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ORIGINAL PAPER

Weather patterns and all-cause mortality in England, UK

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Abstract

Cold- and heat-related mortality poses significant public health concerns worldwide. Although there are numerous studies dealing with the association between extreme ambient temperature and mortality, only a small number adopt a synoptic climatological approach in order to understand the nature of weather systems that precipitate increases in cold- or heat-related mortality. In this paper, the Lamb Weather Type synoptic classification is used to examine the relationship between daily mortality and weather patterns across nine regions of England. Analysis results revealed that the population in England is more susceptible to cold weather. Furthermore, it was found that the Easterly weather types are the most hazardous for public health all-year-long; however, during the cold period, the results are more evident and spatially homogenous. Nevertheless, it is noteworthy that the most dangerous weather conditions are not always associated with extreme (high or low) temperatures, a finding which points to the complexity of weather-related health effects and highlights the importance of a synoptic climatological approach in elucidating the relationship between temperature and mortality.

Keywords Temperature · Mortality · Synoptic climatology · Lamb Weather Types · Atmospheric circulation · Easterly weather

Introduction

Over the last few decades, the impact of prevailing weather on public health has received increased scientific interest, and numerous epidemiological studies have established the association between ambient temperature and adverse health effects (see, e.g., Analitis et al. 2008; Guo et al. 2013; Tsangari et al. 2016; Song et al. 2017), with the greatest research interest being focused on extreme events like cold spells or heat waves. The 148,279 fatalities in subtropical China during a severe cold spell in 2008 (Zhou et al. 2014) and the 80,000 deaths arising from the 2003 European heat wave (Robine et al. 2006) are pertinent examples that highlight the adverse impact of extreme weather on public health. Currently, and especially in the context of early warning systems as an adaptation strategy in response to climatic variability and change, the need to elucidate the relationship between synoptic weather conditions and human health seems more pressing than ever, as extreme weather events are expected to increase in frequency, duration, and intensity due to climate change (McMichael et al. 2006).

In general terms, studies have demonstrated a “U”, “V”, or “J” shape relationship between temperature and adverse health effects (Armstrong 2006; Braga et al. 2002). The lower extrema of the curve depict the comfort zone, while mortality/morbidity increases when there is a displacement from the so-called “temperature threshold”. Both in cold and hot weather, the vast majority of morbidity or mortality incidents are linked to respiratory or cardio/cerebro vascular diseases (see, e.g., Donaldson and Keatinge 1997; Aylin et al. 2001; Hajat and Haines 2002; Keatinge 2002; Carder et al. 2005; Anderson and Bell 2009; Gasparrini et al. 2012; Bunker et al. 2016; Arbuthnott and Hajat 2017). The effects of heat waves on public health are almost immediate, while the results of cold spells are persistent up to 10–25 days after the exposure, forming a lag effect (Hajat and Haines 2002; Keatinge 2002; Carder et al. 2005; Analitis et al. 2008; Anderson and Bell 2009; Chung et al. 2015; Hajat et al. 2016). The severity of weather’s effects on public health depends on many factors, such as the latitude, the vulnerability and acclimatization of population, lifestyle and the quality of housing (Guo et al. 2014; Donaldson and Keatinge 2013). The elderly, probably

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because of their poor thermoregulatory ability (Aylin et al. 2001; Analitis et al. 2008; Conlon et al. 2011; Hajat et al. 2007), children and people with already compromised health (IPCC 2012; Wilkinson et al. 2004; Arbuthnott and Hajat 2017) compose the most vulnerable population groups.

While much of the published literature on climate and health follows an epidemiological approach based on time series analysis, several researchers have adopted a different perspective by considering the large-scale synoptic weather situations associated with noticeable increases in mortality/morbidity. For instance, Kassomenos et al. (2007) examined the daily mortality in relation to air mass types in Athens, Greece and concluded that the highest death rates were associated with southerly flows for both the warm and the cold season. Similarly, southerly flows characterized by warm and humid conditions were found to be hazardous during summer in the Eastern USA (Kalkstein and Grenne 1997). In addition, hot air masses originating from North Africa, caused by the Atlantic low and persistent high pressures over northern and Western Europe, were associated with excess summer mortality in Barcelona, Spain (Peña et al. 2014). Moreover, Lupo et al. (2014) correlated hot, dry summers in Moscow, Russia, like the fatal summer of 2010, with atmospheric blocking and El Niño transitions. In the case of England, winter mortality has been associated with cold air masses originating from continental Europe or with eastern flows resulting in rapid changes in weather conditions (Paschalidou et al. 2017). Additionally, a west-to-east contrast in the nature of air masses linked with increased mortality was identified by Dimitriou et al. (2016) who reported that, for the West Midlands and northwest regions of England, relatively warm weather conditions from the west are associated with the highest daily average winter mortality, whereas, for the northeast, Humberside/York, and the southeast regions, cold continental air advection from northern/eastern Europe appears to be important in mortality terms.

Building on these studies which approach the climate and health research problem essentially from an environment-to-circulation perspective (Yarnal 1994), the purpose of this paper is to present the results of the application of a circulation-to-environment approach, using the Lamb Weather Types (LWT) synoptic weather classification scheme, to the analysis of mortality across England for both the warm and the cold period of the year. To the authors' knowledge, the LWT scheme has not been employed in the analysis of health outcomes in England previously, despite it enjoying wide usage in understanding the degree of dependence of a range of environmental variables on variations in large-scale atmospheric circulation conditions. Specifically, the intent of the paper is to shed light on the climatological association between mortality in nine regions of England and large-scale weather patterns.

Data and methods

Area description and data sources

The research focus of the present study is England, United Kingdom for the period 1981 to 2015. Notwithstanding the region is well-known to be heavily afflicted by excess winter mortality (Aylin et al. 2001; Wilkinson et al. 2001, 2004; Keatinge 2002; Healy 2003; Hajat and Kovats 2014; Gasparrini et al. 2015), many studies have also demonstrated notable rates of heat-related mortality (Gasparrini et al. 2012; Bunker et al. 2016; Hajat et al. 2007; Armstrong et al. 2011), confirming the public health importance of both cold and hot weather. In this study, the response of mortality in nine official Office of National Statistics (ONS) regions, namely (a) Yorkshire and the Humber, (b) the West Midlands, (c) Northeast, (d) Northwest, (e) Southeast, (f) the East Midlands, (g) East of England, (h) Southwest, and (i) London (Fig. 1), is examined for November to March and May to September, defined here as the 'cold' and 'warm' periods, respectively. It is noted that April and October were considered transitional in nature and were excluded from the analysis. As well as the daily catalog of LWT, daily minimum and maximum air temperatures (°C) and all-cause mortality are used in the analysis.

Population and mortality data were obtained from the Office of National Statistics. The mortality data include daily all-cause casualties per region. The temperature data were obtained from the UK Met Office (Met Office 2006) through the Centre for Environmental Data Analysis (CEDA) (http://www.ceda.ac.uk/). In order for the temperature data to be representative of each region, the final temperature values used per region (and day) were calculated by estimating the daily average maximum and minimum values of four different meteorological stations within the region under-study. Table 1 displays the location of the meteorological stations used, their minimum/maximum temperature, and their data coverage (%).

Methodology

At first, all mortality data were standardized as deaths per 100,000 of population to exclude any bias due to regional variability of the population and population trends over time.

In order to identify any seasonality in annual mortality, the cold to warm mortality ratio (n) was estimated, using the equation below:

$$n = \frac{\sum M_i}{\sum M_j}, \quad (1)$$

where M_i and M_j stand for the daily cold (November to March) and warm (May to September) period mortality, respectively.

