Urban Multi-scale Environmental Predictor

– An integrated tool for urban climatology and climate sensitive planning applications

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Outline

- Background
- Tool overview
- The modelling system
- The Application Programming Interface (API)
- Applications
- Summary

Background

- The urban climate is influenced by processes taking place at a range of different scales.
- Based on application, the appropriate scale has to be considered.
- Important to accurately couple and understand the different scale dependent processes.

Göteborg, Sweden

Frankfurt am Main, Germany

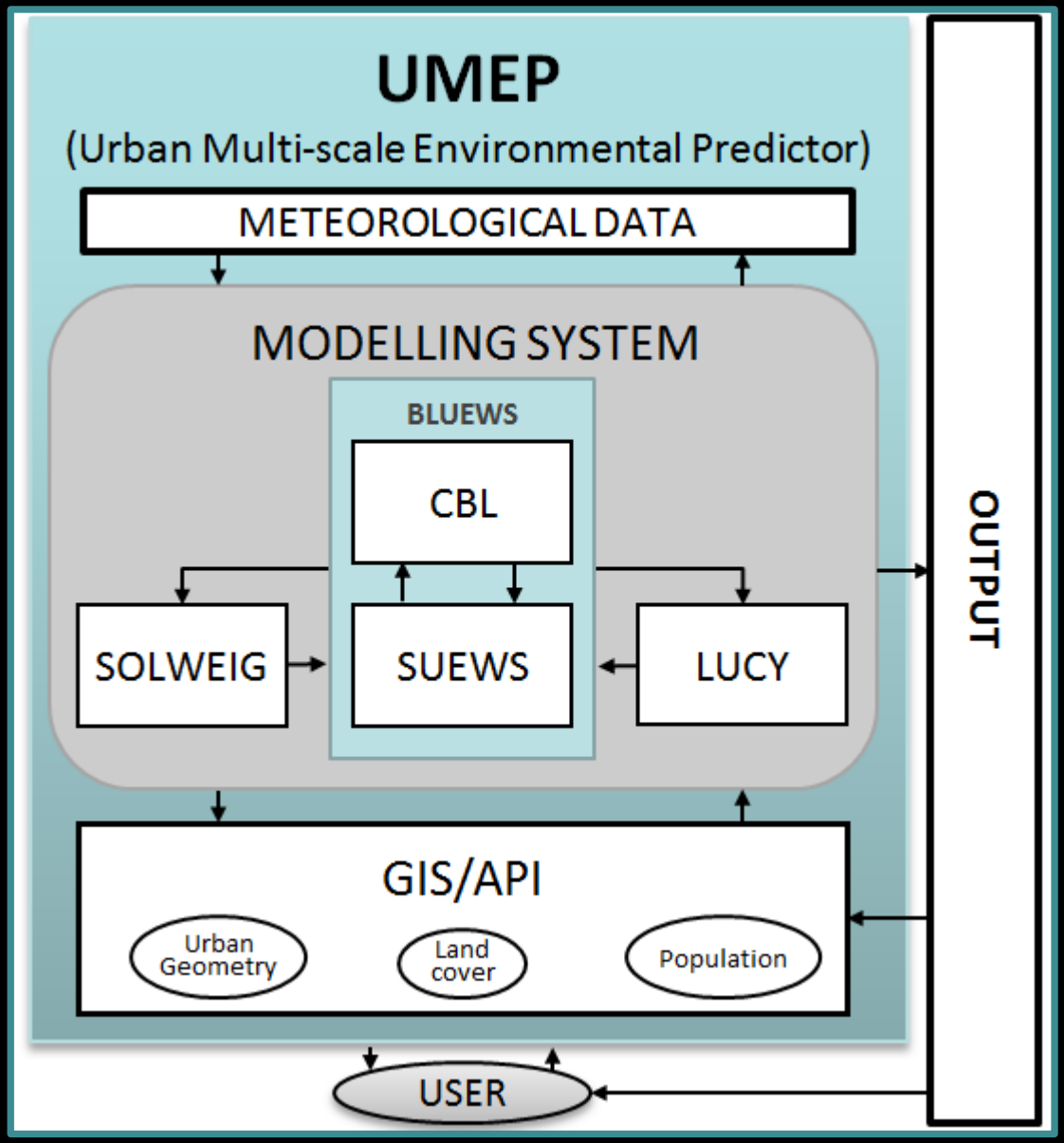
Background

London, United Kingdom

Here, UMEP (Urban Multi-scale Environmental Predictor), an integrated tool for urban climatology and climate sensitive planning applications is presented.

Overview of UMEP

- The tool consists of a coupled modelling system which combines “state of the art” 1D and 2D models.
- The modelling system contained within UMEP is designed to run from the street canyon to city scale (10^0-10^5 m).
- Code restructuring necessary



Overview of UMEP - Stakeholders

- Stakeholder group is connected throughout the development process
- Stakeholders mainly practitioners (architects, urban planners
- Overview description of pedestrian wind is highly prioritized
- Micro scale description of vegetation needs to be addressed
- Data access in general

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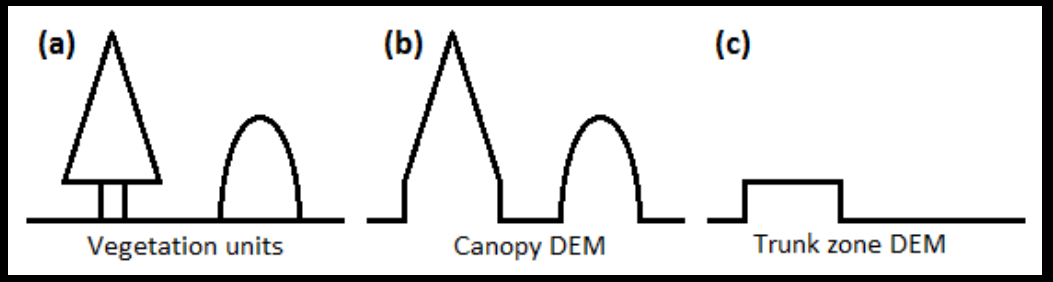
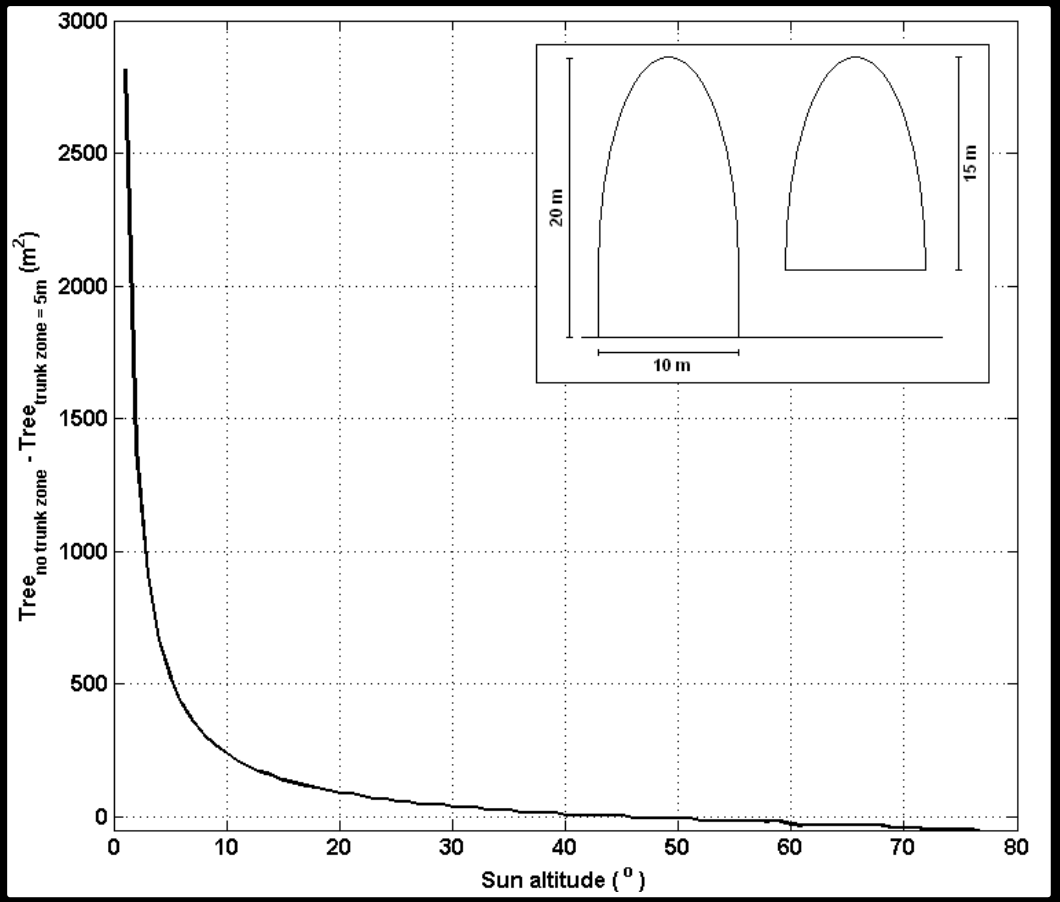




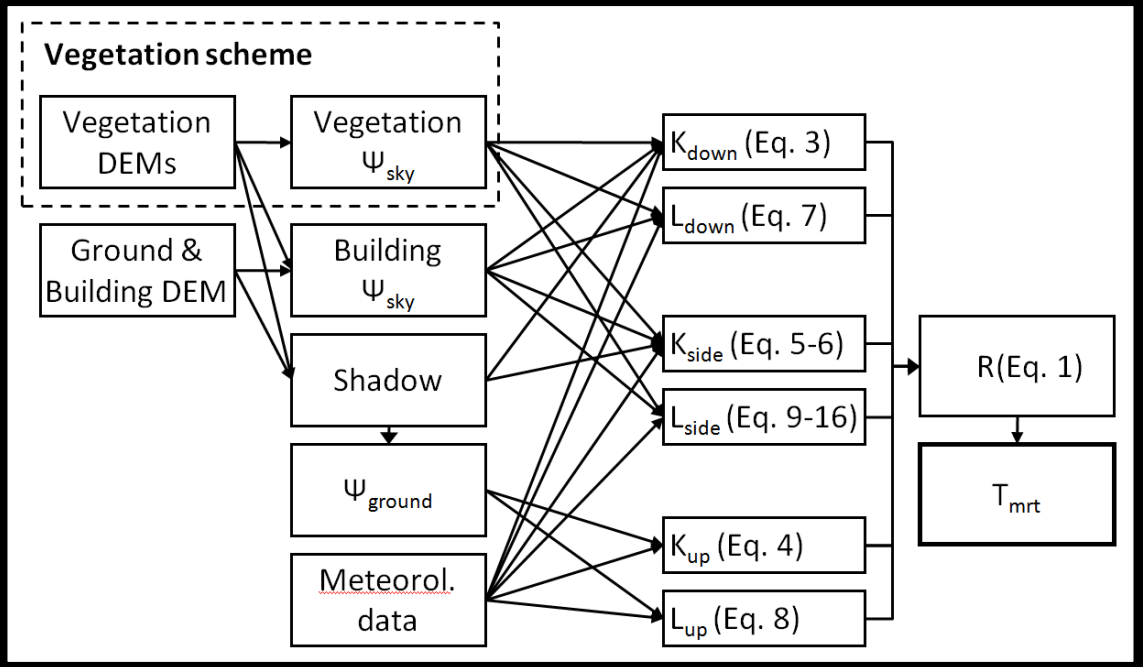
The Modelling system

THE SOLWEIG MODEL (Solar and LongWave Environmental Irradiance Geometry)

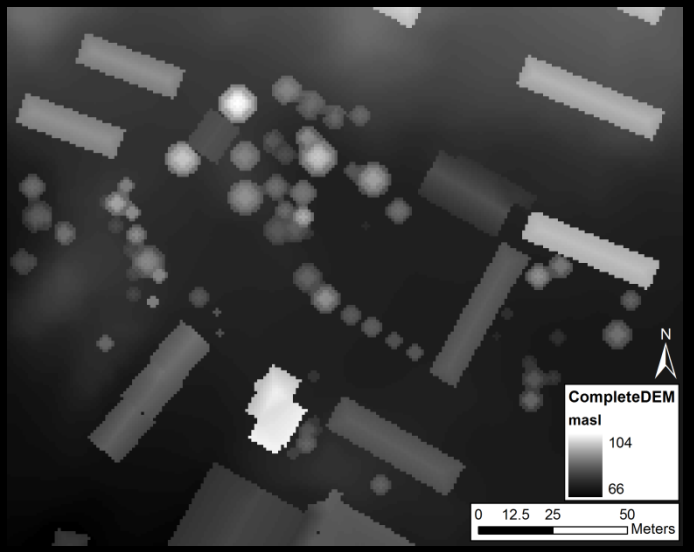
(Lindberg et al. 2008 and Lindberg & Grimmond 2011)

- Simulates spatial variations of 3D radiation fluxes and T_{mrt} in complex urban settings
- The T_{mrt} is derived by modelling shortwave and longwave radiation fluxes
- Sky view factor and shadow patterns are a central elements when estimating the fluxes

Mean radiant temperature (T_{mrt}) = A sum of all shortwave and longwave radiation fluxes to which the human body is exposed.



