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ORIGINAL PAPER

Extreme climatic conditions and health service utilisation across rural and metropolitan New South Wales

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Abstract Periods of successive extreme heat and cold temperature have major effects on human health and increase rates of health service utilisation. The severity of these events varies between geographic locations and populations. This study aimed to estimate the effects of heat waves and cold waves on health service utilisation across urban, regional and remote areas in New South Wales (NSW), Australia, during the 10-year study period 2005–2015. We divided the state into three regions and used 24 over-dispersed or zero-inflated Poisson time-series regression models to estimate the effect of heat waves and cold waves, of three levels of severity, on the rates of ambulance call-outs, emergency department (ED) presentations and mortality. We defined heat waves and cold waves using excess heat factor (EHF) and excess cold factor (ECF) metrics, respectively. Heat waves generally resulted in increased rates of ambulance call-outs, ED presentations and mortality across the three regions and the entire state. For all of NSW, very intense heat waves resulted in an increase of 10.8% (95% confidence interval (CI) 4.5, 17.4%) in mortality, 3.4% (95% CI 0.8, 7.8%) in ED presentations and 10.9% (95% CI 7.7, 14.2%) in ambulance call-outs. Cold waves were shown to have significant effects on ED presentations (9.3% increase for intense events, 95% CI 8.0–10.6%) and mortality (8.8% increase for intense events, 95% CI 2.1–15.9%) in outer regional and remote areas. There was little evidence for an effect from cold waves on health service utilisation in major cities and inner regional areas. Heat waves have a large impact on health service utilisation in NSW in both urban and rural settings. Cold waves also have significant effects in outer regional and remote areas. EHF is a good predictor of health service utilisation for heat waves, although service needs may differ between urban and rural areas.

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Introduction

Extensive research has shown that excursions in ambient temperature are associated with adverse health effects in humans (Armstrong, 2006; Cheng and Su 2010; WHO and WMO 2015; Ye et al. 2012). This relationship is understood to follow a U shape, whereby ambient temperatures of both low and high extremes result in an increased incidence of a range of health effects. At higher ambient temperatures, the health effects include those more directly related to heat such as heat stroke and dehydration as well as more indirect effects such an increased incidence of cardiovascular events (Ye et al. 2012). Colder temperatures have also been associated with health impacts such as increased rates of hypothermia, influenza, and pneumonia (Fleming and Elliot 2005; O'Neill and Ebi 2009; WHO and WMO 2015). Both extreme cold and extreme heat are associated with increases in rates of mortality and health service utilisation (Guo et al. 2014; Schaffer et al. 2012). Periods of sustained, abnormally hot temperatures, known as heat waves, have been established as having significant health effects over and above the effect of high temperature (Barnett et al. 2012; WHO and WMO 2015). Sustained periods of abnormally cold temperatures, known as cold waves, are an emerging area of research. The effect of such events on health and health care utilisation has been investigated in colder climates (De Donato et al. 2013; Huynen et al. 2001); however, research is lacking in warmer regions.

Although the existence of a U-shaped relationship between ambient temperature and adverse health effects is fairly consistent between geographic locations, the ambient temperature at which the least health impact is seen can vary substantially (Diaz et al. 2015; Guo et al. 2014; WHO and WMO 2015). Due to this, a particular temperature will have a variable impact depending on the climatic conditions of the location; a heat wave definition based on temperature alone could be valid for one location but not for another (Diaz et al. 2015). This suggests the importance of acclimatisation for populations which have been shown to include both physiological and behavioural adaptation (WHO and WMO 2015; Ye et al. 2012). Physiological adaptation results from continued exposure to a particular range of temperatures. These include changes to heart rate, stroke volume, plasma volume, sweat rate and alterations in core body temperature allowing the body to better cope with climatic conditions (WHO and WMO 2015). Acclimatisation can also be brought about through behavioural adjustment. Housing, physical activity, outdoor exposure and clothing can differ between communities due to historical climatic conditions of the region as well as time of the year and culture (Sheridan and Allen 2015). Due to the physiological and behavioural aspects of coping with such conditions, certain populations are particularly vulnerable to sudden, sustained changes in temperature. These include the elderly, children, homeless and the socially isolated (O'Neill and Ebi 2009; WHO and WMO 2015).

The literature regarding health service utilisation from extreme climate events, which is predominantly from heat waves, has focused on urban areas. Large densely populated cities provide populations for whom the impact can be more easily assessed. The impact on rural and regional areas is, however, largely undescribed. Within New South Wales (NSW), a state of Australia, rural and remote rural areas have higher rates of disadvantage and less access to services including health (Alston 2002) than urban areas, potentially contributing to their vulnerability to extreme climatic conditions.

The Australian Bureau of Meteorology (ABM) has recently introduced a map-based heat wave forecasting service using the excess heat factor (EHF) formula (Nairn and Fawcett 2015). The statistical characteristics of the cumulative distribution of the EHF are used at each point on the map to create a heat wave severity forecast map across Australia for the general public. An analogous metric, the excess cold factor (ECF), has also been tested for cold waves but has not been released as a public forecast yet. These formulas quantify the intensity of heat waves and cold waves by factoring long-term and short-term temperature anomalies. The mean daily temperature for a 3-day period is contrasted with both the local climatology and a prior 30-day acclimatisation period. The EHF and ECF can be used to measure the intensity of a heat wave or cold wave at any geographical location by reference to the local climatological threshold, rather than a predetermined domain-wide numeric value, to determine the intensity (Nairn and Fawcett 2013). The EHF and ECF, by contrasting the current period with a prior 30-day period, also consider acclimatisation. This 30-day period is an approximation for the 2- to 6-week thermal adjustment of endocrine, renal and cardiovascular systems to changes in heat exposure (Nairn and Fawcett 2013). The comparison to this period of acclimatisation also helps to account for potential effect modification of events which occur earlier in the season (Anderson and Bell 2011). EHF is being recognised increasingly internationally, having been included as a recommended measure in the latest heat wave guidance document from the World Health Organization (WHO) and World Meteorological Organization (WMO) (Scalley et al. 2015; WHO and WMO 2015).

