Modeling the impact of future development pathways in a mid-latitude city on the urban energy balance

Paul John Alexander[1]*, Rowan Fealy[2] & Gerald Mills[3]

***paul.alexander@nuim.ie**

[1] Irish Climate Analysis & Research Units, Maynooth University, Ireland
[2] Department of Geography, Maynooth University, Ireland
[3] School of Geography, Planning & Environmental Policy, University College Dublin, Ireland

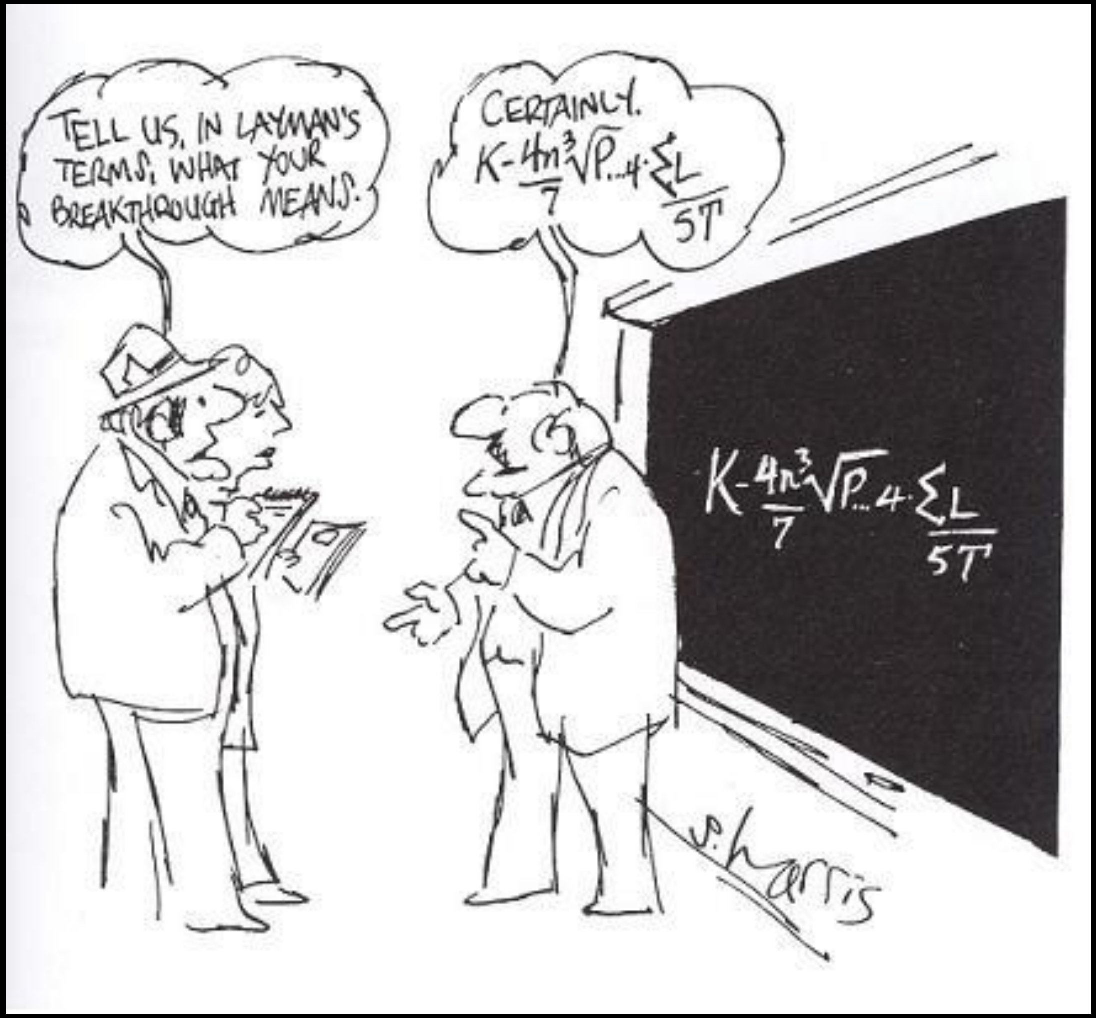
Context

- **Incorporating climate knowledge into urban decision-making will be an important component in planning and creating more sustainable cities since urban form once developed becomes fixed**
- Within the urban climate community a move towards greater integration with planning & environmental policy arenas - see for example, Adler & Kern (2008)
    - *Establishing* ***science-policy*** *capacity and other policy relevant research to support timely and cost-effective adaptation and mitigation decisions at local scale* ***is essential*** *for regional capacity to assess, design and implement policies.*

      - Morlot et al., (2009) OECD environmental report
- **In this respect, urban climate models (UCMs) are a potentially valuable tool for evaluating some of the impacts of different urban designs, land use, population densities and activities on the surface energy and water balances and the consequent effects on the local atmosphere and hydrology, respectively.**

Context

- However urban climate modeling for this problem are scarce in terms of application
  - Differences in nomenclature, scale, objectives, fiscal and social priorities
  - Dubious as to the value of models ‘knowledge circulation failure’ (Hebbert and MacKillop, 2013)
  - Perceived lack of expertise (Eliasson, 2000 - The use of climate knowledge in urban planning *Landscape and Urban Planning* 38(1) 31-44)
  - Data starvation



WUDAPT

World Urban Database

Home | Events | Local Climate Zones | Papers | Want to get involved?

WUDAPT WORKSHOP AT ICUC9

We are holding a WUDAPT workshop at ICUC9 in Toulouse France on Wed 22 July (16.00 to 18.00). During this workshop you will learn more about how to create a Local Climate Zone (LCZ) classification of your city or any city of interest worldwide. If you are interested in attending, please register at this site.

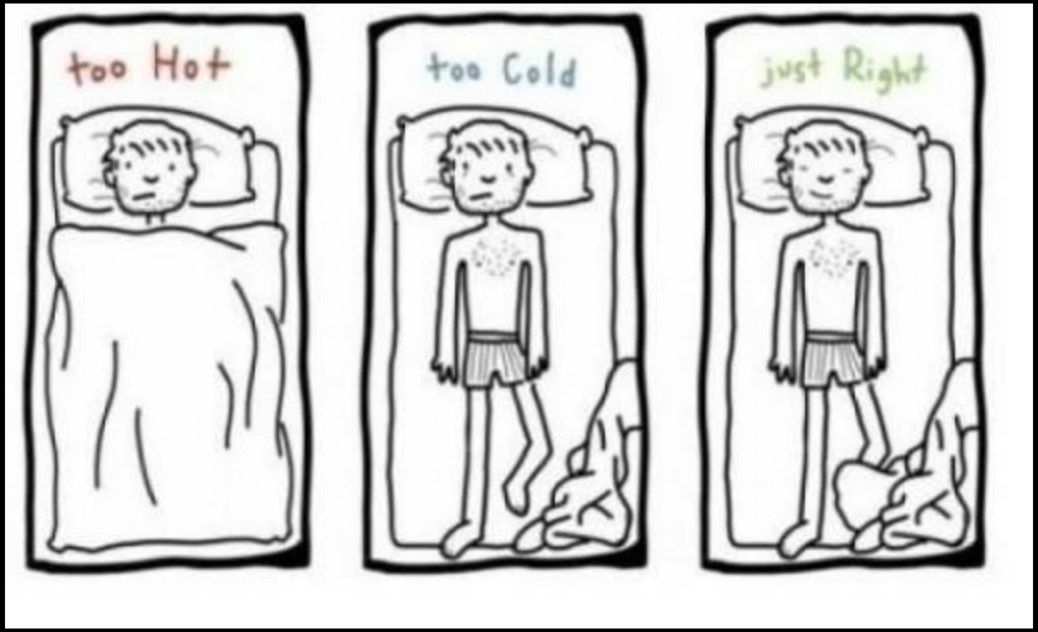
We intend to have two streams to the workshop:

- a demonstration stream
- a more hands-on stream for those wanting to create an LCZ classification during the two-hour session. This second stream will require some pre-workshop preparation but we will guide you through this process.

