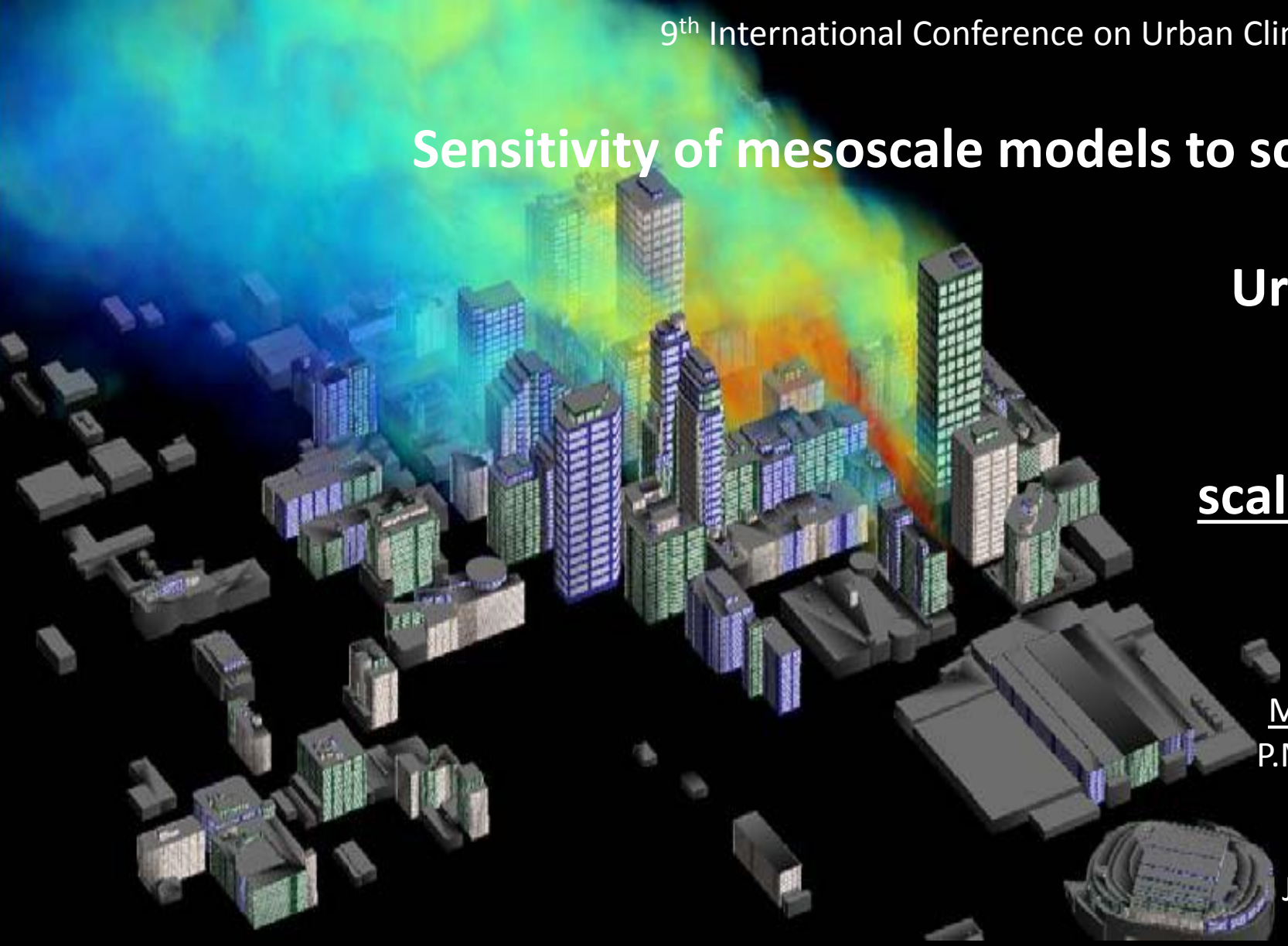
9th International Conference on Urban Climate, 20th -24th July 2015, Toulouse, France

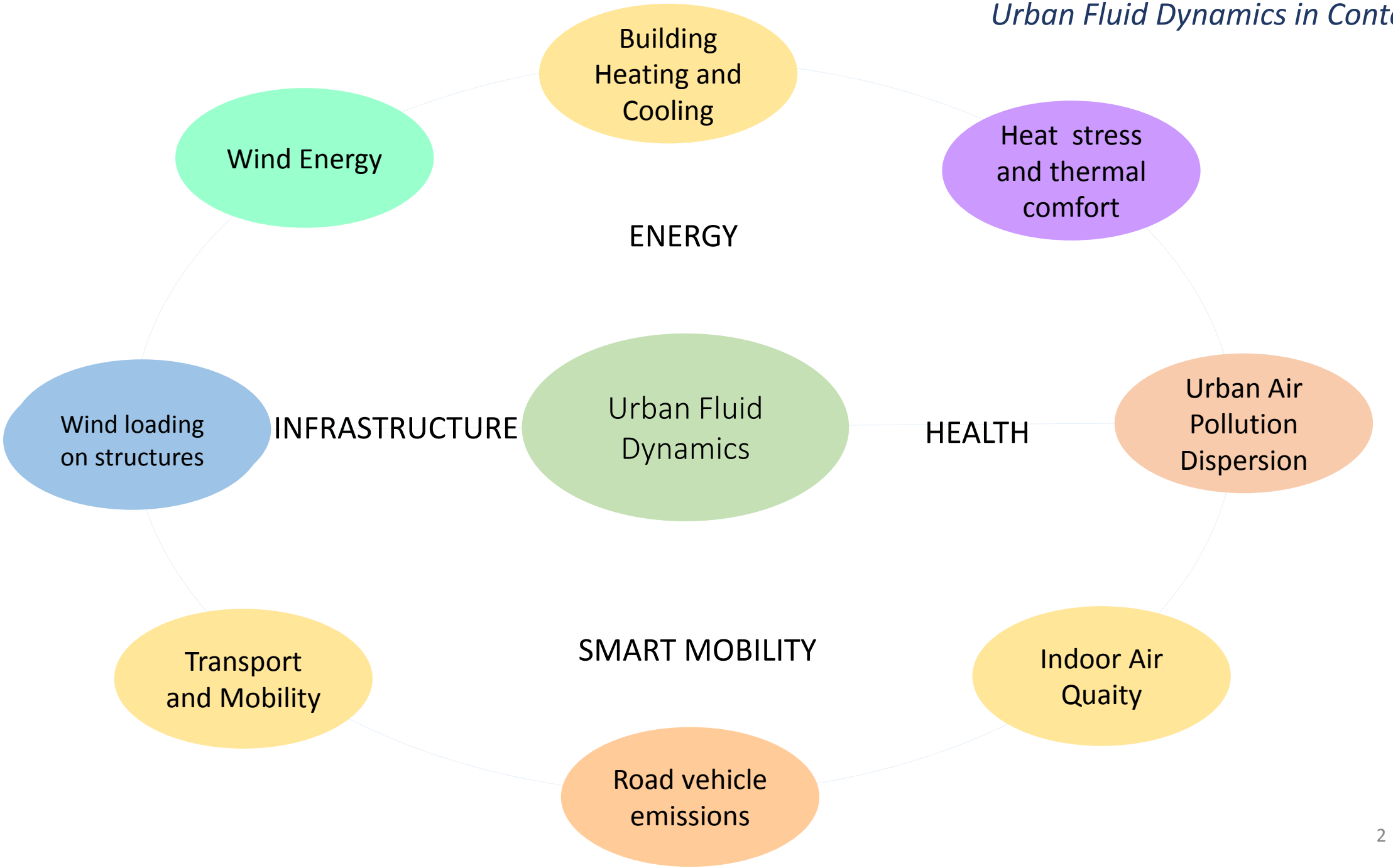
Sensitivity of mesoscale models to scale dependent UCP inputs:

Urban thermofluid dynamics, multi-scale interactions, multi-scale models, and scale-adaptive representations



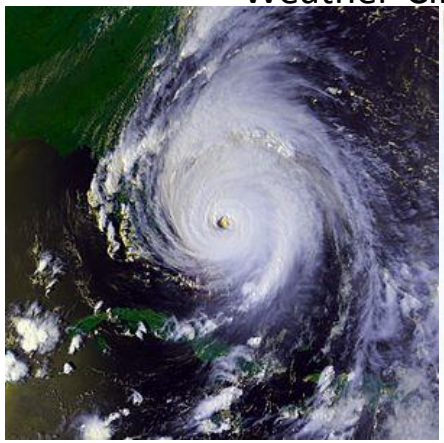
M.Neophytou, University of Cyprus, CYPRUS
P.Mouzourides, University of Cyprus, CYPRUS
A.Kyprianou, University of Cyprus, CYPRUS
R.Choudhary, University of Cambridge, UK
J.Ching, University of North Carolina, U.S.A.

