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Impact of Air Temperature on London Ambulance Call-Out Incidents and Response Times

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Abstract: Ambulance services are in operation around the world and yet, until recently, ambulance data has only been used for operational purposes rather than for assessing public health. Ambulance call-out data offers new and valuable (near) real-time information that can be used to assess the impact of environmental conditions, such as temperature, upon human health. A detailed analysis of London ambulance data at a selection of dates between 2003 and 2015 is presented and compared to London temperature data. In London, the speed of ambulance response begins to suffer when the mean daily air temperature drops below 2 °C or rises above 20 °C. This is explained largely by the increased number of calls past these threshold temperatures. The baseline relationships established in this work will inform the prediction of likely changes in ambulance demand (and illness types) that may be caused by seasonal temperature changes and the increased frequency and intensity of extreme/severe weather events, exacerbated by climate change, in the future.

Keywords: ambulance response times; extreme weather; climate change

1. Introduction

Within England, there are currently 11 National Health Service (NHS) organisations that provide ambulance services and more than 9 million emergency calls were received in the year ending March 2015, of which 72% required an emergency (face to face) response [1]. This is an average of 24,661 calls per day (17.1 calls per minute). The total number of category A (most urgent) emergency patient journeys in that year was 3.14 million and 2 million of these patients were taken to hospital.

The London Ambulance Service (LAS) employs over 5000 staff, including 3150 frontline staff across 70 ambulance stations serving the Greater London population of more than 8 million people. In 2014/15, over 1.9 million emergency ambulance calls were received in London (Figure 1), of which 1.1 million were responded to (on average 3000 incidents/day), and more than half a million were considered life threatening (Category A) and the rest triaged as not requiring an ambulance. Activity levels are steadily increasing with 9% more calls in 2014/15 than in 2013/14 (more than 400 extra calls per day) [2].

The LAS uses the Advanced Medical Priority Dispatch System (AMPDS) to initially triage the patient's chief complaint. In this step, there are more than 30 complaint types that are then further categorised as either Category A (Life Threatening) with a target response of eight minutes or less, and

all other calls (not serious or life threatening), with a target time agreed locally that is normally up to 19 min. The NHS specifies that 75% of Category A should be responded to within an 8 min target.

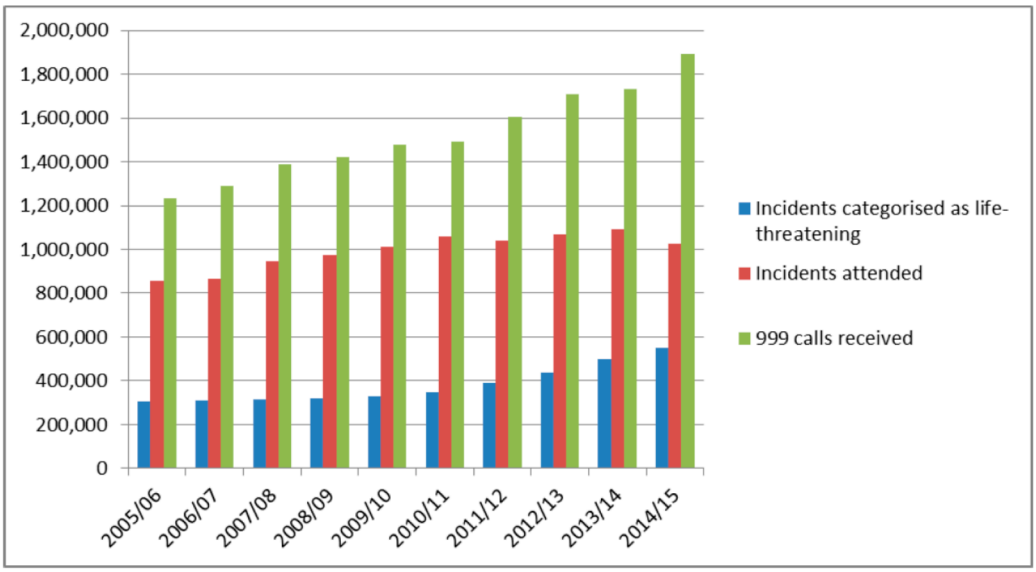

Figure 1. London Ambulance 999 calls 2005/06–2014/15 [1] (note the levelling off of incidents attended due to pressure of resources).

