

Urban Heat Island and Air Quality of London, UK

1. Introduction

Southeast England enjoys a near continental climate that is most pronounced in the Thames Valley. The region is relatively sheltered from the influence of mid-latitude depressions and, as a consequence, is one of the driest and sunniest parts of mainland Britain. Around the Thames estuary annual rainfall totals average just 500 mm, compared with 600-650 mm across the Thames Valley, and over 1000 mm on the South Downs (Mayes, 1997). Unfortunately, the climate of London also favours the development of photochemical smog arising from the production of ozone in the presence of pollutants from vehicles and the catalysing effect of sunshine. Extensive urban and suburban landscapes mean that under light winds and little cloud cover, a heat island may develop too, further aggravating local heat stress (Oke, 1987). This is because the urban fabric changes the energy and radiation balance, hydrology and airflow characteristics relative to rural and suburban sites.

The following sections draw on material from the London Climate Change Partnership (2002) scoping study of climate change impacts. London's urban heat island and air quality are discussed for present and future climate conditions.

2. Present climate

2.1. London's Heat Island

Central London can be several degrees warmer than surrounding rural areas due to the urban heat island effect (Lee, 1992). For example, the average peak temperature difference between the British Museum and a rural reference station in Langley Country Park (about 30km west) was 3°C over the summer of 1999 (Graves et al., 2001). Increased urban temperatures have an impact on the summer cooling demand in relation to the "intensity" of the heat island – defined as the peak difference between urban and rural temperatures. Detailed monitoring indicates that the heat island is most pronounced at night, that it weakens with increasing wind speed and distance from central London, and that the location of the thermal maximum shifts with changes in wind direction (Graves et al., 2001). **Figure 1a** shows that the heat island is also highly changeable from one day to the next (as a consequence of variable weather patterns), attaining differences of up to 7°C between St James's Park and Wisley on some nights. The annual number of nights with intense heat islands (defined herein as greater than 4°C) has been climbing at a rate of over four days per decade since the late 1950s (**Figure 1b**). The average nocturnal heat island intensity increased at the rate of 0.1°C per decade over the same period. Conversely, the number of intense day-time heat-islands has declined to about one event per year since the mid 1980s (**Figure 1c**).

Figure 1a Difference in nocturnal minimum (left column) and day-time maximum (right column) daily temperatures between St James's Park (central London) and Wisley (rural Surrey), July to August 1995.

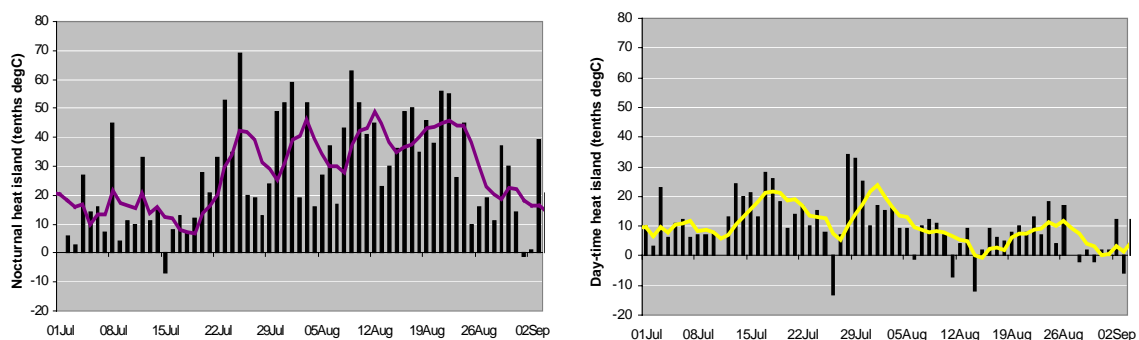


Figure 1b Annual frequency of days with nocturnal heat island intensity greater than 4°C (left column), and annual average nocturnal heat island intensity (right column) between St James's Park (central London) and Wisley (rural Surrey), 1959-1998. Note: data for November-December 1998 are missing.

