Observing London: Weather data needed for London to thrive

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About this document

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LONDON climate change PARTNERSHIP

Foreword

London aims to lead the world in climate resilience. To do so requires access to basic information about the characteristics of its weather and how they are changing. Although there are currently around 260 weather stations in the capital, they are operated by a range of organisations and volunteers, and the data are not coordinated or centrally accessible. This report makes the case that we could and should harness this wealth of information – most notably through the creation of a focused weather portal for London. Improving the quality and access to weather data helps us to better understand and adapt to current and future conditions, ensuring London is a resilient and thriving city.

Improvements to weather data will have significant economic benefits by enabling better operations within sectors such as flood management, transport, insurance, emergency response services, energy use management and building design.

Excitingly, we also expect that a single weather portal would provide a catalyst for new uses and growth due to entrepreneurship, technology and citizen wide initiatives such as the development of mobile applications.

I hope you find this report informative and valuable, but more importantly, that you will work with us to turn the recommendations into reality.

Professor Chris Rapley CBE
Chair, London Climate Change Partnership

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Executive summary

Weather observations are among the most important data required to enable London and cities around the world to function. They have an enormous range of uses. Some users are in public institutions charged with protecting life and property, for example from storms or flooding. Many others are in businesses that use atmospheric information to enhance their operations, whether in energy trading, architectural design, the management of buildings or transport.

By their sheer numbers, the greatest users of weather and air quality data are the members of the general public who use this information to make a range of everyday decisions – such as when to take an umbrella, what transport to use or how to avoid a polluted route to work.

In order to understand the current use and collection of weather data in London, and both the unmet needs of users and the potential benefits that could come from better data availability, a survey was distributed to a wide range of public, private, governmental and commercial stakeholders.

London has a surprising amount of weather data – about 260 stations that measure some aspect of London's atmosphere, including rainfall, temperature and air quality. These are operated by a wide range of organisations and individual volunteers. However, there is a general consensus that: (1) the data are not available at a high enough density across the city and (2) many users cannot take full advantage of the data collected because they are not discoverable nor available in quality controlled, easily accessible formats online.

The key recommendations of this study, with their related benefits, are:

1. **Creation of a single accessible source for weather data – a London Climate Data Portal (LCDP):** This will enable exploitation and innovation in the uses of weather data. The reported benefits of greater data availability include better flood management, enhanced weather forecasting capability, enhanced transport management, air quality services, ecosystem services, emergency response services, energy use management and building design. It is expected that new uses and growth will appear beyond the current needs due to increased technology, entrepreneurship and citizen-led initiatives eg through smart phones.

2. **Improve the quality and usability of the data collected**: Procedures to quality control data that are currently available will enhance their usability and improve the integrity of decisions made using weather data in a wide range of applications.

3. **Evaluate data gaps**: A London Climate Data Portal would enable data-gaps to be understood. A follow-on business case for future investment will enable volunteers and funders alike to evaluate what data London most needs and where for future resilience and economic growth.

Executive Summary

4. **New observations**: where the user need is balanced by the investment, new observations will enable further benefits to be realised in the innovative use of weather and climate data. Technological innovation including wireless sensors, vehicle mounted sensors or mobile sources will likely prove especially attractive. New technologies and opportunities should be actively monitored to ensure ongoing improvements to the spatial and temporal data provided on the London Climate Data Portal.
5. **Ensure continuity of stations to facilitate the study of extremes and London's longer-term climate.** This will enable understanding of the impacts and frequency of severe storms, heat waves and floods over long periods for climate and weather risk management. This will benefit risk management, energy trading and detection of climate variability and change, all enhancing London's resilience.

A focused portal for weather data in London would lead to new applications yielding economic benefits. This has been the experience of other cities both in the UK and internationally, such as Shanghai, Helsinki and Birmingham. London has the opportunity to learn from these cities and develop leadership in this area internationally.

By their nature, applications of weather data help users to adapt to current and future conditions. Thus London will become more resilient and more attractive for its increased capacity to adapt, respond and thrive.

Contributors

We extend special thanks to all those who responded to the survey.

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City of London Corporation
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Greater London Authority
London Borough of Bromley
London Borough of Islington
London Borough of Southwark
Local Authority – Waste Management
Westminster City Council

Government

Environment Agency
Health Protection Agency
Met Office

Other Organisations

Centre for Ecology & Hydrology
Center for Clean Air Policy
CIBSE
Climatological Observers Link
London Fire Brigade
London Sustainability Exchange (LSx)
London Wildlife Trust
Metropolitan Police Service
Railmet
Royal Automobile Club Foundation
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Transport for London

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1. Introduction

Weather observations are among the most important data required to enable London and cities around the world to function. They are used by everyone on a daily basis but they are also critical for transport, businesses and government. Observations allow us to respond to changing conditions, extreme weather events and build long-term resilience. Weather observations are also excellent for the communication of science and for education and community engagement.

Although weather is generated by large scale synoptic and meso-scale features, cities such as London experience modified weather events and conditions as a result of the built environment – reflecting the influence of large areas of buildings of different heights; paved streets and parking spaces; and the release of waste heat and materials. These features contribute to distinct local weather environments characterised by urban warming (the urban heat island[1] effect), urban flooding, altered precipitation patterns, elevated concentration levels of pollutants and aerosols, and street canyon winds.

Given the high density of people and their dependence on a complex infrastructure, urban areas are especially vulnerable to weather related events such as heat waves, thunderstorms, winter storms and cold snaps, air pollution and the rapid spread of airborne disease and pollen. To better prepare and respond to these events, as well as to design and build more sustainable and resilient cities, the field of urban meteorology has grown from simple observations and forecasts for cities and their surroundings, to scientific and technological advances that allow us to predict a wide set of environmental conditions and responses at relatively fine temporal and spatial scales.

There are many end-users of urban weather and climate information. Some are in public institutions charged with protecting life and property, for example from storms or flooding. Many others are in businesses that use atmospheric information to enhance their operations, whether in energy trading, architectural design, the management of buildings or in transport. By their sheer numbers, the greatest users of weather and air quality data are the members of the general public who use this information to make a range of everyday decisions – such as when to take an umbrella, what transport to use or how to avoid a polluted route to work.

Specifying meteorological measurement needs for a city requires insights into the users, the information required for applications, as well as the necessary accuracy, precision, and temporal and spatial resolution of the information. Guidance on data needs also requires an understanding of how meteorological and urban air quality prediction and data assimilation models use these measurements to make predictions of the state of the urban atmosphere. The objectives of this study are to investigate these issues, specifically the needs of users and the availability of weather and climate data in London.

A summary of the range of typical users and their data needs (in terms of meteorological variables, the spatial and temporal resolution, and forecast lead times) are presented in Appendix 1. User groups may share many data requirements but also have their own specialised needs - public health[2] and safety organisations require information to warn the public of an impending hot or cold spell, whilst traders active in the gas and energy markets and those in the sustainable building industry look to balance energy demand with

1 Urban Heat Island (UHI): The well documented effect that urban areas are warmer than their rural surroundings, particularly at night. Traditionally this refers to air temperature difference at typical station screen height. In an urban area, this height is lower than the height of buildings. See Appendix 5 for a fuller description and a history of the study of the UHI in London.

2 http://www.hpa.org.uk/ProductsServices/ChemicalsPoisons/EnvironmentalPublicHealthTracking/EnvironmentalPublicHealthSurveillanceSystem/

1. Introduction

production, and those in the construction industry need to know if the wind speed will permit safe operation of a crane.

In terms of the resilience needed to enable a city to thrive, observations of the intensity, frequency and location of catastrophes such as storms and floods are also essential for designing buildings and for developing risk transfer solutions (Dabberdt, 2012[3]).

While the weather and climate data used may vary broadly, generally three types can be distinguished:

1) **Weather forecasts** are produced using observations and numerical models which predict short-term conditions (hours to days in advance) and are routinely updated. The model data are often interpreted by expert forecasters and the final forecasts are commonly provided by a wide variety of media, websites and other sources (Appendix 2 provides examples). There are both general forecasts and those specialised for the operations of individual sectors (e.g. road maintenance, railways). These models rely on assimilation of observations collected at a large scale to provide the initial state of the weather (called the analysis). Performance of weather forecast models is typically evaluated on an ongoing basis and uses metrics[4] that require observations.

2) **Climate predictions** use models similar to numerical weather models but with additional complexity and predict conditions further into the future, often providing seasonal or longer term climate predictions. Such models are routinely evaluated by running the models for past periods and comparing output with conditions observed. These predictions tend to have a coarser spatial resolution again, although a variety of methods may be used to 'down-scale' output to smaller areas.

3) **Weather and Climate observations**: the conditions actually observed by a sensor capable of reliably measuring the meteorological variable of interest. The operation of the instrument[5] influences what is actually measured, the area and time interval for which it is representative, the repeatability (or consistency) of the observation, how rapidly the sensor responds to changes (e.g. as cloud conditions change, vehicles passing), where the sensor can be located, how much power it needs, how expensive it is, how often it needs to be cleaned, etc. From these observations, analysis products can also be generated which use some form of numerical model to gap-fill[6] missing data or to create a spatially continuous grid of data.

This report is concerned with the last of these three types of data – those observed. However, as noted, the quality of forecasts/predictions of weather and climate are in part dependent on the quality of observations. Appendix 3 gives examples of data density differences between climate forecasts (for 2020), weather forecasts by the Met Office and current observations from a variety of networks.

3 Dabberdt, W 2012: Users, Applications and Needs – Appendix A. In Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs, National Academies of Science, USA.

4 Skill score metric: A statistic (of a number of different types) to measure the improvement of a forecast relative to a (usually 'low-skilled') benchmark forecast.

5 For example, air temperature can be measured by a thermometer with a wide range of operating techniques (e.g. expansion of a liquid, expansion of a solid, electromotive force from a junction of dissimilar metals, the speed of sound, change in resistance).

6 Gap-fill: Process of filling data gaps because of missing data. The missing data may result from an instrument problem or at times of instrument maintenance. Most observations will have some missing data that needs to be 'filled' to make a complete time series (needed for many applications).

Introduction

1.1. Methods used in this study

In order to understand the current use and collection of weather data in London, and both the unmet needs of users and the potential benefits that could come from better data availability, a survey was distributed to a wide range of public, private, governmental and commercial stakeholders (in London and beyond).[7] The results from this survey and a literature review are reported here to document current weather and climate data collection and use, and to make recommendations for the future. The vast majority of those who responded to the survey were data users rather than data collectors. Examples of good practice in other cities and by sector are also included in this report.

Throughout the document, recommendations are made and these are summarised in the final section of the report. Given the large number of acronyms used in this report, these are defined in Appendix 4 rather than in the text. For many topics relevant web links are cited as sources for additional information. In most cases, material is presented in alphabetical order, not ranked by order of importance.

London has played a key role in the history of urban climate studies and in the development of current understanding. Many of the issues highlighted by respondents to the survey undertaken for this report refer to issues (such as air quality, building design and tree planting) that have been the rationale for studies and actions in London for the last millennia. A review of studies in London and key driving factors are presented in Appendix 5. In Appendix 6 a brief overview of observational networks in a selection of other cities is provided.

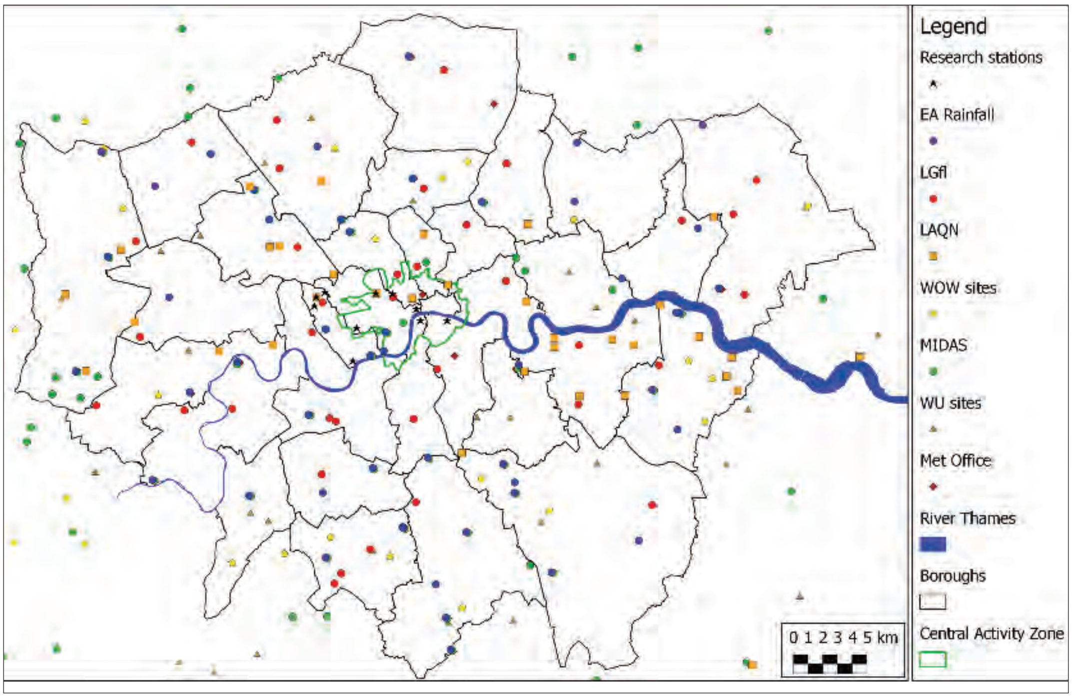
7 The total number of respondents is 162. In a number of organisations, more than one person responded.

2. London data collection

A large number of online sources of current and past weather and climate data for London exist. However, many websites use the same data sources and commonly display data collected at one of the airport sites around London (e.g. London City Airport, London Heathrow). Appendix 2 provides a list of organisations and groups that provide weather related data routinely or sporadically. Figure 1 shows the location of the weather stations involved. Websites that provide future predictions often provide historic data as well (Appendix 5). These may be for the recent past (e.g. yesterday's maximum air temperature, average air temperature in the last hour) or long term records such as the Climate Normals[8]. These data can be used to evaluate models and provide guidance for other uses.

Figure 1 illustrates the distribution of the stations within these networks across Greater London (area ca. 1572 km^2). Automatic weather stations (AWS) typically collect standard meteorological variables (temperature, relative humidity, wind speed and direction, pressure and rainfall). Solar radiation is included in some of the newer private AWS systems (see also Appendices 2 and 3 for more details). It is important to note that some sites are part of more than one network, so the points may not be visible as the symbol for the network. Most of the sites (Fig. 1, Table 1) operate AWS which provide a range of variables (column 1 Table 2). The research stations measure some of the other variables listed in Table 2. Appendix 3 provides links to maps of a number of these individual networks, some of which are dynamic with data

Fig 1: Locations of stations within different networks within Greater London operated by various organisations *(see Appendix 2, Table 1 and text). EA – Environment Agency, LGfL – London Grid for Learning, LAQN – London Air Quality Network, WOW – Weather Observation Website (Met Office), MIDAS Met Office Integrated Data Archive System, WU Weather Underground.*



8 A climate normal is the mean (maximum, minimum etc) value for a specific 30 year period (e.g. 1961-90 or 1971-2000 or 1981-2010).

2. London data collection

availability varying depending. See, for example, the difference between current MIDAS[9] stations (2011) compared to those (the large number) that have been available at some point in the past.

Table 1: Summary of key networks, their purpose, approximate number of currently active stations and quality control of data.

Network	**Features**	**Number of stations** (year last audited)[10]	**Network Quality Control**
Met Office	WMO certified weather stations	7 (2010)	Yes (including retrospective checks)
MIDAS	Land surface stations	39 (2011)	Yes (retrospective)
Weather Underground	AWS at private residences	64 (2010)	No (Data real time)
LGfL	AWS at educational facilities	33 (2013)	No (Data real time)
LAQN	Air Quality	37 (2010)	Yes
WOW	AWS at private residences	24 (2013)	No (Data real time)
Environment Agency	Rain gauges TBR 32/ Storage 14	46 (2013)	Yes
Borough of Bromley	Road maintenance	2 (2013)	
Lambeth Meters	Brixton	1 (2013)	
Research sites: Universities	KCL ACTUAL Imperial (RainDrain)	4 2 3	Yes
Research sites: Companies	ARUP EDF trading (Croydon)	1 1	
Private	Identified but not in a network	1+*	

* There are no doubt many other stations in this category across London

9 Met Office Integrated Data Archive System (MIDAS) Land and Marine Surface Stations Data
http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ukmo-midas

10 2010 from Robinson P (2010) The London Meteorological Monitoring Network Master's Thesis EMMM, King's College London (available from Sue Grimmond)
2011, 2013 from surveys conducted for this report (see Appendix 3)

2. London data collection

2.1. Who collects data in London and why

The data collected in London[11] can be grouped in terms of who collects them and why:

Routinely collected data undertaken professionally: This includes organisations that are required to collect data (e.g. Met Office, Environment Agency, Airport Operators); specialist businesses (e.g. MeteoGroup) that collect data on behalf of others (e.g. King's College London Environmental Research Group who run the London Air Quality Network, Riccardo-AEA); and organisations that require data for their operations (e.g. EDF Trading, The Royal Parks, Lambeth Meters, Transport for London).

> **Required:** The Met Office is required to collect the basic meteorological variables used for weather forecasting and contribute them to the global network of stations. The Environment Agency is required to measure precipitation. Defra is required to measure air quality by EC Directives. Local authorities undertake measurements (or have different agencies undertake them) for a variety of management purposes (e.g. road maintenance, air quality management). Air quality monitoring is required for the poor air quality alert system AirText which provides air quality nowcasts and forecasts for each borough.
>
> **Operations of a company/organisation:** For example, the London Borough of Bromley operates two roadside weather stations to inform its winter gritting service. With this weather information the amount of grit applied should be reduced by targeting the at-risk-areas. This provides both financial and environmental benefits. Energy trading companies (e.g. EDF trading), weather derivative tools (e.g. Speedwell Weather, URS) and hedge fund managers all operate weather stations.

Routinely collected data by volunteers: This includes a wide range of amateur meteorologists, many of whom contribute to networks[12] e.g. COL [The Climatological Observers Link], WOW [Met Office Weather Observation Website], Wunderground; and networks established by retailers of meteorological instrumentation (e.g. ProData Weather Systems).

Routine observations at schools: The London Grid for Learning hosts the weather stations established by the Lottery-funded OPAL project (initiated by APRIL[13], led by Imperial College). Another example is the WeatherBug network, a school based system originating in the USA, with a presence in London.

Research data normally collected for intensive observation periods: Within this category there are programmes run by London based universities (e.g. Imperial, King's College London, and University College London); universities in the near vicinity (e.g. Reading); other UK Universities (e.g. Manchester, Leicester, Birmingham, York); and other International Universities and Research Institutes (e.g. Gothenburg, Sweden, LCSE, France, Paul Scherrer Institut, Switzerland).

11 From the survey, 24 respondents indicated that they were involved in collecting data in London. These can be characterized as: universities (national, international), private companies and government (local, national).

12 Networks: When sites are combined together they create a network of stations. The network may consist of sites that are all operated to one specific standard (e.g. the UK Met Office has a network of 200 automatic stations in the UK http://www.metoffice.gov.uk/learning/science/first-steps/observations/ weather-stations). In London, there are several networks. Here we are recommending a network of networks.

13 http://www.april-network.org/home/

2. London data collection

In addition, commercial companies carry out observations for research (e.g. ARUP). Other examples include BRE and the National Physical Laboratory.

With the development of 'smart sensors' a growing number of researchers are involved in short term campaigns (e.g. Imperial College). The rationale for these stations and networks varies. Current examples include research on day lighting (e.g. ARUP), air quality (e.g. University of Birmingham, KCL, Lancaster University, Manchester University, York University), work on the boundary layer (e.g. KCL, University of Reading), Urban Heat Island (e.g. BRE), linkage between air quality and meteorology (e.g. ClearfLo), imaging (e.g. UCL), and flood/rainfall (Imperial).

Recommendation 1:

To create and maintain a website with key information on what weather related data are collected for London by whom, both currently and in the past. Hereafter this is referred to as the **London Climate Data Portal (LCDP)**. This will require an ongoing commitment of resources to keep the information current. Links would be made to the London Datastore; BADC, UK-Environmental Observation Framework (UK-EOF) amongst many sites (see Appendix 7).

Through a coordinated mechanism, encourage all publicly-funded agencies required to collect weather related data to make such data openly available through existing portals (e.g. BADC, UK-EOF, etc). Other groups who collect meteorological data should also be encouraged to do this.

2.2. Types of data collected

Most of the weather and climate data collected are routine meteorological variables (see Table 2), with observations of air temperature and rainfall most common. Only a subset of these meteorological variables are completely quality assured/quality controlled (QAQC) and 'always' available. For those observations undertaken by volunteers, schools or researchers data availability can be intermittent.

