ASSESSING THE VULNERABILITY OF THE UNITED STATES NORTHERN GREAT PLAINS TO A SEVERE SNOWSTORM OR BLIZZARD

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Bachelor of Science in Meteorology/Climatology

University of Nebraska-Lincoln

Lincoln, Nebraska

2006

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
May, 2013

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UNITED STATES NORTHERN GREAT PLAINS TO A

SEVERE SNOWSTORM OR BLIZZARD

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ACKNOWLEDGEMENTS

I would like to thank my committee for their support and encouragement during this process, especially my advisor Dr. Stephen Stadler. I would also like to thank John Phillips and everyone else in the Government Documents office of Edmon Low Library for allowing me access to the US National Climate Summary books; Dr. Brenda Phillips for her early guidance on social vulnerability research; and Dr. Hongbo Yu for his help on the GIS work. Thank you to all my family and friends for the moral support, suggestions, and advice during this process.

Name: KEELEY S HEISE

Date of Degree: MAY, 2013

Title of Study: ASSESSING THE VULNERABILITY OF THE UNITED STATES NORTHERN GREAT PLAINS TO A SEVERE SNOWSTORM OR BLIZZARD

Major Field: GEOGRAPHY

Abstract: With projected increases in the occurrence of weather extremes in a changing climate, especially in the central United States, the chances of severe snowstorms or blizzards like those of the past happening again are increasing. The northern Great Plains region of the United States is the focus of this study. Using data from the National Oceanic and Atmospheric Administration daily weather map series for 1950-1980, weather data was collected for the twenty-six stations located within the study area for the months of October through April. In order to be chosen for inclusion in the study, the station had to have wind speeds of at least 20 knots, visibility 3 miles or less and snow falling at the time of observation. This data was used to calculate the number of days under blizzard, near blizzard, and snowstorm conditions for each location to determine which areas were at the highest risk for experiencing a severe snowstorm or blizzard. The vulnerability analysis was conducted by downloading county level data from the 2010 US Census. Fourteen variables shown to have an impact on vulnerability were chosen and combined using an additive index created by Susan Cutter called the Social Vulnerability Index. This was done both with and without the poverty variable, which has been shown to be highly correlated with vulnerability, to see if there was a difference in the results. The resulting images appeared to be mirror images of each other with areas showing above average vulnerability with poverty included showing below average vulnerability without it. These results were compared to the storm classification categories to see if the high risk areas coincided with the highly vulnerable areas. With poverty included in the calculations, this was seen to be the case. The vulnerability scores were tested using Moran's I for significance to the pattern which showed there to be significant clustering of like values throughout the area.

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CHAPTER I

INTRODUCTION

1.1 Background

Weather observation has been a part of the United States since the colonial days, with the first regular observations being done during the 1640s in Delaware. By the 18th Century, observers were using instrumentation to take bi-daily temperature readings in response to residents' curiosity as to the extent to which the weather impacted their crops and if the people impacted the weather (Fiebrich 2009). In 1814, the US Surgeon General ordered all army hospitals to keep a daily diary of the weather conditions at their location (Miller 1931; Fiebrich 2009). The Army hospitals continued their daily weather observations through 1870. It was at this time that Congress created the United States Signal Service (USSS), now called the National Weather Service (NWS), to take weather observations. The USSS created a set of standards all observers were required to follow, including standardized observation times (Miller 1931; Fiebrich 2009). Included in this was the creation of state service offices that were charged with accumulating data to develop a climatology of the area that could be used to benefit farmers and doctors (Greely 1889).

As the network of observing stations grew, it became easier to see storms forming and to determine their paths and spatial extent. Larger storms impact a higher number of people and usually caused more damage and therefore tend to draw more media attention. On the Gulf Coast and along the Eastern seaboard, this usually meant hurricanes and tropical storms while in the Great Plains and Midwest, these events are usually tornadoes and snowstorms/blizzards. Snowstorms are difficult to define because there are so many factors that influence the definition which can vary by region (Changnon and Kunkel 2006), but blizzards have a standard definition. Blizzards are snowstorms that have strong winds of at least 30 kts (35 mph) and low visibility (less than a quarter mile) due to blowing or drifting snow (AMS glossary). One of the more common starts to a central plains snowstorm is through a low pressure system called an Alberta Clipper, which contains little moisture but is often associated with strong winds (at least 40 mph) and narrow bands of intense snow (AMS glossary; Weather Notebook 2000; Weather Notebook 2003).

The Great Plains have experienced some very harsh winters, especially in the latter part of the 19th Century, including two of the area's most notable storms. From 13 April to 16 April 1873, South Dakota experienced a particularly severe blizzard with sustained winds of 40 mph called "Custer's Blizzard," named after General George Custer who was camped in Yankton, South Dakota at the time (Glenn 1897). On 12 January 1888, a storm descended upon Nebraska following an unseasonably warm few days, catching many off guard. Some areas experienced temperature drops of 60^{o}F or more in a span of 24 hours as the quick moving storm made its way across the state (US Signal Service 1888). Many of the fatalities and injuries were schoolchildren stuck in their schoolhouses or trying to get home, leading this storm to be dubbed "The Children's Blizzard" (O'Gara 1947; Laskin 2004).

1.2 Research Questions

Storms of this magnitude could happen again at any time. Since snowstorms are so common, people of the Great Plains may not be fully aware of the risk and danger that a major snowstorm possesses which could create complacency and increase vulnerability. This study looks at the hazard and determines how vulnerable today's population of the Great Plains would be to a severe snowstorm or blizzard based on social demographics in the 2010 Census and storm data for 1950-1980. The main research questions that will be answered are:

1. Which areas in this region are most at risk for a severe snowstorm?
2. Which areas in this region are the most vulnerable?
3. Is there a significant geographic pattern to this vulnerability?
4. Do the areas of high risk and high vulnerability coincide?

1.3 Significance and Importance

Population increases, lower incomes, increases in the number of renters, and the changing climate can all increase an area's vulnerability to a disaster. In 2001, White et. al. suggested that growing population and technological advancements are the reasons the number of disasters is increasing worldwide. Cutter, Golledge, and Graf (2002) included vulnerability as one of the big questions that geographers should tackle. They argued that vulnerability and sustainability are things that are rooted in geography. Climate change models predict an increase in the frequency of intense precipitation events and precipitation extremes with climate change (White et al 2001; Gutowski, Jr. et al 2008; Lein et al 2009; Cuevas 2011), which would mean that there is a higher probability of major blizzards occurring in the future. The increase in rainfall and temperatures may also lead to exacerbation of the problems and factors that create individual vulnerabilities, such as increasing rates of poverty and hunger (Cuevas 2011).

Recent research on trends in an ever-changing climate has shown that the total amount of snowfall may be decreasing globally, but this decrease is expected to be confined to the lower latitudes while the higher latitudes will likely see an increase (Kapnick and Delworth 2013). Extreme precipitation events in the U.S. (as measured by the National Weather Service Cooperative Observer Network [NWS COOP]) have already begun to increase in both frequency and severity. The number of regionally severe snowstorms between 1960 and 2010 is more than double what was seen between 1900 and 1960 (Kunkel et al. 2013). If these are accurate predictions and the measured trends continue, it is important that a better understanding of snowstorms and vulnerability to them is achieved.

Attempts to provide a deeper study of storms can be done by conducting disaster mitigation or hazard vulnerability studies. "Hazards research is a range of natural events…that threaten our lives and life support systems, our emotional security, and property and the functioning of our societies. When these threats materialize and overwhelm our coping capabilities, they are known as disasters" (Mitchell 1989, 410). Hurricanes and tornadoes are the most common topics of hazard research while winter weather tends to be overlooked.

Hurricane and tornado vulnerability studies are usually concerned with the potential economic impacts these phenomena could cause (Rae and Stefkovich 2000; Wilhelmi and Wilhite 2002; Beatty 2002; Lincoln 2004; Wisner et al 2004; Kunreuther 2006; Masozera, Bailey, and Kerchner 2007; Wurman et al. 2007; Schneider, Dean, and Brooks 2009). Geographical studies of vulnerability are focused on finding the patterns of social vulnerability in general or with regard to coastal flooding, hurricanes, disease/mortality, extreme heat or general theories on how to conduct this type of study as well as looking at the optimal scale of observation (Cutter 1996; Cutter, Mitchell, and Scott 2000; Stephen and Downing 2001; The Heinz Center 2002; Cutter, Boruff, and Shirley 2003; Borden and Cutter 2008; Cutter and Finch 2008; Maantay and Maroko 2009; de Oliveira Mendes 2009; Cutter, Burton, and Emrich 2010; Yoon 2012; Tate 2012; Chow, Chuang, and Gober 2012).

A more detailed review of the literature on storm research, vulnerability and disaster mitigation studies will be provided in Chapter 2. Explanation of the study area, data collection and analysis techniques can be found in Chapter 3. Results will be given in Chapter 4, and Chapter 5 will give the limitations of the research as well as an overall summary of the results and possible future research avenues. Even though major snowstorms or blizzards do not happen often, they will occur again. This research may help city planners, emergency management, and/or insurance companies to prepare better disaster mitigation plans.

CHAPTER II

REVIEW OF THE LITERATURE

Creating better disaster mitigation plans requires that those writing plans have an understanding of potential impacts that may arise from the disaster of concern and of those people most susceptible to adverse impacts. Facilitating this understanding comes from vulnerability studies of storms that have had a large impact. These storms are studied after the event in an attempt to better understand what caused them to form. Researchers are also interested in determining why the storm progressed the way that it did. The combination of these approaches can lead to an improved warning system that could end save lives.

As computer mapping programs became more advanced and easier to use, these types of studies became more frequent as did studies of vulnerability to natural disasters. Vulnerability, how susceptible a society is to disaster, is a function of many things including exposure to a natural hazard, ability to cope with the hazard, and how easily they would be able to rebuild (Uitto 1998; Oliver-Smith and Hoffman 1999; Cova 1999; Cutter, Mitchell and Scott 2000; Weichselgartner 2001; Wilhelmi and Wilhite 2002; The Heinz Center 2002; Adger 2006; Cutter and Finch 2008; de Oliveira Mendes 2009; Maantay and Maroko 2009; Phillips et al. 2010 Yoon 2012).

2.1 Storm Analysis and Re-creation

Major storms and natural disasters have always been of interest to researchers as well as the residents who experienced them. Storms with large impacts are usually the ones that receive the most media coverage and the most attention from government officials (mainly in regards to recovery assistance). In the months and years immediately following the Children's Blizzard, analyses of the storm were published, but they emphasized the scientific and meteorological conditions of the storm. One study showed that some areas impacted by this storm experienced record cold January temperatures with temperature drops of 60^{o}F or more in 24 hours (US Signal Service 1888). Another examined this storm in the context of other blizzards in the state of South Dakota and concluded that it was one of the worst but not the worst storm in the history of the state (Glenn 1897). No research after 1900 discuss the Children's Blizzard in any detail. Although there have been books written (O'Gara 1947; Laskin 2004), these books are surface studies of the storm with little mention of science and instead focusing on the stories of the people who experienced it.

Historical blizzard analysis emerged in the early 1980s with a focus on East Coast snowstorms. The end of the 19^{th} Century has been a common theme since this time in U.S. history provided some of the worst winter storms along the East Coast (Kocin 1983; Kocin, Weiss, and Wagner 1988; Kocin and Uccellini 2004a). Paul Kocin (1983) collected archived weather data from the U.S. Signal Service and ships from March of 1888. He used this data to re-create and analyze a blizzard that impacted portions of the northeast because no one had yet done so for a storm that some consider the worst blizzard to ever hit the East Coast (Tougias 2003). In the study of the March 1888 New

England storm, Kocin (1983) found that two low pressure systems (one more powerful than the other) were involved but the exact causes of the storm and what made it so severe can never be determined because of the scarcity of data for that time. In 1988, Kocin collaborated with two other meteorologists to do another study using the same data collection and analysis methods as his 1983 study to examine an East Coast blizzard from 1899 that brought 0^{o}F temperatures and blizzard-like conditions to the Gulf Coast (Kocin, Weiss, and Wagner 1988).

More recently, Kocin and Uccellini (2004a,b) re-created and analyzed more than 30 snowstorms that impacted the northeast between 1950 and 2003. Using the same methods as the two previously discussed studies, the authors summarized each storm and provided snowfall measurements obtained through the National Climatic Data Center (NCDC). Because of advancements in technology after the 1980s, they were able to include more factors in their analysis such as satellite imagery and a re-analysis package developed by the National Center for Environmental Prediction (NCEP) that allowed for analysis of the upper level weather conditions (such as temperature, wind, and pressure level heights). Satellite imagery, though, was only available for storms that occurred after 1978. Unlike the other studies, Kocin and Uccellini attempted to estimate the societal impacts of these storms by creating the Northeast Snowstorm Impact Scale (NESIS) which is a combination of the population and area affected by the snowstorm (Kocin and Uccellini 2004a,c).

Snowstorms that hit the east coast affect larger populations and therefore have a larger impact, but snowstorms can also produce significant impacts further inland. One such instance occurred in December 1995 when a snowstorm impacted a small portion of the central United States and dropped large amounts of snow in a small area (Skerritt, Przybylinski, and Wolf 2002). The authors' focus was on the failure of the existing forecasting methods and what could be done to improve them. One such improvement used the concept of frontogenesis (the formation or intensification of a front as warm air converges with the cold air). This new methodology allowed for a more accurate prediction of the actual snowfall totals that were observed than the predictions using the traditional methods (Skerritt, Przybylinski, and Wolf 2002).

2.2 Hazards and Emergency Management

Emergency managers are tasked with trying to create policies and plans to help their communities in the event of a natural hazard or natural disaster, with the main focus of the research efforts going towards creating technological fixes to the problems (Petak 1985). Kasperson and Pijawka (1985) described hazard management as teaching society about hazards and then deciding how to either control or mitigate those hazards. Many of the studies conducted in the area of emergency management emphasize natural hazards such as earthquakes, landslides, flooding, and weather hazards such as hurricanes and tornadoes. Any research on snowfall tended to include only urban snow events to the exclusion of snowstorms that may have impacted a larger rural area (Petak 1985).

Until the 20th Century, policy responses to disaster were based solely in the reactionary phase to provide relief to the affected population instead of trying to mitigate the potential damage. This began to change with the passage of the Flood Control Act in 1936 and then the Disaster Relief Act in 1950 (Clary 1985) bringing the first two phases of emergency management (mitigation and preparedness) onto more equal footing as the last two phases (response and recovery). Policy makers at all levels still lean towards the reactive approach rather than the proactive approach (Clary 1985).

By the end of the 1970s, federal aid for disaster recovery was more than $7 billion (Clary 1985). In 1983, the federal emergency management agency (FEMA) provided over $1 billion of relief while insurance companies had to pay out nearly $2 billion dollars in damages. These numbers do not include damage caused by those events that were not declared federal disasters (Settle 1985). Globally, natural disasters caused more than $680 billion in damage from 1990 to 2000. In the United States, Alaska is the only state that did not have a $1 billion disaster between 1980 and 2000 (Cutter 2003b). This post-disaster financial assistance could be reduced if decision-makers and emergency managers had a better understanding of the potential hazards in their areas and worked with their counterparts at each level of government to finance mitigation of the risk (Petak 1985; Rubin and Barbee 1985) or to educate the populace on the importance of implementing these measures (Kunreuther and Miller 1985).

At the end of the 20th Century, the focus on hazards had begun to wane. Research in hazard and emergency management has shown a trend towards disasters and vulnerability as the economic losses from such events continues to rise globally while also seeing a decrease in the mortality rate of disasters globally (White et al. 2001). Winter storms also started to appear in the research, although most of time they were only mentioned briefly (White et al 2001).

Geographic information systems (GIS) has become an increasingly popular tool for emergency managers in the assessment of risk and vulnerability since it allows the user to combine both physical and socio-economic data into one study (Cutter 2003b).

From an emergency management standpoint, vulnerability to disasters comes from a lack of willingness in the global north to do anything in advance to try to lessen the impacts while the global south has the desire but no money (White et al 2001). In places like Tulsa, Oklahoma, it has been shown that effective and comprehensive planning can help to lessen the impacts of hazards (White et al 2001).

2.3 Vulnerability and Mitigation

While the physical hazard is an important component in the understanding of disasters and vulnerability, the socio-economic conditions must also be included as the people are the ones being impacted. Vulnerability can be described as the pressure part of the pressure and release (PAR) model of disasters which states that a disaster occurs where hazard and vulnerability meet (Cutter 1996; Wisner et al 2004; Wolf 2012).

Vulnerability can also be defined as the susceptibility of a society to a natural disaster because of exposure to or inability to recover from that disaster (Cutter 1996; Uitto 1998; Cova 1999; Oliver-Smith and Hoffman 1999; Cutter, Mitchell and Scott 2000; Weichselgartner 2001; White et al 2001; Wilhelmi and Wilhite 2002; The Heinz Center 2002; Adger 2006; Cutter and Finch 2008; de Oliveira Mendes 2009; Maantay and Maroko 2009; Phillips et al. 2010; Yoon 2012). A disaster is defined as an event in which society is unable to rebuild and quickly return to the pre-storm conditions needed for the society to function and meet the needs of people. A disaster is a combination of the hazard AND the vulnerability (Nigg 1995; Uitto 1998; Oliver-Smith and Hoffman 1999; Wisner 2004; Bankoff, Frerks, and Hilhorst 2007; Phillips et al 2010). In 1989, Mitchell stated that hazards research was an important aspect of current geographical study because of its societal importance, and it was beginning to bleed into other fields of research. Vulnerability science, as described by Cutter in her Association of American Geographers (AAG) presidential address, is growing out of the cross-disciplinary work found in hazards research as it needs to include the interactions between the social and physical aspects of the natural system. She argued that geography must be the field that leads the way (Cutter 2003a). It is important, therefore, that both the social and environmental vulnerabilities are understood.

2.3.1 Environmental Vulnerability

Environmental disaster vulnerability studies require that the researcher understand more than the environmental hazard. James Lewis (1982) argued that vulnerability studies need to include the political and social conditions that created the vulnerability in that particular region. Using the countries of Tonga and Algeria as examples, Lewis showed that an area's "normal" and the degree of cooperation between sectors (political, economic, community) largely determined the vulnerability. More cooperation between the government and the community lowers their vulnerability, especially if the mitigation strategies become part of everyday life (Lewis 1982). For example, government officials in the city of El Asnam in northern Algeria formed a commission following an earthquake in October 1980 that would work with the people to rebuild the city. This commission would determine measures that would aid in minimizing loss should another earthquake of that magnitude happen again.