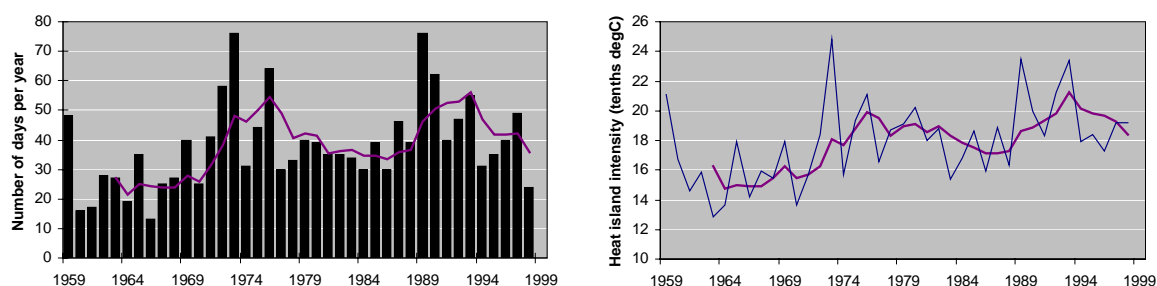
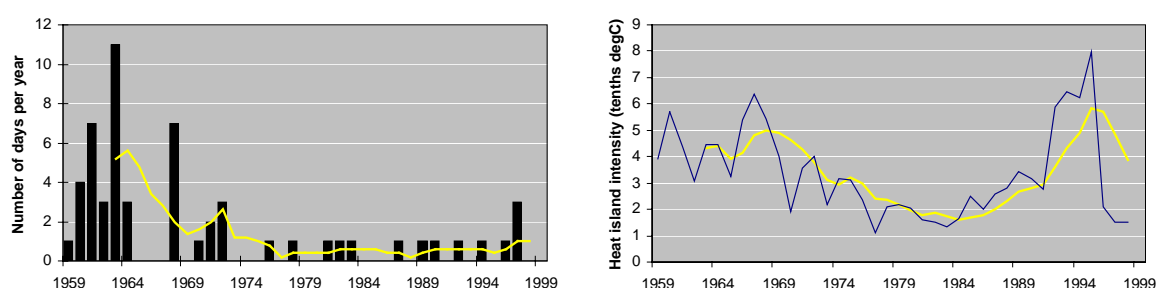


Figure 1c As in Figure 1b, but for day-time maximum temperatures.



2.2 London's Air Quality

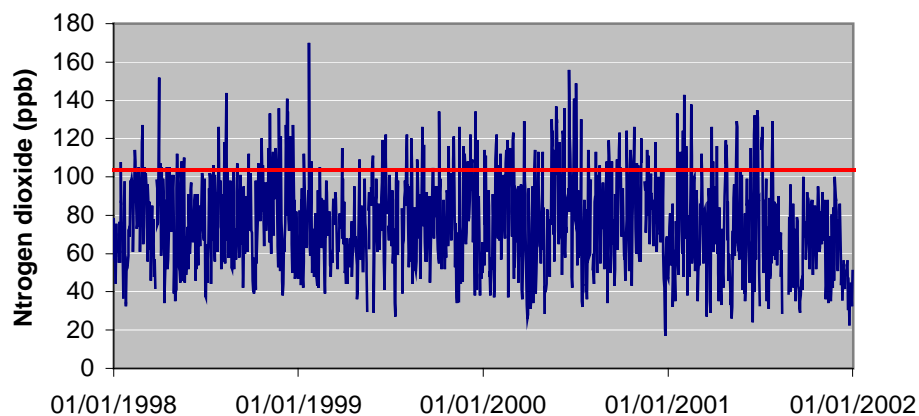
The UK Government's National Air Quality Standards (NAQS) represent defined levels of air quality which avoid significant risks to health for eight pollutants (benzene, 1,3-butadiene, carbon monoxide, lead, nitrogen dioxide, ozone, particulates (PM₁₀), and sulphur dioxide). Air quality is monitored by the National Automated Monitoring Networks and Non-automatic Networks at over 1500 sites across the UK, with data available as far back as 1972 for some sites. The reliable detection of air quality trends is complicated by the brevity of data sets, changes in instrumentation, representativeness of monitoring sites and the strong control exerted by weather patterns on pollution episodes (Crabbe et al., 1999; McGregor and Bamzels, 1995; Scaperdas and Colville, 1999; Comrie, 1992).