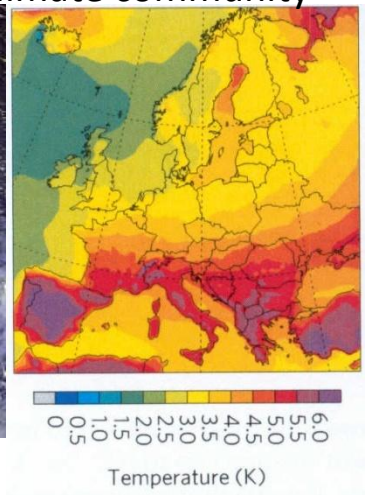
Neophytou, Gowardan, Brown (2011)


Building Heating and Cooling
Wind Energy
Heat stress and thermal comfort
ENERGY
Wind loading on structures
INFRASTRUCTURE
Urban Fluid Dynamics
HEALTH
Urban Air Pollution Dispersion
Transport and Mobility
SMART MOBILITY
Indoor Air Quaity
Road vehicle emissions

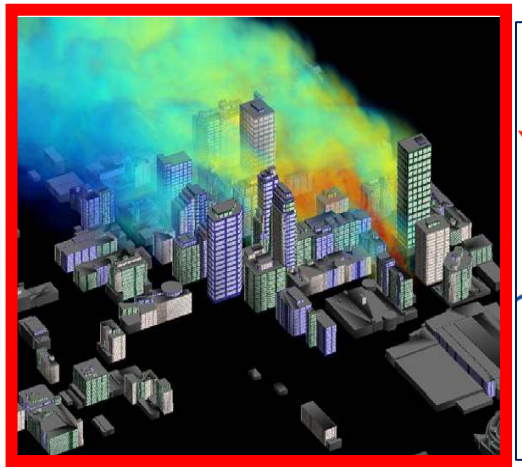
Multi-scale phenomena and interactions

Weather-Climate community

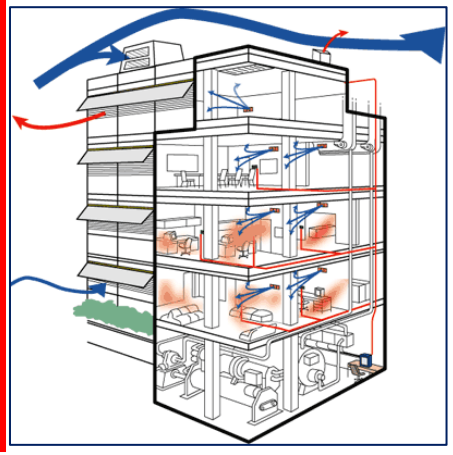


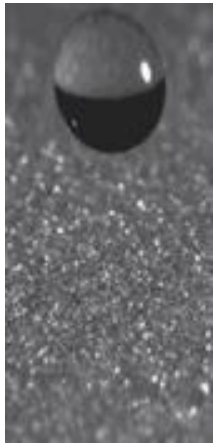


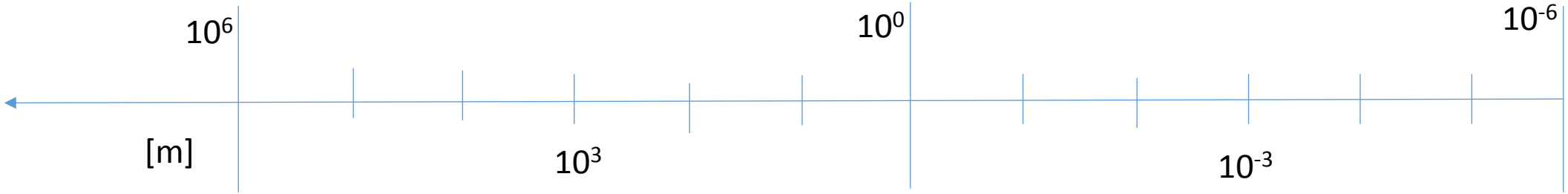
Urban fluid dynamics



Engineering community



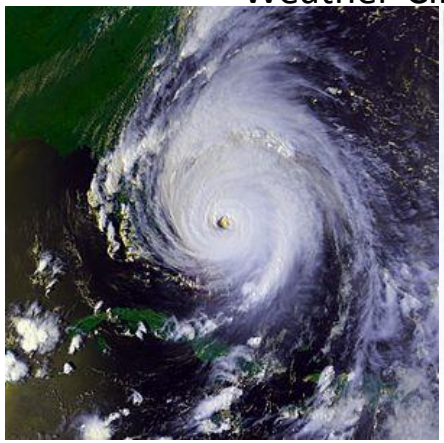


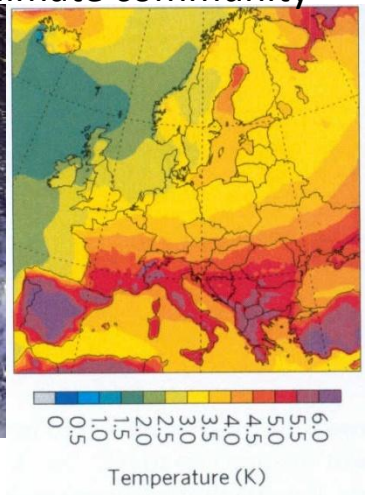


Multi-scale interactions and models

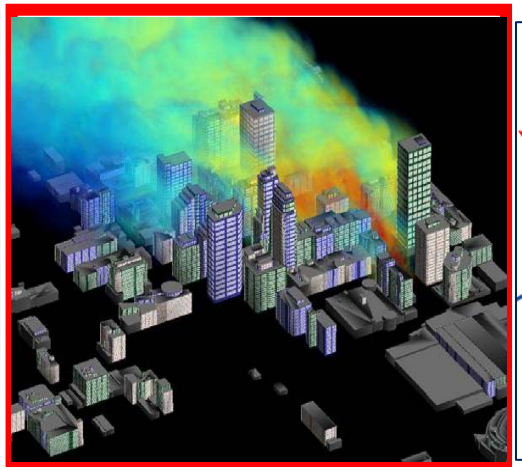
downscaling

Weather-Climate community

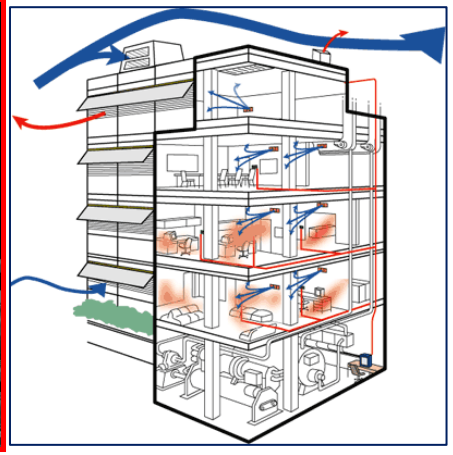


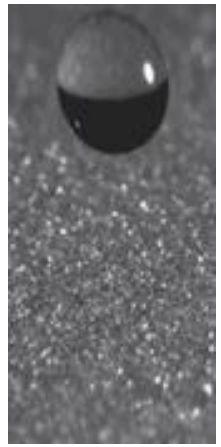


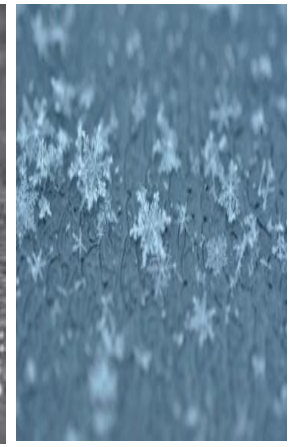
Urban fluid dynamics



Engineering community

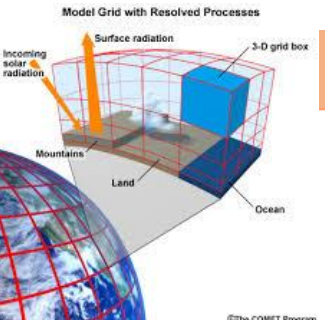






upscaling

10^{6} [m] 10^{3} 10^{0} 10^{-3} 10^{-6}



GCM Global Climate Model Parametrized Scales

RCM Regional Climate Model

Resolved Scales

LES Large Eddy Simulation

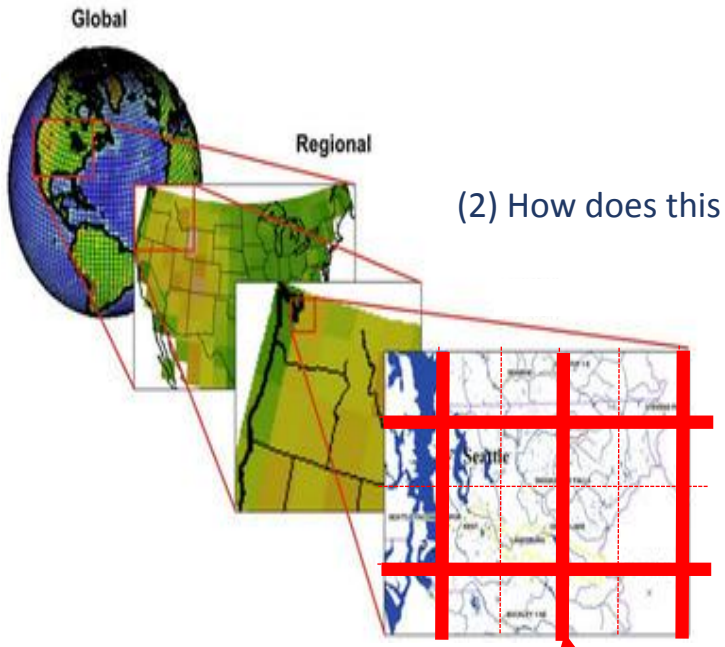
WUDAPT, a worldwide urban database & access portal tools for climate and environmental modeling,

Innovation concepts to reality,

Implications for integrated modeling

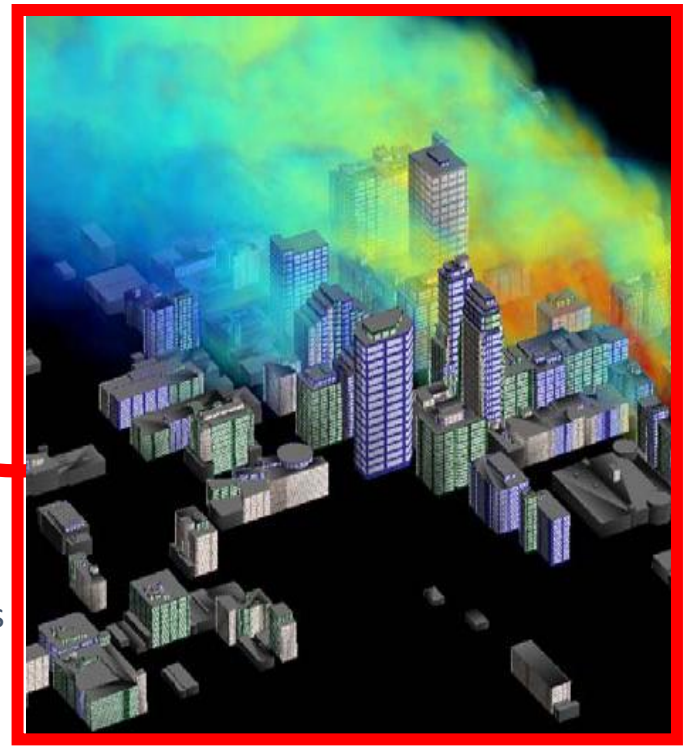
Jason Ching, Gerald Mills, Linda See and collaborators

