EMS Annual Meeting Abstracts
Vol. 10, EMS2013-758, 2013
13th EMS / 11th ECAM

Short-range dispersion in urban areas: simple models of concentration decay and lateral spread

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The study of short-range dispersion from localised releases is important due to the need for quick and accurate prediction of the spread of toxic material in the event of accidental or terrorist releases in an urban area such as London. Current understanding and modelling practice is limited by a seemingly intractable combination of complex turbulent flow within the equally complex geometry of real urban areas. Faced with such complexity it is helpful to focus on simple, yet critical, questions. In an emergency, the most important question is: what area should be evacuated? To answer this one would need to know how the concentration decays with distance and how material spreads laterally, and how these are controlled by the turbulent flow and the building geometry. Analysis of data from direct numerical simulations (DNS), together with experimental data from DAPPLE (www.dapple.org.uk), are used to develop and validate simple methods to model these dispersion characteristics and to throw light on the associated dispersion processes. Specifically, we find that small-scale turbulent fluctuations in the urban canopy mix material efficiently in each street. The horizontal transport in the canopy is controlled by advection by the mean flow along the streets. Lateral spreading is controlled by topological splitting of the mean flow around buildings, with negligible turbulent contribution. Vertical exchange is controlled by turbulence and is well represented by an exchange velocity. These few dominant processes, when incorporated into very simple models, a simple "continuous" model and a "discrete" street network model, have surprisingly good predictive power. In particular, the decay of maximum concentrations with distance is constrained by simple analytical relationships and lateral spread follows a simple binomial-like distribution. These relationships work remarkably well with the DAPPLE wind tunnel and field data.