Analysis of the synoptic winter mortality climatology in five regions of England: Searching for evidence of weather signals

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***Abstract**:* Although heat-related mortality has received considerable research attention, the impact of cold weather on public health is less well-developed, probably due to the fact that physiological responses to cold weather can vary substantially among individuals, age groups, diseases etc, depending on a number of behavioral and physiological factors. In the current work we use the classification techniques provided by the COST-733 software to link synoptic circulation patterns with excess cold-related mortality in 5 regions of England. We conclude that, regardless of the classification scheme used, the most oppressive conditions for public health in England are associated with the prevalence of the Easterly type of weather, favoring advection of cold air from continental Europe. It is noteworthy that there has been observed little-to-no regional variation with regards to the classification results among the 5 regions, suggestive of a spatially homogenous response of mortality to the atmospheric patterns identified. In general, the 10 different groupings of days used reveal that excess winter mortality is linked with the lowest daily minimum/maximum temperatures in the area. However it is not uncommon to observe high mortality rates during days with higher, in relative terms, temperatures, when rapidly changing weather results in an increase of mortality. Such a finding confirms the complexity of cold-related mortality and highlights the importance of synoptic climatology in understanding of the phenomenon.

Keywords: Cold-related mortality, classification methods, atmospheric circulation, Easterly weather

1. Introduction

Extreme weather, in the form of heat waves or cold spells, is associated with adverse health effects in many regions of the world, where strong links between ambient temperature and increased mortality have been reported (Ferreira Braga et al., 2001; Basu and Samet, 2002; Donaldson et al., 2003; Basu et al., 2008; Basu, 2009; Guo et al., 2013; Urban et al., 2014;

Wang et al., 2014; Tsangari et al., 2016). However, the exact shape of the exposure-response curve has been found to vary with location and latitude, depending on a number of physiological and behavioral factors (Guo et al., 2014; Keatinge et al., 2000). Physiological factors include acclimatization to extreme ambient temperatures, as well as the ability of thermoregulation, while behavioral factors include the habits and lifestyle of population, the use of air-conditioning, the quality of housing, the time spent outdoors etc (Donaldson and Keatinge, 2003; Kovats and Kosatsky, 2009; Yu et al., 2012).

According to Carson et al. (2006) and Astrom et al. (2013) a progressive reduction in temperature-related mortality has been reported in many regions of the world since the beginning of the twentieth century. Nevertheless, extreme ambient temperatures still pose a severe threat to public health (Morabito et al., 2012; Scarborough et al., 2012; Astrom et al., 2013), especially for the most vulnerable groups of population, such as the children, the pregnant women and the elderly (Hajat et al., 2007; Xu et al., 2013). Under the changing climate, the frequency, intensity and duration of heat waves are expected to increase, resulting in an increase of heat-related mortality (Huang et al., 2011; Hajat et al, 2014; Heaviside et al., 2016), whereas winter mortality is expected to decrease. However, the future of winter mortality is not completely understood (Wang et al., 2016).

Cold spells have been long-known for their adverse health effects and their impact on mortality (Keatinge 2002). For instance, Curriero et al. (2002) have studied the sensitivity of population to cold weather in 11 cities in the United States, whereas Analitis et al. (2008) have studied the impact of cold spells on public health (in the form of cardiovascular, respiratory and cerebrovascular diseases) in 15 cities in Europe. In China, a severe cold spell in 2008 resulted in 148279 excess deaths, with the highest impact observed in southern and central China, where mortality increased by 44% (Ma et al., 2013; Xie et al. 2013; Zhou et al., 2014). Similarly, the adverse health effects of cold weather have been studied in many areas of the Iberian Peninsula (Gomez-Acebo et al., 2010, Montero et al., 2010; Vasconcelos et al., 2013) and Italy, where an unusual cold spell during 2012 resulted in a 25% increase in mortality among the elderly (75+ years of age) across 14 cities (de' Donato et al., 2013). In England, winter temperature seasonality and cold spells linked to a severe negative phase of the North Atlantic Oscillation have been associated with increased risk of ischemic heart disease and myocardial infarction (McGregor 2005; Bhaskaran et al., 2010).

The majority of studies described above use time series-based Poisson Regression and Generalized Additive Models (GAMs) and/or case-only or crossover studies to analyze the cold weather-related mortality. However, the climatology of winter mortality is less well-developed, mainly due to the fact that winter mortality is very often confounded by social, economic, behavioral and physiological factors (Anderson and Bell 2009; Allen and Lee, 2014). The objective of this paper is to shed light on the climatological associations between winter mortality and cold weather in the United Kingdom, by using synoptic classifications, and to explore the possible link between certain atmospheric patterns and winter mortality, so that the most oppressive conditions for public health can be recognized.

2. Data and Methods

2.1 Area Description and Data Sources

In the present study we focus on the United Kingdom, where cold spells are well-known to play an important role in the yearly variability of excess cold-related mortality (McGregor 2005; Hajat and Kovats 2014). According to Healy (2003), the country presents the highest levels of excess cold-related mortality across Europe, with the cold-related mortality burden accounting for more than one order of magnitude more deaths than heat-related mortality (approximately 61 and 3 deaths per 100,000 population per year, respectively) (Vardoulakis et al., 2014).

For the needs of the study, November to February daily temperature (surface mean, minimum and maximum, in °C) and mortality (all-cause deaths per day) data for the 26-yr period 1974-1999 were used. The data covered the following 5 official Office of National Statistics (ONS) regions in England: (a) Yorkshire and the Humber, (b) the West Midlands, (c) Northeast, (d) Northwest and (e) Southeast regions (Figure 1), as these were the only regions for which mortality data could be obtained. The above regions can be considered to represent the whole of England, as they capture the range of winter temperatures across England, and could therefore provide insights into any geographical variation of cold weather and adverse health effects.

It is noted that the temperature data were obtained from one county-level meteorological station, representative of each region (Figure 1), namely, West Yorkshire (Yorkshire and the Humber), West Midlands (West Midlands), Tyne and Wear (Northeast), Greater Manchester (Northwest), and Hampshire (Southeast). Inevitably small temperature differences probably appeared among the different areas of each region. Nevertheless, the use of the county-level meteorological stations for representing each region is probably the best option, under the circumstances, as no additional information is available on a number of important issues, such as whether the people travelled within the region (or even throughout the country) before dying, in which part of the region they resided etc.

All data were obtained from the ONS and the mortality data were de-trended prior to the analysis.

2.2 Methodology

In order to link winter mortality and prevailing weather systems, the COST-733 Action (http://www.cost733.eu) classification tool (v. 2.0) was used. This software uses a number of well-established classification methods to provide synoptic classification schemes for Europe. For the purposes of the present study, Domain 4 of this software, including 432 cells defined by the 47-62°N and 18-8°E coordinates, and covering the British Isles, Benelux and N. France area was used. For the needs of the study the following 10 available grouping techniques were used: (a) 2 schemes using the Leader Algorithm, namely the ERP (based on the pressure gradient metric; Erpicum et al., 2008) and the LND (based on the correlation coefficient metric; Lund, 1963), (b) 4 Principal Component Analysis (PCA) schemes, namely the KRZ (S-mode without rotation), the PCT (T-mode with oblique rotation), the PTT (T-mode with VARIMAX rotation) and the PXE (S-mode with VARIMAX rotation) and (c) 4 Optimization

Algorithms, namely the CAP (principle components cluster analysis), the CKM which is a k-means by dissimilar seeds, the PXK (K-means reassigned extreme scores) and the SAN (simulated annealing and diversified randomization clustering).

The Leader Algorithm counts the number of elements with similarity to the key-pattern exceeding a certain threshold, in order to find the so-called “leader”, i.e. representative key-patterns for each group. A T-mode PCA recognizes typical patterns and uses loadings to describe the degree of realization, while an S-mode PCA locates temporal variability through typical modes. Finally, the Optimization Algorithms are non-hierarchical methods, in the sense that the various groups can be split up to minimize the within-group variance. A complete description of the aforementioned classification schemes, together with their advantages and disadvantages can be found in Philipp et al. (2010, 2014).

Figure 1. Office of National Statistics study regions.

