Forecasting Air Quality and Extreme Temperature in Cities

Project on Disaster Resilient Cities: Forecasting local level climate extremes and physical hazards for Kuala Lumpur

10th March 2017

Kuala Lumpur

David Carruthers & Jenny Stocker

CERC
Cambridge Environmental Research Consultants
Environmental Software and Services


London smog 1952


Kuala Lumpur


Chang An Avenue, Beijing, in 1979

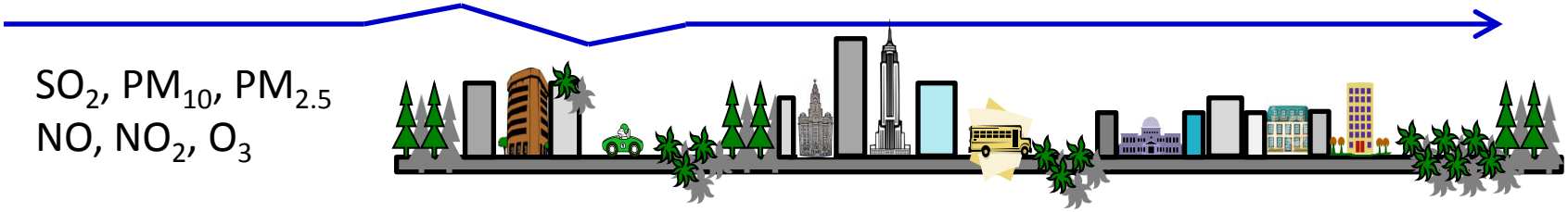

Beijing 2012

Motivation – Forecasting urban air quality

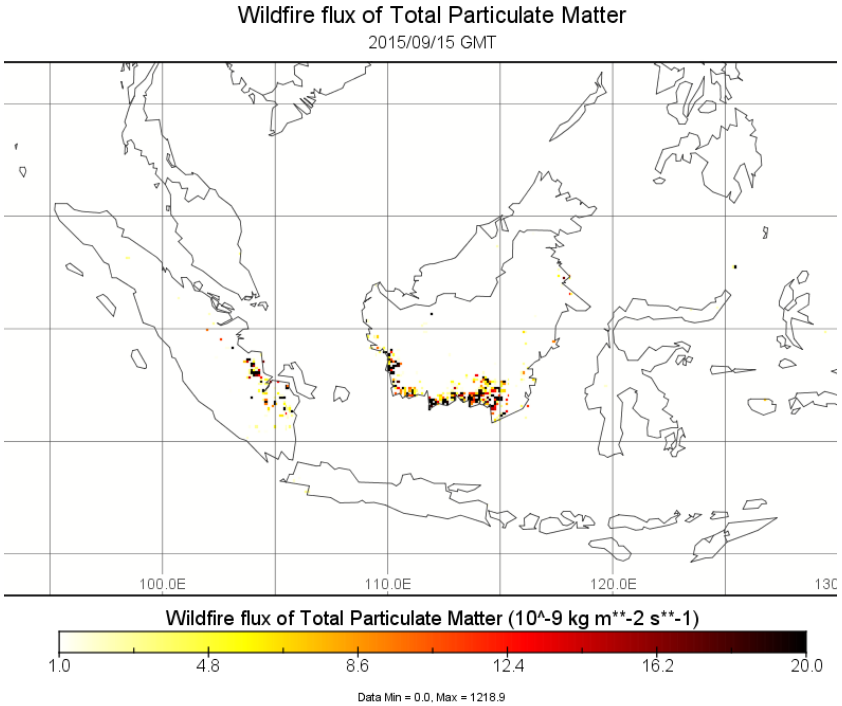
- Urban areas have a high density of **emission sources**:
  - Road & other traffic, power generation, heating/cooling, many other sources
- **Dispersion** of emissions in urban areas are restricted by the built environment:
  - For example pollution trapped within street canyons
- **Population exposed** to pollution suffers health impacts. Particularly relevant to those with heart or lung conditions or other breathing problems
- **Regional Sources** such as biomass burning also important
- Need for air quality forecasting models to warn public and to improve understanding of the key sources – e.g. for planning or interventions

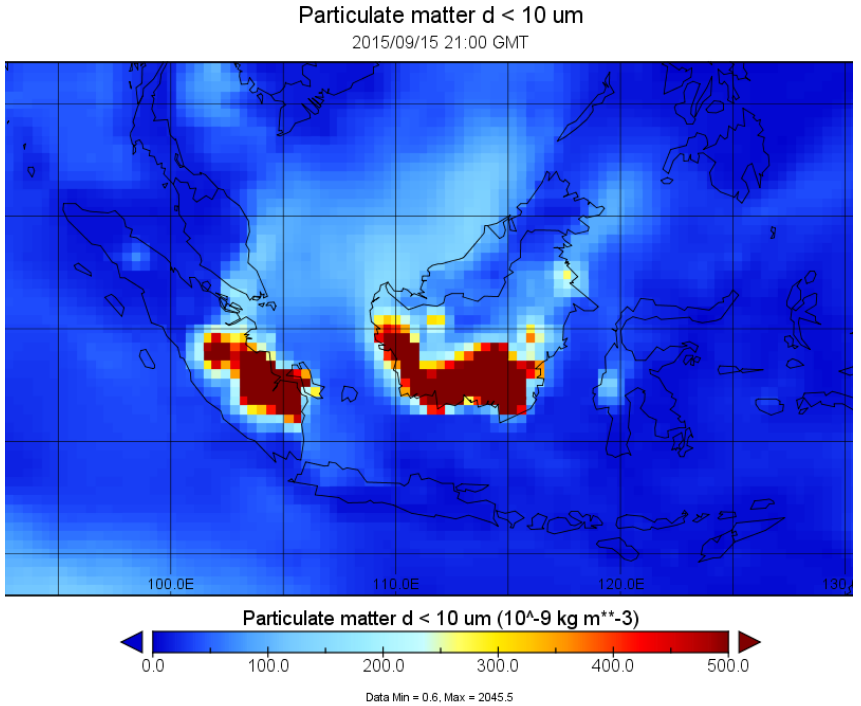
Urban pollution modelling
Regional effects

- Regional pollution need to feed into an urban air quality forecasting system



- This is predicted global/regional chemical transport models e.g. CAMS. WRF-CHEM.....



