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Time-Series Analysis of Heat Waves and
Emergency Department Visits in Atlanta, 1993 to 2012

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Biostatistics

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Zhejiang University
2014

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An abstract of
A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University
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Abstract

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Emergency Department Visits in Atlanta, 1993 to 2012

By Tianqi Chen

Heat waves are extreme weather events that have been associated with adverse health outcomes. However, there is limited knowledge of their impact on population morbidity such as emergency department (ED) visits. We investigated associations between heat waves and ED visits for 17 outcomes in Atlanta over a 20-year period, 1993-2012. Associations were estimated using Poisson log-linear models controlling for continuous temperature, dew-point temperature, day-of-week, holidays, and time trends. We defined heat waves as periods of ≥2 consecutive days with temperatures beyond the 98^{th} percentile of the temperature distribution over the period (1945-2012). We considered 6 heat wave definitions using maximum, minimum, and average temperature and apparent temperature. Effect modification by heat wave characteristics was examined. Among all outcome-heat wave combinations, associations were strongest among ED visits for fluid and electrolyte imbalance and heat waves defined by minimum temperature at lag 0 [relative risk (RR): 1.07, 95% confidence interval (CI): 1.03-1.12], ED visits for acute renal failure and heat waves defined by minimum apparent temperature at lag 1 (RR: 1.14, 95% CI: 1.04-1.24), and ED visits for intestinal infection and heat waves defined by minimum temperature at lag 1 (RR: 1.07, 95% CI: 1.00-1.13). No significant associations were found for respiratory outcomes, and associations with cardiovascular outcomes were weak with little consistency across lags and heat wave definitions.

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Contents

1 Introduction

Heat waves are extreme weather events that can exert notable impacts on the economy and public health (Field et al., 2014). Although the definition of a heat wave varies by countries and regions, it is commonly characterized by a period of sustained abnormally hot weather compared to historical observations (Meehl & Tebaldi, 2004). In the US, a heat wave is often identified as a period of two or more exceedingly hot days, but the temperature metric used and the definition of extreme temperature can vary (Anderson et al. 2013; Chen et al. 2015). While the occurrence of heat waves is mostly a natural phenomenon, human activities that contribute to climate change are found to increase the severity of heat waves (Meehl et al. 2007). Additionally, projections from global climate models indicate that the number of severe heat waves is likely to increase in the future due to increased emissions of greenhouse gases and greater urban heat island effects (Coumou, Robinson, & Rahmstorf, 2013; S. Hajat, Vardoulakis, Heaviside, & Eggen, 2014).

Heat waves have been consistently associated with increased risk of mortality based on evidence from historical extreme events (Semenza et al., 1996) and recent epidemiological studies (Anderson and Bell 2011; D'Ippoliti et al. 2010; Hajat et al. 2006; Wang et al. 2015). High ambient temperature can cause heat-related illnesses such as heat exhaustion and heat stroke, or aggravate several common cardiovascular and pulmonary conditions (Borden & Cutter, 2008; Bouchama et al., 2007; Wilker et al., 2012). In the US, extreme heat accounted for about 31% of all the weather-related deaths during 2006 to 2010 (Berko, Ingram, Saha, & Parker, 2014). A large study of 43 cities in the US estimated that the daily mortality rate during heat wave days was 3.7% higher on average than non-heat wave days during 1987-2005; and the increase in the rate of mortality was enhanced when the heat wave was more intense or longer (Anderson and Bell, 2011). With no remediation, a recent study estimates that future heat waves will lead to 7.5-19.0 times more heat-related deaths in the eastern US during 2057-2059 compared with those during 2002-2004 (Wu et al. 2013).

The elderly and children have been identified as two vulnerable populations for heat-related mortality and morbidity (Schifano et al., 2009). The elderly population is at a higher risk due to physiology and behavioral reasons such as existing cardiovascular diseases, impaired kidney function, and living alone with limited social support (Kovats & Kristie, 2006). Individuals who are confined to bed and unable to care for themselves may be at high risk of death during heat waves, possibly due to their limited access to emergency care (Shakoor Hajat et al., 2006; Knowlton et al., 2009). Children are vulnerable as their renal systems are particularly stressed by a series of thermoregulatory adjustments under excessive heat (Xu et al., 2012).

While numerous studies world-wide have examined relationships between heat waves and mortality, fewer studies have examined associations between heat waves and morbidity using indicators such as hospital admissions and emergency department (ED) visits (Li, Gu, Bi, Yang, & Liu, 2015). In the US, national studies on hospital admissions have relied on the Medicare database where the at-risk population is restricted to those aged 65 and above (Bobb, Obermeyer, Wang, & Dominici, 2014; Gronlund, Zanobetti, Schwartz, Wellenius, & O'Neill, 2014). A study of ED visits in North Carolina from 2007 to 2011 found increased visits during heat wave days compared to non-heat wave days, especially among the elderly, adolescents and people who had high occupational exposure to heat (Fuhrmann, Sugg, Konrad, & Waller, 2016). Similar increases in ED visits were found during the 2006 heat wave in Paris (Josseran et al., 2009), and during the 2011 heat wave in Sydney, Australia (Schaffer, Muscatello, Broome, Corbett, & Smith, 2012).

The objective of this study was to estimate associations between heat waves and daily ED visits in Atlanta, Georgia during the period 1993 to 2012. We build off of previous work in Atlanta in which we observed associations between continuous maximum temperature and maximum apparent temperature and ED visits for all internal causes, heat illness, fluid/electrolyte imbalances, renal diseases, asthma/wheeze, diabetes, and intestinal infections (Winquist et al. In Press). For the current study, we were specifically interested in the effect of sustained extreme heat beyond the continuous temperature-response relationships for daily ED visits. We considered 17 outcomes of interest, as well as six heat wave definitions using different temperature metrics. Our 20-year study represents one of the largest of its kind, and fills an important knowledge gap on the impacts of heat waves on population morbidity as measured by ED visits; previous studies on heat waves and ED visits have predominantly focused on single heat wave events (Fuhrmann et al., 2016; Knowlton et al., 2009; Rydman, Rumoro, Silva, Hogan, & Kampe, 1999). Moreover, the southeastern US tends to experience stronger heat waves with higher temperature and humidity than rest of the US (Bonan, 1997). Atlanta has also experienced rates of increase in heat wave frequency and duration that are higher than the national averages during 1961 to 2010 (Habeeb, Vargo, & Stone, 2015). Hence, our findings can play an important role in supporting local emergency preparedness, performing detailed risk assessment, and protecting public health (Ebi & Schmier, 2005; Frumkin, Hess, Luber, Malilay, & McGeehin, 2008).

2 Materials and Methods

2.1 Data Sources

For the period 1993 to 2004, individual records of ED visit were obtained from hospitals within the 20-county Atlanta metropolitan area; for the period 2005 to 2012, ED visit data were obtained from the Georgia Hospital Association. ED records included admission date, and primary and secondary International Classification of Diseases 9th Revision (ICD-9) diagnosis codes. We calculated daily counts of ED visits for 17 adverse health outcomes of interest. The outcomes were defined either by the primary ICD-9 codes only, or by the presence of the selected codes in any of the diagnoses (i.e. primary and secondary). The choice of outcome definition was made to maximize the specificity of the included diagnosis codes to reflect impacts due to heat, as determined by Winquist et al. (In Press). The outcomes were defined as follows: fluid and electrolyte imbalance (FLEL; primary ICD-9 code 276); all renal disease (primary ICD-9 codes 580-593), nephritis and nephrotic syndrome (primary ICD-9 codes 580-589), acute renal failure (ARF; primary ICD-9 code 584); all circulatory system diseases (primary or secondary ICD-9 codes 390-459), hypertension (primary or secondary ICD-9 codes 401-405), ischemic heart disease (primary or secondary ICD-9 codes 410-414), dysrhythmia (primary or secondary ICD-9 code 427), congestive heart failure (primary or secondary ICD-9 codes 428), ischemic stroke (primary or secondary ICD-9 codes 433-437); all respiratory system diseases (primary ICD-9 codes 460-519), pneumonia (primary ICD-9 codes 480-486), chronic obstructive pulmonary disease (primary or secondary ICD-9 codes 491, 492, and 496), asthma/wheeze (primary ICD-9 codes 493 or 7896.09/.07); diabetes (primary ICD-9 codes 249/250), and intestinal infections (ICD-9 codes 001-009). We also considered all internal causes (ICD-9 codes 001-799).

