Sensitivity of mesoscale models to scale dependent UCP inputs: an example from urban energy demand

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1. Introduction

Mesoscale weather and climate models are useful tools toward improved understanding and providing important insights regarding climate change mitigation and adaptation in urban environments for institutional stakeholder and urban planner communities. For urban applications, the complexities of the urban fabric for each urban area require scale dependent descriptions of the land use and activity patterns, to account for the effects of subgrid scale urban surface cover and buildings in order to better predict the wind, turbulence, and concentration fields. A commonly used method is the inclusion of a set of urban canopy parameters (UCPs) into mesoscale meteorological models to parameterize building-induced drag and turbulence production and the building-modified surface energy balance (e.g. Martilli et al., 2002). Current UCPs used in mesoscale models attempt to capture major structural and material features considered to control the momentum and thermodynamics of the flow. It is anticipated that through the WUDAPT (Ching et al., 2014), being initiated by IAUC, scale dependent UCPs will soon become available for model applications.

In this presentation, we illustrate and explore sensitivity of model outputs to scale dependent UCP inputs to better understand and articulate their implication to model user communities. The MRA (Mouzourides et al, 2013, Mouzourides et al 2014) provides a powerful means to perform weather and climate model scale dependent sensitivity study for urban applications of models. The MRA is a method that can take into consideration the inherent information residing in urban landscapes, and convey this information to multi-scale modelling studies - without discarding redundant details -in some manageable coherent and structured way (Ching, 2012; Mouzourides et al., 2012). For example in a nested grid simulation over an urban area, each cell in the coarse grid simulation will average more buildings than a fine grid cell, leading to different UCP values. In order to obtain meaningful results at all scale, for example in this type of nested simulations, the partitioning of the urban heterogeneity between the part resolved by the grid of the model and the subgrid part treated by the UCP must be derived in a consistent manner across all scales.Given that the majority of the world's populations now reside in urban areas, we focus on demonstrating scale sensitivity in the context of energy usage and urban activities on climate, heat island intensity and other like issues.

2. Theory: Multi-Resolution-Analysis (MRA) fundamentals

The choice of MRA as a tool to analyze urban data was motivated by its capacity for multi-scale sampling and its ability of not losing the details at smaller scales when used to sample signals over larger scales. For a detailed account on the MRA fundamentals, the MRA application in atmospheric modelling and its novel interpretations in multi-scale modelling can be found in Mouzourides et al, 2013 and Mouzourides et al., 2014. Here we briefly review the basic principles for the coherence of this paper.

MRA decomposes a signal, e.g. a 1-D signal, into coarser parts at scales $2^j \Delta t$, where Δt is the sampling period of the original signal. At each decomposition level j a coarser part at scale 2^{j+1} is obtained by removing a rough part that belong to the previous scale. The coarse part at each scale is called approximation Aj whereas the rough part removed from Aj to give the approximation A_{j+1} is called the detail, D_{j+1}. The mathematical framework of MRA dictates that each approximation can be reconstructed using a superposition of dilated and translated versions of a single function. In similar way, 2D MRA, given an image of resolution of nxn pixels $\Delta x \Delta y$, *it* decomposes it iteratively to smoother parts at scales $2^{2j} \Delta x \Delta y$.

The most important implication of MRA, as indicated and illustrated in Mouzourides et al,2013 & Mouzourides et al, 2014, is that it can provide an innovative means to distinguish between urban databases and cities, it can encode the unique information of an urban database the same way as the DNA encodes the genetic information of all living organisms of the same species – in essence providing a DNA-like description of a city. For models, the MRA provides gridded and scaled attributes as well as sub-grid information for a hierarchy of grid sizes. The MRA can, in principle, provide a powerful means to explore and utilize information at the sub-grid scale to inform the mesoscale analyses, a very powerful resource for multiscale modelling studies. This methodology is in the process of being extended to provide an objective and automated link with urban classification such as the Local Climate Zone defined in Stewart and Oke (2012) to provide additional thermal parameters such as the albedo, sky view factor, surface admittance, previous surface fraction.