Environmental vulnerability can also be linked to how society has used its surroundings. Kreimer and Munasinghe (1991) determined, through a review of literature, that a society's vulnerability to disaster increased as they mined the resources of their surrounding landscape. A more urbanized society is, therefore, more vulnerable to natural disasters because urban areas have caused “irreversible degradation of a once natural environment” (Kreimer and Munasinghe 1991, 278) which is compounded by infracture decisions made by city planners. They also found that natural disasters can themselves increase vulnerability because they degrade the environment thereby increasing the risk for future disasters. The authors also argued that the only way to reduce vulnerability is to develop mitigation plans that will increase a society’s ability to cope with or withstand direct and indirect effects of a disaster, such as toxic gases after a volcanic eruption or disease outbreaks after a flood (Kreimer and Munasinghe 1991). Development of a mitigation plan first requires that those writing it have an understanding of which areas are most vulnerable and why.

2.3.2 Social/Socioeconomic Vulnerability

Vulnerability studies are not only done in the environmental sciences but in the social sciences as well. One of the first forays of social scientists into disaster studies was in 1920 after the 1917 explosion of a munitions ship in Halifax, Nova Scotia. At that time, disaster research was almost solely concerned with physical issues (Oliver-Smith and Hoffman 1999). Nigg (1995) and Jones and Chang (1995) discussed the need to study the way society interacts with the environment by reviewing the current status of research up to the early 1990s. These authors showed that vulnerability and risk increased as the population density increased. Nigg argued that disasters fall into four phases: preparedness (developing a response plan), response (implementation of the plan), recovery (rebuilding), and mitigation (finding ways to reduce vulnerability); these phases often overlap. Jones and Chang (1995) stated that vulnerability studies require that the researcher knows how the society sees risk, what that society sets as the acceptable risk limit, and how they would react to that risk. For example, studies of economic vulnerability usually use cost-benefit analysis to determine the point it becomes financially beneficial to mitigate against disaster losses instead of cost prohibitive (Jones and Chang 1995; Kunreuther 2006).

One aspect of disaster and vulnerability studies that is not commonly discussed is the mortality rate of natural disasters. It is often hard to determine which deaths were caused, either directly or indirectly, by a hazard (Borden and Cutter 2008; Phillips et al. 2010). Globally, the highest rates of disaster mortality are found in Asia and Africa (Phillips et al 2010). Borden and Cutter (2008) used data from the Spatial Hazard Event and Loss Database for the United States (SHELDUS) and storm data from NCDC Storm Data to create a profile of natural hazard mortality in the continental U.S. at a regional and county level between 1960 and 2005. They showed that the top three hazards in terms of mortality are heat/drought (19.6%), severe weather (18.8%) and winter weather (18.1%) with winter weather being a major cause of hazard-related deaths in the north-central portion of the country. Also using SHELDUS data from 1975-2007 at the county level, Phillips et al (2010) showed that hazard mortality is generally highest in the mountain west states and along the southern Mississippi Valley. This is only the case if the deaths are standardized by population. When using the raw data, the peak in hazard mortality is found in the southeast and around the Great Lakes. Both of these studies aggregated the mortality data instead of doing a hazard-specific assessment, although Borden and Cutter did provide some data on the percentages of the total attributed to each hazard type.

The way people perceive the causes of these risks/disasters and their responses to them have shifted over time from the ancient days in which they were considered an act of God to the more recent idea that they are caused by bad policies (Weichelgartner 2001). While most vulnerability studies focus on only the risk, Weichelgartner argued for a different approach. He listed a set of five factors that contribute to vulnerability that need to be accounted for in studies of vulnerability: hazard (the actual event), exposure (the people and buildings and infrastructure that are exposed to the hazard), preparedness (the processes and actions undertaken to enable response to the hazard), prevention (the actions taken prior to the hazard to minimize loss), and response (the actions and steps taken right after the hazard to recover and rebuild). These factors can be quantified and overlayed together to create an overall vulnerability map for each individual disaster that can be used to determine the greatest influence on the area's vulnerability to that disaster. Weichelgartner concluded that it is not possible to completely prevent loss from a disaster, but there are steps that can be taken to minimize them. The steps that he suggested are helpful because they can be widely applied, even by those with no previous knowledge of the subject.

2.3.3 Weather and Vulnerability

Using the idea that there are many overlying factors influencing the vulnerability of an area to natural disaster as well as the increasing concern of climate change, meteorological vulnerability studies are becoming more prevalent. Hurricanes and tornadoes are the most common phenomena of interest, especially those that may affect large metropolitan areas. Approximately one year prior to Hurricane Katrina, Eric Lincoln (2004) of the Army Corps of Engineers stressed the need for improvements to the levees protecting New Orleans. His research showed that a storm surge associated with a major hurricane would breach the levees and cause devastating floods throughout the city. After the storm hit and the warned flooding occurred, post-Katrina studies focused on the economic impacts across New Orleans (Kunreuther 2006; Masozera, Bailey and Kerchner 2007). Kunreuther (2006) argued that people have a tendency to think that the disaster will not happen to them and therefore not take the proper measures to protect their assets. This natural disaster syndrome, as he calls it, may be one of the reasons that nothing was done to upgrade the levees and therefore contributed to the high economic impact of Hurricane Katrina. Masozera, Bailey, and Kerchner (2007) showed that the inequality present in the city of New Orleans prior to Katrina was an underlying factor in the extent of the physical and social damage after Katrina and the inability of certain portions of the city to be able to recover.

Hurricanes are not the only weather event that can have a large impact. Tornadoes also have the potential to cause high economic loss and death if they occur in densely populated areas that are not properly prepared. One of the largest tornadoes in U.S. history, the 3 May 1999 Moore, Oklahoma outbreak, is sometimes used in urban vulnerability studies of tornadoes in large cities (Rae and Stefkovich 2000; Wurman et al. 2007). Wurman et al. (2007) estimated that similar tornadoes traveling through the city of Chicago would cause catastrophic financial and human loss. Rae and Stefkovich (2000) also determined that a very high financial loss could result if this outbreak were to happen in a large metropolitan area, but their research focused on the outbreak occurring in Dallas-Fort Worth.

In recent years, meteorological vulnerability studies have expanded from hurricanes and tornadoes into droughts, flooding, and extreme heat. Using Nebraska as a case study, Wilhelmi and Wilhite (2002) used GIS to determine how vulnerable the state is to agricultural drought, which is defined as the loss in production due to a prolonged period of below average precipitation. Their study used weather, agricultural and land use data (weighted based on importance to drought determinacy) to show that Nebraska is only moderately vulnerable to agricultural drought (Wilhelmi and Wilhite 2002). This study, though, did not include any socio-economic variables (i.e. local economies, sources of income, crop insurance) which would have strengthened their results.

More recently, numerous agencies worked together following a flood in Washington State to study the vulnerability of the Green River Valley to a failure of the local dam (White et al. 2012). As a result of this study, additional rain gauges and weather radars were added to the area to enable better detection of possible flooding conditions. The final results of these improvements are not yet conclusive, but the preliminary data appear promising.

Chow, Chuang, and Gober (2012) used seven variables, of which four were measures of social vulnerability and three were measures of heat, to determine the vulnerability of the Phoenix area to extreme heat for 1990 and 2000. They showed that much of Phoenix became less vulnerable over the 10-year period despite western and a small portion of southern Phoenix increasing in vulnerability. The authors pointed out at the end of their article that knowing where the most vulnerable areas are can aid the decision makers in trying to find ways to reduce loss. As these studies showed, there is great importance in understanding the potential impacts of severe weather on a region; but the research thus far seems to focus more on warm season weather.

Comparatively little research has been found thus far that included vulnerability in relation to snowstorms or blizzards, even though they can be some of the most dangerous and costly storms in the United States (Changnon and Kunkel 2006; Changnon 2007). Neal, Perry Jr., and Hawkins (1982) studied blizzard preparation in Wood County, Ohio for the blizzard of January 1978. The authors stated that there is usually complacency among residents about disasters occurring in temporally close proximity, and they began their research with the belief that the area would not have been prepared for the winter of 1977/78 because the previous winter had been severe. Through household surveys, they found that the people of Wood County were more prepared than was expected, thereby decreasing their vulnerability and the blizzard impacts.

One of the first attempts to bring society into measures of snowstorm impacts was by John Rooney. In 1967, Rooney conducted research on the disruption to transportation networks caused by winter storms within seven cities. His research created a scale that ranked storms from first order (devastating, nearly all transportation halted) to fifth order (minimal, hardly any disruption of transportation networks) using a combination of 11 factors (Rooney 1967).

Kocin and Uccellini (2004) conducted an intensive study of New England snowstorms. As a part of their research, they created an impact scale that can be used to determine the severity of a particular storm based on the amount of snow that falls, the area covered by that snowfall, and the number of people in that area. The NCDC has recently created an experimental scale similar to NESIS called the Regional Snowfall

Impact Scale (ReSIS) or just Regional Snowfall Index (RSI); the main difference between NESIS and ReSIS is that ReSIS uses snowfall threshold values that are specific to the particular climate region instead of the static values introduced by Kocin and Uccellini (Enloe 2011; Squires et al 2011, Kunkel et al. 2013).

David Call, in 2005, argued for renaming snowstorms “snow events” by taking into account various non-weather related variables such as transportation, lead times, public reaction, and media coverage using four cities in upstate New York as his case study. By 2011, a Local Winter Storm Scale (LWSS) was created using Newark, New Jersey climate records (Cerruti and Decker 2011). The LWSS used 15 years of climate data, NESIS threshold values, and the disruption scale created by Rooney in 1967 to develop a generalized scale for determining societal disruption of cities in the eastern United States. Sustained winds, wind gusts, snowfall totals, icing totals, and visibility data were used as the meteorolgical variables of interest. While the authors did show that this scale was helpful in measuring the ability of a storm to cause disruption that can be tailored to a location’s specific climatology, they also pointed out that the model does not account for vulnerability and that it was not applicable outside of the eastern U.S. (Cerruti and Decker 2011). Using non-meteorological data in the calculation of these indices is the first step in measuring societal impacts and vulnerability, but population demographics need to be included to gain a better understanding of true vulnerability.

In 2005, social scientists and meteorologists came together to do this with the first workshop of the Weather and Society*Integrated Studies (WAS*IS) program in Boulder, Colorado (Demuth et al 2007). This program, designed through National Center for Atmospheric Research (NCAR) and National Oceanic and Atmospheric Administration

(NOAA), was originally meant to be a one-time session to teach those in the field of meteorology that were interested in the methods to study the societal impacts of extreme weather events. Its\s success and popularity have led to its continuation and yearly workshops. The main goal of these workshops is to promote interdisciplinary work among the sciences with the hope of it becoming a common college course (Demuth et al 2007). As of August 2011, the WAS*IS program had 276 participants worldwide (NCAR 2012).

Another program was created in 2008 at the National Weather Center in Norman, Oklahoma under the direction of Dr. Eve Gruntfest called Social Science Woven into Meteorology (SSWIM) (Gruntfest 2009). According to their website, the program's goal is to bring social science into the studies of weather and climate in order to provide collaborative research that could work to reduce risk and vulnerability to weather hazards. The SSWIM program employs graduate students at the University of Oklahoma in their efforts by using them to collect literature and give presentations on their work. These programs are a step in the right direction in bringing more of the social sciences into geographic hazard studies, but they are still in their infancies and work still needs to be done.

2.4 Vulnerability and GIS

Geographic Information Systems (GIS) is becoming an increasingly popular and helpful tool in vulnerability studies and emergency management because of the relative ease of mapping multiple aspects of the hazard of concern on one map. The study conducted by Rae and Stefkovich (2000) is one example that uses downtown Dallas/Ft Worth as their study area. The authors chose this metropolitan area because of the large population and number of buildings located downtown. Another factor in their choice was that it is large city located in an active area of tornado alley. Using data from an historic tornado outbreak in Oklahoma with information from Dallas/Ft Worth on the number, types, and distribution of buildings, people, and traffic counts, the authors used GIS as a way to determine the potential damage that would occur if a tornado of that magnitude hit that particular city. Another such example is the study done by Wilhelmi and Wilhite (2002) to determine Nebraska's vulnerability to agricultural drought. GIS allowed them to combine multiple components to create one map to show the overall susceptibility of the state to a specific hazard.

The use of GIS in studies of social vulnerability is especially beneficial. As Weichselgartner (2001) suggested, it allows for an easier method of overlaying of all the important factors in order to determine vulnerability. Cutter, Mitchell, and Scott (2000) used data for Georgetown County in South Carolina to demonstrate this GIS ability. The authors obtained maps showing flood zones, hurricane storm surge and wind zones, chemical accident zones, and earthquake zones which were then overlaid with each other to create what they termed a hazard vulnerability map. A social vulnerability map was subsequently made by combining eight social measures at the census block level, which had been standardized to create a scale of zero to one for each variable. Using the same method as before, they overlaid each variable to create their social vulnerability map. These two maps were then combined to make what they called the place vulnerability map. Maantay and Maroko (2009) did a similar study using the flood zone maps for New York City to show that the method of analysis could result in an estimation error in the number of people possibly impacted by a natural hazard. The results of both studies showed that the most vulnerable places are not always the same areas that house the most vulnerable people, and it is important to know where the vulnerable people are in order to help them.

GIS software provides researchers of social vulnerability an easier, more objective way to map their results and study the spatial patterns. Cutter, Boruff, and Shirley (2003) took 42 variables measuring social vulnerability for all counties in the United States, later reduced to 11 factors using factor analysis, to create the Social Vulnerability Index (SoVI) in which each factor is placed into an additive model to calculate the final numbers. The map of the results showed that the areas exhibiting the highest vulnerability based on their factors tended to be clustered along the Mississippi River near Louisiana and in the central/mountainous west United States.

Cutter, Burton, and Emrich (2010) studied the southeastern United States using 36 variables. Using the same methods as were used in the 2003 article, the variables were standardized and mapped for each county in the region. They used GIS to map the overall vulnerability of each county as well as each individual component of the overall vulnerability score. Their results showed that the overall vulnerability exhibited a pattern in which the urban/rural dichotomy is evident. The maps of the individual components, on the other hand, were not as clear and more diverse.

Yoon (2012) followed the same procedures as both of the previous studies, using just the counties along the Gulf and Atlantic Coasts. His study indicated that the most vulnerable areas are found along the Gulf Coast. In each of these studies, the use of GIS was a way to enhance the results by providing a visual representation of the results discussed.

Cova (1999) used GIS to produce an evacuation vulnerability map for a section of Santa Barbara, California. His definition of evacuation vulnerability took the population density divided by the number of exit lanes (number of lanes on the road between where the people are and where they need to go) to calculate the vulnerability to easy evacuation during a disaster. More people over fewer lanes would then translate into higher vulnerability. Through his research, Cova argued that it is essential to know the behavior of the population as well because where the people are located at any particular time of the day will affect the vulnerability. GIS has its limitations, though, in both the availability of spatially referenced data that can be used or produced and the speed with which the mapping can be done.

For example, Andre Zerger (2002) used GIS to model the potential impacts of a storm surge in the city of Cairns, Australia, using elevation data, storm surge information, and economic/insurance information. The author showed that the scale of data available through GIS studies is currently insufficient because of the uncertainty that it causes at the scale needed by those charged with making the disaster plans. This uncertainty arose because the uncertainty imbedded in the datasets being used at the scale available do not provide enough detail. The uncertainty can, however, be changed or improved upon through further research and development of more advanced GIS software.

Another example from Zerger and Smith (2003) again used northern Australia. This study was undertaken with the purpose of determining how well GIS could be used in real-time decision making. The authors, in conjunction with the local emergency management office, used elevation models with building and road networks as well as cyclone (hurricane) data in their study to assess the risk of storm surge flooding in the city of Mackay. The authors argued that the current training and software is insufficient for use in trying to conduct real-time vulnerability and disaster management studies. The current software, they stated, only provided spatial analysis of data where temporal analysis is needed. Management officials stated in interviews that paper maps are still preferred over electronic versions because they are easier to use, but there is hope that these issues will be resolved as the technology continues to improve (Zerger and Smith 2003). In order for those in the field of emergency management to be better able to utilize the available GIS technology, it needs to create an interface that is easy for the general public to use and understand as well as better methods for combining the physical with the social and provide emergency managers with the real-time data they need to make their decisions in a timely manner (Cutter 2003b).

2.5 Summary

Studies in storm re-creation or historical storm analysis are mostly focused on hurricanes and tornadoes, while the studies of blizzards are more common for the East Coast due to the higher population densities. The beginnings of disaster research in the physical and social sciences as well as emergency management had a bias towards the hazard while ignoring the social conditions that helped to create the disaster situation, a focus on reaction instead of mitigation. These disciplines also placed more of an emphasis on hazards such as floods, hurricanes, and tornadoes while winter weather received cursory treatment if mentioned at all. In the last few years, though, the social aspects of disasters are being woven into the fabric of physical studies. While the creation of the WAS*IS and SSWIM programs are a step in the right direction, more needs to be done to bring the two worlds together. As the trend in vulnerability studies continues to increase, snowstorm vulnerability needs to be included because these are some of the most costly and deadly storms in the country. The following chapter will describe the proposed methods that will be used to conduct this proposed research

CHAPTER III

METHODOLOGY

Snowstorms and blizzards are a part of winter life in the north central United States. In any given year, a storm could grow to major status without much warning. With a continuing increase in population and urbanization, this study will assess how vulnerable today's Great Plains population would be to the occurrence of one of these storms. Hazard identification and risk analysis will be used to determine the area or areas of the Great Plains that are most likely to be affected by a severe snowstorm. Once the hazard is identified, a social vulnerability (vulnerability as measured by the population demographics of the area) analysis will be conducted.

3.1 Study Area

Before any mapping or analysis could be completed, storm data and population demographic data must be collected for the study area. The study area for this research includes the states of the northern Great Plains as well as two from the western Midwest region: North Dakota, South Dakota, Colorado, Iowa, Nebraska, Minnesota, Wyoming, and Montana. Only those counties of Colorado, Wyoming, and Montana that fall within the boundaries of the Great Plains as defined by the Center for Great Plains Studies at the

University of Nebraska-Lincoln will be included in the study (Figs.1 and 2). This region was chosen as the focus of this study because of the paucity of research on this area of the country as discussed in Chapter 2. Snow is also common in this area during the cooler months of the year.