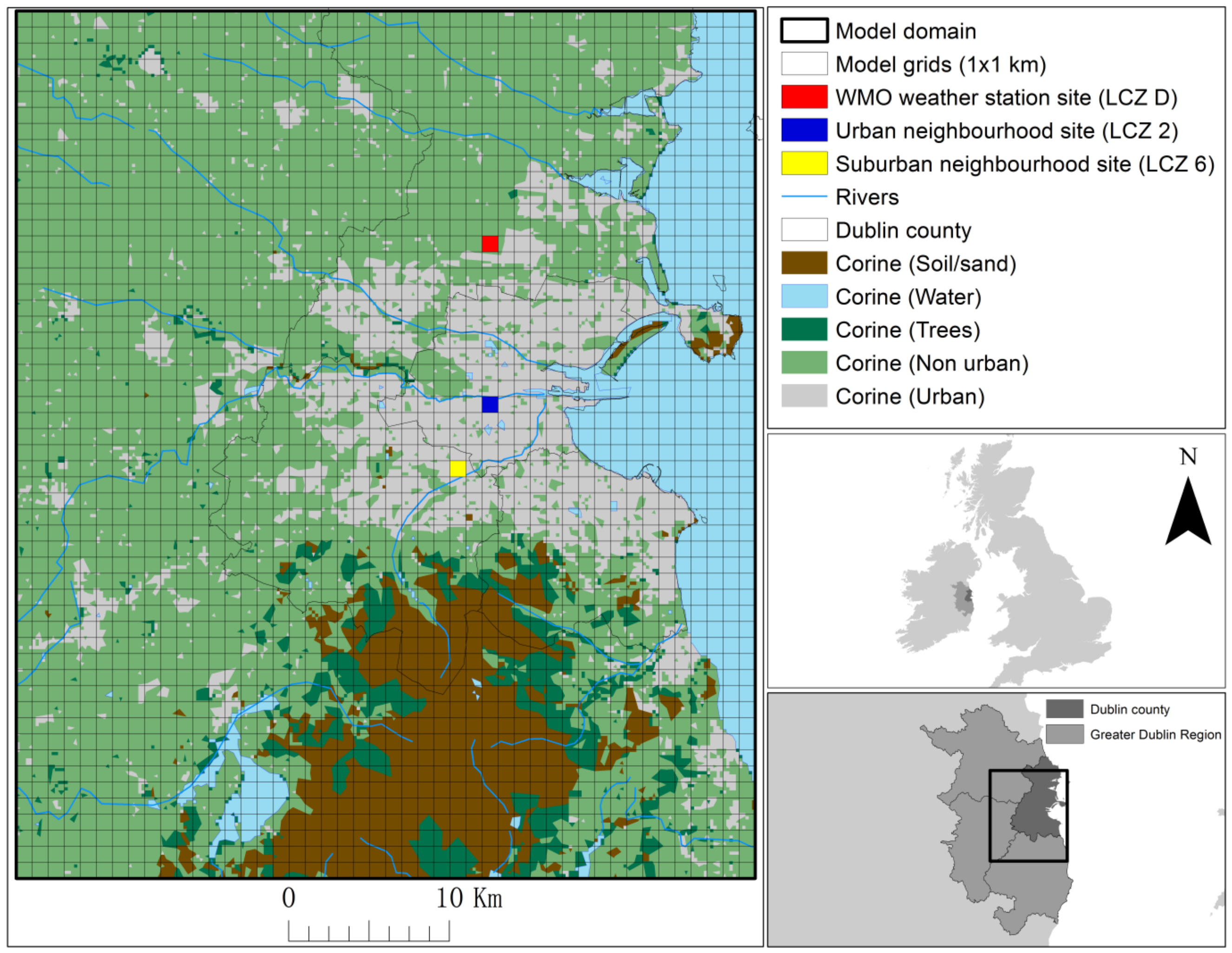
We are particularly interested in classifying the C40 cities. Let us know if you want to be involved in this particular initiative.

In this work

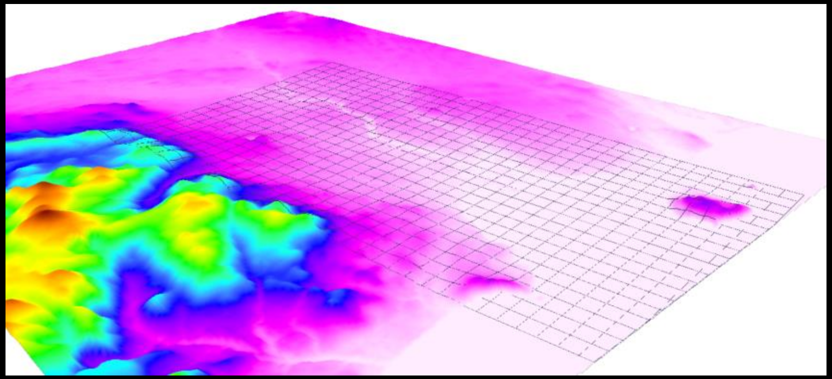
- We Propose to use LCZ as a basis to establish a common language / understanding to explore potential climatic consequences of different planning / policy choices



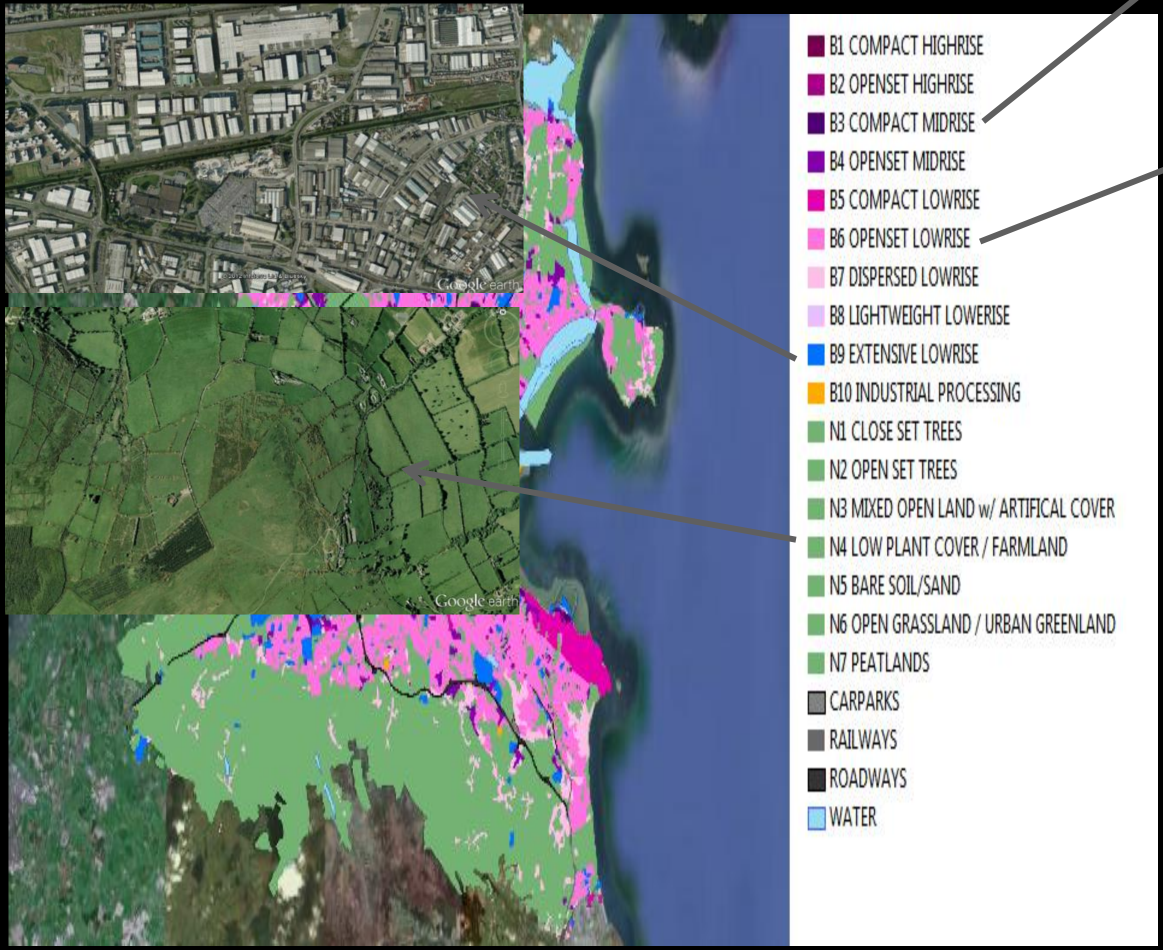
Methods



- Study area: Dublin City ~24x44 km grid domain (~1x1 km)
- Meteorological Forcing from a Typical Climatological Year
- Land cover from MOLAND / LCZ



