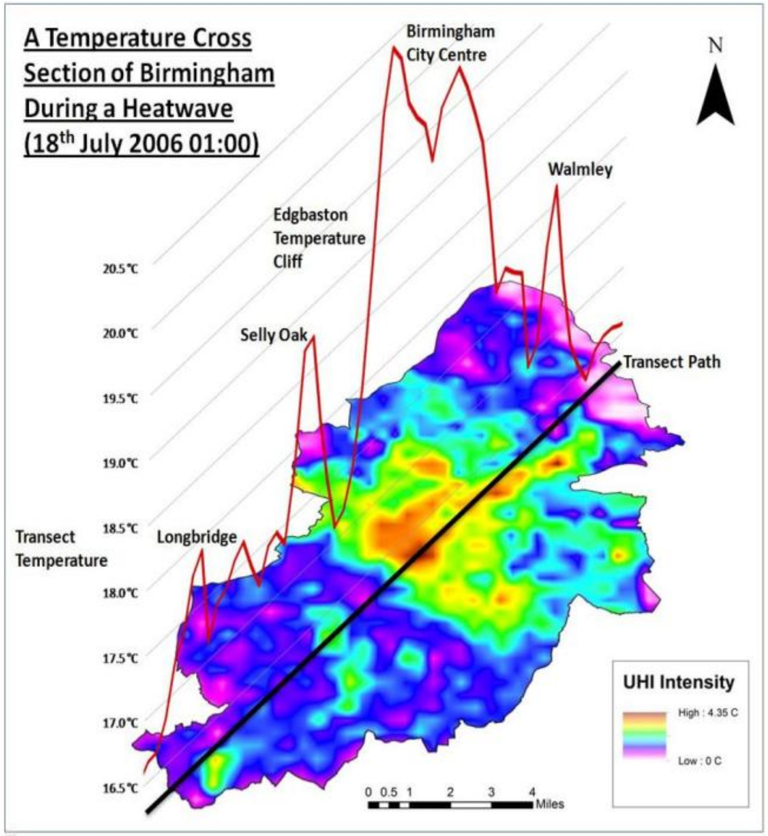
Urban Meteorological Networks: An urban climatologists panacea?



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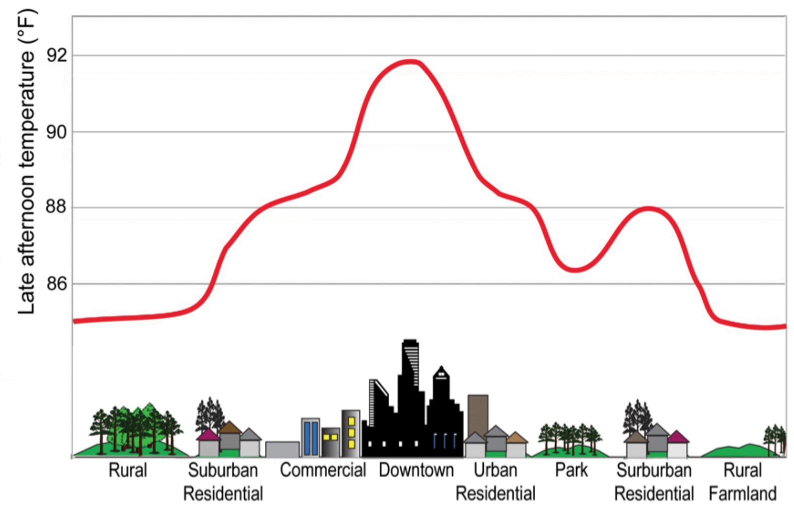
Measuring the Urban Climate

- The heterogeneous nature of the urban environment results in a mosaic of microclimates across our cities.
- Measurements of these variations improve our understanding of urban atmospheric processes.
- We can then verify and improve our urban climate models based on these measurements.



Lemmen & Warren (2004)

- But….
  - Measurements in urban environments are challenging
  - We can't rely on models for everything – what about the need for monitoring?
    - Observations have provided the most important basis for the detection and attribution of climate change to date (IPCC, 2001)
- So, what are the options?

Canopy UHI: Station Pairs

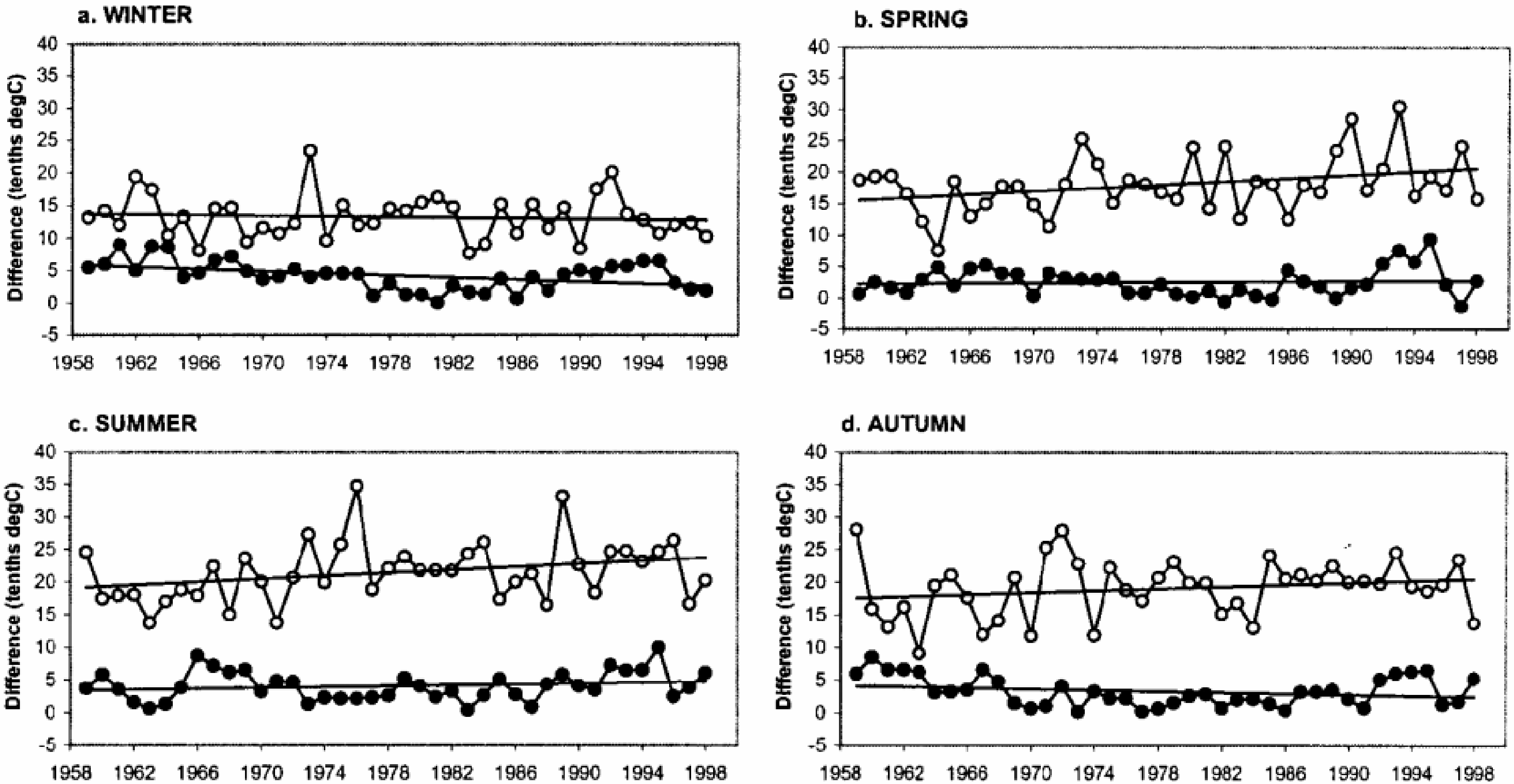


Fig. 3 Seasonal trends in urban heat island intensity calculated from T_{max} (solid circles) and T_{min} (open circles) at St. James's Park minus Wisley, 1959–98

Wilby (2003)

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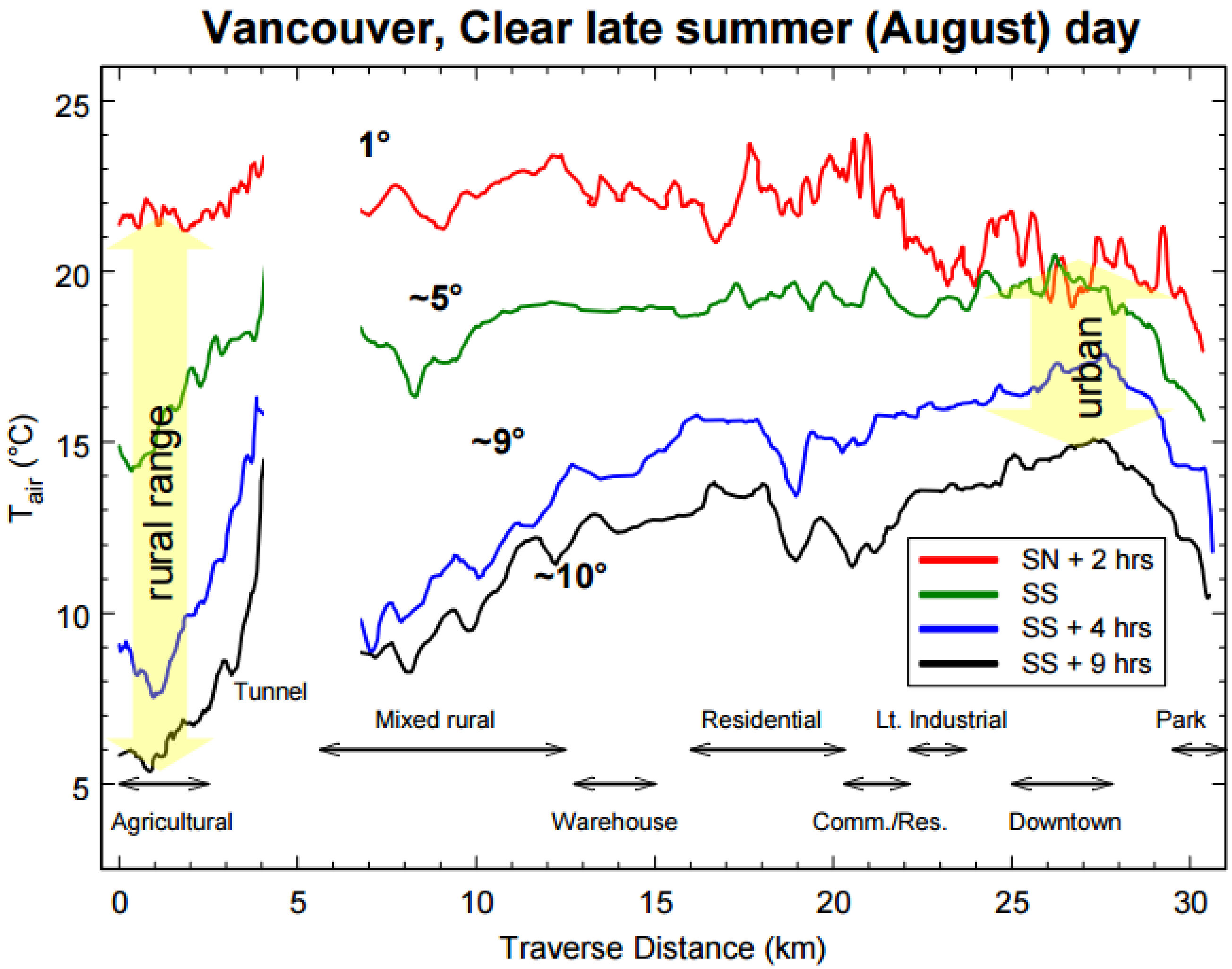
Canopy UHI: Mobile Transects



SN = Solar Noon, SS = Sunset

Voogt (2000)

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Surface UHI: Satellite Imagery

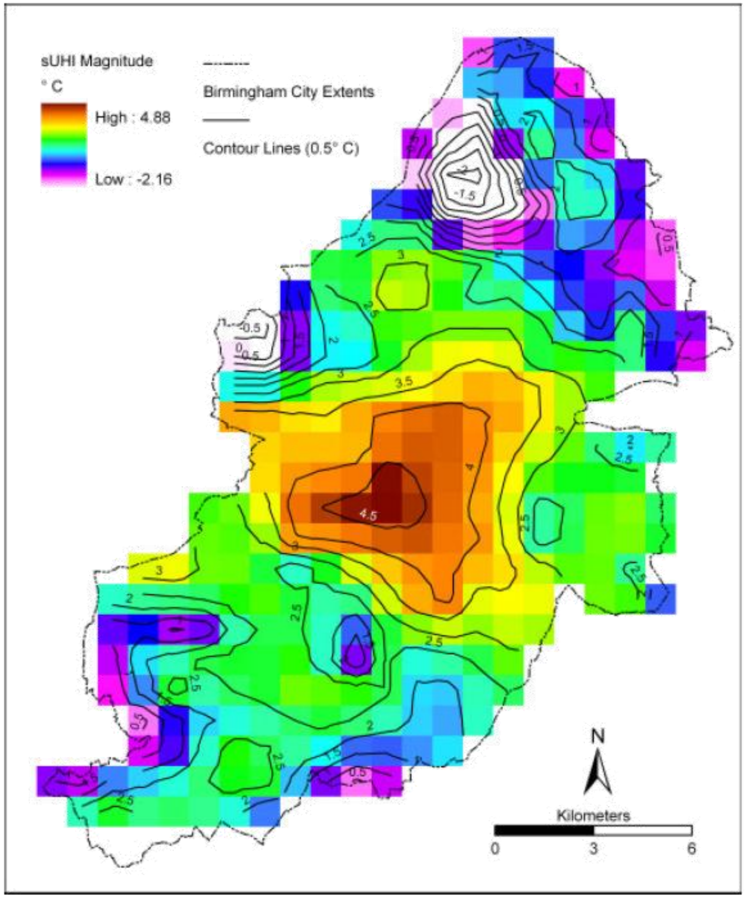

Figure 8. sUHI magnitude within Birmingham city extents for heatwave event (18 July 2006), shown with 0.5 °C contour lines. This figure is available in colour online at wileyonlinelibrary.com/journal/joc

