Quantifying the influence of wind advection on the urban heat island for an improvement of a climate change adaptation planning tool

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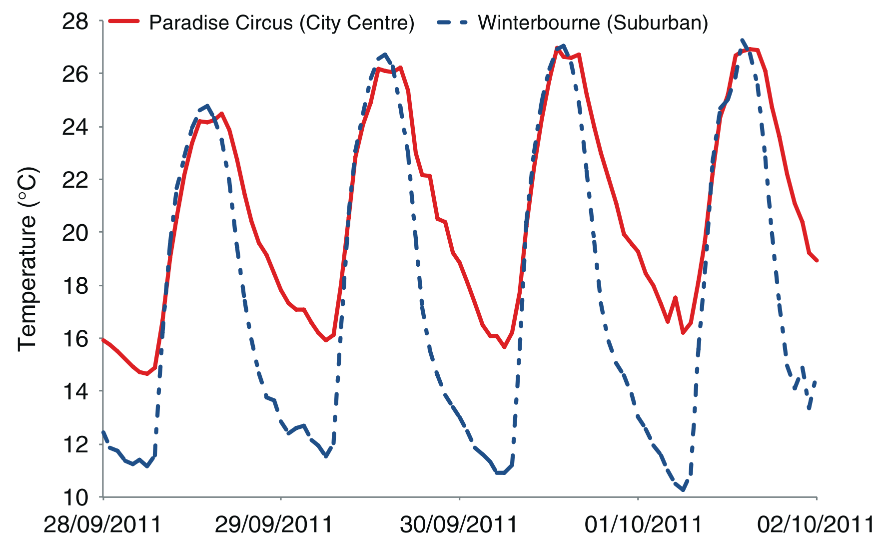
Urban Heat Islands

- Cities are warmer than surrounding rural areas

Urban Heat Islands

- Night-time
- Differences in heating / cooling rates
- Related to city size and function
- Synoptic weather – limiting factor

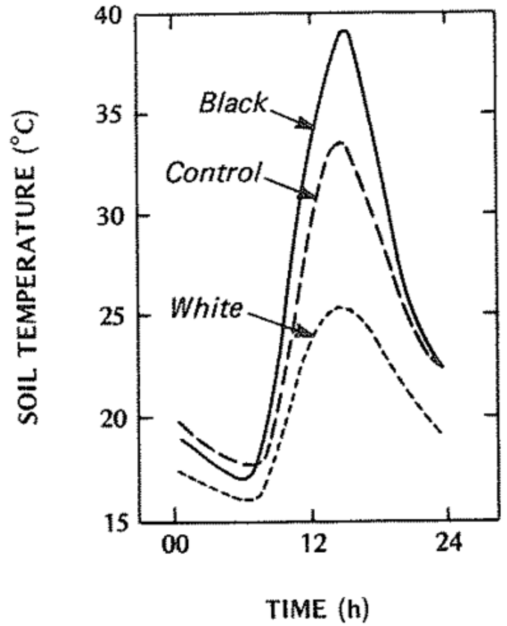


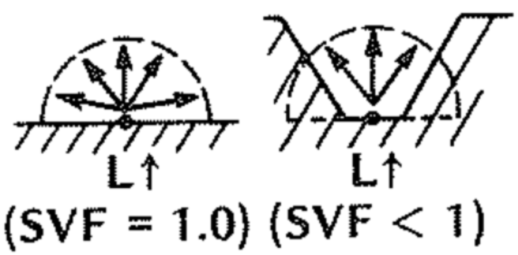
- Annual mean temperature may only be 1 or 2°C warmer in a city, but could be up to 7°C under the right conditions
- Urban cool islands may form during the day (however much smaller in intensity)

Urban Heat Islands

Alteration of the surface energy balance through:

- Radiation trapping (reduced SVF)
- Changes in albedo / thermal properties
- Increased surface area
- Increased roughness
- Lack of Vegetation
- Anthropogenic heat
- Air pollution