After the patient has been seen by an ambulance crew, a further refined illness code is specified with just over a 100 categories used. For example, a patient originally identified as having general breathing problems may, after assessment, be classified more specifically as Chronic Obstructive Pulmonary Disease (COPD). This data is recorded on patient report forms that are available for analysis a few weeks after the event. It is noted that, whilst LAS ambulance staff are trained medical professionals, their diagnostic categories may be changed or updated once the patient arrives at hospital and undergoes further testing. The LAS uses a number of generic category codes such as "other medical conditions", "generally unwell" and "pain (other)" as the exact illness or injury is not always obvious. Given the time and resource pressures, there will be diagnosis errors within the other illness categories, but the illness data is as reliable and consistent as other real-time health data sources such as telephone health lines (such as NHS 111).

In recent years, there has been an increasing awareness of the impact of weather, climate and climate change on public health both in terms of human mortality and morbidity. In particular, the role of hot weather and heatwaves on public health has been widely investigated in the UK [3–5]. Extreme weather impacts directly on the ambulance services through additional calls particularly because of the increased prevalence of temperature dependent call-out categories. Response times are affected by increasing call volume, but weather can also directly impede response times by creating obstacles to reaching patients, for example, flooding, snow, ice, fallen trees and fog.

Most ambulance based studies (Table 1) have looked at the negative impact of heatwaves on ambulance performance, for example in Australia: Adelaide [6], Brisbane [7], and Sydney [8]; Canada: Toronto [9,10]; Italy: Emilia-Romagna [11] and Florence [12]; Switzerland: Ticino [13] and United Kingdom: London [14,15]. For example, during warm weather in London, for every 1 °C above a mean temperature of 20 °C, it has been shown that the total number of ambulance incidents increases by 1% on average [15]. There are fewer studies (Table 2) looking at cold waves, for example: Australia: Brisbane [7] and the United Kingdom: London [15,16] and Birmingham [17]. These results show that severe cold weather has a significant negative impact on ambulance performance. For example, during cold weather in London, for every 1 °C below a mean temperature of 2 °C, it has been shown that Category A performance declines by 1.5% [16].

Table 1. Key impacts of heatwaves on ambulance services.

Adelaide [6]:	Ambulance call-outs increased by 10% and by 16% in the 2008 and 2009 heat waves, respectively. Heat related dehydration appeared to promote acute renal failure.
Brisbane [7]:	Significant relationship between mean temperature and ambulance incidents (2000–2007) with a 1.17% increase in total incidents per 1 °C increase in temperature above a threshold of 22 °C (0 to 1 day lag).
Sydney [8]:	During the 2011 heat wave, all cause ambulance calls increased by 14% the additional calls mostly due to heat stroke, heat exhaustion and dehydration.
Toronto [9]:	Between 1999 and 2002, ambulance calls increased by 10% on oppressively hot days. GIS shows that the urban core experiences the greatest number of calls.
Toronto [10]:	For the summer of 2005, there were 201 ambulance response calls for heat related illness. On average, for every 1 °C increase in maximum temperature above average, there was a 29% increase in ambulance response calls for heat related illness.
Emilia-Romagna [11]:	For the summers of 2002–2006, for people over 35, the percentage change in ambulance dispatches associated with each 1 °C increase in the apparent mean temperature between 25 and 30 °C was 1.5% for non-traumatic diseases and 2.7% for respiratory diseases. Above 30 °C, cardiovascular diseases were positively associated especially for those aged over 75 with an increase of 12% in ambulance dispatches.
Florence [12]:	Ambulance and weather data for the summer of 2005 (13,354 calls) were examined. The overall number of calls rose in hotter conditions during the night: 'oppressive night-time conditions might be more stressful than the maximum temperature'. A rise in alcohol-related diseases in hotter conditions relating to dehydration.
Ticino [13]:	Ambulance data from the 2003 heatwave showed that the number of incidents in June increased by 36% for the 65+ age group and 33% for the 75+ age group.
London [14]:	A heatwave vulnerability index (HVI) for London's 4765 census units was developed for London that offers potential as an a priori spatial indicator of the number of heat related ambulance incidents.
London [15]:	For the London Ambulance Service, the daily percentage of CatA (Category A) (%CATA8) incidents responded to within the target of 8 min declines with increasing maximum daily air temperature. During hot weather for every 1 °C above 20 °C, the total number of incidents increases by 1% on average.

