Restless climate: Lessons using data skills

Royal Geographical Society with IBG
Advancing geography and geographical learning

Lesson 5: Investigating the incidence of heatwaves in London

Lesson objectives

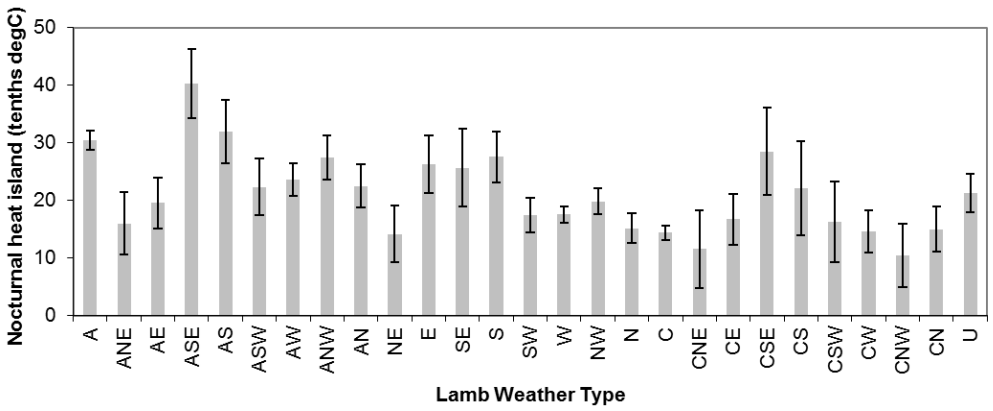
- To use daily air temperature records and the Chi-squared test to investigate weekly and seasonal patterns in the occurrence of severe heatwaves in the city of London.
- To explore possible links between the urban heat island effect and high night-time temperatures in central London since the late 1950s.

Setting the scene

Extreme air temperatures are the deadliest natural disaster affecting Europe and North America. For example, it is estimated that the August 2003 heatwave claimed 72,210 lives across 15 European countries, with the majority in France, Italy and Spain. In the UK, there were 2091 excess fatalities during the period 4-13 August 2003 as temperatures soared to a new of record of 38.5°C (101.3°F). Another heatwave in July 2010 caused 55,700 deaths in the Russian Federation due, in part, to high concentrations of ozone and fine particulates from wildfires.

UK heatwaves are most likely in summer months when there is high atmospheric pressure, clear skies, long days with strong sunshine, and low wind speeds. These anticyclonic (A) weather conditions also favour the development of intense urban heat islands (UHIs) – phenomena manifested by higher temperatures in city centres than surrounding rural areas (Figure 1). The fabric of built environments absorbs solar heating and, with artificial heat sources (from factories, transport systems, air conditioning outlets, etc.), can be 8-10°C warmer than their greener, lightly developed suburbs. The effect is most pronounced on cloudless, still summer and autumn nights.

Figure 1. Mean intensity of London's nocturnal UHI (in tenths °C) under different Lamb Weather Types. *A* denotes anticyclonic, *C* cyclonic, *U* unclassified. Other letters are hybrid A- or C-types with wind direction; hence *ASE* signifies an anticyclonic pressure pattern with southeasterly wind flows. T-bars denote the 95% confidence range of the sample means (i.e. two standard errors).



Rising air temperatures and UHIs combined with ageing and expanding urban populations are all increasing the risk of deadly heatwaves. The National Health Service and Met Office have responded to this serious threat to public well-being by developing a *Heatwave Plan for England*[1]. This includes issuing Heat-Health Watch Alerts for London when maximum temperatures are expected to reach 32°C during the day or 18°C during the night. This lesson examines air temperature data for London to determine when these conditions are most likely and how the frequency of life-threatening temperatures has changed since the 1950s.

The data

Long-term, daily temperature measurements are available in digital format for surprisingly few sites in and around London. The best records are for Kew Observatory since 1881, St James's Park (SJP) from 1907, and Wisley (WIS) after 1931. Unfortunately, Kew Observatory was closed in 1980 and more recent data for Kew Gardens shows a discontinuity with the earlier series. Another record at Heathrow begins in 1949 but has been affected by urban development. Hence, the SJP and WIS records have been used in several studies to represent the temperature difference between central London (i.e. urban) and suburban (i.e. semi-rural) conditions respectively.

