THE GEOGRAPHY OF HYPOTHERMIA IN THE UNITED STATES: AN ANALYSIS OF MORTALITY, MORBIDITY, THRESHOLDS, AND MESSAGING

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CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Overview

Deaths and injuries directly attributable to ambient cold temperatures were called by a variety of names and descriptive phrases for many years. Oftentimes, direct cold weather deaths were termed death by exposure, with other descriptions such as “he/she died because of the elements” commonly used. This phenomena received a more formal description in the years following World War II, when it was termed hypothermia (Guly 2011).

Hypothermia occurs when the human body cannot generate more endogenic heat than is lost to the surrounding environment. This is caused by external environmental conditions or medically-induced internal thermal regulation difficulties acting singly or in concert (Nixdorff-Miller et al. 2006; Turk 2010). There are a number of risk factors that increase an individual’s risk to hypothermia: old age, male gender, and minority ethnic status (Rango 1985; Taylor and McGwin 2000; Thacker et al. 2008). The level of risk can be reduced by behavioral changes, including wearing clothing appropriate to the outside conditions (Castellani et al. 2006).

Cold exposure hypothermia is a winter season contributor to morbidity and mortality in the northern hemisphere’s middle-high latitudes, with most morbidity and mortality research coming from the US and Scandinavia (Thacker et al. 2008; Brandstrom 2012). Hypothermia has also been reported in tropical and sub-tropical environments during local cool seasons (Elbaz et al. 2007; Aitken et al. 2008).

Cold exposure hypothermia deaths and hospitalizations have been previously demonstrated to have ssome association with reported ambient weather conditions (Herity et al. 1991; Tanaka and Tokodome 1991; Taylor and McGwin 2000). In total, US hypothermia fatalities caused by direct cold exposure range from 400 to 700 deaths per year. When compared to other atmospheric hazard events, this exceeds the observed fatality range for tornadoes, hurricanes, lightning, and floods (Ashley 2007; Ashley and Ashley 2008; Ashley and Gilson 2009; Thacker et al. 2008), and itself is only exceeded by heat-related mortality.

The main purpose of this dissertation is to examine hypothermia-related mortality and morbidity from a geographic perspective, as hypothermia research is not well-represented in the geographic literature. This will be done in a series of four inter-related chapters that each examine a component of hypothermia. This first chapter contains basic introductory information and provides an overarching literature review of the key points of hypothermia. The second chapter is a critical examination of hypothermia-related messaging on the World Wide Web. The internet was searched using keywords to determine search results encountered by lay people when looking for hypothermia-related information. The web-based information and messages were then critically compared to the medical literature and graded utilizing a rubric developed by the American Academy of Family Practitioners. The third chapter assesses the spatio-temporal distribution of hypothermia deaths utilizing the Centers for Disease Control and Prevention Compressed Mortality File and data from the National Weather Service. The ambient conditions at the time of death were compared to National Weather Service wind chill alert criteria to determine if fatalities occurred at temperatures warmer or colder than those stipulated by alert thresholds. The fourth chapter of this dissertation concerns hypothermia morbidity in the State of New York. Hypothermia-related hospitalizations were joined to weather station data to compare Spatial Synoptic Classification II weather type with hospitalization rates in seven New York State regions. The fifth and final chapter provides concluding remarks that synthesizes the most important elements of this research, stating the implications of the analysis and possible future directions for research.

This research is important for a number of reasons. In spite of climate warming, the frequency and intensity of cold air outbreaks is expected to persist into the latter half of the 21st century (Kodra et al. 2011). While some models conversely forecast a reduction in cold air outbreak severity by current standards, colder temperatures relative to elevated mean temperatures will continue to occur (Vavrus et al. 2006), so the ability to respond to cold air events should not be reduced (Kodra et al. 2011). Hypothermia has been identified as a significant public health problem with high medical costs (Noe et al. 2012). In spite of this, the geographic distribution of deaths and hospitalizations at the national or regional levels in the US unknown. Hence, the spatial distribution of the deaths was assessed so resources and alert messaging can be efficiently allocated to combat this public health problem. Preliminary emails with the National Weather Service suggested that the wind chill alerts were not constructed using a health outcome-based approach, which is a system that could more effectively warn the public of the most hazardous days. Such health outcome-based systems have been successfully implemented in many cities with positive outcomes for excessive heat days (Sheridan and Kalkstein 2004). Assessing temperatures at which deaths occur allows for the development of effective warning systems based on empirical observation of ambient conditions. Hypothermia morbidity in the US is poorly researched, so assessing New York State data allows us to delineate areas of hypothermia hospitalizations, and affords a comparison to hypothermia mortality. Lastly, hypothermia messaging has been little researched, and the receipt and understanding of hypothermia information by citizens is not understood. Evaluating the accuracy of web-based hypothermia information compared to the medical literature will allow for more streamlined messaging of the most important hypothermia-related information.

The rest of this chapter is dedicated to a review of existing literature on hypothermia, with the primary goal to describe what is currently known about hypothermia and its relationship to geography and biometeorology. A medical overview of hypothermia will be provided along with descriptions of its stages and the associated physiology. Physical environmental factors that can cause the human body to lose heat will be described, along with a related description of wind chill temperatures and their relationship to body cooling. Demographic groups that are at risk for developing hypothermia will be discussed. The spatial distribution of hypothermia mortality and morbidity will be described, along with the association of hypothermia to meteorological parameters. Lastly, a description of cold alert systems will be provided to give an overview of governmental warning and response to conditions that may cause hypothermia and other cold-related ailments.

1.2 Hypothermia and the Cold Response

Humans experience optimum health within a narrow range of ambient temperatures, and healthy humans are able to handle internal temperature deviations of +/-4°C of the normal body temperature of 37° C for limited durations of time (Nixdorff-Miller et al. 2006). Continued exposure to ambient cold can cause a prolonged drop in core body temperature, which the human body attempts to correct through a series of actions called the cold response (Pozos and Danzl 2001). The physiological response to cold stress can result in a wide range of physical and mental impairments, including cardio-respiratory ailments, influenza, and pneumonia, or more acutely, hypothermia (Conlon et al. 2011; Poszos and Danzl 2001). A description of hypothermia stages and associated symptoms with the physiological underpinnings will be explained.

Hypothermia is defined as a core body temperature below 35º C. This can be caused by the aforementioned extreme ambient conditions and/or other underlying individual vulnerabilities, which will be discussed later (Nixdorff-Miller et al. 2006). Three grades of hypothermia are delimited by core body temperature (*Mild, Moderate, and Severe*) and are associated with a number of distinct symptoms (Table 1.1).

Table 1.1. The progression of hypothermia through three stages of severity and their associated core body temperatures. Select symptoms for each stage are listed.

Stage	Core Temperature (Celsius)	Symptoms
Mild Hypothermia	35°-33°	Shivering; poor judgment develops; amnesia and apathy; increased heart rate; increased breathing; cold or pale skin
Moderate Hypothermia	32.9°-27°	Progressively decreasing levels of consciousness and stupor; shivering stops; decreased heart rate and breathing; decreased reflexes and no voluntary motion; paradoxical undressing
Severe Hypothermia	<26.9°	Low blood pressure and bradycardia; no reflexes; loss of consciousness; coma; death

Mild hypothermia occurs when the core body temperature drops between 33-35˚ C. The hypothalamus senses the reduction in core body temperature and attempts to counteract this imbalance, which results in a number of symptoms. Increased muscle rigidity leading to shivering commonly occurs (Poszos and Danzl 2001; Nixdorff-Miller et al. 2006). These rapid muscle contractions are capable of raising core body temperature by nearly 2°C per hour with adequate energy intake (Epstein and Kiran 2006; Mallet 2002; Mulcahy and Watts 2009). Vasoconstriction, or the narrowing of blood vessels near the skin, also occurs as an early component of the cold response during hypothermic events (Pozos and Danzl 2001; Näyhä 2005). Approximately 1 liter of blood is shifted from the extremities and the skin to the core during this process (Näyhä 2005). This is to concentrate blood in the body's core to protect and keep warm vital organs. The narrowing of subcutaneous blood vessels increases blood pressure, blood viscosity, platelet counts, red blood cells, and increases blood cholesterol concentration (Danet et al. 1999; Gorjnac et al. 1999; Keatinge et al. 1984; Näyhä 2005; Pozos and Danzl 2001; Stocks et al.. 2004).

The increase in blood pressure and viscosity places greater stress on the heart, which results initially in tachycardia, followed by a reduction in available oxygen to the heart muscle, presence of arrhythmias, and an increased risk of thrombus (Lloyd 1991; Kyselý et al. 2009; Näyhä 2005; Pozos and Danzl 2001; Stocks et al. 2004). Another impact of vasoconstriction is cold diuresis, which is an increased volume of urine (up to 3.5 times of normal). Blood volume increases in the core, which increases mean arterial pressure; cold diuresis is thought to occur as an attempt to reduce blood pressure through removing extra water in the blood stream and voiding it through the kidneys (Hynyen et al. 1993).

As brain temperature decreases, electrical activity begins to slow down due to impaired conduction (Lansdowne and Scruggs 1976; Poszos and Danzl 2001; Mallet 2002). This has a cascading effect on brain function: first conscious thought is affected, followed by systems that are not under conscious control (breathing, heart rate, etc), leading to a wide range of symptoms. Commonly observed phenomena indicating decreased cognitive ability include apathy, amnesia, slurred speech (incoherence), or generally unusual behavior for the afflicted individual (Poszos and Danzl 2001). These authors go on to note that in military operations it is important to utilize a "buddy system" and that the buddies must understand each other's personality, as some of the listed cognitive decreases are relative to each individual's baseline characteristics. They also emphasized that cognitive decline is somewhat more subjective than physical criteria.

Physical coordination similarly declines as core temperature decreases and it is related to the brain's ability to conduct electrical signals (Poszos and Danzl, 2001). As higher thought is reduced, the ability to coordinate one's movement decreases and vasoconstriction reduces blood flow to the extremities, making gross motor control difficult and movement appear clumsy. Physical coordination issues can occur in both mild and moderate hypothermia (Connolly and Worthley 2000; Nixdorff-Miller et al. 2006).

Moderate hypothermia is a further reduction of core body temperature to 27-32˚ C. When the core temperature drops into this range, the cold response is much more limited and some symptoms are quite serious. Shivering thermogenesis ceases (Poszos and Danzl 2001). Cold diuresis can result in electrolyte imbalance leading to heart beat irregularities, such as the Osborne Wave, a j-shaped trace on an electro-cardio graph (Aslam et al. 2006; Mallet 2002; Mulcahy and Watts 2009; Poszos and Danzl 2001). Slurred speech and other communication difficulties will occur during this stage, if they have not yet occurred in the mild stage. As core body temperature cools further, paradoxical undressing, or the removal of clothes in spite of harsh conditions, can occur. With prolonged shivering and vasoconstriction, the working muscle groups in the extremities become exhausted and vasodilation starts to occur. When this happens, blood starts to return to frozen extremities, which the victim perceives as extreme warmth and removes clothes (Rothschild and Schneider 1995).

Severe hypothermia occurs when the victim's core body temperature drops below 26˚ C. At this stage, major organ systems become too cold to function and begin to fail (Poszos and Danzl 2001). The pulse is extremely low or the heart can stop altogether, a condition called asystole (Aslam et al. 2006). The victim is unconscious and can be comatose; there is no voluntary movement, reflexes, or response to pain, with survival unlikely (Poszos and Danzl 2001). At core temperatures this low, death can result from acid-base and electrolyte imbalances in the blood stream, ventricular fibrillation or complete stoppage of the heart (asystole), or failure of major organ systems from prolonged exposure to cold internal core temperatures (Poszos and Danzl 2001).

1.3 Hypothermia Risk Factors

There are a number physical factors (physical risk factors) that can increase the risk of developing hypothermia. These are ambient conditions and wind chill, as well as exposure to water or sweating. Additionally, a number of demographic characteristics are associated with increased susceptibility of developing hypothermia, including old age, male gender, and ethnic minority status. Lastly, there are a number of individual characteristics that modify risk to hypothermia, most prominently homelessness, alcoholism, and underlying medical conditions.

1.3.1 Physical Risk Factors

1.3.1.1 Brief Overview of Cold Morbidity and Mortality

Much research has examined temperature extremes and the associated human response; however, limited research examines the relationship between ambient outdoor conditions and hypothermia fatalities. Cold weather-related mortality research has identified that higher rates of death occur during the winter season (Healy 2003). This type of research typically examines excess deaths from cardiovascular and respiratory conditions, and compares them relative to local weather and climate around the time of death. Excess cardiovascular deaths accounted 47% of winter deaths (Davie et al. 2007), and a 1º C drop in temperature has been found to be associated with an increase in mortality in selected European cities (Analitis et al. 2008). Respiratory illness is also observed to increase in the winter season compared to the warm season (Curriero et al. 2002; Dushoff et al. 2005). Absolute low temperatures and relative humidity, along with frequent changes in temperature, are suspected to play a role in the increased frequency of respiratory illness cases in the winter (Mäkinen et al. 2009; Shaman et al. 2010).

There are a number of common threads in cold mortality research that are broadly applicable to human temperature response. Cold morbidity and mortality has considerable impacts in the mid-to-high latitudes of northern hemisphere, with cities in Europe, North America and Asia showing relatively high rates of excess deaths (Anderson and Bell 2009; Curriero et al. 2002; Diaz et al. 2005). Areas within moderate climate regions experience the highest rates of cold morbidity and mortality (Curriero et al. 2002; Eurowinter Group 1997). This suggests that sudden changes in temperature, or relative temperature, are more important than absolute temperature in determining morbidity and mortality rates (Conlon et al. 2010; Eurowinter Group 1997).

While urban areas are associated with higher raw frequencies of cold morbidity and mortality, smaller, more rural settings are associated with elevated rates of cold morbidity and mortality (Conlon et al. 2010). Conlon et al. (2010) propose that resilience to cold season temperatures may be enhanced in larger metropolitan areas due to urban heat island effects. In summary, cold weather related hospitalizations and death are more prevalent in the mid-to-high latitude regions of the world. However, areas that are more moderate within these general zones that experience colder than usual temperatures can expect increases in morbidity and mortality.

1.3.1.2 Ambient Weather and Hypothermia

Comparatively little research has examined the relationship between hypothermia and ambient atmospheric conditions. Hypothermia deaths peak during the cold season in the mid-to-high latitudes. A study of 138 hypothermia-related fatalities in Israel from 1999-2005 found that 38% of the victims perished during the winter months (Elbaz et al. 2007); an analysis of temperature-related deaths in Alabama found that the highest numbers of hypothermia-related fatalities occurred during December, January, and February (Taylor and McGwin, 2000). A small number of studies have examined the ambient temperature and its relationship to hypothermia morbidity and mortality. Tanaka and Tokodome (1991) found that 84% of the 157 reported hypothermia victims in Tokyo from 1974-1983 perished when the outdoor temperatures were 5°C or below. Hypothermia incidence in Ireland was found to double with every 5.6° C drop in temperature, with the highest mortality rates occurring at temperatures below 1° C (Herity et al. 1991).

The winter climate in the northern mid to high latitudes is typified by lower temperatures and moisture content with higher wind speeds than what is typical of summer conditions. Windchill is an equivalent measurement for air temperature without wind that would cause the same amount of heat loss from human skin as the combined wind and ambient air temperature (Bluestein and Zecher 1999). High winds create an important secondary hazard to cold temperatures that accelerate heat loss, especially when a person is wearing clothing that is inadequate (Nixdorff-Miller et al. 2006; Yamane et al. 2010).

Windchill temperatures were originally derived from experiments conducted by Antarctic explorers that sought to quantify the additional perceived coldness of the combined ambient air temperature and wind speed (Siple and Passel 1945). Their methodology has since been found to be flawed as it was based on the time it took 250 grams of water in a plastic bottle to freeze while attached to a pole. This did not account for thermal resistance of plastic and the results were not directly transferable to human skin (Bluestein and Zecher 1999). A newer windchill index has been based around experiments with a cylinder approximating an exposed human head moving at walking speed (Osczevski and Bluestein 2005). This windchill scale was put into use with the United States National Weather Service (NWS) in 2001. If the wind speed is less than 5 km $^{h-1}$ (3 mi $^{h-1}$) and/or the air temperature is greater than 10º C (50º F) the NWS does not define the windchill temperature (NWS 2013).

A person's sweat or exposure to moist ambient conditions can also exacerbate core temperature reductions through evaporative cooling (Yamane et al. 2010). Exposure to high winds can also contribute to hypothermia through further evaporative cooling and the creation of small convective currents disrupting the small warm layer of air near the skin (Pugh 1966; Pugh 1967; Young and Castellani 2001; Yamane et al. 2010).

1.3.2 Demographic and Other Risk Factors

1.3.2.1 Age

The elderly have been shown to be at considerable risk for developing hypothermia in epidemiological research, as well as in case studies and cross-sectional research (Rango, 1984; Rango 1985; Taylor and McGwin, 2000; Taylor et al. 2001; Muszkat et al. 2002; Thacker et al. 2008). Thacker et al. (2008) found that the age group of 75 years and greater had crude death rates of approximately 0.7 per 100,000, with the rate increasing to 1.52 per 100,000 for ages greater than 85. Furthermore, prior research in Ireland has indicated that the elderly (defined as 65 years of age or greater) have a higher case fatality rate for hypothermia when compared to other age groups or other causes of death (Herity et al. 1991).

One of the largest contributors to the high level of elderly hypothermia vulnerability is the decreased efficiency of the thermo-regulation system as humans age (Ranhoff 2000; Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006; Pedley et al. 2002). Additionally, actual temperature sensation of the cold is diminished in elderly persons, meaning conditions are not perceived to be as cold (Ballester and Harchelroad 1999; Dharmarajan and Wijidada 2007; Mallet 2002). Many elderly have a smaller body mass index than middle-aged adults. Smaller bodies lose radiative heat more quickly than larger bodies, and many elderly have less subcutaneous fat providing insulation against the cold because of malnutrition (Dharmarajan and Wijidada 2007). Age-related mental decline also contributes to their vulnerability (Dharmarajan and Wijidada 2007).

There are several other factors that confound elderly hypothermia vulnerability. The elderly often live in social isolation, which has been shown to increase vulnerability to natural hazard events, as in, for example, the 1995 Chicago Heat Wave (Smenza et al. 1996). This isolation combined with inefficiencies of the thermo-regulation system can produce a situation in which hypothermia risk is greatly increased, even when indoors. Indoor hypothermia has been noted in several studies and the associated outcome is suggested to be worse for vulnerable groups such as the elderly (Megarbargane et al. 2000; Roeggla et al. 2001; Woodhouse et al. 1989). Eighty-one cases of hypothermia were indentified during the period 1981-1998 in a hospital located in Paris, France (Megarbargane et al. 2000). Twenty-nine of the 81 afflicted individuals perished, with a high percentage of the decedents found indoors. It is thought that indoor hypothermia victims can fare worse than outdoor victims for the following reasons: they are not likely to be found as quickly, there is exposure to moderately cold temperatures for a longer period of time, the victims are more likely to be lightly clothed, and many of these indoor victims are found lying on the ground, which can promote cooling (Lim and Duffou 2008; Megarbargane et al. 2000; Roeggla et al. 2001; Woodhouse et al. 1989). Evidence also suggests if elderly hypothermia victims are in a comatose state at the time of hospital admission survival is less likely (Muszcat et al. 2002).

The elderly appear to have distinct perceptions of natural hazard events that confounds their vulnerability. While there are almost no studies examining the elderly response to cold temperatures (Sherman-Morris 2013), studies examining elderly perception of heat indicate a general “seen it all” attitude. Oftentimes they underestimated the danger, thought that dangerous situations were not as hazardous as the messaging made it seem, or they simply did not self-identify as elderly, so took fewer precautions (Sheridan 2007; Abrahamson et al. 2008).

1.3.2.2 Gender

Males are associated with a higher risk of hypothermia susceptibility compared to females. Several reasons contribute to this higher level of male vulnerability hypothermia. A meta-analysis of psychological research determined that males were more prone to risk-taking behavior (Byrnes et al. 1999), while females have been noted to perceive situations as riskier compared to men (Drabek 1999; Siegrist et al. 2005). Little research exists on gender-specific behavior and response to winter weather conditions; however, women were more likely to perceive higher levels of risk during heat waves (Kalkstein and Sheridan 2007). It is possible women's apparent increase in risk perception might play a protective role against dangerous ambient thermal conditions.

Other factors contribute to this high level of male vulnerability. Men have higher rates of homelessness and alcoholism compared to females, and several case studies have identified high numbers of middle-aged male hypothermia victims who were intoxicated or homeless around the time of death (Tanaka and Tokodome 1991; Gallaher et al. 1992; Taylor and McGwin 2000). In several studies, a considerable number of male victims were found to be intoxicated when they arrived at the hospital, or high blood-alcohol levels were noted during the post-mortem examination (Tanaka and Tokodome, 1991; Gallaher et al.. 1992; Taylor and McGwin, 2000; Taylor et al. 2001). It has also been speculated that the greater numbers of men employed in outdoor, manual labor jobs creates greater exposure to cold temperatures, increasing risk (Taylor and McGwin, 2000; Taylor et al. 2001). However, there have been few studies that gauged the impact of low temperatures on workers employed in outdoor environments.

Several medical studies have found that physiological factors also contribute to male/female gender differences in thermal regulation. During exercise, men generate more internal heat at the same level of oxygen consumption as females, but lose more heat through evaporative heat loss (Gagnon et al. 2008). Women also have lower cutaneous blood flow, meaning that they have a lower skin temperature to environmental temperature gradient and hence lose less heat to the surrounding environment (Stocks et al. 2004).

1.3.2.3 Race/Ethnicity

Race and ethnicity is also an important hypothermia risk factor, as several U.S. studies have found an association between minority status and increased vulnerability to hypothermia (Rango 1984; Rango 1985; Gallaher et al. 1992; Taylor and McGwin, 2000; Taylor et al. 2001; Thacker et al. 2008). Blacks of both genders have higher relative risks than whites of the same gender (Rango 1984; Taylor and McGwin, 2000; Taylor et al. 2001; Thacker et al. 2008). Thacker et al. (2008) also found that people of other races (neither black nor white) had a greater level of hypothermia vulnerability, with crude death rates of approximately 0.6 per one hundred thousand people for both genders. This higher level of minority vulnerability may be a function of lower socio-economic status. One particular case study (Gallaher et al. 1992) examined hypothermia incidence among Native Americans in the state of New Mexico. Their results indicated that Native Americans were 30 times more likely to die of hypothermia than other races in the state. Many of the victims were intoxicated and perished while attempting to walk home to reservations, with deaths concentrated on the outskirts of cities.

1.3.2.4 Individual Risk Factors

Homelessness is a significant risk factor for hypothermia morbidity and mortality, as these individuals are more often exposed to perilous ambient conditions (Taylor and McGwin 2000). Hwang (2001) found that a sample of homeless shelter users in Toronto were sometimes afflicted with cold weather-related ailments. Studies using intensive care unit records in the US (Washington D.C.), Japan, and Austria have found that more than half of all hypothermia-related emergency room admissions in these regions were homeless (Baumgartner et al. 2008; Roeggla et al. 2000; Tanaka and Tokudome 1991). These studies used small sample sizes, so they may not be completely representative of all hypothermia deaths reported in urban areas. Research suggests that sustained cold exposure can lead to diminished cold response (Castellani et al. 2006; Young and Castellani 2007); while it is plausible that the cold response can become blunted in the homeless, no studies directly address this specific aspect. Homeless hypothermia decedents are sometimes found outdoors with high blood alcohol concentrations; alcohol is a significant confounder as it considerably reduces the cold response (Roeggla et al. 2001; Tanaka and Tokudome 1991; Taylor and McGwin 2000). Additional confounders in this population include malnutrition and mental illness (Fazel et al. 2008).

Heavy use of alcohol contributes to a higher risk of developing hypothermia. Ethanol acts as a vasodilator that counteracts the body's vasoconstriction reaction to cold. This means that blood vessels do not contract as vigorously and heat is lost to the surrounding environment, which produces a warm sensation and leads people to perceive that alcohol actually helps combat hypothermia (Epstein and Kiran 2006; Kalant and Le 1984; Mulcahy and Watts 2009; Teresiski et al. 2004). Ethanol also induces a muscle-relaxing effect that hinders shivering thermogenesis (Huttunen 1990; Kalant and Le 1984; Nixdorff-Miller et al. 2006; Teresiski et al. 2004). Intoxication also can act to inhibit shelter-seeking behavior (Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006). Several retrospective studies and reviews have indicated alcoholics have an increased risk for hypothermia morbidity and mortality (Gallaher et al. 1992; Herity et al. 1991; Hislop et al. 1995; Kempainen and Brunette 2004; Roeggla et al. 2001; Taylor and McGwin 2000; Turk 2010).

Underlying medical and mental ailments can also increase one’s susceptibility of developing hypothermia. Physical medical conditions can negatively impact the hypothermia victim’s outcome

(Brändström 2012; Hilsop et al. 1995; Lim and Duffou 2008; Megarbargane et al. 2000; Muszcat et al. 2002; Taylor et al. 2001). Examples of these underlying ailments include respiratory or cardiovascular ailments and stroke (Muszcat et al. 2002). However, diabetes particularly blunts the cold response through decreased cold sensation and so presents a hazard (Kempainen and Brunette 2004).

Mental illnesses (or age-related mental decline) can cause people to incorrectly perceive danger levels and not implement behavioral changes to reduce hypothermia risk. An analysis of descriptive text within the NWS's *Storm Data* uncovered several mentions of a victim that a victim had a mental illness and had gone into cold ambient conditions (Spencer 2009).

1.4 Geography of hypothermia

1.4.1 Hypothermia Deaths and Hospitalizations

The incidence of hypothermia in the United States has been estimated in several studies. Rango (1984) used Centers for Disease Control and Prevention (CDC) data to evaluate the frequency of hypothermia deaths from 1970-1979, identifying 4,826 deaths during the study period. He acknowledged that physicians in emergency departments did not often check for hypothermia when diagnosing patients; as a result, he conjectured that its true incidence was underreported, with as many 50,000 undiagnosed cases of hypothermia each year.

Three subsequent studies have assessed at the national scale the frequency of hypothermia fatalities in the United States. Grey et al. (2002) analyzed hypothermia fatalities for the period 1979-1998. Their study was limited to those deaths in which hypothermia was listed as the primary cause of death on the death certificate, utilizing ICD-9 codes E901.0, E901.8, and E901.9. A total of 13,970 fatalities were identified, an average of approximately 700 deaths per year. The greatest number of deaths occurred in Illinois (859), while Alaska had the highest age-adjusted fatality rate per 100,000 people (2.9). This study did not assess fatalities below the state level.

Dixon et al. (2005) provided an overview of two databases containing temperature-related mortality information, *Storm Data* and the CDC *Multiple Cause of Death File,* in addition to providing a brief descriptive analysis of hypothermia-related fatalities. Expanding upon the research of Grey et al. (2002), they included hypothermia statistics for the year 1999. Hypothermia was the primary cause of death for 598 in people in 1999, and it was listed a secondary injury contributing to death for an additional 1139 people. Therefore, a total of 15,707 hypothermia fatalities from 1979-1999 were attributable to "excessive cold related to weather conditions", an annual mean of 748 deaths (Dixon et al. 2005). Since this study was mainly concerned with database comparison, no spatial analysis of the data was performed.

Thacker et al. (2008) analyzed all natural hazard-related deaths in the United States reported in the CDC dataset from 1979-2004. The study period utilized spanned two ICD classifications schemes, with the data from 1999-2004 using the ICD-10 scheme. Deaths related to natural events could be classified as "other specified origin" and of "other specified origin" when using ICD-9 protocol (Thacker et al. 2008). During the period from 1979-1998, a total of 6782 deaths related to cold weather were classified under one of these classifications; these deaths were not included in Thacker et al.'s analysis. As a result, they identified fewer hypothermia fatalities (10,827, an annual mean of 416) than did Grey et al. (2002), despite using a longer study period. Alaska was the state with the highest crude death rate at 1.45 deaths per 100,000 people, followed by Montana (0.94), New Mexico (0.89) and South Dakota (0.72). The highest crude death rate by region was identified in the Mountain region (AZ, CO, ID, MT, NM, NV, UT, WY), with 0.37 deaths per 100,000 people, compared to a national rate of 0.16 per 100,000 population.

The incidence of hypothermia morbidity has not been well-studied in the United States. Baumgartner et al. (2008) estimated the number of hypothermia-related emergency room visits in the United States by randomly sampling the National Hospital Ambulatory Medical Care survey. A total of 42 cases were identified during a four-week period within short-stay and general care hospitals. Using statistical extrapolation methods, they estimated that 15,574 emergency room visits related to hypothermia occurred from 1995-2004, a yearly average of nearly 1558. There were a number of limitations with this study. The time of year for the random four-week period was not clearly identified, so it is difficult to gauge the overall impact of this period's selection on the results. Secondly, the national estimates arrived at in the study should be assessed cautiously, as the sample size was small, as was the randomly sampled four-week time period. Noe et al. (2012) estimated hypothermia hospitalization for the years 2004-2005 using Medicare insurance claims. They identified 8761 hypothermia-related visits in the US, of which 4% (359) resulted in the death of the patient.

1.5 Hypothermia and Cold Weather Warning Systems

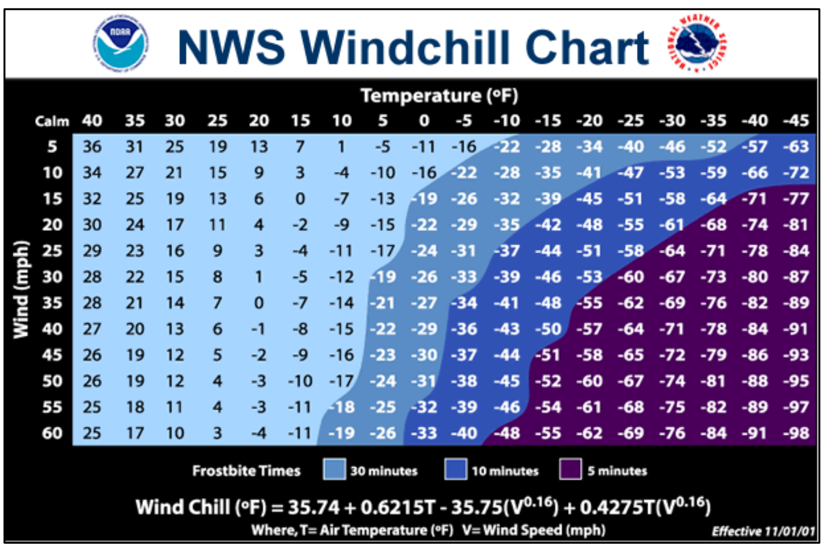
1.5.1 Overview of Heat and Cold Warning and Response Systems

Many cities and municipal areas worldwide have implemented heat-related watch and warning systems (Sheridan and Kalkstein 2004; O' Neill et al. 2011). These systems typically use temperature and humidity criteria to define heat-related events with significant potential to impact public health, and these criteria can vary by region. For example, Toronto, Canada will issue heat alerts when the Humidex is forecast to exceed 40°Celsius (Hassi 2005); in St. Louis, USA, a heat warning is issued when the temperature or heat index is forecast to exceed 41° C (St. Louis Department of Emergency Management 2011). Several cities, such as Philadelphia, Chicago, Toronto, and Seattle, utilize a synoptic methodology to determine past weather types associated with increased heat mortality. When these weather types occur and reach a dangerous threshold, heat warnings are issued and public health responses are put into place (Sheridan and Kalkstein 2004).

Cold weather watches and warnings are not as extensive and many municipalities do not have public health response plans or programs that address the hazards presented by abnormally cold temperatures. Several municipalities/regions have implemented cold warning systems; including Toronto, Ottawa, and the Peel Region of Ontario, Canada; and the Special Administrative Region of Hong Kong, China. The Canadian cities issue cold warnings when Environment Canada forecast temperatures below -15° irrespective of wind chill, if a separate wind chill advisory is issued, or sudden changes that bring wintry conditions are expected (Toronto Shelter, Support, and Housing Administration 2011). In the city of Toronto, teams in Sport-Utility vehicles patrol the streets to inform the homeless of the hazardous weather, and more than 100 public and private organizations in the city prepare indoor space for cold relief (Toronto Shelter, Support, and Housing Administration 2011). This extreme cold warning system is not strictly for the purpose of the general public, but rather to alert and provide additional services to the homeless population. In Ottawa, a general public service announcement is made when these same temperature criteria are met. The Hong Kong Observatory issues cold warnings to the general public when low temperatures are forecast, with bulletins relayed through media outlets such as radio and television.

1.5.2 United States Wind Chill Alerts

The NWS, in addition to performing daily forecasting duties, issues to the public alerts concerning severe and hazardous weather (NOAA Public Affairs 2014). To protect life and property against the threats posed by unusually cold and windy weather (Figure 1.1), WFOs issue a suite of wind chill alert products. The NWS utilizes a tiered system for their wind chill alerts, with each product representing different levels of forecast confidence, as well as event severity and expected impact. These alert levels consist of advisories, watches, and warnings (WFO Winter Weather Products Specification 10-513). Wind chill advisories are issued up to 72 hours in advance of cold and wind events that are anticipated to have “lesser” impacts. This means that seasonably cold temperatures coupled with high winds are expected, but the overall impact and disruption to life and property is not expected to be significant. Wind chill watches and warnings are issued for events that are projected to cause serious disruptions to both life and property. The criteria for watches and warnings feature colder temperatures and higher winds speeds than those for advisories.



Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Figure 1.1. The updated equivalent windchill chart based on more accurate models that better accounted for heat loss from human skin. Displayed on the chart is the equation used to calculate windchill, as well as times to frostbite based on wind speed and temperature (shown in Fahrenheit as this is the temperature scale the NWS utilizes).

While the same criteria and level of disruptiveness apply to watches and warnings, the difference is in the level of forecast confidence. A watch is issued 48 to 72 hours in advance of the anticipated cold and wind event; there is less forecast confidence than a warning. A warning is issued 24 hours or less (sometimes an upgrade to warning occurs while the event is in progress) in advance of the disruptive cold and wind event; the confidence level in the forecast is much higher compared to that of the watch (WFO Winter Weather Products Specification 10-513).

In addition to expected impact and disruption on life and property, all three alert levels have criteria for atmospheric variables that must meet certain thresholds before an alert is issued. These variables include apparent temperature and apparent temperature duration, as well as wind speed and wind speed duration. Typically, the thresholds that initiate alerts for apparent temperatures are colder with distance north. Apparent temperature duration is how long the apparent temperature threshold has to be maintained, for an alert to be issued (typically >3 hours). The next major component is the wind speed, as winds typically need to be above 4.47 m/s or more for an alert to be issued; the wind must also be of a certain duration for an alert to be issued (WFO Winter Weather Products Specification 10-513).

There are some caveats associated with US wind chill alerts. The first issue is one of how criteria are defined in the US NOAA regions. The eastern and central NOAA regions are set by a standard national guidance, while WFOs within NOAA's western and southern regions set their criteria locally. While the wind chill alert temperature criteria generally shows a latitudinal distribution, there are a few things to consider about the criteria: 1) the national guidance is set by the frostbite time chart; 2) local criteria is set less stringently; 3) lastly, definitions of significant impact have considerable variability.

1.6 Conclusions

Hypothermia is a drop in core temperature caused by exposure to cold and exacerbated by physical environmental and demographic factors, along with the victim's underlying physical and mental health status. Hypothermia occurs frequently in the mid-to-high latitudes during the cold season, with drops in temperature associated with increased morbidity and mortality rates. In the US, it is associated with 400-700 recorded deaths per year.

There are a number of physical environmental factors that contribute to an increased hypothermia risk, namely, exposure to cold ambient conditions along with high wind speeds and moist conditions. These conditions promote core cooling, and in the case of the latter two factors, accelerated core temperature decreases through evaporative cooling. Hypothermia goes through three stages of increasing severity, with progressive decreases in cognitive and physical abilities. Death from hypothermia typically occurs through cardiovascular failure from electrolyte imbalance, and the failure of major organ systems as they cannot operate when subjected to such low temperatures.

Demographic factors that are positively associated with increased hypothermia vulnerability are elderly status, male gender and ethnic minority status. Underlying physical and mental impairments, along with homelessness and alcohol abuse, contribute to higher hypothermia susceptibility.

There are a variety of regional responses and alerts related to cold weather events. Administrative areas in Canada, along with Hong Kong, have special responses in place for dealing with cold. This includes opening shelters and directly notifying homeless of the dangerous conditions. In the US, there are no responses to cold weather, only warnings that notify the public of dangerously cold temperature accompanied by high winds.

CHAPTER TWO

INTERNET-BASED HYPOTHERMIA INFORMATION

*This chapter was published in modified format as *Web-Based Hypothermia Information: A Critical Assessment of Internet Resources and a Comparison to Peer-Reviewed Literature* in the journal *Perspectives in Public Health* (2015), in volume 135 (2), pg. 85-91.