Table 2. Key impacts of cold weather on ambulance services.

Brisbane [7]:	Cold weather effects were delayed and long lasting with a 1.30% increase in incidents for a decrease in temperature of 1 °C below the threshold of 22 °C (2–15 day lag). No harvesting was observed.
London [15]:	For December 2010, the coldest December for 100 years, the daily number of CatA incidents for the London Ambulance Service was nearly 20% higher than November 2010.
London [16]:	During cold weather for every 1 °C below 2 °C CatA performance declines by 1.5% on average. In cold weather, there are more incidents for flu, respiratory illnesses, fractures and head injuries.
Birmingham [17]:	Birmingham ambulance data was examined (2007–2011) and compared to air temperature data. Both hot and cold weather have an impact on response times (Target 75% of CatA incidents responded to in 8 min). In December 2010, the response rate fell below 50% for three days in a row with a mean response time of 15 min.

A study in Hong Kong looked at the impact of a range of weather parameters (temperature, humidity, air pressure and cloud) on the daily demand for ambulances [18] and concluded that:

> *The presence of strong weather effects among different target groups indicates the possibility for the development of a short-term forecast system of daily ambulance demand using weather variables. The availability of such a forecast system would render more effective deployment of the ambulance services to meet unexpected increases in service demands* ([18], p. 60).

Such a forecast system would enable much better handling of ambulance demand during severe/extreme weather events likely to be worsened by climate change.

In Germany (Bavaria), the impact of a range of weather conditions (2006–2007) on COPD and the effect on ambulance incidents has been examined [19]. In addition, a few studies have looked at the carbon footprint of ambulance services for example in Australia [20], the United Kingdom [21] and the United States [22].

2. Methods: Long-Term Increase in Ambulance Usage

Example ambulance time series data are shown in Figure 2, which shows the daily rate for the total LAS ambulance Category A life threatening call-outs, as well as "respiratory chest infection", "abdominal pains" and daily air temperature. All of the time series illness data show a significant long-term increase in call-out frequency. The increase from 2005 to 2013 is nonlinear and varies with category, but the average increase is a near doubling. This trend can be separated into two distinct phases characterised by a slow increase between 2005 and 2009, followed by a much more rapid increase between 2009 and 2013. This rapid increase can partly be explained by the changing demographics of an aging population across London (as in the rest of the country). The other significant driver is how the ambulance service is utilised. Some of this change is likely driven by increasing mobile phone usage [2], which makes calling an ambulance easier. Other social changes include more difficult access to doctors' appointments within the National Health Service (NHS) and increased NHS 111 ambulance referrals.

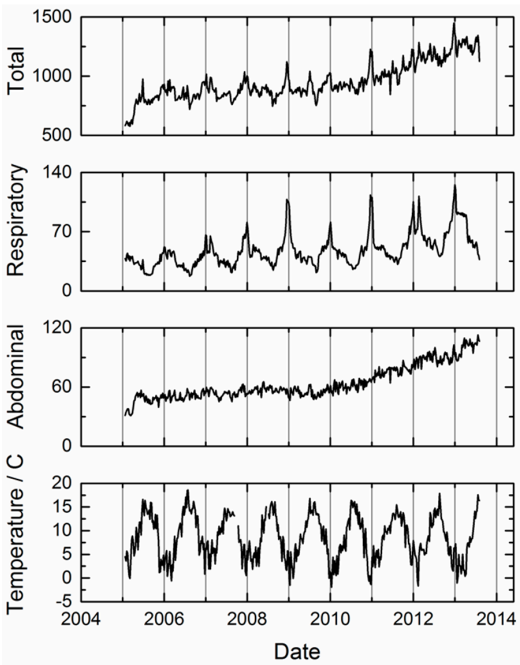

Figure 2. Time series data from 2005 to 2013 showing the London Ambulance daily Category A call-out frequency for selected categories compared to the average mean temperature as recorded at St James Park, London, UK. The 'respiratory' and 'abdominal' refer to the call-out categories 'respiratory chest infection' and 'abdominal pains', respectively.