Digital Surface Model, Göteborg (Sweden)



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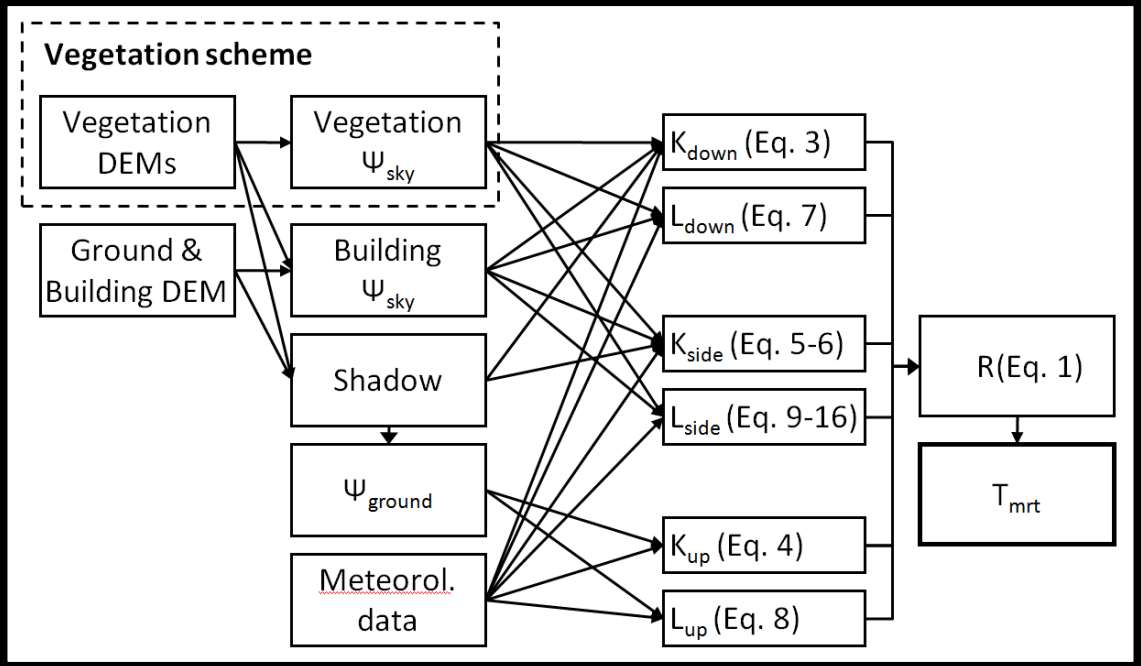
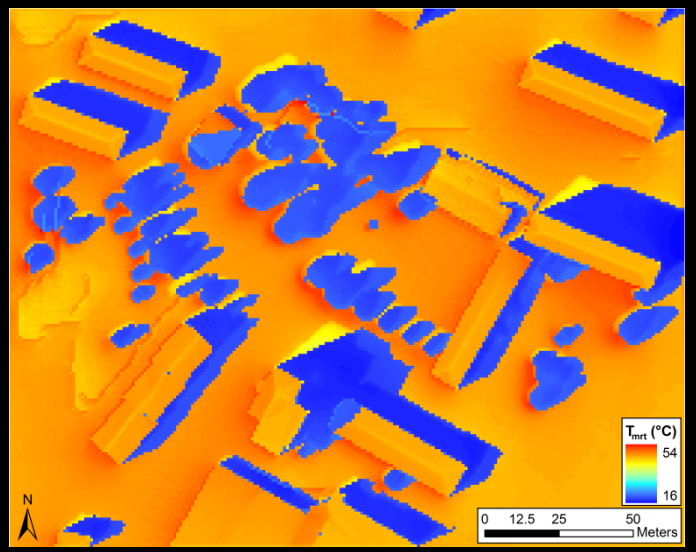


T_{mrt} at 3 pm, 23rd of May 2010

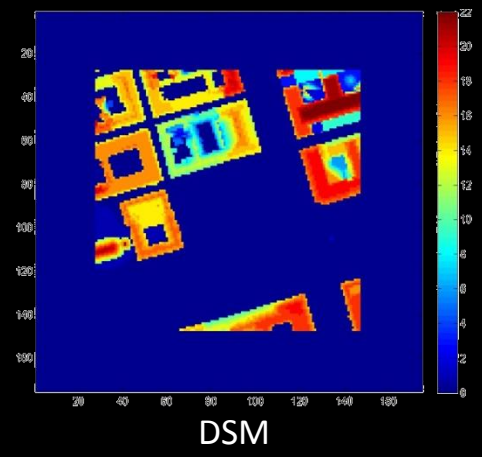


The Modelling system

THE SOLWEIG MODEL (Future developments?)

To calculate thermal indices such as PET and UTCI, wind speed information is needed. The possibility of applying statistical modelling of pedestrian wind speed using high-resolution digital surface models is currently explored (Johansson et al. 2014)

- A model to predict pedestrian wind speed in complex urban settings
- Investigating the statistical relationships between wind speed and different derivatives (measures) of urban geometry



DSM

Frontal Area Index

Sky View Factor

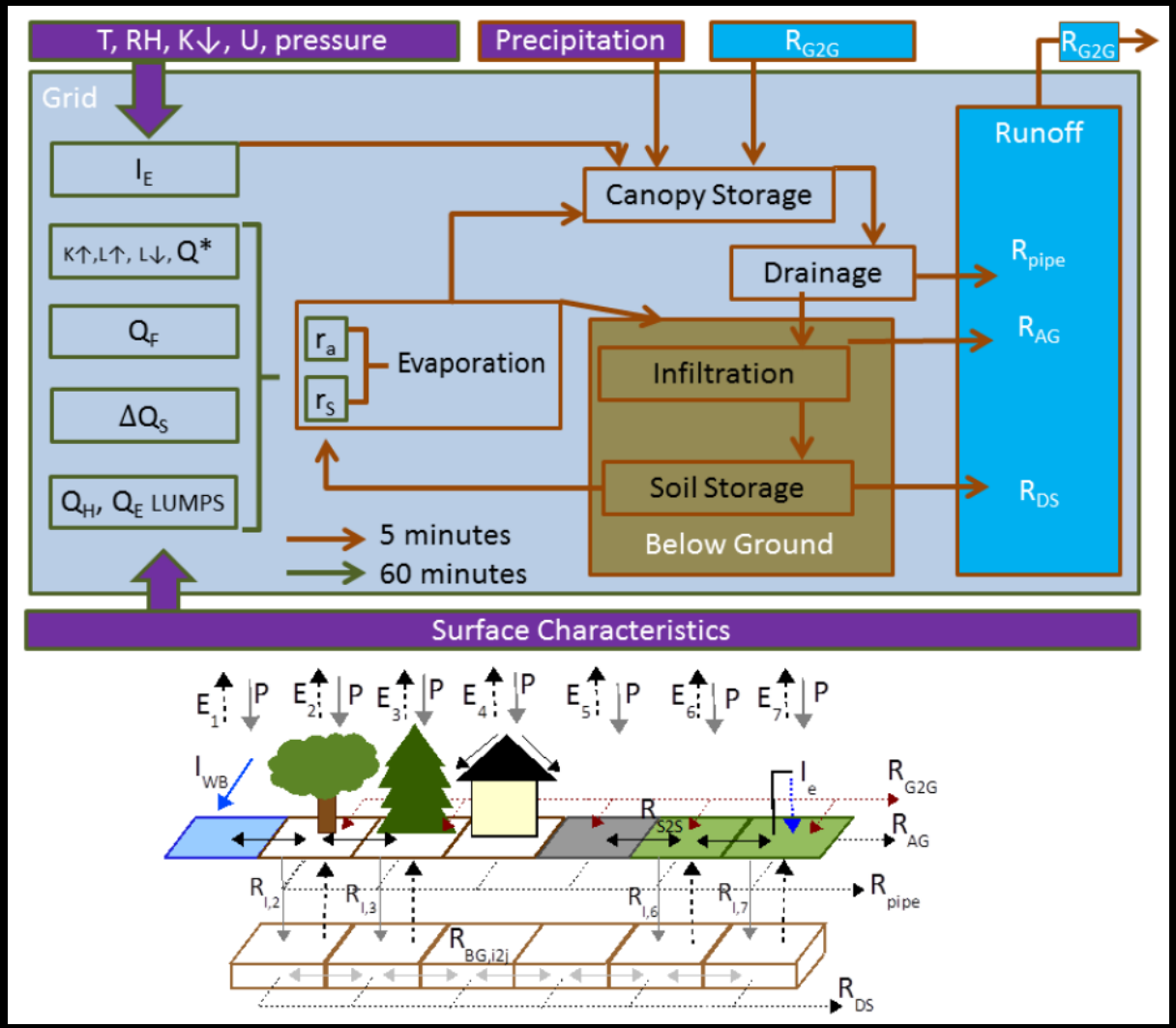
FETCH

The Modelling system

SUEWS (Surface Urban Energy and Water Balance Scheme)

(Järvi et al. 2011)

- SUEWS simulates urban energy and water balances using information on surface cover and basic meteorology
- Several sub-models for Q^*, ΔQ_S, Q_F, I_e
- Q_H is estimated as a residual
- Surface divided into seven interacting surface types
- Latest version: **v2014b** where a new snow module is included (Järvi et al. 2014)



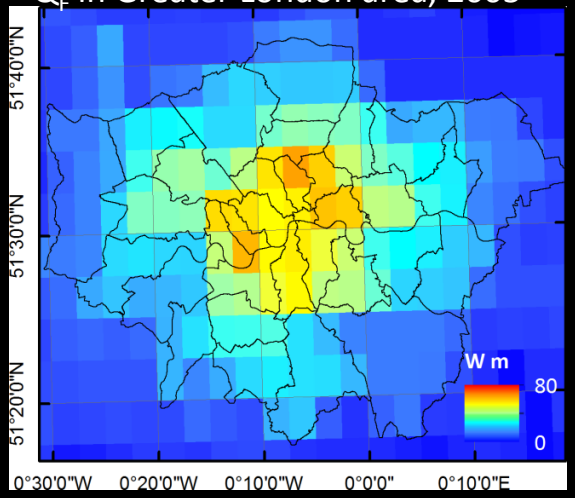
The Modelling system

LUCY (Large scale Urban Consumption of energY model)

