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Relationship between air mass type and emergency department visits for different forms of pain across North Carolina and assessing the potential for weather-based pain forecasts

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Relationship between air mass type and emergency department visits for different

forms of pain across North Carolina and assessing the potential for weather-based

pain forecasts

By

Christopher J. Elcik

A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Earth and Atmospheric Sciences
in the Department of Geosciences

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2019

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Many people around the world are impacted by some form of bodily pain. Outside factors are thought to help trigger pain, especially in those who have pain-related conditions. When it comes to human health and comfort, understanding the potential external factors that aide in triggering pain is essential. Identifying such factors makes prevention and treatment of pain more feasible.

The first part of this study identified how those who suffer from various pain-related conditions (fibromyalgia, rheumatoid arthritis, osteoarthritis, and general back pain) are impacted by different air mass types. Air mass types and emergency department (ED) visits for pain in select North Carolina counties were collected over a seven-year period to determine a potential relationship. Bootstrapping analyses revealed that Moist Tropical air masses resulted in the highest number of ED visits for all pain conditions examined, while Moist Polar air masses resulted in the fewest. The barometric pressure changes associated with Transitional air masses did not have any significant relationships with pain.

The second part of this study sought to determine if regional geographic characteristics impact the relationships found in first part of this study. North Carolina was separated into three

geographic sections: Appalachian Mountains, Piedmont Plateau, and Coastal Plain. In the Plateau region, Moist Tropical and Moist Moderate air masses were frequently associated with the highest rates of ED visits for all the conditions examined, while Polar air masses were often associated with the fewest visits. Several conditions exhibited similar relationships with these air mass types in the Mountains, with migraine and fibromyalgia being the exceptions. Very few statistically significant relationships were found in the Coastal region.

The last part of this study utilized a survey to identify impacts of weather-based migraine/pain forecasts on human behavior. When provided with different scenarios involving weather-based migraine/pain forecasts, the respondents' decision-making processes were altered. When a hypothetical forecast indicated that the weather was conducive to migraines or other types of pain, many respondents indicated that they would likely take preventative measures (e.g. medication). Additionally, as forecast severity or activity length increased, respondents were less likely to continue with a planned activity.

DEDICATION

I would like to dedicate this research to my grandmother, Edna Grap, whose love and unwavering support has helped me accomplish my dream of becoming a meteorologist.

ACKNOWLEDGEMENTS

I would like to express my thanks to Dr. Christopher Fuhrmann, who has served as my advisor over the past five years throughout both my masters and doctorate studies. Without his guidance and expertise this research would not have been possible. I would also like to thank my committee members, Dr. Andrew Mercer, Dr. Kathleen Sherman-Morris, and Dr. Scott Sheridan, for their contributions to this project. Lastly, I would like to thank my family and friends for their help and constant support.

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CHAPTER I

RELATIONSHIP BETWEEN AIR MASS TYPE AND EMERGENCY DEPARTMENT

VISITS FOR DIFFERENT TYPES OF PAIN ACROSS THE TRIANGLE REGION OF

NORTH CAROLINA

1.1 Introduction

Pain can be experienced in many parts of the body including a person's joints, muscles, and even organs. Millions of people around the world suffer from some form of pain. In fact, in the United States alone, 45 million people each year seek medical attention for cerebral pain (Jefferson University Alumni, 2015). Fibromyalgia and Arthritis are two of the more common types of conditions that lead to pain in the body.

Fibromyalgia is a chronic neurological health condition, from overactive nerves, that results in pain being felt all over the body. This pain "waxes" and "wanes" from day to day (National Fibromyalgia & Chronic Pain Association, 2018). While pain is the main symptom, other common symptoms that can be experienced include: tenderness to touch, severe fatigue, sleep problems, and problems with memory. Fibromyalgia affects approximately 2-4% of the world's population (American College of Rheumatology, 2017). People of all ages can have this condition, but women, with a ratio of 8 to 2, are more likely than men to suffer from fibromyalgia. While there is currently no cure for fibromyalgia, multi-disciplinary approaches for management and relief of symptoms are often recommended. Medications, cognitive

behavioral therapies, and gentle exercises are all used to repress symptoms (National Fibromyalgia & Chronic Pain Association, 2018).

Arthritis is the inflammation of one or more of a person's joints. The main symptoms of arthritis include pain and stiffness. Unlike fibromyalgia, arthritis pain and stiffness is often localized around the joints. There are multiple types of arthritis, each affecting the joints in the body in slightly different ways. Osteoarthritis and rheumatoid arthritis are considered the two main types of arthritis.

