Distribution Agreement

Association between cold waves, heat waves and mortality among the older adults in the southeastern US (2000 to 2018)

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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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Extreme weather events are closely related to human health. The objective of this study is to investigate the effects of cold waves and heat waves on the mortality among the older adults (>=65 years old) in the southeastern US from 2000 to 2018. We applied quasi-Poisson time-series regression methods to examine the association between cold waves, heat waves and mortality among the older adults. We obtained the impact of cold waves and heat waves on mortality in the southeastern US and each state by calculating the risk ratio (RR). This study includes a total of 6,378,054 deaths of older adults in the southeastern US from 2000 to 2018. The study showed a significant association between increased mortality and cold waves (RR=1.24, 95% CI: 1.22, 1.26) in the southeastern US, while the heat waves were not significantly associated with increased elderly people's mortality in the southeastern US (RR=0.71, 95% CI: 0.70, 0.72).

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Introduction

Cold waves and heat waves are a regular occurrence in Antarctica, a low-latitude region, but they are a concern when they occur in North America (Wang L et al., 2016). The intergovernmental panel on climate change in 2013 forecasted that the increase in global average surface temperature change is likely to exceed 1.5 ºC by the end of the 21^{st} century compared to that of the beginning of the 20^{th} century (IPCC, 2013). Practical strategies to adapt to climate change need a more complete and thorough understanding of how change in temperature impacts human health. Temperature changes are closely related to human health, especially extreme weather events (heat waves and cold waves), which will bring more significant risks to the population's health. Studies examining the relationship between temperatures and mortality have found a combination of a U-shape relationship (Anderson, B. G., 2009). V-shape relationship (Chestnut LG, 1998; Braga AL, 2001), and J-shape relationship (Curriero F.C., 2002). Regardless of the shape of the relationship, all studies suggest that temperature changes drastically affect human health.

A number of studies have shown that heat waves have become a significant meteorological disaster affecting human health (Barnett A. G., 2007; Allen MJ, 2018; Curriero, F. C., 2007; Kilbourne EM et al., 1982; Davis, R. E., 2003). Heat waves can disrupt the human body's temperature regulation system and make the organs and tissues dysfunctional, causing cardiovascular and respiratory diseases, and even death. In a hot environment, blood vessels in the skin dilate to maintain body temperature and promote the excretion of sweat, resulting in the loss of salt and water. This biological mechanism can increase blood concentration. In a study of 107 communities in the US, the author found a 3% increase in the risk of death during heat waves (Anderson, B. G., 2009). Ma et al. (2015) conducted a study on the mortality rate during the heat waves from 2006 to 2011 in 66 countries in China and found that the mortality rate increased by 5%. A study in 9 European cities, including London and Athens, showed that the population's mortality rate increased significantly during heat waves. The increase in the risk of death in each city ranged from 7.6% to 33.6% (D'Ippoliti, D., 2010). Heat waves can cause death in other ways. For example, the human body is prone to heat stroke when exposed to high temperature for a long time. If patients are not appropriately treated in time, the heat stroke will become severe, causing heat cramps and heat exhaustion. If they continue to develop, excessive body temperature will cause irreversible brain damage, liver damage, kidney damage, and other organs damage, eventually leading to death.

Although human beings are expected to experience more heat waves than cold waves in the context of global warming, many epidemiological studies have confirmed higher risks of mortality related to cold waves than to heat waves worldwide, especially in warm places. (Carmona R., 2016, Allen MJ. 2018, Egondi T. 2015, Son J-Y., 2016). The human body's metabolism slows down to maintain physical strength as much as possible during cold waves, as the temperature decreases. At the same time, the human body's ability to resist diseases is also reduced. When the weather changes drastically and the temperature drops quickly, various cardiovascular, cerebrovascular, and respiratory diseases are more likely to occur, resulting in an increase in deaths (Wang, L., 2016; Anderson, B. G., 2009; Barnett A. G., 2007).