2.1 Introduction

Hypothermia is a drop in core body temperature below 35°C (95º F) caused by exposure to cold air or immersion in cold water, or from thermoregulation inefficiencies attributable to senescence or underlying illness (Ballester and Harchelroad 1999; Epstein and Kiran 2006; Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006;). Prominent hypothermia symptoms include shivering, cardiovascular irregularities, and a reduction in mental and physical capabilities (Connolly and Worthley 2000; Epstein and Kiran 2006; Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006; Turk 2010). Hypothermia progresses through three stages: mild, moderate, and severe (Table 2.1). Hypothermia is a significant cause of winter season morbidity and mortality in middle and high latitude regions (Dixon et al. 2005; Herity et al. 1991; Rango 1984; Tanaka and Tokudome 1991; Thacker et al. 2008). There is much hypothermia-related information on the internet, but its scientific validity has not been assessed. This research took a similar approach to a heat vulnerability review conducted by (Hajat et al. 2010) and analyzed the content of web pages containing hypothermia-related information. Websites were identified using Google searches and were reviewed for suitability.

Table 2.1. The three stages of hypothermia and the associated ranges in core body temperature, as well as the symptoms for each stage.

Stage	Core Body Temperature	Symptoms
Mild Hypothermia	35°-33°	Shivering; poor judgment develops; amnesia and apathy; increased heart rate; increased breathing; cold or pale skin
Moderate Hypothermia	32.9°-27°	Progressively decreasing levels of consciousness and stupor; shivering stops; decreased heart rate and breathing; decreased reflexes and no voluntary motion; paradoxical undressing
Severe Hypothermia	<26.9°	Low blood pressure and bradycardia; no reflexes; loss of consciousness; coma; death

The guidance within the websites was aggregated into categories (vulnerable populations, symptoms, prevention, treatment), and the percent of websites that contained each piece of guidance was calculated. The guidance was then compared to peer-reviewed hypothermia literature to determine its scientific validity. It should be noted that this study exclusively assessed direct cold exposure hypothermia, and it did not analyze excess cold morbidity and mortality-related ailments such as cardiovascular disease.

This research is important for a number of reasons. As hypothermia is a considerable source of winter time morbidity and mortality, it is imperative that the best information be available to internet users. Also, medical practitioners can use this research to guide their patients to additional information that is scientifically sound. Hypothermia guidance sections on websites can be redeveloped to more accurately reflect the peer-reviewed literature, allowing users to better prevent hypothermia morbidity and mortality. Evidence-based symptom information will allow users to better identify hypothermia in others. Additionally, weather forecast offices that regularly issue warnings for dangerous cold can include links to websites with valid hypothermia information to those living within their forecast area.

2.2 Methods

A search strategy and website selection criteria were applied in a manner similar to Hajat et al. (2010). The Google search engine was used to search for websites with hypothermia-related information using several search terms, which were: “hypothermia”, “hypothermia treatment”, and “hypothermia and public health department”. Preliminary research using Google Trends indicated these terms were commonly used to search for hypothermia information. Also, we were trying to emulate the search pattern used by lay people when searching for hypothermia information. The first ten pages of results were searched for usable websites; typically, after five pages many repeat results were returned. The redundancy of the results makes the list of websites robust, so that it accounts for variability in search results.

Several exclusionary criteria were applied to eliminate websites with potentially biased or unusable information. The first criterion was that the website could not be an advertisement. As many websites were company web pages dedicated to selling hypothermia prevention products, with guidance centered on the use of the advertised product, these sites were eliminated from analysis. The second exclusionary criterion was that the website not be video-centric, such as YouTube; many results on these websites were not related to medical hypothermia. The third criterion was PDF and text document results had to have an associated web page; those not associated with an active website or broken web links were not assessed because it was impossible to determine document authorship. The last exclusionary criterion was simply eliminating results that contained no information relevant to hypothermia. Of 139 websites identified, 49 met all inclusion criteria (Table 2.2), and several types of websites were identified in this process. Popular (n=14) websites were associated with a variety of institutions and wrote about hypothermia in simpler, less formal terms and were tailored for broader audiences. Medical (22) websites were associated with medical institutions and public health departments, and featured more technical discussions on hypothermia. Outdoors (11) websites were written for audiences engaged in outdoor activities such as hunting, fishing, and hiking, and strongly focused on preventing hypothermia. Special group (2) websites did not fit into the previous categories and presented hypothermia information to specialized audiences.

Table 2.2. A list of the 49 websites utilized in this research, including the name of the website, its web address, and the website's general category. The medical category represents websites for medical institutions and public health departments that have more technical discussions on hypothermia; the popular category is for websites that feature general information on hypothermia, with a writing style meant to reach a wider audience; outdoors websites were those with hypothermia information tailored to those engaged in pursuing outdoor recreational activities, such as hiking; special groups websites were tailored to groups who did not fit into any of the previous categories (one website was tailored toward military applications, and one website was written for elderly viewers).

Website	Web Address	Type of Website
AARP Below Normal Body Temp	http://healthtools.aarp.org/galecontent/hypothermia/1	Special Group
About.com (Marine)	http://maritime.about.com/od/Safety/a/Hypothermia-Prevention-And-Treatment.htm	Popular
About.com (Sports Medicine)	http://sportsmedicine.about.com/od/enviromentalissues/a/extremecold.htm	Popular
Alaska DNR	http://dnr.alaska.gov/parks/safety/hypother.htm	Popular
Boise Health	http://www.boisehealth.com/what-is-hypothermia.php	Medical
Camping Advice Blog	http://www.campingadviceblog.com/hypothermia-prevention-for-backpackers/	Outdoors
CDC Hypothermia	http://emergency.cdc.gov/disasters/winter/staysafe/hypothermia.asp	Medical

Table 2.2 Continued

City of Columbia, Missouri Department of Health and Human Services	http://www.gocolumbiamo.com/Health/hypothermia.php	Medical
City of Stamford, Connecticut, Health Department	http://www.ci.stamford.ct.us/content/25/52/140/214/364/402/435/4805.aspx	Medical
emedicine	http://www.emedicinehealth.com/hypothermia/article_em.htm#Hypothermia%20Overview	Popular
Enter	http://www.enter.net/~skimmer/coldwater.html	Outdoors
Examiner	http://www.examiner.com/article/hypothermia-prevention-begins-before-leaving-the-house	Popular
Family Camping and Hiking	http://www.family-camping-and-hiking.com/hypothermia-symptoms.html	Outdoors
Free MD	http://www.freemd.com/hypothermia/overview.htm	Popular
Get Outdoors	http://www.getoutdoors.com/go/golearn/128	Outdoors
Google Docs	https://docs.google.com/presentation/d/1-hj0F5bG-CiQg059FsDLSuqyKgpBXw3piKYNaE8JTuo/edit?pli=1#slide=id.p	Popular
High Country Explorations	http://highcountryexplorations.com/Preventing_Hypothermia.html	Outdoors
HowStuffWorks	http://adventure.howstuffworks.com/survival/wilderness/how-to-avoid-hypothermia2.htm	Popular
Hypothermia	http://en.wikipedia.org/wiki/Hypothermia	Popular
Illinois Department of Public Health	http://www.idph.state.il.us/public/hb/hbwinter.htm	Medical
Jefferson County, Kansas Health Department	http://www.jfcountyks.com/index.aspx?NID=279	Medical
Kayak Lake Mead	http://kayak-skills.kayaklakemead.com/hypothermia-definition-cause-prevention.html	Outdoors
King County Public Health (Seattle)	http://www.kingcounty.gov/healthservices/health/preparedness/disaster/hypothermia-english.aspx	Medical
MacScouter	http://www.macscouter.com/keepwarm/hypotherm.asp	Outdoors

Table 2.2 Continued

Mayo Clinic	http://www.mayoclinic.com/health/hypothermia/DS00333/DSECTION=prevention-	Medical
Medicine Net	http://www.medicinenet.com/hypothermia/article.htm	Popular
Medline	http://www.nlm.nih.gov/medlineplus/ency/article/000038.htm	Medical
Minnesota Sea Grant	http://www.seagrant.umn.edu/coastal_communities/hypothermia	Medical
Missouri Department of Health and Senior Services	http://health.mo.gov/living/healthcondiseases/hypothermia/surveillance.php	Medical
Montana Department of Public Health and Human Services	http://www.dphhs.mt.gov/newsevents/newsreleases2005/january/extremecold.shtml	Medical
Nature Skills	http://www.natureskills.com/outdoor-safety/hypothermia-prevention/	Outdoors
New South Wales Department of Health	http://www.health.nsw.gov.au/factsheets/environmental/hypothermia.html	Medical
New York Times	http://health.nytimes.com/health/guides/injury/hypothermia/overview.html	Popular
NHS Choices	http://www.nhs.uk/Conditions/Hypothermia/Pages/Introduction.aspx	Medical
Princeton.edu	http://www.princeton.edu/~oa/safety/hypocold.shtml	Medical
Red Cross	http://www.redcross.org/www-files/Documents/Preparing/Frostbite_and_Hypothermia.pdf	Medical
Scubadoc's Diving Medicine	http://www.scuba-doc.com/hypoth.htm	Outdoors
Seattle Backpacker's Magazine	http://seattlebackpackersmagazine.com/2011/04/01/hypothermia-prevention-identification-and-treatment/	Outdoors
Sherman Health	http://www.shermanhealth.com/blog/tipsadvice/its-cold-outside-tips-on-frostbite-hypothermia-prevention	Medical

Table 2.2 Continued

State of Ohio: Committee for Severe Weather Awareness	http://www.weathersafety.ohio.gov/WinterHealthSafetyTips.aspx	Medical
The Free Dictionary (Medical Dictionary)	http://medical-dictionary.thefreedictionary.com/hypothermia	Popular
Third Age	http://www.thirdage.com/hc/c/hypothermia	Popular
Three Rivers District (Nebraska) Health Department	http://threeriverspublichealth.org/heatlth_topics/hypothermia.htm	Medical
University of Maryland Medical Center	http://www.umm.edu/altmed/articles/hypothermia-000092.htm	Medical
US Army Public Health Command	http://phc.amedd.army.mil/topics/discond/cip/Pages/ColdCasualtiesInjuries.aspx	Special Group
Virginia Department of Public Health	http://www.vdh.virginia.gov/weather/ColdWeatherSafety.htm	Medical
Washington State Department of Health	http://www.doh.wa.gov/Emergencies/EmergencyPreparednessandResponse/Factsheets/Hypothermia.aspx	Medical
Weather.com	http://www.weather.com/activities/recreation/ski/articles/snowboarding_frostbite.html	Popular
Wilderness Utah	http://www.wildernessutah.com/learn/hypothermia.html	Outdoors

The hypothermia information within the websites was placed into one of the following categories:

- Populations of increased hypothermia vulnerability (Vulnerable Populations)
- Symptoms of hypothermia (Symptoms)
- Hypothermia risk mitigation measures (Prevention)
- Pre-hospital management and treatment of hypothermia (Treatment)

The information was coded so the guidance could be tallied, and then the percentage of websites including the information was calculated. The hypothermia literature was reviewed to determine the stated guidance's scientific validity. PubMed, a search engine for medical literature, and Google Scholar were searched for hypothermia articles using various search terms (Table 2.3).

Table 2.3. The search terms utilized to identify peer-reviewed hypothermia publications. The first search term was "hypothermia", and the terms listed in these tables comprise the second phrase used in the internet search.

Acclimatization	Homeless	Moisture
Alcohol consumption	Hunger/nausea	Mountain climbers/hikers
Blankets	Inactivity	Move out of cold weather
Cardiovascular problems	Inadequate clothing	No direct heat/bath
Cold exposure	Inadequate food/hydration	Pale/icy skin
Cold weather clothing	Incoherence	Paradoxical undressing
Cover extremities/head	Infants/children	Reduced energy
Drug use	Insulate from the ground	Remove wet clothes
Elderly	Loss of body heat	Sharing body heat
Ethanol	Loss of consciousness	Warm compresses
Exertion	Malnourishment	Warm liquids
Handle victim gently	Medical conditions	Water immersion
Heart conditions	Mental illness	Wind exposure/wind chill

A larger number of search terms were utilized here compared to the Google searches so medical articles directly addressing the website guidance could be identified. Articles were reviewed for suitability, with a total of 65 peer-reviewed papers identified during this process (Table 2.4). The website guidance was then graded using the Strength of Recommendation Taxonomy (SORT), a criteria scale developed by the American Academy of Family Practitioners. These grades rated the website guidance's congruence to the peer-reviewed literature. This ranking method was employed on a position statement issued by the American College of Sports Medicine in a report on cold weather injury and exercise (Castellani et al. 2006; Ebell et al. 2004). This scale utilizes grade rankings of A, B, and C to evaluate the scientific validity of the guidance. An A grade indicates that the guidance is based on consistent and good patient-based scientific evidence. A B grade indicates there is some scientific evidence, but it is of limited quantity and lower quality. A rank of a C indicates that evidence is based on consensus, opinion, or usual practice.

Table 2.4. The references that were utilized to critically assess the hypothermia information found on web pages (references used in background not listed; full list is in the bibliography).

1	Ainslee, P., and Riley, T., 2003. Physiology of Accidental Hypothermia in the Mountains: A Forgotten Story. *Br J Sports Med*, 37, 548-550.
2	Aslam, A.F., Aslam, A. K., Vasavada, B., Khan, I., 2006. Hypothermia: Evaluation, Electrocardiographic Manifestations, and Management. *Am J Med*, 119, 297-301.
3	Bakkevig, M., Nielsen, R., 1994. Impact of Wet Underwear on Thermoregulatory Responses and Thermal Comfort in the Cold. *Ergonomics*, 37 (8), 1375-1389
4	Bakshi, R. 2003. Fatigue Associated with Multiple Sclerosis: Diagnosis, Impact and Management. *Mult Scler*, 9 (3), 219-227.
5	Ballester, J., Harchelroad, F., 1999. Hypothermia: An Easy-to-Miss, Dangerous Disorder in Winter Weather. *Geriatrics*, 54 (2), 51-57.
6	Baumgartner, E., Belson, M., Rubin, C., Patel, M., 2008. Hypothermia and Other Cold Morbidity-Related Emergency Department Visits, United States: 1995-2004. *Wilderness Environ Med*, 19, 233-237.
7	Beim, J., Koehnke, N., Classan, D., Dosman, J., 2003. Out of the Cold: Management of Hypothermia and Frostbite. *CMAJ*, 168 (3), 305-311.
8	Brändström, H., 2012. Accidental Hypothermia and Local Cold Injury: Physiological and Epidemiological Studies on Risk. Doctoral Dissertation, Umea University.
9	Castellani, J., Young, J., Duchame, M., Geisbrecht, G., Glickman, E., Sallis, R., 2006. Prevention of Cold Injuries During Exercise. *Med Sci Sports Exerc*, 2012-2029.

Table 2.4 Continued

10	Connolly, E., Worthley, L., 2000. Induced and Accidental Hypothermia. *Crit Care Resusc*, 2, 22-29.
11	Daanen, H., 2003. Finger Cold-Induced Vasodilation: A Review. *Eur J Appl Physiol*, 89, 411-426.
12	DeGroot, D., Havenith, G., Kenney, L., 2006. Responses to Mild Cold Stress are Predicted by Different Individual Characteristics in Younger and Older Subjects. *J Appl Physiol*, 101, 1607-1615.
13	Dharmarajan, T., Wijidada, D. 2007. Hypothermia in the Geriatric Population. *Aging Health*, 3 (6), 735-741.
14	Epstein, E., Kiran, A., 2006. Accidental Hypothermia. *BMJ*, 332, 706-709.
15	Fazel, S., Khosla, V., Doll, H., Geddes, J., 2008. The Prevalence of Mental Disorders Among the Homeless in Western Countries: Systematic Review and Meta-Regression Analysis. *PLoS Med*, 5 (12), 1670-1681.
16	Froese, G., Burton, A., 1957. Heat Losses From the Human Head. *J Appl Physiol*, 10 (2), 235-241.
17	Gallaher, M., Fleming, D., Berger, L., Sewel, M., 1992. Pedestrian and Hypothermia Deaths among Native Americans in New Mexico between the Bar and Home. *JAMA*, 267 (10), 1345-1348.
18	Galloway, S., Maughan, R., 1998. The Effects of Substrate and Fluid Provision on Thermoregulatory, Cardiorespiratory, and Metabolic Responses to Prolonged Exercise in a Cold Environment in Man. *Exp Physiol*, 83, 419-430.
19	Galloway, S., Wooton, S., Murphy, J., Maughan, R., 2001. Exogenous Carbohydrate Oxidation from Drinks Ingested During Prolonged Exercise in a Cold Environment in Humans. *J Appl Physiol*, 91 (2), 654-660.
20	Giesbrecht, G., 2001. Emergency Treatment of Hypothermia. *Emerg Med*, 13, 9-16.
21	Giesbrecht, G., Sessler, D., Mekjavik, I., Schroeder, M., Bristow, G., 1994. Treatment of Mild Immersion Hypothermia with Body-to-Body Contact. *J Appl Physiol*, 76 (6), 2373-2379.
22	Hartnett, R., O'Brien, E., Sias, F., Pruitt, A., Pruitt, J., 1980. Initial Treatment of Profound Accidental Hypothermia. *Aviat Space Environ Med*, 51 (7), 680-687.
23	Henrikkson, O., Kuklane, K., Holmer, I., Bjornstig, U., 2009. Protection Against Cold in Prehospital Care: Thermal Insulation Properties of Blankets and Rescue Bags in Different Wind Conditions. *Prehosp Disaster Med*, 24 (5), 408-415.
24	Herity, B., Daly, L., Bourke, G., Horgan, J., 1991. Hypothermia Mortality and Morbidity: An Epidemiologic Analysis. *J Epidemiol Community Health*, 45, 19-23.

Table 2.4 Continued

25	Hislop, L., Wyatt, J., McNaughton, G., Ireland, A., Rainer, T., Olverman, G., Laughton, A., 1995. Urban Hypothermia in the West of Scotland. *BMJ*, 311, 725.
26	Holmer, I., 1985. Heat Exchange and Thermal Insulation Compared in Woolen and Nylon Garments During Wear Trials. *Text Res J*, 55, 511-518.
27	Huttunen, P., 1990. Effect of Alcohol on the Processes of Thermoregulation. *Acta Physiol Pol*, 41, 25-31.
28	Hwang, S., 2001. Homelessness and Health. *CMAJ*, 164 (1), 229-233.
29	Irwin, B., 2002. A Case Report of Hypothermia in the Wilderness. *Wilderness Environ Med*, 13 (2), 125-128.
30	Kalant, H., Le, A., 1984. The Effects of Ethanol on Thermoregulation. *Pharmac Ther*, 23, 313-364.
31	Kempainen, R., Brunette, D., 2004. The Evaluation and Management of Accidental Hypothermia. *Respir Care*, 49 (2), 192-205.
32	Kober, A., Scheck, T., Fülesdi, B., Lieba, F., Vlach, W., Friedman, A., Sessler, A., 2001. Effectiveness of Resistive Heating Compared with Passive Warming in Treating Hypothermia Associated with Minor Trauma: a Randomized Trial. *Mayo Clin Proc*, 76 (4), 369-375.
33	Lansdowne, D., Scruggs, V., 1976. The Temperature Dependence of the Movement of Potassium and Chloride Ions Associated with Nerve Impulses. *J Physiol*, 259, 145-158.
34	Lundgren, P., Henriksson, O., Widfelt, N., Wikstrom, T., 2004. Insulated Spine Boards for Prehospital Care in Cold Environments. *Int J Disaster Med*, 2, 33-37.
35	Mallet, M., 2002. Pathophysiology of Accidental Hypothermia. *QJ Med*, 95, 775-785.
36	Mulcahy, A., Watts, M., 2009. Accidental Hypothermia: An Evidence-Based Approach. *Emerg Med Pract*, 11 (1), 1-26.
37	Murthy, G., Hargens, A., Lehman, S., Rempel, D., 2001. Ischemia Causes Muscle Fatigue. *J Orthop Res*, 19, 436-440.
38	Mustafa, S., Shaikh, N., Gowda, R., Khan, I., 2005. Electrocardiographic Features of Hypothermia. *Cardiol*, 103, 118-119.
39	Nixdorff-Miller, A., Hunsaker, D., Hunsaker III, J., 2006. Hypothermia and Hypothermia Medicolegal Investigation of Morbidity and Mortality from Exposure to Environmental Temperature Extremes. *Arch Pathol Lab Med*, 130, 1297-1304.
40	Pedley, D., Patterson, B., Morrison, W., 2002. Hypothermia in Elderly Patients Presenting to Accident and Emergency during the Onset of Winter. *SMJ*, 47 (1), 10-11.

Table 2.4 Continued

41	Peek, G., Davis, P., Ellerton, J., 2008. Management of Severe Accidental Hypothermia. *Intensive Care Med*, Section IV, 147-159.
42	Poszos, R., Danzl, D., 2001. Human Physiological Responses to Cold Stress and Hypothermia. In Medical Aspects of Harsh Environments (Vol. 1). Washington D.C.: Office of the Surgeon General, U.S. Army.
43	Pretorius, T., Bristow, G., Steinman, A., Giesbrecht, G., 2006. Thermal Effects of Whole Head Submersion in Cold Water on Nonshivering Humans. *J Appl Physiol*, 101 (2), 669-675.
44	Pugh, L., 1966. Accidental Hypothermia in Walkers, Climbers, and Campers: Report to the Medical Commission on Accident Prevention. *BMJ*, 1, 123-129.
45	Pugh, L., 1967. Cold Stress and Muscular Exercise, with Special Reference to Accidental Hypothermia. *BMJ*, 2, 333-337.
46	Rango, N., 1984. Exposure-Related Hypothermia Mortality in the United States, 1970-1979. *Am J Public Health*, 74, 1159-1160.
47	Rango, N., 1985. The Social Epidemiology of Accidental Hypothermia Among the Aged. *Gerontologist*, 25 (4), 424-430.
48	Ranhoff, A., 2000. Accidental Hypothermia in the Elderly. *IJCH*, 59:3-4, 255-259.
49	Richards, M., 2008. Dry and Wet Heat Transfer Through Clothing Dependent on the Clothing Properties Under Cold Conditions. *Int J Occup Saf Ergon*, 14, 69-76.
50	Roeggla, M., Holzer, M., Roeggla, G., Frossard, M., Wagner, A., Laggner, A., 2001. Prognosis of Accidental Hypothermia in an Urban Setting. *J Intensive Care Med*, 16 (3), 142-149.
51	Spencer, J., 2009. Winter Weather-Related Fatalities in the Coterminous United States: An Analysis of Three Databases. Master's Thesis, Northern Illinois University.
52	Sterba, J., 1990. Acrtic Cold Weather Medicine and Accidental Hypothermia. Naval Sea Systems Command.
53	Stone, P., Richards, M., Hardy, J., 1998. Fatigue in Patients with Cancer. *Eur J Cancer*, 34 (11), 1670-1676.
54	Stuart, I., Schneider, A., Turner, T., 1989. Perception of the Heat of Sorption of Wool. *Text Res J*, 59 (6), 324-329.
55	Tanaka, M., Tokudome, S., 1991. Accidental Hypothermia and Death From Cold in Urban Areas. *Int J Biometeorol*, 34, 242-246.
56	Taylor, A., McGwin, G., Davis, G., Brissie, R., Holley, T., Rue III, L., 2001. Hypothermia Deaths in Jefferson County, Alabama. *Inj Prev*, 7, 141-145.

Table 2.4 Continued

57	Taylor, A., McGwin, G., 2000. Temperature-Related Deaths in Alabama. *SMJJ*, 93(8), 787-792.
58	Teresiski, G., Buscewicz, G., Madro, R., 2004. Biochemical Background of Ethanol-Induced Cold Susceptibility. *Leg Med*, 7, 15-23.
59	Thacker, M., Lee, R., Sabogal, R., Anderson, A., 2008. Overview of Deaths Associated with Natural Events, United States, 1979-2004. *Disasters*, 32 (2), 305-315.
60	Turk, E., 2010. Hypothermia. *Forensic Sci Med Pathol*, 6, 106–115.
61	Ulrich, A., Rathlev, N., 2004. Hypothermia and Localized Cold Injuries. *Emerg Med Clin N Am*, 22, 281–298.
62	Vreeman, C., Carroll, E., 2008. Festival Medical Myths. *BMJ*, 337.
63	Yamane, M., Oida, Y., Onishi, Y., Matsumoto, T., Kitigawa, K., 2010. Effects of Wind and Rain on Thermal Responses of Humans in a Mildly Cold Environment. *Eur J Appl Physiol*, 109, 117–123.
64	Young, A., Castellani, J., 2001. Exertion Induced Fatigue and Thermregulation in the Cold. *Comp Biochem Physiol A Physiol*, 128, 769-776.
65	Young, A., Castellani, J., 2007. Exertional Fatigue and Cold Exposure: Mechanisms of Hiker's Hypothermia. *Appl Physiol Nutr Metab*, 32, 793-798.

2.3 Results

Overall, 34 facets of hypothermia guidance from the four categories of web-based hypothermia information were assessed. There are four different types of SORT grades included in the tables: Science, Epidemiology, Usefulness, and Usability. The Science grade reflects the medical and physiological evidence for a specific piece of guidance. The Epidemiology category refers to the evidence regarding the vulnerability of specific populations to hypothermia, and is only applicable to the vulnerable populations category. The Usability grade assesses how well a specific symptom indicates the presence of hypothermia, while the Usefulness grade evaluates how early in the course of hypothermia the symptom occurs. The effects of hypothermia are less reversible later in the course of hypothermia, and symptoms that occur later are accordingly graded lower.

2.3.1 Vulnerable Populations

For vulnerable populations, two SORT grades are provided: one assessing the medical evidence and the other assessing epidemiological evidence (Table 2.5).

Table 2.5. The SORT grades given to vulnerable populations.

Category	N	%	SORT Science	SORT Epidemiology
Elderly	29	59%	A	A
Infants/children	23	47%	A	C
Alcohol abusers	16	33%	A	A
Medical conditions	13	27%	A	B
Homeless	12	24%	B	B
Spend time outdoors	12	24%	A	B
Mental illness	8	16%	C	B
Malnourished	3	6%	A	C

The most frequently listed vulnerable population was the *elderly* (Science and Epidemiology SORT grade of A), who appeared on 59% of the websites assessed. Several factors contribute to the high level of elderly hypothermia vulnerability. First, the cold response mechanism becomes less efficient with age (Mulcahy and Watts 2009; Pedley et al. 2002; Ranhoff 2000). Second, actual temperature sensation of the cold becomes blunted as people age (Ballester and Harchelroad 1999; Dharmarajan and Wijidada 2007; Mallet 2002;). Therefore, ambient conditions are not perceived to be as cold. Additionally, many elderly have a smaller BMI than middle-aged adults. Smaller bodies lose radiative heat more quickly than larger bodies, and many elderly have less subcutaneous fat providing insulation against the cold because of malnutrition (Dharmarajan and Wijidada 2007). However, a study by DeGroot et al. (2006) found weak evidence for body fat as a predictor of elderly hypothermia. Age-related mental decline also contributes to their vulnerability (Dharmarajan and Wijidada 2007).

Epidemiological data demonstrate that the elderly have higher rates of both morbidity and mortality compared to other age groups (Herity et al. 1991; Rango 1984; Rango 1985; Taylor and McGwin 2000; Thacker et al. 2008). Additionally, there is the social confounder of isolated living that contributes to their vulnerability (Dharmarajan and Wijidada 2007).

Small children (A, C) were listed as a vulnerable population on 47% of the websites. Small children and infants can lose much heat to the surrounding environment because of high surface area relative to their overall mass, which hypothetically increases their hypothermia vulnerability (Beim et al. 2003; Nixdorff-Miller et al. 2006). However, epidemiological evidence suggests that this age group is less vulnerable to hypothermia, with low overall death rates compared to older age groups (Rango 1984; Taylor et al. 2001; Thacker et al. 2008). Baumgartner et al. (2008) conducted an analysis of hypothermia morbidity from a small sample of U.S. hospital data, and found that persons under the age of 15 were approximately 5% of the sample.

Alcohol abusers (A, A) were listed as a vulnerable group on one-third of the websites analyzed. Ethanol acts as a vasodilator that counteracts the body's vasoconstriction reaction to cold (Epstein and Kiran 2006; Kalant and Le 1984; Mulcahy and Watts 2009; Teresiski et al. 2004). Ethanol can also have a muscle-relaxing effect that hinders shivering thermogenesis (Huttunen 1990; Kalant and Le 1984; Nixdorff-Miller et al. 2006; Teresiski et al. 2004;). Additionally, intoxication can act to inhibit shelter-seeking behavior (Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006). Several retrospective studies have indicated alcoholics have an increased risk for hypothermia morbidity and mortality (Gallaher et al. 1992; Herity et al. 1991; Hislop, et al. 1995; Kempainen and Brunette 2004; Roeggla et al. 2001; Taylor and McGwin 2000; Turk 2010).

Twenty-seven percent of websites stated *underlying medical conditions* (A, B), or taking medicine for medical issues, increased an individual’s susceptibility hypothermia. There are many medical conditions that can potentially increase one's hypothermia risk (Ballester and Harchelroad 1999; Brändström 2012; Kempainen and Brunette 2004). However, diabetes particularly blunts the cold response through decreased cold sensation (Kempainen and Brunette 2004). While many of the deaths contained in data sets list underlying causes of death, it is not easy to obtain information about the victim's medication. Therefore, epidemiologic knowledge of hypothermia and medical conditions is incomplete.

Approximately one-quarter of the websites investigated stated the *homeless* (C, B) are susceptible to hypothermia, as they are dangerously exposed to cold temperatures. Research suggests that sustained cold exposure can lead to diminished cold response (Castellani et al. 2006; Young and Castellani 2007); while it is plausible that the cold response can become blunted in the homeless, no studies directly address this. There are also significant confounders with substance abuse, malnutrition, and mental illness in this population (Fazel et al. 2008). Epidemiological data are difficult to obtain for the homeless; however, Hwang (2001) found that homeless shelter users in Toronto were sometimes afflicted with cold weather ailments. Homeless hypothermia decedents are sometimes found outdoors with high blood alcohol concentrations (Roeggla et al. 2001; Tanaka and Tokudome 1991; Taylor and McGwin 2000).

People who *spend time outdoors* (hikers and workers who willingly spend time outdoors, distinct from homeless) (A, B) were also listed as vulnerable to hypothermia (24%). The cold response follows a different course in this population. Initially, core temperature increases with heavy exertion, compensating for increased heat loss potential due to vasodilatation. However, when the individual rests, core temperature stops increasing and the cold response does not immediately begin, which rapidly sends the victim to hypothermia through evaporative cooling (Ainslee and Riley 2003; Young and Castellani 2007). Two studies (Taylor et al. 2001; Taylor and McGwin 2000) indicated outdoor workers had higher rates of fatalities compared to the average population. However, their studies had small sample sizes and were geographically limited in scope (Jefferson County, Alabama). These two studies did not examine hypothermia morbidity.

Mental illness (C, B) was purported to increase hypothermia vulnerability on 16% of websites. While mental illnesses do not impact the cold response itself, people with these conditions incorrectly perceive danger levels, and do not implement behavioral changes to reduce hypothermia risk. Lack of behavior changes to a stressor does not constitute medical vulnerability. Additionally, this information is not listed on death certificates and official counts of hypothermia deaths of mentally-ill people are difficult to obtain. *Storm Data* is the official source for storm-related losses in the US, and it contains information on hypothermia-related deaths. While this publication is known for undercounting storm-related deaths, some hypothermia deaths in this database contained text describing the context in which the fatality occurred. Some descriptions mentioned the victim had mental illness and had gone into cold ambient conditions (Spencer 2009). Overall, few epidemiological data demonstrate the hypothermia vulnerability of the mentally-ill.

Malnourishment is described in prevention as *food and hydration-related* guidance (A, C). No studies have examined the relationship between hypothermia fatalities and nutrition status as reported on death certificates (Castellani et al. 2006; Galloway et al. 2001; Galloway and Maughan 1998).

2.3.2 Symptoms

Overall, hypothermia symptoms were listed on a higher percentage of websites than the other categories; six of the ten symptoms were identified on 50% or more of the websites (Table 2.6). Symptoms have a three-part SORT taxonomy that gauges several aspects of the guidance. First, the scientific evidence is assessed to determine if the symptom occurs when the victim becomes hypothermic. The second part of the SORT grade is a usability ranking, or how easy it would be to use this symptom as a specific indicator of hypothermia. The last part of the SORT grade is a usefulness rating; i.e., does this symptom occur in the early stages of hypothermia, or does this occur when the effects of hypothermia are irreversible?

Table 2.6. SORT grades given to commonly listed hypothermia symptoms identified on websites.

Category	N	%	SORT Science	SORT Usability	SORT Usefulness
Shivering	39	80%	A	A	A
Mental impairment	39	80%	A	B	B
Physical/coordination impairment	37	76%	A	A	A
Incoherence	30	61%	A	B	B
Cardio-respiratory problems	26	53%	A	B	B
Reduced energy	25	51%	A	B	C
Loss of consciousness	21	43%	A	C	C
Pale/icy skin	14	29%	A	B	B
Paradoxical undressing	4	8%	B	C	C

Shivering (Science SORT grade of A, Usability SORT A, Usefulness SORT A) tied with mental impairment as the most commonly listed symptom on websites (80%). One of the first stages of the cold response, rapid muscle contractions are capable of raising core body temperature by nearly 2°C per hour with adequate energy intake (Epstein and Kiran 2006; Mallet 2002; Mulcahy and Watts 2009). Overall, identifying shivering does not take advanced medical knowledge, and this symptom is also specific to hypothermia. Shivering occurs early during hypothermia (it stops as hypothermia becomes more severe) when the effects are largely reversible (Connolly and Worthley 2000; Mallet 2002; Ulrich and Rathlev, 2004).

Mental impairment (A, B, B) was also listed on 80% of websites. Successive decreases in core body temperature overwhelm the cold response and (Poszos and Danzl 2001). As brain temperature decreases, electrical activity begins to slow down due to impaired conduction (Lansdowne and Scruggs 1976; Mallet 2002; Poszos and Danzl 2001). This has a cascading effect on brain function- first conscious thought is affected, followed by systems that are not under conscious control (breathing, heart rate, etc), leading to a wide range of symptoms. Because a wide range of impacts are involved, mental impairment could be a non-specific symptom based on context, especially if those involved are not outdoors people or if the ambient conditions are not perceived to be dangerous . As a wide variety of conditions cause mental impairment, it is not a clear indicator of hypothermia.

Physical coordination (A, B, B) similarly declines as core temperature decreases, and this was given as a hypothermia symptom on 76% of websites. This is related to the loss of higher mental function and the brain's ability to conduct electrical signals (Poszos and Danzl 2001). As higher thought is reduced, the ability to coordinate one's movements decreases and vasoconstriction reduces blood flow to the extremities. There are other ailments that might cause a rapid loss of coordination; however, in the absence of mentally-impairing substances, this is a reasonable indicator of hypothermia. Physical coordination issues can occur from mild to moderate hypothermia so has limited usefulness (Connolly and Worthley 2000; Nixdorff-Miller et al. 2006).

Incoherence (A, B, B), or the inability to communicate thoughts clearly, was listed as a hypothermia symptom on approximately 60% of the websites. As brain and core temperature drop, neurons have reduced ability to conduct electricity, with a concurrent loss in conscious thought that also reduces the ability to communicate clearly (Epstein and Kiran 2006; Mallet 2002; Poszos and Danzl 2001). While this can indicate the presence of other ailments, the ability to communicate is also linked to body language and behavior. Early on in hypothermia, behavioral changes render the victims withdrawn and difficult to communicate with, so it is a reasonable early indicator of hypothermia (Poszos and Danzl 2001). If all other factors are known to be equal (victim is with acquaintances who know the personality of the victim, and it is known no drinking is involved), this can be a clear indicator of hypothermia. However, it can occur in the moderate hypothermia stage, so its usefulness is limited (Nixdorff-Miller et al. 2006).

Cardio-respiratory problems (A, B, B) were mentioned on 53% of websites. There are many different manifestations of cardiovascular problems of hypothermia. In the initial stages of hypothermia, the heart rate and breathing speed up; as hypothermia becomes more severe, the heart rate begins to slow down, sometimes becoming almost undetectable (Mallet 2002; Mulcahy and Watts 2009; Mustafa et al. 2005). Later stages of hypothermia are associated with electrolyte imbalance; in severe hypothermia the heart can stop completely (Aslam et al. 2006; Mallet 2002; Mulcahy and Watts 2009; Poszos and Danzl 2001). While pulse changes could be detected, heart irregularities are more difficult to judge. Also, in the absence of other symptoms, pulse changes would be insufficient for a field diagnosis of hypothermia. Heart rate changes are well-defined by stage of hypothermia, so they are a strong indicator of hypothermia severity to knowledgeable people. However, for most of the population, it is of limited usefulness for determining the presence of hypothermia.

Reduced energy (A, B, C) was listed on 50% of websites. Experiments performed by Young et al. (1998) demonstrated that after long-term exertion fatigue the cold response becomes compromised. Hypothermia victims have reduced energy levels as hypothermia progresses (Poszos and Danzl 2001). However, reduced energy or constant fatigue is an underlying symptom in a number of ailments (e.g., Cancer, Ischemia, Multiple Sclerosis), limiting its usability in identifying hypothermia (Bakshi 2003; Murthy et al. 2001; Stone et al. 1998;). Overall, its usability is limited because clear indications of reduced energy occur during moderate and severe hypothermia (Poszos and Danzl 2001) and other, more prominent symptoms occur during mild hypothermia.