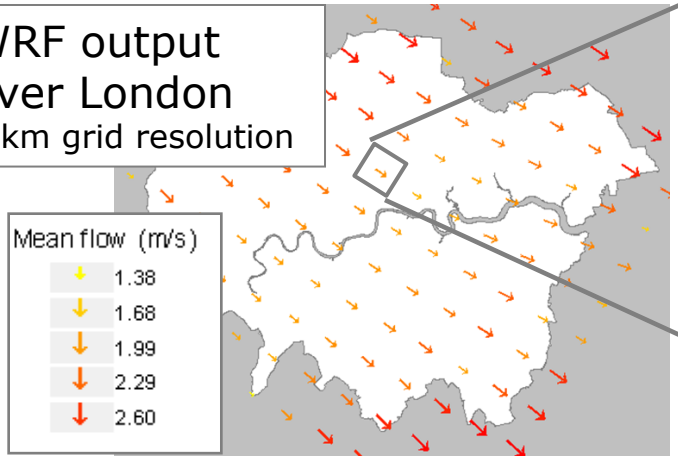


CERC

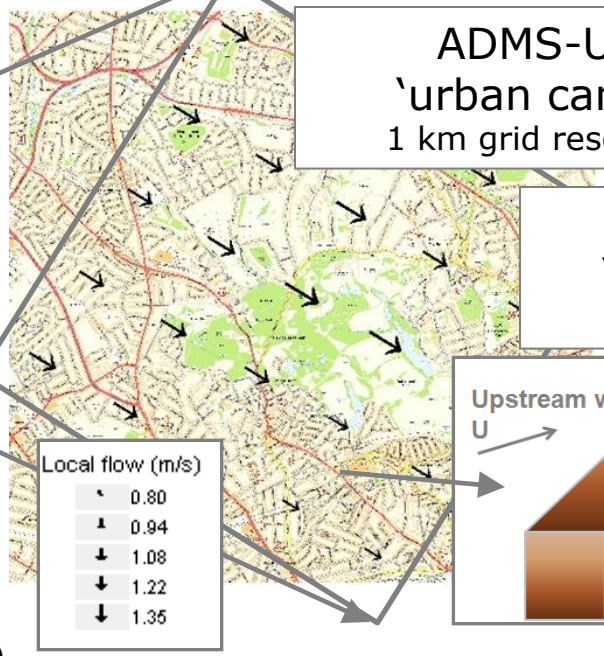
Modelling Urban Air Quality

- Regional to local meteorology

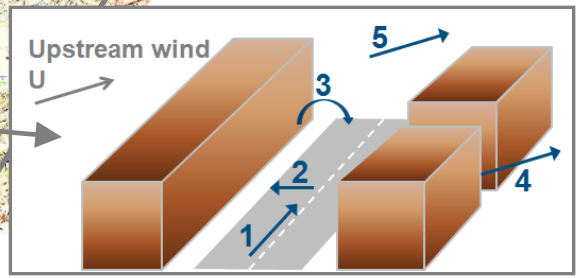
WRF output over London
5 km grid resolution



ADMS-Urban 'urban canopy'
1 km grid resolution

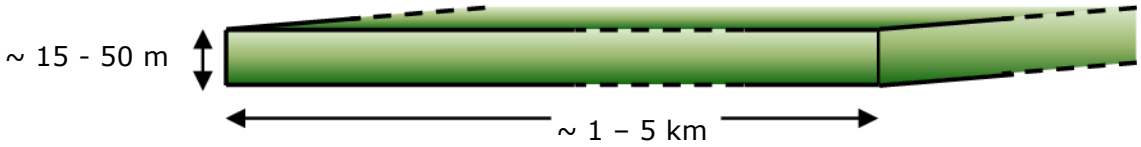


ADMS-Urban 'advanced canyon'
street-scale resolution



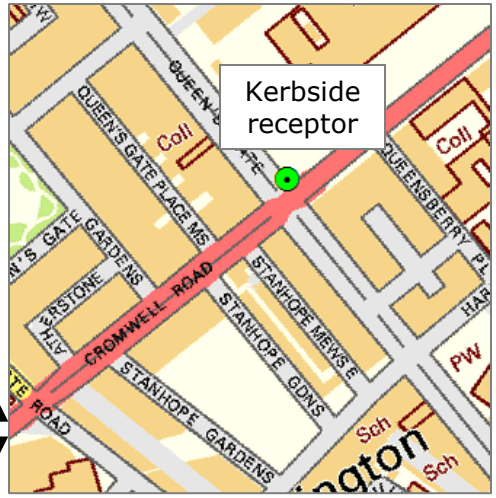
Regional to local emissions

Typical regional model grid cell (lowest layer)



- Source dimensions << regional model grid scale
- Local model explicitly represents source dimensions

