2023_86_AERO_Hamzehloo: Turbulence and drag parameterisations in urban canopy layers using scale-resolving simulations and machine learning

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Modelling meteorology and pollutant dispersion within urban areas is important for many applications such as, among others, air quality, pedestrian comfort, urban climate, urban planning, and epidemiology. The atmospheric processes within the urban canopy layer are complex because of the existence of often heterogeneously distributed obstacles such as buildings, cars, trees, and natural terrain features [1, 2]. To represent such heterogeneity, a common practice is to parameterise the key flow characteristics such as turbulence, drag, and surface energy exchange [1, 2, 3]. The parameterisation is vital for large-scale simulations (city-scale and beyond) that cannot explicitly resolve such microscale physics. Accurate representation of the urban canopy processes is essential for a reliable prediction of pollution concentration, temperature, wind speed, and boundary condition in air quality and Numerical Weather Prediction (NWP) models.

Most mesoscale NWP models employ a single-layer approach where the exchange between the air and the urban facets is calculated according to the Monin-Obukhov similarity theory using either morphometric or micrometeorological methods [4]. However, multi-layer urban canopy models become increasingly appealing as NWP models move towards sub-kilometre spatial resolutions. In such models, the governing equations are solved with terms explicitly representing canopy-related Sub-Grid Scale (SGS) turbulence and drag, enabling a more physics-based parameterisation [5].

This project aims to develop closure models with scale-resolved accuracies for the abovementioned SGS terms using physics-informed Convolutional Neural Networks (CNN) [6]. Specifically, Xcompact3d framework [7] is further developed to perform scale-resolving Direct Numerical Simulations (DNS) of canopy layer flows with idealised geometries under various heterogeneity levels and thermophysical conditions. The DNS results will then be used to train the CNN framework which eventually predicts the SGS terms to the DNS accuracy. The performance of the CNN-based SGS models will be evaluated within the ICON NWP framework [3].

Applicants should hold a degree in mathematics, physics, engineering or atmospheric science, and have a strong background in computational modelling, computing (FORTRAN, Python and C++) and machine learning. The project will involve extensive interactions with researchers from the Atmospheric Modelling Group at the Swiss Federal Laboratories for Materials Science and Technology (Empa). The student will have the opportunity for an extended visit to Empa (Zurich).


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