Motivation for Urban Fluid Dynamics – Open Questions



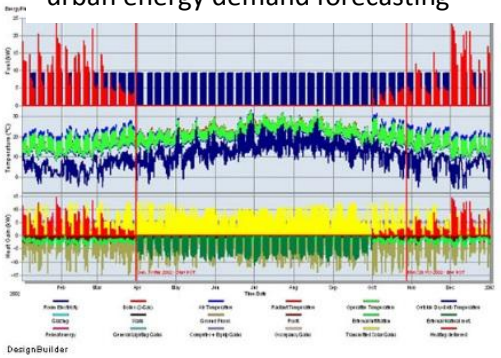
(2) How does this representation change with scale/model resolution

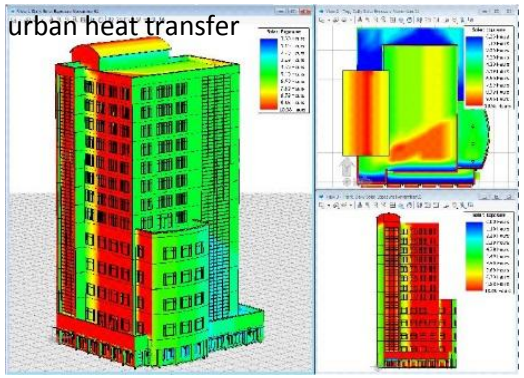
Consistent scale-adaptive and sub-grid scale representations



(1) Macroscopic fluid dynamical feedback of cities into larger scale models

urban energy demand forecasting

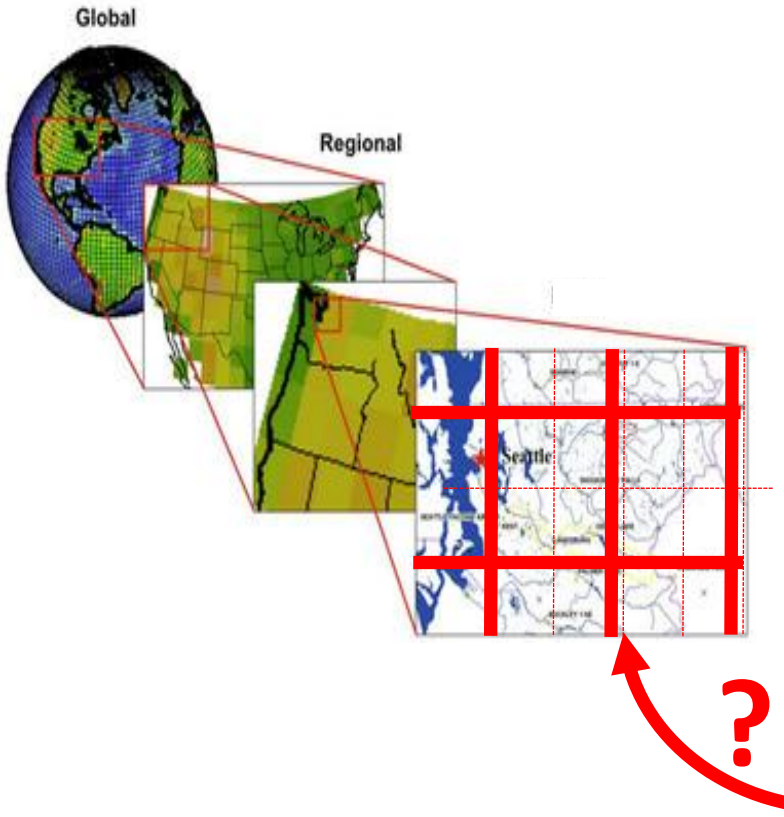




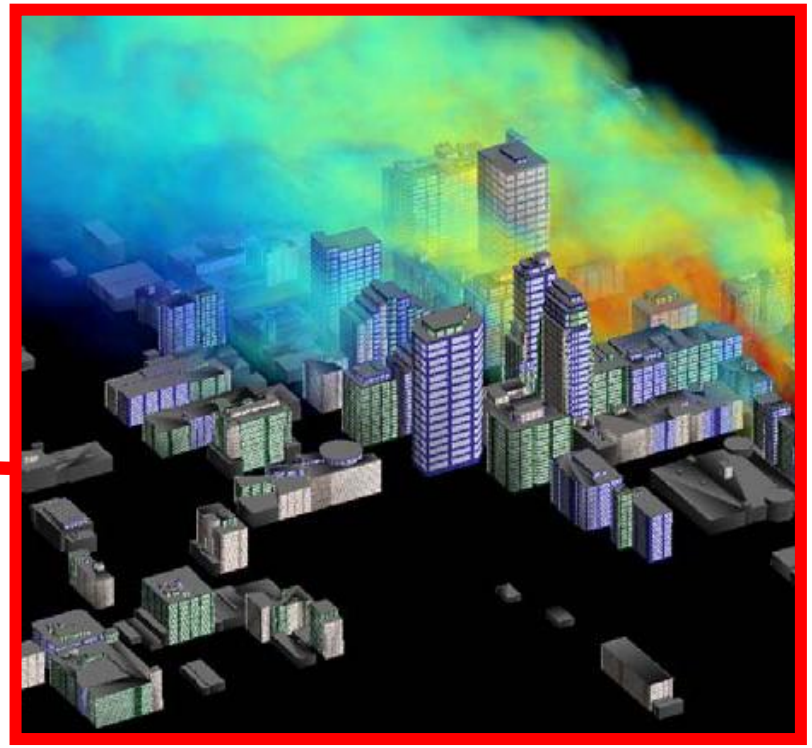
urban wind field

(3) Building unit attributes are determined by local fluid dynamics
e.g. what are the total energy demands for building heating and cooling as a result of the spatial variability of local micro-climate

Motivation



How can we characterize attributes of highly complex geometries with scale-adaptive and spatially varying descriptions, e.g. for model nesting, consistent scale-aware information exchange and appropriate sub-grid scale parameterizations?



Example attributes:
packing density,
Population density,
energy consumption

Presentation Overview

1. Introduction: Background, Motivation, Nature, Context
2. Theory & Methodology: brief overview
3. Preliminary Results
4. Concluding Remarks & Future Work and Challenges

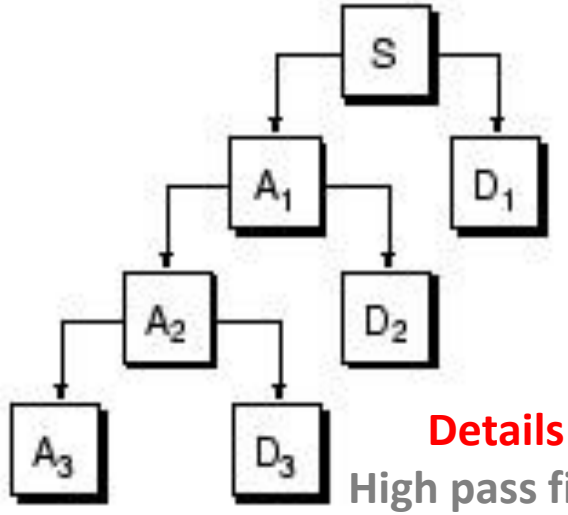
2. Theory & Methodology – brief overview

Multi-Resolution Analysis (Mallat, 2009)

can produce different levels of approximation of an (urban) database,

by decomposing iteratively the "urban signal" into an approximation and a detail

enabling at all times full recovery of the original signal



Approximation
Low pass filter

Details
High pass filter

$$S = A_1 + D_1$$

$$= A_2 + D_2 + D_1$$

$$= A_3 + D_3 + D_2 + D_1$$

Mouzourides, Kyprianou, Neophytou (2013). A scale-adaptive approach for spatially-varying urban morphology characterization in the boundary layer parameterization using Multi-Resolution Analysis. Int. Journal of Boundary-Layer Meteorology, DOI : 10.1007/s10546-013-9848-4

Multi-Resolution Analysis

- MRA repeatedly decomposes a signal $f(x,y)$ to smoother parts at scales $2^n T_s$ producing subsequent multi-scale samples
  - T_s is the sampling distance (or sampling period in spatial variables $\Delta x \Delta y$)
  - n is called decomposition level

Mouzourides, Kyprianou, Neophytou (2013).
A scale-adaptive approach for spatially-varying urban morphology characterization in the boundary layer parameterization using Multi-Resolution Analysis. Boundary-Layer Meteorology, DOI : 10.1007/s10546-013-9848-4

Consequence of MRA axioms (Mallat, 2005)…in mathematical terms:

a Scaling function

$$\phi_{j,n} = \frac{1}{\left(\sqrt{2}\right)^{j}} \phi\left(\frac{t-2^{j} n}{2^{j}}\right)$$

