Geophysical Research Abstracts,
Vol. 11, EGU2009-12900-1, 2009
EGU General Assembly 2009

Modelling Aerosol Dispersion in Urban Street Canyons

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Flow patterns within an urban street canyon are influenced by various micrometeorological factors. It also represents an environment where pollutants such as aerosols accumulate to high levels due to high volumes of traffic. As adverse health effects are being attributed to exposure to aerosols, an investigation of the dispersion of aerosols within such environments is of growing importance. In particular, one is concerned with the vertical structure of the aerosol concentration, the ventilation characteristics of the street canyon and the influence of aerosol microphysical processes. Due to the inherent heterogeneity of the aerosol concentrations within the street canyon and the lack of spatial resolution of measurement campaigns, these issues are an on-going debate. Therefore, a modelling tool is required to represent aerosol dispersion patterns to provide insights to results of past measurement campaigns.

Computational Fluid Dynamics (CFD) models are able to predict detailed airflow patterns within urban geometries. This capability may be further extended to include aerosol dispersion, by an Euler-Euler multiphase approach. To facilitate the investigation, a two-dimensional, multiphase CFD tool coupled with the k-epsilon turbulence model and with the capability of modelling mixed convection flow regimes arising from both wind driven flows and buoyancy effects from heated walls was developed. Assuming wind blowing perpendicularly to the canyon axis and treating aerosols as a passive scalar, an attempt will be made to assess the sensitivities of aerosol vertical structure and ventilation characteristics to the various flow conditions. Numerical studies were performed using an idealized 10m by 10m canyon to represent a regular canyon and 10m by 5m to represent a deep one. An aerosol emission source was assigned on the centerline of the canyon to represent exhaust emissions.

The vertical structure of the aerosols would inform future directives regarding the recommended height for pollutant measurements to represent pedestrian exposure. The vertical structure of aerosols within a street canyon is a topic of constant debate, due to the inability of measurement campaigns to have sufficient spatial resolution to adequately represent the entire vertical structure. Several vertical profiles have been proposed: one where the concentration is the highest at the bottom, decreasing exponentially with increasing height; a homogenous profile across the canyon depth or one with a maximum observed near the road surface. Consistent with previous measurement results, modelling studies found that at the leeward side of the canyon, there was an increase in aerosol concentration up to approximately 2 m in height, followed by a decrease along the height of the canyon. It was also found that the vertical structure of the aerosols would be influenced by the relative contributions of convection and turbulent diffusivities and therefore vary at different locations of the canyon. Using a first-order eddy viscosity turbulence closure, knowledge of the vertical structure of the aerosol concentration would provide insights into the emission velocity structure within the canyon and account for its observed heterogeneity.

Investigation of the different factors which influence the ventilation characteristics of the canyon are presented and we show how these facilitate parameterizations into other modelling platforms. Both vertical turbulent flux and flux due to mean flow contribute to the overall ventilation characteristics of a street canyon and these are described. The influence of micro-meteorological factors on the vertical flux of aerosols at the roof level of the street canyon and the relative contributions of flux due to mean flow and turbulent flux at different flow conditions are also investigated. Turbulent flux was found to be of an order of magnitude higher than mean flow flux in isothermal conditions. Therefore, whilst the net effect of turbulent flux is the loss of aerosols to the urban canopy and the net effect of mean flow flux is to re-entrain aerosols into the canyon, the net effect of both factors is a net loss of aerosols. Consistent with previous measurement campaigns, a strong correlation was found

between turbulent flux and inflow conditions (wind speed and turbulent intensities). Also, the poorer ventilation characteristic of deep canyons is demonstrated. However, when the contribution of buoyancy to the vertical velocity component of the flow field is considered, it was found that the contribution of mean flow flux to the net flux could surpass that of turbulent flux when buoyancy is important. This implies that both mean flow flux and turbulent flux have to be considered together when buoyancy effects are important to the flow regime considered.

The multiphase model was further extended to investigate condensational growth of aerosols within the street canyon due to the presence of organic vapour. Condensational growth is incorporated as a function of the partial pressure of the condensing species and its saturation vapour pressure. The size distribution evolution pattern within the canyon and the sensitivity of aerosol growth to the characteristics of the organic vapour and flow conditions will be discussed.