Other symptoms reported on websites include *loss of consciousness* (43%), *pale/icy skin* (29%), and *paradoxical undressing* (8%). *Loss of consciousness* occurs in the later stages of hypothermia (A, C, C) (Nixdorff-Miller et al. 2006; Poszos and Danzl 2001); however, this symptom is a non-specific diagnostic tool because many other ailments are associated with unconsciousness, and it occurs when the victim's survival is less likely. *Pale/icy skin* (A, B, B), or pallor, refers to the loss of skin color that can occur during hypothermia. This can be concurrent with frostbite and occurs because of reduced blood flow to the extremities and the top layer of skin, making the skin cold to the touch (Poszos and Danzl 2001; Ulrich and Rathlev 2004). This symptom can be indicative of other ailments, so is not hypothermia-specific. However, it can occur in early stages of hypothermia, so it does have some diagnostic utility. *Paradoxical undressing* (B, C, C) is when a victim removes their clothes in the late stages of hypothermia. It is thought that warm blood flowing back to the extremities causes a strong heat sensation, which compels the victim to take off their clothes. This has limited usability and usefulness because paradoxical undressing occurs when the victim's chances of survival are low.

2.3.3 Prevention

Similar to vulnerable populations, only some prevention guidance is mentioned on a high percentage of websites, with the two most commonly observed pieces of guidance centered on clothing-related advice (Table 2.7).

Table 2.7. SORT grades given to hypothermia prevention methods identified on websites.

Category	N	%	SORT Science
Wear appropriate clothing in layers	37	76%	B
Cover extremities/head	25	51%	A
Adequate nutrition and drink	21	43%	A
No alcohol/smoke/caffeine	15	31%	C
Stay dry/do not over-exert	15	31%	A
Avoid cold temperatures/high wind	14	29%	A
Do not wear cotton	7	14%	C
Take time to acclimatize	1	2%	C

Approximately three-quarters of websites listed *wear appropriate clothing in layers* (Science B) as a preventative measure, with 51% of websites also stating to *cover head/extremities* (Science A). Significant heat loss occurs through the skin, and this mitigated by wearing additional clothing (Kempainen and Brunette 2004; Young and Castellani 2001). Heat loss through the head deserves a special explanation, as this specific guidance appeared on many websites. For many years, it was believed that 50% of heat loss occurs through the head, based on flawed early research and a US Military manual (Froese and Burton 1957; Vreeman and Carroll 2008). Pretorius et al. (2006) found that heat loss through the head is no greater than in other parts of the body; uncovered areas lose a proportionally large amount of heat. It is difficult to ascertain what “appropriate” clothing is, and there are a limited number of scientific studies testing the efficacy of various clothing types. In an epidemiological study examining mountain hikers, layered clothing that was alternately removed and added to as activity increased and decreased was the best way to delay the onset of hypothermia (Ainslee and Riley 2003; Young and Castellani 2007). A review of exercise practices in the cold demonstrated that a wind and waterproof outer layer, with a moisture-wicking layer near the skin and a thicker, water absorbent middle layer, was a good way to slow hypothermia onset while engaged in physical activity (Castellani et al. 2006). However, the authors also admitted that it was difficult to give concrete advice in regard to clothing, as individual morphology, and fitness level, played some role in how well subjects resisted the cold. In summary, wearing clothing is paramount to hypothermia prevention, but the exact type of clothing varies based on individual factors. All areas of the body lose heat and need to be covered.

Food and hydration-related guidance (A) appeared on 43% of websites. Increased food intake is needed to fuel the body's cold response and its associated high basal metabolic rate. Without increased energy intake, the body's cold response becomes impaired; however, if properly clothed and not exercising for long periods, the body's core temperature would be higher than resting level and would require only supplementation from small snacks in addition to regular meals (Castellani et al. 2006; Galloway et al. 2001; Galloway and Maughan 1998). *Dehydration* (C) has no impact on the body's cold response (Castellani et al. 2006).

No alcohol, smoking, or caffeine was offered as prevention guidance on 31% of websites. The effects of *alcohol* (A) were analyzed in vulnerable populations under *alcohol abusers*. No research specifically addressed the impacts of *smoking* (C) on hypothermia. *Caffeine* (C) has been noted by several authors (Irwin 2002; Sterba 1990) as a beverage ingredient to avoid because of its diuretic effects. However, as stated earlier, dehydration has no effect on the cold response (Castellani et al. 2006).

Stay dry/do not over-exert (A) was listed on 31% of websites. Water immersion can rapidly cause hypothermia, as water conducts heat 25 times greater than an equivalent volume of air (Turk 2010). Moist ambient conditions can also contribute to core temperature drop through evaporative cooling (Yamane et al. 2010). Exertion can result in perspiration and fatigue, which can impact the cold response (see *reduced energy* and *people who spend time outdoors*).

Avoid cold temperatures and high winds (A) were given as preventative guidance on 29% of the websites assessed. During prolonged exposure to ambient cold temperatures the body loses more heat than it produces, and wind exposure lowers core temperature through evaporative cooling (for perspiring individuals) or the wind creating convection near the skin, which disrupts the stable warm air near the skin (Pugh 1966; Pugh 1967; Yamane et al. 2010; Young and Castellani 2001;). While not capable of cooling the body temperature greatly, the concurrent risk of frostbite makes wind exposure a dangerous phenomenon (Castellani et al. 2006).

Not wearing cotton garments (C) was guidance given on 14% of websites. Some research has attempted to determine the thermal properties of garments in different conditions. Anecdotal evidence states that cotton is a poor insulator when wet, and that wool retains its insulation properties. However, research by Holmer (1985) showed that wet wool garments lost some of their thermal properties when wet, and that wet wool retained thermal properties more than wet nylon garments. Navy diving experiments also demonstrated that wool is a poor insulator when wet (Sterba 1990). Wool has a high heat of sorption, so it is possible this is perceived as increased warmth by the wearer (Stuart et al. 1989). Limited research exists on cotton and its thermal properties when wet. A study by Bakkevig and Nielsen (1994) showed that wet undergarments (cotton, wool, polypropylene, and a wool mix) significantly contributed to cooling; however, the thickness of the garment was more important than the type of fabric in regards to heat retention. Richards et al. (2008) also found that total evaporative heat loss was less for cotton compared to polyester and polypropylene.

One website mentioned that it was useful to take time to *acclimatize to the cold* (C). There are several physiologic mechanisms through which the human body acclimatizes to warm temperatures; in comparison, the body's adaptations to cold are much less robust and are difficult to replicate in a laboratory setting (Castellani et al. 2006). While some anecdotal evidence suggests that people can adapt to cold temperatures, there is little scientific evidence that suggests humans acclimatize to the cold.

2.3.4 Treatment

Field treatment strategies for pre-hospital management of hypothermia were assessed to determine their effectiveness, and were given a SORT grade based on the available scientific evidence (Table 2.8). Generally, the treatment guidance listed on the websites also did not reflect a consensus.

Table 2.8. SORT grades given to pre-hospital treatments administered in the field for hypothermia.

Category	N	%	SORT Science
Move out of cold weather	28	57%	
Remove wet clothes	26	53%	A
Cover with blankets/dry objects	25	51%	A
Warm liquids	19	39%	C
Seek medical attention	18	37%	
Share body heat	17	35%	C
Don't handle roughly	12	24%	B
Insulate from the ground	6	12%	B
No direct heat/bath	6	12%	B

The most commonly listed treatment was to *move out of cold ambient conditions* (57%), followed by *remove wet clothes* (53%), and *cover the victim with blankets and dry objects* (51%). The effectiveness of *moving out of cold weather* depends on the type of environment one moves into. This statement is non-specific and not scientifically assessable.

Removing wet clothes (Science A) was mentioned on 53% of the websites assessed. Wet clothes can lose their insulation properties and contribute to heat loss (Kempainen and Brunette 2004).

Castellani et al. (2006) found that exercising in windy and wet conditions greatly increased the risk of hypothermia. Their recommendations were to have a waterproof outer layer, and to change clothes often, especially socks. Saturated clothing contributing to evaporative clothing is also a problem for mountain hikers, as they exert heavily in cold environments (Ainslee and Rielly 2003; Pugh 1966; Pugh 1967).

Fifty-one percent of the websites in the study stated that *covering the victim with dry blankets* (Science A) was an effective re-warming method. Covering mildly hypothermic victims with blankets has been shown to be effective, because the blankets prevent heat loss while shivering thermogenesis warms the core. Warming rates between 0.5-2° C are possible using this technique (Beim et al. 2003). However, blankets will not work for severely hypothermic patients, as their shivering response completely shuts downs in almost all cases. Such patients need immediate expert medical assistance (Beim et al. 2003; Henrikkson et al. 2009; Peek et al. 2008).

Warm liquids (Science B) were also suggested to be effective hypothermia treatment (40%). The capacity of a warm beverage to raise core temperature is very limited, and its value is primarily limited to providing carbohydrates that can be used as energy for shivering thermogenesis (Giesbrecht 2001).

Approximately 1/3 of the websites stated *sharing body heat* (Science C) was an effective means of treating hypothermia. Geisbrecht et al. (1994) assessed the efficacy of this technique in a small study that immersed volunteers in water to lower their body temperature. Their results indicated that the core temperature increase was less than that of shivering thermogenesis. In fact, they judged the technique to be ineffective because it could blunt the shivering response of the hypothermic individual. Body-to-body rewarming was also demonstrated to produce large afterdrops in temperature (core temperature again dropping after rewarming) than other methods of rewarming such heating pads and inhalation (Hartnett et al. 1980).

One-quarter of the websites stated *do not handle the victim roughly* (Science B), as some field observations suggest that not handling the victim carefully can cause cardiac arrest, as the heart is sensitive to arrhythmias when it is cooled. This was also stated in several peer-reviewed articles (Giesbrecht 2001; Peek et al. 2008; Weinberg 1993; Young and Castellani 2007).

Insulating the victim from the ground (Science B) was guidance given on 12% of the websites. The purpose of this supplemental treatment is to prevent additional core heat from escaping to the ground. A control study from Sweden (Lundgren et al. 2004) indicated that the use of an insulated spine board could provide an important means of temperature regulation during rescue. While the insulated victims did not increase their core temperature faster, their core temperature remained more stable than victims who were placed on the ground without insulation.

No direct heat or immersing them in a warm water bath (Science B) was stated on 12% of the websites. Direct heat is the use of heating pads or blankets to externally warm the victim. Hartnett et al. (1980) found that heating pads did not effectively rewarm the victim, while (Kober et al. 2001) determined that an average rewarming rate of 0.8 C° per hour was possible with heated blankets. This advice is cautioned against because anecdotal evidence suggests that external heat could damage frostbitten skin. Immersing the victim in warm water is capable of providing impressive rewarming rates (Beim et al. 2003; Hartnett et al. 1980). However, this technique makes it difficult to monitor the core temperature of the victim (Beim et al. 2003).

The final guidance given was to *seek medical assistance* (37%). This statement cannot be scientifically assessed; however, this is guidance is sound, especially if the victim's medical status is uncertain.

2.4 Discussion

This paper sought to synthesize available hypothermia information and guidance on the internet and critically compare it to the peer-reviewed literature. This was done because hypothermia information on the internet is widespread, and it has not been assessed for its quality. Overall, 34 pieces of guidance on 49 websites were assessed.

Vulnerable populations were underemphasized on these websites. Additionally, it should be noted that websites do not differentiate between morbidity and mortality for vulnerable populations. The elderly are highly vulnerable to hypothermia, but fewer than 60% of the websites assessed mentioned this. Also, none of the websites identified listed minorities as vulnerable populations. In the U.S. in particular, ethnic minority groups such as African Americans and Hispanics have higher rates of hypothermia deaths than do whites (Thacker et al. 2008). While a review of cold-induced finger vasodilatation demonstrated that blacks had the smallest response (Daanen 2003), the primary driver of this vulnerability is socio-economic disparities (Rango 1984; Thacker et al. 2008).

A considerable portion of the websites focused on stating the symptoms of hypothermia, and comprehensively listed those that could be identified in the field. Shivering, along with mental and physical impairment, were stated as hypothermia symptoms on at least three-quarters of the websites utilized. However, loss of consciousness was stated on 43% of the websites as an important symptom; this symptom is non-specific to hypothermia and is of limited utility for most webpage readers.

Prevention guidance reflected widely varied SORT grades; wearing appropriate clothing in layers was the most frequently stated guidance (76%). While there is a scientific basis to this advice, it is difficult to give concrete guidance in this regard because individual variation impacts cold vulnerability. Nearly one-third of the websites stated that consuming caffeine had a negative impact on the cold response, when in fact the diuretic action of this substance has no appreciable impact on the cold response. In some instances, some guidance based on solid science was not emphasized enough on these websites. For instance, staying dry and not over-exerting was listed on 31% of websites. Staying dry prevents evaporative cooling and not over-exerting allows more of the body's energy reserves to be used for the cold response.

Pre-hospital treatment guidance did not represent a consensus among the websites. No treatment guidance exceeded 60% and there were in general lower SORT grades for this category than for the others. Warm liquids and sharing body heat were treatment strategies stated on 39% and 35% of websites, respectively. Warm liquids have a very small capacity to increase core body temperature, and sharing body heat is in some cases detrimental to the victim. The first and foremost treatment guidance that needs to be emphasized is seeking medical attention. While this statement cannot be assessed for its validity, most mild cases of hypothermia are reversible if the victim receives medical care soon enough, and severe cases require immediate medical intervention.

2.5 Conclusion

An internet search was conducted to obtain websites with hypothermia guidance, and then compare them to peer-reviewed literature to determine their scientific validity. A total of 49 websites were analyzed and compared to 65 peer-reviewed articles. While some symptoms were listed on a high percentage of websites, most other guidance was listed on a smaller percentage of websites. Several populations were highly vulnerable to hypothermia, but these groups were not listed on a considerable percentage of websites. No single treatment method was discussed on more than 60% of websites, and pages featuring this information tended to strongly advocate their use. However, the treatment category was characterized by overall low SORT scores.

While much of the guidance is based on some research, it was oftentimes not easy to determine where a website got its information from. The authors suggest that not only do websites list information sources, but guidance associated with low SORT grades be eliminated. Additionally, increased mention of vulnerable populations will help users identify people around them who might be potentially at risk. These suggestions should make web-based hypothermia information more scientifically sound.

CHAPTER 3

HYPOTHERMIA MORTALITY IN THE UNITED STATES: A QUANTITATIVE ASSESSMENT OF METEOROLOGICAL THRESHOLDS

3.1 Introduction

Excessive heat and its associated hazards have an extensive body of literature that includes vulnerability studies, morbidity/mortality assessments, synoptic climatology analyses, reviews of web-based heat vulnerability guidance, and the effectiveness of municipal watch/warning systems (Bassil and Cole 2010; Basu 2009; Hajat et al. 2010; Sheridan and Kalkstein 2004; Sheridan et al. 2009; Sheridan et al. 2012). In contrast, there is a comparatively small body of research examining these same aspects for excessive cold weather. Hypothermia occurs when core body temperature drops below 35° Celsius (95º Fahrenheit), and is caused by exposure to excess cold temperatures, high winds, or moist conditions, or any combination of all three of these (Turk 2010). There are additional socio-economic factors, including age, gender, and minority status, that increase one's vulnerability to hypothermia (Ballester and Harchelroad 1999; Epstein and Kiran 2006; Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006). While the medical physiology of hypothermia is well-defined, research concerning the spatio-temporal aspects of hypothermia mortality is not well-researched in the United States.

This paper investigates the spatio-temporal distribution of hypothermia mortality in the United States for the years 1979-2004. The Centers for Disease Control and Prevention (CDC) mortality data were obtained for hypothermia deaths for the period of study. These data were assessed spatially by

Combined Statistical Area (CSA) and Metropolitan Statistical Area (MSA) to ensure an adequate sample size. Weather data from the National Climate Data Center (NCDC) were obtained and minimum daily windchill was calculated from temperature and wind data. Descriptive statistics and binomial probability distributions were utilized to determine the probability of a hypothermia death event occurring within a CSA for temperatures ranging from -50º C to 10º C (highest temperature for which wind chill is valid).

The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) is a governmental organization whose mission is to protect life and property from hazardous weather events. The NWS has several products concerning temperature-related warnings, including several wind chill alert products (WFO Winter Weather Products Specification 10-513). To determine the efficacy of the NWS's wind chill-related products, alert data were obtained by consulting NWS websites and guidance products, and by conducting brief email surveys of warning coordination meteorologists. NWS wind chill criteria were obtained for Advisories, Watches, and Warnings for all Weather Forecast Office (WFO) county warning areas. Each CSA was then matched up with the appropriate county warning area wind chill alert criteria. The frequency and probability of hypothermia fatalities were then compared to the criteria to determine how well NWS wind chill alert criteria align with thresholds of hypothermia mortality.

3.2 Background Information

3.2.1 Hypothermia

Hypothermia is medically defined as a drop in core body temperature below 35° C (95° F) (Nixdorff-Miller et al. 2006) and occurs when more heat is lost to the surrounding environment than is generated internally. This can occur through exposure to cold air or immersion in cold water (Turk 2010). A person's sweat or exposure to moist ambient conditions can also exacerbate core temperature reductions through evaporative cooling (Yamane et al. 2010). Exposure to high winds can also contribute to hypothermia through further evaporative cooling and the creation of small convective currents disrupting the small warm layer of air near the skin (Pugh 1966; Pugh 1967; Young and Castellani 2001; Yamane et al. 2010). In addition to environmental factors, there are a number of individual factors that are associated with a person having a greater risk of developing hypothermia: advancing age and its associated thermoregulation inefficiencies, male gender, ethnic minority status, underlying illness, and alcohol consumption (Ballester and Harchelroad 1999; Epstein and Kiran 2006; Gallaher et al. 1992; Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006; Thacker et al. 2008;).

Hypothermia progresses through three stages (Table 3.1): mild, moderate, and severe (Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006). Each of these stages are associated with a set of symptoms. The signs generally associated with hypothermia include shivering, breathing problems and heart arrhythmias, and severe reductions in mental and physical capabilities (Connolly and Worthley 2000; Epstein and Kiran 2006; Mulcahy and Watts 2009; Nixdorff-Miller et al. 2006; Turk 2010). If hypothermia goes unnoticed or untreated, unconsciousness, followed by coma and death, can occur. Therefore, hypothermia constitutes a serious medical emergency.

High numbers of hypothermia deaths are noted to occur in the mid-to-high latitudes in the northern hemisphere, with most epidemiological research on the topic taking place in the US and Scandinavia. We will focus on discussing the epidemiology of hypothermia in US. Rango (1984) used CDC data to evaluate the frequency of hypothermia deaths from 1970-1979, identifying 4,826 deaths during the study period. He acknowledged that physicians in emergency departments did not often check for hypothermia when diagnosing patients; as a result, he conjectured that its true incidence was underreported, with as many 50,000 undiagnosed cases of hypothermia each year.

Table 3.1. The three stages of hypothermia and their associated core body temperature ranges and symptoms.

Stage	Core Body Temperature	Symptoms
Mild Hypothermia	35°-33°	Shivering; poor judgment develops; amnesia and apathy; increased heart rate; increased breathing; cold or pale skin
Moderate Hypothermia	32.9°-27°	Progressively decreasing levels of consciousness and stupor; shivering stops; decreased heart rate and breathing; decreased reflexes and no voluntary motion; paradoxical undressing
Severe Hypothermia	<26.9°	Low blood pressure and bradycardia; no reflexes; loss of consciousness; coma; death

Three subsequent studies have assessed at the national scale the frequency of hypothermia fatalities in the United States. Grey et al. (2002) analyzed hypothermia fatalities for the period 1979-1998. Their study was limited to those deaths in which hypothermia was listed as the primary cause of death on the death certificate, utilizing ICD-9 codes E901.0, E901.8, and E901.9. A total of 13,970 fatalities were identified, an average of approximately 700 deaths per year. The greatest number of deaths occurred in Illinois (859), while Alaska had the highest age-adjusted fatality rate per 100,000 people (2.9). This study did not assess fatalities below the state level.

Dixon et al. (2005) provided an overview of two databases containing temperature-related mortality information, *Storm Data* and the CDC *Multiple Cause of Death File,* in addition to providing a brief descriptive analysis of hypothermia-related fatalities. Expanding upon the research of Grey et al. (2002), they included hypothermia statistics for the year 1999 and also included 1139 deaths in which hypothermia was listed as a secondary cause. Therefore, a total of 15,707 hypothermia fatalities from

1979-1999 were attributable to “excessive cold related to weather conditions”, an annual mean of 748 deaths (Dixon et al. 2005).

Thacker et al. (2008) analyzed all natural hazard-related deaths in the United States reported in the CDC dataset from 1979-2004, which included hypothermia deaths. This time period spanned two ICD classification schemes, with the data from 1979-1998 using the ICD-9 scheme, and the 1999-2004 period utilizing the ICD-10 scheme. ICD-9 protocol allowed deaths related to natural events to be classified as “other specified origin” and of “other unspecified origin” (Thacker et al. 2008). This means the coroner was unable to determine if the hypothermia was attributable to natural cold exposure. During the period from 1979-1998, a total of 6782 deaths related to cold weather were classified as other specified or unspecified; these deaths were not included in Thacker analysis. As a result, they identified fewer hypothermia fatalities (10,827, an annual mean of 416) than did Grey et al. (2002) or Dixon et al. (2005), despite using a longer study period. Alaska was the state with the highest crude death rate at 1.45 deaths per 100,000 people, followed by Montana (0.94), New Mexico (0.89) and South Dakota (0.72).

The incidence of hypothermia morbidity has not been well-studied in either the US or abroad. Baumgartner et al. (2008) estimated the number of hypothermia-related emergency room visits in the United States by randomly sampling the National Hospital Ambulatory Medical Care survey. A total of 42 cases were identified during a four-week period within short-stay and general care hospitals. Using statistical extrapolation methods, they estimated that 15,574 emergency room visits related to hypothermia occurred from 1995-2004, a yearly average of approximately 1558.

Limited research examines the relationship between ambient outdoor conditions and hypothermia fatalities. Tanaka and Tokodome (1991) found that 84% of the 157 reported hypothermia victims in Tokyo from 1974-1983 perished when the outdoor temperatures were 5°C or below.

Hypothermia incidence in Ireland was found to double with every 5.6° C drop in temperature, with the highest mortality rates occurring at temperatures below 1° C (Herity et al. 1991). A study of 138 hypothermia-related fatalities in Israel from 1999-2005 found that 38% of the victims perished during the winter months (Elbaz et al. 2007); an analysis of temperature-related deaths in Alabama found that the highest numbers of hypothermia-related fatalities occurred during December, January, and February (Taylor and McGwin 2000).

3.2.2 Windchill

The winter climate in the northern mid to high latitudes is typified by lower temperatures and moisture content with higher wind speeds than what is typical of summer conditions. Windchill is an equivalent measurement for air temperature without wind that would cause the same amount of heat loss from human skin as the combined wind and ambient air temperature (Bluestein and Zecher 1999). As stated earlier, high winds create an important secondary hazard to cold temperatures that accelerate heat loss, especially when a person is wearing clothing that is inadequate (Nixdorff-Miller et al. 2006; Yamane et al. 2010).

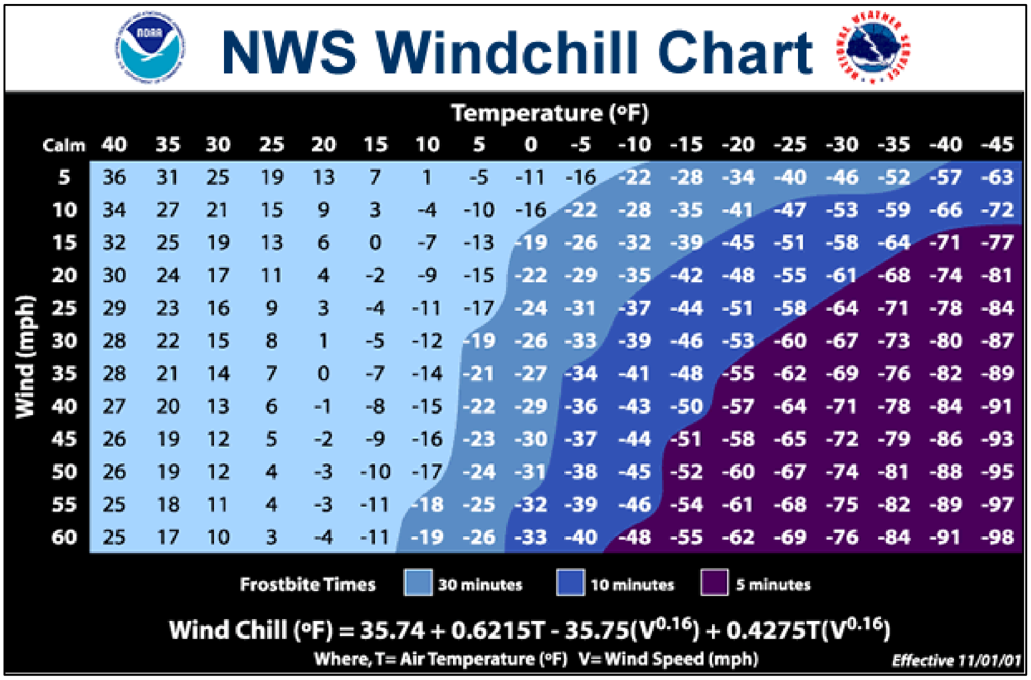
Windchill temperatures were originally derived from experiments conducted by Antarctic explorers that sought to quantify the additional perceived coldness of the combined ambient air temperature and wind speed (Siple and Passel 1945). Their methodology has since been found to be flawed as it was based on the time it took 250 grams of water in plastic bottle to freeze while attached to a pole. This did not account for thermal resistance of plastic and the results were not directly transferable to human skin (Bluestein and Zecher 1999). A newer windchill index has been based around experiments with a cylinder approximating an exposed human head moving at walking speed (Osczevski and Bluestein 2005) (Figure 3.1). This windchill scale was put into use with the US NWS in

2001. If the wind speed is less than 5 km $^{h-1}$ (3 mi $^{h-1}$) and/or the air temperature is greater than 10º C (50º F) the NWS does not define the windchill temperature (NWS 2013).

3.2.3 National Weather Service Windchill Advisories, Watches, and Warnings

The NWS, in addition to performing daily forecasting duties, issues to the public alerts concerning severe and hazardous weather. To protect life and property against the threats posed by unusually cold and windy weather, WFOs issue a suite of wind chill alert products. The NWS utilizes a tiered system for their wind chill alerts, with each product representing different levels of forecast confidence, as well as event severity and expected impact. These alert levels consist of advisories, watches, and warnings (WFO Winter Weather Products Specification 10-513).

Wind chill advisories are issued up to 72 hours in advance of cold and wind events that are anticipated to have "lesser" impacts. This means that seasonably cold temperatures coupled with high winds are expected, but the overall impact and disruption to life and property is not expected to be significant. Wind chill watches and warnings are issued for events that are projected to cause serious disruptions to both life and property. The criteria for watches and warnings feature colder temperatures and higher winds speeds than those for advisories. While the same criteria and level of disruptiveness apply to watches and warnings, the difference is in the level of forecast confidence. A watch is issued 48 to 72 hours in advance of the anticipated cold and wind event; there is less forecast confidence than a warning. A warning is issued 24 hours or less (sometimes an upgrade to warning occurs while the event is in progress) in advance of the disruptive cold and wind event; the confidence level in the forecast is much higher compared to that of the watch (WFO Winter Weather Products Specification 10-513).



Wind (mph)	Temperature (°F)																	
Calm	40	35	30	25	20	15	10	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
5	36	31	25	19	13	7	1	-5	-11	-16	-22	-28	-34	-40	-46	-52	-57	-63
10	34	27	21	15	9	3	-4	-10	-16	-22	-28	-35	-41	-47	-53	-59	-66	-72
15	32	25	19	13	6	0	-7	-13	-19	-26	-32	-39	-45	-51	-58	-64	-71	-77
20	30	24	17	11	4	-2	-9	-15	-22	-29	-35	-42	-48	-55	-61	-68	-74	-81
25	29	23	16	9	3	-4	-11	-17	-24	-31	-37	-44	-51	-58	-64	-71	-78	-84
30	28	22	15	8	1	-5	-12	-19	-26	-33	-39	-46	-53	-60	-67	-73	-80	-87
35	28	21	14	7	0	-7	-14	-21	-27	-34	-41	-48	-55	-62	-69	-76	-82	-89
40	27	20	13	6	-1	-8	-15	-22	-29	-36	-43	-50	-57	-64	-71	-78	-84	-91
45	26	19	12	5	-2	-9	-16	-23	-30	-37	-44	-51	-58	-65	-72	-79	-86	-93
50	26	19	12	4	-3	-10	-17	-24	-31	-38	-45	-52	-60	-67	-74	-81	-88	-95
55	25	18	11	4	-3	-11	-18	-25	-32	-39	-46	-54	-61	-68	-75	-82	-89	-97
60	25	17	10	3	-4	-11	-19	-26	-33	-40	-48	-55	-62	-69	-76	-84	-91	-98

Figure 3.1. The updated equivalent windchill chart based on more accurate models that better accounted for heat loss from human skin. Displayed on the chart is the equation used to calculate windchill, as well as times to frostbite based on wind speed and temperature (shown Fahrenheit as this is the temperature scale the NWS utilizes).

In addition to expected impact and disruption on life and property, all three alert levels have criteria for atmospheric variables that must meet certain thresholds before an alert is issued. These variables include apparent temperature and apparent temperature duration, as well as wind speed and wind speed duration. Typically, the thresholds that initiate alerts for apparent temperatures are colder with distance north. Apparent temperature duration is how long the apparent temperature threshold has to be maintained, for an alert to be issued (typically >3 hours). The next major component is the wind speed, as winds typically need to be above 4.47 m/s or more for an alert to be issued; the wind must also be of a certain duration for an alert to be issued (WFO Winter Weather Products Specification 10-513).

There are some caveats associated with US wind chill alerts. The first issue is one of how criteria are defined in the US NOAA regions. The eastern and central NOAA regions are set by a standard national guidance, while WFOs within NOAA's western and southern regions set their criteria locally. While the wind chill alert temperature criteria generally shows a latitudinal distribution, there are a few things to consider about the criteria: 1) the national guidance is set by the frostbite time chart; 2) local criteria is set less stringently; 3) lastly, definitions of significant impact have considerable variability.

3.3 Data and Methods

3.3.1 Hypothermia Death Data

Hypothermia death data come from the CDC Primary Cause Multiple Cause of Death File. These data are processed annually by county and state medical examiners and are sent to CDC headquarters to be processed and added to the national dataset. This data set is a comprehensive listing of all deaths that occur in the United States each year, and includes cause of death, time, the victim's county of residence, as well as their demographic data. The fatalities are classified under the International Cause of Death classification scheme (ICD-9 and ICD-10) according to the information given on the death certificate (Table 3.2). Deaths that occurred before 1999 use the ICD-9 scheme, and those that occurred after 1999 use the ICD-10 scheme. More detailed information concerning the classification of weather-related mortality data in the CDC database is available in Dixon et al. (2005).

One caveat associated with the use of the CDC dataset is the underlying cause of death is determined by a medical examiner/physician, so it cannot always be determined if the hypothermia fatality was directly caused by a weather event and/or prolonged exposure to below-freezing ambient temperatures. This means caution needs to be exercised when comparing the temporal trends of hypothermia mortality to patterns of atmospheric variability. It is possible that hypothermia incidence in the US is underreported, which can result from the inability of coroners to identify hypothermia, misidentifying hypothermia as other ailments, and unavailability of low-temperature thermometers, which are critical for diagnosing hypothermia (Rango 1984; Taylor and McGwin 2000).

Table 3.2. Comparison of ICD-9 and ICD-10 categories for hypothermia fatalities.

ICD-9	ICD-9 Category Description	ICD-10	ICD-10 Category Description
E 901.0	Hypothermia due to weather conditions, excessive cold	X31	Hypothermia due to weather conditions, excessive cold, or not otherwise specified
E 901.8	Other unspecified origin	“”	E 901.8 moved to X-31
E 901.9	Other specified origin	“”	E 901.9 moved to X-31
E 901.1	Of man-made origin	W93	Of man-made origin

This study utilized CDC death data from 1979-2004 for the codes E901.0, E901.8, E901.9 (ICD-9) and X31 (ICD-10). As the E901.0, E901.8, and E901.9 codes were pooled to a single code for ICD-10, we utilized these three E-codes for years corresponding to ICD-9 (1979-1999) and the X31 code for years corresponding to ICD-10 (2000-2004) for this research. The only code that was not utilized in this study was E901.1, which is for unnatural causes of hypothermia. To limit the possibility of non-weather related deaths in the dataset, only fatalities for the cool season between November and April were assessed. This monthly range was most associated with cold, wintry conditions that would result in hypothermia fatalities. Each fatality was geographically identified by a FIPS code, or a numeric identifier for the county which it occurred in. County-level data were aggregated to larger geographic units of analysis (Combined Statistical Areas and Metropolitan Statistical Areas) to create a viable sample size. A minimum of 26 fatalities, or one per year, was required for an area to be analyzed. A total of 88 CSAs and MSAs met this criterion (Table 3.3 and Figure 3.2). Only one area in this study that was not a CSA or MSA was included: the Gallup area, which consists of three adjacent counties in western New Mexico and eastern Arizona. This region had a large number of deaths (233), so these counties were combined and assessed.

Table 3.3 Metro areas and associated weather stations utilized in the study period. The average population was derived by using 1990 and 2000 Census data, interpolating the population in the intermediate years, and then calculating the mean. The # column is for the numbers associated with each study site for mapping purposes (Figure 4).