Fig. 1 ONS study regions. Star symbols indicate the place of meteorological stations. Place names are for major regional cities.

With the aim of elucidating the link between mortality and prevailing weather conditions, the Lamb Weather Types (LWT) synoptic classification (Lamb 1950) was used. According to this classification, synoptic weather can be classified into a total of 27 types, namely (a) 7 basic types: Anticyclonic (A), Cyclonic (C), Westerly (W), North-Westerly (NW), Northerly (N), Easterly (E), and Southerly (S); (b) 19 hybrid types; and (c) the unclassifiable type (U) (Table 2). The anticyclonic/cyclonic type reflects the occurrence of anticyclones/depressions, while the remaining five basic types refer to the general direction of air movement. Moreover, in general terms, a hybrid type indicates a condition between two or more basic types, e.g., AW stands for anticyclonic westerly flows. Jenkinson and Collison (1977) developed an objective classification scheme based on Lamb's prior work by using grid-point mean sea level pressure data to determine geostrophic flow and vorticity over the British Isles in order to automatically classify the daily weather type. The subjective (Lamb 1950) and objective (Jenkinson and Collison 1977) schemes are in very good agreement, according to Jones et al. (1993).

For this study, the daily classification of LWT for the period 1981 to 2015, according to the catalog of weather pattern types as set out in Table 2 below, was used.

So as to control for the varying frequency of the various LWT, the number of deaths was standardized according to level of mortality for each weather type (C_i), using the PI sign-test (Paschalidou and Kassomenos 2016).

$$PI_i = 100 \times \left(\frac{\text{Number of Deaths in } C_i / \text{Total Number of Deaths}}{\text{Number of days in } C_i / \text{Total Number of Days}} - 1 \right), \qquad (2)$$

Table 1 Location, minimum/maximum temperature recorded and data coverage for the meteorological stations used

	East of England				East Midlands				London			
src_id	471	454	456	436	539	578	384	393	695	697	708	723
Latitude (decimal degrees):	51.8062	52.1935	52.4012	52.0902	53.2577	52.2732	53.1751	53.0935	51.5601	51.5042	51.4787	51.4813
Longitude (decimal degrees):	− 0.35858	0.13113	− 0.23532	0.62961	− 1.91242	− 0.87937	− 0.52173	− 0.17119	− 0.17839	− 0.12948	− 0.44904	− 0.29276
Elevation (m)	128	13	41	55	307	127	68	6	137	5	25	6
Max temperature (°C)	33.8	36.9	35.5	37.3	32.7	34.7	27.8	29.3	37.4	39.7	32.5	38.1
Min temperature (°C)	− 17	− 16.1	− 16.6	− 16.1	− 14	− 16.8	− 14	− 13.3	− 11.9	− 10.3	− 11.8	− 12
Data coverage (%)	99.95	96.11	98.59	99.96	99.92	99.98	99.99	99.97	98.86	98.83	99.98	97.58
	North East				North West				South East			
src_id	326	315	289	310	16851	1073	1070	1105	808	605	863	830
Latitude (decimal degrees):	54.7679	55.4208	55.2343	55.2129	54.0761	54.6699	54.9342	54.0138	50.7587	51.758	50.7845	51.4408
Longitude (decimal degrees):	− 1.58455	− 1.59966	− 2.579	− 1.68615	− 2.85825	− 2.78644	− 2.96223	− 2.77371	0.28458	− 1.57649	− 0.98462	− 0.93662
Elevation (m)	102	23	201	95	7	169	28	95	15	82	4	66
Max recorded temperature (°C)	32.5	24.2	30	32.6	32.7	31.1	26.6	32.1	32.6	28.9	31.5	36.4
Min recorded temperature (°C)	− 16.1	− 12.3	− 25	− 12	− 29.2	− 25.4	− 14.8	− 10	− 14	− 20.9	− 9.4	− 14.5
Data coverage (%)	99.73	99.98	92.01	98.60	99.49	88.24	98.16	99.48	96.36	99.98	97.77	99.80
	South West				West Midlands				Yorkshire and The Humber			
src_id	1393	1395	1302	1362	658	622	638	643	513	525	367	17314
Latitude (decimal degrees):	50.0838	50.2178	51.0059	50.2922	52.0996	52.9986	52.7243	52.7943	53.811	53.381	54.1048	54.2968
Longitude (decimal degrees):	− 5.25609	− 5.32656	− 2.64148	− 3.65074	− 2.05856	− 2.2688	− 2.84043	− 2.66329	− 1.86526	− 1.48986	− 0.64149	− 1.53145
Elevation (m)	76	87	20	32	37	179	71	72	262	131	175	33
Max temperature (°C)	26.5	29.4	29.1	29.2	34.9	32.9	34.6	26.6	32.1	34.3	33.2	24.9
Min temperature (°C)	− 10.9	− 9.4	− 16.1	− 8	− 19.2	− 12.5	− 22.6	− 25.2	− 11.9	− 9.2	− 14.6	− 17.9
Data coverage (%)	99.95	99.96	99.95	98.19	98.07	98.65	92.76	99.99	99.03	99.74	95.37	99.99

Table 2 The Lamb Weather Types number coding

Lamb Weather Types					
− 1	U	− 9	Non-existent day		
0	A			20	C
1	ANE	11	NE	21	CNE
2	AE	12	E	22	CE
3	ASE	13	SE	23	CSE
4	AS	14	S	24	CS
5	ASW	15	SW	25	CSW
6	AW	16	W	26	CW
7	ANW	17	NW	27	CNW
8	AN	18	N	28	CN

where C_i stands for the different weather types. Values of PI_i equal to 0 or − 100 indicate that the number of deaths is equally divided among weather types or there is a "mortality-free" type, respectively. Positive/negative PI_i values indicate that the fatal incidents are more/less frequent in the specific weather type.

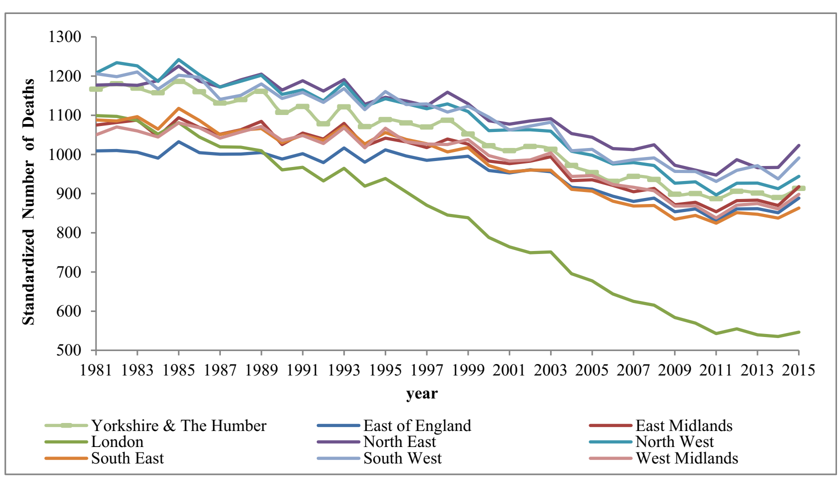
Results and discussion

For the period between 1981 and 2015, 17,140,715 deaths were recorded. Figure 2 demonstrates the standardized number of deaths per year and region. It is apparent that there is a clear reduction trend in annual mortality over time for all nine regions studied. In case of London, this reduction is more substantial, as the number of deaths almost halves over the years. It is noteworthy that 366,597 fatalities were recorded for the period 1981–1985, while for the period 2011–2015, the number decreased to 229,160. It should be noted that in this study, we used all-cause mortality, rather than heat- or cold-related events exclusively, as to establish the latter is considered beyond the scope of the present work. Notwithstanding this, Carson et al. (2006) note that the vulnerability of population to thermal stress has declined over the 20th century for London and Donaldson and Keatinge (1997) have confirmed this declining trend for the elderly in Southeast England. As Carson et al. (2006) highlighted, determining and quantifying the factors that affect the vulnerability of population is not an easy task. Among the influencing factors are the improvements in infrastructure and house insulation, different lifestyles, the development and provision of health-care services (e.g., vaccination for influenza), improvements in nutrition and the decrease of time spent outdoors (Donaldson and Keatinge 1997; Wilkinson et al. 2001; Keatinge 2002; Rau 2007).