According to the Sustainable Development Unit, Defra, there has been a decline in the number of days nationally when air pollution was classified as moderate or high at urban sites from an average of 59 days per site in 1993, to 21 days in 2001. However, air quality remains at unacceptable levels in many parts of London. For example, in Marylebone particulate concentrations exceeded NAQS on over 30 days in 1998 and 1999 (EA, 2001). Furthermore, a positive correlation has been shown between air pollution and social deprivation in London, with higher concentrations of nitrogen dioxide and particulates found in areas exhibiting higher social deprivation (Pye et al., 2001).

Traffic emissions of nitrogen dioxide and particulates have replaced sulphur dioxide from coal-burning as the most significant air quality problems currently facing London (Eagleson et al., 1992). The highest concentrations of nitrogen dioxide are found in central London (**Figure 2**) and along busy road corridors. Background concentrations of particulates are highest in the east of the Thames Region due to secondary particles, such as sulphate and nitrate formed from chemical reactions in the atmosphere, that originate from mainland Europe. Concentrations of sulphur

dioxide are also highest in the East Thames Corridor due to emissions from a number of power stations and a refinery (EA, 2001). Maximum concentrations of ozone, however, tend to occur at weekends outside of central London due to transportation by wind (Wilby & Tomlinson, 2000), as well as lower concentrations of ozone destroying pollutants (principally nitric oxide) in rural areas. Peak ozone concentrations in central London typically occur under stable summer anticyclonic weather which favours photochemical action (O'Hare & Wilby, 1994).

Figure 2 Daily maximum hourly average nitrogen dioxide concentrations (ppb) kerbside at Marylebone Road, 1998-2001. Note: the National Air Quality Standard for nitrogen dioxide is 105 ppb for a one hour mean. This limit should not be exceeded more than 18 times per year.



Data source: National Environmental Technology Centre.

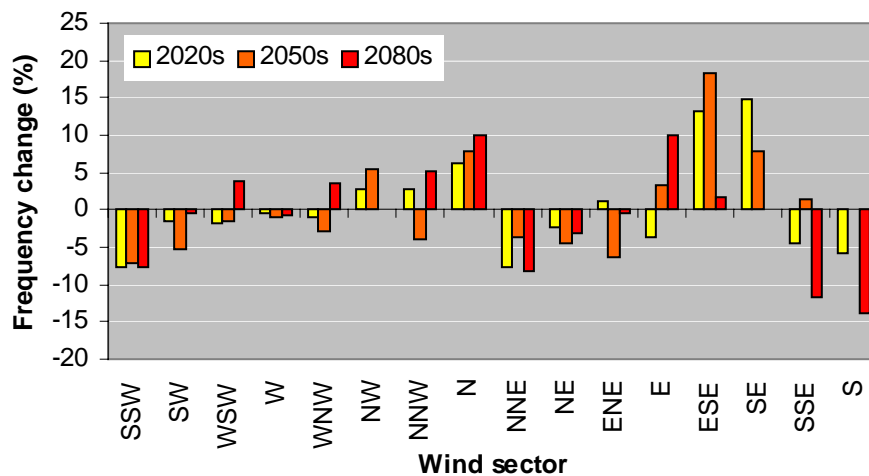
3. Future climate

3.1 Projected changes in the urban heat island

Heat waves may increase in frequency and severity in a warmer world. Urban heat islands exacerbate the effects of heat waves by increasing summer temperatures by several more degrees Celsius relative to rural locations (see **Figure 1b**). This can lead directly to increases in mortality amongst sensitive members of the population (Kunst et al., 1993; Laschewski and Jendritzky, 2002). For example, the heat waves in the summers of 1976 and 1995 were associated with a 15% increase in mortality in greater London (Rooney et al., 1998). Conversely, it has been estimated that 9000 wintertime deaths per year could be avoided by 2025 in England and Wales under a 2.5°C increase in average winter temperatures (Langford and Bentham, 1995).