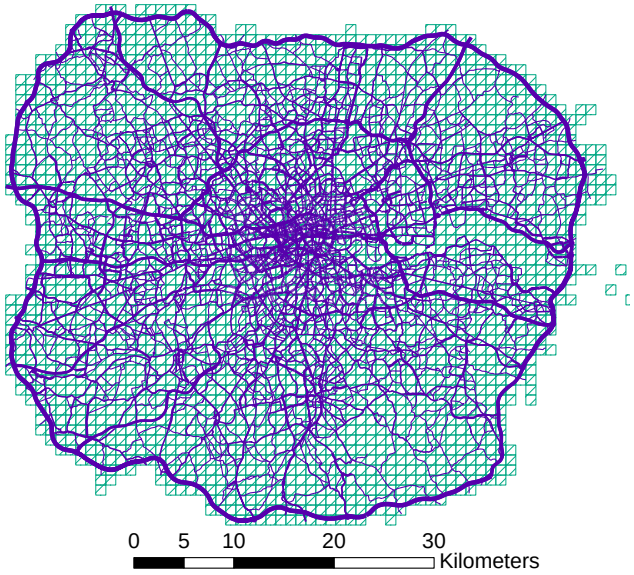
Vehicle heights
~ 1.5 - 5 m



Road widths
~ 6 - 50 m

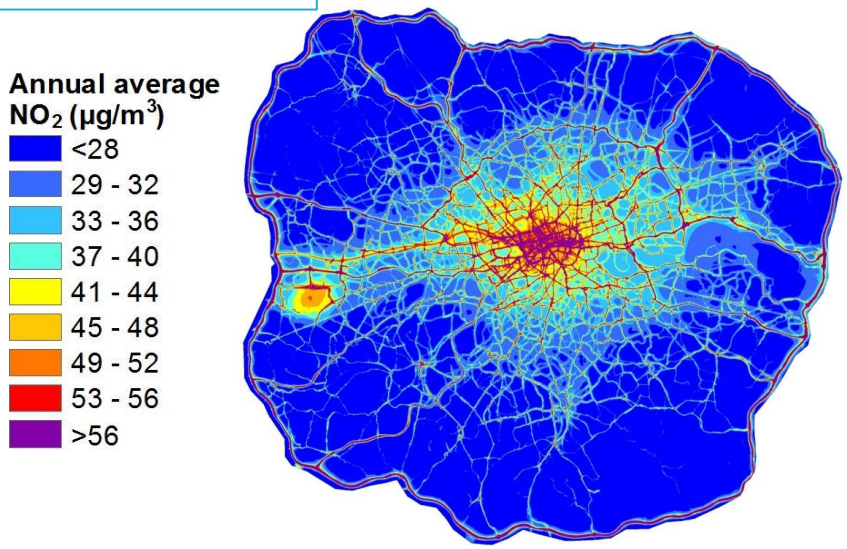
Urban Air Quality - ADMS-Urban

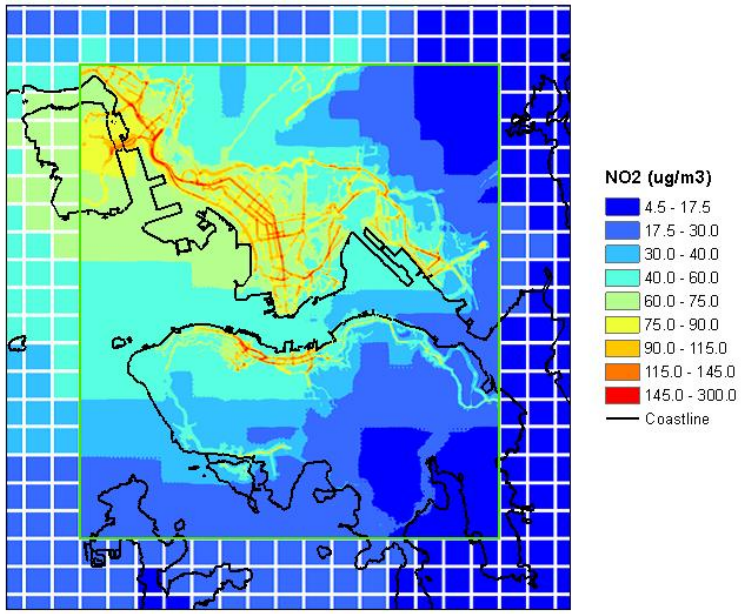
Emissions

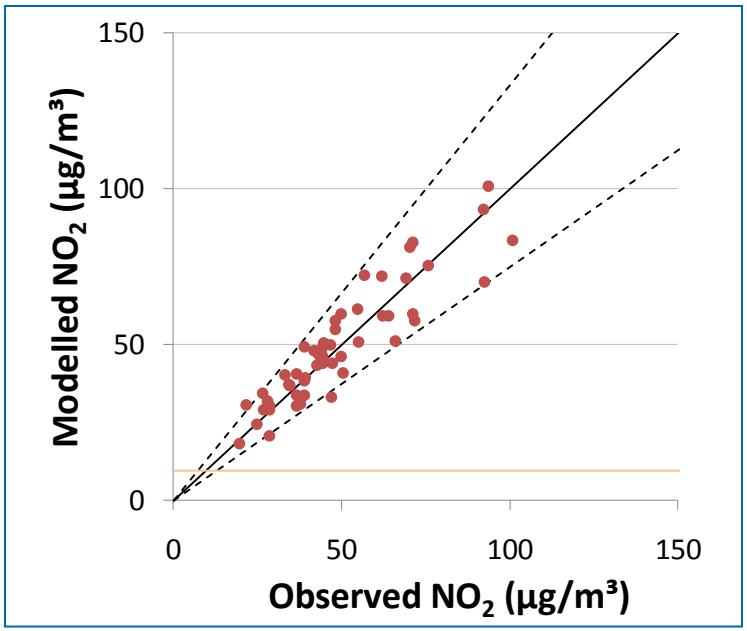


Concentrations

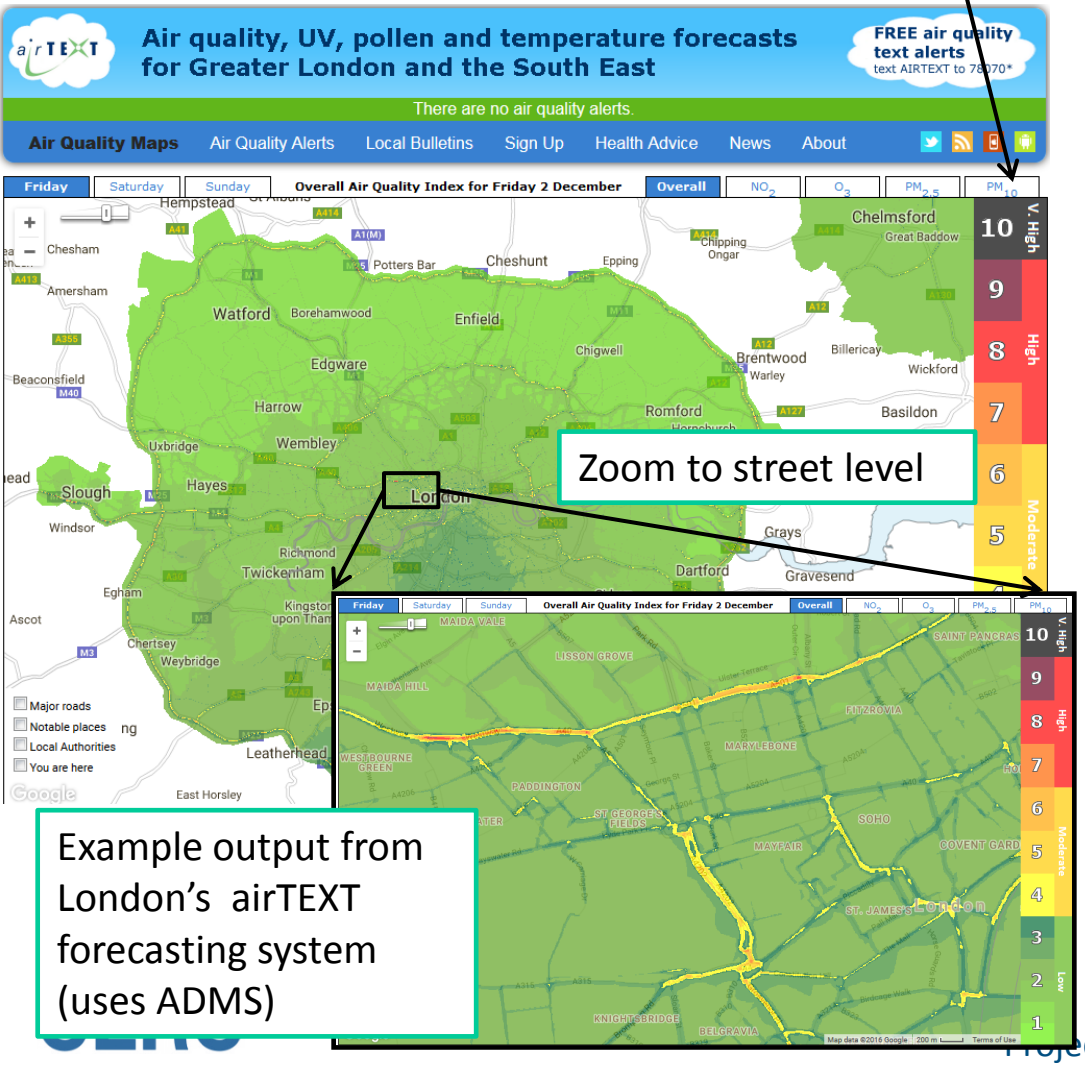
Modelled annual average NO_2 2012







Air Quality Forecasting: Output from ADMS



- **Pollution maps**: Health-related daily statistics e.g. daily average or daily maximum (derived from hourly values) at street-scale resolution (~ 10 m near roads, ~ 50 m urban background)
- **Frequency**: one or more 3+ day forecasts per day (
- **Communication**: web, high pollution alerts by text, e-mail etc.

Atmospheric Hazards

Extreme Wind & Rain

WRF + UK Met Office model

Extreme Temperatures

WRF + UK Met Office model

*

ADMS Temperature & Humidity
- ✓Customised tropical boundary layer*
- ✓ High humidity modifications*
- ✓ Temporally varying surface wetness*