To understand the effect of temperature, and hence seasonality, on the call-out rates the long-term trend needs to be removed from the data. There are various statistical methodologies that can be used to remove long-term trends [23]. We assume the data follows a classical decomposition model where the data is comprised of three components: long-term trend, seasonality and noise, where the noise is not necessarily random. The long-term trend is modelled using a cubic least squares fit to the call-out rate data and is removed from the data set via division of the observed data by the fit. Hence, the de-trended data set retains the seasonal and noise components of the original dataset. Linear fits between the de-trended call out rates and temperature are then calculated.

3. Results: The Effect of Air Temperature on Ambulance Response Times

Daily data has been extracted from the LAS for 2003–2013 including the number of calls, responded incidents, the number of Category A calls, the percentage of responses within 8 min and illness codes. During those years, 14,717,476 calls were received; 9,947,927 incidents were responded to with a frontline vehicle (68%) and 3,359,572 Category A life threatening calls were assessed (23% of all calls). The response data was then compared to mean daily temperature data from St James Park (SJP, longitude and latitude coordinates 54.97554, −1.62162) in London over the same period (see Figure 2, bottom panel), a location that is approximately within the centre of the LAS's geographical remit. The hourly output temperature data from this station was obtained via the British Atmospheric Data Centre (BADC) [24]. The heatwaves of 2003 and 2006 and the warm summer of 2013 plus the very cold December of 2010 are present within the dataset providing a wide cross section of weather events.

Figure 3 shows how both call-out volume and response rate performance vary with mean daily temperature. The call-out volume has the long-term trend removed as detailed above and values shown are representative for the call-out volume received in 2013. It can be seen that, as temperature rises above 20 °C and goes below 2 °C, the total ambulance call-out volume increases and the percentage of responses within the 8 min target reduces. Both call-out volume and percentage of responses rise in a near-linear fashion beyond the hot and cold threshold temperatures. Figure 3 (bottom panel) shows that performance drops off more quickly as the mean temperature drops below 2 °C compared to the reduction in performance when the temperature rises above 20 °C. A 20% increase in daily callouts, compared to the average, leads to a decrease in performance (measured as % response in 8 min) of 14.4% and 8.2% for temperatures below 2 °C and temperatures above 20 °C, respectively. This difference between hot and cold periods can partly be explained because performance at low temperatures is affected by slippery roads due to ice and snow, whereas, in warm temperatures, the roads and traffic are not normally affected. This figure shows that the weather does not have to be severe for an impact on ambulance services to occur at low or high temperatures.

There is also a seasonal temperature change in the number and type of incidents, which means that the performance of the ambulance service in London is marginally better in spring and autumn than in summer and winter. Unseasonably warm and cold weather both exaggerate these variations and cause a significant reduction in performance, especially during 'heatwaves' and 'coldwaves'.