Effects of extreme weather on mortality can differ significantly by population and region. In the US, mortality significantly increases during cold waves and heat waves. This fact is evident in all age groups but is the most significant in absolute and relative terms in older adults (Anderson, B. G., 2009; Curriero, F. C., 2007; Kilbourne EM et al., 1982). Previous studies have found that extreme weather events has a larger impact on the health of older people than younger people (W. Yu., 2012, K.C. Conlon., 2011). Another study also observed that the heat and cold waves-related mortality increased significantly among people aged 75 years and older and moderately among people aged 15 to 75 years (J. Berko., 2014). Older adults with pre-existing diseases have relatively poor abilities to adapt to cold weather. Older adults are more susceptible to extreme weather events because heat waves and cold waves can cause the aggravation of pre-existing diseases, resulting in far more deaths.

The US encountered more extreme weather events in the 21st century, and the southeastern US was one of the hardest-hit areas by extreme weather. The relationship between extreme weather and mortality varies by region, with Curriero's (2002) study finding greater heatwave effects in the northeastern US and lower or even negligible effects in the southeastern US. Therefore, examining the association between cold waves and mortality in the southeastern US is important. This analysis can provide a scientific basis for customizing prevention and control strategies during extreme weather. However, many previous studies have focused on the association between heat waves and mortality in the southeastern US. Few studies addressed the influence of both heat waves and cold waves on mortality among the older adults in this region.

In this study, the quasi-Poisson time series analysis was employed to investigate the impact of heat waves and cold waves on mortality among the older adults in the southeastern US from 2000 to 2018. This analysis also estimated the different effects of heat waves, cold waves in the seven states in the southeastern US. We also calculated the daily mortality by race, sex, and dually enrollment in the Medicare and Medicaid. The objective of this study is to estimate the association between heat waves, cold waves, and mortality among older adults in the southeastern US. From a public health perspective, our findings can be crucial in supporting local and state governments to perform effective risk assessments and make practical extreme weather prevention plans for vulnerable populations, such as older adults. These prevention plans can be essential for reducing extreme weather-related mortality.

Materials and Methods

Study Domain

The spatial domain of our study was the southeastern US, comprising the states of Tennessee, North Carolina, South Carolina, Mississippi, Georgia, Florida, and Alabama. The climate of the southeastern US was strongly affected by its latitude and its close relationship to the Atlantic Ocean and the Gulf of Mexico. A number of extreme weather events, such as heatwaves, cold waves, hurricanes, floods, and tornadoes, affect the southeastern US significantly (Ingrid H.H., 2016).

Study Population

The mortality data from 2000 to 2018 among the Medicare population ≥ 65 years old in the southeastern US were derived from the Centers for Medicare and Medicaid Services(CMS). The CMS data set lists information on age, race, sex, Medicaid eligibility, ZIP code of residence, and date of death (if any) for each Medicare enrollee. Daily mortality in this study was aggregated by ZIP code because ZIP code is the finest spatial resolution in the Medicare data. We matched the daily mortality data with the corresponding heat waves/ cold waves exposure. The

Meteorological data in this study, including daily mean temperature, daily maximum temperature, daily minimum temperature, and daily dew point temperature, were derived from the Daymet dataset at 1-km resolution. The dew point temperature was calculated using the following formula:

$$Dp(T, RH) = \frac{\lambda * \left(\ln\left(\frac{RH}{100}\right) + \frac{\beta * T}{\lambda + T} \right)}{\beta - \left(\ln\left(\frac{RH}{100}\right) + \frac{\beta * T}{\lambda + T} \right)}$$

In this formula, RH is the relative humidity, and T is the temperature. The daily mean temperature was calculated by adding daily maximum and daily minimum temperature and then divided by 2.