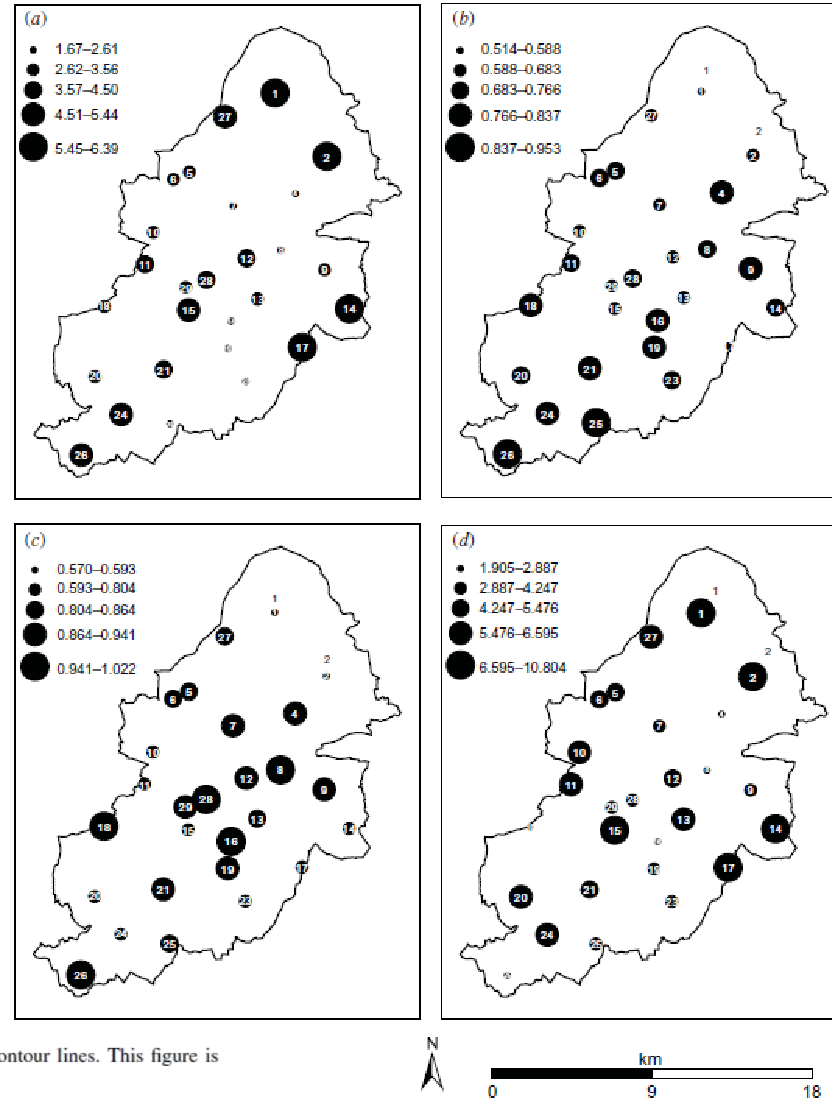

Figure 3. Spatial plots illustrating (*a*) average difference between T_{air} and T_{LST} as explained in section 2.2 and the results of regression analysis, (*b*) R^2 values, (*c*) slope values and (*d*) intercept values as explained in section 3.3. Numbers within plots are station identifiers.

Tomlinson et al (2012a, 2012b)

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Urban Meteorological Networks

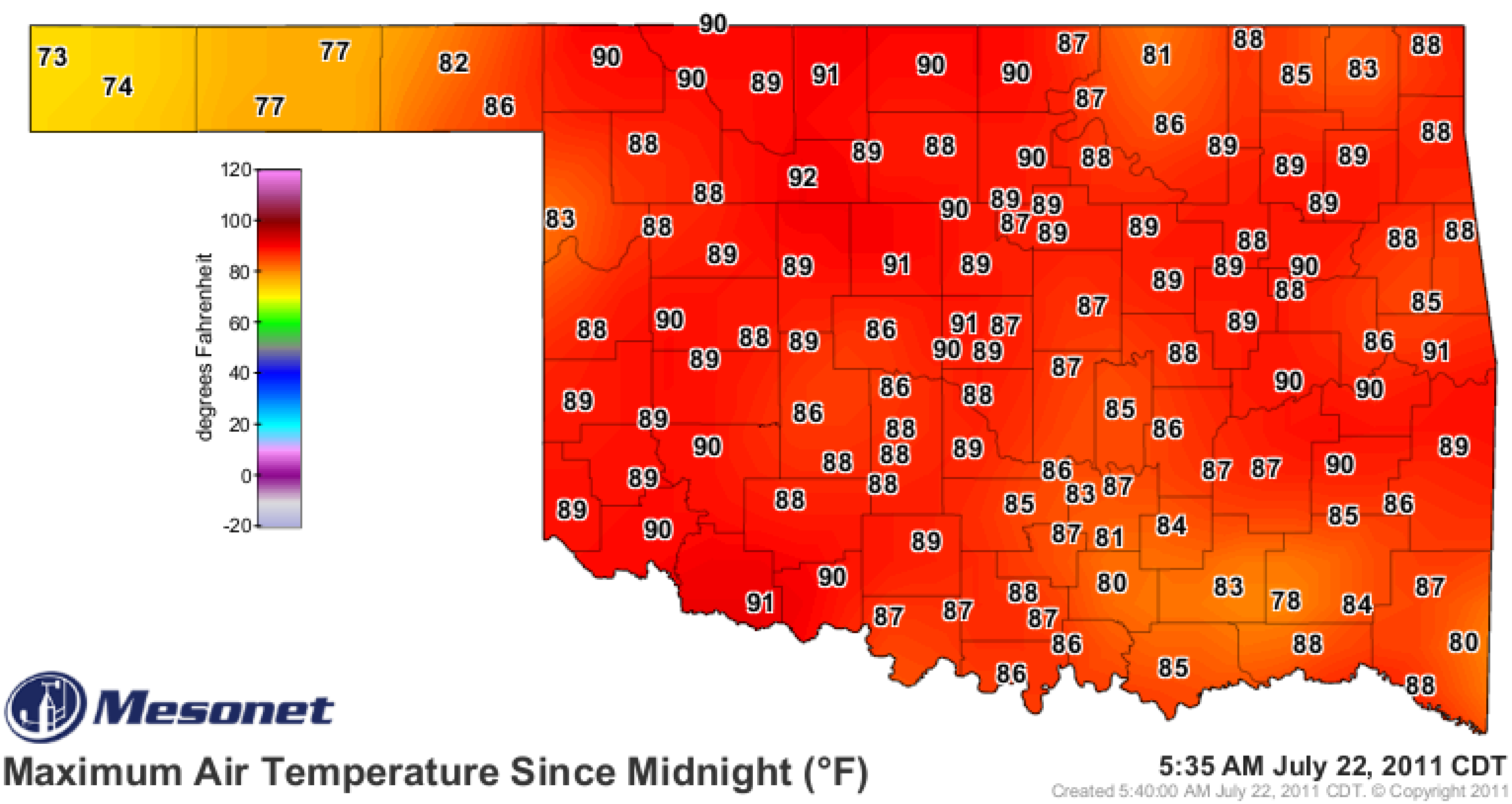
- Studies are often limited to station pairs due to sparse coverage in urban areas
  - National networks ‘avoid’ cities as they are unrepresentative of the regional climate
  - Issues with site location
  - Other problems – e.g. vandalism
- Many cities just have a single ‘urban’ weather station
  - Clearly insufficient to resolve the complex urban environment
  - Many more sites are needed

- This was the situation for the last 200 years...

- Advances in technology, communications and miniaturisation of electronics are changing the measurement paradigm
  - Enabling innovation, increasing reliability and at a lower cost
- A new generation of high resolution ‘Urban Meteorological Networks’ is emerging.
  - Near-real time communications
  - Potential to become permanent installations (as opposed to field campaigns)
  - Operate over a range of spatial scales

Oklahoma Mesonet

- 120 monitoring stations run by the University of Oklahoma
- High quality and uniform instrumentation based on 10m towers; Air Temperature (1.5m & 9m), Relative Humidity, Windspeed & Direction, Rainfall, Pressure, Solar Radiation
- Applications include agriculture, tornadoes and monitoring fire risk
- http://www.mesonet.org/ (Brock et al, 1995)



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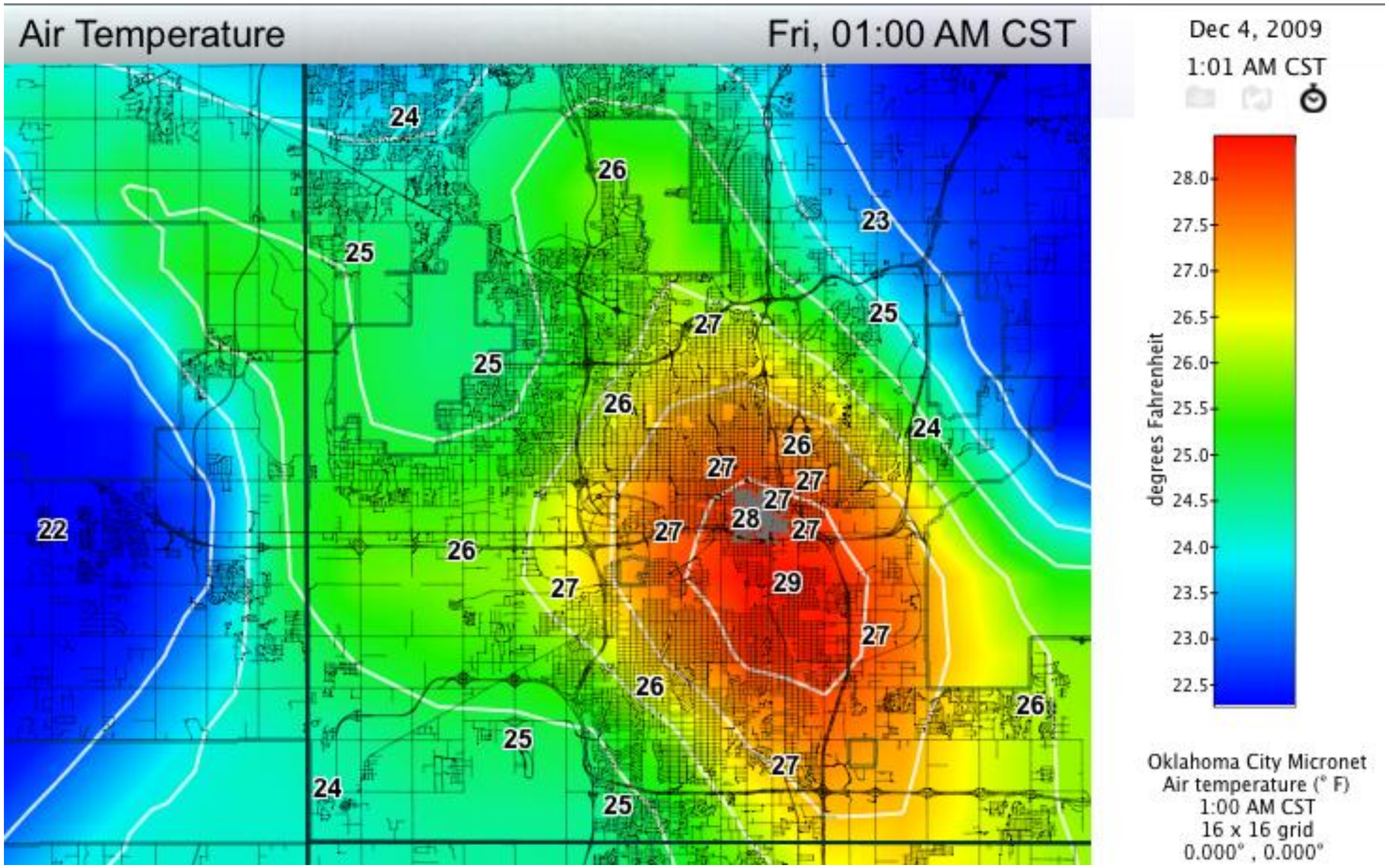
Oklahoma City Micronet

- Oklahoma city micronet (Basara et al, 2011)
  - Scaled down version of the 'mesonet' in the city
  - 4 mesonet sites (Air Temperature, humidity, pressure, wind and rainfall)
  - 32 micronet sites located on traffic lights
  - Communications via WiFi
  - Currently run out of funding