The grouping techniques described above were used to associate synoptic circulations and winter mortality and τo investigate any evidence of weather signals. The groupings were carried out with a 4 days sequence length (i.e. a 4-days averaging), using mean sea-level pressure as the classification variable. The 4 days sequence length was used, as winter mortality can manifest itself in a time distributed way, often referred to as the “lag effect” (Gasparini et al., 2010; Allen and Sheridan, 2014; Zeka et al., 2014), as opposed to heat-related mortality which has an acute response (Gosling et al., 2009). The various classification schemes used resulted in a number of classes (9 or 10 depending on the specific configuration used) with distinct synoptic circulation patterns. Then, mortality data were summarized across the different synoptic circulations.

Next, we used the PI sign-test (Duckstein et al., 1993; Paschalidou and Kassomenos, 2016) to check the frequency of excess mortality in the various classes:

$$PI_i = 100 \times \left(\frac{number\ of\ deths\ in\ C_i / total\ number\ of\ deaths}{number\ of\ days\ in\ C_i / total\ number\ of\ days} - 1\right) \qquad (1)$$

where C_i stands for the different classes. In Eq. 1, values of PI equal to 0 denote mortality is equally spread among classes, whereas positive/negative PI values show that the occurrence of deaths is more/less frequent under the conditions of the specific classes. PI values equal to –100 indicate “mortality-free” classes.

Finally, centroid maps produced by the COST-733 software were discussed, in order to study the synoptic winter mortality climatology.

3. Results and Discussion

3.1 Presentation of the classes

During the 26-y period 1974-1999 a total of 2916300 all-cause casualties were recorded in the 5 regions studied. The number of deaths per year for each of the five regions is presented in Figure 2. Not surprisingly the biggest number of fatalities for most of the years appears in the Northwest region (194.6 deaths per year), where, according to the Office of National Statistics, this is the most populated region (approximately 498 inhabitants per Km^2). A closer look reveals a progressive reduction in winter mortality for all five regions of England. Although not all of the incidents can be attributed/related to cold weather, the general decreasing trend is in agreement with Carson et al. (2006) and Astrom et al. (2013) who reported descending trends in cold-related mortality for London and Stockholm, respectively. Such a decreasing trend probably reflects the changing vulnerability of the population due to improvements in infrastructure, lifestyle, technology, and general health. According to Vardoulakis et al. (2014), the decreasing trend is projected to continue due to climate change and to reach approximately 42 deaths per 100,000 population per year in the

UK, whereas the heat-related mortality burden is expected to increase to approximately 9 deaths per 100,000 population per year by the 2080s.

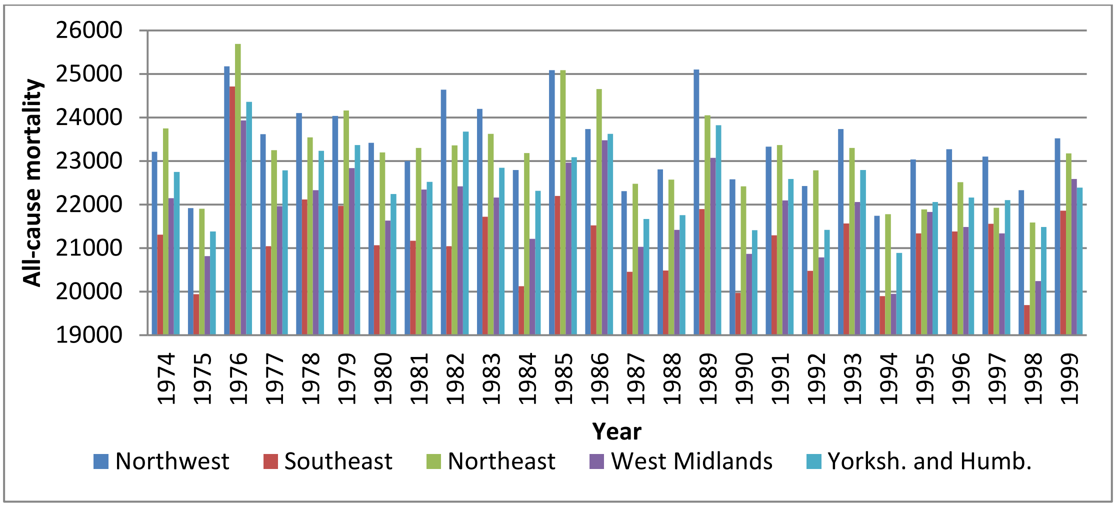


Figure 2. The number of deaths per year for each of the five regions

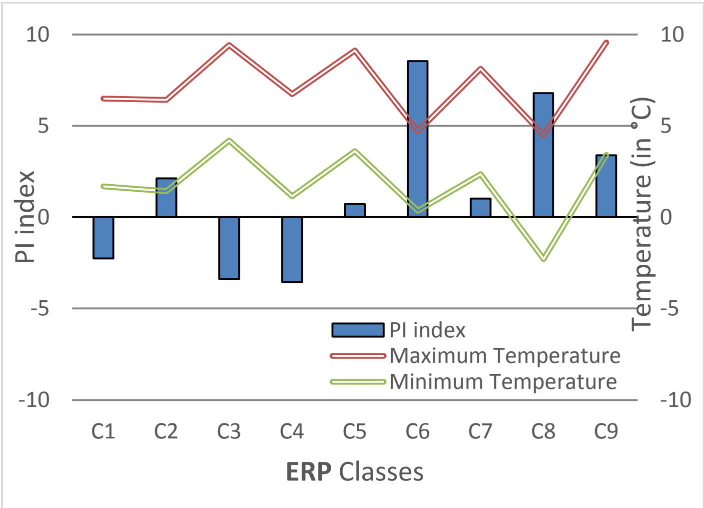
Tables 1-5 present the results of all 10 classification techniques performed for each one of the 5 regions studied, namely the number of days per class, the maximum/minimum/mean surface temperature (in °C) and the total number of deaths. It appears that for each classification scheme there are a number of classes that reflect the most oppressive conditions, in terms of excess winter mortality. This finding is highlighted in Figure 3, where the PI index for each classification scheme is shown for the Northwest region (figures for the rest of the regions are omitted).

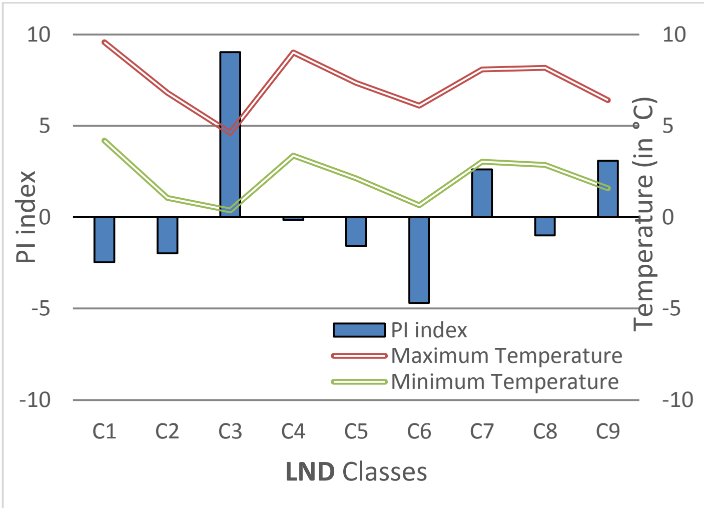
Specifically for the Northwest region ERP classes C6 and C8 reflect the most oppressive conditions for public health, as they present the biggest PI values (Figure 3). It is noteworthy that these classes feature the lowest maximum (4.7 °C and 4.5 °C, respectively), as well as the lowest minimum temperatures (0.3 °C and -2.3 °C, respectively), confirming that winter mortality is associated with low temperatures (Keatinge 2002). Similar is the pattern for the Southeast (Table 2), the West Midlands (Table 3), the Yorkshire and Humber (Table 4) and the Northeast region (Table 5), where classes C6 and C8 presenting the lowest maximum/minimum temperatures are linked with the highest PI values (figures not shown). This finding is in agreement with results provided by Dimitriou et al. (2016) who defined atmospheric pathways linked with winter low temperature episodes (LTE) in the same 5 regions of England for the same time period and revealed associations with excess mortality rates. According to them, a statistically significant increase in mortality was calculated for LTE days across all 5 regions studied. LND class C3, with PI value equal to 9.04, appears to be the most dangerous for public health in the Northwest region. This class comprises 10% of the total winter days (November – February) for the period studied and is linked with the lowest maximum and minimum temperatures in the region (4.6 °C and 0.4 °C, respectively). The pattern of the highest mortality being linked to the lowest temperatures is repeated in the Southeast (Table 2), the West Midlands (Table 3), the Yorkshire and Humber (Table 4) and the Northeast region (Table 5).