Osteoarthritis (OA) commonly affects the elderly population. In fact, OA is often cited as being one of the top causes of disability in the oldest age brackets. This type of arthritis involves the wear-and-tear damage to the joint's cartilage, which is the slick padding on the ends of bones that is important for movement. If enough damage is done to the joint's cartilage it can result in bone grinding directly on bone, leading to pain and restricted movement. The wear-and-tear associated with OA can occur over many years, or it can be the result of a joint injury or infection. OA tends to occur in joints of the hands, spine, hips, knees, and great toes. The American College of Rheumatology states that, "the lifetime risk of developing OA of the knee is about 46%, and the lifetime risk of developing OA of the hip is 25%, according to the Johnston County Osteoarthritis Project, a long-term study from the University of North Carolina and sponsored by the Centers for Disease Control and Prevention (often called the CDC) and the National Institutes of Health" (The American College of Rheumatology, 2017).

Rheumatoid arthritis (RA) is one of the most disabling types of arthritis. It is also one of the most common types, affecting more than 1.3 million Americans, with about 75% being women. It is estimated that between 1-3% of women will suffer from RA in their lifetime (The American College of Rheumatology, 2017). RA is an autoimmune disease. The immune system

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is supposed to attack bacteria and viruses, by creating inflammation. A person suffering from RA will have an immune system that incorrectly sends inflammation to healthy tissue. This inflammation leads to joint pain and swelling. If the inflammation remains present for a long period of time, it can cause damage to the joint. This damage typically cannot be reversed (The American College of Rheumatology, 2017).

Because of the disabling nature of these various pain-related conditions, a person's routine can be drastically impacted. Due to the number of people suffering from these conditions, the associated economic strain is estimated to be quite large. The age of these sufferers also contributes to the high economic costs. Approximately two-thirds of adults in the United States with arthritis are between the ages of 18-64, which is considered "working age" (Arthritis Foundation, 2018). Missed work days and decreased productivity have negative impacts on the economy. In the United Kingdom, more than 25 million working days each year are lost due to OA and RA, making arthritis one of the nation's biggest causes of sick leave (Arthritis Research UK, 2018). In addition to work days missed, these conditions also remove talent from the workforce, with roughly 25% of arthritis sufferers leaving the workforce or retiring earlier than expected (Arthritis Research UK, 2018).

Those who suffer from rheumatoid or other pain-inducing conditions often report "flare-ups" or "flares." A flare is a period of increased disease activity or worsening symptoms. Due to the disabling nature and economic costs associated with these conditions, it is important to understand what outside factors trigger symptoms or lead to flares. Identifying these potential triggers is important because it allows individuals to avoid such conditions and take preventative measures (e.g. medication). Many different triggers are thought to cause the onset of flares. For fibromyalgia patients, commonly reported triggers include: stress, weather, hormonal changes,

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traveling and/or changes in schedule, changes in treatment, diet, and poor sleep. Arthritis patients report some similar triggers: stress, weather, bacterial infections, and certain medications. Interestingly, in both cases, patients identify weather as a factor when it comes to flare-ups.

Weather may be defined as "the meteorological day-to-day variations of the atmosphere and their effects on life and human activity" (NOAA, 2014). Human health in particular has been known to be impacted by weather. This fact has led to the development of the field of Biometeorology, which is an interdisciplinary science that focuses on the numerous relationships between weather and health. When it comes to pain-related conditions, research has been conducted to determine how weather influences the onset of symptoms (i.e. pain). Much of this research has focused on individual weather variables (e.g. barometric pressure) and their effect on pain frequency; however, the results have been generally inconclusive and, in some cases, contradictory. Other studies have successfully identified statistically significant relationships between specific weather patterns and pain frequency. This makes physical sense, as humans and other elements of the biosphere do not necessarily respond to single weather variables, but rather, respond to multiple variables acting synergistically. The author's previous work, Elcik et al. (2017), examined the relationship between emergency department (ED) visits for head pain (migraine) and air mass type in the Triangle region of North Carolina (Orange, Durham, and Wake counties) from 2007-2013. The results of this work supported those of previous studies that examined large-scale weather "patterns" rather than individual weather variables. This type of approach, known as the synoptic or air mass approach, has been utilized in numerous environmental and human health studies (Hondula et al. 2014); however, to the author's knowledge, it has not been applied to forms of pain other than migraines. Therefore, the goal of

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this research is to determine if air mass types are a trigger for flares in those who suffer from a broader range of pain-related conditions.

Air masses can be conceptualized as large volumes of air that occupy a particular location at any given time. The National Oceanic and Atmospheric Administration (NOAA) formally defines an air mass as "a large body of air that has similar horizontal temperature and moisture characteristics" (NOAA, 2014). Therefore, at any instant a location's air mass type can be determined based on observations of temperature and humidity. Each type of air mass has distinct weather conditions associated with it, which are acquired from source regions. For an air mass to form, air has to sit relatively stagnant over land or ocean surfaces that have uniform temperature and moisture characteristics. Over time the air will begin to take on the characteristics of the surface over which it resides. Once an air mass is formed it can be advected horizontally over new areas. As an air mass moves, its characteristics change slightly, but the identity of its source region remains.