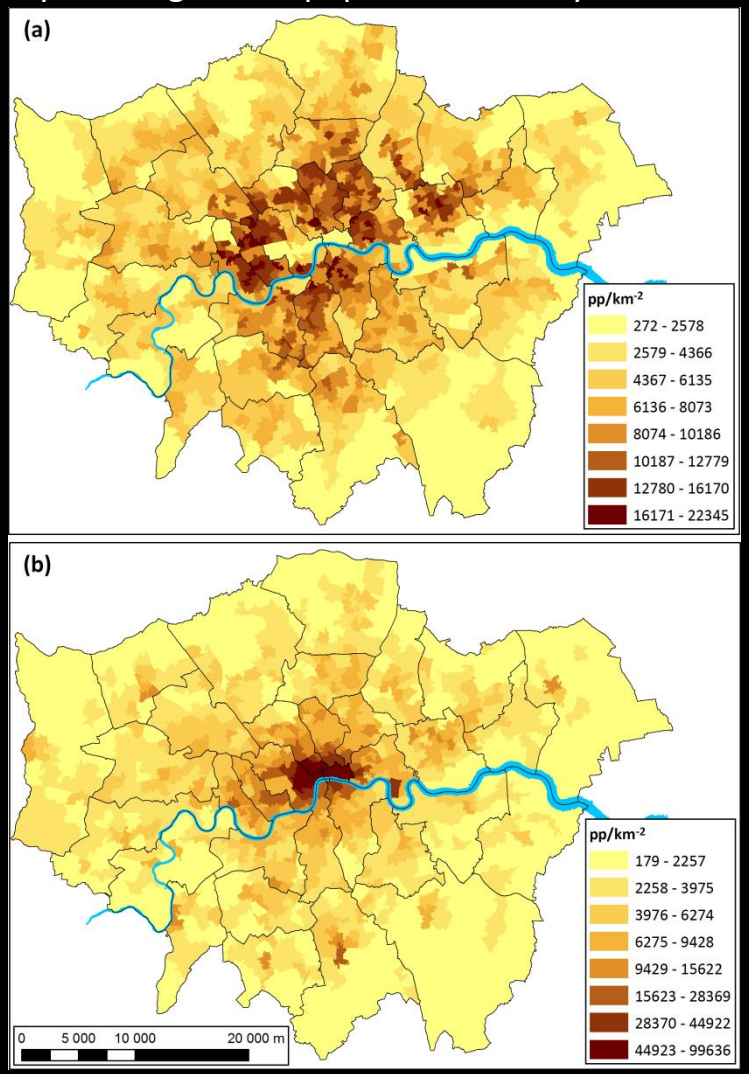
(Allen et al. 2010, Lindberg et al. 2013)

- LUCY simulates all components of anthropogenic heat flux (Q_F) from global to neighborhood scale.
- It can be applied to any part of the world.
- LUCY operates at multiple scales specified by input data. Data could be replaced and refined based on application.
- Forcing data includes population, energy consumption, traffic numbers and air temp.

Q_F in Greater London area, 2005



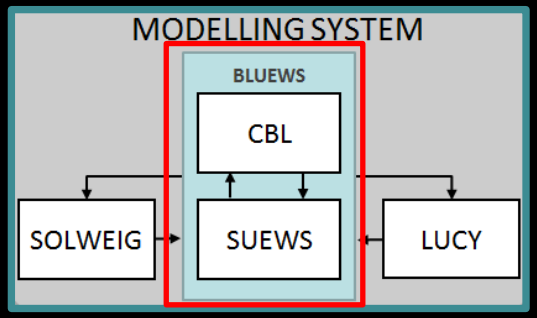
Day- and nighttime population density in London



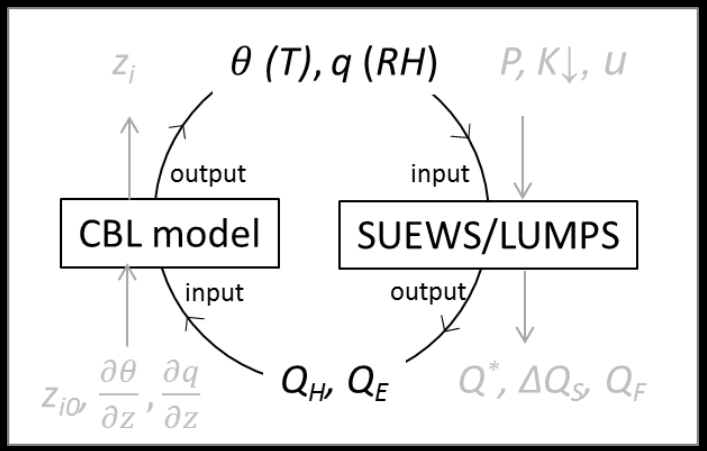
The Modelling system – existing coupling

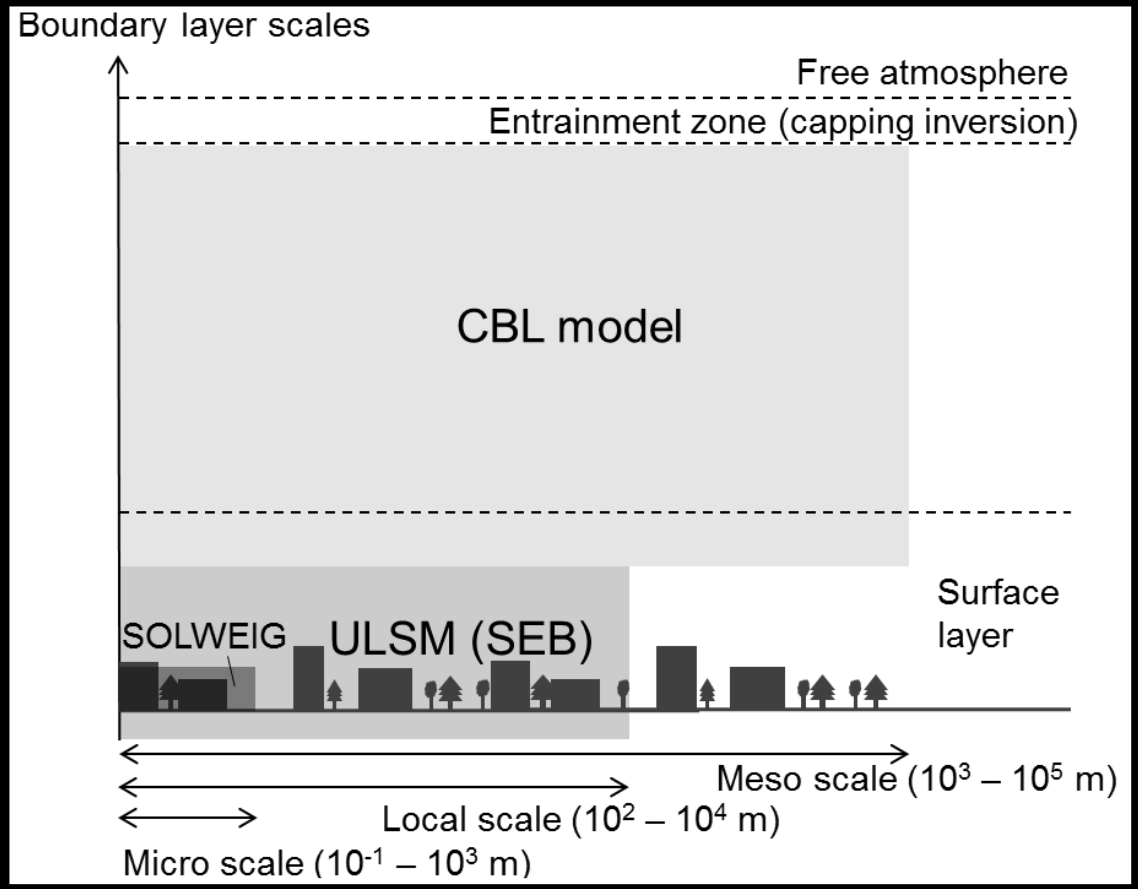
BLUEWS (Boundary Surface Urban Energy and Water Balance Scheme)

(Onomura et al. 2014)



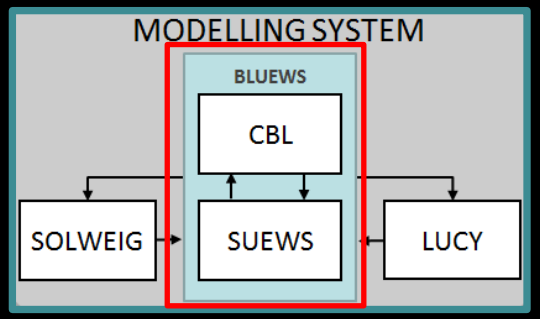
- A convective boundary model is coupled to the SUEWS scheme to estimate daytime temperature and humidity based on the surface energy fluxes





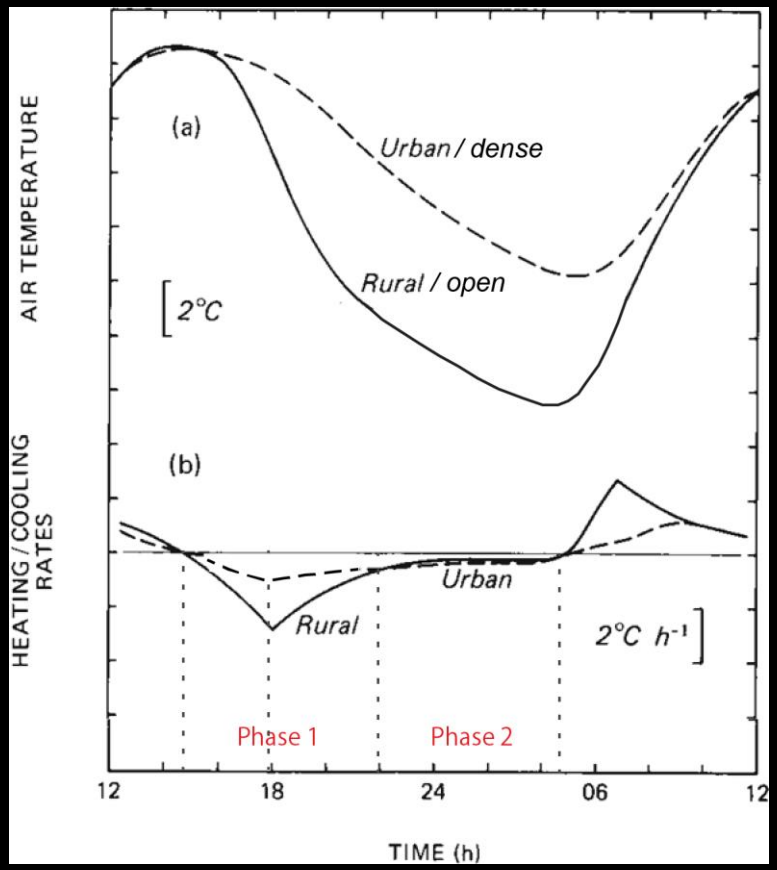
The CBL modelling scheme (Cleugh and Grimmond, 2001)

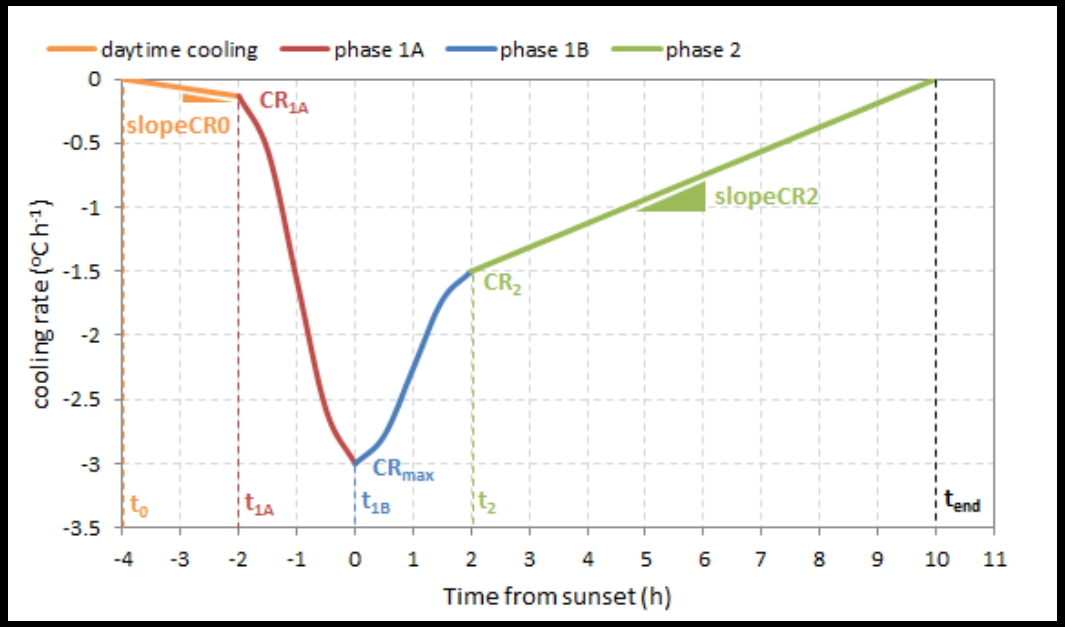
The Modelling system – planned coupling



BLUEWS

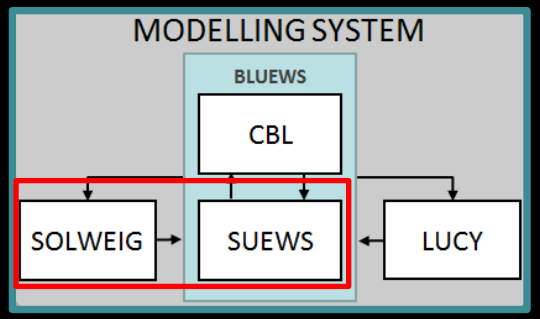
- Intra urban nighttime T_a cooling rate scheme will be included in BLUEWS.
- The scheme is based on empirical relationships using weather parameters and urban geometry.
- This scheme can also be used to obtain initial parameters for the daytime CBL scheme





