NATIONAL CENTRE FOR RESILIENCE

BUILDING SCOTLAND'S RESILIENCE TO NATURAL HAZARDS

eprints.gla.ac.uk/165571/

## Research report

# Associations between ambient outdoor temperature and patterns of morbidity and mortality in Scotland

Dr Colin Ramsay, Health Protection Scotland
Professor C. Robertson, Strathclyde University, Health Protection Scotland
Dr Ray Carragher, Strathclyde University
Dr Stephen Corson, Strathclyde University

**March 2018**

**This report investigates the association between ambient air temperature and health impacts, measured as morbidity (hospital admissions) and mortality, in Scotland to determine what evidence there is to reject the (null) hypothesis that there is no relationship.**

The National Centre for Resilience is a partnership hosted by the University of Glasgow glasgow.ac.uk/ncr

# Associations between ambient outdoor temperature and patterns of morbidity and mortality in Scotland

Dr. Colin N. Ramsay, Health Protection Scotland

Professor C. Robertson, Strathclyde University, Health Protection Scotland

Dr Ray Carragher, Strathclyde University

Dr Stephen Corson, Strathclyde University

**1 March 2018**

# Executive Summary

This report investigates the association between ambient air temperature and health impacts, measured as morbidity (hospital admissions) and mortality, in Scotland to determine what evidence there is to reject the (null) hypothesis that there is no relationship.

The mortality and hospital admission data came from the ACADME data mart and were available at a weekly level only, by age group and gender. All-cause mortality and cause specific mortality rates were obtained. The specific causes considered were: influenza, pneumonia, Chronic Obstructive Pulmonary Disease (COPD), cardiovascular and trauma. Morbidity was captured through emergency admissions to hospital with total weekly admissions for the same five specific causes. The morbidity and mortality data are available from 1981 onwards to the end of 2016.

Daily ambient temperature data were extracted from the Met Office integrated data archive system (MIDAS) land and marine surface stations data. A weekly ‘average’ temperature was calculated from the maximum and minimum air temperatures from all stations reporting in the week. A number of weekly summary temperatures were also calculated – average minimum, average maximum and a weighted average using Shepherd’s inverse distance weighting method.

For a restricted time period from 2009 to 2016 weekly GP consultation data for influenza like illness (ILI) and acute respiratory illness (ARI) were available from Health Protection Scotland (HPS).

The statistical analysis used generalised additive Poisson regression modelling with smooth spline terms for temperature and time and the logarithm of consultations and an autoregressive term to take into account serial correlation in the weekly data.

The analysis of the deaths data identified that there is an association between all-cause mortality and temperature. As average weekly temperature increases, the average weekly all-cause mortality rate decreases until about 10$^{o}$C, where it levels off and begins to increase again.

The association between all-cause mortality and temperature is present in all age groups but is less pronounced in those aged under 65. The increasing risk at higher temperatures is more evident in those aged 75-84.

The association between decreasing mortality and increasing temperature is also evident for specific causes of death - influenza deaths, deaths due to COPD and cardiovascular deaths. Data coding issues, associated with coding changes over time, prevented similar analyses for pneumonia and trauma deaths.

With respect to hospital admissions data, there are associations between temperature and the proportions of emergency hospitalisations associated with

influenza, pneumonia, COPD, cardiovascular and trauma. With the exception of trauma the general pattern is for lower proportions of admissions for the selected causes with increasing temperature. For COPD, there is the same up turn at higher temperatures above an average of 10ºC for the week. Trauma has a V shaped association with higher admission risk at both low and high temperatures.

After adjustment for ARI consultations, the association between mortality and morbidity, and temperature for all-cause mortality, for cause specific mortality and morbidity is not as strong. This suggests that the main driver of the observed association with temperature is respiratory infection but there is still a residual impact of temperature.

While colder temperatures are associated with higher mortality and morbidity, there is no strong evidence of a step change in the association between mortality and morbidity, and temperature such that there is an even greater impact of very low temperatures on mortality. There is no evidence of the existence of a temperature below which there is a step change in the increased risk of mortality or an increased gradient.

Different measures of weekly average temperature produced similar interpretations. All-cause mortality decreases with increasing temperature and then there is a slight rise at higher temperatures. The only difference with different temperature measures is the location of the nadir. This means that this analysis should not be used to set temperature thresholds (for intervention actions) as they will depend on the weekly temperature summary statistic used.

## Background

A recent review of the Scottish Climate Change Adaptation Programme (SCCAP) recommended that the Scottish Government consider conducting further research related to the effects on public health of projected changes in ambient temperature associated with climate change. It is predicted that Scotland's climate will become warmer and wetter but there may also be greater extremes of temperature and more extreme weather events. As part of the work to address these research gaps, HPS identified a need to increase the general level of understanding of the current link between ambient temperature and health impacts (measured as morbidity/mortality).

An improved understanding of this link could allow the Scottish Government to develop concrete actions based on possible temperature thresholds, with the aim of increasing population resilience to climate change related threats more broadly and specifically related to extreme temperatures. Outcomes of this work may include formulating advice to the population at large and/or vulnerable groups in advance of spells of extreme high or low temperatures. It should also allow the Scottish Government to demonstrate, through the SCCAP, that the possible effects on public health of changing temperatures in relation to climate change in Scotland (rather than UK wide) have been considered in more detail.

Alternatively, a finding of 'no relationship' would allow the SCCAP to set the level of risk to public health from temperature extremes in the correct context.

The impact of ambient temperature on public health is also an issue relevant for the development of the Scottish Risk Assessment (SRA). This has been highlighted as a gap at one of the SRA workshops, and if better information on this were available it would significantly improve the robustness of the fatalities impact assessment for the severe cold and snow scenario being developed as part of suite of Scottish–specific risks.

The chief outcome from this study is to plug a gap in our understanding of the link (or absence of a link) between heat and cold and impacts on public health. Understanding the underlying relationship and investigating whether there are identifiable thresholds where heat and cold affect public health relatively more, could allow us to design evidence based interventions to prepare the population for spells of extreme heat and cold. Alternatively, an increased understanding could permit an informed decision to be taken that such interventions are not necessary. This research is also a key part of the HPS effort to support the Scottish Government Health Protection Team in responding to the needs of the Scottish Climate Change Adaptation Programme (SCCAP).

In Scotland, to-date there has been no specific effort to collect and analyse relevant data in detail to investigate the significance of ambient temperature as a determinant of public health. There is therefore no Scotland specific evidence at present on which to base a programme of public health action aimed at mitigating the potential impacts associated with unusual ambient temperature variation including extreme high temperature scenarios (heatwaves).

Some work has been carried out in the past on “excess winter deaths” attempting to assess the relative impacts of cold and other factors on the rise in death rates conventionally seen in the winter period. However, there has been no comprehensive investigation of data on patterns of morbidity and mortality relation to the entire span of temperature including temperature extremes, from untypically hot to untypically cold.

To inform any possible public health policy or programme in Scotland with respect to potentially preventable health impacts related to temperature variation, and in particular to temperature extremes, there is a need to investigate the underlying evidence. This is required in order to establish what the relationship between morbidity, mortality and ambient air temperature in Scotland is. If the relationship between health and ambient air temperature was investigated systematically and better understood, that could create opportunities to consider what public health interventions would be practical in Scotland to try to mitigate impacts associated with extreme temperature scenarios (either untypical high or untypical low ambient temperatures).

## Study Aims

The purpose of the study was to investigate the basic hypothesis that morbidity and mortality in Scotland is related to ambient temperature and to determine what evidence there is to accept or reject the hypothesis.

We wished to determine the nature of any statistical association between temperature and health impacts, particularly as a means of identifying evidence of a threshold effect. If threshold temperatures for both extremely high or low temperatures were was found to exist, this might provide the basis for designing a possible public health impact mitigation programme.

We also wished to investigate a range of known potential confounding factors that could influence any apparent association between ambient temperature and health impacts (e.g. coincidental seasonal or other morbidity, especially respiratory disease and cardiovascular disease, and additional factors such as the role of latitude (and potentially vitamin D levels)).

The analyses in this report are extensions to models used in the Population Effectiveness of the National Seasonal Influenza Vaccination programme in Scotland (PENSIVE) project at HPS. This project investigated the impact of universal seasonal influenza vaccination for individuals aged 65 or more in Scotland, which was introduced in 2000. It used data from 1988 to 2013 and provided estimates of the excess mortality and morbidity in the winter periods of successive influenza seasons from 2000/01 to 2013/14, taking into account variations in mortality and morbidity associated with temperature.

This exploratory study was therefore to be based on previous work carried out in HPS on temperature modelling and health impacts specifically in relation to an analysis of influenza vaccine uptake impacts (the Pensive project). This used modelling of estimated weekly minimum and average temperatures for Scotland (as a whole). This study also modelled the expected numbers of deaths and hospitalisations on a weekly basis. The aim was therefore to update this dataset with more recent temperature and health impact data to provide an extended time series dataset.