Among the 4 PCA classifications schemes in the Northwest region, namely KRZ, PCT, PTT and PXE, KRZ class C7, PCT class C8, PTT class C3 and PXE class C9 (Figure 3) appear to be linked with the most adverse effects on public health. These classes comprise 10%, 9%, 20% and 8%, respectively, of the total winter days studied. Although KRZ class C7 presents some of the lowest maximum and minimum temperatures (5.5 °C and 1.0 °C, respectively), classes PCT C8, PTT C3, PXE C9 are associated with slightly higher maximum (6.7 °C, 6.9 °C and 7.8 °C, respectively) and minimum temperatures (2.4 °C, 2.1 °C and 3.3 °C, respectively). Similar is the situation in the Southeast (Table 2), the West Midlands (Table 3), the Yorkshire and Humber (Table 4) and the Northeast region (Table 5), where the highest levels of winter mortality are not always linked to the lowest temperatures. This finding does not come as a surprise, as Hajat and Kovats (2014) state that a significant number of cold-related deaths are linked to moderate temperatures. Additionally, Gasparrini and Leone (2014) conclude that 70% of cold-related mortality in London is observed during days with temperature higher than 5 °C and not necessarily during days with the absolute minimum temperatures. Such a pattern could also mean there is a temperature range (zone), centered around the lowest temperatures, that could cause the excess mortality. In the presence of various confounding factors, it can be the slightly higher temperatures that are linked to excess mortality. Furthermore, Dimitriou et al. (2016) concluded that in some cases mortality in the 5 regions studied is linked to rather increased winter temperatures associated with long-distance west-to-east flows, resulting in rapidly changing weather, as opposed to stable conditions linked with blocking to the east. Rapidly changing atmospheric pressure and/or temperature have been longed blamed for adverse health effects. For instance Dawson et al. (2008) showed that rapid falls in atmospheric pressure are associated with increased risk of morbidity due to hemorrhagic stroke in Glasgow. Finally, the excess mortality during days with relatively higher temperatures could be explained as lagged mortality after a period of cumulative exposure to oppressive cold weather.

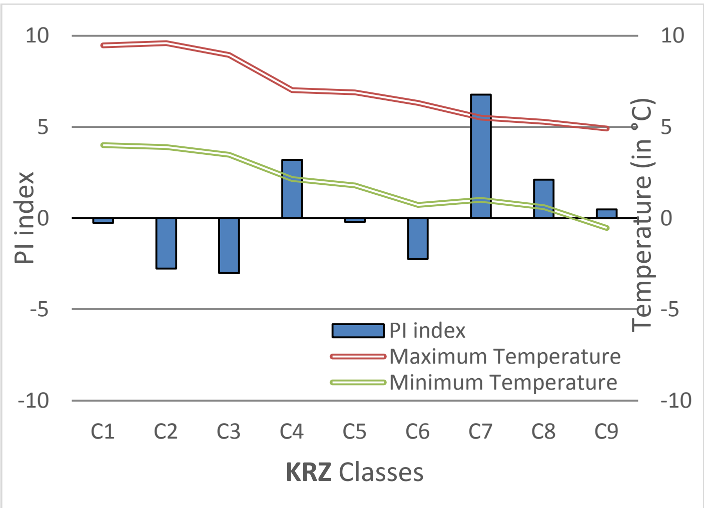
With regards to the 4 optimization algorithm classification schemes, CAP class C2, CKM class C2, PXK class C10 and SAN class C4 are associated with the most dangerous conditions for public health, in terms of winter mortality in the North west region. These classes comprise 8%, 10%, 6% and 9%, respectively, of the total winter days studied and present some of the lowest maximum (6.1 °C, 5.1°C, 4.2°C and 5.9°C, respectively) and minimum temperatures (1.3 °C, 0.3°C, 0.0°C and 1.2 °C, respectively) in the region (Table 1). Almost identical is the pattern observed for the Southeast (Table 2), the West Midlands (Table 3), the Yorkshire and Humber (Table 4) and the Northeast region (Table 5), where CKM C2 and PXE C10 are associated with the lowest temperatures and the highest levels of excess mortality, while classes CAP C2 and SAN C4 also present some of the lowest maximum/minimum temperatures.

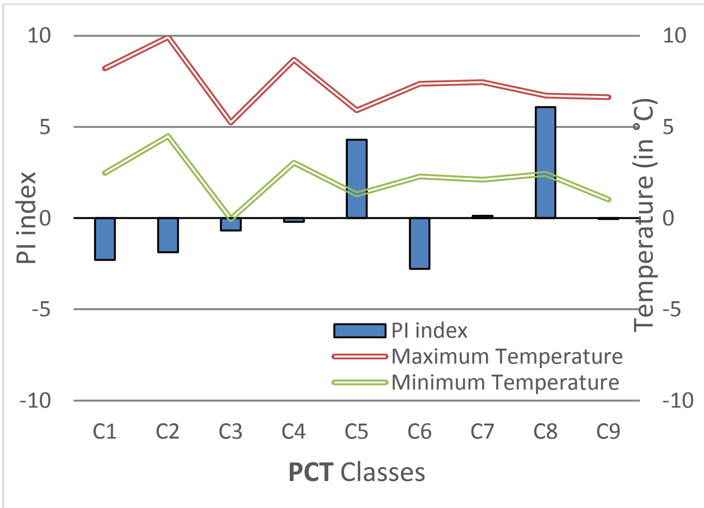
On the whole, the pattern of the "most dangerous" classes described above is repeated almost identically (Tables 2-5), confirming the adverse impact of the specific classes' climatology on winter mortality. Specifically, there appears to be little-to-no regional variation with regards to the most oppressive classes among the 5 regions, suggesting a spatially homogeneous response of mortality in the 5 regions to atmospheric patterns.





(a) (b)





(c) (d)