Adoption of the synoptic approach in research involves classification of the atmospheric state. While it is impossible to characterize all the different conditions of the atmosphere into a finite set of categories/classifications, the synoptic approach strives for all classification types to be mutually exclusive (i.e. each classification type must be different) and collectively exhaustive (i.e. the classification types must represent a full complement of all the possible atmospheric states). Many different schemes for classifying the large-scale condition of the atmosphere have been developed. These include Mueller's Map Classification, the Temporal Synoptic Index (TSI), the Spatial Synoptic Classification (SSC), and the Gridded Weather Typing Classification (GWTC). The SSC and GWTC are two of the more recent schemes that have been used to address synoptic and applied climatological research questions. The SSC was originally

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developed by Lawrence Kalkstein and colleagues (SSC1) in the early 1990s (Kalkstein et al. 1996) and was later revised by Scott Sheridan (Sheridan, 2002). The current Sheridan methodology (SSC2) characterizes the daily surface weather at various locations around the world into one of seven types: Dry Polar (DP), Dry Moderate (DM), Dry Tropical (DT), Moist Polar (MP), Moist Moderate (MM), Moist Tropical (MT), and Transitional (TR). The Transitional category differs from the other types, as it represents a shift from one air mass type to another, as might occur along a frontal boundary (Hondula and Davis, 2011). While these classifications have often just been thought of as air masses, they can also be described as "synoptic weather types". The GWTC characterizes both daily surface and upper-air conditions at various grid points. The classifications include Dry Cool (DC), Dry (D), Dry Warm (DW), Cool (C), Seasonal (S), Warm (W), Humid Cool (HC), Humid (H), Humid Warm (HW), Cold Frontal Passage (CFP), and Warm Frontal Passage (WFP) (Lee, 2014). Many of these types closely resemble those from the SSC. For example, the DW type from the GWTC is similar to the DT type from the SSC.

In this module, the methodology from the author's previous work on migraine headaches (Elcik et al. 2017) was adopted to determine the relationship between air mass type and the occurrence of other forms of pain in the Triangle region of North Carolina (i.e. Orange, Durham, and Wake counties). The frequency of pain in these counties was assessed using daily ED visit data obtained from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) for the years 2007-2013. Corresponding SSC air mass types were obtained from the automated first-order weather station at the Raleigh-Durham International Airport. By adopting the same study region and time period, direct comparisons could be made between the

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relationships found for migraines in Elcik et al. (2017) and those for other pain-related conditions.

1.2   Literature Review

Weather impacts people and society in many ways. Weather has been frequently linked to human health. Koppe et al. (2013) identified the general influences of weather on human health in Germany. About half of the country was found to be "weather sensitive", meaning they had their health impacted by weather in some way. While Germany was the sole focus of that study, it is widely accepted that weather impacts human health worldwide.

In the report, "A Human Health Perspective on Climate Change", the impact of weather on various medical conditions are mentioned. Asthma, respiratory allergies, airway diseases, cancer, cardiovascular diseases, stroke, and neurological diseases are all listed as conditions affected by weather (Portier et al. 2010). Ultimately, weather impacts each of these conditions in a different way. For example, higher temperatures are found to increase volatilization of chemicals that can lead to cancer, while high precipitation rates increase mold that can cause respiratory diseases.

With regards to human health, doctors have often considered weather to impact different types of pain. Cooperation amongst doctors and meteorologists have led to the term meteoropathy, which is defined as the symptoms or reactions, including pain, that are associated with atmospheric conditions (Licanin, 2012). The impact of weather on migraines, a type of head pain, has been a frequently visited topic. Marmura (2018) reviewed the literature to identify triggers for migraine headaches. Based on patient surveys, diaries, and clinical trials, many triggers have been discovered. These include stress, menstrual cycle changes, sleep disturbances, alcohol, and certain foods. Marmura (2018) also found literature supporting weather as a trigger

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for this type of head pain as well. Surveys, based on headache sufferers' perceptions, have repeatedly identified weather as a potential trigger of migraine headaches (Turner et al. 1995; Kelman 2007; Wang et al. 2011).

Over the past five decades, research has been conducted with the goal of determining the ways in which weather affects the frequency of migraine occurrence. Various meteorological variables including barometric pressure, temperature, humidity, cloud cover and opacity, and precipitation type have been examined. Some work has even been done to investigate more obscure weather variables, such as lighting (Martin et al. 2013). The results of many of these studies are summarized in Table 1.1. In general, these studies have largely failed in establishing consistent relationships between specific weather variables and head pain frequency. In fact, contradictory findings are a common occurrence in the literature.