## Methods

Existing available data on ambient temperature in Scotland and routine data on mortality and morbidity were used. The mortality and hospitalisation data came from the ACADME data mart and were available at a weekly level only, by age group and gender. All-cause mortality and cause specific mortality were obtained. The specific causes were influenza, pneumonia, COPD, cardiovascular and trauma. Attributing a death to these causes was based upon the ICD10 codes and used the standard ISD groupings of these codes for the specified causes of death.

Morbidity was captured through emergency admissions to hospital with total weekly admissions and the same five specific causes. The morbidity and mortality data are available from 1981 onwards to the end of 2016.

Daily ambient temperature data were extracted from the Met Office integrated data archive system (MIDAS) land and marine surface stations data (1853 - current) [Internet]. British Atmospheric Data Centre. 2012. Available from: http://catalogue.ceda.ac.uk/uuid/220a65615218d5c9cc9e4785a3234bd0. We calculated the 'average' temperature as the mean of the minimum and maximum air temperature. The weekly average temperature for all Scotland was calculated as the mean of the 'averages' of all stations reporting in the week. We also calculated the 'average', maximum and minimum air temperatures using a weighted average temperature using Shepherd's inverse distance weighting method. This calculates the weekly temperatures for the Geographical Centre of Scotland. A sensitivity analysis was carried out using different temperature measurements but most results are presented using the raw average temperature.

The major confounder for the impact of temperature on health outcomes is respiratory infection and we extracted the weekly consultation rates for influenza and ARI, by age group, from autumn 2009 onwards. These data were based upon the Piper level 5 surveillance system at HPS. These are the best data to use as they are available by age group in both the summer and winter and are derived from all GP practices in Scotland, so providing national coverage.

There are two data sets for analysis. One is from 1981-2016 and has weekly deaths and emergency hospital admissions by age group as well as mean weekly temperature. This data set is used to investigate the impact of temperature, adjusting for a temporal trend over the years. It is also used to investigate a step change in the impact of temperature.

The second data set is a subset of the first, from August 2009 to the end of 2016. The mortality, hospital admission and temperature data are the same. Two additional covariates are available – average weekly GP consultations for ILI and for ARI. These data are published by HPS and are a measure of activity associated with respiratory viruses. These data were used in preference to the GP virology data set as they are available for both the summer and winter months, while the GP Sentinel System for virological testing for influenza is only available for the winter months. This second data set is used to investigate the impact of temperature, adjusting for a temporal trend over the years and the impact of respiratory viruses.

Statistical modelling is based upon Generalised Additive (GAM) Poisson regression models. The GAM uses the temperature data to model the seasonal variability in mortality/hospitalisations and adjusts the model predictions for severity of temperature. The models will contain an offset term to allow for changes in the population size/number of hospitalisations over time. When analysing mortality the offset is equal to the logarithm of the population at risk. This offset is not suitable for the analysis hospitalisations since the number of hospitalisations per head of population (population at risk offset) changes more rapidly than the number of hospitalisations per head of hospitalised population (offset equal to the logarithm of the total number of hospital admissions). Therefore, when analysing hospitalisations the offset is equal to the logarithm of the total number of emergency hospitalisations. This means that the hospital consultation model is a model for the changing proportion of admissions for specific causes associated with temperature changes.

The aim of the modelling is to assess the impact of ambient temperature on mortality/morbidity independently, and also in addition, to any impact of influenza in the winter.

The model equation for data set 1 for mortality is

$$D(t) \sim Poisson(N(t)\theta(t))$$

$$\log\big(\theta(t)\big) = \beta_0 + s_1\big(Y(t)\big) + s_2\big(T(t)\big)$$

$D(t)$ is the total number of deaths in week t, where t is an index going from 1 in week 1 of 1981. $N(t)$ is the total population, and $\theta(t)$ is the death rate per head of population in week t. The linear equation relates the log of the rate to the two spline terms, $s_1\big(Y(t)\big)$ and $s_2\big(T(t)\big)$, to give a smooth, potentially non-linear relationship between year, $Y(t)$, and temperature, $T(t)$.

A spline is a smooth curve which describes the relationship between a response variable and a measured explanatory variable. A spline is constructed by allowing there to be special knot points at a small number of, usually regularly spaced, intervals along the explanatory variable. The shape of the curve can change at these knot points in a smooth fashion. The simplest spline is a linear spline which is a series of straight lines which have different slopes after each knot point. A cubic spline is more common as this permits a smoother relationship. Splines are used in statistical modelling to take into account potential non-linear associations between a response and explanatory variable. In this analysis we anticipated that there might not be linear associations between mortality and admissions and temperature and spline curves are an ideal way of estimating the nature of the association from the data.

For data set 2 the linear equation is

$$\log(\theta(t)) = \beta_0 + s_1(t) + s_2(T(t)) + s_3(\log(ARI(t))) + s_4(\log(ILI(t)))$$

In this model *t,* the index for week begins in week beginning 17 August, 2009. As the span is only 8 years the temporal trend, $s_1(t)$, is based upon week and so will include a potential for a strong seasonal effect to be pick up in this part of the model. $ARI(t)$ and $ILI(t)$ are the consultations for acute respiratory illness and influenza like illness respectively. The log transformation was used as there is a large range for the consultations – two orders of magnitude.

When the model is explaining the relationship between morbidity (cause specific emergency hospital admissions) and temperature then $D(t)$ is the total number of admission to hospital in week *t* to the specified cause and $N(t)$ is the total number of emergency admission to hospital in that week.

Cubic regression spline functions were used. There are smooth functions which are connected at a sequence of knot points. The exact number of knots used is determined by cross validation within the function performing the model fitting. Initially a large number of equally spaced knots, 12, was specified over the range of temperature and consultations.

Residual autocorrelation in the sequential observations was fitted by including a first order autoregressive error term.

A number of sequential models were fitted to investigate the impact of temperature. These include temperature on its own temperature plus trend, temperature, trend plus consultations. Only the results for the final models are presented. These are the models with the greatest deviance explained and included auto correlation.

Threshold effects were investigated by a grid search over the specification of the knot points for the spline terms. Two and three knots were permitted and the model with the smallest Akiake Information Criterion (AIC) was chosen as the most suitable.

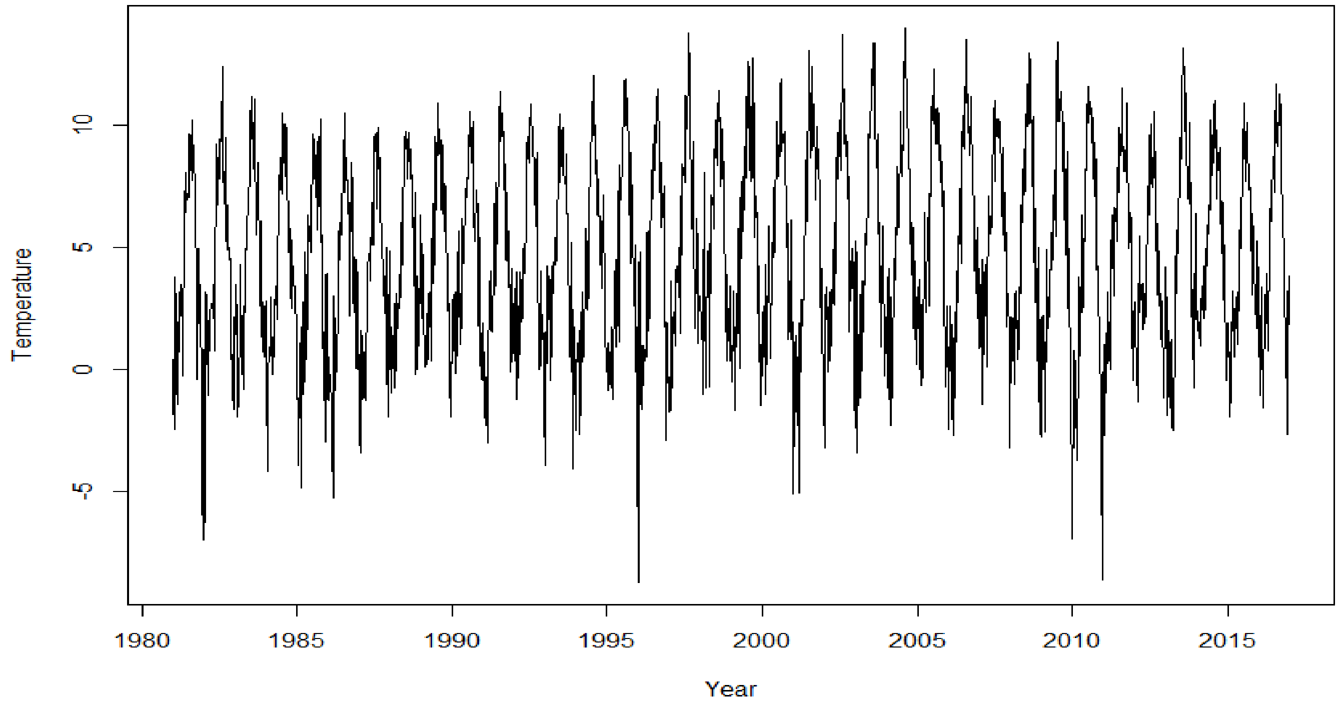
All statistical analysis was carried out using the R program and the mgcv library was used to fit the models.