And a Wavelet function exist

$$\psi(t) = \sqrt{2} \sum_{n} g_{n} \phi(2t-n)$$

such that

Producing multi-scale samples and corresponding details

$$f_{j} = f_{j+1} + d_{j+1}$$

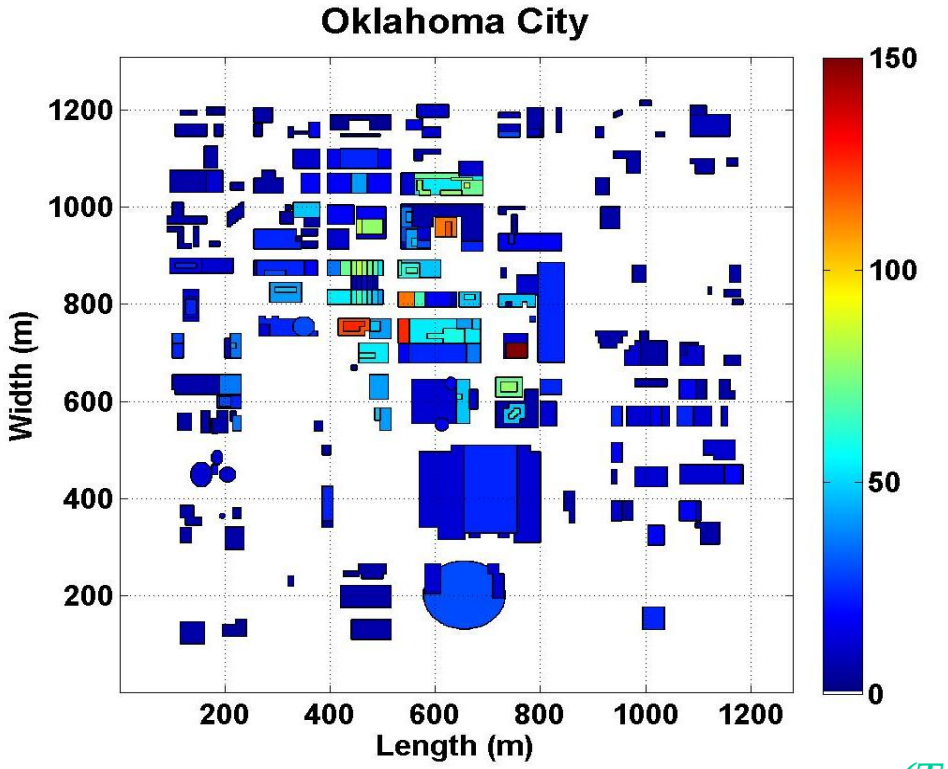
Methodology – Example from a building data set Oklahoma City

Apply 2D MRA to an urban database with building height information, *h=f(x,y)*

A mesoscale grid cell Of size ~1X1 km

Oklahoma City (Google image)

Digitized within-cell signal (height)



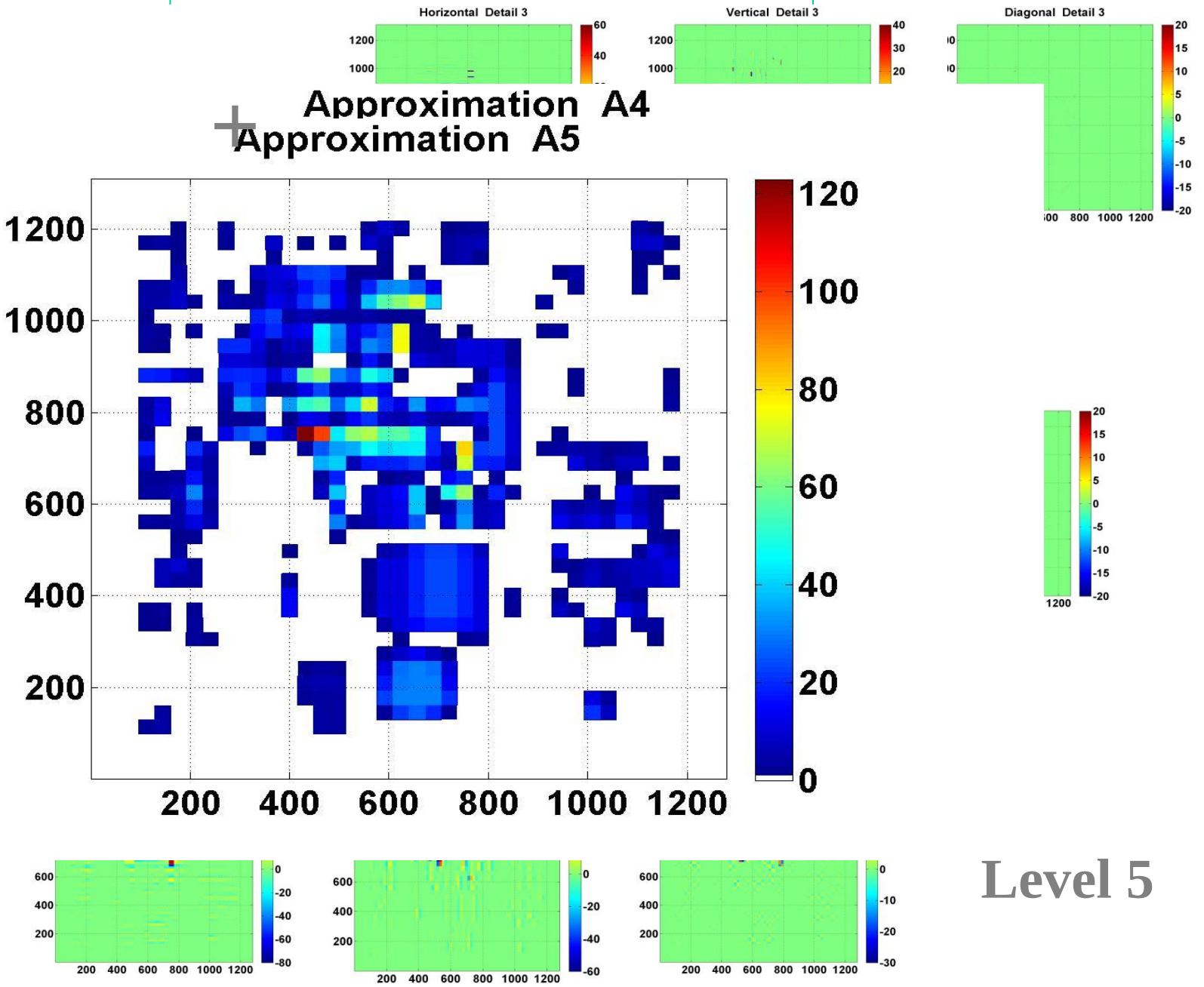
Initial/Original resolution: 1 pixel – 1 m² (T_s)

MRA Analysis

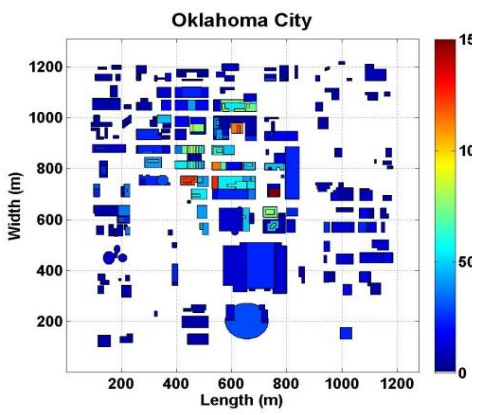
Level 3

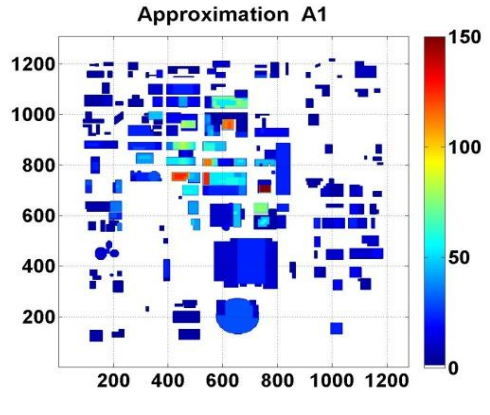
Level 4

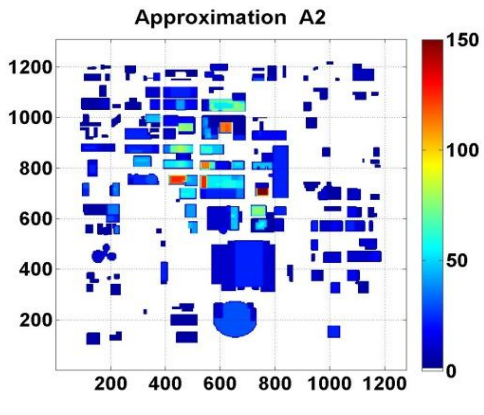
Level 5

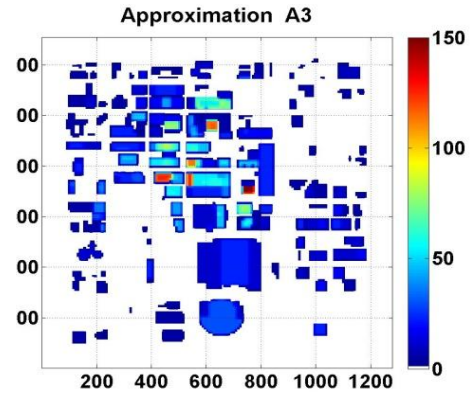


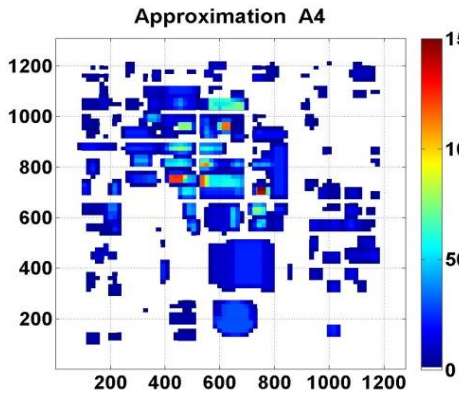
MRA analysis of Oklahoma City (CBD) Building Database Information