Study Site	Weather Station	#	Average Population
Albany-Schenectady-Amsterdam, NY (CSA)	Albany International Airport	1	1100280
Albuquerque, NM (MSA)	Albuquerque International Sunport	2	607672
Allentown-Bethlehem-Easton, PA-NJ (MSA)	Lehigh Valley International Airport	3	601513
Anchorage, AK (MSA)	Ted Stevens Anchorage International Airport	4	231430
Asheville-Brevard, NC (CSA)	Asheville Regional Airport	5	343269
Atlanta-Sandy Springs-Gainesville, GA-AL (CSA)	Hartsfield-Jackson Atlanta International Airport	6	3502025
Atlantic City-Hammonton, NJ (MSA)	Atlantic City International Airport	7	228561
Augusta-Richmond County, GA-SC (MSA)	Augusta Regional Airport	8	424523
Austin-Round Rock-Marble Falls, TX (CSA)	Camp Mabry	9	906757
Birmingham-Hoover-Cullman, AL (CSA)	Birmingham-Shuttlesworth International Airport	10	1040247
Boston-Worcester-Manchester, MA-RI-NH (CSA)	Logan International Airport	11	5403915
Buffalo-Niagara-Cattaraugus, NY (CSA)	Buffalo Niagara International Airport	12	1186456
Charleston-North Charleston-Summerville, SC (MSA)	Charleston International Airport	13	513199
Charlotte-Gastonia-Salisbury, NC-SC (CSA)	Charlotte Douglas International Airport	14	1560969

Table 3.3 Continued

Chattanooga-Cleveland-Athens, TN-GA (CSA)	Chattanooga Metropolitan Airport	15	572940
Chicago-Naperville-Michigan City, IL-IN-WI (CSA)	Chicago O'Hare International Airport	16	8524426
Cincinnati-Middletown-Wilmington, OH-KY-IN	Cincinnati-Northern Kentucky International Airport	17	1905808
Cleveland-Akron-Elyria, OH (CSA)	Cleveland Hopkins International Airport	18	2872572
Columbia-Newberry, SC (CSA)	Columbian Metropolitan Airport	19	596771
Columbus-Auburn-Opelika, GA-AL (CSA)	Columbus Metropolitan Airport	20	384890
Columbus-Marion-Chillicothe, OH (CSA)	Port Columbus International Airport	21	1646933
Dallas-Fort Worth, TX (CSA)	Dallas/Fort Worth International Airport	22	4319226
Davenport-Moline-Rock Island, IA-IL (MSA)	Quad City International Airport	23	352091
Dayton-Springfield-Greenville, OH (CSA)	Dayton International Airport	24	1081632
Denver-Aurora-Boulder, CO (CSA)	Stapleton International Airport (1979-1995); Denver International Airport (1995-2004)	25	1961815
Des Moines-Newton-Pella, IA (CSA)	Des Moines International Airport	26	461261
Detroit-Warren-Flint, MI (CSA)	Detroit Metropolitan Wayne County Airport	27	5134971
Duluth, MN-WI (MSA)	Duluth International Airport	28	240548
El Paso, TX (MSA)	El Paso International Airport	29	604812
Evansville, IN-KY (MSA)	Evansville Regional Airport	30	281571
Fayetteville, NC (MSA)	Fayetteville Pope Air Force Base	31	278826
Gallup, NM-AZ (Counties)	Gallup Municipal Airport	32	220503
Grand Rapids-Muskegon-Holland, MI (CSA)	Gerald R. Ford International Airport	33	1108897
Greensboro-Winston-Salem-High Point, NC (CSA)	Piedmont Triad International Airport	34	1118959
Greenville-Spartanburg-Anderson, SC (CSA)	Pitt-Greenville Airport	35	692401
Hartford-West Hartford-Willimantic, CT (CSA)	Bradley International Airport	36	1230929
Houston-Baytown-Huntsville, TX (CSA)	George Bush Intercontinental Airport	37	3999171
Huntsville-Decatur, AL (CSA)	Huntsville International Airport	38	434149
Indianapolis-Anderson-Columbus, IN (CSA)	Indianapolis International Airport	39	1632100
Jacksonville, FL (MSA)	Jacksonville International Airport	40	935792
Jackson-Yazoo City, MS (CSA)	Jackson Evers International Airport	41	480382
Johnson City-Kingsport-Bristol (Tri-Cities), TN-VA (CSA)	Tri-Cities Regional Airport	42	442654

Table 3.3 Continued

Kansas City-Overland Park-Kansas City, MO-KS (CSA)	Kansas City International Airport	43	1726738
Knoxville-Sevierville-La Follette, TN (CSA)	McGhee Tyson Airport	44	684878
Lansing-East Lansing-Owosso, MI (CSA)	Capital Regional International Airport	45	504990
Lexington-Fayette-Frankfort-Richmond, KY (CSA)	Blue Grass Airport	46	526837
Little Rock-North Little Rock-Pine Bluff, AR (CSA)	Clinton National Airport	47	709921
Los Angeles-Long Beach-Riverside, CA (CSA)	Los Angeles International Airport	48	14807846
Louisville-Jefferson County-Elizabethtown-Scottsburg, KY-IN (CSA)	Louisville International Airport	49	1195073
Madison-Baraboo, WI (CSA)	Dane County Regional Airport	50	490953
Memphis, TN-MS-AR (MSA)	Memphis International Airport	51	1026552
Miami-Fort Lauderdale-Pompano Beach, FL (MSA)	Miami International Airport	52	3295152
Milwaukee-Racine-Waukesha, WI (CSA)	General Mitchell International Airport	53	1619541
Minneapolis-St. Paul-St. Cloud, MN-WI (CSA)	Minneapolis-Saint Paul International Airport	54	2879039
Mobile-Daphne-Fairhope, AL (CSA)	Mobile Regional Airport	55	486423
Montgomery-Alexander City, AL (CSA)	Montgomery Regional Airport	56	311378
Nashville-Davidson-Murfreesboro-Columbia, TN (CSA)	Nashville International Airport	57	1144767
New Orleans-Metairie-Bogalusa, LA (CSA)	Louis Armstrong New Orleans International Airport	58	1315505
New York-Newark-Bridgeport, NY-NJ-CT-PA (CSA)	LaGuardia Airport	59	19957973
Oklahoma City-Shawnee, OK (CSA)	Will Rodgers World Airport	60	1049473
Omaha-Council Bluffs-Fremont, NE-IA	Eppley Airfield	61	732733
Orlando-Deltona-Daytona Beach, FL (CSA)	Orlando International Airport	62	1322651
Philadelphia-Camden-Vineland, PA-NJ-DE-MD (CSA)	Philadelphia International Airport	63	5612531
Phoenix-Mesa-Glendale, AZ (MSA)	Phoenix Sky Harbor	64	2390489
Pittsburgh-New Castle, PA (CSA)	Pittsburgh International Airport	65	2558714
Portland-Lewiston-South Portland, ME (CSA)	Portland International Jetport	66	553243
Portland-Vancouver-Hillsboro, OR-WA (MSA)	Portland International Airport	67	1864238
Raleigh-Durham-Cary, NC (CSA)	Raleigh-Durham International Airport	68	1007703
Richmond, VA (MSA)	Richmond International Airport	69	885271

Table 3.3 Continued

Rochester-Batavia-Seneca Falls, NY (CSA)	Greater Rochester International Airport	70	1101462
Sacramento-Arden-Arcade-Yuba City, CA-NV	Sacramento Executive Airport	71	1638684
Salt Lake City-Ogden-Clearfield, UT (CSA)	Salt Lake City International Airport	72	1201044
San Antonio-New Braunfels, TX (MSA)	San Antonio International Airport	73	1364894
San Diego-Carlsbad-San Marcos, CA (MSA)	San Diego International Airport	74	2545389
San Jose-San Francisco-Oakland, CA (CSA)	San Francisco International Airport	75	6410396
Scranton-Wilkes-Barre, PA (MSA)	Wilkes-Barre/Scranton International Airport	76	636413
Seattle-Tacoma-Olympia, WA (CSA)	SeaTac International Airport	77	3097993
Shreveport-Bossier City-Minden, LA (CSA)	Shreveport Regional Airport	78	404094
South Bend-Elkhart-Mishawaka, IN-MI (CSA)	South Bend International Airport	79	459736
St. Louis-St. Charles-Farmington, MO-IL (CSA)	Lambert International Airport	80	2648480
Syracuse-Auburn, NY (CSA)	Syracuse Hancock International Airport	81	740668
Tampa-St. Petersburg-Clearwater, FL (MSA)	Tampa International Airport	82	2117165
Toledo-Fremont, OH (CSA)	Toledo Express Airport	83	716849
Tucson, AZ (MSA)	Tucson International Airport	84	693410
Tulsa-Bartlesville, OK (CSA)	Tulsa International Airport	85	824001
Virginia Beach-Norfolk-Newport News, VA-NC (MSA)	Newport News/Williamsburg International Airport	86	1462189
Washington-Baltimore-Northern Virginia, DC-MD-VA-WV (CSA)	Reagan National Airport	87	6796202
Wichita-Winfield, KS (CSA)	Wichita Mid-Continent Airport	88	556941

3.3.2 Weather Data

Weather data were obtained from the NCDC from both the NCDC Climate Data Online website (2013) and from Dr. Scott Sheridan’s Spatial Synoptic Classification homepage (2013) for the period from 1979-2004 for the months November through April. Most weather stations selected were first-order weather stations located at international airports, as these stations have robust data sets with consistent data collection (Table 3.3). If a first-order weather station was unavailable, an alternate station was chosen based on completeness of record, availability of variables to analyze, and if possible, central location within the geographic area being analyzed.

The NCDC data were collected daily and included minimum temperature, maximum temperature, total precipitation, and snowfall. These data were collected four times daily (3 CST, 9 CST, 3 CST, 9 CST) and included temperature and wind speed. Wind chill temperatures were calculated for each observation time in the SSC dataset. If the wind speed was less than 5 km $^{h-1}$ (3 mi $^{h-1}$) or the air temperature was greater than 10º C (50º F), then the wind chill temperature for that time was not calculated and the ambient air temperature was used instead. Then the minimum windchill temperature/air temperature for each day was determined. These data were then joined with the hypothermia fatality data.

3.3.3 Windchill Alert Data

Wind chill alert information was obtained by several means. Firstly, basic information on the types and definitions of various wind chill alert levels were found at the NOAA glossary. Then, NOAA directives for the Eastern, Central, and Alaskan regions were used to complete centralized tables containing all relevant wind chill alert information. As stated earlier, these winter weather directives contain information on the suggested wind chill thresholds, or national guidance. Offices that fall within these regions follow this national guidance, though the temperature thresholds typically decrease with more northerly latitudes. Offices that are located within NOAA's Western and Southern regions are allowed to set local criteria themselves.

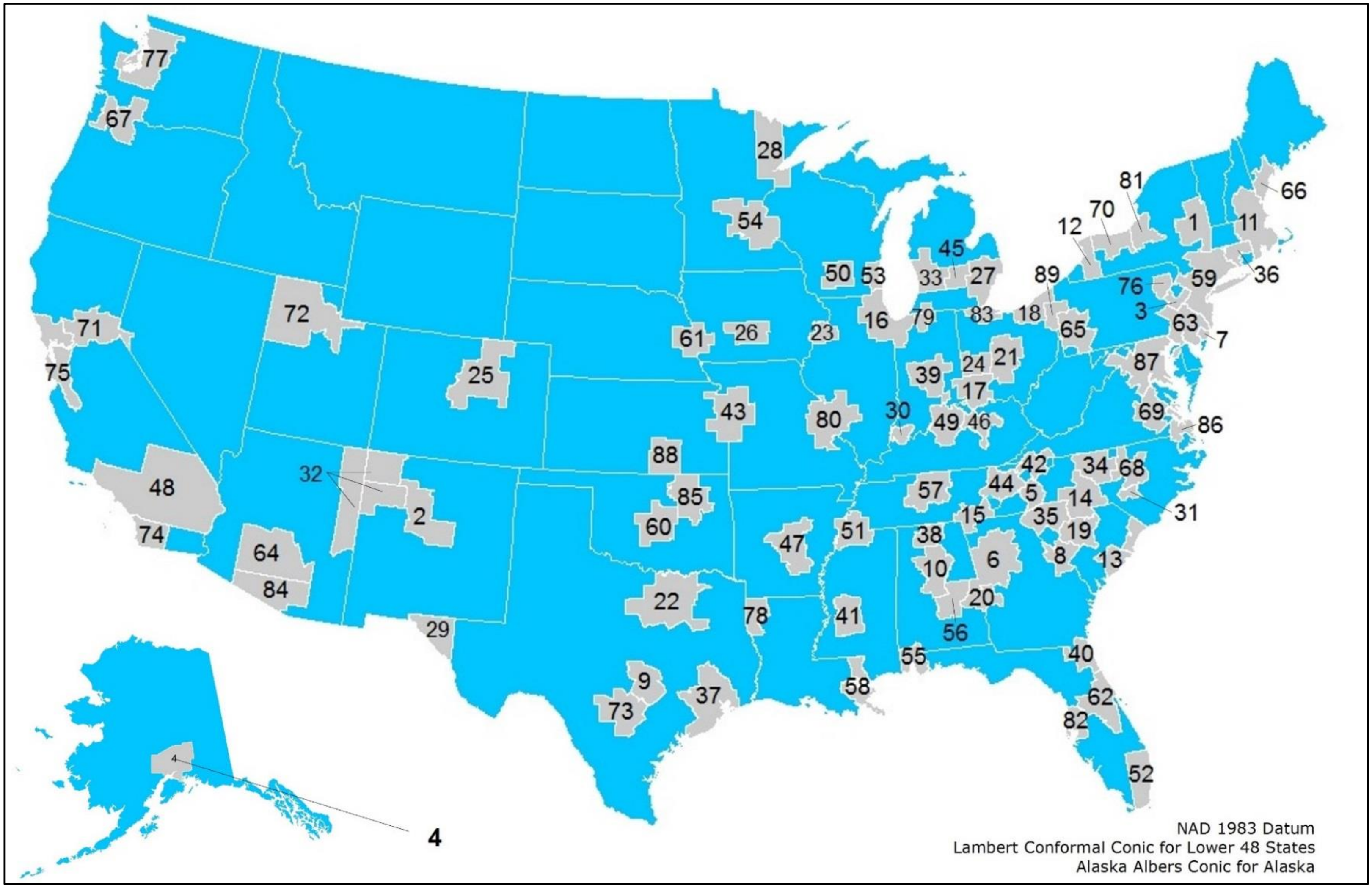


Figure 3.2. The study sites utilized within this research. The sites were sorted alphabetically and then assigned an ordinal rank for drawing the map.

While some of this information was available via the specific WFO website, most offices within this region had to be contacted to determine specific alert information. The WCM at each of these offices was emailed and asked the following questions:

- What are the wind chill products issued by this weather forecast office?
- What criteria are used to determine if and what type of alert should be issued?
- What methods were used to develop these criteria? How were these apparent temperature thresholds selected?

This small questionnaire was developed after reading the directives and determining what types of information and weather variables go into the alert issuance decision process, so that the same information would be obtained from the Western and Southern WFOs. These questions also allowed the WCM to elaborate any additional information that is important when issuing a warning. The information contained within the web sources, personal communications, and directives were summarized and placed into one of the following categories:

- Temperature threshold, or the apparent temperature required to issue a warning
- Temperature duration, or how long that apparent temperature threshold had to be maintained to issue an alert
- Wind speed, or the minimum speed needed to activate an alert
- Wind duration, or the minimum time that a particular wind speed must be maintained for an alert to be issued
- Lead time, or the amount of time the aforementioned variables were forecast to reach and maintain threshold criteria (the lead time impacts the severity of the warning)

The ranges of temperatures and wind speeds were binned into several categories so the general patterns of alert thresholds could be mapped in a geographic information system (GIS). The WFO code was used as a location proxy and joined with location data from the wind chill alert data table.

3.3.4 Population Data

Data from the US Census Bureau were obtained from the US Census Bureau American FactFinder Website to determine the population of each area that was analyzed. County-level data were aggregated into CSA and MSA level population counts, and the average population for the study period was interpolated from 1990 and 2000 Census data.

3.3.5 Additional Data Analysis Methods

3.3.5.1 Descriptive Statistics

Spreadsheet tables were tabulated to determine the total number of deaths that occurred within each analysis area during the study period. These total counts along with the population estimates were used to calculate the death rate per 100,000 population for each metro area. Additionally, wind chill temperature bins were created, and the number of days that each wind chill temperature range occurred was determined, as well as the number of fatalities within these wind chill temperature ranges. The wind chill temperatures bins ranged from -50º C to 10º C with an interval of 5º C. The rates of death per 100,000 population per 100 temperature range occurrences was then calculated from these counts. This allowed for a comparison of vulnerability between each of the metro areas. The metro areas were binned into regions, or areas of similar characteristics so that a broader overview of regional vulnerable could be examined. The data were then mapped using geographic information system software, and the data were categorized using a five-class Jenks Natural Breaks classification scheme.

3.3.5.2 Binary Regression and Binomial Probability

To further determine hypothermia vulnerability at the CSA level, binary logistic regression was performed to determine the probability that a hypothermia death event (dependent variable) would occur based on windchill temperature (independent variable). Each day had hypothermia death data and was classified using a binary scheme; any day with no fatalities was a "0", and any day with one or more fatalities was a "1". The binary logistic regression was then performed to determine the line of best fit between minimum wind chill value and days with hypothermia fatalities. The constant and coefficient obtained from the binary regression line of best fit were utilized to calculate a binomial probability distribution using the logistic curve equation $P = e^{a+bX}/1 + e^{a+bX}$. This logistic curve related the independent variable (windchill temperature) to the dependent variable (a hypothermia death event occurring) and resulted in a percent probability of a death event occurring at a given temperature.

3.3.5.3 Median Threshold Temperature

To directly compare the relative vulnerabilities of the metro areas, a threshold analysis was performed. Each metro area's hypothermia data was ordered and the median daily minimum windchill temperature associated with hypothermia deaths was calculated.

3.4 Results

3.4.1 Hypothermia Fatalities

3.4.1.1 Descriptive Statistics

3.4.1.1.1 Overview of Deaths

Hypothermia deaths were analyzed for the United States from 1979-2004 for the cool season months (November to April). A total of 89 metro areas met the inclusion criteria (>26 deaths for the period) and these were a mix of combined statistical areas, metropolitan statistical areas, and one three-county area non-CSA/MSA. A total of 16,272 hypothermia deaths were identified from 1979-2004 for the months November to April for the entire US. During the study period, a total of 9185 fatalities occurred within the analyzed areas, an annual average of approximately 353 deaths.

The seasonal pattern (November through April) of fatalities demonstrated considerable interseasonal variability, with a maximum of 576 in 1983-1984 and a minimum of 221 in 1997-1998. Fatalities rapidly increase from November to December and reach a peak of 2875 in the month of January (Figure 3.3). The number of deaths then decreases, reaching a minimum of 388 in the month of April. In spite of the January maximum, a large number of deadly calendar days and outbreak sequences occurred in the month of Decemeber; these are detailed in the following section.

3.4.1.1.2 Deadliest Days

There were a number of individual days and/or sequences of days that contributed greatly to the total number of hypothermia deaths. The single deadliest day observed in the sample was December 25, 1983, for which 75 deaths were reported (Table 3.4). December 25 was the deadliest day of the year within the study period for the metro areas assessed, with a total of 174 fatalities reported.

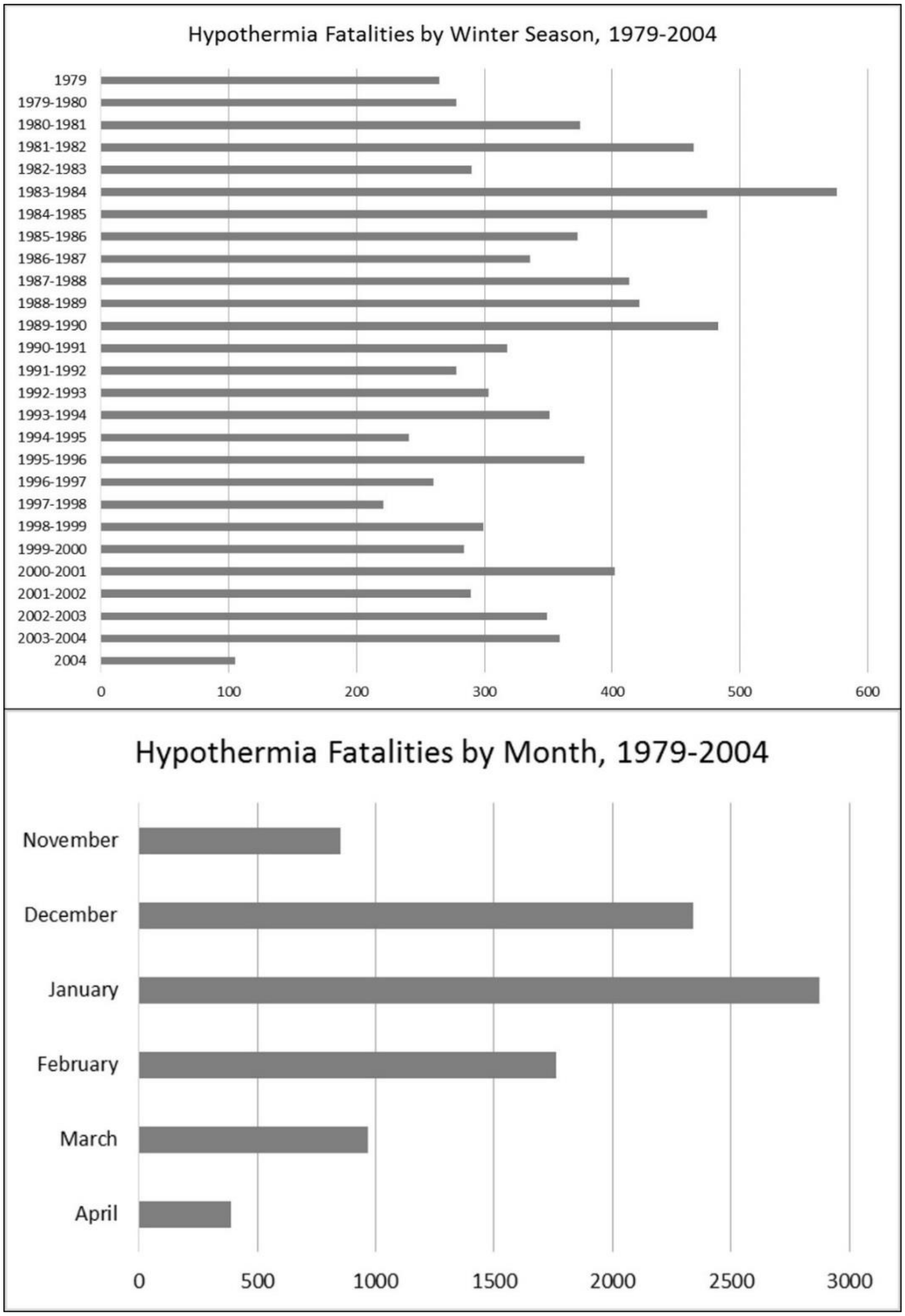


Figure 3.3 The top chart shows the seasonal distribution of hypothermia deaths. The first and last seasons are incomplete because the endpoints encompass the full range of the data. The bottom charts shows the monthly distribution of hypothermia deaths.

Table 3.4. The ten deadliest calendar dates for hypothermia-related fatalities.

Date	Number of Fatalities
25th December 1983	75
26th December 1983	43
21st January 1985	40
24th December 1989	28
24th December 1983	25
23rd December 1989	23
27th December 1983	23
22nd December 1985	23
11th January 1982	22
20th January 1985	20

There were four significant cold air outbreaks during the study period: January 1982, December 1983, January 1985, and December 1989. These cold air intrusions were associated with strong surface anti-cyclones along with an associated strengthening of the polar vortex. A total of 604 hypothermia deaths occurred during these outbreak sequences; this was approximately 7% of the deaths reported for the study areas from 1979-2004. Furthermore, two of these outbreaks occurred around the Christmas Holiday, which contributed to high mortality counts observed on the calendar days around Christmas.

3.4.1.1.3 Rates of Death

The metro areas with the highest total counts of deaths are northern cities with large populations. By examining vulnerability rates, a different picture of hypothermia susceptibility emerges (Table 3.5).

The lowest rates of death are found in a belt that stretches from the Deep South (a geographic area encompassing the far southern parts of the US, including the Florida, the Gulf Coast and the Desert

Southwest along the US/Mexico border) and along the Pacific Coast (Figure 3.4). Higher rates of hypothermia fatalities are found in the central United States, in metro areas on the periphery of the Great Plains region, such as Duluth, and in the large northern metro area, such as Chicago and Detroit. In spite of the southwestern Desert regions of the US having generally low fatality rates, the overall highest rates for any metro area was observed in the three-county area in northern New Mexico and adjacent Arizona (Figure 3.4). A total of 233 deaths were reported in this lightly-populated area during the study, for an overall rate of 105.67 deaths per 100,000 population. This area is associated with a number of unique social and physical vulnerability factors that accounts for the higher total death rates observed here, which are explained in the discussion section.

Table 3.5. Hypothermia fatality rates for the study period per 100,000 population and per 100 wind chill temperature category occurrences. A dash indicates that windchill temperatures within that range were not observed at that station. Bold and italicized text indicates that five or fewer people died.

Metro Areas	Total Rate	<-35	-35 to -25	-25- to -15	-15 to -5	-5 to 5	>5
Albany	4.91	0.00	***0.26***	0.16	0.13	0.05	***0.03***
Albuquerque	9.05	-	0.00	***0.70***	0.30	0.15	***0.08***
Allentown	4.65	0.00	0.00	0.24	0.16	0.05	0.00
Anchorage	22.04	0.00	0.76	0.58	0.46	0.33	0.00
Asheville	13.98	***29.13***	0.00	0.86	0.64	0.16	***0.03***
Atlanta	5.57	-	0.00	0.89	0.39	0.11	0.02
Atlantic City	12.69	0.00	***3.80***	1.11	0.41	***0.06***	***0.13***
Augusta	6.36	-	***3.93***	***0.74***	0.32	0.15	***0.05***
Austin	4.85	-	-	***1.16***	0.78	0.15	0.04
Birmingham	9.13	-	***1.60***	1.60	0.61	0.20	0.06
Boston	5.96	0.00	0.44	0.31	0.17	0.06	0.03
Buffalo	9.69	***3.37***	0.42	0.51	0.19	0.09	***0.03***
Charleston	5.07	-	-	***4.87***	0.52	0.16	***0.03***
Charlotte	4.68	-	0.00	1.21	0.31	0.08	0.03
Chattanooga	7.33	-	***5.82***	***1.03***	0.60	0.10	***0.03***
Chicago	9.09	1.51	0.70	0.41	0.18	0.10	0.04
Cincinnati	5.09	***1.75***	***0.44***	0.35	0.15	0.06	***0.02***
Cleveland	4.56	***1.93***	0.35	0.14	0.12	0.07	0.05

Table 3.5 Continued

Columbia	10.05	-	-	5.91	0.63	0.22	0.06
Columbus, GA	14.03	-	***25.98***	4.52	1.52	0.29	0.09
Columbus, OH	3.76	0.00	***0.25***	0.25	0.16	0.04	***0.03***
Dallas	3.22	-	***2.32***	0.67	0.25	0.07	0.02
Davenport	8.52	0.00	***0.29***	0.60	0.23	***0.03***	0.00
Dayton	3.88	***6.16***	***0.57***	0.23	0.11	0.04	***0.03***
Denver	7.54	0.00	0.92	0.38	0.14	0.12	***0.03***
Des Moines	9.76	***1.35***	0.62	0.43	0.18	0.10	0.00
Detroit	6.91	***1.08***	0.44	0.35	0.15	0.07	0.03
Duluth	18.29	***0.72***	1.00	0.57	0.21	0.21	0.00
El Paso	5.95	-	-	***1.84***	0.39	0.12	0.05
Evansville	9.23	***35.52***	0.00	1.36	0.34	0.14	0.00
Fayetteville	11.84	-	-	0.00	0.70	0.38	*0.07*
Gallup	105.67	0.00	***2.83***	5.78	2.25	1.23	0.00
Grand Rapids	4.51	0.00	***0.52***	0.21	0.09	0.05	0.00
Greensboro	11.98	-	***8.94***	1.73	0.65	0.14	0.09
Greenville	21.37	-	***14.44***	5.30	1.46	0.36	0.12
Hartford	9.51	***8.12***	0.73	0.36	0.25	0.14	***0.02***
Houston	1.53	-	-	*0.63*	0.36	0.06	0.01
Huntsville	5.99	-	***4.61***	***1.38***	0.40	0.07	***0.01***
Indianapolis	8.88	3.45	1.21	0.40	0.22	0.09	***0.02***
Jacksonville	5.45	-	-	0.00	***0.34***	0.25	0.06
Jackson	8.53	-	0.00	***1.30***	0.79	0.21	0.02
Johnson City	9.26	0.00	0.00	0.99	0.25	0.18	***0.09***
Kansas City	5.50	***0.45***	0.27	0.31	0.16	0.06	***0.02***
Knoxville	10.80	***14.60***	0.00	***0.24***	0.55	0.23	***0.03***
Lansing	8.32	***4.95***	***0.52***	0.25	0.21	***0.06***	0.00
Lexington	11.39	0.00	0.00	***0.33***	0.39	0.25	***0.02***
Little Rock	8.03	-	0.00	***0.67***	0.58	0.16	0.05
Los Angeles	1.24	-	-	-	-	0.14	0.02
Louisville	8.20	0.00	***1.61***	0.67	0.34	0.11	*0.01*
Madison	6.93	***0.51***	0.39	0.19	0.18	***0.04***	***0.09***
Memphis	7.89	-	9.74	1.41	0.46	0.13	***0.03***
Miami	1.55	-	-	0.00	***6.07***	0.58	0.02
Milwaukee	6.11	***0.69***	0.51	0.25	0.12	0.06	0.00
Minneapolis	5.56	***0.12***	0.20	0.18	0.08	0.03	0.00
Mobile	7.81	-	0.00	*5.61*	1.01	0.23	0.06
Montgomery	11.56	-	-	24.98	1.24	0.28	***0.06***
Nashville	7.95	***4.37***	3.74	1.09	0.44	0.11	***0.01***
New Orleans	3.80	-	-	***4.75***	0.65	0.14	0.04
New York	4.15	-	0.69	0.31	0.14	0.06	0.02
Oklahoma City	9.43	0.00	2.04	1.02	0.36	0.13	0.05
Omaha	5.46	0.00	0.66	0.36	0.06	0.05	***0.03***
Orlando	2.57	-	-	-	***1.16***	0.09	0.04

Table 3.5 Continued

Philadelphia	7.68	-	1.78	0.67	0.26	0.11	0.02
Phoenix	2.34	-	-	-	-	0.11	0.04
Pittsburgh	6.88	2.34	***0.21***	0.47	0.18	0.07	0.04
Portland, ME	5.60	0.00	***0.18***	0.22	0.12	0.07	***0.21***
Portland, OR	4.18	-	0.00	***0.32***	0.23	0.09	***0.03***
Raleigh	9.13	-	***4.96***	2.35	0.42	0.18	0.06
Richmond	12.43	-	0.00	2.60	0.54	0.20	0.07
Rochester	5.72	0.00	0.57	0.29	0.11	0.07	0.00
Sacramento	3.97	-	-	-	*0.41*	0.12	0.06
Salt Lake City	5.75	0.00	***0.52***	0.24	0.16	0.10	***0.04***
San Antonio	2.49	-	-	***2.09***	***0.21***	0.08	0.03
San Diego	3.22	-	-	-	-	***0.07***	0.07
San Francisco	1.64	-	-	0.00	0.00	0.06	0.03
Scranton	8.96	0.00	1.43	0.49	0.23	0.10	***0.03***
Seattle	3.00	-	-	0.00	0.12	0.06	0.05
Shreveport	8.91	-	-	***2.47***	1.44	0.21	***0.02***
South Bend	7.83	***3.11***	1.43	0.44	0.14	***0.03***	0.00
St. Louis	7.48	0.00	0.43	0.46	0.19	0.09	***0.02***
Syracuse	5.67	***0.00***	0.24	0.23	0.16	0.05	0.00
Tampa	1.46	-	-	-	***1.01***	0.09	0.02
Toledo	6.42	***2.09***	***0.39***	0.38	0.10	0.08	***0.03***
Tucson	9.09	-	-	0.00	***0.70***	0.35	0.09
Tulsa	7.89	-	***1.10***	0.96	0.45	0.12	***0.03***
Virginia Beach	5.33	-	***6.84***	***0.68***	0.35	0.11	***0.02***
Washington DC	5.96	-	1.66	0.77	0.29	0.09	0.02
Wichita	5.39	***2.57***	***1.03***	***0.19***	0.11	0.10	***0.02***
Youngstown	4.72	0.00	*0.50*	0.27	0.10	0.05	0.00

Hypothermia death rates were then examined for six windchill temperature bins (<35º C, -35º C to -25º C, -25º C to -15º C, -15º to -5º C, -5º C to 5º C, and >5º C). The coldest temperature bin (Figure 3.5) displays some of the general trends observed for the total death rates, with the South and the Pacific Coast having the lowest rates of deaths. However, low death rates are observed for larger portions of the country compared to the total death rates. The highest death rates are found in the southern Midwest and in Asheville, North Carolina. The temperature category for -35º C to -25º C (Figure 3.5) shows an increase in death rates in the southern Midwest and the southern

Appalachian/Piedmont region. The Appalachian/Piedmont region encompasses an area starting at Birmingham, Alabama with the northern terminus of the region in south central Virginia.

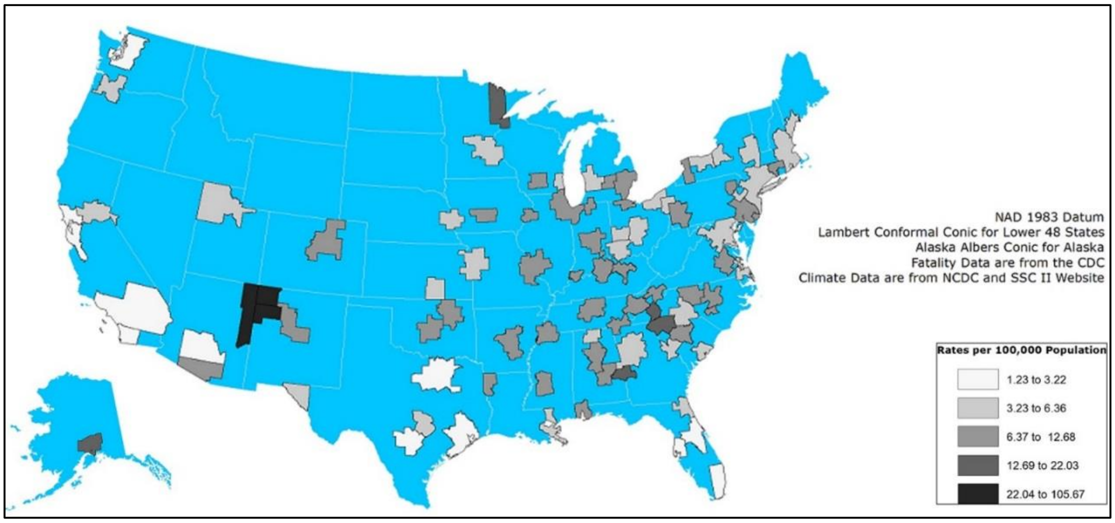


Figure 3.4. Total hypothermia death rates for all 89 metro areas utilized in the study.

Also included in this region is eastern Tennessee and Kentucky along with the western portions of the Carolinas. The 25º C to -15º C temperature bin (Figure 3.5) once again shows lower death rates along the southern and western edges of the US. However, death rates in the Midwest have dropped, and a more spatially-widespread increase in higher death rates is evident in southern Appalachia/Piedmont region.

The next two temperature bins (-15º to -5º C and -5º C to 5º C) had considerably lower fatality rates than did the coldest three temperatures bins (Figure 3.5). While the death rates are far lower with these warmer temperatures, the southern Appalachia/Piedmont region has higher death rates relative to other areas in the US (Figure 3.5).

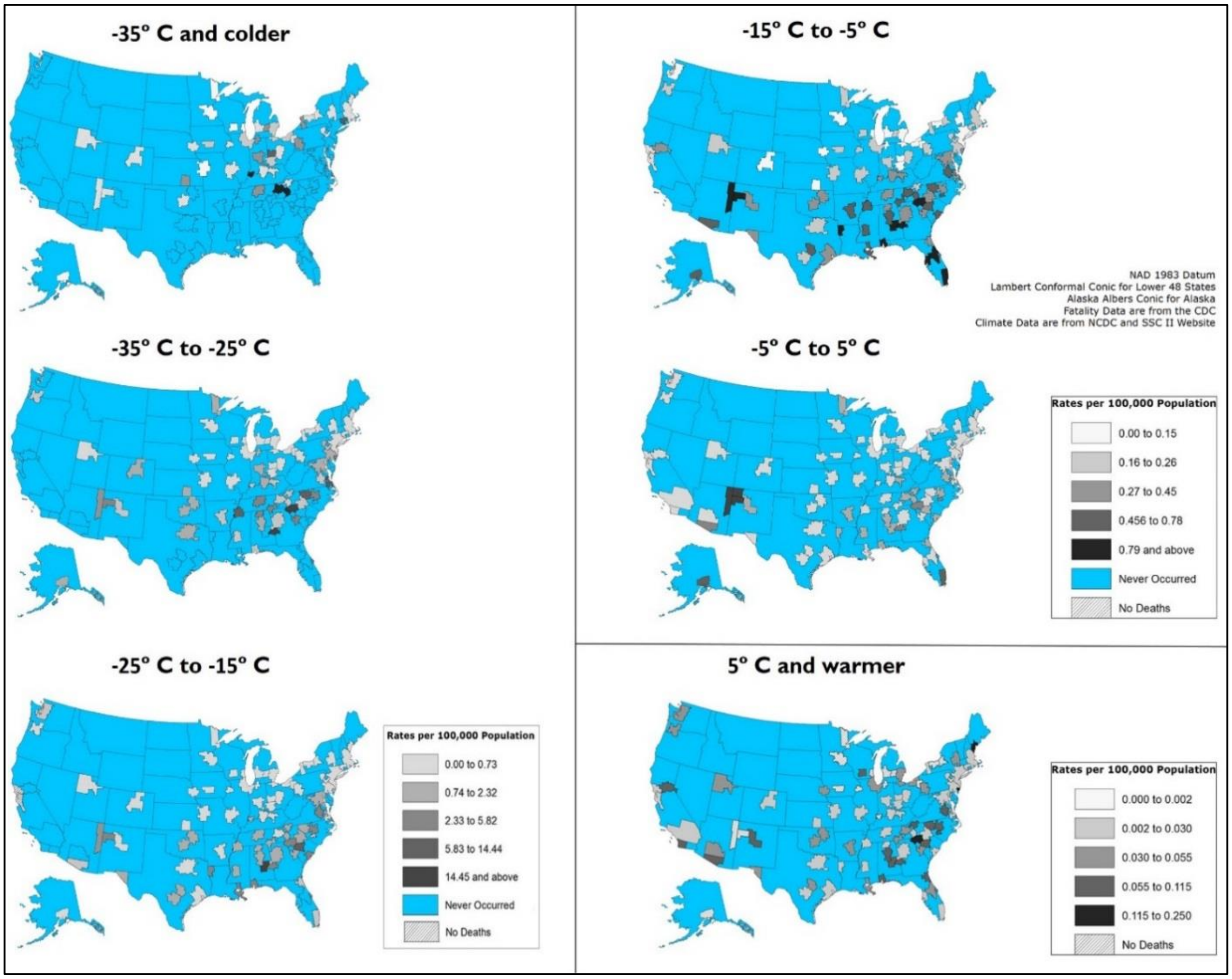


Figure 3.5. Hypothermia fatality rates for the six different windchill temperature categories. The legend within each section of the figure corresponds to the maps within those sections. The blue background represents areas not assessed in this study, the blue background with a metro area outline indicates windchill temperatures within that category did not occur within that metropolitan region, and the lightest gray with cross-hatching indicates that those windchill temperatures occurred there, but no deaths were reported.

High levels of relative vulnerability are found in the Deep South for these temperature ranges in contrast to the other temperature bins (Figure 3.5). The -5º C to 5º C temperature bin has lower overall rates compared to the previous temperature bin, with the highest rates found in the southern portions of the US (Figure 3.5).