Early surveys of London's heat island indicated that the peak usually lies north-east of central London in Hackney and Islington, reflecting the density of urban development, and the displacement of the heat-island by prevailing south-westerly winds (Chandler, 1965). More recent monitoring has highlighted the mobility of the peak in relation to hourly shifts in wind direction (Graves et al., 2001). The thermal centre typically moves by several kilometres in line with the change in wind direction, therefore, future changes in the frequency of different wind directions could have an impact on the future location of the thermal centre. **Figure 3** indicates a general increase in airflows from the east and south-east at the expense of airflows from the south and south-west under the SRES A2 emissions scenario. This implies that the thermal centre could lie more often over the west and north-west sectors of the City. However, this inference should be treated with extreme caution because the storm tracks in HadCM3 are known to be displaced too far south over Europe, adversely affecting the realism of modelled airflows over southern England (Hulme et al., 2002). Furthermore, projected changes in airflow are generally small relative to natural variability.

Figure 3 Changes in the frequency of daily airflows over Eastern England projected by HadCM3 under the SRES A2 emissions scenario by 2020s, 2050s and 2080s. Changes are

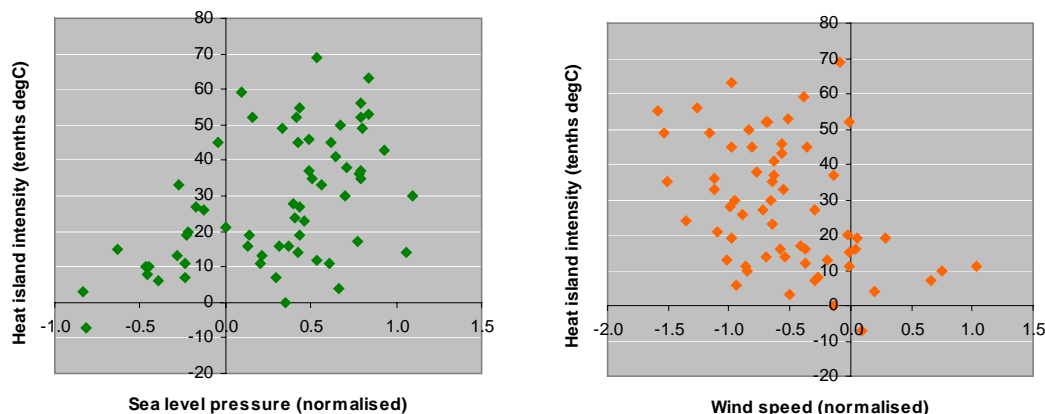


with respect to the 1961 to 1990 average.

The intensity of London’s nocturnal heat island has been modelled using daily minimum temperatures for St James’s Park (urban site) and Wisley in Surrey (rural reference station 30 km to the southwest) (Wilby, 2003). The average nocturnal heat island intensity for the period 1961 to 1990 was +1.8°C, ranging from +10.0°C (on 14 January 1982) to –8.9°C (on 31 May 1970), with 5% of days having an intensity of 5°C or more. In comparison, the average day-time heat island intensity was just +0.3°C, ranging between +11.7°C (on 30 May 1963) and –6.7°C (on 12 December 1963).