This study aims to investigate the effect of heat waves and cold waves on health service utilisation—including ambulance call-outs, emergency department presentations and mortality—across all regions of NSW which include varying climatology in both urban and rural areas.

Methods

Study setting

NSW is the most populous state in Australia with 7.4 million residents (2013) and has more than twice the landmass of Germany. The Australian Bureau of Statistics (ABS) publishes a Remoteness Structure which defines the relative remoteness of regions within the state. Regions are defined as major city, inner regional, outer regional, remote and very remote (ABS 2013). We combined the latter three more sparsely populated groups into one for the purpose of our study to increase statistical power due to the low counts of health outcomes in these areas. The state has also historically been divided, for statistical and administrative purposes, into 198 statistical local areas (SLAs) which were used as the geographic unit for analysis in this study (ABS 2011). Figure 1 (right) displays the SLAs of NSW by remoteness. Remoteness was assigned to SLAs from smaller spatial units based on the level of remoteness in which the majority of the population resided. This was to minimise misclassification of residents in larger areas which covered multiple remoteness levels. This meant that the Far West SLA was considered remote, although

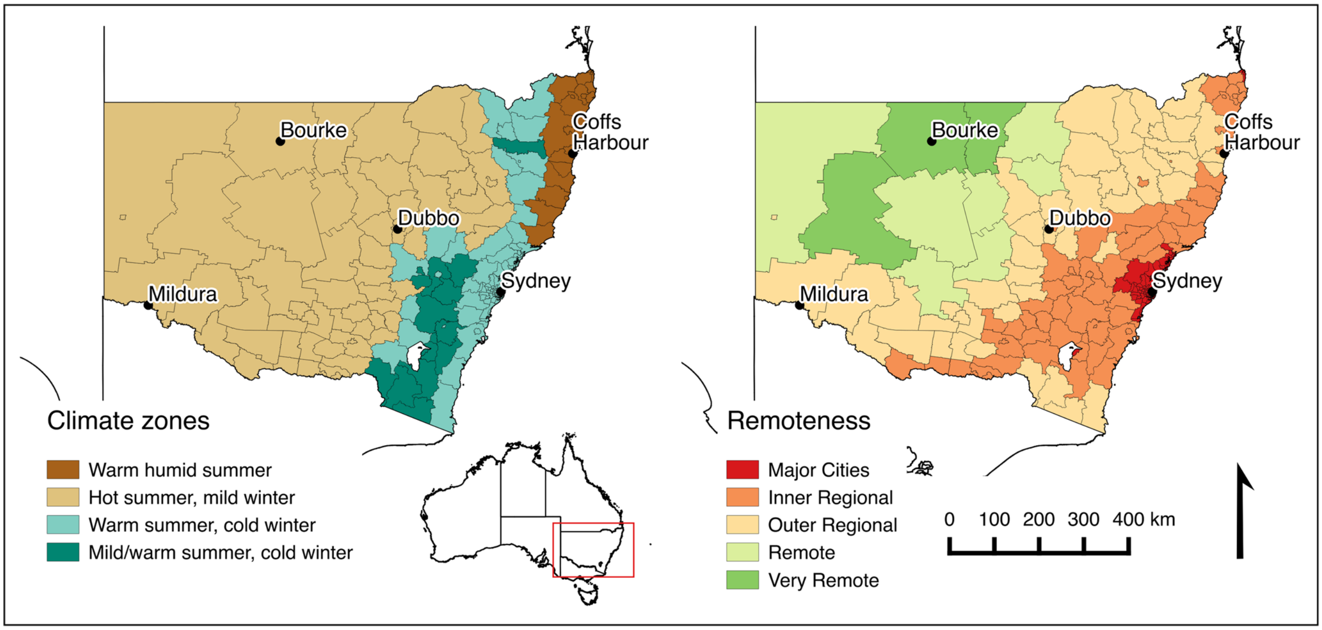

Fig. 1 Maps of the Australian Bureau of Meteorology's temperature and humidity climate zones (*left*) (ABM 2012) and remoteness structure (*right*) (ABS 2011) by statistical local area (SLA) in New South Wales, Australia. Each SLA was assigned the classifications from smaller spatial units by residential population

the majority of the area was considered very remote, due to the distribution of the population. All statistical analyses were performed using R (R Core Team, 2016) and plots were produced with package ggplot2 (Wickham, 2009).

Meteorological data—excess heat factor and excess cold factor

Meteorological data were sourced from the ABM for population representative points within each SLA. The sub-area (census collection district) with the greatest population density within each SLA was selected as the representative point to provide the best estimate of exposure for the population. In non-urban areas, this was usually the largest town in the SLA. Daily mean (average of maximum and minimum) temperatures were acquired for the 10-year study period, from 1 April 2005 to 31 March 2015, using the ABM's low-resolution (0.25° × 0.25°, approximately 25 × 20 km) operational daily temperature analyses (Jones et al. 2009).

The EHF and ECF data were derived from the meteorological data as described in detail elsewhere (Nairn and Fawcett 2013). EHF and ECF both comprise two components. The first compares the mean daily temperature for a 3-day period with the 95th percentile of daily temperatures for that location from the reference period of 1971 to 2000 to assess extremity. The second component compares the mean daily temperature for the same 3-day period with the preceding 30-day period to account for acclimatisation (Nairn and Fawcett 2013).

The severity levels of events are derived from the ratio of EHF (ECF) to the historical 85th (15th) percentiles of values of all positive EHF (all negative ECF) at each specific location. A low-intensity event occurs with a value of this ratio between zero and one. An intense event occurs for values from one to less than three. The criterion for a very intense heat wave event is for values three times the intense threshold and greater. These levels equate to those published on the ABM's heat wave service described as "low intensity", "severe" and "extreme". For this study period, there were few events with an ECF greater than three times the intense threshold, so a lower criterion of two times the intense threshold was used to define a very intense cold wave.

