Pollutant Dispersion in Urban Environments: Background

R.E. Britter
Professor of Environmental Fluid Dynamics
Department of Engineering
University of Cambridge, UK

Abstract

Increasing urbanization and concern about sustainability and quality of life issues have produced considerable interest in flow and dispersion in urban areas. This can be addressed at four spatial scales; regional, city, neighbourhood and street. The flow is one over and through a complex array of structures. Most of the local fluid mechanical processes are understood; how these combine and what is the most appropriate framework to study and quantify the result is less clear. Extensive and structured experimental data bases have been compiled recently in several laboratories and a number of major field experiments in urban areas have been completed very recently with more planned. These have aided both understanding and model development and evaluation.

Introduction

Much of the global population currently lives and works in urban areas and this urbanisation is expected to increase. This trend has led recently to many urban-centred studies. Many are of a fluid mechanical nature, either in isolation or in combination with other disciplines such as chemistry, epidemiology and pedestrian and vehicular mobility.

Large-scale weather prediction and mesoscale meteorological models require the parameterisation of urban areas to provide boundary conditions. Regional air pollution models are used to estimate the transport of pollutants from and to cities. Urban climatology (Oke 1987) addresses the mass, momentum and energy transfers through an urban area and the resulting temperatures, humidities, radiant fluxes etc. This influences, for example, general urban planning, green space provision, and energy usage in cities.

Studies of urban air quality (Fenger et al 1999) focus strongly on the wind flow over and through the city and the sources of pollutants within and beyond the city. A major pollutant source within the city is vehicle emissions and this leads to an interaction between mobility, air quality and the possible regulation of vehicles in cities. The wind flow within cities, in particular the local turbulence levels, directly affect pedestrian mobility and comfort. This same wind flow, but on a larger scale, represents the wind environment within which new buildings are to be placed and is of concern both for wind loading problems (Cook 1990) and for the provision of clean air to the buildings and the removal of exhaust air from the urban canopy. This wind environment, and the building construction will affect some of the exchange processes between the building interior and exterior and, consequently, on building air quality and energy use. Hazardous materials in large quantities are normally prohibited from heavily populated areas but where this is not the case there is a need on behalf of emergency authorities and civil defence personnel to have operational tools available to determine what action to take in case of an accident. Very recently there has been increased concern about the non-accidental release of hazardous materials in urban areas.

There is a need to understand the flow of the wind through and above the urban area and/or the dispersion of material in that flow (Hanna and Britter, 2002). We address these by considering the problem at different scales. At each of the scales there are observations from the field and the laboratory that are interpreted in terms of various physical (and possibly chemical) processes. These processes, once recognized, are often combined and reformed into mathematical models that can form an hierarchy of complexity or sophistication; each with it's own regime of applicability and accuracy. A detailed interpretation at one scale is commonly parameterised to assist in interpretation at the next larger scale.

Space and time scales in the urban context

Urban air pollution involves physical and chemical processes over a wide range of space and time scales. The regional scale is affected by the urban area. For example, the urban heat island circulations, any enhanced precipitation, and the urban pollutant plume can extend to these distances. At this scale the mean synoptic meteorological patterns are given and the urban area represents a perturbation, causing deceleration and deflection of the flow, as well as changes to the surface energy budget and the thermal structure.

The city scale represents the diameter of the average urban area. At these scales, the variations in flow and dispersion around individual buildings or groups of similar buildings have been mostly averaged out. Wind flow models developed for this range pay little attention to the details of the flow within the urban canopy layer. Most of the mass of any pollutant cloud travelling over this distance will be above the height of the buildings. The city contains its own inhomogeneities, frequently with a city centre having larger buildings and an outlying area of lower industrial or residential areas as in Figure 1 of a section of Birmingham,UK.

On the neighbourhood scale buildings may still be treated in a statistical way however the approach may be different to that on the city scale; here we want to know more about the flow within the urban canopy. The wind flow, particularly within the canopy, may also be changing from neighbourhood to neighbourhood. Much of the mass of a pollutant cloud travelling over this distance may remain within the urban canopy.

The street (canyon) scale addresses the flow and dispersion within and near one or two individual streets, buildings or intersections. This would be of interest when considering turbulence affecting pedestrian comfort and the direct exposure of pedestrians and near road residences to vehicular emissions. It can be of particular interest when regulatory pollutant monitoring stations are placed within street canyons. Peak pollutant concentrations will obviously occur when the pollutant source and receptor are nearby, for example when the receptor (an individual or a pollutant monitoring station) is at roadside and the pollutant source (vehicles, at high traffic density) is also within the street. Consequently processes at the street (or street canyon) scale, that may be up to 100 or 200m, are of particular interest. At this scale the geometric arrangement of the buildings, street canyons and intersections directly affect the dispersion processes.

There are also processes of interest at the "tailpipe" scale where the formation or growth of ultrafine (sometimes nano-) particles can be influenced by the details of the mixing process between the exhaust gas and the atmosphere.

For each spatial scale there is a corresponding time scale that is the spatial scale divided by a representative advective velocity, typically the wind speed.