Figure 1: Center for Great Plains Studies definition of the Great Plains region of the United States. Image obtained from http://www.unl.edu/plains/about/map.shtml

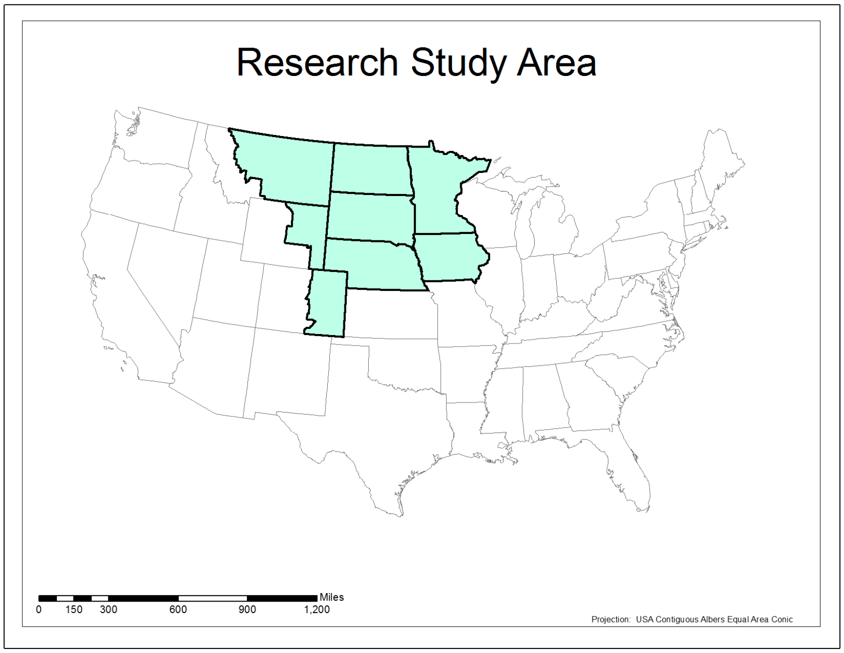


Figure 2: Study Area. Counties of Montana, Wyoming and Colorado used in research based on the Great Plains area defined by the US State Department shown in Fig. 1

3.2 Hazard Identification

Hazard identification and analysis is a method commonly used in the field of emergency management to associate certain vulnerability studies and mitigative responses to specific hazards, and this method is as rigorous and scientific as the researcher desires to make it (Drabek and Hoetmer 1991). Part of this process includes a hazard analysis which shows where the greatest hazard risk exists which can be done be using mapping software, such as GIS, to show the risk areas determined using past events (Drabek and Hoetmer 1991). This is the method that was used to conduct this hazard identification and hazard analysis.

3.2.1 Storm Selection

Two sources were used to determine when and where the snowstorms occurred. The first source was the *U.S. Weather Bureau Climatological Data National Summary* which provides a monthly summary of the temperature and precipitation nationwide and gives special attention to severe storms. The second source used was the NOAA Daily Weather Map series, which is available online through the NOAA documents library. Because the Weather Bureau source is only available for 1950-1980, this 31-year time frame was selected as the study period. In this region of the country, the snow season is generally considered to be between October and April (Kunkel et al 2013), so these are the months of interest.

The storm data obtained from the national summaries provided a reference point for selecting storms from the daily weather maps by allowing for a comparison to ensure that the storm dataset was as complete as possible. Twenty-six first-order weather stations fell within the study area on the daily weather maps (Fig. 3). In order for a station to be selected on a particular day, all three of the following conditions had to be met:

1) Visibility of 3 miles or less
2) Wind speeds at least 20 knots
3) Snow falling (indicated by **, ***, or **** symbol on the weather station model)

A visibility of 3 miles or less was chosen as a selection criteria because this indicates a significant drop in visibility with falling and blowing snow. Wind speeds of 20 knots (23 mph) are strong enough to cause difficulty in travel by lowering the visibility and outdoor work by dropping temperatures. These criteria were based on the NWS definition of a blizzard, and they were expanded in order to capture more data points and include severe snowstorms that do not reach blizzard conditions.

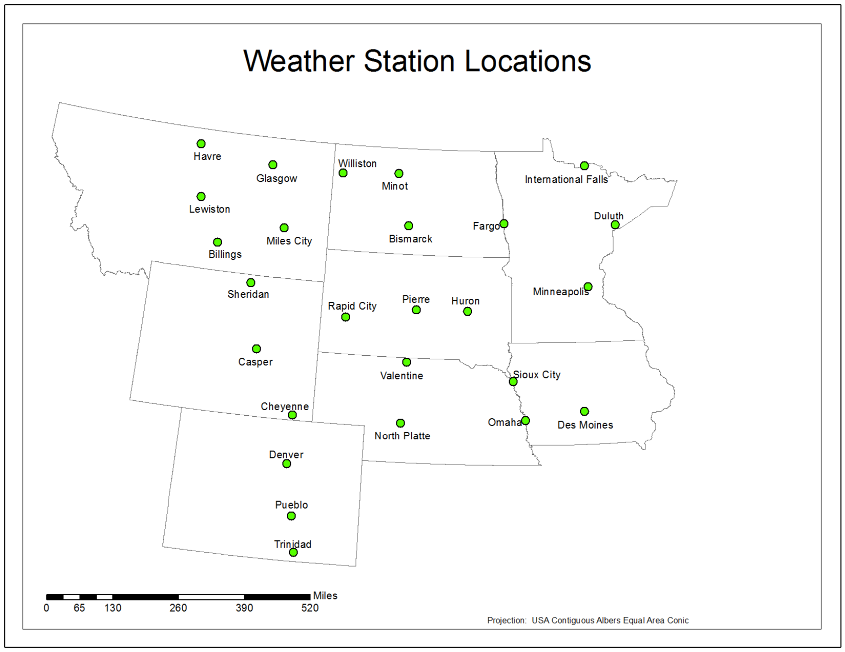


Figure 3: Locations of the weather stations used for the hazard identification analysis

3.2.2 Classifying storms

Once the stations/storms were selected, each storm location was added to a database that included the date and time of observation as well as various weather data such as wind speed, visibility, and temperature (Table 1). Wind speed was converted from knots to miles per hour because the wind chill factor equation uses miles per hour. To convert from knots to mph, the wind speed in knots is multiplied by 1.151. The wind chill factor equation (NWS 2009) is:

$$\textit{Wind Chill}=35.75+(0.6215*\textit{Temp in }^{o}F)-(35.75*\textit{Wind}^{0.16})+(0.4275*\textit{Temp}*\textit{Wind}^{0.16})$$

Each entry in the database was then classified as either blizzard conditions, near blizzard conditions, or snowstorm conditions. Blizzard conditions, according to the NWS, include winds of at least 30 knots (35mph) and visibility of ¼ mile or less. Near blizzard conditions were 1) days in which visibility was ¼ mile or less with winds less than 30 knots or 2) winds were at least 30 knots with visibility between ¼ mile and 1 mile. All others were classified as snowstorm days. A total count of each storm category throughout the study area as well as per decade was tallied for each of the 26 stations to obtain a total number of days under each condition for each time period (Appendix 2).

Table 1: Data Collected for Each Weather Station

Variable	Measured or Calculated
Temperature	Measured
Wind Direction	Measured
Wind Speed (knots)	Measured
Wind Speed (mph)	Calculated
Visibility	Measured
Weather	Measured
Wind Chill	Calculated
Pressure	Measured

3.2.3 Mapping and Analyzing the Risk

Total day counts of each storm category as well as the decadal totals of each storm category were mapped using the interpolation methods provided in ArcGIS 10 Geostatistical Analysis toolbox (ESRI ArcGIS 10.1). The blizzard counts were done using both the IDW ("weight" field was left blank) and kriging methods of interpolation in order to determine which provided a more accurate map. No discernible differences were seen in the two results, and IDW was chosen as the method to use for all of the hazard maps (ESRI ArcGIS 10.1). The areas determined to be the highest risk in each classification are those which experienced the most days under each condition.

Average wind chill during snowstorm conditions throughout the study period at each station was calculated, and these numbers were mapped using the same interpolation method as was used for the day count analysis. Although wind chill is not included in the official NWS definition of a blizzard, prolonged exposure to extremely cold temperatures can cause health issues such as frost bite or hypothermia (NWS 2009; NWS 2010). Areas with low wind chill values were determined to also be of high risk. The wind chill map was compared to the risk maps to see if the areas of low wind chill corresponded with the areas that spent the most amount of time from 1950-1980 under snowstorm conditions.

3.3 Vulnerability Analysis

<u>3.3.1 Data Collection</u>

Data for the social vulnerability portion of the research is available through the U.S. Census factfinder2 website (factfinder2.census.gov). The data used was from the current 2010 census. A list of the variables that were used as well as their effect on vulnerability can be seen below in Table 2. As many researchers who have addressed social vulnerability are quick to point out, poverty is a key factor in determining a population's vulnerability but poverty does not automatically equal vulnerability (Mitchell, and Scott 2000; Stephen and Downing 2001; McIntire 2004; Cutter, Wisner et al 2004; Bankoff, Frerks, and Hilhorst 2007; Phillips et al 2010; Yoon 2012). The variables in Table 1 were chosen based on a review of the work done in the field of social vulnerability (Cutter, Mitchell, and Scott 2000; The Heinz Center 2002; Cutter, Boruff, and Shirley 2003; Cutter and Finch 2008; de Oliveira Mendes 2009; Cutter, Burton, and Emrich 2010; Phillips et al 2010; Yoon 2012; Tate 2012; King and MacGregor 2013). County level variables were downloaded.

<u>3.3.2 Social Vulnerability Index</u>

The vulnerability analysis was conducted for the entire study area at the county level. All research reviewed thus far relating to social vulnerability studies and the Social

Table 2: Demographic variables and their impact on vulnerability

Variable	Increase (+) or Decrease (-) Vulnerability
% Poverty	+
% Female	+
% White	-
% Over 65	+
% Under 16	+
% Under 5	+
% Rural	+
% Unemployed	+
% Renters	+
% Female headed household	+
% With a high school diploma	-
% With a college diploma	-
% Primary employment	+
% English speaking	-

Vulnerability Index states that standardization of the variables is required before conducting the vulnerability analysis (Cutter, Mitchell, and Scott 2000; Cutter, Boruff, and Shirley 2003; de Oliveira Mendes 2009; Yoon 2012; King and MacGregor 2013). Since all the variables are stated in percentages, further standardization should not be required. However, many of these studies employ the use of z-scores to create their vulnerability index value. This is done to create a score with a mean at zero allowing for a more logical scale in which positive numbers indicate higher vulnerability and negative numbers indicate lower vulnerability. Calculating the z-score also allows for an easier comparison among different sets of data. Therefore, the data was converted into z-scores using the following equation given in Yoon (2012):

$$Z = \frac{value - mean}{standard\ deviation}$$

The individual variable scores are then combined into an overall composite score through the additive SoVI model (factors increasing vulnerability are added whereas factors decreasing vulnerability are subtracted) for each county and mapped to create an overall view of the social vulnerability throughout the study area. This will address the second major question of this study: which areas are most vulnerable. The SoVI was calculated with and without poverty to see if there is any difference in the high vulnerability areas. Calculations of the index without poverty were based on the raw numbers obtained from the U.S. Census Bureau while the index including poverty was based on the percentage values. This was done because the raw numbers of the total population living below the poverty line could not be easily obtained due to the multiple ways with which to define the poverty level.

3.3.3 Pattern Analysis

In order to determine if there is a pattern to the two vulnerability results (research question number three), global and local Moran's I analyses were conducted (Burt, Barber, and Rigby 2009). The global Moran's I analysis provides a number between -1 and 1 that shows the strength of the clustering with a positive value indicating clustering of like values. To conduct the global Moran's I analysis, a matrix was built to indicate neighboring counties using the queen's case (counties in all directions sharing a border, even if it is just a corner to corner touch, are counted as neighbors). Neighbors are indicated with a 1 while all others are labeled with a 0, and each row was then totaled to get a row sum. A regression analysis (regression #1) was run in Excel using the SoVI scores (one for the scores without poverty, one for the scores with poverty) as the independent variable and sum of each counties neighbor's scores as the dependent variable. Another regression (regression #2) was run using the row sums of the neighbor matrix as the dependent variable and a column of ones as the independent variable. Moran's I was then calculated by taking the slope of the corresponding SoVI regression divided by the slope of the row sum regression. Significance of this value was tested using the following equations and variables (Burt, Barber, and Rigby 2009):

A = $\sum\sum wij$ = sum of the column of row sums

B = $\frac{1}{2}\sum\sum(wij + wji)$^2 =sum of a matrix in which each matrix square is equal to the corresponding square of the original matrix times 2 and then squared

C = $\sum(\sum wij + \sum wji)$^2 = sum of the row sum times two and then squared

n = number of counties in the study area (473)

E(I) = $\frac{-1}{n-1}$ = expected value of I for significance testing

I = $\frac{slope\ of\ regression\ \#1}{slope\ of\ regression\ \#2}$ = Moran's I

Var(I) = $\frac{n^2B - nC + 2\left(\frac{n-2}{n-1}\right)A^2}{A^2(n^2-1)}$ = variance assuming normality

σI = $\sqrt{Var(I)}$ = standard deviation

z = $\frac{I - E(I)}{\sigma I}$ = statistic used to test significance of I

p-value = calculated in Excel using (1-normsdist(z))*2

The Local I analysis required a standardized neighbor matrix. In order to create this matrix, every value in each row was divided by its row sum so that each row sum now equaled one. This matrix was then multiplied by the column of SoVI scores (with and without poverty) to obtain one value per county. Local I was calculated by taking the value from the matrix multiplication multiplied by that county's respective SoVI score. Positive local I scores indicated clustering of like values (the county is surrounded by similar values) and vice versa for negative values (the county is surrounded by dissimilar values). Higher values of the local I indicate a stronger clustering pattern (Burt, Barber, and Rigby 2009).

The final question of coincidence of areas was determined through a side-by-side comparison of the final results of the hazard identification for 1950-1980 and the vulnerability analyses to see if the most highly vulnerable counties fell within the boundaries of the areas determined to be most at risk. Analysis and results of the hazard identification and analysis, vulnerability analysis, and pattern analysis can be found in Chapter 4.

CHAPTER IV

RISK AND VULNERABILITY

4.1 Hazard Identification

4.1.1 Blizzard Risk

The first category of storms used for classification was the number of days under NWS-defined blizzard conditions (NWS 2013). In order for a data point to be included in this category, the station needed to have visibility of ¼ mile or less and winds of at least 30 kts (35 mph). For the period 1950-80, the count ranged between 0 days and 14 days (counts by station can be found in Appendix 2.1). For all of the following hazard maps in Section 4.1, the areas shaded in red are considered to be the areas of highest risk while the blues are the areas of lowest risk. The main area of blizzard activity is centered on Rapid City and Pierre in central and western South Dakota. Secondary "bulleyes" can be seen around Fargo, North Dakota and Duluth, Minnesota. Iowa, Colorado and Montana experience very few days, in comparison, of blizzard conditions between 1950 and 1980 (Figure 4).

Breaking the data down by decade, the same pattern can be seen from 1950-59 (Figure 5) with a range of 0 to 9 days under blizzard conditions during this decade. The highest counts were in central South Dakota around the capital city of Pierre. Rapid City and Duluth also had higher counts and formed secondary peaks. It was in this decade that the study area saw the majority of its total blizzard days.

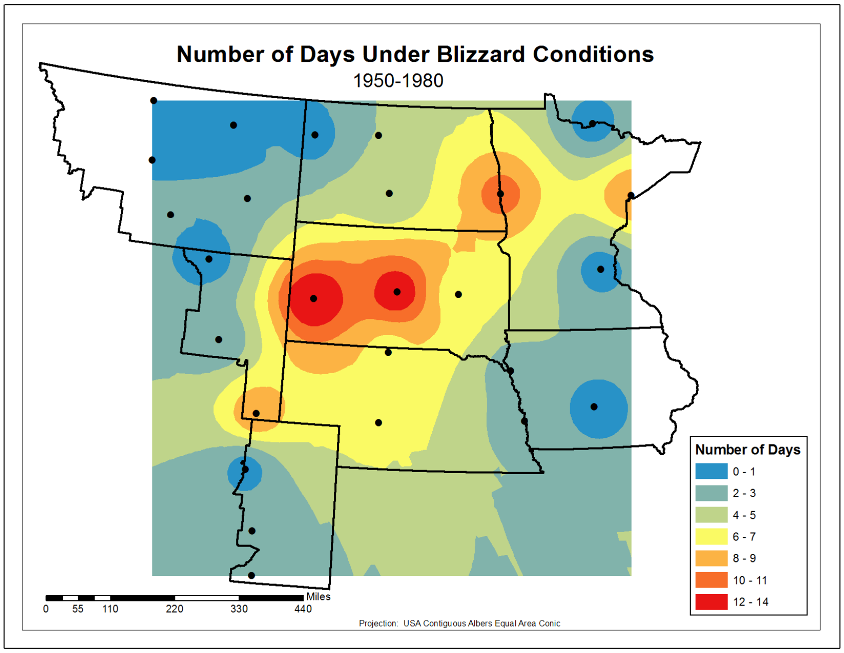


Figure 4: Number of Days under Blizzard Conditions for entire study period, 1950-1980. Dots on the image are locations of the stations used in the analysis.

