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Progress in observing and modelling the urban boundary layer

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A B S T R A C T

The urban boundary layer (UBL) is the part of the atmosphere in which most of the planet's population now lives, and is one of the most complex and least understood microclimates. Given potential climate change impacts and the requirement to develop cities sustainably, the need for sound modelling and observational tools becomes pressing. This review paper considers progress made in studies of the UBL in terms of a conceptual framework spanning microscale to mesoscale determinants of UBL structure and evolution. Considerable progress in observing and modelling the urban surface energy balance has been made. The urban roughness sub-layer is an important region requiring attention as assumptions about atmospheric turbulence break down in this layer and it may dominate coupling of the surface to the UBL due to its considerable depth. The upper 90% of the UBL (mixed and residual layers) remains under-researched but new remote sensing methods and high resolution modelling tools now permit rapid progress. Surface heterogeneity dominates from neighbourhood to regional scales and should be more strongly considered in future studies. Specific research priorities include humidity within the UBL, high-rise urban canopies and the development of long-term, spatially extensive measurement networks coupled strongly to model development.

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1. Introduction

The urban boundary layer is the part of the atmosphere in which most of us on the planet now live, and is one of the most complex and least understood microclimates. As urbanization proceeds ever more quickly, the need for accurate weather forecasting at the urban scale becomes critical, and longer term studies of urban microclimate become more important for health and well-being as cities become larger, hotter and more polluted. In the face of climate change, sustainable design and planning of our cities is essential and a sound understanding of the microclimate must play a role in planned changes such as increasing green infrastructure and densification.

Whilst the best known urban climate phenomenon is the urban heat island (UHI), observed at the surface, the processes controlling it act at a range of spatial and temporal scales spanning the depth of the urban boundary layer (UBL). Further progress in simulating thermal comfort, air quality and city ventilation depends on accurate observations and modelling of UBL processes. This review paper considers the progress made in studies of the UBL. Firstly, a brief history of key research milestones is outlined. Then a conceptual framework is described to provide definition of the various layers and scales relevant to the UBL. There follows a systematic review of research into the UBL starting from the microscale up to the regional scale. Conclusions are drawn as to what the research priorities are for the future, particularly for theoretical development as a sound basis for operational models.

2. Development of observational and modelling techniques

There have been various milestones in studies of the urban boundary layer as shown in Table 1. Key points in the study of rural boundary layers are also shown for reference. Progress in terms of observational and modelling techniques are briefly discussed, but the reader is also referred to the excellent reviews of Grimmond (2005) and Martilli (2007), following plenary lectures at the International Conference for Urban Climate (ICUC) held in 2003 and 2006, respectively. For extensive, general information on urban modelling, see also Baklanov et al. (2009), and for a focus on dispersion, see the review by Britter and Hanna (2003).

2.1. Observations

One of the first experiments involving study of the UBL was the Urban Air Pollution Dynamic Research Network in New York in the 1960s (Davidson, 1967; Bornstein, 1968). Using helicopter-based temperature measurements, pilot balloons and some of the first numerical modelling, an investigation was made into the spatial extent of the UHI with height, essentially the UBL structure. The Metropolitan Meteorological Experiment (METROMEX – Changnon et al., 1971; Changnon, 1981) was another major US campaign in the early 1970s that had more of a focus on the hydrological cycle, considering urban-induced moisture convergence and the impact on rain formation. More sophisticated instrumentation was used, including rain radars and aircraft flights. Later, RAPS (Schiermeier, 1978) took place in the same city, this time focusing on air pollution. An important US-based review of progress occurred in 1983 at a conference in Baltimore. The resulting monograph (Kramer, 1987) raised a sophisticated range of questions that are still not answered today, about advection and vertical profiles. During the same period, the classic US Kansas and Minnesota experiments were taking place to investigate, respectively, the turbulent surface and mixed layers of the rural boundary layer. These definitive experiments formed the basis of our understanding of land-based rural boundary layers, and their results provide a benchmark to which UBL results can be compared (see Sections 4.3 and 4.4).

Internationally, air quality has been the most common motivation for observing the UBL. IMADA-AVER (Doran et al., 1998) was an important study into Mexico City's UBL: lying within a mountain basin, its pollution episodes are infamous and several wind profilers complemented regular radiosonde and rawinsonde releases in investigating mean wind, temperature and humidity structure. ESQUIF in Paris (Menut et al., 2000) was a major collaboration involving extensive UBL and air pollution measurements, as well as development of mesoscale air quality modelling techniques. A COST Action is a European Union scheme for promoting co-operation in science across all European coun-

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