3. Methodology

This section discusses the methodology followed in the application of MRA on an urban database in order to obtain multi-scale representations of such an urban information. The illustrated example is taken from London City and in particular from Westminster Borough for which data on the building height, as well as heating demands at two different hours in the day – representing early morning and early afternoon. The investigated area specifically derives from the central business district (CBD) and has an approximate size of 6000 × 7000m^2. This urban area is depicted in Fig. 1 where each pixel corresponds to a 10 × 10m^2 area and the colour of each pixel maps the corresponding urban attribute. This urban database information as represented in Fig. 1(left) will be treated as our 2-D signals to be analyzed using MRA.

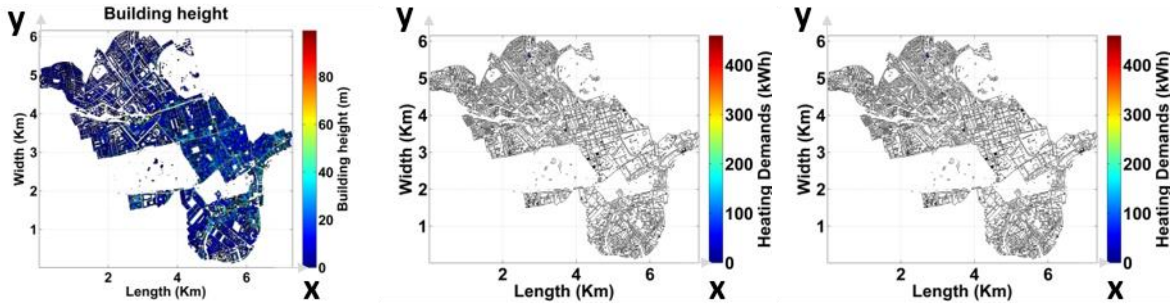

Figure 1: Building height (left), heat demands at 4am (center) and heat demands at 4pm (right) for the Westminster Borough.

The selection of the proper scaling and wavelet functions in the MRA is dictated by the nature of the application. For urban building datasets the square shape of the Haar function is proposed, since it enables the demarcation of the characteristics of an urban area domain, where buildings have similar square- or rectangular-like shapes. An additional advantage of the Haar function is that its operation corresponds to simple averaging and differencing of 2 × 2 cell neighbourhoods (Mouzourides et al, 2013). In this paper, we treat for first time non-geometrical attributes and specifically the urban heating demand. Such attributes are of major concern to relevant authorities and any related decision –making relies substantially on predicting peak values of demand at an associated scale. Since this is the first time that MRA is applied to energy-related attributes of urban canopies in order to derive scale-adaptive representations, in this paper we will also illustrate the selection rationale of the analyzing function, by means of a comparison between the Haar and Symlet 4 scaling and wavelet functions (Mouzourides et al, 2013). Specifically, at the first level of decomposition for example, the Haar transform performs sequential averaging and differencing of 2 × 2 adjacent pixels; conceptually, this process can be viewed as a structural averaging process in which the building attribute difference between adjacent cells in the horizontal *(x)*, vertical *(y)* and diagonal directions is tracked. Due to the shape of the Symlet 4 function, it would be used for example in detecting or capturing phenomena dominated by peaks or sudden occurrences. Thus for the MRA analysis of a building database information it is recommended that the Haar analyzing function is used. The MRA analysis was implemented in Matlab© using its wavelet toolbox.

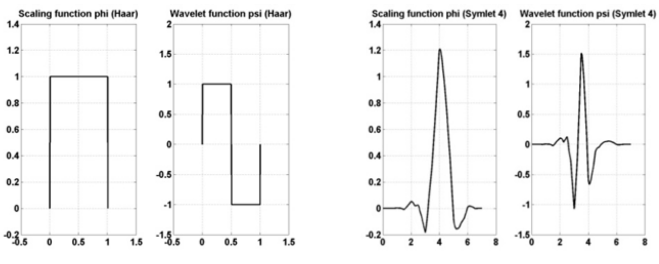

Fig2: The Haar (left) and Symlet4 (right) scaling and wavelet functions illustrated in the 1-D form.

4. Results and Discussion

In this section we present the scale-adaptive representations of urban attributes with their associated sub-grid information (at each scale) as obtained from the MRA for the building height (m) in Figure 3, as well as the heating demands at 4am and 4pm on a typical day (kWh) for the London-Westminster in Figures 4 and 5 respectively.