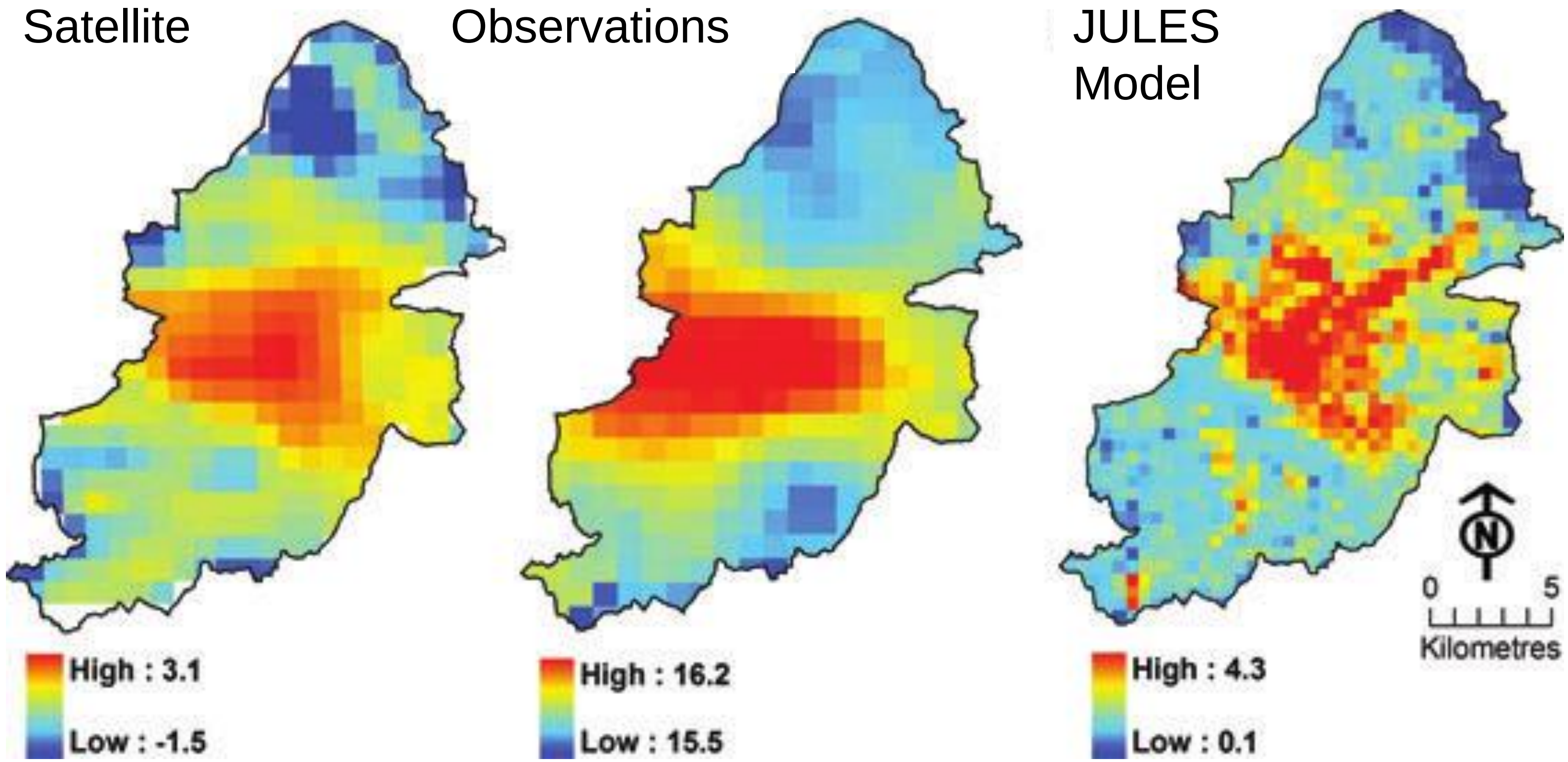


Soil temperature vs. albedo (top)

SVF (left)

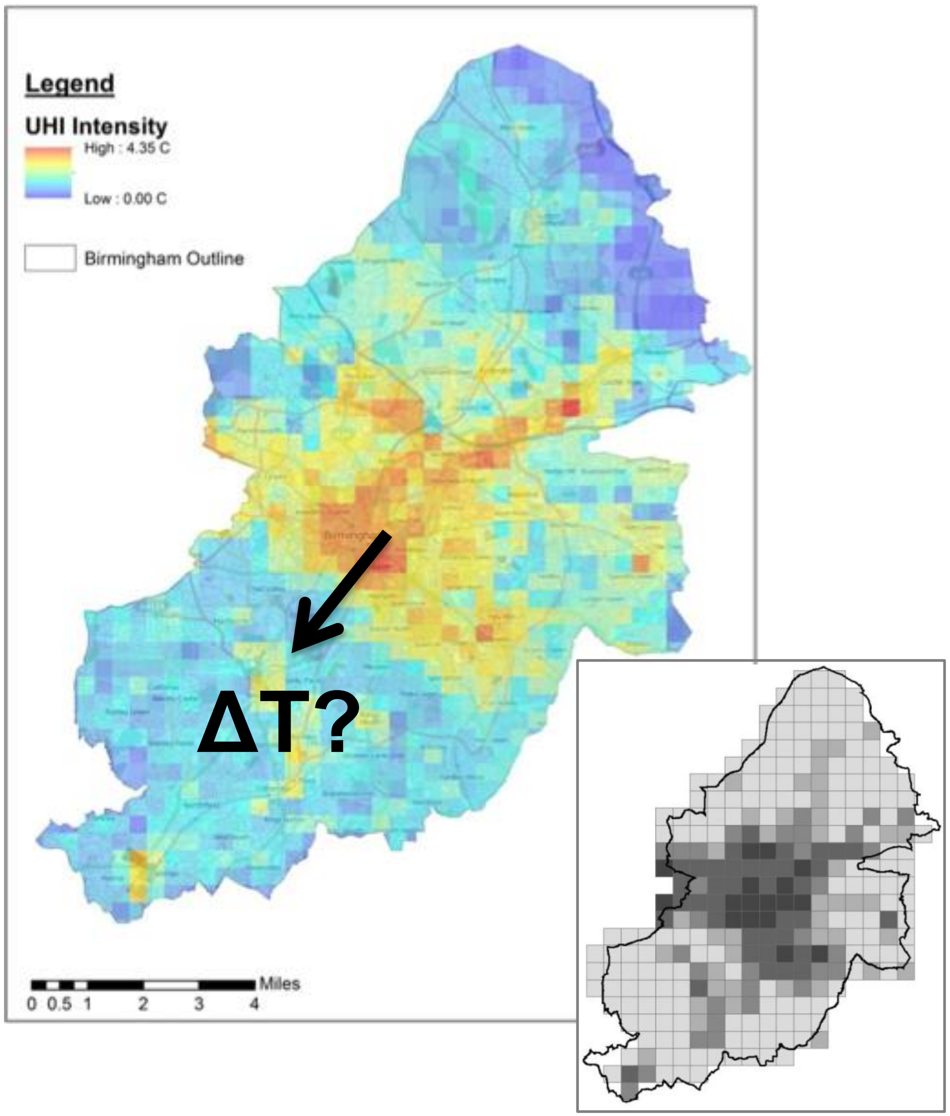
(Oke, 1987)