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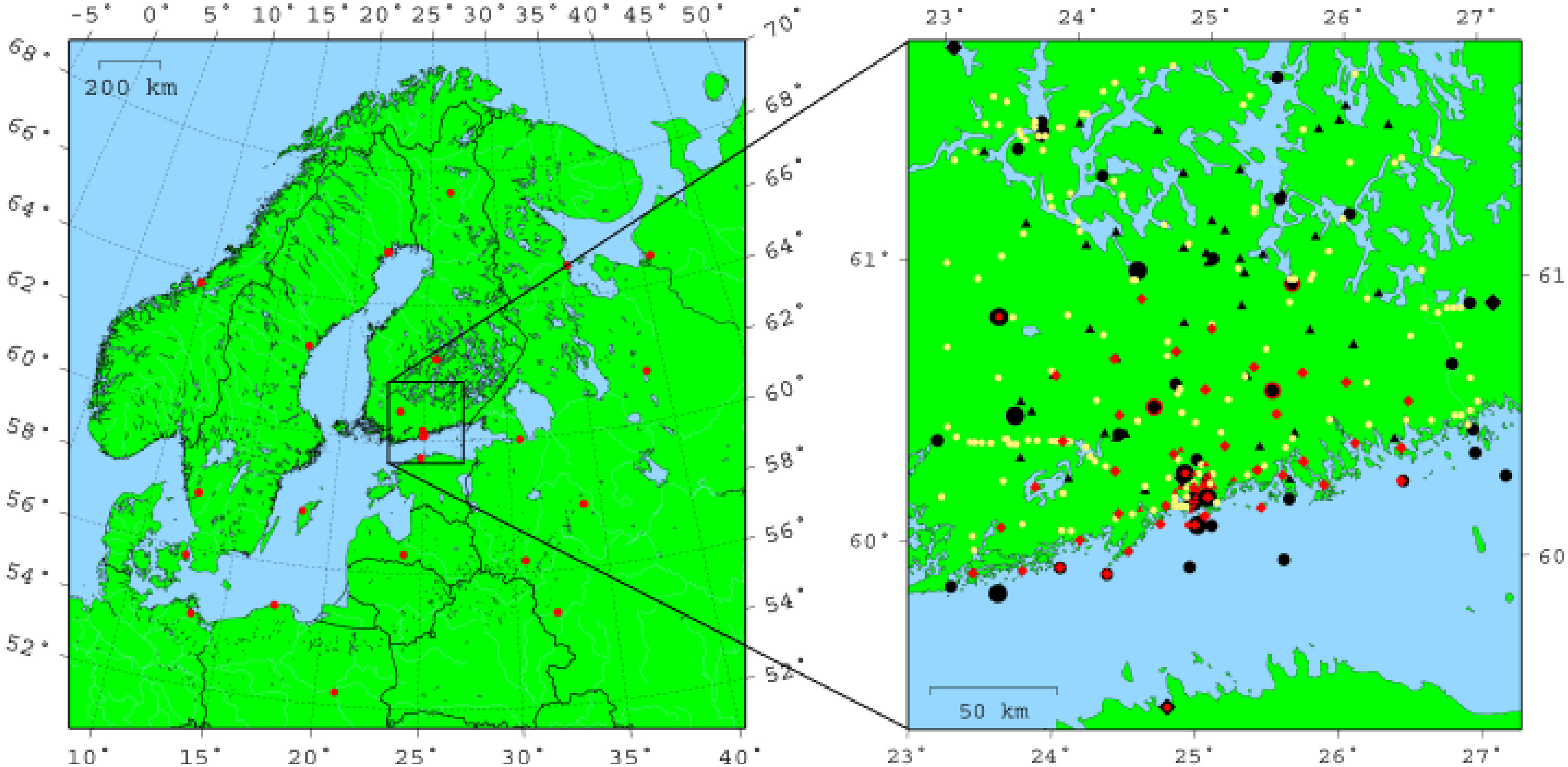
Helsinki Testbed



No.	Sites in Helsinki Testbed domain	
46	FMI weather stations	●
34	FMI precipitation stations	▲
13	Off-line temperature loggers in greater Helsinki area	▲
8	Weather transmitters in greater Helsinki area	▲
191	Road weather stations	●
292	**Surface weather stations, total**	
42	Pairs of weather transmitters in masts	◆
5	Optical backscatter profilers (new ceilometers)	●
6	FMI ceilometers	●
4	C-band Doppler radars	◆
1	Dual polarization Doppler radar	◆
4	RAOB sounding stations	●
1	UHF wind profiler	▲
-	Total lightning network	-

- http://testbed.fmi.fi/
- Koskinen et al (2011)

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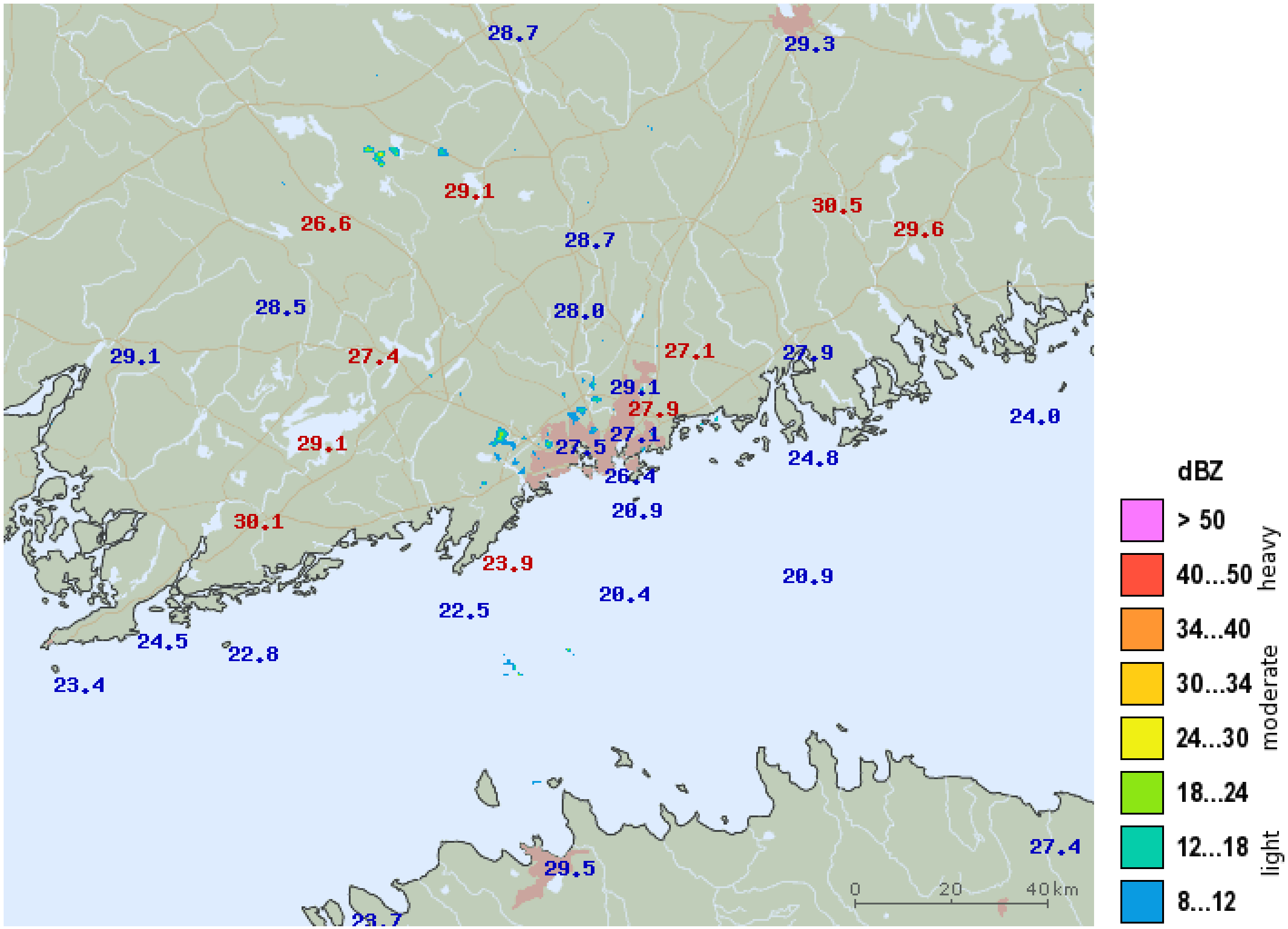
Helsinki Testbed



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City Scale Networks

Table II. (*Continued*).

Scale[a]	Network/Site/ Project name	City/Area	Approximate spatial extent	Number of sites	Time period	Measurement variables	Main aims of project/network	Communication method	References/ websites
	DCNet[b] [PN]	Washington DC, USA	177 km^2	16	2003 to present	T, RH, SPD, DIR, TI	Forecasting dispersion of hazardous trace gases and particles in urban areas	NS	Hicks *et al*., 2012
	Vancouver Island School-Based Weather Station Network	Vancouver Island, BC, Canada	2500–3000 km^2	138	2002 to present	T, RH, SPD, DIR, P, PRECIP, RAD_UV	Education	School broadband	Wiebe, personal communication; Wiebe, 2012; http://www.islandweather.ca/
City-scale	Oklahoma City Micronet (OKCNET) [Off]	Oklahoma, USA	1440 km^2	40 (36 micronet; 4 mesonet)	2007–2010	T, P, PRECIP, RH, SPD, DIR	Operational surface observing network designed to improve atmospheric monitoring across the Oklahoma City	Public OKC LAN	Basara *et al*., 2010; http://okc.mesonet.org
	Metropolitan Environmental Temperature and Rainfall Observation System (METROS) [Off]	Tokyo, Japan	2187 km^2	120	2002–2005	T, RH, SPD, DIR, PRECIP, P	Temperature and precipitation observing system	NS	Mikami *et al*., 2003; Takahashi *et al*., 2009
	Taipei Weather Inquiry-Based Learning Network (TWIN) [PN]	Taipei, Taiwan	271.79 km^2	60	2003 to present	T, RH, P, RAD_SW, RRATE, DIR, SPD	Education/public information	School WiFi	Chang *et al*., 2010; http://www.aclass.com.tw/products.aspx?BookNo=weather_01

Muller *et al* (2013)

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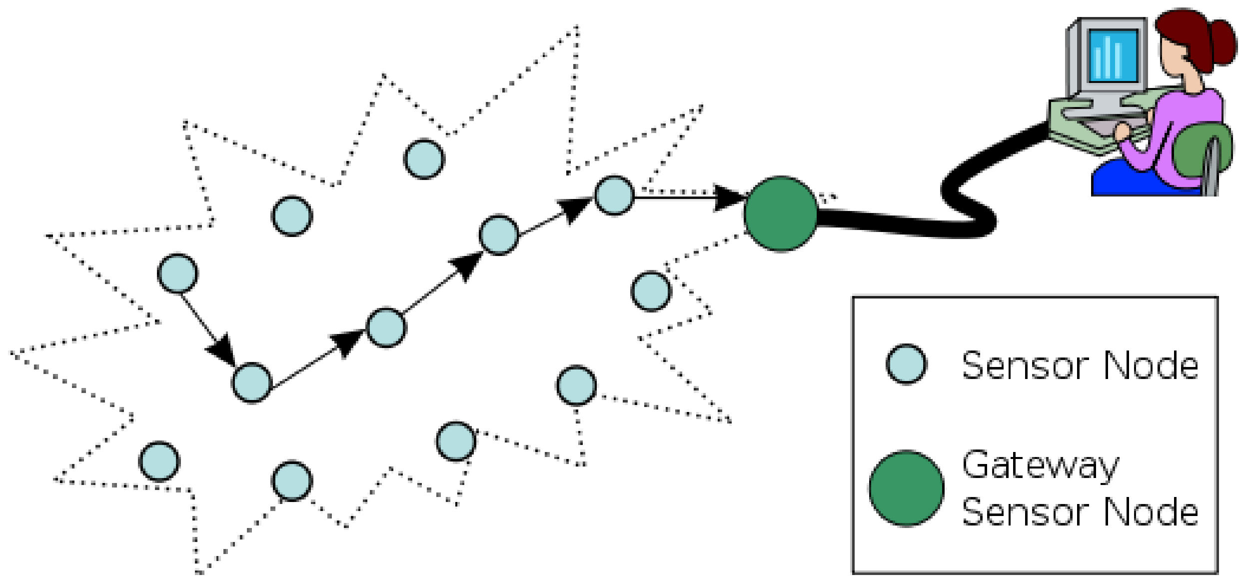
Logistics

- A correctly designed network will allow the user to deploy hundreds if not thousands of sensors
- This enables a spatial resolution to be covered which would be impossible with traditional weather stations.
- There are many considerations
  - Cost
  - Power
  - Communications
- The resolution is ultimately controlled by the budget.



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Cost

- Deploying hundreds of sensors can be expensive

- Low cost options are often chosen
  - Compromise in data quality?
  - Need careful calibration

- What about maintenance costs for hundreds of sites?

- Different way of thinking to traditional measurements
  - Many sensors means if some are reading erronously, then the bigger picture will still remain
  - So what if a few sensors are down at any one time?
  - Other than the sensor, the cost of power and communications also need to be considered

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Power

- Each node will need power
- Mains
  - Rarely available
  - Often prohibited due to cost limitations
- Batteries
  - Cheap!
  - Will need routine replacement
  - Low power sensors needed to be practical
- Energy Harvesting
  - Solar?

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Communications

- Each node will need a means of communication
    - Modem (luxury!)
    - GSM (luxury!)
    - Wi-Fi
    - Other radio networks – e.g. Zigbee

- Communications can be power hungry and will sap battery life

- Any autonomous sensor which needs manual reading or data collection is effectively standalone – it does not constitute part of a network.

Network Design Considerations

- Guidelines for locating urban weather stations are quite disparate.
- Existing WMO guidelines are for single sites as opposed to networks
  - WMO 2008 (mostly regional and not urban)
- Guidelines are essential for data quality assurance
  - Requirements for each variable
  - Siting, exposure and source areas
  - Data management and QA/QC
- Many standard WMO guidelines just don’t work in cities!