Based on the limited success in examining individual weather variables (through univariate and multivariate analysis), some studies, including Yang et al. (2011), Piorecky et al. (1997), and Cooke et al. (2000), focused instead on broader weather patterns and large-scale weather features. The prevailing weather pattern is the result of multiple meteorological variables, such as temperature, humidity, and pressure, occurring simultaneously. Looking at weather patterns, rather than individual weather variables, may be the preferred method when it comes to determining the effect of weather on pain because a person's body at any given time is constantly subjected to multiple variables acting synergistically. Piorecky et al. (1997) and Cooke et al. (2000) both looked at chinook wind events, which are the warm and dry winds that descend rapidly along the lee side of mountains. Both studies found that the onset of migraine increased significantly on days with chinook winds, as well as the days that preceded them.

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Motivated by the results of Piorecky et al. (1997) and Cooke et al. (2000), the previous work of this author, Elcik et al. (2017), took a synoptic approach to look at the relationship between migraines and weather. This study focused on the impact of synoptic air mass types (SSC) on migraine frequency in the triangle region of North Carolina. Daily ED visits for migraine were compared to synoptic classifications to identify possible relationships. Bootstrapping analysis revealed that Tropical air masses (moist and dry) resulted in greater numbers of migraine ED visits over the study period, whereas Polar air masses led to fewer. These results support the findings from Cooke et al. (2000) and Piorecky et al. (1997), as dry Tropical air masses, which have the temperature and moisture characteristics of chinook winds, were likewise found to lead to increases in migraine frequency.

In addition to migraine, the effect of weather on other types of pain, such as arthritis, fibromyalgia, and chronic pain, has also been examined. Jamison et al. (1995), in a study of 558 chronic pain patients in San Diego, CA, Nashville, TN, Worcester, MA, and Boston, MA, found that the weather was consistently listed as a contributing factor in the frequency of symptoms. Shutty et al. (1992) also found that most of the 70 chronic pain patients in their study identified weather as an influential factor, with many able to identify the specific meteorological variables responsible for their symptoms. Drane et al. (1997) studied the pain diaries of 53 RA patients from Sydney, Australia and found that, while specific weather variables did not account for much of the variance in pain frequency, about 60% of patients did report some sensitivity to weather. NG et al. (2004) also found that rheumatic patients identified weather as a factor when it came to their experienced pain. In their study, 200 patients in a tertiary hospital were given a 10-item questionnaire. Seventy-four percent of the patients reported weather sensitivity (including 100% of patients with fibromyalgia), with humidity and low temperatures most

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frequently associated with worsening of symptoms (66% and 72%, respectively). Of those patients who were weather-sensitive, 70% described pain exacerbation prior to and/or during changes in the weather.

As with migraines, research has been conducted to determine the specific relationship between weather and the pain felt by those who suffer from various medical conditions. Different meteorological variables have been examined, with most studies focusing solely on temperature, pressure, and humidity. The conclusions from these studies are included in Table 1.1. As with migraine research to date, a clear relationship between specific weather variables and pain has not been determined. Some studies suggest that temperature, pressure, and atmospheric moisture have an impact on pain in those who suffer from pre-existing conditions. Strusberg et al. (2002) used the diaries of 183 test subjects in Cordoba, Argentina to examine relationships between weather (daily temperature, pressure, and relative humidity) and various forms of pain. They found that low temperatures, high atmospheric pressure, and high humidity were significantly correlated with pain in those who suffered from RA. Low temperatures and high humidity were significantly correlated with OA, while low temperatures and high atmospheric pressure impacted the pain in those who suffered from fibromyalgia.

Guedj et al. (1990) and Verges et al. (2004) took a similar approach to Strusberg et al (2002) by focusing on patients with different rheumatic pain conditions. Sixty-two patients were examined in Guedj et al. (1990). For those suffering from RA, pain was influenced most strongly by barometric pressure and temperature. For OA patients, pain was mainly influenced by temperature, precipitation, and barometric pressure, while those suffering from fibromyalgia were most influenced by barometric pressure. Verges et al. (2004) observed 92 patients with rheumatic disorders and a control group of 42 subjects in order to determine a relationship

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between pain and weather. The results indicated that OA sufferers experienced joint pain in response to decreases in pressure and low pressure in general. Low temperatures were associated with an increase in joint pain in those suffering from RA, which supports the results from Strusberg et al. (2002). Verges et al. (2004) suggest that, based on their results, pharmacological and non-pharmacological treatments could be regulated for some OA patients depending on the forecasted weather predictions.