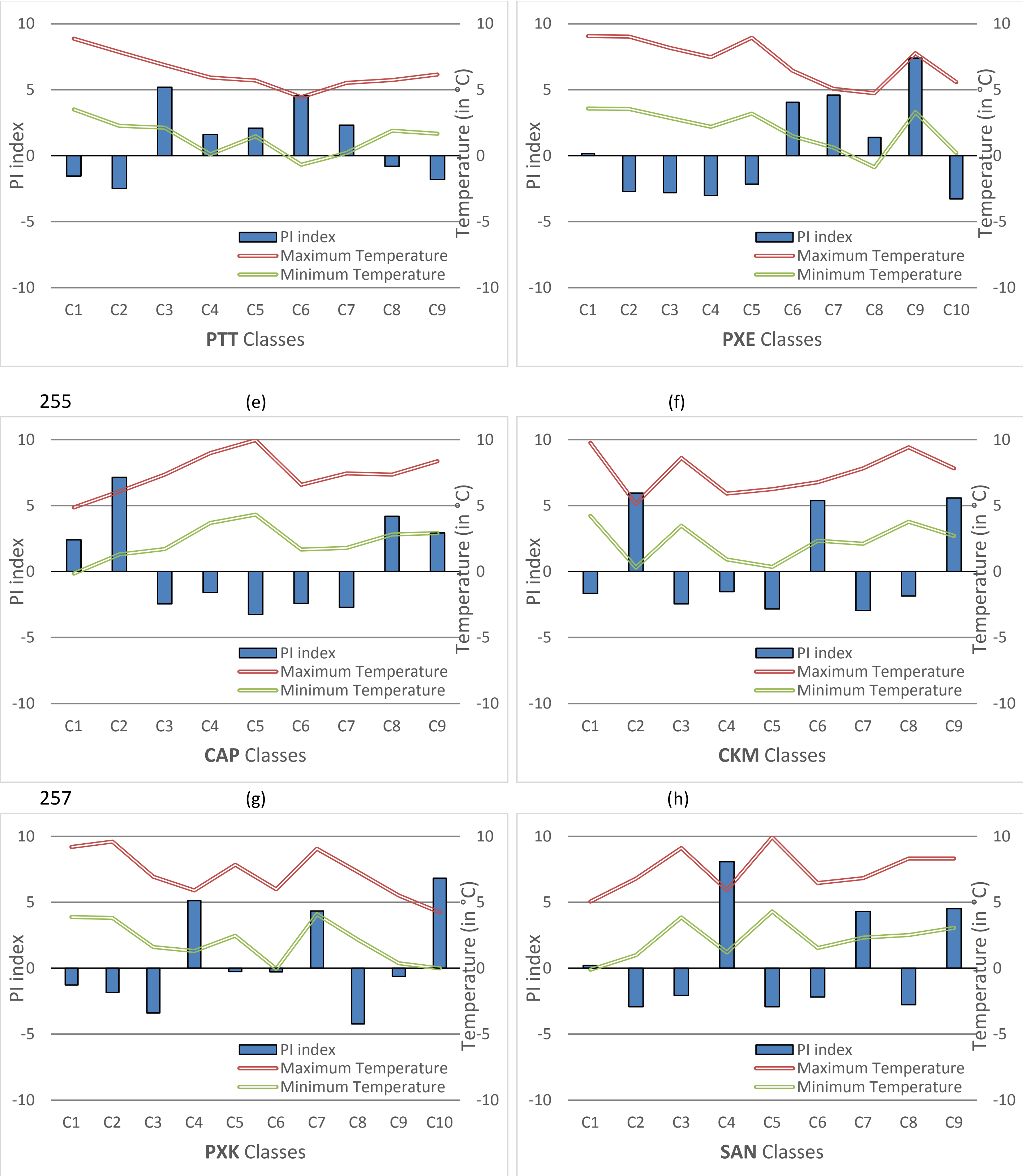


Figure 3. The PI index together with the minimum and maximum temperature for the 10 classification schemes, in the Northwest region

Table 1. The number of days for each class, together with the maximum/minimum/mean temperature (in °C) and the total mortality for each classification scheme in the Northwest region. The classes showing the most oppressive (in terms of excess mortality) conditions are given in bold

		CLASSES									
		1	2	3	4	5	6	7	8	9	10
ERP	Total days	168	628	595	499	765	**223**	219	**21**	8	-
	Max T	6.5	6.4	9.4	6.7	9.1	**4.7**	8.1	**4.5**	9.6	**-**
	Min T	1.7	1.4	4.2	1.1	3.6	**0.3**	2.3	**-2.3**	3.4	-
	Mean T	3.9	3.9	6.7	3.8	6.3	**2.5**	5.2	**1.1**	6.5	-
	Tot Mort	31947	124778	111856	93629	149910	**47095**	43041	**4363**	1609	-
LND	Total days	680	472	**304**	439	262	210	330	209	**220**	-
	Max T	9.6	6.8	**4.6**	9.0	7.3	6.1	8.1	8.2	**6.4**	-
	Min T	4.2	1.1	**0.4**	3.4	2.1	0.7	3.0	2.9	**1.6**	-
	Mean T	6.8	3.8	**2.5**	6.1	4.7	3.3	5.4	5.4	**3.9**	-
	Tot Mort	129048	90018	**64493**	85280	50174	38938	65891	40257	**44129**	-
KRZ	Total days	617	427	564	**291**	180	275	**324**	222	226	-
	Max T	9.5	9.6	8.9	**7.0**	6.9	6.3	**5.5**	5.3	4.9	**-**
	Min T	4.0	3.9	3.5	**2.1**	1.8	0.7	**1.0**	0.6	-0.5	-
	Mean T	6.6	6.7	6.1	**4.5**	4.3	3.5	**3.2**	2.9	2.1	-
	Tot Mort	119727	80782	106438	**58426**	34948	52308	**67312**	44105	44183	-
PCT	Total days	503	554	237	433	**343**	298	207	**294**	257	-
	Max T	8.2	9.9	5.2	8.7	**5.9**	7.4	7.4	**6.7**	6.6	-
	Min T	2.5	4.5	-0.0	3.0	**1.3**	2.3	2.1	**2.4**	1.0	-
	Mean T	5.3	7.1	2.5	5.8	**3.5**	4.7	4.7	**4.5**	3.8	-
	Tot Mort	95618	105781	45797	84069	**69608**	56364	40329	**60680**	49983	-
PTT	Total days	1129	916	**612**	195	87	**65**	59	19	44	-
	Max T	8.9	7.9	**6.9**	5.9	5.7	**4.4**	5.5	5.7	6.2	-
	Min T	3.5	2.3	**2.1**	0.1	1.5	**-0.7**	0.2	1.9	1.7	-
	Mean T	6.1	5.0	**4.4**	3.0	3.5	**1.8**	2.9	3.7	3.9	-
	Tot Mort	216301	173800	**125246**	38556	17281	**13224**	11746	3667	8406	-
PXE	Total days	551	525	346	238	301	329	**217**	185	**235**	199
	Max T	9.1	9.0	8.2	7.5	8.9	6.4	**5.1**	4.7	**7.8**	5.6
	Min T	3.6	3.6	2.7	2.2	3.2	1.5	**0.6**	-0.9	**3.3**	0.2
	Mean T	6.2	6.2	5.4	4.8	6.0	3.9	**2.8**	1.9	**5.5**	2.8
	Tot Mort	107381	99379	65435	44911	57300	66602	**44163**	36497	**49106**	37453
CAP	Total days	304	**236**	297	388	504	391	306	**245**	455	-
	Max T	4.9	**6.1**	7.4	8.9	9.9	6.6	7.4	**7.4**	8.4	-
	Min T	-0.2	**1.3**	1.7	3.7	4.3	1.7	1. 8	**2.8**	2.9	-
	Mean T	2.3	**3.6**	4.4	6.2	7.0	4.1	4.5	**5.0**	5.6	-
	Tot Mort	60566	**49194**	56365	74291	94865	74240	57921	**49670**	91117	-
CKM	Total days	480	**303**	392	437	228	244	338	398	**306**	-
	Max T	9.8	**5.1**	8.6	5.9	6.2	6.8	7.8	9.4	**7.8**	-
	Min T	4.2	**0.3**	3.5	0.9	0.4	2.3	2.1	3.8	**2.7**	-
	Mean T	6.9	**2.6**	5.9	3.4	3.3	4.5	4.9	6.5	**5.2**	-
	Tot Mort	91837	**62454**	74400	83732	43103	50026	63817	75999	**62861**	-
PXK	Total days	524	576	361	**315**	294	240	279	216	134	**187**

	Max T	9.2	9.6	6.9	**5.9**	7.8	5.9	9.1	7.3	5.5	**4.2**
	Min T	3.9	3.8	1.6	**1.3**	2.5	-0.1	4.1	2.2	0.4	**0.0**
	Mean T	6.5	6.6	4.2	**3.5**	5.1	2.9	6.5	4.6	2.9	**2.1**
	Tot Mort	100649	110011	67851	**64430**	57054	46569	56638	40252	25910	**38866**
SAN	Total days	267	278	435	**269**	481	397	241	369	**389**	-
	Max T	5.0	6.8	9.1	**5.9**	9.9	6.5	6.8	8.3	**8.3**	-
	Min T	-0.1	0.9	3.8	**1.2**	4.3	1.5	2.3	2.5	**3.1**	-
	Mean T	2.4	3.9	6.3	**3.5**	7.0	4.0	4.5	5.3	**5.6**	-
	Tot Mort	52056	52509	82886	**56561**	90857	75553	48906	69807	**79093**	-

Table 2. The number of days for each class, together with the maximum/minimum/mean temperature (in °C) and the total mortality for each classification scheme in the Southeast region. The classes showing the most oppressive (in terms of excess mortality) conditions are given in bold