The warmest temperature category encompassed temperatures warmer than 5º C and was characterized by the lowest death rates (Figure 3.5). While the overall fatality rates for this temperature category are low, higher levels of relative vulnerability are more geographically widespread compared to other temperature bins. While higher rates of death are still observed in the Appalachia/Piedmont region, higher rates are also observed in the Desert Southwest and the Pacific Coast.

3.4.1.2 Binomial Probability Distribution

The binomial probability distribution was calculated to determine the probability that a hypothermia death would occur in a metro area for a given temperature. As this statistic cannot be normalized, cities were stratified by population using a four-class Jenks Natural Breaks Optimization so that the probabilities could be more equitably compared. The probabilities were binned into six windchill temperature categories and averaged within the category's windchill temperature range (Table 3.6). Metro areas were categorized as mega metros, large metros, mid-size metros, or small metros.

There are a number of general patterns that are observed with the binomial probability distribution. Higher percentages for probability of death are observed in the mega metros, which is a function of their large populations. However, there are a number of notable exceptions to this pattern. For example, of the ten metros with the highest probabilities in the <-35º C windchill temperature bin, five are categorized as small to mid-size metros. One notable area of small to mid-size metro areas with high observed death probabilities was located in the Middle South, from the Carolinas Piedmont, through the southern Appalachian Mountains, and into northern Alabama, southeastern Tennessee, and northern Georgia. Metro areas within this belt include Greensboro, North Carolina; Greenville, South Carolina; Columbus, Georgia; and Knoxville, Tennessee. For all windchill temperature categories these metro areas displayed relatively high death probabilities even when compared to much larger metro areas.

The other pattern that was generally noted was the latitudinal distribution of death probabilities, with metro areas in the northern US generally having higher observed percentages, especially for the lowest windchill temperature categories. Once again, there were variations to this generalized pattern. While Anchorage, Alaska, had the highest probability of death for the <-35º C windchill temperature category, its probability dropped significantly for the -35º C to -25º C. The highest probabilities within this category were found within the Megalopolis region (heavily urbanized US eastern seaboard from Virginia to Boston) and within the aforementioned Middle South Piedmont/Appalachia region. For the two warmest windchill temperature categories (-5º C to 5º C; >5º C), far southern metro areas display the highest percentages. These metro areas include Los Angeles (the highest percentage because of its population), Miami, San Antonio, Phoenix, and San Diego.

Table 3.6. The binomial probability of death by metro area in the US from 1979 to 2004. A dash indicates windchill temperatures within that range were not observed. The threshold temperature is the median daily minimum windchill temperature for which 50% of hypothermia deaths occurred.

Metro Area	Threshold Temperature	<-35	-35 to -25	-25 to -15	-15 to -5	-5 to 5	>5
Mega Metros (>8,524,246 population)							
Chicago	-13.61	66.9%	44.4%	26.8%	14.3%	7.1%	4.0%

Table 3.6 Continued

Los Angeles	8.42	-	-	-	-	23.0%	6.2%
New York	-8.17	-	70.7%	48.2%	24.5%	10.1%	4.6%
Large Metros (3,999,171 to 6,797, 202)							
Boston	-10.69	45.7%	33.8%	17.6%	8.2%	3.6%	1.8%
Dallas	-4.13	-	51.8%	34.0%	11.5%	3.1%	1.0%
Detroit	-12.16	47.7%	31.7%	16.5%	7.7%	3.4%	1.8%
Houston	0.00	-	-	28.0%	11.4%	2.9%	0.9%
Philadelphia	-7.50	-	59.5%	34.9%	14.8%	5.3%	2.2%
San Francisco	5.00	-	-	0.0%	11.8%	5.7%	1.8%
Washington DC	-6.94	-	67.7%	44.3%	18.3%	5.8%	2.1%
Mid-Size Metros (1,506,969 to 3,502,025)							
Atlanta	-3.30	-	50.9%	29.4%	10.9%	3.4%	1.3%
Charlotte	-4.93	-	40.5%	22.0%	6.2%	1.5%	0.5%
Cincinnati	-9.54	54.5%	25.3%	10.6%	4.2%	1.6%	0.7%
Cleveland	-7.10	33.4%	21.1%	10.9%	5.3%	2.5%	1.4%
Columbus, OH	-9.56	19.3%	11.4%	4.8%	2.0%	0.8%	0.4%
Denver	-9.40	20.3%	13.1%	6.9%	3.5%	1.7%	1.0%
Indianapolis	-11.68	34.5%	16.9%	7.6%	3.2%	1.3%	0.6%
Kansas City	-11.29	13.9%	8.4%	4.4%	2.3%	1.2%	0.7%
Miami	9.40	-	-	0.0%	47.9%	22.0%	4.6%
Milwaukee	-14.94	20.6%	9.1%	4.2%	1.9%	0.8%	0.4%
Minneapolis	-18.30	9.2%	5.7%	3.8%	2.5%	1.6%	1.2%
Phoenix	6.70	-	-	-	-	4.4%	1.4%
Pittsburgh	-11.56	43.0%	24.3%	11.0%	4.5%	1.7%	0.8%
Portland	-7.76	-	12.5%	8.5%	3.9%	1.7%	0.9%
Sacramento	3.87	-	-	-	6.5%	2.6%	1.0%
San Diego	10.60	-	-	-	-	5.0%	2.2%
Seattle	-0.21	-	-	8.6%	4.5%	2.0%	1.0%
St. Louis	-10.00	28.3%	18.2%	9.6%	4.9%	2.4%	1.4%
Tampa	8.47	-	-	-	7.4%	2.7%	1.0%
Small Size Metros (220,503 to 1,462,189)							
Albany	-10.00	5.6%	4.4%	3.3%	2.4%	1.8%	1.4%
Albuquerque	-4.88	-	9.6%	5.4%	2.2%	0.9%	0.4%
Allentown	-10.76	6.2%	4.1%	1.8%	0.8%	0.3%	0.2%
Anchorage	-11.68	82.5%	28.0%	3.0%	0.2%	0.0%	0.0%
Asheville	-7.20	10.2%	4.5%	1.6%	0.6%	0.2%	0.1%
Atlantic City	-11.70	21.4%	10.5%	3.1%	0.9%	0.2%	0.1%
Augusta	-2.20	-	12.9%	6.0%	1.9%	0.6%	0.2%
Austin	-0.51	-	-	17.6%	6.2%	1.7%	0.6%

Table 3.6 Continued

Birmingham	-3.30	-	37.1%	19.5%	6.7%	2.0%	0.8%
Buffalo	-13.56	20.3%	11.7%	5.4%	2.4%	1.0%	0.5%
Charleston	-2.20	-	-	15.3%	5.0%	0.9%	0.2%
Chattanooga	-6.83	-	25.6%	10.1%	2.8%	0.7%	0.2%
Columbia	-3.59	-	-	28.4%	7.4%	1.4%	0.3%
Columbus, GA	-3.86	-	63.5%	36.0%	8.8%	1.5%	0.3%
Davenport	-13.90	6.6%	2.7%	1.3%	0.6%	0.3%	0.1%
Dayton	-8.30	11.4%	6.3%	2.7%	1.1%	0.5%	0.2%
Des Moines	-17.67	8.5%	3.9%	1.8%	0.8%	0.4%	0.2%
Duluth	-19.40	3.5%	2.0%	1.2%	0.7%	0.4%	0.3%
El Paso	0.00	-	-	7.2%	2.9%	0.8%	0.3%
Evansville	-8.71	22.7%	13.5%	4.1%	1.1%	0.3%	0.1%
Fayetteville	-2.21	-	-	7.3%	3.1%	0.9%	0.3%
Gallup	-10.60	44.7%	24.3%	11.6%	5.1%	2.1%	1.1%
Grand Rapids	-14.04	10.5%	6.3%	2.6%	1.0%	0.4%	0.2%
Greensboro	-6.99	-	48.1%	24.4%	7.7%	2.1%	0.7%
Greenville	-4.72	-	58.0%	35.0%	11.2%	2.7%	0.8%
Hartford	-10.37	17.5%	12.4%	6.1%	2.8%	1.3%	0.7%
Huntsville	-10.81	-	23.4%	10.4%	1.9%	0.3%	0.1%
Jacksonville	1.33	-	-	20.4%	8.9%	2.2%	0.7%
Jackson	-3.30	-	34.7%	19.3%	4.7%	1.0%	0.3%
Johnson City	-5.00	14.1%	8.1%	3.6%	1.5%	0.7%	0.3%
Knoxville	-4.29	32.7%	21.4%	8.9%	3.3%	1.2%	0.5%
Lansing	-11.04	6.0%	3.6%	1.8%	0.8%	0.4%	0.2%
Lexington	-5.26	7.4%	5.0%	2.9%	1.7%	1.0%	0.6%
Little Rock	-3.30	-	22.2%	12.2%	4.6%	1.6%	0.7%
Louisville	-8.83	36.7%	22.4%	9.4%	3.5%	1.3%	0.6%
Madison	-12.96	3.3%	1.9%	1.1%	0.7%	0.4%	0.3%
Memphis	-8.07	-	46.7%	19.9%	5.5%	1.3%	0.4%
Mobile	-0.53	-	37.4%	22.9%	6.3%	1.4%	0.4%
Montgomery	-2.20	-	-	29.5%	7.0%	1.1%	0.2%
Nashville	-8.30	56.7%	38.7%	14.2%	4.1%	1.1%	0.4%
New Orleans	1.60	-	-	23.7%	10.4%	2.8%	0.9%
Oklahoma City	-7.56	0.0%	23.4%	10.7%	3.9%	1.4%	0.6%
Omaha	-19.33	12.6%	5.0%	2.0%	0.7%	0.3%	0.1%
Orlando	10.60	-	-	-	8.3%	2.9%	1.0%
Portland	1.10	2.0%	1.6%	1.0%	0.7%	0.4%	0.3%
Raleigh	-3.57	-	42.0%	20.7%	6.5%	1.8%	0.6%
Richmond	-5.60	-	43.0%	19.4%	6.1%	1.7%	0.6%

Table 3.6 Continued

Rochester	-12.96	11.8%	7.3%	3.2%	1.4%	0.6%	0.3%
Salt Lake City	-6.48	11.2%	8.1%	4.1%	2.1%	1.0%	0.6%
San Antonio	2.20	-	-	8.0%	4.1%	1.5%	0.6%
Scranton	-12.96	14.9%	9.3%	3.8%	1.5%	0.6%	0.3%
Shreveport	-3.86	-	-	25.1%	6.3%	1.0%	0.2%
South Bend	-16.68	18.2%	6.6%	2.1%	0.7%	0.2%	0.1%
Syracuse	-13.30	6.5%	3.7%	1.9%	0.9%	0.5%	0.3%
Toledo	-14.13	6.2%	3.6%	1.9%	1.0%	0.5%	0.3%
Tucson	2.82	-	-	0.0%	6.3%	2.5%	0.9%
Tulsa	-6.83	-	22.8%	10.1%	3.3%	1.0%	0.4%
Virginia Beach	-3.90	-	36.6%	18.2%	5.7%	1.6%	0.6%
Wichita	-7.20	6.4%	4.0%	1.9%	0.9%	0.4%	0.2%
Youngstown	-13.27	10.5%	4.7%	1.9%	0.8%	0.3%	0.2%

3.4.1.3 Threshold Temperature

The threshold temperature analysis entailed determining the median daily minimum wind chill temperature associated with hypothermia deaths in each metro area. The pattern of hypothermia median isotherms is generally latitudinal, with the lowest median daily wind chill temperatures associated with hypothermia fatalities found in the northern US, with hypothermia fatalities in the southern US associated with warmer median daily windchill temperature values. Median daily minimum windchill values associated with hypothermia also tend to be somewhat warmer along the coasts (Figure 3.6).

Only two metro areas had median daily minimum windchill temperatures of 10º C or greater: Orlando, Florida, and San Diego, California. Median daily minimum windchill temperatures of 0º C or warmer are found within the southern and western US, in an area extending from south Atlantic coast of Georgia through the Desert Southwest and north to Seattle near and along the Pacific Coast. Pockets of colder threshold temperatures relative to the surrounding area (closed off -10º C contours) are found in higher elevation areas, such as the Gallup, New Mexico area. Median daily minimum windchill temperatures below -10º C are found in a large area throughout the northern US. This area encompasses much of the northern Great Plains, the Great Lakes region, and New England, and includes metro areas such as Chicago, Minneapolis, and Detroit.

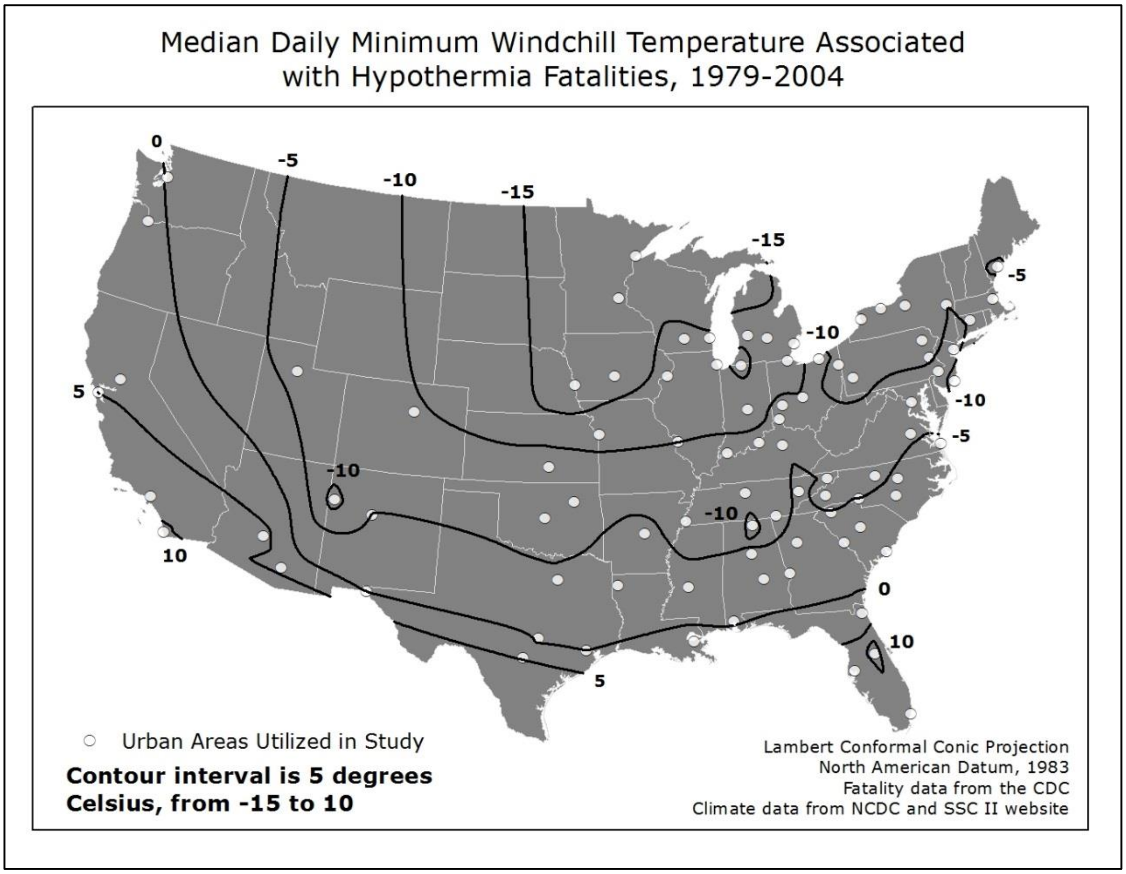


Figure 3.6. The median minimum daily windchill temperature at which hypothermia fatalities occurred was calculated for each metro area, and the results were interpolated using an inverse distance weighted technique. The results in the Northern High Plains was based on a limited sample of data, so they should be interpreted with caution.

3.4.2 NWS Windchill Alerts

NOAA directives, WFO websites, and personal communication with WCMs from southern and western region offices were utilized to obtain a complete dataset on NWS wind chill alerts, the thresholds that determine if an alert is issued, and how the thresholds were determined. WCMs had a fairly wide variety of responses as to how alert threshold criteria were selected. These responses were reviewed and coded, with the following categories created:

- Determined before current WCM and unknown (Unknown)
- Outside correspondence with emergency managers and other local public health authorities (Outside Correspondence)
- Based on climatology, with warnings issued for the coldest 5-15% of days (Climatology)
- Attempted to achieve balance between too many and too few warnings (Warning Balance)
- Selected to be close to national guidance of -18°F (National Guidance)
- Based on other apparent temperature from wind chill/frostbite chart (Wind Chill Chart)
- Did not issue wind chill warnings (No warnings)
- Followed the criteria set by a neighboring/nearby office (Nearby Office)
- Did not state how criteria were determined (Did not State)

The results of the email survey sent to NWS WCMs indicates that many offices in the western and southern regions base their wind chill alert criteria on some of form of national guidance, including the aforementioned directives or the “time to frostbite” chart (Figures 3.2 and 3.8). Eight offices were not aware of how their alert process was developed, and stated that it was developed some time before the current WCM arrived. Offices that utilized outside correspondence were those that took user input and other community users of alert information to formulate the best times for alert issuance. For example, one office worked with the community outreach shelter for homeless individuals to gauge when shelter use peaked. This indicated to the office that the weather conditions coinciding with shelter use was an appropriate time issue wind chill alerts. Other offices used a more subjective approach to developing their thresholds in that they were developed to strike a balance between issuing too many and too few alerts. Other offices followed what their neighboring office did.

Information of temperature and wind speed criteria and duration was tabulated, and wind chill warning temperature criteria were mapped (Figure 3.9). Generally speaking, there was a latitudinal distribution for wind chill alert thresholds. That is, advisories, as well as watches and warnings, were triggered with warmer temperatures in south than were in the north. The coldest temperatures to trigger alerts were in the northern high plains, where cold artic air masses and higher wind speeds are common; Alaska, which is an extreme continental climate with harsh winters; and mountainous areas in New Mexico and Nevada (Figure 3.9). The same general pattern applied to wind chill advisories; however, it should be noted that wind chill advisories were not issued in some WFO areas in the western United States.

To gauge if NWS alert thresholds were in line with hypothermia mortality, a sample of metro areas were chosen and the wind chill warning thresholds were compared to hypothermia fatality thresholds. This determined the percentage of hypothermia fatalities that occurred at windchill temperatures warmer than the warning threshold. The metro areas chosen for this analysis were Anchorage, Alaska; Greenville, South Carolina; Chicago, Illinois; Tucson, Arizona; and Seattle, Washington.

For each metro area other than Chicago, all fatalities occurred at temperatures warmer than the windchill warnings. In Chicago, approximately 95% of deaths occurred at minimum windchill temperatures warmer than the windchill warning threshold.

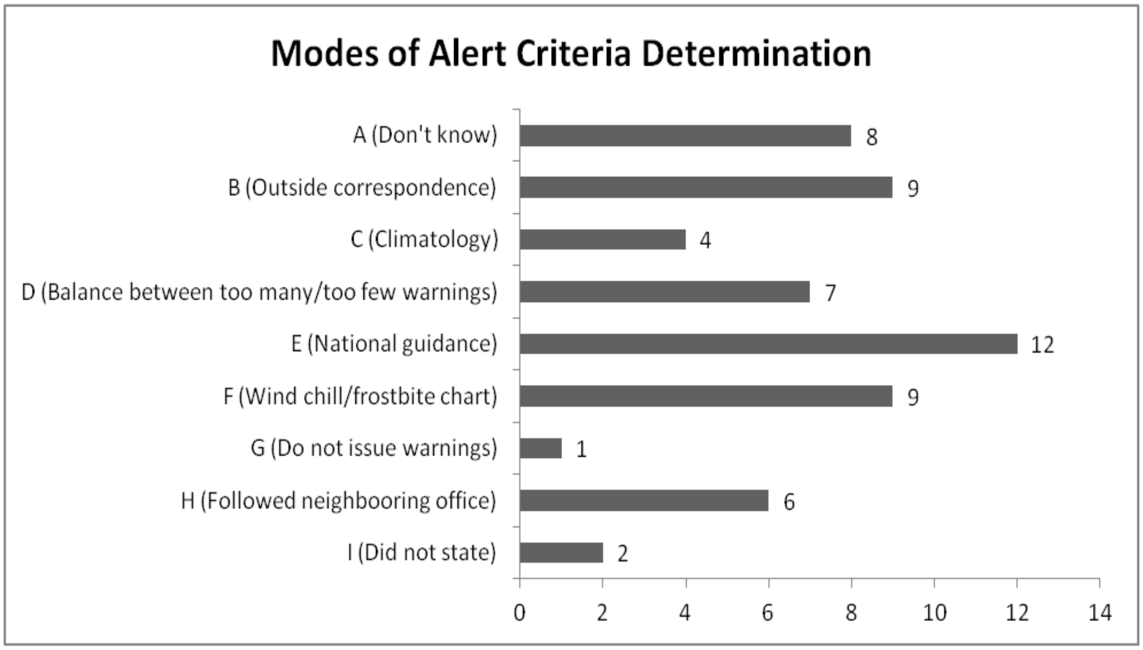


Figure 3.7. The results of the questionnaire sent to warning coordination meteorologists in the western and southern US that indicated how they determined alert criteria. Four offices utilized a climatological approach, using the 5-10% coldest days to determine when an alert should be issued. Two offices did not specifically state what methods they used to determine their alert thresholds, and one office did not issue wind chill alerts of any type.

Wind chill advisories thresholds were also analyzed to determine if any deaths occurred before a warmer threshold was reached. Seattle and Tucson's associated WFOs did not issue wind chill advisories; in Anchorage, 1 death occurred after the advisory threshold was reached. In Chicago and Greenville, approximately 90% and 95% of the deaths in each metro, respectively, occurred at temperatures warmer than the windchill advisory criteria temperature.

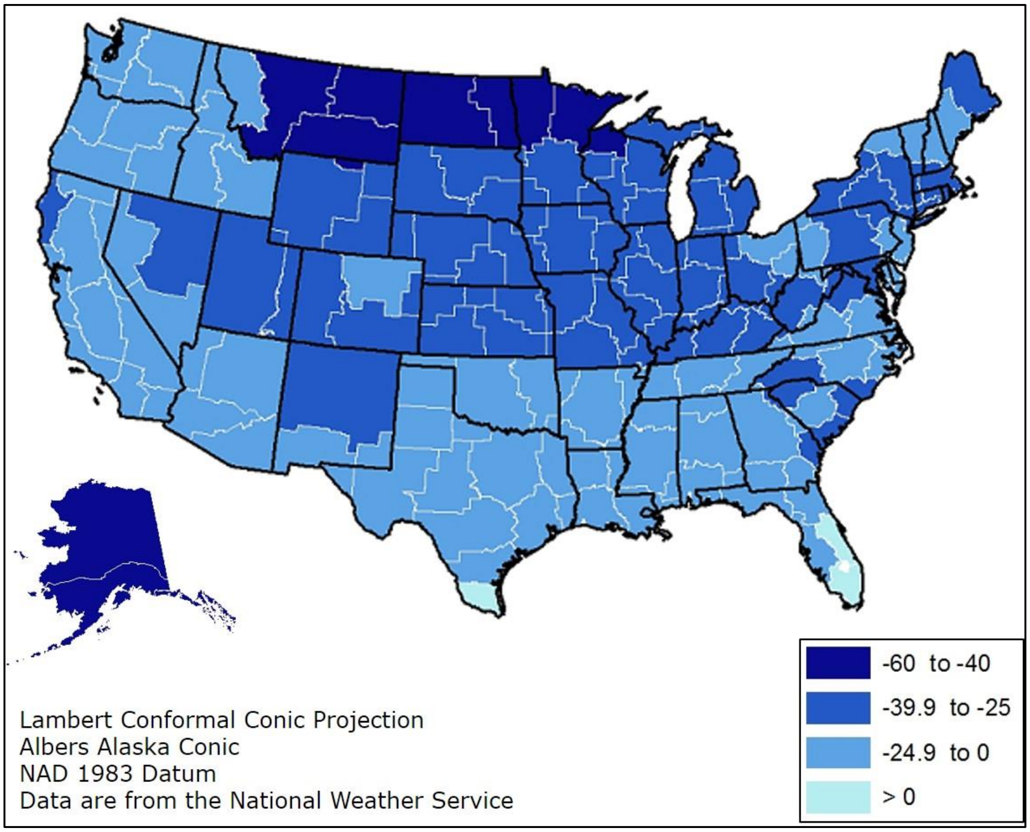


Figure 3.8. The distribution of windchill threshold temperatures for the continental US and Alaska (Hawaii not illustrated). The temperatures shown here are in Fahrenheit, as the National Weather Service utilizes Fahrenheit in its forecasts and alert products.

3.5 Discussion

Hypothermia fatalities were analyzed for 89 US metro areas from 1979-2004 for the cool season. The death data showed considerable interannual variability, while the monthly pattern of deaths approximated a bell-shaped distribution, with January being the deadliest month.

It was observed that there were several calendar days with high fatatlity counts. While there is no research that specifically links hypothermia to calendar day, there are a number of factors that could have created these deadly days. The deadliest calendar day was December 25th, with 174 deaths; December 25th 1983 had 75 deaths alone (Table 3.4). Christmas Day has been identified as being deadly in other non-weather research. In the period from 1979-2004, Christmas Day was found to have the highest daily mortality for all causes and settings (Phillips et al. 2010), with an excess of approximately 42,000 deaths during the study's time frame. The informal "winter holiday season" corresponds to climatologically cool temperatures in the northern mid-latitudes. Additionally, there were two large and noteworthy cold outbreaks that occurred around the Christmas holiday during the temporal span of the research. These large Artic air intrusions had dangerously low ambient temperatures/wind chills and could have exerted a considerable negative impact on at-risk populations. According to the US Bureau of Transportation Statistics, travel during the Christmas/New Year's Holiday season increases 23% over normal travel rates and that most long-distance holiday travel (50 or miles) is by car (US Bureau of Transportation Statistics 2001). This increase may put people outdoors in cold temperatures when they would have otherwise stayed in. Thus, environmental, social, and individual behavioral factors act synergistically to create a time of increased hypothermia deaths around the holidays.

Heat research in the US has shown that some of the most vulnerable cities to heat waves in the US are in the Midwest, Megalopolis, and the Pacific Coast (Sheridan and Kalkstein 2010). These are cooler areas that, with the exception of areas near the Pacific Coast, have significant seasonal variability in temperature. A similar underlying idea is present when examining hypothermia vulnerability, in that cooler than average temperatures in an area are assoicated with higher rates of hypothermia fatalities. Fourteen of the 20 leading metro areas for hypothermia death rates were located in the southern United States, with a large concentration in the Piedmont/southern Appalachian region. Previous cold mortality research has identified that temperate regions have higher levels of cold-related mortality than do areas that are consistently cold (Curriero et al. 2002; Analitis et al. 2008). The lowest temperature bin in this area had low fatality rates (Figure 3.5). The data from this region indicated that these temperatures rarely occurred here. Temperatures between -35º C and -15º C occurred more frequently, but were outside the range of average temperatures in this region. Temperatures between -25º C and -15º C had the highest death rates in the Piedmont region and led the US for this temperature bin (Figure 3.5).

There are social factors that could contribute to the high level of vulnerability observed in this region. Many of the Southern/Piedmont metro areas have higher percentages of African Americans. As stated earlier, minority populations appear to be disproportionately vulnerable to hypothermia (Rango 1984; Thacker et al. 2008). A study of cold-induced vasodilation of the finger indicated that blacks had a diminished response, which could contribute to their vulnerability (Daneen 2003). Also, some counties within the southern Piedmont metro areas have low median household income values (US Census Bureau). Socio-economically disadvantaged groups can have difficulties coping with these temperatures, as adequate clothing and housing is required to maintain healthy body temperature.

The Desert Southwest was shown to have low overall rates of hypothermia fatalities, with the exception of Gallup, which had the highest overall hypothermia death rates (as well as for most temperature categories). There are a number of social and physical factors that contribute to the high rates of fatalities observed in this area. A study by Gallaher et al. (1992) analyzed Native American populations in New Mexico and found a high number of hypothermia deaths that occurred while individuals were walking home intoxicated. Alcohol use has been identified as a health problem in some Native American groups, and Chronic Liver Disease and Cirrhosis are several of the leading causes of death among Native Americans (CDC 2012). These three counties have high percentages of Native American populations that far exceed the national average (US Census Bureau 2000). A vulnerable population with high rates of alcoholism, combined with the established impacts of alcohol on the cold response and shelter-seeking behavior (Kalant and Le 1984; Mulcahy and Watts 2009) likely contributes to the high rates of deaths observed in this area. Additionally, these three counties have low median household income values, which can contribute to their vulnerability (US Census Bureau 2000). A study by the National Homeless Coalition suggests that hypothermia risk increases when nighttime temperatures are below of 4.4º C (40º F), and when the overnight temperatures are markedly colder than warm daytime temperatures (NHC 2010). It is possible that large differences between the daily maximum and minimum temperatures contributes to the Gallup populace's vulnerability.

While there is limited research linking hypothermia with ambient weather conditions, many of this study's findings fit it with what is known about hypothermia and its relationship with the weather. This research was limited to the cool season months (November-April) and identified December, January, and February as the peak months for hypothermia deaths, which was also identified by Taylor and McGwin (2000) and Elbaz et al. (2007) as the fatality maximum. Tanaka and Tokodome (1991) found that most hypothermia deaths in their sample perished when the outdoor temperature was below 5º C, while Herity et al. (1991) found that most fatalities occurred when the temperature was below 1º C. The results of this research indicate that colder temperatures are associated with higher fatality rates. However, there was some spatial variability to the death rates. For the coldest windchill temperatures, very high death rates (the highest rates for all categories) were found in northern US metro areas. For warmer temperature categories, the highest categorical rates moved to metro areas located in the southern US. Additionally, in the binomial analysis we found that some southern metro areas had higher probabilities of death than northern metros of larger sizes. As stated earlier, areas that are less often cold in absolute terms have greater difficulties in adjusting to very cold temperatures (Analitis et al. 2008; Curriero et al. 2002). In summary, northern metro areas have very high rates of death for the coldest windchill temperatures, and the rates of death drop with warmer windchill temperature categories. In southern US metros, high rates of death start at warmer temperatures, and do not drop as drastically as in northern metros. Some southern metro areas have higher rates of death for most windchill temperature categories than do northern cities for the same windchill temperature category.

In the analysis of wind chill alerts, most WFOs went with a variety of methods to determine when to issue an alert. Most offices in the southern and western regions of NOAA utilized a climatological approach or followed some form of centralized guidance or a nearby office. No WFO stated that they used a health-based approach to determine when to issue warnings. In a comparison of windchill alerts and hypothermia deaths, most deaths occurred well before alert thresholds (both advisory and warnings) were reached.

3.6 Conclusions

Hypothermia attributable to cold weather exposure from 1979-2004 was analyzed for 89 metro areas of varying size across the US. A total of 9185 deaths were identified during the study period between the months of November and April for the metro areas that met inclusion criteria. The toal amount of hypothermia fatalities not attributable to man-made causes for the entire US during this period was 16,272. An average of 353 deaths per season occurred within the study area, with the maximum number of deaths reported in the month of January. The deadliest individual calendar day was December 25th, with 175 deaths. This likely results from a synergy of physcial factors (climatologically cold temperatures, two large polar air outbreaks) and social factors (holiday travel).

Deaths rates demonstrated considerable geographic variability across the US. A general minima of death rates was observed in the Deep South and along the Pacific Coast. In spite of the low death rates observed in the Desert Southwest, the highest overall death rates were found in a three-county region located within Arizona and New Mexico. Once again, a combination of physical factors (large diurnal temperature range) and social factors (vulnerable ethnic minority population that is socio-economically disadvantaged with high rates of alchoholism) creates this geographic maxima. Another area of high deaths was the southern Appalachia/Piedmont region. High binomial probabilities of death, some higher than more populated northern cities, were found within this region. This area is usually temperate/warm, but is subject to occasional cold air outbreaks. This, combined with social vulnerablities (large ethnic minority populations, low median income), creates a widespread secondary fatality maxima. Median daily minimum wind chill temperature associated with hypothermia was analyzed and mapped. The pattern shows a clear latitudinal distribution, with warmer temperatures associated with hypothermia deaths in the southern US and along the west coast. The analysis of death rates and their association with ambient conditions fits the limited amount of prior research on the topic, which indicates that most hypothermia fatalities occur when temperatures are colder than 5º C, and higher levels of cold vulnerability occur in areas that are more temperate. The results of this assessment also indicated that the population in southern US metro areas were more vulnerable than northern metro areas at equivalent windchill temperatures, especially when those temperatures were 0º C and warmer.

National Weather Service offices in the Southern and Western NOAA regions were surveyed to see how they determined wind chill alert criteria and thresholds. While the WFOs within these regions were allowed to locally set criteria themselves, most offices within this region based their alerts off of NOAA's national guidance or the frostbite time chart. Other offices corresponded with the community or other forecast offices, and some offices did not know how their criteria was set. A sample of metro areas was selected to determine if wind chill alert thresholds were in line with hypothermia mortality. The assessment of sample metro areas showed that most fatalities occurred before wind chill warning and advisory thresholds were met.

There are a number of possible directions that future research could take to build upon this analysis. Hypothermia morbidity and its association with weather conditions is not well-understood. A sample of hospitalizations could be analyzed to determine if weather conditions associated with non-fatal hypothermia are significantly different than the conditions associated with fatal hypothermia.

The most prominent and widespread hypothermia fatality spatial maxima was located in the southeastern US within the Appalachia/Piedmont region. While physical and socio-economic factors provide some explanation of the high fatality rates within this region, an assessment of specific behavioral factors could further illuminate the observed hypothermia vulnerability within the Piedmont. Survey work could gauge the resident's perception of cold weather danger, their preparedness and knowledge of cold weather, and whether or not they received and heeded warnings, or understand the messaging contained within. The results of such research could be to tailor educational materials that bring awareness to this prominent regional weather hazard.

The results of windchill alert and hypothermia fatatlity comparison indicated that most deaths occurred before threshold temperatures were reached. Additional research could determine the optimum method of altering windchill alert to encompass the most dangerous days, while not over-warning the population. This could possibly include a more centralized process to determine locally relevant windchill alert criteria and thresholds.

CHAPTER FOUR

HYPOTHERMIA MORBIDITY IN NEW YORK: HOSPITALIZATIONS AND THE SPATIAL SYNOPTIC CLASSIFICATION

4.1 Introduction

Hypothermia is a medical condition associated with a drop in core body temperature (Nixdorff-Miller et al. 2006). This can diminish physical and mental capacities and result in death or coma if untreated. Hypothermia is typically induced by exposure to ambient cold temperatures and water immersion. There are a number of populations that are vulnerable to hypothermia, including the elderly, ethnic minorities, people with underlying medical conditions, the homeless, and substance abusers (Dharmarajan and Wijidada 2007; Mulcahy and Watts 2009). The elderly in particular have compromised abilities to physiologically respond to the cold (Megarbargane et al. 2000; Roeggla et al. 2001). Hypothermia mortality is a wintertime ailment in the northern mid-high latitudes, with up to 750 deaths occurring in the US each year (Dixon et al. 2005). While the condition is most commonly associated with the colder locales and the cold season, hypothermia cases have also been observed in tropical and sub-tropical environments (Aitken et al. 2008; Elbaz et al. 2007).

In this research, data from the New York State Department of Health was used to assess whether hypothermia morbidity was associated with Spatial Synoptic Classification (Sheridan 2002) weather types. Hypothermia morbidity hospitalizations within New York State from 1991-92 to 2005-06 for the months November to March were analyzed to determine if an association existed between ambient weather types and hypothermia-related hospitalizations. The geographic distribution of admissions was assessed to determine areas with the highest rates of hospitalizations, as well as to compare urban and rural hospitalization rates. A demographic analysis was also performed to determine what population subgroups were most vulnerable to hypothermia morbidity. The exact nature in which weather patterns impact hypothermia hospitalization rates is not well-understood, so a synoptic climatological analysis was performed by examining hospitalizations and weather type over several temporal scales.

This research is important for a number of reasons. Hypothermia morbidity has been poorly researched in the United States, and there are no long-term studies that show its geographic and temporal distribution either for the country or regions within the country. The relationship between weather conditions and hypothermia hospitalizations has not been researched. The limited morbidity research has focused on small sample sizes or estimates to gauge hypothermia-related hospitalizations (Baumgartner et al. 2008). Rango (1984) surmised that hypothermia morbidity incidence was seriously undercounted. An analysis of nationwide Medicare insurance claims for the years 2004-05 indicated that while hypothermia hospitalizations happened less than hyperthermia hospitalizations, hypothermia victims were more likely to die, more likely to stay in the hospital longer, and were more likely to have an expensive stay, with $98 million in hypothermia claims compared to $36 million in hyperthermia claims (Noe et al. 2012). These same authors also noted that hypothermia hospitalizations were a significant but preventable public health burden. Additionally, the US population is now aging, and New York's population is projected to have higher percentages of middle age and elderly by 2030 (US Census Bureau, 2010), cohorts which are vulnerable to hypothermia (Thacker et al. 2008). Climatologically, cold outbreaks are expected to be of equal or greater severity for a time in spite of climatic warming (Walsh et al. 2001). Therefore, with an aging population in New York State and the possibility of cold air outbreaks not diminishing, and little prior research on hypothermia hospitalizations, an analysis of this type is required. This allows us to examine historical hypothermia hospitalizations rates and their connection with ambient conditions via a simple metric (the SSC). The results of this study enables hospital administration to prepare for high hypothermia hospitalization days based on weather types. Emergency managers and public health officials can ascertain what areas are most vulnerable, and what cohorts of the population are at-risk and implement appropriate preventative and response measures.