Health data

Health service demand was determined based on the number of ambulance call-outs, emergency department (ED) presentations and mortality. For mortality, daily counts were aggregated by the SLA of residence of the patient. ED presentations were also aggregated by the SLA of residence of the patient. Records for which the SLA of residence was not known were assigned to the SLA of the hospital. For ambulance call-outs, the analysis used the SLA from the geocoded location of the call-out. For each of the outcomes, total daily counts were summed irrespective of the nature or cause of the call-out, presentation or death. As such, we refer to these outcomes as "all cause".

Ambulance call-outs were obtained from NSW Ambulance: ED presentations and mortality were acquired from the NSW Ministry of Health through the Admitted Patient, Emergency Department Attendance and Deaths Register (APEDDR). All ambulance call-outs during the period were required to be reported through the NSW Ambulance data centre. ED presentations increased in completeness throughout the study period as more remote hospitals came "online". There are currently 157 hospitals out of 188 reporting through the ED database. The proportion of ED presentations in NSW included in the dataset increased from 80% in 2005 to over 95% in 2015. Mortality data are considered final and complete up to 2013, and preliminary records were acquired for 2014 to 2015. Preliminary records indicate that the records may not be finalised; however, these are considered complete for deaths occurring in NSW.

Estimated resident population data were acquired from the NSW Ministry of Health for each 6-month period from 2005 to 2015.

Area-level characteristics

Rates of health care utilisation differ between SLAs due to variation in demographic and geographic factors such as age distribution, socioeconomic status and access to care. Covariates are included in the models to account for such differences.

The Index of Relative Socio-economic Disadvantage (IRSD) is an area-based ranking assigned by the ABS, ranging from most disadvantaged to least disadvantaged. The index takes into account census data on household income, housing, education, employment and other variables considered relevant to social disadvantage (ABS 2013). The SLAs in the study area were divided into quintiles based on their IRSD score.

In terms of average temperature and humidity, New South Wales encompasses four climatic zones (Fig. 1, left), classified by the ABM, ranging from "hot dry summer, cold winter" across most of the west of the state to "mild/warm summer, cold winter" in parts of the southeast (Australian Bureau of Meteorology (BoM) 2012). As with remoteness, climate zones were assigned to SLAs from a smaller spatial unit (high-resolution grid) based on the climate zone in which the majority of the population of that SLA resided.

To adjust for the effect of age distribution on health care utilisation between areas, age-stratified, estimated resident population was used to calculate the percentage of each SLA which was below 15 and over 65 years of age for each 6-month period.

Statistical analysis

To estimate the effect of heat waves and cold waves of varying severity on rates of health care utilisation at state and regional level, we fitted 24 over-dispersed or zero-inflated Poisson regression models with using different distribution and covariates depending on the exposures and outcomes being measured. These models were chosen as mortality, and health data tend to be "over-dispersed", which means that the variance exceeds the mean and, as such, does not meet the criteria for a Poisson distribution. There was one model for each combination of region (major city, inner regional, outer regional remote, all NSW), outcome (ambulance, ED, death) and exposure (heat wave and cold wave). Each model included ten 6-month periods. For heat waves, the warmer months of October to March were used and the cooler months of April to September were included when modelling cold waves. This is so that the health outcomes following heat waves (cold waves) are compared with non-heat wave (non-cold wave) days in the same climatic period. By the EHF and ECF definitions, in the study period, no heat waves occurred in the cooler months and no cold waves occurred in the warmer months. The covariates were included to adjust the model for temporal patterns as well as SLA-level characteristics which may confound the effect of heat waves and cold waves. The health effects of heat wave and cold wave may occur on the days following exposure (Barnett et al. 2012). To account for these delayed effects, we used a sum of the total outcome count for 7 days, inclusive, following the event as the dependent variable. This also smoothed weekly patterns in ED presentations and ambulance call-outs (Scalley et al. 2015). Population was included as an offset to control for differences in populations between SLAs as well as over time.

The basic model can be represented by the equation:

$$\log[E(Y_{at})] = \beta_0 + ns(\mathrm{time}_t) + \beta_s sev_{at} + COV_{at} + \log(pop_{at}).$$

Here, $E(Y_{at})$ is the expected number of the health outcome for the 7 days inclusive following day t in SLA a. $ns(\mathrm{time}_t)$ is a natural spline function of time in days with three degrees of freedom per 6-month period. This is a series of cubic functions which follows the seasonal patterns of the outcomes as demonstrated in Fig. 2. By controlling for these long-term trends, they are separated out so that we can explore the relationship between extreme events and the short-term variation in the outcomes of interest (Bhaskaran et al. 2013). sev is the categorical variable for heat wave and cold wave severity with non-wave days as the reference category. β_s represents regression coefficients for each of the levels of event severity. The time-specific and SLA-specific variables are shown as COV_{at}, and $\log(pop)$ is the offset of population. Public holiday was a time-specific variable included for ED presentations and ambulance call-outs to account for additional spikes in counts which coincide with such days. The other covariates, percentage of children and elderly, remoteness, IRSD and climate zone were included to account for geographic and demographic differences between SLAs which may contribute to rates of incidence for each of the outcomes.