2.3. Where data are collected

Not surprisingly, given the wide range of people involved in data collection and the diverse purposes and applications (see Figure 1 and Appendix 2), there is little consistency in where meteorological and air quality measurements in London are taken (Table 3). The standard guidance of the World Meteorological Organization (WMO) or Met Office for a weather station is that it should be sited in an area away from buildings, above an area of green well-irrigated grass[14]. By design such sites are intended to be more broadly representative of larger areas and not reflecting local urban conditions.

For many urban applications, however, it is the specific site that is of interest (e.g. the influence of the city itself, the conditions on the roads etc.). Consequently, it is critical to know details of urban meteorological observation sites and conditions in the near vicinity to ensure the data collected are appropriate for the application at hand.

A WMO standard does exist for siting climate stations in urban areas.[15] This recognises the complexity of trying to undertake observations

14 http://www.metoffice.gov.uk/learning/science/first-steps/observations/weather-stations
http://library.wmo.int/pmb_ged/wmo_8_en-2012.pdf
http://www.rmets.org/sites/default/files/pdf/guidelines/aws-guide.pdf
15 WMO (2008) Guide to Meteorological Instruments and Methods of Observation, WMO no 8, http://library.wmo.int/pmb_ged/wmo_8_en-2012.pdf (Chapter 11)

2. London data collection

Table 2: Meteorological and related variables collected in London routinely and specialist data

Near Surface, On Rooftops	At Surface	Within Boundary Layer or above	Specialist
Air temperature	Surface temperature	Radar	Aerosol Optical Depth
Atmospheric Pressure	Groundwater levels	Cloud cover	Boundary Layer structure (Doppler lidar)
Solar radiation	Soil temperature		Global, direct and diffuse horizontal illuminance
Precipitation	Soil moisture		Latent heat flux
Air quality (e.g. PM_{10}, NO_x, O_3, CO_2 etc)	Water quality		Longwave radiation
Relative humidity	Water temperature		Net all wave radiation
Wind speed & gusts Wind direction	River levels and Flows		Sensible heat flux
Noise (sound)			
Webcam data			

in a busy city environment, at the same time ensuring the instruments used do not interfere with its functions. Often what results is that meteorological and air quality sensors in cities are located in some sort of compromise location that varies with the objective of the measurements and other logistical issues (such as the need to avoid vandalism or theft).

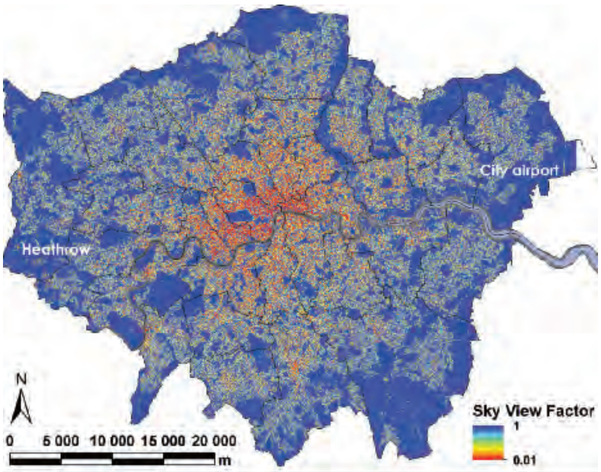
In London, the Met Office standard weather stations include those located at London Heathrow Northolt, Kew Gardens and St James's Park. The airport site is very open in comparison to the typical built up area of the city (Fig. 2 – all London), but it may still be influenced by aircraft and other vehicle activity. The St James's Park and Kew Garden sites clearly also are more open than is typical of London and have a large amount of vegetation around them compared to much of the city (Fig 2).

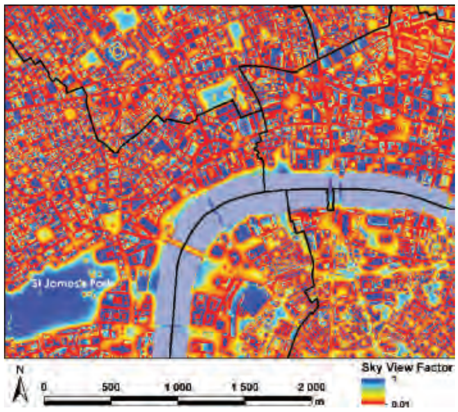
Given the wide range of applications and logistical constraints in London, sensors are (or have been) located: on tops of containers (e.g. LAQN network), on rooftops (e.g. OPAL network), on lamp posts (e.g. BRE UHI study), in sewers (e.g. Imperial study), on tall towers (e.g. Kotthaus and Grimmond 2012, ClearfLo), on the BT Tower (e.g. ACTUAL, ClearfLo, REPARTEE), in soil (Londonclimate.info), in water (Londonclimate.info, Imperial, Environment Agency), amongst other places (Table 3). Some of these sites have been used for specialist studies (Table 3). What is actually measured at each of these sites is representative of areas of very different scales.

2. London data collection

Figure 2: Map of London showing sky view factor (SVF).

Sky view factor is a measure of the openness of a site. Lower SVF (closer to 0) implies more built up area, or higher values (closer to 1) more open. (left) Central London has a lower (red) SVF than the outer areas. Parks can be clearly identified. (right). Compare the SVF of Heathrow, City Airport and St James's park to the built up surroundings. (Figures modified from Lindberg and Grimmond 2010)[16]





Recommendation 2:

Ensure that all networks/individual sites report instrument and site metadata (including photographs in all directions, data processing methods) in the LCDP. This should be accompanied by clear guidance on the conditions and applications for which the data use are appropriate (see later discussion of need for intelligent search engine, as proposed in Appendix 7). For data with restrictions or embargo on use, details on when they will be released should be recorded in site metadata on the LCDP. Ensure additional information about the sites, instruments and data are collected as they become available, and before critical details are lost (e.g. because personnel have moved or are involved in other projects).

16 Lindberg F & CSB Grimmond 2010: Continuous sky view factor from high resolution urban digital elevation models, Climate Research 42: 177-183 doi:10.3354/cr00882

2. London data collection

Table 3: Locations where measurements are taken in London

Extent of networks

- Across Greater London – in all or most Boroughs (e.g. Environment Agency, LAQN, OPAL)
- In a particular Borough (e.g. by individual local councils, companies, universities)

Types of sites

- At building sites (e.g. construction cranes)
- In parks (e.g. Royal Parks)
- In ponds
- In rivers
- On major roads (e.g. LAQN)
- On minor roads (e.g. LAQN)
- At schools (e.g. OPAL)

Installation – routine

- Standard weather screen height
- At street level (at person height)
- In water
- 10 m above ground level (e.g. wind)
- On top of containers (e.g. air quality)
- On roof tops
- On roads (e.g. air quality, highway maintenance)
- Environment Agency rain gauges at ground level

Installation – specialist

- High above roofs (e.g. > 10 m above roof level)
- Road side weather stations
- Satellites, e.g. NASA MISR
- On aircraft e.g. AMDAR, NERC ARSF
- On tall towers
- On lamp posts e.g. BRE
- In sewers
- In the soil
- Profiles down the side of a building and tower on top of the building
- In water

2. London data collection

2.4. Who funds the data collection

Given the wide range of reasons why data are collected, a number of funding mechanisms exist:

1) **Research funding agencies**, most notably RCUK (NERC, EPSRC) and European Union, have provided funds to a wide range of institutions to allow specific focused observation programmes. The resulting data may be embargoed while the research groups undertaking the research have the first opportunity to use the data for research purposes. Typically, these projects are not long term so data collection is not maintained.

2) **Personal funds**: Most amateur meteorologists have funded the purchase of equipment and operation (e.g. providing data routinely online) from their own personal resources.

3) **Lottery fund**: OPAL, which installed a weather station at schools in each Borough across London, was funded by the Big Lottery Fund. The ongoing costs for operation and funding will be borne by LGfL but there are no funds for quality assurance/quality control.

4) **Central Government funds**: Mandated data collection is funded from ear-marked funds. These may be supplemented by costs of data provision being charged to profit-making organisations. Some of these funds are used directly by the organisations to collect data, whereas others commission other organisations to undertake this work. Funding comes from sources including the water resources abstraction licence fees, highway maintenance budgets, and local council air quality management budgets.

5) **Private companies**: For both operations and research and development, businesses collect meteorological data. These data may be embargoed for variable periods of time and/or never released into the public domain.

2.5. Availability of data

Key to access for many users is whether the data are available at no cost or have to be paid for, and how quickly the data are available after collection (Appendix 2). Broadly, data in London can be categorised in terms of:

1) **Data available at no cost to the end-user**: Such data may be available to download directly or after obtaining some form of permission and/or agreeing to specific conditions of use.

2) **Data have to be paid for**: This varies from paid subscription (e.g. MDA, Speedwell Weather), an administration fee (e.g. Environment Agency), or a charge for the data (e.g. Met Office) which may depend on the type of user. A number of groups repackage data in a variety of different formats for particular niche markets. For example, for the building design industry (e.g. CIBSE) and for transportation operations (e.g. RailMet). This includes products with new data formats, time gap-filled data and spatial re-analysis.

3) **Data not available** beyond the organisation (e.g. EDF Trading).

2. London data collection

Many organisations use advertising on their websites to generate funds (Appendix 2). Some repackage the current weather conditions without providing additional products, whereas others provide additional products or subscription services (Appendix 2).

Data become available over a range of time periods: immediately (e.g. ARUP); after 10 minutes or one hour (e.g. LAQN, Met Office); on the following day (e.g. LUMA), following week (e.g. City of London Corporation); following month (e.g. EA); after quality assurance which may occur over varying time intervals and often triggered in response to a data request; and after an embargo period of two years (e.g. ClearfLo). In many cases data are released in some form online rapidly (Appendix 2) with additional QAQC later.

Recommendation 3:

Determine the "shelf life" of the current commercial data. If the observations currently are not publicly available, explore if these could be released after an embargo period. Record this in the LCDP.

3. London data use

3.1. Uses of weather and climate data in London

Many more organisations are users of London's weather data than data collectors. As expected, such use is for a very wide range of purposes (Table 4). Almost all of those who responded to the survey indicated that they used the data for multiple purposes. The most common uses cited are for research followed by resilience and emergency response, and personal use.

The variables currently used include both standard and more specialised meteorological variables (Table 4). Other variables cited but not listed because of small numbers are:

- air pressure
- wind shear
- wind direction
- vertical velocity
- turbulence
- atmospheric stability
- heat fluxes
- long wave radiation
- vertical profiles
- lightning
- freezing level
- hydrological (e.g. river flow, water management, flooding)
- oceanographic (e.g. sea surface temperature; water height above elevation for storm surge)
- traffic data
- surface canopy parameters from DEM and LiDAR

The data used are from a number of sites (Table 5). Whilst the data applies to London, it is clear that the sources of data also come from outside of London. There is a general sense amongst respondents that data currently used are not as site specific as might be appropriate.

The majority of respondents stated they want data at a higher spatial resolution. Several people note that it is rare that the data are available for the area of their specific interest. They also stress the need for good quality control of the data. Most users recognise that the airport data are not representative of the urban area, explicitly mentioning that Heathrow does not provide data that are spatially representative of London's urban heat island. Most recognise that sometimes data may be available from closer stations, but the quality of the data needs to be known better.

Many respondents indicated London wide responsibilities, but the Boroughs listed below were identified as having specific data needs:

- City of London
- City of Westminster
- London Borough of Bromley
- London Borough of Croydon
- London Borough of Hackney
- London Borough of Haringey
- London Borough of Islington
- London Borough of Southwark

Note: Not all Boroughs responded to the survey, and, it is likely there is a more general interest across London. Organisations involved in collecting or funding the main data used (most notably Met Office, Environment Agency, TfL, and LAQN) all indicated that they would benefit from a greater density of stations too. Some of those who responded have interests in extreme conditions and highlighted the importance of temporal continuity of data collection too.

3. London data use

Table 4: Summary of how survey respondents use specific weather or climate data

Many respondents use data for multiple purposes, hence there are more responses in total than respondents. The numbers in each cell indicate percentage engaged in that application (row) using the variable (column). Rows are ordered from highest number of reasons for use to least (right hand most column).

How do you use weather/ climate data?	Air Temperature	Relative Humidity	Wind	Surface temperature	Precipitation + Snow	Solar Radiation	Cloud cover	Radar	Air Quality	Soil moisture	Boundary Layer Height	Other	Number of responses
Research	70	58	70	43	63	47	39	16	37	21	21	16	105
Resilience & emergency response	71	38	67	55	74	29	33	31	33	19	7	12	42
Personal use	65	43	68	40	63	35	38	20	25	15	8	10	40
Design	67	61	64	33	48	55	52	15	27	15	6	15	33
Education	78	69	72	44	75	50	38	16	41	16	13	19	32
Weather forecasting	87	70	80	57	90	50	50	47	37	30	23	20	30
Long term operations	88	65	85	62	96	38	38	42	38	23	15	23	26
Health	68	58	63	68	74	53	47	11	58	16	16	5	19
Transportation planning	79	53	68	63	84	32	47	32	32	42	21	11	19
Construction	63	58	63	42	53	58	47	16	47	11	11	16	19
Water Management	88	53	71	53	100	29	35	59	29	29	12	24	17
Insurance	44	19	81	38	81	13	19	44	6	44	25	31	16
Other public	62	54	54	38	62	38	38	31	31	15	15	8	13
Air Quality related	54	54	62	38	54	54	54	15	62	15	54	15	13
Other commercial	67	67	67	11	56	44	44	22	44	22	33	22	9
Strategic planning	86	29	57	57	86	0	29	43	29	0	14	43	7
Short term operations	80	60	80	40	80	20	60	40	60	0	0	0	5
Energy Trading	100	67	100	67	100	67	67	67	67	33	33	33	3
Energy Usage	100	50	50	0	50	50	50	50	50	50	50	50	2
Waste	0	0	0	100	100	0	0	0	0	0	0	0	2
Software Development	100	100	100	50	100	50	50	100	50	100	100	100	2

Percentage use

Lowest — Highest

0	10	20	30	40	50	60	70	80	90	100

3. London data use

Table 5: Sites explicitly identified as current sources of data

Airport sites (mentioned as a group)
Biggin Hill
Botley Hill, Surrey
Bracknell
Bromley stations
EA stations
Gatwick
Heathrow
London Weather Centre[17]
MORECS[18]
Own research sites
St James's Park

In addition respondents also identified additional data that needs to be collected (Table 8 provides a full list). Examples include

- For Heathrow, soil temperature data at additional depths (0.1, 0.3, 1.0 m)
- Indoor air temperatures for health related purposes[19]
- More boundary layer information beyond AMDAR which has limited spatial coverage
- Improved meteorological information both in terms of variables and spatial coverage for a number of air quality related issues

There are mixed opinions about whether sufficient **metadata** are reported about the sites. More information about the surroundings of measurement sites, especially for wind measurements is the clearest specific request (see Recommendation 10). Some groups use online imagery to understand the impact of potential siting issues when they use data.

Recommendation 4:

Develop a procedure to quality control data that are currently available (Figure 1), to enable broader range of sites (e.g. beyond airports) to be more widely used. This would improve the spatial resolution of basic meteorological variables from the rather limited sites that are currently used (Table 5).

Recommendation 5:

As part of LCDP, provide metadata about the networks and sites following the format used by the BADC, IAUC[20], WOW, FluxNet[21] and/or as recommended by Muller et al. (2013)[22] (as appropriate for site type). This needs to be INSPIRE[23] compliant. Ensure sites have more complete metadata, ideally using a common approach so that metadata can be easily compared.

17 London Weather Centre closed in 2010 as the rooftop site had become increasing cluttered.
18 Met Office Rainfall and Evaporation Calculation System (MORECS) nation modelled at 40 km spatial resolution, provides real-time assessments of rainfall, evaporation and soil moisture. Different soil, crops and topography are accounted for. It should be noted that system does not take urban characteristics into account.
19 Smart phones may provide a method of collecting this data (see WeatherSignal.com).
20 http://www.urban-climate.org/resources/the-urban-flux-network/
21 http://fluxnet.ornl.gov/
22 Muller CL, L Chapman, CSB Grimmond, DT Young, X Cai 2013: Towards a standardised metadata protocol for urban meteorological networks BAMS doi: http://dx.doi.org/10.1175/BAMS-D-12-00096
23 http://inspire.jrc.ec.europa.eu/
The European INSPIRE Directive covers 34 spatial data themes that are used in environmental applications. Many of these are directly relevant to the data covered here e.g. coordinate reference systems, transport network, buildings, land use, atmospheric conditions, meteorological geographical features, oceanographic geographical features, elevation, and land cover. Metadata are also explicitly addressed.

3. London data use

For most applications users find the temporal resolution of the data available acceptable. Respondents stated they use data collected at intervals of:

- 1 minute
- 30 minutes
- 60 minutes
- Day/Night
- Daily
- Extremes (i.e. over the duration of the record)

Some respondents indicated they need hourly data but only have access to daily data. Specific requests for temporally higher resolution data include sub-hourly data, notably rainfall. Data at 1, 5, 15 and 30 minutes resolution would be used for applications related to environmental engineering, air quality, extreme event analysis, and model performance evaluation. Such data would better trigger response activities, highlighting the need for data to be available in real time. Air quality consultants stated they too need more variables, faster and at higher spatial resolution.

An important issue for users of standardised data is the length of record. For a wide range of applications, users need long term data (e.g. for energy forecasting, flood probabilities, building related industries, insurance/ reinsurance). The 2010 closure of the London Weather Centre impacted some organisations in terms of modelling (e.g. for energy forecasting, insurance, reinsurance). However, there are companies that provide a synthetic data product for the previous LWC site using data observed elsewhere and numerical modelling techniques (e.g. Speedwell).

Building related organisations (e.g. CIBSE) cite the need for hourly data for periods of 20 years for their industry. They would like such data updated more frequently (e.g. every 5 years). Closure of stations and gaps in the data are problematic. The currently available data (1961-90) are regarded as being too out of date. There are, however, other data sets and methods that have been generated from other groups (e.g. Adaptation and Resilience to a Changing Climate Coordination Network[24] projects, COPSE[25], Prometheus[26]).

Most of the respondents currently use free data or pay for some data (Table 6). Only a small number of respondents pay for all the data they use.

Table 6: Data used for London related work

Total Responses	98
All data used is free	36
Some free/some paid for	35
All data used are paid for	7
No response	20

24 http://www.arcc-cn.org.uk/
25 http://www.arcc-cn.org.uk/project-summaries/completed-projects/copse/
26 http://www.arcc-cn.org.uk/project-summaries/completed-projects/prometheus/

3. London data use

3.2. Methods used to purchase or obtain data

Organisations currently fund the purchases of data through a variety of methods (Table 7). Many note that "data costs are not trivial". Private companies can build these charges into their operating costs by charging clients. One respondent noted that differential pricing (e.g. between universities and private companies) disadvantages SMEs.

3.3. Other groups who could be using weather data in London

Despite a wide range of sectors responding to the survey, a number of other sectors and organisations also use meteorological data (see Appendix 1). These include London's airports and the Port of London; taxi and car clubs; tourist and event venues; retail organisations; and those concerned with security. Future efforts should make sure their needs are identified.

Table 7: Examples of methods used to obtain or finance the purchase of data by organisation type (ordering is alphabetical).

Organisation Type	Method of Funding or Obtaining Data
Borough authorities	General Budget Highway Maintenance Budgets
Greater London Authority	Collaborate with universities (therefore can access data)
Government Agencies	Base funded Clients – Built into costing model Advertising generated revenue
London Fire Brigade	Revenue Budget
Private companies	Base funding Clients- Built into costing model Grants Internal funding with strict business case requirements LAQN (free) R & D budget Advertising generated revenue
Transport for London	Business funded Contract includes cost of use of data (3rd party users) Internal budget
Universities	Free access from BADC Research Councils/Other funding bodies various grants

4. Improvements to London's weather observations

4.1. Respondents' suggestions

Respondents to the survey, both London based and non-London based, made a number of suggestions.

Standard methods between cities
Given many of the companies in London operate internationally, procedures (for measurements and analysis) are needed that are appropriate globally. In this regard, guidance from London could provide leadership at a national and international level.

Metadata (see Recommendation 5)
Respondents indicated that for much of the data currently available, more details are needed specifically on:

- Instrument and siting details[27]. One specific example raised relates to below canopy urban air temperature sensors. These are often located in very low natural ventilation conditions and thus ideally sensors would be within actively ventilated radiation shields. Details on instrument shielding thus are important to understand potential spatial anomalies. Rain gauges like many other meteorological sensors are strongly influenced by height.
- QAQC procedures of data need to be available and clearly stated.
- Site characterization: It is critical that the methods used are consistent across London, and ideally that they are repeatable beyond London. The Stewart and Oke (2012[28]) classes, or Local Climate Zones, provide an initial tool to identify the spatial variability of London. The LCZ were developed to help standardise interpretation internationally of the UHI.

For most applications there is a specified standard of data (e.g. spatial and/or temporal resolution, standard WMO conditions) that are needed. Appropriate metadata[29] allow the user to determine if the observed data or derived data products meet the requirements.