UHI measurement in Birmingham



Tomlinson et al. 2013

Influence of wind advection on the UHI



- Recent studies (Bohnenstengel et al. 2011; Heaviside et al. 2014) demonstrate that the UHI pattern can be influenced by wind advection, even at low speeds

- **Aim: Under what weather conditions and to what extent does wind advection affect the UHI pattern ?**

- **Aim: Can a transferable methodology be developed to correct static UHI fields?**

Influence of wind advection on the UHI

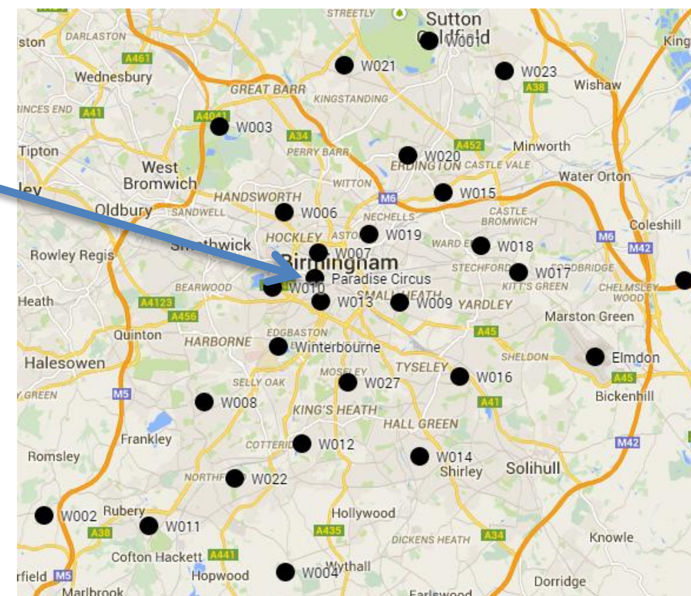
Two methods:

(1) Observations

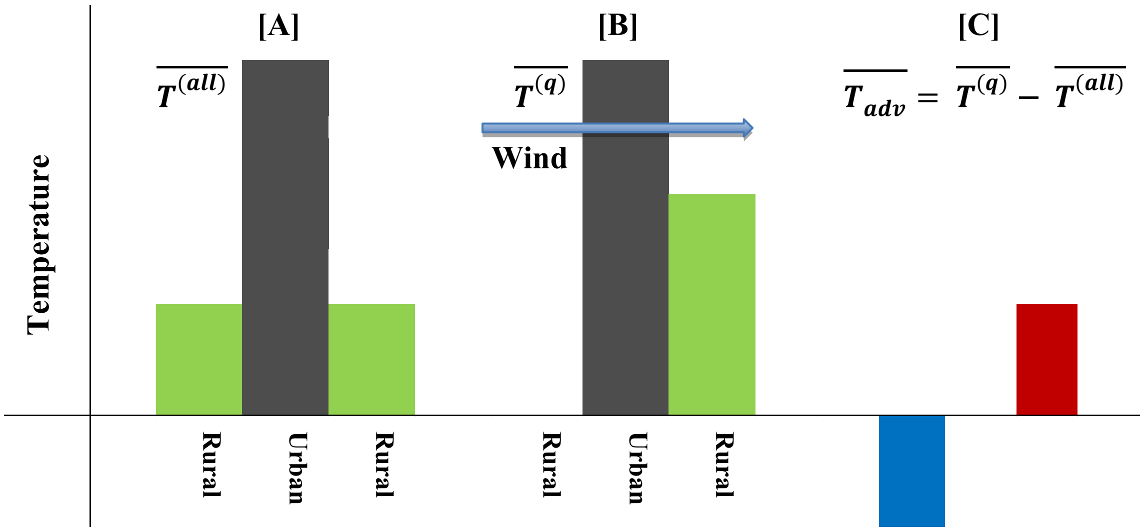
(2) BlueBEAR simulations - Weather Research & Forecasting Model (WRF)