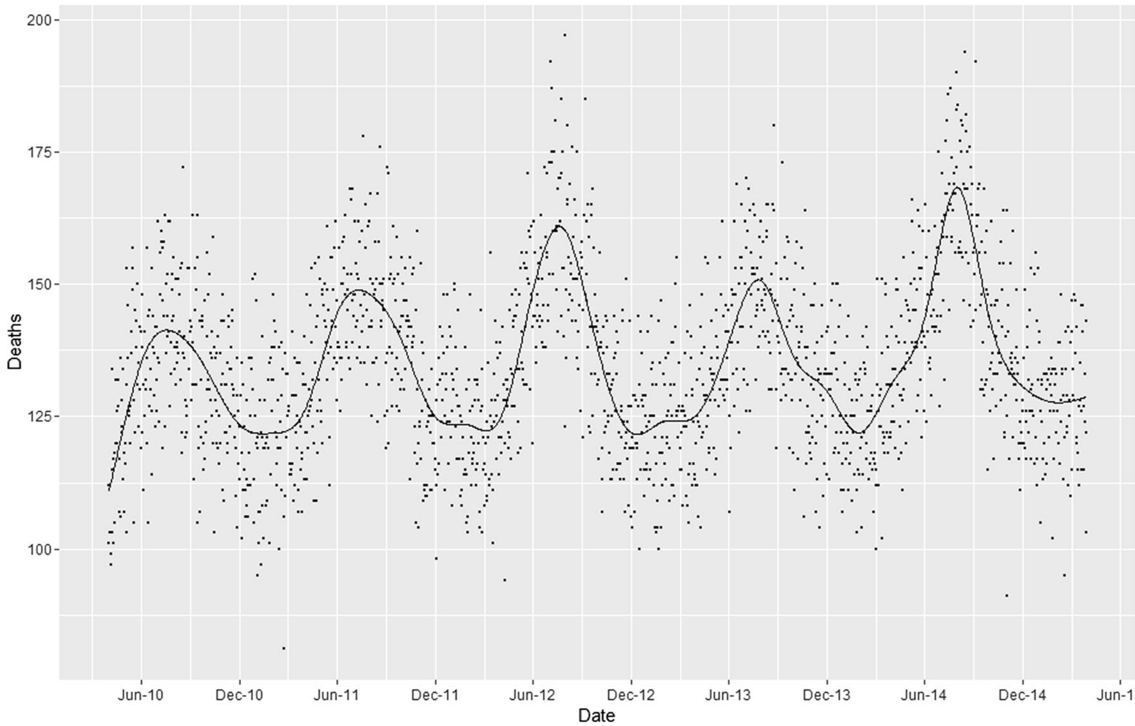

Fig. 2 An example of the natural spline function included in the regression models to account for seasonal variation in health outcomes. The *points* are total deaths per day in NSW, and the *line* is a natural spline function with 30 degrees of freedom (six per year) from April 2010 to March 2015

Results

Exposure

Summary statistics on the number of heat waves and cold wave days experienced in SLAs, by level of remoteness, are shown for the period of April 2005 to March 2015 in Table 1. Most SLAs experienced at least 20 low-intensity heat wave days per year on average. Intense heat wave days were less common, occurring on less than 5 days per year on average, and very intense days occurred every few years across the state. There were 60 SLAs which did not experience any very intense heat wave days during the study period. The median number of low-intensity and intense heat wave days experienced by SLAs increased with the level of remoteness (Fig. 3). Cold wave days followed the same trend as heat wave days; however, there were fewer low-intensity and intense cold wave days than heat wave days across the areas.

Health outcomes

There were a total of 7,118,805 ambulance call-outs; 20,708,866 ED presentations and 473,745 deaths included in the study. Of these, 69.6% of the ambulance call-outs, 65.7% of the ED presentations and 67.6% of the deaths occurred in the major cities. Table 2 presents the summary statistics of daily counts of each of the health outcomes by remoteness area in NSW.

Heat waves and health care utilisation

Each level of heat wave was shown to have an increased rate of ambulance call-outs, on the 7 days following the first day of the heat wave, for all of NSW as well as by level of remoteness (Fig. 4). There was also evidence of a dose-response relationship by severity of heat wave and ambulance call-outs for each level of remoteness. For all of NSW, the incidence rate ratio (IRR) for ambulance call-outs was 1.018 (95% CI 1.015, 1.022) which equates to a 1.8% (95% CI 1.5, 2.2%) increase on the week following a low-intensity heat wave day when compared with a non-heat wave day (Table 3). There was a 4.7% (95% CI 3.9, 5.6%) increase for intense heat wave days and a 10.9% (95% CI 7.7, 14.2%) increase after very intense heat wave days (Table 3). The effects for each level of heat wave in each of the regions were found to be statistically significant.

ED presentations increased significantly after intense heat waves in all levels of remoteness (Fig. 4). Low-intensity heat waves resulted in increased ED presentations in major cities, inner regional and all of NSW; however, no effect was observed in ED presentations in outer regional to remote areas. Very intense events only had a significant effect in inner regional areas. In this region, there was an increasing significant effect with each level of heat wave (Fig. 4). In all of NSW, there was a 0.9% (95% CI 0.4, 1.4%) increase in ED presentations following low-intensity events, a 3.4% (95% CI 2.4, 4.8%) increase for intense events and a 3.8% (95% CI −0.8, 8.6%) increase for very

Table 1 Number of heat wave and cold wave days by severity and level of remoteness experienced in statistical local areas in NSW, from April 2005 to March 2015

	Heat wave days			Cold wave days		
	Median (interquartile range)			Median (interquartile range)		
	Low intensity	Intense	Very intense	Low intensity	Intense	Very intense
Major cities	199 (195–204.25)	38 (35–46)	5 (3–5)	101 (95–106)	11 (9–12)	4 (4–4)
Inner regional	210 (200.5–228.75)	55.5 (47–63.75)	0 (0–3)	129.5 (106.75–146.75)	19 (14–24)	3 (0–7)
Outer regional, remote and very Remote	240.5 (223–256.75)	59.5 (52.75–70)	3 (0–4)	149 (130.5–162.25)	22 (17–26.25)	4 (3–8)
NSW	207 (197–235)	49 (38–62)	3 (0–5)	116 (101–146)	15 (11–23)	4 (3–7)

intense events (Table 3). In the outer regional and remote area, no effect was seen after low-intensity events; however, significant increases in ED presentations occurred following intense and very intense events.