Recommendation 6:

Map Local Climate Zones (LCZ) for London to identify what types of areas (in terms of land cover/use) are well supported by observational infrastructure and what are underrepresented. This should then guide installation of future sites to enhance spatial resolution and also to make it clear to users what type of urban area the data at a particular station are representative of. Spatial mapping using mobile sensors will help finalize locations and assess their representativeness.

Recommendation 7:

Provide guidance on how to interpret metadata on the LCDP and also to identify those who can give guidance on interpretation for a particular application.

27 Robinson (2010) recently completed a detailed survey of a large number of the climate stations located within London which reveal marked differences between networks and sites. See footnote 10 for more details.
28 Stewart, I. D., T. R. Oke, 2012: Local Climate Zones for Urban Temperature Studies. BAMS, 93, 1879–1900. doi: http://dx.doi.org/10.1175/BAMS-D-11-00019.1
29 See also Muller CL, L Chapman, CSB Grimmond, DT Young, X Cai 2013:Towards a standardised metadata protocol for urban meteorological networks BAMS doi: http://dx.doi.org/10.1175/BAMS-D-12-00096

4. Improvements to London's weather observations

Format of data

Many respondents from a wide range of backgrounds highlight the need for data to be in an easily usable format and cite the lack of access to data in a user-friendly format as a limiting factor. Many regard the Met Office data as requiring considerable processing (e.g. gap filling and changes in format) to be usable. Some industries use specific formats already (e.g. building related industries use TRY, DSY data formats) with data are sold in these formats. Others use data in different formats (e.g. NASA Ames, netCDF, GRIB). These have changed through time with technology and ease of data transfer.

Recommendation 8:

Provide information on the LCDP not only about the data format used by the meteorological networks but also (1) software and its availability for converting data between formats; (2) details of companies that provide services for converting data into other formats and who may provide additional products, such as gap-filled data; (3) links to resources on how to convert non-proprietary formats to other commonly used data formats; and (4) references to standard protocols for gap filling data and software, if available.

4.2. Benefits of additional data availability

A number of companies and organisations utilise data from the current observational network to generate new and specialised products (e.g. CIBSE, Met Office, RailMet, Speedwell, Appendix 2). It is very likely that additional commercial products can and will be created by repackaging new data streams, both to improve the current products and for new users and applications (e.g. improved and new mobile phone applications). Appendix 1 provides examples of how some cities used meteorological data. Featured here is the Helsinki Testbed, which highlights some unanticipated benefits that resulted from a greatly enhanced observational network.

Benefits from additional data could be generated through activities such as DataPoint[31] which encourages application developers, or from Hackathons where applications are developed through short intense periods of development. For example the Ordnance Survey in collaboration with a number of organisations runs GeoVation[32] which encourages a wide range of users to develop applications to use their data and to solve problems which may also be considered as business opportunities[33]. One particular realm of interest to London residents would be phone applications. While the LAQN and AirText already have smartphone application for air quality, and the Met Office for weather information, a wealth of other applications could be developed using such an approach.

Respondents to the survey highlighted a broad range of benefits from greater data availability in London (Table 8). These relate to immediate operations and also research to develop improved operations across a wide range of end-user applications.

31 http://www.metoffice.gov.uk/datapoint
32 http://www.geovation.org.uk/ Community needs are addressed by combining geography, entrepreneurs, developers, community groups, and innovators.
33 http://www.geovation.org.uk/resources/environment-powwow/

4. Improvements to London's weather observations

Helsinki Testbed Case Study[30]

FMI and Vaisala established an observational network for both research (which was open for use) and a "quasi-operational program". More than 40 telecommunication masts (40 that are 120 m high and one that is 300 m high) were instrumented at multiple heights. Additionally an operational radio sounder (and occasional supplemental ones), ceilometers, aerosol-particle and trace-gas instrumentation on an urban flux-measurement tower, a wind profiler, and four Doppler weather radars, three of which have dual-polarimetric capability were installed. Development and testing of new observational instruments, systems, and methods (e.g. NASA Global Precipitation Measurement (GPM)) was undertaken. In 2010, the Testbed website had 450,000+ weekly visits and 600+ registered users of historical data records.

One of the applications tested focused on improving weather forecasting by using data assimilation techniques. The Helsinki area was modelled at a 1 km resolution. Using additional funding, there was active development of new application areas for:

- aviation
- dispersion of hazardous substances
- nuclear power safety preparedness
- public transport
- road maintenance
- urban air quality

From two online user surveys (2006, 2008), individuals identified data from the Testbed were used for activities and applications as varied as:

- aviation and flight planning for civil aviation
- barbequing
- bike couriering
- bird migration observations
- building projects
- coating of roofs
- deciding how to go to work or school (e.g., public transport, biking)
- emergency centre work
- estimating the occurrence of overnight frost
- estimating whether there is threat of falling trees during high wind speeds
- fire department work
- fishing
- lawn mowing
- playing sports and planning sporting events
- predicting the spread of forest fire
- radio astronomy
- storm chasing
- teaching – deciding assignments
- timing of farm work
- walking dogs

This example illustrates both intended and unintended benefits. The same would be expected in London with greater investment in observational infrastructure.

30 Koskinen JT and Co-authors, 2011: The Helsinki Testbed: A Mesoscale Measurement, Research, and Service Platform. Bull. Amer. Meteor. Soc., 92, 325–342.

4. Improvements to London's weather observations

Table 8: Benefits identified by survey respondents given greater data availability
Responses are grouped by application.

Flood forecasting and water management

Improved rainfall data would assist with:

- Flood forecasting
- Sizing of pipework for future design

In addition to rainfall, other variables (e.g. radiation, etc) would be beneficial to

- Hydrological modelling
- Modelling to assess impacts to water management to inform operations, real time data

Numerical Weather Prediction (NWP)

Improved weather data horizontally and vertically could result in

- Improved capability to verify forecasts and evaluate modelling systems and parameterisations
- Assessing urban effects, such as
  - UHI effect on the pressure gradient and hence winds surrounding London
  - Improved development and evaluation of Urban Climate Models (UCM)
  - Consideration of large roughness elements (Buildings)
- Potential to improve forecasts through use of **data assimilation**.

Improvements to **NWP** would have positive ramifications for many applications.

- Surface flood forecasting
- Air quality modelling
- Local scale forecasting / scenario testing for climate change projections
- Use of impact models and specifically catastrophe models, expanding beyond insurance into many commercial areas and also into public management of risk

Transport/data assimilation

- Improvement to observational data availability around Heathrow would allow improved understanding of fog behaviour in the vicinity and improve operations

4. Improvements to London's weather observations

Air quality forecasting

- Would benefit from improvements to UCM and NWP
- Improved assessment of linked models (e.g. WRF/CMAQ, ADMS-urban) to identify parameterizations that need improvements
- Improved spatial data resolution would allow improvements to **Nowcasting** products (e.g., http://www.londonair.org.uk/london/asp/nowcast.asp) through improved and increased **data assimilation**.

Improvements to air quality modelling could improve operations related to:

- Health and exposure
- Transport e.g. improved information about air quality hot-spots can be used to adjust transport operations and hence improve air quality

Ecology/ ecosystem services

Improved information about both **phenology**[34] and weather conditions

- Would provide useful information on trends in how species respond to seasonal changes, potential long-term trends of rainfall and drought to inform land management, future conservation planning, impacts of climate on pathogens and pests, etc.
- **Pollen forecasts** are carried out daily[35] for London but given the wide range of species that cause problems for individuals and the different[36] controls on the individual species improving understanding and therefore modelling would have health benefits

Emergency response

With improved real time data

- Emergency response triggers could be improved to sudden changes, e.g. heat or cold extremes and snow, or heavy rain.
- Combined with increased use of GIS would assist risk assessment activities
- Assist incident management

34 With changes in climate there have been documented changes in phenological conditions (e.g. Dragoni et al. 2010) that are enhanced in urban areas (e.g. Zhang et al. 2004).
Dragoni D, C Wayson, H Potter, HP Schmid, CSB Grimmond, JC Randolph 2010: Evidence of increased net ecosystem productivity associated with a longer vegetated season in a deciduous forest in south-central Indiana, USA, Global Change Biology, 17, 886-897 doi:10.1111/j.1365-2486.2010.02281.x
Zhang X, M Friedl, CB Schaaf, AH Strahler, A Schneider 2004: The footprint of urban climates on vegetation phenology, Geophys. Res. Let., 31, L12209, doi:10.1029/2004GL020137.

35 e.g. http://www.airtext.info/

36 http://www.metoffice.gov.uk/health/public/pollen-forecast#calendar

4. Improvements to London's weather observations

Health

With improved spatial data:

- Tie data to spatially referenced health outcomes
- Develop strong policies requiring buildings to be designed to mitigate overheating risk through passive measures as far as possible, reducing cooling demand. If vegetation is shown to reduce UV exposure, it could be used to help reduce the UV exposure as a result of the triple glazing, high albedo reflecting surfaces/paint in the city and surrounds
- Improve alert systems to vulnerable people and the public in general

Building design/energy use/ indoor climate

With improved data availability:

- Improve testing, evaluation of models leading to:
  - Provision of improved design guidance.
  - Greater energy efficiency / cost savings
  - Improved daylighting design in buildings, which would reduce energy consumption
  - Improvements to urban design, retrofit activity and maintenance and management of green spaces within London
- Understand better how changes in internal climate measured at some locations are a function of the external climate.

Policy tools

Improved data:

- Would be used in conjunction with a range of factors and scenarios by decision makers concerned with interlocking impacts e.g. policy makers, planners, any project managers of retrofit/new build, building services, health professionals etc.
- Development of an assessed tool (i.e. using the new data) to quantify impacts of proposed developments on future temperatures and therefore potentially secure a financial contribution towards mitigation measures (e.g. if developing a large hard heat generating building, mitigate impact on urban heat island by securing funding to plant xx street trees).
- Build the evidence base for future changes in our urban climate

4. Improvements to London's weather observations

Unmet needs by sector have also been identified by the recent NRC report[37]

Flood control (municipal and public safety officials)

- Rainfall and snowmelt runoff and storm water datasets
- Urban flooding and/or overloading of combined storm water/sewage systems due to localized precipitation and ability/inability of urban pervious surfaces to store water

Electric power (power producers, grid operators, local utilities)

- Air temperature for assessing energy demands and related loads on the grid
- Wind and solar radiation data for renewable energy assessments

Insurance/reinsurance (company officials)

- Accurate and timely forecasting of extreme events
- Surface roughness, overland decay, and wind speed

Business (company officials, public and private service providers)

- Solar radiation, precipitation, and air quality data for agriculture (e.g. for agricultural regions near and/or impacted by cities)
- Canyon-level wind flow (e.g. for construction sector)

Urban design (architects, urban planners, municipal officials)

- Vegetation stress index for cities/optimization
- Urban air quality
- Assessment of urban heat island mitigation measures such as green roofs and tree planting campaigns
- Development of climate change mitigation and adaptation strategies of cities and regions,
- More dense array of first order meteorological stations in and around urban areas
- Improved methods for assessing the extent to which rural meteorological stations are subject to the impacts of local land use change

Transportation management (officials in departments overseeing highways, railroads, airports, harbours, rivers)

- Canyon-level wind flow
- Precipitation and its form (i.e., rain, freezing rain, sleet or snow)
- Representativeness of surface observations
- High spatial resolution forecasts (e.g. roadway scale)
- Road surface temperatures

37 National Research Council 2012. Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs. Washington, DC: The National Academies Press.

4. Improvements to London's weather observations

Public health (health department officials, environmental protection agency officials, air quality management districts, public safety officials, emergency managers)

- Solar radiation, wind, humidity and air temperature at matching scales for health (e.g., heat indices)
- Consistent UHI baseline datasets for vulnerability/risk assessments (standardised methods and data)
- Spatially explicit datasets that characterize the UHI (i.e., further than just surface air temperature measurements; surface skin temperature, air temperature, humidity, wind and radiation data may provide a more comprehensive assessment of "heat")
- Heat and cold wave and physical stress forecasts with temporal and spatial resolution at city scale
- Street-level air quality
- Extreme precipitation event forecasts
- Extreme localized heat/cold advisories, disease vector, and air quality advisories

Security (public safety and security officials)

- Higher temporal, vertical, and horizontal spatial resolution data (e.g. urban boundary layer structure and mixing layer heights, vertical profiles of winds, turbulence, temperature of particular importance to dispersion applications)
- Dual-use leveraging of data from other applications (e.g., radar-derived precipitation calibrated with rain-gauge data for flood predictions)
- Regularly updated urban data (e.g. land-use characteristics, building footprint data)

Emergency response (public and industrial safety officials)

- Street-level detailed flood information
- High spatial and temporal resolution wind, temperature, and moisture data in and above the urban canopy

4. Improvements to London's weather observations

4.3. New data needs

While a large number of individuals (representing a wide range of organisations) identified potential improvements to the observational network in London, there is a general consensus on where improvements should be made.

Not unexpectedly, improvement in **spatial resolution** is of great interest to the broadest number of people given the current coarse availability of data from Met Office stations. This has both horizontal and vertical dimensions. The horizontal spatial scale requested is at about 5 km across the Greater London area, with high density networks that capture the variation of land use change/urban morphology over short distances/ at the local neighbourhood scale. This higher horizontal spatial resolution needs to be related to the surface characteristics. Thus as already recommended (Recommendation 6) mapping urban characteristics at this scale across London would be a critical first step to ensure appropriate spatial representativeness.

The desire and the need to know about the variability across Boroughs and between neighbourhoods comes up repeatedly. Many indicate that having data presented in a mapped format would be useful. This is done in Seattle, Shanghai and in London for air quality (KCL/LAQN) for air temperature (LondonClimate.info) and Birmingham plans to do so. Ideally such presentations would have Borough borders also shown.

Recommendation 9:

Given many users want to use meteorological data in conjunction with other spatial data, provide links on the LCDP to other relevant spatial data (e.g. London Data Portal, UK-EOF) (that is INSPIRE compliant).

Recommendation 10:

Use maps to show availability of data, with links to metadata (e.g. QAQC status, height or sensor, scale of measurement etc), so proximity to areas of interest can be determined easily.

Generally the request for the improved horizontal spatial resolution is for hourly data of temperature, humidity, solar radiation, wind, and cloud cover. Sub-hourly (e.g. 30 s) data of solar radiation/ illuminance and cloud cover at this scale is also requested by designers. Other requests include high resolution radar data (sub km scale) to improve the monitoring of summer thunderstorm activity.

Improved spatial resolution of wind speeds, for example near the River Thames, is needed for a wide range of applications. At the moment there is extremely limited good quality wind data across London. Similarly, there is a need for both more and better quality precipitation data (e.g. one respondent stated the "St James's Park site, the site replacing LWC, gets blocked with leaves in autumn"). Improved precipitation data would be very beneficial to flood forecasting within London i.e. to inform localised flooding.

Recommendation 11:

Once an improved QAQC spatial data set is available, and evaluation made of the urban characteristics (e.g. LCZ map) represented, identify where new stations are needed to enhance both spatial resolution but more so the representativeness of the areas observed. These new stations are most likely to be needed for wind and precipitation.

4. Improvements to London's weather observations

Recommendation 12:

Encourage those involved in data collection to improve the quality of currently collected data (e.g. ensuring leaves do not block rain gauges) wherever possible. This could be facilitated by cross network QAQC processes with an email to site operators when problems are identified. Automated systems allow these to be picked up rapidly, e.g. LondonClimate.info has a system that operates continuously looking for missing data or outliers and emails are generated when a problem is identifed.

Weather data needs to be collected over long time periods (multi-year) so that the nature of anomalies and thresholds can be determined for applications with a focus on climate adaptation. As Boroughs need to make many of these decisions "the granularity required to inform adaptation decisions (at and within the Borough) is [currently] a limiting factor". The need for new sites to be "long term and reliable" is critical to a number of potential applications (e.g. design and risk related) as more information about extreme weather zevent return periods is needed.

Recommendation 13:

Where possible try to ensure continuity of stations so that the longer term statistical characteristics can be determined. In order to try to ensure continuity of stations, the LCCP should facilitate/encourage dialogue between network operators and land owning authorities with a vested interest in long term observations. Where station changes or closures are unavoidable, wherever possible the GCOS Climate Monitoring Principles should be followed. GCOS Climate Monitoring Principles.

Improved **vertical spatial resolution** is of interest for numerous applications (e.g. meteorological and air quality forecasting, building design). This needs to supplement traditional below canopy observations and to be representative of the neighbourhood scale (i.e. above canopy at the blending height) and then at a series of higher levels as could be obtained from wind profilers. Although AMDAR data are available this is not regarded as being sufficient to meet the current needs. The BT Tower (see Appendix 8) could provide such a location for data collection if it is maintained.

Recommendation 14:

Enhance the collection of vertical meteorological information. This would be extremely beneficial for weather and air quality forecasting. One site that could be used to provide this infrastructure is the BT Tower (Appendix 8). This would require ongoing support to ensure data quality and an agreement with BT for access. This would also allow for a wide range of research. Potential funders include: NERC, EPSRC, Met Office, Defra and private companies.

There is also a need for data within buildings; e.g. indoor air temperature would allow assessment of actual human exposure to heat/cold. Similar to new devices already built into cars, new sensors are being installed in buildings that may be able to gather data that are useful for health and energy operations and planning purposes. Integrating these new devices could permit developments of a system able to respond to site specific nowcast and forecasts (e.g. adjust shading, use of nocturnal heating) which would improve energy efficiency and make a more comfortable work/living environment. These could aid meeting government energy and carbon targets.

4. Improvements to London's weather observations

Table 9 summarises requests for new observations, both in real time and for long term analyses. Data requested are for variable periods ranging from morning/afternoon/night-time to daily, weekly, monthly, seasonally and annual averages, maxima and minima.

Table 9: Summary of new observations requested by respondents to the survey

Temperature and humidity

- Air temperatures measured with actively ventilated shields

Precipitation and cloud cover

- Radar rainfall at < 100 m resolution
- Cloud cover
- Precipitation
- Freezing level
- Snow
- Polarised rainfall RADAR (to identify precipitation type)
- Ground based water vapour imagery

Wind and pressure

- Wind speed (including peak gusts)
- Wind direction
- Wind shear
- Air pressure on a smaller scale than currently recorded (e.g. to understand impacts on building during storms, thermally driven winds)

Vertical structure

- Vertical structure of the boundary layer
- Wind speed profiles – better coverage than AMDAR
- Boundary layer height
- Turbulence variables

Air quality

- PM1/PM2.5
- Data to run ADMS and Aermod dispersion models
- Increasing demand for neighbourhood scale measurements of pollutants alongside atmospheric turbulence.
- Combine meteorological and air quality observations across London to form an observatory or testbed e.g. Helsinki

4. Improvements to London's weather observations

Soil moisture[38]

Radiation

- Long-wave radiation
- Solar radiation real time

Surface-layer turbulent fluxes

- Any available resolution, for timescales of order of days or longer
- Neighbourhood scale energy balance
- Observations above building height in central London
- Energy and water balance flux measurements co-located with pollutant super-sites
- Turbulence variables

Specific areas

- Impact of UHI on peak summer temperatures
- Impact of green roofs/urban greening/vegetation/ large developments on temperature, humidity, pollution and UV levels.
- Impact of concreting over/decking over/putting astroturf over the remaining gardens/ permeable green space in London

Oceanographic, hydrological, river flow

- Water height above elevation for storm surge
- Sea surface temperature

Morphology

- Surface canopy parameters from DEM and lidar

Techniques

- More satellite based measurements and other remote sensing data
- Mobile data that can cover large geographical areas and give information about variations in climate and other relevant variables to society

38 Important for example, subsidence, heave, tunnelling, and thus for insurance and construction industries.

4. Improvements to London's weather observations

For some sectors suggestions were made that sensors be located at specific types of sites. For example, in the **health** sector, care homes where the residents may be particularly vulnerable to temperature extremes. Some private care homes in London monitor indoor air temperatures to ensure a comfortable living environment for their residents.

The **building design** sector use standardised data (e.g. from CIBSE, ASHRAE). Currently the whole of the UK is represented by 14 sites. Based on RCUK funded research other alternatives have been developed, in particular for future weather files (e.g. Prometheus). The CIBSE data are regarded as "useful but expensive" so this may enhance the use of the free-to-use versions of data.

Recommendation 15:

Include in the LCDP a central repository of links to research papers and reports published on London meteorological and air quality data.

4.4. New approaches

New and novel techniques offer special opportunities for London. In some cases London is leading in their application and in other cases these are being used elsewhere and London could replicate or learn from those experiences.

4.4.1. Remote sensing

A number of techniques for looking "up from the surface" to the atmosphere (e.g. different forms of LiDAR), across the atmosphere (e.g. scintillometry), or down through the atmosphere to the surface (e.g. satellite mounted sensors) exist. A major constraint to carrying out many measurements is the immense siting restrictions encountered in a dense urban environment. However, relatively new technologies (e.g. Doppler LiDAR, Ceilometer) would provide the variables that many users indicate they require. Depending on the wavelength used, different information can be obtained, such as wind, turbulence and aerosol backscatter. From some of the sensors boundary layer height can be determined.