## Results

The appendices contain full details of the analysis. All figures in the results are also presented in the appendix. The majority of the results presented used the weekly average temperature. Analyses were carried out using the minimum and maximum weekly temperature with similar results.

The average weekly temperatures in Scotland fluctuate by season over the year (Figure 1). The variation in the maximum and minimum average weekly temperatures over the period is also shown. While there are a number of years which display very cold weeks during winter, 1981-2, 1995-96, 2009-10, 2010-11, extremely cold and extremely hot temperatures are unusual.

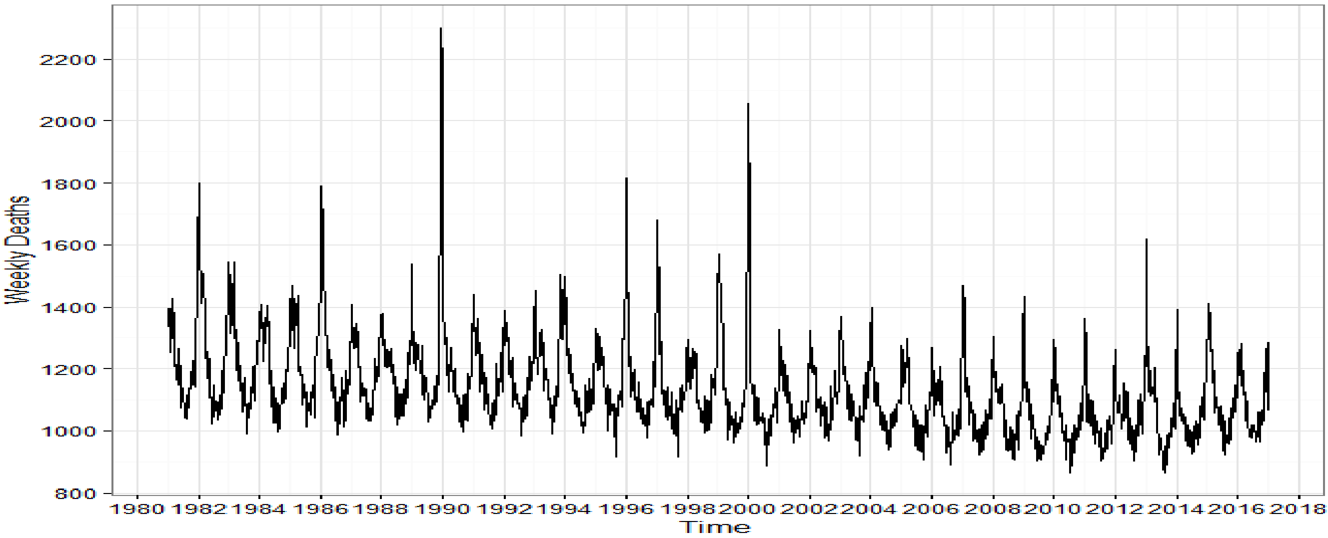
Figure 1: Average Weekly Temperature, $^{o}$C, 1981-2016 plotted against Time




## All-cause mortality 1981-2016

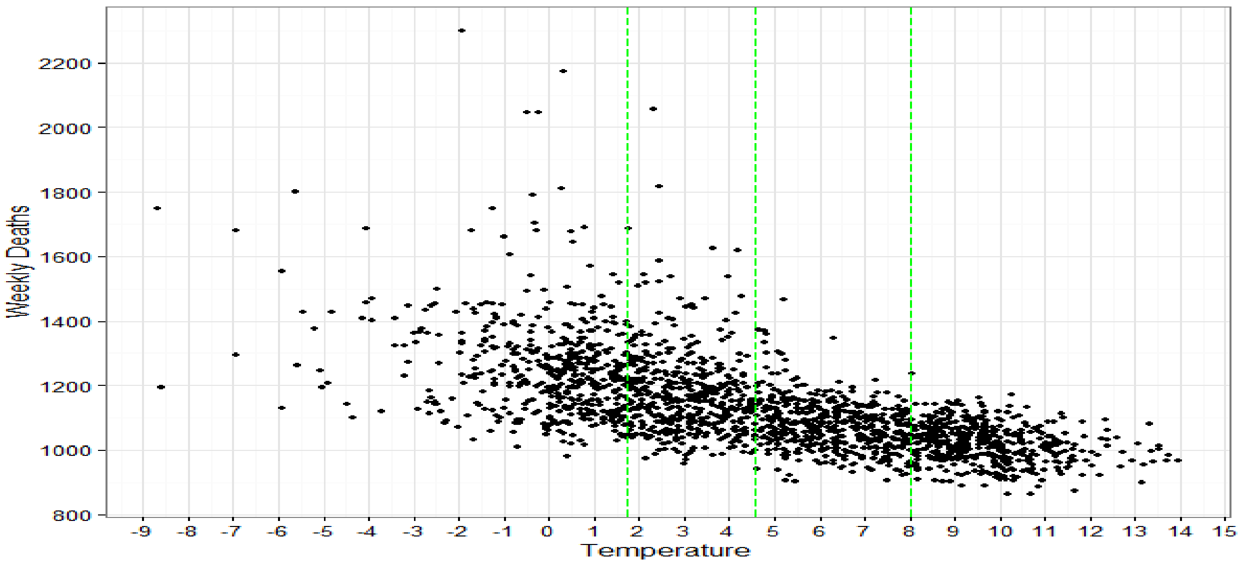
The trend plot of weekly deaths in Figure 2 shows the seasonal pattern to the weekly deaths with clear peaks every winter. It is clear that there is a general reduction in average weekly deaths since 1981 to about 2010 with an apparent visual increase since then. Some years have a very high peak – 1982, 1986, 1990, 1996, 1997, 2000 and 2013 with over 1600 deaths in these weeks. The nadir in the summer months in each year is less variable.

Figure 2: Weekly Deaths 1981-2016 plotted against Time




The temperature plot, Figure 3, shows a negative association between temperature and weekly deaths. The green (dashed) vertical lines are at the quartiles of the temperature distribution. Almost 25% of the weeks had an average temperature below 2ºC and a quarter above 8ºC. It is important to note the sparsity of data below -2ºC.

Figure 3: Weekly Deaths 1981-2016 plotted against weekly average temperature




The uncorrelated generalised additive model on time and temperature explained 67% of the deviance, which is quite high considering there are only two terms in the model and nearly 1879 weeks of data. Both variables are important with the greater contribution to explaining the weekly variability associated with temperature differences having a higher deviance per degree of freedom at 1245, compared to 262 for time as a variable.

The plots in Figure 4 and Figure 5 show the fitted spline trends over time and temperature, respectively. The 'y' axis is the deviation of the predicted value on the log rate scale from the average weekly mortality. The term (variable, number) indicates the variable in the spline term and the number of degrees of freedom in the function. The higher the degrees of freedom, the more curving there is in the association. A straight line would have 1 degree of freedom and a quadratic curve 2. Positive values above zero are associated with higher mortality than average; values below zero are associated with lower mortality that the weekly average.

Figure 4 is a summary of the trends in Figure 2 in that the weekly mortality rate decreased in a largely linear fashion from 1981 until a nadir in 2010-2012 where it began to increase again, such that in 2016, it is at a level similar to that of 2005.