Conceptual cooling rate model (Holmer et al. 2007)

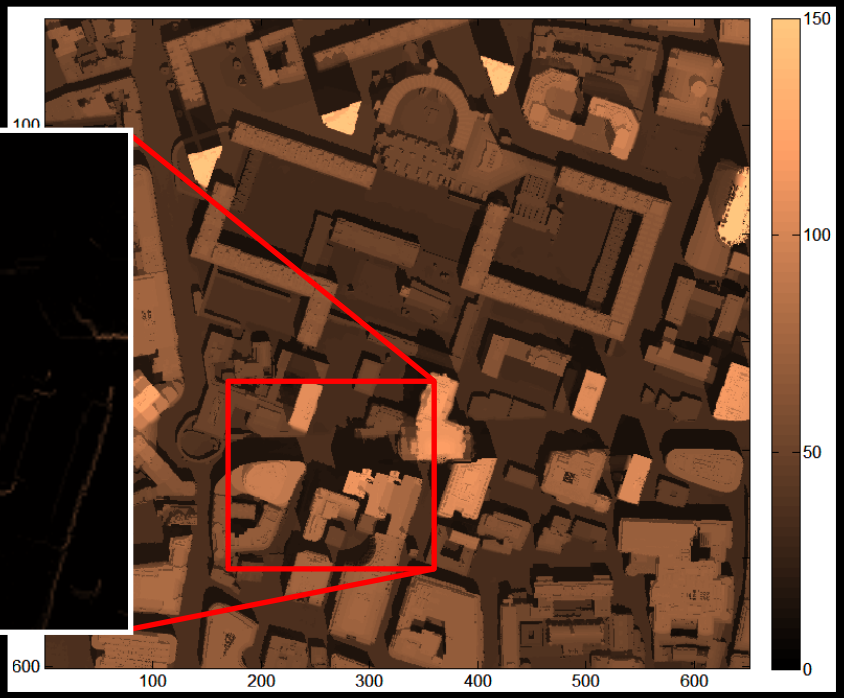
The Modelling system – planned coupling

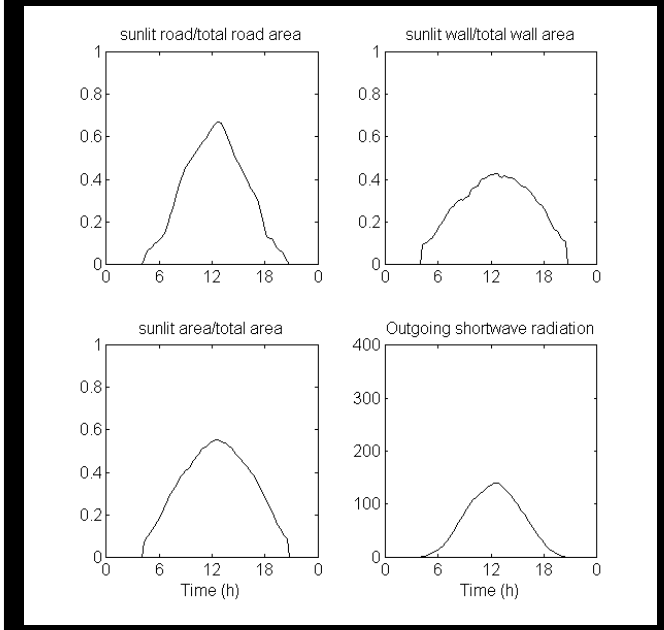


- Air temperature and humidity is used as forcing input to SOLWEIG
- SOLWEIG output will be used to improve outgoing radiation fluxes used in SUEWS/BLUEWS

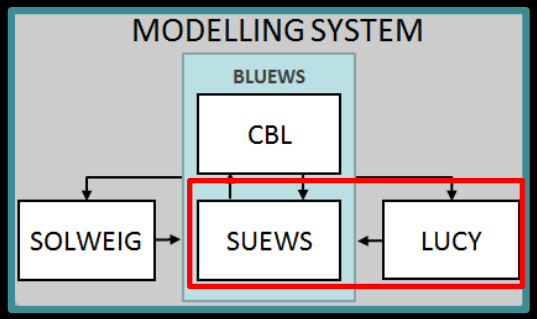
Sun/shade patterns 1130, 3 June. Barbican London

Sunlit walls

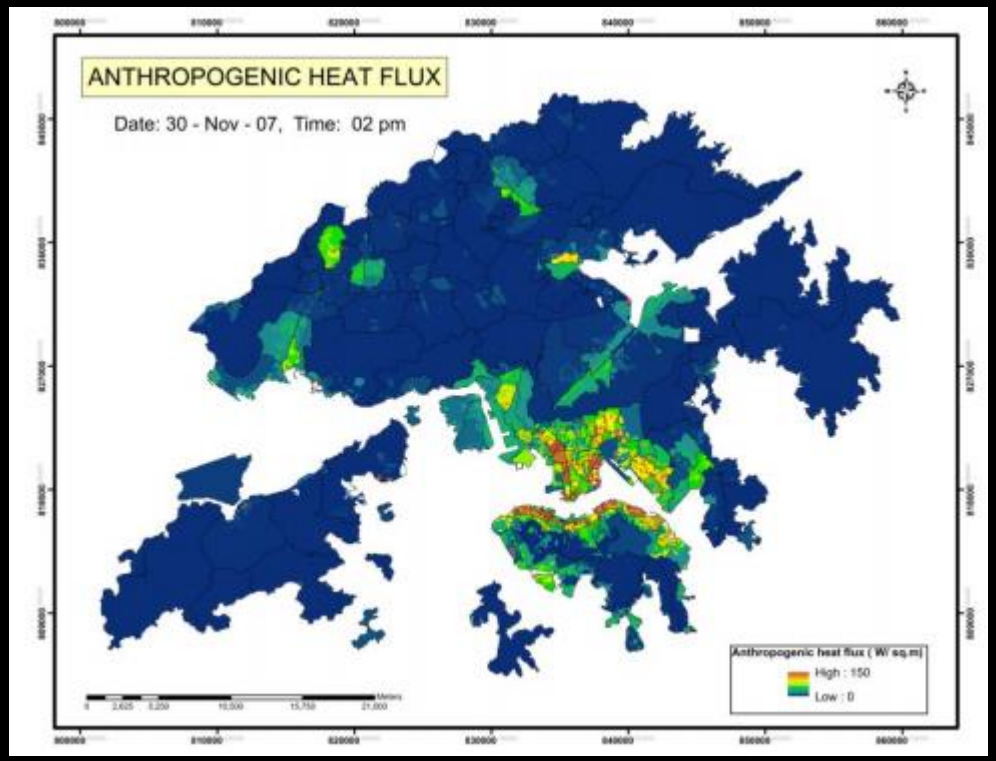




The Modelling system – planned coupling



- Air temperature will be forced into LUCY
- LUCY will be able to provide more detailed information on anthropogenic heat flux to the modelling system
- New features will also be included in the Q_F modelling e.g. detailed traffic information and/or agent based modelling



Anthropogenic heat flux (Q_F) in Hong Kong using high resolution population data (Yogeswaran, 2014)

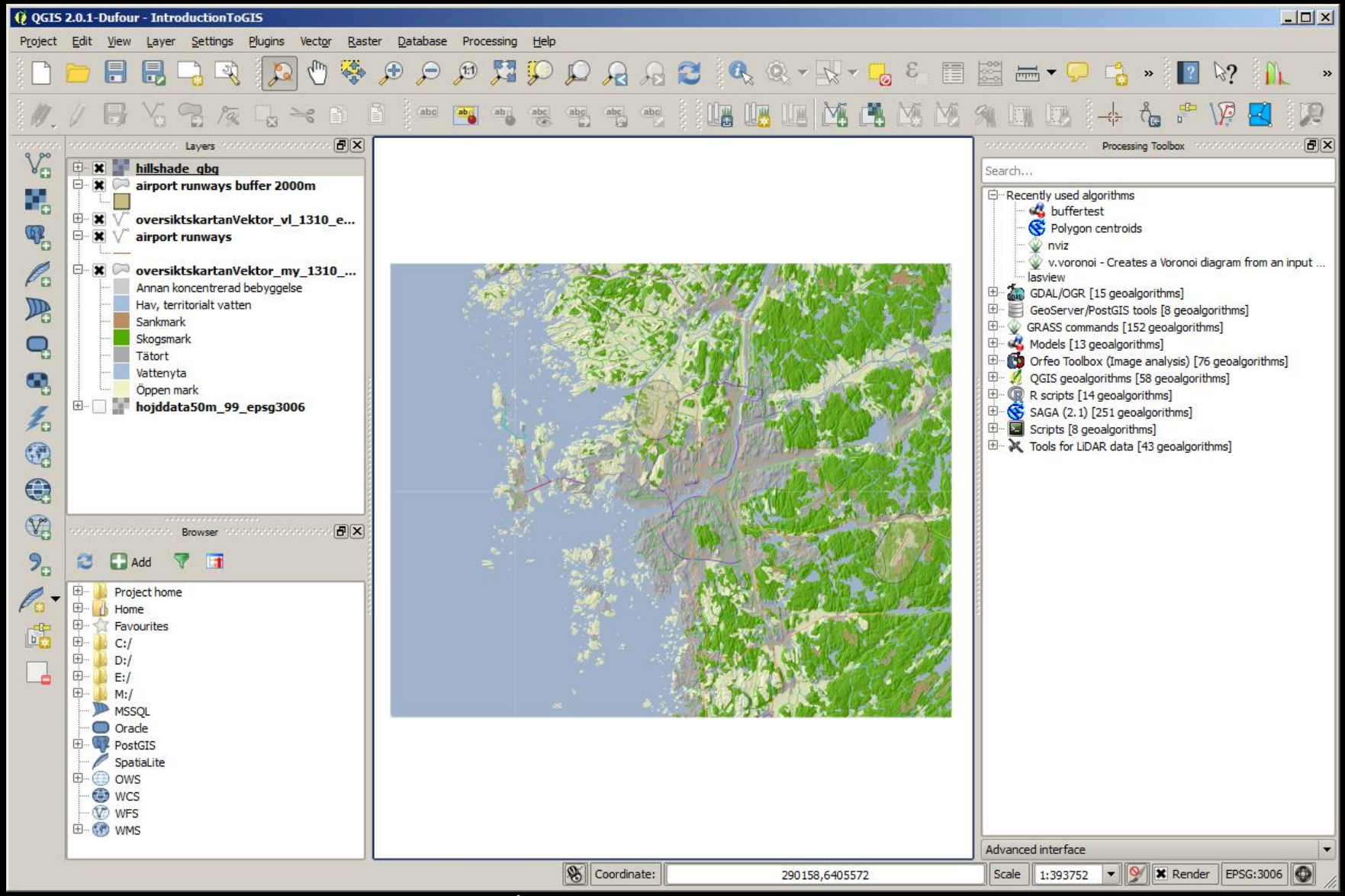
The interface (API)

One main purpose of UMEP is that it should be available and assessable for as many uses as possible (researchers and practitioners)

- A graphical user interface is needed
- A GIS-based approach is needed
- Many types of formats and data information should be able to be processed
- The interface should be able to do both pre- and post processing of information
- The interface should provide users with tips and recommendations

The interface (API)

Instead of starting from the beginning **QGIS** will be used as API/GIS



The QGIS GUI, version 2.0

The interface (API)