Weather data for Atlanta were obtained from the National Climatic Data Center for the first-order weather station located at the Atlanta Hartsfield International Airport. These data were used to calculate daily metrics (i.e. maximum, minimum, average) of temperature (i.e., MAXT, MINT, AVGT), apparent temperature (MAXAT, MINAT, AVGAT), and dew-point temperature. Apparent temperature is a measure that combines temperature and humidity in the metric (Steadman, 1984). There is no universally recognized definition of heat wave; however, a heat wave event should reflect duration and intensity of extreme heat. We examined 6 heat wave metrics, defined as periods with ≥2 consecutive days with daily maximum, minimum or average temperature or apparent temperature beyond the 98th percentiles. The 98th percentile threshold values were determined based on the distributions of year-round daily maximum, minimum, and average temperature and apparent temperature over the station records from 1945-2012. The use of percentile thresholds have been common in several previous studies (Hajat et al. 2006; Anderson and Bell 2011). We also characterized heat waves according to their duration, timing and intensity. For duration, heat wave days were categorized as being the first, second, third, or later consecutive day within the each heat wave. For timing, each heat wave was categorized as being the first, second, or later heat wave within each year. Finally, the intensity of a heat wave was characterized by the average temperature across days of the heat wave, using the temperature metric that defined the heat wave.

2.2 Statistical Analysis

We assessed the increase in risk of ED visits during heat wave days compared with non-heat wave days, using a Poisson log-linear model, allowing for over-dispersion. We did not restrict the study period to warm seasons. The primary model was specified as:

$$\text{Log}(\mu_t^a) = \beta_0 + \beta_1\left(\text{HW}_t^b\right) + \beta_2\text{Tem}_t^b + \beta_3(\text{Tem}_t^b)^2 + \beta_4(\text{Tem}_t^b)^3 + \beta_5\text{DPT}_t + \beta_6(\text{DPT}_t)^2 + \beta_7(\text{DPT}_t)^3 + \sum_{k=1}^{k=6}\gamma_k DOW_{tk} + \sum_{k=1}^{k=2}\delta_k\text{HOLIDAY}_{tk} + \sum_{k=1}^{k=42}\xi_k\text{HOSPITAL}_{tk} + ns(\text{DATE}, 12*20)$$

where μ_t^a is the expected number of ED visits for health outcome *a* on day *t*; β_1 is the log relative risk for ED visits on heat wave days versus non-heat wave days; HW_t^b is 0 when day *t* is a non-heat wave day or the first day of every heat wave (in order to only capture sustained heat effects), and 1 when day *t* is the second or later days in heat wave under definition *b*; Tem_t^b is the temperature (in Celsius) with the same metric used in heat wave definition *b* on day *t*, modeled with linear, quadratic and cubic terms to account for possible non-linear relationships with ED visits (Winquist et al. In Press).; DPT_t is the maximum dew-point temperature (in Celsius) on day *t* but it is not included in models with heat wave defined using apparent temperature because the dew point temperature was used in calculating apparent temperature; DOW_{tk} is the categorical variable for day *k* of the week on day *t*; HOLIDAY_{tk} includes dichotomous variables that indicate days on which different federal holidays are observed; HOSPITAL_{tk} denotes hospital indicators to account for hospitals' contributions of the total ED visits, coded 1 when hospital *k* contributes ED visits on day *t*; ns(DATE, 12*20) is the natural cubic spline of calendar date with 12 degrees-of-freedom for each year to account for the short-range seasonality and long-time patterns of the ED visits. We also examined heat waves lagged up to 3 days, while controlling for temperature at the same lag. Sensitivity analyses were conducted by replacing Tem_t^b with different temperature metrics while fixing the heat wave definition.

To examine effect modification by heat wave characteristics, the main heat wave indicator (HW_t^b) was replaced by the categorical variables for heat wave duration or timing with non-heat wave days serving as the reference; all other covariates remained the same. We also assessed the effects of heat wave intensity by replacing HW_t^b with the average temperature during the heat wave and non-heat wave days assigned the value zero.

3 Results

Table 1 presents a summary of the heat waves occurring in Atlanta during 1993-2012, according to the 6 different heat wave definitions. Heat waves defined by maximum temperature (>= 2 consecutive days exceeding the 98th percentile threshold of 35.0 C) had the fewest heat waves overall (n=91 events) with average durations of 3.1 days per heat wave. All heat wave definitions had a median duration of 2 days. Heat waves defined by minimum temperature had the most heat waves overall (n=232 events). Table 2 examines the pairwise concordance and discordance between heat wave days defined using different heat wave metrics. Overall, there was only moderate concordance across the different definitions. The concordance percent ranged from 25% for heat waves defined by maximum temperature and minimum apparent temperature, to 65% for heat waves defined by maximum apparent temperature and average temperature.

Table S1 presents descriptive statistics of the ED visits. This study included a total of 23,667,947 ED visits to Atlanta metropolitan area hospitals during 1993-2012, of which 17,379,588 had primary ICD-9 codes indicating internal causes. The overall mean daily count of ED visits for internal causes was 2,379, with the overall mean daily counts of cause-specific ED visits ranging from 6.1 for ARF to 624 for all circulatory diseases. For most outcomes, the mean daily counts during heat waves defined by minimum temperature were the highest, while those during heat waves defined by maximum temperature were the lowest. The mean daily counts during heat waves defined by daily temperature were similar to those defined by apparent temperature using daily maximum, minimum or average.

Figure 1 shows observed associations of heat waves, using the six different heat wave metrics, and FLEL and ARF ED visits, controlling for cubic continuous temperature. We observed significant heat wave associations at lag 0 for FLEL based on average apparent temperature (RR: 1.06, 95% CI: 1.011, 1.12) and minimum temperature (RR: 1.07, 95% CI: 1.03, 1.12). For ARF, we also found positive heat wave associations at lags 0 and 1 using different metrics; e.g., at lag 1 for minimum apparent temperature (RR: 1.14, 95% CI: 1.04, 1.24) and for average apparent temperature (RR: 1.13, 95% CI: 1.04, 1.23). For associations between FLEL and heat waves defined using minimum temperature, there was evidence that the relative risk decreased with increasing lags. In this study, we examined whether heat waves conferred effects in addition to those conferred by continuous temperature found by Winquist et al (In Press). Figure S1 shows the cubic associations between ED visits for FLEL and ARF and different temperature metrics. Overall, we observed a non-linear increase in risk with increasing temperature for all six temperature metrics. In sensitivity analyses, the estimated relative risks for FLEL and ARF were robust to the use of different continuous temperature control.

Relative risk estimates and 95% confidence interval for all ED outcomes by heat wave metrics are given in the Supplementary Materials Table S2. Additional significant associations were detected for heat waves defined using either minimum temperature or minimum apparent temperature. These included associations for outcome groups that contained ED visits for ARF, i.e., all renal diseases (lag 0 RR: 1.04, 95% CI: 1.00-1.08) and nephritis and nephrotic syndrome (lag 1 RR: 1.11, 95% CI: 1.02-1.18); associations of heat waves and ED visits for intestinal infections were also significant (lag 1 RR: 1.07, 95% CI: 1.00-1.13). We found no significant associations between heat waves and ED visits for total and cause-specific respiratory outcomes, and diabetes mellitus. Significant associations with total and cause-specific circulatory system outcomes were weak (RR estimates < 1.03) and inconsistent across lags or heat wave definitions.

Results of the effect modification analyses by the order of days in each heat wave and the sequence of the heat wave within a year for FLEL and ARF ED visit outcomes are given in

Tables S3 to S6 in the Supplementary Materials. We found no consistent evidence of later days within a heat wave being associated with stronger risk compared to earlier days (Tables S2 and S4), nor that heat waves occurring later in a year were associated with lower risk compared to earlier heat waves (Tables S3 and S5), as may be anticipated with short-term population adaptation.

Table 3 presents associations between heat wave intensity (as measured by average temperature during a heat wave) and ED visits for FLEL and ARF across lags, using heat waves defined by minimum temperature or minimum apparent temperature. Estimates for all heat wave metrics are given in Table S7. For FLEL, we found positive significant associations across multiple metrics and lags; again the strongest association occurred during heat waves defined by minimum temperature. For example, a per 1 °C increase in average minimum temperature during a heat wave (defined by minimum temperature) was associated with a RR of 1.0029 (95% CI: 1.0012-1.0045) for FLEL. Similar associations were found for ARF, with the strongest associations again seen for minimum temperature and minimum apparent temperature. These results indicate a potential exposure-response relationship for heat wave intensity.