According to Christidis et al. (2010), the population over 50 in the UK has adapted better to cold rather than heat, resulting, for the period 1976 to 2005, in a reduction of cold-related mortality (and on the other hand in a small increase of heat-related mortality). Under a changing climate, an increase in heat-related mortality is expected (Huang et al. 2011; Hajat and Kovats 2014; Heaviside et al. 2016), whereas winter mortality is projected to decrease, although the future of winter mortality is confounded by many factors and is not completely understood (Wang et al. 2016). Specifically, for the UK, Vardoulakis et al. (2014) have reported that the decreasing trend in winter mortality is going to continue and reach approximately 42 deaths per 100,000 of population per year, whereas the heat-related mortality is projected to rise to approximately 9 deaths per 100,000 of population per year as of the 2080s.

Table 3 shows the ratio of cold to warm standardized number of deaths. It is evident that the cold to warm mortality ratio is always greater than 1, in agreement with previous studies, such as Carson et al. (2006) who calculated the ratio in London equal to 1.22, for the decade

Fig. 2 The standardized number of deaths per year and region



1986–1996. Furthermore, estimates of the winter to non-winter mortality ratio for the elderly in UK were found equal to 1.31 (Wilkinson et al. 2004). These results do not come as a surprise, as the UK presents some of the highest rates of excess winter mortality in Europe, surpassing other colder countries like the Scandinavian (Keatinge et al. 1997; Aylin et al. 2001; Wilkinson et al. 2001; Healy 2003; Gasparrini et al. 2015).

Tables 4 and 5 present the number of days falling in each LWT, the maximum/minimum temperature (in °C), the total standardized number of deaths and the PI index for each LWT for the nine regions studied for the cold and warm period, respectively. It is apparent that some classes (weather types) present a greater level of hazard than others for public health, as indicated by high PI values. Closer examination reveals that the PI values in cold period are considerably higher than in warm period, corroborating the results of previous studies that found the population in England to be more susceptible to cold- compared to heat-related mortality.

Table 3 Cold to warm ratio of the standardized number of deaths

	East of England	East Midlands	London	North East	North West	South East	South West	West Midlands	Yorkshire and The Humber	95% CI	
1981	1.24	1.20	1.21	1.21	1.20	1.22	1.23	1.22	1.21	1.20	1.22
1982	1.26	1.28	1.23	1.23	1.24	1.22	1.24	1.23	1.25	1.23	1.25
1983	1.22	1.21	1.23	1.20	1.23	1.22	1.22	1.17	1.19	1.19	1.23
1984	1.18	1.16	1.19	1.17	1.21	1.18	1.17	1.21	1.20	1.17	1.20
1985	1.28	1.28	1.31	*1.27*	*1.31*	1.29	1.25	1.27	1.27	1.27	1.29
1986	1.25	1.24	1.28	1.23	1.25	1.26	*1.29*	1.25	1.26	1.24	1.27
1987	1.15	1.15	1.20	1.19	1.18	1.18	1.17	1.17	1.18	1.17	1.19
1988	1.22	1.19	1.23	1.20	1.21	1.19	1.20	1.21	1.20	1.20	1.22
1989	1.27	1.24	1.27	1.21	1.28	1.25	1.28	1.28	1.25	1.24	1.27
1990	1.16	1.17	1.15	1.15	1.18	1.15	1.17	1.17	1.16	1.15	1.17
1991	1.23	1.25	1.24	1.20	1.22	1.24	1.22	1.25	1.25	1.22	1.25
1992	1.18	1.24	1.21	1.20	1.20	1.19	1.20	1.19	1.20	1.19	1.21
1993	1.25	1.24	1.27	1.23	1.23	1.22	1.22	1.24	1.25	1.23	1.25
1994	1.15	1.17	1.14	1.16	1.15	1.14	1.16	*1.14*	1.17	1.14	1.16
1995	1.25	1.21	1.22	1.15	1.21	1.21	1.22	1.21	1.23	1.19	1.23
1996	1.24	1.18	1.26	1.22	1.23	1.22	1.22	1.24	1.22	1.21	1.24
1997	1.26	1.24	1.24	1.21	1.22	1.26	1.27	1.23	1.23	1.23	1.25
1998	1.20	1.25	1.18	1.22	1.19	1.17	1.15	1.19	1.21	1.17	1.22
1999	*1.30*	*1.28*	*1.32*	1.27	1.28	*1.30*	1.26	*1.35*	*1.29*	1.27	1.31
2000	1.23	1.25	1.24	1.24	1.21	1.26	1.23	1.21	1.24	1.22	1.25
2001	1.15	1.17	1.15	1.16	1.17	*1.14*	1.15	1.16	1.17	1.15	1.17
2002	1.17	1.17	1.15	1.19	1.19	1.17	1.14	1.15	1.16	1.15	1.18
2003	1.17	1.19	1.14	1.18	1.18	1.16	1.16	1.19	1.19	1.16	1.19
2004	1.14	*1.15*	1.17	1.17	1.15	1.15	1.18	1.16	1.17	1.15	1.17
2005	1.20	1.20	1.20	1.17	1.20	1.20	1.20	1.21	1.20	1.19	1.21
2006	1.18	1.15	*1.13*	1.16	*1.13*	1.19	1.16	1.15	*1.13*	1.14	1.17
2007	1.18	1.19	1.17	1.19	1.18	1.17	1.19	1.20	1.19	1.18	1.19
2008	1.23	1.22	1.26	1.24	1.24	1.22	1.21	1.22	1.22	1.22	1.24
2009	1.22	1.20	1.21	1.17	1.21	1.23	1.21	1.23	1.21	1.20	1.22
2010	1.21	1.20	1.20	1.16	1.20	1.21	1.20	1.20	1.17	1.18	1.21
2011	1.15	1.17	1.14	1.14	1.15	1.16	1.14	1.16	1.15	1.14	1.16
2012	1.16	1.16	1.20	*1.14*	1.14	1.19	*1.13*	1.14	1.15	1.14	1.18
2013	1.19	1.22	1.19	1.18	1.22	1.19	1.21	1.23	1.20	1.19	1.22
2014	*1.14*	1.16	1.17	1.16	1.18	1.15	1.16	1.18	1.16	1.15	1.17
2015	1.22	1.23	1.19	1.24	1.22	1.22	1.22	1.23	1.21	1.21	1.23