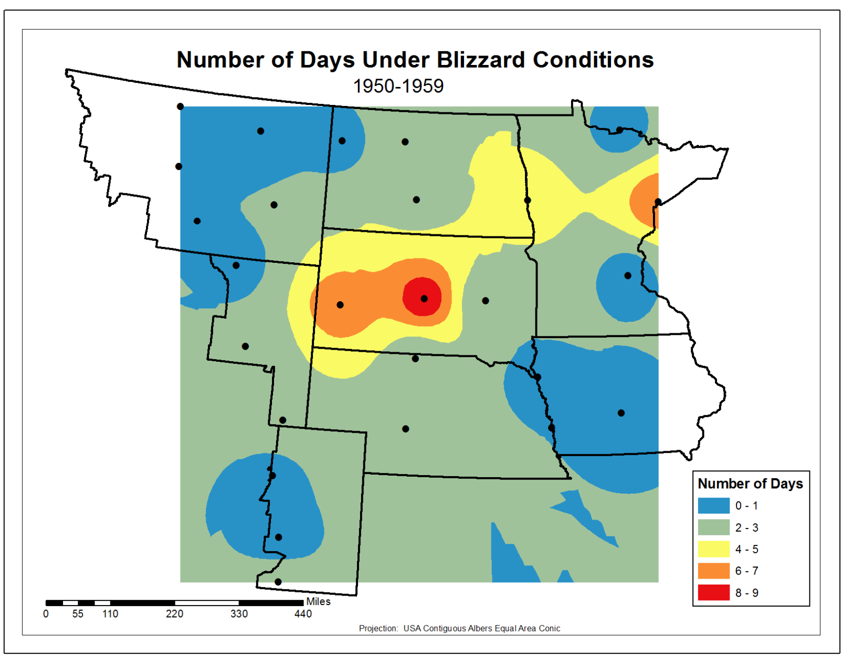


Figure 5: Number of Days under Blizzard Conditions for 1950-1959. Dots on the image are locations of the stations used in the analysis.

After the relatively active decade for blizzards in the 1950s, the 1960s (Figure 6) and 1970s (Figure 7) were much quieter. The area of high risk shifted back into western South Dakota during the 1960s while secondary peaks disappeared. During the 1970s, the peak count was found farther west in southeastern Wyoming around Cheyenne with a weak secondary peak appearing near Fargo, North Dakota. The highest risk for blizzard conditions in this area of the country appears to be in western and central South Dakota.

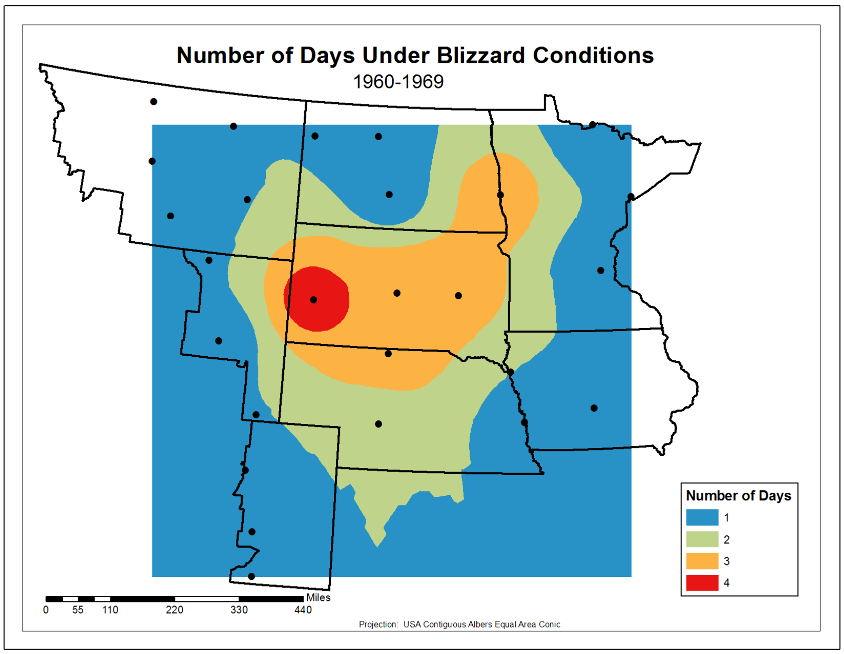


Figure 6: Number of Days under Blizzard Conditions for 1960-1969. Dots on the image are locations of the stations used in the analysis

<u>4.1.2 Blizzard and Near Blizzard Risk</u>

The second category of storm classification was the number of days under blizzard or near blizzard conditions. All days included in the blizzard category were used in this analysis plus those that were under near blizzard conditions. This was done to expand the dataset to include storms that were an intermediate condition between blizzard and snowstorm. The inclusion of near blizzard conditions added between 0 and

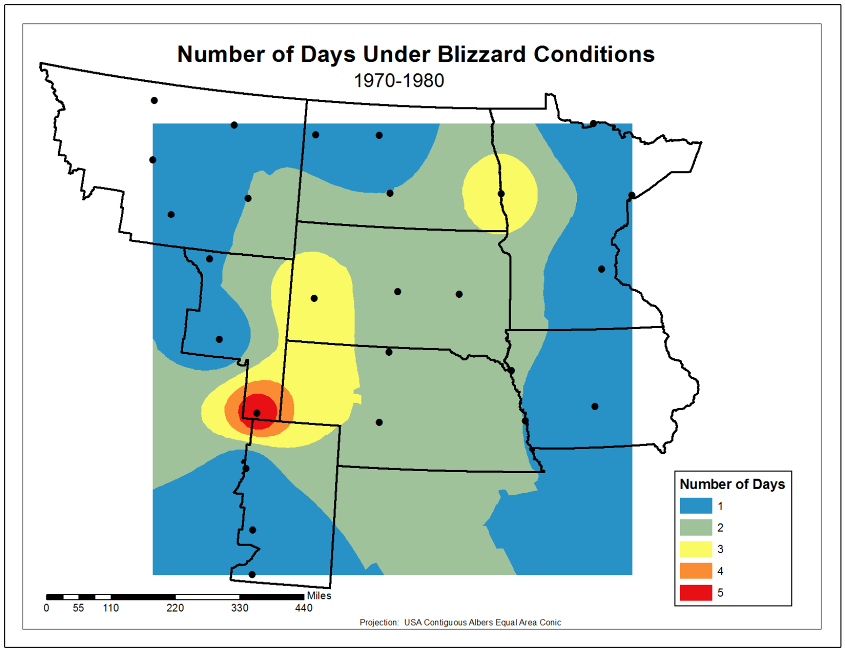


Figure 7: Number of Days under Blizzard Conditions for 1970-1980. Dots on the image are locations of the stations used in the analysis

18 days to the counts, depending on the station. Near blizzard conditions were defined as days experiencing one of the following conditions:

1. Winds less than 30 kts (35 mph) but visibility ¼ mile or less
2. Winds at least 30 kts (35 mph) but visibility between ¼ mile and 1 mile

Counts by station for this category can be found in Appendix 2.2. From 1950-1980, these counts ranged from 0 to 31 days under these conditions. The highest counts were again located in western and central South Dakota, and Fargo was also a peak area. A secondary peak area was seen around Duluth. Colorado and Montana, with some isolated locations in Minnesota, showed the fewest number of days (Figure 8).

As was seen with the blizzard data, the 1950s was relatively active compared to the 1960s and 1970s with some locations seeing more than half of the days during this time. Secondary peaks around Duluth and Fargo formed during the 1950s. Bismarck

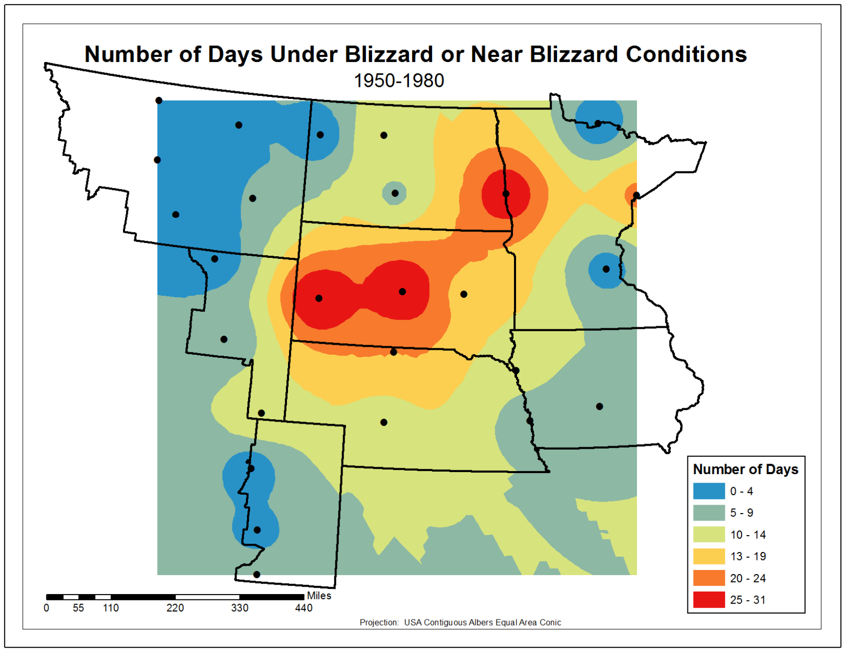


Figure 8: Number of Days under Blizzard or Near Blizzard Conditions for entire study period, 1950-1980. Dots on the image are locations of the stations used in the analysis

seems to have been isolated from these conditions during the '50s as it had a low count compared to the rest of the surrounding area (Figure 9).

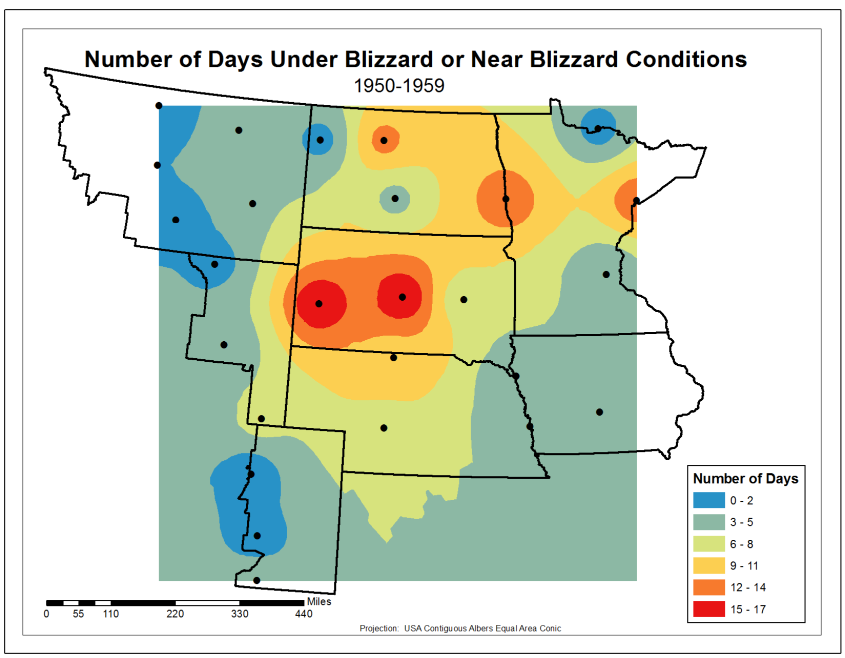


Figure 9: Number of Days under Blizzard or Near Blizzard Conditions for 1950-1959. Dots on the image are locations of the stations used in the analysis

An isolated low count area was found around International Falls in northern Minnesota and in northwestern North Dakota.

From 1960-1969, the area most likely to experience blizzard or near blizzard conditions shifted to central and eastern South Dakota while almost all of the state was found in the two highest count categories (Figure 10). In the 1970s, the peak occurred in eastern North Dakota and western Minnesota near Fargo (Figure 11). Southeastern Wyoming and parts of South Dakota showed secondary peaks. Central Montana and eastern Montana, which to this point did not experience these more severe conditions, began to see some activity with 2-4 days of the 1970s falling under blizzard or near blizzard conditions. When looking at the entire study period, the areas of highest risk were found in western South Dakota into eastern North Dakota. If the data is broken down by decade, the high risk area shifted from western South Dakota in the 1950s into

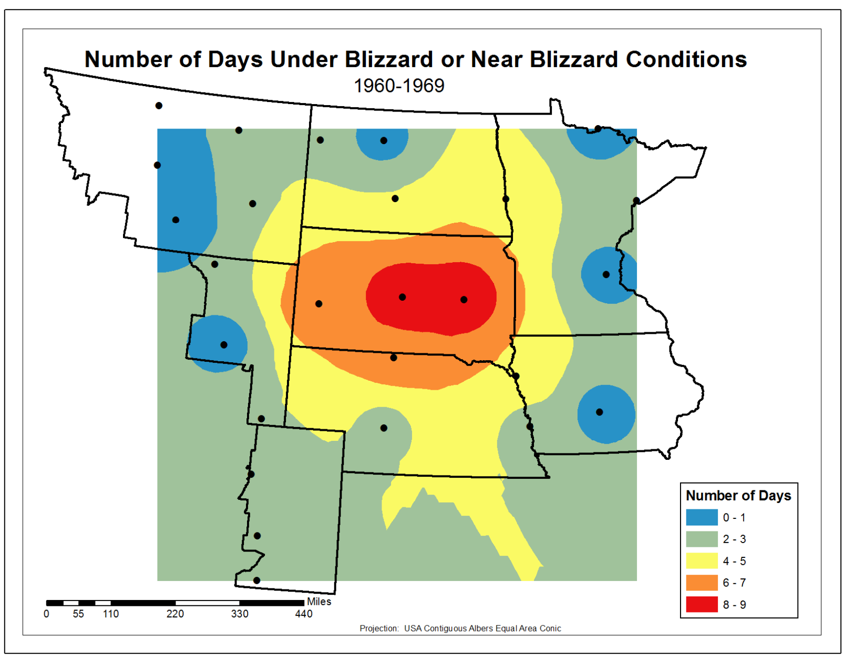


Figure 10: Number of Days under Blizzard or Near Blizzard Conditions for 1960-1969. Dots on the image are locations of the stations used in the analysis

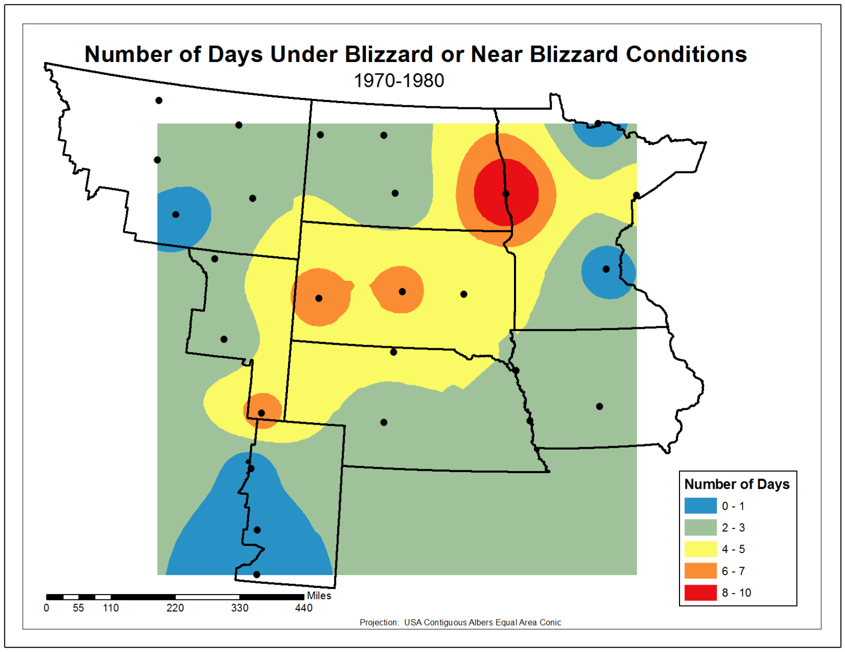


Figure 11: Number of Days under Blizzard or Near Blizzard Conditions for 1970-1980. Dots on the image are locations of the stations used in the analysis

central South Dakota during the 1960s and ended up in eastern North Dakota/western Minnesota during the 1970s.

4.1.3 Overall Snowstorm Risk

The final category counted days under all storm conditions for each station (total snowstorm counts can be found in Appendix 2.3). During the entire study period, every location in the study area experienced at least 3 days under some level of snowstorm condition (Figure 12). The highest counts of around 100 days, or more, are seen in eastern North Dakota. A very small area of high risk is centered on Pierre. Montana was once again on the lowest end of the range.

In the first decade (1950-1959), the peak in South Dakota around Pierre is larger than is seen in Figure 12 while the peak around Fargo remains (Figure 13). The stronger delineation seen in Figure 12 from the Dakotas westward or eastward was not as strong in the 1950s indicating a more gradual transition of the number of days throughout the study area. All areas during this time also experienced at least three days of snowstorm

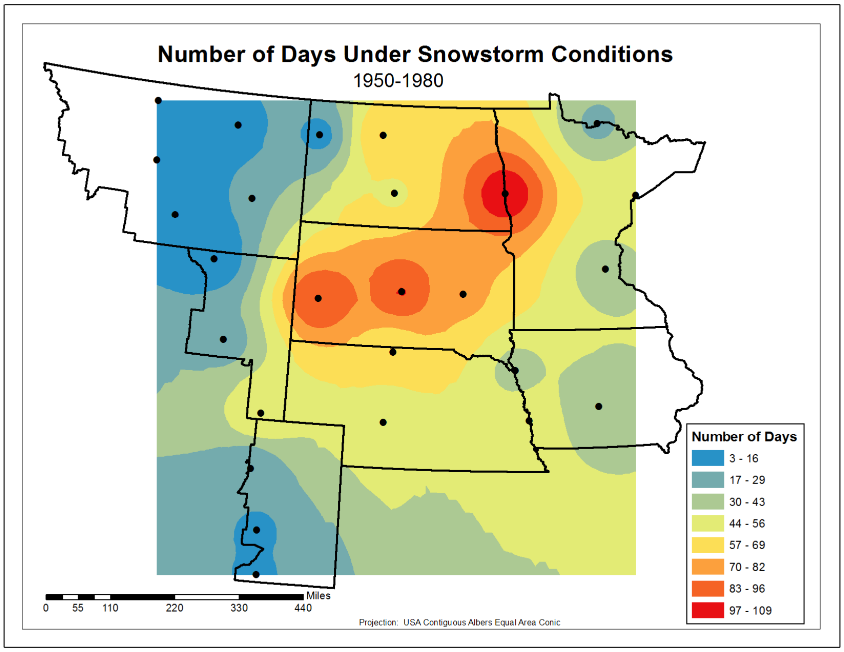


Figure 12: Number of Days under all Snowstorm conditions for the entire study period, 1950-1980. Dots on the image are locations of the stations used in the analysis

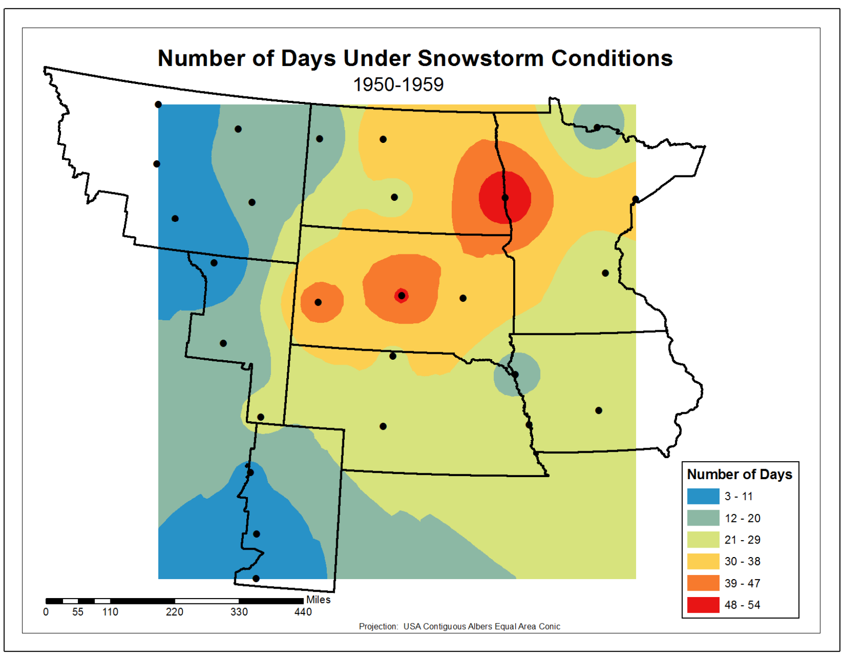


Figure 13: Number of Days under all Snowstorm conditions for 1950-1959. Dots on the image are locations of the stations used in the analysis

conditions, and some areas once again having more than half of the storm counts in this decade.