4 Discussion

In this 20-year time-series analysis of heat wave and daily ED visits in Atlanta, we found the strongest evidence of significant associations for FLEL (lag 0) and renal outcomes, particularly ARF (lags 0 and 1), and intestinal infections among the 17 outcomes examined. When exposed to extreme heat, an individual acquires acute thermoregulatory adjustments to accelerate heat loss in the body (Libert et al., 1988). Acute renal failure can happen when the adjustment produces stress on the renal system. The kidney is mainly responsible for maintaining the balance of body fluid and electrolyte (Karmarkar & MacNab, 2012) and ARF can result in FLEL. Several studies have found significant association between heat wave and ARF for hospitalization (Bobb et al. 2014; Fletcher et al. 2012; Hansen et al. 2008). Among the limited studies that examined cause-specific ED visits, Knowlton et al. (2009) found that ED visits for FLEL and ARF were higher during the 2006 California heat wave compared to reference periods before and after the heat wave (RR of 1.16; 95% CI, 1.15-1.15 for FLEL and RR of 1.15; 95% CI 1.11-1.19 for ARF). During three heat warning events in North Carolina, Fuhrmann et al. (2015) also found significant increases in ED visits for ARF with percent excess visits ranging from 28% to 34%. These previous estimates are similar to those obtained in our 20-year time-series analysis in Atlanta. Finally, regarding associations between heat wave and intestinal infection, sustained heat may enhance environmental bacterial grown conditions. High temperature has been associated with bacillary dysentery cases in China (Zhang, Bi, & Hiller, 2008), and incidence of hospital admissions for infectious gastroenteritis and inflammatory bowel disease (Manser, Paul, Rogler, Held, & Frei, 2013).

Epidemiologic studies have consistently found that cardiovascular, cerebrovascular, and respiratory illnesses account for a large proportion of increased mortality and hospital admissions during heat waves (Fouillet et al., 2006; Kovats & Kristie, 2006; Michelozzi et al., 2009). However heat wave studies assessing ED visits for these diseases have shown contradictory findings. In studies in New York and Taiwan , the number of ED visits for cardiovascular and respiratory illness were significantly higher during heat wave days compared to non-heat wave days, especially among the elderly (Lin et al. 2009; Wang et al. 2012). Some studies did not observe such associations (Hansen et al., 2008; Zacharias, Koppe, & Mücke, 2014), which is similar to the weak and null associations between heat waves and cardiorespiratory ED visits observed in our study. One study in Europe observed that high temperature had a positive impact on respiratory admissions but not for cardiovascular admissions (Michelozzi et al., 2009). Heterogeneity in associations may be due to differences in population composition, geographical location, outcome and heat wave definitions, and population resilience. Our previous study in Atlanta examining associations between continuous daily maximum temperature and ED visits did identify several associations for cardiovascular and respiratory conditions (Winquist et al. In Press). It may be that sustained high heat does not confer additional cardiorespiratory risks in our study region in southeastern US.

We examined six definitions for heat waves using daily maximum, minimum and average of temperature or apparent temperature. We found that associations of heat waves and ED visits can be sensitive to the temperature metric used. For example, the strongest associations of heat waves and FLEL ED visits were observed when minimum temperature was used to define heat waves. One reason for this observation may be because heat waves defined using minimum temperature were more frequently observed in our dataset, leading to increased power compared to other heat wave metrics. It is also possible that these heat waves represented sustained heat stress that was not alleviated during the evening, which may increase the risk of FLEL. Few studies have examined the health effects of daily minimum temperature. A study of mortality and heat stress in Houston, Texas found that daily minimum temperature provided better model fit compared to other temperature metrics (Heaton et al., 2014). Kalkstein and Davis (1989) also found minimum temperature to be associated with mortality in several US cites. Interestingly, we found that heat waves defined using minimum temperature or minimum apparent temperature were more likely to be associated with ED visits with other diagnoses. Since the concordance between heat wave definitions is only moderate, the different heat wave metrics may represent different heat stress characteristics. This warrants further examination for other health outcomes and in additional geographical regions.

We did not evaluate the association between heat waves and heat illness (ICD-9 code 992) due to model convergence issues, although this outcome had very strong association with continuous maximum temperature in previous analyses (Winquist et al. In Press). Heat illness includes outcomes such as heat stroke, heat syncope, heat cramps, and heat exhaustion. In our 20-year study period, there were only a total of 9,155 heat illness ED visits and 23.2% occurred during heat waves defined using minimum temperature. Heat stroke is a life-threatening condition. In the US, it is estimated that heat strokes give rise to about 200 deaths and increased hospitalizations per year (Leon & Helwig, 2010). The admission rate and case-fatality rate have been reported to be substantially higher for heat stroke ED visits than any other ED visit (X. Wu, Brady, Rosenberg, & Li, 2014). Hence, quantifying the added effect of heat waves on heat illness should be considered in future studies with a longer time series or larger study population.

There are several considerations when interpreting the results of this study. The study is restricted to Atlanta metropolitan area, therefore the results may not apply to other areas. For example, the prevalence of air conditioning in Atlanta is higher than some other locations in the

US. The Atlanta metropolitan area has an air conditioning prevalence of 94% according to the 2011 American Housing Survey (Donovan, Jones, Pritzker, & Gallagher, 2013), that likely modifies Atlanta residents personal exposures to ambient heat in a way that dampens the impacts of heat waves on health. We did not identify effect modifications by heat wave timing and duration for FLEL and ARF ED visits. However, in a time-series study of mortality, Anderson and Bell (2011) found increased risk for longer and earlier heat waves, with the strongest effect modifications being in northeastern US. Second, we did not control for air pollution as a confounder as done in some studies (Benmarhnia et al., 2014; Schwartz & Dockery, 1992; Tong, Ren, & Becker, 2010). Ambient air pollution concentrations, such as fine particulate matter and ozone, may be higher during heat waves from increased emission due to higher electricity demands, and from increased formation of secondary pollutants due to favorably meteorological conditions. By not including daily air pollution concentration in the health model, our estimated heat wave associations include the effects that are potentially mediated through increases in air pollution (Buckley, Samet, & Richardson, 2014). Finally, we excluded the first day of the heat wave period from the study in order to capture only the increased risks associated with sustained heat exposure longer than a single day; this approach differs from previous studies, and may impact comparability with other studies.

5 Conclusions

Our results support the hypothesis that heat wave events are associated with increased morbidity as measured by emergency department visits, even in an area with high air conditioning prevalence. Hence prolonged heat exposure may confer adverse health impacts in addition to the risk due to higher daily temperature. We did not identify effect modification by heat wave duration and timing, but heat waves wither higher intensity (average temperature) were associated with higher risks. Associations of heat waves with ED visits can be sensitive to heat wave definitions and we found stronger associations when heat waves are defined using minimum temperature and minimum apparent temperature.

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6 Appendices

Table 1. Descriptive statistics of heat-wave characteristics. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded.

Heat wave Definitions	**98th Percentile[1] Threshold Temperature** (℃)	**Total Number**	**Average Number per Year**	**Average Duration**	**Mean Temperature During Heat Waves** (℃)
MAXT	35.0	91	1.5	3.1	36.6
MINT	23.3	232	3.2	3.6	24.2
AVGT	28.9	123	1.8	3.5	30.2
MAXAT	35.6	109	1.9	3.0	37.2
MINAT	26.1	96	1.8	2.7	27.2
AVGAT	30.6	118	1.8	3.3	31.9

[1] Thresholds are determined by records from 1945 to 2012.

Table 2. The concordance-discordance between heat wave metrics. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded.

Heat Wave Definitions	MAXT	MINT	AVGT	MAXAT	MINAT	AVGAT
MAXT		256	133	122	150	143
MINT	67 (26%)		251	259	232	245
AVGT	81 (61%)	104 (41%)		141	154	147
MAXAT	78 (64%)	82 (32%)	91 (65%)		154	139
MINAT	37 (25%)	96 (41%)	65 (42%)	51 (33%)		139
AVGAT	66 (46%)	105 (43%)	94 (64%)	88 (63%)	75 (54%)	

The upper triangular elements give the number of days where heat wave occurred using either metrics (union days). The lower triangular elements give the number of days where heat waves occurred using both metrics (intersection days). The concordance percentages are calculated by dividing the number of intersection days by the number of union days.

Table 3. Relative risk (RR) estimates and 95% confidence interval (CI) for ED visits due to fluid and electrolyte imbalance (FLEL) and acute renal failure (ARF) associated with per 1°C increase in average temperature during heat waves. Heat waves are defined as periods of ≥ 2 consecutive days with minimum temperature (MINT) or minimum apparent temperature (MINAT) exceeding the 98th percentile. The first day of the heat wave period is excluded and the reference period is any non-heat wave day.

