Urban Climate 17 (2016) 196–215

Contents lists available at ScienceDirect

Urban Climate

journal homepage: http://www.elsevier.com/locate/uclim

Linking urban climate classification with an urban energy and water budget model: Multi-site and multi-seasonal evaluation

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ARTICLE INFO

Article history:
Received 4 February 2016
Received in revised form 8 August 2016
Accepted 10 August 2016

Keywords:
UEB
SUEWS
LCZ
Urban model evaluation
Flux measurements

ABSTRACT

There are a number of models available for examining the interaction between cities and the atmosphere over a range of scales, from small scales - such as individual facades, buildings, neighbourhoods - to the effect of the entire conurbation itself. Many of these models require detailed morphological characteristics and material properties along with relevant meteorological data to be initialised. However, these data are difficult to obtain given the heterogeneity of built forms, particularly in newly emerging cities. Yet, the need for models which can be applied to urban areas (for instance to address planning problems) is increasingly urgent as the global population becomes more urban. In this paper, a modeling approach which derives the required land cover parameters for a mid-complex urban energy budget and water budget model (SUEWS) in a consistent manner is evaluated in four cities (Dublin, Hamburg, Melbourne and Phoenix). The required parameters for the SUEWS model are derived using local climate zones (LCZs) for land cover, and meteorological observations from off-site synoptic stations. More detailed land cover and meteorological data are then added to the model in stages to examine the impact on model performance with respect to observations of turbulent fluxes of sensible (Q_H) and latent (Q_E) heat. Replacing LCZ land cover with detailed fractional coverages was shown to marginally improve model performance, however the performance of model coupled with 'coarse' LCZ data was within

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http://dx.doi.org/10.1016/j.uclim.2016.08.003

the same range of error (20–40 W m^{-2} for Q_E and 40–60 W m^{-2} for Q_H) as high resolution data.

1. Introduction

There has been considerable progress in the representation of urban-scale processes within atmospheric models. A variety of urban-scale models now exist which are capable of simulating the urban heat island either empirically or using physical models (Taha et al., 1988; Myrup, 1969; Atkinson, 2003; Bottyán and Unger, 2003; Kusaka and Kimura, 2004; Hoffmann et al., 2012), urban air quality (Shir and Shieh, 1974; Huang et al., 2000; Karppinen et al., 2000), human thermal comfort in the outdoor urban environment (de Dear and Brager, 1998; Ali-Toudert and Mayer, 2006), energy demand and anthropogenic emissions of heat (Block et al., 2004; Fan and Sailor, 2005; Allen et al., 2011). There are a wide number of surface schemes for modeling fluxes of mass, momentum and energy in urban areas (i.e. the urban energy balance - UEB), which vary in complexity in terms of their parameterisation and hence, their input requirements. More complex UEB schemes have been shown to be very useful in examining, for instance, the detailed hygrothermal impact of different urban forms and functions on the micro-scale climate (Barlow et al., 2004; Harman et al., 2004; Dupont et al., 2004). Such models are invaluable for understanding the processes in operation within urban environments. Moreover, there are some examples of where UEB models have been coupled with meso-scale models (Harman and Belcher, 2006; Bueno et al., 2013; Stewart et al., 2014; Onomura et al., 2015; De Ridder et al., 2015) which would effectively allow for micro-scale meteorological forecasts.

These complex UEB models however are incapable of being run in many data poor settings, or at least routinely, for cities in the economically developing world where the application of such models to planning problems and adaptation to extreme weather conditions would have the largest potential benefit. There is now a clear need to overcome this knowledge gap so as to allow greater integration of urban climate knowledge with the planning and policy communities (Mills et al., 2010; Ching, 2013; Hebbert and Mackillop, 2013; Heaphy, 2015). For instance, a comparison of 33 models by Grimmond et al. (2010) highlighted the large number (145) of input parameters required by the group of models considered. Providing such parameters for a single neighbourhood is challenging, and this is before we consider the parameters required for an entire urban area. In order to carry out simulations across an entire urban domain, generalisations will be needed in the interim.

Obtaining the necessary input parameters in data poor settings is only part of the problem, greater rigour in evaluating models in differing background climates and in different cities is also urgently needed. As stated by Oke (2006), without extensive model evaluation exercises the utility of UEB models for planning problems remains dubious. The international urban climate model comparison (Grimmond et al., 2010; Grimmond et al., 2011) went a large way towards discovering the general ability of UEB models in simulating the urban effect on turbulent fluxes and prioritising the most important input parameters. Research on specific model performance in different settings is also beginning to emerge (Loridan and Grimmond, 2012). Despite this there is still a noted lack of integration of urban climate knowledge in the planning process. Very few examples exist of UEB models being applied to real planning problems in collaboration with city planners (Eliasson, 2000). In order to bridge this knowledge gap, more specific evaluation of individual UEB models needs to be undertaken, with clearer links to planning applications, as proposed by Masson et al. (2014). It is unlikely that there will emerge a one-model-fits-all scheme that will apply to all situations, however a starting point may be to seek a balance between realistically representing urban processes, ensuring good model accuracy and requiring readily obtained input parameters that are derived in a consistent manner so as to allow inter-city comparisons.

While concerted effort has been placed on model development (Hidalgo et al., 2008) to better represent urban climate processes and move towards operational use in forecasting models, there is a clear need for more general models which are also capable of studying the impacts of urbanisation on the environment with fewer input requirements. One example is the local scale urban meteorological parameterisation scheme (LUMPS – Grimmond and Oke, 2002) which has been shown to accurately simulate the UEB in multiple cities requiring only simple input parameters. The simple treatment of vegetation and water availability i.e. urban water balance (UWB) within LUMPS limits its application to real planning challenges. Hence a mid-complex