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Climate warming will not decrease winter mortality

Philip L. Staddon[1]*, Hugh E. Montgomery[2] and Michael H. Depledge[3]

It is widely assumed by policymakers and health professionals that the harmful health impacts of anthropogenic climate change[1–3] will be partially offset by a decline in excess winter deaths (EWDs) in temperate countries, as winters warm[4–6]. Recent UK government reports state that winter warming will decrease EWDs[7,8]. Over the past few decades, however, the UK and other temperate countries have simultaneously experienced better housing, improved health care, higher incomes and greater awareness of the risks of cold. The link between winter temperatures and EWDs may therefore no longer be as strong as before. Here we report on the key drivers that underlie year-to-year variations in EWDs. We found that the association of year-to-year variation in EWDs with the number of cold days in winter (<5 °C), evident until the mid 1970s, has disappeared, leaving only the incidence of influenza-like illnesses to explain any of the year-to-year variation in EWDs in the past decade. Although EWDs evidently do exist, winter cold severity no longer predicts the numbers affected. We conclude that no evidence exists that EWDs in England and Wales will fall if winters warm with climate change. These findings have important implications for climate change health adaptation policies.

Seasonal variation in death rates in temperate countries has long been recognized. EWDs in the UK are defined as the number of deaths from December to March minus the average number of deaths in the preceding August to November, and the following April to July[9]. Despite fewer cases in northern than southern Europe[10], EWDs are causally attributed to seasonal variations in temperature, with low temperatures thought to cause death directly (for example, through hypothermia or falls in icy conditions) and by altering vulnerability to communicable or non-communicable diseases, such as influenza and myocardial infarction, which are more common in winter[11]. We collated data from the past 60 years to identify key factors associated with the decreasing trend in EWDs in England and Wales, and its year-to-year variation. We deliberately considered a very broad set

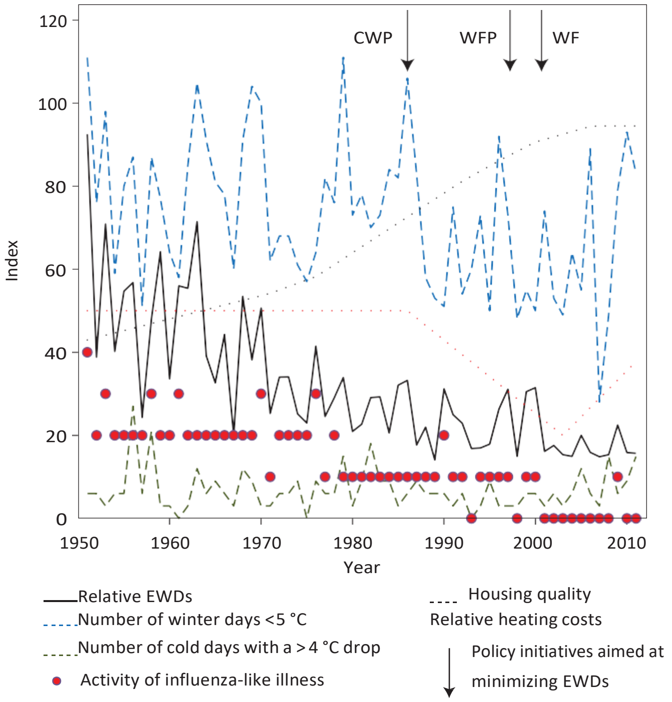

Figure 1 | Relative excess winter mortality for England and Wales over the past 60 years presented alongside key determinants. An index is used to allow for easy comparison in trends and year-to-year variation. Policy initiatives are cold weather payments (CWP), winter fuel payments (WFP) and warm front (WF). EWDs are expressed relative to the size of the population over 65 years old. Before indexation, activity of influenza-like illness was categorized on a scale of 0 to 4, with 0 as baseline and 4 the level of the 1951 epidemic. Housing quality is based on four parameters: inside toilet, hot water, central heating and double glazing. Heating cost is measured as relative to household expenditure.