	Lag0 R.R. (95%C.I.)	Lag1 R.R. (95%C.I.)	Lag2 R.R. (95%C.I.)	Lag3 R.R. (95%C.I.)
FLEL				
MINT	1.0029 (1.0012, 1.0045)	1.0040 (1.0024, 1.0056)	1.0050 (1.0035, 1.0066)	1.0053 (1.0037, 1.0069)
MINAT	1.0013 (0.9992, 1.0033)	1.0021 (1.0001, 1.0042)	1.0034 (1.0013, 1.0054)	1.0037 (1.0016, 1.0057)
ARF				
MINT	1.0028 (1.0002, 1.0054)	1.0034 (1.0008, 1.0059)	1.0051 (1.0026, 1.0076)	1.0053 (1.0028, 1.0078)
MINAT	1.0035 (1.0003, 1.0066)	1.0035 (1.0004, 1.0067)	1.0053 (1.0021, 1.0084)	1.0056 (1.0024, 1.0087)

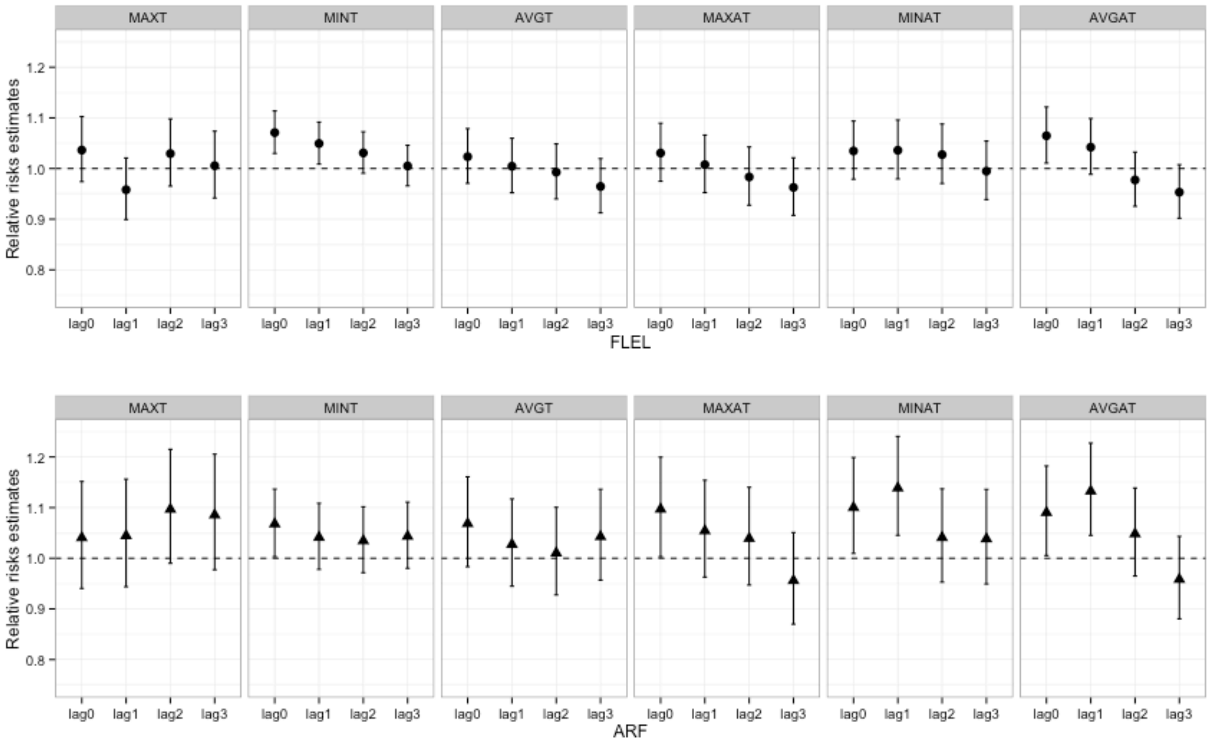

Figure 1. Estimated relative risks and 95% confidence intervals for fluid and electrolyte imbalance (FLEL, upper panel) and acute renal failure (ARF, lower panel) ED visits associated with heat wave days compared to non-heat wave days, with heat waves defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG) temperature. The first day of the heat wave period was excluded from analyses.

7 Supplemental Material

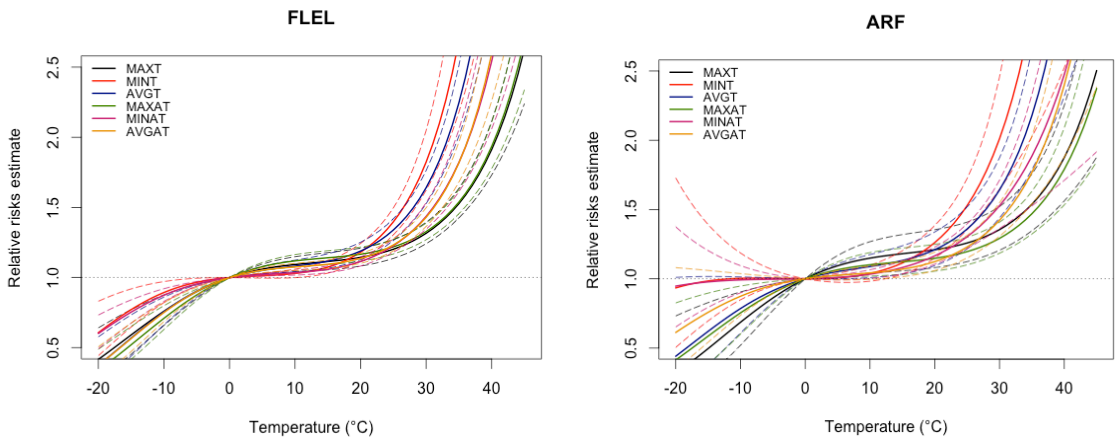

Figure S1: Cubic associations between daily same-day continuous daily temperature metrics (i.e. maximum, minimum, average of temperature [MAXT, MINT, AVGT] and apparent temperature [MAXAT, MINAT, AVGAT]), and emergency department visits for fluid and electrolyte imbalance (FLEL) and acute renal failure (ARF) in Atlanta, 1993-2012. Relative risks are relative to a reference of 0 °C in the temperature metric. 95% confidence intervals are indicated by dashed lines.

Table S1. Descriptive statistics for daily emergency department (ED) visits based on primary ICD-9 codes, Atlanta, 1993-2012. Mean daily visits are calculated across the entire study period and during heat wave days. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded.

Outcome	ICD9 Code(s)	Total ED Visits	Total Mean Daily ED Visits	Mean Daily ED Visits, during heat waves defined by					
				MAXT	MINT	AVGT	MAX AT	MIN AT	AVG AT
All ED visits	All	23,667,947	3240	2570	3249	2827	2664	3193	2969
All internal causes	001-799	17,379,588	2379	1831	2366	2043	1909	2332	2165
Fluid and electrolyte[1] imbalance	276	167,080	23	22	27	24	23	26	25
All renal disease[1]	580-593	309,787	42	43	56	49	46	56	52
Nephritis and nephrotic syndrome[1]	580-589	51,957	7	9	11	10	9	11	11
Acute renal failure[1]	584	44,494	6	8	10	9	8	10	10
All circulatory system disease[2]	390-459	4,558,549	624	533	761	634	573	740	694
Hypertension[2]	401-405	3,583,538	491	431	624	517	464	605	568
Ischemic heart disease[2]	410-414	889,351	122	102	145	123	110	143	134
Dysrhythmia[2]	427	699,405	96	79	115	96	86	113	105
Congestive heart failure[2]	428	569,616	78	62	90	74	67	88	82
Ischemic stroke[2]	433-437	170,796	23	20	27	23	22	27	25
All respiratory system disease[1]	460-519	2,847,921	390	207	253	224	206	253	232
Pneumonia[1]	480-486	302,887	42	20	26	22	20	25	23
Chronic obstructive pulmonary disease[2]	491-492, 496	563,848	77	61	87	73	65	85	79
Asthma/wheeze[1]	493 or 7896.09/.07	500,359	69	43	49	44	41	51	47
Diabetes mellitus[1]	250 or 249	166,220	23	20	27	23	21	28	25
Intestinal infection[1]	001-009	92,890	13	10	12	11	10	11	11

[1]primary ICD-9 codes only; [2]presence of the selected ICD-9 codes in any of the diagnoses (i.e. primary and secondary).

Table S2. Relative risk (RR) estimates and 95% confidence intervals (CI) of associations of heat wave days compared to non-heat wave days for ED visits for all 17 health outcomes. Heat waves were defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period was excluded from analyses.