(1) Observations

HiTemp network of sensors



(1) Observations



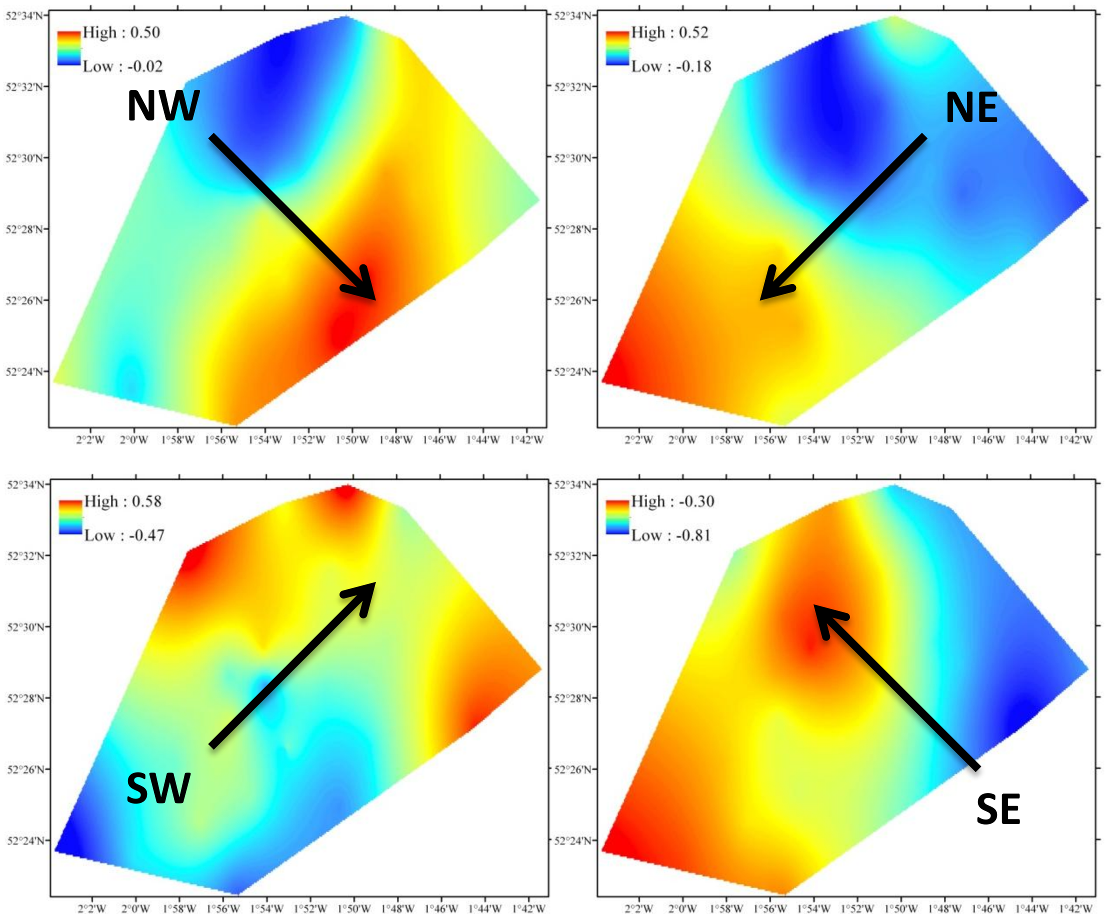
Hypothetical advection diagram (adapted from Heaviside et al. 2014)

[A] Typical mean UHI with all wind directions considered

[B] Downwind temperatures warm and upwind temperatures cool with a horizontal wind

