Urban Heat Island modelling with ADMS-Urban: London case study

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Motivation

- Local governments are increasingly interested in **green infrastructure**, knowing it can lead to:
  - elevated community health and well-being
  - improvements in air quality
  - reductions in the impact on the local climate

- Urban areas can have a large effect on the local climate, increasing the temperature; known as the Urban Heat Island (UHI)

- **New developments** can be designed, constructed and operated with minimal impact on the local climate

- Increasingly, the impact of new developments on **local climate** are considered alongside the impacts on **air quality**

- ADMS-Urban has been developed to model changes in the local climate due to land use and anthropogenic heat emissions allowing a joined up approach to planning assessments
Theory & model overview

- Urban fabric and morphology influences climate
- Climate variations: local & city scale

Meteorological conditions change:
- Wind speeds reduce
- Turbulent mixing increases due to high building densities
- Boundary layer height increases due to the increase in turbulent mixing
- Urban fabric retains more heat & has less moisture than rural areas – alters heat flux balance

Pollutant dispersion is influenced by meteorological variations. Also:
- Chemical reaction rates are temperature dependent (e.g. ozone production)
- UHI temperature increases alter relative plume buoyancy
Theory & model overview

- The **surface energy balance** equation defines how much heat is available at the surface to be converted into surface sensible and latent heat:

  \[
  \text{Net radiation (long and short wave)} + \text{Anthropogenic heat} - \text{Ground heat flux} = \text{Surface sensible heat flux} + \text{Latent heat flux}
  \]

- **Surface sensible heat flux**, together with friction velocity and temperature, define the upwind profile.
Theory & model overview

SOURCE DATA

- Detailed land use dataset
- Buildings data
- Traffic data
- Meteorological measurements or mesoscale model output

INPUT DATA

- Surface albedo
- Thermal admittance
- Surface resistance to evaporation
- Surface roughness
- Normalised building volume data
- Buildings heat emissions
- Traffic heat emissions
- Meteorological data

MODEL

ADMS-Urban Temperature & Humidity module

OUTPUT DATA

- Temperature & humidity perturbations from upwind values
- Temperature & humidity increments due to anthropogenic heat sources

CERC
Model applications

- To date, primarily research applications

Modelling local land use changes

Pre-Olympic temperature perturbations to the upwind boundary layer profile at 2m due to land use variations 19:00 on 10/06/2006 overlaid onto a map. © Crown copyright, All rights reserved. 2009 Licence number 0100031673
Model applications

• To date, primarily research applications


Modelling local climate mitigation scenarios

Daily temperature variations on green and cool roof compared to ‘normal’ roof
Model applications

• To date, primarily research applications


City-scale modelling & comparisons to other models
Model applications

• To date, primarily research applications
• The Temperature & Humidity module will be available* as part of ADMS-Urban 4.1 for commercial applications
  – Currently being used by Barcelona Regional to model the Barcelona Urban Heat Island
  – Used for climate modelling in ‘Coupling Regional and Urban processes: Effects on Air Quality’ project (NERC)

*extended licence required
Case Study: London
Model configuration: source data

- Input data derived from land use data:
  - Albedo
  - Surface resistance to evaporation
  - Thermal admittance

Corine land use data (2006), 100m resolution

Colours represent land use types e.g. urban, woodland, construction
Case Study: London
Model configuration: source data

- Input data derived from **buildings data**:
  - Roughness
  - Normalised building volume
  - Buildings anthropogenic heat

Use 3-D buildings data to calculate parameters $\lambda_p$ and $\lambda_F$ (ArcGIS tools)

Use typical heat emission rates ($W/m^2$)

Colours are of non-domestic buildings within each ward

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Case Study: London
Model configuration: source data

• Input data derived from road traffic data:
  – Road traffic anthropogenic heat

Model converts CO$_2$ emission rates to heat energy emission rates (W/km)
Case Study: London
Model configuration: source data

- **Meteorological data:**
  - Standard ADMS met data parameters
  - Temperature & humidity values must be upwind (cf. pollutant background data)
  - Upwind measurement heights above sea level required as input
  - London: 5 stations used