Outcome	Heat Wave	lag0 R.R. (95% C.I.)	lag1 R.R. (95% C.I.)	lag2 R.R. (95% C.I.)	lag3 R.R. (95% C.I.)
All internal causes	MAXT	1.00 (0.98, 1.01)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	0.99 (0.97, 1.01)
	MINT	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
	AVGT	0.99 (0.98, 1.00)	1.00 (0.98, 1.01)	1.00 (0.98, 1.01)	0.99 (0.98, 1.00)
	MAXAT	0.99 (0.98, 1.01)	0.99 (0.98, 1.01)	0.99 (0.98, 1.01)	0.99 (0.97, 1.00)
	MINAT	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)	1.00 (0.98, 1.01)	0.99 (0.98, 1.01)
	AVGAT	1.00 (0.99, 1.01)	1.00 (0.99, 1.02)	1.00 (0.98, 1.01)	0.99 (0.97, 1.00)
Fluid and electrolyte imbalance	MAXT	1.04 (0.97, 1.10)	0.96 (0.90, 1.02)	1.03 (0.97, 1.10)	1.01 (0.94, 1.07)
	MINT	**1.07 (1.03, 1.11)**	**1.05 (1.01, 1.09)**	1.03 (0.99, 1.07)	1.01 (0.97, 1.05)
	AVGT	1.02 (0.97, 1.08)	1.00 (0.95, 1.06)	0.99 (0.94, 1.05)	0.96 (0.91, 1.02)
	MAXAT	1.03 (0.97, 1.09)	1.01 (0.95, 1.07)	0.98 (0.93, 1.04)	0.96 (0.91, 1.02)
	MINAT	1.03 (0.98, 1.09)	1.04 (0.98, 1.10)	1.03 (0.97, 1.09)	0.99 (0.94, 1.05)
	AVGAT	**1.06 (1.01, 1.12)**	1.04 (0.99, 1.10)	0.98 (0.93, 1.03)	0.95 (0.90, 1.01)
All renal disease	MAXT	1.02 (0.98, 1.07)	0.98 (0.94, 1.02)	1.00 (0.96, 1.05)	1.03 (0.99, 1.07)
	MINT	1.02 (0.99, 1.04)	1.02 (0.99, 1.04)	1.02 (0.99, 1.05)	**1.03 (1.00, 1.05)**
	AVGT	1.03 (0.99, 1.06)	1.01 (0.98, 1.05)	1.00 (0.96, 1.03)	1.02 (0.99, 1.06)
	MAXAT	1.03 (0.99, 1.07)	0.97 (0.93, 1.01)	0.99 (0.95, 1.03)	1.01 (0.97, 1.05)
	MINAT	**1.04 (1.00, 1.08)**	**1.04 (1.00, 1.08)**	1.01 (0.97, 1.05)	**1.03 (1.00, 1.07)**
	AVGAT	**1.03 (1.00, 1.07)**	1.02 (0.99, 1.06)	1.02 (0.99, 1.06)	1.02 (0.99, 1.06)
Nephritis and nephrotic syndrome	MAXT	1.03 (0.94, 1.14)	1.05 (0.96, 1.16)	**1.11 (1.00, 1.22)**	1.08 (0.98, 1.20)
	MINT	1.05 (0.99, 1.12)	1.04 (0.98, 1.10)	1.01 (0.96, 1.08)	1.02 (0.97, 1.09)
	AVGT	1.04 (0.96, 1.12)	1.02 (0.94, 1.10)	1.02 (0.94, 1.11)	1.04 (0.96, 1.13)
	MAXAT	1.06 (0.97, 1.15)	1.03 (0.95, 1.12)	1.05 (0.96, 1.15)	0.97 (0.89, 1.06)
	MINAT	**1.08 (1.00, 1.17)**	**1.11 (1.02, 1.21)**	1.01 (0.93, 1.10)	1.02 (0.94, 1.11)
	AVGAT	1.07 (0.99, 1.15)	1.10 (1.02, 1.18)	1.05 (0.97, 1.13)	0.96 (0.89, 1.04)
Acute renal failure	MAXT	1.04 (0.94, 1.15)	1.04 (0.94, 1.16)	1.10 (0.99, 1.22)	1.09 (0.98, 1.21)
	MINT	**1.07 (1.00, 1.14)**	1.04 (0.98, 1.11)	1.03 (0.97, 1.10)	1.04 (0.98, 1.11)
	AVGT	1.07 (0.98, 1.16)	1.03 (0.94, 1.12)	1.01 (0.93, 1.10)	1.04 (0.96, 1.14)
	MAXAT	**1.10 (1.00, 1.20)**	1.05 (0.96, 1.15)	1.04 (0.95, 1.14)	0.96 (0.87, 1.05)
	MINAT	**1.10 (1.01, 1.20)**	**1.14 (1.05, 1.24)**	1.04 (0.95, 1.14)	1.04 (0.95, 1.14)
	AVGAT	**1.09 (1.01, 1.18)**	**1.13 (1.05, 1.23)**	1.05 (0.96, 1.14)	0.96 (0.88, 1.04)

Table S2-continued

Outcome	Heat Wave	lag0 R.R. (95% C.I.)	lag1 R.R. (95% C.I.)	lag2 R.R. (95% C.I.)	lag3 R.R. (95% C.I.)
All circulatory system disease	MAXT	1.01 (0.99, 1.02)	1.00 (0.99, 1.02)	**1.01 (1.00, 1.03)**	1.00 (0.98, 1.01)
	MINT	1.00 (0.99, 1.01)	**1.01 (1.00, 1.02)**	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
	AVGT	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)	1.01 (0.99, 1.02)	1.00 (0.98, 1.01)
	MAXAT	1.00 (0.98, 1.01)	1.01 (0.99, 1.02)	**1.01 (1.00, 1.02)**	1.00 (0.98, 1.01)
	MINAT	**1.01 (1.00, 1.02)**	1.01 (0.99, 1.02)	1.00 (0.99, 1.02)	1.00 (0.98, 1.01)
	AVGAT	**1.01 (1.00, 1.02)**	**1.02 (1.00, 1.03)**	1.00 (0.99, 1.02)	0.99 (0.98, 1.01)
Hypertension	MAXT	**1.02 (1.00, 1.03)**	1.01 (0.99, 1.02)	**1.01 (1.00, 1.03)**	1.00 (0.98, 1.01)
	MINT	1.00 (0.99, 1.01)	**1.01 (1.00, 1.02)**	1.00 (0.99, 1.01)	1.00 (0.99, 1.01)
	AVGT	1.00 (0.99, 1.02)	1.00 (0.99, 1.01)	1.01 (0.99, 1.02)	1.00 (0.99, 1.01)
	MAXAT	1.00 (0.99, 1.02)	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	0.99 (0.98, 1.01)
	MINAT	1.01 (0.99, 1.02)	1.01 (0.99, 1.02)	1.00 (0.99, 1.02)	1.00 (0.99, 1.02)
	AVGAT	**1.01 (1.00, 1.02)**	**1.01 (1.00, 1.03)**	1.00 (0.99, 1.01)	0.99 (0.98, 1.01)
Ischemic heart disease	MAXT	0.99 (0.97, 1.02)	0.99 (0.96, 1.02)	**1.03 (1.01, 1.06)**	0.98 (0.95, 1.01)
	MINT	**1.01 (0.99, 1.02)**	**1.01 (1.00, 1.03)**	1.00 (0.98, 1.02)	0.99 (0.98, 1.01)
	AVGT	1.00 (0.98, 1.02)	0.99 (0.97, 1.02)	1.01 (0.99, 1.04)	0.99 (0.97, 1.01)
	MAXAT	0.99 (0.97, 1.02)	0.99 (0.97, 1.02)	1.02 (0.99, 1.04)	0.98 (0.95, 1.00)
	MINAT	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	0.99 (0.97, 1.02)	1.00 (0.97, 1.02)
	AVGAT	1.00 (0.98, 1.03)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)	0.98 (0.95, 1.00)
Dysrhythmia	MAXT	0.99 (0.96, 1.03)	1.00 (0.96, 1.03)	1.03 (0.99, 1.06)	1.00 (0.97, 1.03)
	MINT	**1.02 (1.00, 1.03)**	1.01 (0.99, 1.03)	1.00 (0.99, 1.02)	1.00 (0.98, 1.02)
	AVGT	1.00 (0.97, 1.02)	0.99 (0.96, 1.01)	1.01 (0.99, 1.04)	0.99 (0.97, 1.02)
	MAXAT	0.98 (0.95, 1.01)	1.00 (0.97, 1.03)	1.01 (0.99, 1.04)	1.02 (0.99, 1.05)
	MINAT	1.01 (0.99, 1.04)	1.00 (0.97, 1.03)	0.99 (0.96, 1.01)	0.99 (0.96, 1.02)
	AVGAT	1.00 (0.98, 1.03)	**1.02 (1.00, 1.05)**	1.02 (0.99, 1.04)	1.00 (0.98, 1.03)
Congestive heart failure	MAXT	0.98 (0.94, 1.01)	0.98 (0.94, 1.01)	1.02 (0.99, 1.06)	0.95 (0.92, 0.99)
	MINT	0.99 (0.97, 1.01)	1.01 (0.99, 1.03)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)
	AVGT	**0.96 (0.94, 0.99)**	0.99 (0.97, 1.02)	1.02 (0.99, 1.05)	0.99 (0.96, 1.02)
	MAXAT	0.99 (0.95, 1.02)	1.01 (0.97, 1.04)	1.02 (0.99, 1.05)	0.97 (0.94, 1.00)
	MINAT	0.99 (0.96, 1.02)	0.98 (0.95, 1.01)	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)
	AVGAT	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)	1.01 (0.98, 1.04)	0.99 (0.96, 1.02)
Ischemic stroke	MAXT	1.03 (0.97, 1.09)	1.02 (0.96, 1.08)	1.00 (0.94, 1.06)	1.05 (0.99, 1.11)
	MINT	1.00 (0.96, 1.03)	1.00 (0.96, 1.03)	1.00 (0.96, 1.04)	0.99 (0.96, 1.03)
	AVGT	1.00 (0.95, 1.05)	1.03 (0.98, 1.08)	1.02 (0.97, 1.07)	1.02 (0.97, 1.08)
	MAXAT	1.01 (0.96, 1.07)	0.98 (0.93, 1.04)	0.96 (0.91, 1.01)	1.03 (0.98, 1.09)
	MINAT	1.02 (0.97, 1.07)	**1.06 (1.00, 1.11)**	1.00 (0.95, 1.06)	0.99 (0.94, 1.04)
	AVGAT	1.01 (0.96, 1.06)	1.03 (0.98, 1.08)	1.00 (0.95, 1.05)	1.01 (0.96, 1.06)