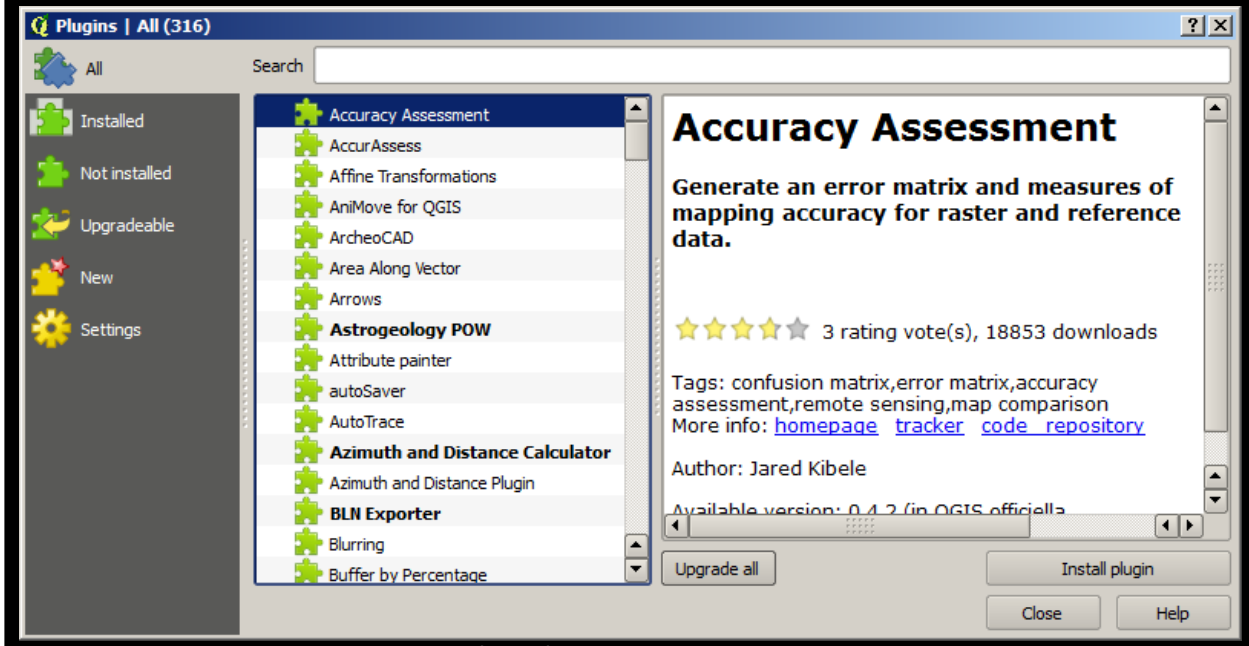
QGIS makes is possible to:

- make use of all the mapping capabilities within the API (e.g. ogr/gdal)
- make use of all the geoprocessing capabilities within the API (e.g. GRASS, SAGA)
- extend the API by developing new components (as plugins)

Quantum GIS was founded in 2002. QGIS is an official project of the OSGeo (osgeo.org).

QGIS provides a continuously growing number of capabilities provided by core functions and plugins. You can visualize, manage, edit, analyze data, and compose printable maps.

Written in C++ and binds with Python.

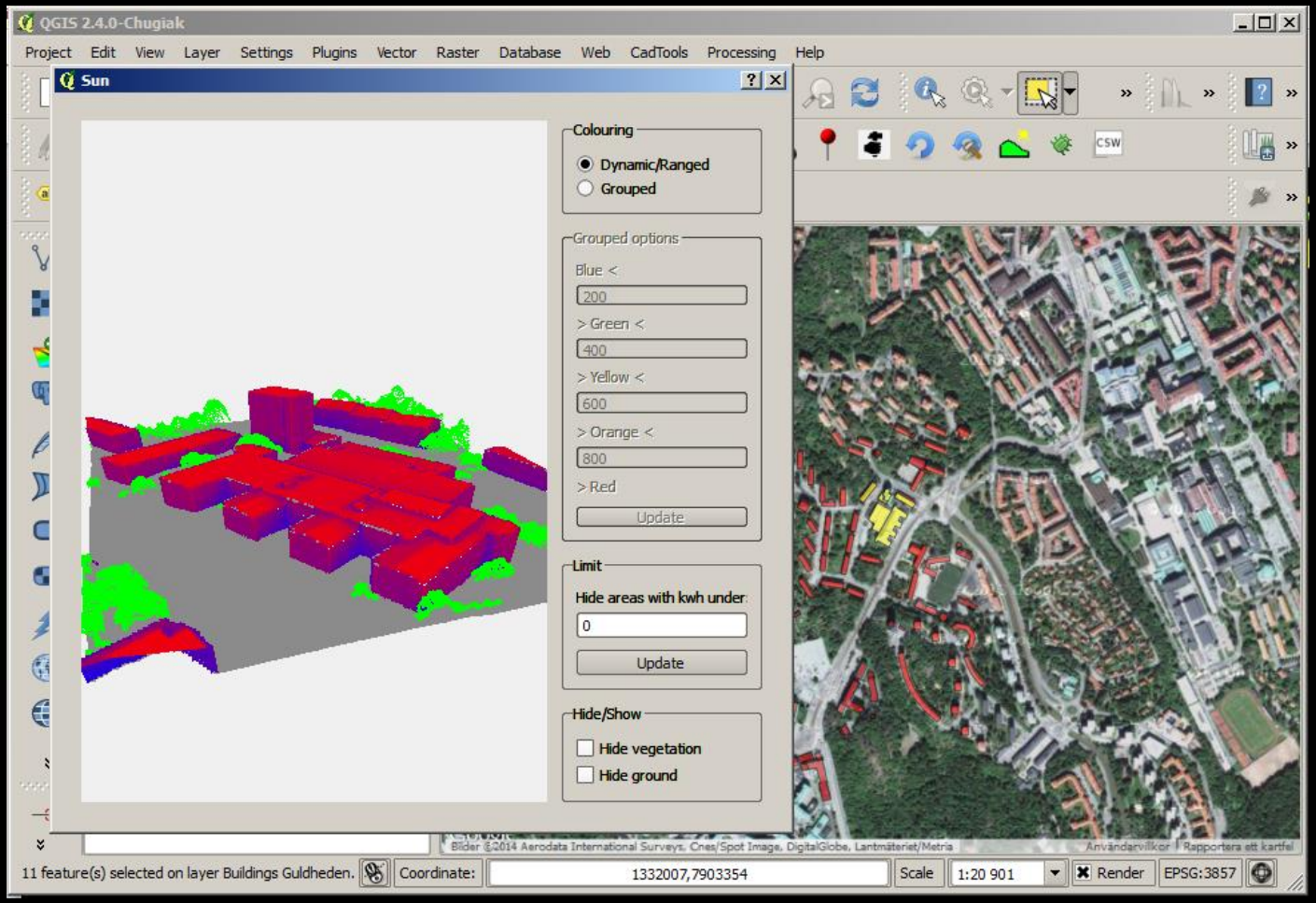


The Plugin manager in QGIS 2.4

The interface (API)

Plugin example (SUN):

- Plugin that visualize model results from a 3D solar energy model (SEBE, Solar Energy of Building Envelopes)



SUN plugin, version 0.9, experimental

The interface (API)

The UMEP plugin will consist of three separate parts:

Pre-processor

- Input data preparation
- Grid generation for sub-grid modelling
- Simple weather generator to produce example input data
- Generation of general morphology info such as sky view factor, PAI, FAI, H/W-ratios etc.

Processor

- Execution of the actual modelling system
- Models can run separately or coupled
- Models can be run with the focus on time, space or in combination

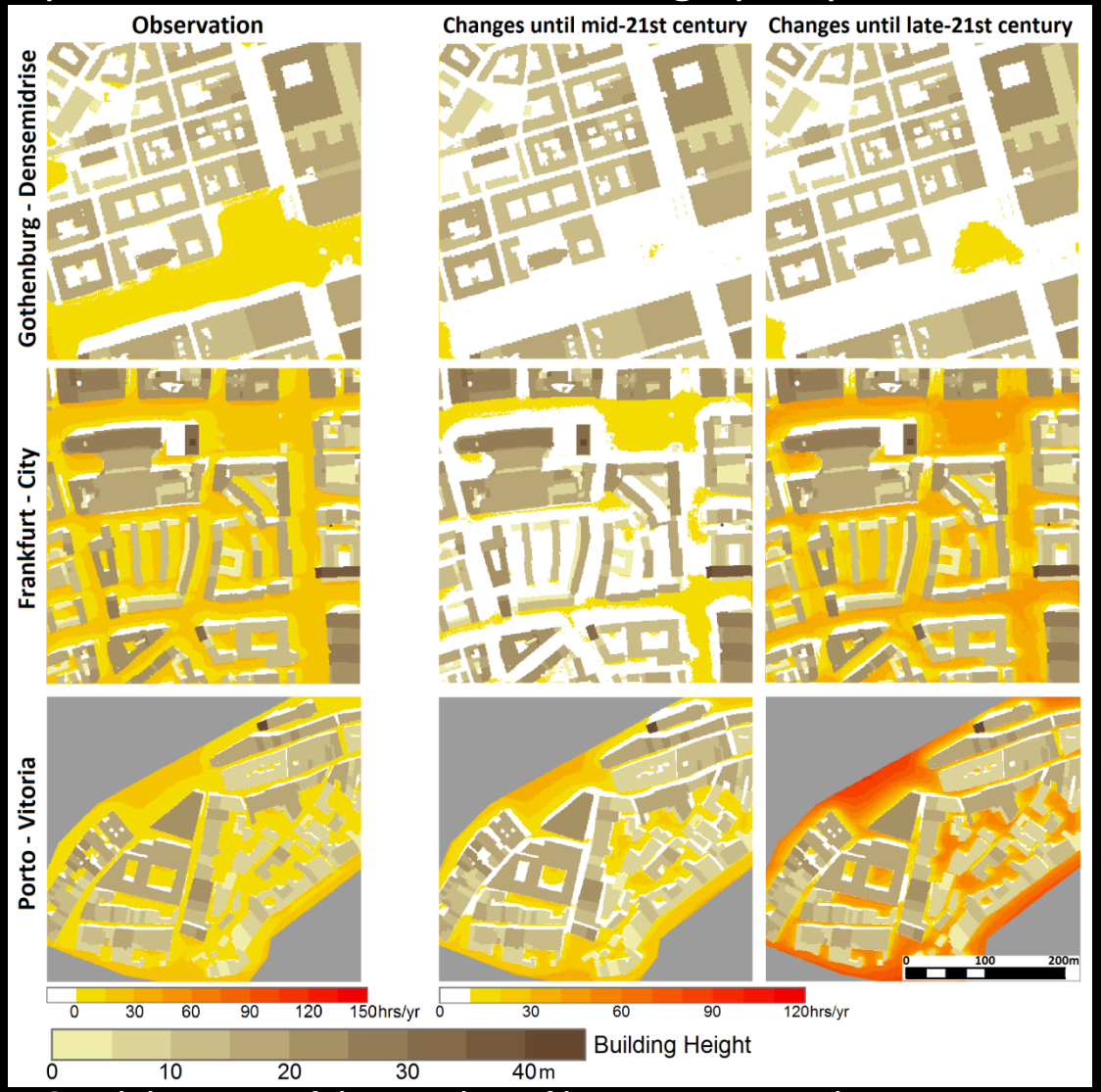
Post-processor

- Possibilities to visualize output data
- Map generation
- Averaging and statistical analysis of output data