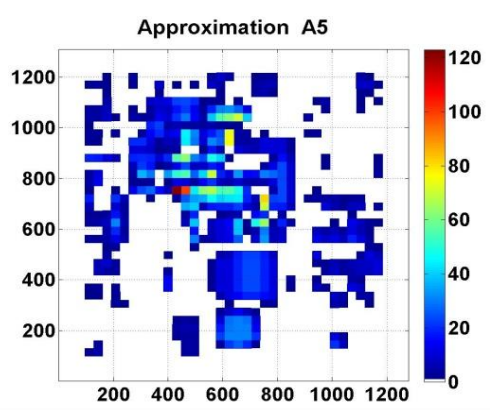


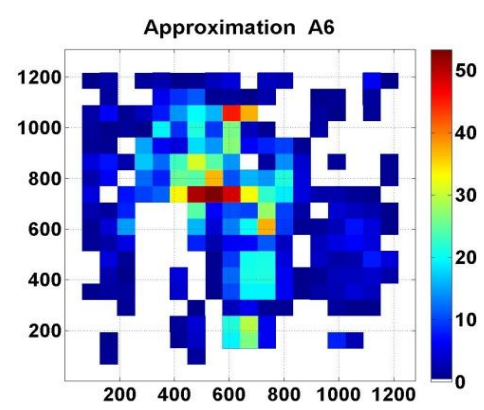


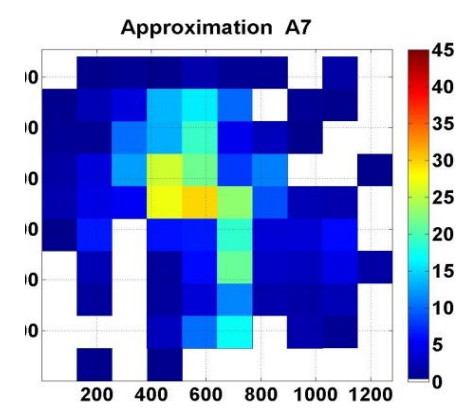


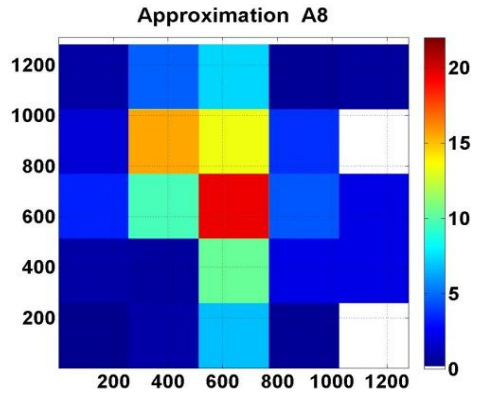


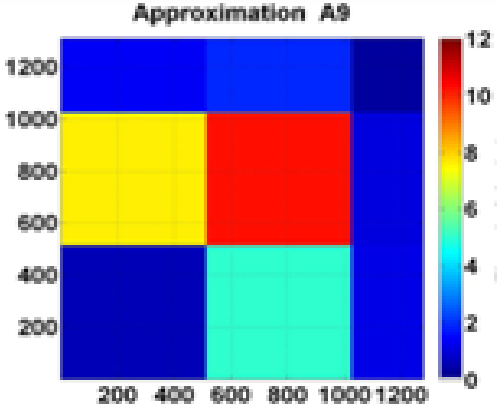


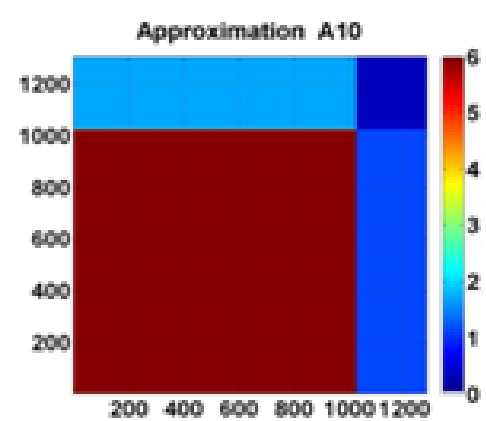




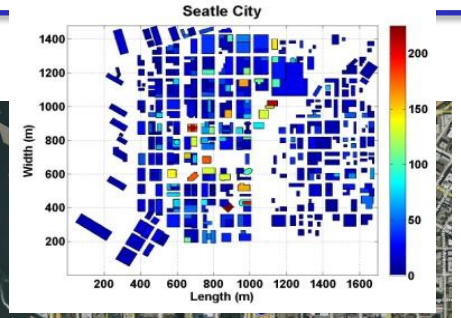






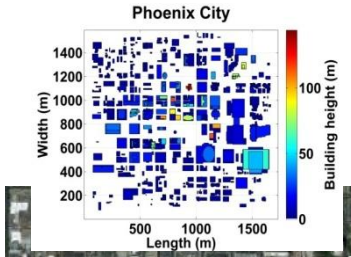


Example: Inter-comparison of Cities



Seattle

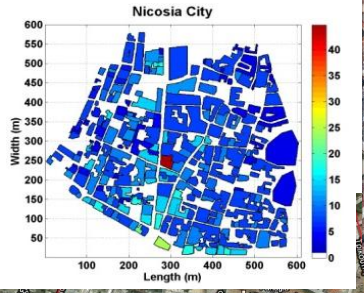
New York

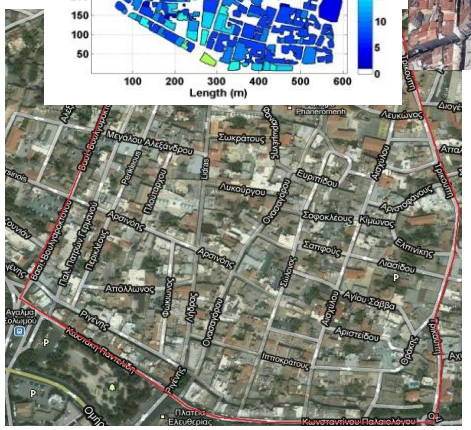


Phoenix

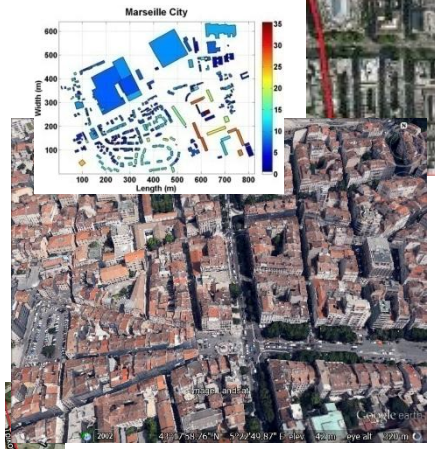
Building height; packing density; roughness

Scale-adaptive characterization of heterogeneity





Nicosia



Marseille

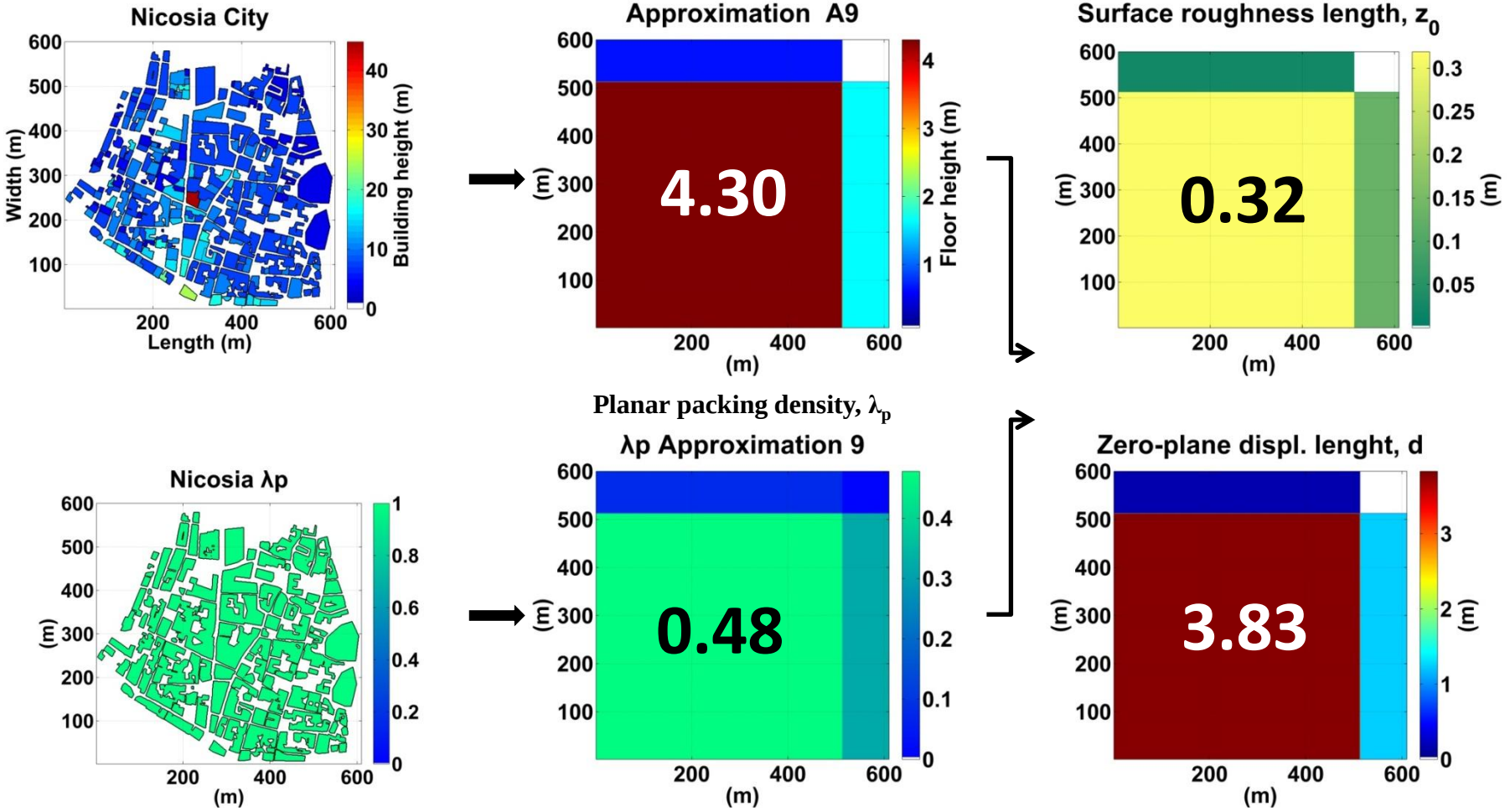
London

Mouzourides, Kyprianou, Carissimo, Choudhary, Brown, Neophytou (2014). Searching for the distinctive signature of a city: Could the MRA provide the DNA of a city? Int. Journal of Urban Climate