We found a statistically significant adverse effect of intense (2.4% increase, 95% CI 0.8, 4.1%) and very intense (10.8% increase, 95% CI 4.5, 17.4%) heat waves on rates of mortality for all of NSW (Table 3). The effect was similar for major cities, although no statistically significant adverse effect was found in inner regional and outer regional and remote areas. Low-intensity heat waves only had a statistically significant effect on inner regional areas with a 1.5% (95% CI 0.2, 2.7%) decrease (Table 3).

Cold waves and health care utilisation

The analysis of the effect of cold waves on ambulance call-outs in each of the regions gave consistent, statistically insignificant results (Fig. 4) apart from an apparent protective effect of intense cold waves in major cities with an IRR of 0.976 (95% CI 0.956, 0.997, Table 3). For ED presentations, however, in outer regional and remote areas, there was a

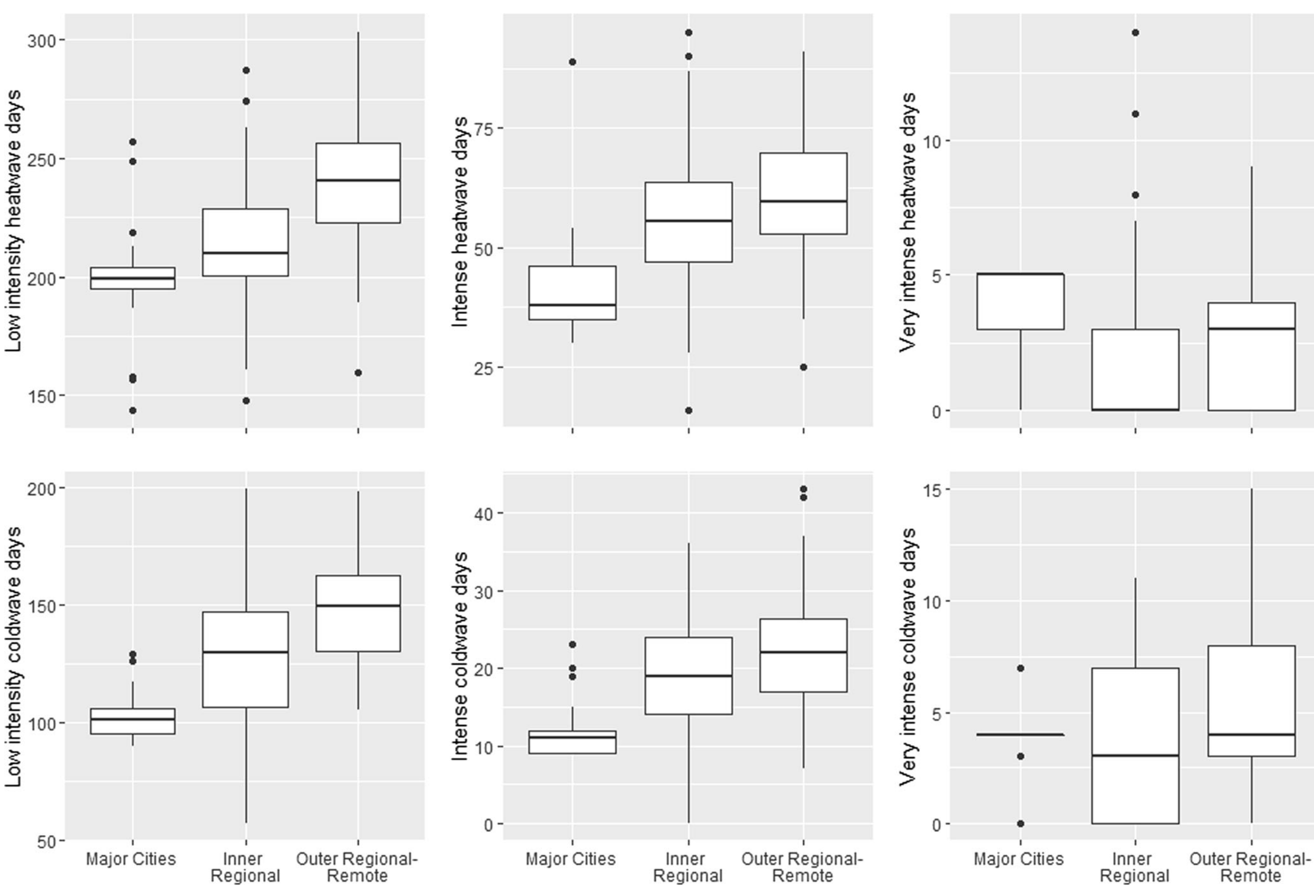

Fig. 3 Box plots of heat wave and cold wave days by severity experienced in statistical local areas from April 2005 to March 2015, by region of NSW

Table 2 Daily mean count of health outcome by level of remoteness in NSW, from April 2005 to March 2015

Region	Ambulance call-outs Mean (SD)	ED presentations	Deaths
Major cities	1303.7 (137.5)	3609.2 (451.6)	87.7 (14.1)
Inner regional	439.9 (51.4)	1503.9 (281.7)	32.5 (6.8)
Outer regional, remote and very remote	129.1 (17.5)	378.3 (105.0)	9.5 (3.3)
All NSW	1872.8 (191.1)	5491.4 (819.8)	129.7 (18.7)

significant increase in rate following cold wave events of each level of severity. This ranged from 5.2% (95% CI 4.2, 5.2%) for low-intensity events to 9.3% (95% CI 8.0, 10.6%) for intense cold waves and an 8.2% (95% CI 5.0, 11.6%) following very intense events. Inner regional areas experienced a small increase in presentations following each level of cold wave. For all of NSW and major cities, significant effects in ED presentations were found in low-intensity and intense events, however, not in very intense events. Across NSW, there was a 1.5% (95% CI 0.6, 2.4%) increase in mortality following low-intensity events and 2.5% (95% CI 0.0, 5.1%) for intense heat waves. In outer regional and remote areas, an increase in the rate of mortality of 3.2% (95% CI 0.6, 5.9%) was found following low-intensity cold waves and 8.8% (95% CI, 2.1, 15.9%) after very intense events.