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of factors to minimize the risk of erroneous conclusions. To clarify the thrust of this paper, we are interested in explaining the year-to-year variation in EWDs not the daily variation, and we are not saying that temperature does not play a role, if it did not there would be no EWDs. What we aim to demonstrate is that how harsh a winter is no longer predicts how many EWDs there will be.

Figure 1 presents relative EWDs and variables identified as possible mediating or causal factors. Between 1951 and 2011, both absolute and year-to-year variation in EWDs declined over time. Three distinct periods in EWD changes were apparent (Supplementary Fig. 1): 1951–1970, where EWDs exhibited very high year-to-year variation and a strongly decreasing overall trend; 1971–2000, where year-to-year variation EWDs halved compared with the preceding period and the decreasing trend continued, albeit less strongly; and 2001–2011, where year-to-year variation was very small and the EWD rate was flat.

Table 1 | Multivariate regression analysis of the relationship between EWDs and independent variables for selected periods between 1951 and 2011.

			Significance level (*p*) and standardized coeficient (*β*)						
	R-square		**Total**	**HQ**	**HC**	**Pol**	**CD**	**TD**	**FA**
On unmodified data									
1951–2011	0.78	*p*	0.000	0.002	0.032	0.312	0.000	0.544	0.000
		β		−0.597	−0.404	0.204	0.329	0.041	0.621
1951–2011	0.77	*p*	0.000	0.000	0.000	X	0.000	X	0.000
		β		−0.523	−0.525	X	0.350	X	0.612
1951–1971	0.72	*p*	0.000	0.025	NA	NA	0.002	0.461	0.178
		β		−0.377	NA	NA	0.606	−0.109	0.241
1971–1991	0.61	*p*	0.022	0.844	0.622	0.437	0.023	0.592	0.003
		β		0.077	−0.171	−0.265	0.560	0.102	0.796
1991–2011	0.72	*p*	0.003	0.141	0.299	0.290	0.622	0.455	0.000
		β		−0.873	−0.288	0.623	0.094	0.175	0.765
1951–1976	0.75	*p*	0.000	0.011	NA	NA	0.001	0.654	0.011
		β		−0.323	NA	NA	0.510	−0.053	0.340
1976–2011	0.65	*p*	0.000	0.170	0.089	0.932	0.092	0.318	0.000
		β		−0.498	−0.521	−0.031	0.221	0.125	0.681
On smoothed* data									
1951–2011	0.92	*p*	0.000	0.000	0.016	0.040	0.534	0.633	0.712
		β		−1.542	−0.351	0.357	0.066	−0.028	−0.057
1951–2011	0.92	*p*	0.000	0.000	0.010	0.009	X	X	X
		β		−1.517	−0.320	0.366	X	X	X
1951–1985	0.97	*p*	0.000	0.000	NA	NA	0.002	0.010	0.241
		β		−0.952	NA	NA	0.154	0.130	−0.068
1951–1985	0.97	*p*	0.000	0.000	NA	NA	0.000	0.000	X
		β		−0.907	NA	NA	0.176	0.161	X
1986–2011	0.88	*p*	0.000	0.012	0.409	0.058	0.147	0.101	0.058
		β		−1.187	−0.196	0.677	0.412	−0.239	0.376
1986–2011	0.85	*p*	0.000	0.000	X	0.057	X	X	0.007
		β		−1.202	X	0.695	X	X	0.489
On detrended† data									
1951–2011	0.43	*p*	0.000	NA	NA	NA	0.000	0.982	0.000
		β		NA	NA	NA	0.411	−0.002	0.470
1951–1976	0.62	*p*	0.000	NA	NA	NA	0.000	0.636	0.025
		β		NA	NA	NA	4.383	−0.480	2.404
1976–2011	0.40	*p*	0.000	NA	NA	NA	0.207	0.938	0.000
		β		NA	NA	NA	0.181	−0.011	0.627

HQ, housing quality; HC, heating costs; Pol, policy initiatives; CD, number of cold days; TD, number of cold days with strong temperature drop; FA, flu activity; NA, not applicable; X, removed. *Analysis carried out on smoothed data (ten-year moving average)—to identify the variables behind the decreasing trend. †Analysis carried out on detrended data (time component removed)—to identify the variables behind the year-to-year variation.