Gorin et al. (1999) used the diaries of 75 RA patients to determine how meteorological conditions impacted their pain. Similar to other studies, they found that pain levels were highest on cold, overcast days, as well as subsequent days with high barometric pressure. Increases in pain were also found to be related to day-to-day changes in relative humidity. Timmermans et al. (2015) examined 810 elderly patients in six European countries who were suffering from OA. Using a multilevel regression model, they found that both daily average temperature and humidity influenced joint pain. In particular, the effect of humidity on pain was stronger when coupled with relatively cold weather conditions.

Aikman (1997) sought to establish a possible relationship between the pain and rigidity of arthritis and weather variables in the Australian inland city of Bendigo. Pain and rigidity levels were scored by 25 participants with OA and/or RA four times per day for one month from each season. Stepwise multiple regression analysis indicated that several meteorological variables (temperature, relative humidity, barometric pressure, wind speed, precipitation) as well as time of day accounted for 38% of the variance in pain and rigidity. As with Timmermans et al. (2015), humidity and temperature were found to influence joint pain. In particular, Aikman (1997) identified lower temperatures as well as higher humilities as factors that lead to increased pain and increased rigidity in arthritis sufferers. Abasolo et al. (2013) conducted a case-crossover

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study of ED visits for RA and meteorological conditions in Madrid, Spain between 2004 and 2007. They found that lower temperatures corresponded to pain in patients between the ages of 50 and 65. The association between low temperatures and arthritis is consistent with the results of Timmermans et al. (2015) and Aikman (1997); however, contradictory results were identified for humidity, as no relationship was found.

Brennan et al. (2011) examined 53 patients with end-stage OA of the hip. Daily pain severity visual analogue scale (VAS) scores were recorded over a one-month period. Using a generalized linear mixed model, pain levels were shown to increase as a function of absolute change in atmospheric pressure from one day to the next. Precipitation and temperature were not shown to influence pain severity, contradicting the results of Timmermans et al. (2015) and Aikman (1997).

Jones et al. (2005) focused on those suffering from sickle cell disease. By comparing the number of patients administered to King's College Hospital, London and environmental data, a relationship between pain and weather was identified. Increased admissions were significantly associated with increased wind speed and low humidity, but no relationship was identified with temperature, rainfall or barometric pressure. A potential lag relationship between weather and the onset of pain from gout was explored in Alter et al. (1993). They determined that changes in temperature and pressure were significantly associated with acute gout attacks 4-5 days later.

While many studies have found a statistically significant relationship between weather variables and pain, others have found no statistical relationships. Redelmeier et al. (1996) studied 18 arthritis patients for over a year and found no statistically significant associations between arthritis pain and weather. Wilder et al. (2003) examined the diaries of 154 OA patients and found no statistically significant relationships with any of the weather variables selected by the

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patients (barometric pressure, precipitation, and temperature). Fors et al. (2002) examined 55 female patients diagnosed with fibromyalgia and did not find a statistically significant relationship between any weather variable and pain. As with Fors et al. (2002), Blecourt (1993) attempted to correlate patient complaints of musculoskeletal disorders, including fibromyalgia, with weather conditions and found no statistically significant associations.

Despite many studies concluding that low temperatures, high barometric pressure, and high humidity lead to pain in those who suffer from various pain-related diseases, there is still enough conflicting evidence from other works to cast a shadow over these findings. Previous research (Cook et al. 2000; Piorecky et al. 1997; Elcik et al. 2017) used a synoptic approach to identify the large-scale meteorological conditions associated with an increased incidence of migraine headache. A similar approach has yet to be undertaken for other types of pain. Therefore, the goal of this research is to determine the relationship between air mass type and the frequency of pain in those who suffer from fibromyalgia, RA, OA, and general back pain.

Table 1.1   Previous Literature Results

Study	Type of Pain	Study Location	Variable Found to Trigger Pain					
			High Pressure	Low Pressure	Temp.	Humidity	Pressure Increases	Pressure Decreases
Villeneuve et al. (2006)	Migraine	Ottawa, Canada	x	x	x	x	x	x
Hoffmann et al. (2011)	Migraine	Berlin, Germany	x	x	✓	✓	x	x
Osterman et al. (1980)	Migraine	Uppsala, Sweden	✓		✓	x		
Mukumal et al. (2009)	Migraine	Boston, USA		✓	✓			
Zebenholzer et al. (2010)	Migraine	Vienna, Austria	✓					
Cull (2005)	Migraine	N/A	✓					✓
Kimoto et al. (2011)	Migraine	Utsunomiya, Japan	x	x				✓
Ozeki et al. (2014)	Migraine	Western Shizuoka Prefecture, Japan						✓

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Table 1.1 (continued)