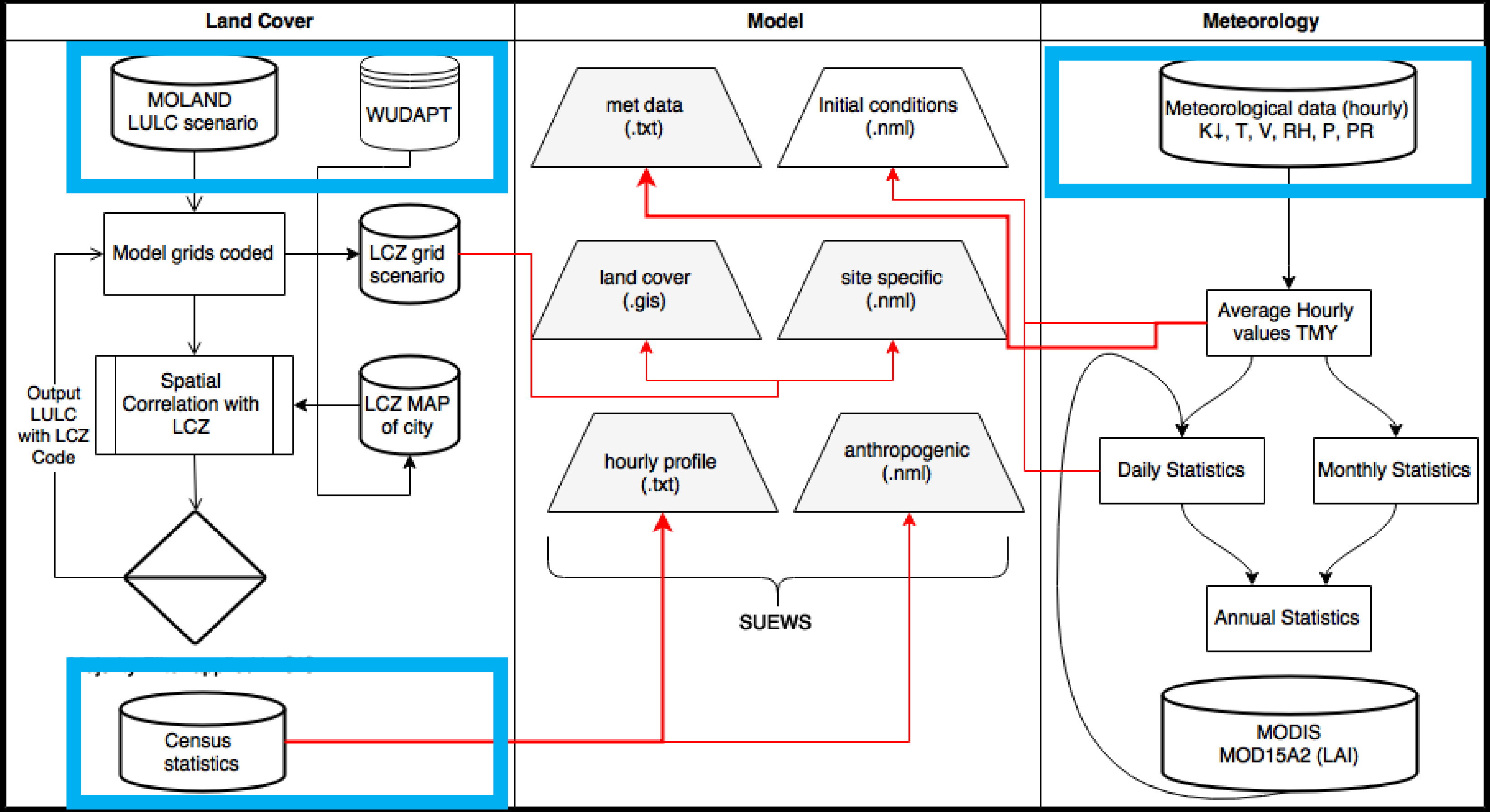
Methods



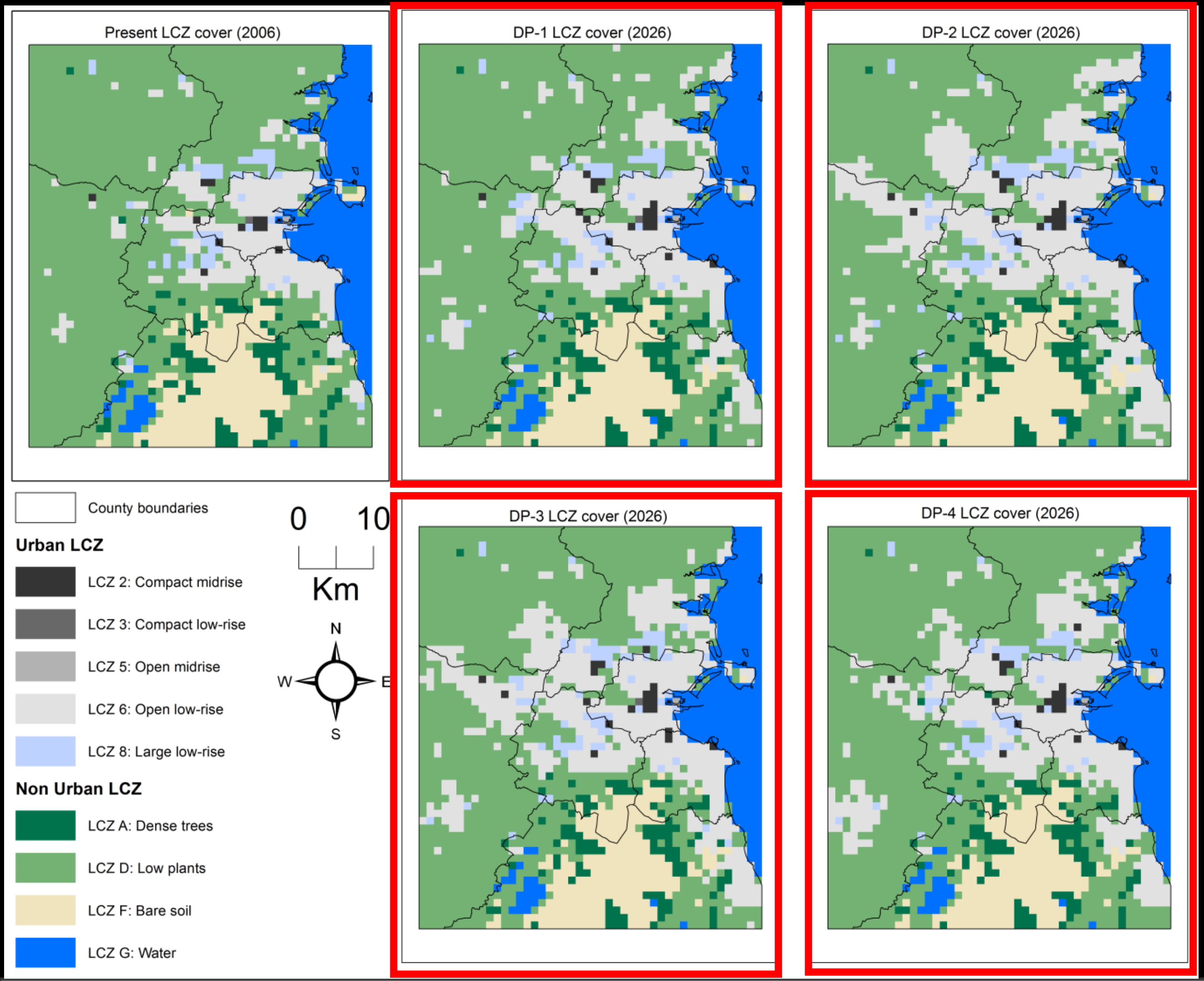
- Example of high resolution LCZ map and LCZ classes for Dublin
- Resampled to 1x1 Km (previous slide) based on majority rule
- Correlated with MOLAND LULC
- Fractional coverage + z parameters for each land cover class calculated for SUEWS
  - Alexander & Mills (2015)
- *Technically* level 1 data