Multifactorial regressions were carried out on the whole data set and by selected periods (Table 1). Over the entire period, housing quality, heating costs, number of cold days and influenza (flu) activity were highly significant in explaining the level of EWDs and together account for about 77% of its variation. However, factors associated with EWDs differ over time when analysed in 20-year segments and were: for 1951–1971, housing quality and number of cold days; for 1971–1991, the number of cold days and flu activity; and for 1991–2011, flu activity. For the data split in 1976, which is the approximate time of correlation breakdown between EWDs and number of cold days (see below), the following factors were significant in explaining EWD variation: for 1951–1976, housing quality, the number of cold days and flu activity; and for 1976–2011, flu activity. Other splits show a similar pattern, with impacts of housing and cold days disappearing, leaving only the impact of influenza to explain year-to-year variation in EWDs.

Multifactorial regression analysis of smoothed data for the whole period and for the periods before and after 1986 adds further insight (Table 1). Note that as the smoothed data are for ten-year rolling periods, 1986 (that is, ten-year average to 1986) was chosen rather than 1976 (as above), so that the second period contained only data after the correlation breakdown between EWDs and number of cold days. This division resulted in two periods of identical length. For the whole period, housing quality, heating costs and policy initiatives explain around 92% of the time trend variation. As for the previous analysis on split data, there is a difference in the factors that are significant, depending on the period. Up to 1986, housing quality, number of cold days and number of cold days with a large drop in temperature were all significant; after 1986, it was housing quality, flu activity and policy initiatives (marginally significant) that explain most of the variation over time. The difference between these two periods is striking (Supplementary Fig. 2).

The analysis of the detrended data and the causes of year-to-year variation in EWDs are shown in Table 1. Over the whole period, the number of cold days and flu activity were highly significant, explaining about 43% of the variation. Before 1976, most of the variation is explained by the number of cold days, but with a proportion explained by flu activity. After 1976, only flu activity accounts for any of the year-to-year variation in EWDs.

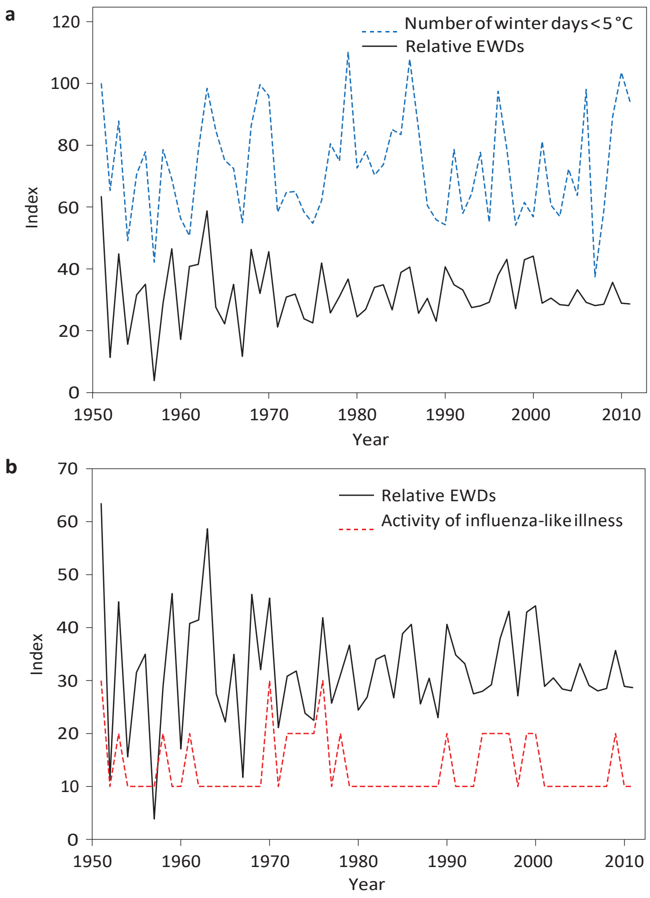

Figure 2 | Detrended data showing the year-to-year variation in relative excess winter mortality compared with the number of cold days and the activity level of influenza-like illness. Data were detrended by removing the time component. **a**,**b**, The year-to-year variation in EWDs compared with that for number of winter days < 5 °C (**a**) and influenza activity (**b**). An index is used to allow for easy comparison of peaks. EWDs are expressed relative to the size of the population over 65 years old. Before indexation, activity of influenza-like illness was categorized on a scale of 0 to 4, with 0 as baseline and 4 the level of the 1951 epidemic.