High air pollution & Haze

WRF-Chem + UK Met Office model and/or CAMS

*

ADMS-Urban
- ✓with customised tropical boundary layer*

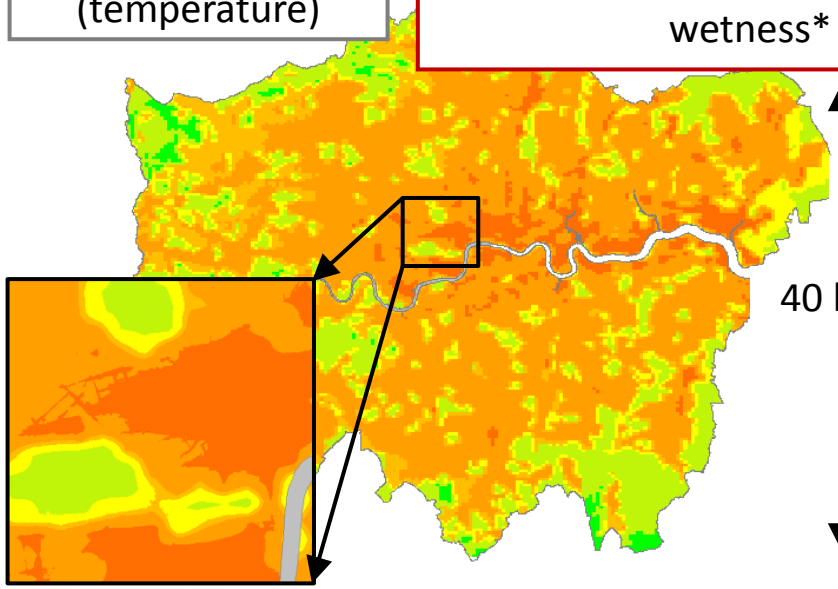
Regional models

coupled to

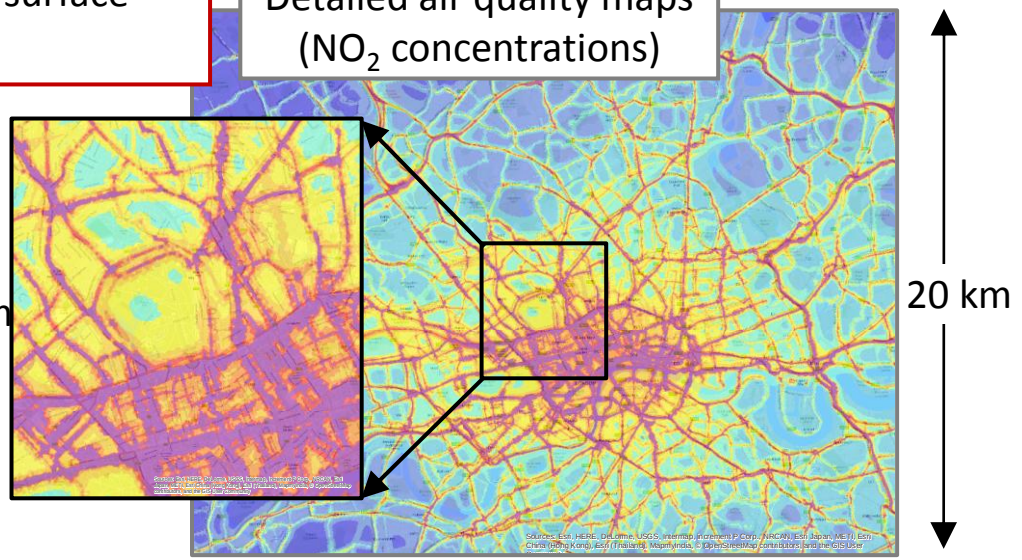
Local models

*New developments during the project

City-scale & local climate modelling (temperature)

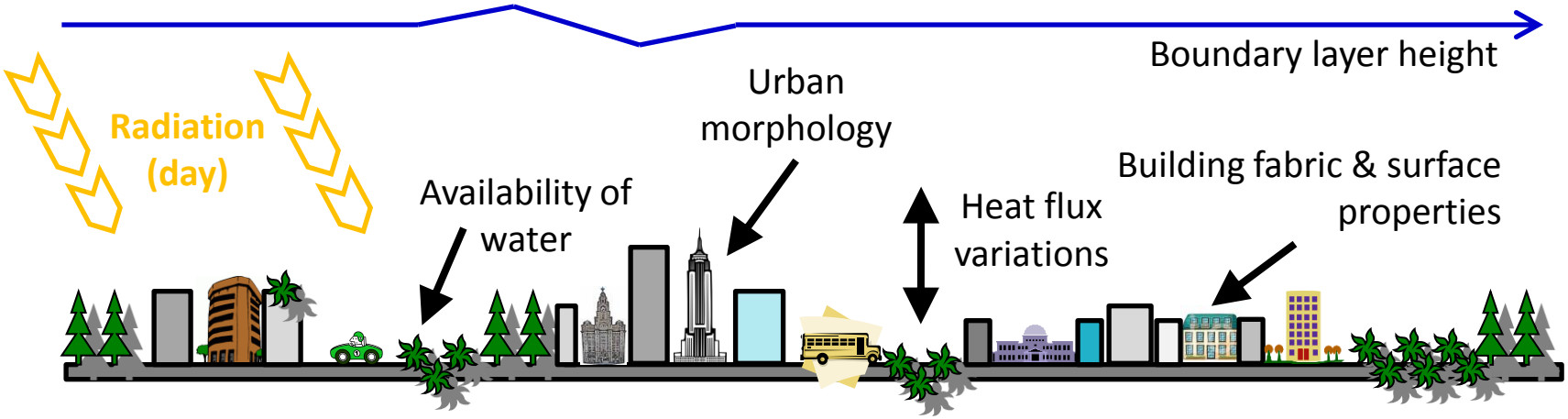


Detailed air quality maps (NO_2 concentrations)



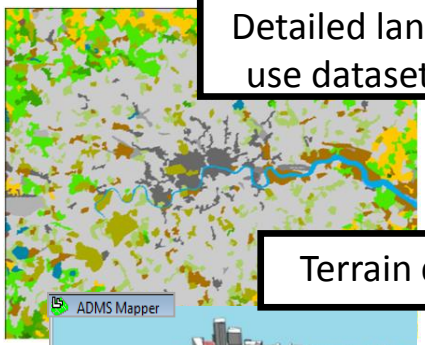
Modelling Extreme Temperatures – why?