		CLASSES									
		1	2	3	4	5	6	7	8	9	10
ERP	Total days	168	628	595	499	765	**223**	219	**21**	8	-
	Max T	6.7	7.3	9.7	7.8	9.9	**5.8**	9.3	**5.2**	9.9	**-**
	Min T	1.3	1.6	4.1	1.2	4.4	**0.6**	3.2	**-1.7**	4.8	-
	Mean T	4.0	4.5	6.9	4.5	7.1	**3.2**	6.2	**1.8**	7.4	-
	Tot Mort	29083	113117	101300	85760	135453	**42677**	39016	**4041**	1351	-
LND	Total days	680	472	**304**	439	262	210	330	209	**220**	-
	Max T	10.5	7.7	**5.1**	9.6	8.2	7.5	8.7	8.4	**6.9**	-
	Min T	4.9	1.1	**0.1**	3.8	2.3	1.2	3.5	2.3	**1.7**	-
	Mean T	7.7	4.4	**2.6**	6.7	5.2	4.4	6.1	5.4	**4.4**	-
	Tot Mort	116564	81544	**59361**	76712	45858	35848	59039	37060	**39810**	-
KRZ	Total days	617	427	564	291	180	275	**324**	**222**	226	-
	Max T	10.1	10.3	9.9	7.9	7.7	7.3	**6.2**	**5.7**	5.7	**-**
	Min T	4.7	4.6	3.7	2.4	1.7	0.7	**1.1**	**0.2**	-0.2	-
	Mean T	7.4	7.4	6.8	5.2	4.7	4.0	**3.6**	**3.0**	2.7	-
	Tot Mort	108337	73092	96225	52793	31596	47971	**61142**	**40668**	39975	-
PCT	Total days	503	554	237	433	**343**	298	207	**294**	257	-
	Max T	9.2	10.5	5.8	9.1	**6.5**	9.4	7.6	**7.7**	7.1	-
	Min T	2.7	5.0	0.0	3.6	**1.3**	3.4	1.5	**2.8**	0.6	-
	Mean T	5.9	7.8	2.9	6.3	**3.9**	6.4	4.6	**5.3**	3.8	-
	Tot Mort	85756	95384	41881	76030	**63905**	51719	36807	**54511**	45804	-
PTT	Total days	1129	916	612	195	87	**65**	**59**	19	44	-
	Max T	9.7	8.9	7.5	6.3	5.3	**4.2**	**5.7**	7.2	7.8	-
	Min T	4.1	2.6	2.5	-0.5	0.4	**-1.2**	**-0.7**	2.2	2.4	-
	Mean T	6.9	5.8	5.0	2.9	2.9	**1.5**	**2.5**	4.7	5.1	-
	Tot Mort	195843	157534	113137	35195	15898	**12060**	**10967**	3408	7756	-
PXE	Total days	551	525	346	238	301	329	**217**	185	**235**	199
	Max T	9.2	10.3	8.8	8.6	10.0	6.9	**5.3**	5.0	**8.9**	7.1
	Min T	3.6	4.5	2.8	2.5	3.8	1.4	**0.2**	-1.2	**4.2**	0.9
	Mean T	6.4	7.4	5.8	5.6	6.9	4.1	**2.7**	1.9	**6.5**	4.0
	Tot Mort	97191	90147	59714	41312	51378	59669	**41000**	33167	**43995**	34224

CAP	Total days	**304**	**236**	297	388	504	391	306	245	455	-
	Max T	**5.1**	**6.6**	8.1	9.3	10.7	6.6	8.8	8.7	9.9	-
	Min T	**-0.7**	**1.5**	1.6	3.6	5.1	0.9	2.4	3.7	4.2	-
	Mean T	**2.2**	**4.1**	4.9	6.5	7.9	3.7	5.6	6.2	7.1	-
	Tot Mort	**55807**	**44633**	50976	67652	86231	68440	52366	44297	81397	-
CKM	Total days	480	**303**	392	437	228	**244**	338	398	306	-
	Max T	10.2	**5.6**	8.9	5.9	7.1	**8.1**	9.1	10.5	9.5	-
	Min T	4.3	**0.2**	2.8	0.2	0.6	**2.9**	2.7	5.0	3.9	-
	Mean T	7.5	**2.9**	5.9	3.0	3.8	**5.5**	5.9	7.8	6.7	-
	Tot Mort	83487	**57170**	67766	77098	39309	**44952**	57822	68459	55735	-
PXK	Total days	524	576	361	**315**	294	240	279	216	134	**187**
	Max T	10.1	10.1	8.9	**6.6**	7.8	6.6	10.1	7.9	5.7	**4.7**
	Min T	4.6	4.4	2.5	**1.5**	1.6	-0.2	4.9	2.1	-0.1	**-0.2**
	Mean T	7.3	7.2	5.7	**4.1**	4.7	3.2	7.6	5.0	2.8	**2.2**
	Tot Mort	91464	98332	61997	**58484**	52393	42294	50316	36931	23794	**35792**
SAN	Total days	267	278	435	**269**	481	397	**241**	369	389	-
	Max T	5.2	7.9	9.4	**6.4**	10.6	6.4	**8.2**	9. 6	9.9	-
	Min T	-0.8	1.4	3.5	**1.3**	5.1	0.8	**3.0**	3.2	4.5	-
	Mean T	2.2	4.6	6.5	**3.8**	7.8	3.6	**5.6**	6.4	7.2	-
	Tot Mort	47851	47860	75383	**51313**	82461	69667	**43936**	62842	70485	-

Table 3. The number of days for each class, together with the maximum/minimum/mean temperature (in °C) and the total mortality for each classification scheme in the West Midlands region. The classes showing the most oppressive (in terms of excess mortality) conditions are given in bold

		CLASSES									
		1	2	3	4	5	6	7	8	9	10
ERP	Total days	168	628	595	499	765	**223**	219	**21**	8	-
	Max T	6.0	5.9	9.2	6.7	9.0	**4.1**	8.4	**3.7**	9.5	-
	Min T	1.3	0.7	3.7	0.7	3.3	**-0.7**	2.4	**-3.2**	3.9	-
	Mean T	3.7	3.3	6.4	3.7	6.1	**1.7**	5.4	**0.3**	6.7	-
	Tot Mort	29845	116735	104550	88387	139961	**44267**	39737	**4064**	1445	-
LND	Total days	680	472	**304**	439	262	210	330	209	**220**	-
	Max T	9.8	6.7	**3.7**	8.8	7.3	6.2	7.5	7.6	**5.6**	-
	Min T	4.1	0.5	**-0.8**	2.9	1.8	0.6	2.3	1.8	**0.8**	-
	Mean T	7.0	3.6	**1.4**	5.9	4.6	3.4	4.9	4.7	**3.2**	-
	Tot Mort	119301	84370	**61017**	80150	47426	36725	60577	38265	**41161**	-
KRZ	Total days	617	427	564	291	180	275	**324**	**222**	226	-
	Max T	9.4	9.7	9.1	6.5	6.6	6.2	**4.7**	**4.5**	4.6	-
	Min T	3.7	3.7	3.2	1.4	1.0	0.1	**0.1**	**-0.4**	-1.1	-
	Mean T	6.6	6.7	6.1	4.0	3.8	3.2	**2.4**	**2.1**	1.7	-
	Tot Mort	111239	75406	99424	54524	32449	49479	**63008**	**41766**	41697	-
PCT	Total days	503	554	237	433	**343**	298	207	**294**	257	-
	Max T	8.2	9.9	4.8	8.5	**5.0**	8.1	7.0	**6.1**	6.2	-
	Min T	2.1	4.3	-0.5	2.5	**0.3**	2.3	1.3	**1.7**	0.0	-
	Mean T	5.2	7.1	2.1	5.5	**2.7**	5.2	4.2	**3.9**	3.1	-

	Tot Mort	88913	97377	43577	78502	**65671**	53097	37997	**56526**	47331	-
PTT	Total days	1129	916	**612**	195	87	**65**	59	19	44	-
	Max T	8.9	7.9	**6.1**	5.4	4.8	**3.5**	4.9	5.6	6.4	-
	Min T	3.3	1.9	**1.3**	-1.2	0.6	**-1.5**	-0.7	1.2	1.3	-
	Mean T	6.1	4.9	**3.7**	2.1	2.7	**1.0**	2.1	3.4	3.8	-
	Tot Mort	201008	163368	**116871**	36531	15871	**12596**	11175	3625	7946	-
PXE	Total days	551	525	346	238	301	329	**217**	185	**235**	199
	Max T	8.5	9.4	8.2	7.7	9.1	5.7	**4.0**	4.3	**7.4**	5.6
	Min T	2.8	3.5	2.3	1.9	2.9	0.5	**-0.3**	-1.6	**2.8**	0.1
	Mean T	5.7	6.4	5.2	4.9	6.0	3.1	**1.8**	1.3	**5.1**	2.8
	Tot Mort	100058	92345	60778	42617	53952	62290	**41721**	34375	**45394**	35461
CAP	Total days	**304**	**236**	297	388	504	391	306	245	455	-
	Max T	**4.1**	**5.3**	7.3	8.8	10.1	5.9	7.6	6.9	8.6	-
	Min T	**-1.3**	**0.4**	1.1	3.1	4.2	0.8	1.6	2.2	2.8	-
	Mean T	**1.4**	**1.4**	1.4	1.4	1.4	1.4	1.4	1.4	1.4	-
	Tot Mort	**57387**	**45961**	52057	69065	88769	70506	54470	46064	84713	-
CKM	Total days	480	**303**	392	437	228	**244**	338	398	306	-
	Max T	9.8	**4.2**	8.4	5.2	6.1	**6.2**	7.9	9.6	8.0	-
	Min T	3.9	**-0.8**	2.8	0.0	0.0	**1.6**	1.9	3.7	2.5	-
	Mean T	6.8	**1.7**	5.6	2.6	3.0	**3.9**	4.9	6.7	5.3	-
	Tot Mort	85158	**58853**	69340	79306	40510	**46487**	60019	71098	58219	-
PXK	Total days	524	576	361	**315**	294	240	279	216	134	**187**
	Max T	9.5	9.4	7.3	**5.0**	7.2	5.7	9.0	7.1	4.9	**3.3**
	Min T	3.8	3.5	1.5	**0.4**	1.3	-0.6	3.8	1.4	-0.2	**-1.2**
	Mean T	6.6	6.5	4.5	**2.7**	4.2	2.6	6.4	4.2	2.4	**1.0**
	Tot Mort	93500	102361	63739	**60352**	54026	43780	51847	37852	24621	**36913**
SAN	Total days	267	278	435	**269**	481	397	**241**	369	389	-
	Max T	4.5	6.7	8.9	**4.9**	9.9	5.8	**6.4**	8.5	8.6	-
	Min T	-1.2	0.7	3.2	**0.2**	4.1	0.7	**1.6**	2.3	3.0	-
	Mean T	1.7	3.7	6.1	**2.6**	7.1	3.3	**4.0**	5.4	5.8	-
	Tot Mort	49316	49347	76534	**52617**	85053	71745	**45588**	65541	73249	-