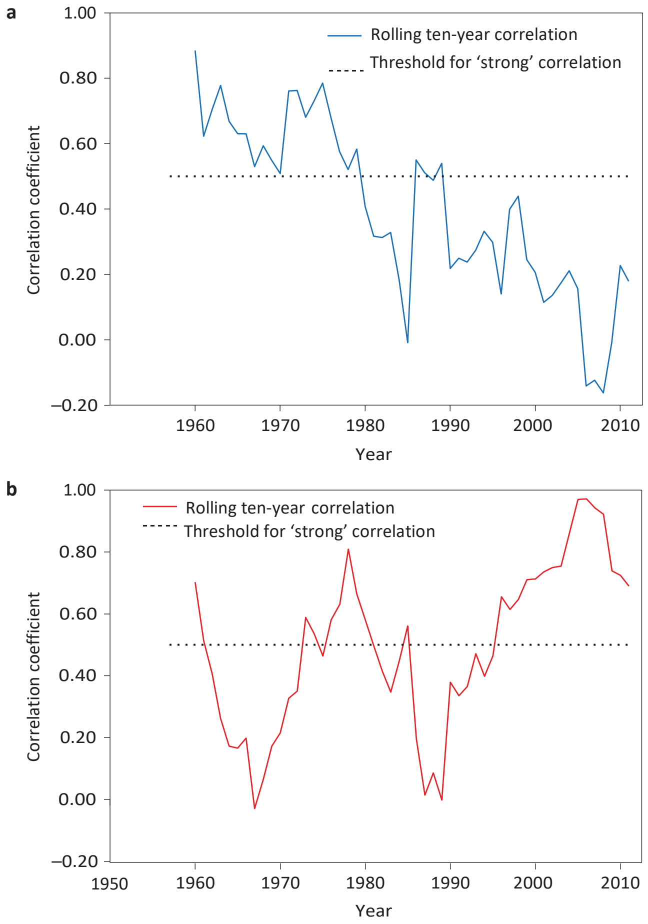

Figure 3 | Rolling ten-year correlation between relative excess winter mortality and the two main predictors of year-to-year variation: number of winter cold days and activity of influenza-like illness. Correlation coefficients are from ten-year rolling correlations. Correlation above 0.50 is deemed strong. **a**, The relationship between EWDs and number of cold days exhibits a classic correlation breakdown in the late 1970s. **b**, The relationship between EWDs and influenza activity stabilizes and strengthens from the mid 1990s

Figure 2 presents the detrended data for EWDs in relation to the number of cold days (Fig. 2a) and seasonal flu activity (Fig. 2b).

By carrying out rolling correlations between EWDs and factors exhibiting year-to-year variation, namely the number of cold days, the number of cold days with a large temperature drop and the magnitude of flu activity, it emerged that the correlation between EWDs and the independent variable, when significant, was not stable over time. This is illustrated in Fig. 3 for the number of cold days (Fig. 3a) and flu activity (Fig. 3b). EWDs remained strongly correlated with the number of cold days only up to the mid- to late-1970s, after which the correlation was weak to non-existent. Similarly, for most of the period from 1951 to the mid 1990s, EWDs were correlated weakly with flu activity, whereas a strong correlation between the two has emerged in recent years. For winter temperature volatility, the correlation with EWDs was rarely strong and there was no established stable period (data not shown).