During the 1960s, the stronger delineation in this region west toward the Rocky Mountains has returned with the peak count once again centered in western South Dakota around Rapid City (Figure 14). However, a secondary peak was still seen around Fargo and Pierre. The 1960s did also see some locations free from snowstorm conditions on the far eastern and western edges of the study area.

The peak number of snowstorm days in the 1970s can be seen within a small area around Fargo with secondary peaks near Rapid City and Pierre (Figure 15). All areas were again found to have at least a few days in which snowstorm conditions occurred after a decade in which some locations remained snowstorm free. Throughout the 31-year study period, the area of highest risk for snowstorm activity remains in eastern North Dakota/western Minnesota around the Fargo metropolitan area. A secondary high risk

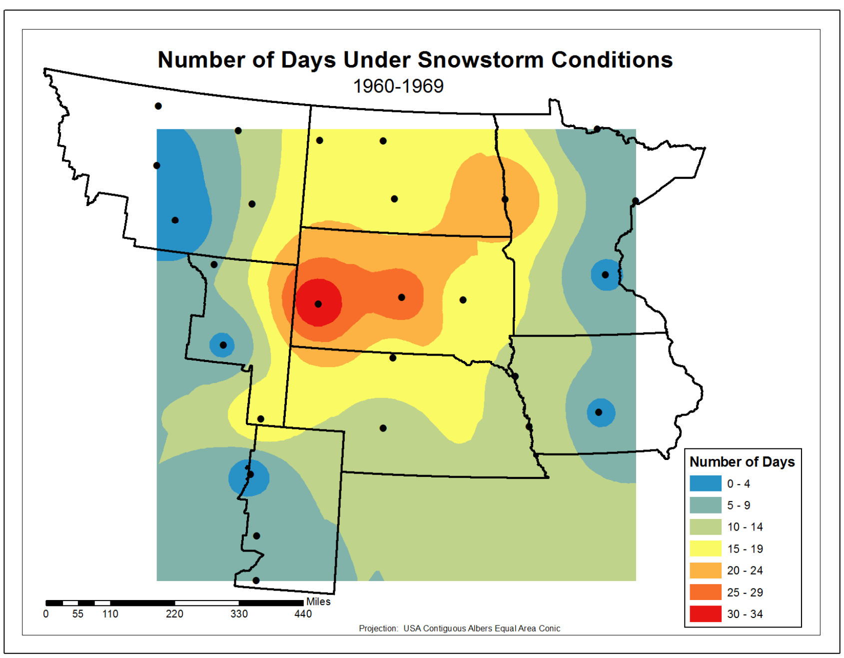


Figure 14: Number of Days under all Snowstorm conditions for 1960-1969. Dots on the image are locations of the stations used in the analysis

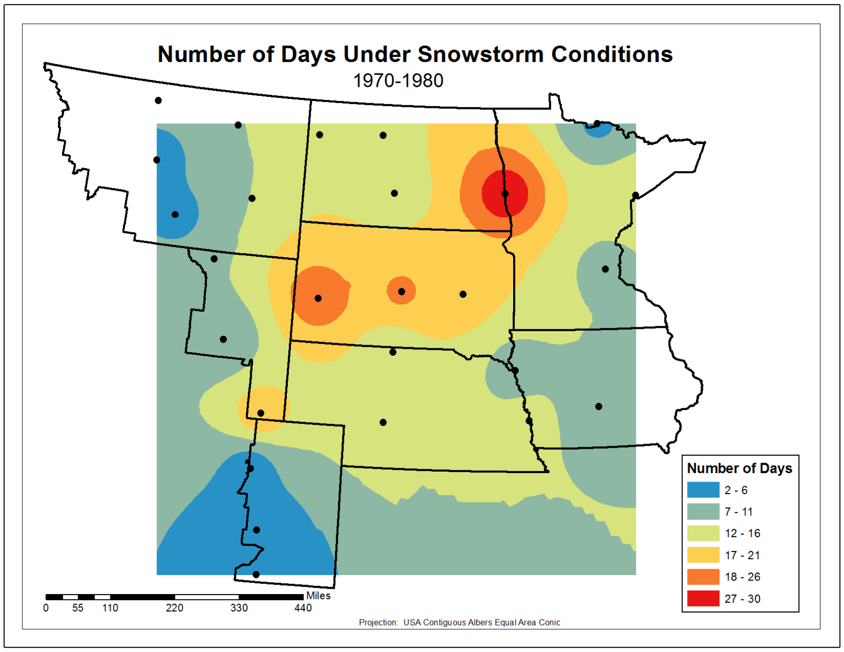


Figure 15: Number of Days under all Snowstorm conditions for 1970-1980. Dots on the image are locations of the stations used in the analysis

area is found in western South Dakota around Rapid City. Decadally, this secondary peak in South Dakota shifted from the central part of the state in the 1950s to western South Dakota in the 1960s and 1970s.

4.1.4 Comparison Among Classification Categories

Looking at the full time period and comparing the three different classification categories, there are two common areas of higher risk in all three images. These areas are the Black Hills and Badlands regions of western South Dakota (Figure 16). If only blizzard conditions are taken into account, a weaker secondary peak is seen on the North Dakota-Minnesota border. This secondary peak became stronger and comparable (in the same respective category) to that found in western South Dakota when the near blizzard conditions or all snowstorm conditions were considered.

The high risk area for the blizzard and near blizzard conditions in South Dakota (Figure 16, middle image) was the widest spread of the three categories. Montana exhibited the lowest risk under each category, as it fell into to the lowest classification for each image. The same can be said for Iowa and southern Minnesota for the blizzard and blizzard/near blizzard categories. This area, though, did have more general snowstorm condition activity than can be found in Montana. The stations in Minnesota, central Iowa, central Wyoming, and Colorado showed isolated lower counts for each storm category.

For each category, the 1950s were the most active decade for snowstorm activity. In this decade, the high risk areas each saw more than half of the days occur. The remaining days were divided relatively evenly between the 1960s and 1970s. Another common characteristic of the geographic pattern for each category is the areal extent of the high risk areas decade by decade. Smaller geographic areas of high risk were generally seen within the decades than when aggregated together for the longer time span. Gradients of the number of days also tended to decrease from decade to decade when moving from the high risk to low risk areas. The isolated locations seen in the overall count images are also seen on many of the decade maps.

The location of these high risk areas is logical from a meteorological standpoint. North and South Dakota are situated in a location in which a system called an Alberta Clipper is common during the winter months (AMS glossary, Weather Notebook 2000, Weather Notebook 2003, NWS 2013). Alberta Clippers, as defined by the NWS, are low pressure systems that come out of Alberta Canada into the northern plains and upper Midwest. These systems usually bring strong winds, cold temperatures, and light snow

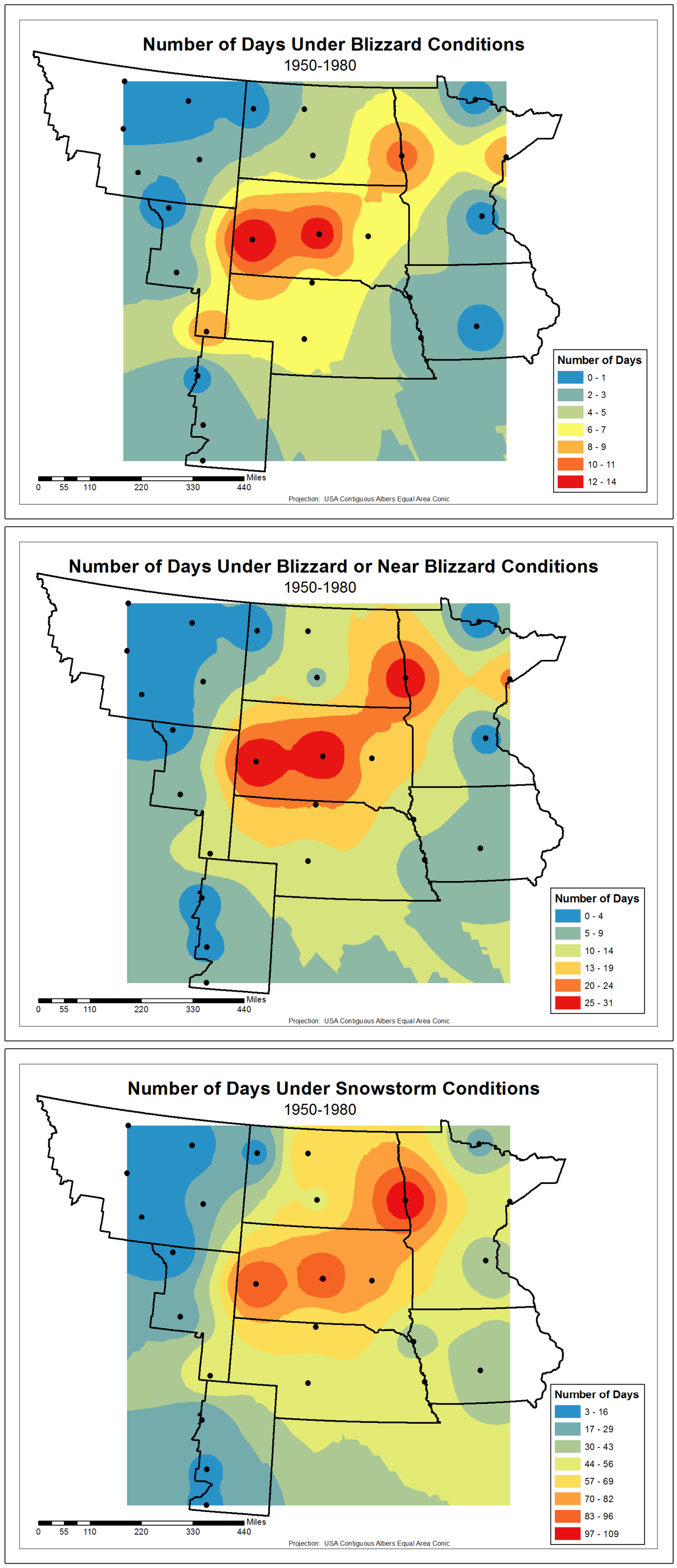


Figure 16: Comparison of Number of Days under each Condition, 1950-1980. Blizzard conditions (top image), blizzard/near blizzard conditions (middle image), and all snowstorm conditions (bottom image). Images previously used individually earlier in this chapter. Dots on the images are locations of the stations used in the analysis.

as they move across the area. If the winds are strong enough, the visibility can be reduced due to blowing or drifting snow, thus creating the conditions required by the NWS for a blizzard designation. The stronger winds in combination with the colder temperatures help create lower wind chill values that can heighten risk.

The secondary peaks that appear around Duluth also make sense because of its location on the western shores of Lake Superior. The stations of Colorado are found along the front range of the Rocky Mountains. These cities are located on the leeward side of the mountains, which is usually the drier side of any mountain range. Air flowing over a mountain range loses most of its moisture as it travels up the windward side. This leaves little moisture available for precipitation to form without any other meteorological influences. One possible explanation for the occurrence of low risks around some cities is the location of the stations at the airports, which could be providing some protection.

4.1.5 Wind Chill Analysis

Although temperature is no longer included in the official NWS definition of a blizzard or snowstorm, temperature is an important factor from a medical perspective. As discussed in Chapter 3, prolonged exposure to extremely cold temperatures can cause medical conditions such as hypothermia and frostbite. The wind chill temperature is calculated based on temperature and wind speed, and it tells someone what the temperature "feels like" when the wind is blowing. There is no set threshold on what constitutes a dangerous wind chill, but the NWS says that a wind chill of -20^{o}F is a general rule of thumb for dangerous conditions (NWS 2013).

The average wind chill was calculated for each station (values can be found in Appendix 3) under all snowstorm conditions from 1950-1980 (Figure 17). As is generally seen with maps of temperature gradients, there is an overall latitudinal pattern to the data with wind chill with the exception of Iowa and southeastern Minnesota. In general, wind chill temperatures decrease with increasing latitude. When compared to the images in Figure 16, the high risk area around Fargo also exhibits the lowest average wind chill. In the area of Rapid City and Pierre, the wind chill averages between 0°F and -3°F. The area of North Dakota that also showed a higher risk exhibited an average wind chill temperature of -6°F to -9°F during the study period. These areas are, according to this data, more likely to experience colder temperatures during these events which could mean an increase in their risk for a severe winter storm. This makes sense as one of the conditions typically associated with an Alberta Clipper, as discussed previously in Section 4.1.4, includes colder temperatures and stronger winds which work together to create lower wind chills.

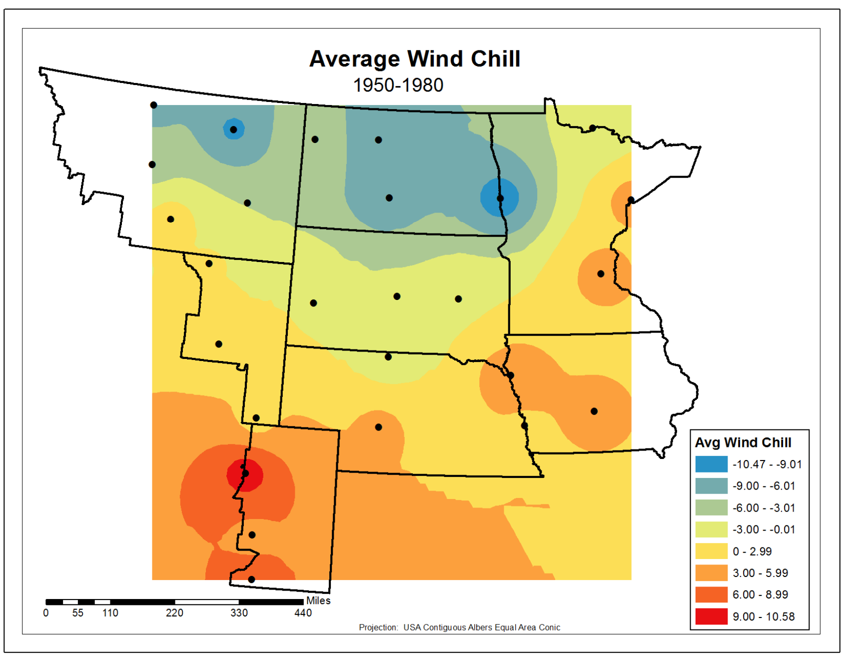


Figure 17: Average Wind Chill temperatures for the entire study period, 1950-1980. Dots on the image are locations of the stations used in the analysis.

4.2 Vulnerability Analysis

<u>**4.2.1 Social Vulnerability Index**</u>

The Social Vulnerability Index (SoVI), as was shown in Chapter 2, is a tool used to assess the vulnerability of an area using socioeconomic variables such as age, race, and employment. This method is a simple additive model in which each variable is either added or subtracted based on its relationship to vulnerability (Table 2, Chapter 2). For this research, the index was calculated with and without poverty in order to determine if there were any differences in the outcome. Values of this index can vary based on the data. The number of variables, the value of the variables, and the normalization method used on the variables all have an influence on the final SoVI scores. Because the method used in this research employed z-scores to normalize the data, a score of 0 is the average. Positive scores, therefore, indicate above average vulnerability; and negative scores show below average vulnerability. Larger numbers on either end of the spectrum mean that area is farther away from the average (i.e. higher positive values are areas of higher vulnerability).

<u>***4.2.1.1 Without Poverty***</u>

The first vulnerability analysis was conducted with 13 of the 14 variables listed in Table 1 (Chapter 2) chosen. Poverty was the variable left out because if its strong correlation with vulnerability. The areas that showed above average vulnerability under these conditions were the major metropolitan areas of Colorado, Nebraska, and Minnesota (Figure 18). One possible explanation for this pattern may stem from renting patterns in major cities. In the vulnerability literature reviewed in Chapter 2, higher numbers of renters were shown to increase a location's vulnerability. The majority of the populations in larger and more populous cities are renters (Majur and Wilson 2011).

Many, if not all, of these cities also house a college or university in which many of the students are under the age of 25. Of those under the age of 25, approximately 78% are renters. In general, younger populations rent more often because it allows for greater mobility in the early stages of their careers (JCHS 2011). Another segment of the population that may be found in higher numbers in the cities and suburbs are those over the age of 65. This age group is more likely to live in a rental unit if they live in urban locations (JCHS 2011). Much of the study area shows near or below average vulnerability (shades of blue). The areas of lowest vulnerability are mainly found in central South Dakota, central Nebraska, and eastern Montana. No logical reason was identified as to why these locations exhibited such low vulnerability.