Study	Type of Pain	Study Location	Variable Found to Trigger Pain					
			High Pressure	Low Pressure	Temp.	Humidity	Pressure Increases	Pressure Decreases
Yilmaz et al. (2015)	Migraine	N/A			✓	✓		
Hoffmann et al. (2014)	Migraine	Berlin, Germany	x	x	x	x	x	x
Scheidt et al. (2013)	Migraine	Germany			✓			
Fors et al. (2002)	Fibromyalgia	Trondheim, Norway	x	x	x	x		
Blecourt (1993)	Fibromyalgia	Groningen, Netherlands	x	x	x	x		
Gorin et al. (1999)	Rheumatoid arthritis	N/A	✓		✓	✓		
Abasolo et al. (2013)	Rheumatoid arthritis	Madrid, Spain			✓			
Timmermans et al. (2015)	Osteoarthritis	N/A	x	x	✓	✓		
Wilder et al. (2003)	Osteoarthritis	N/A			x		✓	x
Brennan et al. (2011)	Osteoarthritis	N/A			x		✓	✓
Aikman (1997)	Arthritis	Bendigo, Australia	x	x	✓	✓		
Redelmeier et al. (1996)	Arthritis	N/A	x	x	x	x	x	x
Alter et al. (1993)	Gouty arthritis	N/A	✓		✓			
Strusberg et al. (2002)	Rheumatic pain	Cordoba City, Argentina	✓		✓	✓		
Verges et al. (2004)	Rheumatic pain	Barcelona, Spain		✓	✓			✓
Guedj et al. (1990)	Rheumatic pain	N/A	✓		✓	✓		
Jones et al. (2005)	Sickle Cell Disease	London, England	x	x	x	✓		

✓ = Variable found to trigger pain; x = Variable found not to trigger pain

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1.3   Data and Methods

1.3.1   Study Region and Study Period

To facilitate comparisons with the author's prior research (Elcik et al. 2017), the same study region and study period (2007-2013) were chosen. The study region is the Research Triangle of North Carolina, which includes Durham, Orange, and Wake Counties (Figure 1.1). North Carolina is located in the mid-latitudes and is therefore influenced by many different air masses throughout the year. As such, it is a suitable region to study the influence of different air masses on human health. The three counties comprising the Research Triangle region make up one of most populated regions of North Carolina, thereby maximizing the amount of data available for the study (described below).
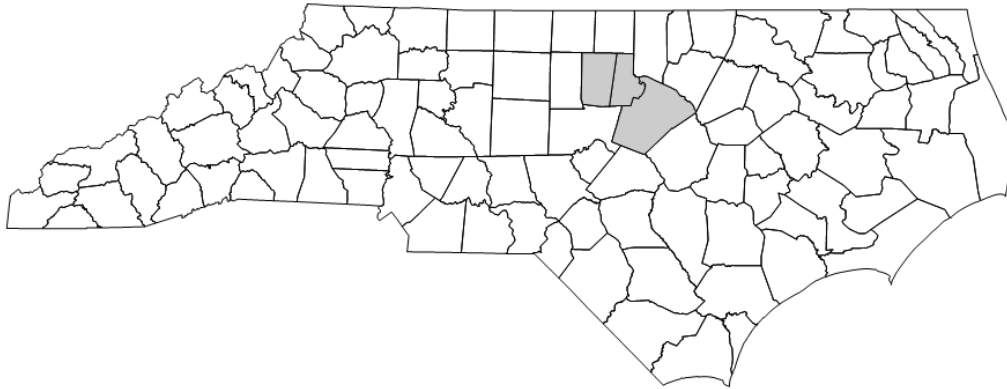
Figure 1.1   Durham County, Orange County, and Wake County, North Carolina

1.3.2   Pain Frequency Data

As in Elcik et al. (2017), two datasets were required for this portion of the study. The first dataset involved daily pain frequency, which was determined from the number of emergency department (ED) visits with a primary diagnosis of fibromyalgia, rheumatoid arthritis (RA),

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osteoarthritis (OA), and general back pain. Daily records of ED visits from the study region were acquired from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT). NC DETECT is a web-based, public health surveillance system developed and maintained by the Carolina Center for Health Informatics at the University of North Carolina at Chapel Hill, in collaboration with the North Carolina Department of Health and Human Services (NC DETECT, 2015). Using the International Classification of Diseases, 9th Revision, Clinical Modification (ICD-9-CM) codes, patients with a primary diagnoses of fibromyalgia (729.1), rheumatoid arthritis (714), osteoarthritis (715), and general back pain (724) were counted. All sub-codes of RA, OA, and general back pain were included in this study.

1.3.3   Air Mass Data

The second dataset that was necessary for this portion of the study contains the daily air mass type experienced in the Triangle region of North Carolina. The Spatial Synoptic Classification (SSC), which identifies the synoptic meteorological surface characteristics of a location, was utilized for this study.