An extensive literature attests to the fact that changes in daily temperature influence health outcomes at the local levels and that EWDs are influenced by temperature. However, our data suggest that year-to-year variation in EWDs is no longer explained by the year-to-year variation in winter temperature: winter temperatures now contribute little to the yearly variation in excess winter mortality so that milder winters resulting from climate change are unlikely to offer a winter health dividend. Our research paints a clear picture of why EWDs have been decreasing in the UK over the past six decades and which factors explain most of the year-to-year variation in EWDs. These include better housing, better standards of living, increased help for vulnerable sections of the population, as well as better healthcare. This confirms proposed mechanisms, presented in several recent studies in temperate countries[12–14], that explain the general decreasing trend in EWDs over the past century. Although the key driver for year-to-year variation in EWDs was winter temperature until the mid 1970s, we show that it has been superseded by the impact of influenza-like illnesses despite their absolute impact being small; this is consistent with recent studies by the UK Office for National Statistics[15,16]. This time-dependency explains why there is so much confusion about the link between winter temperatures *per se* and EWDs. Many of the papers that concluded that climate change would lead to fewer EWDs are not recent and rely on relatively old data (from about two decades ago)[12,17–19]. On the basis of the evidence available at the time, these early papers[17–19] predicting that climate change would cause a decrease in EWDs were correct. However, more recent papers are either inconclusive[20], or conclude that there will be little impact of climate change on EWDs[21–23]. By analysing more recent data and carrying out rolling correlation analysis on time-detrended data, we show unequivocally that the correlation between the number of cold winter days per year and EWDs, which was strong until the mid 1970s, no longer exists.

We used a threshold model to identify a strong relationship between the annual number of cold days and EWDs before the mid-1970s and to show that this relationship has since disappeared. The relationship between mortality and local daily temperature is variable and specific to local areas and it is likely that the exposure–response relationship of daily mortality to temperature will have changed over the past decades in response to improved housing, health and wealth. A future avenue of research would be to explore our observations further, by the use of exposure–response analysis of continuous and locally applied data.

Our results should also be considered in light of the latest findings relating to the influence of climate change on winter temperatures. The view that winter temperatures would simply ‘ramp up’ has been replaced by recognition that extreme events, including cold spells and storms, are likely to increase in frequency[5,24]. Indeed, there is already evidence that winter temperature volatility has increased in the UK over the past 20 years. For example, the number of days per winter with a mean daily temperature <5 °C and showing a 4 °C drop from the previous day (that is, high variability), exhibits an increasing trend from 1990 to 2011 (R-square 0.31; *p* 0.007). If this is exacerbated by climate change in the coming decades then winters will feel fundamentally different from now, being generally warmer, but with more days of severe cold. The nefarious effects on EWDs could be substantial, with especially the vulnerable being caught off-guard by abrupt changes in temperature. This behaviour- mediated impact of temperature variability on EWDs may be one of the reasons countries with milder winters often exhibit higher levels of EWDs than countries with colder winters[11]. It is also possible that increased temperature volatility could increase influenza deaths, although this is yet to be proved conclusively.

The fact that climate change will not reduce EWDs in England and Wales has important implications for health policy. Probable increases in future winter temperature volatility[25] mean that EWDs are more likely to rise than fall. Added to this, and irrespective of whether climate-change-induced winter temperature volatility increases the risk of EWDs, the absolute number of EWDs may increase in the coming decades simply because of a growing and ageing population. The recent policy focus on protecting the public from heatwaves should not be at the expense of preventing the much more numerous EWDs. Energy efficiency regulations and government retrofitting initiatives to improve the thermal efficiency of older homes, including double glazing, cavity wall and loft insulation, should continue to capture co-benefits for both health and climate change mitigation[14,26]. In view of our findings, particular attention should also be paid to public health initiatives to reduce the risk of infection with flu-like illnesses. Influenza vaccination, despite its decreasing effectiveness in people over 70, provides some protection[27]. Improving uptake in the over 65s would be very beneficial[28].

From a health perspective, managing risk uncertainty is a priority[29] and prevention is better than cure. Urgently reducing greenhouse gas emissions to mitigate against climate and weather change is therefore essential[5]. This goes hand-in-hand with the need for a sound strategy for health adaptation for an ageing population in a changing climate.