Comparing this result to the results from section 4.1, the highly vulnerable areas do not coincide with the high risk areas (Figures 19-21). The areas that show the highest

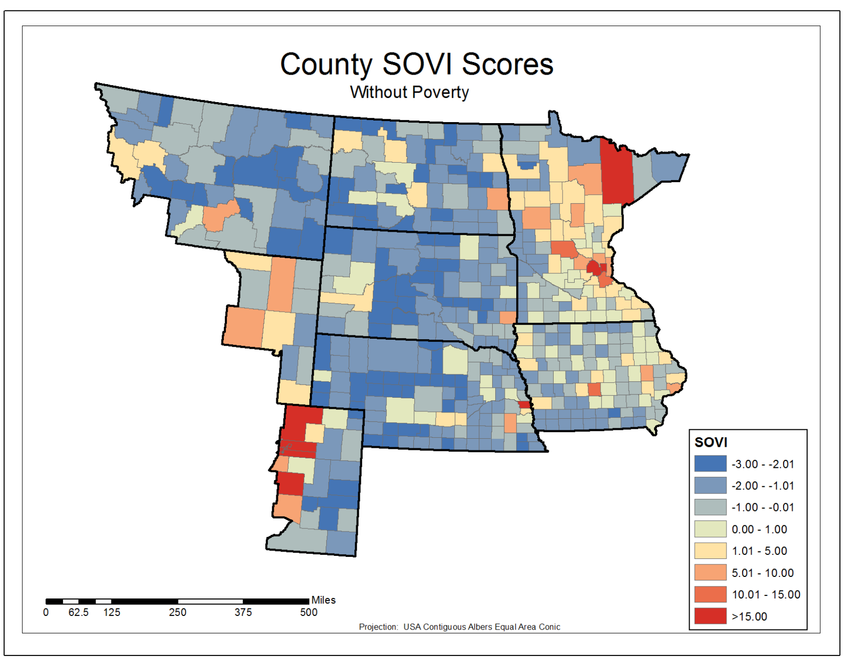


Figure 18: Social Vulnerability Index without Poverty at the county level.

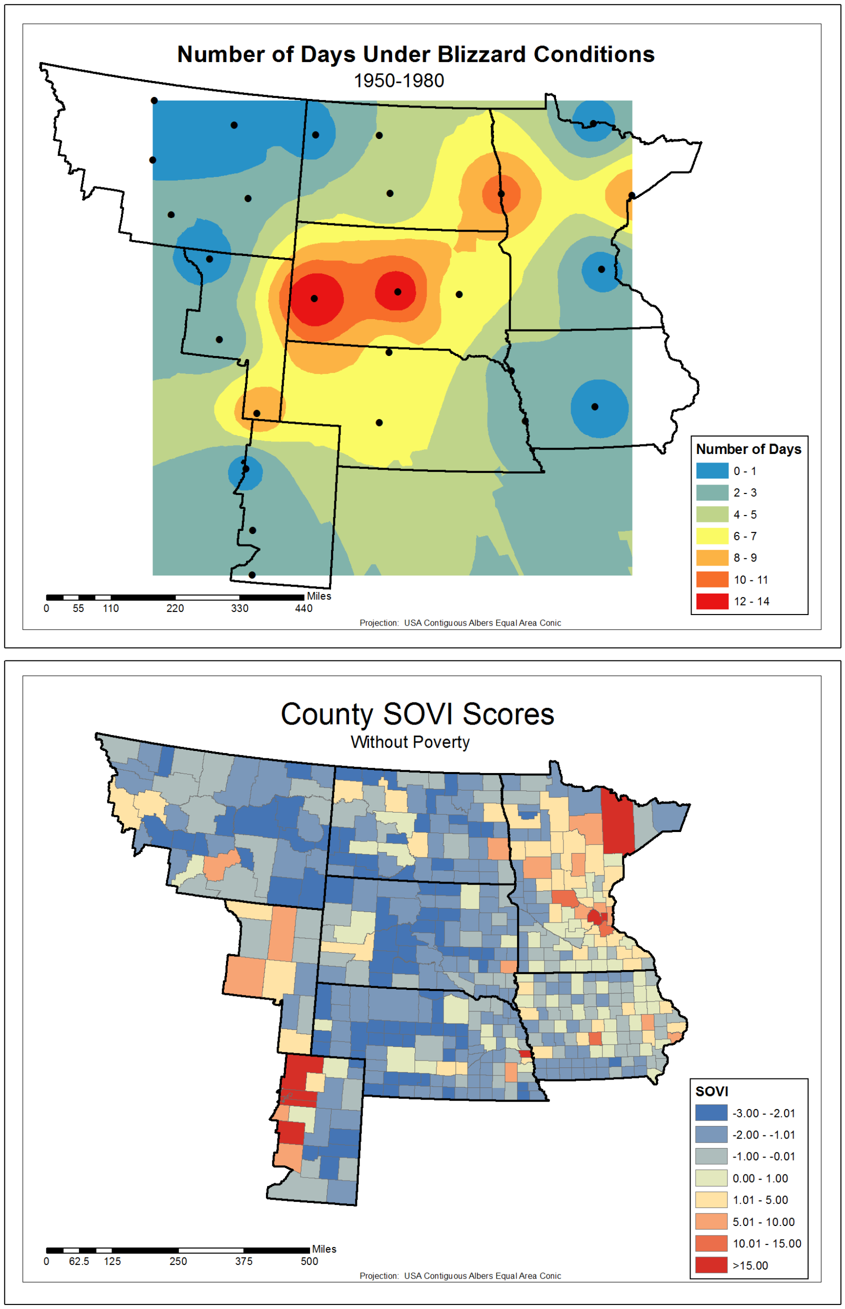
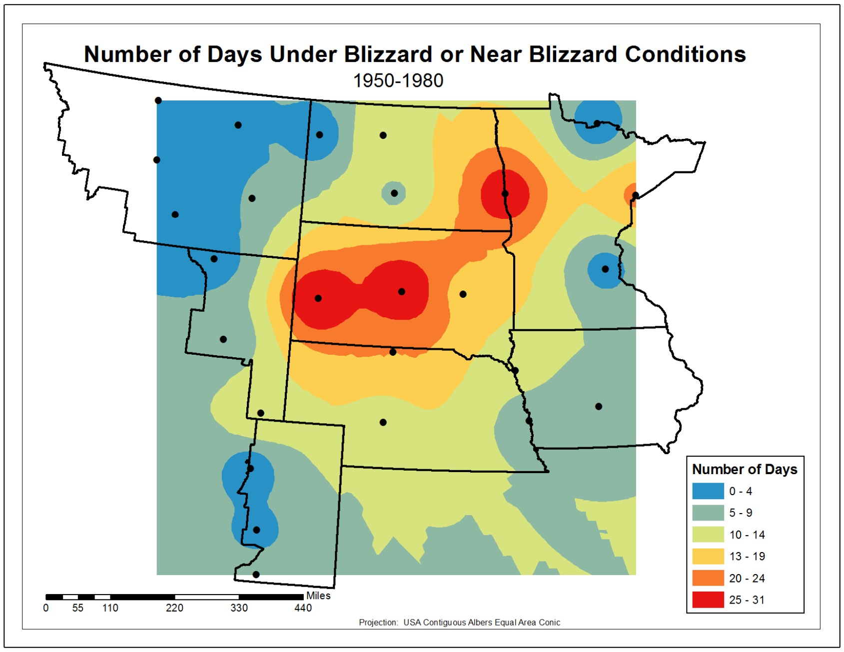


Figure 19: SoVI without Poverty (bottom) versus Blizzard Count 1950-1980 (top). Images previously used individually earlier in this chapter. Dots on the image on the left are locations of the stations used in the analysis.



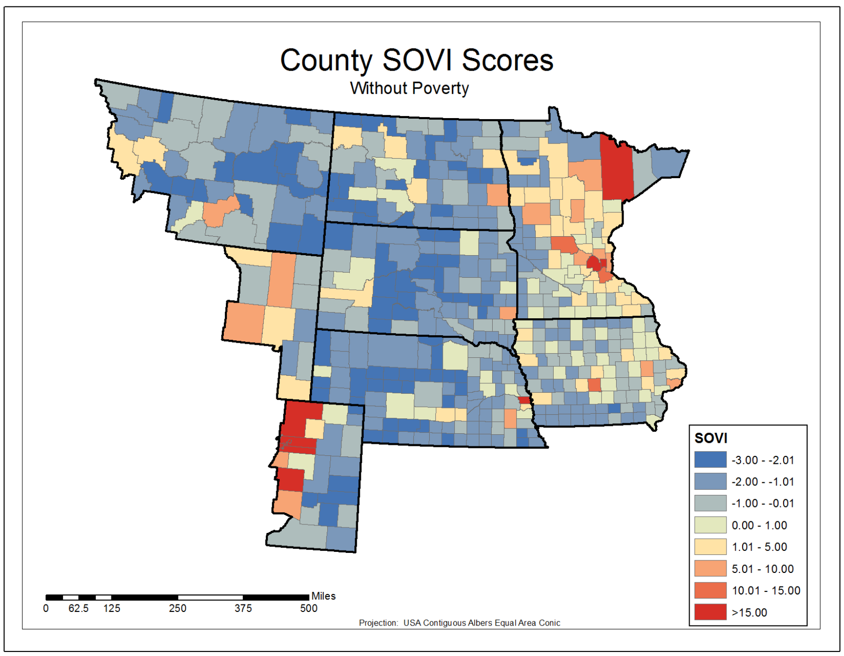


Figure 20: SoVI without Poverty (bottom) versus Blizzard/Near Blizzard Count 1950-1980 (top). Images previously used individually earlier in this chapter. Dots on the image on the left are locations of the stations used in the analysis.

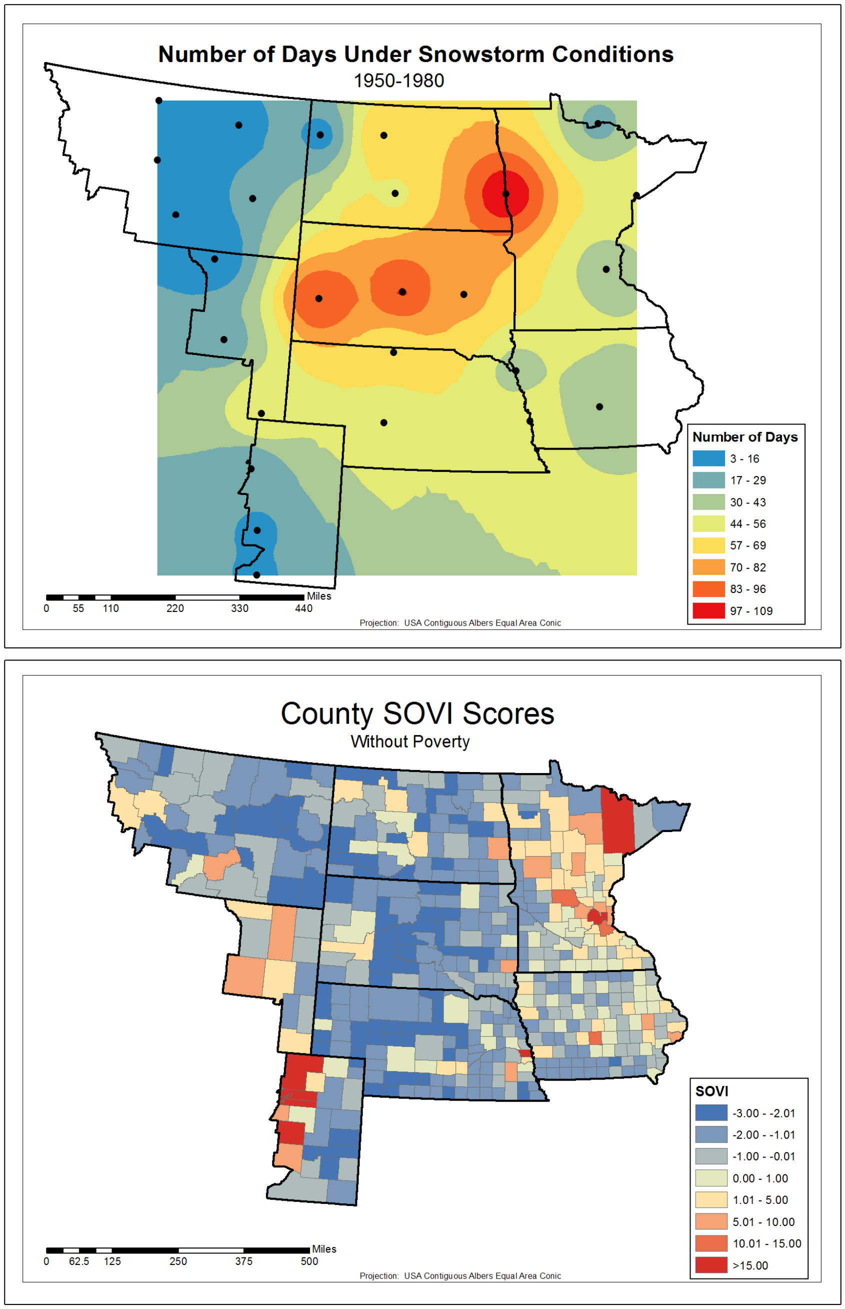


Figure 21: SoVI without Poverty (bottom) versus Total Snowstorm Count 1950-1980 (top). Images previously used individually earlier in this chapter. Dots on the image on the left are locations of the stations used in the analysis.

risk for a severe winter storm exhibit some of the lowest vulnerabilities (or average vulnerability in the case of Rapid City). On the other hand, the areas that show the highest vulnerability coincide with areas that have the lowest risk to severe snowstorms. The exception appeared to be the area of Minnesota in which Duluth and International

Falls are located (the isolated red county in northeastern Minnesota in the images on the bottom of Figures 19-21) which shows a high vulnerability with a moderate risk for severe snowstorms. Reservations, especially Pine Ridge, are usually listed among the poorest places in the United States (Stanley 1978; DeMallie 1978), so it makes sense that they are also some of the most vulnerable since poverty is so highly correlated with vulnerability. It is likely, although further testing would be needed to verify, that the poverty variable is the largest contributor to these results.

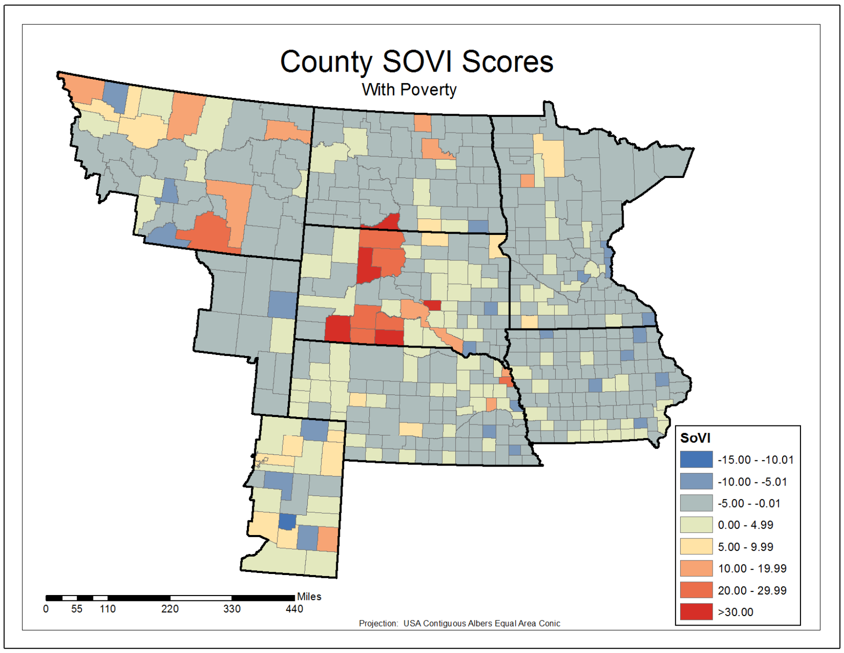


Figure 22: Social Vulnerability Index with Poverty at the county level.

Comparison with the hazard risk identification results showed differing results in the areas of high risk versus areas of high vulnerability than those found in the previous section (Figures 24-26). The high vulnerability areas of South Dakota coincided well with the higher risk areas (red and darker oranges on the image on the top) when looking at the blizzard and overall snowstorm risk (Figures 24 and 26). When looking at the risk for blizzard or near blizzard conditions alone (Figure 25), the area of higher risk in South

Figure 23: Locations of Reservations in Nebraska and the Dakotas. (image obtained from http://www.blm.gov/cadastral/biamaps/biagrplains.htm on 28 March 2013)

Dakota was much broader and encompasses most of the state which also includes the areas of highest vulnerability. The secondary high risk area in eastern North Dakota/western Minnesota, though, was near or below average in the vulnerability scores. Overall, the vulnerability analysis in which poverty was included provided a better match to the risk analysis with the lower risk areas generally coinciding well with the lower vulnerability areas and vice versa.