Figure 4: Weekly Deaths 1981-2016 Fitted Spline Trend over Time

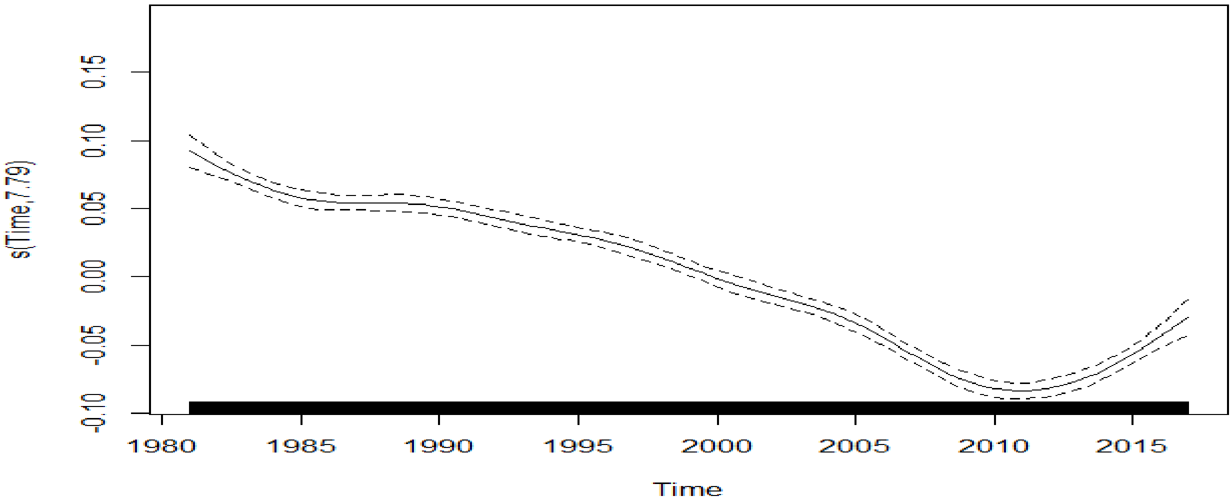
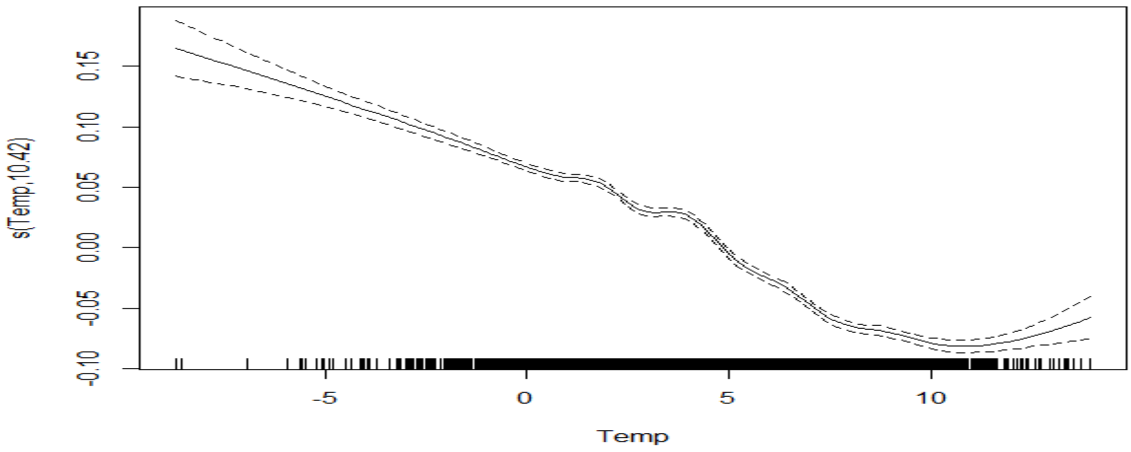



Figure 5 is a summary of the trends in the association between mortality and temperature in Figure 3. This curve shows some interesting characteristics. The main one is that there is a decreasing association with decreasing mortality rate, in relation to increasing temperature from minus 5ºC -10ºC to about 10ºC-12ºC. After this point there is a reversal of the trend, resulting in the mortality rate increasing slightly as temperature continues to increase beyond that point. The decreasing trend in death rate is largely linear from minus 10ºC to 2ºC-4ºC where there are a couple of changes of gradient followed by a sharper, linear decline, from 4ºC to 10ºC. The linear trend from minus 10ºC to 2ºC is partly an artefact of the model as there is sparse data below minus 3ºC.

While there is some evidence of a threshold effect at around 10ºC-12ºC where the association between weekly mean temperature and mortality changes direction, there is no suggestion of any specific threshold effect at the lower temperatures. If anything the relationship between decreasing temperature and increasing mortality is slightly shallower in the range of temperatures from 0ºC to 2ºC than it is in the region from 4ºC to 10ºC.

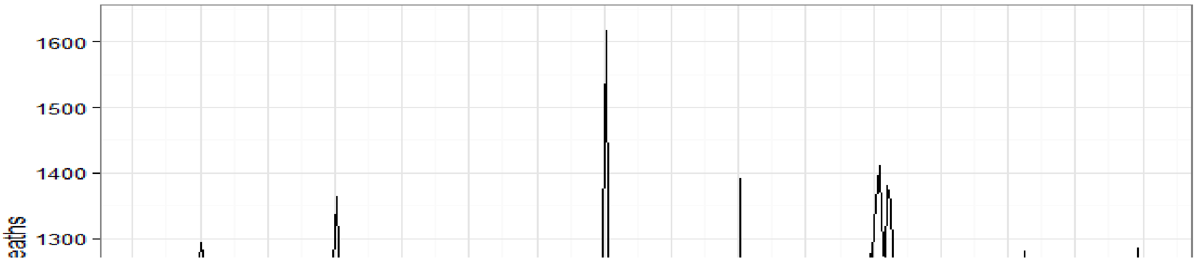
Figure 5: Weekly Deaths 1981-2016 Fitted Spline Trend over Temperature

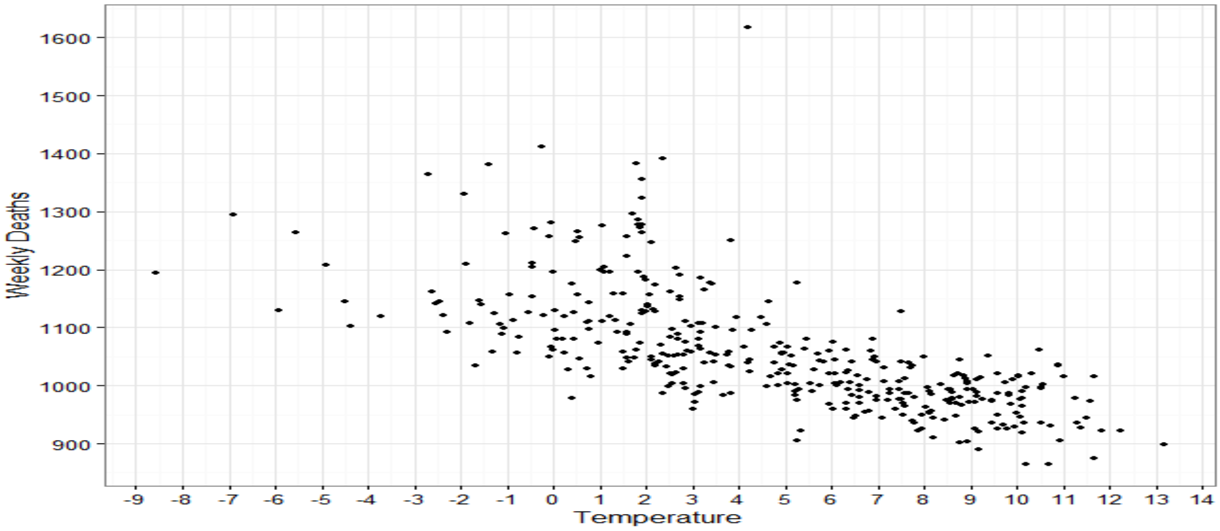

s(Temp,10.42)
0.15
0.10
0.05
0.00
-0.05
-0.10
-5
0
5
10
Temp

## All cause mortality 2009-2016 with Respiratory GP consultations

The trend plot of weekly deaths in Figure 6 shows the seasonal pattern of the weekly deaths with clear peaks every winter. This is from the more recent period (2009 onwards), where there is a slight increase in the trend in the numbers dying per week.

Figure 6: Weekly Deaths 2009 - 2016 plotted against Time




The temperature plot Figure 7, shows the same negative association between temperature and weekly deaths as in Figure 3. However, the range of temperatures is not as extreme with only 8 weeks where the average temperature was below minus 3$^{o}$C.

Figure 7: Weekly Deaths 1981-2016 plotted against weekly average temperature

The ILI consultations are shown in Figure 8 and the ARI consultations are shown in Figure 9. The ARI consultation rate is more regular each season compared to the ILI rate which exhibits severe spikes in 2010 and 2011 with lower peaks in recent years associated with a decrease in influenza activity.