Methods

Data sources and quality. An initial search of the Web of Knowledge was carried out to identify factors influencing EWD rates. The search encompassed all years and excluded non-English-language articles. Many combinations of search terms were explored (Supplementary Information). Secondary searches were carried out on references cited by articles discussing EWDs and their causes.

Articles relating to the causes of EWDs were identified as targets for data retrieval. These were supplemented by source data: temperature data were obtained from the UK's Meteorological Office–Hadley Centre Central England Temperature data set[30]; and economic, social, population and mortality data from the Office for National Statistics. When the required data were unavailable, such as those relating to housing quality or to government initiatives to combat EWDs, a web search using Google was initiated, which was focused on information held in government departments, agencies and other organizations holding specialist housing data sets (Supplementary Information).

Data were collected for the period from 1951 to 2011 and a full list of all data sources used is provided in Supplementary Table 1. Population (and a subset aged over 65 years old), excess winter mortality and incidence of influenza-like illness in England and Wales were documented. Daily mean temperatures for central England were also obtained. These data, being representative of a national geographical mean[30], were sufficient for our study of national trends. We therefore collected demographic, EWD, influenza incidence and winter temperature data representative of England and Wales. Certainly different regions will experience different temperatures, but they are all highly correlated to this central England value. Also, EWDs are surprisingly stable across regions, for example with the number of EWDs in Cornwall, the mildest part of England, being nearly identical to that for England and Wales.

A range of extrinsic factors influencing seasonal, temperature-related mortality were also documented. Specific factors were excluded only when their impacts or characteristics were already represented within another factor (for example, income level versus percentage household expenditure on fuel). We recorded expenditure on heating as a percentage of income, policy initiatives aimed at combating EWDs (cold weather payment, winter fuel allowance, warm front) and four key housing quality factors, each focused on a particular housing characteristic affecting health in winter (availability of inside toilet, access to tapped hot water, central heating and double glazing). Data were drawn from the domestic energy fact file, the UK housing energy fact file, the English housing survey and the Halifax housing data set, which contains a reliable description of the changing condition of the UK housing stock. Housing quality improvements were assumed to be linear between available years. This assumption was validated for double glazing, where data for the full period were available. For statistical analyses, all four housing quality measures were combined by simple averaging into a single measure.

Statistical analyses. EWDs were expressed as a function of population over 65 years old (as about 90% of total EWDs occur in this age group[9]) to remove changing demographics as a factor. The raw daily temperature data were transformed into two measures: number of days per winter period below 5 °C (a measure of winter cold intensity); and number of days per winter below 5 °C and showing a 4 °C drop from the previous day (a measure of volatility within cold spells, defined as one or more days below 5 °C). Cold days were calculated for the same period as EWDs, namely 1 December to 31 March. Correlation analysis was used to determine the interdependence of variables. Linear multifactor regression analysis identified those factors associated independently with EWDs. This was achieved by carrying out a series of regressions removing the least significant factor at each repeat until only highly significant factors remained. We also ensured that the amount of variation explained by the fitted model, R-square, remained relatively stable. To explain the trend over time in more detail, a moving average method was employed with a period of ten years. This allowed the smoothing of the data to eliminate most of the year-to-year variation. Linear multifactor regression analysis was applied to the smoothed data. To assess year-to-year variation, the relevant data were detrended by removal of the time component and analysed by linear multifactor regression. Using separate data sets, that is, a smoothed data set and a detrended data set, allowed the elimination of confounding time-dependent factors when addressing the two specific questions of: what is causing the long-term trend in decreasing EWDs; and what is causing the short-term year-to-year variation in EWDs. We also tested for correlation breakdown between EWDs and the factors with strong year-to-year variation. To further explain factors associated with EWDs, data were split into subsets characterized by key changes in factors, or the introduction of new factors (such as a policy initiative).

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Author contributions

The idea for this work arose from a meeting between the three authors. P.L.S. searched the literature, collected the data, carried out the analysis and wrote the first draft. All authors contributed to the final version of the paper. P.L.S. had full access to all the data in the study and had final responsibility for the decision to publish this article.