- Oke (2006b, 2009) was among the first to advise on urban meteorological protocols:
  - Scale of studies
  - Site classification

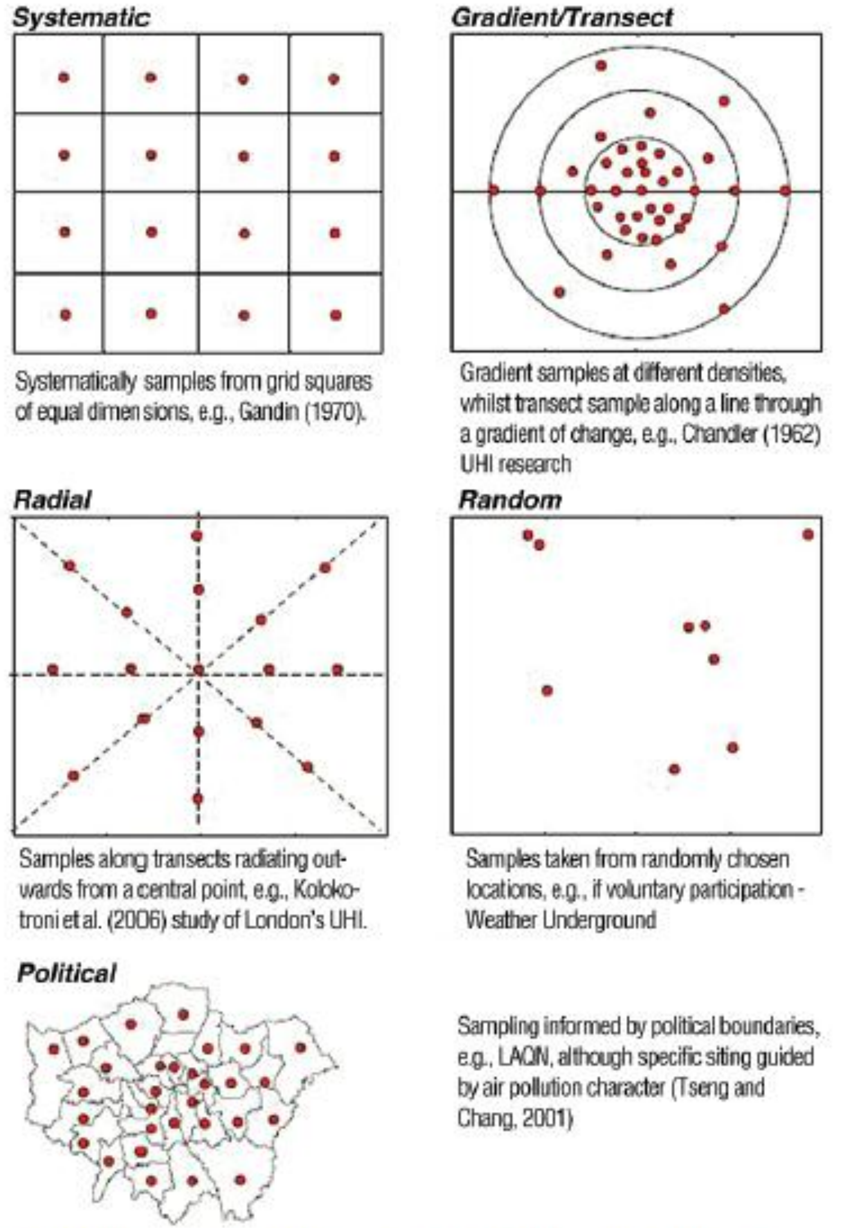

Fig. 3. Main approaches taken toward network design, with references (after Robinson 2010).

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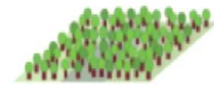
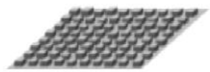
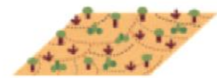
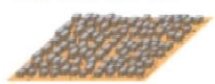
Built types	Definition	Land cover types	Definition
1. Compact high-rise 	Dense mix of tall buildings to tens of stories. Few or no trees. Land cover mostly paved. Concrete, steel, stone, and glass construction materials.	A. Dense trees 	Heavily wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
2. Compact midrise 	Dense mix of midrise buildings (3–9 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	B. Scattered trees 	Lightly wooded landscape of deciduous and/or evergreen trees. Land cover mostly pervious (low plants). Zone function is natural forest, tree cultivation, or urban park.
3. Compact low-rise 	Dense mix of low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Stone, brick, tile, and concrete construction materials.	C. Bush, scrub 	Open arrangement of bushes, shrubs, and short, woody trees. Land cover mostly pervious (bare soil or sand). Zone function is natural scrubland or agriculture.
4. Open high-rise 	Open arrangement of tall buildings to tens of stories. Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	D. Low plants 	Featureless landscape of grass or herbaceous plants/crops. Few or no trees. Zone function is natural grassland, agriculture, or urban park.
5. Open midrise 	Open arrangement of midrise buildings (3–9 stories). Abundance of pervious land cover (low plants, scattered trees). Concrete, steel, stone, and glass construction materials.	E. Bare rock or paved 	Featureless landscape of rock or paved cover. Few or no trees or plants. Zone function is natural desert (rock) or urban transportation.
6. Open low-rise 	Open arrangement of low-rise buildings (1–3 stories). Abundance of pervious land cover (low plants, scattered trees). Wood, brick, stone, tile, and concrete construction materials.	F. Bare soil or sand 	Featureless landscape of soil or sand cover. Few or no trees or plants. Zone function is natural desert or agriculture.
7. Lightweight low-rise 	Dense mix of single-story buildings. Few or no trees. Land cover mostly hard-packed. Lightweight construction materials (e.g., wood, thatch, corrugated metal).	G. Water 	Large, open water bodies such as seas and lakes, or small bodies such as rivers, reservoirs, and lagoons.
8. Large low-rise 	Open arrangement of large low-rise buildings (1–3 stories). Few or no trees. Land cover mostly paved. Steel, concrete, metal, and stone construction materials.	**VARIABLE LAND COVER PROPERTIES** Variable or ephemeral land cover properties that change significantly with synoptic weather patterns, agricultural practices, and/or seasonal cycles.	
9. Sparsely built 	Sparse arrangement of small or medium-sized buildings in a natural setting. Abundance of pervious land cover (low plants, scattered trees).	*b. bare trees*	Leafless deciduous trees (e.g., winter). Increased sky view factor. Reduced albedo.
		s. snow cover	Snow cover >10 cm in depth. Low admittance. High albedo.
10. Heavy industry 	Low-rise and midrise industrial structures (towers, tanks, stacks). Few or no trees. Land cover mostly paved or hard-packed. Metal, steel, and concrete construction materials.	*d. dry ground*	Parched soil. Low admittance. Large Bowen ratio. Increased albedo.
		w. wet ground	Waterlogged soil. High admittance. Small Bowen ratio. Reduced albedo.

Stewart and Oke (2012)

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Metadata

- Guidelines are essential for data quality assurance and the value of data is maximised by the availability of comprehensive metadata.
- “regularly updated metadata of urban observations using standardised urban protocols” NRC (2012)
- Poor metadata is often a critique of urban meteorological studies.
- Stewart (2011) review of UHI studies highlighted that many studies failed to:
  - adequately describe experimental design
  - justify the choice of sites
  - make provision for metadata

Table 2. Summary of minimum metadata required. More complete details in the following tables. Letters correspond to those in Fig. 2.

(a) Network (and subnetworks)	(b) Individual station/site		(c) Instrumentation	(d) Network operations	
Network type	Site	Maintenance	Instrument	Communication network topology	Formulas
Network contact	Status	Relocation	Manufacturer	Data format	Language
Network variables	Site name	Enclosure	Model	Version numbers	Website
Network contact e-mail	Site alias (es)	Enclosure latitude	Type	Correction	Management
Network history	Type of site	Enclosure longitude	Variables	Measurement units	
Network implementation date	Latitude	Enclosure elevation	Representativeness	Missing data flag	
Network end date	Longitude	Mount location	Installation date	Language	
Network offline dates	Elevation	Type of mount	Decommissioned	Spatial resolution	
Network areal extent	Orographic setting	Height of sensor(s)	Start date	Temporal resolution	
Network spatial density	Date of metadata collection	Surface cover	End date	Time format	
Number of sites	Version number	Material below cover	Operating principals	Geographic extent	
Network map(s)	Observer	Terrain slope	Instrument communication type	Access rights	
	Start date	Building type	Data transmission frequency	Processing level	
	Stop date	Source areas	Sampling time	Other special codes	
	Instruments	Tree height	Averaging period	Metadata	
	Type of measurements	Traffic density	Precision	Server	
	Noticeable changes	Irrigation	Range	Storage	
	Station history	SVF	Response time	Backup	
	Remarks	Aspect ratio	Reporting frequency	Transmission	
	Urban structure (mean)	Moisture/heat vents	Accuracy	Access	
	Water bodies	Maps/sketches	Corrections	Archive data center	
	Mountain ranges	Photographs (winter and summer)	Known errors	Software	
	Traffic density	Relocation	Measurement units	Hardware	
	Surface cover	Site classification		Processing	
	Urban fabric			Error flags	
	Urban metabolism			QC/QA	
	Buildings (mean)			Filtering	
	Terrain			Data reduction	
	Aspect ratio			Programs	
	Maps/imagery			Algorithms	

Muller et al (2013)

Site: *S041*	Network: *BUCL-S*	Update Date: *02/10/2012*	Observer: *CLM*	Version: *2.0*

UMN STATION METADATA EXAMPLE:
An urban air temperature sensor sited in a non-standard location

(Note: Added input shown in *blue italics* for clarity; *Private information not shown here and shouldn't be supplied to end user; **BOLD**: considered 'mandatory' elements)

General Station Information

Station Name: *Holte Secondary School*		**Commissioned:** *02/10/2012*
Station ID: *S041*	Alias: *Lozells/Mayfield*	**Type of Site:** *School*
Elevation: *138* m (a.m.s.l.)	**Latitude:** *52.50015* ° N	**Longitude:** 1.90093 ° W
Address: *Wheeler Street, Birmingham, B19 2EP, UK*		
Site Contact: *Mrs. Smith**		Phone: *0121 #######**
Email: *example@email.com* *		

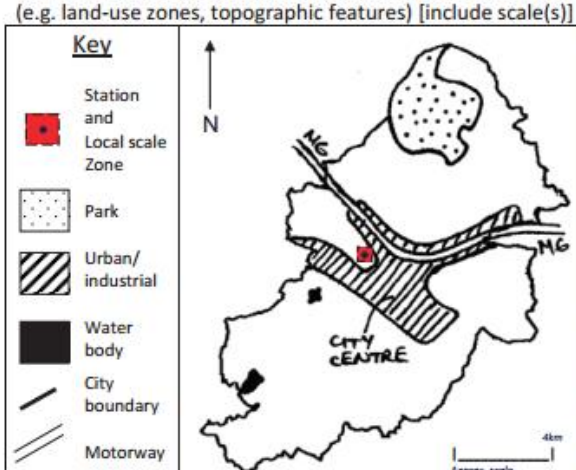
Technical information *(NOTE: template edited to specify information required for this particular UMN)*

ICT/Other Contact: *Mr J. Bloggs**	Phone: *0121 #######**
Email: *example@email.com**	
Communications network name: *SSID**	Type: *WiFi – WPA2*
MAC: *##:##:##:##:##:##**	IP: *##.##.##.##**
Channel(s): *1,11*	Subnet mask: *###.###.###.##**
Gateway: *##.##.##.##**	Access-point:
Passkey: *PASSWORD**	Other:

Instrumentation

Equipment	ID	Enclosure	**Variable(s) Observed**	**Height (m)**	Serial Number	**Installation Date**	**Testing/ Calibration Date**
Temperature Sensor	*B0153*	*Lamppost*	*Tair*	*3*	*11581*	*02/10/12*	*13/07/12*
Radiation Shield	*B0270*	*Lamppost*	~	~	~	*02/10/12*	~

City scale map + Aerial photograph(s): showing location of station and local area zone plus important features (e.g. land-use zones, topographic features) [include scale(s)]



Location of Holte within Birmingham conurbation (Aerial photograph from Google Earth©)

Muller et al (2013)

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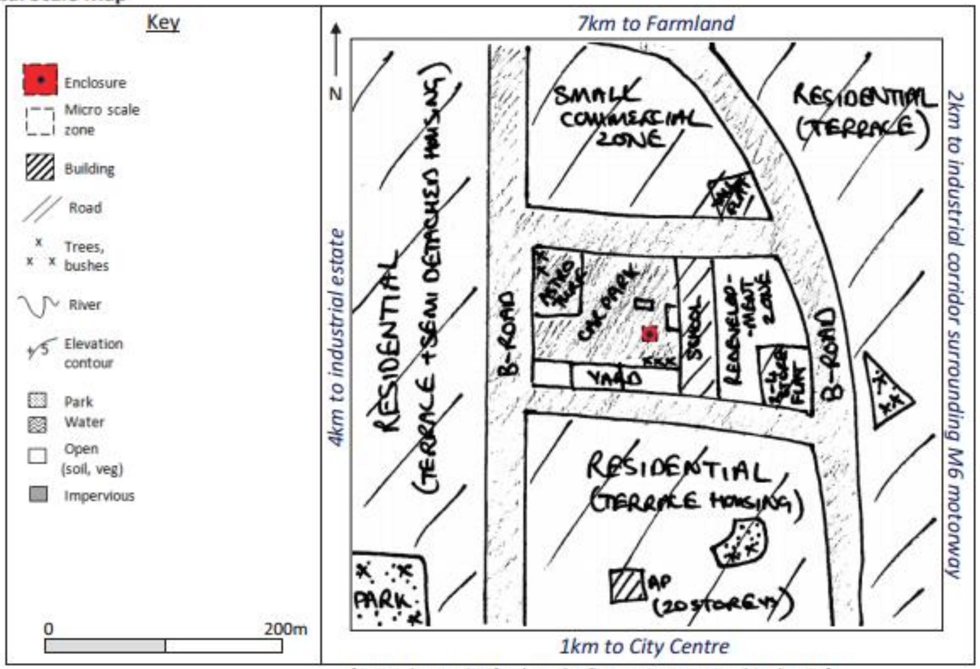
Site: *S041*	Network: *BUCL-S*	Update Date: *02/10/2012*	Observer: *CLM*	Version: *2.0*

Local Scale

Local Scale Map



[Around map give fetch to the first major topographic change]

General Information

Local land-classification (e.g. Local Climate Zone [LCZ]): *$LCZ6_{BB}$ (See Stewart and Oke, 2012)*			
Dominant Land Use: *Residential*	Notes: *Mostly terrace housing (2-3 storey); some semidetached (2-storey), occasional apartment (20-storey)*		
Davenport Roughness Class (DRC) upwind of enclosure (500 m):			
6 N	*6* E	*6* S	*5* W
Land Cover (% in 500 m radius area):			
32 % Vegetated	*59* % Built	*9* % Bare	*0* %Water
Mean Tree Height: *10* m		**Mean Building Height:** *2* Storeys	
Lawn/ Garden Irrigation/External water use: *Few small front lawns and back gardens; two small parks – possible irrigation in summer*			
Typical Wall Material: *Brick*		**Typical Road Material:** *Asphalt*	
Typical Roof Design: *Gable/flat*		**Typical Roof Material:** *Concrete tile/asphalt*	
Space heating? *No*		**Space cooling?** *No*	
Traffic Density: *Light-medium*			
Recent Changes/Development since last metadata update (e.g. new residential development): *Note. Wasteland and boarded up houses to east (possible future development?)*			