Existing examples of applications - SOLWEIG

Outdoor heat stress across European cities - in a climate change perspective

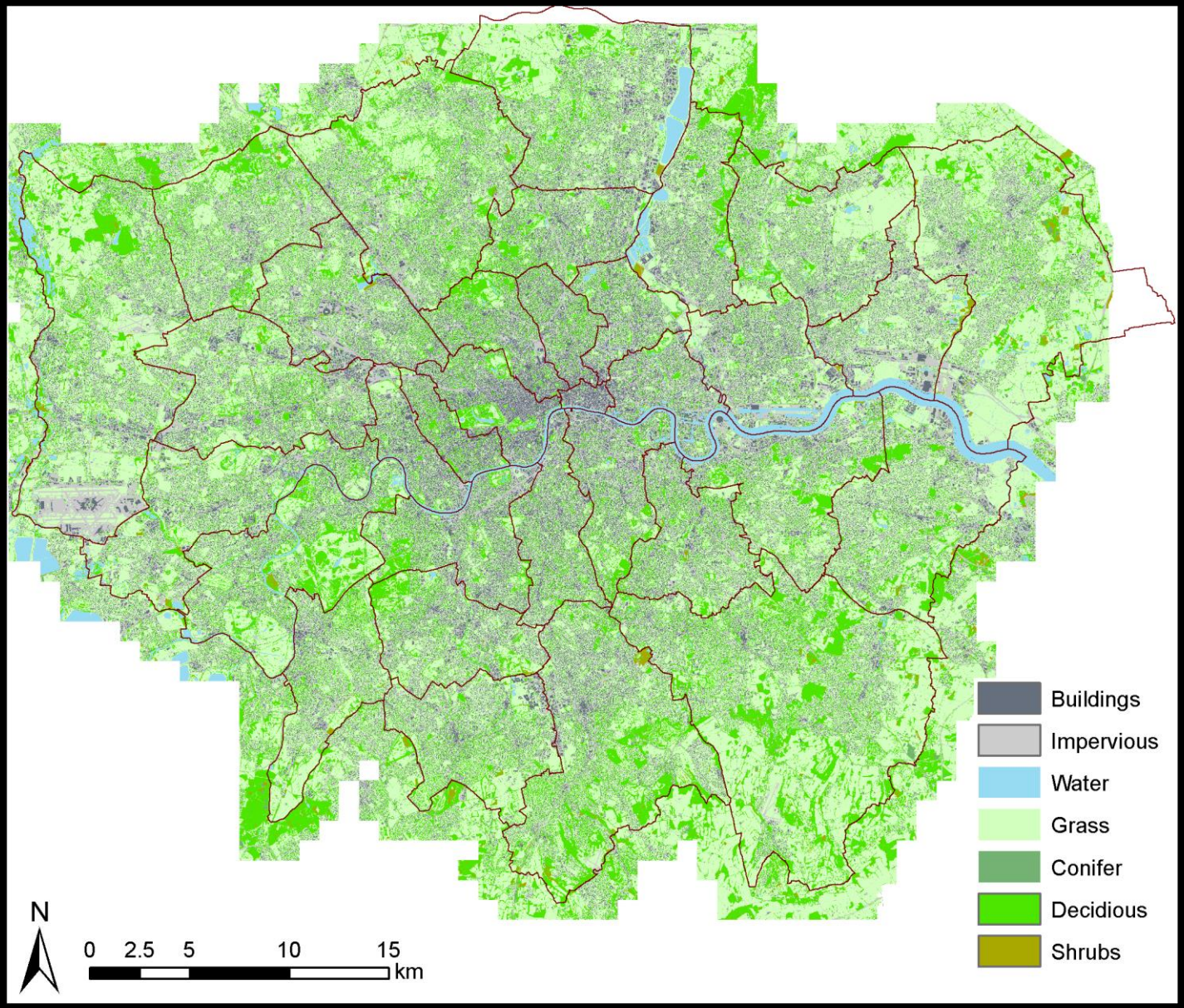
- Heat stress in three European cities (Gothenburg, Frankfurt and Porto) is analyzed using the mean radiant temperature, T_{mrt}
- Although air temperature is projected to increase in all cities by 2100, changes in solar radiation due to changes in cloudiness may counterbalance or aggravate the effect
- In Gothenburg the number of severe heat stress days will be more or less the same by the end of the century, whereas it will double in Frankfurt and triple in Porto



Spatial pattern of the number of hours per year when $T_{mrt} \geq 60^{o}C$. Projected future changes in number of hours by mid- and late-21st century are shown to the right.

Existing examples of applications - SUEWS

Spatial variations of energy fluxes in London



1. Input data

Land cover

Existing examples of applications - SUEWS

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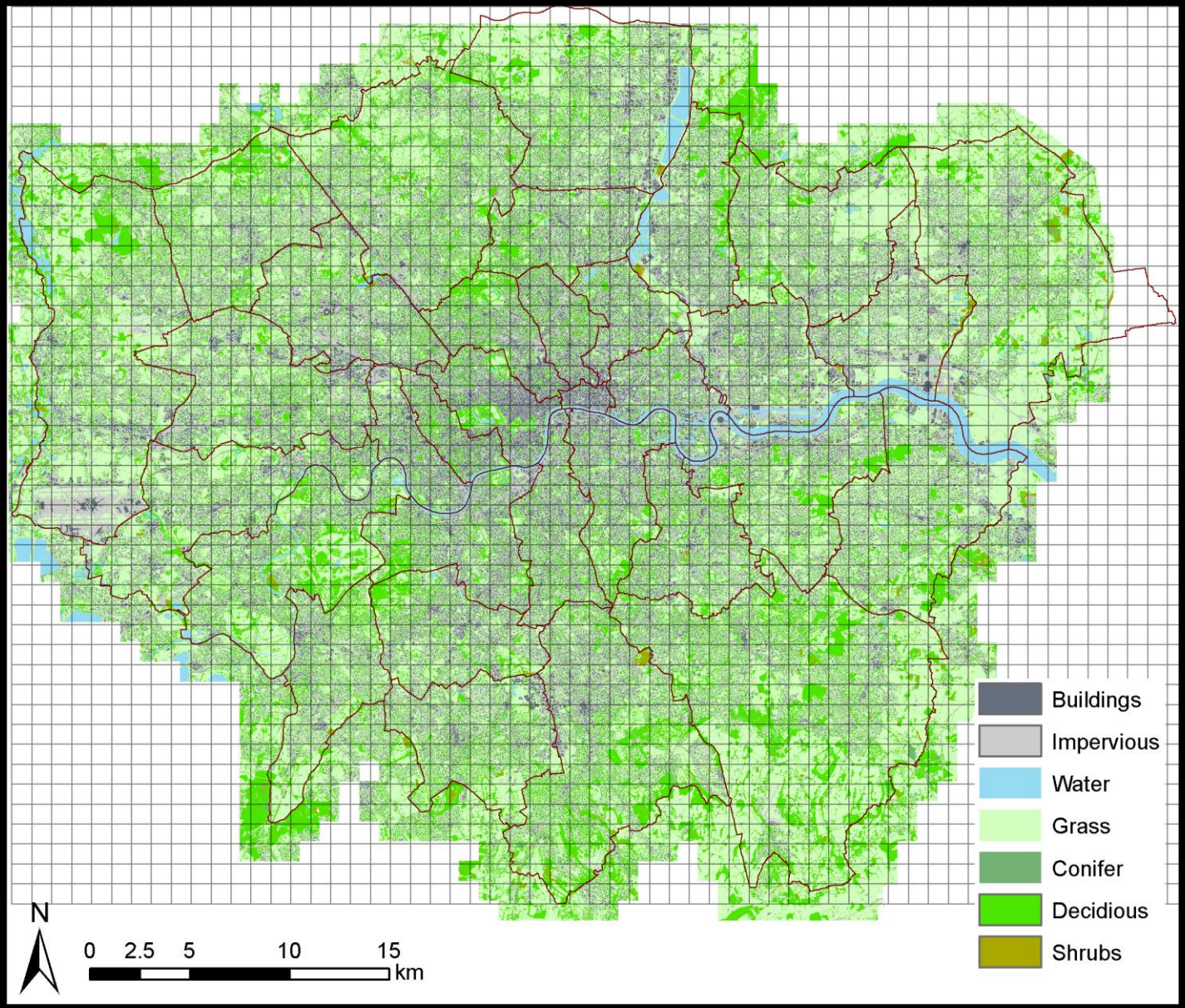

1. Input data
2. Possibility to aggregate data (grid or adm. areas)

Land cover

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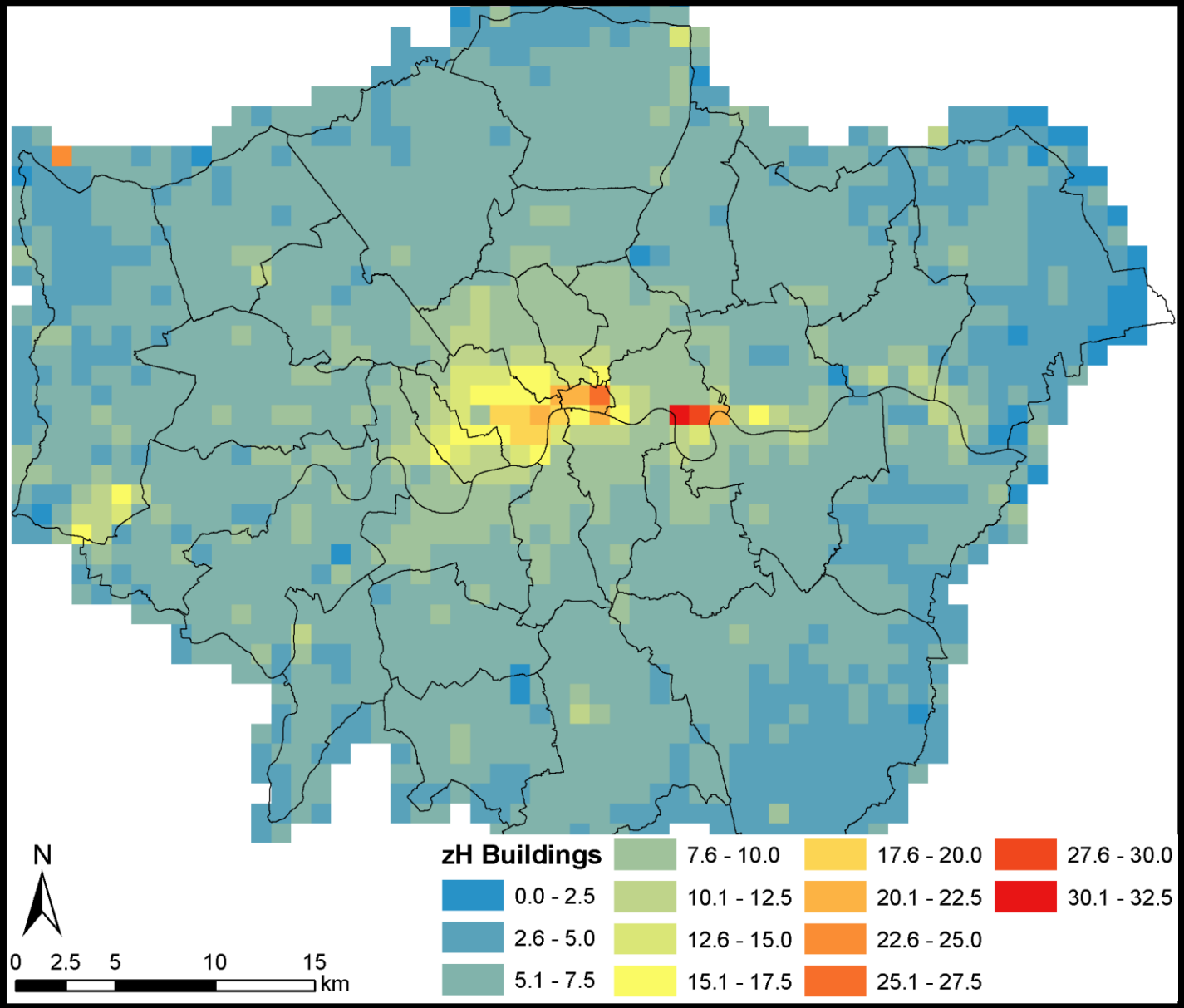
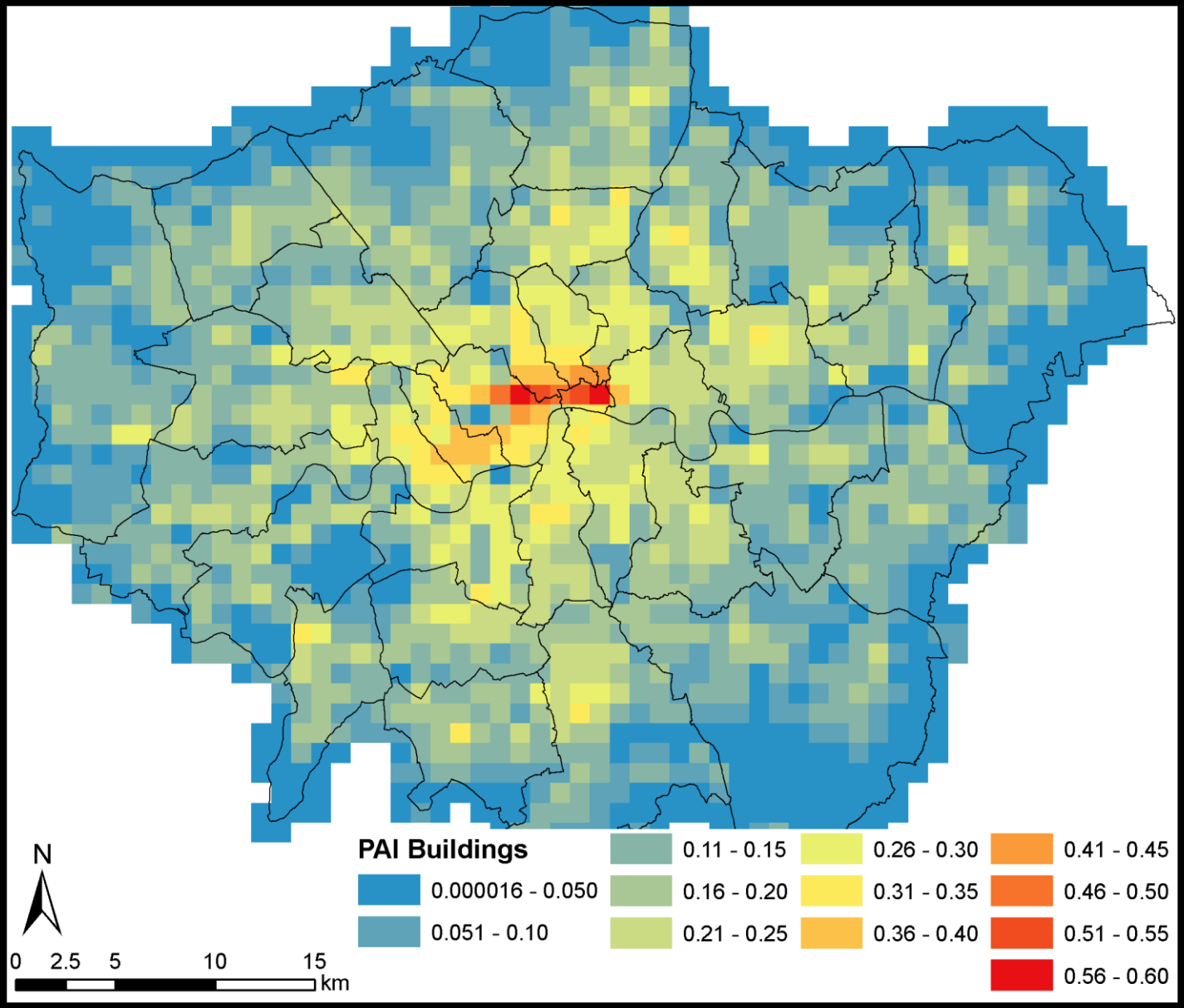