Recommendation 16:

Develop a coordinated network between institutions to identify which technologies should be tested to facilitate operations and move from research infrastructure to on-going operations.

4.4.2. Enhanced spatial information

A wide range of new technologies allow the collection of enhanced spatial information. These include the use of **wireless sensors** to measure air quality. For example, Envirowatch[39] (established from the EPSRC[40] funding into wireless technology) have developed sensors now being installed by them and other firms[41] to monitor air quality in association with road based transportation. Recently sensors have been installed by Liverpool Council (70), Stockport (30) and by Medway Council (120). These sensors are predominately installed on lampposts along roadways.

Similarly the SNAQ[42] project built on the same EPSRC funded MESSAGE project. A high density air quality sensor network has been deployed both in and around London's

39 Envirowatch: http://www.envirowatch.ltd.uk/e-mote.html?start=2
40 Company established from the EPSRC funded MESSAGE project http://bioinf.ncl.ac.uk/message/
41 http://www.tdcsystems.co.uk/solutions/air-quality-monitoring/air-quality-monitoring
42 http://www.snaq.org/ Mark Hayes & Rod Jones (Cambridge University),NERC funded (Jan 2011– Dec 2013)

4. Improvements to London's weather observations

Heathrow Airport using low cost sensors to monitor gases and particulates (NO, NO_2, CO, CO_2, SO_2, O_3, VOCs). This project has involved collaboration between a number of national and local agencies (DfT, BAA, BA, OMEGA and London Boroughs adjacent to Heathrow Airport) and is funded by NERC.

The EU funded project MobiRoma[43] has been exploring the use of **sensors in vehicles** to determine road conditions. The data gathered include: ABS, STC, outdoor air temperature, and outdoor pressure, and fog using the vehicle sensors with the goal of determining road slipperiness. Information from mobile and fixed measuring stations are combined to achieve better temporal and spatial coverage. In Sweden the vehicle fleet used are postal vehicles. A number of new sensors are being developed to allow **smart phones**[44,45] to collect data.

Recommendation 17:

Include data from new technologies in the LCDP and QAQC data products. Following gap analyses (Recommendation 6), consider investing in combining new technologies (e.g. wireless sensors, vehicle interrogated sensors from standard vehicle fleets – or other mobile sources – such as mobile smart phones and/or vehicles more generally) with more standard sensors and smart computing to provide high spatial resolution information near the surface with sufficient redundancy that real-time QA/QC could be performed to provide a reliable product in close to real-time. Subsequent re-analysis could provide a further higher quality product for a wide range of variables.

43 http://mobiroma.eu/ ; http://mobiroma.eu/Map.aspx Groups involved: Klimator, Semicon
44 http://www.sensorcon.com/sensordrone/
45 http://weathersignal.com

4. Improvements to London's weather observations

Birmingham Case Study

In Birmingham, with RUCK funding[46] an environmental networks of sensors is being designed as part of the Hi-Temp[47] project, a stratified sampling approach is being used to deploy three densities of sensors:

Network 1 (coarse array):
30 AWS sited primarily in schools
(average spacing of 3 km)

Network 2 (wide array):
100 air temperature sensors located in schools (one in every medium super output area (MSOA), or areas containing a population of 7,200)

Network 3 (fine array):
100 air temperature sensors located on lampposts on infrastructure corridors and in the CBD.

The aim is to deploy an air temperature and weather station sensor network using existing infrastructure. This project, which is currently at the stage of installing the sensors, has the potential to provide useful insight for London about density of sensors. Hi-Temp intends to have near real time (hourly) air temperature available via an online GIS system. The complete data stream will consist of temperature, precipitation, relative humidity, wind speed and direction, pressure, and solar radiation.

The above networks are using new technologies to establish fixed networks for the periods of the funded research. Other alternatives use new sensor technologies mounted on mobile platforms. The EPSRC funded MESSAGE project deployed sensors on buses to collect data along their routes. This, however, is no longer operational.

Shanghai Case Study

Shanghai[48] has undertaken continuous meteorological observations since 1872 at the Zikawei Observatory. Through this 140 year period, new instruments and/or new observation technologies have been added including routine meteorological balloon soundings in 1931; radar in 1959 (a Marconi Radar SNW-51); a new doplar radar (WSR-88D) in 1997; a LAP-3000 Wind profiler in 1999; a mobile X-band dual polarimetric radar in 2007; and mobile satellite communication; and in 2008 a MPL4 Lidar. These instruments have provided insights into vertical and spatial aspects of atmospheric conditions.

46 NERC funded Hi-Temp (Lee Chapman, Xiaoming Cai Univ. of Birmingham; Sue Grimmond King's College London)
47 http://www.birmingham.ac.uk/schools/gees/centres/bucl/hitemp/index.aspx
48 Source for this material Tan JG, Tang X et al. (in preparation) Urban Integrated Meteorological Observation—practice and experience in Shanghai Megacity.

4. Improvements to London's weather observations

Shanghai Case Study *(cont)*

In 1958 a network of stationswere established with each of the 10 counties of Shanghai (about 120 km by 120 km) having weather stations installed. An intentionally urban meteorological observation network was established in the 1970's – early 80's with 10+ monitoring sites to investigate urban effects (Zhou, 1990[49]).

From 2000, there has been widespread use of AWS, increased radio soundings, ceilometer and precipitation gauges. Today the combined networks of instruments (AWS, Met-towers, wind profilers, lightning mapping system, remote sensing systems etc) form a dense urban observation network covering the whole of Shanghai and nearby seashores with 14 types of system or instrumentation deployment types (see table below). The urban integrated observation network aims to provide measurements of all the processes that influence the urban regional environment across temporal and spatial scales; including physical and chemistry characteristics, in the boundary layer and above.

Weather station, observation sites and observation capacities in Shanghai

	Number	Frequency
First-order observatory	1	60 min
Second-order observatory	9	60 min
Automatic weather stations	+250	1 min
Weather radar (S band)	2	6 min
Mobile X-band radar	1	
Wind profiler	10	30 min
Instrumented met-towers	13	1 min
L-band radiosonde	1	6 h
Microwave radiometer	1	
Lightning positioning system	7	1 s
GPS/MET	31	30 min
Atmospheric component stations	10	1 min
Mobile AWS, sodar, AWS, Ceilometer, etc	5	
Remote sensing capacity		NOAA,FY, TM, MODIS, etc.

49 Zhou SZ 1990. Five islands effects of Shanghai urban climate, Science in China (series B), 33(1): 67-78.

4. Improvements to London's weather observations

Shanghai Case Study *(cont)*

Surface weather stations are distributed across Shanghai, with observation at 1 s for wind direction and wind speed, and temperature, humidity and pressure. The 10 wind profiles provide more detailed information about the boundary layer wind field and mixing layer. Instrumented broadcasting masts (13) provide wind and temperature data at 10, 30, 50, 70, and 100 m.

The four foci for the Shanghai urban integrated observation network are: high impact weather observation, urban environment and micro-meteorological observation, special observation for end-users, and data acquisition, integration and assimilation system. As Shanghai is located in a subtropical monsoon area, the main high impact weather experienced includes typhoons, heavy storms, thunder and lightning, fog, haze, heat wave, and storm surges etc. These occur when conditions are changing rapidly associated with low pressure systems (e.g., severe convective weather) and periods when conditions are more stagnant (e.g., fog and haze).

The Shanghai urban weather-sensitive applications include: flood control, urban design, public health (pollen, radiation, heat stress, air quality), energy production and transmission, transportation management, security and emergency response, port and transport operations, urban agriculture, biometeorological, and construction. The user-driven observations allow for tailored, information-rich products and services to be developed.

The integrated system is: multi-purpose (forecast, research, service, etc), multi-function (high impact weather, urban environment and special end users); multi-scale (macro/meso-scale, urban scale, neighbourhood scale, street canyon, building and indoor), multi-variable (thermal, dynamic, chemical, bio-meteorological, ecological, etc), and multi-platform (radar, wind profiler, photo, ground-based, aero-borne, satellite based, in-situ observation or sampling, etc). The observation networks are linked with a data management system to facilitate exchange of data and information. Moving forward Shanghai Meteorological Service aims to:

- improve coordination between strategies and instruments
- identify observing gaps based on science-and-user-driven requirements
- intelligently combine observations from a variety of platforms by using a data assimilation system that is tuned to produce the best estimate of the current state of the urban atmosphere.

4. Improvements to London's weather observations

4.5. Continuity of sites and data streams

Because of the vagaries of funding many data streams are not continuous. This impacts both research funded sites (e.g. BRE temperature network, LUCID network, Lottery funded OPAL project, NERC funded ClearfLo, NERC Birmingham Hi-Temp sites) and out-sourced or contracted sites (e.g. some Borough's air quality sites).

In addition, for contracted data collection, such as various measures of air quality, not all groups provide their data online to a central data portal (e.g. LAQN). Thus when there is a change in contractor there is a loss of data continuity and/or availability.

Numerous sites have been impacted because of changes in ownership of the property (e.g. Westminster City Council), renovations of properties (e.g. Roof work at London Weather Centre, Guy's Hospital, Dartrey Tower).

Recommendation 18:

Encourage individual data collection groups and funders to provide regular and on-going updated information about data availability to LCDP. Have the host of the data portal undertake a routine 3-6 monthly check that all links are working and follow up with organisations regularly so that there is an expectation that information on site or data changes is kept up to date and with changing personnel information is not lost. Actively monitor and evaluate new technologies and opportunities to improve the spatial and temporal data provided through the LCDP.

5. Concluding comments

A number of cities in the UK (including London) and around the world are undertaking interesting and relevant weather observations. There is a large demand within London, by a broad range of users, for improved weather and climate data. This community is diverse and interested in a wide range of applications.

For more than two centuries London has led the world in terms of the observations of urban weather. It has been at the cutting edge of developments in terms of siting, technologies and research agendas. Today it remains a hub of leading research and practice however, uneven funding and discontinuities means records and current information are not as complete as they should be.

Having a community of users is clearly important. Their knowledge and interests should be harnessed to guide future investments and to maximise collective value. Such a community could be sustained online, through the proposed data portal, via a bespoke LinkedIn group, and through regular meetings.

The recommendations made in the text can be grouped into the following (see Appendix 9 for complete list):

Recommendation for a London Climate Data Portal (LCDP)

Create and maintain a website with key information on what weather related data are collected for London by whom, both currently and in the past. The LCDP should include (either directly or as links):

- Searchable map and database of locations where data are collected with links to site metadata (e.g. QAQC status, height of sensor, scale of measurement etc.)
- Data (from publicly-funded agencies that are required to collect data and other groups who will provide it; data with restrictions or embargoes with information on when it will be released)
- Determine the "shelf life" of the current commercial data. If these observations currently are not publicly available, explore if they could be released after an embargo period.
- Guidance on how to interpret metadata and identify providers who can give guidance for a particular application.
- Links to research papers and reports published on London meteorological and air quality data
- Information about the data formats used by the meteorological networks, plus (1) software and its availability to convert data between formats; (2) details of companies that provide services to convert data into other formats and who may provide additional products (e.g. gap-filled data); (3) links to resources on how to convert non-proprietary formats to other commonly used data formats; and (4) references to standard protocols for gap filling data and software, if available.
- Links to other relevant spatial data
- Guidance of what types of areas data sites are representative of (e.g. maps of Local Climate Zones)

The LCDP should:

- Be INSPIRE compliant
- Make use of available web sites and portals where possible (e.g. London Datastore data.London.gov.uk; BADC http://badc.nerc.ac.uk/home/; UK-EOF http://www.ukeof.org.uk/)
- Be kept current. The host of the data portal should undertake routine (e.g. 3-6 monthly) checks that all links are working and follow up with organisations regularly so that there is an expectation that information on site or data changes are kept up to date and not lost with changing personnel.

5. Concluding comments

This will need an ongoing commitment of resources (Appendix 7).

Recommendation to improve quality of currently collected data

- Develop protocols and procedures to quality control the data that are currently available (as identified by LCDP)
- Encourage data collectors to improve the quality of currently collected data (e.g. ensuring leaves do not block rain gauges) wherever possible. This could be facilitated by cross network QAQC process (e.g. email site operators when problems are identified). Automated systems allow these to be picked up rapidly (e.g. LondonClimate.info has a system that operates continuously looking for missing data or outliers with emails sent when a problem is identified).

Recommendation to evaluate data gaps:

- Map Local Climate Zones (LCZ) for London to identify the types of areas (in terms of land cover/use) that are well supported by observational infrastructure (using LCDP) and those that are underrepresented. This should guide installation of future sites to enhance spatial resolution and provide guidance to users about what type of urban area the data at a particular station are representative of. Maps and site guidance should be added to the LCDP.
- Once improved QAQC spatial data sets are available, and evaluation made of the urban characteristics (e.g. LCZ map) represented, identify where new stations are needed to enhance both spatial resolution and representativeness of the areas observed. These are most likely to be needed for measurements of wind and precipitation.

Recommendation to ensure continuity of stations

- Where possible try to ensure continuity of stations so that the longer term statistical characteristics, critical for many applications, can be determined. In order to try to ensure continuity of stations, the LCCP should facilitate/encourage dialogue between network operators and land owning authorities with a vested interest in long term observations.

Recommendations for new observations:

- Enhance the collection of vertical meteorological information - this would be extremely beneficial to weather and air quality forecasting. One site that could be used to provide this infrastructure is the BT Tower (Appendix 8). This would require ongoing funding support to ensure data quality and an agreement with BT for access. This would also allow for a wide range of research.
- Include data from new technologies in the LCDP and QAQC data products
- Following gap analyses, invest in combining new technologies (e.g. wireless sensors, vehicle interrogated sensors from standard vehicle fleets or in the future other mobile sources such as smart phones and/or vehicles more generally) with more standard sensors and smart computing to provide high spatial resolution information near the surface with sufficient redundancy that real-time QA/QC could be performed to provide a reliable product in close to real- time. Subsequent re-analysis could generate further higher quality products a wide range of variables.

5. Concluding comments

- Develop a coordinated network between institutions to identify which technologies should be tested to facilitate operations and move from research infrastructure to on-going operations.
- Actively monitor and evaluate new technologies and opportunities to improve the spatial and temporal data provided on the LCDP.

Numerous economic and environmental benefits could result from improving the availability of weather and climate data in London. For example, sustainable buildings could be better designed for the microclimates they are located in, with implications for new builds, retrofits and energy /carbon consumption more broadly. Small thermal gradients influence passive cooling; if the urban heat island is not appropriately taken into account, such systems will not be correctly designed. Data at greater temporal and spatial resolution available in real time will help to improve models to predict weather, air quality, and flooding. This would enhance responses and allocation of resources, with implications for health protection of vulnerable people, emergency response, energy usage, transport operations etc.

By creating a resource for end-users in London, experience in other cities internationally suggests new applications will follow with additional economic benefits. Building on a tradition of leading studies and applications of urban climate, from the work of Luke Howard almost 200 years ago, understanding the impact of urban areas on local weather and climate is instrumental to helping London thrive.

Appendix 1: Example of users

Examples of some common urban applications of atmospheric information and their respective user groups, with a subjective assessment of data requirements (based on Dabberdt, 2012[50]).

KEY:

Atmospheric Data:

AQ = pollution concentrations
CC = cloud coverI = icing
L = lightning
pp = precipitation

T = temperature
U = humidity
V = wind
VSBY = visibility.

Forecast Period:

NC (nowcast) = ≤ 2h
Sh = 2-12h
Md = 12-48h
Ln = >48h.

Characteristic data requirements					
Application Type	**End User Group**	**Atmospheric Data**	**Spatial Resolution**	**Temporal Resolution**	**Forecast Period**
Electric power	Power producers Grid operators Local utilities	T, L, CC I T, pp, V	City Neighbourhood Neighbourhood	≤1 - ≤1	NC, Sh, Md, Ln - NC, Sh, Md, Ln
Building systems management	Building managers	T, L	Block	1-3	Sh, Md
Transportation management	Highway departments Railroads Airports Harbour/River masters	T, I , pp, V, VSBY T, I , pp, V, VSBY T, I , pp, V, VSBY, CC T, I , pp, V,VSB, Y	Neighbourhood City Neighbourhood Neighbourhood	≤1 ≤1, 1-3 ≤1 ≤1, 1-3	Sh, Md Sh, Md NC, Sh, Md, Ln, NC, Sh, Md
Public health and safety	Health departments and emergency managers	T, U, pp, L, V, CC	Neighbourhood	≤1	Md
Air quality	Air quality management Public safety officials	AQ,T, U	Block, Neighbourhood	1-3	Md
Emergency response	Public and industrial safety officials	T, U, pp, V, AQ	Block, Neighbourhood	≤1	NC, Sh
Flood control **Insurance**	Municipal officials Company officials	pp, T pp, T, I ,L, V	Block, Neighbourhood Block, Neighbourhood	1-3 ≤1	NC, Sh Md, Ln
Retail sales Management	Company officials	pp, T	Neighbourhood, City	>3	Ln

50 Dabberdt, W 2012: Users, Applications and Needs – Appendix A. In Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs, National Academies of Science, USA.

Appendix 1: Example of Users

Research	Basic and applied researchers	VSBY, CC	Block, Neighbourhood,	≤1, 1-3,	NC, Sh, Md, Ln City >3
Urban planning	Municipal officials	T, U, V, AQ	Neighbourhood	1-3	>3 (climate averages & extremes)
Tourism	Public visitor bureaus and private service providers	T, U, V,pp, L, AQ, VSBY, CC	City	1-3	Md
Personal Decision Support	General public (local)	T, U, V, pp, I , L, AQ, VSBY, CC	Neighbourhood	1-3	Sh, Md, Ln

Appendix 2: Organisations that provide data

The following is basic information on organisations that provide weather and climate information for London or the vicinity (listed by organisation in alphabetical order). Information of this type with links and search capability would provide a good starting point for the proposed. For some of these examples, maps available on their sites are provided in Appendix 3.