Distinctive capacity

MRA deduced results

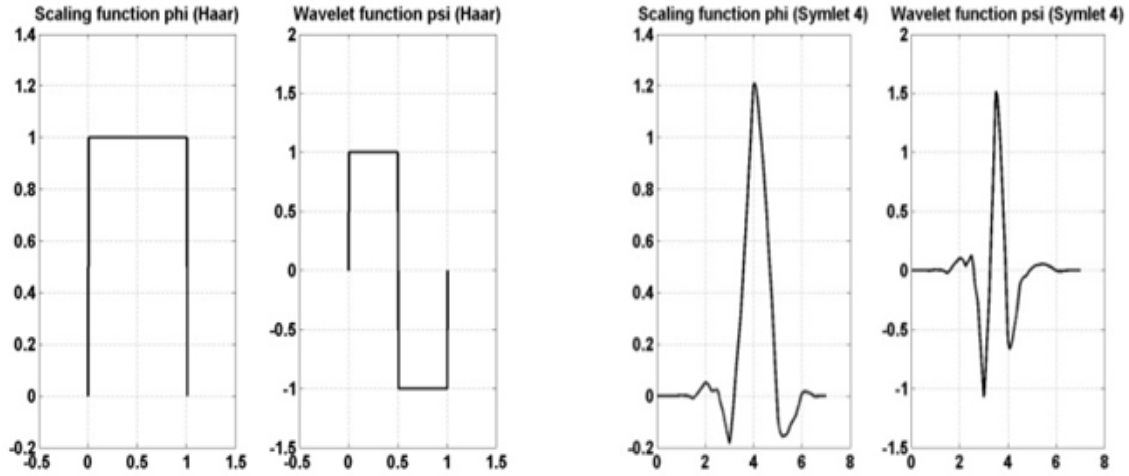
Calculated results
(based on Kastner-Klein and Rotach (2004) model)



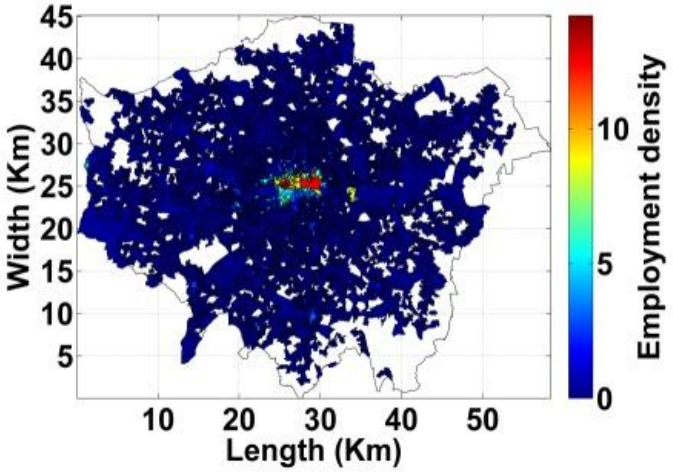
Scaling and Wavelet functions within MRA analysis

-Depending on the nature to be captured e.g. mean or peak characteristics

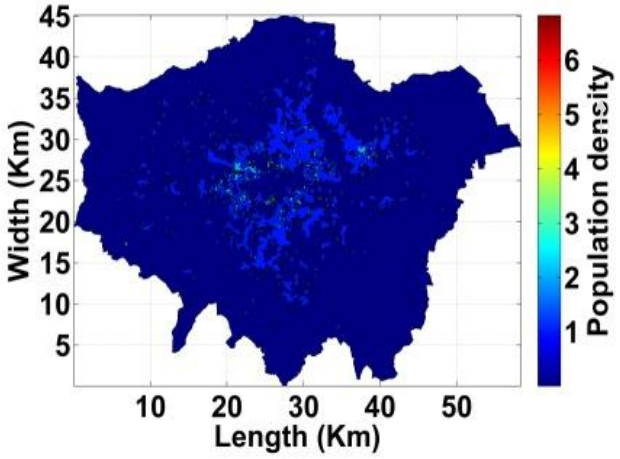
- Time-dependent characteristics



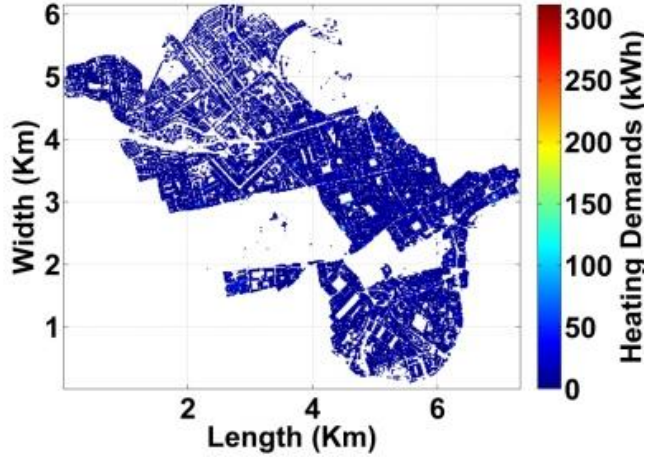
London (UK) and Westminster City Council Data



Employment Density



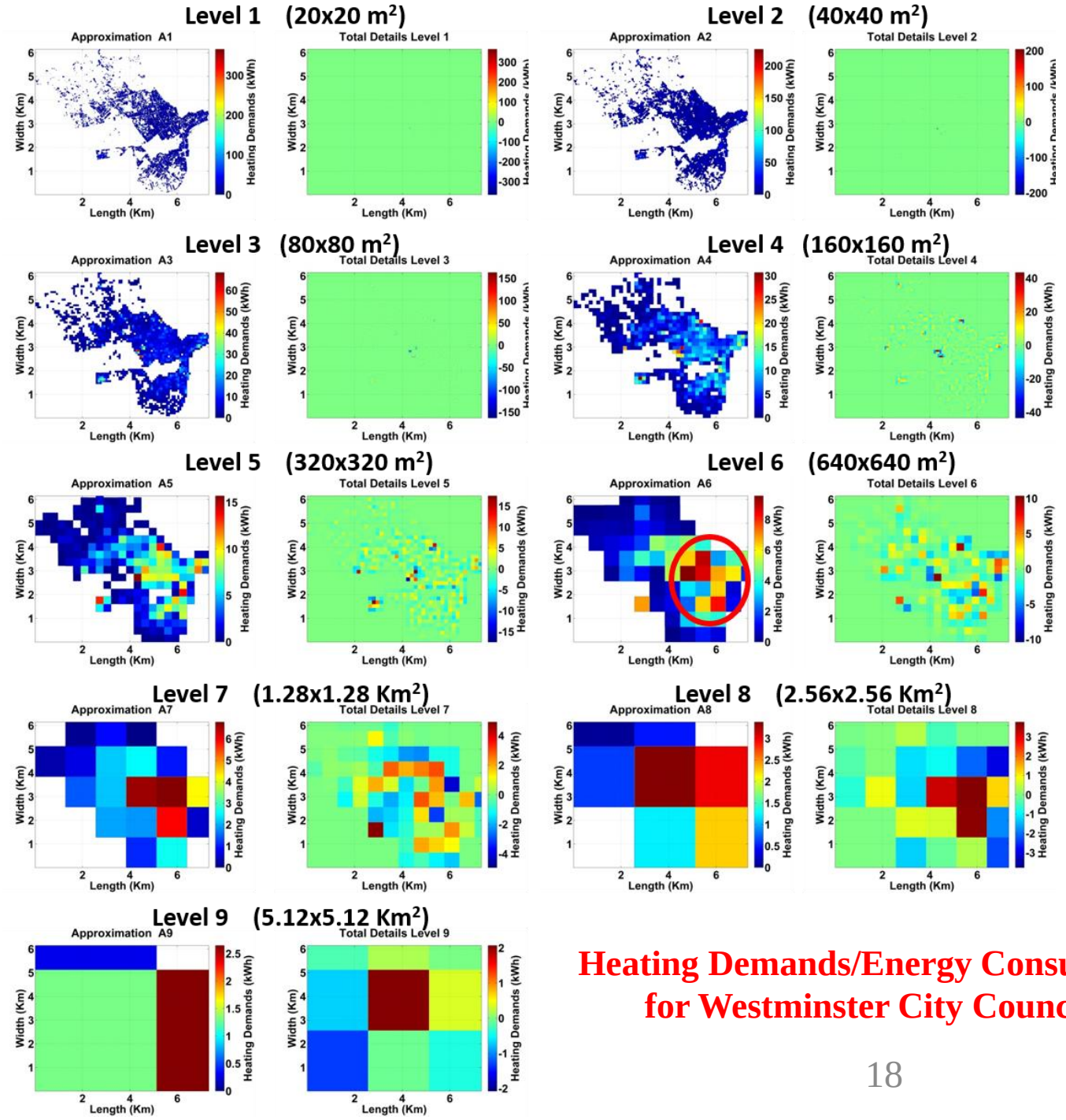
Population Density



Heating Demands/Energy Consumption at 4pm

3. Results

Approximation

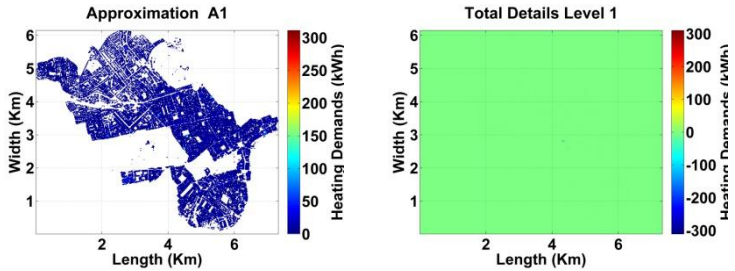


Detail

Heating Demands/Energy Consumption for Westminster City Council at 4am

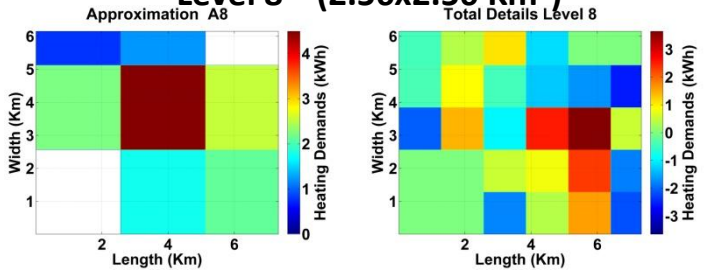
Heating Demands/Energy Consumption for Westminster City Council at 4pm