[C] Difference or advected component

(1) Observations



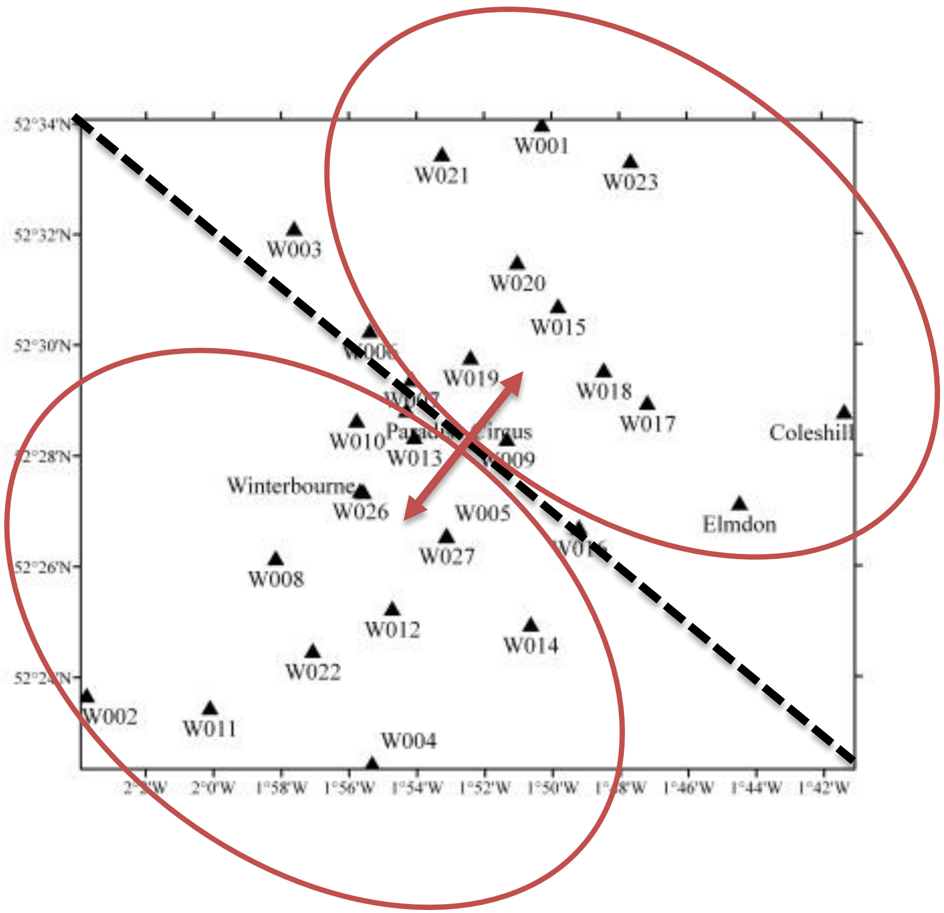
Wind speed 2-3 m/s

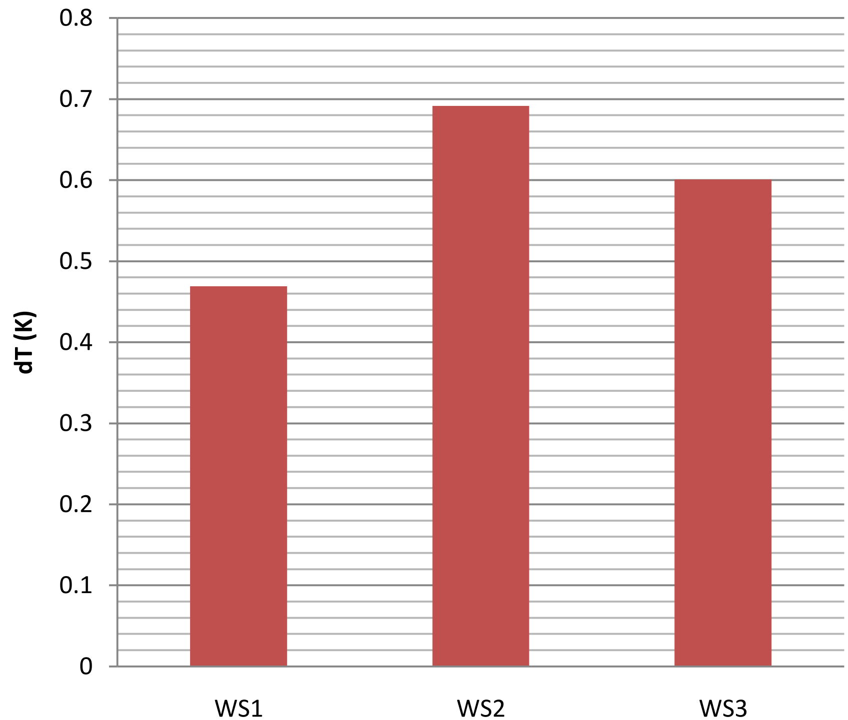
$$\overline{T^{(q)}_{adv\,(i)}} = \overline{\Delta T^{(q)}_{i-u}} - \overline{\Delta T^{(all)}_{i-u}}$$