The meteorological data were aggregated to the ZIP code level because the health records were at the ZIP code level. We linked the ZIP code centroid to the closest 32km × 32km temperature grid cell, and then we assigned the gridded meteorological data to the population living in that linked ZIP code.

Cold waves and heat waves are the exposure data. There is no universally agreed definition of cold waves and heat waves. In this study, we use the definition provided by (Schwartz, J., 2005) where cold wave is defined as a weather process with a maximum daily temperature at or lower than the 1^{st} percentile and a duration of more than three days. Similarly, we use the definition for heat wave as a weather process with a minimum daily temperature at or higher than the 99^{th} percentile and a duration of more than three days.

Statistical Analysis

We applied a quasi-Poisson generalized linear model (GLM) to analyze the effect of cold waves and heat waves on mortality and adjusted for time, average temperature, maximum temperature, minimum temperature, and dew point temperature. The analysis in this study of cold seasons was from October to March and warm seasons from April to September. The following statistical formula was used in this study:

$$\text{Log}\left(\mu_{at}\right)=\beta_0+\beta \text{CW}_{bt}/\text{HW}_{bt}+$$

$$ns\left(\text{Tavg}_t\right)+\text{ns}\left(\text{Tmin}_t\right)+\text{ns}\left(\text{Tmax}_t\right)+\text{ns}\left(\text{DPT}_t\right)+ns\left(\text{DATE}_t\right)$$

In this formula, μ_{at} is the expected number of deaths$a$ on day t; t is the date of observation; CW_{bt} and HW_{bt} is the cold wave/ heat wave exposure on day t (1= cold wave/ heat wave days, 0 = non- cold wave/ heat wave days). β_0 is the intercept; β is the vector of regression coefficients, the model also adjusted for time, daily mean temperature, daily maximum temperature, daily minimum temperature, and daily dew point temperature. ns is a natural cubic spline. DPT_t is the dew point temperature, and Tavg, Tmin, and Tmax are the temperature on day t, with 4 degrees of freedom to account for possible nonlinear relationships with mortality among the older adults. The degree of freedom of time is 6, adjusting for long-term trends and seasonal change. df were chosen based on the Akaike information criterion (AIC). Then, we use the following formula to calculate the risk ratio per 1 unit increase in exposure, estimating the associations between mortality and extreme weather events:

$$Risk\ Ratio=[exp(\beta)]\times 100\%$$

We also calculated their 95% confidence interval (CI) in this study. Risk ratios for the associations between extreme weather events and mortality were estimated based on the daily deaths from 2000 to 2018. All data was analyzed using the R software and Jupyter notebook.

Results

Table 1 presents descriptive statistics of the total daily deaths. This study includes 6,378,054 deaths of older adults in the southeastern US from 2000 to 2018. The total daily deaths are categorized according to race, Medicaid eligibility, and sex. Among people of different racial groups, the total number of deaths is highest for older white adults (5,359,365 deaths), while it is lowest for North American Native persons (6,090 deaths). Older adults who are not eligible for Medicaid have higher daily total deaths (5,383,941) than those eligible for Medicare and Medicaid (994,113). Male older adults have a lower daily total deaths, 2,833,473, than female older adults.

Table 1. Descriptive data for deaths during cold season (October to March) in the southeastern US, 2000-2018.

Category	**Daily total deaths**
All	6,378,054
Race	

Unknown	18,101
White	5,359,365
Black	827,428
Other	31,615
Asian	26,365
Hispanic	109,090
North American Native	6,090
Sex	
Male	2,833,473
Female	3,544,581
Medicare and Medicaid	
Not eligible	5,383,941
Eligible	994,113

Table 2 presents associations between cold wave days and mortality among the older adults in the southeastern US and each state. A 1ºC increase in temperature during a cold wave was associated with a risk ratio (RR) of 1.24, a 95% confidence interval (CI: 1.22, 1.26) for all mortality. These results indicated that cold wave was significantly associated with increased mortality (RR=1.24, 95% CI: 1.22, 1.26).