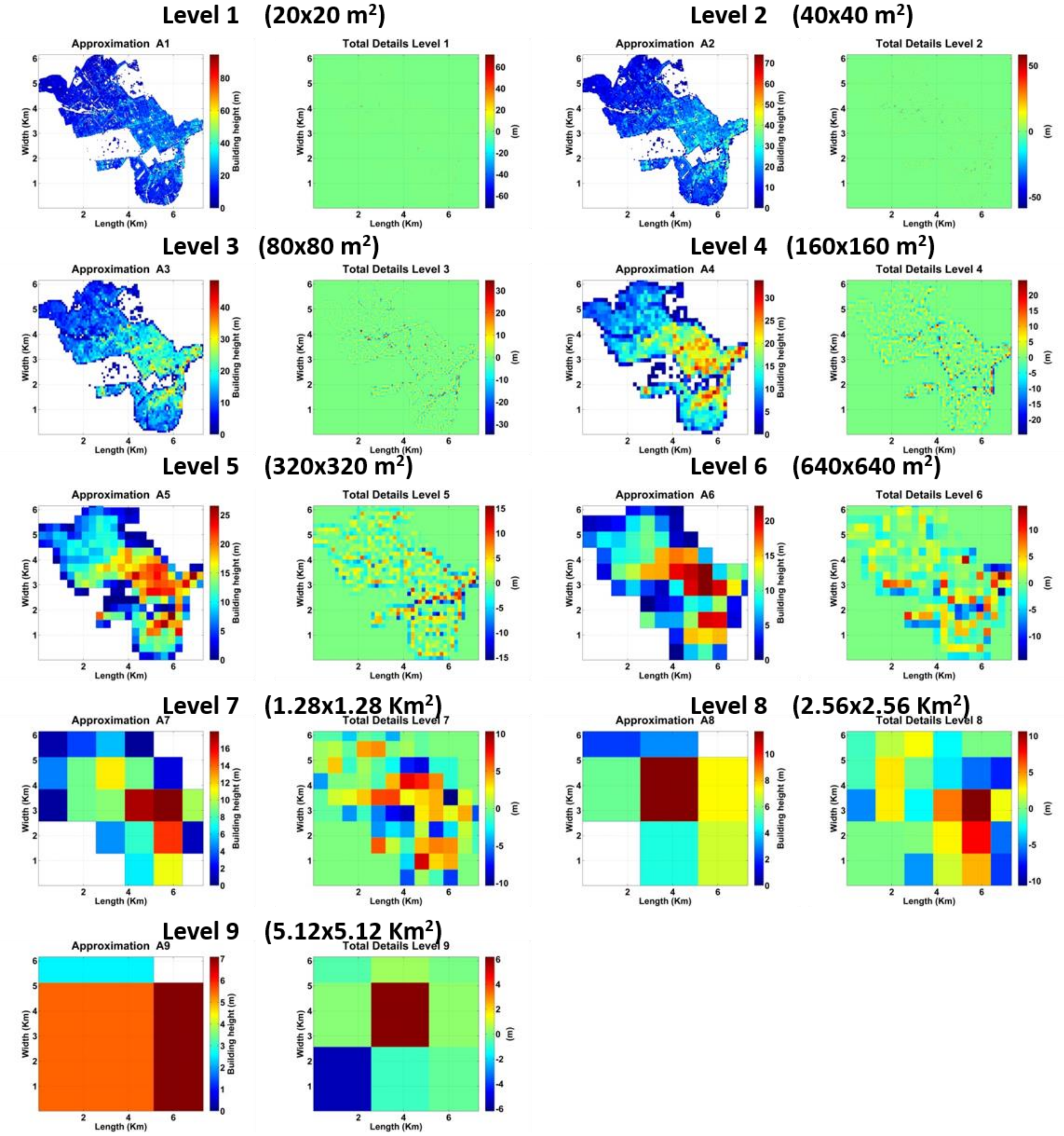

Fig. 3: Scale-adaptive representations and associated sub-grid information as obtained through MRA for the Building heights (m) in London Westminster Borough

Figure 3 demonstrates the complete set of reconstructed *approximations* and *details* obtained from the MRA of the London urban building 2-D signal, by analyzing the original digitized image in figure 1 (left). The plots in two consecutive columns depict the *approximation* and *detail* reconstructions of the urban signal at consecutive levels. There are 9 levels overall resulting from MRA since the size and resolution of the original 2-D urban signal allows up to 10^2x2^9 (51200) m to be covered/completed. The number denoting each level, corresponds to the exponents e.g. 1, 2 of the scales (as area sizes), that are used to label the scales.