Table S2-continued

Outcome	Heat Wave	lag0 R.R. (95% C.I.)	lag1 R.R. (95% C.I.)	lag2 R.R. (95% C.I.)	lag3 R.R. (95% C.I.)
All respiratory system disease	MAXT	1.00 (0.96, 1.04)	1.01 (0.97, 1.05)	0.99 (0.95, 1.03)	0.97 (0.94, 1.01)
	MINT	0.99 (0.97, 1.01)	1.00 (0.98, 1.02)	1.00 (0.97, 1.02)	0.98 (0.96, 1.00)
	AVGT	0.98 (0.95, 1.01)	0.99 (0.96, 1.03)	0.98 (0.95, 1.01)	0.97 (0.94, 1.00)
	MAXAT	0.98 (0.95, 1.02)	0.99 (0.96, 1.03)	0.99 (0.96, 1.03)	0.97 (0.94, 1.00)
	MINAT	0.99 (0.96, 1.02)	1.00 (0.97, 1.03)	0.99 (0.95, 1.02)	0.97 (0.94, 1.01)
	AVGAT	0.99 (0.96, 1.02)	1.00 (0.97, 1.03)	1.00 (0.96, 1.03)	0.98 (0.95, 1.01)
Pneumonia	MAXT	0.96 (0.90, 1.02)	0.92 (0.86, 0.99)	0.97 (0.91, 1.04)	0.98 (0.92, 1.05)
	MINT	1.00 (0.96, 1.04)	1.00 (0.96, 1.04)	1.00 (0.96, 1.04)	0.97 (0.93, 1.01)
	AVGT	0.94 (0.89, 1.00)	0.96 (0.91, 1.02)	0.94 (0.89, 1.00)	0.96 (0.90, 1.01)
	MAXAT	0.95 (0.90, 1.01)	0.96 (0.91, 1.02)	0.96 (0.91, 1.02)	0.96 (0.90, 1.02)
	MINAT	0.98 (0.92, 1.03)	1.02 (0.96, 1.08)	1.00 (0.95, 1.07)	0.95 (0.90, 1.01)
	AVGAT	0.97 (0.92, 1.03)	0.99 (0.94, 1.05)	0.99 (0.94, 1.05)	0.96 (0.91, 1.01)
Chronic obstructive pulmonary disease	MAXT	1.00 (0.96, 1.03)	0.99 (0.96, 1.03)	1.02 (0.98, 1.06)	0.99 (0.96, 1.03)
	MINT	1.01 (0.99, 1.03)	1.01 (0.99, 1.03)	1.00 (0.98, 1.02)	1.00 (0.98, 1.02)
	AVGT	1.01 (0.98, 1.04)	0.99 (0.96, 1.02)	1.00 (0.97, 1.03)	0.99 (0.96, 1.02)
	MAXAT	0.99 (0.96, 1.03)	0.99 (0.95, 1.02)	1.02 (0.99, 1.06)	0.98 (0.95, 1.01)
	MINAT	1.01 (0.98, 1.04)	1.00 (0.97, 1.03)	0.98 (0.95, 1.01)	1.00 (0.97, 1.03)
	AVGAT	1.00 (0.97, 1.02)	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)	0.99 (0.96, 1.02)
Asthma /wheeze	MAXT	1.03 (0.98, 1.08)	1.02 (0.97, 1.08)	1.01 (0.96, 1.06)	0.97 (0.92, 1.02)
	MINT	0.99 (0.96, 1.02)	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)	1.01 (0.98, 1.05)
	AVGT	0.95 (0.91, 1.00)	0.98 (0.93, 1.02)	0.98 (0.93, 1.02)	0.98 (0.93, 1.02)
	MAXAT	0.98 (0.93, 1.03)	0.97 (0.93, 1.02)	0.96 (0.91, 1.00)	0.93 (0.89, 0.98)
	MINAT	1.02 (0.97, 1.07)	1.00 (0.95, 1.04)	0.98 (0.93, 1.02)	1.00 (0.95, 1.05)
	AVGAT	1.01 (0.97, 1.06)	1.00 (0.96, 1.05)	0.97 (0.93, 1.02)	0.98 (0.94, 1.02)
Diabetes mellitus	MAXT	0.94 (0.88, 1.00)	1.00 (0.94, 1.06)	1.05 (0.99, 1.11)	0.98 (0.93, 1.05)
	MINT	0.98 (0.95, 1.02)	1.01 (0.97, 1.04)	1.02 (0.98, 1.05)	1.00 (0.97, 1.04)
	AVGT	0.97 (0.92, 1.02)	0.99 (0.94, 1.04)	1.00 (0.96, 1.05)	0.94 (0.89, 0.98)
	MAXAT	0.96 (0.91, 1.01)	1.00 (0.95, 1.05)	0.99 (0.94, 1.05)	0.95 (0.90, 1.00)
	MINAT	1.03 (0.98, 1.08)	1.01 (0.96, 1.06)	1.00 (0.95, 1.06)	0.98 (0.93, 1.04)
	AVGAT	0.98 (0.94, 1.03)	0.98 (0.93, 1.03)	1.02 (0.98, 1.08)	0.96 (0.92, 1.01)
Intestinal infection	MAXT	0.94 (0.85, 1.04)	0.99 (0.90, 1.10)	1.05 (0.95, 1.16)	0.99 (0.90, 1.09)
	MINT	**1.06 (1.00, 1.13)**	**1.07 (1.00, 1.13)**	**1.06 (1.00, 1.13)**	0.99 (0.93, 1.05)
	AVGT	0.98 (0.90, 1.07)	1.06 (0.98, 1.16)	1.05 (0.96, 1.14)	1.02 (0.94, 1.11)
	MAXAT	0.99 (0.90, 1.08)	1.02 (0.93, 1.11)	1.07 (0.98, 1.17)	1.06 (0.97, 1.16)
	MINAT	0.96 (0.88, 1.05)	1.06 (0.97, 1.16)	1.07 (0.98, 1.16)	0.99 (0.90, 1.08)
	AVGAT	1.01 (0.93, 1.10)	1.06 (0.98, 1.15)	1.08 (0.99, 1.17)	1.02 (0.94, 1.11)

Table S3. Relative risk (RR) estimates and 95% confidence interval (CI) for ED visits due to fluid and electrolyte imbalance (FLEL) associated with one day passed in the duration of heat wave. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded.