CI confidence interval for the whole country

Table 4 Estimations for the cold period

LWT	-1	0	1	2	3	4	5	6	7	8	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26	27	28
Total Days	22	1003	28	31	44	77	159	233	310	58	64	65	128	290	652	667	297	161	618	20	21	33	94	146	135	91	46
Total Days%	0.40	18.26	0.51	0.56	0.80	1.40	2.89	4.24	5.64	1.06	1.17	1.18	2.33	5.28	11.87	12.14	5.41	2.93	11.25	0.36	0.38	0.60	1.71	2.66	2.46	1.66	0.84
East of England																											
Max T	7.41	6.53	5.41	3.37	5.52	6.79	7.85	8.80	8.29	7.06	4.77	3.76	5.14	7.13	8.95	9.83	8.70	6.14	8.62	6.18	5.59	6.93	8.65	9.81	9.30	9.18	7.66
Min T	2.44	0.76	1.08	-1.57	0.58	0.19	1.18	2.60	2.64	1.47	0.74	-0.02	0.65	1.56	2.85	3.96	3.01	0.96	3.42	0.92	0.90	2.62	3.51	4.11	3.77	3.35	2.41
Standardized	63.68	2871.31	84.83	100.91	127.39	226.33	450.37	665.15	895.84	164.59	185.58	199.77	376.44	843.21	1887.23	1922.73	847.97	459.73	1787.33	61.41	62.39	95.84	269.18	417.73	390.51	260.62	127.78
PI index	0.34	-0.76	5.02	**12.84**	0.36	1.89	-1.81	-1.04	0.18	-1.63	0.52	6.54	1.95	0.79	0.34	-0.07	-1.03	-1.01	0.26	6.44	2.99	0.68	-0.73	-0.82	0.28	-0.72	**-3.70**
London																											
Max T	7.79	6.87	5.63	3.55	6.11	7.29	8.05	9.03	8.43	7.42	5.31	4.54	5.81	7.69	9.30	10.00	8.92	6.66	9.16	6.84	6.33	7.67	9.22	10.20	9.70	9.52	7.98
Min T	3.52	2.06	2.18	-0.28	2.04	1.95	2.68	3.71	3.43	2.54	1.75	1.35	2.15	3.04	4.16	5.06	3.83	1.75	4.70	2.56	2.91	4.22	4.95	5.38	5.06	4.42	3.19
Standardized	52.52	2499.54	72.95	97.04	110.37	203.04	397.67	576.61	781.46	144.13	160.05	177.08	337.95	750.15	1629.21	1653.91	728.80	395.01	1528.47	54.45	53.82	85.51	230.46	358.25	330.37	227.73	106.71
PI index	-4.59	-0.40	4.13	**25.12**	0.26	5.40	-0.04	-1.09	0.76	-0.68	-0.05	8.89	5.53	3.39	-0.13	-0.89	-1.92	-1.94	-1.15	8.81	2.44	3.57	-2.01	-1.93	-2.19	0.02	**-7.28**
North East																											
Max T	5.55	6.17	5.09	3.48	5.13	5.18	6.87	8.35	7.47	5.84	4.23	4.00	4.46	5.84	7.82	8.62	7.31	5.33	6.28	4.57	4.51	5.43	6.82	7.64	7.51	6.79	5.83
Min T	1.17	0.80	0.91	-0.53	1.42	-0.41	1.28	3.20	2.20	0.53	0.41	0.66	0.97	1.16	2.68	3.56	2.27	0.41	1.88	-0.51	0.91	1.92	2.25	2.81	2.64	2.08	1.02
Standardized	74.44	3298.74	95.96	108.84	149.08	255.98	517.87	773.07	1016.65	184.76	212.56	220.23	441.61	977.36	2171.75	2227.79	980.95	523.30	2063.63	70.01	68.42	111.62	305.31	484.18	459.25	300.14	146.16
PI index	1.91	-0.95	3.22	**5.73**	2.04	0.12	-1.91	-0.08	-1.24	-4.07	0.02	2.04	3.90	1.50	0.31	0.59	-0.53	-2.11	0.56	5.42	-1.88	1.86	-2.18	-0.13	2.45	-0.67	**-4.31**
North West																											
Max T	6.14	6.18	5.10	3.76	5.80	6.03	7.44	8.37	7.51	6.30	4.56	4.40	5.17	6.98	8.52	8.97	7.74	5.81	7.33	4.74	4.72	5.95	7.98	8.63	8.39	7.85	6.39
Min T	1.59	0.89	0.36	-0.44	0.86	0.75	2.42	4.03	2.61	0.72	0.39	0.52	1.37	2.40	3.96	4.54	3.20	0.80	2.95	-0.07	1.18	2.30	3.55	4.23	3.97	3.13	1.75
Standardized	70.31	3264.72	91.57	115.57	148.93	255.11	518.95	752.90	1007.38	186.13	207.58	226.16	431.63	968.59	2152.40	2185.88	943.39	520.30	2038.49	69.71	71.19	110.70	309.17	476.99	444.05	297.96	144.54
PI index	-2.53	-0.73	-0.26	**13.70**	3.23	1.05	-0.46	-1.45	-0.89	-2.12	-1.08	6.12	2.85	1.87	0.69	-0.05	-3.12	-1.44	0.60	6.31	3.39	2.31	0.31	-0.36	0.32	-0.14	**-4.16**
South East																											
Max T	7.93	6.94	5.94	3.63	6.31	7.09	7.94	8.95	8.65	7.82	5.60	4.53	5.75	7.64	9.12	9.84	9.08	6.96	9.17	7.28	6.58	7.87	9.03	9.90	9.71	9.55	8.24