Figure 8:  ILI Consultations, rate per 100,000, 2009 - 2016 plotted against Time

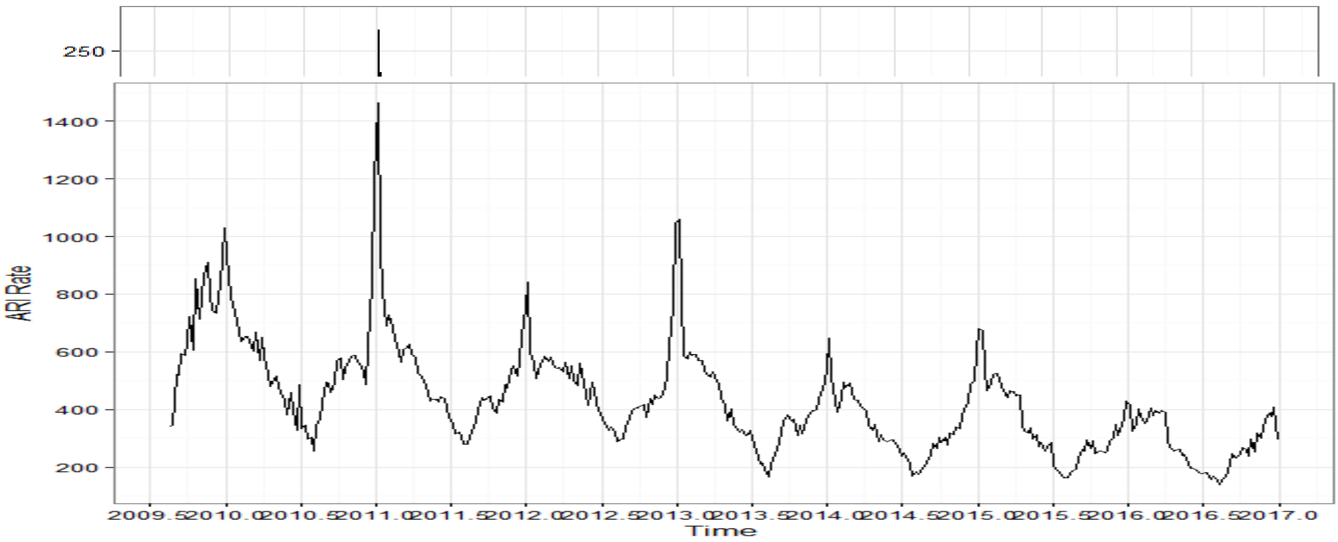



Figure 9:  ARI Consultations, rate per 100,000, 2009 - 2016 plotted against Time

The uncorrelated gam model with time, ARI consultation rate and temperature applied to the restricted data set from 2009 to 2016 explained 78.7% of the deviance. This is an improvement on using only temperature and time alone as variables of interest. All three variables are important in explaining the observed associations with mortality rate. The most important variable is ARI consultations (with a deviance to degree of freedom ratio of 100), followed by time (ratio at 62) and temperature (ratio at only 14.7). This means that GP - ARI consultations (a measure of the amount of ARI circulating in the community) is a stronger predictor of the mortality rate that either time (of year) or the average weekly ambient temperature in Scotland for the relevant week.

The plots in Figure 10, Figure 11 and Figure 12 show the fitted spline trends over time, temperature, and log ARI rate respectively. In this analysis, there appears to be an increasing effect of time as a variable as indicated by Figure 10. Also there is less of a temperature effect (Figure 11) compared to that shown in

Figure 5 (where ARI is not considered). The strongest effect however, is with log ARI consultations (Figure 12), which shows a steady increase in mortality rate with increasing numbers of ARI consultations.

Adjusting for the association between weekly mortality rate and ARI consultations, there is still a negative association between mortality and temperature (deaths decrease as temperature increases). This association levels off at about $8^{o}$C and there is then a clear reverse in the trend with a positive association between increasing temperature and increasing mortality. At low temperatures (below the plateau point), there is no evidence of any identifiable threshold effect. It is difficult to identify any impact of very low temperatures, as the weekly average temperature (as opposed to the daily ambient average temperature) in Scotland is seldom very low.

Figure 10:  Weekly Deaths 2009-2016. Fitted Spline Trend over Time

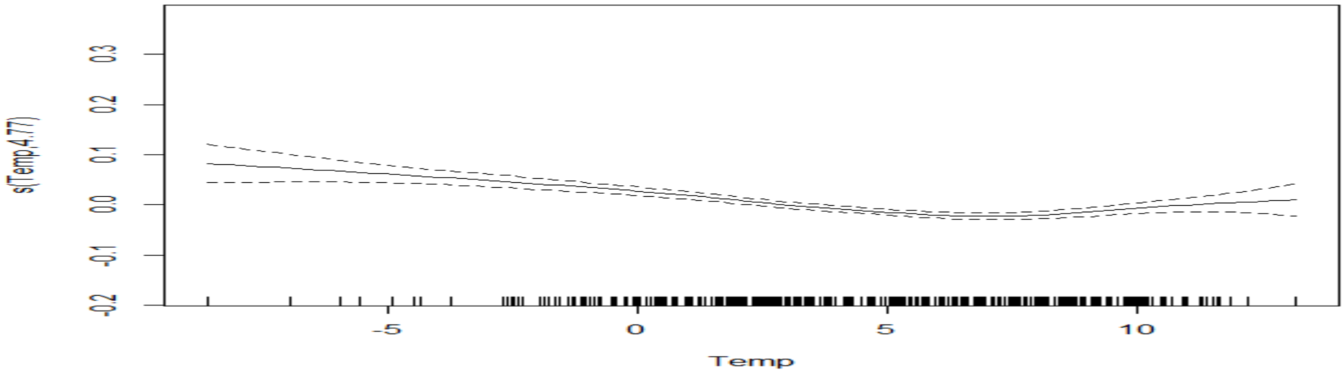
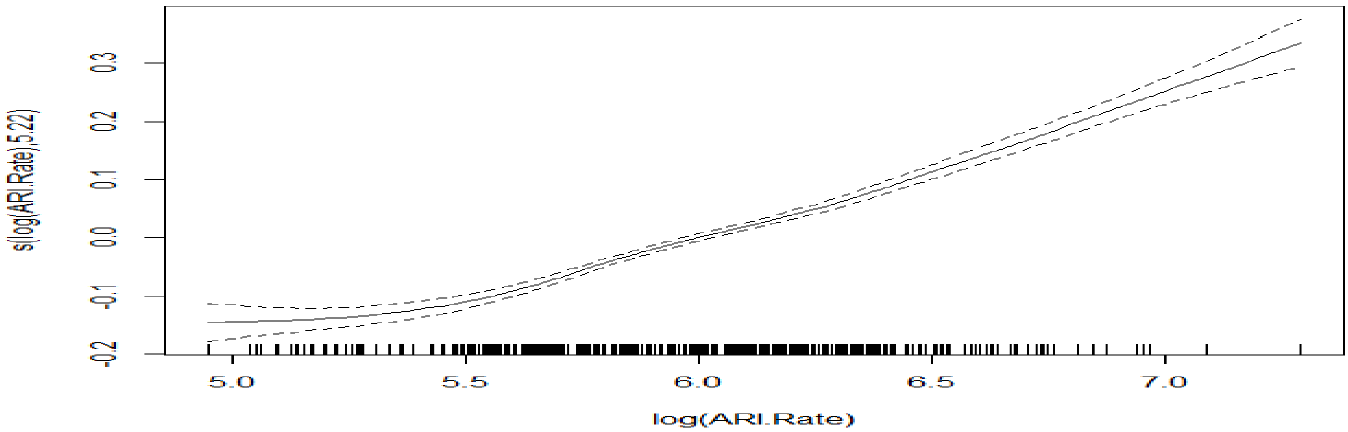




Figure 11:  Weekly Deaths 2009-2016. Fitted Spline Trend over Temperature

Figure 12:  Weekly Deaths 2009-2016. Fitted Spline Trend over Log ARI Rate



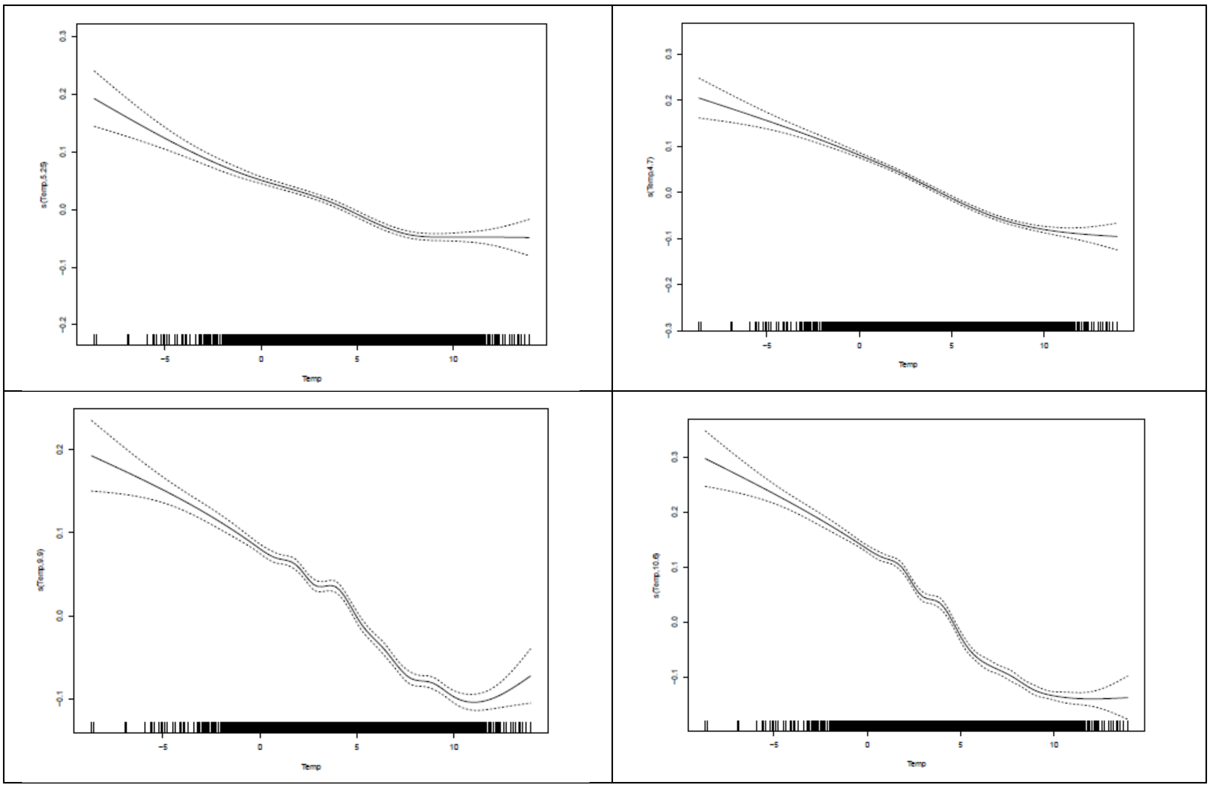
## Temperature Threshold Effects on all cause mortality – Data 1981-2016