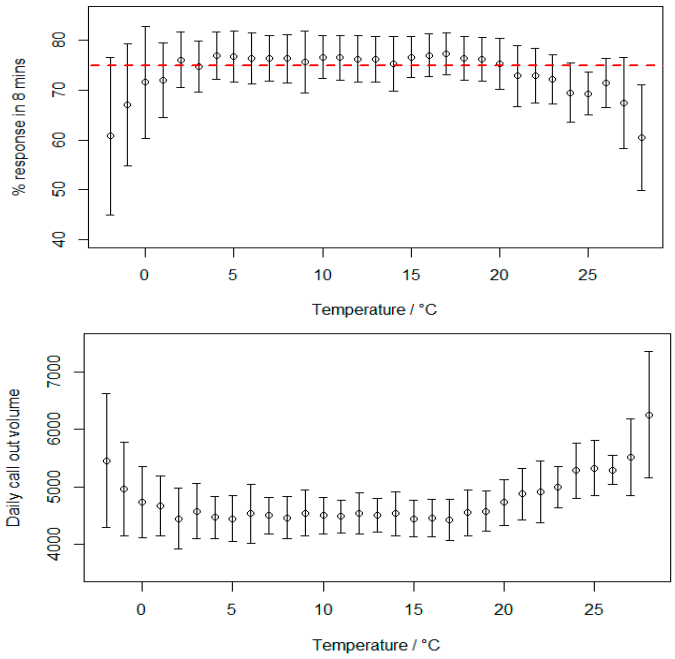

Figure 3. *Cont.*

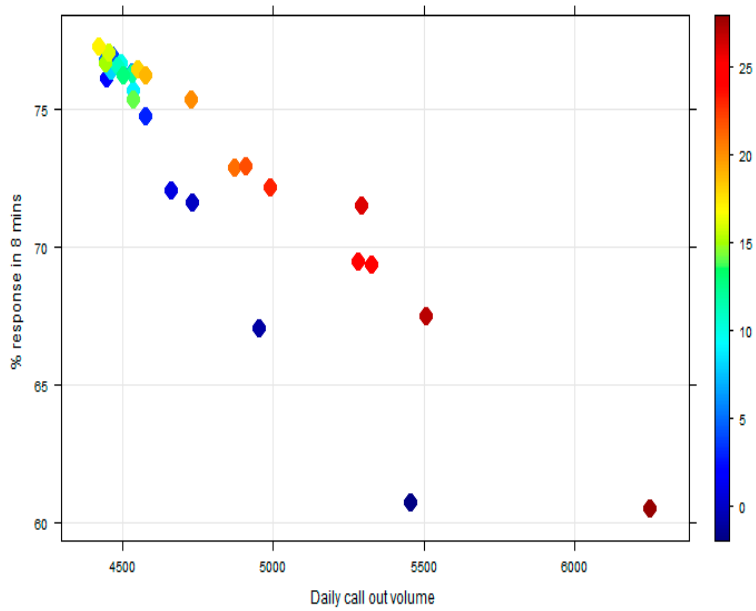

Figure 3. London mean daily temperature versus ambulance call-out metrics (2003–2013). Top panel—temperature dependence of response rate as % of category A incidents responded to within 8 min. Each data point represents the daily averaged data, which has a mean temperature within a set temperature range (the width of the temperature bins is 1 °C). Red dashed line shows NHS (National Health Service) target of 75% or responses to be completed within 8 min. Middle panel—temperature dependence of ambulance call-out volume. The long-term trend in data has been removed. Error bars represent 1 standard deviation (1σ). Bottom panel—dependence of response rate on call-out volume. The colour of the data points represents the mean daily temperature (see legend).

4. Discussion: Ambulance Illness Codes versus Air Temperature

The top ten Category A call-out categories as defined by total incidence rate in the years from 2005 to 2013, in decreasing order of incidence, are "other medical conditions", "dyspnoea", "pain (chest)", "generally unwell", "pain (other)", "alcohol related", "abdominal pain", "dizzy (near faint or loss of coordination)", "respiratory chest infection" and "vomiting". The top ten conditions account for approximately 50% of all Category A callouts, and the top twenty conditions account for approximately 75%.

To compare the temperature data with the call-out data, both data sets are converted into weekly data sets. The rationale behind the use of weekly data is twofold: firstly, it increases the data density, by an approximate scaling of seven, of the call-out categories, thereby increasing the statistical robustness of any correlations observed with temperature. Secondly, weekly data removes 'day of the week' effects. For example, call-out categories associated with alcohol show a clear weekly cycle: data for Monday to Thursday have near identical frequencies but a significant frequency increase is associated with the weekend with a Saturday peak. It is noted that weekly data does not remove the effects of holidays or special days on the data. For example, it is well known that New Year's Day is the busiest day of the year for the ambulance service. Weekly data does not remove the effect of these special days, but it does lessen their impact. The weekly temperature data used is the mean average temperature. Initial testing indicated that little variation in outcome occurred if maximum and minimum weekly temperature was averaged instead of averaging the daily means.

Figure 4 provides the percentage changes for the summer (June, July and August) and winter (December, January and February) seasons compared to the total de-trended data set. It can be seen that the warmer temperatures associated with the summer season lead to a reduction in the top ten callout categories associated with negative temperature dependence and an increase in the "alcohol related" category, which has a positive temperature dependence. The winter season has the opposite

