Climate warming will not decrease winter mortality

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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 previously. Here we report on the key drivers which 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 last decade. Whilst excess winter deaths 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 recognised. Excess winter deaths (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 (e.g. 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 of factors to minimise 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 didn't 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 excess winter deaths (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 EWDs changes were apparent (Supplementary Fig. S1): (1) 1951-1970, where EWDs exhibited very high year-to-year variation, and a strongly decreasing overall trend; (2) 1971-2000, where year-to-year variation EWDs halved compared to the preceding period, and the decreasing trend continues, albeit less strongly; and (3) 2001-2011, where year-to-year variation is very small and the EWDs rate is flat.

Multi-factorial regressions were carried out on the whole dataset 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 ca. 77% of its variation. However, factors associated with EWDs differ over time when analysed in 20 year segments, and were: (1) for 1951-1971, housing quality and number of cold days; (2) for 1971-1991, the number of cold days and flu activity; and (3) 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 EWDs variation: (1) for 1951-1976, housing quality, the number of cold days, and flu activity; and (2) 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.

Multi-factorial regression analysis of smoothed data for the whole period, and for the periods before and after 1986, add further insight (Table 1). Note that as the smoothed data are for 10 year rolling periods, 1986 (i.e. 10 year average to 1986) was chosen rather than 1976 (as above), so that the second period only contained 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 which 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. S2).

The analysis of the de-trended 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 ca. 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 presents the de-trended data for EWDs in relation to (A) the number of cold days, and (B) seasonal flu activity.

By performing 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 (A) and flu activity (B). 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, while 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. Whilst 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 *ca*. two decades ago).[12,17-19] Based on 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 performing 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 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 <5ºC *and* showing a 4ºC drop from the previous day (i.e. 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 the 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 70s, 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 performed to identify factors influencing excess winter death rates. The search encompassed all years and excluded non-English language articles. Multiple combinations of search terms were explored (Supplementary Information Search Terms). Secondary searches were performed 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 dataset;[30] and economic, social, population and mortality data from the Office for National Statistics (ONS). 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 focussed on information held in government departments, agencies and other organisations holding specialist housing datasets (Supplementary Information Search Terms).

Data were collected for the period 1951 to 2011 and a full list of all data sources used are provided in Supplementary Information (Table S1). Population (and a subset aged over 65 years), 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, with for example the EWDs in Cornwall, the mildest part of England, being near identical that for England and Wales.

A range of extrinsic factors influencing seasonal, temperature-related mortality were also documented. Specific factors were only excluded when their impacts or characteristics were already represented within another factor (e.g. income level versus percentage household expenditure on fuel). We recorded expenditure on heating as a percentage of income, policy initiatives aimed at combating excess winter deaths (cold weather payment, winter fuel allowance, ‘warm front’), and four key housing quality factors, each focussed on a particular housing characteristic affecting health in winter (availability of inside toilet, access to tapped hot water, central heating, and double glazing). Data was drawn from the Domestic Energy fact file, the UK Housing Energy fact file, the English Housing Survey, and the Halifax housing dataset, 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

Excess winter deaths (EWDs) were expressed as a function of population over 65 years (as *ca*. 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 are calculated for the same period that EWDs are, namely 01 December to 31 March. Correlation analysis was used to determine the interdependence of variables. Linear multi-factor regression analysis identified those factors associated independently with excess winter deaths. This was achieved by performing 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 10 years. This allowed the smoothing of the data to eliminate most of the year-to-year variation. Linear multi-factor regression analysis was applied to the smoothed data. To assess year-to-year variation, the relevant data were de-trended by removal of the time component and analysed by linear multi-factor regression. Using separate data sets, i.e. a smoothed data set and a detrended data set, allows the elimination of confounding time dependent factors when addressing the two specific questions of (1) what is causing the *long-term* trend in decreasing EWDs, and (2) what is causing the *short term* year to year variation in EWDs. We also tested for correlation breakdown between excess winter deaths and the factors with strong year-to-year variation. To further elucidate factors associated with EWDs, data were split into subsets characterised by key changes in factors, or the introduction of new factors (such as a policy initiative).

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Author contributors

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

Competing financial interests

The authors declare no competing financial interests.

Table 1| Multivariate regression analysis of the relationship between excess winter deaths and independent variables for selected periods between 1951 and 2011

			Significance level (*p*) and standardized coefficient (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[a] 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[b] 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; [a] analysis performed on smoothed data (10 year moving average) - to identify the variables behind the decreasing trend; [b] analysis performed on detrended data (time component removed) - to identify the variables behind the year-to-year variation.

FIGURE LEGENDS

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). Excess winter deaths are expressed relative to the size of the population over 65 years old. Before indexation, activity of influenza like illness was categorised 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.

Figure 2| Detrended data showing the year-to-year variation in relative excess winter mortality compared to the number of cold days and to the activity level of influenza like illness

Data was detrended by removing the time component. The year-to-year variation in excess winter deaths is compared with that for (A) number of winter days < 5ºC, and (B) influenza activity. An index is used to allow for easy comparison of comparison of peaks. Excess winter deaths are expressed relative to the size of the population over 65 years old. Before indexation, activity of influenza like illness was categorised on a scale of 0 to 4, with '0' as baseline, and '4' the level of the 1951 epidemic.

Figure 3| Rolling 10 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 10 year rolling correlations. Correlation above 0.50 is deemed strong. (A) The relationship between excess winter deaths and number of cold days exhibits a classic correlation breakdown in the late 1970s. (B) The relationship between excess winter deaths and influenza activity stabilises and strengthens from the mid 1990s.