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Multi-Box Modelling of Cooking-Generated Aerosols within an Urban Street Canyon

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HIGHLIGHTS

- Coagulation and deposition are implemented in box models.
- Boxes are based on dynamical partitioning of the canyon space.
- Multi-box model eliminates the need for explicit segregation corrections.
- Dynamical partitioning increases accuracy relative to identical boxes.

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ABSTRACT

Multi-box models describing the evolution of cooking-generated aerosols emitted inside an urban street canyon are developed. By contrast with previous box models of urban pollutants, multiple boxes are introduced by partitioning the canyon space into dynamically distinct boxes. Aerosol dynamical processes, namely coagulation and deposition, are represented through standard parameterisations; the exchange or ventilation timescale between boxes is specified by the mean residence time, which is obtained from a Lagrangian particle model. Comparison with predictions from a large-eddy simulation model with a coupled sectional aerosol model indicates improved agreement when nine boxes are used in place of a single box; for example, the relative error in the canyon-averaged number concentration for deep-frying emissions decreases from $\sim 30\%$ to $\sim 5\%$. The improvement is smaller for boiling emissions, which contain fewer small particles. The inclusion of extra boxes eliminates the need for explicit segregation corrections and enables the size spectrum and coarse-grained spatial structure of the aerosol number concentration to be captured.

1. Introduction

The dynamics of urban aerosols depend on atmospheric flow and the transformation of pollutants by chemical and physical means (Karl et al., 2016). The most accurate numerical models are obtained by coupling building-resolving computational fluid dynamics (CFD) with an online aerosol module (Wang et al., 2020). However, coupled CFD–aerosol models are computationally expensive. According to Kurppa et al. (2019), including aerosol dynamical processes can increase the computational cost by a factor of 10, largely on account of the need to advect additional scalar fields that represent the discretised size spectrum. Simplified models that sacrifice accuracy for computational efficiency are therefore desirable for certain applications (e.g. operational air quality prediction (Liu et al., 2022)).

Box modelling is an attractive alternative to CFD in chemical engineering and atmospheric chemistry (Seinfeld and Pandis, 2016; Tan et al., 2017; Yang et al., 2018). Briefly, box models solve for the time evolution of the mean concentration within a region by including terms representing emissions, ventilation, and chemical or physical processes. In the standard formulation, temporal (turbulent) fluctuations and the three-dimensional spatial structure are ignored, yielding enormous computational savings. More realistic, multi-environment models are obtained by introducing additional boxes or subregions (Fox, 2003). For multi-environment models, the concentration is not uniform over the entire domain and a micromixing term that models the elimination of concentration differences is required. Applications of box modelling are ubiquitous. For example, Mehta and Tarbell (1983) applied a four-environment model to describe the turbulent flow within a chemical reactor. Harrison et al. (2006) used a box model to elucidate the cycling of short-lived species in tropospheric chemistry. Sander et al.

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