2

Muller et al (2013)

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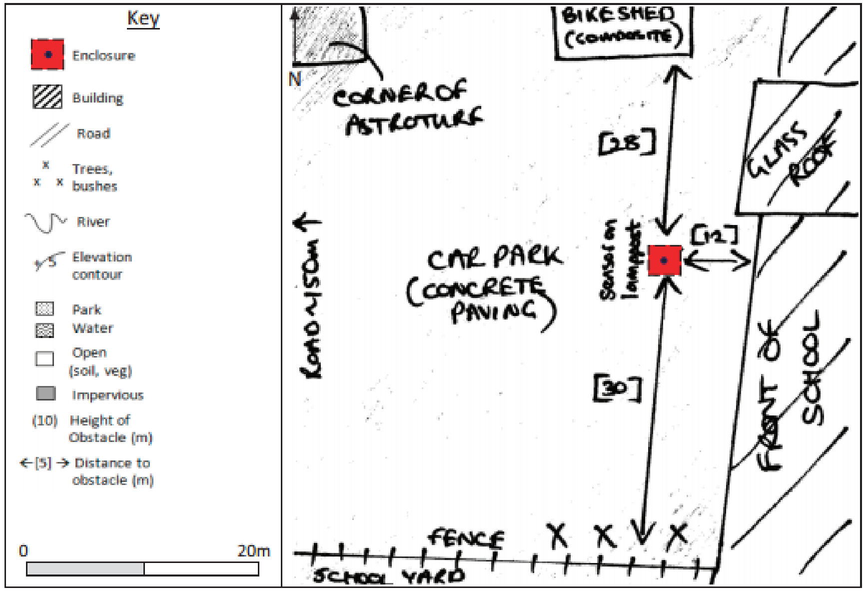
Site: *S041*	Network: *BUCL-S*	Update Date: *02/10/2012*	Observer: *CLM*	Version: *2.0*

Micro Scale (Instrument Exposure)

Micro Scale Sketch Map



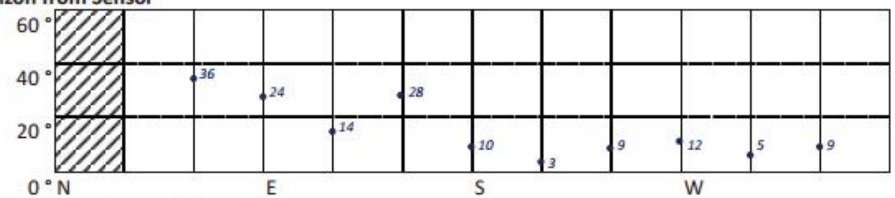
General Information

Enclosure ID (if applicable): *S041a*	**Elevation:** *138 m (a.m.s.l.) (+ 3 m sensor height)*
Latitude: *52.50018* ° N	**Longitude:** *1.90086* ° W
Mount/enclosure type: *Metal lamppost*	**Mount/enclosure location:** *Front of school/car park*
Temp/Humidity Sensor Height: *3* m	**Ventilated shield?** *No*
Anemometer Height: *N/A* m	**Anemometer direction:** *N/A*
Precipitation Gauge Rim Height : *N/A* m	(Additional information): *Instrument orientated South*
Surface Cover Below Sensor: *Concrete paving*	
Soil/ Material under cover: *(not yet analysed)*	**Building Materials:** *Concrete, brick, composite, glass*
Building Types: *School*	**Building Height:** *2* storeys
Tree Type (deciduous/coniferous): *Young deciduous*	**Tree Height:** *<4* m
Roof shape: *Flat*	**Roof material:** *Asphalt*
Site land-classification: *$LCZ8_E$ (See Stewart and Oke, 2012)*	
SVF: Winter: *0.967*	Summer: *(Will be assessed for Summer 2013)*
Traffic Density (e.g. none, light, medium, heavy): *none (intermittent/car park)*	**Time:** *11:15*
Heat / Moisture Vents: *Heat from cars and minibuses @ 8/9am and 3/4pm*	

Muller et al (2013)

Site: *S041*	Network: *BUCL-S*	Update Date: *02/10/2012*	Observer: *CLM*	Version: *2.0*

Horizon from Sensor



Horizon notes (e.g. notable features):

-Lamppost, *-School building*, *-School building*, *-School building*, *-School building*, *-Deciduous tree*, *-Classroom*, *-Far tree*, *-Terrace house*, *-Far tree*, *-Terrace house*

Photograph Check-list

Sensor Location	✓	**Cardinal Directions**	✓
Panoramic	✓	Sky View	✓

Cardinal Photographs (from sensor height and location)

Muller et al (2013)

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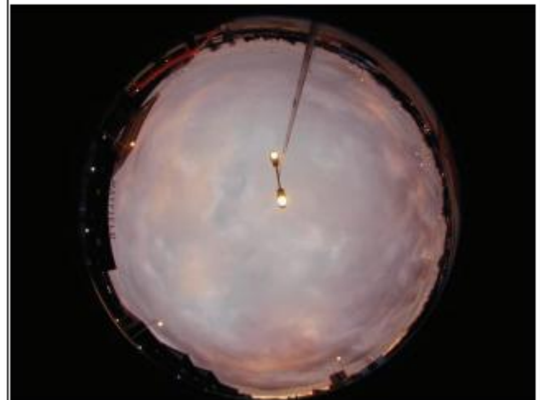
Site: *S041*	Network: *BUCL-S*	Update Date: *02/10/2012*	Observer: *CLM*	Version: *2.0*

Sensor Location

Sky View photograph (taken with fish eye lens)



Panoramic photograph(s)

N E S

S W N

Additional Comments (e.g. noticeable changes, remarks)

Landscaping/building work going on to east of school (behind school) – check on follow-up visit.
Astroturf pitch 100-200m to NW.
Mayfield is the joint school

Muller et al (2013)

Site: *S041*	Network: *BUCL-S*	Update Date: *02/10/2012*	Observer: *CLM*	Version: *2.0*

Maintenance Log (Station history, instrument history, site changes)

Date	Description
22/11/11	*Initial visit and site selection; photos and metadata v1.0 taken at ground level.*
02/10/12	*Sensor + shield installed.* *NOTE: initial issues with communication – sensor can be seen on the network, but not connecting. Issue with either Link2ICT or school. Needs troubleshooting.* *General, micro-scale and local-scale (visual) metadata v2.0 collected (inc. horizon and photographs).*
05/10/12	*Sensor started transmitting data (firewall issue resolved).*

Muller et al (2013)

Birmingham Urban Climate Laboratory

- The primary focus of the HiTemp project was to provide a series of demonstration sensor networks to measure air temperature
- The design is a nested network of sensors:
    - 25 full weather stations [coarse array]
    - 84 low cost air temperature sensors located in schools [wide array]
- Birmingham is now one of the most densely instrumented urban area in the world.

Coarse Array: AWS Network

- The coarse array consists of 25 full weather stations located across Birmingham.
- Located in 'representative' sites in schools across the city and so also used for school outreach.
- Additional sites in the surrounding rural areas to record background conditions (e.g. Sandwell & Sutton park)
- Average spacing: 1 per 10km2

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Equipment: Weather Stations

- A full suite of weather variables are available (air temperature, humidity, wind speed, wind direction, barometric pressure, precipitation, solar radiation).
- Data loggers (CR1000), communications and mountings (Campbell Scientific)
- Vaisala WXT520 – precipitation, wind speed, wind direction, temperature, relative humidity, pressure
- SKYE SKS1110 pyranometer
- Power: Solar
- Data Communication: GSM/GPRS

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Wide Area Array: Air Temperature Network

- The wide area array consists of 84 air temperature sensors located in schools
- Plus a few in 'rural' schools /parks/farms outside conurbation
- Average spacing: 1 per 3km2
- Extensive metadata collected at all sites for quality control.
- Deployment based around the 'Internet of Things'

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The Internet of Things

- Literally means things that connect to the internet
  - Computers
  - Smart Phones
  - Curtains, lights, central heating...
  - Sensors
- Since 2008, these things now outnumber users online
- Lots of potential via the smart cities agenda
  - Miniaturisation of technology
  - Decreasing cost of sensor networks

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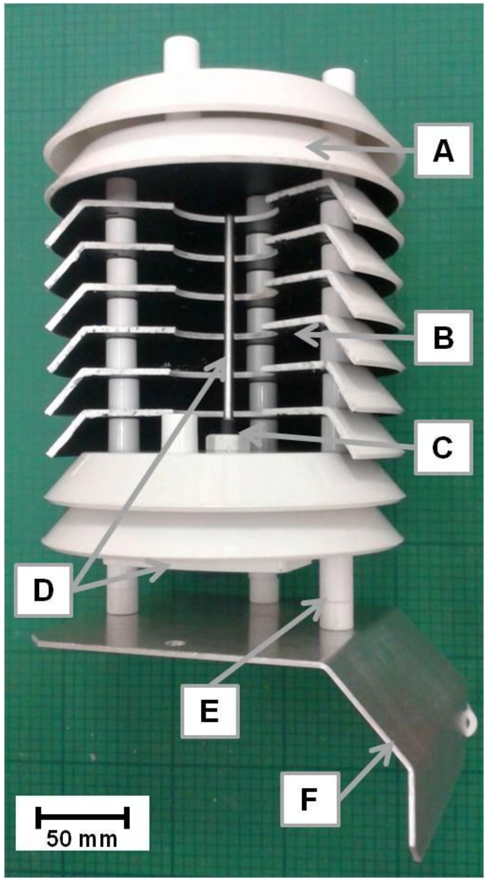
Low Cost Air Temperature Sensors

- Bespoke self contained air temperature sensor was designed to produce a high resolution network across Birmingham:
  - 10kΩ Negative Temperature Coefficient Thermistor
  - Bespoke radiation shield
  - Comms provided via a wireless communication card
  - Power provided from a Lithium-Thionyl Chloride battery which last for 3 years under ideal conditions
  - Very cheap - £87!
  - Tested at UKMO calibration lab with an absolute error of ±0.22°C



- Can be deployed anywhere where there is a WiFi network

- A good example of a low cost thing in the IoT
  - No ongoing costs for communication / power
  - Cheap to install in a large network
  - Has led to a number of successful ‘spin-off’ projects

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But is 'cheap' any good?

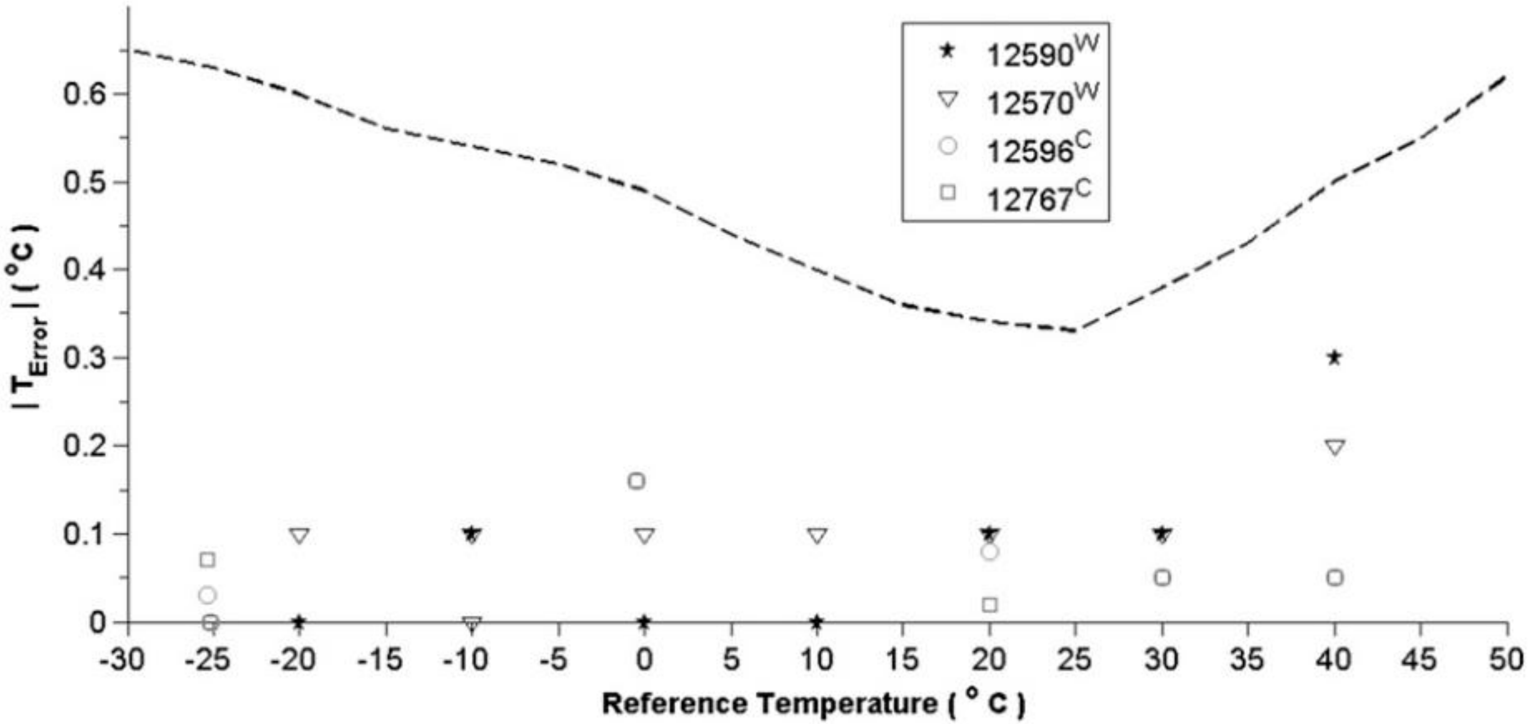

FIG. 3. Observed temperature errors of four ASM probes (serial numbers given in key) relative to a reference temperature (UKMO PRT, traceable to national standards) of a water bath (superscript W) and atmospheric chamber (superscript C) during experiments undertaken within the UKMO Instrumentation Laboratory. Dashed line represents the probe accuracy as reported by Aginova.