The statistical downscaling model SDSM (Wilby et al., 2002) was calibrated using 1961 to 1990 daily minimum temperature differences between St James’s and Wisley, and gridded climate variables for Eastern England. Significant correlations were found between the intensity of the heat island and several regional climate indices (most notably mean sea level pressure, strength of airflow, vorticity and near surface relative humidity). For example, **Figure 4** shows the relationship between the nocturnal heat island intensity and pressure/ wind speed during the summer of 1995. The scatterplots show that the intensity is greater under conditions of high pressure and low wind speeds (i.e., anticyclonic weather). Interestingly, the nocturnal heat island intensity is only weakly correlated with regional temperatures, suggesting that future changes in the heat island will be largely independent of projected temperature changes.

Figure 4 The relationship between London’s nocturnal heat island intensity and sea level pressure, and wind speed, July to August 1995.



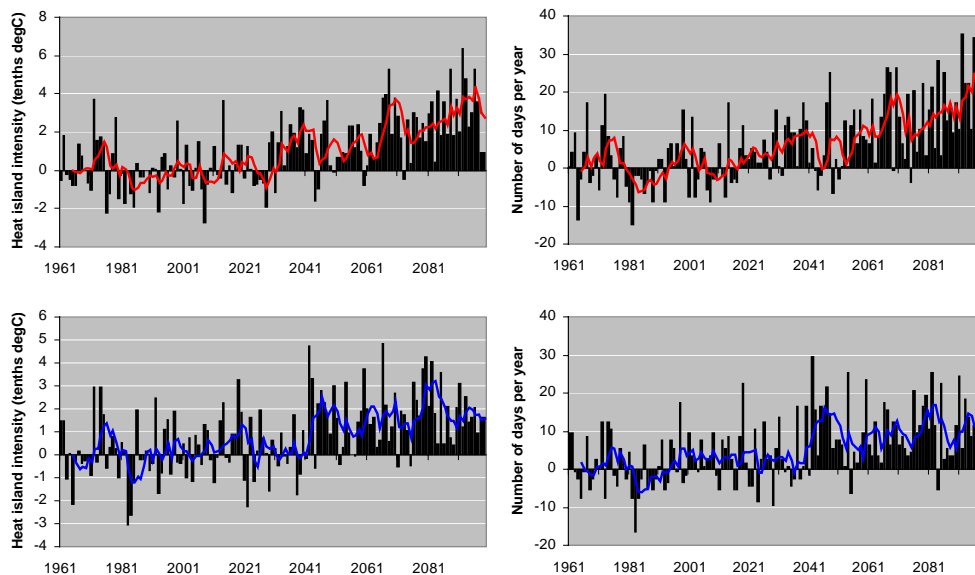
Having established the historic relationship between the nocturnal heat island intensity and regional weather, SDSM was then used to produce future estimates of the heat island under the SRES A2 and B2 emissions scenarios (Wilby, 2003). Under both scenarios there are progressive increases in both the intensity (i.e., annual average temperature difference between the sites) and number of days on which the intensity exceeded 4°C (Table 1). In line with past experience, there remains considerable interannual variability in both measures (Figure 5). Under the A2 emissions scenario, the nocturnal heat island intensity increases by 0.26°C and the number of intense urban-rural differences by 15 days/year by the 2080s. Note that these heat island temperature changes are in *addition* to projected regional warming, and relate to annual averages (Table 1). For example, as a first-order approximation for introducing heat island effects, the additional annual average temperature increase for London relative to rural sites in the region could be ~ 2.1°C under the A2 emissions scenario (i.e., 1.8°C from 1961-90 plus 0.26°C intensification by the 2080s). However, observed data suggest that the most intense nocturnal heat islands develop in summer, and that these could have more adverse consequences for London in the future, including reduced night-time relief during heat-waves, and reduced ambient cooling of the London Underground transport system.

Table 1 Changes in the average nocturnal heat island intensity, net temperature[†] and, change in the number of intense (>4°C urban-rural difference) heat island days in central London (A2, and B2 emissions, downscaled from HadCM3 output), for the 2020s, 2050s and 2080s with respect to the 1961 to 1990 average.