Min T	3.71	1.88	1.93	-0.54	1.88	1.79	2.71	3.86	3.52	2.69	1.69	1.01	1.97	3.26	4.36	5.26	4.15	1.97	4.80	2.68	2.71	4.36	5.04	5.60	5.15	4.78	3.45
Standardized	64.63	2946.96	86.49	107.64	132.99	234.05	465.81	687.95	916.43	168.47	189.31	202.79	393.39	872.55	1937.67	1961.40	867.34	464.02	1833.99	63.69	64.02	97.80	275.32	430.57	398.63	262.22	129.82
PI index	-0.73	-0.72	4.38	**17.33**	2.13	2.71	-1.01	-0.23	-0.11	-1.85	-0.05	5.42	3.85	1.67	0.42	-0.63	-1.32	-2.61	0.28	7.61	3.02	0.14	-1.03	-0.35	-0.22	-2.63	**-4.64**
South West																											
Max T	8.02	6.91	5.82	4.05	7.06	7.70	8.26	9.07	8.70	7.57	5.88	5.13	7.40	9.01	9.85	10.04	9.31	7.27	9.71	7.47	7.54	9.25	10.01	10.44	10.36	9.64	8.42
Min T	4.52	2.73	2.02	0.43	3.72	4.02	4.00	4.73	4.37	3.20	2.10	1.75	4.11	5.28	5.88	6.22	5.18	2.97	5.58	3.33	3.51	5.69	6.15	6.55	6.13	5.29	4.07
Standardized	69.79	3270.37	93.99	115.38	148.89	256.11	514.90	753.60	1026.82	188.59	213.68	228.66	438.85	974.72	2140.88	2175.66	955.04	518.15	2021.50	68.51	72.59	113.86	306.77	479.97	443.61	294.87	145.80
PI index	-3.36	-0.67	2.26	**13.39**	3.08	1.32	-1.35	-1.47	0.90	-0.95	1.71	7.16	4.44	2.39	0.03	-0.63	-2.04	-1.96	-0.35	4.35	5.30	5.10	-0.58	0.15	0.10	-1.29	**-3.45**
East Midlands																											
Max T	5.92	5.28	4.46	2.07	4.52	5.01	6.24	7.57	6.94	5.62	3.83	2.95	3.76	5.50	7.53	8.52	7.39	5.00	6.97	4.60	4.18	5.29	6.99	8.30	7.97	7.53	5.92
Min T	2.06	0.90	1.16	-1.46	0.76	0.10	1.29	2.99	2.57	1.00	0.47	-0.09	0.49	1.36	2.89	3.99	2.90	0.65	2.83	0.53	0.75	2.07	3.04	3.80	3.45	2.91	1.68
Standardized	65.20	2975.33	87.26	101.35	134.49	237.69	470.74	685.63	929.95	170.13	194.09	206.74	395.44	887.68	1964.15	2008.29	883.23	478.32	1867.13	64.71	63.88	97.87	288.19	436.15	408.86	269.09	134.85
PI index	-1.38	-1.28	3.71	**8.80**	1.72	2.73	-1.48	-2.08	-0.17	-2.39	0.92	5.84	2.81	1.86	0.25	0.20	-1.04	-1.13	0.54	7.68	1.23	-1.31	2.02	-0.59	0.79	-1.60	**-2.44**
West Midlands																											
Max T	6.06	5.89	5.05	2.99	4.99	5.97	7.16	8.49	8.01	6.62	4.29	3.54	4.59	6.66	8.65	9.46	8.39	5.96	7.91	5.34	4.47	6.15	8.09	9.33	9.09	8.44	7.02
Min T	1.78	0.39	0.54	-1.62	0.45	0.31	1.18	3.01	2.57	1.02	0.43	-0.03	0.68	1.80	3.27	4.24	3.27	0.69	3.04	0.54	0.61	2.60	3.25	4.21	3.90	3.23	1.75
Standardized	66.52	2980.03	85.06	105.96	133.44	235.14	472.63	682.10	935.42	173.68	191.29	205.14	394.33	883.80	1963.36	1987.08	868.66	475.48	1861.53	64.72	65.28	100.21	278.44	434.48	402.82	264.92	134.62
PI index	0.99	-0.76	1.46	**14.16**	1.29	2.00	-0.72	-2.22	0.78	0.01	-0.17	5.41	2.90	1.79	0.58	-0.50	-2.31	-1.36	0.61	8.08	3.83	1.42	-1.07	-0.61	-0.34	**-2.77**	-2.25
Yorkshire & The Humber																											
Max T	5.26	5.33	4.36	1.89	4.36	4.98	6.38	7.86	6.91	5.43	3.53	2.89	3.47	5.43	7.54	8.53	7.23	4.92	6.37	4.12	3.63	4.76	6.66	7.93	7.64	7.06	5.70
Min T	1.57	0.93	1.05	-1.39	1.05	0.16	1.45	3.39	2.48	0.89	0.25	-0.02	0.44	1.43	3.14	4.07	2.77	0.54	2.47	0.06	0.82	1.75	2.79	3.63	3.32	2.62	1.26
Standardized	69.46	3127.71	88.75	107.58	137.96	247.43	493.81	725.04	979.90	181.96	200.93	216.44	416.81	924.67	2078.78	2098.68	916.02	503.59	1945.25	67.90	67.22	104.89	297.93	464.73	429.98	284.63	138.64
PI index	0.16	-1.08	0.54	**10.08**	-0.54	1.93	-1.48	-1.29	0.27	-0.48	-0.41	5.62	3.29	1.14	1.14	-0.19	-2.17	-0.78	-0.15	7.69	1.53	0.83	0.54	0.97	1.03	-0.78	**-4.39**