The SSC is a hybrid classification scheme that utilizes both automated and manual processes (Sheridan, 2002). The classifications in the SSC were manually determined after a detailed historical climatological analysis (Kalkstein et al. 1996). The foundation of the SSC rests upon identifying the common surface conditions associated with each of the classifications. As the character associated with these classifications change from season to season, typical days in each, known as "seed days", were picked for different times of the year. Using algorithms, hypothetical seed days for each day of the year were developed. Actual conditions on each day can then be compared to these seed days. Temperature, dew point, cloud cover, and mean sea level pressure are the parameters used in these comparisons. Such comparisons allow a day to be

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characterized based on the classification type it most closely resembles (Spatial Synoptic Classification, 2015). The classifications of the SSC can be thought of as "synoptic weather types". Over a short time period (i.e. a couple days), a location could experience multiple different SSC types, while remaining under the same Bergeron air mass. This can be the result of the local surface characteristics of a location, such as the prevailing wind direction relative to a body of water. For example, initially a location near a lake could experience an extreme thermal SSC weather type when under a classic Bergeron Maritime Tropical air mass. A change in surface winds, where the air from above the lake is moved over land, could lead to a more thermally-moderate SSC weather type, despite remaining under the same Bergeron air mass.

The SSC provides daily classifications for various point locations around the globe. As in Elcik et al. (2017), the Raleigh-Durham International Airport in Morrisville, North Carolina (KRDU) was chosen as the base location for synoptic classifications in this research. The airport is located in Wake County, North Carolina and therefore falls within the study region. Moreover, the airport remains centralized with regards to the study area as a whole. Having a centralized station helps ensure that the daily SSC weather types identified are representative of the entire study region.

The SSC air mass types include: Dry Polar (DP), Moist Polar (MP), Dry Tropical (DT), Moist Tropical (MT), Transitional (TR), Dry Moderate (DM), and Moist Moderate (MM). Many of these air mass types mirror the classic air mass types developed by the Bergen School of Meteorology (Sheridan, 2002). For example, DP classifications are synonymous with continental polar (cP) air masses. These air masses are typically horizontally advected from cold, polar regions. They are associated with the lowest temperatures observed in a region for a particular time of the year, as well as clear, dry conditions (Spatial Synoptic Classification, 2015). In North

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America, these often develop over the central and northern parts of Canada. The MP classification is representative of a Maritime Polar (mP) air mass. These air masses can be the result of frontal overrunning or can be advected inland from a cool ocean. These air masses lead to cloudy, humid, and cool conditions (Spatial Synoptic Classification, 2015). MP air masses that impact the United States usually form off the coast of Nova Scotia or off the coast of Washington. DT classifications are analogous to Continental Tropical (cT) air masses. These air masses can be advected from desert regions or produced by rapidly descending air (i.e. chinook environments). The hottest and driest conditions found at any location are typically associated with these air masses (Spatial Synoptic Classification, 2015). In the United States, these air masses typically come from central Mexico or the Mojave Desert. MT classifications are comparable to Maritime Tropical (mT) air masses. These air mass types are associated with warm and humid conditions. They are often found in the warm sector of a mid-latitude cyclone, but can also exist in the return flow on the western side of an anticyclone. In the United States, the source region for MT air masses is typically the Gulf of Mexico or the Caribbean Sea. These air masses are what lead to the "moist tongue", which is an area of high humidity that extends into the Deep South region of the United States. The frequency of this air mass decreases with increasing distance from the equator (Spatial Synoptic Classification, 2015). Two "oppressive" sub-sets of the MT air mass, MT+ and MT++, are defined as days where the apparent temperature exceeds the MT seed day mean. Due to their infrequent occurrence across the study region, they were not considered in this study.

During Transitional (TR) days, one air mass type yields to another, leading to changes in pressure, dew point, and wind over the course of the day (Spatial Synoptic Classification, 2015). Therefore, TR days are representative of frontal passages. The DM classification does not have a

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traditional analog. This classification type is typically found with zonal flow in the mid-latitudes, especially on the lee side of mountain ranges. Mild and dry conditions are associated with this type of classification. They can also occur when air masses are advected far away from their source regions. (Spatial Synoptic Classification, 2015). The MM type also does not have a traditional analog. This classification type is typically found equatorward of MP air masses. They tend to occur when cloudy conditions suppress the temperature of a traditional MT air mass. Mild and humid conditions are typically found with this classification type (Spatial Synoptic Classification, 2015).

The climatology of SSC characteristics for the months of January to July are shown in Table 1.2. This table displays what type of conditions would constitute a particular classification. The seasonal impacts on the classification types themselves can also be seen in this table. For example, temperature (Tp), dewpoint temperature (Tdp), and apparent temperature (Ta) all lower from July to January.