Scenario	SRES A2 emissions			SRES B2 emissions		
	ΔIntensity (°C)	ΔTemperature (°C)	ΔFrequency (days)	ΔIntensity (°C)	ΔTemperature (°C)	ΔFrequency (days)
2020s	0.07	2.4 – 2.9	5	0.03	2.3 – 2.8	3
2050s	0.16	4.0 – 4.5	9	0.17	3.5 – 4.0	10
2080s	0.26	5.6 – 6.1	15	0.19	4.5 – 5.0	11

[†] Change in net temperature = baseline heat island (1961-1990) + heat island intensification (by date) + regional warming (by date)

Figure 5 Change in annual average nocturnal heat island intensity (left column) and the number of intense (>4°C urban-rural difference) heat island days (right column) in central London (A2 emissions [top row], and B2 emissions [bottom row], downscaled), with respect to



the 1961 to 1990 average.

3.2 Projected changes in air quality

Air pollution is already a serious health problem in many cities even under the current climate (Anderson et al., 1996; COMEAP, 1998). Climate change is expected to cause further deterioration in air quality in large urban areas. This is because future weather will have a major influence on the production, transport and dispersal of pollutants. Any increase in the frequency of hot, anticyclonic weather in summer will favour the creation of more temperature inversions trapping pollutants in the near-surface layer of the atmosphere. For example, it has been estimated that a 1 degree Celsius rise in summer air temperatures (also a proxy for the amount of catalysing sunshine) is associated with a 14% increase in surface ozone concentrations in London (Lee, 1993).

Higher air temperatures increase natural and man-made emissions of volatile organic compounds (VOCs) (Sillman and Samson, 1995), exacerbating the health effects of ozone pollution (Sartor et al., 1995). Climate change is also expected to affect the seasonality of pollen-related disorders such as hay fever (Emberlin, 1994). Meteorological factors are shown to exert strong controls on the start date and length of the pollen season (Emberlin, 1997), as well as the total pollen count (Takahashi et al., 1996). Acute asthma epidemics have also been linked to high pollen levels in combination with thunderstorms (Newson et al., 1998). During one such event in 1994 London health departments ran out of drugs, equipment and doctors (Davidson et al., 1996). Finally, deteriorating air quality as a result of climate change could have secondary impacts on the vitality of urban forests and parkland. For example, surface ozone has adversely impacted the structure and productivity of forest ecosystems throughout the industrialized world (Krupa and Manning, 1988). Levels of acid deposition are also closely linked to the frequency of large-scale weather patterns across the UK (Davies et al., 1986).

As noted previously, weather patterns are a strong determinant of ambient air quality and pollution episodes (O'Hare and Wilby, 1994). Therefore, future air pollution concentrations in London will reflect local and regional patterns of emissions, as well as the frequency of large high-pressure systems over the south-east. Whilst it is beyond the scope of the present study to model the complex interactions between pollutant emissions, photochemistry, transport and dispersal, it is possible to speculate about the future frequency of "pollution-favouring" weather patterns. Whereas vigorous westerly airflows favour the dispersal of pollutants, stagnant anticyclonic weather provides ideal conditions for *in situ* pollution episodes (e.g., Bower et al., 1992).

Figure 6 Change in the number of summer weather patterns favouring pollution episodes over the Eastern England grid-box under the A2 emissions (left column) and B2 emissions (right column) scenarios, with respect to the 1961 to 1990 average.