effect to summer for the same reasons; lower average temperatures lead to an increases of incidence for the negatively temperature correlated categories and a decrease in the "alcohol related" category. In addition to the summer and winter seasons, the individual months of July and December are investigated, which allows for the effect of a heat wave (July 2006) and a cold wave (December 2010) to be investigated with the de-trended data sets. The average mean weekly temperatures in July 2006 and December 2010 were 21.4 ± 3.4 °C and 1.4 ± 1.2 °C, respectively. The average July and December temperatures over the eight year study period were 18.6 ± 2.8 °C and 6.0 ± 1.4 °C, respectively. The average summer and winter temperatures over the eight-year study period were 17.7 ± 2.7 °C and 5.9 ± 1.4 °C, respectively. As expected, the 2010 cold wave led to significant increases, compared to the average December and winter, in all of the negatively temperature correlated categories. The "alcohol related" call-out did not reduce as much as might be expected (based on temperature alone) in December 2010 and the average December categories, but this is likely due to the confounding influence of seasonal Christmas period alcohol drinking. The average summer, average July and the July 2006 heat wave call-outs behave mostly as expected with temperature dependencies playing a central role. However, there are a few unexpected results. For example, the "dyspnoea" category call-out frequency increases in the July 2006 heat wave when a prediction based just on a linear temperature dependence would suggest a decrease in call-out rate. This indicates that factors, in addition to temperature, were likely to be significant during the heat wave. The increased levels of air pollution associated with the heat wave are a likely cofactor that the simple temperature dependent model does not take into account [25]. The impact of short-lived air pollution episodes on ambulance incidents has recently been shown to be significant across England [26], in London [27] and also in the Italian Region of Emilia-Romagna [28].

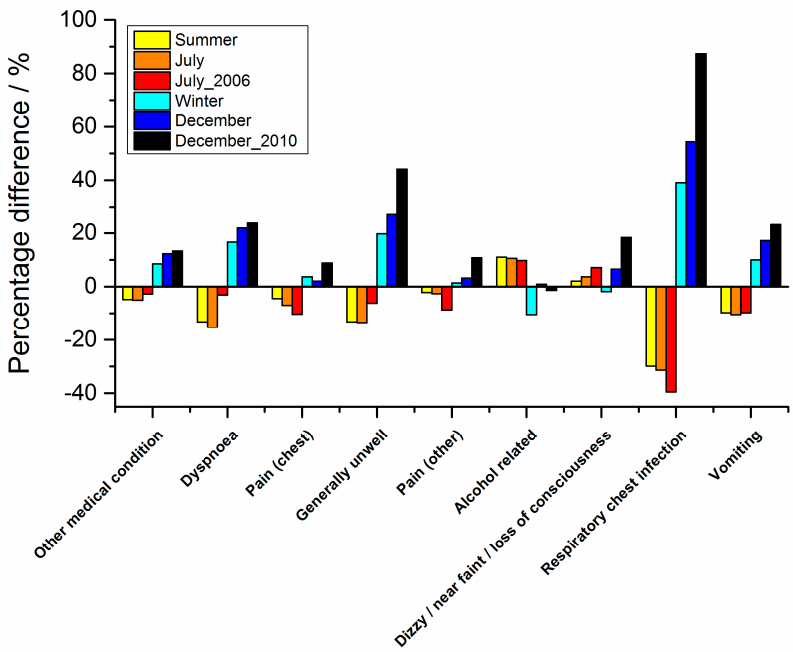

Figure 4. Seasonal percentage differences in ambulance call-out rates for the top ten categories. Winter is defined as the months of December, January and February. Summer is defined as the months of June, July and August.

Using the relationship between temperature and ambulance call-outs, after controlling for air pollution and other confounding factors such as influenza, could inform future studies and help forecast ambulance call out numbers up to a week ahead (the time period for which robust meteorological forecasts are available). In addition to short term forecasting, the effect of climate could be used for yearly projections. Figure 5 below shows an example statistical prediction of the 2012/2013 respiratory

chest infection call outs. The model uses the previous three years of data to train both the long-term trend and temperature dependence of the model. It is noted that the actual measured temperature used in the forecast model would not be available in advance. However, long-term climate projections are available. It can be seen that the model captures much of the detail of the actual ambulance call outs. The only major feature missed by the model is the influenza season peak, which occurs at the end of 2012. It indicates that good long-range ambulance call out rate projections can be generated if the appropriate meteorological forecasts, of sufficient skill, are available. This modelling approach could also serve as an early warning tool for health surveillance systems as well as ambulance services.