Table 5 Estimations for the warm period

LWT	-1	0	1	2	3	4	5	6	7	8	11	12	13	14	15	16	17	18	20	21	22	23	24	25	26	27	28
Total Days	110	1242	31	49	61	82	133	180	106	73	78	84	147	231	402	472	297	188	756	38	29	48	99	133	114	97	75
Total Days%	2.05	23.19	0.58	0.92	1.14	1.53	2.48	3.36	1.98	1.36	1.46	1.57	2.75	4.31	7.51	8.81	5.55	3.51	14.12	0.71	0.54	0.90	1.85	2.48	2.13	1.81	1.40
East of England																											
Max T	19.85	19.31	17.15	18.10	20.43	21.24	20.12	19.63	18.78	16.40	16.24	18.07	20.27	19.91	19.93	19.40	18.36	16.35	18.55	17.27	18.52	21.20	20.05	19.47	19.21	18.29	17.88
Min T	11.15	9.23	9.52	9.99	9.80	9.82	9.53	9.80	9.42	8.68	8.76	10.03	10.37	9.86	10.18	10.38	9.76	9.15	10.94	9.63	10.00	11.15	11.08	10.57	11.26	10.18	10.13
Standardized	253.74	2927.70	72.86	116.35	142.59	198.22	320.49	423.51	251.53	175.66	191.86	204.35	350.86	552.83	951.24	1103.66	693.23	436.53	1773.97	91.12	68.52	119.31	235.07	312.44	265.01	225.31	178.27
PI index	**-2.25**	-0.10	-0.39	0.62	-0.94	2.44	2.12	-0.29	0.56	1.98	4.24	3.10	1.15	1.42	0.28	-0.91	-1.08	-1.60	-0.56	1.62	0.14	**5.34**	0.63	-0.45	-1.49	-1.57	0.73
London																											
Max T	19.82	19.41	16.99	18.20	20.41	21.21	19.87	19.32	18.84	16.78	16.34	18.02	20.25	19.80	19.65	19.04	18.22	16.40	18.20	17.23	18.71	20.98	19.76	19.04	18.89	18.02	17.73
Min T	12.88	11.26	10.95	11.46	12.13	12.25	11.62	11.32	11.05	10.06	10.18	11.44	12.66	11.93	11.93	11.91	11.09	10.33	12.16	11.17	11.92	13.15	12.75	12.08	12.57	11.49	11.39
Standardized	224.14	2549.96	64.05	98.81	124.69	174.33	282.42	377.33	216.87	153.67	172.12	175.46	297.66	477.09	804.10	956.25	591.48	383.83	1497.36	77.87	61.43	106.09	204.55	274.87	220.14	187.29	154.25
PI index	0.03	0.79	1.42	-1.01	0.35	4.37	4.24	2.91	0.44	3.34	8.33	2.55	-0.59	1.39	-1.80	-0.54	-2.23	0.23	-2.77	0.60	3.98	**8.50**	1.43	1.46	-5.20	**-5.21**	0.97
North East																											
Max T	16.58	16.43	14.02	14.20	16.10	17.35	16.99	16.81	15.87	13.82	12.82	13.63	15.95	16.56	16.83	16.45	15.52	13.54	15.21	13.38	13.98	16.68	16.33	16.20	16.18	15.17	14.43
Min T	9.41	8.15	7.71	7.89	7.99	8.57	8.93	9.28	8.32	7.10	7.29	7.94	8.76	8.72	9.47	9.62	8.84	7.72	9.26	7.90	8.28	10.12	9.32	9.43	9.85	8.93	9.04
Standardized	297.76	3397.52	83.58	134.62	165.09	234.28	380.09	495.52	288.67	208.75	218.19	238.29	406.93	633.59	1107.79	1284.93	806.80	529.52	2062.36	105.95	81.39	134.41	270.35	364.07	300.75	258.39	210.98
PI index	-1.40	-0.35	-1.79	0.08	-1.41	4.08	4.10	0.28	-0.80	**4.16**	1.90	3.33	0.84	-0.09	0.38	-0.83	-1.05	2.60	-0.63	1.56	2.24	2.00	-0.52	-0.29	**-3.90**	-2.97	2.47
North West																											
Max T	17.96	16.89	15.90	17.32	18.57	18.32	17.10	16.27	15.73	14.96	14.76	16.47	18.19	17.66	16.85	16.02	15.34	14.42	16.05	15.26	16.12	18.64	17.55	16.37	16.23	15.21	15.58
Min T	10.62	9.31	8.37	8.75	10.11	10.51	10.35	10.79	9.78	7.94	8.09	9.14	10.58	10.70	10.99	11.00	10.11	8.52	10.54	8.90	9.60	11.60	11.20	10.91	11.16	10.12	10.07
Standardized	291.49	3332.92	82.10	130.26	169.98	230.52	361.45	485.13	283.62	200.65	216.85	232.72	404.11	628.03	1061.57	1255.10	788.15	499.80	2021.90	102.99	79.56	134.38	268.02	361.14	302.17	253.89	199.85
PI index	-1.31	-0.06	-1.37	-0.99	3.78	**4.70**	1.22	0.38	-0.35	2.37	3.54	3.18	2.38	1.26	-1.65	-0.97	-1.17	-0.99	-0.39	0.94	2.17	4.27	0.83	1.13	-1.28	**-2.52**	-0.76
South East																											
Max T	19.24	18.66	17.11	18.34	19.26	19.75	18.73	18.60	18.16	16.21	15.98	17.36	19.32	18.65	18.44	18.21	17.71	16.15	17.39	16.55	17.67	19.34	18.48	18.07	18.13	17.46	17.12
Min T	12.48	10.95	10.69	11.41	11.80	11.75	11.19	11.31	10.94	9.82	10.02	11.22	12.31	11.66	11.83	11.93	11.20	10.42	12.11	11.03	11.86	12.73	12.31	12.07	12.71	11.67	11.41
Standardized	267.79	3024.40	75.10	120.12	149.83	199.84	331.03	440.14	255.07	179.08	199.50	211.56	361.11	570.89	964.17	1129.43	706.35	459.21	1820.44	95.34	74.33	123.32	241.83	321.84	272.94	226.56	184.25
PI index	0.24	0.27	-0.25	0.93	1.13	0.35	2.48	0.68	-0.92	1.01	5.31	3.70	1.15	1.76	-1.24	-1.47	-2.07	0.57	-0.85	3.31	5.53	**5.79**	0.58	-0.36	-1.42	**-3.83**	1.15
South West																											
Max T	17.04	16.96	15.93	16.29	17.06	17.61	16.88	16.75	16.43	15.15	14.37	15.35	16.88	16.77	16.78	16.63	16.07	15.07	15.66	14.76	15.21	16.83	16.54	16.25	16.54	15.70	15.42
Min T	11.78	10.70	10.25	11.22	11.86	11.35	10.52	10.71	10.53	9.53	9.77	10.95	12.28	11.69	11.33	11.37	10.85	10.18	11.35	10.00	10.91	12.26	12.11	11.60	12.08	10.95	10.83
Standardized	293.95	3353.53	84.92	132.01	169.60	224.56	360.18	488.43	284.32	199.00	221.17	236.28	399.81	626.99	1070.67	1262.08	798.41	503.62	2022.23	102.97	80.14	135.75	264.51	355.27	298.92	253.01	205.25
PI index	-0.81	0.22	1.67	0.00	3.20	1.64	0.51	0.71	-0.44	1.18	**5.24**	4.41	0.95	0.74	-1.15	-0.75	-0.22	-0.57	-0.72	0.57	2.57	4.97	-0.83	-0.85	-2.68	**-3.19**	1.58
East Midlands																											
Max T	17.59	16.76	14.55	15.91	17.42	18.47	17.51	16.96	16.10	13.99	13.83	15.34	17.65	17.59	17.62	16.92	15.91	14.03	16.34	14.88	15.39	18.31	17.55	17.10	17.05	15.76	15.51
Min T	10.96	9.41	9.18	9.57	9.79	10.19	9.96	10.19	9.53	8.30	8.39	9.50	10.37	9.98	10.47	10.52	9.74	8.73	10.48	9.33	9.69	11.34	10.80	10.55	11.03	9.90	10.01
Standardized	270.50	3043.88	76.64	118.19	152.82	207.79	329.17	446.50	261.10	181.54	204.62	214.28	363.74	579.80	988.37	1146.52	715.58	454.93	1846.90	96.38	71.97	124.14	243.37	328.58	272.96	234.39	184.44
PI index	0.07	-0.27	0.60	-1.85	1.95	3.12	0.72	0.94	0.24	1.20	**6.76**	3.81	0.70	2.14	0.05	-1.15	-1.95	-1.53	-0.58	3.21	0.99	5.25	0.04	0.54	**-2.56**	-1.67	0.08
West Midlands																											
Max T	18.34	17.80	15.86	16.83	18.77	19.49	18.28	17.74	16.95	15.30	14.86	16.46	18.45	18.26	18.05	17.55	16.65	15.07	16.73	15.77	16.45	19.29	18.04	17.59	17.55	16.30	16.15
Min T	10.45	8.93	8.71	9.22	9.84	10.03	9.38	9.66	9.32	7.98	8.27	9.16	10.45	10.01	10.31	10.39	9.49	8.43	10.37	9.41	9.77	11.34	10.88	10.30	10.92	9.85	9.59
Standardized	273.18	3036.36	73.54	121.32	153.96	206.71	325.79	435.42	256.06	179.04	199.52	214.49	364.02	571.74	970.35	1141.08	716.60	460.03	1856.74	94.56	74.84	121.30	246.34	328.58	273.34	232.48	187.46
PI index	1.40	-0.18	**-3.14**	1.10	3.06	2.93	0.02	-1.23	-1.36	0.14	4.45	4.26	1.11	1.06	-1.44	-1.29	-1.48	-0.09	0.28	1.61	**5.37**	3.19	1.60	0.88	-2.10	-2.14	2.06
Yorkshire & The Humber																											
Max T	17.12	16.46	13.59	14.84	16.57	17.83	17.18	16.80	15.77	13.75	12.97	14.27	16.52	17.04	17.15	16.52	15.47	13.61	15.70	14.06	14.61	17.46	16.93	16.66	16.41	15.29	14.91
Min T	10.49	9.02	8.62	8.68	9.10	9.88	9.90	10.14	9.28	7.76	7.73	8.66	9.58	9.85	10.45	10.51	9.54	8.16	10.14	8.75	9.03	10.80	10.56	10.39	10.85	9.73	9.63
Standardized	285.28	3218.97	77.79	123.37	157.11	214.72	343.31	462.05	271.49	190.53	206.90	219.02	378.57	605.86	1029.41	1207.12	755.23	482.64	1951.25	99.88	77.60	131.27	257.45	347.97	286.20	248.54	197.56
PI index	0.44	0.37	**-2.81**	-2.49	-0.25	1.41	-0.03	-0.59	-0.81	1.08	2.73	0.98	-0.26	1.58	-0.83	-0.95	-1.52	-0.57	-0.04	1.79	3.63	**5.92**	0.71	1.32	-2.77	-0.77	2.02