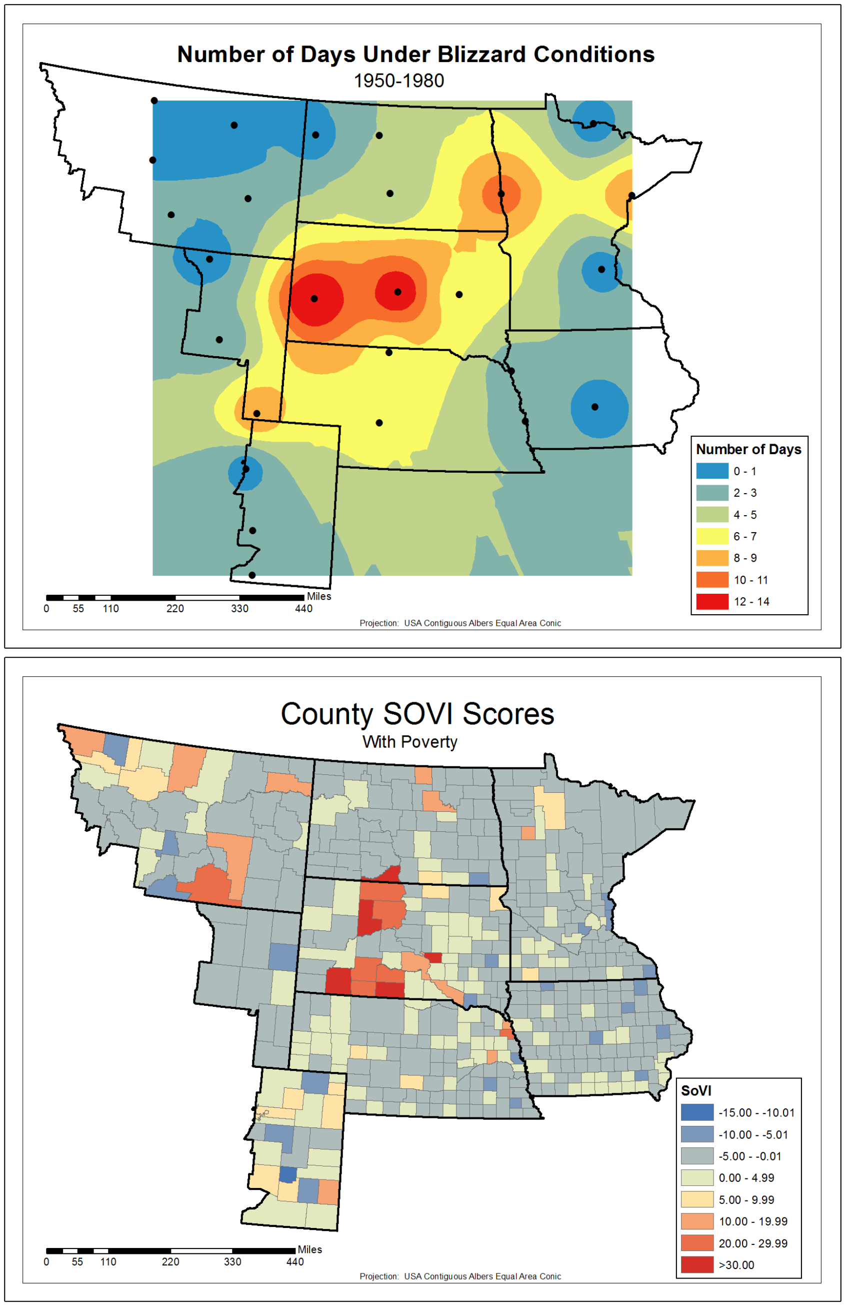


Figure 24: SoVI with Poverty (bottom) versus Blizzard Count 1950-1980 (top). Images previously used individually earlier in this chapter. Dots on the image on the left are locations of the stations used in the analysis.

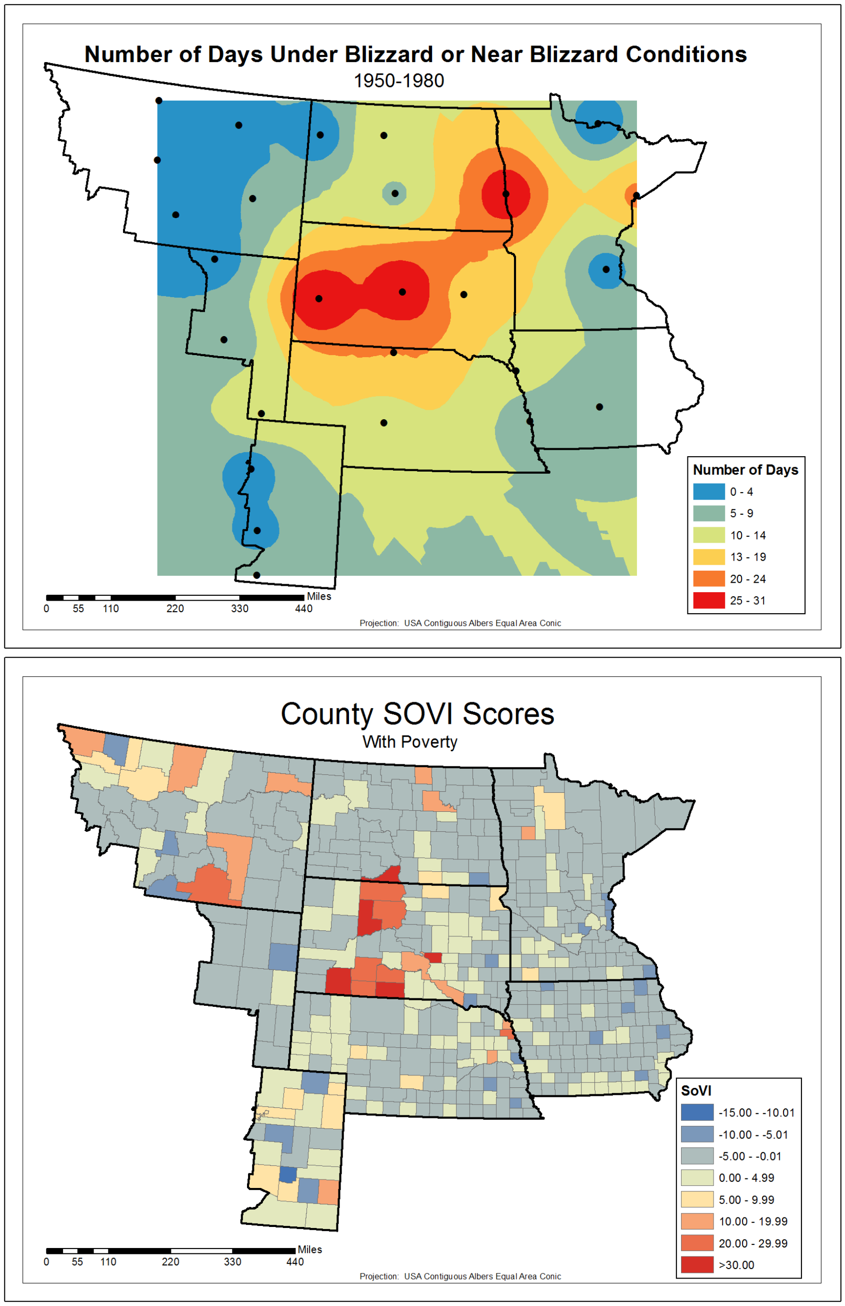


Figure 25: SoVI with Poverty (bottom) versus Blizzard/Near Blizzard Count 1950-1980 (top). Images previously used individually earlier in this chapter. Dots on the image on the left are locations of the stations used in the analysis.

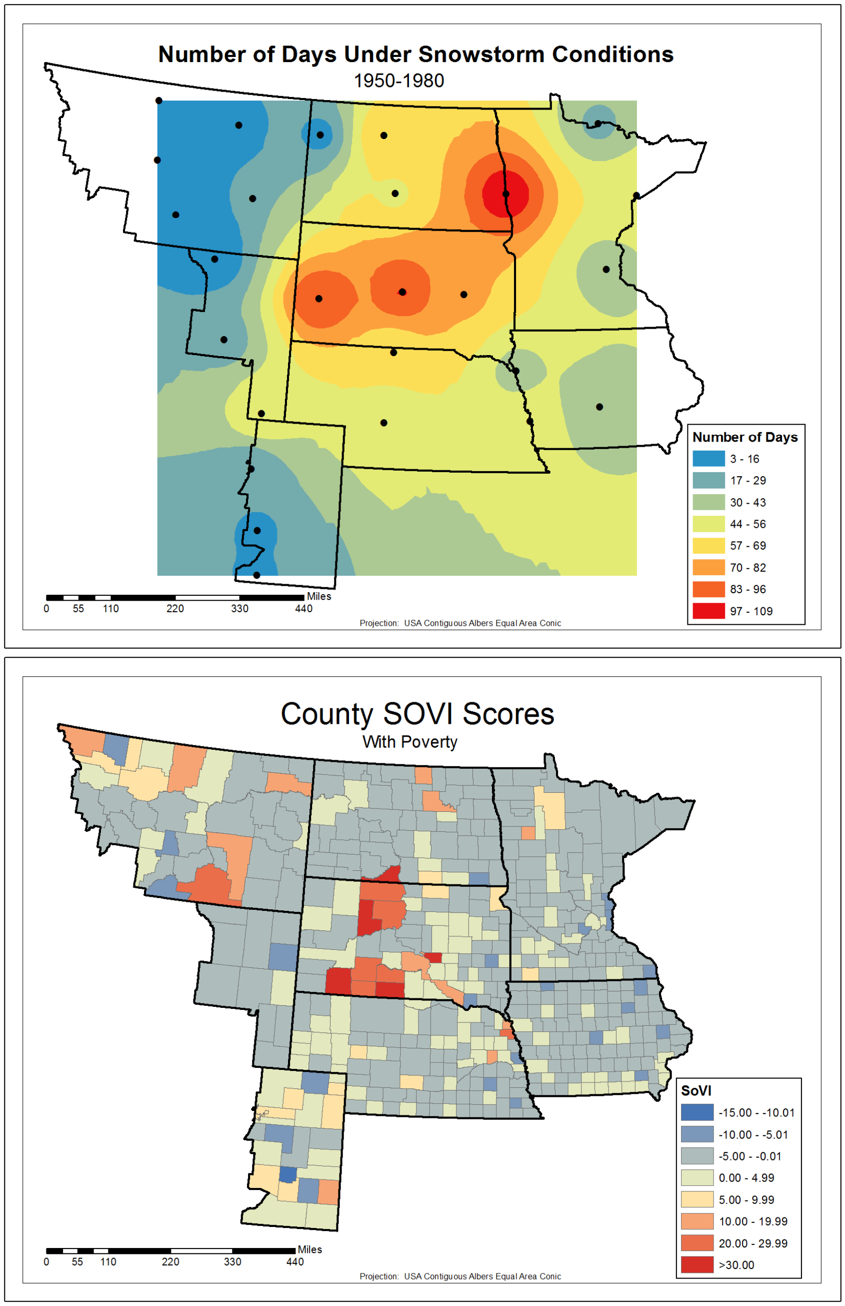


Figure 26: SoVI with Poverty (bottom) versus Total Snowstorm Count 1950-1980 (top). Images previously used individually earlier in this chapter. Dots on the image on the left are locations of the stations used in the analysis

4.2.1.3 Comparison of SoVI with and without Poverty

When looking at the results of the two SoVI scores side-by-side, the images are largely opposites of each other (Figure 27). The Minneapolis area became an area of below average vulnerability with the inclusion of poverty, while Omaha and Denver were

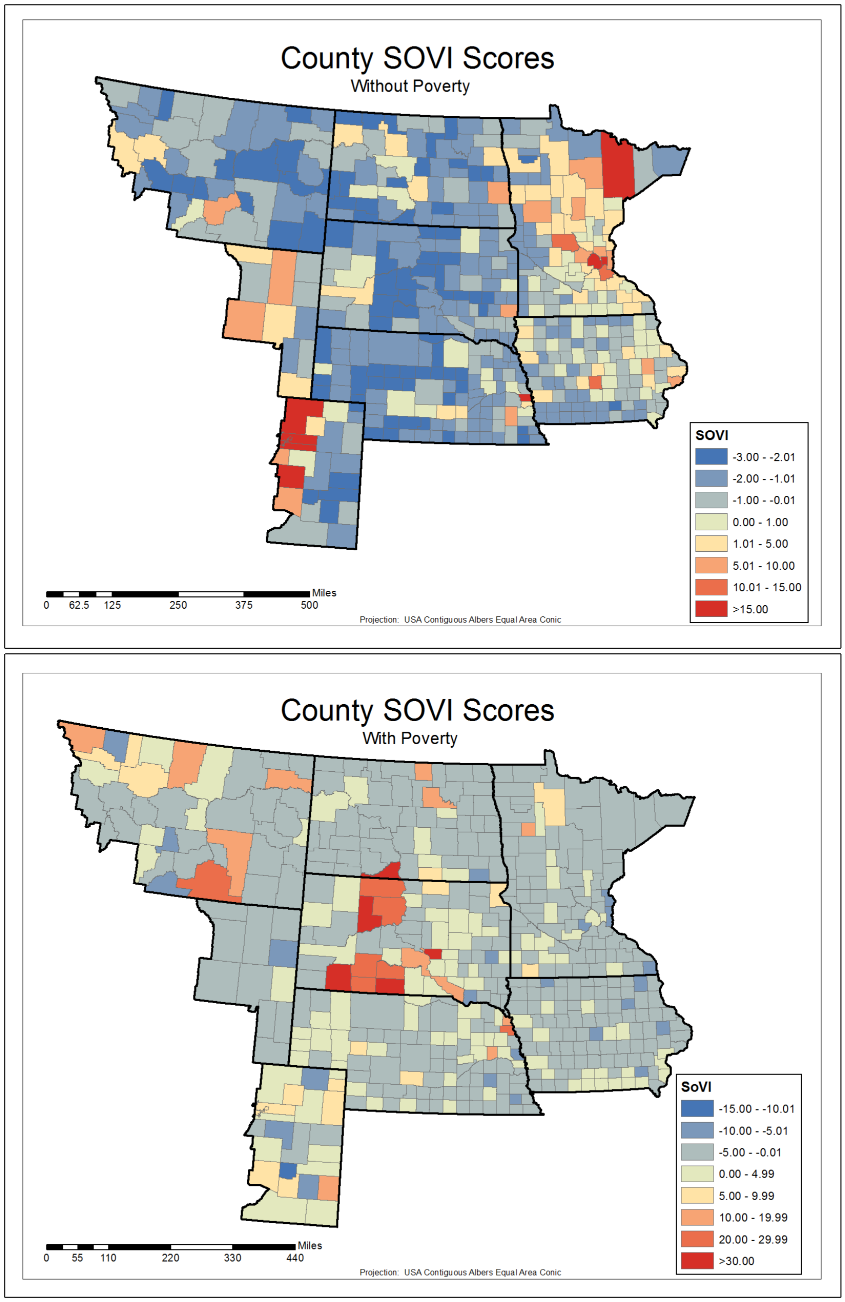


Figure 27: SoVI without Poverty (top) versus SoVI with Poverty (bottom). Images previously used individually earlier in this chapter.

still above average but not as much above as before. Sioux City, near the corner of where Iowa, Nebraska, and South Dakota meet, showed below average vulnerability without poverty included. However, the inclusion of poverty shifted it to one of the areas most above the average. One of the other greatest shifts was directly east of the Black Hills of

South Dakota. Without poverty, this region exhibited below average vulnerability. Once poverty was added, this area made a dramatic shift to exhibit vulnerability scores high above the average. As was mentioned in the previous section, these areas of high vulnerability in the second image (Figure 27, bottom image) are regions in which Native American reservations can be found which are usually found to be some of the poorest areas in the country (Stanley 1978; DeMallie 1978). The previous section also showed that the inclusion of poverty created a much better connection between the high risk and high vulnerability areas of the region.

<u>4.2.2 Pattern Analysis</u>

With the SoVI scores calculated, an analysis was conducted to determine if there was a significant pattern to the scores. Moran's I was done at both a global and local level with positive values indicative of some clustering in the SoVI results. Moran's I was chosen as the method for pattern analysis because it is a commonly used statistic in testing for patterns in spatial data (Burt, Barber, and Rigby 2009). The Local I test was used over another common test, the G-statistic, because it compares the value of the county to all of its neighbors to determine if it is similar or dissimilar that the surroundings. The G-statistic, on the other hand, compares the surrounding counties to each other while excluding the county of interest. This could, in some cases, produce a positive value where the Local I would produce a negative value making the I statistic easier to interpret (Burt, Barber, and Rigby 2009)

<u>*4.2.2.1 Global Moran's I*</u>

Moran's I was calculated for both the SoVI scores with and without poverty. Global I falls within a range of -1 to +1, and it is interpreted the same way as a correlation statistic (i.e. the closer the value to -1 or +1, the stronger the relationship/pattern) and provides a result on the spatial pattern of the entire study area with one value (Burt, Barber, and Rigby 2009). For the SoVI scores that did not include poverty data, the Global I was 0.3122 with a significance (p-value) of 0.00. This indicates significant moderate clustering of like values throughout the study area. With the poverty data included, the value of Moran's I drops to 0.2473 while the p-value increases slightly to 3.129×10^{-11}. Moderate clustering of like values is shown with this value as well. This clustering is still significant but slightly less significant than that without poverty. Because the difference in these results is so small, it does not appear that the inclusion of poverty is necessary or will change the results in a significant manner.

4.2.2.2 Local Moran's I

In order to discern the local clustering pattern, local Moran's I was calculated for each county (Figure 28). As was seen with the SoVI scores, the range of values was larger when the poverty data are included in the calculations (Figure 28, bottom image). Positive values of this statistic mean the county is surrounded by similar values whereas negative values mean the county is surrounded by dissimilar values. Local I values show the strength of that clustering, so larger values of I indicate a clustering of very similar SoVI scores. When looking at the two maps showing the SoVI scores both with and without poverty (Figure 27), it can be seen that there is some clustering of like values being exhibited as the majority of counties in both images were above zero.