Wind rose indicates dominant wind directions

Meteorological sites upwind of model domain
Case Study: London
Model configuration: model domain & receptor network

**Model domain:**
- 80 km x 65 km, Greater London
- Land-use calculations use ‘FLOWSTAR’ internal grid (e.g. 256 x 256 → 312 m x 234 m)

**Receptor network:**
- Measurement sites
- Full receptor network (regular & source-oriented grids)

Most ‘Met Office standard’ sites are located in open spaces, usually parks

- Olympic Park (2 sites)
- London City
- Kew Gardens
- St James Park
- Hampstead

St James Park

Olympic Park S

Olympic Park N

London City

Kew Gardens

Hampstead

Most ‘Met Office standard’ sites are located in open spaces, usually parks
Case Study: London
Model results

- Absolute temperatures:
  - Box and whisker plot
  - Frequency scatter plots
- Temperatures perturbations
  - Box and whisker plot
  - Average diurnal profiles
- August and January 2012

- Note
  - Calculation grid resolution may not resolve land use inputs
  - Unrefined receptor locations
Case Study: London
Model results: absolute temperatures

- Absolute temperatures (August 2012)
  - Box and whisker plot
  - The ‘box’ shows the 25th, 50th and 75th percentiles*

*The inter-quartile range (IQR) = 75th %ile - 25th %ile. Lower whisker = the lowest concentration value still within 1.5 x IQR of the lower quartile. Upper whisker = the highest concentration value still within 1.5 x IQR of the upper quartile.
Case Study: London
Model results: absolute temperatures

- Absolute temperatures (August 2012):
  - Frequency scatter plots of hourly temperatures
  - How does it compare to just using upwind temperatures?
Case Study: London

Model results: temperature perturbations

- Temperature perturbations (August 2012)
  - Very good performance at some sites
  - Negative temperatures not displayed
Case Study: London
Model results: temperature perturbations

- Temperature perturbations (August 2012) relative to upwind

Temperature perturbation °C

August - Hampstead
August - St James Park
August - London City
August - Olympic Park North
August - Olympic Park South
August - Kew Gardens

Corine land use data from 2006, site re-developed for the Olympics (greener)

Missing anthropogenic heat source on site?
Case Study: London
Model results: temperature perturbations

- Temperature perturbations (January 2012)
  - Good performance at all sites
  - Negative temperatures not displayed

![Temperature perturbation results](chart.png)
Case Study: London
Model results: heat maps

Example satellite image of land surface temperature (June 2011)

Example modelled temperature ~ 3.0 m (August 2012)

LandSat image of land surface temperature (°C) (26th June 2011) with Greater London area border overlaid.

Taken from “Reducing urban heat risk: A study on urban heat risk mapping and visualisation” July 2014

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ADMS-Urban modelled surface temperature (°C) (18 August 2012)
Case Study: London
Model results: heat maps

- Example daily variations (August 2012)

7 am

Midday
Temperature perturbation °C

Specified points (14)
Temp pert (°C), 7 am
-6
-4
-2
0
2
4
6
8
10

7 pm

Midnight
Case Study: London
Model results: heat maps

- Example daily UHI variations
- Street-scale resolution contour model output for planning

Resolution of model inputs for this figure:

- Traffic anthropogenic heat ~ street scale
- Buildings anthropogenic heat ~ 5 km
- Land use ~ 400 m

Higher resolution buildings and land use inputs can be used

Temperature °C
18th August
7 pm

Regents Park
Piccadilly Circus
Hyde Park
Green Park
St James Park
Thames

Resolution ~3.5 km

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Case Study: London
Model results: heat maps

- Example daily UHI variations
- Street-scale resolution contour model output for planning
- Model validation at all site types e.g. data from wunderground.com

~4° UHI even on a cloudy late afternoon in the autumn
Summary

- ADMS-Urban 4.1 will include a ‘Temperature & Humidity’ module*

- Good model performance at the city scale
- Ongoing projects to validate at the local scale

- As for air quality, ADMS-Urban is able to model hourly temperature and humidity variations to a high spatial resolution

- Applications include:
  - Planning applications
  - Climate change mitigation scenarios
  - UHI modelling

*extended licence required
Any questions?