In Florida, Mississippi, North Carolina, and Tennessee, a 1ºC increase in temperature during cold wave was associated with a RR of 1.34 (95% CI: 1.31, 1.40), 1.20 (95% CI: 1.14, 1.27), 1.08 (95% CI: 1.05, 1.12), and 1.07 (95% CI: 1.03, 1.11), respectively. These results indicated that cold waves were significantly associated with increased mortality in Florida, Mississippi, North Carolina, and Tennessee.

In Georgia, Alabama and South Carolina, a 1ºC increase in temperature during cold waves were associated with a RR of 0.84 (95% CI: 0.81, 0.87), 0.94 (95% CI: 0.90, 0.97), and 0.92 (95% CI: 0.88, 0.97), respectively. These results indicated that cold waves were not significantly associated with increased mortality in Georgia, Alabama, and South Carolina.

Table 2. Risk ratios (RR) and 95% confidence intervals (CI) for mortality among the older adults per 1ºC increase in temperature during cold waves in the southeastern US (2000-2018).

	RR	95% CI
All states	1.24	1.22, 1.26
Georgia	0.84	0.81, 0.87
Florida	1.34	1.31, 1.40
Alabama	0.94	0.90, 0.97
Mississippi	1.20	1.14, 1.27
North Carolina	1.08	1.05, 1.12
South Carolina	0.92	0.88, 0.97
Tennessee	1.07	1.03, 1.11

Table 3 presents associations between heatwave days and mortality among the older adults in the southeastern US. A 1ºC increase in temperature during a heatwave was associated with a RR of 0.71 (95% CI: 0.70, 0.72) for all-cause mortality. These results indicated that heatwave was not significantly associated with increased mortality.

In Georgia, North Carolina, and South Carolina, a 1ºC increase in temperature during a heatwave was associated with a RR of 1.17 (95% CI: 1.13, 1.21), 1.14 (95% CI: 1.10, 1.18), and 1.03 (95% CI: 0.98, 1.08), respectively. These results indicated that cold waves were significantly associated with increased mortality in Georgia, North Carolina, and South Carolina.

In Florida, Alabama, Mississippi and Tennessee, a 1ºC increase in temperature during heat waves was associated with a RR of 0.84 (95% CI: 0.82, 0.85), 0.93 (95% CI: 0.89, 0.97), 0.85 (95% CI: 0.81, 0.90), and 0.95 (95% CI: 0.91, 0.98), respectively. These results indicate that cold waves were not significantly associated with increase in mortality in Georgia, Alabama, and South Carolina. In North Carolina, both cold waves and heat waves affected mortality significantly.

Table 3. Risk ratios (RR) and 95% confidence intervals (CI) for mortality among the older adults per 1ºC increase in temperature during heat waves in the southeastern US (2000-2018).

	RR	95% CI
All states	0.71	0.70, 0.72
Georgia	1.17	1.13, 1.21
Florida	0.84	0.82, 0.85
Alabama	0.93	0.89, 0.97
Mississippi	0.85	0.81, 0.90
North Carolina	1.14	1.10, 1.18
South Carolina	1.03	0.98, 1.08
Tennessee	0.95	0.91, 0.98

Discussion

From this 19-year time-series analysis of cold waves, heat waves, and mortality among older adults in the southeastern US, we found that after controlling for potential confounders, the occurrence of cold wave has a significant impact on the increase in mortality among this population. In contrast, heat waves do not indicate a significant influence on the rise in the mortality among the older adults in the southeastern US.