4.2 Literature Review

Cold temperatures are one the deadliest of all natural hazards in the US (Thacker et al. 2008). Hypothermia attributable to direct cold exposure causes between 400 and 750 fatalities in the US annually (Dixon et al. 2005; Grey et al. 2002; Thacker et al. 2008). In comparison to hypothermia mortality, hypothermia morbidity has been poorly researched in the United States. One study was identified that focused on hypothermia-related morbidity and hospitalizations (Baumgartner et al. 2008). This research utilized a four-week sample from the National Ambulatory Medical Care Survey to estimate yearly hypothermia morbidity incidence in the United States from 1995-2004. Their sample of short-term and general care patients from hospitals that participate in this data program yielded a total of 42 admissions in the four-week period. An algorithm was used to estimate that approximately 15,800 hypothermia hospitalizations occurred during the study period, an average of approximately 1580 per year. Noe et al. (2012) examined Medicare-related hypothermia insurance claims in the US for 2004-2005. They identified 8761 hypothermia-related visits in the US, of which 4% (359) resulted in the death of the patient.

Since the literature on hypothermia morbidity is sparse, the review of existing information will include both morbidity and mortality. Hypothermia morbidity and mortality in the US is strongly associated with elderly status, typically defined as age 65 and older, with age 85 and older having the highest rates of inpatient visits (Rango 1984; Rango 1985; Noe et al. 2012; Thacker et al. 2008;). Research in the United Kingdom has also demonstrated that the elderly are more susceptible to developing hypothermia (Herity et al. 1991; Hillsop et al. 1995). This high risk of fatality is because of a diminished cold response, decreased temperature sensation, and social isolation (Dharmarajan and Wijidada 2007; Mulcahy and Watts 2009; Ranhoff 2000). A study on New Zealand hypothermia hospitalizations found that age extremes (elderly and infants) were the largest percentage of the sample size (Taylor et al.. 1994). Prospective case studies have shown that elderly presenting with comorbidities and other underlying illnesses are more likely to perish of hypothermia (Muszkat et al. 2007; Pedley 2002).

Hypothermia risk is also strongly associated with male gender in descriptive epidemiological studies (Elbaz et al. 2007; Herity et al. 1991; Noe et al. 2012; Taylor and McGwin 2000; Thacker et al. 2008). The association between gender and hypothermia morbidity as not as clear as the relationship between gender and mortality. An estimation of US hypothermia morbidity suggested that 55% of non-fatal hypothermia-related hospital admissions were male (Baumgartner et al. 2008). Herity et al. (1991) determined that in a sample of 1259 hypothermia cases (435 deaths and 857 survivors), men and women had equal hypothermia hospitalization incidence, though men were more likely to perish of hypothermia. A study of hypothermia incidence in Queensland, Australia, showed that in a sample of 280 hospitalization there was no association between gender and hypothermia vulnerability (Aitken et al. 2008).

The relationship between hypothermia morbidity and ambient weather conditions has not been well-researched. Previous studies have shown that as temperature decreases hypothermia mortality tends to increase (Herity et al. 1991; Tanaka and Tokodome 1991; Taylor and McGwin 2000). A study of hypothermia mortality and morbidity in Ireland (Herity et al. 1991) found that hypothermia incidence and mortality increased with decreasing temperature, peaking for temperatures below -1º C. Elderly hypothermia hospitalizations in an emergency department in Dundee, Australia peaked during the coldest times of the year (Pedley et al. 2002).

The geographic distribution of hypothermia deaths has been analyzed in several US studies (the geographic distribution of morbidity has not been analyzed). At the state level, the highest frequency of deaths was identified in the state of Illinois, with 859 deaths from 1979-2004. However, the intermontane west (Rocky Mountains through the Basin and Range region) had the highest rates of mortality. This region is sparsely populated, and low population density has been suggested to increase risk for both hypothermia morbidity and mortality (Herity et al. 1991; Thacker et al. 2008).

4.3 Data and Methods

4.3.1 Hospitalization Data

The hypothermia morbidity data come from the New York State Department of Health SPARCS database (Statewide Planning and Cooperative Research System). These data are the product of a cooperative effort between the state government of New York and private health care industry. This system collects information on patient demographics (age, gender, and race), diagnosis, treatment, and the total expenses for each hospital admission in New York State since 1979 (New York State Department of Health). Spatial identifiers within this dataset are for the victim’s residence and include county, zip code, city, and occasionally, latitude and longitude coordinates. Hospitalizations for people who are not residents of the state are coded as 99, and homeless individuals receive a code of 88.

This research utilized SPARCS data entries with the code E901.0, or hypothermia attributable to cold weather exposure. This admission code is based on the International Classification of Disease (ICD), 9th revision, for injuries and cause of death. While a tenth revision of the ICD took effect in the year 2000, the diagnostic codes for victims included in this dataset are converted back to ICD-9 values. A full description of ICD codes related to exposure to extreme atmospheric temperatures, as well as the caveats associated with these data, appears in Dixon et al. (2005).

4.3.2 Weather Data

Synoptic climatology relates atmospheric conditions to an event that occurs at earth's surface (Yarnal 1993). With weather typing, meteorological variables are categorized over broad spatio-temporal scales, which allows synoptic climatologists to define generalized atmospheric states that are easily understood and can be applied to health outcome events at earth's surface (Lee 2012). Therefore, weather types allow researchers to examine atmospheric conditions associated with hypothermia from a holistic standpoint, assessing the combined impact of multiple atmospheric variables. While synoptic weather types have been used to examine atmospheric conditions and their relationship to a variety of health problems (Davis et al. 2012; Lee et al. 2013; Sheridan and Dolney 2003), hypothermia morbidity has not been analyzed using these synoptic methods.

The weather data come from Spatial Synoptic Classification stations (Sheridan 2002). This scheme classifies each day at first-order weather station into weather types based on the observed surface conditions of the following variables: temperature, dew point temperature, atmospheric pressure, wind speed, and cloud cover. The weather types are spatially variable and SSC nine climate regions have been delimited based on weather type characteristics. For example, dry polar weather types can occur in the far southern portions of the US, but "cold and dry" is defined relative to local characteristics. The data and additional information can be found at: http://sheridan.geog.kent.edu/ssc_html.

The weather type categories are as follows: Dry Polar, Dry Moderate, Dry Tropical, Moist Polar, Moist Moderate, Moist Tropical, and Transitional air masses. Dry Polar, Moist Polar, and Transition weather types were utilized in this research (Table 1). New York State is situated within the SSC climate zone 3a, or the Laurentian region. This region is typified by high levels of climate variability with large differences between winter and summer (Spatial Synoptic Classification Homepage).

Dry polar (DP) is a cold weather type that can be associated with extended extreme cold outbreaks. In the New York region, it is associated with temperatures ranging from 3º C to -15º C, low dew points and dry air, with high barometric pressure values typically 1020 millibars and higher (Table 4.1). Cloud cover is typically sparse because of dry air and high pressure, and wind speeds range between 3 Km/h and 7 km/h.

Table 4.1. The climatology of dry polar weather types for each station throughout the study period twice-daily measurements at 3 AM and 3 PM. The data are average values, and wind speed is measured in Km/h.

Albany				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	105	-2.9	-6.8	3.0	4	2.9	-7.0	4.6	4
Dec	154	-7.4	-11.8	3.5	3	-2.9	-11.1	4.4	3
Jan	177	-11.5	-16.0	3.7	4	-7.0	-15.5	5.1	4
Feb	171	-10.5	-15.2	3.5	4	-3.7	-14.3	5.1	3
Mar	145	-6.5	-11.5	3.5	3	1.5	-10.7	5.7	3
Watertown				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	105	-4.4	-7.4	2.9	5	1.5	-6.1	3.9	6
Dec	141	-9.9	-12.9	3.4	5	-4.7	-10.9	3.8	6
Jan	156	-15.5	-19.2	3.7	5	-9.7	-16.2	4.4	5
Feb	172	-14.4	-18.1	3.3	4	-6.3	-14.3	4.8	4
Mar	170	-8.8	-12.2	3.2	4	-0.6	-9.6	5.2	4

Table 4.1 Continued

Binghamton				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	103	-3.9	-6.8	3.7	6	0.2	-7.2	4.1	5
Dec	143	-8.9	-12.0	3.8	6	-4.9	-11.4	4.1	5
Jan	152	-12.9	-16.0	4.3	6	-8.7	-15.1	4.8	5
Feb	151	-11.2	-14.6	4.1	6	-5.4	-14.7	4.9	4
Mar	138	-7.7	-11.3	3.7	4	-0.1	-10.9	5.3	4
Buffalo				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	69	-2.2	-5.4	3.8	5	2.2	-5.6	4.5	6
Dec	92	-8.0	-11.2	4.1	5	-4.1	-10.3	4.4	6
Jan	121	-11.5	-15.0	4.7	6	-8.5	-14.7	5.5	6
Feb	125	-10.5	-14.0	4.4	6	-5.8	-13.1	5.5	7
Mar	132	-6.6	-10.5	3.9	4	-0.7	-9.6	5.9	5
New York				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	90	1.4	-5.9	5.1	3	5.8	-6.2	5.8	5
Dec	102	-3.5	-11.3	5.9	3	0.2	-11.0	5.6	5
Jan	129	-6.9	-14.5	6.8	3	-2.5	-13.6	6.4	5
Feb	122	-5.1	-13.4	5.8	3	-0.2	-12.5	6.3	5
Mar	111	-2.0	-10.7	5.9	3	3.8	-9.6	7.0	5
Massena				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	114	-4.4	-7.4	3.1	5	0.7	-6.4	3.8	5
Dec	194	-10.6	-14.4	3.2	5	-6.9	-13.0	4.0	5
Jan	201	-16.2	-19.7	3.6	5	-11.8	-18.0	4.5	5
Feb	210	-15.1	-18.6	2.7	4	-7.3	-15.7	4.6	4
Mar	190	-9.4	-13.2	2.9	3	-1.2	-10.8	5.1	4
Rochester				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	99	-1.7	-4.8	4.1	8	1.7	-4.2	5.1	8
Dec	110	-1.6	-5.0	4.0	8	2.1	-4.6	5.3	8
Jan	119	-0.6	-3.8	4.2	8	2.0	-3.5	5.3	8
Feb	110	-1.7	-5.2	3.9	8	2.5	-4.2	5.0	7
Mar	115	-1.4	-4.4	3.8	8	2.0	-4.1	5.2	8

Moist Polar (MP) weather types are cold air masses with higher moisture content, which results in heavier cloud coverage than compared to the dry polar weather type (Table 4.2). The barometric pressure values are slightly lower compared to dry polar, ranging between 1005 and 1017 millibars. Wind speeds are generally comparable to the dry polar weather type.

Table 4.2. The climatology of moist polar weather types for each station throughout the study period twice-daily measurements at 3 AM and 3 PM. The data are average values, and wind speed is measured in Km/h.

Albany				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	72	0.0	-1.9	2.4	8	2.5	-0.6	4.0	9
Dec	95	-3.5	-6.1	3.2	7	-0.9	-4.3	3.8	8
Jan	93	-5.9	-8.3	2.8	8	-3.4	-6.5	3.6	8
Feb	56	-3.8	-6.6	2.8	8	-0.8	-4.6	4.5	9
Mar	93	-1.1	-3.8	3.5	9	1.2	-3.2	5.1	9
Watertown				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	81	0.1	-1.8	3.8	9	1.5	-1.5	4.8	10
Dec	109	-3.2	-5.5	3.7	9	-1.4	-4.5	4.2	10
Jan	101	-6.3	-8.7	3.9	10	-4.3	-7.4	4.8	10
Feb	80	-4.4	-7.3	3.9	9	-2.1	-5.5	5.2	9
Mar	105	-2.2	-4.5	4.1	9	0.1	-4.1	5.6	9
Binghamton				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	86	-0.2	-2.2	3.7	9	0.7	-2.0	4.3	10
Dec	113	-3.6	-5.5	4.3	9	-2.6	-5.3	4.5	9
Jan	106	-6.2	-8.1	3.9	9	-4.7	-7.4	4.2	9
Feb	88	-5.6	-8.1	4.2	9	-3.6	-7.4	4.8	9
Mar	126	-3.0	-4.9	4.2	9	-0.9	-4.7	5.0	9
Buffalo				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover

Table 4.2 Continued

Nov	111	1.0	-1.9	4.5	9	2.0	-1.8	4.9	9
Dec	153	-3.1	-5.8	4.7	9	-1.9	-5.4	5.2	9
Jan	132	-4.7	-7.1	5.1	10	-3.8	-7.1	5.9	9
Feb	96	-4.8	-7.2	4.7	9	-3.2	-6.5	5.8	9
Mar	112	-2.2	-4.6	4.6	9	-0.5	-3.8	6.2	9
New York				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	23	2.9	-0.4	4.6	7	5.1	0.2	5.2	9
Dec	50	-0.3	-3.6	4.9	7	1.5	-2.9	6.0	8
Jan	68	-2.0	-5.6	4.6	9	0.0	-4.5	5.3	8
Feb	41	-2.6	-5.7	4.3	8	0.1	-4.2	5.3	9
Mar	66	1.0	-1.9	4.5	9	3.2	-0.7	5.8	9
Massena				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	64	0.2	-1.7	3.7	9	1.2	-1.0	4.4	9
Dec	88	-5.7	-7.3	3.5	8	-3.0	-5.3	4.4	10
Jan	66	-8.3	-10.4	3.3	9	-5.9	-8.1	3.9	9
Feb	38	-7.1	-9.0	3.7	9	-4.9	-7.1	5.1	9
Mar	62	-3.8	-6.0	3.8	9	-1.9	-4.7	4.9	10
Rochester				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	140	-2.8	-5.8	4.1	8	0.9	-5.1	5.3	8
Dec	129	-1.3	-4.6	4.4	8	1.5	-4.1	5.8	8
Jan	125	0.4	-3.0	4.3	8	3.9	-2.4	5.3	8
Feb	120	-1.5	-4.7	3.8	7	2.5	-4.0	5.1	8
Mar	90	-2.5	-5.7	5.4	7	1.5	-4.5	7.2	7

The transitional (TR) weather type does not fit into any of the other categories delimited by the SSC system. As its name implies, it is a day marked by changing weather conditions or lack of spatial coherence of weather patterns (Table 4.3). Because of this, regional variation of transition weather characteristics is large. However, wind speeds tend to be higher than that of the polar weather types, and cloud cover generally tends to be greater.

Table 4.3. The climatology of transition weather types for each station throughout the study period twice-daily measurements at 3 AM and 3 PM. The data are average values, and wind speed is measured in Km/h.

Albany				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	47	6.2	3.2	4.3	7	7.2	1.7	6.7	8
Dec	47	-0.9	-3.7	3.6	8	0.3	-5.6	6.9	7
Jan	59	-5.6	-9.0	3.7	8	-2.3	-7.3	6.3	7
Feb	54	-4.2	-8.1	3.2	7	-1.5	-8.3	7.8	7
Mar	51	1.1	-1.7	3.8	7	3.7	-3.1	7.1	7
Watertown				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	44	5.9	1.8	4.8	7	8.0	2.8	6.4	8
Dec	55	-5.7	-8.6	5.3	8	-2.1	-7.8	5.4	8
Jan	67	-7.9	-11.6	5.3	7	-5.4	-10.6	5.8	8
Feb	44	-8.2	-11.5	4.5	7	-3.6	-8.8	5.8	8
Mar	53	-2.7	-6.1	4.4	7	1.8	-4.4	6.6	8
Binghamton				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	55	5.4	2.0	5.2	8	6.2	1.7	6.1	8
Dec	40	-0.7	-3.5	5.0	8	-1.5	-5.8	6.4	8
Jan	49	-3.9	-6.3	4.9	8	-3.8	-7.8	6.4	9
Feb	44	-2.8	-6.5	4.8	8	-1.1	-6.0	6.7	8
Mar	52	0.1	-3.0	4.6	8	1.1	-4.8	7.0	9
Buffalo				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	50	8.3	4.1	6.1	8	8.1	3.1	7.8	9
Dec	41	0.6	-2.4	5.5	9	0.4	-4.6	7.9	9
Jan	59	-3.2	-6.5	5.2	9	-2.4	-6.4	7.5	9
Feb	51	-1.6	-5.2	5.7	9	-0.8	-5.4	7.3	9
Mar	45	1.3	-2.6	5.3	9	4.2	-1.4	8.0	9
New York				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	60	10.1	7.0	5.8	8	11.4	3.8	8.2	7
Dec	65	4.3	1.2	5.4	9	5.2	-1.9	8.2	7

Table 4.3 Continued

Jan	66	0.8	-3.3	5.9	8	3.0	-3.4	7.6	8
Feb	57	1.5	-2.6	5.0	8	3.8	-4.7	7.6	7
Mar	54	4.1	0.7	5.4	9	6.6	-1.2	9.5	7
Massena				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	54	3.5	0.5	4.6	8	6.4	0.9	6.3	8
Dec	51	-6.6	-9.0	4.1	7	-5.1	-10.0	6.2	7
Jan	68	-10.9	-13.5	3.8	7	-6.9	-11.2	5.9	8
Feb	57	-10.7	-13.5	3.5	7	-5.9	-11.4	6.1	7
Mar	53	-4.7	-6.8	3.1	6	0.4	-5.3	6.2	8
Rochester				3 AM				3 PM	
Month	Freq	Temp	Dew Pt	Wind Spd	Cloud Cover	Temp	Dew Pt	Wind Spd	Cloud Cover
Nov	57	-1.2	-5.0	4.0	9	2.2	-4.2	5.1	9
Dec	38	-1.3	-4.3	4.3	8	3.1	-3.6	5.1	8
Jan	40	0.1	-2.8	3.8	7	4.0	-2.3	5.8	8
Feb	51	-0.8	-4.2	4.1	8	2.7	-2.8	5.4	9
Mar	63	-1.7	-4.9	4.1	7	2.6	-4.2	5.3	8

4.3.2.1 Joining Weather Data and Hospitalization Data

To assess hypothermia morbidity using a synoptic methodology, seven weather stations were selected, and each county was assigned to a weather station based on proximity (Figure 4.1). One weather station per region was adequate to describe weather types because SSC classifications are region-specific, and are typically large air masses that encompass hundreds to thousands of square kilometers. Each hospitalization in the dataset had spatial identifiers available at a variety of geographic scales, though sometimes specific location information was suppressed. County of residence was chosen as this information was available for all cases. The hypothermia hospitalization information was joined to the SSC weather data by matching the county of residence to the location of the SSC weather station. That way, each hospitalization was associated with the atmospheric conditions present in the general area for the reported date of the hospitalization.

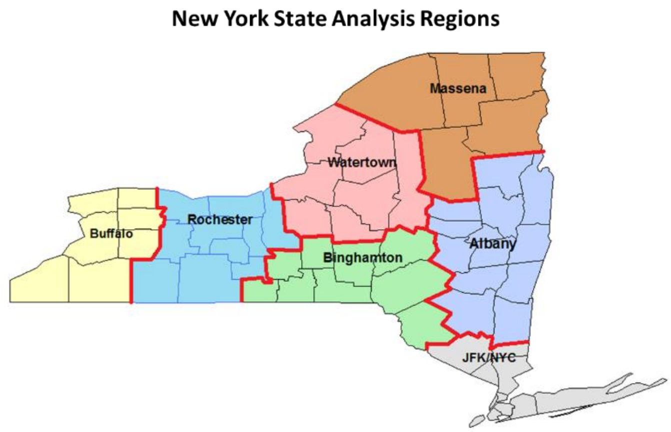


Figure 4.1. The regions used for aggregation and spatial analysis of hospitalizations. The regions are named after the weather stations chosen to represent them. Each hospitalization was associated with a daily SSC weather type to determine the association between hospitalization rates and atmospheric conditions.

As stated earlier, there are both dry and moist weather types. When analyzing hospitalizations by weather type, the dry polar and moist polar weather types were pooled together to create a larger sample size (Table 4.4). The level of moisture content that differentiates these two weather types can be small so the impact on analysis is negligible. Polar weather types occurred approximately 50% of the days at each station, with the exception of New York City, where moderate weather types occur more frequently than polar weather types. Transition weather types occurred between 11-13% of days at each station. Moderate weather types are included here so that the variability of weather types can be visualized; while hospitalizations were associated with them, the rates were very low so they were not included in later analysis. In general, 2/3 of the days at each station were associated with polar or transition weather types.

Table 4.4. The percentage of each SSC weather type reported at the stations for the duration of the study. The dry and moist weather types were pooled together to create a more robust sample size, and moderate and tropical are only included for comparison purposes. The highest percentage of weather types at each station was generally polar, with the exception of New York City.

Region	Moderate	Polar	Transition	Tropical	Missing	Total
Albany	0.34	0.51	0.11	0.04	0.00	2269
Watertown	0.26	0.54	0.12	0.05	0.04	2266
Binghamton	0.30	0.53	0.11	0.05	0.01	2269
Buffalo	0.34	0.50	0.11	0.05	0.00	2269
New York City	0.43	0.35	0.13	0.09	0.00	2269
Massena	0.27	0.54	0.12	0.03	0.04	2269
Rochester	0.33	0.51	0.11	0.05	0.00	2269
Grand Total	5130	7926	1838	805	181	15880

4.3.3 Geographic and SSC Analysis

Hypothermia hospital admissions for direct cold exposure (ICD-9 E901.0) was assessed for the years 1991-92 to 2005-06 for the months November through March. While it is known that cold exposure can result in hypothermia, it is not known how specific patterns of weather types contribute to hypothermia-related hospital admissions. To address this, a day-in-sequence analysis was performed. This type of analysis examines how many days in a row a particular weather type was reported a particular weather station (persistence). Exploratory analysis of the data indicated that weather types rarely persisted for more than seven days, and transition weather types rarely lasted longer than three days. Therefore, two day-in-sequence categories were created to broadly categorize weather type persistence: less than 3 days, and three to seven days. Total rates of hospitalization were calculated for each region and were normalized per 100,000 population and per 100 weather type persistence category occurrences, along with daily rates of hospitalization per 100,000 population per 100 weather type occurrences. These rates were then summed and significance tested using a Kruskal-Wallis test for independent samples (α = .05). The daily rates for the following day-in-sequence categories and weather types were compared: polar weather types were compared to themselves for both persistence categories, polar less than three days was compared to transition, and polar three to seven days was compared to transition weather types.

Hospitalizations were also binned by core months of meteorological winter (December, January, and February) and peripheral months of winter (November and March) to determine if hypothermia rates were different. A binary variable was created ("winter core" and "not winter core") and total hospitalization rates per 100,000 population and per 100 weather types was computed. Then daily hospitalization rates for polar and transition weather types were calculated and normalized per 100,000 population, per 100 weather type occurrences. The daily hospitalization rates for the winter core and peripheral winter were tested for statistical significance using a Kruskal-Wallis non-parametric test (α = .05).

4.3.3.1 Demographic Analysis

Descriptive statistics were computed to determine the frequency with which hypothermia morbidity was observed. The victims' age and sex characteristics were reported at the time of admission, so an analysis of age and sex was performed. For the age analysis, each case in the dataset was categorized as non-elderly (below age 65) and elderly (age 65 and greater). The total rate of hospitalization for each region for polar and transition weather types was calculated. The annual number of elderly/non-elderly hospitalizations were normalized by 100,000 elderly/non-elderly population and per 100 weather type occurrences, to determine age specific vulnerability by weather type. A rate ratio was the calculated for each region to determine how much more frequently the elderly were hospitalized than the non-elderly, as previous research has indicated a high level of elderly vulnerability to hypothermia (eg. Rango 1985). Daily rates of hospitalizations were then computed and tested for statistical significance using a Wilcoxon Rank-Sum Test (α =.05).

An examination of sex-specific vulnerabilities was also conducted utilizing similar methods to the age analysis. Each victim in the dataset was listed as male or female. The total rate of male and female hospitalizations per 100,000 male/female population and per 100 weather type occurrences, was calculated to determine sex-specific vulnerabilities to hypothermia. A rate ratio was calculated to determine how much more frequently males were hospitalized compared to females, as previous research has indicated males have a higher vulnerability to hypothermia (eg. Thacker et al. 2008). Daily rates of hospitalizations were then computed and tested for statistical significance using a Wilcoxon Rank-Sum Test (α =.05).

4.3.3.2 Urban to Rural Analysis

The victim's county of residence was chosen as the level of spatial analysis. All counties in the US are given a rural-urban classification using the US Census Bureau's Urban to Rural Continuum. These codes are on a scale from one to nine, with one being the largest metro areas (greater than 1 million population) and nine being rural counties of less than 2500 population not adjacent to any type of metropolitan area. This analysis used a binary classification, categorizing codes one through three as urban and codes four through nine as rural, as codes one through three represent counties with metropolitan areas of 250,000 or more, while codes four through nine are non-metropolitan counties with urban populations less than 20,000. Total rates of hospitalization were calculated and normalized by 100,000 urban/rural population and per 100 weather type occurrences. Daily rates of hospitalization for urban and rural areas were calculated to ascertain the rate difference between these two distinct types of areas. To determine if there was a statistically significant difference between urban and rural daily hospitalization rates, a Wilcoxon rank-sum test was performed ($\alpha = .05$). Limited prior research has indicated that hypothermia rates are higher in rural environments (e.g. Herity et al. 1991); hence, the rate ratio was calculated by dividing rural rates by urban rates to determine the relative rates of hospitalization.

4.4 Results

4.4.1 Descriptive Statistics

A total of 4147 hypothermia-related hospitalizations for all ICD-9 codes (E 901.0, E901.1, E901.8, E901.9) were identified within the data set. In the period from November to March for the years 1991-92 to 2005-06, a total of 2313 hypothermia hospitalizations were reported for the ICD-9 code E901.0 in association with polar and transition weather types (Figure 4.2). The number of cases exhibited considerable annual variability, with a minimum of 32 in 2001-02 and a maximum of 389 in 1993-94.

The observed minimum for hypothermia hospitalizations occurs in November with an increase through December (Figure 4.3). The highest frequency of hypothermia hospitalizations occurs during January, with approximately 42% of E901.0 cases during the study period occurring during this month. After the January peak hospitalizations decrease through February and into March. The total rates of hypothermia hospitalizations varied among the weather types and also demonstrated spatial variability (Figure 4.4). The pooled polar weather types were associated with higher rates of hospitalizations compared to the transition weather type for all seven regions, with the exception of Watertown (Table 4.5).

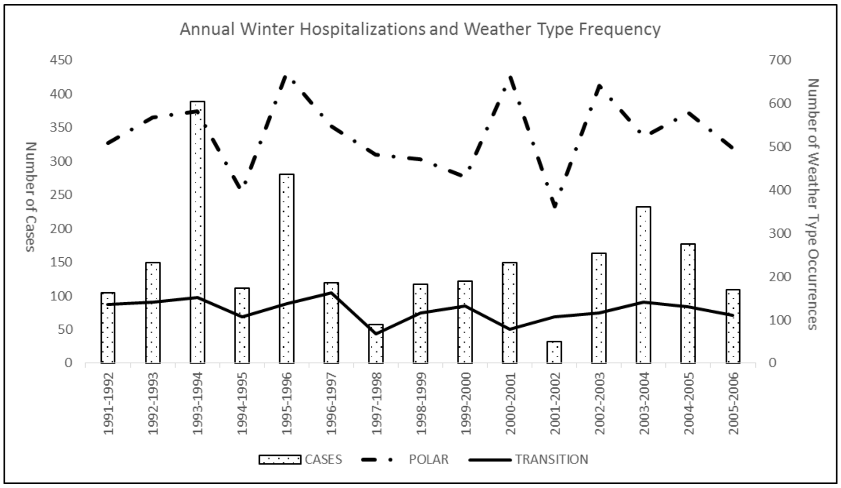


Figure 4.2. The frequency of hospitalizations (cases) by winter season and the number of polar and transition weather types for all seven regions from 1991-92 to 2005-06. As all seven regions are pooled together here, the totals can add up to more than 365.

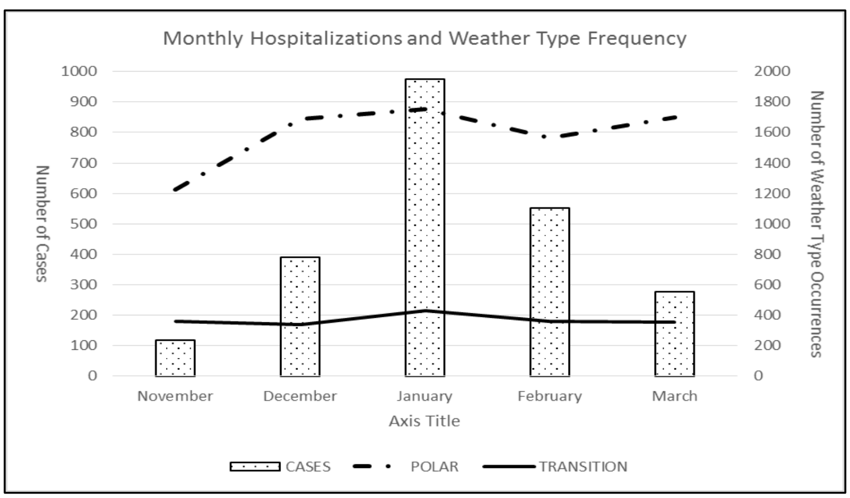


Figure 4.3. The monthly frequency of hypothermia hospitalizations (cases) during the study period with polar and transition weather type frequency displayed. As all seven regions are pooled together here, the totals can add up to more than 365.

For polar weather types, higher rates of hospitalizations were generally associated with regions whose constituent counties had higher percentages of rural population such as Massena. Lower rates were identified in regions with mid-size cities (Albany, Buffalo, Rochester) in a longitudinal swath through the central portion of the state.

Table 4.5. Frequency of hospitalizations (cases) and weather types, along with the total hospitalization rates per 100,000 population per 100 weather type occurrences. The average population for each region was calculated using US Census data for 1990 and 2000.

Region	Average Total Population	Polar Cases	Polar Frequency	Polar Rate	Transition Cases	Transition Frequency	Transition Rate
Albany	1612679	139	1161	0.74	30	258	0.72
Binghamton	725178	93	1206	1.06	17	240	0.98
Buffalo	1545391	186	1143	1.05	28	246	0.74
Massena	287134	57	1227	1.62	13	283	1.60
New York City	12220353	1165	802	1.19	269	302	0.73
Rochester	1294688	142	1167	0.94	22	246	0.69
Watertown	1093833	109	1220	0.82	43	263	1.50

One exception to the general pattern of higher rates of rural vulnerability is New York City, which had the second highest rates of hypothermia for polar weather types. Hospitalization rates for transition weather types had a less distinct pattern. The lowest rates of hypothermia associated with transition weather types were found in regions with higher percentages of urban populations (Albany, Buffalo, New York City, Rochester). As for polar weather types, the highest rates associated with transition weather types were identified in the Massena region.

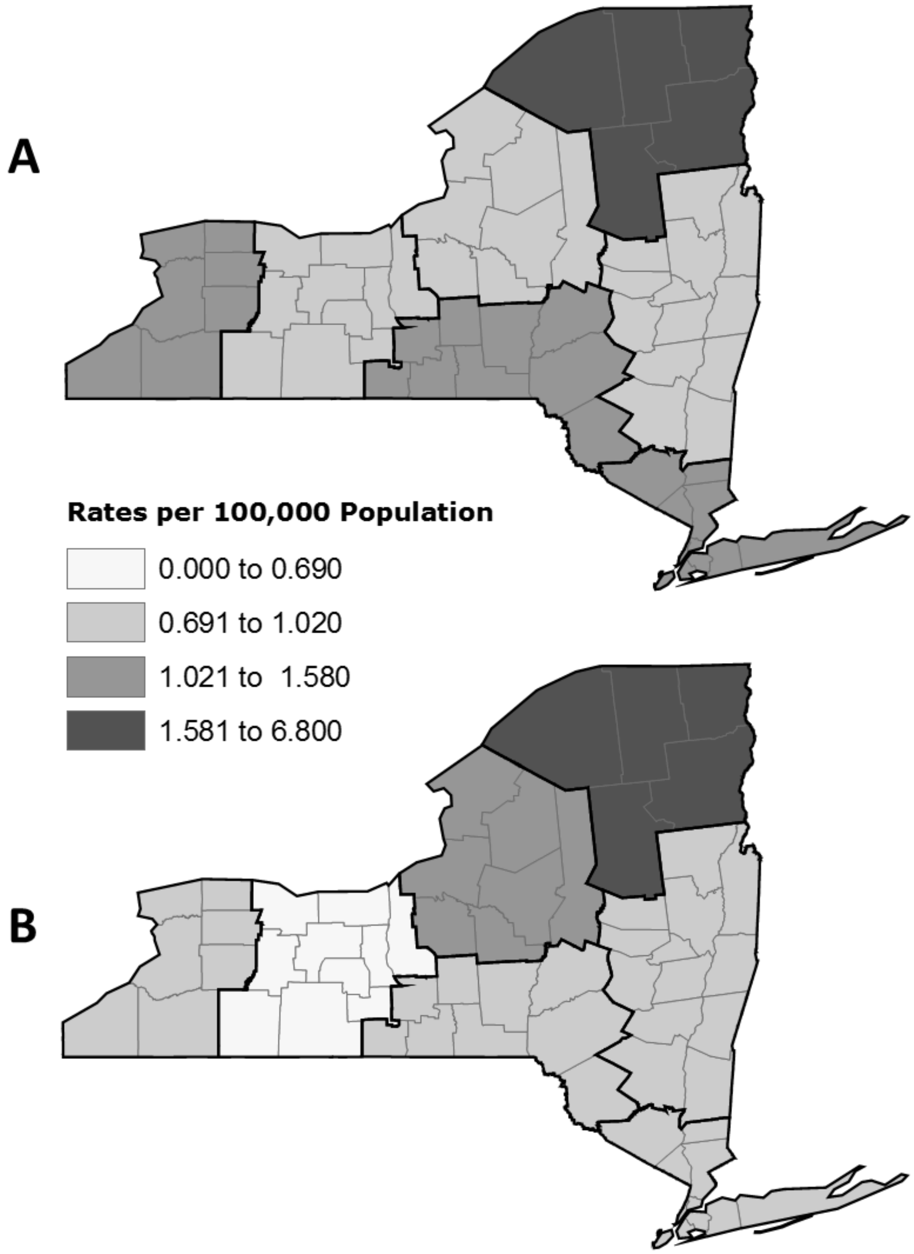


Figure 4.4. The spatial distribution of hypothermia hospitalizations for polar weather types (A) and for transition weather types (B). The legend displays an equal-frequency classification with all data measurements.

4.4.1.1 Days with High Hospitalizations

There were a number of days or sequences of days that made a considerable contribution to the total number of observed hospitalizations (Table 4.6). The sequence of days with the highest amount of hospitalizations was observed in the middle of January 1994. Twenty or more hypothermia hospitalizations were reported each day for a three-day period from January 19th to January 21st, and in the one-week period from January 15th to January 23rd, a total of 115 hospitalizations occurred. January of 1994 was associated with a cold polar outbreak, with record lows for much of the US starting on the 18th, and particularly cold temperatures in the New York region. Overall, January of the 1993-1994 winter season was associated with 213 hospitalizations, the highest observed monthly frequency in the dataset.

Another large cold outbreak in the northeast United States occurred in mid-January of 2004 (Hornberger 2010). This cold wave was associated with daytime temperatures below -17º C. A total of 50 hospitalizations occurred in the period from January 15th to January 19th. The other significant cold outbreak associated with hypothermia hospitalizations occurred in mid-January of 1996. Over a five-day period from the 5th to the 10th, 64 hypothermia cases were reported. The total number of reported hospitalizations in the course of these cold waves was 229, which is nearly 10% of the total reported hospitalizations assessed in the dataset. The only day that was not a January cold wave was February 5th, 1996. February 1-4 was associated with arctic air that made its way into large portions of the north-central and northeastern portions of the US. The hospitalizations were reported for the day after the initial cold wave sequence, and could represent a delay in reporting.

Table 4.6. The days with the highest observed hospitalizations in the dataset. The number of hospitalizations for each day is the total for all regions, but does not include any hospitalizations associated with moderate or tropical weather types.

Date	Hospitalizations
1/21/1994	26
1/20/1994	25
1/19/1994	20
1/16/2004	17
2/05/1996	14
1/10/2004	13
1/08/1996	13
1/06/1996	13
1/23/1994	12
1/10/1996	12

4.4.2 Demographic Analysis

4.4.2.1 Sex Analysis

An analysis of sex was performed to determine if males or females were more frequently hospitalized with hypothermia. Of the 2313 cases associated with polar and transition weather types during the study period, 1724 were male and 589 were female. The overall percentage of male victims (approximately 75%) is consistent with previous hypothermia mortality research in the US (Thacker et al. 2008). Rates of hospitalization and rate ratios were calculated for each of the seven regions (Table 4.7).