This lesson uses four indices of London's urban heat island for the period 1959 to 2010:

(a) ***The nocturnal urban heat island (nUHI) index*** for London based on the difference between daily minimum air temperatures (Tmin) at SJP and WIS. When nUHI is positive central London is warmer at night than surrounding suburbs.
(b) ***The day-time urban heat island (dUHI) index*** for London based on the difference between daily maximum air temperatures (Tmax) at SJP and WIS. When dUHI is positive central London is warmer during the day than surrounding suburbs.
(c) ***The annual frequency of intense nUHI*** defined here as nUHI higher than or equal to 4°C.
(d) ***The frequency of hot-nights*** defined here as when minimum air temperatures in central London do not fall below 18°C – the local 'danger' threshold used by the Met Office National Severe Weather Warning Service.

The raw data are available in Microsoft Excel file 'L5_Data_UHI.xlsx', the accompanying 'Datasheet 5'. The first tab in the file 'Daily nUHI' contains the following data:

Table 1. Indicators of nocturnal urban heat island intensity (nUHI) in London.

Day	Mean nUHI intensity (tenths °C)	Maximum nUHI intensity (tenths °C)	Frequency of intense nUHI (nUHI ≥ 4°C)	Frequency of hot nights (Tmin ≥ 18°C)
Sun	17.8	95	306	35
Mon	17.7	135	268	32
Tue	18.2	116	317	31
Wed	17.6	123	282	26
Thu	18.2	139	310	24
Fri	17.7	133	296	29

Tasks

1. **How much does the strength of London's nocturnal UHI vary during the week?**
   Use the data in Table 1 and graph paper to plot separately (1) the mean nUHI and (2) maximum nUHI by day of week. What day(s) on average have the most/least intense nocturnal heat islands? What factors might explain ***weekly*** variations in nUHI in London?

   Take it further: Plot weekly variations in (3) the frequency of hot nights by day of week. Account for any differences between graph (3) and the findings in graphs (1) and (2) above.

[1] https://www.gov.uk/government/publications/heatwave-plan-for-england

2. How significant are weekly variations in London's nocturnal UHI?
Use the Chi-squared (χ^2) test to evaluate the statistical significance of weekly variations in the frequency of intense nUHI events. State your null (H_0) and alternative (H_1) hypotheses.

Manually calculate the χ^2 statistic using the following steps to populate Table 2. Relevant cells in Table 2 are cross-referenced to steps (a) to (h) below:

a) Enter the sum of the observed frequencies for all days of the week
b) Fill in the expected frequency (E) of intense nUHI episodes for each day of the week (this is the mean frequency);
c) Enter the observed minus expected (O-E) frequencies;
d) Enter the square of each (O-E) value;
e) Sum the squares of (O-E);
f) Divide the sum of the squares by the expected frequency (E) from step (b) to give χ^2;
g) Determine the degrees of freedom (number of cells containing data minus 1);
h) Refer to a table of critical values for χ^2 and enter the value for significance level 0.05 and degrees of freedom from step (g);
i) If your χ^2 value (cell f) is equal or greater than the critical value (cell h) then the null hypothesis (H_0) can be rejected and the alternative hypothesis (H_1) is accepted.

Table 2. Contingency table for the frequency of intense nUHI in London by day of week.

Day	**Observed *(O)***	**Expected *(E)***	***(O-E)***	***$(O-E)^2$***
Mon	306	(b)	(c)	(d)
Tue	268	(b)	(c)	(d)
Wed	317	(b)	(c)	(d)
Thu	282	(b)	(c)	(d)
Fri	310	(b)	(c)	(d)
Sat	296	(b)	(c)	(d)
Sun	283	(b)	(c)	(d)
Sum	(a)			(e)
			Chi-squared (χ^2)	(f)
			Degrees of freedom	(g)
			Critical value of χ^2 at 0.05 significance level	(h)

Based on your analysis, does the day of week significantly affect the likelihood of intense nocturnal urban heat island episodes in London?