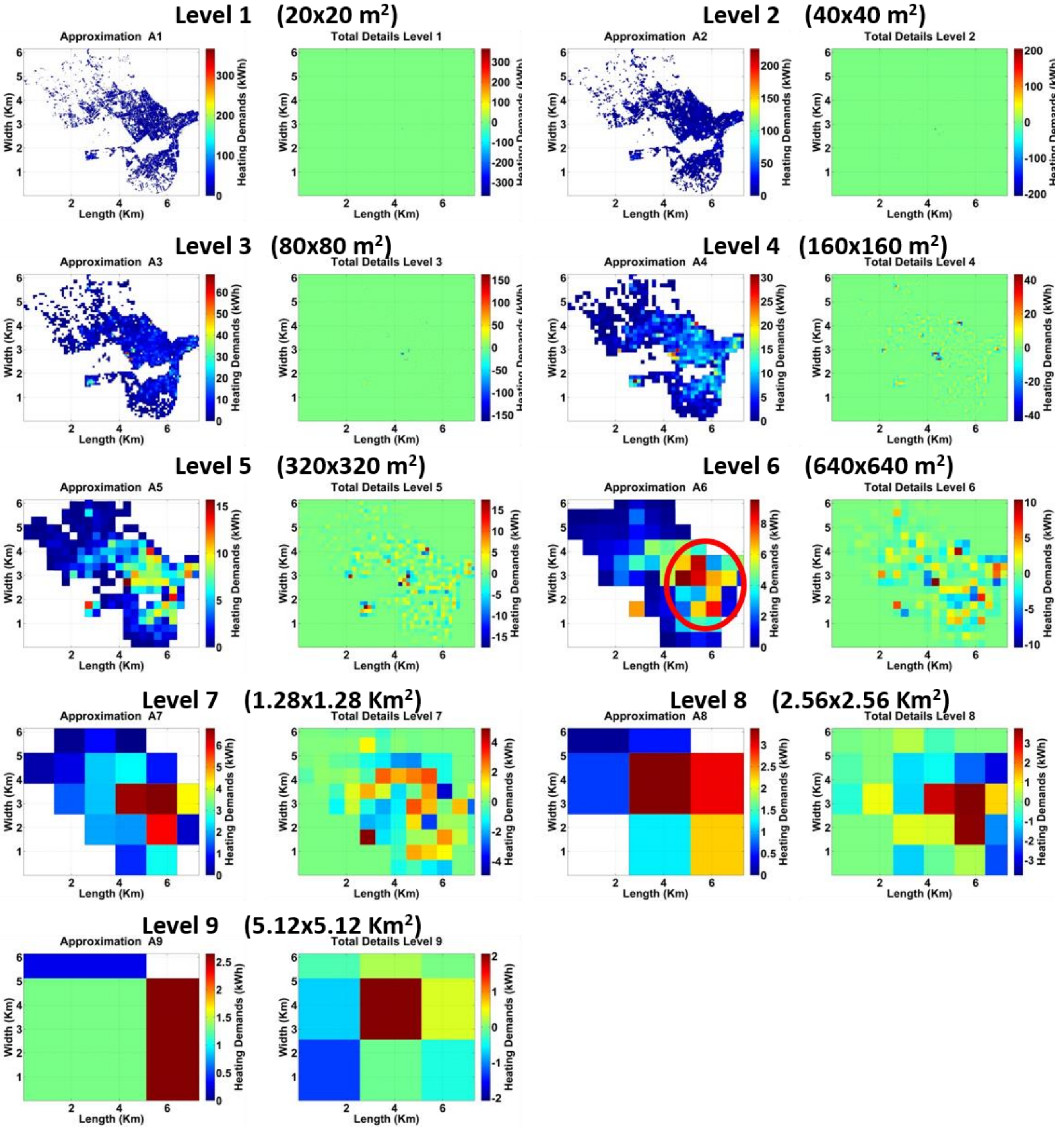

Fig. 4: Scale-adaptive representation and associated sub-grid information as obtained through MRA for the Heating Demands at 4am (kWh) in London Westminster Borough