Name	**Association of British Insurers**
Country of Origin	UK
Organisation Type	Member Organization
Description	Represents general insurance, investment & long-term savings industry. Formed 1985. 300+ members. Accounts for 90% of UK premiums

Name	**AccuWeather**
Country of Origin	USA
Organisation Type	Routine Professional
Description	Private weather forecasting company
Costs to User	Free with adverts general weather forecast. Commercial subscription services available
Current data	Multiple sites
Meta data	None visible
Historical data	Available
Forecast	Weather forecast: Hourly, daily, weekly, monthly
Radar feed	Radar feed
Satellite feed	NASA

Name	**ACTUAL**
Country of Origin	UK
Organisation Type	Research
Description	EPSRC funded. Lead: Janet Barlow (Univ. Reading). Monitor & simulate urban climate from city to building scale. Integrate results directly into engineering & policy areas which transform urban infrastructure.
Costs to User	Free
Current data	BT Tower, Westminster City Council
Meta data	Site description and map provided; Publications listed
Historical data	Graphical form; By contact with group, numerical data available

Name	**AIR-Worldwide**
Country of Origin	USA, London office
Organisation Type	Routine Professional
Description	Company: risk modelling software & consulting services. Founded: 1987. Model risk for natural catastrophes & terrorism internationally; Provides services to insurance, reinsurance, financial, corporate, & government, insurance-linked securities. Includes detailed site-specific wind, etc. Publish research peer reviewed papers relevant to urban areas
Costs to User	No products visible publicly
Current data	Nothing visible
Historical data	None visible

Appendix 2: Organisations that provide data

Name	AirText
Country of Origin	UK
Organisation Type	Routine Professional
Description	Air quality, UV, grass pollen & maximum & minimum temperature forecasts for today, tomorrow & the day after.
Costs to User	Free
Historical data	None visible
Specialist forecasts	Each borough Air quality forecast; Nowcast

Name	Astrium
Additional site	London pilot project
Country of Origin	France
Organisation Type	Routine Professional
Data Type	Air Quality
Description	Multi-national company. Focus: Space related products. Took CO_2 measurements in London 2012 (with NPL)
Costs to User	Commercial subscription services available
Current data	Nothing visible
Meta data	Some details provided
Historical data	Not freely available

Name	BADC
Country of Origin	UK
Data Type	Climate data,
Description	MIDAS, MetDB datasets
Costs to User	No costs for certain users
Current data	Nothing visible
Data collected by	Others
Historical data	Wide range of data available from research groups, project, Met Office and other agencies
Satellite feed	Satellite feed

Name	BBC
Country of Origin	UK
Organisation Type	Routine Professional
Description	National broadcasting organisation
Costs to User	Free
Current data	Multiple sites; need to specify location – not shown on map e.g. LCA
Data collected by	Met Office data feed e.g. London Heathrow
Historical data	Average conditions (period from not specified); Source: http://www.helicon.co.uk/
Forecast	Weather forecast Hourly/daily. Source: Met Office
Radar feed	Radar feed
Satellite feed	Satellite feed

Appendix 2: Organisations that provide data

Name	**Centre for Pervasive Sensing, Imperial College London**
Country of Origin	UK
Organisation Type	Research
Description	Number of projects: involve data collection in London using new sensors
Current data	Nothing visible
Historical data	None visible

Name	**CIBSE**
Country of Origin	UK
Data Type	Climate data
Description	Chartered Institution of Building Services Engineers. Professional body
Costs to User	Fee per site
Current data	Nothing visible
Meta data	Not freely available; Number of reports for purchase
Historical data	Available

Name	**ClearfLo Clean Air for London**
Country of Origin	UK
Organisation Type	Research
Description	NERC funded. Univ. Reading (lead Stephen Belcher), Manchester, King's College London, Birmingham, York, Leeds, Hertfordshire, East Anglia, Leicester, CEH –Edinburgh, NCAS. Air pollution & meteorological measurements to investigate boundary layer pollution across London.
Costs to User	Free
Current data	Multiple sites
Data collected by	All current data available from other websites
Meta data	Available via BADC or other websites
Historical data	Available via BADC or other websites

Name	**COPSE Coincident probabilistic climate change weather data for a sustainable built environment project**
Country of Origin	UK
Data Type	Climate data
Description	EPSRC funded Univ. Manchester (Lead Geoff Levermore). Methodology to derive weather data for building designers based on UKCP09;
Costs to User	Free
Meta data	Report (pdf), Code used for development available
Historical data	Available
Climate Forecast	Available via geoff.levermore@manchester.ac.uk

Name	**DataPoint**
Country of Origin	UK
Organisation Type	Routine Professional
Description	Met Office data feeds. Format suitable for application developers
Costs to User	After registering
Current data	Multiple sites
Historical data	Variety of products

Appendix 2: Organisations that provide data

Name	**DECC**
Country of Origin	UK
Data Type	Climate data
Description	Government department. Responsible: securing, clean, affordable energy supplies & promoting international action to mitigate climate change.
Costs to User	Free
Current data	Nothing visible
Historical data	Average for UK rather than by site, LHR
Climate Forecast	Climate Forecast

Name	**Defra**
Additional site	Climate Projections
Country of Origin	UK
Data Type	Climate data, Air Quality
Description	Government department. Responsible: policy & regulations on environmental, food & rural issues
Costs to User	Free
Current data	Air Quality data; 25 km grid resolution
Meta data	Sites operated by KCL ERG, Riccardo-AEA, NPL, Bureau Verita; Map, photos, variables measured, station type, network, site operators. Description etc. start date (and end date it applicable); About to publish a report on WRF performance and meteorological measurements ; Procedures for calculation and guidance for user provided on website
Historical data	National Atmospheric Emissions Inventory
Specialist forecasts	CMAQ using for air quality forecast; Model runs every 3 h for 48 h forecast for 10 km resolution;
Climate Forecast	Precipitation, Cloud and surface conditions); UK Climate Projections (UKCP09)
Forecast	Weather forecast: WRF used for meteorological modelling

Name	**EDF Trading**
Country of Origin	France
Organisation Type	Routine Professional
Description	Energy Company
Current data	Nothing visible; Croydon
Meta data	Not freely available
Historical data	Not freely available

Name	**EnergyPlus**
Country of Origin	USA
Data Type	Climate data
Description	US Dept. of Energy
Costs to User	Free
Current data	N
Meta data	Available, web
Historical data	Yes, London Gatwick

Appendix 2: Organisations that provide data

Name	**Environment Agency**
Country of Origin	UK
Data Type	Climate data
Description	Executive non-departmental public body. Responsible to Secretary of State for Environment, Food & Rural. Protects & improve the environment, & promote sustainable development; Flooding
Costs to User	Charges may be levied dependent on the purpose for which the data are required.
Current data	Not on web
Meta data	Rain gauges: generally at ground level, usually tipping bucket rain gauges with an independent check gauge at the same location. Some gauges, but not all, would meet Met Office standards; some are not ideally placed (e.g. with regards to proximity to large trees). EA Flood Estimation Guidelines for purchase.
Historical data	Rain gauge information is available by request from Data.info@environment-agency.gov.uk.
Available	River level information
Specialist forecasts	Flood Forecast

Name	**EQECat**
Country of Origin	USA, London Office
Organisation Type	Routine Professional
Description	Catastrophe risk modelling. Products & services to global property & casualty insurance, reinsurance & financial markets. Founded 1994. Subsidiary of ABSG consulting Inc.
Costs to User	Commercial subscription services available
Meta data	Reports after hazard events on line; descriptions of services

Name	**Lambeth Meters**
Country of Origin	UK
Organisation Type	Routine Professional
Description	Commercial property agent, facilities manager, energy efficiency consultant, energy meter specialist
Costs to User	Free with adverts
Current data	Brixton
Meta data	Photo of instrument/site
Historical data	None visible
Forecast	Weather forecast

Name	**London Air Quaility Network (LAQN) (KCL ERG)**
Country of Origin	UK
Organisation Type	Routine Research/Professional
Data Type	Air Quality
Description	Air quality & meteorological data collected. Multiple boroughs across London. Undertaken on behalf of boroughs
Costs to User	Free
Current data	Multiple sites
Meta data	Address, Map, Site photos, Grid Ref, Latitude & Longitude, Classification, QA/QC, Monitoring Dates, Distance to Road, Sampling Height, Species Monitored;
Historical data	Available
Specialist forecasts	Air quality forecast; NowCast

Appendix 2: Organisations that provide data

Name	**London Borough of Bromley**
Country of Origin	UK
Organisation Type	Routine Professional
Description	London local government; Used for road maintenance with Met Office Road Forecast product
Current data	Nothing visible; Bromley
Meta data	Not available on web
Historical data	None visible

Name	**London Grid for Learning**
Country of Origin	UK
Organisation Type	Routine Schools
Description	Network of stations: OPAL (lead Linda Davies, Imperial College London). Web: company Atomwide (Established:1987 for IT/network support to schools).
Costs to User	Current conditions; Historic data distributions available at no cost, can be purchased from Atomwide
Current data	Originally one site in every borough. Available via a number of different graphical viewing options
Meta data	Visible, available
Historical data	Available

Name	**London Urban Micrometeorology Archive (LUMA)**
Country of Origin	UK
Organisation Type	Research
Description	Urban micrometeorological research. Funded: EUf7 BRIDGE, NERC ClearfLo at King's College London /University of Reading (lead: Sue Grimmond)
Costs to User	Free
Current data	Multiple sites; Updated daily with yesterday's data
Meta data	LUMA provides details
Historical data	Last 7 days visible, Available

Name	**MDA Weather Services, EarthSat**
Country of Origin	USA
Organisation Type	Routine Professional
Description	Company: numerous forecast products based upon real time data
Costs to User	Commercial subscription services available
Current data	All by subscription costs
Meta data	Unknown if take they own measurements
Historical data	None visible
Available	Not freely available

Appendix 2: Organisations that provide data

Name	Met Office
Country of Origin	UK
Organisation Type	Routine Professional
Description	UK national weather service agency; Government agency with responsibility to collect weather data, forecasting. Commercial & Research arms. Trading Fund within Department for Business Innovation and Skills, operating on a commercial basis. Open Road: forecast product: used about a third of London boroughs
Costs to User	Free with adverts, Commercial subscription services available
Current data	Provides feed to WMO, BBC etc.
Meta data	http://www.metoffice.gov.uk/public/weather/climate-network/ See WOW below; Standard METEOSAT, METARs, SYNOPs and NCM data. Vaisala sensors; Green A 2010, From Observations to Forecasts – Part 7. A new meteorological monitoring system for the United Kingdom's Met Office. Weather, 65: 272–277. doi: 10.1002/wea.649; http://onlinelibrary.wiley.com/doi/10.1002/wea.649/abstract
Historical data	Last 24 h available on web, also BADC site http://badc.nerc.ac.uk/home/index.html
Forecast	Weather forecast
Radar feed	Radar feed
Satellite feed	Eumetsat

Name	Met Office Weather Observation Website (WOW)
Country of Origin	UK
Organisation Type	Routine Volunteer
Description	Met Office co-ordinated volunteer weather observing community portal for submission of observations. Allows any type of equipment to be used for the data collection. Stated June 2011
Costs to User	In map format
Current data	Mutliple sites, Displays on map
Meta data	Range of information collected about each site using a standard protocol; can be seen by clicking on the site
Historical data	Available from same map as current condition by changing time period

Name	MeteoConsult
Country of Origin	France
Organisation Type	Routine Professional
Description	Company: forecasts for numerous places worldwide
Costs to User	Free with adverts
Current data	Nothing visible
Historical data	None visible
Forecast	Weather forecast: Hourly, weekly

Appendix 2: Organisations that provide data

Name	**MeteoGroup**
Additional site	Weathercast
Country of Origin	Originally the Netherlands, has UK office
Organisation Type	Routine Professional
Description	Company: meteorological services & products; RoadCast http://www.roadcast.co.uk/; Network Rail http://www.smtweather.co.uk/
Costs to User	Forecast free; Data can be downloaded for a charge per year of data (£260/year) but it is not clear at what temporal resolution
Current data	Nothing visible
Meta data	None visible
Historical data	Not freely available
Forecast	Weather forecast for the next couple of days at www.weathercast.co.uk

Name	**MeteoProg**
Additional site	UCEWP
Country of Origin	Ukraine
Organisation Type	Routine Professional
Description	FanMedia & Ukrainian Center of Environmental and Water Projects. Founded: 1999 Academy of Sciences of Ukraine. Weather forecasting, rivers and floods hydrology, environment pollution, environmental management, etc
Costs to User	Free with adverts
Current data	Single Site? road maps for areas in London
Data collected by	Others?
Meta data	Not clear what site data are provided
Historical data	Available
Specialist forecasts	Road Forecast; Up to 7 -14 days, Road weather available online for selected route
Satellite feed	FU Berlin and US Air Force Weather Agency

Name	**National Physical Laboratory**
Country of Origin	UK
Organisation Type	Research
Description	Established: 1900. National measurement Institute. Government Owned – Contractor Operated facility (by Serco Group plc). April 2014: strategic partnership between Department for Business, Innovation and Skills (BIS) & one or more national / international academic partners or applied science organisations will be established. Centre for Carbon Measurement; Links to EarthNetworks (see above) and Astrium (an EADS company)
Costs to User	Consulting service
Current data	Nothing visible
Meta data	Instrument type
Historical data	Short periods of CO_2 data collected in 2012; Building performance;

Appendix 2: Organisations that provide data

Name	**NOAA**
Additional site	AMDAR
Country of Origin	USA
Data Type	Climate data
Description	US national climate data archive. Includes international data. Website: designed to be a gateway for scientists, resource managers, businesses & other interested members of the public who want to find & use climate data; AMDAR data
Costs to User	Free
Current data	Multiple sites
Data collected by	Others
Meta data	Elevation, network codes, period available, latitude, longitude
Historical data	Available

Name	**OASIS LMF**
Country of Origin	UK
Organisation Type	Routine Professional
Description	Not for profit company owned by the insurance industry. Building an open architecture loss modelling framework; Academics (e.g. Imperial), Met Office, Insurance Companies
Costs to User	In development
Current data	Nothing visible
Meta data	In development

Name	**Passivhaus/ BRE**
Additional site	BRE Trust
Country of Origin	UK
Data Type	Climate data
Description	Established: 1921 central Government-funded Building Research Station (BRS). Privatised: 1997 Includes: The BRE Trust (registered charity) for support of the built environment research for the public benefit. Group undertakes research, consultancy, certification (e.g. BREEAM), testing and training. http://www.bre.co.uk/index.jsp
Costs to User	Free; Can purchase more site specific datasets; Subscription services
Current data	Hammersmith and Fulham; Kensington and Chelsea; Westminster; Islington; City of London; Hackney; Tower Hamlets; Newham; Lewisham; Southwark; Lambeth; Wandsworth
Meta data	Conducted data collection for short periods in London using a network of specially installed stations. Data are not freely available
Climate Forecast	Data available for use in their software

Name	**ProData weather systems**
Country of Origin	UK
Organisation Type	Routine Volunteer
Description	Company. Established: 1996. Sells weather monitoring equipment.
Costs to User	Free from map to sites
Current data	Map
Meta data	Many standard equipment but siting not standard Information provided
Historical data	Can click on sites on map and see individual web sites and graphs

Appendix 2: Organisations that provide data

Name	**Prometheus – Probabilistic climate data to for design decisions in the buildings sector**
Additional site	Prometheus
Country of Origin	UK
Data Type	Climate data
Description	Funded: EPSRC Lead: D Coley, Univ. Exeter; Probabilistic reference years for building designers.
Costs to User	Free
Current data	Nothing visible
Meta data	Eames M, T Kershaw, D Coley 2011: On the creation of future probabilistic design weather years from UKCP09; Building Serv. Eng. Res. Technol., 32 127-142
Historical data	5 km resolution data- modelled
Climate Forecast	Based on UKCP09 – Typical Meteorological Year;
Name	**RailMet http://www.railmet.eu/**
Country of Origin	EU & UK
Organisation Type	Type Member organisation and consultancy
Description	Assistance to train operating companies and infrastructure managers during times of severe weather disruption.
Costs to User	Free and subscription services
Data Type	Weather and forecast
Current data	London City Airport (from Met Office) (free), 3 h weather feed (subsciption)
Meta data	Not for current data but source clear, other unknown
Radar feed	UK 1 h rain. lightning
Satellite feed	EUmetsat/Met Office
Forecasts	Flood forecast every 15 min (subscription)
Historical data	Reports available
Name	**RainGain; River Roding tributary**
Country of Origin	EU – UK partner
Organisation Type	Research
Description	EU Interreg IVB NWE funded research project concerned with the prediction of pluvial floods in cities; Imperial College London (Čedo Maksimović), Met Office
Current data	Nothing visible
Meta data	Publications on web site
Historical data	Not visible on web
Name	**RMS**
Country of Origin	USA, London office
Organisation Type	Routine Professional
Description	Catastrophe Risk Modelling Company; Model numerous weather related events globally: floods, winter storms, wind storms, severe convective storms, tropical cyclones
Costs to User	Commercial subscription services available
Current data	Nothing visible
Meta data	A Guide to Catastrophe Modelling (pdf)
Historical data	None visible
Available	Products by subscription

Appendix 2: Organisations that provide data

Name	**Royal Parks**
Country of Origin	UK
Organisation Type	Routine Professional
Description	Executive agency, Dept. for Culture, Media and Sport (DCMS). Look after Bushy Park (with the Longford River); The Green Park; Greenwich Park; Hyde Park; Kensington Gardens; The Regent's Park (and Primrose Hill); Richmond Park; St James's Park; tend other spaces including Victoria Tower Gardens, Brompton Cemetery, the gardens of 10, 11 and 12 Downing Street, and Grosvenor Square Gardens
Current data	Nothing visible; Multiple sites, Availability unknown
Meta data	None visible
Historical data	None visible

Name	**SoDa**
Country of Origin	France
Data Type	Climate data
Description	Broker. Services related to solar radiation by several providers in Europe
Costs to User	Pre 2004; more recent data
Current data	Nothing visible
Meta data	Available, web
Historical data	Solar radiation data based on various satellite sources; 20 km spatial resolution (others also available)

Name	**SPAT, Imperial College London**
Country of Origin	UK
Organisation Type	Research
Description	CO_2 observations and OPAL/LGfL network. Lead Ralph Toumi (Imperial)
Costs to User	See LGfL, Contact Principal Investigator
Current data	See LGfL
Meta data	Ryder CL, Toumi R 2011: An urban solar flux island: Measurements from London. Atmospheric Environment , 45, 3414-3423; Sparks, N; Toumi, R 2010: Remote sampling of a CO_2 point source in an urban setting Atmospheric Environment, 44, 5287-5294 ;Rigby M, Toumi R London 2008:air pollution climatology: Indirect evidence for urban boundary layer height and wind speed enhancement Atmospheric Environment, 42,4932-4947
Historical data	See LGfL

Appendix 2: Organisations that provide data

Name	Speedwell Weather
Country of Origin	Offices in UK and USA
Organisation Type	Routine Professional
Data Type	Climate data
Description	Founded: 1999. Provides weather data (historic & real-time), forecasts & software to energy, agriculture, insurance, investment funds & banking clients internationally; Direct data supply agreements with wide range of national meteorological services. Developers of weather derivative pricing & risk management software (SWS). Speedwell Weather Derivatives Limited (SWD) helps companies looking to hedge against weather risk by quantifying such exposure. SWD is authorised and regulated by the UK Financial Services Authority
Costs to User	Commercial subscription services available
Current data	Nothing visible
Data collected by	Others
Meta data	None visible
Historical data	Not freely available
Available	By subscription, Inventory; Heathrow, Northolt; secondary sites: Kenley, St James's Park, Gravesend-Broadness

Name	Transport for London (Tfl)
Country of Origin	UK
Organisation Type	Routine Professional
Description	Created: 2000. Responsible: London's transport system, implements Mayor's Transport Strategy for London. Services: London's buses; London Underground; Docklands Light Railway; London Overground; Tramlink, London River Services, Victoria Coach Station. Responsibilities: Congestion Charge management; maintain 580 km main roads, all of London's traffic lights, regulate city's taxis & private hire trade, coordinate accessibility schemes for people with impaired mobility & run Dial-a-Ride with London boroughs Taxicard scheme; promote walking & cycling initiatives. Statutory corporation regulated under local government finance rules.
Costs to User	Free
Current data	Nothing visible
Meta data	None visible
Historical data	Not freely available; Temperature in tubes and in stations ; worked with RCUK research projects (e.g. MESSAGE providing a platform for other sensors)
Forecast	5 day weather forecast – origin not clear

Name	The Climatological Observers Link (COL)
Country of Origin	UK
Organisation Type	Routine Volunteer
Data Type	Climate data
Description	Organisation: people interested in weather. Members: mainly amateur meteorologists, but many professionals and observers from schools, universities and research establishments also belong to COL. Many members run weather stations and keep records,
Costs to User	Membership fee
Current data	Nothing visible; Multiple sites, Members have it but not on website
Meta data	Can contact members
Historical data	Monthly bulletin

Appendix 2: Organisations that provide data

Name	**The Weather Channel (TWC)**
Country of Origin	USA
Organisation Type	Routine Professional
Description	Part of TWC – a USA TV channel. The UK website was launched in July 2001 to weather information across the UK.
Costs to User	Free with adverts
Data collected by	Others
Historical data	None visible
Forecast	Weather forecast: Hourly, daily. 10 day, monthly
Radar feed	Branded by TWC
Satellite feed	Branded by TWC

Name	**UK Snow map**
Country of Origin	UK
Organisation Type	Routine Volunteer
Description	Uses Tweets (#uksnow) to generate an up-to-the-minute map of where it is currently snowing in the UK.
Costs to User	Free with adverts
Current data	Map depending on data availability
Meta data	Location (postcode, town N or geotag your tweet), and rate the snow that is falling out of ten (0/10 for nothing – 10/10 for a blizzard).
Historical data	None visible

Name	**UKCIP**
Country of Origin	UK
Data Type	Climate data
Description	Established in 1997 by the UK government. Works between scientific research, policy making and adaptation practice.
Costs to User	Free
Historical data	Wide range of reports that cover areas of London ; Wide range of web links

Name	**University College London**
Additional site	London data
Country of Origin	UK
Organisation Type	Research
Description	Imaging Group, Dept of Space & Climate Physics, Mullard Space Science Laboratory led by Jan Peter Muller, operate Sun radiometer; Satellite Imagery; Part ESR and AeroNET
Costs to User	Contact Principal Investigator
Current data	Single Site
Meta data	Located by the UCL-UAO (Urban Atmospheric Observatory) on the 11th floor roof of 1–19 Torrington Place, in central London, close to a main east-west arterial traffic zone. Campanelli et al. 2011: Monitoring of Eyjafjallajökull volcanic aerosol by the new European Skynet Radiometers (ESR) network. Atmospheric Environment, 48, 33-45. doi:10.1016/j.atmosenv.2011.09.070
Historical data	1 site

Appendix 2: Organisations that provide data

Name	**University of Birmingham**
Country of Origin	UK
Organisation Type	Research
Description	Air quality related research led by Roy Harrison; Includes lead of REPARTEE, REPARTEE-II and other analysis
Costs to User	Contact Principal Investigator
Current data	Nothing visible
Meta data	Key publications since 2001 (pdf) REPARTEE and REPARTEE II, http://www.atmos-chem-phys-discuss.net/special_issue95.html
Historical data	Multiple sites

Name	**Weather Analytics**
Country of Origin	USA
Data Type	Climate data
Description	Company started around 2005/6 which provides a wide range of data products, to forecast weather impact and weather risk; model and manage energy use and production; Score and map risk exposure; create environmental safety measures; discover energy-efficient engineering solutions
Costs to User	Graphs are generated on screen for points selected; commercial services for data in a wide range of formats
Data collected by	Available via map interface
Meta data	Procedures for data determination are not given beyond the sources of the input data. (e.g. it is not clear if urban spatial characteristics taken into account)
Historical data	Station Data – gap-filled hourly data; Generated for any location from data re-analysis modelling at 35 km x 35 km; Resolution