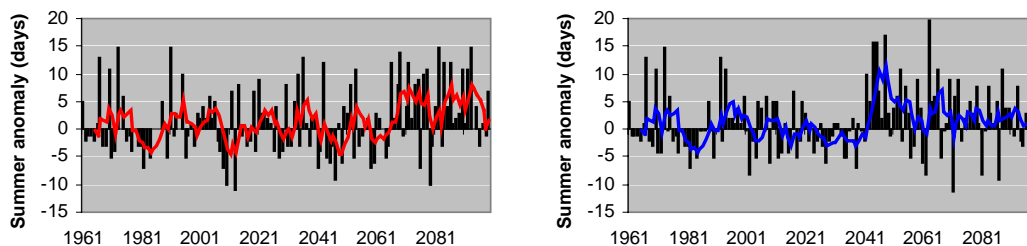


Figure 6 shows changes in the frequency of high-pressure systems over Eastern England projected by HadCM3 under the A2 and B2 emissions scenarios. Under A2 emissions there is an average increase in the frequency of weather patterns

favouring pollution episodes of over 4 days per summer by the 2080s compared with the 1961 to 1990 mean. The change under the B2 emissions is just over 2 days per summer by the 2080s. A shift to more frequent airflows from the east and south-east (**Figure 3**) would also favour more frequent incursions of (polluted) air from continental Europe (O'Hare and Wilby, 1994). However, **Figure 6** indicates considerable inter-annual variability in the frequency of summer pollution episodes, and caveats related to future airflows projections by HadCM3 apply. Notwithstanding significant reductions of diffuse emissions over north-west Europe, the model projections are still indicative of deteriorating air quality conditions for London under future climate change.

Bibliography

- Anderson, H.R., Ponce de Leon A, Bland J.M. 1996. Air pollution and daily mortality in London: 1987-92. *British Medical Journal*, 312, 665-669.
- Ashmore, M., Bell, N. and Rutter, J. 1985. The role of ozone in forest damage in West Germany. *Ambio*, 14, 81-87.
- Atkinson, B.W. 1968. A preliminary examination of the possible effect of London's urban area on the distribution of thunder rainfall 1951-60. *Transactions of the Institute of British Geographers*, 44, 97-118.
- Bower, J.S., Broughton, G.F.J., Stedman, J.R. and Williams, M.L. 1994. A winter NO₂ smog episode in the UK. *Atmospheric Environment*, 28, 461-475.
- Chandler, T.J. 1965. *London Weather*, London: Hutchinson.
- COMEAP, 1998. *Quantification of the effects of air pollution on health in the United Kingdom*. Great Britain Committee on the Medical Effects of Air Pollutants. HMSO: London, 78pp.
- Comrie, A.C. 1992. A procedure for removing the synoptic climate signal from environmental data. *Journal of Climatology*, 12, 177-183.
- Crabbe, H., Beaumont, R., Norton, D., 1999. Local air quality management: a practical approach to air quality assessment and emissions audit. *The Science of the Total Environment* 235, 383-385.
- Davidson, A., Emberlin, J. and Cook, A. 1996. A major outbreak of asthma associated with a thunderstorm: experience of accident and emergency departments and patients' characteristics, Thames Regions Accident and Emergency Trainees Association. *British Medical Journal*, 312, 601-604.
- Davies, T.D., Kelly, P.M., Brimblecombe, P., Farmer, G. and Barthelmie, R.J. 1986. Acidity of Scottish rainfall influenced by climate change. *Nature*, 232, 359-361.
- Eagleson, S., Hackman, M.P., Heyes, C.A., Irwin, J.G., Timmis, R.J. and Williams, M.L. 1992. Trends in urban air pollution in the UK during recent decades. *Atmospheric Environment*, 26B, 227-239.
- Emberlin, J. 1994. The effects of patterns in climate and pollen abundance on allergy. *Allergy*, 94, 15-20.
- Emberlin, J. 1997. The trend to earlier birch pollen seasons in the UK: a biotic response to changes in weather conditions. *Grana*, 36, 29-33.
- Environment Agency 2001. *State of the environment report for London*. Environment Agency: Reading.
- Graves, H.M., Watkins, R, Westbury, P and Littlefair, P.J. 2001. *Cooling buildings in London*, BR 431, London, CRC Ltd.
- Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. 2002. *Climate Change Scenarios for the UK: The UKCIP02 Scientific Report*, Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich, UK. 120pp.
- Krupa, S.V. and Manning, W.J. 1988. Atmospheric ozone: formation and effects on vegetation. *Environmental Pollution*, 50, 101-137.