FLEL	Day	Sample size	Lag0 R.R. (95%C.I.)	Lag1 R.R. (95%C.I.)	Lag2 R.R. (95%C.I.)	Lag3 R.R. (95%C.I.)
MAXT	2	29	1.06 (0.98, 1.15)	0.95 (0.87, 1.04)	1.00 (0.91, 1.08)	1.08 (0.99, 1.17)
MAXT	3	18	0.93 (0.83, 1.05)	1.07 (0.95, 1.19)	**1.18 (1.06, 1.32)**	0.97 (0.87, 1.09)
MAXT	4	10	1.11 (0.96, 1.28)	1.10 (0.95, 1.27)	1.04 (0.90, 1.21)	0.92 (0.79, 1.08)
MAXT	>4	34	1.05 (0.94, 1.17)	1.00 (0.90, 1.12)	0.97 (0.87, 1.09)	0.93 (0.83, 1.04)
MINT	2	**64**	**1.07 (1.01, 1.13)**	1.04 (0.99, 1.10)	1.04 (0.99, 1.10)	1.01 (0.95, 1.06)
MINT	3	**44**	**1.08 (1.01, 1.16)**	**1.08 (1.01, 1.15)**	1.04 (0.98, 1.12)	1.04 (0.97, 1.11)
MINT	4	29	1.07 (0.98, 1.16)	**1.08 (1.00, 1.17)**	1.03 (0.94, 1.11)	0.96 (0.89, 1.05)
MINT	>4	95	1.07 (1.01, 1.13)	1.03 (0.97, 1.09)	1.00 (0.94, 1.06)	1.01 (0.95, 1.07)
AVGT	2	35	1.03 (0.96, 1.11)	1.05 (0.97, 1.12)	1.04 (0.97, 1.12)	0.98 (0.91, 1.05)
AVGT	3	22	1.04 (0.94, 1.14)	**1.12 (1.02, 1.23)**	1.00 (0.91, 1.10)	0.96 (0.87, 1.06)
AVGT	4	14	1.09 (0.96, 1.24)	1.02 (0.90, 1.16)	0.94 (0.83, 1.08)	0.91 (0.80, 1.05)
AVGT	>4	52	0.96 (0.88, 1.06)	0.95 (0.87, 1.05)	0.95 (0.86, 1.05)	0.96 (0.87, 1.05)
MAXAT	2	37	1.00 (0.93, 1.07)	1.07 (0.99, 1.15)	0.95 (0.88, 1.03)	1.01 (0.94, 1.09)
MAXAT	3	24	1.09 (0.99, 1.20)	1.00 (0.91, 1.11)	**1.10 (1.01, 1.21)**	1.00 (0.91, 1.11)
MAXAT	4	15	0.98 (0.87, 1.10)	1.15 (1.03, 1.28)	1.10 (0.98, 1.23)	0.97 (0.86, 1.10)
MAXAT	>4	33	1.09 (0.98, 1.21)	1.04 (0.93, 1.17)	0.93 (0.83, 1.05)	0.89 (0.79, 1.00)
MINAT	2	35	1.02 (0.95, 1.10)	1.03 (0.96, 1.12)	**1.08 (1.00, 1.16)**	1.02 (0.95, 1.10)
MINAT	3	21	1.04 (0.95, 1.15)	**1.12 (1.02, 1.23)**	1.02 (0.93, 1.13)	1.01 (0.91, 1.12)
MINAT	4	13	**1.16 (1.03, 1.31)**	1.03 (0.91, 1.17)	0.97 (0.85, 1.10)	0.90 (0.79, 1.03)
MINAT	>4	27	0.97 (0.87, 1.07)	0.98 (0.89, 1.09)	1.00 (0.90, 1.10)	1.02 (0.92, 1.13)
AVGAT	2	36	1.03 (0.96, 1.11)	**1.11 (1.04, 1.19)**	1.02 (0.95, 1.09)	1.00 (0.93, 1.07)
AVGAT	3	22	**1.12 (1.03, 1.22)**	**1.09 (1.00, 1.19)**	1.02 (0.93, 1.12)	0.96 (0.87, 1.06)
AVGAT	4	15	1.08 (0.97, 1.20)	1.04 (0.94, 1.16)	0.97 (0.86, 1.09)	0.99 (0.88, 1.11)
AVGAT	>4	45	1.06 (0.97, 1.16)	0.98 (0.89, 1.08)	0.95 (0.87, 1.05)	0.89 (0.81, 0.98)

Table S4. Relative risk (RR) estimates and 95% confidence interval (CI) for ED visits due to fluid and electrolyte imbalance (FLEL) associated with one order increase in the sequence of heat wave periods per year. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded.

FLEL	SEQ	Sample size	Lag0 R.R. (95%C.I.)	Lag1 R.R. (95%C.I.)	Lag2 R.R. (95%C.I.)	Lag3 R.R. (95%C.I.)
MAXT	1	11	1.00 (0.92, 1.10)	0.97 (0.87, 1.09)	1.06 (0.95, 1.18)	1.06 (0.95, 1.19)
MAXT	2	10	1.03 (0.95, 1.11)	0.99 (0.91, 1.08)	1.02 (0.94, 1.12)	0.99 (0.90, 1.08)
MAXT	≥3	8	1.07 (0.98, 1.17)	1.04 (0.95, 1.15)	1.04 (0.94, 1.14)	0.98 (0.89, 1.08)
MINT	1	17	**1.10 (1.04, 1.16)**	**1.12 (1.05, 1.19)**	**1.13 (1.06, 1.20)**	**1.10 (1.04, 1.17)**
MINT	2	14	**1.11 (1.04, 1.18)**	1.05 (0.97, 1.13)	0.97 (0.90, 1.05)	0.95 (0.87, 1.03)
MINT	≥3	33	**1.06 (1.01, 1.12)**	1.02 (0.97, 1.07)	0.99 (0.94, 1.04)	0.97 (0.92, 1.02)
AVGT	1	12	1.05 (0.97, 1.13)	**1.1 (1.00, 1.21)**	**1.10 (1.00, 1.21)**	1.01 (0.91, 1.12)
AVGT	2	10	1.05 (0.97, 1.13)	1.01 (0.93, 1.10)	0.99 (0.91, 1.08)	0.99 (0.91, 1.08)
AVGT	≥3	13	1.02 (0.94, 1.09)	1.02 (0.94, 1.10)	0.94 (0.87, 1.02)	0.91 (0.84, 0.99)
MAXAT	1	12	1.03 (0.95, 1.11)	**1.10 (1.01, 1.20)**	1.02 (0.93, 1.11)	1.00 (0.91, 1.09)
MAXAT	2	10	1.04 (0.96, 1.14)	1.09 (0.98, 1.20)	1.02 (0.92, 1.12)	0.98 (0.89, 1.09)
MAXAT	≥3	15	0.99 (0.92, 1.06)	1.02 (0.95, 1.10)	1.00 (0.93, 1.08)	0.97 (0.90, 1.05)
MINAT	1	15	**1.09 (1.02, 1.16)**	1.06 (0.99, 1.14)	1.06 (0.99, 1.14)	1.02 (0.94, 1.10)
MINAT	2	10	1.09 (0.99, 1.20)	0.99 (0.88, 1.12)	1.03 (0.92, 1.17)	1.08 (0.96, 1.22)
MINAT	≥3	10	1.02 (0.92, 1.13)	1.04 (0.95, 1.15)	0.99 (0.90, 1.09)	0.93 (0.85, 1.03)
AVGAT	1	13	**1.08 (1.01, 1.16)**	**1.10 (1.02, 1.19)**	1.04 (0.95, 1.12)	1.00 (0.92, 1.08)
AVGAT	2	11	1.05 (0.97, 1.13)	1.05 (0.96, 1.14)	0.98 (0.90, 1.07)	0.96 (0.88, 1.05)
AVGAT	≥3	12	**1.13 (1.05, 1.22)**	1.06 (0.98, 1.15)	0.98 (0.90, 1.06)	0.94 (0.87, 1.02)

Table S5. Relative risk (RR) estimates and 95% confidence interval (CI) for ED visits due to acute renal failure (ARF) associated with one day passed in the duration of heat wave. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded

ARF	Day	Sample size	Lag0 R.R. (95%C.I.)	Lag1 R.R. (95%C.I.)	Lag2 R.R. (95%C.I.)	Lag3 R.R. (95%C.I.)
MAXT	2	29	1.00 (0.87, 1.15)	1.06 (0.92, 1.21)	1.07 (0.94, 1.22)	**1.14 (1.00, 1.30)**
MAXT	3	18	1.05 (0.86, 1.29)	1.09 (0.89, 1.33)	**1.22 (1.01, 1.48)**	1.03 (0.84, 1.26)
MAXT	4	10	1.00 (0.80, 1.26)	1.18 (0.95, 1.47)	1.13 (0.90, 1.41)	0.85 (0.66, 1.09)
MAXT	>4	34	1.14 (0.96, 1.34)	1.04 (0.88, 1.23)	1.06 (0.89, 1.27)	0.96 (0.80, 1.14)
MINT	2	64	1.05 (0.97, 1.15)	1.07 (0.98, 1.16)	1.01 (0.93, 1.10)	**1.08 (1.00, 1.18)**
MINT	3	44	1.06 (0.95, 1.18)	1.02 (0.92, 1.14)	1.09 (0.98, 1.21)	1.06 (0.95, 1.18)
MINT	4	29	1.08 (0.95, 1.23)	**1.15 (1.02, 1.30)**	1.06 (0.94, 1.20)	1.03 (0.90, 1.17)
MINT	>4	95	1.08 (0.99, 1.19)	1.06 (0.97, 1.16)	1.00 (0.92, 1.10)	0.98 (0.90, 1.07)
AVGT	2	35	1.03 (0.92, 1.15)	1.08 (0.97, 1.20)	1.01 (0.90, 1.13)	1.05 (0.94, 1.18)
AVGT	3	22	1.10 (0.95, 1.28)	1.02 (0.88, 1.19)	0.98 (0.84, 1.15)	1.04 (0.89, 1.21)
AVGT	4	14	1.04 (0.85, 1.28)	1.08 (0.89, 1.32)	1.06 (0.87, 1.30)	1.03 (0.83, 1.27)
AVGT	>4	52	1.13 (0.98, 1.03)	1.08 (0.94, 1.25)	1.05 (0.90, 1.21)	0.92 (0.79, 1.06)
MAXAT	2	37	1.05 (0.94, 1.18)	1.03 (0.91, 1.16)	**1.16 (1.03, 1.30)**	1.03 (0.92, 1.16)
MAXAT	3	24	1.06 (0.90, 1.24)	**1.29 (1.12, 1.49)**	1.08 (0.93, 1.26)	0.87 (0.74, 1.03)
MAXAT	4	15	**1.28 (1.08, 1.51)**	1.14 (0.96, 1.34)	0.91 (0.75, 1.10)	1.07 (0.89, 1.27)
MAXAT	>4	33	1.11 (0.93, 1.31)	1.01 (0.85, 1.22)	0.99 (0.83, 1.18)	0.82 (0.68, 0.98)
MINAT	2	35	1.03 (0.91, 1.16)	**1.16 (1.03, 1.3)**	1.04 (0.93, 1.18)	1.09 (0.97, 1.23)
MINAT	3	21	1.14 (0.99, 1.32)	**1.17 (1.02, 1.35)**	1.06 (0.92, 1.24)	0.95 (0.80, 1.11)
MINAT	4	13	**1.24 (1.05, 1.48)**	1.2 (1.00, 1.43)	0.96 (0.79, 1.17)	1.19 (0.99, 1.43)
MINAT	>4	27	1.10 (0.94, 1.27)	1.15 (0.99, 1.33)	1.13 (0.98, 1.30)	1.01 (0.87, 1.17)
AVGAT	2	36	1.00 (0.89, 1.13)	**1.16 (1.04, 1.30)**	**1.13 (1.01, 1.26)**	1.01 (0.90, 1.13)
AVGAT	3	22	1.08 (0.94, 1.23)	**1.26 (1.12, 1.43)**	1.05 (0.92, 1.20)	0.97 (0.83, 1.12)
AVGAT	4	15	**1.25 (1.09, 1.45)**	1.12 (0.96, 1.30)	1.03 (0.87, 1.21)	0.99 (0.84, 1.17)
AVGAT	>4	45	1.13 (0.99, 1.29)	1.08 (0.93, 1.24)	1.01 (0.88, 1.16)	0.89 (0.77, 1.02)