Discussion

The study aimed to assess the effect of heat waves and cold waves on health service utilisation across urban and rural areas of New South Wales. We found, for heat waves and cold waves, that the magnitude of effects on ambulance call-outs was consistent across areas of different levels of remoteness while ED presentations and mortality effects differed between regions. This may

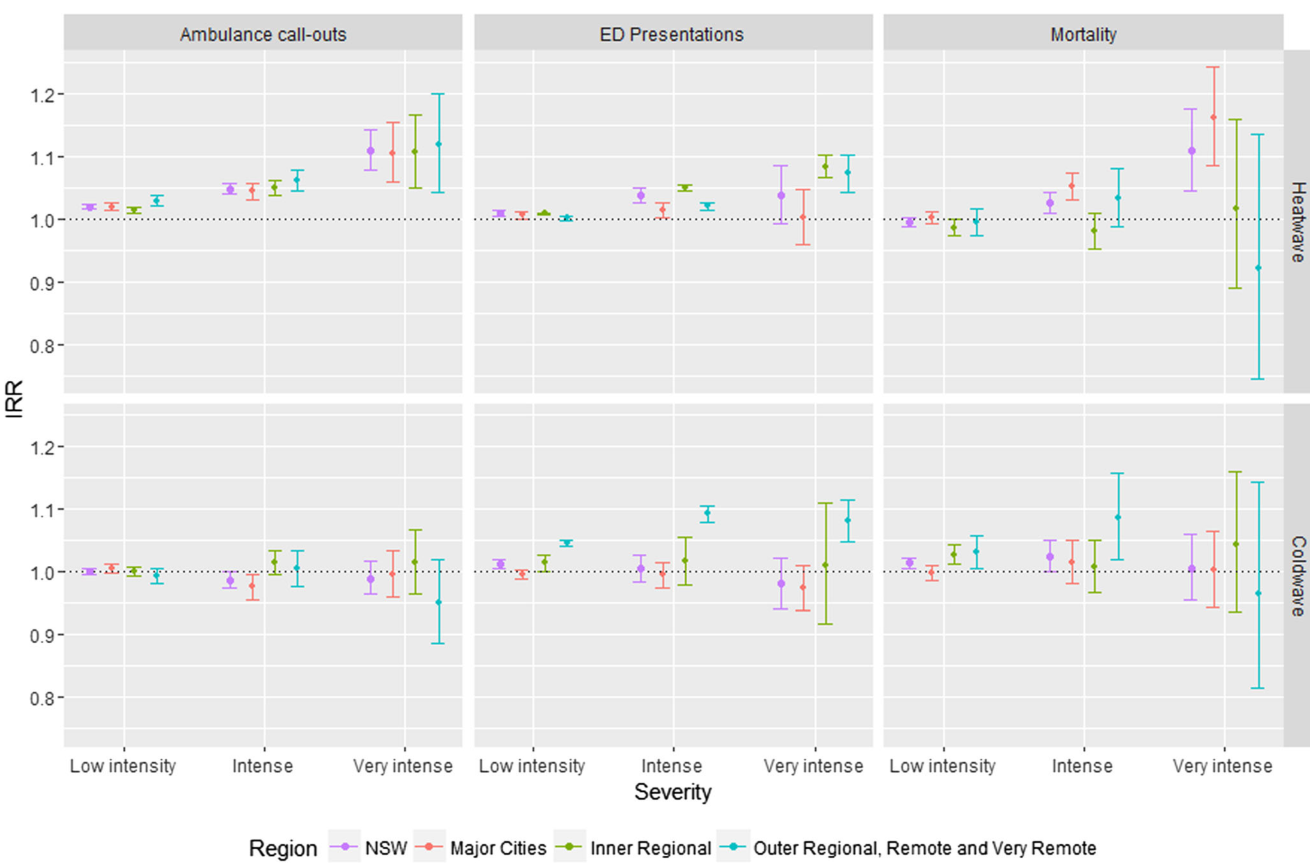

Fig. 4 Incidence rate ratios (IRR) and 95% confidence intervals of each level of heat waves and cold wave by health outcome and region in New South Wales (NSW), 2000–2015

Table 3 Incidence rate ratios of health outcomes by heat wave and cold wave severity and level of remoteness in New South Wales (NSW), from April 2005 to March 2015