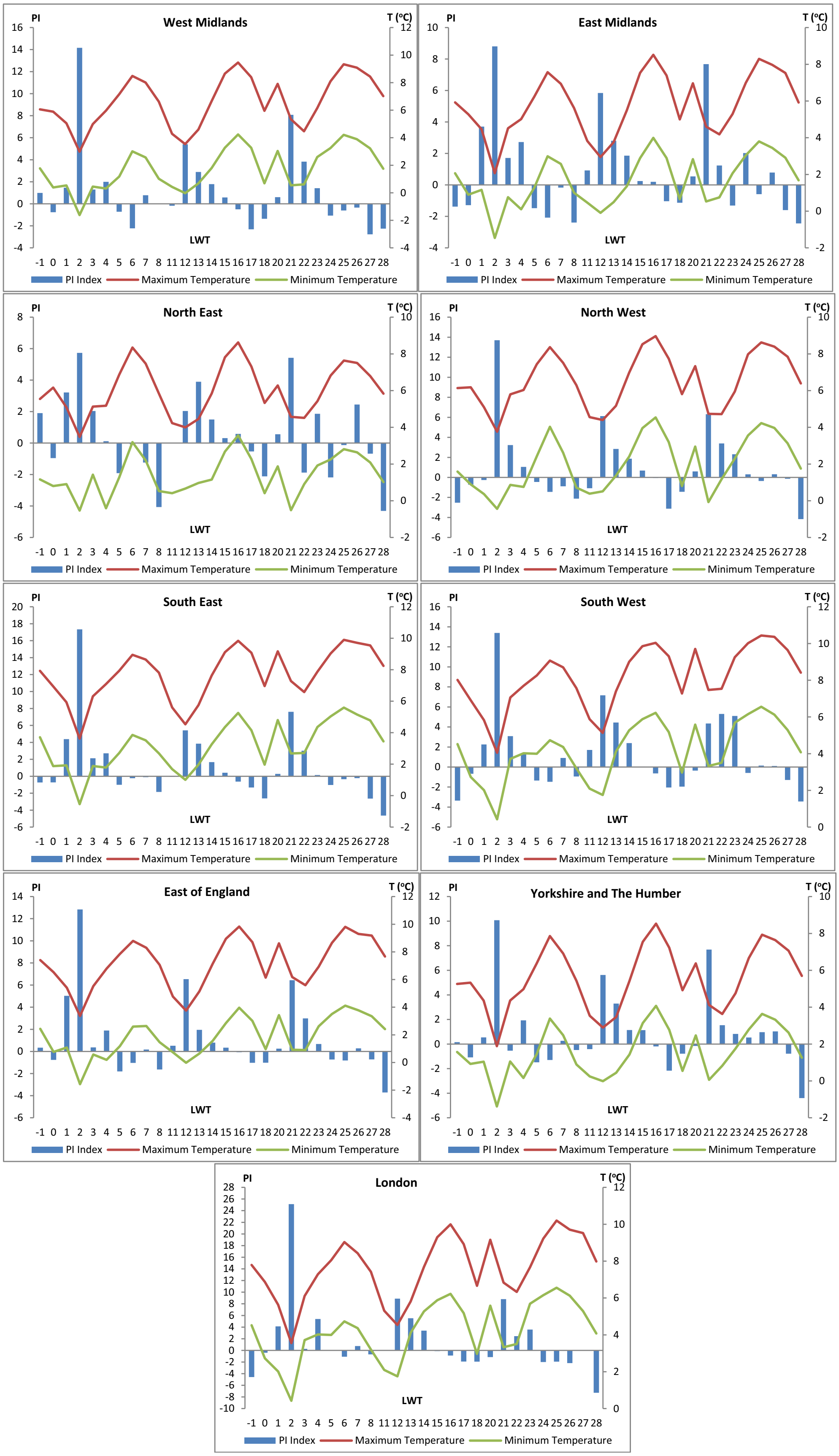


Fig. 3 PI values during the cold period for each LWT per region

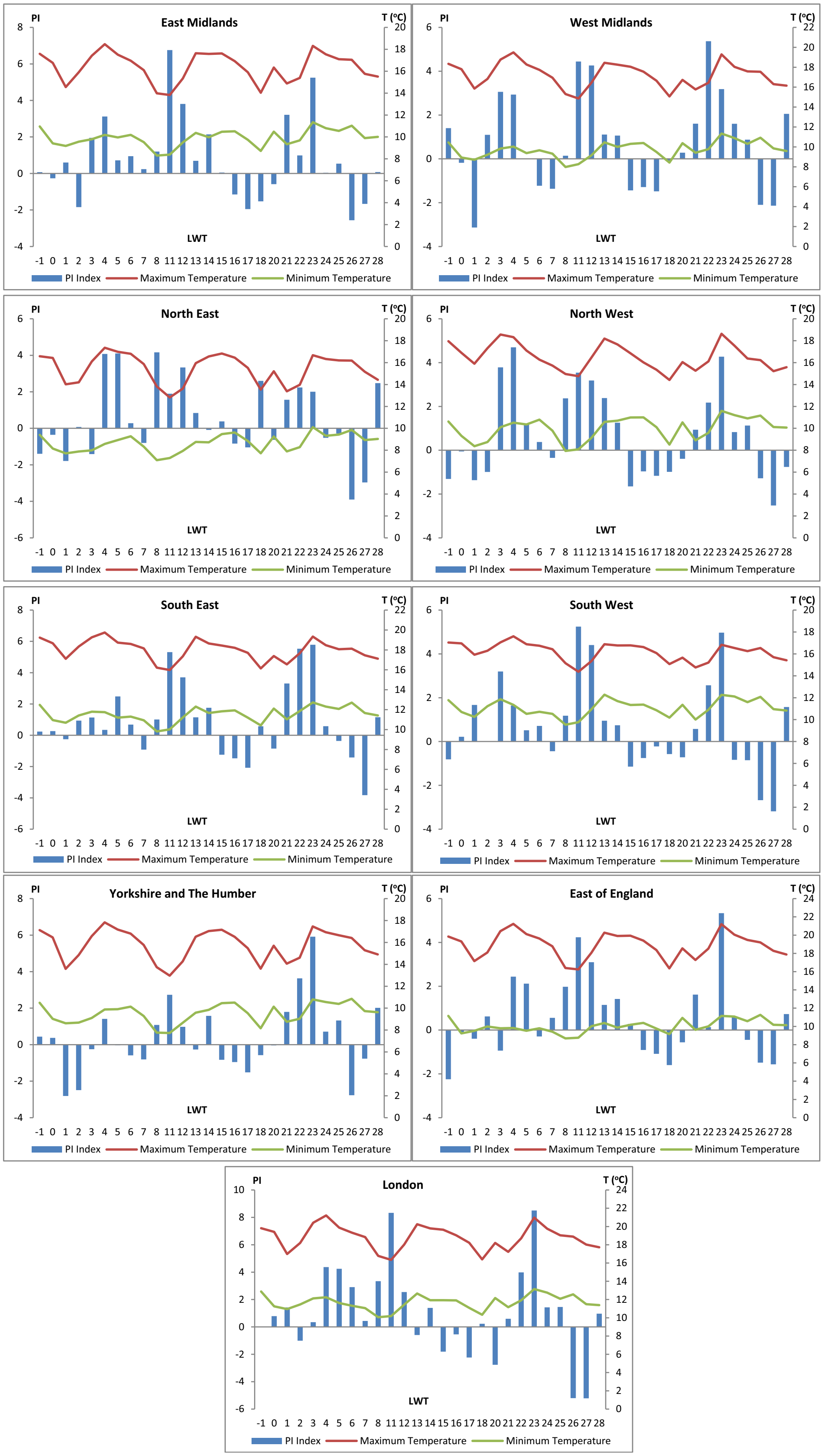


Fig. 4 PI values during the warm period for each LWT per region

For the cold period, the PI index for each LWT per region is illustrated in Fig. 3. For all cases, the highest PI values are found in LWT 2 (AE) which exhibits the lowest minimum and maximum temperatures (ranging from − 1.62 to 4.05 °C) and comprises 0.56% of the total cold period days (November–March). For almost all regions, the second lowest temperatures are presented in LWT 12 (E) (ranging from − 0.09 to 5.13 °C) which comprises 1.18% of the total cold period days and represents one of the most hazardous classes, as the high PI values indicate (Table 4). These findings support those of Dimitriou et al. (2016) who found statistically significant positive correlations between mortality and specific atmospheric pathways related to Low Temperature Episodes (LTE) for five regions across England.