With the exception of female hospitalization rates during transition weather type days in Buffalo, male hospitalization rates exceeded female rates for both weather types in all regions. The Massena region had the overall highest hospitalization rates for men and women for both weather types. The Massena and Binghamton regions had the lowest rate ratios, or the hospitalization rate difference between men and women, for polar weather types.

Table 4.7. The total rate of hypothermia hospitalizations for each region by sex for polar and transition weather types. Hospitalization rates are calculated per 100,000 for each gender's respective population, per 100 weather type occurrences. Bold indicates statistically significant rate differences.

Region	Polar Male Cases	Polar Female Cases	Polar Male Rate	Polar Female Rate	Polar Rate Ratio
Albany	91	48	0.94	0.48	1.96
Binghamton	58	35	1.35	0.78	1.73
Buffalo	125	61	1.47	0.67	2.20
Massena	36	21	2.09	1.30	1.61
New York City	920	245	1.97	0.48	4.11
Rochester	96	46	1.30	0.59	2.19
Watertown	83	26	1.27	0.38	3.33
Region	Transition Male Cases	Transition Female Cases	Transition Male Rate	Transition Female Rate	Transition Rate Ratio
Albany	19	11	0.85	0.47	1.79
Binghamton	12	5	1.28	0.51	2.50
Buffalo	12	16	0.67	0.83	0.80
Massena	9	4	2.47	1.17	2.11
New York City	217	52	1.23	0.27	4.57
Rochester	18	4	1.11	0.23	4.73
Watertown	28	15	2.13	1.09	1.95

Hospitalizations associated with the transition weather types were lowest for males in regions with mid-size cities (Albany, Buffalo, Rochester), while the lowest rates of female hypothermia with the transition weather type were identified in Albany, New York City, and Rochester (Figure 4.5). For both weather types, New York City had the highest rate ratio, with men approximately 4 times more likely to be hospitalized than women.

Daily hospitalization rates were calculated and tested using a Wilcoxon Rank-Sum Test to determine if the differences in daily rates between male and female hospitalizations were statistically significant. Male rates exceeded female rates for polar weather types and this rate difference was significant for all regions except Massena. For transition weather types, the rate differences were significant for Albany, Binghamton, New York City, and Rochester.

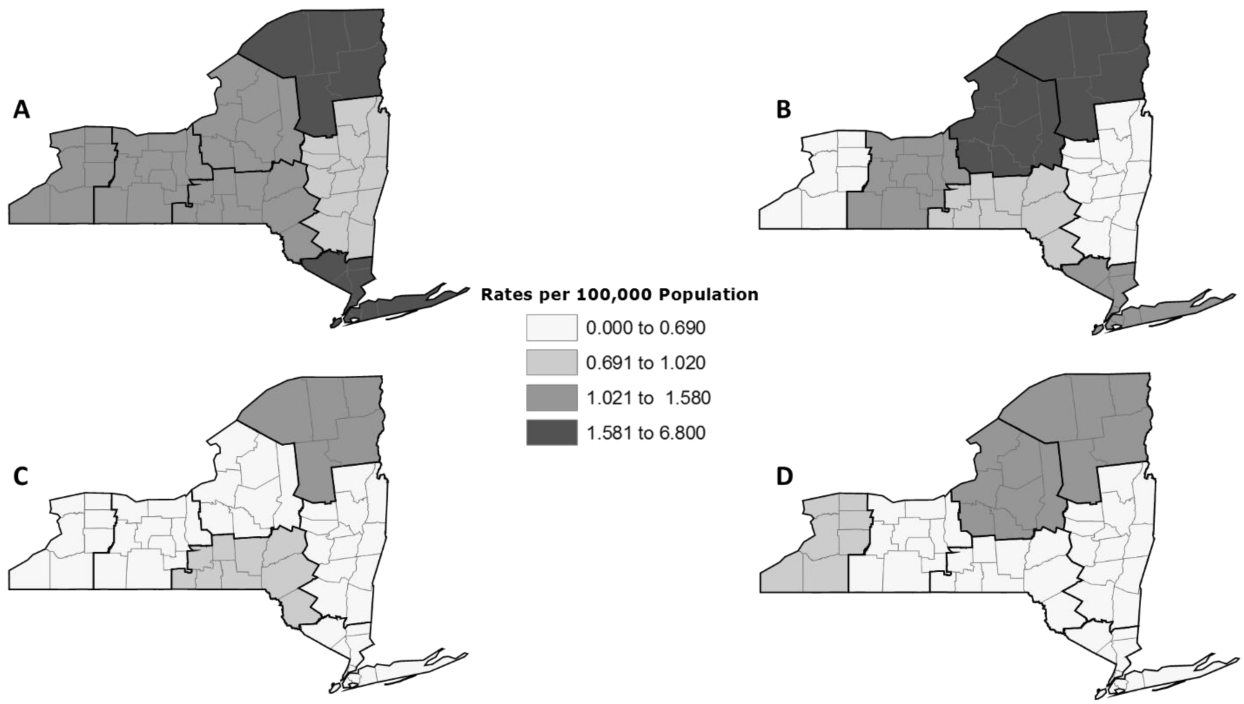


Figure 4.5 Comparison of male and female hospitalization rates for polar and transition weather types, with male polar (A), male transition (B), female polar (C), and female transition (D). The legend displays an equal-frequency classification with all data measurements.

4.4.2.2 Age Analysis

This study defined elderly as 65 years of age or older and used a binary variable to denote elderly or non-elderly status for each case. This was performed to determine if the elderly were more likely to be hospitalized with hypothermia. Within the SPARCS dataset 1216 non-elderly patients were identified, while 701 patients over the age of 65 were found. However, the rates of hospitalization for the elderly were much higher compared to the non-elderly (Table 4.8).

Table 4.8. The total rate of hypothermia hospitalizations for each region by elderly and non-elderly status for polar and transition weather types. Hospitalization rates are calculated per 100,000 of each age group's population, per 100 weather type occurrences. Bold indicates statistically significant rates.

Region	Polar Elderly Cases	Polar Non-Elderly Cases	Polar Elderly Rate	Polar Non-Elderly Rate	Polar Rate Ratio
Albany	62	77	2.38	0.48	4.96
Binghamton	45	48	3.57	0.64	5.58
Buffalo	87	99	3.20	0.66	4.85
Massena	31	26	6.80	0.85	8.00
New York City	263	902	2.25	1.08	2.08
Rochester	61	81	3.05	0.62	4.92
Watertown	40	69	2.17	0.60	3.62
Region	Transition Elderly Cases	Transition Non-Elderly Cases	Transition Elderly Rate	Transition Non-Elderly Rate	Transition Rate Ratio
Albany	9	21	1.55	0.59	2.63
Binghamton	8	9	3.19	0.60	5.32
Buffalo	13	15	2.22	0.47	4.72
Massena	6	7	5.71	0.99	5.77
New York City	57	212	1.32	0.67	1.97
Rochester	6	16	1.43	0.58	2.47
Watertown	13	30	3.28	1.21	2.71

Elderly rates of hospitalization exceeded those of non-elderly victims for both weather types in all regions (Figure 4.6). The highest rates of hospitalization among the elderly occurred in Massena for both polar and transition weather types, respectively. The highest rate ratios for both weather types occurred in regions with more rural counties such as Massena and Binghamton, with a ratio of 8 for polar weather types in the former region. While New York City had among the lowest rates of hospitalization for elderly individuals, it had the highest rates for polar weather types among non-elderly victims. Hence, this region has lowest rate ratio.

Daily rates were calculated and a Wilcoxon Rank-Sum Test was performed to determine if the rate differences between elderly and non-elderly populations was significant. Hospitalization rate differences for polar weather types were significant for all regions, while rate differences for transition weather types were not significant for any region.

4.4.3 SSC Analysis

4.4.3.1 Day-in-Sequence Analysis

While it is known that hypothermia cases occur most often during the cool season in vulnerable populations, the specific relationships between weather type and the pattern of hospitalizations has not been researched. To assess this association a day-in-sequence analysis was performed, which counted the number of consecutive days a weather type persisted at a weather station. This was done for polar weather types that persisted less than three days, polar weather types that lasted three to seven days, and transition weather types that lasted less than three days.

Overall, the Massena region had the highest hypothermia rates for all weather type persistence categories. With the exception of Massena and Binghamton, polar weather types that lasted less than three days were associated with lower rates of hospitalization than more persistent polar weather types (Table 4.9). Polar weather types lasting between three and seven days had the overall highest rates of hospitalization. Generally, transition weather types were associated with lower rates of hospitalization than polar weather types in both persistence categories.

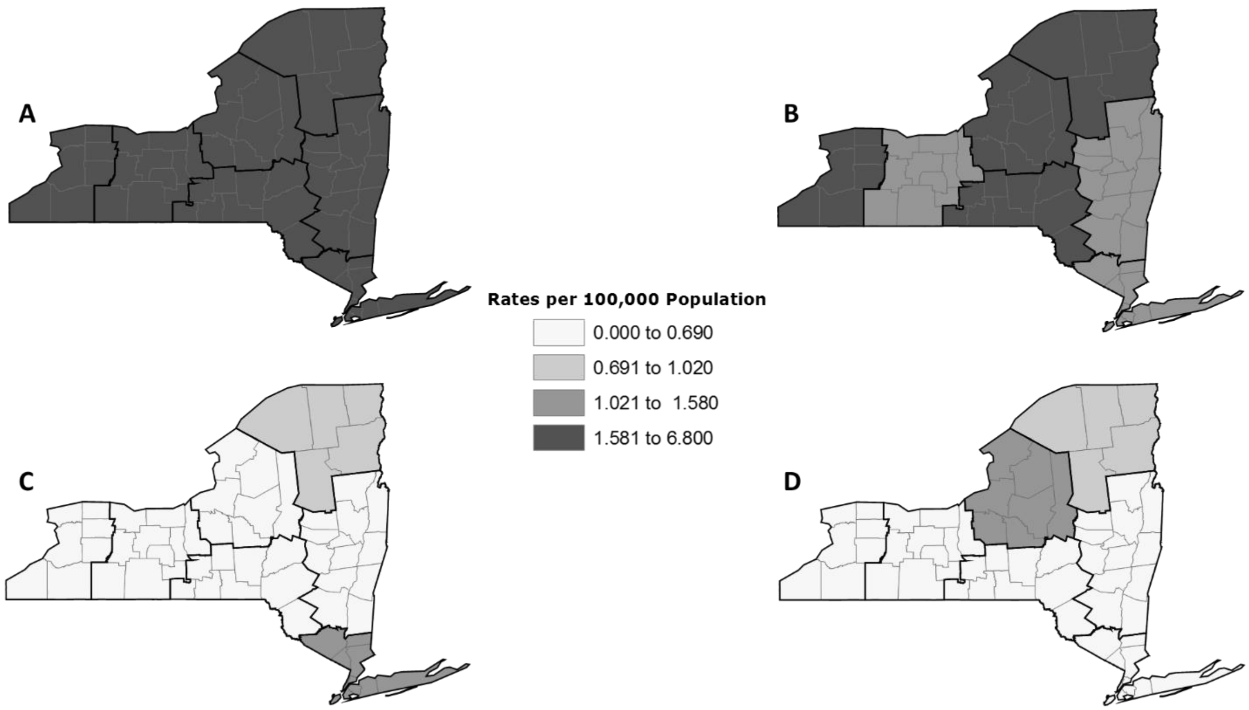


Figure 4.6. Comparison of elderly and non-elderly hospitalization rates for polar and transition weather types, with elderly polar (A), elderly transition (B), non-elderly polar (C), non-elderly transition (D). The legend displays an equal-frequency classification with all data measurements.

Table 4.9. Total rates of hospitalization for each region by weather type persistence. Rates were normalized by 100,000 population and by 100 occurrences of each persistence category.

Station	Polar (<3 days)	Polar (3-7 days)	Transition (<3 days)
Albany	0.53	0.95	0.73
Binghamton	1.12	1.01	0.94
Buffalo	0.80	1.31	0.74
Massena	1.81	1.43	1.53
New York City	1.04	1.43	0.72
Rochester	0.78	1.10	0.70
Watertown	0.75	0.89	1.42

Daily rates of hospitalization were calculated and significance testing using a Kruskal-Wallis Test at the .05 significance level. Polar weather types persisting between three and seven days had higher hospitalization rates than polar weather types lasting less than three days for Albany, Buffalo, and New York City, and these differences were statistically significant. For the Watertown region, transition weather type hospitalization rates exceeded polar rates for both persistence categories, and these differences were significant. Other rate differences were not statistically significant.

4.4.3.2 Winter Core/Winter Periphery Analysis

As exploratory analysis indicated that March and November had considerable weather variability, the monthly period of study was divided into a winter core (December, January, and February) and a peripheral winter (November and March) to determine temporal variability of hospitalizations. The goal was to determine if more variable weather types or more persistent weather types led to higher rates of hospitalizations.

Generally, the highest rates of hospitalization occurred during the core of winter, with lower rates occurring in the months of peripheral winter (Table 4.10). This was true within weather types and occasionally occurred between weather types. For example, hospitalization rates associated with transition weather types in the core of winter exceeded those of core polar weather types for Albany and Watertown. The polar rate ratios indicated that the likelihood of hospitalization ranged from 2.2 to 3.8 times greater for the core compared to the periphery of winter, with ratios ranging between 1.4 and 4 for transition weather types.

Table 4.10. Comparison of total hospitalization rates for each weather type by winter season division. Bold indicates statistical significance.

Station	Polar Winter Core	Polar Winter Periphery	Polar Core/Periphery Rate Ratio	Transition Winter Core	Transition Winter Periphery	Transition Core/Periphery Rate Ratio
Albany	0.96	0.36	2.67	1.01	0.25	4.04
Binghamton	1.36	0.58	2.34	1.24	0.64	1.94
Buffalo	1.32	0.60	2.20	0.90	0.48	1.88
Massena	1.63	0.52	3.13	1.02	0.31	3.29
New York City	2.18	0.57	3.82	1.98	0.98	2.02
Rochester	1.20	0.53	2.26	0.78	0.56	1.39
Watertown	1.05	0.44	2.39	1.87	0.85	2.20

Daily hospitalization rates by core and periphery of winter were calculated and significance tested using a Kruskal-Wallis Test. The rate differences for the core and periphery of winter for polar weather types are significant for all regions, and are significant for Albany, New York City, and Watertown for transition.

4.4.4 Urban and Rural Comparison

Each county within the study area was given a rural or urban code, so overall hospitalization rates for each region's urban and rural areas were calculated (Table 4.11). Hospitalization rates for polar weather types were higher in rural areas than urban areas, with the exception of the Buffalo and Watertown regions (Figure 4.7). Transition weather type hospitalizations by urban/rural status had a less definable pattern, with urban rates higher in Albany, Buffalo, and Watertown.

Table 4.11. Hospitalization rates per 100,000 urban/rural population per 100 occurrences of polar and transition weather types. Bold indicates statistical significance.

Region	Polar Urban Rate	Polar Rural Rate	Polar Rate Ratio	Transition Urban Rate	Transition Rural Rate	Transition Rate Ratio
Albany	0.71	0.96	1.35	0.80	0.18	0.23
Binghamton	0.73	1.58	2.16	0.94	1.03	1.10
Buffalo	1.06	1.04	0.98	0.80	0.50	0.63
Rochester	0.83	1.28	1.54	0.66	0.79	1.20
Watertown	0.82	0.77	0.94	1.55	1.10	0.71

Daily rates of hospitalization by urban/rural status were calculated and tested for statistical significance using a Kruskal-Wallis Test (.05 alpha). The rate differences for polar weather types were all significant except Rochester, with all rate differences except Binghamton and Rochester significant for transition weather types.

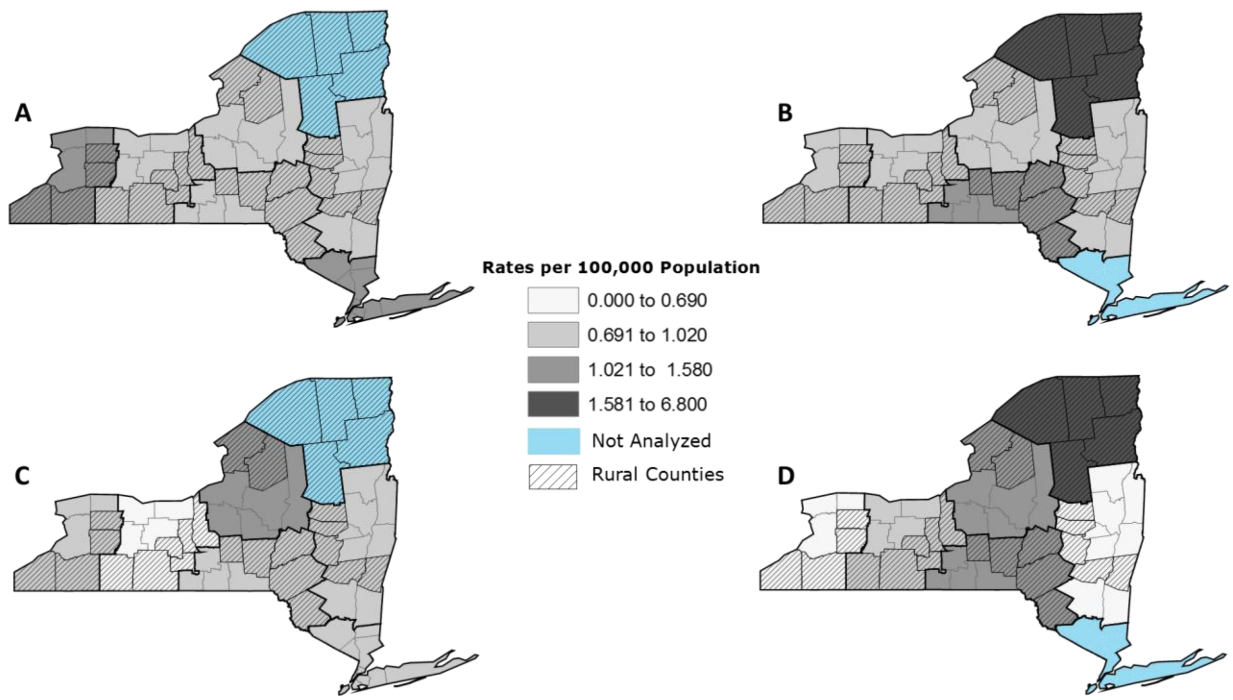


Figure 4.7. Comparison of urban and rural rates for polar and transition weather types, with urban polar (A), urban transition (B), rural polar (C), rural transition (D). The legend displays an equal-frequency classification with all data measurements.

4.5 Discussion

As hypothermia morbidity research in the US is extremely limited, the results will be situated and discussed with respect to both hypothermia mortality and morbidity research. A total of 2313 hypothermia hospitalizations attributable to direct cold exposure from November-March for the years 1991-92 to 2005-2006 were identified in this research. The overall number of cases for the whole of New York State varied considerably from one winter season to the next, with a minimum of 32 in 2001-02 and a maximum of 389 in 1993-94. The monthly distribution of hypothermia fatalities peaked in January. Previously, it was unknown what the monthly pattern of hypothermia hospitalizations was, so the finding is consistent with previous research on hypothermia fatalities, in which colder periods are associated with increased death rates (Elbaz et al. 2007; Herity et al. 1991; Noe et al. 2012; Tanaka and Tokodome 1991; Taylor and McGwin 2000;). This suggests that hospitalizations and death occur in close temporal proximity.

Additionally, there were three January cold waves (1994, 1996, 2004) that resulted in high frequencies of hospitalizations, and these accounted for 10% of reported hypothermia cases reported in the dataset. These cold outbreaks were associated with intruding Arctic air masses throughout the state, with the stations reporting persistent polar weather types. Cold temperatures with respect to a human vulnerability context are defined relative to a local "normal", in which temperatures that are markedly cooler for the location and time of year have the greatest potential to result in cold-related illness; this has been found in general cold mortality research (Analitis et al. 2008). While people become accustomed to the temperature range in areas in which they live, the human body lacks significant physiological capacity to adapt to cold temperatures and its thermoregulation response becomes less efficient if it is activated frequently (Castellani et al. 2006; Young et al. 1998;). Thus, persistent cold weather can tax the cold response of susceptible populations and result in increased rates of hypothermia-related hospitalizations. This principle has been further identified in Swedish research, which found that non-Norse populations had much higher rates of cold-weather related illnesses compared to native Norse populations (Rocklov et al. 2014).

The SSC had not been utilized previously in hypothermia research. As the SSC utilizes local climatology to define weather types as simple metric, it works well for examining health outcomes and comparing them to local conditions. This finding that persistent cold weather relative to local averages having significant impacts on the population is also seen in the day-in-sequence and winter core-periphery analysis. Polar weather types generally had higher hospitalization rates than did transition weather types, and long-lasting polar weather types generally had the highest rates of hospitalizations.

This indicates that long-lasting polar weather types drive increases in hospitalization rates. Related to weather type persistence, the core of winter (December, January, February) had generally elevated rates of hypothermia cases compared to the periphery of winter (November and March). Originally, it was thought that the inherent variability of the peripheral winter months would increase rates, as temperatures that are outside of the seasonal average can drive spikes in cold-related mortality (Analitis et al. 2008; Curriero et al. 2002). However, the core of winter is associated with longer-lasting polar weather types that can tax the cold response, especially that of vulnerable populations.

This research utilized demographic metrics in the data to determine populations with higher susceptibility to hypothermia. While vulnerable populations have been identified through death certificate research (e.g., Thacker et al. 2008), knowledge of demographic characteristics with respect to hypothermia morbidity is poorly understood. It was not known if the demographic characteristics of those injured were distinct from those that perished. However, the results suggest that the demographic pattern of vulnerability is similar for hospitalizations compared to deaths. The hospitalization rates indicated that men were more likely to be hospitalized than women; in the case of the New York City region, by a factor of four. Several reasons contribute to this higher level of male vulnerability to hypothermia. A meta-analysis of psychological research determined that males were more prone to risk-taking behavior (Byrnes et al. 1999), while females have been noted to perceive situations as riskier compared to men (Drabek 1999; Siegrist et al. 2005). Little research exists on gender-specific behavior and response to winter weather conditions; however, women were more likely to perceive higher levels of risk during heat waves (Kalkstein and Sheridan 2007). It is possible women's apparent increase in risk perception might play a protective role against dangerous ambient thermal conditions. Other factors contribute to this high level of male vulnerability. Men have higher rates of homelessness and alcoholism compared to females, and several case studies have identified high numbers of middle-aged male hypothermia victims who were intoxicated or homeless around the time of death (Gallaher et al. 1992; Tanaka and Tokodome 1991; Taylor and McGwin 2000). With men four times more likely to be hospitalized of hypothermia than women in New York City, a possible confounding factor is the homeless population, as New York State is estimated to have the second highest homeless population in the US (Department of Housing and Urban Development). This could contribute to the higher level of observed male vulnerability. Additionally, men are more frequently employed in outdoor manual labor jobs; this may contribute to their vulnerability by exposing them to colder temperatures for longer periods of time (Taylor and McGwin 2000). Lastly, several medical studies have found that physiological factors also contribute to male/female gender differences in thermal regulation. During exercise, men generate more internal heat at the same level of oxygen consumption as females, but lose more heat through evaporative heat loss (Gagnon et al. 2008). Women also have lower cutaneous blood flow, meaning that they have a lower skin temperature to environmental temperature gradient and hence lose less heat to the surrounding environment (Stocks et al. 2004).

Persons over the age of 65 (elderly) had the higher rates of hypothermia-related hospitalizations than any cohort assessed in the research. They were much more likely to be hospitalized of hypothermia when compared to non-elderly (<65 years old). In the case of the Massena region, elderly were 8 times more likely to be hospitalized than younger age groups. Thermal regulation inefficiency is one of the most significant elderly hypothermia risk factors, and it can work synergistically with other aspects to create the elderly's susceptibility to hypothermia (Nixdorff-Miller et al. 2006). The ability to regulate one's internal temperature as well as perceive temperature extremes accurately also decreases with age. Thus, the elderly might not realize they are hypothermic until serious medical problems are imminent and also far more difficult to treat (Nixdorff-Miller et al. 2006). Decreased thermal efficiency means that the elderly can become hypothermic indoors at moderate temperatures. As it is less likely that indoor hypothermia victims will be found quickly, the survival prognosis is poorer in indoor settings

(Megarbargane et al. 2000; Roeggla et al. 2001). Social isolation is another confounding factor that increases elderly vulnerability to hypothermia (Dharmarajan and Wijidada 2007). While there are almost no studies examining the elderly response to cold temperatures (Sherman-Morris 2013), studies examining elderly perception of heat indicate a general "seen it all" attitude. Oftentimes they underestimated the danger, thought that dangerous situations were not as hazardous as the messaging made it seem, or they simply did not self-identify as elderly, so took fewer precautions (Abrahamson et al. 2008; Sheridan 2007;). In this study it was noted that the New York City region had the lowest rate ratios for elderly victims compared to non-elderly victims. The reasons for this are unclear, but it is possible the city's high population density means there are always neighbors to check on the elderly, so they can find medical assistance faster if they have a problem. Conversely, the highest elderly/non-elderly rate ratios were generally identified in regions with more rural counties, especially Massena for polar weather types. It is possible the intrinsic isolation of rural areas compounds with elderly social isolation to create an area of vulnerability.

With the exception of New York and Massena, which were 100% urban and rural, respectively, each region in this study was composed of counties classified as urban and rural. A comparison of urban and rural counties was undertaken to determine which areas had higher rates of fatalities. Rural counties within each of the regions generally had slightly higher rates than their urban counterparts. While hypothermia is often stereotyped as an affliction of the urban poor and homeless, this is often due to high raw numbers of hypothermia cases that impact city homeless (Hwang 2001). Thacker et al. (2008), in their study on US natural hazard-related mortality, found that the mountainous western states (with their extensive areas of rural terrain) had the highest hypothermia mortality rates. Herity et al. (1991) found that rural areas within Ireland had higher rates of hospitalizations. It is possible the remoteness of rural areas creates accessibility difficulties, especially with respect to medical care. In this research, the Massena and Binghamton regions had considerable elderly populations, which could serve as a confounding factor that drives increased rates of hospitalization in rural areas.

4.6 Conclusions

Hypothermia hospitalization data was obtained from the New York State Department of Health SPARCS system to determine if an association exists between SSC weather type and hypothermia hospitalizations in New York State. This study was the first to utilize certain data and techniques to research hypothermia, namely the use of hypothermia hospitalization data, along with the SSC. Generally speaking, the hospitalization data showed that similar vulnerability profiles exist between morbidity and mortality. The SSC, with its locally defined parameters, makes for a reliable method of associating a particular health outcome to single holistic climate metric. A total of 2313 hospitalizations were identified that were attributable to direct cold exposure (ICD-9 code E901.0). These hospitalizations increased through November and December, peaked in January, and then decreased through March.

Several separate results together indicate that persistent polar weather types are the most significant contributor to hypothermia hospitalizations. First, the monthly distribution of deaths peaks in January, which is concurrent with the coldest temperatures at this latitude. Three significant polar outbreaks associated with long-lasting arctic air masses also occurred during January. The coldest portion of winter, the winter core (Dec-Jan-Feb), had higher daily rates of hospitalization compared to periphery winter. Long-lasting polar weather types (3-7 days) were associated with the highest rates of hospitalizations. Hence, cold temperatures relative to the local average that are persistent across space and time drive increases in hospitalization rates, especially across vulnerable populations.

The demographic results were generally consistent with what is known concerning hypothermia mortality. Males and the elderly (>65 years of age) were found to have higher rates of hospitalization compared to females and non-elderly, respectively. Male vulnerability is surmised to be a combination of risk-taking, higher rates of alcoholism, more frequent employment in outdoor environments, and lastly, higher rates of homelessness. Elderly were considerably more likely to be hospitalized than non-elderly, a product of decreased thermal regulation, perception difficulties, and social isolation. The highest rates of elderly hospitalizations were identified in the Massena area, a region of rural character, while the lowest rate ratio difference between elderly and non-elderly was identified in New York City. This means that the low population density and the intrinsic isolation of rural regions may confound elderly vulnerability.

There are several suggestions that stem from the results of this research. Polar weather types that are forecasted to persist for several days or more need to be accompanied by extensive warnings. These alerts need to be targeted to the most vulnerable populations, particularly the elderly and the homeless. Younger, healthier relatives and neighbors need to be notified that while rural areas are much more lightly populated, the hospitalization rates are comparatively high. Alerts specifically targeted to rural residents to alert them to cold hazards could help reduce hospitalization rates in these regions.

There are a number of potential avenues of future research. The results of this research could be compared to New York State hypothermia mortality data to determine if there are differences between hypothermia decedents and those that survive hypothermia. Hypothermia morbidity data could be obtained for the US to determine temperature-specific vulnerabilities by region. These data could also be compared to mortality data to determine if there are meteorological thresholds that discriminate between survival and non-survival, which could then be used to develop more effective cold weather warnings. A number of groups were demonstrated to have higher rates of hospitalizations. Surveys of these groups could illuminate behavioral patterns that create higher levels of risk for these populations.

CHAPTER 5

SYNTHESIS OF RESEARCH CHAPTERS AND CONCLUDING REMARKS

5.1 Discussion of Research Results

Hypothermia is a considerable public health problem in the US, and its association with cold weather makes it one of the deadliest atmospheric hazards in the US (Thacker et al. 2008). This dissertation has sought to evaluate hypothermia from a geographic perspective, as knowledge from this viewpoint is fairly limited. This dissertation accomplished this through three separate but related papers: a critical review of internet web pages offering hypothermia information and guidance, and comparing it to peer-reviewed medical literature; an examination of the geographic distribution of hypothermia deaths in US Combined and Metropolitan Statistical Areas, with a comparison to National Weather Service wind chill alert criteria; and lastly, an examination of hypothermia morbidity patterns in New York State by using SSC weather types. Each one of these papers had unique conclusions, while still contributing to a greater overall understanding of hypothermia's geographic perspective. This chapter will summarize the most important findings of the individual papers, and will then describe common threads that unite the three manuscripts.

While the medical physiology of hypothermia and groups of people who are vulnerable to it are well-known (Dharmarajan and Wijidada 2007; Gallaher et al. 1992; Nixdorff-Miller et al. 2006), there are a number of knowledge areas this dissertation expanded. First of all, an assessment of hypothermia messaging on the World Wide Web had yet to be undertaken. An analysis of this type had been performed with respect to heat vulnerability information on the internet (Hajat et al. 2010). The results of their research indicated that much information between websites was contradictory, the most important protection information was not clearly emphasized, and much of the information on the web was not supported by peer-review literature (especially papers cited on the websites). Their basic conclusion was that internet-based information for heat vulnerability was of generally of poor quality, and often contradictory. This dissertation contributed to hazards-based internet information knowledge by assessing hypothermia in this context for the first time, with similar general conclusions reached: Internet-based hypothermia information was generally mediocre, and was not always backed by medical and scientific evidence. Sources were not frequently cited and information between and within websites could be contradictory, with many important pieces of information excluded from some websites (e.g., elderly vulnerability missing on approximately 40% of websites). There are a number of future avenues for research in the hazards domain with respect to internet-related information. While our sample of 49 websites was robust and captured considerable variability in the information available to internet users, this research could possibly be expanded to include wider search parameters, or to include related phenomena such frostbite or cold mortality.

The geographic distribution of hypothermia below the state level, namely at the Combined Statistical Area and Metropolitan Statistical Area level, was previously unknown. Thacker et al. (2008) analyzed region-level US hypothermia deaths from 1979-2004, identifying mountainous western states as having the highest rates of deaths. This dissertation expanded on this prior research by performing a finer-scale spatial analysis to more precisely delimit the geographic distribution of hypothermia deaths, as well as assessing windchill temperatures associated with fatalities. One caveat to note is that this research only examined regions with some type of urban population, and rural regions were largely ignored, with the exception of the Gallup area in New Mexico/Arizona (one of the areas with the highest death tolls).

It was found that areas in the southeastern US had especially high rates of deaths at temperatures that were mild in the absolute sense, though these temperatures were low for the local populace. In some cases, small and mid-size metropolitan areas in the southeastern US had greater numbers of fatalities than larger northern metropolitan areas, indicating strong region-specific vulnerabilities in these areas. While some areas of the American Southwest had lower rates of hypothermia deaths, the area with the highest observed rates in this research was a tri-county rural area near the city of Gallup, New Mexico. The high death rates here fit in with what is known about hypothermia vulnerability, specifically, Native American vulnerability to hypothermia based primarily on social risk factors (Gallaher et al. 1992). While in this analysis urban areas were sought for larger sample sizes, rural areas have been demonstrated to have higher rates of hypothermia fatalities (Herity et al. 1991; Thacker et al. 2008). A research report by the National Homeless Coalition (2010) found that areas with significant differences between day and night temperatures have a higher probability of hypothermia deaths occurring; the Gallup region's highland desert climate exhibits this considerable day-night temperature variability. While this dissertation did not explicitly examine diurnal temperature variation and its association with fatalities, future studies of this type could play a significant role in developing public health responses to cold weather hazards.

A few small regional studies have examined the hypothermia/temperature relationship, and found that as temperature dropped, hypothermia fatalities increased (Herity et al. 1991; Tanaka and Tokodome 1991). This dissertation expanded the regional case study view to a large-scale spatial analysis of hypothermia deaths. While this assessment confirmed what was previously known about hypothermia (temperature decrease, death increase), the spatial/temperature pattern was demonstrated to be more complex and have significant local variation, in that "temperature drop" and "cold temperatures" are defined relative to the climate conditions of an area and the capacity of the local populace to adapt. Hence, while this was previously unknown for hypothermia at a large-national scale, the findings of this portion of the research fit in with what we know about heat and cold-related excess mortality. Sheridan et al. (2009) found that US cities with milder and cooler climates, especially those in the Pacific Northwest, had large heat mortality responses during heat waves (this was partially explained by social factors like the lack of widespread air conditioning usage in this region). With respect to cold mortality, milder areas, such as the US southeast, have a more difficult time coping when low temperatures relative to local climate averages enter the area. The excess cold mortality response to these low temperatures can be considerable (Analitis et al. 2008; Curriero et al. 2002). The results of this dissertation research suggests that these vulnerability principles found in heat/cold vulnerability analyses can apply to more acute cold exposure, and that people are vulnerable to cold weather outside of the realm of what they normally experience.

In the assessment of morbidity in New York State, it was found that patterns of hypothermia vulnerability that were delineated in case studies with deceased victims held true for hypothermia morbidity, as well. Hypothermia rates in rural New York counties tended to have higher rates of death than did their urban counterparts. This higher level of rural hypothermia rates has been observed in several retrospective studies that have analyzed deaths (Herity et al. 1991; Tanaka and Tokodome 1991; Taylor and McGwin 2000; Thacker et al. 2008). The SSC system had also never been utilized in hypothermia research. This is important because the second chapter had demonstrated temperatures that are cold for the local population result in higher rates of death (e.g., Analitis et al. 2008). In the morbidity study, it was shown that persistent cold weather types (for SSC weather types, cold is defined relative to local conditions) resulted in hospitalization spikes. This seems to further indicate that locally cold temperatures have significant impacts on the local populace with respect to hypothermia, a result shown in previous mortality and hypothermia death research (Analitis et al. 2008; Curriero et al. 2002; Herity et al. 1991; Tanaka and Tokodome 1991). As the SSC takes into account local climate characteristics and turns them into a simple metric (Sheridan 2002), it is a good system for judging the short to mid-term impact of weather types. Since the belt of high hypothermia death rates occurs in the South, a mild area with a population acclimatized to warmer conditions, and morbidity rates were examined in a colder environment, it is difficult to directly compare results. However, the results of these two studies, when taken together, indicate that air masses that are locally cold and long-lasting can increase hypothermia deaths and injuries. While Barnett et al. (2012) examined mortality, their research found that longer lasting cold waves were not strongly associated with increased excess mortality in a sample of US cities. They attributed this to adaptive behavior on the part of the populace. More research will be needed to determine the relationship between hospitalization rates and the duration of cold waves. Since morbidity occurs with greater frequency and is less studied, future research that examines morbidity at finer spatial scales in the southeast and other vulnerable areas in the US will not only clarify morbidity and mortality differences, but also reveal more about the relationship of hypothermia to weather conditions. This valuable information could be utilized to develop health-based outcomes for specific cold weather and wind chill alert criteria.