Figures 4 and 5 show the scale-adaptive representation of the urban heating demands of the Westminster Borough at 4am and 4pm respectively on a typical winter day as obtained from MRA using the Haar function; overall the afternoon values (as bulk averages) appear higher than those during the early morning hour. To investigate how these scale-adaptive representation may differ as different characteristics of the attributes are wished to be captured (i.e. peak versus bulk average), the MRA analysis was repeated for one case using also the Symlet4 function. Figure 6 shows these scale-adaptive representations and associated sub-grid information as obtained through MRA for the Heating Demands at 4am (kWh) in London Westminster Borough using different scaling functions – depicting only the last two Levels (Levels 8 and 9); the Levels depicted on the left-hand-side columns were obtained using the Haar function as in all previous figures; the Levels depicted on the right-hand-side columns were obtained using Symlet4 function. As it can be seen from Figure 6, Symlet 4 can provide representations reflecting peak values and patterns within the cell-size.

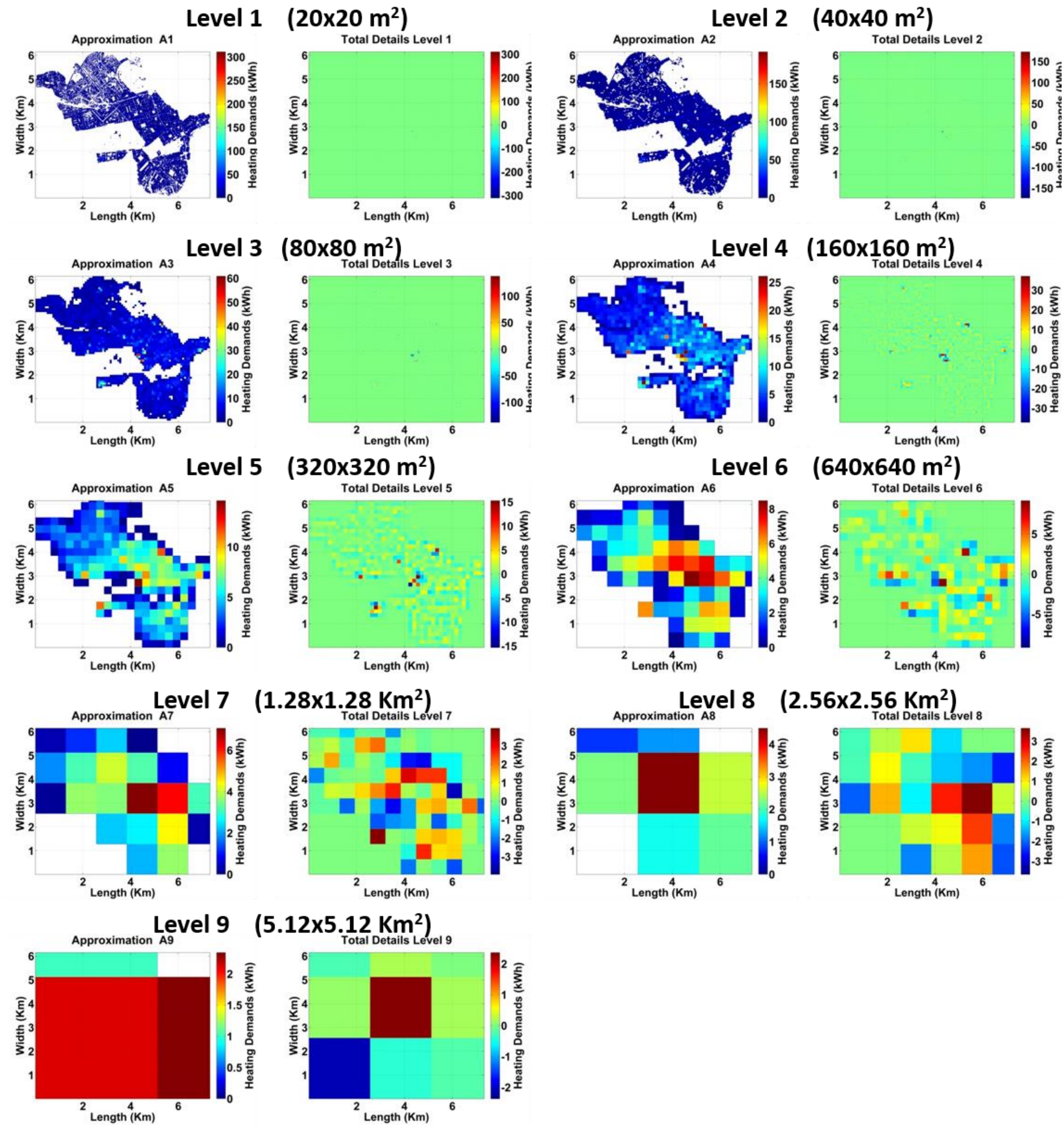

Fig. 5: Scale-adaptive representation and associated sub-grid information as obtained through MRA for the Heating Demands at 4pm (kWh) on a typical winter day in London Westminster Borough