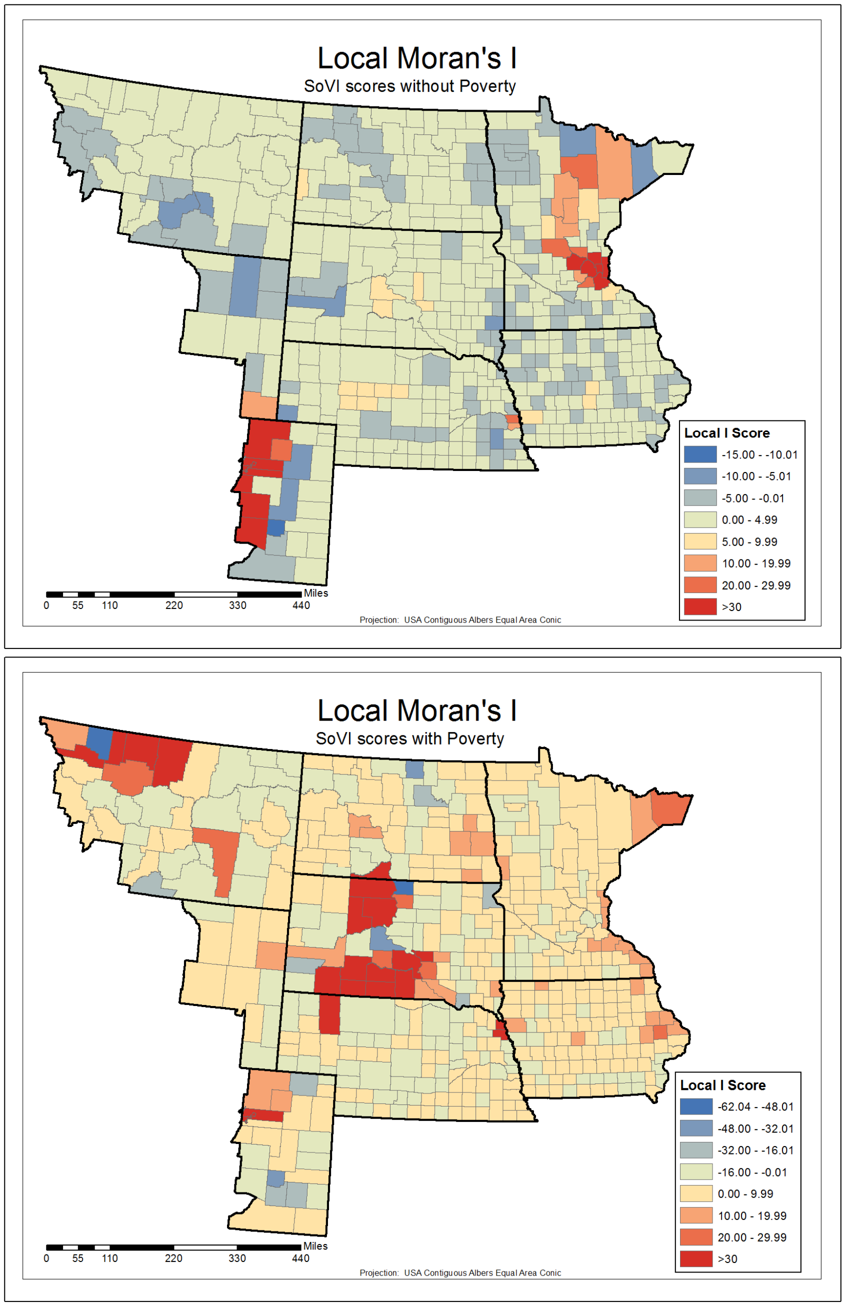


Figure 28: Local Moran's I without Poverty (top image) versus Local Moran's I with Poverty (bottom image)

Without poverty (Figure 28, top image), the strongest clustering can be found in eastern Colorado which includes the Denver metropolitan area, eastern Nebraska around the Omaha metropolitan area, and south central Minnesota around the Minneapolis-St. Paul metropolitan area. The areas around Billings, MT; Sheridan, WY; Rapid City, SD;

Pueblo, CO; and Lincoln, NE show the highest values on the negative side of the scale indicating that these areas have SoVI scores that differ from those of the surrounding counties. Looking back at the actual scores (Figure 18), the respective counties for each of these cities registered with above average vulnerability while the counties around them showed below average vulnerability.

When poverty is added (Figure 28, bottom image), the strongest clustering was found in central South Dakota, the Denver metropolitan area, and northern Montana. This follows with the change in pattern seen in the map of the SoVI scores in which the most vulnerable counties were now found in South Dakota instead of around the major metropolitan areas of Minnesota, Colorado, and Nebraska. As is expected, the isolated counties of high/low SoVI scores (see Figures 18 and 22) are among the most negative Local I scores (i.e. northwestern Montana, north central South Dakota, north central North Dakota).

In both maps, most of the study area exhibited positive values of the Local I statistic. The results of these two pattern analyses suggest that counties with above average vulnerability are more likely to be surrounded by other counties with some degree of above average vulnerability than by those with below average vulnerability. A summary of the results presented in this chapter as well as possible future research avenues and the limitations of the study can be found in the final chapter.

CHAPTER V

SUMMARY, LIMITATIONS, AND THE FUTURE

5.1 Summary of Results

5.1.1 Hazard Identification

An analysis of the number of days under certain snowstorm conditions from 1950-1980 showed a common area of high risk in the northern Great Plains. For blizzard, blizzard/near blizzard, and all snowstorm conditions, western South Dakota was found to be at the highest risk. The spatial expanse for the blizzard/near blizzard risk was the largest of the three categories. An area of eastern North Dakota/western Minnesota was also found to be at high risk for blizzard/near blizzard or overall snowstorm conditions. When looking at blizzard conditions only, this area had a moderately high risk but not as high as in western and central South Dakota. With this area being in the typical path of an Alberta Clipper (cold temperatures, strong winds, and light snow with smaller bands of intense snowfall), it is not unexpected to find these areas under such a high risk for blizzard or snowstorm conditions.

Decadally, each classification category shows relatively high activity during the 1950s before quieting down in the 1960s and 1970s. Blizzard conditions were the least common overall with just 14 days total from 1950 to 1980 in the peak area of South Dakota. More than half of these days occurred in the 1950s with the remaining days split between the next two decades. On a decadal scale, the high risk area for blizzard shifted from South Dakota into southeastern Wyoming by the 1970s. For the blizzard/near blizzard conditions, the 1950s were again the most active decade with 2 areas of peak activity with a third on the far eastern edge of the study area near Duluth. Moving into the 1960s, the high risk area near Fargo disappeared and the area in South Dakota shifted into the central part of the state. By the 1970s, the high risk in South Dakota was gone with a small area of high risk once again appearing near Fargo.

With all possible snowstorm conditions considered, it was once again the 1950s which saw the majority of the activity in the high risk areas with approximately half of the 109 days (54 days) occurring. The largest high risk was found in eastern North Dakota with a small area of high risk around Pierre, South Dakota. During the 1960s, the high risk area had shifted to west central South Dakota around Rapid City while the risk in eastern North Dakota decreased. The 1970s saw the highest risk once again centered around Fargo, although the area was much smaller than during the 1950s. When looking at the average wind chill during these conditions, the typical latitudinal pattern was seen with the temperatures becoming colder with increased latitude. The two areas of highest risk also experienced an average wind chill below zero during these storms.

The answer to the first research question posed in Chapter 1 (Which areas are most at risk?) would appear to be western South Dakota and eastern North Dakota into western Minnesota are the areas most at risk.

5.1.2 Vulnerability Analysis

The vulnerability analysis calculated SoVI scores both with and without poverty. When poverty was not considered, the areas of highest vulnerability were the major metropolitan areas such as Denver, Omaha, and Minneapolis with the areas of lowest vulnerability mainly found in the Dakotas and Montana. One possible explanation of this is the higher rates of renting that are typically found in larger cities (Majur and Wilson 2011) and with the younger and older populations (JCHS 2011), although further analysis is needed to test this hypothesis.

Once poverty was included, the vulnerability rates of these areas changed. The metropolitan areas that were high vulnerability areas were now at or below average while the low vulnerability areas of South Dakota and southern North Dakota were now the areas of highest vulnerability. As mentioned in Chapter 4, these areas of the Dakotas are where many Native American reservations can be found. These reservations are commonly listed as some of the poorest areas of the country (Stanley 1978; DeMallie 1978).

This analysis provided the second research question listed in Chapter 1 (Which areas are the most vulnerable?) with two different answers: if poverty is not taken into account, the larger cities are the most vulnerable but central South Dakota is the most vulnerable when poverty is included in the analysis. A logical explanation for this pattern was not able to be determined. Further analysis is required in order to determine which variables were most likely influencing these results.

The third research question (Is there a significant pattern to the vulnerability?) can be answered with the results of the Moran's I analyses. The values of the Global

Moran's I calculations showed a moderate amount of clustering in both sets of the county SoVI scores. A test of the significance of both scores produced significance values (p-values) near zero indicating that the values are indeed significant. This also seems to suggest that the inclusion of poverty does not change the results. The same results were provided through the Local Moran's I analyses which showed most of the study area with positive scores (positive values indicating that a county is surrounded by similar values, the higher the score the more alike the surrounding values are shown to be).

The fourth research question (Do the high risk and high vulnerability areas coincide?) also has two answers, depending on which set of SoVI scores are used. When comparing the SoVI scores that did not include poverty to the three different risk categories, the areas of high risk were found to coincide mostly with the areas of lowest vulnerability while the high vulnerable areas were found to coincide with the lower risk. This would suggest that the northern Great Plains does not exhibit much vulnerability to a severe snowstorm or blizzard.

The results of the vulnerability analysis that did include poverty appeared to match closely to the results of the hazard analysis. With the exception of eastern North Dakota, the areas of highest vulnerability were found to coincide with the areas of higher risk and vice versa. In South Dakota, the Black Hills region was found within the high risk area on all the hazard categories as well as the high vulnerability area. As was already mentioned, Fargo North Dakota is the exception. Although shown to be at a high risk for a severe snowstorm, this area showed a below average vulnerability. When poverty was considered, the northern Great Plains appeared to be highly vulnerable to a severe winter storm event as the high risk areas overlapped with the high vulnerability areas.

The literature discussion in Chapter 2 demonstrated that little attention has been given to the northern Great Plains in the analysis of snow hazards in the United States. It was also shown that few of the studies linking vulnerability to weather included cold season weather events. Much of the literature in this category emphasized vulnerability to hurricanes, flooding, and earthquakes and showed that poverty and vulnerability are closely linked. The results of this vulnerability analysis verify some of the previous research in vulnerability by showing that the highly vulnerable areas of the Great Plains were regions in which poverty is seen as a common problem. By focusing on this vulnerability and how it relates to severe winter weather, this research adds a component to both the vulnerability literature and weather hazard literature

5.2 Limitations of the Study

There were some limitations to this research. Many obstacles/limitations occurred with the hazard identification. With the hazard analysis, the main obstacle/limitation was the time frame of overlapping data available. Data after 1980 were not used because one of the sources was only published from 1950-1980 (U.S. Weather Bureau National Climatological Data National Summary: 1950-1980). Another limitation with the weather data was trying to find winter storms that did not also include icing events. If icing does occur, it can cause a risk of its own. Icing bands within snowstorms, though, are usually not as frequent or widespread in this part of the country. The first-order stations used in this study may not, then, experience the events, so this was not a major limitation.

Looking at the data provided in the tables in Appendix 2, another limitation can be seen. After 1959, some of the stations reported on the daily weather map series changed in Montana, Wyoming, and North Dakota. Because of a lack of space, some data and observation stations were not used on the published maps (the exact number of stations omitted is not known) which limited the data available for use in this study. Finally, the time of observations shown on each daily weather map changed in 1958 and then again in April 1968. In the years prior to 1958, the maps were created using observations at 12:30am Central Standard Time. From 1958 through April 1968, the time was pushed back to midnight. The time of observation was then changed to 6:00am in April 1968. A minor problem was that a few of the maps of the 1970s obtained from the NOAA Daily Weather Map Series were blurry and hard read so some storm locations could have been missed under both of these limitations (ease of reading and time changes).

The final issue with the hazard identification was the criteria used to choose the storms and conduct the analysis. While choosing storms that fit the AMS definition of blizzard may be considered valid criteria, others may opt for a different way. These other options may include criteria such as only using those that affected the most people, using those that impacted the largest area, or using those that are considered to be "typical" storms for the region. The inclusion of the months outside of the climatological winter (December-February) is done to try to account for all possible severe snowstorms or blizzards in the area. People could argue that only those within the season are important because this is when they are more likely to happen. Others could say that only the off-season storms should be counted because these are the storms most likely to catch people off guard. Different choices in the criteria may lead to changes in the final results.

The social vulnerability analysis had limitations as well. The spatial resolution of the data available for use in the research, even at the smallest level, contains the risk that deeper trends in the data are getting masked and possibly oversimplifying the issue. Household level data would be optimal, but the collection of that data would be extremely time-consuming and costly (Uitto 1998; Stephen and Downing 2001).

Another limitation is the variables available for use. There are some indicators/factors that could affect a region's vulnerability that are either not recorded or are not easily obtained or quantified such as church membership, type of heat/energy used, human behavior/reaction to the warnings, impact on the homeless, average warning lead times, and average time to restore power. Variables are often treated as being of equal importance in their role in creating vulnerability, but that is likely not the case. Unfortunately, it is difficult to accurately ascertain the proper weights that would be needed to design a more accurate vulnerability analysis.

5.3 Future Research Possibilities

With this research, there are many possible avenues to take to provide more insight into the data/results. The study period could be expanded using the daily weather map series to include the years from 1981 through the present or to include the entire period of record in order to obtain a more robust hazard identification. Data from NWS or NCDC could also be incorporated to fill in the gaps left by the daily weather maps series. The data could also be broken down into monthly storm counts to see when these storms are most likely to occur. A division into winter months versus non-winter months is also possible to determine if these events are more likely to happen outside of or during climatological winter (December – January).

Expansion of the vulnerability analysis is planned for future dissertation research, focusing on the area found to have the highest social vulnerability. This expansion would include interviews with emergency managers, policy makers, political leaders, and tribal leaders (as the highest risk area is home to many Native American reservations) to identify plans in place and actions taken when certain thresholds are met (i.e. how far in advance from a warned storm are the salt trucks, maintainers, and snow plows deployed? Does this change with the predicted severity of the storm? What sort of relief effort, if any, is in place for those hardest hit?). Interviews with citizens living in the area would also be conducted to see what plans, if any, they have if a severe snowstorm were to be forecast for the area. Another possibility for this future research would be to see if it is possible to determine appropriate weights for each of the socioeconomic variables to better estimate the vulnerability of the area. Regression analysis and factor analysis would be needed to determine which variables have the strongest influence on the vulnerability results. The goals of future research would be to work with policy makers and tribal leaders to improve mitigation and response plans in an attempt to lessen their vulnerability to a disaster by knowing where the vulnerable people are and what is creating this vulnerability.

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APPENDICES

Appendix 1: Acronyms

AAG: Association of American Geographers
AMS: American Meteorological Society
COOP: NWS Cooperative Observer Network
FEMA: Federal Emergency Management Agency
GIS: Geographic Information Systems
IDW: Inverse Distance Weighted
JCHS: Joint Center for Housing Studies
LWSS: Local Winter Storm Scale
NCAR: National Center for Atmospheric Research
NCDC: National Climatic Data Center
NCEP: National Center for Environmental Prediction
NESIS: Northeast Snowstorm Impact Scale
NOAA: National Oceanic and Atmospheric Administration
NWS: National Weather Service
PAR: Pressure and Release
ReSIS: Regional Snowfall Impact Scale
RSI: Regional Snowfall Index
SHELDUS: Spatial Hazard Event and Loss Database for the United States
SoVI: Social Vulnerability Index
SSWIM: Social Science Woven into Meteorology
USSS: United States Signal Service
WAS*IS: Weather and Society*Integrated Studies

Appendix 2: Station Storm Counts

2.1: Number of Days under Blizzard Conditions for Each Time Period

Station	1950-1959	1960-1969	1970-1980	1950-1980
Miles City	0	0	0	0
Billings	1	0	0	1
Glasgow	0	--	--	0
Havre	0	--	--	0
Lewiston	--	0	1	1
Sheridan	0	--	--	0
Casper	1	0	0	1
Cheyenne	3	1	5	9
Denver	0	0	0	0
Trinidad	2	0	0	2
Pueblo	0	1	0	1
Valentine	1	3	2	6
North Platte	2	1	2	5
Omaha	1	0	1	2
Huron	1	3	2	6
Pierre	9	3	1	13
Rapid City	7	4	3	14
Williston	0	--	--	0
Bismarck	2	0	1	3
Fargo	4	3	3	10
Minot	3	0	0	3
Minneapolis	0	0	0	0
International Falls	0	0	0	0
Duluth	7	1	1	9
Sioux City	0	1	1	2
Des Moines	0	0	0	0

Dashes used to indicate data not available for that station during the time period

2.2: Number of Days under Blizzard or Near Blizzard Conditions for Each Time Period

Station	1950-1959	1960-1969	1970-1980	1950-1980
Miles City	2	3	1	6
Billings	1	0	0	1
Glasgow	3	--	--	3
Havre	0	--	--	0
Lewiston	--	0	2	2
Sheridan	1	--	--	1
Casper	2	0	2	4
Cheyenne	6	3	6	15
Denver	0	1	0	1
Trinidad	3	2	0	5
Pueblo	1	2	0	3
Valentine	10	6	3	19
North Platte	7	2	2	11
Omaha	2	2	2	6
Huron	6	9	3	18
Pierre	17	9	6	31
Rapid City	17	7	6	31
Williston	1	--	--	1
Bismarck	4	3	1	8
Fargo	13	5	10	28
Minot	12	0	2	14
Minneapolis	2	0	0	2
International Falls	1	0	0	1
Duluth	13	2	4	20
Sioux City	2	5	3	10
Des Moines	3	0	1	4

* ***Dashes used to indicate data not available for that station during the time period***

2.3: Number of Days under All Snowstorm Conditions for Each Time Period

Station	1950-1959	1960-1969	1970-1980	1950-1980
Miles City	16	7	12	35
Billings	6	0	5	11
Glasgow	11	--	--	11
Havre	4	--	--	4
Lewiston	--	1	5	7
Sheridan	3	--	--	3
Casper	11	3	6	20
Cheyenne	22	20	20	62
Denver	10	1	3	14
Trinidad	7	5	2	14
Pueblo	4	7	2	13
Valentine	28	17	12	57
North Platte	24	10	13	47
Omaha	24	14	13	51
Huron	36	17	19	72
Pierre	48	28	22	97
Rapid City	42	34	25	102
Williston	11	--	--	11
Bismarck	27	15	12	54
Fargo	54	25	30	109
Minot	37	18	15	70
Minneapolis	22	3	9	34
International Falls	16	4	5	25
Duluth	35	5	14	55
Sioux City	16	13	8	37
Des Moines	21	3	6	30

* ***Dashes used to indicate data not available for that station during the time period***

Appendix 3: Wind Chill Averages 1950-1980

***wind chills rounded to 2 decimal places, units is ^{o}F*

Station	**Wind Chill**	**Station**	**Wind Chill**
Miles City	-8.27	Omaha	2.85
Billings	1.49	Huron	-0.19
Glasgow	-9.49	Pierre	-2.84
Havre	-7.25	Rapid City	-0.33
Lewiston	-3.79	Williston	-2.74
Sheridan	0.18	Bismarck	-8.05
Casper	1.75	Fargo	-10.47
Cheyenne	2.16	Minot	-9.22
Denver	10.58	Minneapolis	3.95
Trinidad	6.60	International Falls	-2.30
Pueblo	5.62	Duluth	3.94
Valentine	-1.77	Sioux City	4.84
North Platte	3.64	Des Moines	3.43

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