Table S6. Relative risk (RR) estimates and 95% confidence interval (CI) for ED visits due to acute renal failure (ARF) associated with one order increase in the sequence of heat wave periods per year. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded

ARF	SEQ	Sample size	Lag0 R.R. (95%C.I.)	Lag1 R.R. (95%C.I.)	Lag2 R.R. (95%C.I.)	Lag3 R.R. (95%C.I.)
MAXT	1	11	0.89 (0.76, 1.04)	**1.22 (1.02, 1.46)**	1.08 (0.90, 1.30)	1.04 (0.86, 1.26)
MAXT	2	10	0.98 (0.86, 1.12)	0.96 (0.83, 1.11)	1.07 (0.93, 1.23)	1.02 (0.88, 1.18)
MAXT	≥3	8	**1.17 (1.02, 1.34)**	1.10 (0.96, 1.27)	**1.15 (1.00, 1.32)**	1.06 (0.92, 1.23)
MINT	1	17	1.19 (1.08, 1.31)	**1.16 (1.05, 1.29)**	1.02 (0.93, 1.13)	1.04 (0.94, 1.15)
MINT	2	14	1.08 (0.97, 1.21)	**1.18 (1.04, 1.34)**	1.00 (0.87, 1.14)	1.01 (0.88, 1.15)
MINT	≥3	33	1.01 (0.93, 1.08)	0.99 (0.92, 1.07)	1.05 (0.97, 1.13)	1.05 (0.98, 1.14)
AVGT	1	12	1.08 (0.94, 1.23)	**1.21 (1.04, 1.41)**	1.01 (0.85, 1.19)	1.01 (0.85, 1.21)
AVGT	2	10	0.96 (0.85, 1.09)	0.96 (0.84, 1.10)	0.98 (0.86, 1.13)	1.03 (0.90, 1.18)
AVGT	≥3	13	1.07 (0.96, 1.20)	1.08 (0.96, 1.21)	1.05 (0.93, 1.18)	1.00 (0.89, 1.13)
MAXAT	1	12	0.96 (0.84, 1.09)	1.07 (0.93, 1.23)	1.05 (0.91, 1.22)	0.97 (0.83, 1.12)
MAXAT	2	10	0.96 (0.83, 1.10)	1.01 (0.86, 1.18)	1.07 (0.91, 1.25)	0.94 (0.80, 1.10)
MAXAT	≥3	15	**1.12 (1.00, 1.24)**	**1.16 (1.04, 1.30)**	1.08 (0.96, 1.21)	0.98 (0.87, 1.11)
MINAT	1	15	1.09 (0.98, 1.21)	1.09 (0.97, 1.22)	1.07 (0.95, 1.20)	1.10 (0.97, 1.24)
MINAT	2	10	1.00 (0.87, 1.17)	**1.31 (1.11, 1.55)**	1.10 (0.92, 1.32)	1.17 (0.98, 1.39)
MINAT	≥3	10	**1.20 (1.03, 1.39)**	1.20 (1.04, 1.38)	1.02 (0.88, 1.17)	0.94 (0.81, 1.08)
AVGAT	1	13	1.02 (0.90, 1.14)	1.08 (0.95, 1.22)	1.03 (0.91, 1.17)	0.96 (0.84, 1.10)
AVGAT	2	11	1.03 (0.92, 1.16)	**1.21 (1.07, 1.37)**	1.12 (0.98, 1.27)	1.00 (0.87, 1.14)
AVGAT	≥3	12	1.11 (0.99, 1.25)	**1.21 (1.07, 1.36)**	1.07 (0.95, 1.21)	0.96 (0.84, 1.08)

Table S7. Relative risk (RR) estimates and 95% confidence interval (CI) for ED visits due to fluid and electrolyte imbalance (FLEL) and acute renal failure (ARF) associated with per °C increase in average temperature during heat waves. Heat waves are defined as periods of ≥ 2 consecutive days with temperature (T) or apparent temperature (AT) exceeding the 98th percentile using daily maximum (MAX), minimum (MIN), or average (AVG). The first day of the heat wave period is excluded.

	Lag0 R.R. (95%C.I.)	Lag1 R.R. (95%C.I.)	Lag2 R.R. (95%C.I.)	Lag3 R.R. (95%C.I.)
FLEL				
MAXT	1.0009 (0.9992, 1.0026)	1.0014 (0.9998, 1.0031)	**1.0040 (1.0023, 1.0057)**	**1.0047 (1.0030, 1.0064)**
MINT	**1.0029 (1.0012, 1.0045)**	**1.0040 (1.0024, 1.0056)**	**1.0050 (1.0035, 1.0066)**	**1.0053 (1.0037, 1.0069)**
AVGT	1.0007 (0.9990, 1.0025)	1.0016 (0.9999, 1.0034)	**1.0040 (1.0023, 1.0058)**	**1.0047 (1.0029, 1.0064)**
MAXAT	1.0008 (0.9993, 1.0023)	1.0014 (0.9999, 1.0029)	**1.0037 (1.0022, 1.0051)**	**1.0044 (1.0029, 1.0059)**
MINAT	1.0013 (0.9992, 1.0033)	**1.0021 (1.0001, 1.0042)**	**1.0034 (1.0013, 1.0054)**	**1.0037 (1.0016, 1.0057)**
AVGAT	**1.0020 (1.0003, 1.0036)**	**1.0027 (1.0011, 1.0044)**	**1.0046 (1.0030, 1.0062)**	**1.0052 (1.0035, 1.0068)**
ARF				
MAXT	1.0010 (0.9983, 1.0038)	1.0016 (0.9988, 1.0043)	**1.0034 (1.0007, 1.0061)**	**1.0044 (1.0017, 1.0071)**
MINT	**1.0028 (1.0002, 1.0054)**	**1.0034 (1.0008, 1.0059)**	**1.0051 (1.0026, 1.0076)**	**1.0053 (1.0028, 1.0078)**
AVGT	1.0023 (0.9995, 1.0051)	1.0027 (0.9999, 1.0054)	**1.0049 (1.0022, 1.0075)**	**1.0056 (1.0030, 1.0083)**
MAXAT	**1.0025 (1.0001, 1.0049)**	**1.0028 (1.0005, 1.0052)**	**1.0044 (1.0021, 1.0067)**	**1.0053 (1.0030, 1.0076)**
MINAT	**1.0035 (1.0003, 1.0066)**	**1.0035 (1.0004, 1.0067)**	**1.0053 (1.0021, 1.0084)**	**1.0056 (1.0024, 1.0087)**
AVGAT	**1.0028 (1.0002, 1.0053)**	**1.0029 (1.0003, 1.0054)**	**1.0047 (1.0022, 1.0071)**	**1.0053 (1.0028, 1.0078)**