Science of the Total Environment 647 (2019) 342–351

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

The influence of extreme cold events on mortality in the United States

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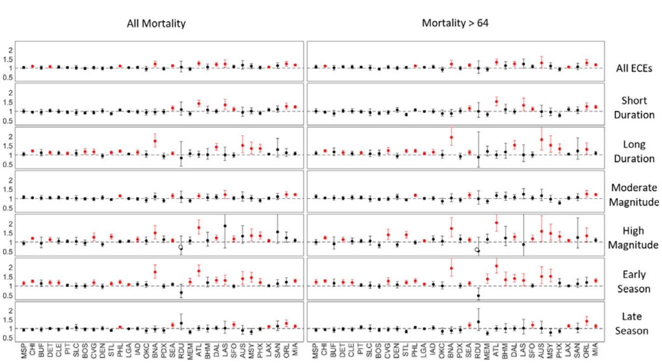
HIGHLIGHTS

- Increased mortality during ECEs is most likely during early winter.
- Warmer cities generally have a larger increased RR during ECEs.
- Magnitude and duration of ECEs significantly increase RR of mortality.
- Atlanta, Austin, and Nashville had largest increased RRs of mortality during ECEs.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 11 June 2018
Received in revised form 25 July 2018
Accepted 31 July 2018
Available online 02 August 2018

Editor: P. Kassomenos

Keywords:
Extreme cold events
Climate
Human mortality
Hazards
Vulnerability
United States

ABSTRACT

Many studies have analyzed the effects of extreme heat on human mortality, however fewer studies have focused on the effects of cold related mortality due to the complicated nature of the lagged response. This study utilized a Distributed Lag Non-Linear Model with a 30-day lag to determine the cumulative effects of extreme cold events (ECEs) on mortality across 32 cities in the United States for the period of 1975–2010. ECEs were divided into specific categories based on duration, magnitude, and timing of occurrence. Mortality was divided into all-age mortality as well as mortality of individuals >64 years old. The findings suggest a strong relationship between a city's latitude as well as the timing of an ECE with mortality. Early season ECEs result in a much higher relative risk of increased mortality, particularly in cities with higher mean winter temperatures, while the RR of mortality of individuals >64 was consistently higher for each city. This study suggests early season ECEs should receive enhanced preparedness efforts as individuals may be particularly vulnerable when not acclimatized to extreme cold.

1. Introduction

There is a well-documented connection between increases in human mortality and extreme temperature events (e.g., Gasparrini et al., 2015; Anderson and Bell, 2009; McMichael et al., 2008). Temperature extremes, especially those lasting multiple days, put a strain on cardiovascular, cerebrovascular, and respiratory systems (Gasparrini et al., 2015). However, these impacts may be reduced with increased preparedness and by limiting exposure (Barnett et al., 2012). This said, understanding the spatial and temporal variability in extreme-temperature vulnerability is key to any mitigation efforts. Research has generally shown that locations ill-prepared for extreme temperature are more substantially impacted; for instance, cities in warmer climates tend to exhibit greater sensitivity to cold extremes, and vice versa (e.g. Anderson and Bell, 2009, Analitis et al., 2008, Curriero et al., 2002, Ng et al., 2014), although the magnitude varies from study to study. In differentiating between the impacts of heat and cold, far more studies

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https://doi.org/10.1016/j.scitotenv.2018.07.466

have discussed the effects of extreme heat on mortality (Allen and Lee, 2014), since the impacts are relatively easy to model. The effects of extreme cold on health have been studied less frequently, as the relationship has been more difficult to model due to a greater lagged influence (Allen and Sheridan, 2018), a result of there being a greater proportion of winter-related mortality being indirectly associated with extreme temperature (Kinney et al., 2015). Further, while the heat-mortality literature includes studies that look at heat waves as well as the overall temperature-mortality relationship (Allen and Sheridan, 2018), the majority studies that have examined extreme cold and mortality tend to analyze the overall temperature-mortality relationship (Ng et al., 2014; Ma et al., 2014), with few analyzing cold waves explicitly. Those that have defined cold waves (e.g. Barnett et al., 2012, Rocklöv et al., 2014) have utilized absolute percentiles of temperature as criteria for their definition.

There is no formally accepted definition of an extreme temperature event, which has thus led to myriad different definitions. The classification a discrete cold event requires both a duration and magnitude criteria. The magnitude is often determined via anomalies, percentiles, or standard deviations. Wheeler et al. (2011) used standardized anomalies to develop a climatology of cold air outbreaks (CAOs) across North America. Cellitti et al. (2006) used the top 30 coldest 5-day anomalies from 17 stations in the eastern U.S. to classify CAOs. Vavrus et al. (2006) defined the magnitude and duration of CAOs by using general circulation models to look at surface temperatures two standard deviations below the December through February mean for 2 consecutive days. Barnett et al. (2012) used the 95th–99th percentiles as thresholds for cold waves which lasted a minimum of two consecutive days.