Name	**Weather Online**
Country of Origin	UK
Organisation Type	Routine Professional
Description	International. Number of specialised services related to travel, sports (golf, sailing, winter sports, Wimbledon), agriculture; Wide range of weather maps provided from different meteorological services
Costs to User	Free with adverts; Commercial subscription services available
Current data	Multiple sites
Data collected by	Probably Met Office data feed
Meta data	Details about most products provided but not for observations
Historical data	Available
Climate Forecast	14 day, Monthly, Seasonal; http://www.weatheronline.co.uk/cgi-bin/expertcharts?LANG=en&CONT=euro&MODELL=gfs&VAR=prec
Forecast	Weather forecast 48 h
Radar feed	Radar feed
Satellite feed	Eumetsat -Meteosat 9

Appendix 2: Organisations that provide data

Name	**WeatherBug, Earth Networks**
Country of Origin	USA
Organisation Type	Routine Schools
Description	Established 1993. Delivers current weather products to consumers through broadcast television partner network and other applications including works, agriculture, education, energy and utilities, government (federal, state and local), media, sports and recreation, broadcasting and transportation.
Costs to User	Free with adverts; Number of subscription services including monitoring of the boundary layer
Current data	Weather Bug-multiple sites; Graphically including CO_2 and CH_4 (see NPL) (testing at the moment)
Data collected by	Met Office stations
Meta data	Map shows general site location; Standard weather station
Historical data	None visible
Forecast	Weather
Satellite feed	Satellite feed

Name	**WeatherSignal**
Country of Origin	UK
Organisation Type	Routine Professional
Description	London based company. Established OpenSignal. Build smartphone applications (Android) to geolocate maps of weather variables
Costs to User	Free
Data collected by	Variable
Meta data	None visible
Historical data	Limited availability

Name	**Windfinder**
Country of Origin	Germany
Organisation Type	Routine Professional
Description	Company history and background not available on web. Link to sporting activities (e.g. kitesurfing). Two different forecasts available
Costs to User	Current conditions, Forecasts; Past data and some forecast services can be purchased
Current data	Multiple sites
Meta data	Location and height
Historical data	Available
Forecast	Two forecasts: GFS-model from NOAA horizontal resolution is about 27 km four times a day (at about 5, 11, 17 and 23 UTC).; horizontal resolution of 12 km hourly time-steps forecasts are generated four times a day (about 4, 10, 16 and 22 UTC)

Appendix 2: Organisations that provide data

Name	**Wunderground**
Country of Origin	USA
Organisation Type	Routine Volunteer
Description	Company. Established: 1991, University of Michigan, spun out from University 1995. Large network personal weather stations (23,000 stations in US and > 13,000 rest of world). Provide local weather conditions. July 2012 – part of The Weather Channel Companies (see above).
Costs to User	Click on map and get individual site data graphically
Current data	Multiple sites
Meta data	Location and height
Historical data	Available
Forecast	With dynamic mapping capability
Radar feed	Radar feed
Satellite feed	Satellite feed

Name	**YourWeather**
Country of Origin	Spain
Organisation Type	Routine Professional
Description	Generated by parent company Tiempo.com which provide weather information. GFS model used.
Costs to User	Free with adverts
Current data	Single site unknown
Data collected by	Others
Historical data	None visible
Forecast	Hourly, 1-7 day, 8-14 day
Radar feed	No
Satellite feed	Eumetsat

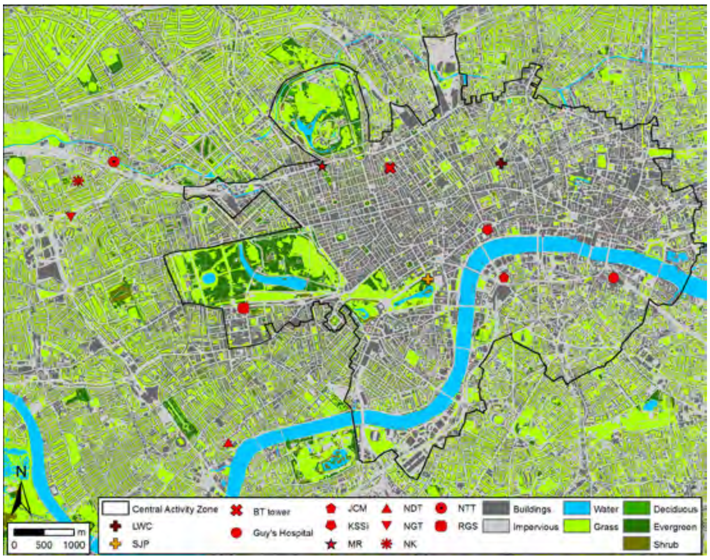
Appendix 3: Locations of Observations Stations

Example maps of where sites are located within different networks plus measurement climate and weather forecast maps.

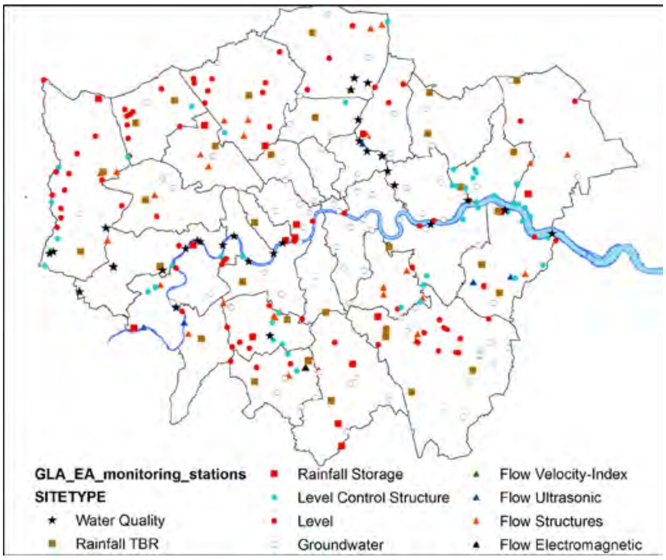
Location of M25 and GLA outer boundary to provide context for the other figures[53]	Example of UKCP09 Climate projections[54] Note that there is no spatial variability shown across London.
Radar sites[55] RainDrain study area[56] see also radar map of coverage.	Example of a commercial international site providing real-time data.[57] In this case this site is oriented towards sports, notably kite-surfing. Historical data including wind roses, current data and forecasts are available by clicking on a particular site.
Weather Forecast Data – UK Met Office provide expected data across London[58]	Current Observations[59] - provided by UK Met Office. Only two sites are within Greater London: Northolt (north of Heathrow) and Heathrow. Within the M25 (but outside GL) are Kenley and Gravesend-Broadness. These four sites also provide wind speed data.
Weather Underground stations[60] current conditions. The stations with the sun symbols are airports: London Heathrow, Biggin Hill and London City Airport. Shown is wind direction, wind speed and temperature. By clicking on a particular site: rainfall, pressure, humidity, visibility. Are revealed along with past data and meta data: (latitude, longitude, elevation, stationID).	Met Office WOW stations[61] By clicking on site other meteorological variables can be seen (e.g. wind direction, pressure etc) and metadata. The site details have a standard format and if completed by volunteer are quite extensive.
London Grid for Learning[62] temperature, wind and rainfall data can be mapped. By clicking on the site other details can be obtained (right) or via clicking on the list to the left. Other meta data are not available on the web. Historic data are available (33 stations).	London Air Quality Network[63] can select a range of variables, historical data is available for download, metadata available for each site.

53 http://www.tfl.gov.uk/tfl/livetravelnews/realtime/road/default.aspx?showLez=true&showCc=true
54 http://ukclimateprojections.defra.gov.uk/21863
55 http://www.raingain.eu/en/london
56 http://www.raingain.eu/en/london
57 http://www.windfinder.com/weather-maps/report/unitedkingdom#10/51.4882/-0.0439
58 http://www.metoffice.gov.uk/public/weather/forecast/london#?tab=map&map=ScreenTemperature&zoom=9&lon=-0.17&lat=51.55&fcTime=1366747200
59 http://www.metoffice.gov.uk/public/weather/observations/#?tab=map&map=Temperature&zoom=9&lon=-0.19&lat=51.57&fcTime=1366747200
60 http://www.wunderground.com/wundermap
61 http://wow.metoffice.gov.uk/
62 http://weather.lgfl.org.uk/map.aspx?view=london
63 http://www.londonair.org.uk/london/asp/publicstats.asp?region=0&site=&la_id=&network=All&postcode=&MapType=Google&VenueCode=&zoom=9&lat=51.431751825946115&lon=-0.17578125&laEdge=

Appendix 3: Locations of Observations Stations

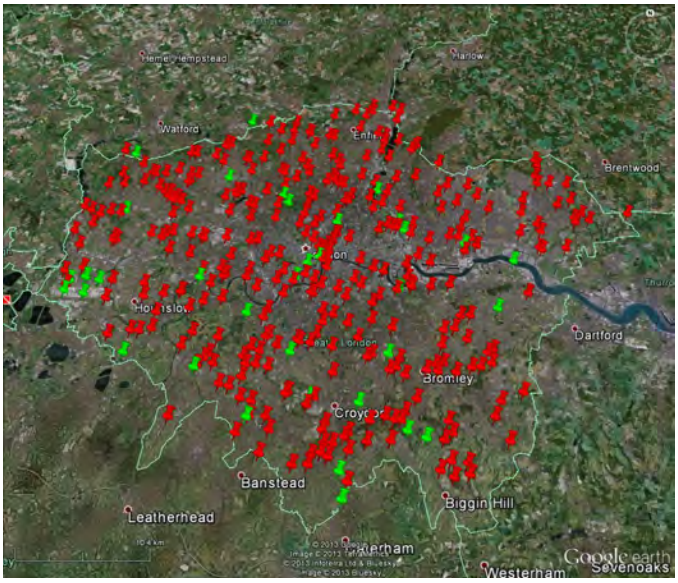


Sites in Central London[64] operated as part of the ClearfLO project. This includes Air quality sites (NK, MR), ceilometer sites (KSSi, MR, RGS, NK), eddy covariance (BT Tower, KSSi). Doppler LiDAR (near MR)



Location of Environment Agency rain gauges (TBR, storage) and other data collection within Greater London (2013). Data from EA.

MIDAS station sites (last updated 05-Jan-2011)[65]. Red sites (below) are no longer and the operational, Green operational (below & left)



Met Office Land surface synoptic sites near London[66] (May 2010, see Figure 3). Detailed metadata, data access procedures are available via the BADC website[67]

Met Offfice[68] Synoptic and climate stations London. Website allows user to click on sites determine sitename.

64 http://Londonclimate.info
65 http://badc.nerc.ac.uk/search/midas_stations/google_earth.html
66 http://www.metoffice.gov.uk/media/pdf/k/5/Fact_sheet_No._17.pdf
67 http://badc.nerc.ac.uk/view/badc.nerc.ac.uk__ATOM__dataent_ukmo-midas
68 http://www.metoffice.gov.uk/public/weather/climate-network/

Appendix 4: Acronyms used in this report

Given the report covers a wide range of fields, a list of acronyms is provided. In some cases a website link is provided for more details.

ABS	Anti-lock braking system
ACP	Atmospheric Chemistry and Physics
ACT	Australian Capital Territories
ACTUAL	Advanced Climate Technology Urban Atmospheric Laboratory (led by Prof Janet Barlow)
ADMS	Atmospheric Dispersion Modelling System
AMDAR	Aircraft Meteorological Data Relay
AMS	Automatic Meteorological Station
APRIL	Air Pollution Research in London (led by GLA and Prof Janet Barlow)
ATDD	Atmospheric Turbulence and Diffusion Division
AURN	Automatic Urban and Rural Network
AWS	Automatic Weather Station
BADC	British Atmospheric Data Centre
BAMS	Bulletin of the American Meteorological Society
BRE	Building Research Establishment
BSER & T	Building Services Engineering Research and Technology (a journal)
CBD	Central Business District
CC	Climate change
CCAP	Centre for Clean Air Policy
CERC	Cambridge Environmental Research Consultants
CIBSE	Chartered Institution of Building Services Engineers
ClearfLo	Clean Air for London (led by Prof Stephen Belcher)
CMAQ	Community Multi-scale Air Quality modelling system
COL	Climatological Observers Link
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia's national science agency
DAPPLE	Dispersion of Air Pollution and its Penetration into the Local Environment (led by Prof Alan Robbins)
DECC	Department of Energy and Climate Change
Defra	Department for Environment, Food and Rural Affairs
DFW	Dallas Fort Worth
DSY	Design Summer Years
EDF	Energy company
EPSRC	Engineering and Physical Sciences Research Council
EUf7	European Union Framework 7
FMI	Finnish Meteorological Institute
GHG	Greenhouse Gas
GIM	Geographic Information Management
GLA	Greater London Authority
GPRS	General Packet Radio Service
GRIB	Grid In Binary. Data format designed to be self-describing, compact and portable across computer architectures. Designed and maintained by WMO
HPA	Health Protection Agency (about to be renamed Public Health England)
Hz	Hertz (number of times per second)
IJC	International Journal of Climatology (a journal)
INSPIRE	Infrastructure for Spatial Information in Europe
KCL	King's College London

Appendix 4: Acronyms used in this report

LCCP	London Climate Change Partnership
LCZ	Local Climate Zones
LFB	London Fire Brigade
LGfL	London Grid for Learning
LUCID	The Development of a Local Urban Climate Model and its Application to the Intelligent Design of Cities (led by Prof Mike Davies)
LWC	London Weather Centre (a Met Office operated climate station that no longer is operational)
MIDAS	Met Office Integrated Data Archive System (MIDAS) Land and Marine Surface Stations Data
MODIS	Moderate Resolution Imaging Spectroradiometer (satellite deployed by NASA)
MORECS	Met Office Rainfall and Evaporation Calculation System
MSOA	Medium super output area
NASA	National Aeronautics and Space Administration
NASA Ames	Format for Data Exchange, originally from NASA aircraft campaigns. First formalised at the Ames Research Centre, California. Uniform rules to record data to facilitate data exchange but with minimal software needed to analyse and display different datasets.
NCAS	National Centre Atmospheric Sciences
NERC	Natural Environment Research Council
netCDF	network Common Data Form - interface for array-orientated data access. Many groups have adopted netCDF as a standard way to represent their scientific data. Software was developed at the Unidata Program Center in Boulder, Colorado.
NOAA	National Oceanic and Atmospheric Administration (US Department of Commerce)
NSF	National Science Foundation (US research funding agent)
NWP	Numerical Weather Prediction
OPAL	Open Air Laboratories
PHE	Public Health England (new name for HPA)
PI	Principal Investigator
QAQC	Quality Assurance / Quality Control
RCUK	Research Councils UK
REPARTEE	Regent's Park and Tower Environmental Experiment (led by Prof Roy Harrison)
RIBA	Royal Institute of British Architects
RMS	Risk Management Solutions
RSL	Roughness sub layer
SoDa	Solar Radiation Data
STC	Stability and traction control
TBR	Tipping bucket rain gauge
TfL	Transport for London
TMY	Typical Meteorological Year
TRY	Test Reference Year-type weather data format
UCL	University College London Urban Canopy layer
UCM	Urban canopy models
UHI	Urban heat island
UK-EOF	UK-Environmental Observation Framework
URS	Energy and Environment Consultants
VITO	Vision on Technology, Belgium
WMO	World Meteorological Organisation
WOW	Weather Observation Website (Met Office)
WRF	Weather Research and Forecasting Model - mesoscale numerical weather prediction system

Appendix 5: Brief history of data collection in London[69]

London has played a key role in the history of urban climate studies and in the development of current understanding. Many of the issues highlighted by respondents to the survey undertaken for this report refer to the same issues (such as air quality, building design and tree planting) that have been the rationale for studies and actions in London over the last millennia.

Helmut Landsberg[70] in his history of urban climate studies uses London as a key focus. He highlights the attempts to ban coal burning in 1273 and 1306 by King Edward I and then by Queen Elizabeth I (1533-1603) for periods when Parliament was sitting, and John Evelyn's (1661[71], The Rota 1976[72]) attempts to influence Charles II. Evelyn's early description of London's atmosphere[73,74], recognise the influence of urban form (building shape and spacing) and encouraged tree planting[72]. These themes remain at the fore of urban air quality and health studies today (e.g. EPSRC and then Home-Office, DAPPLE[75] project which was initiated from the APRIL[76], and also NERC funded ClearfLo project – Appendix 2).

Before measurements could begin instruments had to be developed. Key roles were played by leading scientists through the Royal Society in London. Robert Hooke, in his Micrographia[77] included descriptions of his thermometer, modified from an Italian design with a scale, which acted as a standard until 1709[78]. The Royal Society promoted the establishment of an international meteorological network (Jurin 1723[79], Camuffo 2002[80]), with recommendations for sensor location and measurement procedures based on John Locke[81] and Robert Hooke[82].

Observations of rainfall[83] in London started later (1727), after temperature[84] (1659), with daily rainfall data from 1772[85]. Unfortunately, for the period January 1707-October 1722 the data were not kept as the Royal Society at that time perceived the data were of no further use (Manley 1974, p391[86]). Routine collection of temperature data in the vicinity of London appear to have begun around 1763[87] at a time when a number other cities in Europe began to collect similar observations[88], with hourly air temperatures collected at the Greenwich Observatory from 1814.

69 For more on this see Grimmond S 2011: London's urban climate: historical and contemporary perspectives in City Weathers: meteorology and urban design 1950-2010, (eds) M Hebbert, V Jankovic, B Webb Manchester Architecture Research Centre, University of Manchester, http://www.sed.manchester.ac.uk/architecture/research/csud/workshop/2011CityWeathers.pdf, ISBN: 978-1-907120-98-5

70 Landsberg H 1981: The Urban Climate. Academic Press.

71 Evelyn J 1661: Fumifumigium or The Inconveniencie of the AER and SMOAK of LONDON DISSIPATED. With fome Remedies humbly proposed available: http://ia600204.us.archive.org/6/items/fumifugium00eveluoft/fumifugium00eveluoft.pdf

72 The Rota 1976: Front pages in Evelyn (166169)

73 Chandler TJ 1962: London's Urban Climate, The Geographical Journal 128, 279-98

74 Atkinson BW 1985: The Urban Atmosphere. Cambridge University Press, 85 pp

75 http://www.dapple.org.uk/

Arnold SJ, H ApSimon, J Barlow, S Belcher, M Bell, JW Boddy, R Britter, H Cheng, R Clark, RN Colvile, S Dimitroulopoulou, A Dobre, B Greally, S Kaur, A Knights, T Lawton, A Makepeace, D Martin, M Neophytou, S Neville, M Nieuwenhuijsen, G Nickless, C Price, A Robins, D Shallcross, P Simmonds, RJ Smalley, J Tate, AS Tomlin, H Wang, P Walsh 2004: Introduction to the DAPPLE Air Pollution Project. Science of the Total Environment 332:139-153.

Dobre A, Arnold SJ, Smalley RJ, Boddy JWD, Barlow JF, Tomlin AS, Belcher SE 2005: Flow field measurements in the proximity of an urban intersection in London, UK. Atmospheric Environment, 39:4647-4657

Tomlin AS, Smalley RJ, Tate JE, Arnold SJ, Dobre A, Barlow JF, Belcher SE, Robins A 2009: A field study of factors influencing the concentrations of a traffic-related pollutant in the vicinity of a complex urban junction. Atmospheric Environment, 43: 5027-5037

Wood CR, Arnold SJ, Balogun AA, Barlow JF, Belcher SE, Britter RE, Cheng H, Dobre A, Lingard JJN, Martin D, Neophytou MK, Petersson FK, Robins AG, Shallcross DE, Smalley RJ, Tate JE, Tomlin AS, White IR 2009: Dispersion Experiments in Central London: The 2007 DAPPLE project. BAMS, 90:955-970

76 http://www.april-network.org/home/

77 Hooke R 1665: Micrographia. http://www.gutenberg.org/ebooks/15491

78 Patterson LD 1951: Thermometers of the Royal Society, 1663–1768, American J. of Physics 19, 523 -535

Quinn TP, J P Compton 1975: The foundations of thermometry Rep. Prog. Phys. 38, 151-239

79 Jurin AJ 1723: Invitatio ad Observationes Meteorologicas Communi Consilio Instituendas, Philosophical Transactions, 32, 422-427 (in Latin)

80 Camuffo D 2002: History of the long series of daily air temperature in Padova (1725–1998) Climatic Change 53: 7–75.

81 No reference given by Camuffo 2002: but the paper: Locke J (1704-1705) A Register of the Weather for the Year 1692, Kept at Oates in Essex. Philosophical Transactions, 24, 1917-1937 has data observed by day and hour.

82 Kington J 1997: Observing and measuring the weather: a brief history, in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Routledge, London, 137-152.