LCZ	Built	Impervious	Unmanaged	Trees	Grass	Water	(n)
2 Compact Mid	33	55	0	6	6	0	5
3 Compact Low	22	61	0	7	10	0	5
5 Open Mid	13	48	0	11	28	0	5
6 Open Low	14	52	0	11	23	0	10
8 Large Low	30	61	0	4	5	0	5
10 Industrial	16	69	0	8	7	0	5
101 Close Trees	1	2	4	48	45	0	5
104 Low Plant	3	8	3	18	67	0	10
105 Bare Rock	9	49	0	14	29	0	2
106 Bare Sand	6	20	55	19	0	0	1
107 Water	0	0	0	0	0	100	---

Methods

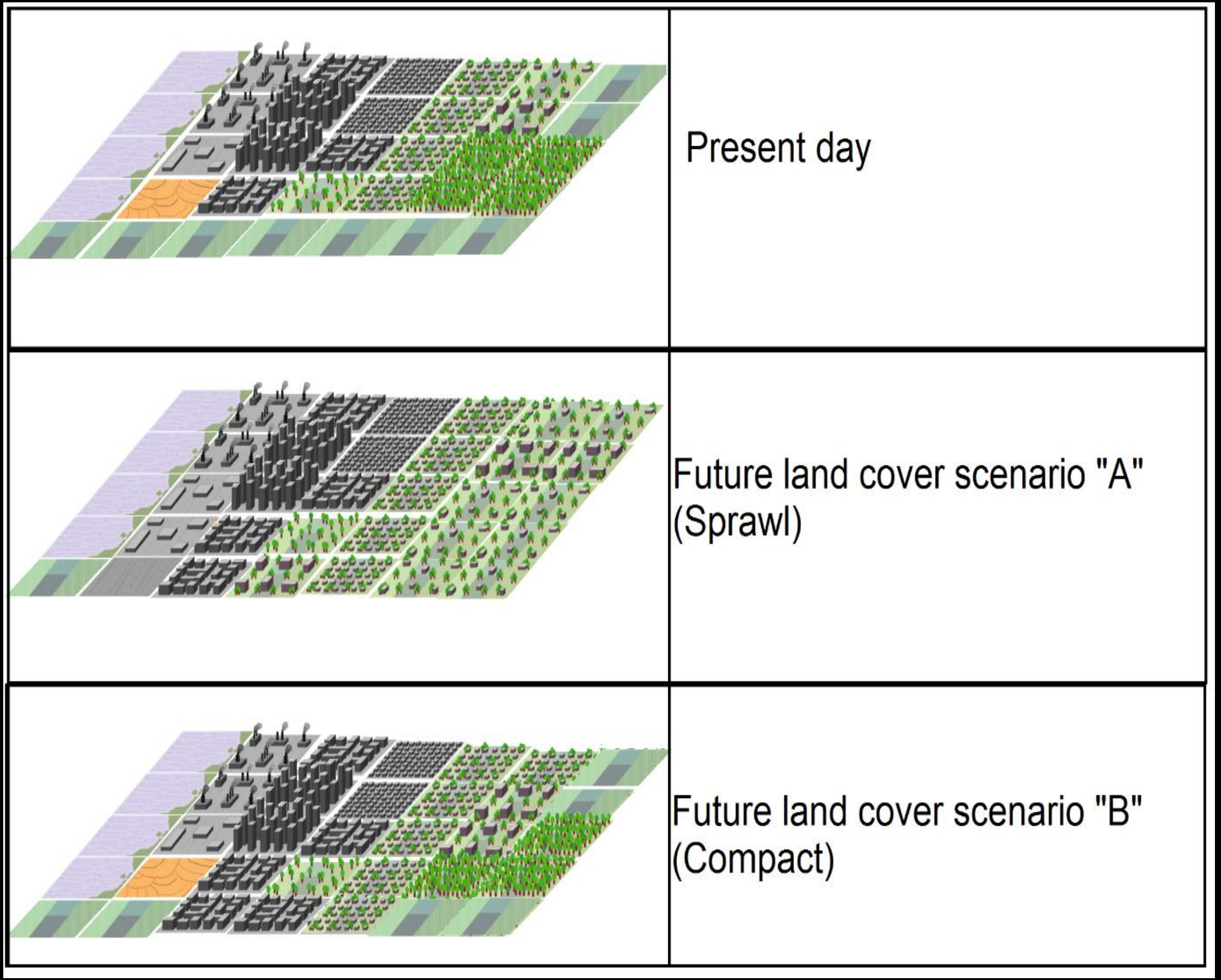

Land Cover
Model
Meteorology
MOLAND
LULC scenario
WUDAPT
Model grids coded
LCZ grid
scenario
Spatial
Correlation with
LCZ
LCZ MAP
of city
Output
LULC
with LCZ
Code
Census
statistics
met data
(.txt)
Initial conditions
(.nml)
land cover
(.gis)
site specific
(.nml)
hourly profile
(.txt)
anthropogenic
(.nml)
SUEWS
Meteorological data (hourly)
K↓, T, V, RH, P, PR
Average Hourly
values TMY
Daily Statistics
Monthly Statistics
Annual Statistics
MODIS
MOD15A2 (LAI)