1. Input data
2. Possibility to aggregate data (grid or adm. areas)
3. Derive forcing data to the modelling system

z_H (Mean Building Heights)

Existing examples of applications - SUEWS

Spatial variations of energy fluxes in London



1. Input data
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λ_P (Building fraction)

Existing examples of applications - SUEWS

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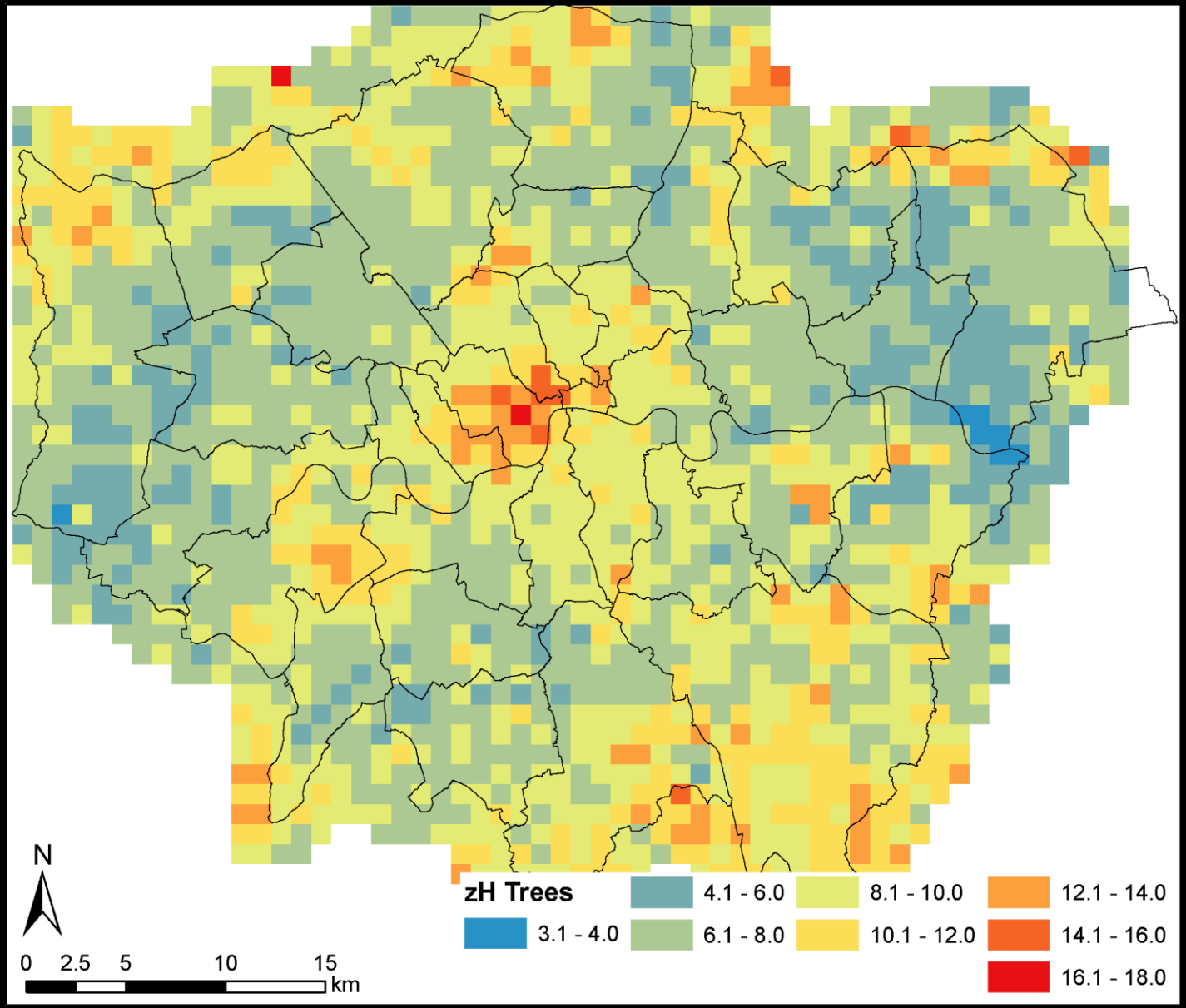

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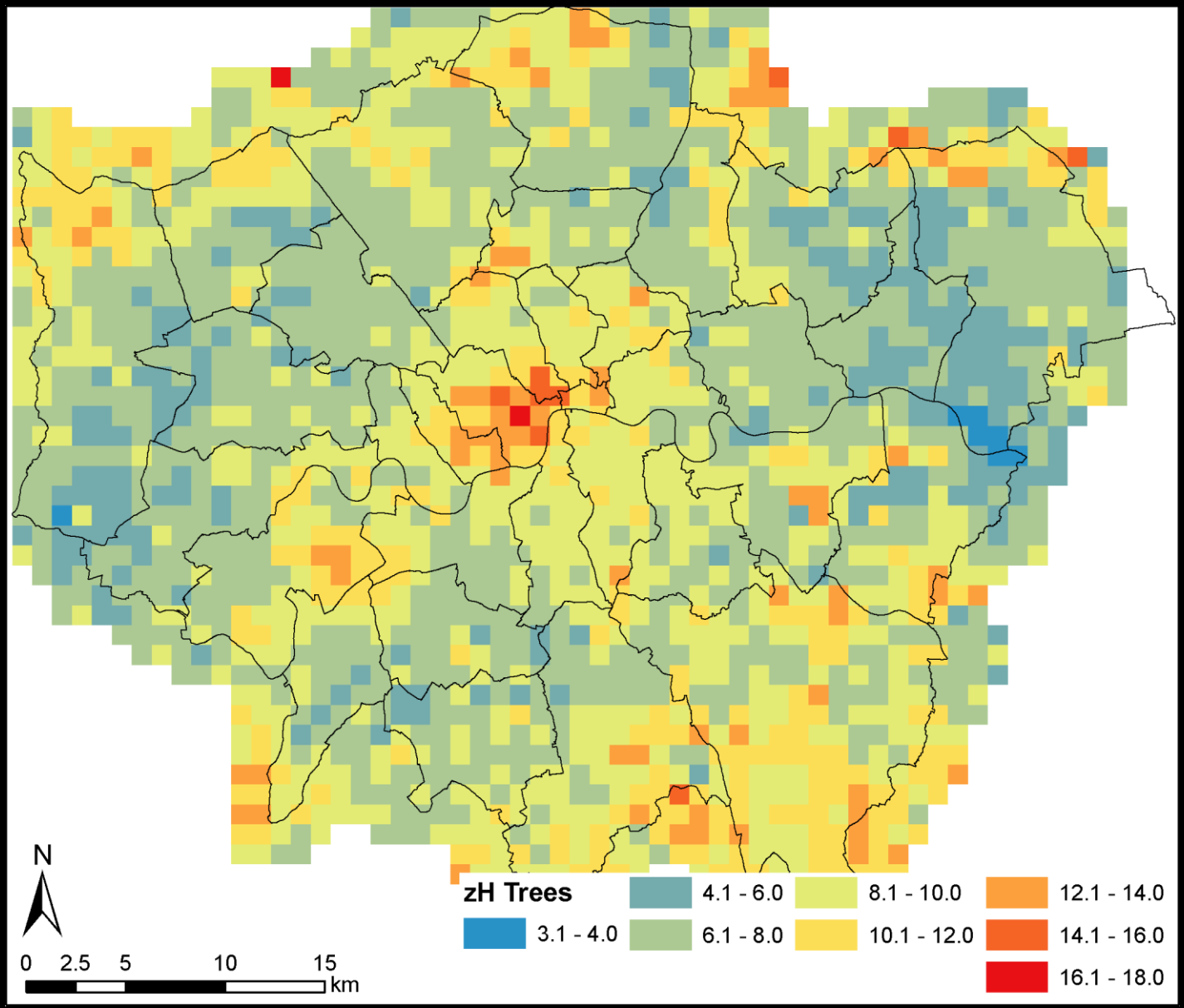
$z_{H\ (VEG)}$ (Tree heights)

