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Sunlit fractions on urban facets – Impact of spatial resolution and approach

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ABSTRACT

The extent of the surface area sunlit is critical for radiative energy exchanges and therefore for a wide range of applications that require urban land surface models (ULSM), ranging from human comfort to weather forecasting. Here a computationally demanding shadow casting algorithm is used to assess the capability of a simple single-layer urban canopy model, which assumes an infinitely long rotating canyon (ILC), to reproduce sunlit areas on roofs, walls and roads over central London. Results indicate that the sunlit road areas are well-represented but somewhat smaller using an ILC, while sunlit roofs areas are consistently larger, especially for dense urban areas. The largest deviations from real world sunlit areas are for roofs during mornings and evenings. Sunlit fractions on walls are overestimated using an ILC during mornings and evenings are found. The implications of these errors are dependent on the application targeted. For example, (independent of albedo) ULSMs used in numerical weather prediction applying ILC representation of the urban form will overestimate outgoing shortwave radiation from roofs due to the overestimation of sunlit fraction of the roofs. Complications of deriving height to width ratios from real world data are also discussed.

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1. Introduction

The modelling of exchanges (momentum, water vapour or energy) between the surface and the atmosphere is one of the key challenges for meteorological applications, whether pollutant dispersion, weather forecasting, or climate mitigation studies. For cities, full representation of the complexity of the urban form in models is constrained by computer resources and data availability, making the simplification of the three dimensional geometry a requirement. Grimmond et al. (2011) provide a detailed review of the range of simplifying assumptions made in state-of-the-art urban land surface energy balance models (ULSM), identifying three classes according to the level of detail represented, i.e. slab, single-layer and multi-layer models. The more sophisticated single and multi-layer schemes explicitly represent the urban form in two (or three) dimensions (2 or 3D).

To simulate shortwave energy input to the urban system, assumptions are needed to estimate how much solar radiation reaches the different facets: walls, roofs and roads (e.g. Arnfield, 1982; Masson, 2000; Martilli et al., 2002; Kusaka and Kimura, 2004; Kanda et al., 2005; Harman and Belcher, 2006; Krayenhoff and Voogt, 2007; Schubert et al., 2012). The fractions of shaded and sunlit surfaces affect the distribution of the direct component of solar radiation, which is the dominant component of shortwave energy input, especially during clear weather situations. The complexity of the models varies from 'simple' where, for example, two perpendicular infinitely long canyons (ILC) are used (Arnfield, 1982), to 'more complex' where 3D representation of the surface is based on regular building arrays (Kanda et al., 2005). One common approach used within the single-layer urban canopy model (SLUCM) of Kusaka et al. (2001) and Kusaka and Kimura (2004) is to determine the portion of surface that is sunlit from a simple shadow casting algorithm in conjunction with a rotating ILC (Masson, 2000; Chen et al., 2011; Lemonsu et al., 2012; Loridan and Grimmond, 2012).

Detailed 3D geographical data for urban areas are becoming more widely available. Techniques such as aircraft mounted LiDAR (Light Detection Aperture Radar) make it possible to derive very high resolution digital surface models (DSM) that describe urban form (e.g. Goodwin et al., 2009; Lindberg and Grimmond, 2011). This detailed information has been used in studies of urban climate (Lindberg, 2007; Gál and Unger, 2009; Martilli, 2009; Yu et al., 2009), human thermal comfort (Lindberg et al., 2008; Thorsson et al., 2011) as well as urban planning and architecture (Ratti and Richens, 2004; Ratti, 2005). The advantage of a high resolution DSM is, as it is very close to a 'real world' representation of the urban environment, that it can be used to study detailed features and phenomena within the city. However, the high level of detail makes it computationally difficult to model very large areas such as whole cities.

The purpose of this paper is to examine how simplifications made with regards to urban form in a typical ULSM impact the representation of shadow patterns in a complex urban setting. This comparison is made from analysis of sunlit fractions derived from two different methods applied in the city centre of London: (i) a simplified approach using an ILC as occurs in a number of ULSMs and (ii) a more detailed approach using high resolution urban DSMs. ULSMs are typically used in meso- or larger area 3-D weather or climate forecasting model; whereas DSMs are typically used in micro- to local scale modelling for human comfort and urban planning. Here we analyse an area of central London (Fig. 1) where both high resolution (1 km^2) meso-scale simulations (e.g. Bohnenstengel et al., 2011; Chemel and Sokhi, 2012; Loridan et al., 2013) and detailed analyses of DSMs have been independently studied (e.g. Lindberg and Grimmond, 2011).

2. Study area and spatial data

This study focuses on the Central Activity Zone (CAZ, Fig. 1) of London, UK, an 'urban heat island action area' and key 'climate change adaptation strategy area' (GLA, 2010). For SLUCM the analysis is conducted at 1 km horizontal resolution (see Fig. 1); this is at the detailed end of the range of resolutions used in state of the art meso-scale modelling. A high resolution DSM was generated from building height and location data across the CAZ, derived from the vector dataset "Virtual London" which has ground elevation and building footprints including height attributes (Evans et al., 2006). Data were converted into a raster DSM with a pixel resolution of 4 m. Typical ULSM model parameters,