Level 1 (20x20 m^2)

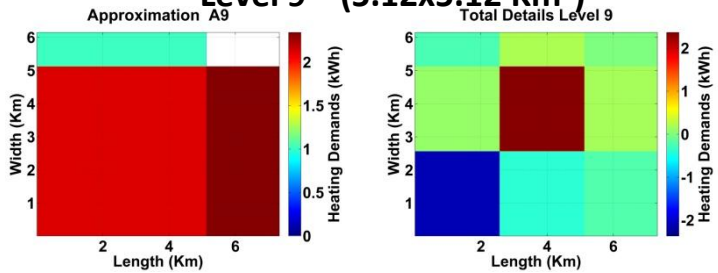


....

Level 8 (2.56x2.56 Km^2)



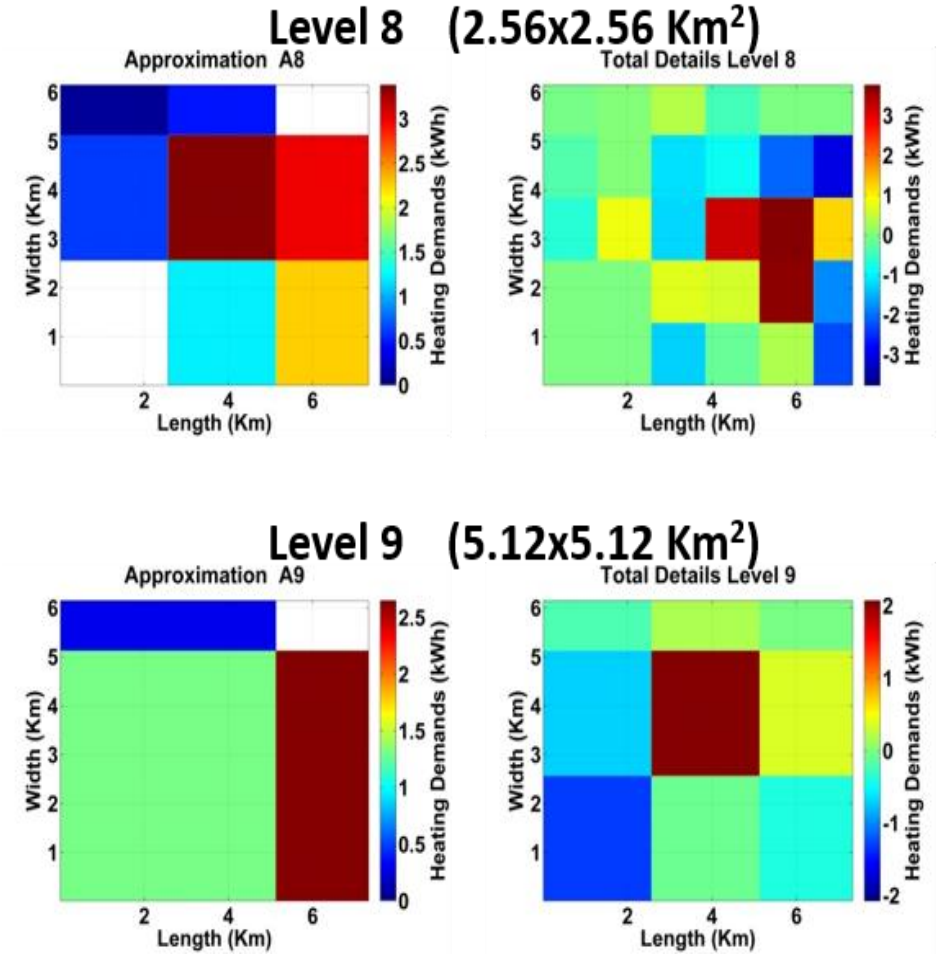
Level 9 (5.12x5.12 Km^2)



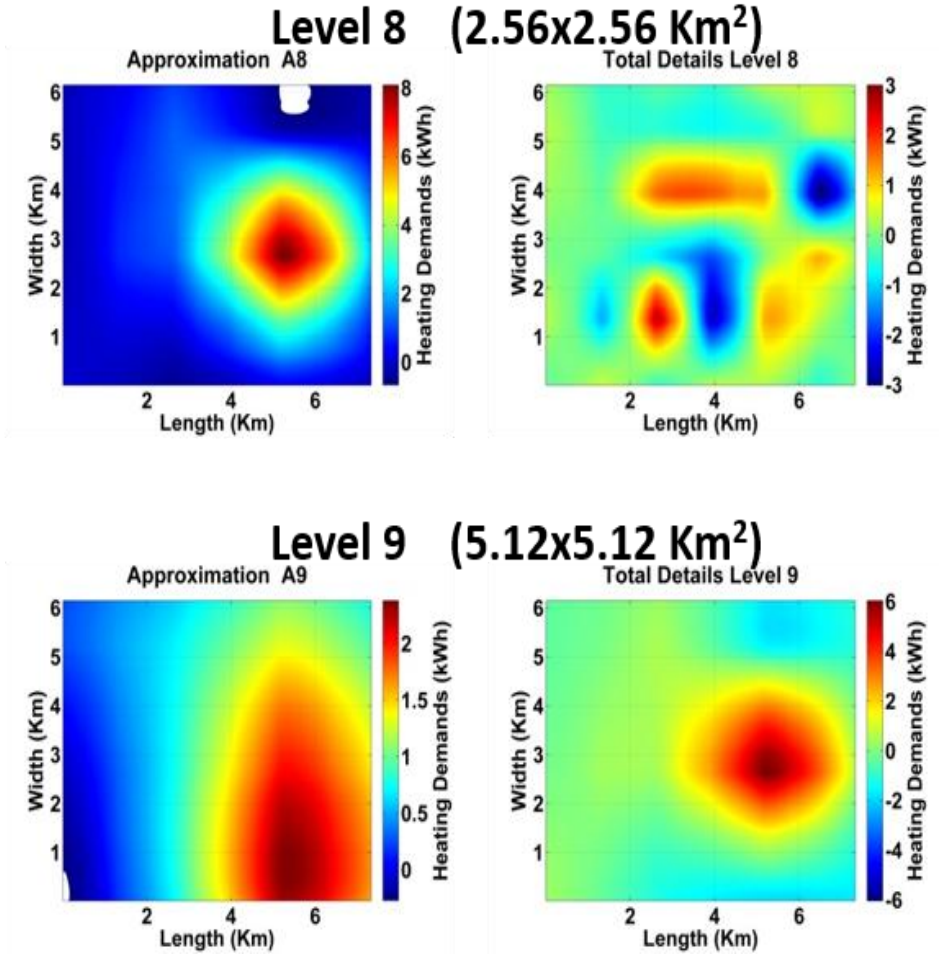
Scale-adaptive representations and associated sub-grid information

Heating Demands at 4am (kWh) in London Westminster Borough

Effect of MRA function - mean versus peak characteristics



Haar scaling and wavelet function



Symlet4 scaling and wavelet function

4. Conclusions & Future Work

-Rigorous and consistent scale-adaptive representations are obtained

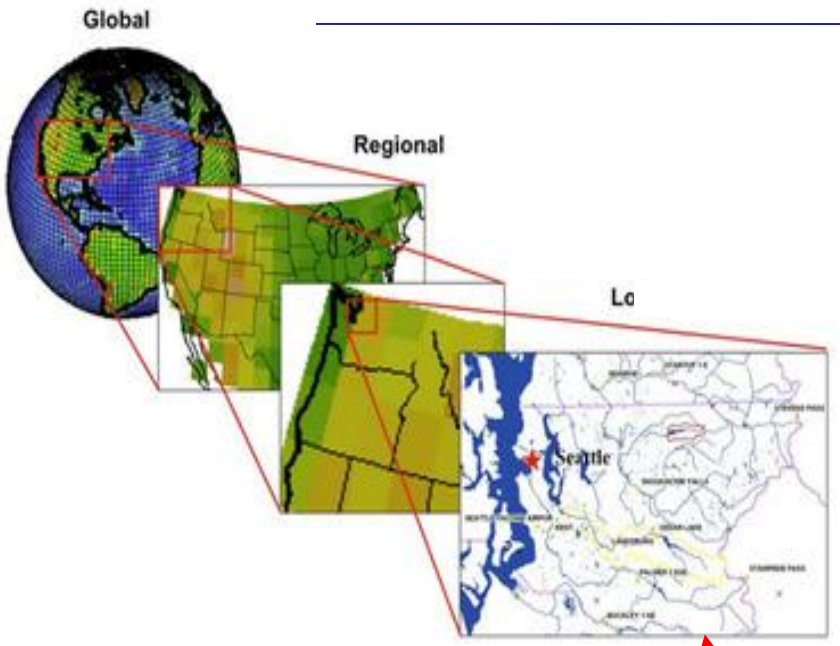
-Spatial inhomogeneity is enabled
-Different natures (mean vs peak values) can be captured

- the analysis enables a city (or urban database) to retain its distinctive signature/identity