Existing examples of applications - SUEWS

Spatial variations of energy fluxes in London



1. Input data
2. Possibility to aggregate data (grid or adm. areas)
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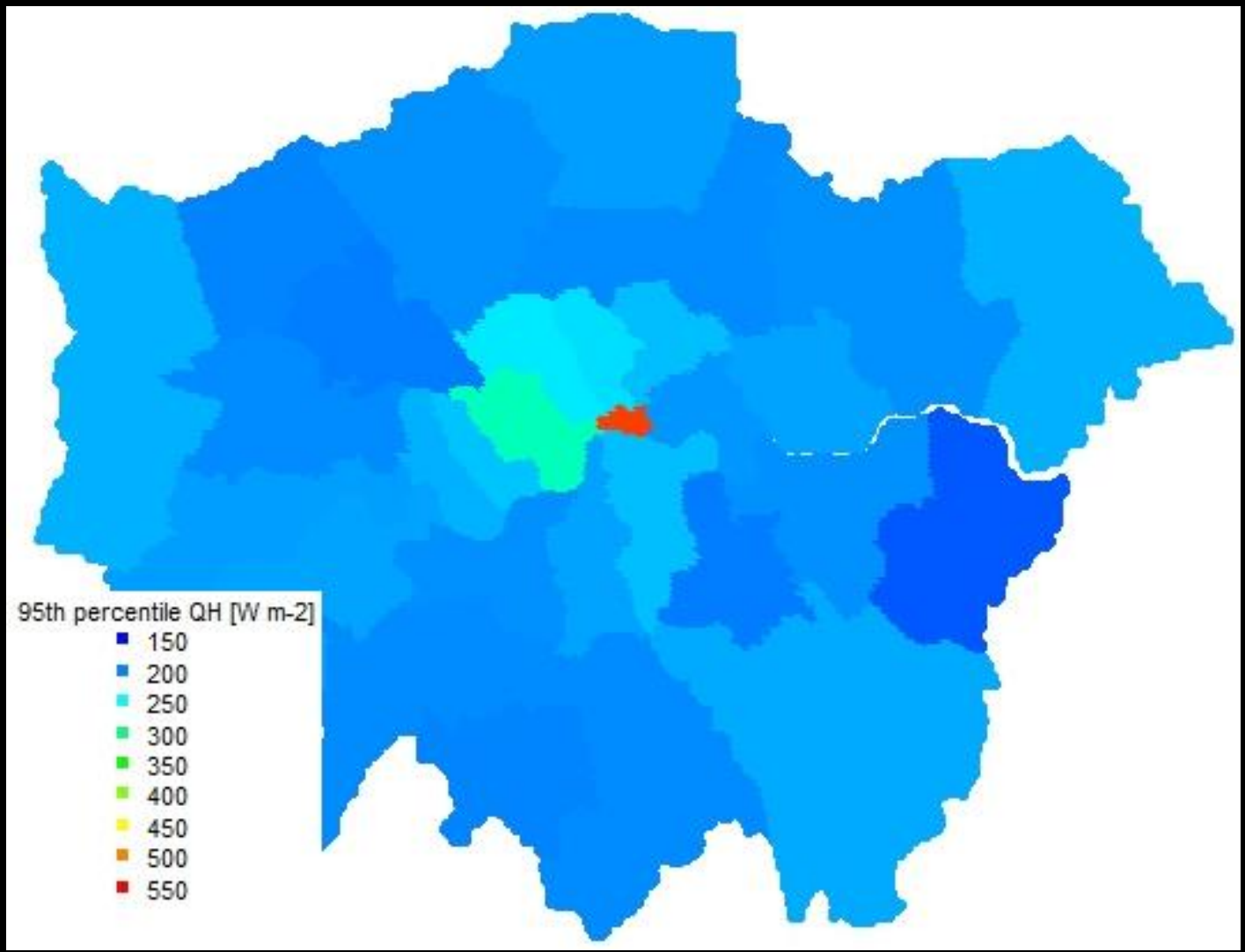
4. Model results presented in map of adm. areas.

$z_{H\ (VEG)}$ (Tree heights)

Existing examples of applications - SUEWS

Spatial variations of energy fluxes in London



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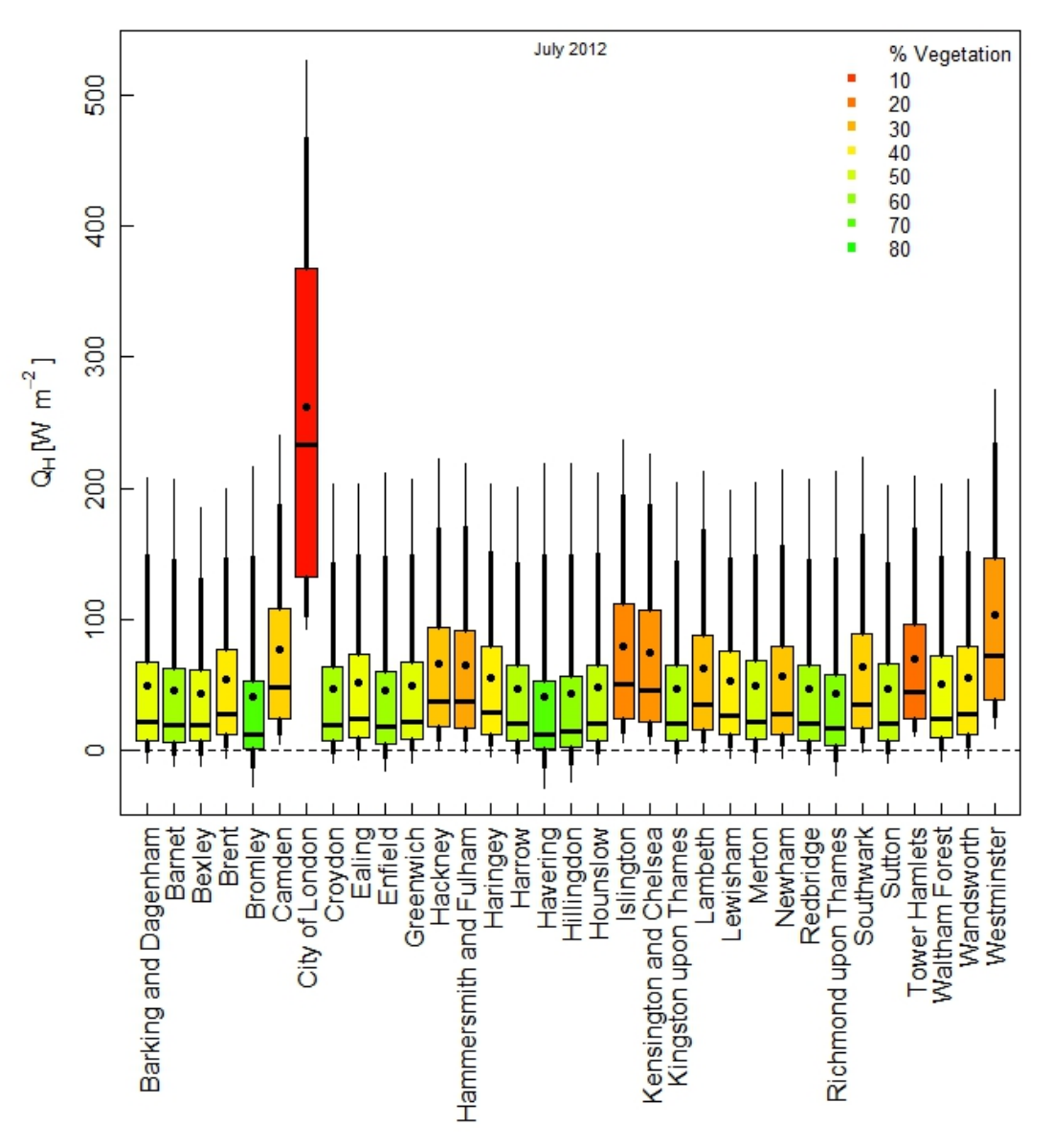
Q_H (Sensible Heat Flux statistics for July 2012)

Existing examples of applications - SUEWS

Spatial variations of energy fluxes in London

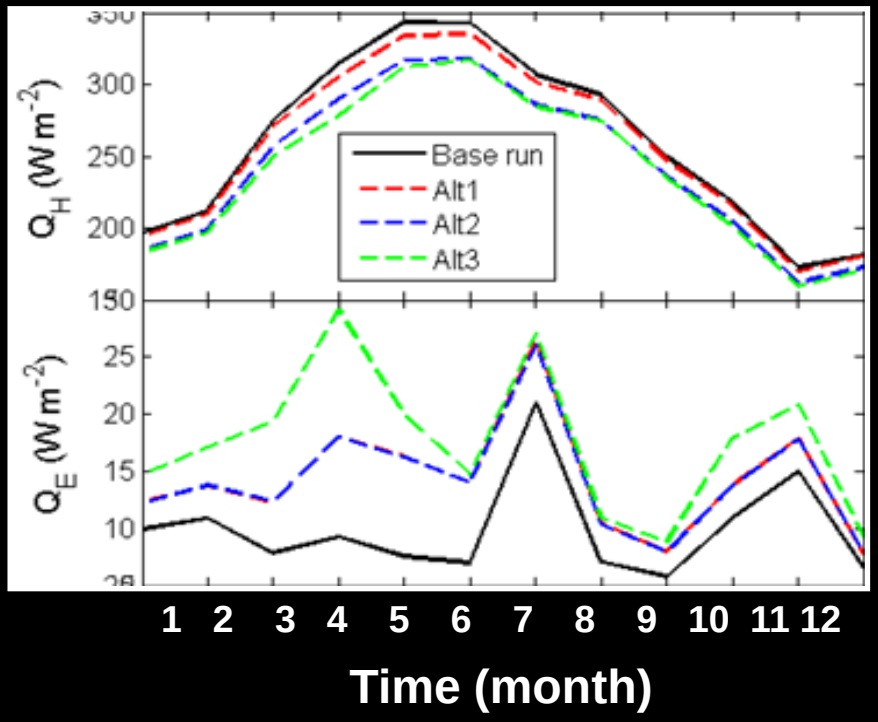


1. Input data
2. Possibility to aggregate data (grid or adm. areas)
3. Derive forcing data to the modelling system
4. Model results presented in map of adm. areas.
5. Model results presented as graphs

Q_H (Sensible Heat Flux statistics for July 2012 related to vegetation fraction)

Existing examples of applications - SUEWS

Heat and water exchanges with different planning alternatives in the center of London



- Alternative 1:

  Adding 10% of street trees

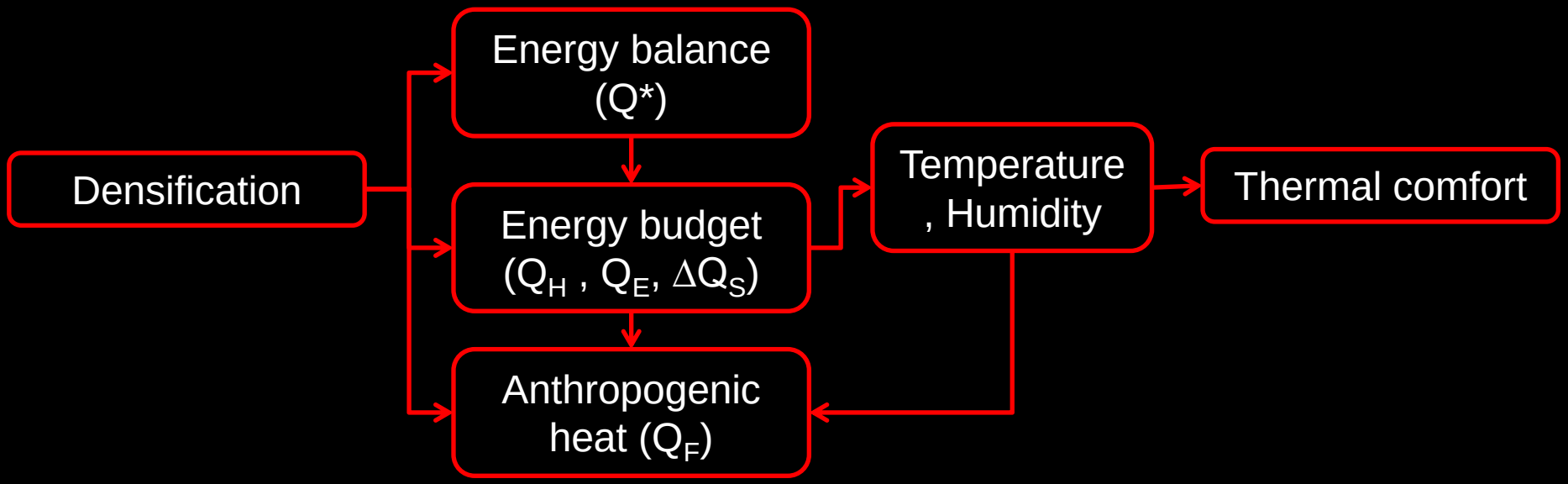
- Alternative 2:

  Changing 2% of the roofs to green roofs

- Alternative 3:

  Alternative 1 + Alternative 2

Examples of future applications - coupling



Summary

- The concept of UMEP (Urban Multi-scale Environmental Predictor), an integrated tool for urban climatology and climate sensitive planning applications is presented.
- The tool consists of a coupled modelling system which combines “state of the art” 1D and 2D models related to the processes essential for scale independent urban climate estimations
- UMEP will become available as a plugin in QGIS, which is an OSGIS API
- First release, hopefully in first half of 2015

Thank you