As mentioned, the increased mortality associated with extreme cold can persist for several or more weeks (Anderson and Bell, 2009). Because of this lagged response of mortality with extreme cold, cumulative measures are needed to fully encapsulate the impacts, however few studies agree on the ideal lag to incorporate, and the seasonal cycle of mortality can be a substantial confounder in terms of using any lag (Kinney et al., 2015). Lee (2015) showed that dry cool weather patterns resulted in a significant increase of cardiovascular related mortality during the 2 weeks following the event. Analitis et al. (2008) found that the effects of cold could last up to 23 days and affected warmer cities more than colder cities. Anderson and Bell (2009) found that cold waves resulted in increased mortality for up to 25 days. The relative risk has been shown to be particularly useful for determining the cumulative risk of increased mortality during extreme cold. Recent studies (Ng et al., 2014; Ma et al., 2014; Barnett et al., 2012) have utilized the Distributed Lag Non-Linear Model (DLNM), first developed by Gasparrini (2011), to examine cumulative impacts of extreme temperatures on mortality percentiles.

It is important to fully understand the impacts of winter weather on human health, as with demographic changes, the percentage of the population most vulnerable to extreme temperature events will increase more rapidly. Moreover, climate change may result in more extreme cold events even with an overall warming, and the overall notion that a warmer world would lead to a decrease in winter mortality has been questioned (Staddon et al., 2014). To contribute to this understanding, in this study we assess the association between discrete ECEs in 32 cities across the United States for the period 1975–2010, sub-setting the impacts of ECEs by duration, magnitude, location, age, and time of year. ECEs are defined in relative, not absolute terms, based on a city's climate and seasonality.

2. Data and methods

2.1. Extreme cold events

Quality controlled daily maximum and minimum temperature were obtained from NOAA for the surface weather stations located at the primary airports of the 32 metropolitan areas used in this study (Table 1).

Table 1
Surface weather stations.

Weather station	FAA location ID
Atlanta, Georgia	ATL
Austin, Texas	AUS
Birmingham, Alabama	BHM
Boston, Massachusetts	BOS
Buffalo, New York	BUF
Chicago, Illinois	Chicago Area
Cincinnati, Ohio	CVG
Cleveland, Ohio	CLE
Dallas, Texas	DAL
Denver, Colorado	DEN
Detroit, Michigan	DET
Los Angeles, California	LAX
Las Vegas, California	LAS
Memphis, Tennessee	MEM
Miami, Florida	MIA
Minneapolis-Saint Paul, MN	MSP
Nashville, Tennessee	BNA
New Orleans, Louisiana	MSY
New York, New York	LGA
Oklahoma City, Oklahoma	OKC
Orlando, Florida	Orlando Area
Phoenix, Arizona	PHX
Philadelphia, Pennsylvania	PHL
Pittsburgh, Pennsylvania	PIT
Portland, Oregon	PDX
Raleigh, North Carolina	RDU
San Diego, California	SAN
Seattle, Washington	SEA
San Francisco, California	SFO
Salt-Lake City, Utah	SLC
St. Louis, Missouri	STL
Washington D.C.	IAD

Threaded Station Extremes (ThreadEX stations), listed as Area Stations in Table 1, were used for Chicago, IL and Orlando, FL due to significant amounts of missing data. The temperature data were gathered for the months of November through March, from 1975 to 2010, and were used to calculate the magnitude and duration of the ECEs. The criteria used to define an ECE comes from Smith and Sheridan (2018) in which the mean daily maximum and minimum temperature is required to be at least 1.25 σ below the 35-year climatological mean for a minimum of 5 consecutive days.

For each city, the mean and standard deviation of temperature for each day from 1 November to 31 March over the 1975–2010 period was calculated. To smooth day-to-day fluctuations, a 2nd order polynomial was fit to the mean and standard deviation values; it is these fitted values that are used as the reference climatological mean and standard deviation for each day. This definition thus identifies ECE that represent extremely cold conditions relative to a given time of year in a given city. Thus, it may account for seasonal acclimatization and the seasonal variability of mortality associated with early season ECEs (Barnett et al., 2012). Individuals ill-acclimatized to extreme cold may be more heavily impacted by an early season ECE that features a dramatic change in temperature following a period of higher temperatures.

2.2. Mortality data

According to Analitis et al. (2008) and Anderson and Bell (2009), cold waves may result in increased mortality for up to 25 days after the onset. However, multiple cities experienced an increased RR of mortality beyond 25 days, thus a 30-day lag was used to explore the RR of increased mortality after the onset of an ECE. Of all mortality datasets, all-cause total mortality is the least influenced by limitations (Dixon et al., 2005), therefore, all-cause mortality is used instead of specific cause mortality to eliminate the subjectivity of the medical examiner while also providing a larger sample size. All-cause mortality data were obtained from the National Center for Health Statistics (NCHS)