- Kunst, A.E., Looman, C.W.N. and Mackenbath, J.P. 1993. Outdoor air temperature and mortality in the Netherlands: a time-series analysis. *American Journal of Epidemiology*, **137**, 331-341.
- Langford, I.H. and Bentham, G. 1995. The potential effects of climate change on winter mortality in England and Wales. *International Journal of Biometeorology*, **38**, 141-147.
- Laschewski, G. and Jendritzky, G. 2002. Effects of the thermal environment on human health: an investigation of 30 years of daily mortality data from SW Germany. *Climate Research*, **21**, 91-103.
- Lee, D.O. 1992. Urban warming?: an analysis of recent trends in London's heat island. *Weather*, **47**, 50-56.
- Lee, D.O. 1993. Climatic change and air quality in London. *Geography*, **78**, 77-79.
- London Climate Change Partnership, 2002. *A climate change impacts in London evaluation study*. Final Technical Report, Entec UK Ltd.
- Mayes, J, 1997. South-east England. In: Wheeler, D. and Mayes, J. (Eds.) *Regional climates of the British Isles*, London: Routledge.
- McGregor, G. and Bamzels, D. 1995. Synoptic typing and its applications to the investigation of weather air pollution relationships, Birmingham, UK. *Theoretical and Applied Meteorology*, **51**, 223-236.
- Newson, R., Strachan, D., Archibald, E., Emberlin, J., Hardaker, P. and Collier, C. 1998. Acute asthma epidemics, weather and pollen in England, 1987-1994. *European Respiratory Journal*, **11**, 694-701.
- O'Hare, G.P. and Wilby, R.L. 1995. Ozone pollution in the United Kingdom: an analysis using Lamb circulation types. *Geographical Journal*, **161**, 1-20.
- Oke, T.R. 1987. *Boundary layer climates*. London: Routledge.
- Pye, S., Stedman, J., Adams, M. and King, K. 2001. *Further analysis of NO₂ and PM₁₀ air pollution and social deprivation*. A report produced for the Department for Environment, Food and Rural Affairs, The National Assembly for Wales, and Department of the Environment in Northern Ireland. AEAT/ENV/R/0865.
- Rooney, C., McMichael, A.J., Kovats, R.S. and Coleman, M. 1998. Excess mortality in England and Wales, and in Greater London, during the 1995 heatwave. *Journal of Epidemiology and Community Health*, **52**, 482-486.
- Sartor, F., Snacken, R., Demuth, C. and Walckiers, D. 1995. Temperature, ambient ozone levels, and mortality during summer 1994 in Belgium. *Environmental Research*, **70**, 105-113.
- Scaperdas, A. and Colvile, R.N., 1999. Assessing the representativeness of monitoring data from an urban intersection site in central London, UK. *Atmospheric Environment* **33**, 661-674.
- Sillman, S. and Samson, P.J. 1995. Impact of temperature on oxidant photochemistry in urban, polluted rural, and remote environments. *Journal of Geophysical Research*, **100**, 11497-11508.
- Takahashi, Y., Kawashima, S. and Aikawa, S. 1996. Effects of global climate change on Japanese cedar pollen concentration in air – estimated results obtained from Yamagata City and its surrounding area. *Arerugi*, **45**, 1270-1276.
- Wilby, R.L. 2003. Past and projected trends in London's urban heat island. *Weather*, **58**, 251-260.
- Wilby, R.L. and Tomlinson, O.J. 2000. The "Sunday Effect" and weekly cycles of winter weather in the UK. *Weather*, **55**, 214-222.
- Wilby, R.L., Dawson, C.W. and Barrow, E.M. 2002. SDSM – a decision support tool for the assessment of regional climate change impacts. *Environmental and Modelling Software*, **17**, 145-157.
- Zierl, B. 2002. Relations between crown condition and ozone and its dependence on environmental factors. *Environmental Pollution*, **119**, 55-68.