Take it further: Follow the same steps to evaluate the statistical significance of weekly variations in the frequency of hot nights.

3. **When are intense nocturnal heat islands and hot nights most likely in London?**
The second tab 'Monthly nUHI' in the Excel file holds raw data on the occurrence of nUHI and hot nights by calendar month. The sheet contains the following data:

Table 3. Mean nocturnal heat island intensity and frequency of hot nights by month.

Month	Mean nUHI (tenths °C)	Frequency of intense nUHI (days when nUHI ≥ 4°C)	Frequency of hot nights at SJP (nights when Tmin ≥ 18°C)	Frequency of hot nights at WIS (nights when Tmin ≥ 18°C).
Jan	12.0	69	0	0
Feb	13.9	81	0	0
Mar	15.2	126	0	0
Apr	18.4	171	0	0
May	20.4	235	0	0
Jun	21.0	204	18	0
Jul	21.2	216	94	9
Aug	22.2	235	90	14
Sep	22.2	277	5	1
Oct	19.3	218	0	0
Nov	15.4	131	0	0
Dec	13.6	99	0	0

Use graph paper to plot separately (1) the frequency of intense nUHI then the frequency of hot nights by month at (2) SJP and (3) WIS.

What months(s) have the greatest frequency of intense heat islands and hot nights? What factors might explain these ***annual*** variations?

Take it further: To what extent do intense nocturnal heat island episodes contribute to dangerous night-time temperatures in central London? What is the average enhancement of night-time temperatures in central London by the heat island effect (during months with heatwaves)?

4. How significant are annual variations in London's nocturnal UHI?
Repeat the steps in Task 2, this time completing all the missing cells in Table 4 to calculate the χ^2 statistic using the monthly frequency of intense nUHI episodes in London.

Table 4. Contingency table for the frequency of intense nUHI in London by month.

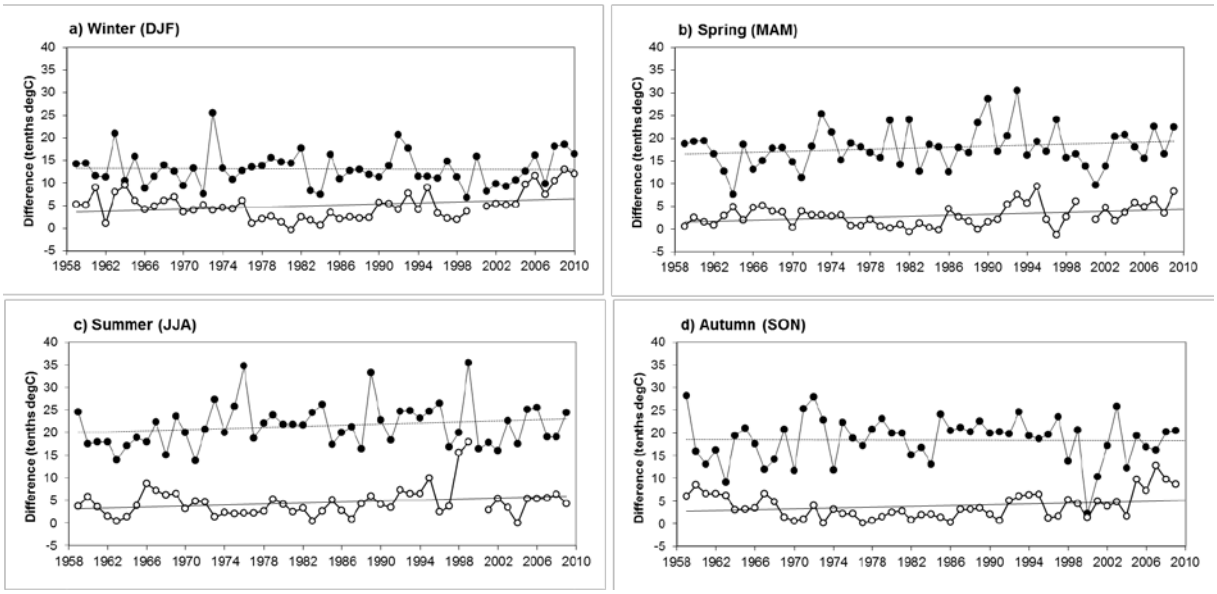
Month	**Observed *(O)***	**Expected *(E)***	***(O-E)***	***$(O-E)^2$***
Jan	69	(b) 172	(c) -103	(d) 10609
Feb	81	(b) 172	(c) -91	(d) 8281
Mar	126	(b) 172	(c) -46	(d) 2116
Apr	171	(b) 172	(c) -1	(d) 1
May	235	(b) 172	(c) 63	(d) 3964
Jun	204	(b) 172	(c) 32	(d) 1024
Jul	216	(b)	(c)	(d)
Aug	235	(b)	(c)	(d)
Sep	277	(b)	(c)	(d)
Oct	218	(b)	(c)	(d)
Nov	131	(b)	(c)	(d)
Dec	99	(b)	(c)	(d)
Sum	(a) 2062			(e)
			Chi-squared (χ^2)	(f)
			Degrees of freedom	(g)
			Critical value of χ^2 at 0.05 significance level	(h)

