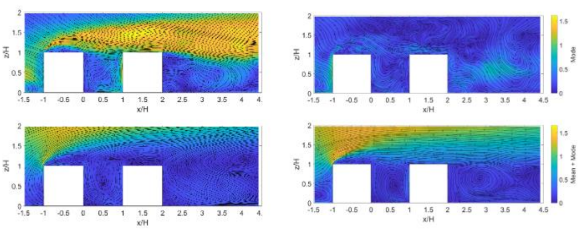

Figure 2: SPOD modes with the real and imaginary parts of the eigenfunction

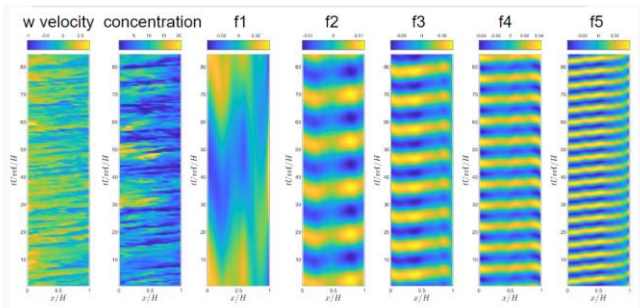

Figure 3: SPOD cospectra for vertical velocity components and concentrations.

References

[1] A. Towne, O.T. Schmidt, T. Colonius, Spectral proper orthogonal decomposition and its relationship to dynamic mode decomposition and resolvent analysis, *J. Fluid Mech.* 847 (2018) 821–867, https://doi.org/10.1017/jfm.2018.283.