- ❑ Spatial Kriging
- ❑ Data pre-processed in Unix
- ❑ Analysis conducted in R

(1) Observations

- ❑ NE/SW: Downwind – Upwind mean temperature difference



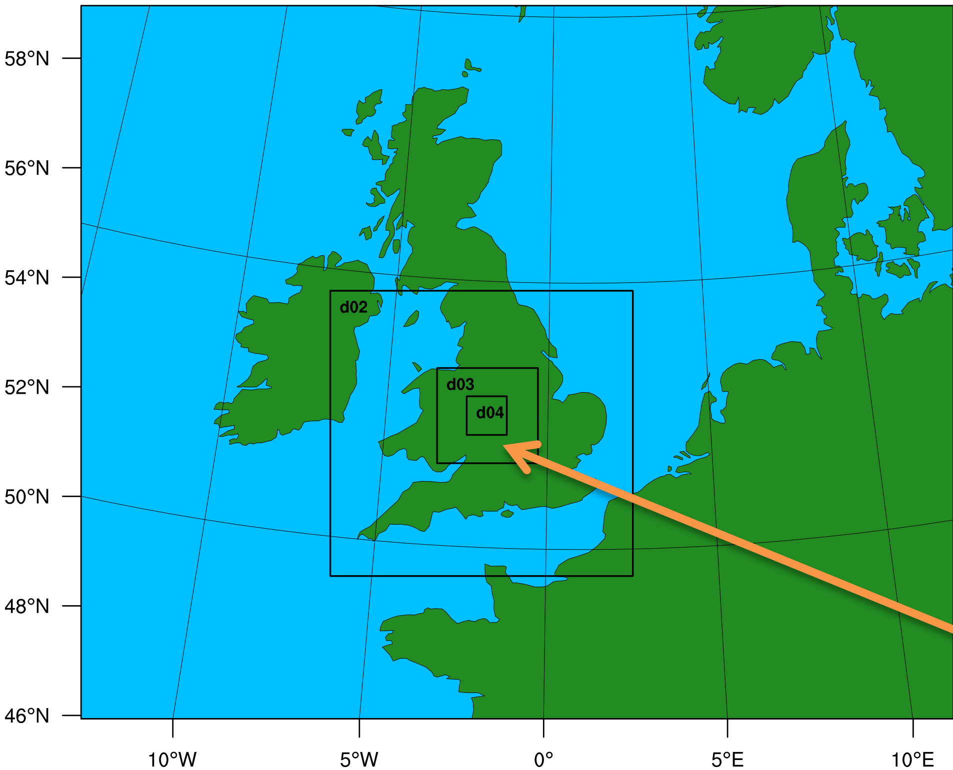


(2) BlueBEAR simulations

- Weather Research & Forecasting Model (WRF)
  - Community NWP model
  - Operational forecasting and atmospheric research applications
  - WRF can be used over a range of scales
  - Physics options to represent radiation, surface, boundary layer, cloud and precipitation processes
  - Parameterisation options for urban areas
  - V3.6 installed on BlueBEAR

WRF THE WEATHER RESEARCH & FORECASTING MODEL

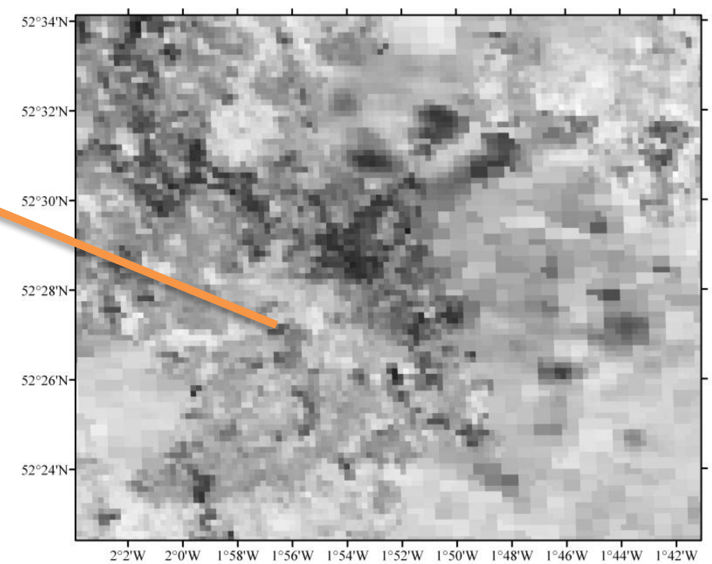
(2) BlueBEAR simulations



Domain	01	02	03	04
Resolution	36km	12km	3km	1km
Grid cells (Horizontal x Vertical)	50x41	52x29	69x65	82x79