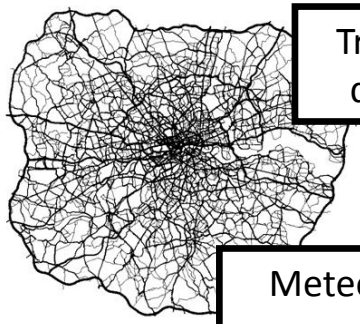
- Urban fabric and morphology influences climate
- Climate variations: local & city scale
- Meteorological conditions change:
  - Wind speeds reduce
  - Turbulence intensity increases
  - Boundary layer height increases due to the increase in turbulent mixing
  - Urban fabric retains more heat & has 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



Modelling Extreme Temperatures – how?

SOURCE DATA | INPUT DATA | MODEL | OUTPUT DATA





Detailed land use dataset

Terrain data

Buildings data

Traffic data

Meteorological measurements or mesoscale model output

Surface albedo

Thermal admittance

Surface resistance to evaporation

Terrain elevation

Surface roughness

Normalised building volume data

Buildings heat emissions

Traffic heat emissions

Meteorological data

Temperature & humidity variations due to land use

ADMS-Urban Temperature & Humidity module

Temperature & humidity perturbations from upwind values

Temperature & humidity increments due to anthropogenic heat sources

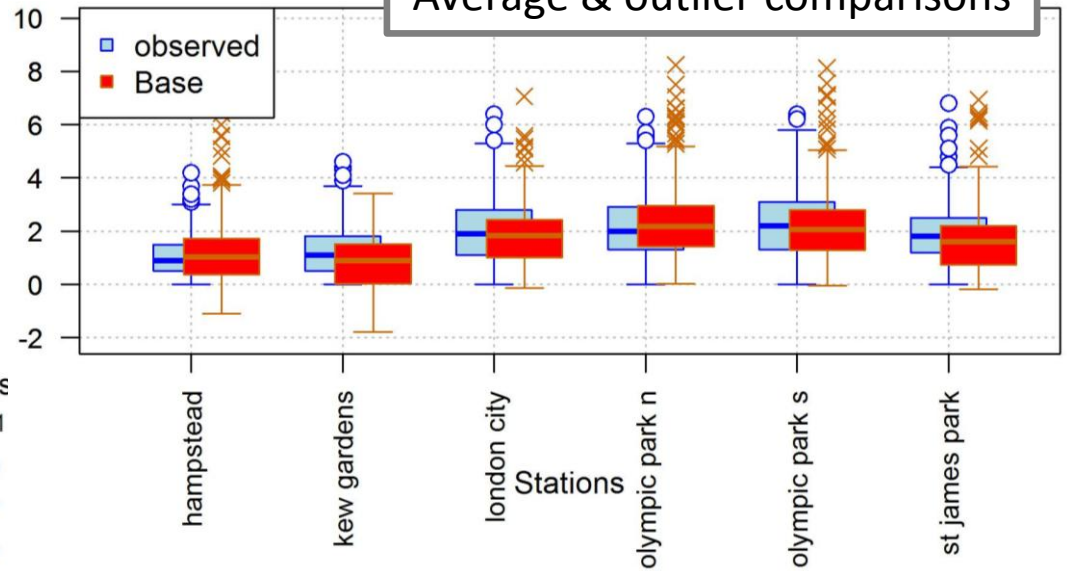
CERC

Modelling Extreme Temperatures - results

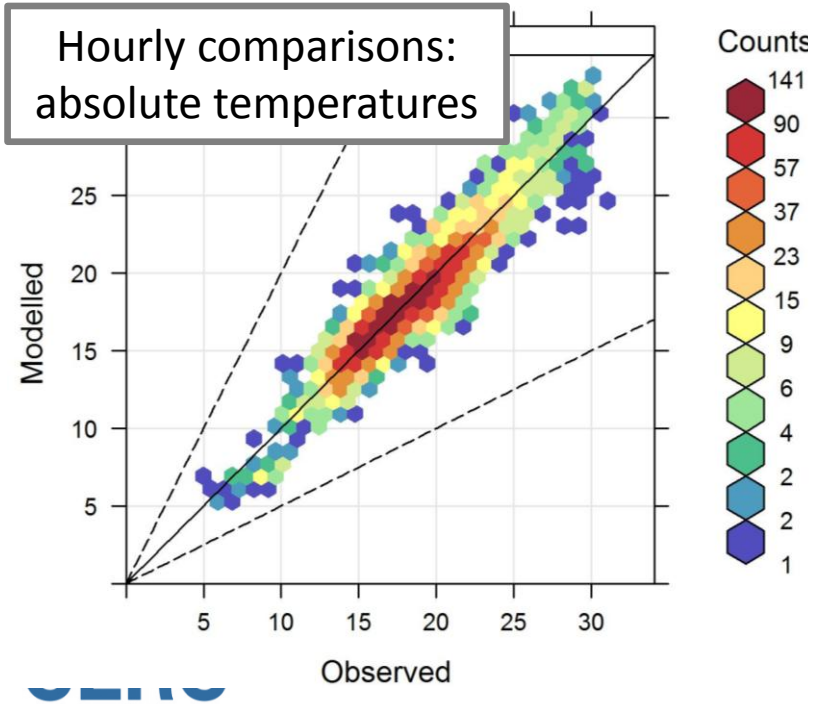
- Evaluate model predictions of **relative** temperatures at measurement sites