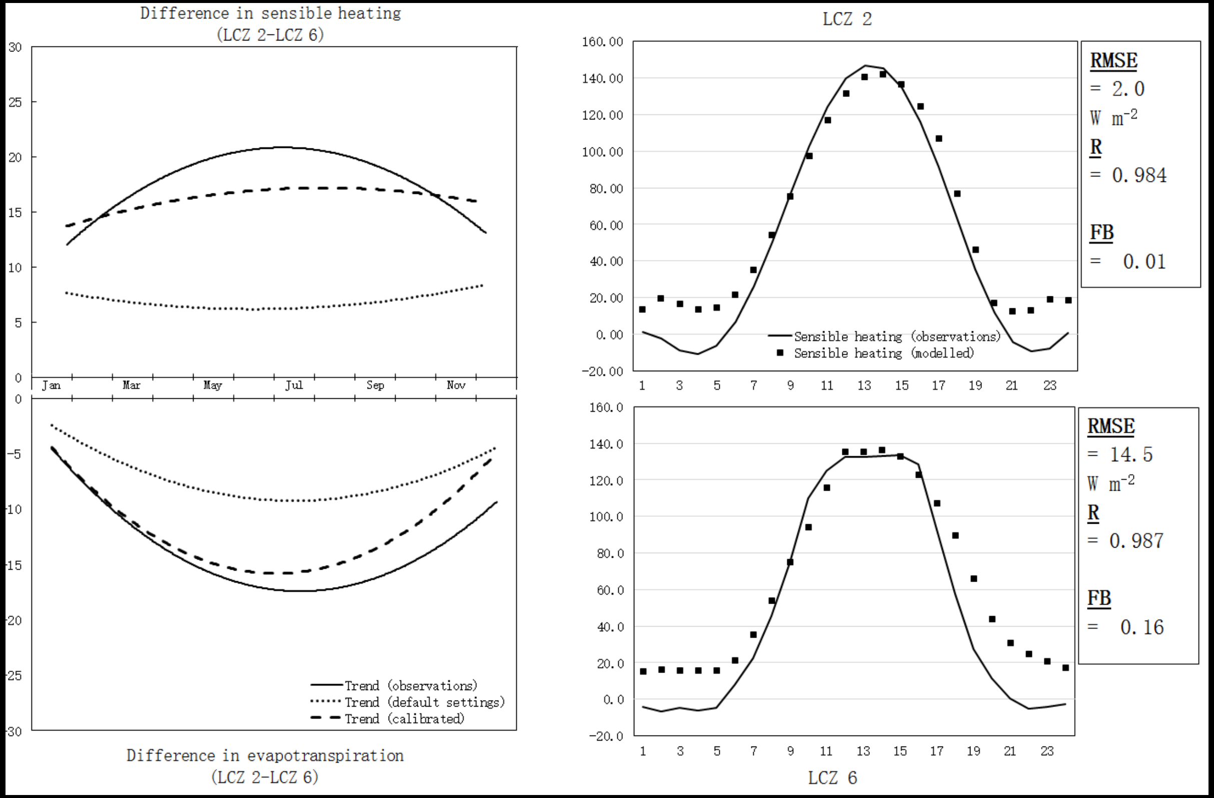
Methods



Scenario short name	Alias	Description	Urban Extent
DP-1	Business as usual	As the alias suggests, this scenario explores a continuation of the current, dispersed settlement patterns. Therefore simulates a "business as usual" future, whereby implementation of pre-existing development policies have been weak. Reflecting the current economic climate, several transportation projects are delayed in this scenario until 2020. With the divergence of policy and practice concerning Green Belts in mind, this scenario does not contain a greenbelt layer as outlined in Brennan et al. (2009).	19.8% (+6.1%)
DP-2	Undirected sprawl	In this scenario development is strongly directed toward an expanded metropolitan footprint (MF), which is extended along key transport corridors. Strictly enforced Strategic Green Belts are used to discourage excessive development in rural areas and link protected areas together. Two types of Green Belts were created; large Outer Green Belts designed to designate areas where development should be kept to a minimum; and smaller Connector Green Belts, designed to preserve links between urban green space and rural areas.	25.8% (+12.1%)
DP-3	Directed Sprawl	This scenario explores a strong consolidation policy, whereby growth was focused within the existing envelope of the MF and towards a limited number of key towns in the Hinterland. Increased densities were delivered by infilling areas within the MF and in the main towns of the Hinterland. Green Belts were more extensive and strategically placed than DP-2.	25.4% (+11.7%)
DP-4	Densificati-on	In this scenario, consolidation is promoted, development is focused within the existing MF and development centres. Growth in the Mid-East at public transport nodes within the MF and in designated towns on high quality public transport routes. Although densification within the existing MF was a focus of this scenario, there was a drive to keep towns distinct from one another.	23.2% (+9.5%)