Young et al, 2014

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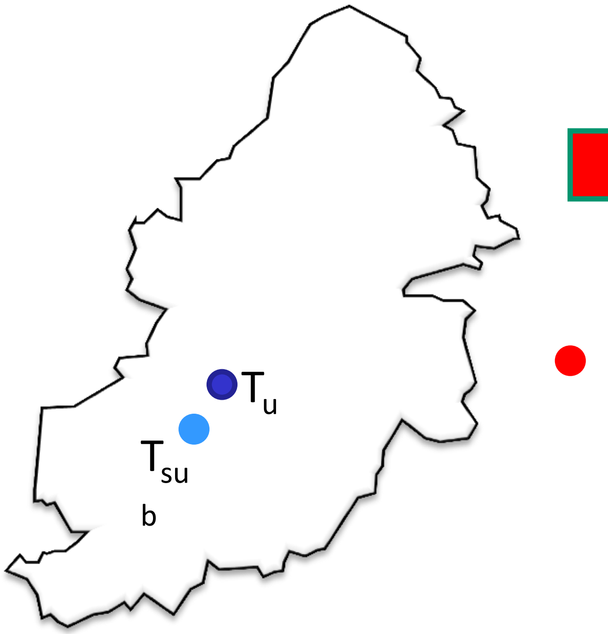
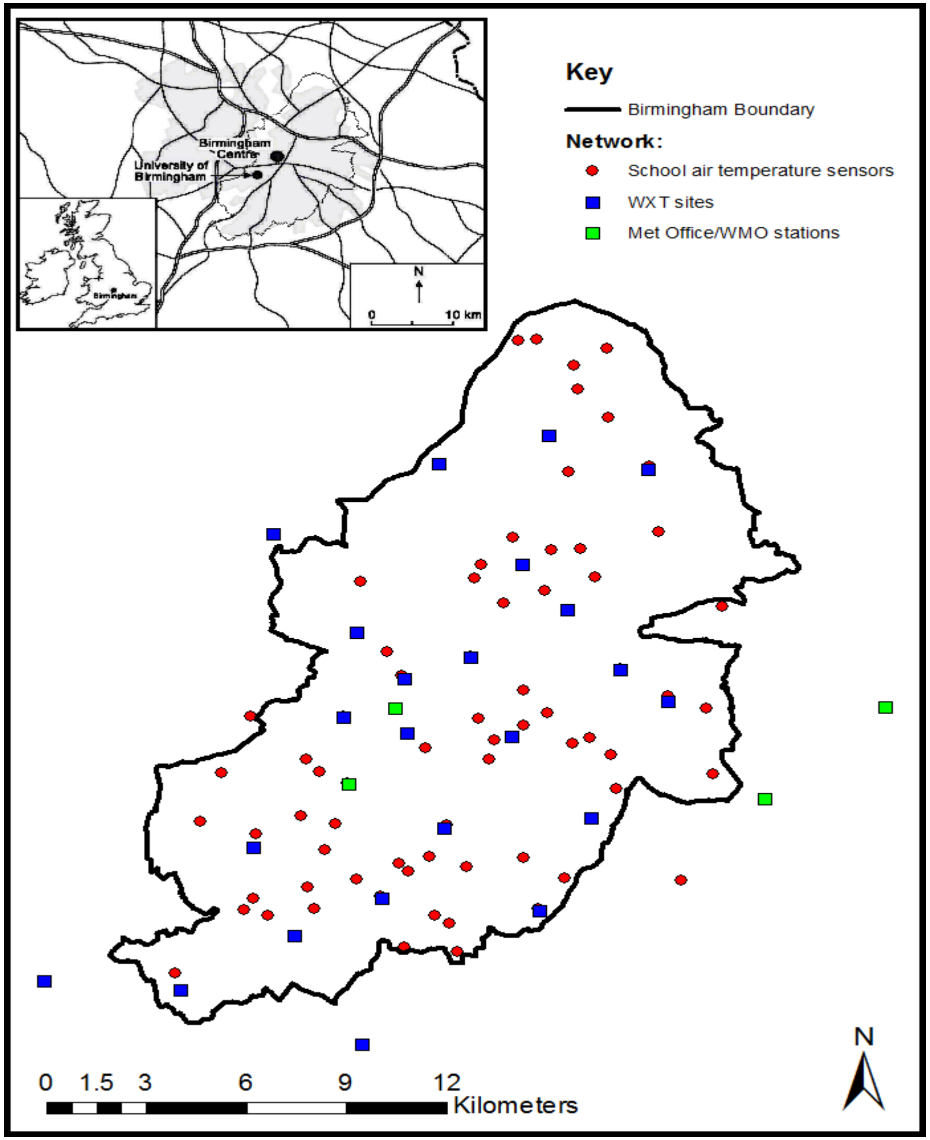
Birmingham Urban Climate Laboratory





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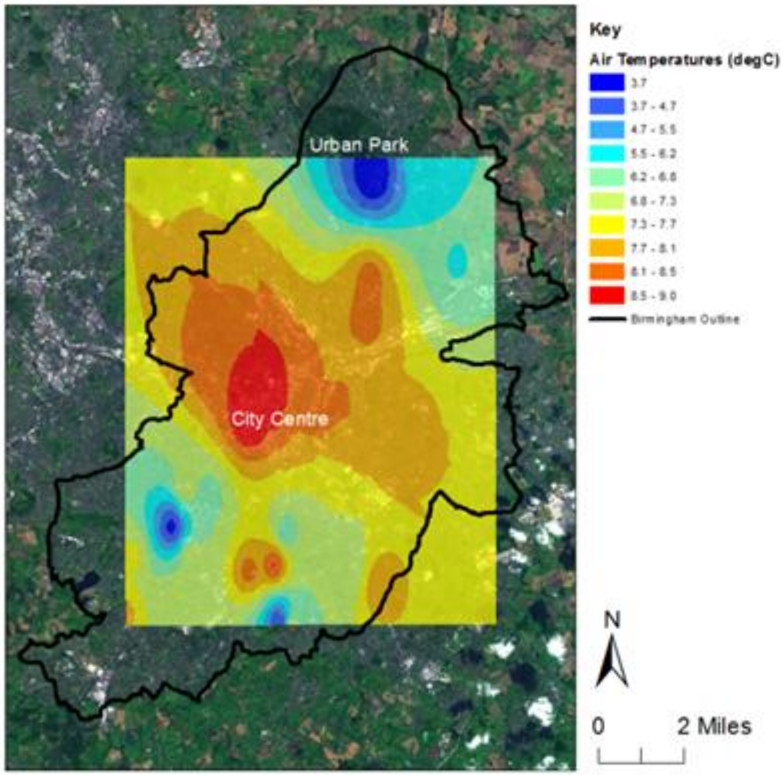
(a)



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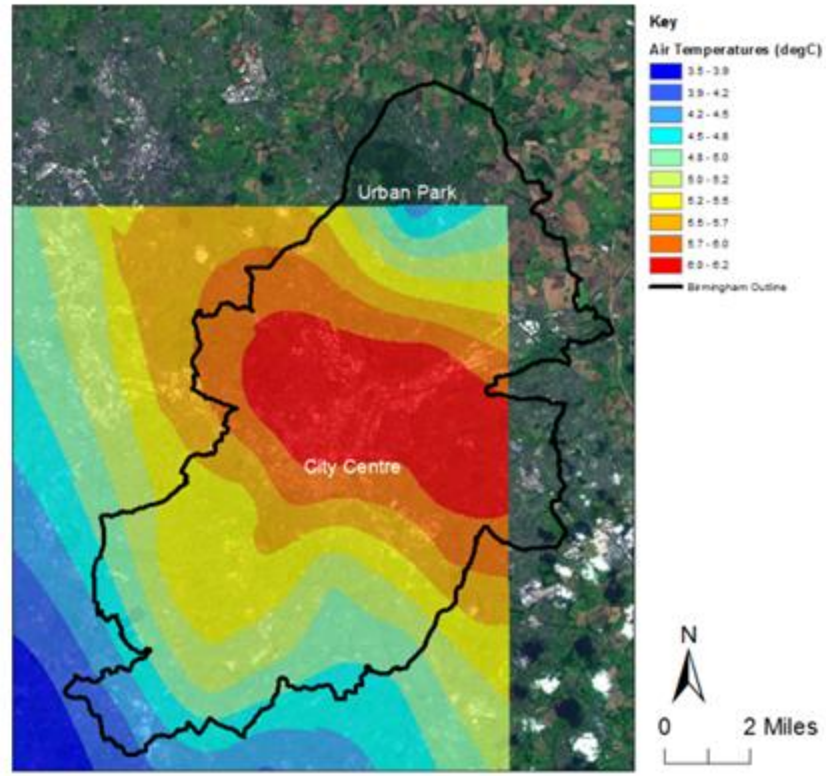

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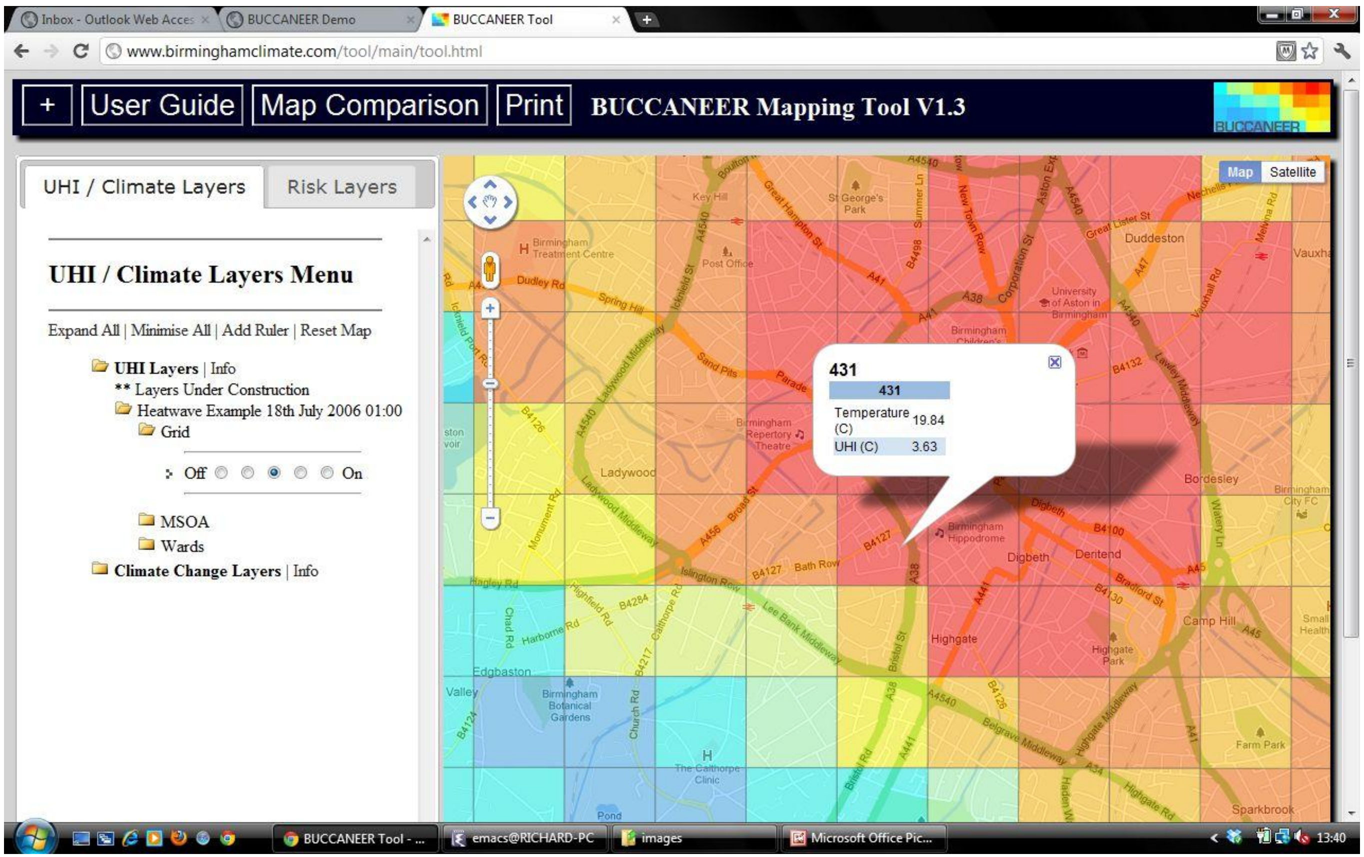
Use Case: BUCCANEER

- Birmingham Urban Climate Change Adaptation with Neighbourhood Estimates of Environmental Risk
- 2 year Knowledge Transfer Partnership with Birmingham City
- Linked climate change scenarios with urban heat data to show combined impact at different spatial and temporal scales.
- Used as a planning tool to target adaptation measures (e.g. Urban Greening)



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Heat Health Risk

- Identifies where vulnerable population live in relation to the urban heat island
  - Elderly
  - Ill health
  - High population density
  - High rise buildings
- Informs heatwave protection plans and prioritisation of other adaptation measures

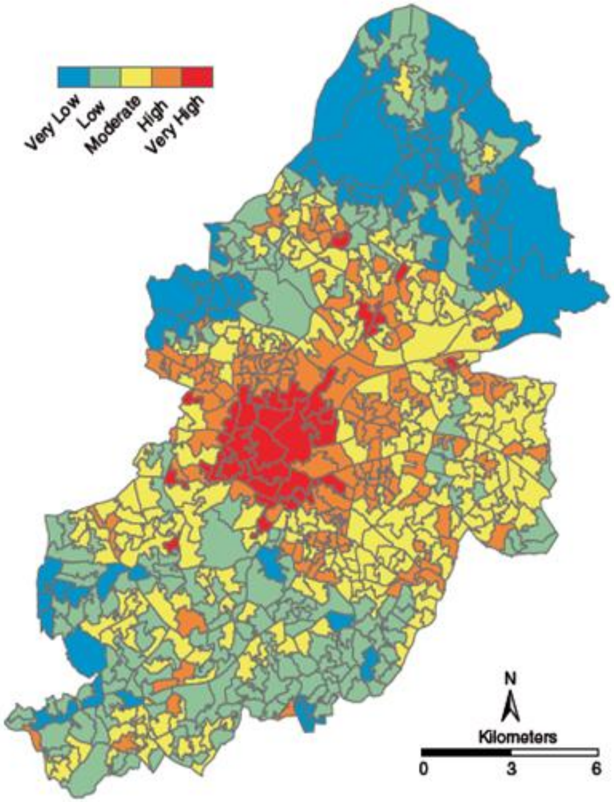

Figure 4. Spatially assessed heat-health risk across Birmingham, after Tomlinson et al. (2011b).