Model set up

- ERA-40 initial conditions
- Specific urban land use



(2) BlueBEAR simulations

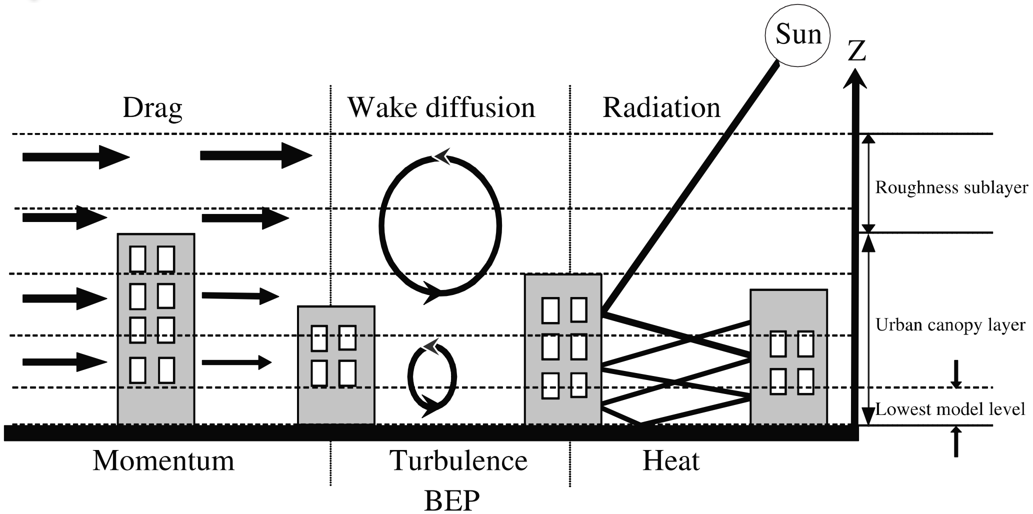
COMPLEXITY

Urban parameterisation in WRF

i. SLAB scheme (Liu et al. 2006)

ii. Single-layer UCM(Kusaka et al. 2001)

iii. Multi-layer UCM: BEP (Martilli et al. 2002)



BEP Schematic (Chen et al. 2011)

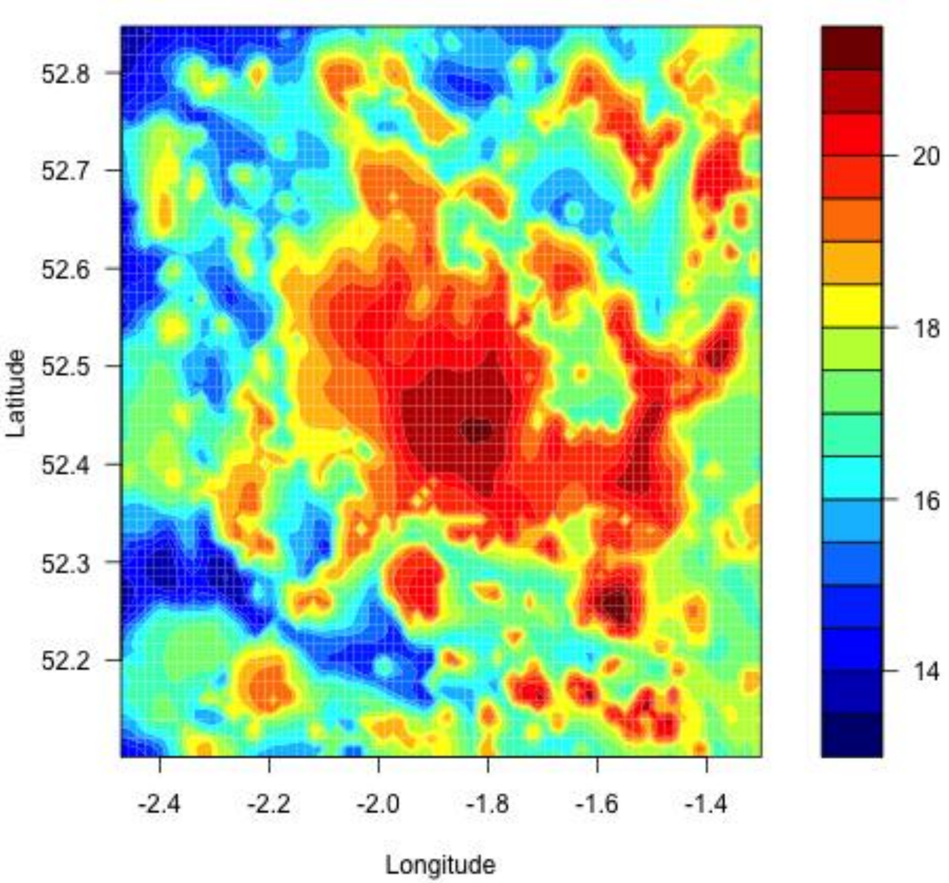
- Sophisticated 3D urban representation
- Radiation shadowing, reflecting and trapping improves the urban energy budget, and urban canopy thermal structure
- Vertical and horizontal effects of buildings on momentum better represents vertical wind profiles in the urban canyon
- Direct integration with the boundary layer