A number of epidemiological studies conclude similar results. The death risks in the US older adults increase with cold waves, while the deaths risks in the US older adults have decreased with heat waves over time (Barnett, 2007). Cold wave effects are more significant in the southern US, while heat wave effects on mortality are more significant in the northern US. (Anderson B. G., 2009). Curriero (2002) found that temperature-mortality is closely related to latitude, with lower temperatures having a more significant impact on the mortality risk in the southern US cities, while higher temperatures have a more substantial impact on that in the northern US cities. In this study, North Carolina, which is the most northern state in the southeastern US, is the only state where mortality among the older adults were affected by both heat waves and cold waves. This result shows that extreme weather-related mortality is associated with regions in the US, which is consistent with the previous literature.

We found that the effects of cold waves on mortality among the older adults in the southeastern US have persisted during the study years. Mortality associated with cold temperatures was more significant in areas with higher proportions of the elderly population, which was long ago, considered physiologically vulnerable to extreme temperatures (Kilbourne EM, 1997). Mortality among older adults can result from cardiovascular, cerebrovascular, and respiratory diseases, which are common diseases among older adults. As indicated in a city case study conducted during cold weathers, the odds ratio (OR) of deaths caused by lung inflammation was 1.028 (95%CI: 0.979-1.079). The OR of death from cardiovascular disease was 1.053 (95%CI: 1.036~1.070). The OR of death from myocardial infarction was 1.030 (0.999~1.062). The OR of death from cardiac arrest was 1.137 (95%CI: 1.051~1.230). The OR for death from atrial fibrillation was 1.052 (95%CI: 0.993-1.115). (Mercedes et al., 2006), which indicates that the deaths caused by those diseases are significantly related to cold waves. A study showed that both slow temperature drop, and sudden temperature drop considerably impact human health, accounting for 43% of all the causes. In particular, cold weather mainly affects hypertension and cerebrovascular diseases, accounting for 34% of the total number of causes (Chen XH et al., 2006). Related research found that myocardial infarction patients increase significantly when the temperature suddenly drops, and the air pressure suddenly rises (Guo LF et al., 2006). Those diseases are always accompanied by increased blood pressure, and blood clotting. Cold waves can affect the body's circulatory system. When exposed to cold air, the blood supply to the skin decreases, resulting in excess blood in vital organs such as heart lungs, liver, and kidney. The vital organs to excrete excess blood. Part of the blood is excreted by the kidneys, while the other amount of the blood is sedimented in the intercellular space (Sun XG., 2015). We can conclude from previous studies that cold waves can cause respiratory, cardiovascular and cerebrovascular diseases and lead to deaths among the older adults, which can support our results that the cold waves have significant influence on mortality among the older adults.

Our results for heat waves, however, contradict with previous heat wave-related studies conducted in the US, which concluded a significant positive association between heat waves and mortality (Anderson, B. G., 2009; Barnett A. G., 2007; Allen MJ, 2018; Curriero, F. C., 2002). Several possible explanations might explain such a discrepancy. First, socioeconomic factors might reduce the influence of heat waves on mortality in the southeastern US. Second, several studies suggested that the prevalence of air-conditioning is essential in protecting people from deaths during heat waves. The heat waves-related mortality rate became lower in cities with more central air-conditioning, as indicated in a study in 44 US metropolitan areas (Lauraine G, 1998). Air-conditioning is more prevalent in the southern US than in the northern US. (Barnett A. G. 2007, Curriero, F. C. 2002). As a result of the high prevalence of air-conditioning during hot seasons, the residents in the southeastern US were less exposed to heat and were more adaptive to high temperatures (Braga et al., 2001), and the heat waves-related mortality in the southeastern US decreased significantly with people's increased adaption to high temperatures (Davis, R. E., 2003). However, due to economic conditions, the population of air-conditioners does not necessarily equal the high utilization rate. The relationship between heat waves and mortality can be further studied by considering the efficient utilization rate of air-conditioning.