83 Nicholas FJ, Glasspoole J 1931: General monthly rainfall over England and Wales 1727 to 1931, British Rainfall 1931, 299-306. cited by Jones PD, D Conway, K Briffa1997: Precipitation variability and drought. in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Routledge, London, 196-219.

84 This is referred to as the Central England Temperature data set as not all data are actually for London for a variety of reasons (Manley 1974). The data are presented in a number of papers and summarized in Hulme and Barrow 1997, (Appendix D) Jones PD, D Conway, K Briffa1997: Precipitation variability and drought. in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Routledge, London, 196-219.

85 Parker DE, Legg TP, Folland C 1992: A new daily central England temperature series, 1772–1991. International Journal of Climatology, 12: 317–342. doi: 10.1002/joc.3370120402

86 Manley 1974: cites Philos. Trans., 24, 1707, p. 347; Symons Magazine, 59, 1924, pp. 183-184.

87 January 1764 is first monthly data reported by Brunt (1925) but he indicates there is annual data for 1763

88 Brunt D 1926: Periodicities in European Weather Philosophical Transactions of the Royal Society of London. Series A, 225, 247-302

Appendix 5: Brief history of data collection in London[69]

Rainfall was measured from 1813 at this site and at Camden Square from 1856[88].

Luke Howard's observations taken when London had a population of just over one million (1.45 million by 1821[89]) resulted in his books 'The Climate of London' published in 1818, 1820 and 1833[90]. These seminal works recognise human effects on city climates and are widely viewed as the foundation of urban climate studies[91]. Howard observed air temperature in a variety of different locations around London over a period of 25 years[92], analysing these in conjunction with measurements established at Somerset House in 1806[93]. Although the exposure of the instruments varied between the sites, and was not always known[94], the daily data allowed him to draw conclusions that identified what we would now refer to as the 'urban canopy air temperature urban heat island (UHI)[95].

Luke Howard also observed other variables including rainfall, pressure, and clouds. Through consideration of the impact of sites, instrumentation and exposure, he was able to conclude that London, specifically the urban emissions (e.g. of anthropogenic heat from fires, metabolism of people), urban morphology (the shape of the buildings and their arrangement influencing wind and radiation), and differences (in evaporation rates) affected the observations.

Since Howard, many have analysed data collected in London. Some for its meso-scale features or regional location (e.g. Brunt 1926) and some (e.g. Bilham 1938[96]) focused on 'Town Climates'. In addition to air quality concerns, Bilham provides a climatology of sunshine hours comparing central London to its suburbs, documenting a deficit in the central area of London (recently also documented by Ryder and Toumi (2011[97], their Figure 3)).

Bilham's (1938) comparison of mean monthly (mean, maximum and minimum) air temperature between Westminster (also known as St James's Park) and Wisley (1906-1935), and Kensington and Croydon (1921-1935) documented that the city had higher temperatures by night and day in almost all months. After accounting for site elevations, he identified the 'retention of heat by the brickwork' and reduced nocturnal radiation loss as the key controls. The latter relates to the sky view factor, which has a high correlation with the UHI[98] (see Figure 2).

From Bilham's (1938) analysis of wind data observed at South Kensington (30′ above roof, 110′ above ground level, Science Museum), Kew Observatory and Croydon (105′ above ground level, most open and the "outskirts" of London) the role of buildings in reducing wind speeds also was clearly documented.

Air pollution has been another enduring theme stimulating observations, dating back to Evelyn's (1661) writings. A series of "killer smog" events in the 1940s and 1950s related to exposure to sulphurous oxides (SO_2 and SO_4) from the burning of coal (Molina and Molina 2004) culminated in the "Great Smog of December 1952". The latter resulted in the premature deaths of 12,000 (Bell et al. 2003[99]) and was sufficient to trigger public awareness of air pollution with consequent legislation (The 1956 Clean Air Act). In 1957 a smoke-free zone in central London was initiated (Chandler 1962). More recent examples of studies on air pollution and health/mortality include DAPPLE[75], REPARTEE[100] and ClearfLo[101].

89 Population of London since 1100. Data sources: http://www.visionofbritain.org.uk/; http://www.londononline.co.uk/factfile/historical/; http://en.wikipedia.org/wiki/History_of_London
90 Howard L 1818: The Climate of London; Howard L 1820: The Climate of London, Vol 2; Howard L 1833: The Climate of London, 2nd Edition
91 Landsberg (1981), Chandler (1962), Lee DO 1984: Urban climates Progress in Physical Geography 8: 1-31
Mills G 2008: Luke Howard and The Climate of London. Weather, 63,153-157. See his Table 1 for sites in London
92 Chandler (1962), Lee (1984)
93 Chandler (1962)
The Royal Society moved into Somerset House in 1780 and given the long connection already with the thermometer, the 1806 date may refer to Howard's initial measurements rather than the Royal Society's.
94 Chandler (1963), Lee (1984),
The Royal Society was located to the east of the Strand Entrance (Courtauld Institute of Art now occupies (http://royalsociety.org/about-us/history/somerset-house/). A probable location could be determined.
95 The warmer air temperature near the surface in cities
96 Bilham EG 1938: The Climate of the British Isles, Macmillian and Co Ltd, London, 347pp, especially p303-311
97 Ryder CL, Toumi R 2011: An urban solar flux island: measurements from London. Atmospheric Environment, 45. 3414-3423. doi: 10.1016/j.atmosenv.2011.03.045
98 Oke TR 1981: Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations. J. Climatol., 1: 237–254. doi: 10.1002/joc.3370010304
99 Bell ML, Davis DL, Fletcher T 2003: A Retrospective Assessment of Mortality from the London Smog Episode of 1952: The Role of Influenza and Pollution. Environ Health Perspect 112: doi:10.1289/ehp.6539
100 http://nora.nerc.ac.uk/8465/REPARTEE-I and http://nora.nerc.ac.uk/8465/REPARTEE-II, http://www.atmos-chem-phys-discuss.net/special_issue95.html
101 http://www.clearflo.ac.uk/ (see Table 1)

Appendix 5: Brief history of data collection in London[69]

The Great Smog was associated with particularly cold temperatures. As people burnt coal to heat their houses, emissions combined with those from factories were trapped by the lower boundary layer. This impacted visibility and brought the city to a halt. Today, new instruments, many based on some form of LiDAR, allow almost real-time observations of boundary layer height. In conjunction with air quality measurements and forecast modelling, these provide the basis of systems to communicate rapidly warnings to those who are vulnerable (e.g. Air Alert[102]; Air Text[103]).

Air quality remains an important issue in London today both for health reasons (e.g . Kaur et al. 2005[104], 2007[105]) and because EU Law requires directives to be met (GLA 2010, Defra 2011). As one of Europe's Mega-cities, in a national context which is committed to more sustainable cities, and with a local government administration (GLA) that takes an active interest in climate issues and actively engages the scientific community, London remains a particularly interesting location to study urban climate and its implications for urban design.

The urban heat island

The best known urban climate effect is the urban heat island (UHI). Landsberg (1981) ascribed the first use of the term to Manley's (1958[106]) discussion of the effect of the artificial warmth of London relative to snowfall patterns, where he notes an inverse relation between 'heat island' strength and wind speed. He comments on the expected change in the precipitation from snow to sleet. However, this term appears earlier in Balchin and Pye's (1947[107]) study of Bath (p 303, 304). Also, in the English translation of Kratzer's (1956, 2nd edition) book the city is described as being 'like an island in a sea of cold air produced by the terrain' (p96). As Kratzer's book demonstrates there had been extensive research on German and Austrian urban climates in the early part of the century.

Manley's (1958) analysis, like Bilham's (1938), uses data collected from stations often at airfields. In one of the first detailed studies of London's UHI, Chandler (1960, 1962, 1965[108]) identifies that although there are 17 stations in London and vicinity, which may be considered to be 'lavish' in comparison to other areas, there were insufficient data for spatial analyses. He added 39 supplementary stations (primarily at schools) in the north east Lea Valley area and performed automobile traverses[109] to understand the 'changing intensity and form' of the UHI. Chandler (1962) also used fixed stations to analyse the presence and temporal characteristics of the UHI using daily and hourly records, along with mobile transects too (from Ware, north east of London along the terraces of the Lea to Canning Town or to Liverpool Street and then back to Ware). Importantly, he noted the impact of choice of the rural environment as influencing the results of urban-rural differences (he compares the implications of choosing Wisley, Swanley and Bayfordbury). He highlighted the effect of vegetation surrounding Kensington Palace and St James's Park site. His explanation of the UHI focused on differences in heat capacity and conductivity of materials; presence of haze/fog (altering solar radiation receipt); mixing of air because of increased roughness of the surface; and nocturnal radiation trapping. He suggested that high thermal capacity is the most important single factor.

The discussion after Chandler's (1962) paper, suggests plans to use the Crystal Palace tower and the Post Office tower (now known as the BT tower) for measurements. It is unclear if Chandler conducted measurements on the BT tower, but its use as a platform for conducting observations has been pursued more recently (e.g. Wood et al. 2010[110], Martin et al. 2011[111], Helfter et al. 2011[112]).

102 http://www.airalert.info
103 http://www.airtext.info/
104 Kaur S, MJ Nieuwenhuijsen, RN Colvile 2005: Personal exposure of street canyon intersection users to PM2.5, ultrafine particle counts and carbon monoxide in Central London, UK, Atmospheric Environment 39:3629–3641
105 Kaur S, MJ Nieuwenhuijsen, RN Colvile 2007: Fine particulate matter and carbon monoxide exposure concentrations in urban street transport microenvironments. Atmospheric Environment, 41:4781-4810
106 Manley G 1958: On the frequency of snowfall in metropolitan England. QJRMS, 84: 70-72
107 Balchin WGV, N Pye 1947: A micro-climatological investigation of Bath and the surrounding district. QJRMet Soc. 73, 297-319.
108 Chandler TJ 1965: The Climate of London Hutchinson & Co., Ltd: London.
109 These appear to be the first mobile traverses in London (Discussion of Chandler 1962 paper), but others had previously conducted such studies elsewhere using cars and bicycles; for example in Vienna (Tollner 1932; cited by Middleton and Millar (1936), Karlsruhe (Peppler 1929a,b), Munich (Budel and Wölf 1933) and in Toronto (Middleton and Millar 1936).
110 Wood CR, Lacser A, Barlow JF, Padhra A, Belcher SE, Nemitz E, Helfter C, Famulari D & Grimmond CSB 2010: Turbulent flow at 190 metres above London during 2006-2008: a climatology & the applicability of similarity theory. Boundary Layer Meteorology 137, 77-96 DOI10.1007/s10546-010-9516-x
111 Martin D, Petersson KF, White IR, Henshaw SJ, Nickless G, Lovelock A, Barlow JF, Dunbar T, Wood CR, Shallcross DE 2011: Tracer concentration profiles measured in central London as part of the REPARTEE campaign. ACP, 11, 227-239.
112 Helfter C, D Famulari, GJ Phillips, JF Barlow, CR Wood, CSB Grimmond, E Nemitz 2011: Controls of carbon dioxide concentrations & fluxes above central London] ACP. 11, 191-1928 doi: 10.5194/acp-11-1913-2011

Appendix 5: Brief history of data collection in London[69]

Lee's (1991[113]) study of urban/rural differences in humidity, like Chandler's (1962, 1965), was concerned with the actual processes in the city. He also studied the UHI, using the London Weather Centre (LWC) and Gatwick stations. Atkinson (1985[114]) cites a number of other studies of London UHI conducted by Lee in 1975[115], 1977[116], 1979[117].

The long temperature record of London's has made it of interest for larger scale regional and global warming trends (e.g. Moffitt 1972[118], Lee 1992, Barrow and Hulme 1997 p37, Dukes and Eden 1997 p263) following numerous corrections (related to change in siting, instrumentation, discontinued data sets, urban 'contamination') (summarized in Jones and Hulme 1997[119]).

Based on analysis of monthly data from the Kew Observatory (compared with Rothamsted) (for 1878-1968). Moffitt (1972) concluded that since the 1880's urbanisation may have impacted temperature. He also identified the role of changing air quality on temperature differences. With improved air quality, winter air temperatures differences increased because of greater solar radiation receipt. The role of anthropogenic heat also was demonstrated to be important. The 1950's reduction of coal fires changed the method of building heating, as well as reduced the amount of smoke. Subsequent domestic heating has become more efficient (Moffitt 1972).

Noting the decrease in London's population, Lee (1992[120]) set out to determine if there had been an associated decrease in the UHI using the St James's Park and Wisely stations for 1962-89. He is careful to comment about the appropriateness of the two, with neither being ideal. He documents that the magnitude of the daytime UHI decreased while the night time UHI increased in this period. From this he concludes that the population relation[121] does not hold with decreasing population size and suggests that the reduced daytime UHI may relate to reduced anthropogenic heat emissions. However, that conclusion seems unlikely given the trends recently documented in these data[122].

Lee's (1992) study has been updated[123,124], to help to understand future climate conditions using the same sites (St James's Park and Wisely) and expanded[125] to include other stations (e.g. LWC, LHR, amongst others) and for longer periods with Wisley[126] and Rothamsted as the 'rural' sites. These studies provide more details about the sites than had been used for some years in publications; notably, the locations of the LWC station are given: Kingsway (1959-1965), High Holborn (1965-1992), Clerkenwell Rd (1992-2010[127]). They conclude that since 1901 the warming trends at St James's Park, Rothamstead and Wisley are statistically the same. Thus since 1901 there is not urban 'contamination' (it has not changed), so the sites can be used for global change investigations. However, the site at London Heathrow has experienced an increasing urbanizing effect from 1949 to 1980. When the change in UHI through time (1958—2010) is considered with attention to gap filling of data, length of record analysed and meteorological conditions, it is concluded there is need for care with analysing periods of data and identify that meteorological conditions only explains half of the summer-time night-time UHI[128].

Additional recent studies of the UHI characteristics at the micro and local scale have been concerned with the

113 Lee DO. 1991: Urban-rural humidity differences in London. IJC, 11: 577–582.
114 Atkinson (1985)
115 Lee DO 1975: Rural atmospheric stability and the intensity of London's heat island, Weather, 30, 102-108.
116 Lee DO 1977: Urban influence on wind direction over London, Weather, 32, 162-170.
117 Lee DO 1979: Contrasts in warming and cooling rates at an urban and rural site, Weather, 34, 60-66.
118 Moffitt BJ 1972: The effects of urbanization on the mean temperature at Kew Observatory. Weather, 27,12-129
119 Jones P, M Hulme 1997: The Changing temperature of' Central England'. in Hulme and Barrow (ed) 'Climate of the British Isles: present, past and future' Routledge, London, 173-196.
120 Lee DO 1992: Urban warming? An analysis of recent trends in London's urban heat island. Weather, 47:50-56
121 Oke TR 1973: City size and the urban heat island. Atmospheric Environment, 7,769-779,
122 Iamarino M, Beevers S, CSB Grimmond 2011: High Resolution (Space, Time) Anthropogenic Heat Emissions: London 1970-2025 IJC 32: 1754–1767. DOI: 10.1002/joc.2390
123 Wilby RL 2003: Past and projected trends in London's urban heat island. Weather, 58, 251-260. This study was conducted for LCCP.
124 Wilby RL 2008: Constructing climate change scenarios of urban heat island intensity and air quality Environment and Planning B: Planning and Design, 35:902 - 919
125 Jones PD, Lister DH 2009: The urban heat island in Central London and urban-related warming trends in Central London since 1900. Weather, 64: 323–327. doi: 10.1002/wea.432
126 Burt S, P Eden 2004: The August 2003 heatwave in the United Kingdom: Part 2 – The hottest sites, Weather, 59:239-242. Wisely is regarded to have become more sheltered with time.
127 Closed in 2010 (Wilby et al. 2011)
128 Wilby RL, PD Jones, DH Lister 2011: Decadal variations in the nocturnal heat island of London, Weather, 66: 59-64.

Appendix 5: Brief history of data collection in London[69]

implications for building design[129] along with heat waves and health[130] and information for decision makers[131]. These studies have used data gathered from relatively low cost sensors deployed across the city for short periods e.g. by BRE[133] and LUCID[134]. MODIS satellite observations of surface temperature, which give a complete spatial pattern at one instance in time but which are limited by the spatial resolution of the pixels (1 km) and the surfaces in the field of view of the sensor[135], have also been used. Numerical modelling of London UHI uses observations in a variety of ways including: statistical[136,137] artificial neural networks[138] and meso-scale numerical techniques[139,140]); and through analysis of global climate model generated data[141,142].

Other applications have resulted in numerous reports for the LCCP including: 'London's changing climate - in sickness and in health' (2011[143]), 'Adapting to climate change: creating natural resilience' (2009[144]), 'Wild weather warning: a London climate impacts profile' (2009[145]) and 'Your Home in a Changing Climate' (2008[146]), along with reports by others[147].

129 Watkins R, J Palmer, M Kolokotroni and P Littlefair 2002a: The London Heat Island—surface and air temperature measurements in summer 2000, ASHRAE Trans 2002 108 (Pt1).
Watkins R, J. Palmer, M. Kolokotroni and P. Littlefair 2002b: The balance of the annual heating and cooling demand within the London urban heat island, BSER & T 23: 207–213
Watkins R, J Palmer, M Kolokotroni, and P Littlefair 2002c: The London Heat Island: results from summertime monitoring BSER & T, 2002 : 97-106
Short CA, Lomas KJ, Woods A 2004: 'Design strategy for low-energy ventilation and cooling within an urban heat island', Building Research & Information, 32: 3, 187-206
Kolokotroni M, Y Zhang, R Watkins 2007: The London Heat Island and building cooling design. Solar Energy 81:102 –110

130 Rooney C, McMichael AJ, Kovats RS and Coleman M 1998: Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. J. Epidemiol. Community Health, 52,.482-486
Mavrogianni A, Davies M, Wilkinson P, Pathan A 2010: London Housing And Climate Change: Impact on Comfort and Health - Preliminary Results of a Summer Overheating Study Open House International, 35, 49-59
Mavrogianni A, M Davies, M Batty, SE Belcher, SI Bohnenstengel, D Carruthers, Z Chalabi, B Croxford, C Demanuele, S Evans, R Giridharan, JN Hacker, I Hamilton, C Hogg, J Hunt, M Kolokotroni, C Martin, J Milner, I Rajapaksha, I Ridley, JP Steadman, J Stocker, P Wilkinson, Z Ye 2011: The comfort, energy and health implications of London's urban heat island BSER &T 32, 35–52

131 McGregor GR, Belcher S, Hacker J, Kovats S, Salmond J, Watkins RW, Grimmond S, Golden J, Wooster M.

133 Graves H, R Watkins, P Westbury, P Littlefair 2001: Cooling buildings in London: overcoming the heat island BRE Report 431, 36 pp.

134 http://www.lucid-project.org.uk/; ESPRC funded 2007-2010 Lead: Mike Davies (UCL)

135 Voogt JA, TR Oke 2003: Thermal remote sensing of urban areas. Remote Sensing of Environment 86, 370-384.

136 Kolokotroni M, Giridharan R, 2008: Urban heat island intensity in London: an investigation of the impact of physical characteristics on changes in outdoor air temperature during summer. Solar Energy 82, 986–998.

137 Giridharan R, Kolokotroni M 2009: Urban heat island characteristics in London during winter Solar Energy, 83: 1668-1682

138 Kolokotroni M, Davies M, Croxford B, Bhuiyan S, Mavrogianni A 2010: A validated methodology for the prediction of heating and cooling energy demand for buildings within the Urban Heat Island Case-study of London Solar Energy, 84: 2246-2255

139 Atkinson BW 2003: Numerical Modelling of urban heat-island intensity. Bound.-Layer Meteorology 109:285-310

140 Bohnenstengel SI, Evans S, Clark PA, Belcher SA 2011: Simulations of the London urban heat island. Quarterly Journal of the Royal Meteorological Society,137 (659) 1625-1640.doi:10.1002/qj.855

141 Kershaw T, M. Sanderson, D. Coley and M. Eames 2010: Estimation of the urban heat island for UK climate change projections Building Serv. Eng. Res. Technol. 31,3, 251–263

142 McCarthy MP, MJ Best, RA Betts 2010: Climate change in cities due to global warming and urban effects, Geophys. Res. Lett., 37, L09705, doi:10.1029/2010GL042845.