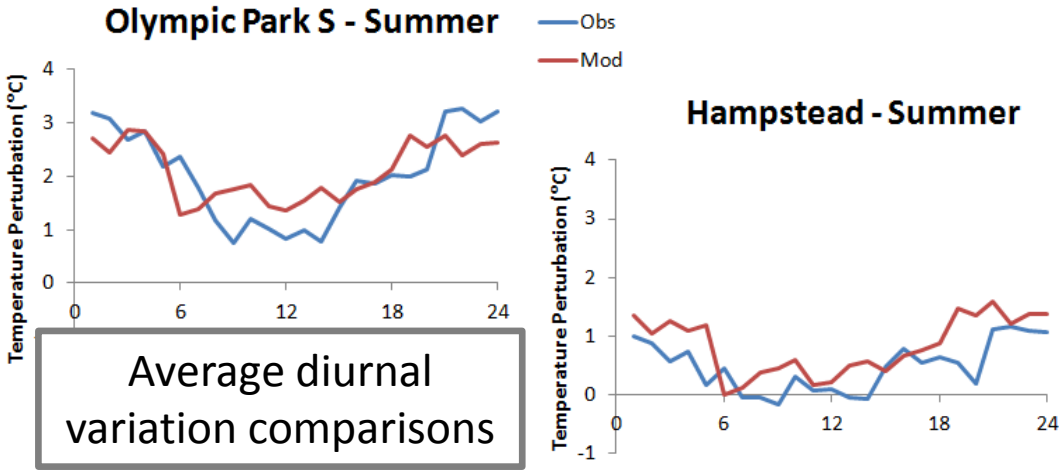
ADMS-Urban Temperature & Humidity model configured for London

Average & outlier comparisons



Hourly comparisons: absolute temperatures





Average diurnal variation comparisons

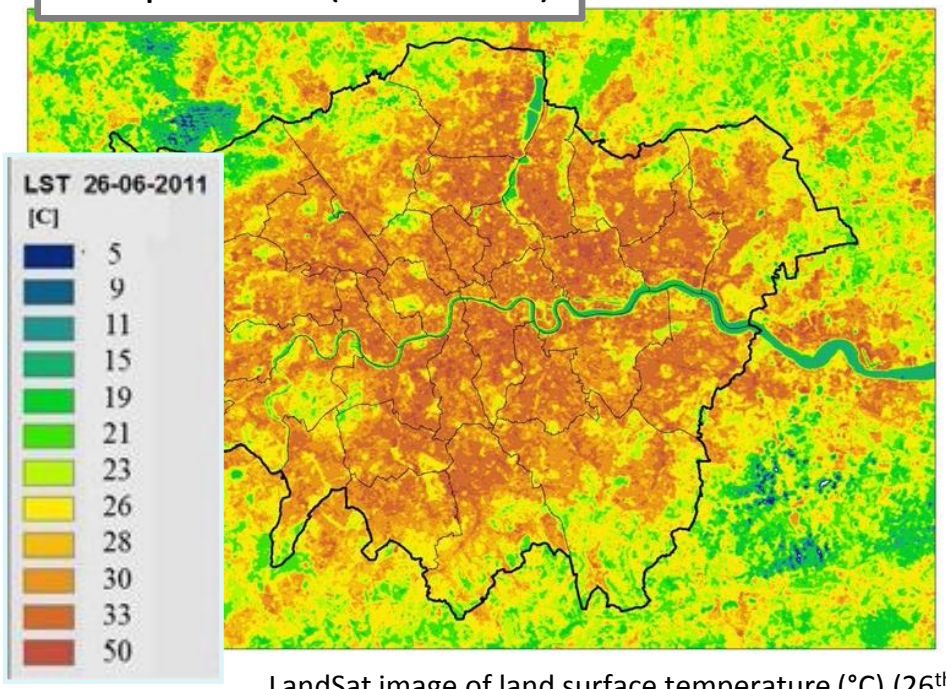
Modelling Extreme Temperatures - results

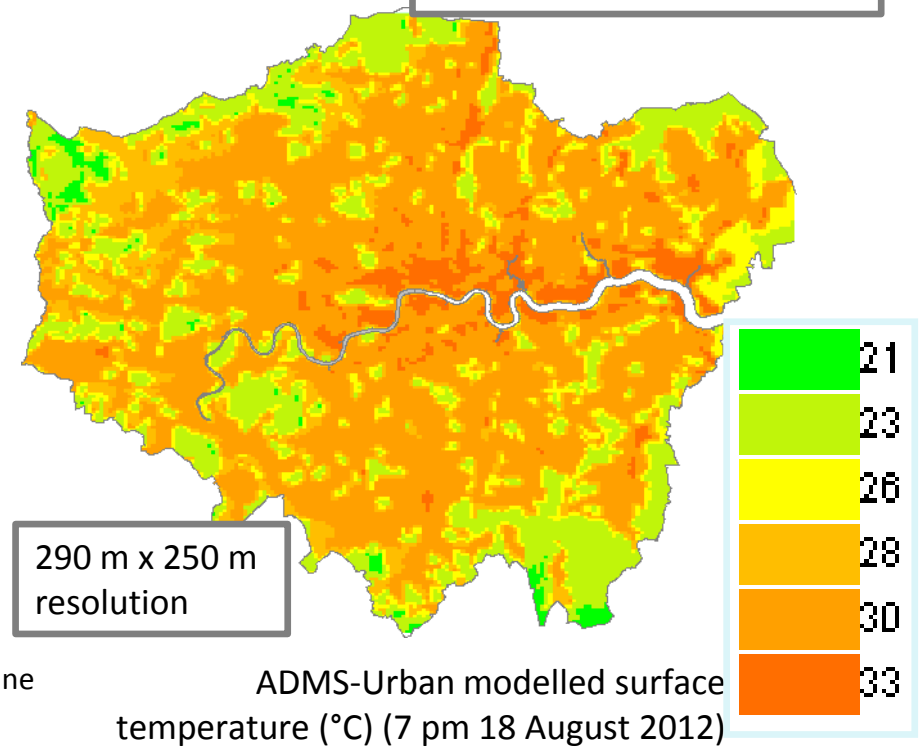
- Evaluate model predictions of **relative** temperatures at measurement sites
- Assess spatial variation of model predictions