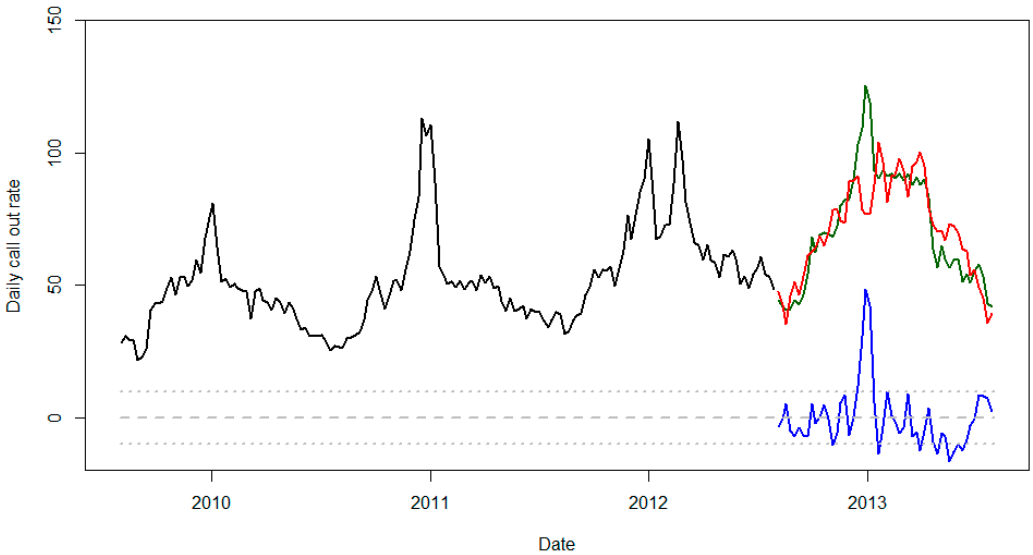

Figure 5. Forecast prediction of 2012/2013 respiratory/chest infection call out rates. The model is trained using three years of data from 2009 to 2012 shown by the black line. The 2012/2013 forecast is shown by the red line, and the actual call out for 2012/2013 is shown in green. The residual between the forecast and actual is shown by the blue line. The grey dotted lines indicate the +10 and −10 daily call out rates, and the dashed line gives a call out rate equal to zero.

5. Conclusions

Ambulance services are placed under stress due to increased demand whenever the weather is severe (often at a time when patients are also under increased stress) particularly during heatwaves and cold weather. This paper illustrates this concept with air temperature data but adjusting for snow, ice, gales, heavy rain, floods, air pollution and fog would also be beneficial. Currently, daily estimates of the number of LAS ambulances likely to be required for the week ahead are based on statistics for the same days of the year for the last three years. This takes into account weekends and holidays, but only accounts for changes in the weather on a seasonal basis. However, the weather is rarely the same on a particular day, or in a particular week, from year to year. Therefore, further research to enable bespoke weather forecasts to be built into the ambulance service prediction models is recommended. Better prediction of call-out rates would allow for improved operational resilience, as well as reducing air pollution caused by idling ambulances on urban streets.

Warming temperatures, due to climate change, may reduce the total number of ambulance callouts in winter and conversely increase them in summer, although changes in population size and structure and in other climatic factors (e.g., precipitation), not examined in this paper, may have the opposite effect. There is also evidence that heatwaves and coldwaves could increasingly cause increased demand and ambulance response time delays.

The weather impacts directly on day-to-day operations whilst the climate contributes to the level of service required (e.g., the total number of staff and ambulances). As the climate changes affecting

the frequency of hot and cold weather events, the ambulance service needs to become more resilient and would be better prepared by using bespoke weather forecasts for day-to-day operations and climate predictions for strategic planning.

The impact of weather and climate on ambulance services is a relatively new research area and there is much scope for further research. For example, research into the impact of relative humidity and air pollution on the number of call-out incidents is currently ongoing by the authors. In addition, the importance of lags in the system is being explored to look at the impact on illness types, for example, a delayed respiratory response in hot and cold weather. In order to improve the prediction of 999 call numbers and illness types in severe weather, the use of satellite air temperature estimates, to give a more accurate spatial prediction, should be considered. Recent improvements in estimating air temperature from satellite data are available [29,30]. The urban heat island in London and other cities compounds the health impact of heatwaves for ambulance and other health services [31,32].

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