The full results from this investigation are given in the Appendix. The cubic spline model fits the data best but the piecewise linear splines are reasonable. The best 2 change point model has changes in slopes at 4.2$^{o}$C and 5.5$^{o}$C and the best 3 change point model has changes in slope at 3$^{o}$C, 4.2$^{o}$C and 5.5$^{o}$C. This analysis has not found evidence for the existence of a strong threshold effect, meaning any specific temperature point below which the impact on the death rate of reducing average weekly temperatures is greater.

## Age Specific Mortality Data 1981-2016

The association between mortality and temperature (Figure 12) was investigated separately for ages 0-64, 65-74, 75-84 and 85+. The uncorrelated gam model with both time and temperature explained 77% of the deviance for the 0-64 age group, 89% for those aged 65-74, 81% for those aged 75-79 but only 53% for those aged 85+. Temperature had a greater association with the mortality rate for the three older age groups than it did for the 0-64 age group. The fitted spline trends are shown in Figure 13. In all 4 plots, the negative association between mortality rate and temperature is visible. In all age groups there is a levelling off in the downward trend at a temperature of about 10$^{o}$C, though only in the 75-84 is there a reversal of the trend with an increase in death rate at higher temperatures. This is of particular potential interest in identifying potential needs for specific mitigation interventions.

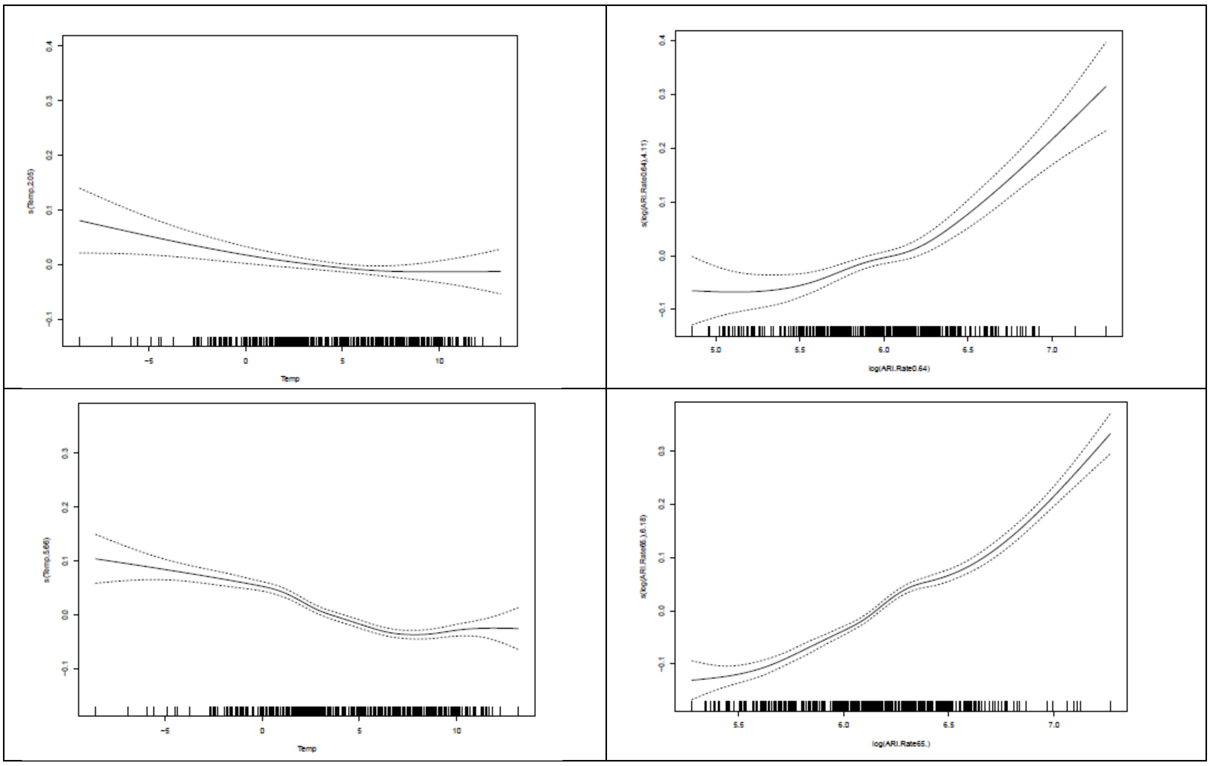
Figure 13: Weekly Deaths 1981-2016. Fitted Spline Trend by Age Group and Temperature From the top row left to right, the graphs are from age groups 0-64, 65-74, bottom row left to right 75-84 and 85+.



## Age Specific Mortality Data 2009-2016

In this analysis a subset of the mortality data (*2009-2016)* is used to allow comparison with GP-ARI consultations. Adjusting for the association between ARI consultations and mortality resulted in a diminution in the association between death rate and temperature in the 0-64 age group especially but also in the 65+ age group. The patterns for both ARI consultations and temperature are similar in the two age groups.

Figure 14: Weekly Deaths 2009-2016. Fitted Spline Trend. From the top row left to right, the graphs are from age group 0-64 – temperature and log ARI rate, bottom row left to right 65+ – temperature and log ARI rate.

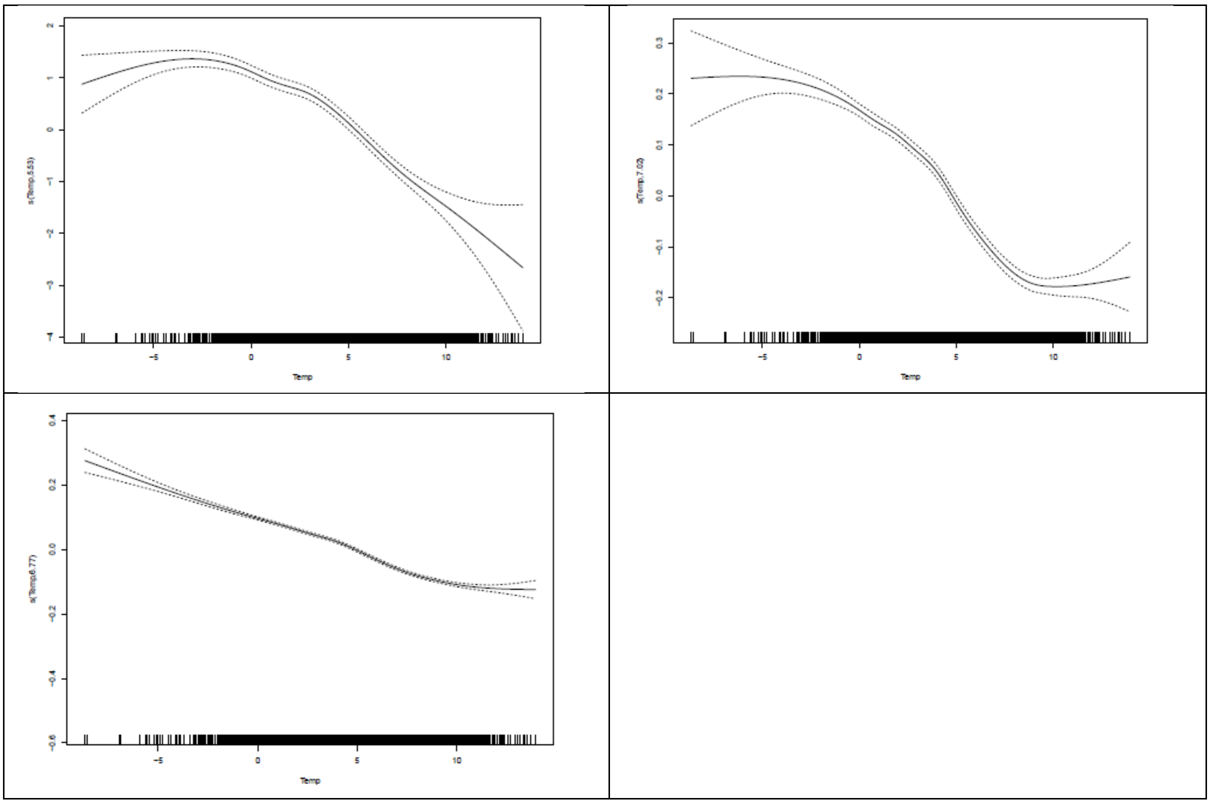


As there is a similar pattern to the association between temperature and all cause mortality rate in all age groups, only the “all age” analyses are presented in the rest of the report.