Example satellite image of land surface temperature (June 2011)

London

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

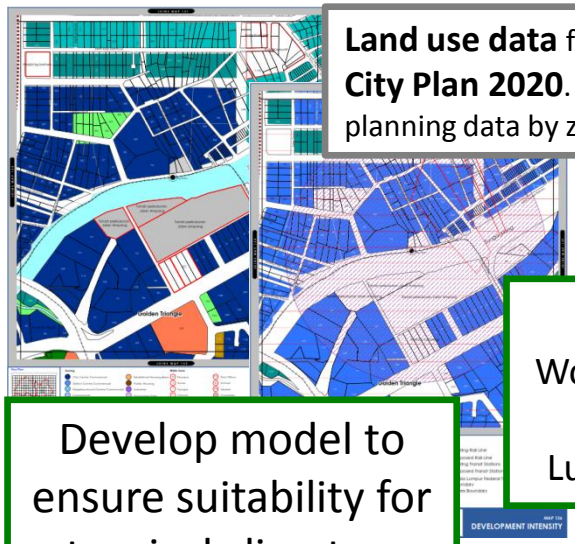
ADMS-Urban modelled surface temperature (°C) (7 pm 18 August 2012)

CERC

Modelling Extreme Temperatures - results

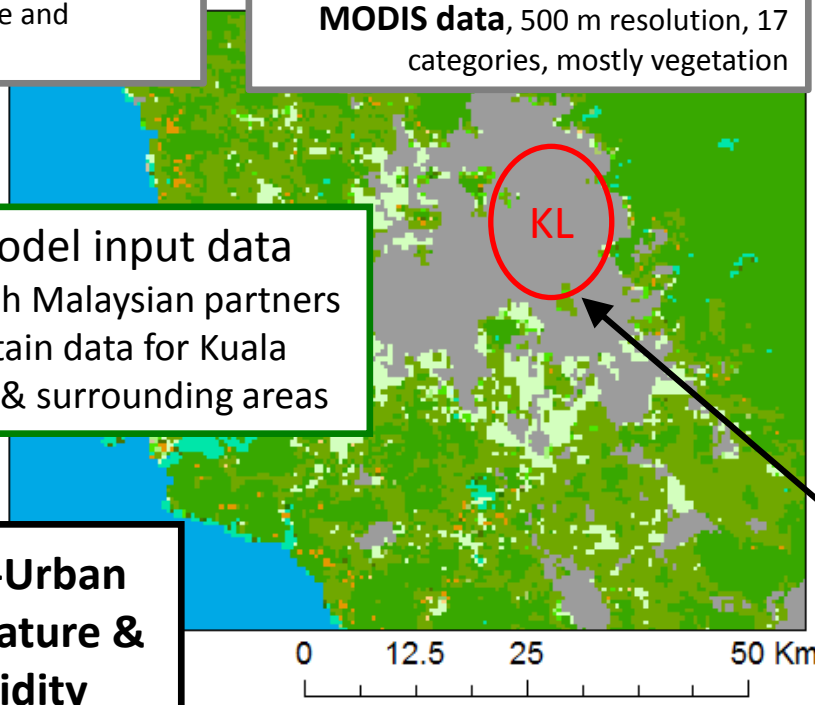
- Evaluate model predictions of **relative** temperatures at measurement sites
- Assess spatial variation of model predictions
- Use model:
  - Micro-climate modelling (next presentation)
  - Forecasting
  - Future climate scenarios
  - Couple with air quality modelling

Modelling Extreme Temperatures - KL



Land use data from **Kuala Lumpur City Plan 2020**. Land use and planning data by zone

2013 land cover type data from **MODIS data**, 500 m resolution, 17 categories, mostly vegetation



Land Cover Types

- 0 Water
- 1 Evergreen needleleaf forest
- 2 Evergreen broadleaf forest
- 3 Deciduous needleleaf forest
- 4 Deciduous broadleaf forest
- 5 Mixed forest
- 6 Closed shrublands
- 7 Open shrublands
- 8 Woody savannas
- 9 Savannas
- 10 Grasslands
- 11 Permanent wetlands
- 12 Cropland
- 13 Urban and built-up
- 14 Cropland/natural vegetation
- 15 Snow and ice
- 16 Barren

The MODIS land cover data product was retrieved from the online Data Pool, courtesy of the NASA Land Processes Distributed Active Archive Center (LP DAAC), USGS/Earth Resources Observation and Science (EROS) Center, Sioux Falls, South Dakota, https://lpdaac.usgs.gov/data_access/data_pool.

KL model input data

Work with Malaysian partners to obtain data for Kuala Lumpur & surrounding areas

Develop model to ensure suitability for tropical climates:

- Customised tropical boundary layer
- High humidity modifications
- Temporal variations of surface wetness

ADMS-Urban Temperature & Humidity module

Model evaluation & application

- Evaluate model predictions of **relative** temperatures at measurement sites
- Assess spatial variation of model predictions
- Use model:
  - Micro-climate modelling (next presentation)
  - Forecasting

CERC

Thank you

David.Carruthers@cerc.co.uk

Jenny.Stocker@cerc.co.uk