Another factor that affects mortality among the older adults during heat waves might be the housing conditions, especially the indoor temperature. The indoor temperature plays an important role in improving the heat adaptation ability of older adults. (Chapman R., 2009). Older adults spend a lot of time indoors, especially during hot weather. Indoor temperature is affected by solar radiation, outdoor temperature, building orientation, and so on. Therefore, indoor temperature can be adjusted by improving housing conditions. With the increasing use of reflective materials such as thermal insulation on the outside of the building in the southeastern

US, sunlight can be reflected efficiently, reducing the heat waves' impact on indoor temperature. Heat waves-related mortality among the older adults can be reduced eventually.

This study has some limitations. The relationship between cold waves, heat waves, and mortality among the older adults are inconclusive from this study. First, air pollution can also be a significant confounding factor. Previous studies found that air pollution is associated with daily mortality (Schwartz, 1992; Shi LH, 2016; Benmarhnia. T, 2014). Exposure to air pollution can trigger hypertension, cardiovascular diseases and respiratory diseases among people, and eventually leading to deaths. Ambient air pollution concentrations can be higher during extreme weather because the fuel is burned for heating purposes. Also, cold air circulates less so that the pollutants such as dust and hydrocarbons would settle in place much longer during cold waves. Air pollutants such as ozone, PM2.5 are likely to increase during hot waves. As air pollution is found to be associated with temperature, the air pollution can function as a mediator between extreme weather and mortality (Nawrot, T. S., 2007). The estimated associations between mortality among the older adults and cold waves might be inaccurate without considering daily air pollution concentrations(Daniel G., 2003).

Second, it is important to consider lag effects when estimating the association between extreme weather and mortality in time-series analysis, but we did not considerlag effects in our study. Sometimes the effects of exposure are not limited to our observation period. The effects could be delayed. Many time-series studies have reported that exposure to extreme weather can affect human health for several days after exposure. (Anderson, B. G., 2009; Curriero, F. C., 2002; Allen MJ, 2018; Carmona R, 2016; Egondi T, 2015; Son J-Y, 2016). Besides, lag effects can also happen when extreme weather affect vulnerable populations. As our study is focused on the association between cold waves, heat waves, and mortality among the older adults, lag effects can affect the results of our study. A quasi-Poisson regression model that considers lag effects should be applied in the future to acquire more accurate and comprehensive results.

Despite these limitations, the current study provides evidence for future research in the relationship between extreme weather and mortality. Given that other social factors such as race, sex, health insurance, and socioeconomic factors play a significant role in the mortality among the older adults (XinQi Dong., 2008; van Steen, Y., 2019; Finkelstein, 2008), we can consider these factors as potential effect modifiers when estimating the impact of heat waves and cold waves on mortality, such that we could identify the more vulnerable population. In this study, we found that the number of deaths of different races varied significantly. The number of deaths of older adults who are eligible to Medicare and Medicaid was much high than that of not eligible population. We hypothesized that race, sex, Medicare and Medicaid can affect mortality among the older adults in the southeastern US. Further studies can be done to compare the association between extreme weather and people's mortality of different race, sex, and eligibility to health insurance.

Besides, this study also provides evidence for future research in the association between extreme weather and mortality in broader areas. Our study domain is the southeastern US, and the results from this study cannot be applied to other regions in the US due to the difference in weather conditions across the regions. However, cold waves and heat waves were found to influence a lot of regions in the US (Anderson, B. G., 2009, Curriero, F. C., 2002, J. Berko., 2014, Mercedes

MR., 2006, Davis, R. E., 2003, Chestnut LG., 1998). If more comprehensive research on other regions in the US can be carried out under the same framework, more scientific and accurate conclusions can be drawn.

Conclusion

This study estimated the cold and heat waves-related mortality of older adults in the southeastern US and projected the mortality from 2000 to 2018. The results support our hypothesis that the effect of cold waves on mortality among the older adults in the southeastern US was significant. In contrast, the impact of heatwaves on mortality among older adults was not statistically significant in the southeastern US. This study suggests implementing public health plans to control extreme weather, especially cold waves, in the southeastern US, best be directed at the older adults.

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