## Cause Specific Mortality 1981-2016

Results are only presented for influenza, COPD and cardiovascular deaths as there were coding issues with the pneumonia and trauma morbidity data. For all three causes of death, there were strong associations between temperature and the mortality rate. However, the pattern was not the same in all three causes (Figure 15) though all exhibited a general downward association. The curvature (trend reversal) at around 10$^{o}$C, which was previously noted, is not present for influenza and is most noticeable for COPD. For both COPD and Influenza deaths there is a levelling off at the lowest temperatures, below minus 3$^{o}$C. This pattern is not present for cardiovascular deaths, which has a monotonic association (a consistent one directional trend) over the full range of temperatures observed.

Figure 15: Weekly Deaths 1981-2016. Fitted Spline Trend by Temperature by causes of death. From the top row left to right, the graphs are influenza deaths, COPD deaths, bottom row left to right cardiovascular.



## Cause Specific Mortality 2009-2016, adjusting for ARI consultations

In the adjusted models, there was a much greater association between influenza mortality rate, COPD mortality rate, and log ARI consultations than there was between influenza and COPD mortality variables with temperature. In both analyses there was a significant residual association between temperature and mortality but it was not as strong as in the unadjusted analysis, Figure 14. For cardiovascular deaths, both ARI consultations and temperature have associations of a similar magnitude, explaining similar amounts of deviance per degree of freedom. The spline plots were similar to those in Figure 14 and so are not presented in the report but are included in the appendix.

## Cause Specific Hospital Admissions 1981-2016

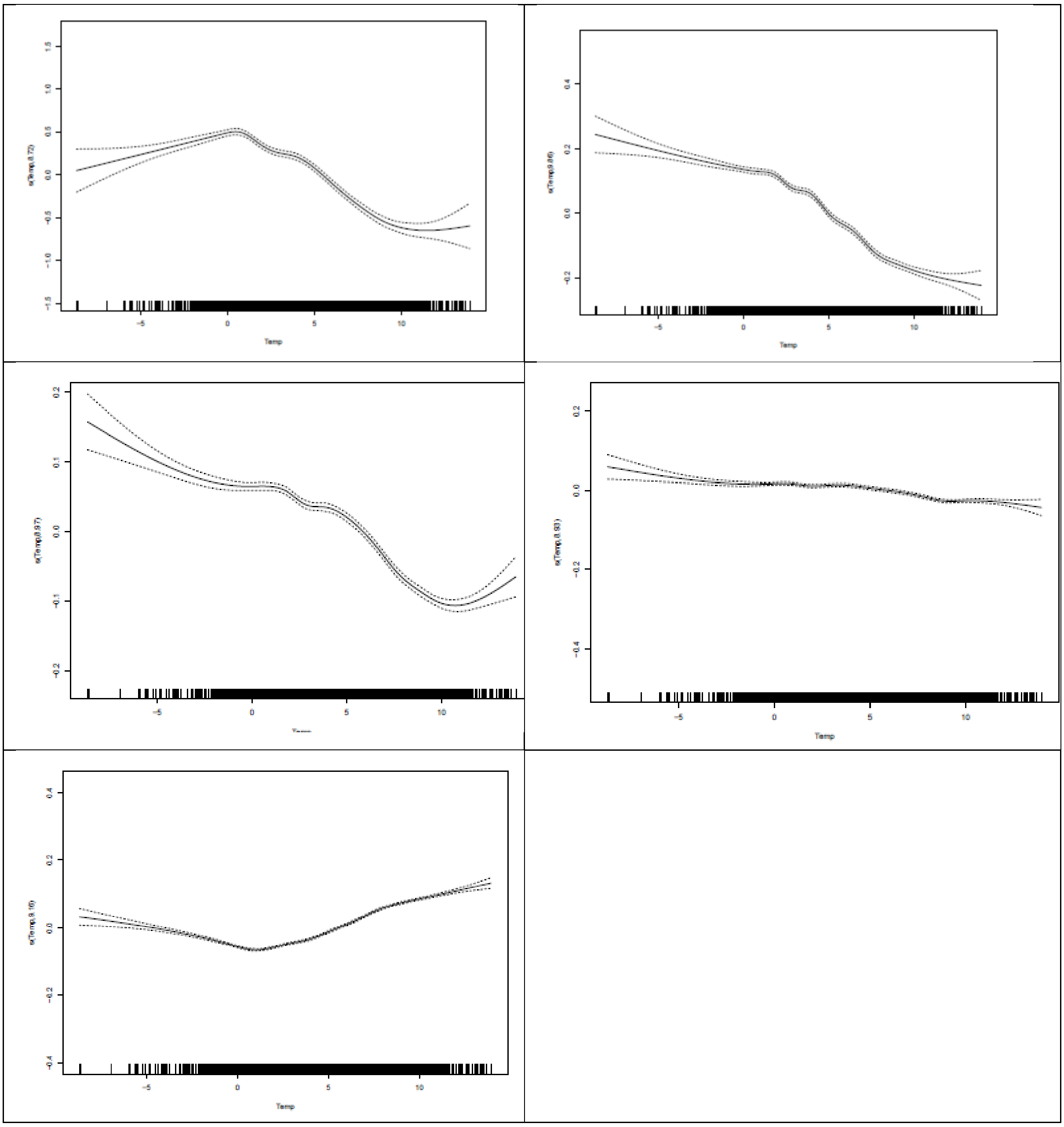
In this analysis the response variable is the proportion of all emergency admissions, which are due to the specific cause. Proportions are used rather than absolute numbers of admissions because year on year, there has been a trend for a large increase in the number of admissions to hospital, although these have generally been for a shorter duration.

The relationships between temperature and the proportion of emergency admissions are shown in Figure 16. The patterns of the associations between temperature and both COPD and cardiovascular admissions are similar to those seen in Figure 15 for cause specific deaths. There is a stronger association between temperature and COPD hospital admissions than between temperature and cardiovascular admissions. For both, there is a general trend for a smaller proportion of all admissions to be due to COPD or cardiovascular causes, as temperature increases. The association with temperature is reasonably linear for cardiovascular admissions but for COPD admissions there is evidence of a slight increase at higher temperatures above an average temperature of 10°C.

The pattern for the association between influenza admissions and temperature is not quite the same as that shown for influenza deaths. At temperatures above 0°C the proportion of all emergency hospital admissions due to influenza decreases with increasing temperature until about 10°C when there is a levelling off and then a constant proportion at increasing temperatures. At temperatures below 0°C it appears as if the proportion of admissions associated with influenza reduces with decreasing temperature whereas for mortality it levelled off.

The pattern for trauma admissions is a V shaped association, with the minimum proportion of trauma admissions (peak of the V) at a weekly average temperature of 1°C. This means that a higher proportion of emergency admissions due to trauma occurred at temperatures below 1°C and also at temperatures above 1°C.

Figure 16: Emergency Hospital Admissions 1981-2016. Fitted Spline Trend by Temperature by causes of admission. From the top row left to right, the graphs are influenza admissions, pneumonia, middle row left to right COPD, cardiovascular, bottom row trauma.



## Cause Specific Emergency Hospital Admissions 2009-2016, adjusting for ARI consultations

When using the data for the period when the ARI consultation rate was available, the temperatures trends for Cause Specific Emergency Hospital Admissions were similar to those in Figure 16 (for the entire study period 1981 to 2016), so are provided only in the appendix.