There are a number of even more generalized conclusions stemming from this research that cuts through the three different papers, or combinations of two of the three papers, presented within. The first general theme is that of miscommunication regarding hypothermia, which was initially indicated during the assessment of hypothermia-based web pages. Many of these internet sites strongly supported claims that had limited scientific validity, but omitted information that was more practical and could likely bring higher degrees of awareness, especially with regards to vulnerable populations (for example, “killer cotton” but no focus on the high vulnerability of the elderly). This miscommunication theme extended to the quantitative analysis of hypothermia-related deaths and wind chill temperatures. When gathering information on wind chill alert information and criteria, no centralized website from the NWS provided this information. Much of these data were difficult to collect and collate for an experienced researcher; this would likely be more difficult for a lay person with less scientific background. It took some fairly extensive searching to locate the National Guidance, as well. As wind chill alerts and their criteria are set locally (or based on the National Guidance), it is imperative to make the criteria clearly available to all users. This miscommunication theme less directly extended to the New York morbidity research paper. However, the results of this paper show that morbidity follows some of the general patterns of mortality, except in a greater magnitude, and further highlights the need for a greater emphasis on cold weather alerts and communicating to the public the hazards presented by cold weather. To this last point, it is unknown how dangerous the public perceives cold weather and hypothermia to be. As one of the deadliest atmospheric hazards, it is important to know the public's viewpoint so that clearer communication of this serious weather hazard is developed. This would likely prove to be a very fruitful area of future research.

Another theme that cross-cut the three papers was that of a lack of health-based outcomes related to hypothermia. In regards to the first paper, this was previously stated with respect to the lack of internet hypothermia guidance that is backed by the medical literature. This general theme very strongly relates to the second and third papers. In the second paper, hypothermia deaths were mapped to determine high-vulnerability regions, and median temperature of death was contoured. In all cases, median temperature of death was considerably warmer than what was stated for wind chill warning criteria. After surveying NWS warning coordination meteorologists, their responses indicated that wind chill alert criteria was chosen based on a combination of national guidance, climatology, and following the practices of neighboring offices. Only the national guidance of -18° F (-27.8 C°), which is based on 30 minutes to frostbite, can be construed as utilizing some type of health outcome for determining warnings. However, no frostbite deaths were observed for the period of record (compared to approximately 16,000 hypothermia deaths during the same period), and the epidemiology of frostbite morbidity is unknown. Also, quantifying frostbite morbidity could be difficult, as some frostbite is quite minor (chilblains, etc.) and related to superficial exposure to weather. By comparing deaths and New

York state hospitalizations to wind chill temperatures and SSC weather types, respectively, this study demonstrated the viability of using hypothermia as metric to assess the spatial variations of cold weather vulnerability, while simultaneously showing the lack of health outcome-based criteria at the national and state levels. Health-based outcomes have been used to successfully adopt heat-health warning systems in cities throughout the world and have been effective in reducing heat mortality (Sheridan and Kalkstein 2004). Cold weather warning systems have been applied in a much smaller number of cases, particularly in Canadian locales and Hong Kong. While the Canadian alerts are based on a selected windchill temperature, the Hong Kong alert system is based on a Weather Stress Index that warns for the coldest 2.5% of days in the region, which was demonstrated to have the largest effect on mortality in the city (Li and Chan 2000). Using the windchill associations investigated in this research would provide a starting point for developing more effective cold warning systems in the US.

To summarize, this dissertation with its three separate but related chapters, demonstrated the lack of hypothermia knowledge from the climatological and public health perspective. There is much that we know about heat with regards to ambient conditions and health outcome, but relatively little about cold weather-related hazards. Hajat et al. (2014) demonstrated that in the UK, cold-related deaths will continue to outstrip heat-related deaths until the 2080s, in spite of a warming climate. This means that any research that delineates the hazards presented by cold weather and hypothermia is critical information for the public, weather forecasters, emergency managers, and academics. We need to start by communicating what we know already about hypothermia to the public more effectively, and by undertaking smaller-scale studies to determine the fine-scale spatial distribution of deaths and hospitalizations. This research built upon our understandings of heat and cold-related mortality, along with prior knowledge of hypothermia, to view direct cold deaths from a different perspective. Future studies that further build upon this research will further help to delimit our cold vulnerability.

REFERENCES

Abrahamson, V., Wolf, J., Lorenzoni, I., Fenn, B., Kovats, S., Wilkinson, P., Adger, W. N. and Raine, R., 2008. Perceptions of Heat Wave Risks to Health: Interview-Based Study of Older People in London and Norwich, UK. *J of Publ Health*, 31:1, 119–126.

Ainslee, P., and Riley, T., 2003. Physiology of Accidental Hypothermia in the Mountains: A Forgotten Story. *Br J Sports Med*, 37, 548-550.

Aitken, L., Hendricks, J., Dulhunty, J., and Rudd, M., 2009. Hypothermia and Associated Outcomes in Seriously Injured Trauma Patients in a Predominantly Sub-Tropical Climate. *Resus*, 80, 217–223.

Analitis, A., Katsouyanni, K., Biggeri, A., Baccini, M., Forsberg, B., Bisanti, L., Kirchmayer, U., Ballester F., Cadum, E., Goodman, P., Hojs, A., Sunyer, J., Tiittanen, P., and Michelozzi, P., 2008. Effects of Cold Weather on Mortality: Results from 15 European Cities within the PHEWE Project. *Am J Epidemiol*, 168, 1397-1408.

Anderson, B., and Bell M., 2009. Weather-Related Mortality: How Heat, Cold, and Heat Waves Affect Mortality in the United States. *Epidemiol*, 20, 205-213.

Ashley, S., and Ashley, W., 2008. Flood fatalities in the United States. *J of Appl Meteorol and Climatol*, 47, 805-818.

Ashley, W., 2007. Spatial and Temporal Analysis of Tornado Fatalities in the United States: 1880–2005. *Weather Forecast*, 22, 1214-1229.

Ashley, W., Gilson, C., 2009. A Reassessment of U.S. Lightning Mortality. *B Am Meteorol Soc*, 90, 1501-1518.

Aslam, A.F., Aslam, A. K., Vasavada, B., Khan, I., 2006. Hypothermia: Evaluation, Electrocardiographic Manifestations, and Management. *Am J Med*, 119, 297-301.

Bakkevig, M., Nielsen, R., 1994. Impact of Wet Underwear on Thermoregulatory Responses and Thermal Comfort in the Cold. *Ergonomics*, 37 (8), 1375-1389

Bakshi, R. 2003. Fatigue Associated with Multiple Sclerosis: Diagnosis, Impact and Management. *Mult Scler*, 9 (3), 219-227.

Ballester, J., Harchelroad, F., 1999. Hypothermia: An Easy-to-Miss, Dangerous Disorder in Winter Weather. *Geriatrics*, 54 (2), 51-57.

Bassil, K., Cole, D., 2010. Effectiveness of Public Health Interventions in Reducing Morbidity and Mortality during Heat Episodes: a Structured Review. *Int J Environ Res Public Health*, 7 (3), 991-1001.

Basu, R., 2009. High Ambient Temperature and Mortality: A Review of Epidemiologic Studies from 2001 to 2008. *Environ Health*, 8 (40). <<Published Online Open Access>>.

Baumgartner, E., Belson, M., Rubin, C., Patel, M., 2008. Hypothermia and Other Cold Morbidity-Related Emergency Department Visits, United States: 1995-2004. *Wilderness Environ Med*, 19, 233-237.

Beim, J., Koehnke, N., Classan, D., Dosman, J., 2003. Out of the Cold: Management of Hypothermia and Frostbite. *CMAJ*, 168 (3), 305-311.

Bluestein, M., Zelcher, J. 1999. A New Approach to an Accurate Wind Chill Factor. *B Am Meteorol Soc*, 80 (9) 1893-1899.

Brändström, H., 2012. Accidental Hypothermia and Local Cold Injury: Physiological and Epidemiological Studies on Risk. Doctoral Dissertation, Umea University.

Byrnes, J., Miller, D., Schaeffer, W., 1999. Gender Differences in Risk Taking: A Meta-Analysis. *Psych Bul*, 125, 367-383.

Castellani, J., Young, J., Duchame, M., Geisbrecht, G., Glickman, E., Sallis, R., 2006. Prevention of Cold Injuries During Exercise. *Med Sci Sports Exerc*, 2012-2029.

Centers for Disease Control and Prevention Minority Health: American Indian and Alaska Native Populations. http://www.cdc.gov/minorityhealth/populations/REMP/aian.html. <<Accessed on 2/2/2015>>.

City of Toronto Extreme Cold Weather Alerts, 2013. Available from <http://www.toronto.ca/housing/extremecold.htm>. <<Accessed on 29 July 2013>>.

Conlon, K., Rajkovich, N., White-Newsome, J., Larsen, L., O'Neill, M., 2011. Preventing Cold-Related Morbidity and Mortality in a Changing Climate. *Maturitas*, 69, 197-202.

Connolly, E., Worthley, L., 2000. Induced and Accidental Hypothermia. *Crit Care Resusc*, 2, 22-29.

Curriero, F., Heiner, K., Samet, J., Zeger, S., Strug, L., Patz, J., 2002. Temperature and Mortality in 11 Cities of the Eastern United States. *Am J Epidemiol*, 155, 80-87.

Daanen, H., 2003. Finger Cold-Induced Vasodilation: A Review. *Eur J Appl Physiol*, 89, 411-426.

Danet, S., Richard, F., Montaye, M., Beauchant, S., Lemaire, B., Graux, C., Cottel, D., Marècaux, N., Amouyel, P., 1999. Unhealthy Effects of Atmospheric Temperature and Pressure on the Occurrence of Myocardial Infarction and Coronary Deaths: A 10 Year Survey: The Lille-World Health Organization Monica Project (Monitoring Trends and Determinants In Cardiovascular Disease). *Circulation*, 100, E1-E7.

Danzl, D., Pozos, R., 1994. Accidental Hypothermia. *N Engl J Med*, 331 (26), 1756-1760.

Davie, G., Baker, M., Hales, S., Carlin, J., 2007. Trends and Determinants of Excess Winter Mortality in New Zealand: 1980 to 2000. *BMC Pub Health*, 7, 263.

Davis, R., Rossier, C., Enfield, K., 2012. The Impact of Weather on Influenza and Pneumonia Mortality in New York City, 1975–2002: A Retrospective Study. *PloS One,* 7 (3), e34091.

DeGroot, D., Havenith, G., Kenney, L., 2006. Responses to Mild Cold Stress are Predicted by Different Individual Characteristics in Younger and Older Subjects. *J Appl Physiol*, 101, 1607-1615.

Dharmarajan, T., Wijidada, D. 2007. Hypothermia in the Geriatric Population. *Aging Health*, 3 (6), 735-741.

Dixon, P., Brummer, D., Hedquist, B., Kalkstein, A., Goodrich, G., Walter, J., Dickerson IV, C., Penny, S., Cerveny, R., 2005. Heat Vs Cold Mortality: A Study of Conflicting Databases in the US. *B Am Meteorol Soc*, 937-943.

Drabek, T., 1999. Understanding Disaster Warning Responses. *Soc Sci J*, 36, 515–523.

Dushoff, J., Plotkin, J., Viboud, C., Earn, D., Simonsen, L., 2006. Mortality Due to Influenza in the United States: An Annualized Regression Approach Using Multiple-Cause Mortality Data. *Am J Epidemiol*, 163, 181-187.

Ebell, M., Siwek, J., Weiss, B., Woolf, S.., Susman, J., Ewigman, B., Bowman, M., 2004. Strength of Recommendation Taxonomy (SORT): A Patient-Centered Approach to Grading Evidence in the Medical Literature. *Am Fam Physician*, 69 (3), 548-556.

Elbaz, G., Etzion, O., Delgado, J., Porath, A., Talmor, D., Novack, V., 2008. Hypothermia in a Desert Climate: Severity Score and Mortality Prediction. *Am J Emer Med*, 26, 683-688.

Epstein, E., Kiran, A., 2006. Accidental Hypothermia. *BMJ*, 332, 706-709.

Eurowinter Group, Donaldson, G., Keatinge W., 1997. Cold Exposure and Winter Mortality from Ischaemic Heart Disease, Cerebrovascular Disease, Respiratory Disease, and All Causes in Warm and Cold Regions of Europe. *Lancet*, 349, 1341-1346.

Fazel, S., Khosla, V., Doll, H., Geddes, J., 2008. The Prevalence of Mental Disorders among the Homeless in Western Countries: Systematic Review and Meta-Regression Analysis. *PLoS Med*, 5 (12), 1670-1681.

Froese, G., Burton, A., 1957. Heat Losses from the Human Head. *J Appl Physiol*, 10 (2), 235-241.

Gagnon, D., Jay, O., Lemire, B., Kenny, G., 2008. Sex-related differences in evaporative heat loss: the importance of metabolic heat production. *Euro J Appl Physiol*, 104 (5), 821-829.

Gallaher, M., Fleming, D., Berger, L., Sewel, M., 1992. Pedestrian and Hypothermia Deaths among Native Americans in New Mexico between the Bar and Home. *JAMA*, 267 (10), 1345-1348.

Galloway, S., Maughan, R., 1998. The Effects of Substrate and Fluid Provision on Thermoregulatory, Cardiorespiratory, and Metabolic Responses to Prolonged Exercise in a Cold Environment in Man. *Exp Physiol*, 83, 419-430.

Galloway, S., Wooton, S., Murphy, J., Maughan, R., 2001. Exogenous Carbohydrate Oxidation from Drinks Ingested During Prolonged Exercise in a Cold Environment in Humans. *J Appl Physiol*, 91 (2), 654-660.

Giesbrecht, G., 2001. Emergency Treatment of Hypothermia. *Emerg Med*, 13, 9-16.

Giesbrecht, G., Sessler, D., Mekjavik, I., Schroeder, M., Bristow, G., 1994. Treatment of Mild Immersion Hypothermia with Body-to-Body Contact. *J Appl Physiol*, 76 (6), 2373-2379.

Gorjanc, M., Flanders, W., Vanderslice, J., Hersh, J., Malilay, J., 1999. Effects of Temperature and Snowfall on Mortality in Pennsylvania. *Am J Epidemiol*, 149, 1152-1160.

Grey, T., Rolfs, R., Chambers, M., Niskar, A., 2002. Hypothermia-Related Deaths: Utah, 2000, and United States, 1979–1998. *Morbidity and Mortality Weekly Report*, 51, 76–78.

Guly, H., 2011, History of Accidental Hypothermia. *Resus*, 82, 122-125.

Hajat, S., O'Connor, M., Kosatky, T., 2010. Health Effects of Hot Weather: From Awareness of Risk Factors to Effective Heatlh Promotion. *Lancet*, 375, 856-863.

Hajat, S., Vardoulakis, S., Heavside, C., Eggen, B., 2014: Climate Change Effects on Human Health: Projections of Temperature-Related Mortality for the UK During the 2020s, 2050s and 2080s. *J Epidemiol Community Health*, 0, 1-8.

Hartnett, R., O'Brien, E., Sias, F., Pruitt, A., Pruitt, J., 1980. Initial Treatment of Profound Accidental Hypothermia. *Aviat Space Environ Med*, 51 (7), 680-687.

Hassi, J., Veli-Pekka, R., Maire, H. 2003. Health-Check Questionairre for Subjects Exposed to Cold. *IJCH*, 62 (4), 436-443.

Healy, J., 2003. Excess Winter Mortality in Europe: A Cross Country Analysis Identifying Key Risk Factors. *J Epidemiol Community Health*, 57, 784-789.

Henrikkson, O., Kuklane, K., Holmer, I., Bjornstig, U., 2009. Protection Against Cold in Prehospital Care: Thermal Insulation Properties of Blankets and Rescue Bags in Different Wind Conditions. *Prehosp Disaster Med*, 24 (5), 408-415.

Herity, B., Daly, L., Bourke, G., Horgan, J., 1991. Hypothermia Mortality and Morbidity: An Epidemiologic Analysis. *J Epidemiol Community Health*, 45, 19-23.

Hislop, L., Wyatt, J., McNaughton, G., Ireland, A., Rainer, T., Olverman, G., Laughton, A., 1995. Urban Hypothermia in the West of Scotland. *BMJ*, 311, 725.

Holmer, I., 1985. Heat Exchange and Thermal Insulation Compared in Woolen and Nylon Garments During Wear Trials. *Text Res J*, 55, 511-518.

Hornberger, K., 2010: Comparative Analyses of the January 2004 Cold Air Outbreak. Doctoral Dissertation, Georgia Institute of Technology.

Huttunen, P., 1990. Effect of Alcohol on the Processes of Thermoregulation. *Acta Physiol Pol*, 41, 25-31.

Hwang, S., 2001. Homelessness and Health. *CMAJ*, 164 (1), 229-233.

Irwin, B., 2002. A Case Report of Hypothermia in the Wilderness. *Wilderness Environ Med*, 13 (2), 125-128.

Kalant, H., Le, A., 1984. The Effects of Ethanol on Thermoregulation. *Pharmac Ther*, 23, 313-364.

Kalkstein, A., Sheridan, S., 2007. The Social Impacts of the Heat-Health Watch/Warning System in Phoenix, Arizona: Assessing the Perceived Risk and Response of the Public. *Int J Biometeorol*, 52, 43–55.

Keatinge, W., Coleshaw, S., Cotter, F., Mattock, M., Murphy, M., Chelliah, R., 1984. Increases in Platelet and Red Cell Counts, Blood Viscosity, and Arterial Pressure During Mild Surface Cooling: Factors in Mortality from Coronary and Cerebral Thrombosis in Winter. *Br Med J (Clin Res Ed)*, 289, 1405-1408.

Kempainen, R., Brunette, D., 2004. The Evaluation and Management of Accidental Hypothermia. *Respir Care*, 49 (2), 192-205.

Kober, A., Scheck, T., Fülesdi, B., Lieba, F., Vlach, W., Friedman, A., Sessler, A., 2001. Effectiveness of Resistive Heating Compared with Passive Warming in Treating Hypothermia Associated with Minor Trauma: a Randomized Trial. *Mayo Clin Proc*, 76 (4), 369-375.

Kodra, E., Steinhaeuser, K., Ganguly, A., 2011. Persisting Cold Extremes Under 21st-Century Warming Scenarios. *Geophys. Res. Lett*, 38.

Kyselý, J., Pokorna, L., Kyncl, J., Kriz, B., 2009. Excess Cardiovascular Mortality Associated with Cold Spells in the Czech Republic. *Biomed Central Public Health*, 9, 19.

Lansdowne, D., Scruggs, V., 1976. The Temperature Dependence of the Movement of Potassium and Chloride Ions Associated with Nerve Impulses. *J Physiol*, 259, 145-158.

Lee, C., Sheridan, S., Lin, S., 2012. Relating Weather Types to Asthma-Related Hospital Admissions in New York State. *EcoHealth*, 9 (4), 427-439.

Lim, C., Duflou, J., 2008. Hypothermia Fatalities in a Temperate Climate: Sydney, Australia. *Anatom Pathol*, 40, 46-51.

Lundgren, P., Henriksson, O., Widfelt, N., Wikstrom, T., 2004. Insulated Spine Boards for Prehospital Care in Cold Environments. *Int J Disaster Med*, 2, 33-37.

Mäkinen, T., Juvonen, R., Jokelainen, J., Harju, T., Peitso, A., Bloigu, A., Silvennoinen-Kassinen, S., Leinonen, M., Hassi, J., 2009. Cold Temperature and Low Humidity are Associated with Increased Occurrence of Respiratory Tract Infections. *Respir Med*, 103, 456–462.

Mallet, M., 2002. Pathophysiology of Accidental Hypothermia. *QJ Med*, 95, 775-785.

Megarbane, B., Axler, O., Chary, I., Pompier, R., Brivet, F., 2000. Hypothermia with Indoor Occurrence is Associated with Worse Outcome. *Intensive Care Med*, 26, 1843-1849.

Mulcahy, A., Watts, M., 2009. Accidental Hypothermia: An Evidence-Based Approach. *Emerg Med Pract*, 11 (1), 1-26.

Murthy, G., Hargens, A., Lehman, S., Rempel, D., 2001. Ischemia Causes Muscle Fatigue. *J Orthop Res*, 19, 436-440.

Mustafa, S., Shaikh, N., Gowda, R., Khan, I., 2005. Electrocardiographic Features of Hypothermia. *Cardiol*, 103, 118-119.

Muszkat, Mordechai; Durst, Ronen M. and Arie Ben-Yehuda, 2002. Factors Associated with Mortality among Elderly Patients with Hypothermia. *Am J of Med*, 113, 234-237.

National Weather Service Wind Chill Advisory Information Webpage. http://www.weather.gov/glossary/index.php?word=wind%20chill%20advisory. <<Accessed May 10, 2011>>.

National Weather Service Winter Storm Safety Page. http://www.nws.noaa.gov/om/winter/windchill.shtml. <<Accessed August 15th, 2013>>.

Näyhä, S., 2005. Environmental Temperature and Mortality. *IJCH*, 64, 451-458.

Nixdorff-Miller, A., Hunsaker, D., Hunsaker III, J., 2006. Hypothermia and Hypothermia Medicolegal Investigation of Morbidity and Mortality from Exposure to Environmental Temperature Extremes. *Arch Pathol Lab Med*, 130, 1297-1304.

Noe, R., Jin, J., Wolkin, A., 2012. Exposure to Natural Cold and Heat: Hypothermia and Hyperthermia Medicare Claims, United States, 2004–2005. *Am J Public Health*, 102 (4), e11-e18.

Osczevski, R., Bluestein, M., 2005. The New Wind Chill Equivalent Temperature Chart. *B Am Meteorol Soc.*, 86, 1453–1458.

Pedley, D., Patterson, B., Morrison, W., 2002. Hypothermia in Elderly Patients Presenting to Accident and Emergency during the Onset of Winter. *SMJ*, 47 (1), 10-11.

Peek, G., Davis, P., Ellerton, J., 2008. Management of Severe Accidental Hypothermia. *Intensive Care Med*, Section IV, 147-159.

Phillips, D., Baker, G., Brewer, K., 2010. Christmas and New Years as Risk Factors for Death. *Soc Sci and Med*, 71 (8), 1463-1471.

Poszos, R., Danzl, D., 2001. Human Physiological Responses to Cold Stress and Hypothermia. In Medical Aspects of Harsh Environments (Vol. 1). Washington D.C.: Office of the Surgeon General, U.S. Army.

Pretorius, T., Bristow, G., Steinman, A., Giesbrecht, G., 2006. Thermal Effects of Whole Head Submersion in Cold Water on Nonshivering Humans. *J Appl Physiol*, 101 (2), 669-675.

Pugh, L., 1966. Accidental Hypothermia in Walkers, Climbers, and Campers: Report to the Medical Commission on Accident Prevention. *BMJ*, 1, 123-129.

Pugh, L., 1967. Cold Stress and Muscular Exercise, with Special Reference to Accidental Hypothermia. *BMJ*, 2, 333-337.

Rango, N., 1984. Exposure-Related Hypothermia Mortality in the United States, 1970-1979. *Am J Public Health*, 74, 1159-1160.

Rango, N., 1985. The Social Epidemiology of Accidental Hypothermia among the Aged. *Gerontologist*, 25 (4), 424-430.

Ranhoff, A., 2000. Accidental Hypothermia in the Elderly. *IJCH*, 59 (3-4), 255-259.

Richards, M., 2008. Dry and Wet Heat Transfer through Clothing Dependent on the Clothing Properties under Cold Conditions. *Int J Occup Saf Ergon*, 14, 69-76.

Rocklov, A., Forsberg, B., Ebi, K., Bellander, T., 2014. Susceptibility to Mortality Related to Temperature and Heat and Cold Wave Duration in the Population of Stockholm County, Sweden. *Glob Health Action*, 7, 22734.

Roeggla, M., Holzer, M., Roeggla, G., Frossard, M., Wagner, A., Laggner, A., 2001. Prognosis of Accidental Hypothermia in an Urban Setting. *J Intensive Care Med*, 16 (3), 142-149.

Semenza, J., Rubin, C., Falter, K., Selanikio, J., Flanders, D., Howe, H., Wilhelm, J., 1996. Heat Related Deaths During the July 1995 Heat Wave in Chicago. *New Engl J Med*, 335, 84-91.

Shaman, J., Pitzer, V., Vibound, C., Grenfell, B., Lipsitch, M., 2010. Absolute Humidity and the Seasonal Onset of Influenza in the Continental United States. *PLOS Biology*, 8 (2), e1000316.

Sheridan, S., 2002. Redevelopment of a weather-type classification scheme for North America. *Int J of Clim*, 22, 51-68.

Sheridan, S., 2007. A survey of public perception and response to heat warnings across four North American cities: an evaluation of municipal effectiveness. *Int J Biometeorol*, 52, 3–15.

Sheridan, S., Dolney, T., 2003. Heat, Mortality, and Level of Urbanization: Measuring Vulnerability across Ohio, USA. *Clim Res*, 24 (3), 255-265.

Sheridan, S., Kalkstein, L., 2004. Progress in Heat Watch/Warning System Technology. *B Amer Meteorol Soc*, 1931-1941.

Sheridan, S., Kalkstein, A., Kalkstein, L., 2009. Trends in heat-related mortality in the United States, 1975–2004. *Nat Hazards*, 50 (1), 145-160.

Sherman-Morris, K., 2013. The Public Response to Hazardous Weather Events: 25 Years of Research. *Geography Compass*, 7 (10), 669-685.

Siegrist, M., Gutscher, H., Earle, T., 2005. Perception of risk: the influence of general trust, and general confidence. *J Risk Res,* 8, 145–156.

Siple P., Passel C., 1945. Measurements of dry atmospheric cooling in subfreezing temperatures. *Proc Am Philos Soc*, 89, 177–199.

Spatial Synoptic Classification Homepage. http://sheridan.geog.kent.edu/ssc_html. <<Accessed on February 15th, 2010>>.

Spencer, J., 2009. Winter Weather-Related Fatalities in the Coterminous United States: An Analysis of Three Databases. Master's Thesis, Northern Illinois University.

St. Louis Government Webpage for Weather Hazards. http://www.co.st-louis.mo.us/LawandPublicSafety/EmergencyManagement/Hazards/ExtremeHeat. <<Accessed on May 10th, 2011>>.

Sterba, J., 1990. Acrtic Cold Weather Medicine and Accidental Hypothermia. Naval Sea Systems Command.

Stocks, J., Taylor, N., Tipton, M., Greenleaf, J., 2004. Human Physiological Responses to Cold Exposure. *Aviat Space Env Med*, 75, 444-457.

Stone, P., Richards, M., Hardy, J., 1998. Fatigue in Patients with Cancer. *Eur J Cancer*, 34 (11), 1670-1676.

Stuart, I., Schneider, A., Turner, T., 1989. Perception of the Heat of Sorption of Wool. *Text Res J*, 59 (6), 324-329.

Tanaka, M., Tokudome, S., 1991. Accidental Hypothermia and Death from Cold in Urban Areas. *Int J Biometeorol*, 34, 242-246.

Taylor, A., McGwin, G., 2000. Temperature-Related Deaths in Alabama. *SMJ*, 93 (8), 787-792.

Taylor, A., McGwin, G., Davis, G., Brissie, R., Holley, T., Rue III, L., 2001. Hypothermia Deaths in Jefferson County, Alabama. *Inj Prev*, 7, 141-145.

Teresiski, G., Buscewicz, G., Madro, R., 2004. Biochemical Background of Ethanol-Induced Cold Susceptibility. *Leg Med*, 7, 15-23.

Thacker, M., Lee, R., Sabogal, R., Anderson, A., 2008. Overview of Deaths Associated with Natural Events, United States, 1979-2004. *Disasters*, 32 (2), 305-315.

Turk, E., 2010. Hypothermia. *Forensic Sci Med Pathol*, 6, 106–115.

U.S. 2000 Census, Census 2000 Gateway. http://www.census.gov/main/www/cen2000.html. <<Accessed on April 15th, 2014>>.

U.S. Bureau of Transportation Statistics: U.S. Holiday Travel. http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/america_on_the_go/us_holiday_travel/html/entire.html. <<Accessed on April 15th, 2014>>.

Ulrich, A., Rathlev, N., 2004. Hypothermia and Localized Cold Injuries. *Emerg Med Clin N Am*, 22, 281–298.

Vavrus, S., Walsh, J., Chapman, W., Portis, D., 2006. The behavior of extreme cold air outbreaks under greenhouse warming. *Int J Climatol*, 26 (9), 1133-1147.

Vreeman, C., Carroll, E., 2008. Festive Medical Myths. *BMJ*, 337.

Walsh, J., Phillips, A., Portis, D., Chapman, W., 2001. Extreme Cold Outbreaks in the United States and Europe, 1948-1999. *J Clim*, 14, 2642-2658.

Weinberg, A., 1993. Hypothermia. *Ann Emerg Med*, 22 (2), 104-111.

Weller, A., Stroud, M., Greenhaff, P., McDonald, I., 1997. Physiological Responses to a Cold, Wet, and Windy Environment during Prolonged Intermittent Walking. *Am J Physiol Regul Integr Comp Physiol*, 272 (1), 226-233.

Woodhouse, P., Keatinge, W., Coleshaw, S., 1989. Factors associated with hypothermia in patients admitted to a groups of inner-city hospitals. *Lancet*, November 18, 1989, 1201-1204.

World Health Organization. International Classification of Disease, Revision Nine. http://apps.who.int/classifications/apps/icd/icd10online/. <<Accessed on November 15, 2009>>.

Yamane, M., Oida, Y., Onishi, Y., Matsumoto, T., Kitigawa, K., 2010. Effects of Wind and Rain on Thermal Responses of Humans in a Mildly Cold Environment. *Eur J Appl Physiol*, 109, 117–123.

Yarnal, B., 1993. Synoptic Climatology in Environmental Analysis: A primer. Belhaven Press, 195 pp.

Young, A., Castellani, J., 2001. Exertion Induced Fatigue and Thermregulation in the Cold. *Comp Biochem Physiol A Physiol*, 128, 769-776.

Young, A., Castellani, J., 2007. Exertional Fatigue and Cold Exposure: Mechanisms of Hiker's Hypothermia. *Appl Physiol Nutr Metab*, 32, 793-798.

Young, A., Castellani, J., O'Brien, C., Shippee, R., Tikuisis, P., Meyer, L., Blanchard, L., Kain, J., Cadarette, B., Sawka, A., 1998. Exertional Fatigue, Sleep Loss, and Negative Energy Balance Increase Susceptibility to Hypothermia. *J Appl Physiol*, 85 (4), 1210-1217.

APPENDIX A: WIND CHILL ALERT CRITERIA BY NATIONAL WEATHER SERVICE WEATHER FORECAST OFFICE

Table A1. The ambient temperatures in Fahrenheit needed for a watch/warning and/or advisories to be issued at each weather forecast office in the United States. The ambient temperature needs to be combined with a sustained wind of greater than 5 km $^{h-1}$ (3 mi $^{h-1}$), lasting at least one hour or more, for an alert to be issued.

WFO	State	Region	Watch/Warning Temperature	Advisory Temperature
Aberdeen	South Dakota	Central	-35	-25
Albany	New York	Eastern	-25	-20
Albuquerque	New Mexico	South	-35	No advisories/no data
Amarillo	Texas	South	-15	-5
Anchorage	Alaska	Alaskan	-60	-40
Austin/San Antonio	Texas	South	No warnings/no data	0
Baltimore/Washington	Virginia	Eastern	-25	-5
Billings	Montana	Western	-40	-20
Binghamton	New York	Eastern	-25	-15
Birmingham	Alabama	South	-10	0
Bismarck	North Dakota	Central	-40	-25
Blacksburg	Virginia	Eastern	-20	-5
Boise	Idaho	Western	-20	No advisories/no data
Boston	Massachusetts	Eastern	-30	-15
Brownsville	Texas	South	Zapata, Brooks, Jim Hogg, and Kenedy: 15; elsewhere, 20	25
Buffalo	New York	Eastern	-30	-15
Burlington	Vermont	Eastern	-15	-20

Table A1 Continued

Caribou	Maine	Eastern	-25	-20
Charleston	West Virginia	Eastern	-25	0
Charleston	South Carolina	Eastern	-25	-10
Cheyenne	Wyoming	Central	-30	-20
Chicago	Illinois	Central	-30	-20
Cleveland	Ohio	Eastern	-15	-10
Columbia	South Carolina	Eastern	-15	0
Corpus Christi	Texas	South	-18	0
Dallas/Fort Worth	Texas	South	-18	0
Davenport/Quad Cities	Iowa	Central	-30	-20
Denver/Boulder	Colorado	Central	-25	-15
Des Moines	Iowa	Central	-30	-20
Detroit/Pontiac	Michigan	Central	-25	-15
Dodge City	Kansas	Central	-25	-15
Duluth	Minnesota	Central	-40	-25
El Paso	Texas	South	-18	0
Elko	Nevada	Western	-35	No advisories/no data
Eureka	California	Western	-30	No advisories/no data
Fairbanks	Alaska	Alaskan	-60	-50
Flagstaff	Arizona	Western	-20	-20
Gaylord	Michigan	Central	-35	-20
Glasgow	Montana	Western	-40	-20
Goodland	Kansas	Central	-25	-15
Grand Forks	North Dakota	Central	-40	-25
Grand Junction	Colorado	Central	-25	-15
Grand Rapids	Michigan	Central	-25	-15
Gray/Portland	Maine	Eastern	-20	-20
Great Falls	Montana	Western	-40	-20
Green Bay	Wisconsin	Central	-30	-20
Greenville-Spartanburg	South Carolina	Eastern	-25	0
Hastings	Nebraska	Central	-30	-20
Houston/Galveston	Texas	South	-18	0
Huntsville	Alabama	South	-10	0
Indianapolis	Indiana	Central	-25	-15
Jackson	Kentucky	Central	-25	-10
Jackson	Mississippi	South	-15	9
Jacksonville	Florida	South	Florida: 10; Georgia: 0	No advisories/no data
Juneau	Alaska	Alaskan	-55	-30

Table A1 Continued

Kansas City/Pleasant Hill	Missouri	Central	-25	-15
Key West	Florida	South	25	35
La Crosse	Wisconsin	Central	-35	-20
Lake Charles	Louisiana	South	0	13
Las Vegas	Nevada	Western	-20	No advisories/no data
Lincoln	Illinois	Central	-25	-15
Los Angeles/Oxnard	California	Western	-20	No advisories/no data
Louisville	Kentucky	Central	-25	-10
Lubbock	Texas	South	No warnings/no data	0
Marquette	Michigan	Central	-35	-25
Medford	Oregon	Western	No warnings/no data	No advisories/no data
Melbourne	Florida	South	20	35
Memphis	Tennessee	South	-18	0
Miami	Florida	South	25	35
Midland/Odessa	Texas	South	-15	No advisories/no data
Milwaukee/Sullivan	Wisconsin	Central	-35	-20
Minneapolis/Twin Cities	Minnesota	Central	-35	-25
Missoula	Montana	Western	No warnings/no data	No advisories/no data
Mobile/Pensacola	Alabama	South	No warnings/no data	0
Morristown/Knoxville	Tennessee	South	-10	No advisories/no data
Mount Holly/Philadelphia	New Jersey	Eastern	-20	-10
Nashville	Tennessee	South	-15	No advisories/no data
New Orleans/Baton Rouge	Louisiana	South	No warnings/no data	13
New York	New York	Eastern	-35	-15
Newport/Morehead City	North Carolina	Eastern	-15	0
Norman/Oklahoma City	Oklahoma	South	-20	-5
North Little Rock	Arkansas	South	-15	0
North Platte	Nebraska	Central	-30	-20
Northern Indiana	Indiana	Central	-25	-15
Omaha/Valley	Nebraska	Central	-30	-20
Paducah	Kentucky	Central	-25	-10
Peachtree City/Atlanta	Georgia	South	-15	0
Pendleton	Oregon	Western	-20	No advisories/no data
Phoenix	Arizona	Western	-20	No advisories/no data
Pittsburgh	Pennsylvania	Eastern	-15	-10

Table A1 Continued

Pocatello	Idaho	Western	-20	No advisories/no data
Portland	Oregon	Western	-20	No advisories/no data
Pueblo	Colorado	Central	-25	-15
Raleigh	North Carolina	Eastern	-20	0
Rapid City	South Dakota	Central	-35	-25
Reno	Nevada	Western	-20 (below 7000); -35 (above 7000)	No advisories/no data
Riverton	Wyoming	Central	-30	-20
Sacramento	California	Western	No warnings/no data	No advisories/no data
Salt Lake City	Utah	Western	-30	No advisories/no data
San Angelo	Texas	South	No warnings/no data	No advisories/no data
San Diego	California	Western	-20	-10
San Francisco Bay Area/Monterey	California	Western	No warnings/no data	-20
San Joaquin Valley/Hanford	California	Western	-20	No advisories/no data
Seattle	Washington	Western	-20	No advisories/no data
Shreveport	Louisiana	South	-15	9
Sioux Falls	South Dakota	Central	-35	-20
Spokane	Washington	Western	-20	No advisories/no data
Springfield	Missouri	Central	-25	-10
St. Louis	Missouri	Central	-25	-15
State College	Pennsylvania	Eastern	-25	-15
Tallahassee	Florida	South	0	20
Tampa	Florida	South	Northern: 10; central: 20	25
Topeka	Kansas	Central	-25	-15
Tucson	Arizona	Western	-20	No advisories/no data
Tulsa	Oklahoma	South	-20	No advisories/no data
Wakefield	Virginia	Eastern	-15	-5
Wichita	Kansas	Central	-25	-15
Wilmington	Ohio	Eastern	-30	0
Wilmington	North Carolina	Eastern	-25	-10