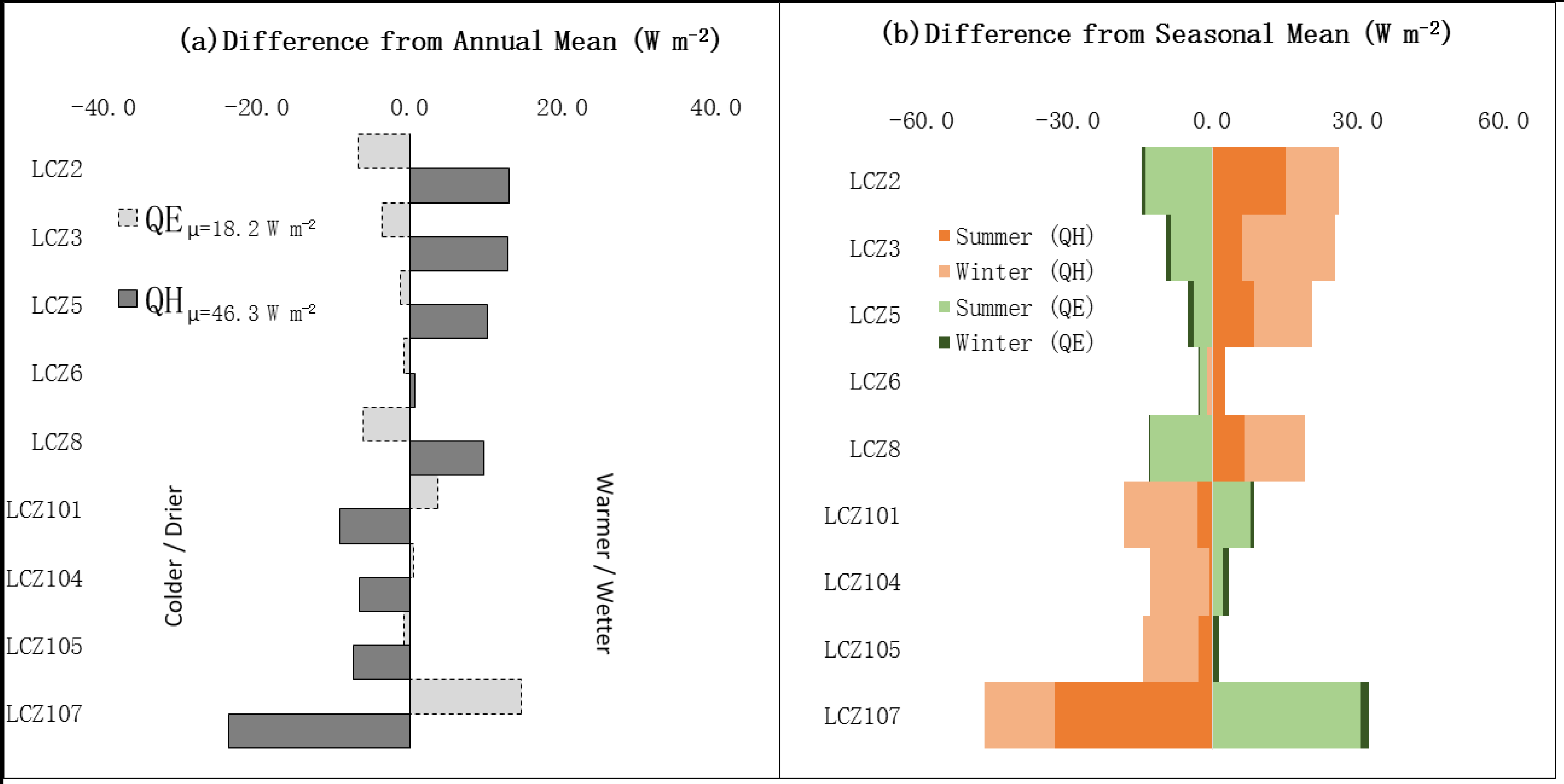
Methods – *proviso*

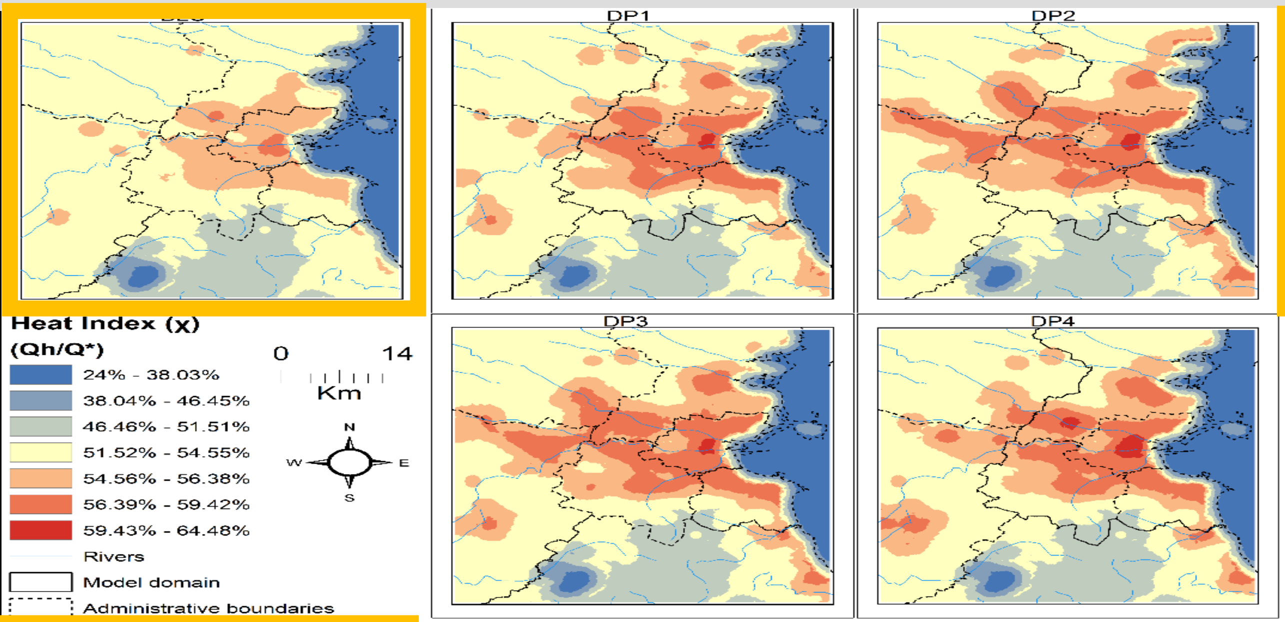


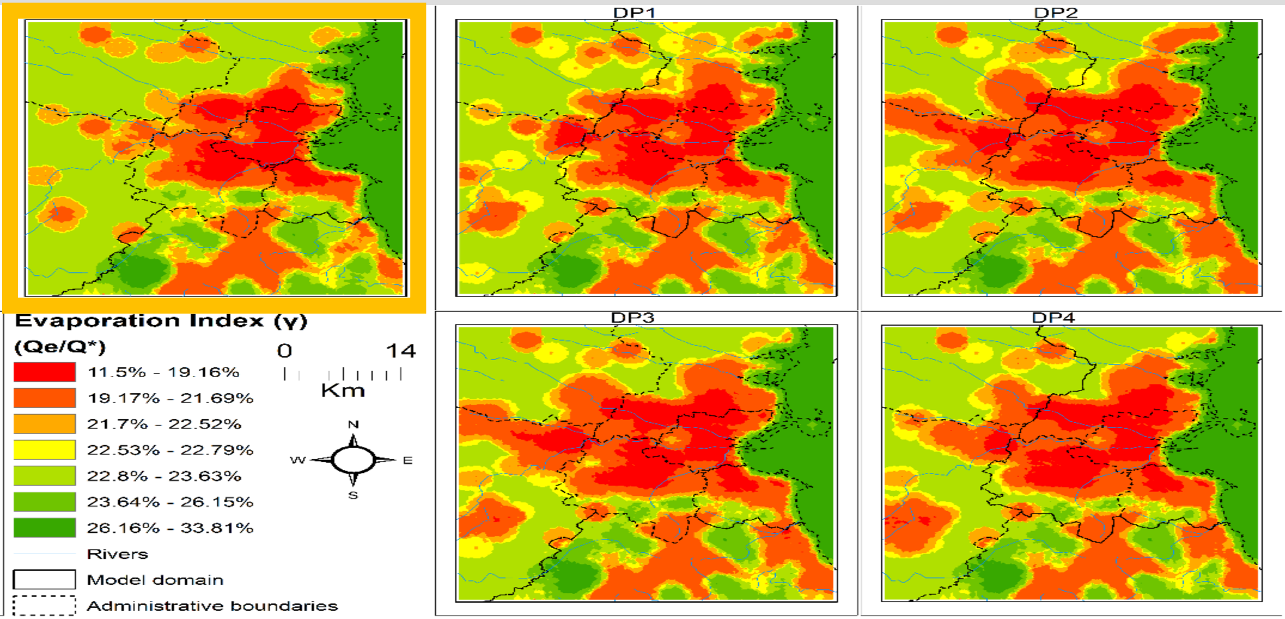


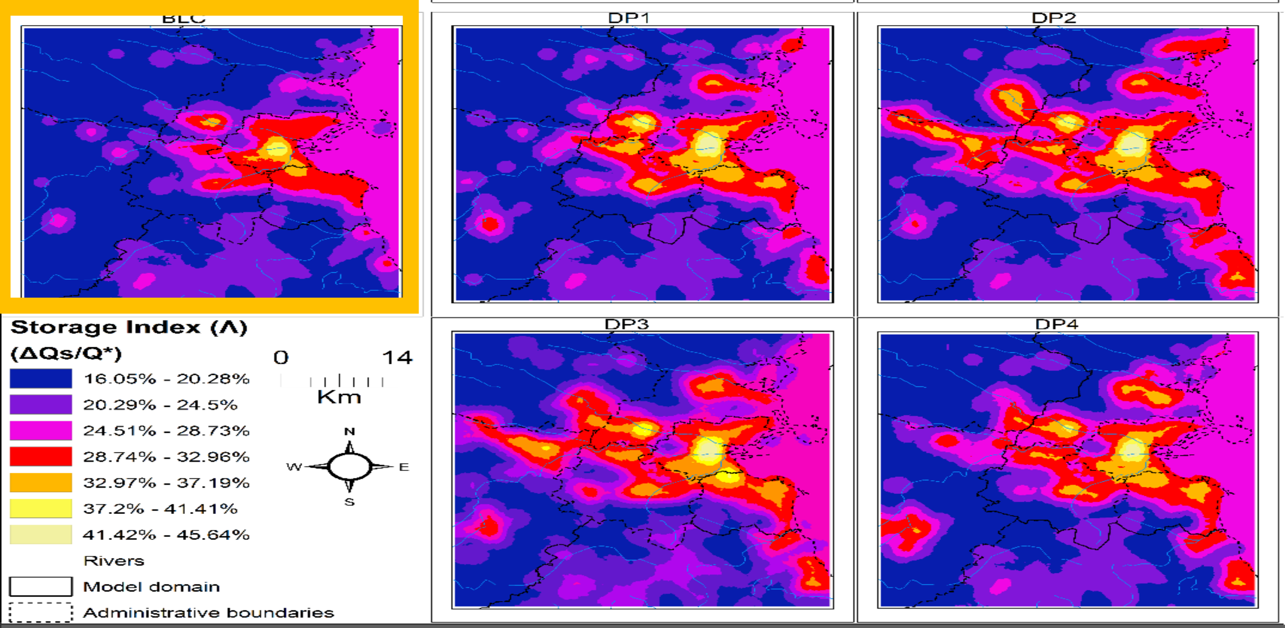
Extensive model evaluation was undertaken but results are excluded here – see Alexander et al. (2015)