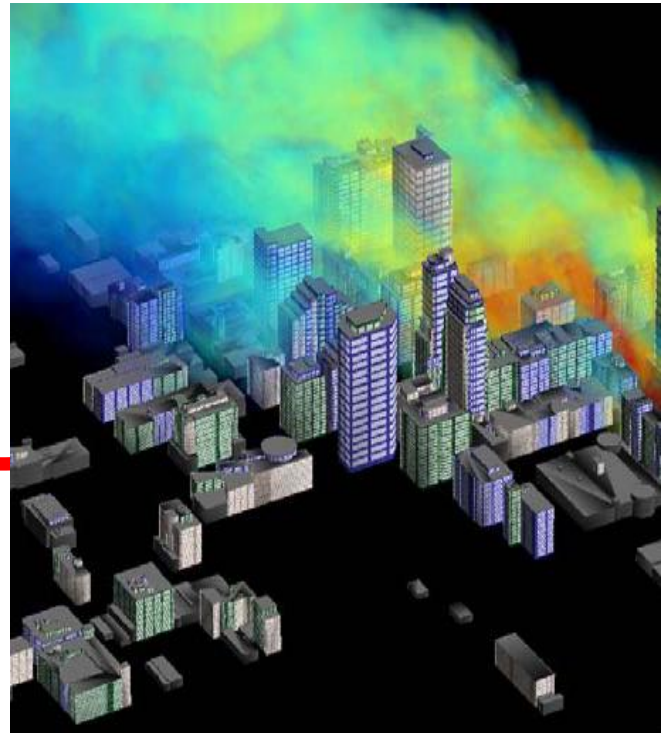
→ **hence the DNA of a city!**

Mouzourides, Kyprianou, **Neophytou** (2013). A scale-adaptive approach for spatially-varying urban morphology characterization in the boundary layer parameterization using Multi-Resolution Analysis**.** Int. Journal of *Boundary-Layer Meteorology,* DOI : 10.1007/s10546-013-9848-4

4. Conclusions & Future Work



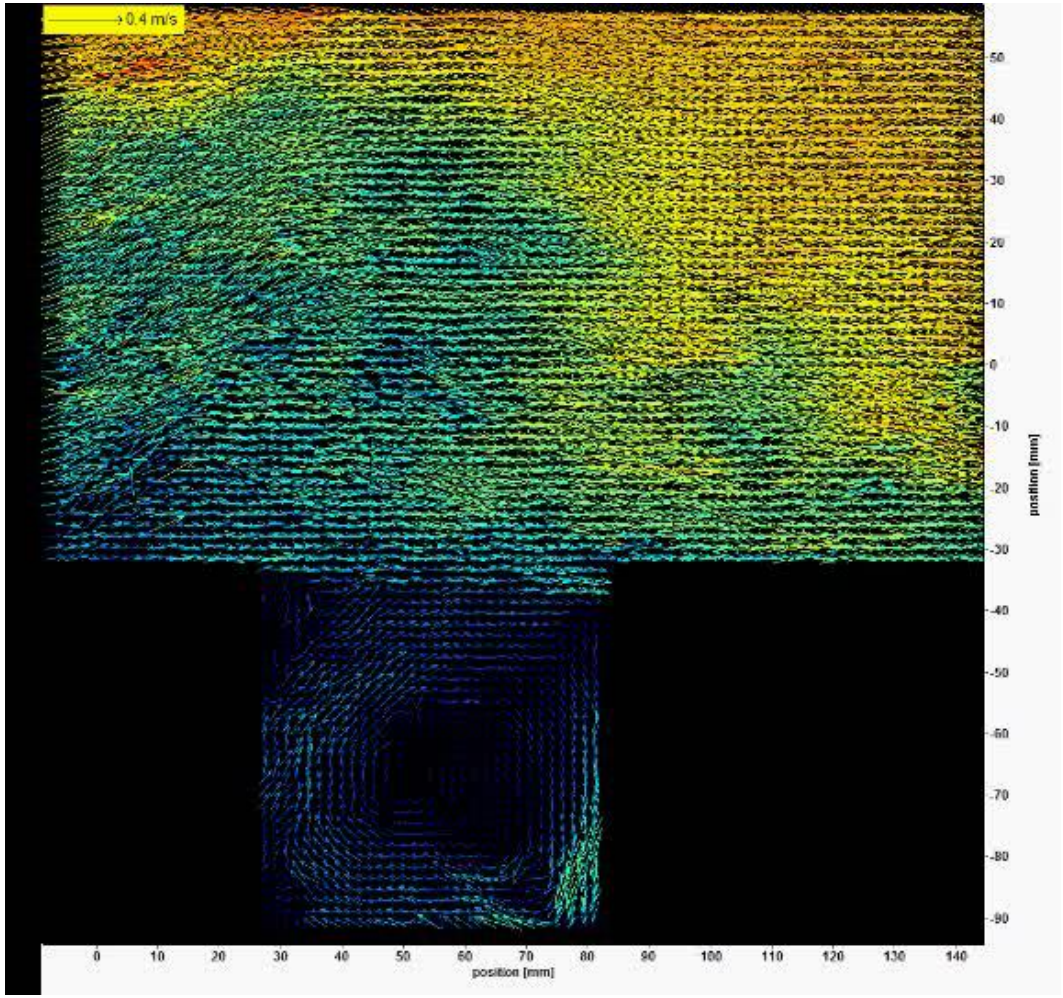
-WUDAPT and WRF modelling applications are under design
to illustrate the impact of MRA consistent scale-adaptive representations
- Coupling of urban-scale models with Building Energy Models to illustrate the Capacity to retrieve the details if needed



Mouzourides, Kyprianou, **Neophytou** (2014). Searching for the distinctive signature of a city: Could the MRA provide the DNA of a city? Int. Journal of *Urban Climate (online)*

Further applications: coupling knowledge from idealized lab experiments

Extraction of dynamic characteristics: e.g. exchange and breathability variation with packing density

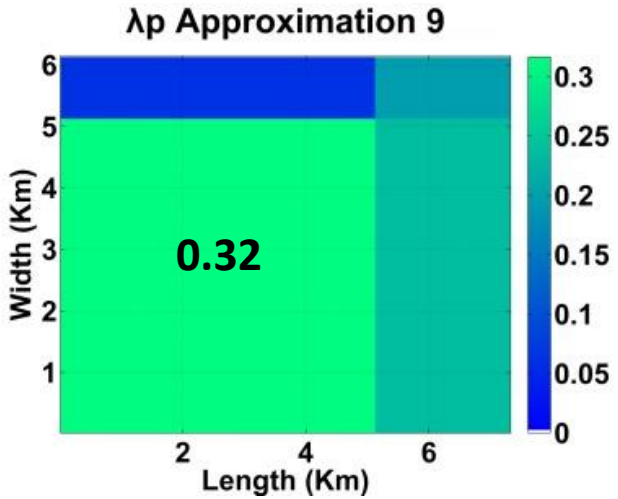


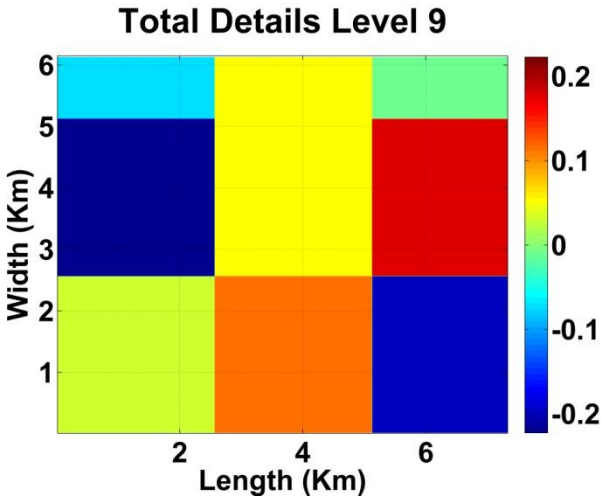
Neophytou, Markides, Fokaides (2014):
An experimental study of the flow through and over two dimensional rectangular roughness elements: Deductions for urban boundary layer parameterizations and exchange processes. Physics of Fluids ***26****, 086603*

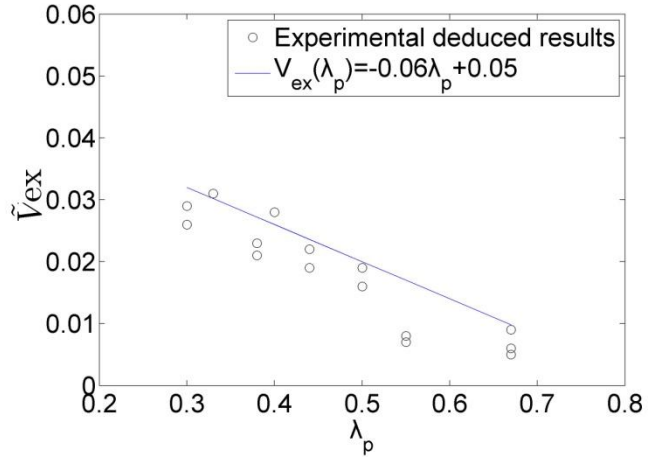
Examples of further applications (for tailored policy – making) :

Westminster's Breathability

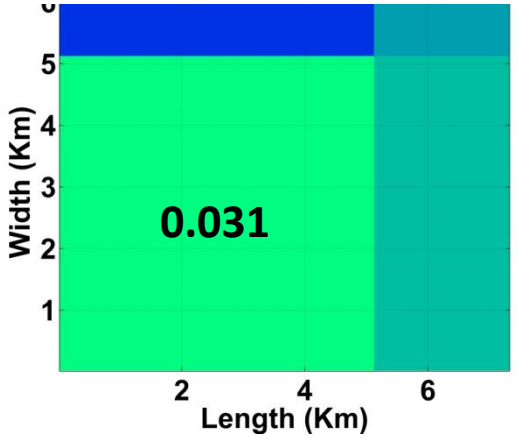
Level 9 (5.12x5.12 Km^2)







Normalized exchange velocity



Thank you!