It is worth mentioning that high PI values in Fig. 3 do not always coincide with the lowest temperatures. For instance, LWT 21 (CNE), which features as one of the most hazardous for all regions, is associated in almost all regions with higher temperatures than LWT 11 (NE) which has almost zero or even negative PI values (Table 4). Such a finding is not uncommon in the scientific literature, as moderate winter-time temperatures have been found to be associated with a perceptible increase in mortality (Hajat and Kovats 2014; Gasparrini et al. 2015; Hajat et al. 2016). Similarly, Paschalidou et al. (2017), who studied the relationship between winter mortality and prevailing weather in 5 regions of England by using synoptic classification, confirmed the correlation between low temperatures and mortality, but also linked elevated risk of winter casualties to sometimes relatively higher temperatures. In addition, Gasparrini and Leone (2014), in a previous study for London, reported that the greatest proportion of cold-related deaths (almost 70%) occurred in days with temperatures above 5 °C. Increased number of deaths during days with moderate temperatures could be explained as a lagged result of a previous cold-spell or it could indicate that excess mortality may be associated with a zone of low temperatures and not necessarily the lowest temperatures (Paschalidou et al. 2017). Rapidly changing weather producing temperature increases can also result in increased winter mortality, as noted by McGregor (2001) and Dimitriou et al. (2016). Another explanation could be that the extremes such as extremely low temperatures are understood by a larger segment of the population to be hazardous and people, hence, avoid going outside into danger. This could result in higher rates of hypothermia deaths during relatively warmer days.

During the warm period, in the majority of regions, the highest PI values are found in LWT 23 (CSE) and LWT 11 (NE) which comprise 0.9% and 1.46% of the total warm period days, respectively (Table 5, Fig. 4). In almost all cases, the 'hottest' LWT is 4 (AS) which is not among the two most dangerous classes in any of the regions studied, except for the North West and the North East regions. The most hazardous LWT (CSE) records the second highest temperatures. In general terms, high PI values do not necessarily coincide with the highest temperatures, as opposed to epidemiological studies which observed concomitant increase in both mortality rates and temperature beyond regional thresholds (Baccini et al. 2008; Armstrong et al. 2011; Gasparrini et al. 2012; Bunker et al. 2016). A similar trend is observed when only the hottest months (June to September) are considered. For instance, LWT 22 (CE) presents the highest PI values for most of the regions, although it does not include the highest temperatures (estimations and figures are omitted). Similarly, Gasparrini et al. (2015) found for 13 countries including the UK that the highest rates of heat-related deaths were attributed to moderately high rather than extreme high temperatures.

Similar to the case of cold-related mortality, elevated mortality during moderately hot days may be the result of a previous heat wave or it could indicate that heat-related mortality is associated with a zone of high temperatures. From another perspective, the aforementioned increased mortality during moderately hot (or cold) weather could imply that other atmospheric properties besides temperature may play a dominant role in elevated mortality. For example, previous studies have stated that a fall in atmospheric pressure is associated with elevated morbidity or mortality from hemorrhagic stroke (Dawson et al. 2008), myocardial infarction or coronary disease (Danet et al. 1999), and cardiovascular diseases (Plavcová and Kyselý 2014).

In terms of synoptic classification, during the cold period, LWT 2 (AE) appears to be the most hazardous class for all regions, followed by types 12 (E) and 21 (CNE) in almost all cases. These are all Easterly weather types associated with flows of 'cold' air from over the North Sea or the wider European continent originating as far away as Siberia. The same pattern is repeated during the warm period (and also during the hottest months), when the most hazardous classes appear to be LWT 23 (CSE) and LWT 11 (NE), for almost all regions studied.

According to Lamb (1950), the Easterly weather type is characterized by anticyclonic conditions over Scandinavia, which often extend towards Iceland, and depressions that circulate over the western North Atlantic and the Bay of Biscay region. This atmospheric pattern is generally associated with cold weather in autumn, winter, and spring, while extremely low temperatures and occasional snowy weather is reported in the southern districts. Similarly, Easterly flows can bring snow or sleet showers in the eastern and northeastern districts, but fine weather and dry conditions in the western and northwestern districts. They are notorious for provoking persistent low temperatures in wintertime. These freezing flows are associated with subsidence of several hundred hPa before they reach the surface (Walsh et al. 2001) and are linked to a negative phase of the North Atlantic Oscillation (NAO) coupled with positive sea level pressure anomalies over the Arctic (Walsh et al. 2001; Cattiaux et al. 2013). During summer, Easterly flows are associated with warm weather and dry conditions especially in the west, sometimes thundery though. Concerning air advection, Easterly flows trigger cold spells (in wintertime) and heat waves (in summertime) transferring cold or warm air masses originating from continental Europe (Plavcová and Kyselý 2019).

Easterlies have already been blamed for their adverse outcome on public health in the UK, both for the winter and the summer time. Paschalidou et al. (2017) linked the easterly weather type to low winter temperatures and to a significant increase in mortality. During summer, Petrou et al. (2015) established strong connections between East-Southeast flows and heat casualties in the West Midlands and North West regions. Along the same lines, Pope et al. (2016) concluded that Easterly and Anticyclonic conditions lead to enhanced levels of ozone concentrations and elevated risk of mortality during the warm period (April to September). On the other hand, Dimitriou et al. (2016) noted that high winter mortality is observed not only during Low Temperature Episodes due to Easterly flows but also when marine air flows from the Atlantic dominate (especially for northwest and central England).

In the case of the CSE type, warm air advection from the general region of France or the Iberian Peninsula may induce an increase in heat-related mortality. In contrast, the summer occurrence of a north-easterly weather pattern brings summer cool weather which may increase the chances of summer cold-related mortality as a result of intra-seasonal variability.

Finally, the European heat wave of 2003 was used as a case study, and data from the first fortnight of August were analyzed. During that period, anomalously anticyclonic conditions and blocking patterns occurred in Western Europe (Black et al. 2004). This was also confirmed by our methodology for England, where LWT 0 (A) was found to strongly predominate (occurring in 9 days). For the majority of the regions studied, LWT 8 (AN) that occurred in the 6th of August appeared to be either the hottest or the most dangerous class or, in some cases, both (estimations and figures are omitted). These findings support the hypothesis that the highest rates of mortality do not necessarily coincide with the highest temperatures and are also in agreement with Pope et al. (2016) who reported the importance of anticyclonic weather on summer mortality.

Conclusions

The link between Lamb Weather Types and mortality at the daily time-scale, both for the cold and warm period, has been considered in this study, in order to bring new perspectives to the understanding of the climatology of mortality across nine regions of England. Study results have revealed:

(a) The susceptibility of the English population to temperature is more profound in cold period, for which the highest PI values were observed.
(b) During the cold period, Easterly weather types were found to be the most hazardous for public health for all nine regions, highlighting a spatial homogeneity in the response of mortality to weather patterns across England.
(c) During the warm period, although there appears to be some regional variation with regards to the most hazardous LWT in relation to public health, weather patterns originating from the east are generally the most hazardous.
(d) Regardless of season, it is not necessarily the lowest/highest temperatures that are linked to the most hazardous LWT, indicating the complexity of weather-related health effects and confirming the importance of synoptic climatology in elucidating the relationship between temperature and mortality.

These findings highlight that, although weather-related mortality is confounded by a series of factors including socio-economic, physiological, or behavioral parameters, the changing likelihood of adverse health outcomes, as a result of short-term weather changes, can be understood via adopting a synoptic climatological perspective with benefits accruing in the case of the development of early warning systems focused on climate-sensitive health outcomes. Therefore, weather-related mortality can be predicted and prevented by applying intervention strategies for alerting the public, allocating the healthcare resources, and consequently reducing exposure and effect.

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Compliance with ethical standards

Conflicts of interest The authors declare that they have no conflicts of interest.

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