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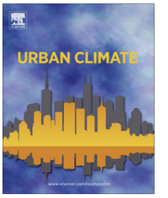

Energy exchange in a dense urban environment – Part II: Impact of spatial heterogeneity of the surface

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ABSTRACT

The centre of cities, characterised by spatial and temporal complexity, are challenging environments for micrometeorological research. This paper considers the impact of sensor location and heterogeneity of the urban surface on flux observations in the dense city centre of London, UK. Data gathered at two sites in close vicinity, but with different measurement heights, were analysed to investigate the influence of source area characteristics on long-term radiation and turbulent heat fluxes. Combining consideration of diffuse radiation and effects of specular reflections, the non-Lambertian urban surface is found to impact the measurements of surface albedo. Comparisons of observations from the two sites reveal that turbulent heat fluxes are similar under some flow conditions. However, they mostly observe processes at different scales due to their differing measurement heights, highlighting the critical impact of siting sensors in urban areas. A detailed source area analysis is presented to investigate the surface controls influencing the energy exchanges at the different scales.

1. Introduction

Surface characteristics, such as the arrangement of roughness elements, the locations of heat and moisture sources, or the texture of materials, all play a role in the formation of climate conditions in

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the lowest part of the atmosphere. Urban areas often have a particularly complex mix of surface materials, with buildings and roads (made of e.g. concrete or asphalt), right next to vegetation (e.g. street trees, gardens or parks) or water bodies (e.g. rivers or lakes). This combination of surface materials and their spatial arrangement are instrumental in generating distinct urban climates. The manipulation of these so called 'blue/green/grey' surfaces is core to many sustainable urban planning strategies aimed at mitigating negative urban climatic effects. The diversity of surface characteristics creates challenges for boundary layer and urban meteorology research and applications. This spatial variability has implications for all studies of the urban climate, independent of measurement technique or modelling approach. Scale and representativeness become central issues to consider when results obtained with different techniques are combined (Schmid, 1997).

To date, the spatial variability of urban eddy covariance energy flux measurements have been addressed in three ways. First, intra-urban variations have been evaluated through simultaneous observations at multiple sites within a city (e.g. Basel, Christen and Vogt, 2004; Łódź, Offerle et al., 2006; Melbourne, Coutts et al., 2007; Essen, Weber and Kordowski, 2010; Helsinki, Nordbo et al., 2012), in some cases with a rural reference site. Second, variations of turbulent sensible heat fluxes within one land use unit have been observed for short periods (e.g. multiple sites in a suburban area of Vancouver at the local-scale, Schmid et al., 1991; in a densely built up residential area of Tokyo within the roughness sublayer, Kanda et al., 2006). Third, vertical flux variations have been investigated (e.g. Rotach, 1995; Grimmond et al., 2004), allowing consideration of where the blending height or top of the roughness sublayer may be located.

Given the patchiness of the urban surface and its complex roughness characteristics it is often challenging to undertake EC observations in urban areas that are representative of a local-scale land use (e.g. Schmid et al., 1991; Vesala et al., 2008a; Feigenwinter et al., 2012). However, the need to better understand energy exchange processes in these environments is leading to an increase in the number of EC sites being operated – even in dense city centres such as in this study. The objective of this study is to investigate how flux observations can be used to study energy exchanges in a dense urban city centre. Here two nearby sites with different measurement heights in London (UK) are analysed with respect to the impact of site location and heterogeneity of the urban surface on flux observations. Evaluation is made as to whether simple source area modelling can aid interpretation of the results and the aspects most crucial to improve understanding. Details of the measurements (e.g. data collection, processing methods) and their temporal variability are presented in a companion paper (Kotthaus and Grimmond, 2013). First the methodology for footprint calculations is presented (Section 2). Second, the surface influence on short-wave radiative fluxes is analysed (Section 3). Third, the spatial variations of the observed turbulent fluxes are interpreted with respect to their source areas and a comparison between two nearby sites is presented (Section 4). Implications of these findings for turbulent flux source area modelling in urban areas and the critical aspect of siting are discussed (Section 5). Conclusions of this study (Section 6) outline both the challenges of energy flux observations in dense urban settings and the new interpretations obtained.

2. Methods

Net all-wave radiation Q^* and the turbulent fluxes of sensible heat Q_H and latent heat Q_E are important components of the surface energy exchange in urban areas (Oke, 1987). For this study, all three were obtained by *in-situ* observations. The companion paper Kotthaus and Grimmond (2013) provides details on these and other surface energy balance components.

2.1. Measurement site

The study area is located in the 'Central Activities Zone' (CAZ) of London, UK (see Kotthaus and Grimmond, 2013 for further details). At the Strand Campus of King's College London (KCL, 51°30′ N, 0°7′ W), two measurement towers, referred to as *KSS* and *KSK*, were located approximately 60 m apart (Fig. 1).