(2) BlueBEAR simulations

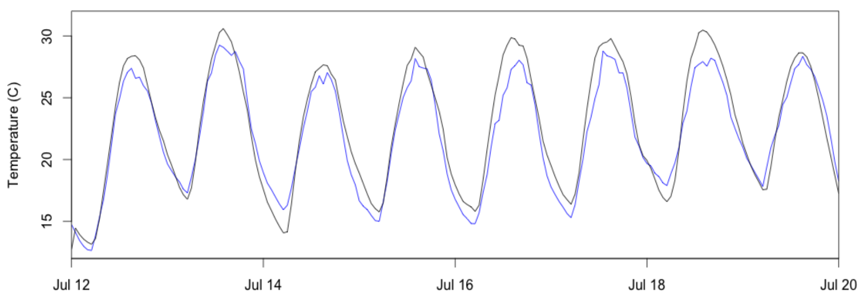
- Model run for an 8-day period (12^{th} -20^{th} July 2013)

- Simulations take approximately 7 hours using 32 processors. Total CPU time for the run is approximately 225 hours

(2) BlueBEAR simulations



WRF domain 4 2m Temperature (°C)
15th July 00:00AM



RMSE (Root Mean Square Error) for urban simulations at Paradise Circus (Figure 5) of 1.3°C

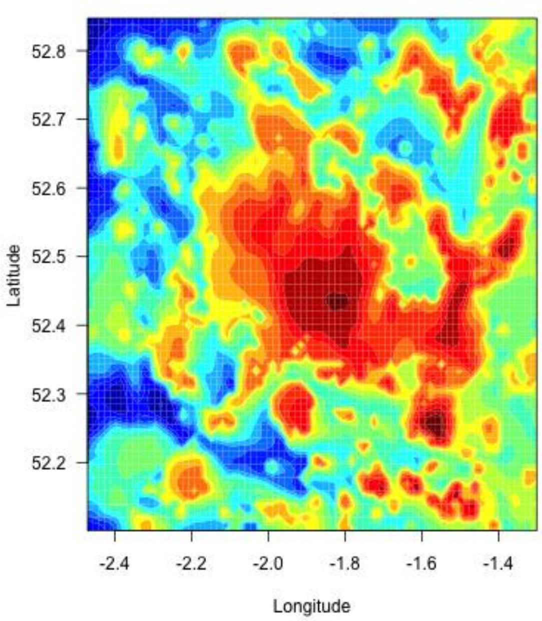
WRF model seems to under predict daytime rural temperatures and does not cool down as much as the observations

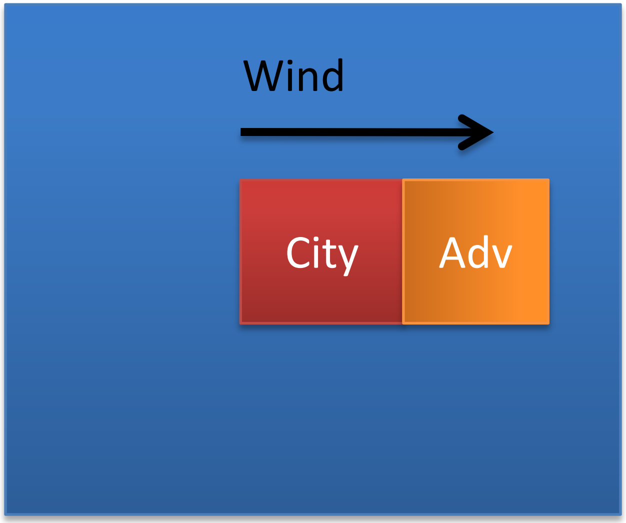
(2) BlueBEAR simulations - Directions

- Initial simulation shows the WRF model is able to capture urban temperatures
- However fine-tuning specifically for Birmingham is still required
- A series of sensitivity tests will be conducted, e.g. changing initial conditions such as the soil moisture

(2) BlueBEAR simulations - Directions

- A series of idealised simulations will be run to further determine the advected heat contribution when the complex nature of an urban area is simplified





- Develop a generic methodology of correcting UHI patterns from local-equilibrium models (no grid cell transport of heat and momentum)

Conclusions

- Observational analysis indicates a strong advection signal in Birmingham
- WRF model has been run on BlueBEAR, further simulations are planned
- Impact generated through the improvement of a UHI mapping tool

Thank you

References

- Chen, F.,Kusaka, H.,Bornstein, R., et al. (2011) The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems. International Journal of Climatology, 31: (2): 273-288.
- Heaviside C, Cai X-M, Vardoulakis S. 2014 The effects of horizontal advection on the urban heat island in Birmingham and the West Midlands, United Kingdom during a heatwave. Q. J. R. Meteorol. Soc.
- HiTemp. High Density Measurements within the Urban Environment http://goo.gl/CMha6h
- Martilli A, Clappier A, Rotach MW. 2002. An urban surface exchange parameterisation for mesoscale models. Boundary-Layer Meteorology 104: 261–304.
- Oke TR. 1987. Boundary Layer Climates. Methuen: London.

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