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Article

Fast Models for Predicting Pollutant Dispersion inside Urban Canopies

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Abstract: A fast pollutant dispersion model for urban canopies is developed by coupling mean wind profiles to a parameterisation of turbulent diffusion and solving the time-dependent advection–diffusion equation. The performance of a simplified, coarse-grained representation of the velocity field is investigated. Spatially averaged mean wind profiles within local averaging regions or repeating units are predicted by solving the three-dimensional Poisson equation for a set of discrete vortex sheets. For each averaging region, the turbulent diffusion is parameterised in terms of the mean wind profile using empirical constants derived from large-eddy simulation (LES). Nearly identical results are obtained whether the turbulent fluctuations are specified explicitly or an effective diffusivity is used in their place: either version of the fast dispersion model shows much better agreement with LES than does the Gaussian plume model (e.g., the normalized mean square error inside the canopy is several times smaller). Passive scalar statistics for a regular cubic building array show improved agreement with LES when wind profiles vary in the horizontal. The current implementation is around 50 times faster than LES. With its combination of computational efficiency and moderate accuracy, the fast model may be suitable for time-critical applications such as emergency dispersion modelling.

Keywords: building array; coarse graining; computational fluid dynamics (CFD); effective diffusivity; wind profile

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1. Introduction

Fast and accurate prediction of pollutant dispersion is important for practical applications such as operational air-quality modelling and emergency dispersion modelling. Computational fluid dynamics (CFD), which has been extensively applied to pollutant dispersion in idealised [1] and realistic [2,3] urban areas, features relatively high accuracy; however, it is too computationally demanding for time-critical applications. Hence, there is a need for a fast dispersion model that can provide useful predictions without significant computational resources, extensive training data or many adjustable parameters.

The simplest dispersion model is the Gaussian plume model (GPM) [4], which is still widely used. In the original formulation, the pollutant concentration downwind of a point source is estimated by assuming flat terrain and an eddy diffusivity that increases linearly with downwind distance [5]. The GPM is therefore not well-suited to the urban canopy layer, where pollutants are emitted and many people live and work. The intrinsic limitations of the GPM have helped spur the development of fast dispersion models that are more appropriate for urban areas. The Quick Urban & Industrial Complex (QUIC) model is based on a variational solution for a steady velocity field [6] and a Lagrangian stochastic model for the time-dependent dispersion [7]. Although QUIC has been successfully applied in a variety of contexts (e.g., [8]), accuracy is potentially limited by the initial guess for the velocity and the nonlocal mixing parameterisation. The urban dispersion models