4. Conclusions and Future Work

Through an illustrated example from London City, it has been demonstrated that :

1. Modelling and associated decision making is strongly scale-dependent and appropriate rigorously derived scale-adaptive representations are needed, as our input datasets become more and more complete.
2. As the multi-scale nature of urban problems urges for coupling and nesting of different models, not only consistent and coherent scale-adaptive representations are required but also associated consistent sub-grid scale representations are required, that MRA can rigorously provide.
3. Depending on the nature of the urban attribute, and its associated impact (e.g. interested in the bulk average versus peak values), MRA can appropriately adjust its scale-adaptive representation procees in order to capture that (with appropriate scaling and wavelet functions).

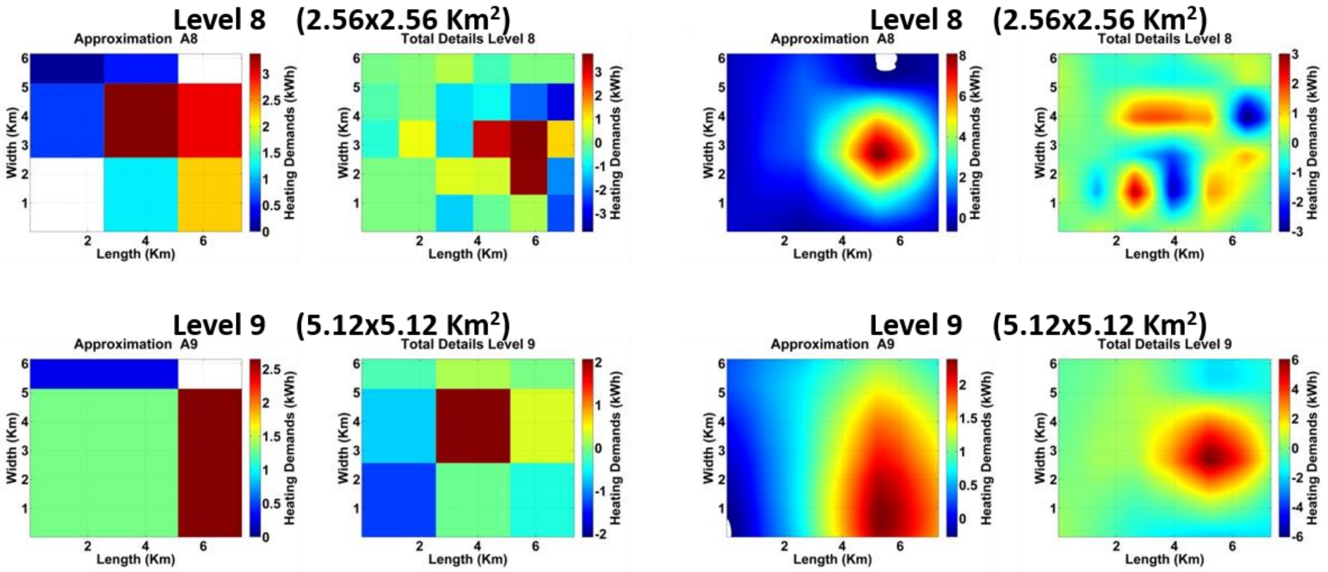

Fig. 6: Scale-adaptive representations and associated sub-grid information as obtained through MRA for the Heating Demands at 4am (kWh) in London Westminster Borough using different scaling functions – depicting only the last two Levels (Levels 8 and 9); the Levels depicted on the left-hand-side columns were obtained using the Haar function as in all previous figures; the Levels depicted on the right-hand-side columns were obtained using Symlet4 function, depending on whether representations ought to reflect best the bulk average or peak values.

5. References.

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