Table 4. The number of days for each class, together with the maximum/minimum/mean temperature (in °C) and the total mortality for each classification scheme in the Yorkshire and Humber region. The classes showing the most oppressive (in terms of excess mortality) conditions are given in bold

		CLASSES									
		1	2	3	4	5	6	7	8	9	10
ERP	Total days	168	628	595	499	765	**223**	219	**21**	8	-
	Max T	5.8	5.1	8.9	6.0	8.3	**3.3**	7.2	**3.7**	8.8	-
	Min T	1.3	0.5	3.7	0.5	2.8	**-1.0**	1.4	**-2.5**	2.9	-
	Mean T	3.5	2.8	6.3	3.3	5.6	**1.1**	4.3	**0.6**	5.9	-
	Tot Mort	30140	119958	106700	90792	144469	**45468**	41495	**4138**	1568	-
LND	Total days	680	472	**304**	439	262	210	330	209	**220**	-
	Max T	3.7	0.5	**-0.6**	2.5	1.5	0.3	1.8	1.7	**0.4**	-
	Min T	6.4	3.3	**1.3**	5.3	4.1	2.8	4.4	4.5	**2.6**	-

	Mean T	6.4	3.3	**1.3**	5.3	4.1	2.8	4.3	4.5	**2.6**	-
	Tot Mort	124020	87017	**61840**	81906	48071	37413	63035	39129	**42296**	-
KRZ	Total days	617	427	564	291	180	275	**324**	**222**	226	-
	Max T	8.8	8.9	8.2	5.8	5.9	5.6	**3.9**	**4.1**	3.9	-
	Min T	3.3	3.3	2.8	0.9	0.7	0.1	**0.0**	**-0.2**	-1.0	-
	Mean T	6.1	6.1	5.5	3.3	3.3	2.8	**2.0**	**2.0**	1.5	-
	Tot Mort	115461	77954	102629	55713	33247	49994	**64012**	**43063**	42654	-
PCT	Total days	503	554	237	433	**343**	298	207	**294**	257	-
	Max T	7.4	9.3	4.2	8.0	**4.5**	6.9	6.6	**5.2**	5.7	-
	Min T	1.9	3.8	-0.5	2.4	**0.2**	1.6	1.4	**1.2**	0.1	-
	Mean T	4.7	6.5	1.9	5.2	**2.3**	4.3	4.0	**3.2**	2.8	-
	Tot Mort	91360	101983	44293	80378	**66391**	54625	38984	**58080**	48634	-
PTT	Total days	1129	916	**612**	195	87	**65**	59	19	44	-
	Max T	8.2	7.1	**5.4**	4.9	4.6	**3.3**	4.7	4.3	4.9	-
	Min T	2.8	1.7	**0.9**	-0.9	0.9	**-1.2**	-0.4	0.3	0.4	-
	Mean T	5.5	4.4	**3.1**	2.0	2.8	**1.1**	2.2	2.3	2.7	-
	Tot Mort	207230	167469	**119964**	37516	16464	**12831**	11287	3686	8281	-
PXE	Total days	551	525	346	238	301	329	**217**	185	**235**	199
	Max T	8.2	8.5	7.5	6.8	8.0	5.1	**3.8**	3.9	**6.3**	4.8
	Min T	2.6	3.0	2.2	1.2	2.6	0.2	**-0.2**	-1.3	**2.1**	-0.2
	Mean T	5.4	5.8	4.9	4.0	5.3	2.7	**1.8**	1.3	**4.2**	2.3
	Tot Mort	103835	95659	63495	43292	54536	63661	**42432**	35274	**46401**	36142
CAP	Total days	**304**	**236**	297	388	504	391	306	245	455	-
	Max T	**3.7**	**4.5**	6.6	8.4	9.3	5.8	6.5	5.8	7.5	-
	Min T	**-0.8**	**0.0**	1.1	2.9	3.7	1.2	1.1	1.3	2.1	-
	Mean T	**1.5**	**2.3**	3.9	5.6	6.5	3.5	3.8	3.6	4.8	-
	Tot Mort	**58646**	**46856**	54418	71220	92768	71004	55650	47255	87078	-
CKM	Total days	480	**303**	392	437	228	244	338	398	**306**	-
	Max T	9.1	**3.7**	8.1	5.1	5.6	5.2	6.9	8.6	**6.9**	-
	Min T	3.5	**-0.8**	2.8	0.5	-0.1	0.8	1.4	2.9	**1.8**	-
	Mean T	6.3	**1.4**	5.5	2.8	2.7	3.0	4.1	5.8	**4.3**	-
	Tot Mort	88769	**60331**	71328	80227	41823	47427	61493	73613	**59716**	-
PXK	Total days	524	576	361	**315**	294	240	279	216	134	**187**
	Max T	8.6	8.8	6.2	**4.2**	6.9	5.2	8.1	6.7	4.5	**2.9**
	Min T	3.2	3.2	1.0	**0.0**	1.3	-0.6	3.2	1.6	-0.2	**-1.0**
	Mean T	5.9	6.0	3.6	**2.1**	4.1	2.3	5.6	4.1	2.1	**0.9**
	Tot Mort	96474	105760	65761	**61338**	55939	44816	53528	38712	24843	**37557**
SAN	Total days	267	278	435	**269**	481	397	**241**	369	389	-
	Max T	4.2	6.1	8.6	**4.3**	9.3	5.6	**5.2**	7.3	7.5	-
	Min T	-0.6	0.4	3.2	**-0.2**	3.6	1.0	**0.8**	1.7	2.2	-
	Mean T	1.8	3.3	5.9	**2.1**	6.4	3.3	**3.0**	4.5	4.9	-
	Tot Mort	50373	50491	79640	**53780**	88491	72329	**46762**	67780	75083	-

Table 5. The number of days for each class, together with the maximum/minimum/mean temperature (in °C) and the total mortality for each classification scheme in the Northeast region. The classes showing the most oppressive (in terms of excess mortality) conditions are given in bold