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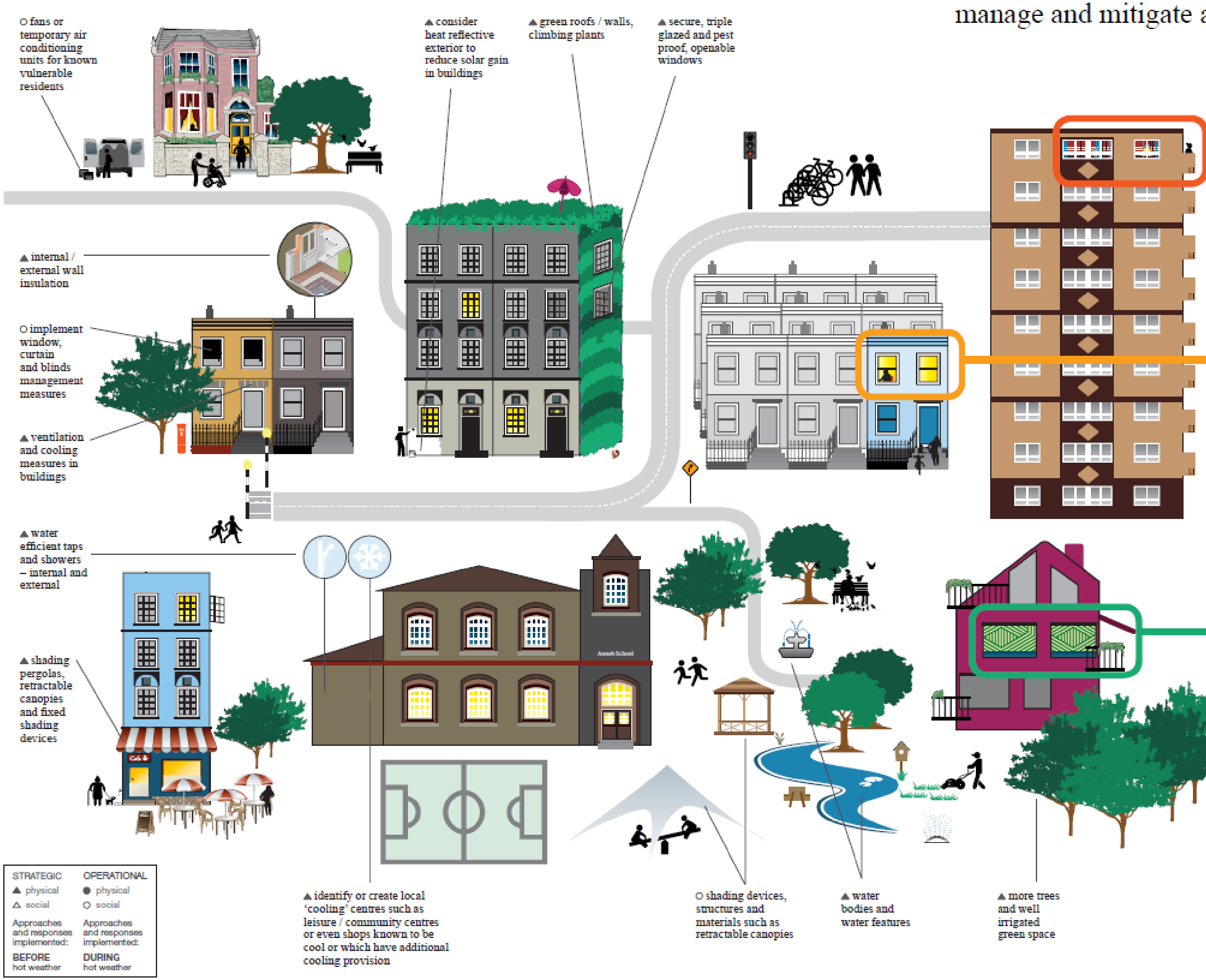
Summary of approaches and responses to manage and mitigate against urban heat risk



High risk example

Ms X is 68 years old with limited mobility and a respiratory condition. Her days are spent mostly at home with occasional visitors. Her top floor flat is in a tower block with poorly insulated walls, south facing windows and balcony and no external shading. She lives within a UHI, close to a main road with no green or blue space in the area.

Medium risk example

Mr and Mrs Y are both 36 with two children, both under five years old. Mr Y works from home in the evenings and during the day, looks after the children, one of which suffers from asthma. They live in a top floor flat of a converted terraced house which has poorly insulated walls and roof. It is dual aspect but with no garden, no external shading and west facing windows. Situated within a UHI, there is no green or blue space or mature trees in the local area.

Low risk example

Mr and Mrs Z are a young couple with no children who spend most of the day away from home. They live in a mid-level floor flat with well insulated walls and roof on a quiet residential estate. The flat is outside the UHI, has west facing windows with a balcony and external shading, and is located close to blue space and mature trees.

Other Users

- Local government are not the only potential users of the data:

- Networks can be linked to other forecast systems:
  - Transport
  - Flood forecasting

- Powerful educational resource

- Academic research!
  - Model verification and improvement
  - Satellite ground truthing
  - Testing schemes and protocols

- Longer term monitoring campaigns – i.e. Climate change impacts on cities

Key Challenges

- Many networks have proved to be unsustainable over the medium term, often not outlasting the demonstration phase. Why?

- Time consuming:
  - Ongoing QA/QC – some can be automated, but rotation of sensors to allow for calibration is very time consuming. Sensor drift is a known issue with low cost sensors (Fiebrich et al, 2010)
  - Metadata needs regular updating
- Expensive:
  - Needs dedicated technical support
  - GSM communications are a monthly ongoing cost

- Time consuming + expensive = unsustainable...
- ...unless end-users (as well as academics) can foot the bill

- Sustainable Urban Meteorological Networks workshop brought together key end users of urban meteorological data:
  - Insufficient financial support available in the public sector
  - Preference for bespoke monitoring networks from the private sector

Infrastructure Monitoring

- There are numerous impacts of weather on infrastructure networks
- High resolution models help infrastructure operators mitigate the risks
- In an environment of increasing litigation, end-users are wary of relying on model output alone
- Low-cost sensing can provide the measurements to overcome this barrier and unlock millions of pounds of potential savings
- Can the Internet of Things provide the solution?

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WINTER SENSE

*winter**sense** is an EPSRC project, co-created with Amey, that is adapting the technology to measure road surface temperatures for gritting applications.*

- Thermistor replaced with a low cost IR thermopile sensor.
- Sensors relay data back to central server using existing city-wide Wi-Fi installed by Amey
- High resolution network will quantify thermal variations around the road network (up to 20°C on a marginal night)
- Save money by selective salting and dynamic routing
- Potential for ground truthing satellite LST data?

It’s all about smart cities…

- Crucial to the success of the idea is the proliferation of internet connectivity along infrastructure corridors
  - Smart Cities
  - Smart Motorways
  - 900MHz Wireless Connectivity on the Railways and rural areas

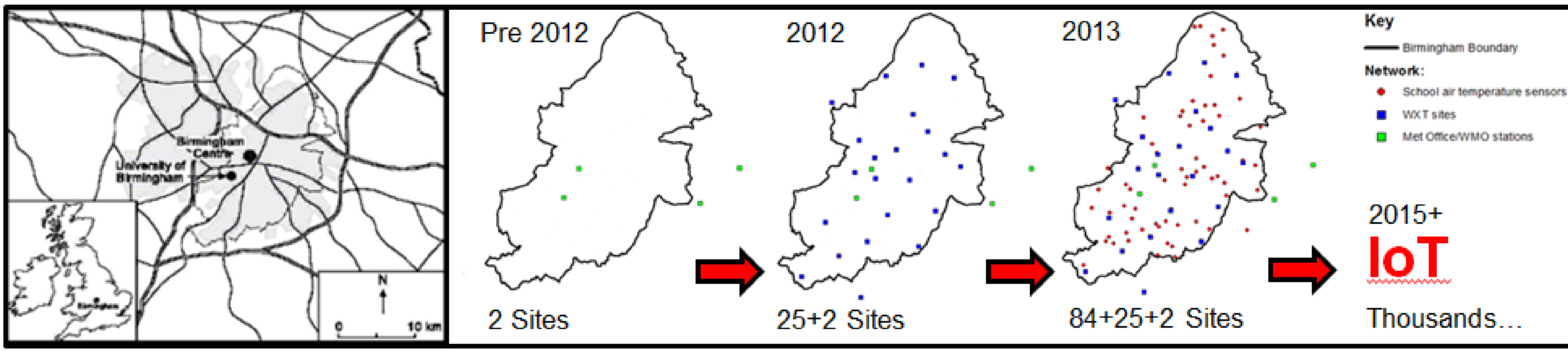
- Harnessing existing communications infrastructure massively reduces the cost per node.

- Still very challenging!
  - Technology doesn’t stand still! The wifi protocol used by the device has now been superseded: 802.11n instead of 802.11b/g
  - Batteries not 100% reliable and drain quickly if communications are poor
  - Maintenance is a potentially enormous task!
  - Annual calibration of 1000s of sensors would be fun.

- The Internet of Things is a game changing approach

Future Thinking

- Weather monitoring has come a long-way since the use of a single weather site for each urban area
- Birmingham: 1 site > 4 sites > 25+84 > 1000s!?



- A genuine city-wide effort involving universities, schools, the city council and local industry
- An exemplar for urban climate research worldwide and continues to push boundaries via smart cities agenda
- Do I recommend this approach to everyone? Should every city try and deploy an Urban Meteorological Network?

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Future Thinking

- NO!
- It is very unusual for Urban Meteorological Networks to survive the demonstration phase
- They represent the old paradigm of observations.

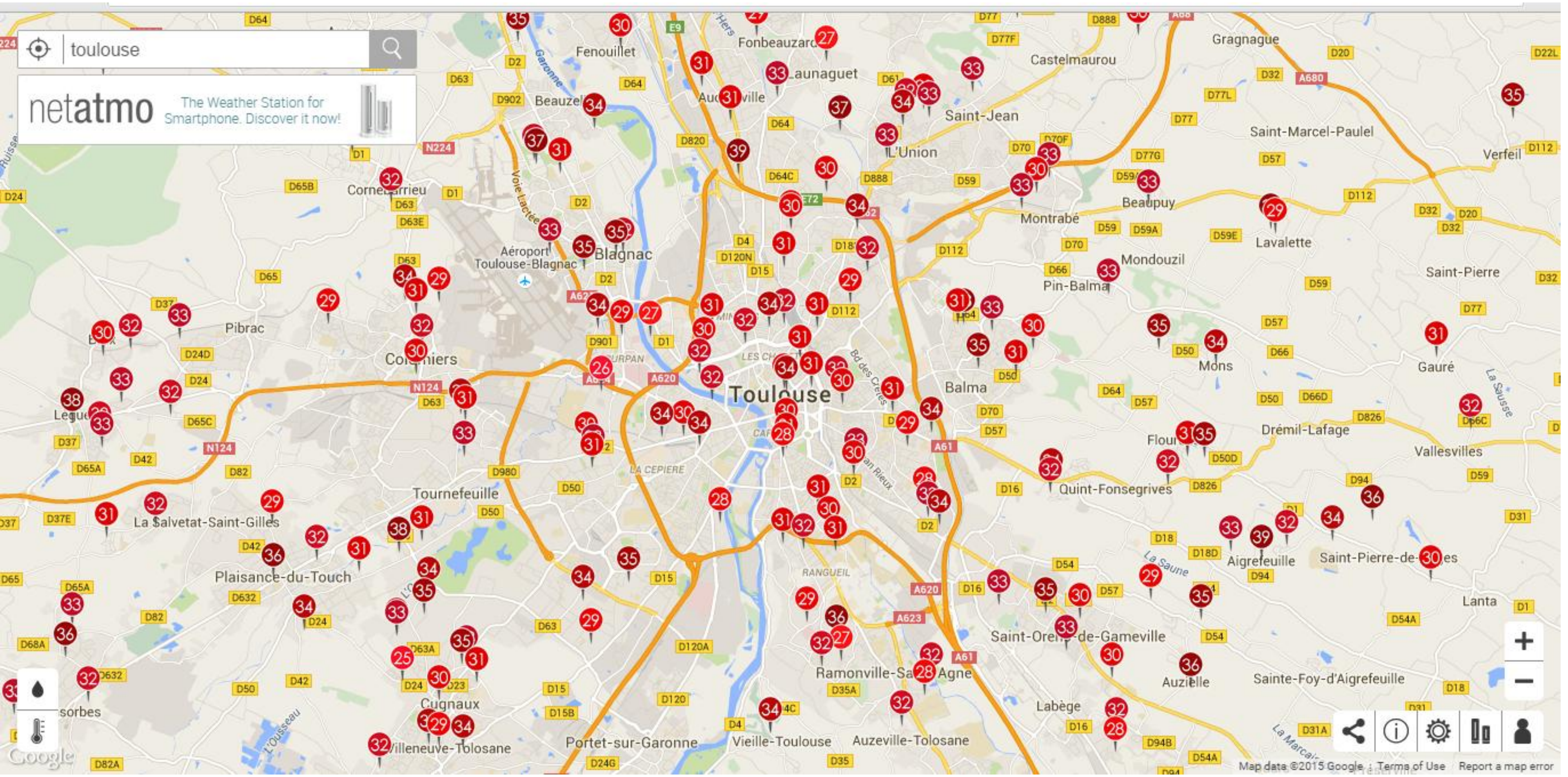
- New approaches are needed which are sustainable and allow us to instrument the urban environment at an unprecedented scale
  - Allows us to measure the micrcolimate instead of worrying about representative locations
  - Do representative locations actually exist anyway in an urban area!?