Results

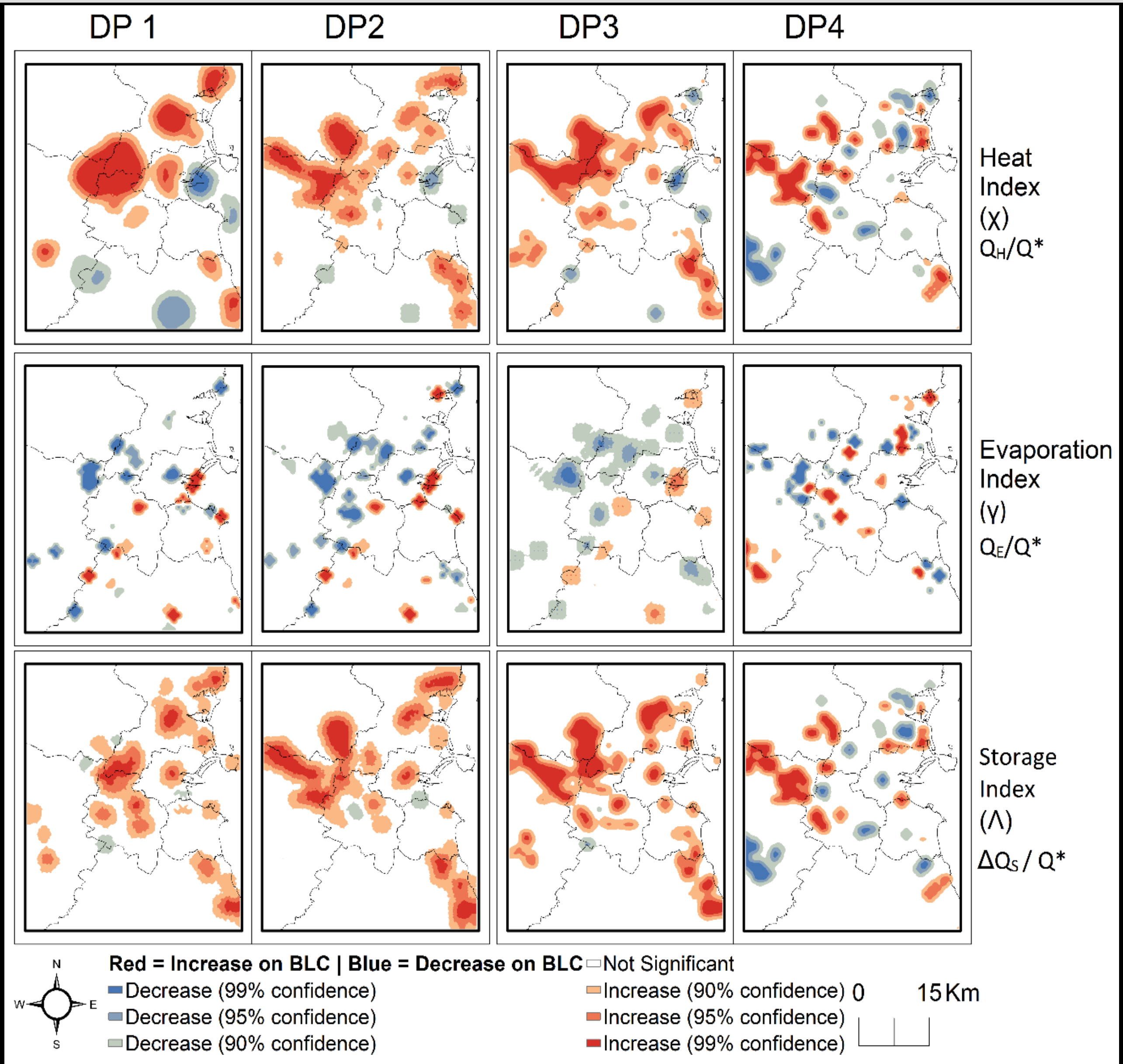

(a) Difference from Annual Mean (W m-2)
-40.0
-20.0
0.0
20.0
40.0
LCZ2
LCZ3
LCZ5
LCZ6
LCZ8
LCZ101
LCZ104
LCZ105
LCZ107
QE μ=18.2 W m-2
QH μ=46.3 W m-2
Colder / Drier
Warmer / Wetter
(b) Difference from Seasonal Mean (W m-2)
-60.0
-30.0
0.0
30.0
60.0
Summer (QH)
Winter (QH)
Summer (QE)
Winter (QE)

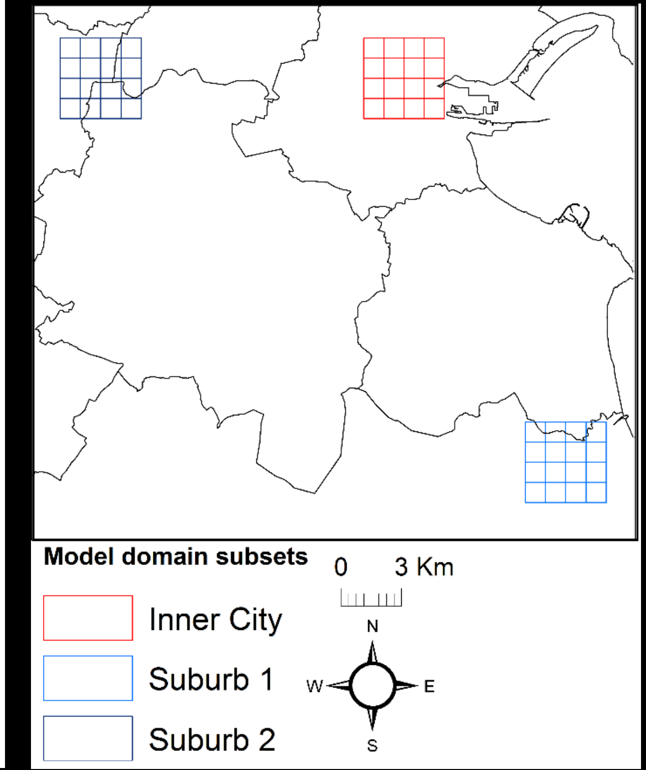

DP1
DP2
DP3
DP4
Heat Index (χ)
(Qh/Q*)
24% - 38.03%
38.04% - 46.45%
46.46% - 51.51%
51.52% - 54.55%
54.56% - 56.38%
56.39% - 59.42%
59.43% - 64.48%
Rivers
Model domain
Administrative boundaries
0 14
Km
N
W E
S

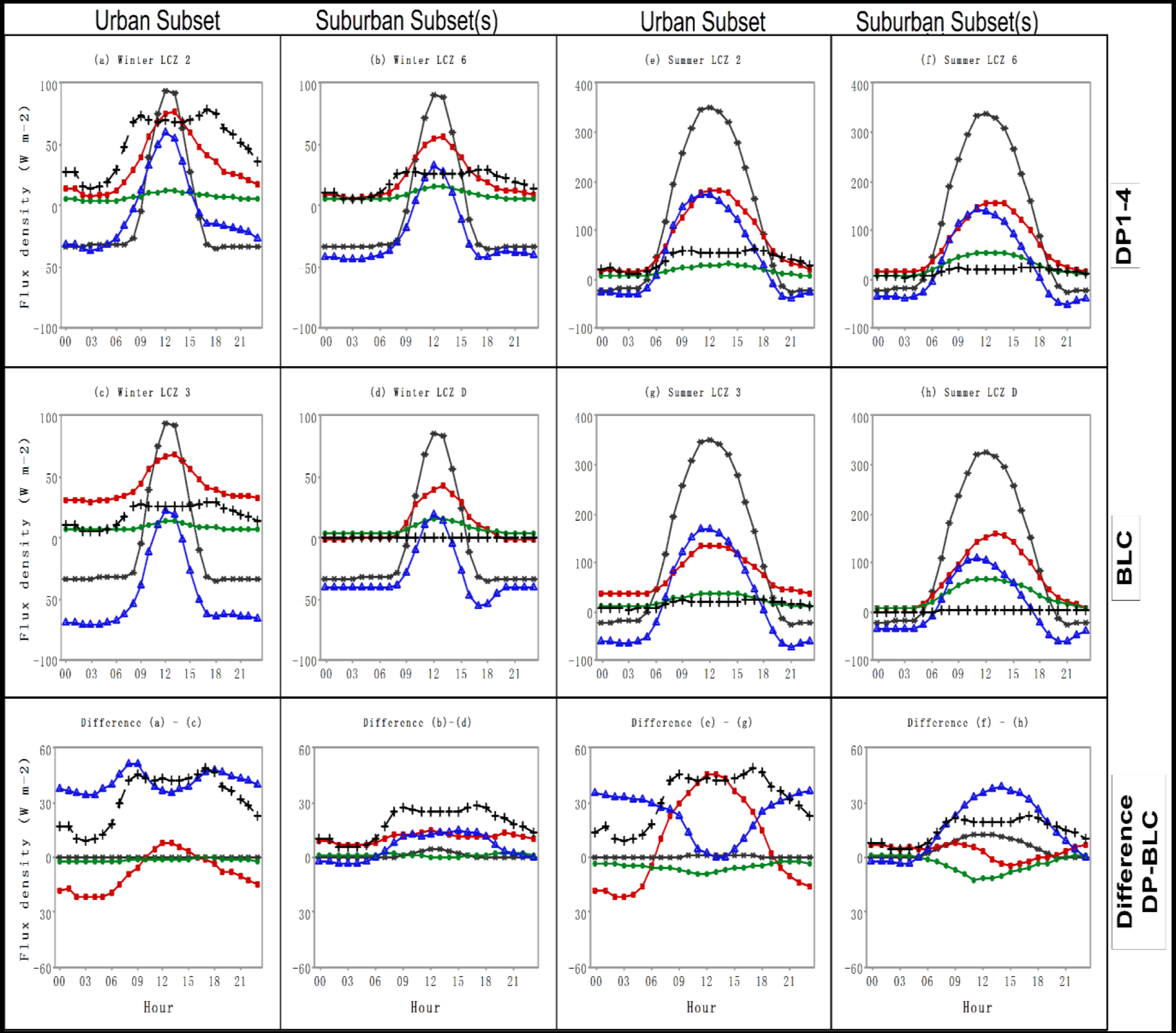

DP1
DP2
DP3
DP4
Evaporation Index (γ)
(Qe/Q*)
11.5% - 19.16%
19.17% - 21.69%
21.7% - 22.52%
22.53% - 22.79%
22.8% - 23.63%
23.64% - 26.15%
26.16% - 33.81%
Rivers
Model domain
Administrative boundaries
0 14
Km
N
W E
S