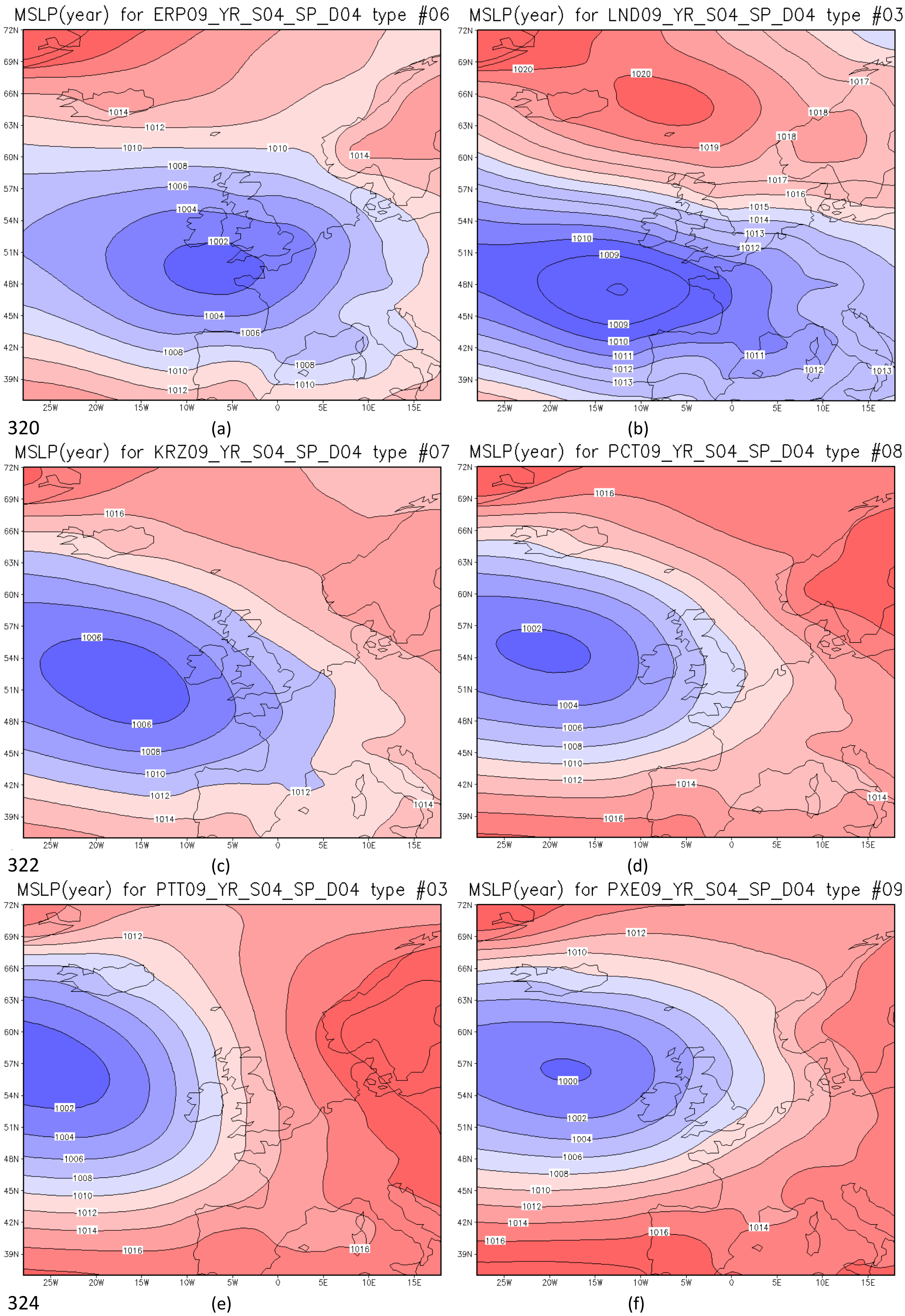
		CLASSES									
		1	2	3	4	5	6	7	8	9	10
ERP	Total days	168	628	595	499	765	**223**	219	**21**	8	-
	Max T	7.1	6.3	9.9	6.9	9.0	**4.9**	7.8	**5.1**	9.7	-
	Min T	2.7	2.0	4.6	1.7	3.8	**0.9**	2.2	**-0.9**	4.1	-
	Mean T	4.9	4.2	7.2	4.3	6.4	**2.9**	5.0	**2.1**	6.9	-
	Tot Mort	31723	121646	110930	93821	148527	**46415**	43598	**4411**	1486	-
LND	Total days	680	472	**304**	439	262	210	330	209	**220**	-
	Max T	9.7	7.0	**5.1**	8.9	7.6	6.2	7.8	8.4	**6.2**	-
	Min T	4.3	1.8	**1.4**	3.6	2.5	1.4	2.9	2.9	**2.3**	-
	Mean T	7.0	4.4	**3.3**	6.2	5.0	3.8	5.3	5.7	**4.2**	-
	Tot Mort	128481	90218	**62648**	84060	50113	38281	64093	40887	**43774**	-
KRZ	Total days	617	427	564	291	180	275	**324**	**222**	226	-
	Max T	9.5	9.6	8.9	6.7	6.8	6.6	**5.6**	**5.7**	5.3	-
	Min T	4.0	4.2	3.7	2.2	2.2	1.5	**1.8**	**1.6**	0.8	-
	Mean T	6.7	6.9	6.3	4.5	4.5	4.0	**3.7**	**3.6**	3.0	-
	Tot Mort	118771	80666	106411	57162	34675	52260	**64751**	**44071**	43788	-
PCT	Total days	503	554	237	433	343	298	207	**294**	**257**	-
	Max T	8.2	10.0	5.7	8.9	5.9	7.3	7.7	**6.5**	**6.7**	-
	Min T	2.9	4.5	1.3	3.6	1.8	2.4	2.7	**2.9**	**1.3**	-
	Mean T	5.6	7.2	3.4	6.3	3.9	4.8	5.2	**4.7**	**4.0**	-
	Tot Mort	94384	105703	45399	82492	68026	56254	39882	**59317**	**51099**	-
PTT	Total days	1129	916	612	**195**	87	**65**	59	19	44	-
	Max T	8.9	8.0	6.7	**6.1**	6.5	**5.1**	6.1	5.8	6.1	-
	Min T	3.7	2.8	2.6	**0.7**	2.8	**0.9**	1.3	2.3	1.3	-
	Mean T	6.3	5.4	4.6	**3.4**	4.7	**3.0**	3.7	4.1	3.7	-
	Tot Mort	214404	173334	121906	**39016**	16864	**13065**	11724	3781	8463	-
PXE	Total days	551	525	346	238	301	329	**217**	185	**235**	199
	Max T	9.2	9.0	8.5	7.5	8.8	6.4	**5.6**	5.3	**7.3**	5.8
	Min T	3.7	3.8	3.3	2.0	3.5	2.1	**1.8**	0.5	**3.2**	1.1
	Mean T	6.5	6.4	5.9	4.7	6.2	4.2	**3.7**	2.9	**5.3**	3.4
	Tot Mort	106007	99439	65893	44744	57061	65197	**43109**	36551	**47607**	36946
CAP	Total days	304	**236**	297	388	504	391	306	**245**	455	-
	Max T	5.3	**5.8**	7.7	9.3	9.9	7.5	7.3	**6.8**	7.9	-
	Min T	1.1	**1.5**	2.4	3.9	4.3	2.8	2.2	**2.7**	2.9	-
	Mean T	3.2	**3.7**	5.0	6.6	7.1	5.1	4.8	**4.8**	5.5	-
	Tot Mort	60164	**47475**	56192	73555	94323	73811	57479	**48893**	90664	-
CKM	Total days	480	**303**	392	437	228	244	338	398	**306**	-
	Max T	9.9	**5.2**	9.1	6.8	6.5	6.3	7.6	8.9	**7.5**	-
	Min T	4.3	**1.0**	3.9	2.3	1.3	2.4	2.4	3.6	**2.8**	-
	Mean T	7.1	**3.1**	6.5	4.5	3.9	4.4	5.0	6.3	**5.2**	-
	Tot Mort	90601	**61076**	73705	83262	43222	48212	63799	76486	**62193**	-
PXK	Total days	524	576	361	**315**	294	240	279	216	134	**187**
	Max T	9.4	9.6	6.8	**5.8**	8.0	6.2	8.7	7.7	5.7	**4.8**
	Min T	3.8	4.2	1.9	**1.8**	2.7	0.9	4.1	2.9	1.3	**1.1**
	Mean T	6.6	6.9	4.4	**3.8**	5.4	3.6	6.4	5.4	3.5	**2.9**
	Tot Mort	100529	108783	67380	**62707**	57836	46159	54956	40145	25587	**38473**
SAN	Total days	267	278	435	**269**	481	397	241	369	**389**	-
	Max T	5.7	6.9	9.5	**5.6**	9.9	7.3	6.4	8.0	**7.9**	-

Min T	1.2	1.8	4.1	**1.5**	4.3	2.7	2.3	2.7	**3.1**	-
Mean T	3.4	4.3	6.8	**3.6**	7.0	5.0	4.3	5.4	**5.5**	-
Tot Mort	52010	52670	81556	**54696**	90012	75071	47937	70319	**78283**	-

3.2 Analysis of the atmospheric patterns

In order to study the climatology of the most oppressive, as defined above, classes for the five regions studied, centroid maps of the surface atmospheric pressure regimes are given in Figure 4. It appears that all Figure 4 maps more-or-less depict the same circulation patterns, i.e. the most dangerous class, in terms of excess winter mortality for each classification scheme is characterized by weak (rather shallow) low atmospheric pressure systems located west (and sometimes southwest, for example see ERP class 6 and LND class 3) of the British Isles, whereas anti-cyclonic conditions prevail over Scandinavia and west continental Europe for almost all cases. It is also noteworthy that the semi-permanent Icelandic Low seems to be absent in all 10 classification schemes.