- The Internet of Things is one such disruptive technology
- Are there any others?

Crowdsourcing

- *"In the next century, planet earth will don an electronic skin. It will use the Internet as a scaffold to support and transmit its sensations. These will probe and monitor cities, the atmosphere, highways, conversations, our bodies, even our dreams"* (Neil Goss)
- The term 'crowdsourcing' has gained much popularity; traditionally defined as 'obtaining data or information by enlisting the services of a large number of people',
- It now often refers to obtaining information from a range of public sensors, typically via the Internet.
- Data is often routinely collected – it just needs harvesting and /or repurposing
- Many other scientific disciplines are using this data, but less so in the atmospheric sciences
- There is a vast range of data out there, just ready to be used...

Smart Devices



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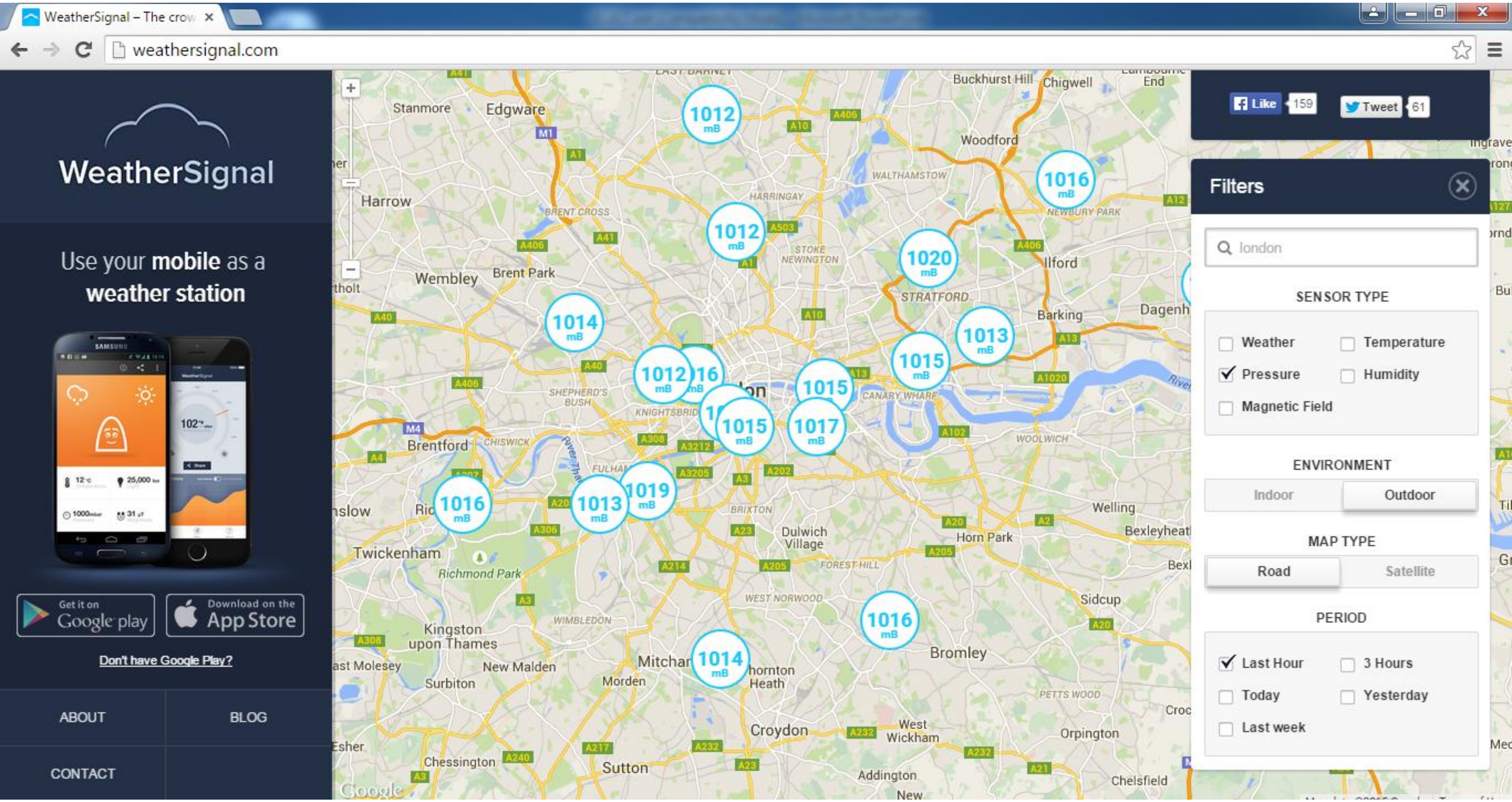
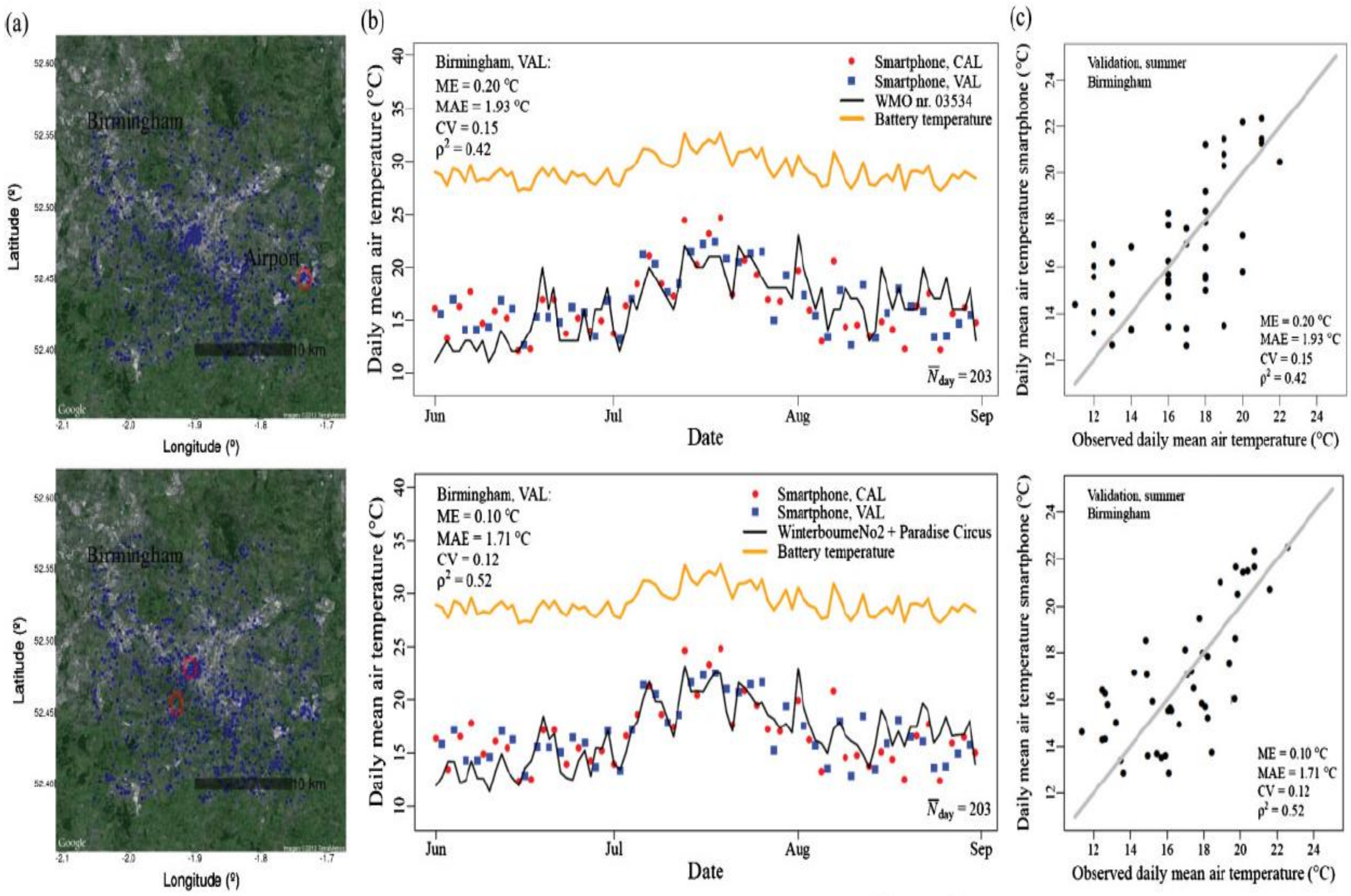
Mobile Phones



Mobile Phones



Overeem et al, 2013; Muller et al; 2015

Vehicles

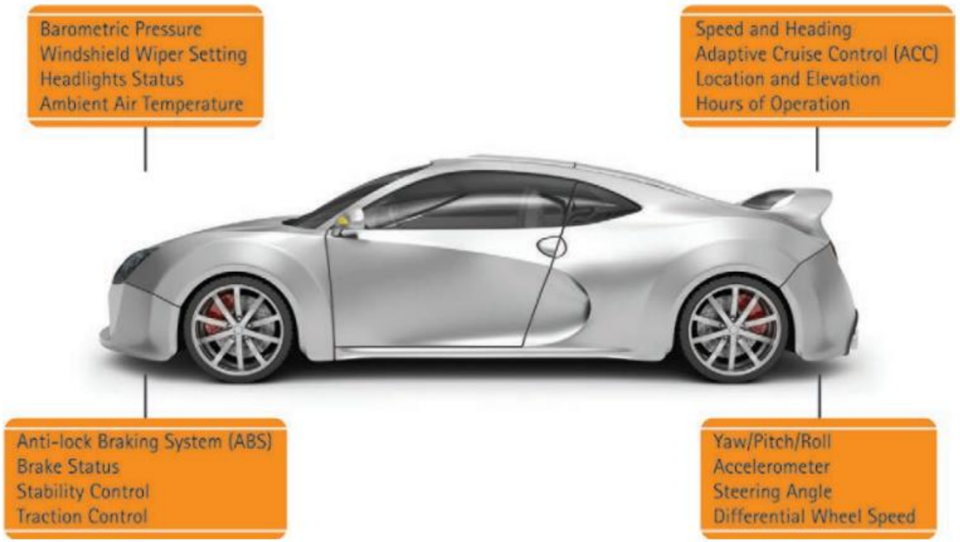
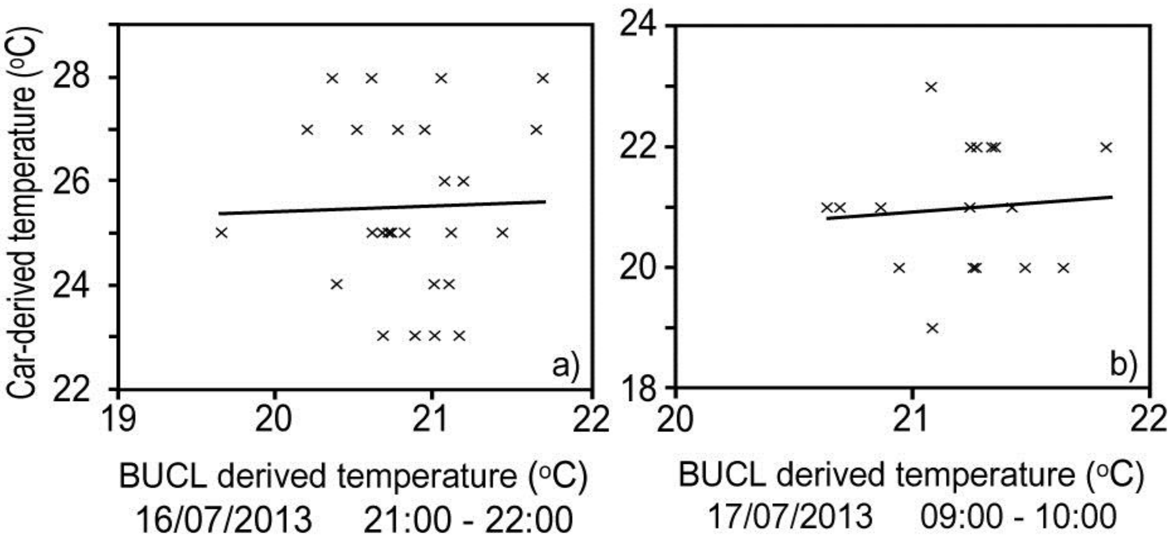


FIG. 1. Graphical illustration of selected data elements now commonly available within the CANbus on passenger vehicles.

Mahoney & O'Sullivan, 2012



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Summary

- Other technologies are our best hope of monitoring the urban climate at a high resolution

- Quality Assurance / Control is the crucial step to make these techniques accepted by the scientific community

- Effort needs to be focussed into a few key networks to be repurposed as testbeds for modelling campaigns and investigating the viability of these more sustainable techniques (e.g. IoT, crowdsourcing)

- These techniques can then be rapidly applied across the world and will continue to build our urban climate resilience

- The current paradigm of measurements is unsustainable . Innovation is the true urban climatologists panacea.

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