Based on your analysis, does the likelihood of intense nocturnal urban heat island episodes depend on the month?

Take it further: Examine the seasonal trends in the mean intensity of the nUHI and dUHI shown in Figure 2. During what season(s) and part of the day has there been greatest intensification of London's urban heat island? What factors could explain these long-term trends? What are the implications for the health of the citizens of London?

Tip: Cooler temperatures at night provide relief from extreme day-time temperatures. However, persistent spells of high nocturnal temperatures can be lethal. This was a critical factor during the August 2003 heatwave when minimum temperatures in central London did not fall below 18°C for 9 nights in a row (5-13 August).

Figure 2. Trends in the intensity of London's nocturnal (black circles) and day-time (white circles) UHI during a) winter (December-January-February), b) spring (March-April-May), c) summer (June-July-August) and d) autumn (September-October-November). Adapted from Wilby et al. (2011).



Plenary

Return to the main lesson questions: (1) how does the incidence of extreme heat vary during the week and within the year and; (2) how does the urban heat island exacerbate potentially deadly night-time temperatures in central London?

Show Figure 3 to the group. Based on the insights from Tasks 1 to 4, discuss the changing likelihood of dangerously hot nights in central London (SJP) and the suburb of Wisley (WIS).

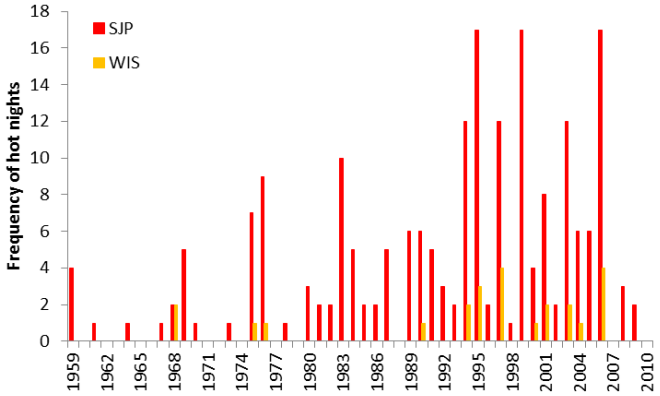


Figure 3. Annual frequency of dangerously hot nights in central London (SJP) and a suburb (WIS) during the period 1959-2009

As a group, list practical steps that can be taken to protect vulnerable citizens during heatwaves.

Further reading

Record breaking heat and sunshine in July 2006:
http://www.metoffice.gov.uk/climate/uk/interesting/july2006

Hot spell August 2003
http://www.metoffice.gov.uk/climate/uk/interesting/aug03maxtemps.html