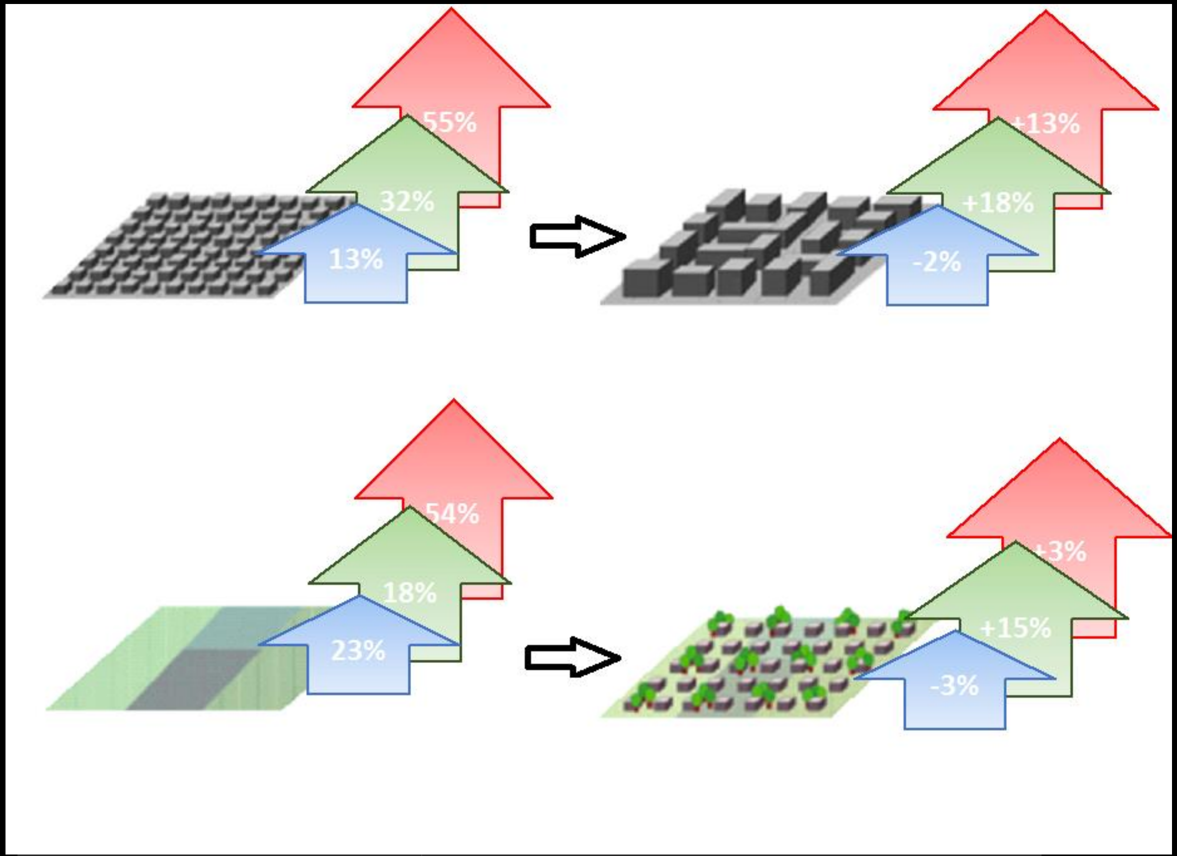

BLC
DP1
DP2
DP3
DP4
Storage Index (Λ)
(ΔQs/Q*)
16.05% - 20.28%
20.29% - 24.5%
24.51% - 28.73%
28.74% - 32.96%
32.97% - 37.19%
37.2% - 41.41%
41.42% - 45.64%
Rivers
Model domain
Administrative boundaries
0 14
Km
N
W E
S

Results


DP 1
DP2
DP3
DP4
Heat Index (χ) QH/Q*
Evaporation Index (γ) QE/Q*
Storage Index (Λ) ΔQS / Q*
N
W
E
S
Red = Increase on BLC | Blue = Decrease on BLC
Not Significant
Decrease (99% confidence)
Decrease (95% confidence)
Decrease (90% confidence)
Increase (90% confidence)
Increase (95% confidence)
Increase (99% confidence)
0 15 Km

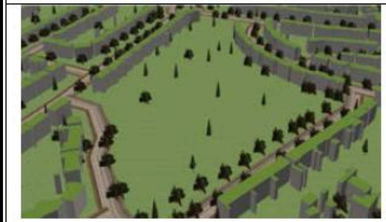

Model domain subsets
0 3 Km
Inner City
Suburb 1
Suburb 2
N
W
E
S





Construction Materials	Increased ΔQ_S	Increased thermal admittance at night
Absence of water bodies / vegetation	Increased Q_H	Increased surface / air heating
Construction Materials	Decreased Q_E	Increased water-proofing / increase runoff
Canyon Geometry	Decreased Q_A	Reduces wind speed

Results

GIS model of example area	Exemplar image of existing area	Description
		**BLC area (LCZ 6)** Area comprises Lowrise buildings (μ = 2.45m) 15% building cover 10% tree cover (all deciduous) and remainder split between pavements and unirrigated grasses
		**Design intervention 1** Buildings as with BLC area (above). Tree cover and unirrigated grasses are increased (5% each) replacing paved areas. Tree species are modified to be predominantly coniferous (80:20 split between coniferous and deciduous)
		**Design intervention 2** Building coverage is reduced by 5% height increased by 2.45m. Tree cover and unirrigated grasses are increased (2.5% each) replacing building areas. Trees are modified to be a mix of species (50:50 split between coniferous and deciduous)
	 1	**Design intervention 3** As with design intervention 2, however additionally green roof design are introduced to all buildings. Unirrigated vegetation type used to modify OHM coefficients for storage. Albedo and emissivity values (α, ε) for building roof tops also modified

Design 1 reduces the impact of urban development on summertime evapotranspiration by 34.0%

Design 2 reduces the impact on summertime evapotranspiration by 47.7%

Design 3 reduced the impact by 52.2%

The impact of urban development on the annual magnitude of surface / air heating (sensible heat) was reduced by 30.1%, 37.5% and 38.6% in design 1, 2 and 3 respectively,

The impact on heat storage was reduced by 7.9%, 15.8% and 21.7%, meaning the green roof design reduced the impact of urban development the most.

Middel, A. et al., (2014) Impact of urban form and design on mid-afternoon microclimate in Phoenix Local Climate Zones. *Landscape and Urban Planning*, 122, pp.16–28:

Smart Growth + Smart Design = Optimal Path

Conclusions

- Urban Climate Community
  - UCPs can be employed to furnish a complex model with the required parameters quickly and efficiently
  - Reduces the simulation requirements & allows for results to be extended across a wider urban area
  - LCZ map + meteorology = first pass UEB for every city included in WUDAPT
  - Overcomes the problem of data poor settings while taking into account the “urban effect”
  - SUEWS is capable of reproducing well the UEB at multiple sites within the study area with low RMSE and MFB

Conclusions

- Planning Community
  - LCZ represent a common language between communities for describing the UHI (thus the UEB) and the form and function of a city
  - A LCZ map is *likely* to coincide with other land use land cover maps – here MOLAND / CORINE areas had clear relationship with LCZ
  - Offers an additional evidence base for policy choice / planning decisions
  - Allows neighbourhoods to be tested for effectiveness in terms of modification (cost-benefit analysis?) leading to optimal L.I.D

Thank you for your attention / Merci pour votre attention / Vielen Dank für Ihre Aufmerksamkeit / Grazie per l'attenzione / Σας ευχαριστώ για την προσοχή σας / 感谢您的关注

I wish to Acknowledge the kind support of the post-graduate travel fund Maynooth University for part-funding my participation at ICUC9

- Contact: paul.alexander@nuim.ie
- Dublin LCZ / UHI paper:
  - Alexander, P.J.; Mills, G. (2014) Local Climate Classification and Dublin's Urban Heat Island. *Atmosphere* 2014, 5, 755-774.
- Some other works cited in presentation:

  - Alber, G.,; Kern, K. (2008) Governing Climate Change in Cities: Modes of Urban Climate Governance in Multi-level systems. In Documentation *Cities and Climate Change Conference,* Milan, Italy October 9-10, 2008. Available https://search.oecd.org/gov/regional-policy/50594939.pdf#page=172 [Accessed 04 March 2015]
  - Morlot, Jan, Lamia Kamal-Chaoui, Michael G., Donovan, Ian, Cochran, Alexis Robert and Pierre-Jonathan Teasdale (2009), "Cities, Climate Change and Multilevel Governance", *OECD Environmental Working Papers N° 14*, 2009, OECD publishing, © OECD.

- Any questions / comments would be most welcome