143 http://climatelondon.org/publications/in-sickness-and-in-health/

144 http://climatelondon.org/publications/adapting-to-climate-change/

145 http://climatelondon.org/publications/wild-weather-warning/

146 http://climatelondon.org/publications/your-home-in-a-changing-climate/

147 Something in the air. http://www.policyexchange.org.uk/images/publications/something%20in%20the%20air.pdf
http://www.policyexchange.org.uk/publications/category/item/something-in-the-air-the-forgotten-crisis-of-britain-s-poor-air-quality
Gething B 2010: Design for Future Climate: opportunities for adaptation in the built environment Technology Strategy Board - concerned with building design and future climate, with a guide to the interpretation of scientific climate data. Issues addressed are: thermal comfort, treatment of water, flood risk management, structural and construction design. Three summary sheets identify the primary climate variables of interest for building design: to manage water, for comfort, for construction

Appendix 6: Cities with Weather Networks

A number of cities have already implemented networks[148] of sensors to collect weather and climate data for a wide range of applications (e.g. solar power, flooding, multi-hazards early warning system, water use). Some networks of these have been operational for a number of years (e.g. Washington DC, Helsinki, Phoenix), some are no longer operational (e.g. the London BRE network and the MESSAGE mobile network; Tokyo, and Oklahoma City), and some are just starting to come online (e.g. Birmingham, Dallas Fort Worth). For all cities funding is a critical issue. The following Table provides an overview of some of these urban networks. In addition, there are networks of urban flux sites that collect data on heat, water and carbon dioxide exchanges[149].

Examples of cities with meteorological networks: links and references (footnoted) are provided for further details.

Adelaide, Australia	Impact of a large park area[150]
Baltimore, USA	LTER http://www.beslter.org/
Beijing, China	Tall tower data collection 320 m tower Institute of Urban Meteorology, Chinese Meteorological Administration Institute of Atmospheric Physics (IAP), Chinese Academy of Sciences (CAS) State Key Laboratory of Atmospheric Boundary Layer Physics and Atmospheric Chemistry (LAPC)
Berlin, Germany	
Canberra, Australia	Distributed solar power
Chicago, USA	Chicago Urban Climate Forest Project[151]
Copenhagen, Denmark	Copenhagen Climate Change Adaption plan 2011 cloudburst
Dallas Fort Worth, USA	Urban Demonstration Network[152] http://www.casa.umass.edu/main/research/urbantestbed/
Florence, Italy	Carbon dioxide[153]
Hamburg, Germany	Urban Soil Climate Observatory: interactions between pedosphere and atmosphere in the urban environment
Helsinki[154], Finland	Testbed UrbanNet
Hong Kong, China	Typhoons Ventilation and Health
Melbourne, Australia	Water sensitive urban design.
Montreal, Canada	Environmental Prediction in Canadian Cities

148 Muller CL, Chapman L, Grimmond CSB, Young DT, Cai X 2013: Sensors and the city: a review of urban meteorological networks. International Journal of Climatology 33: 1585–1600. doi: 10.1002/joc.3678
149 UrbanFlux network http://www.geog.ubc.ca/urbanflux/
150 Guan et al. (2013) Mapping mean monthly temperatures over a coastal hilly area incorporating terrain aspect effects. Journal of Hydrometeorology, 14, 233-250
Zhu et al. (2013) Influence of sky temperature distribution on sky view factor and its applications in urban heat island International Journal of Climatology DOI: 10.1002/joc.366
151 http://www.nrs.fs.fed.us/pubs/gtr/gtr_ne186.pdf
152 http://www.meteo.fr/cic/meetings/2012/ERAD/extended_abs/QPE_060_ext_abs.pdf
http://www.nap.edu/openbook.php?record_id=13328&page=153
153 Gioli B, Toscano P, Lugato E, Matese A, Miglietta F, Zaldei A, Vaccari FP (2012). Methane and carbon dioxide fluxes and source partitioning in urban areas: The case study of Florence, Italy. Environmental Pollution, 164, 125–131.
Matese A, Gioli B, Vaccari FP, Zaldei A., Miglietta F (2009). CO2 Emissions of the city center of Firenze, Italy: measurement, evaluation and source partitioning. Journal of Applied Meteorology and Climatology, 48, 1940-1947.
154 http://journals.ametsoc.org/doi/pdf/10.1175/2010BAMS2878.1
Wood CR and Järvi L (2012): An overview of urban climate observations in Helsinki. Magazine of the Finnish Air Pollution Prevention Society 3: 30-33.
http://urban.fmi.fi/papers/Wood/Wood+J%C3%A4rvi_2012_AirPoll.pdf

Appendix 6: Cities with Weather Networks

Oklahoma City, USA	Joint Urban 2003[155] http://www.noaa.inel.gov/projects/ju03/ju03.htm http://www.rap.ucar.edu/projects/ju2003/ Micronet http://okc.mesonet.org/redirect.php?/no longer operational
Paris, France	MegaPoli intensive campaign[156]. Government driven climate sensitive design competition LSCE CO2 Map – Eiffel tower instrumented to provide vertical information
Phoenix, USA	AZMET Azmet sites- Phoenix and other urban areas Special reports: Phoenix Area Turf Water Use Report (generated Mondays from February through August) CAPLTER direct site http://caplter.asu.edu/ Long term ecological research site
Rotterdam, Netherlands	UHI, Mobile networks http://knowledgeforclimate.climateresearchnetherlands.nl/hotspots/rotterdam-region
San Francisco, USA	http://datasf.org/story.php?title=san-francisco-wind-monitoring-data-2
Seattle, USA	Rainwatch Snow Watch Wind Climate change
Seoul, South Korea	http://www.wise2020.org/bbs/board.php?bo_table=203 http://www.wise2020.org/bbs/board.php?bo_table=news&wr_id=2 NIMR WISE
Shanghai, China	Multi Hazard Early Warning System; Health Warning System; Chemical Weather System; Integrated with modelling systems; Nested region and Shanghai Expo2010 Shanghai GURME Pilot Project (PDF) Shanghai Meteorological Bureau Observation Data
St Louis, USA	Ameren
Taipei, Taiwan	AClass
Tokyo, Japan	In the past there have been other networks Tokyo Metropolitan Area Convection Study for Extreme Weather Resilient Cities (TOMACS) – current Dense meteorological network (2011-2013) Research and operational instruments
Toronto, Canada	Toronto's Future Weather and Climate Driver Study (primarily modelling)
Vancouver, Canada	Environmental Prediction in Canadian Cities Data
Washington DC & Baltimore, USA	DCNet (downtown) and UrbaNet (extends to Baltimore Maryland) Baltimore Ecosystem Study BalNet

155 Alwine KJ , JE Flaherty (2006) Joint Urban 2003: Study Overview and Instrument Locations http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15967.pdf
156 http://www.atmos-chem-phys.net/special_issue248.html

Appendix 7: Possible Structure of the London Climate Data Portal

The portal proposed in this report would house some information but to the greatest extent possible utilise existing web sites (i.e. provide links rather than duplicating content). However, given the large number of short term projects that have collected valuable data, there would be the capability to archive information about these and the data they have collected to ensure these are not lost. This may include: data, reports, metadata, names of individuals who were involved etc. The portal would act to facilitate archiving in a common way and future-proof this[157].

The intelligent search engine would facilitate those looking for data and select what would be appropriate for particular applications (e.g. purchased freely available, metadata, siting characteristics, quality control) and provide links across the different user communities for relevant information to specific applications. Also the portal will provide links to further information about other key aspects of the analysis of meteorological and climate data (e.g. gap filling, conversion of formats etc). Thus it would act as a network of networks: for meteorological stations, data providers (raw and value added) and data users.

LCDP

Intelligent search engine

Data	**Metadata Map based**	**Services**	**Tools**	**Knowledge Exchange**	**Events Opportunities**	**People**	**Applications**	**Best practice**
Current | Past | F								
S | S | BADC | UK EOF | WOW | S Providers Historical projects	S | S | S Support data e.g. BADC, London Data Portal	S | S | S Providers e.g. of specialised products	S | S | S Gap filling techniques Data formats, for example	Reports Research Projects (past, current) Journal Publications S | S | S	S | S | S	S | S | S Groups/ Companies working in the field	Overheating (heat stress) Flooding, Building Design Energy use, for example	S | S | S

S – site – many examples are given in Appendix 2
F – weather, climate, hydrological, flood, air quality forecasts

157 During the writing of this report there have been requests individuals for data and other's who would like to provide data.

Appendix 8: BT Tower – Vertical Facility

For weather forecasting and air quality forecasting improved vertical information of the atmosphere is extremely important (Grimmond et al. 2010[158], NRC 2011[159], NRC 2012[160]). In London, the BT Tower has provided unique research infrastructure for a wide range of research projects (e.g. REPARTEE, ACTUAL, ClearfLo). Currently access is granted on a case by case basis and requires a large amount of time in each case for permission to be obtained.

If the BT Tower was a facility used more continuously, the observations could be used for research and operations (e.g. skill testing of models, data assimilation) to enhance understanding of meteorology and air quality. For example the following observations could be undertaken using (in most cases) already available equipment:

1) Eddy covariance and other meteorological sensors (Barlow-ACTUAL/Reading, Nemitz- CEH) to monitor turbulent fluxes, wind direction, and wind speed. This would bolster the existing time series which have suffered from prolonged instrument downtime. In particular, spring data are very patchy. Without an extension to the measurement period full seasonal variations, which we know to be important for CO_2, will not be documented. There are few long (i.e. > 6-12 months) methane observations and this is especially true in urban environments.

2) Large aperture scintillometry (Grimmond - Reading) to measure turbulent sensible heat flux at scales that are similar to meso-scale forecasting models.

3) Gradient system (CEH) – to evaluate storage terms the top of the tower is known to become decoupled from street level at night and in winter. This is a crucial for correcting fluxes derived by eddy-covariance.

4) DELTA sensor (Nemitz-CEH) to measure good regional concentrations for NH_3, SO_2, HCl and inorganic aerosol components. This measurement complements the surface concentrations made as part of the Defra funded AGANet. It would provide a measurement which is not made anywhere else and will provide valuable information about the atmospheric composition at that altitude above London that is useful for modellers at relatively low cost and maintenance (monthly changeovers).

5) Aethalometer (Harrison- Birmingham)

6) NO_x,O_3 instruments (Lee -York university): If combined with a gradient system (CEH) measurements of NO_x (10 s) then emission of NO_x from London could be continuously monitored, something of vital importance to Defra. With additional funding, a fast NO_x and eddy covariance (Reading) gives direct NO_x fluxes from calculations

7) High resolution NH_3 instrument (Braban- CEH) a low maintenance instrument is needed.

This would provide ongoing data that could be used to improve meteorological and air quality forecasting while building up a climatology of conditions. Applications include providing estimates of emissions. For example, Helfter et al. (2011)[161] compared CO_2 observations against the NAEI (National Atmospheric Emissions Inventory). CO_2 emissions and were found to agree to within 10%. Previously (see Appendices 2 and 5) other trace gases have been measured during REPARTEE and ClearfLo.

A number of cities round the world have developed permanent vertical observatories (e.g. Shanghai has 13 towers, Beijing, and Paris have such infrastructure).

158 Grimmond CSB, M Roth, TR Oke, YC Au, M Best, R Betts, G Carmichael, H Cleugh, W Dabberdt, R Emmanuel, E Freitas, K Fortuniak, S Hanna, P Klein, LS Kalkstein, CH Liu, A Nickson, D Pearlmutter, D Sailor, J Voogt 2010: Climate & More Sustainable Cities: Climate Information for Improved Planning & Management of Cities (Producers/Capabilities Perspective) Procedia Environmental Science, 1, 247-27

159 NRC 2011: When weather matters National Academies of Science, USA.

160 NRC 2012: Urban Meteorology: Forecasting, Monitoring, and Meeting Users' Needs, National Academies of Science, USA.

161 Helfter C, D Famulari, GJ Phillips, JF Barlow, CR Wood, CSB Grimmond, E Nemitz 2011: Controls of carbon dioxide concentrations & fluxes above central London. Atmos. Chem. Phys. 11, 191-1928 doi: 10.5194/acp-11-1913-2011

Appendix 9: Recommendations

Recommendation 1:

To create and maintain a website with key information on what weather related data are collected for London by whom, both currently and in the past. Hereafter this is referred to as the **London Climate Data Portal (LCDP)**. This will require an ongoing commitment of resources to keep the information current. Links would be made to the London Datastore; BADC, UK-Environmental Observation Framework (UK-EOF) amongst many sites (see Appendix 7). Through a coordinated mechanism, encourage all publicly-funded agencies required to collect weather related data to make such data openly available through existing portals (e.g. BADC, UK-EOF, etc). Other groups who collect meteorological data should also be encouraged to share their data.

Recommendation 2:

Ensure that all networks/individual sites report instrument and site metadata (including photographs in all directions, data processing methods) in the LCDP. This should be accompanied by clear guidance on the conditions and applications for which the use of data are appropriate (see later discussion of need for intelligent search engine, as proposed in Appendix 7). For data with restrictions or embargo on use, details on when they will be released should be recorded in site metadata on the LCDP. Ensure additional information about the sites, instruments and data are collected as they become available, but before critical details are lost (e.g. because personnel have moved or are involved in other projects).

Recommendation 3:

Determine the "shelf life" of the current commercial data. If the observations currently are not publicly available, explore if these could be released after an embargo period. Record this in the LCDP.

Recommendation 4:

Develop a procedure to quality control data that are currently available (Figure 1), to enable broader range of sites (e.g. beyond airport sites) to be more widely used. This would improve the spatial resolution of basic meteorological variables from the rather limited sites that are currently used (Table 5).

Recommendation 5:

As part of LCDP, provide metadata about the networks and sites following the format used by the BADC, IAUC, WOW, FluxNet and/or as recommended by Muller et al. (2013) (as appropriate for site type). This needs to be INSPIRE compliant. Ensure sites have more complete metadata, ideally using a common approach so that metadata can be easily compared.

Recommendation 6:

Map Local Climate Zones (LCZ) for London to identify what types of areas (in terms of land cover/use) are well supported by observational infrastructure and what are underrepresented. This should then guide installation of future sites to enhance spatial resolution and also to make it clear to users what type of urban area the data at a particular station are representative of. Spatial mapping using mobile sensors will facilitate finalizing locations and their representativeness.

Recommendation 7:

Provide guidance on how to interpret meta data in the LCDP and also to identify those who can give guidance on interpretation for a particular application.

Appendix 9: Recommendations

Recommendation 8:

Provide information on the LCDP not only about the data format used by the meteorological networks but also (1) software and its availability for converting data between formats; (2) details of companies that provide services for converting data into other formats and who may provide additional products, such as gap-filled data; (3) links to resources on how to convert non-proprietary formats to other commonly used data formats; and (4) references to standard protocols for gap filling data and software, if available.

Recommendation 9:

Provide links on the LCDP to other relevant spatial data (e.g. London Data Portal, UK-EOF) (that is INSPIRE compliant). Given many users want to use meteorological data in conjunction with other spatial data

Recommendation 10:

Use maps to show availability of data, with links to metadata (e.g. QAQC status, height of sensor, scale of measurement etc), so proximity to areas of interest can be determined easily.

Recommendation 11:

Once an improved QAQC spatial data set are available, and evaluation made of the urban characteristics (e.g. LCZ map) represented, identify where new stations are needed to enhance both spatial resolution but more so the representativeness of the areas observed. These new stations are most likely to be needed for measurements of wind and precipitation.

Recommendation 12:

Encourage those involved in data collection to improve the quality of currently collected data (e.g. ensuring leaves do not block rain gauges) wherever possible. This could be facilitated by cross network QAQC processes, with an email to site operators when problems are identified. (e.g. LondonClimate.info has a system that operates continuously looking for missing data or outliers and emails are generated when a problem is identified).

Recommendation 13:

Where possible try to ensure continuity of stations so that the longer term statistical characteristics can be determined. In order to try to ensure continuity of stations, the LCCP should facilitate/encourage dialogue between network operators and land owning authorities with a vested interest in long term observations.

Recommendation 14:

Enhance the collection of vertical meteorological information. This would be extremely beneficial for weather and air quality forecasting. One site that could be used to provide this infrastructure is the BT Tower (Appendix 8). This would require ongoing funding support to ensure data quality and an agreement with BT for access. This would also allow for a wide range of research. Potential funders include: NERC, EPSRC, Met Office, Defra and private companies.

Recommendation 15:

Include in the LCDP a central repository or links to research papers and reports published on London meteorological and air quality data.

Appendix 9: Recommendations

Recommendation 16:

Develop a coordinated network between institutions to identify which technologies should be tested to facilitate operations and move from research infrastructure to on-going operations.

Recommendation 17:

Include data from new technologies in the LCDP and QAQC data products. Following gap analyses (Recommendation 6), consider investing in combining new technologies (e.g. wireless sensors, vehicle interrogated sensors from standard vehicle fleets, other mobile sources such as smart phones and/or vehicles more generally) with more standard sensors and smart computing to provide high spatial resolution information near the surface with sufficient redundancy that real-time QA/QC could be performed to provide a reliable product in close to real-time. Subsequent re-analysis could provide further higher quality products for a wide range of variables.

Recommendation 18:

Encourage individual data collection groups and funders to provide regular and on-going updated information about data availability to LCDP. Have the host of the data portal undertake a routine 3-6 monthly check that all links are working and follow up with organisations regularly so that there is an expectation that information on site or data changes is kept up to date and with changing personnel. Actively monitor and not lost evaluate new technologies and opportunities to improve the spatial and temporal data provided through the LCDP.

These can be grouped into the following:

Recommendation for a London Climate Data Portal (LCDP)

Create and maintain a website with key information on what weather related data are collected for London by whom, both currently and in the past. The LCDP should include (either directly or as links):

- Searchable map and database of locations where data are collected with links to site metadata (e.g. QAQC status, height of sensor, scale of measurement etc)
- Data publicly-funded agencies that are required to collect data and other groups who will provide it; data with restrictions or embargoes with information on when it will be released)
- Determine the “shelf life” of the current commercial data. If these observations currently are not publicly available, explore if they could be released after an embargo period.
- Guidance on how to interpret metadata and identify providers who can give guidance to for a particular application.
- Links to research papers and reports published on London meteorological and air quality data
- Information about the data formats used by the meteorological networks, plus (1) software and its availability to convert data between formats; (2) details of companies that provide services to convert data into other formats and who may provide additional products (e.g. gap-filled data); (3) links to resources on how to convert non-proprietary formats to other commonly used data formats; and (4) references to standard protocols for gap filling data and software, if available.
- Links to other relevant spatial data
- Guidance of what types of areas data sites are representative of (e.g. maps of Local Climate Zones)

Appendix 9: Recommendations

The LCDP should:

- Be INSPIRE compliant
- Make use of available web sites and portals where possible (e.g. London Datastore data.London.gov.uk BADC http://badc.nerc.ac.uk/home/; UK-EOF http://www.ukeof.org.uk/)
- Be kept current. The host of the data portal should undertake routine (e.g. 3-6 monthly) checks that all links are working and follow up with organisations regularly so that there is an expectation that information on site or data changes are kept up to date and with changing personnel. This will not need an ongoing commitment of resources (Appendix 7)

An ongoing commitment of resources would be needed to keep the information current (Appendix 7)

Recommendation to improve quality of currently collected data

- Develop protocols and procedures to quality control the data that are currently available (as identified by LCDP)
- Encourage data collectors to improve the quality of currently collected data (e.g. ensuring leaves do not block rain gauges) wherever possible. This could be facilitated by cross network QAQC process (e.g. email site operators when problems are identified). Automated systems allow these to be picked up rapidly (e.g. LondonClimate.info has a system that operates continuously looking for missing data or outliers with emails sent when a problem is identified).

Recommendation to evaluate data gaps:

- Map Local Climate Zones (LCZ) for London to identify the types of areas (in terms of land cover/use) that are well supported by observational infrastructure (using LCDP) and those that are underrepresented. This should guide installation of future sites to enhance spatial resolution and provide guidance to users about what type of urban area the data at a particular station are representative of. Maps and site guidance should be added to the LCDP.
- Once improved QAQC spatial data sets are available, and evaluation made of the urban characteristics (e.g. LCZ map) represented, identify where new stations are needed to enhance both spatial resolution and representativeness of the areas observed. These are most likely to be needed for measurements of wind and precipitation.

Recommendation to ensure continuity of stations

- Where possible try to ensure continuity of stations so that the longer term statistical characteristics, critical for many applications, can be determined. In order to try to ensure continuity of stations, the LCCP should facilitate/encourage dialogue between network operators and land owning authorities with a vested interest in long term observations.

Recommendations for new observations:

- Enhance the collection of vertical meteorological information – this would be extremely beneficial to weather and air quality forecasting. One site that could be used to provide this infrastructure is the BT Tower (Appendix 8). This would require ongoing funding support to ensure data quality and an agreement with BT for access. This would also allow for a wide range of research.
- Include data from new technologies in the LCDP and QAQC data products. Following gap analyses, invest in combining new technologies (e.g. wireless sensors, vehicle interrogated sensors from standard vehicle fleets or other sources such as mobile smart phones and/or vehicles more generally) with more standard sensors and smart computing to provide high spatial resolution information near the surface with sufficient redundancy that real-time QA/QC could be performed to provide a reliable product in close to real-time. Subsequent re-analysis could generate further higher quality products a wide range of variables.
- Develop a coordinated network between institutions to identify which technologies should be tested to facilitate operations and move from research infrastructure to on-going operations.
- Actively monitor and evaluate new technologies and opportunities to improve the spatial and temporal data provided on the LCDP.

Observing London:
Weather data needed for London to thrive

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