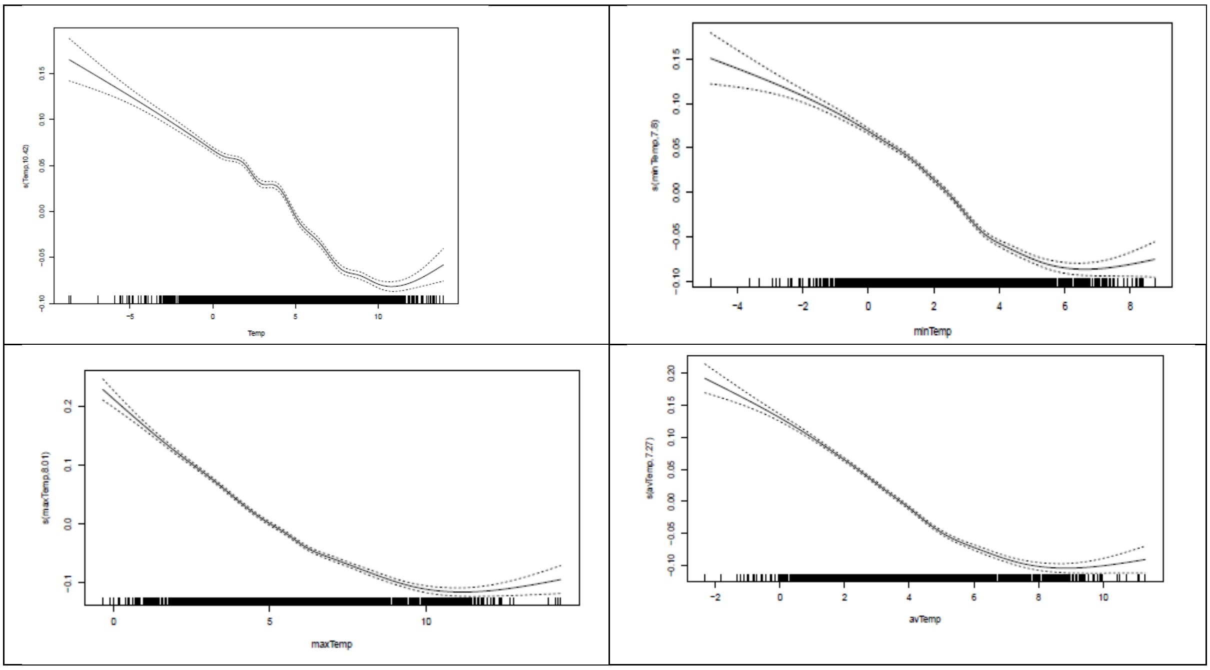
After adjustment for ARI consultations the strength of the associations between emergency admission for influenza, pneumonia, COPD and cardiovascular causes, and temperature were all reduced. For all causes there was a slight negative association between the proportion of admissions and temperature, meaning there was a reduced proportion of admissions as temperature increased. However, the dominant association in all cases was with the log ARI consultations variable. As the GP-ARI consultation rate increased, so too did the proportion of admissions associated with influenza, pneumonia and COPD. For cardiovascular admissions since 2009, there was a reduction in the proportion of admissions as the log ARI rate increased and also a slight reduction as temperature increased. In all four cases the association between the admission diagnosis and ARI consultations, adjusted for temperature, was stronger than that with temperature, adjusted for consultations.

When adjusting for ARI consultation rate, the trauma admissions rate had the same V shaped association with temperature as it did in the longer time series. However, there was more variability in the association in this reduced sample period. The association between trauma admissions and ARI consultations, adjusting for temperatures, was a negative one with a lower proportion of trauma admissions when the ARI consultation rate was highest.

## Sensitivity Analysis on the different temperature measurements

The sensitivity analysis to the different ways of measuring the average weekly temperature was based upon mortality (all cause only) using the data from 1981-2016. The correlated generalised additive model adjusting for time was used. Irrespective of the temperature measure, these models explained about 60-65% of the deviance. All 4 measures exhibit the same relationship between mortality and temperature, Figure 17. There is a monotonic decrease in risk of death as temperature increase from low values, followed by a levelling off and a rise in risk at the highest temperature levels. The only thing that changes is the location of the nadir of the relationship. Using minimum average ambient temperature, the nadir is at about an average weekly minimum of 6$^{o}$C; for the average for the geographic centre of Scotland it is at 9$^{o}$C; for the raw average it is at 11$^{o}$C and for the average weekly maximum it is at 12$^{o}$C. This suggests that it is not all that important which temperature measure is used for describing the association between mortality and temperature. However, it will become important if the results were used to extrapolate temperatures at which there might be a relatively greater adverse health impact.

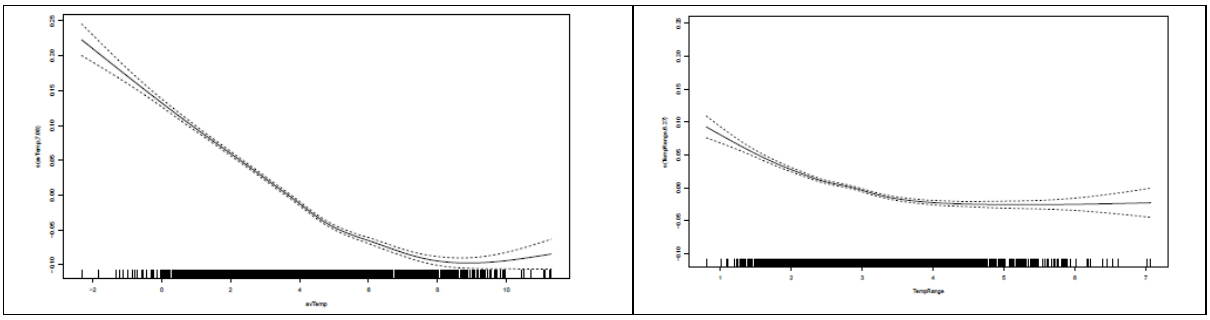
Figure 17: All-Cause Mortality 1981-2016. Fitted Spline Trend by Temperature for different temperatures summary measures. Top row: raw average weekly temperature; average minimum temperature over a week for geographic centre of Scotland using Shepherd's method.




Bottom row: average maximum temperature over a week for geographic centre of Scotland using Shepherd's method; average temperature over a week for geographic centre of Scotland using Shepherd's method.

The final temperature model fitted has time, weekly average temperature for the geographic centre of Scotland and the average weekly range (Maximum – Minimum), Figure 18. The graphs show that the association with average temperature is exactly the same as when only temperature and time were in the model and that there is an additional impact of temperature range, but only when the range is small. Above a temperature range of 4ºC there is no impact of the range on mortality; below a range of 4ºC mortality rises in weeks when there is little or no difference between minimum and maximum. Such weeks tended to occur in the winters prior to 2000. This is likely to indicate periods when the ambient temperature remained relatively stable (and low) over a week period, as may occur during cold spells in winters.

Figure 18: All Cause Mortality 1981-2016. Fitted Spline Trend by Temperature for average temperature and temperature range



# Conclusions

In Scotland, there is not a great deal variation in average weekly temperature over the course of a year. The results presented here have demonstrated that there is an association between temperature and health outcomes measured as mortality and morbidity (emergency hospital admissions). This association is present in all age groups and is also present over the range of causes of morbidity and mortality investigated.

There is no evidence of a change point effect (threshold) with a relatively greater impact of very low temperatures on mortality or morbidity. There is, however, evidence that higher weekly average temperatures (above a plateau point) are associated with increased mortality and morbidity, particularly in those aged 75-84, for a variety of causes) and for COPD for all ages.

Weeks with a relatively higher average temperature arise due to a sustained period of warmer weather or as the results of a few days in a week with very high temperatures. As we only have weekly data we are not able to assess the relative importance of these two possibilities. This would require a more detailed analysis of daily data, as opposed to the weekly temperature and health outcome data used in this investigation.

For causes of death and reasons for emergency hospital admission associated with respiratory viruses – influenza, pneumonia and COPD – the impact of temperature was reduced after adjustment for the impact of GP-ARI consultations. This suggests that temperature is not the only driver for the winter excess of deaths or for emergency hospitalisations but that there is an association with ambient temperature over and above the association with GP-ARI consultations.

This investigation was only intended as an initial exploratory study of the association between health outcomes (measured as mortality and hospital morbidity) and temperature using readily and freely available data. There are many limitations to this work as it is not a detailed investigation of weekly average data which may smooth out more subtle variation. Improvements could be to improving our understanding of the basic epidemiology of temperature related health outcomes in Scotland by using daily data and considering the effect of lagged temperatures. Also, assuming all of Scotland can be represented by one single value for temperature is a very large assumption;  a spatial analysis allowing for variation by location would take into account regional differences in temperature. Rather crude average temperatures were used and more sophisticated population weighted average values may be more appropriate. However the sensitivity analysis on temperature showed that similar conclusions were reached with different (temperature) measures.

The study has achieved its main objective to investigate the possible relationship between health and ambient temperature in Scotland, in particular to try to identify evidence for any threshold effects that might be used as a basis for designing some form of temperature based health intervention initiative to mitigate adverse impacts in vulnerable population groups.

The underlying message is that there is robust evidence of a relationship between ambient temperature and a variety of health outcome measures, based on weekly averaged data. However, the relationship is heavily confounded by other factors, especially the prevalence of acute respiratory illness in the population at any one time.

Estimating the potential impact of increases in ambient temperature, as postulated in standard climate change scenarios used in e.g. the SCCAP, is beyond the scope of this project. Although the data for temperatures at the higher end of the temperature scale were sparse, there are indications that the elderly are impacted disproportionately by increased temperatures above the trend plateau point (around 10ºC). If this trend does persist at elevated temperatures, then this suggests that the elderly in particular may be at more risk of adverse impacts, including death, at high average temperatures. This would be consistent with patterns identified elsewhere, when heat waves have been associated in particular with a rise in deaths among the elderly.

This initial investigation also indicates that a more detailed understanding of the relationship between temperature variation and health may be possible, including understanding the role of confounding variables such as respiratory illness, if more detailed data analysis could be carried out. Such further work could also be of benefit in exploring further the opportunities to design potential intervention and mitigation initiatives relevant to Scotland.