This type of weather is known as the Easterly type and is generally characterized by anticyclones over Scandinavia (sometimes extending towards Iceland) and depressions circulating over the western North Atlantic, as well as the Bay of Biscay, where the Azores Anticyclone is generally absent (Lamb, 1950). The aforementioned Easterly type of weather is associated with low temperatures in autumn, winter and spring and sometimes extremely low temperatures with occasional snow in southern districts, snow or sleet showers in eastern and northeastern districts, and dry conditions in western regions (Lamb, 1950). In terms of air masses' movement, the Easterly type of weather is associated with advection of air originating from continental Europe. These flows are characterized by subsidence of several hundred hPa before they land (Walsh et al., 2001) and they are responsible for the low temperatures observed in England, as opposed to relatively warm and humid air originating from the Atlantic. Walsh et al. (2001) and Cattiaux et al. (2013) state that this atmospheric pattern is related to a negative phase of the North Atlantic Oscillation, as well as to positive pressure anomalies over the Arctic.


MSLP(year) for ERP09_YR_S04_SP_D04 type #06
MSLP(year) for LND09_YR_S04_SP_D04 type #03
MSLP(year) for KRZ09_YR_S04_SP_D04 type #07
MSLP(year) for PCT09_YR_S04_SP_D04 type #08
MSLP(year) for PTT09_YR_S04_SP_D04 type #03
MSLP(year) for PXE09_YR_S04_SP_D04 type #09

(a) (b) (c) (d) (e) (f)

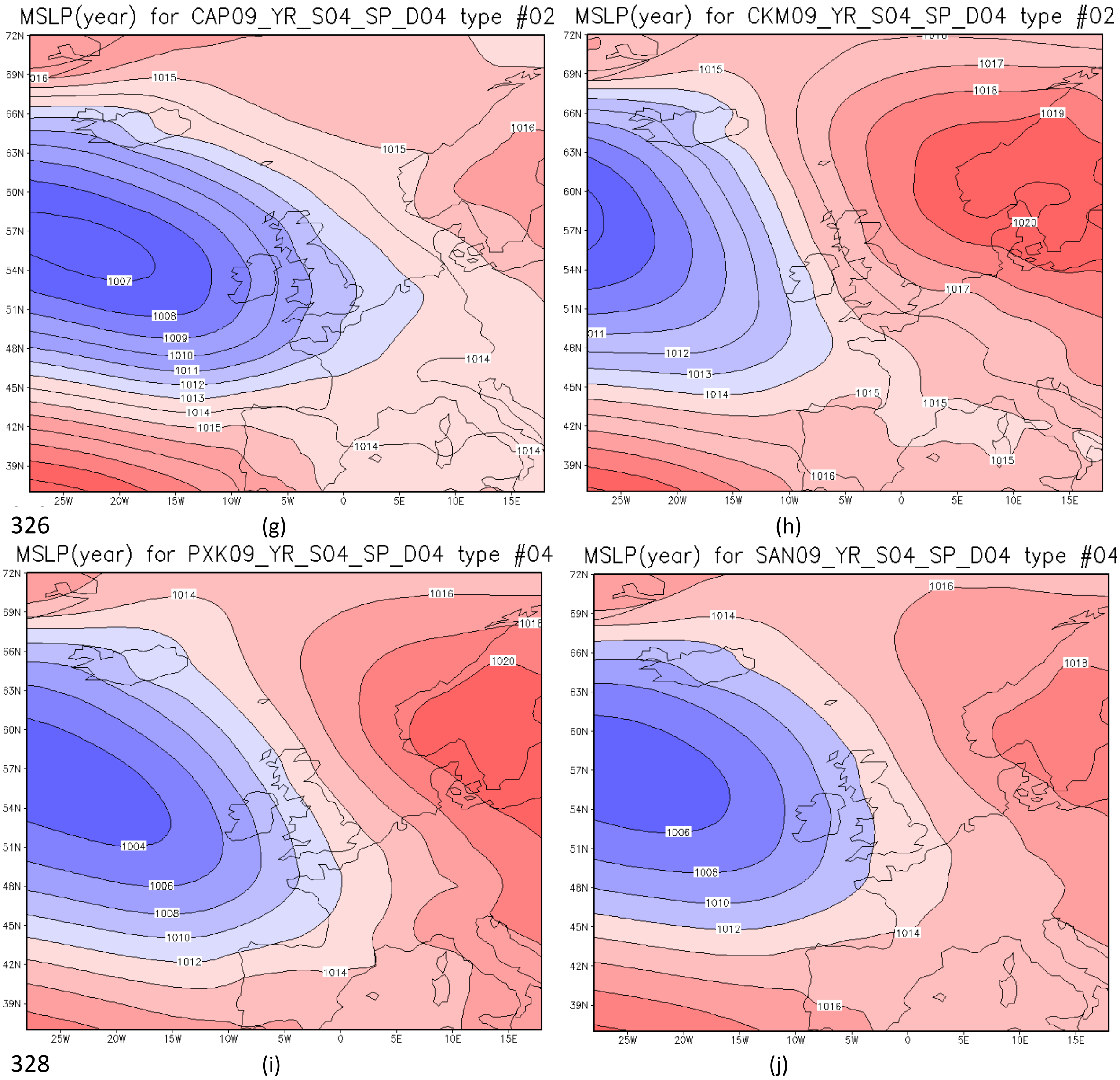


Figure 4. Centroid maps of surface atmospheric pressure for the most oppressive conditions, as described by ERP class 6 (a), LND class 3 (b), KRZ class 7 (c), PCT class 8 (d), PTT class 3 (e), PXE class 9 (f), CAP class 2 (g), CKM class 2 (h), PXK class 4 (i), SAN class 4 (j).

According to Dimitriou et al. (2016), easterly flows in England are very often associated with unfavorable conditions for public health, as the advection of very cold continental air from northern/eastern Europe that continues for several days, results in low temperatures and excess mortality. This type of weather is very often associated with a blocking pattern over Western Europe or increased pressure over Eastern/Northern Europe. Specifically for the northwest region, Dimitriou et al. (2016) found that easterly short-range flows were linked to a 5.3% increase in winter mortality.

4. Conclusions

The objective of the present work has been to study the link between atmospheric patterns and cold-related mortality at the daily time-scale in England, in order to shed light on the climatology of health outcomes. In doing so, 10 different classification methods provided by the COST-733 tool were used. The use of the specific classification techniques brought a new perspective to the understanding of the climatological associations between mortality and winter weather, and appears to be a valuable addition to the suite of tools available for climate/health data analysis.

Our results showed that the most unfavorable conditions for public health in the 5 regions of England were associated with Easterly weather, which is known to favor advection of cold air originating from continental Europe. The fact that little-to-no variation among the 5 regions was observed, when grouping the days to form the most oppressive classes for public health, suggested a spatially homogeneous response of the population to the specific atmospheric patterns identified.

Not surprisingly, in most of the cases examined through the different classification schemes, excess mortality was linked to the lowest daily minimum/maximum temperatures in the 5 regions, in agreement with previous researchers. Nevertheless in a number of cases high mortality rates were associated with relatively higher temperatures, probably due to rapidly changing weather. This finding is indicative of the complexity of cold-related health outcomes and highlights the role of synoptic climatology on confounding the relationship between temperature and mortality.

On the whole, the results provided here show that although cold-related health outcomes can be fatal, they can also be predictable and preventable (Ghosh et al., 2014), as policy-makers can be informed appropriately and design intervention strategies towards allocating resources and reducing the adverse health effects of cold weather. In any case further analysis is needed to clarify how the various climatic elements can increase population vulnerability. Additionally, further analysis with more recent data is needed, where due consideration should be given to how to control for regional variation due to socioeconomic differences.

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