Exposure	Outcome	Region	Incidence rate ratio (95% CI) Low intensity	Intense	Very intense
Heat wave	Ambulance call-outs	Major cities	*1.019 (1.013–1.024)*	*1.044 (1.031–1.057)*	*1.105 (1.058–1.154)*
		Inner regional	*1.013 (1.008–1.019)*	*1.049 (1.037–1.061)*	*1.107 (1.050–1.167)*
		Outer regional, remote and very remote	*1.028 (1.020–1.036)*	*1.061 (1.043–1.079)*	*1.118 (1.043–1.199)*
		NSW	*1.018 (1.015–1.022)*	*1.047 (1.039–1.056)*	*1.109 (1.077–1.142)*
	ED presentations	Major cities	*1.005 (1.000–1.010)*	*1.013 (1.001–1.025)*	1.001 (0.959–1.046)
		Inner regional	*1.007 (1.006–1.009)*	*1.049 (1.046–1.053)*	*1.083 (1.065–1.102)*
		Outer regional, remote and very remote	1.001 (0.998–1.005)	*1.019 (1.013–1.026)*	*1.072 (1.042–1.102)*
		NSW	*1.009 (1.004–1.014)*	*1.036 (1.024–1.048)*	1.038 (0.992–1.086)
	Mortality	Major cities	1.001 (0.992–1.010)	*1.051 (1.030–1.073)*	*1.161 (1.084–1.242)*
		Inner regional	*0.985 (0.973–0.998)*	0.980 (0.953–1.008)	1.015 (0.890–1.158)
		Outer regional, remote and very remote	0.995 (0.973–1.017)	1.033 (0.987–1.081)	0.920 (0.746–1.136)
		NSW	0.994 (0.987–1.001)	*1.024 (1.008–1.041)*	*1.108 (1.045–1.174)*
Cold wave	Ambulance call-outs	Major cities	1.005 (0.998–1.012)	*0.976 (0.956–0.997)*	0.997 (0.961–1.035)
		Inner regional	1.000 (0.993–1.007)	1.015 (0.996–1.035)	1.016 (0.967–1.069)
		Outer regional, remote and very remote	0.994 (0.983–1.005)	1.006 (0.978–1.035)	0.951 (0.886–1.021)
		NSW	1.001 (0.996–1.006)	0.987 (0.975–1.000)	0.990 (0.964–1.017)
	ED presentations	Major cities	0.996 (0.989–1.003)	0.995 (0.975–1.016)	0.974 (0.939–1.010)
		Inner regional	*1.015 (1.001–1.028)*	1.017 (0.980–1.055)	1.010 (0.918–1.110)
		Outer regional, remote and very remote	*1.047 (1.042–1.052)*	*1.093 (1.080–1.106)*	*1.082 (1.050–1.116)*
		NSW	*1.013 (1.005–1.020)*	1.006 (0.985–1.027)	0.981 (0.941–1.024)
	Mortality	Major cities	0.999 (0.987–1.010)	1.016 (0.983–1.050)	1.003 (0.944–1.067)
		Inner regional	*1.028 (1.013–1.044)*	1.009 (0.969–1.051)	1.043 (0.937–1.160)
		Outer regional, remote and very remote	*1.032 (1.006–1.059)*	*1.088 (1.021–1.159)*	0.966 (0.816–1.144)
		NSW	*1.015 (1.006–1.024)*	*1.025 (1.000–1.051)*	1.006 (0.956–1.060)

Italic entries denote statistically significant differences in incidence rates, based on the calculation of a 95% confidence interval

suggest that while there is some consistency with regard to the acute effects of these events, requirements for health service preparation for heat waves and cold waves may differ between urban and rural areas.

Heat waves

The effect estimates for very intense heat waves on health service utilisation in major cities are consistent with findings from other studies conducted in Sydney as well as nationally (Scalley et al. 2015; Schaffer et al. 2012; Wilson et al. 2013). The rarity of very intense events and smaller population and number of outer regional and remote areas meant that the effects in these areas were less likely to yield a significant result in the analysis. That is, the lack of statistical significance might more reflect the small sample size than the absence of an effect. These SLAs are also larger by area, which may lead to potential misclassification of temperature exposure which would also bias to the null in terms of day-to-day changes.

Ambulance call-outs

Following heat wave events, there was a clear gradient in the effect of increasing intensity and ambulance call-outs in each of the three regions (Fig. 4). For each level of intensity, the incidence rate ratio was similar across the regions although the effect of low intensity events was slightly higher in the outer regional and remote region compared with the others. Even with low-intensity heat wave events, there is a small but notable increase in call-outs for each region. Considering the high frequency of these events (>20 days per year) and an increase of 1–2% could present a substantial burden: particularly in smaller centres with limited ambulance services covering a greater area. We found a stepwise increase in ambulance call-outs with increasing severity. Each ambulance call-out was matched to global positioning system (GPS) coordinates to provide a precise location of the patient at the time of the call. This may explain why ambulance counts tend to be more acute and the exposures relate more precisely than the outcomes such as ED presentations and mortality across all regions as seen in this and other studies (Schaffer et al. 2012; Sun et al. 2014) and may attest to the sensitivity of the EHF method in detecting acute health effects of heat waves consistently across different levels of remoteness.

ED presentations

In contrast to ambulance call-outs, the impact on ED presentations was not consistent across the regions. Increasing magnitude of adverse effects, from moderate to large, was seen in inner regional and outer regional remote areas for intense and very intense events while there was little evidence of any effect in major cities at any level. There are a number of potential reasons for this including age distribution, types of exposure, prevalent illness and patterns of health service utilisation. In the major city areas, it may be possible that patients with acute health effects would attend a primary health care centre where in regional and remote areas, these services may not be as readily available or may not be open after hours (Callen et al. 2008). Rural areas area likely to have a greater proportion of the workforce employed in agricultural, mining and manufacturing industries which could lead workers to longer periods of heat exposure (Davies et al. 2009).

Mortality

In major cities, we found that intense heat waves resulted in a large increase in the risk of mortality with an even greater effect following very intense heat waves. Given the frequency of intense events and the magnitude of the effect of very intense heat waves, there is substantial risk in these areas from very intense heat events. In inner regional and outer regional remote areas, the effect was either not pronounced or indicated a protective effect; however, none of the estimates for intense and very intense events in these areas was statistically significant. This could be a result of uncertainty produced by the infrequency of these events and the small populations and mortality rates in addition to less precise exposure estimates. This is not necessarily evidence of no adverse effect in these areas. However, if indeed there is a larger effect of intense and very intense heat waves on mortality in major cities than regional and remote areas, this may be caused by the urban heat island (UHI) effect. This is where materials used in the construction of the dense built environment of cities absorb heat energy and maintain high temperatures throughout the night, prolonging exposure to heat (Loughnan et al. 2014). Large effects in the major cities and the whole state following very intense events reinforce the importance of a public health response to heat wave warnings of this magnitude to mitigate significant loss of life.

The small and statistically non-significant (in major cities) and seemingly protective effect (in NSW, inner regional and outer regional remote) of low-intensity heat waves on rates of mortality suggests that the optimal point in the U-shaped relationship between temperature and adverse health outcomes may differ between morbidity and mortality (Ye et al. 2012).

Cold waves

Our analyses found a consistent null or slightly protective effect of cold waves on ambulance call-outs across all regions of NSW. The effect was similarly small and insignificant among ED presentations and mortality in major cities and inner regional areas with the exception of a small effect of low intensity events in inner regional. We did not find an effect of cold waves on mortality in the major city areas; however, ECF was associated with large mortality effects for low-intensity and intense events in outer regional and remote areas and smaller effects in inner regional areas following low-intensity cold waves. This suggests that the extended exposure to extreme cold does not have a significant additional impact in major cities or inner regional areas when compared to the generally cooler weather of this period and that no particular preparation would be required for such events. The substantial effect found in outer regional and remote areas is potentially of concern. The lack of an increase in ambulance call-outs indicates that there is no acute effect following cold waves; however, the increase in mortality and ED presentations may represent a large impact of the cumulative exposure to cold temperatures. The relatively high ED presentation rate may also be a symptom of the distance to other primary care facilities or their hours of operation as previously mentioned. These findings suggest that cold wave warnings may be useful in remote areas to prepare for additional service demand pressures, especially in smaller centres.

Strengths and limitations

This is the first study to estimate the human health effects of heat waves and cold waves at this level of geography and for this period of time. By studying a 10-year period and an entire state, we were able to analyse the effect of rare heat waves and cold wave events across different regions of NSW with greater power rather than focusing on densely populated metropolitan areas alone. It is also the first study in NSW to utilise the Australian Bureau of Meteorology's updated formula for excess heat factor (EHF) to define levels of heat wave severity. This study will inform the response to this recently developed routine forecast measure within Australia.

The study did face some limitations which should be considered. The emergency department data obtained from the Ministry of Health's Rapid Surveillance Department had issues with completeness, especially in regional and remote areas. Data became available from some regional hospitals at different points in time during the study period. The effect of this limitation was minimised by only including data from hospitals in a 6-month period if that period was complete to eliminate the chance of an artificial spike during a heat wave or cold wave event. We controlled for this effect further by using a natural spline function of time in days in the regression models. Furthermore, the dataset includes the vast majority of ED presentations and includes ED presentations from all broad regions within the state.

There were potential border issues with areas close to other Australian states, including the Australian Capital Territory (ACT), Queensland, South Australia and Victoria. For these SLAs, the closest or most appropriate hospital may have been across the border—the data for which were not accessible. This would have a likely bias toward the null and would represent a small proportion of health outcomes given the small size of these border communities.

With regard to exposure, entire areas were assumed to have the same EHF and ECF as the most populous point. For very large areas, this may have resulted in misclassification for some residents. It was also assumed that for most ED presentations and mortality, exposure was related to their place of residence. This meant that people who were away from their home SLA at the time of presentation or death will have been misclassified. It also means that people who presented to hospital or died during this period in NSW but resided elsewhere were excluded from the study. This made up less than 2% of the ED presentations during this period.

Our study only uses one method to estimate the presence of heat or cold wave conditions. Other methods have been used to signify such events; however, EHF has been shown to predict higher rates of health service utilisation than other methods (Scalley et al. 2015). EHF and ECF provide a useful comparison of events through incorporating the extremity of events as well as acclimatisation. Our study focused on the severity of heat wave events and did not explore the effect of duration nor did we adjust for the effects of temperature (Gasparrini and Armstrong 2011). The study aimed to estimate the overall effects of heat waves and cold waves, when compared with non-heat wave and non-cold wave days, rather than the additional effect of the event over the response to high and low temperatures. Also, by taking the 7-day average of each health outcome, acute increases following events may have been masked.

This analysis has used predefined thresholds of EHF and ECF to designate heat waves and cold waves, respectively. The use of these categories may reduce the statistical power of the analysis when compared with a continuous metric (Greenland 1995). However, EHF is currently only published in this categorical form and, as such, this study aimed to estimate the health effects of these events in this context. Further investigation to validate the thresholds using continuous metrics would be useful for a more in-depth analysis of the relationship between extreme temperature, acclimatisation and health effects.

Policy implications and future research

Heat-health warning systems (HHWSs) have been used in a number of jurisdictions globally to assist decision-makers in responding to heat wave events (WHO and WMO 2015). There is evidence to suggest that appropriate HHWSs can reduce mortality and potentially morbidity following heat wave events (Toloo et al. 2013). Local thresholds of heat wave status are required in the system to provide a trigger for such responses. EHF can be used across geographic areas to report three levels of severity of heat wave. Results of this study contribute to decision making regarding trigger points and enacting response plans.

In this study, we have not explored the effect of heat waves and cold waves on different age groups or different causes of illness or death. These have been studied before in the context of Sydney and other capital cities in Australia (Nitschke et al. 2007; Wilson et al. 2013); however, further research is required on the age- and cause-stratified health effects regionally. The effects of cold waves in regional areas which were found to be significant in this study should be investigated in future research to understand the effect of such events on these potentially vulnerable communities. Effects of heat waves on other measures of vulnerability including area-level socioeconomic status should also be explored to improve protection of people who are particularly susceptible to the effects of extreme climatic events. As the frequency and intensity of extreme heat events is predicted to increase with climate change, further research is also required into adaptation strategies including urban planning and behavioural changes to mitigate potential increases in the burden of disease due to these exposures (Keatinge and Donaldson 2004).

Conclusions

Heat waves have large impacts on health care utilisation across the state of NSW within Australia; however, the effects differed by remoteness and increased with the intensity of the event. The impact on ED presentations was higher in rural and remote areas while an increase in mortality was only found in major cities following intense and very intense events. The effect of cold waves on health outcomes was consistently low in major cities and inner regional areas. However, we found that cold waves had a large impact on ED presentations and mortality in outer regional and remote areas which may indicate that these areas are more susceptible to the effects of sustained, abnormally cold temperatures. This study further suggests the efficacy of EHF in predicting health outcomes across a range of geographic areas and suggests its potential to be used in a heat wave warning system more broadly.

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Compliance with ethical standard

Competing interests The authors declare that they have no competing interests.

Ethical Approval This study did not require ethics committee approval.

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