Table 1.2   SSC Climatology for RDU station

SSC Type	January				July			
	Frequency	Tp	Tdp	Ta	Frequency	Tp	Tdp	Ta
Dry Moderate (DM)	25.9%	11	-2	6	17.2%	31	16	30
Dry Polar (DP)	22.8%	3	-12	-2	3.8%	28	14	26
Dry Tropical (DT)	5.4%	17	-1	11	7.0%	36	19	36
Moist Moderate (MM)	12.4%	9	6	6	20.8%	26	21	28
Moist Polar (MP)	12.3%	2	-1	-3	0.7%	21	19	21
Moist Tropical (MT)	10.1%	19	12	16	44.2%	31	21	33
Transitional (TR)	11.2%	9	-1	3	6.2%	28	18	28

2100 UTC [Temperature (Tp, ℃), Dew Point (Tdp, ℃), Apparent Temperature (Ta, ℃)]

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1.3.4   Statistical Methods

As in Elcik et al. (2017), chi-square (χ^2) tests were first conducted to determine if the ED visits were normally distributed. Determining the general nature of the data helps identify the most appropriate statistical method to use for analysis. If the data had been normally distributed, parametric testing methods, such as the two-sample t-test, would have been the most appropriate option. However, as was the case in Elcik et al. (2017), the results of the chi-square tests indicated the existence of non-normally distributed datasets. Therefore, bootstrapping was utilized to analyze the data. Bootstrapping is a non-parametric technique that does not require datasets to be normally distributed or to have the same distribution type. Bootstrapping uses resampling, with replacement, to generate quantile values for statistical measurements, such as the mean or standard deviation. Based on vector sizes, the data were resampled 2,000 times to create the quantile values.

Bootstrapping was first used to determine if statistically significant differences existed between the mean number of daily fibromyalgia, RA, OA, and general back pain ED visits for each air mass type. Ninety-five percent bootstrap confidence intervals of mean daily ED visits for each condition were created for each of the air mass types. The null hypothesis was that the means were equal, while the alternative hypothesis was that the means were not equal. The confidence intervals were compared to see if the null hypothesis could be rejected. Additionally, standard deviation bootstraps were created to determine the variability in daily ED visits for each air mass type. Bootstraps were also created for each of the four meteorological seasons (i.e. winter: DJF; spring: MAM; summer: JJA; fall: SON) to determine if certain air masses were more strongly associated with ED visits during certain times of the year.

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Bootstrapping was utilized to identify any potential lag relationships between air mass type and pain. Similar to Elcik et al. (2017), 1 to 5-day lags were examined. To carry this out, the daily number of ED visits for each of the pain-related conditions were compared to the air mass type that occurred 1 to 5 days prior. For each lag, 95% bootstrap confidence intervals of mean daily ED visits for each air mass type were created. The null hypothesis was that the means were equal, while the alternative hypothesis was that the means were not equal.

The influence of TR air masses on pain-related ED visits was examined in two ways. First, bootstrapping was used to determine if a statistically significant difference existed between the average number of daily ED visits for each condition during TR air mass days with a positive (increasing) 4am to 10pm pressure change and TR air mass days with a negative (decreasing) 4am to 10pm pressure change. Positive pressure changes are typically indicative of a cold frontal passage, while negative pressure changes typically correspond to a warm frontal passage or an approaching low pressure system. Ninety-five percent bootstrap confidence intervals of mean daily ED visits for both positive and negative pressure change days were created. The null hypothesis was that the means were equal, while the alternative hypothesis was that the means were not equal. As with the other bootstrapping tests, the confidence intervals were compared to determine if the null hypothesis could be rejected. Lastly, Pearson correlation coefficients were calculated using hourly surface pressure data from KRDU and ED visits on TR air mass days to determine if there was an association between the magnitude of pressure change and pain frequency. Correlation coefficients were calculated for positive and negative 4am to 10pm pressure change magnitudes.

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1.4 Results

1.4.1 Data Characteristics

A total of 4,680 ED visits for fibromyalgia, 644 ED visits for rheumatoid arthritis, 1,746 visits for osteoarthritis, and 73,357 visits for general back pain were recorded across the Triangle region of North Carolina from 2007 to 2013. As in Elcik et al. (2017), ED visits were separated into 12 mutually exclusive age groups (Figure 1.2). For fibromyalgia and general back pain, the greatest number of ED visits were found between the ages of 18 and 54, with a secondary peak in individuals 75 and older. In contrast, the greatest number of ED visits for RA and OA were found among the elderly. For example, over two-thirds of visits for OA were found among those 75 and older, while no visits were recorded among those under 18. Females comprised the majority of ED visits for all conditions, particularly RA (70%) (Figure 1.3). The difference was less notable for general back pain. Figure 1.4 illustrates the seasonal distribution of ED visits for each condition. In general, ED visits were more frequent during the warmer times of the year and less frequent during the colder times of the year. This was particularly the case for both RA and OA.

22
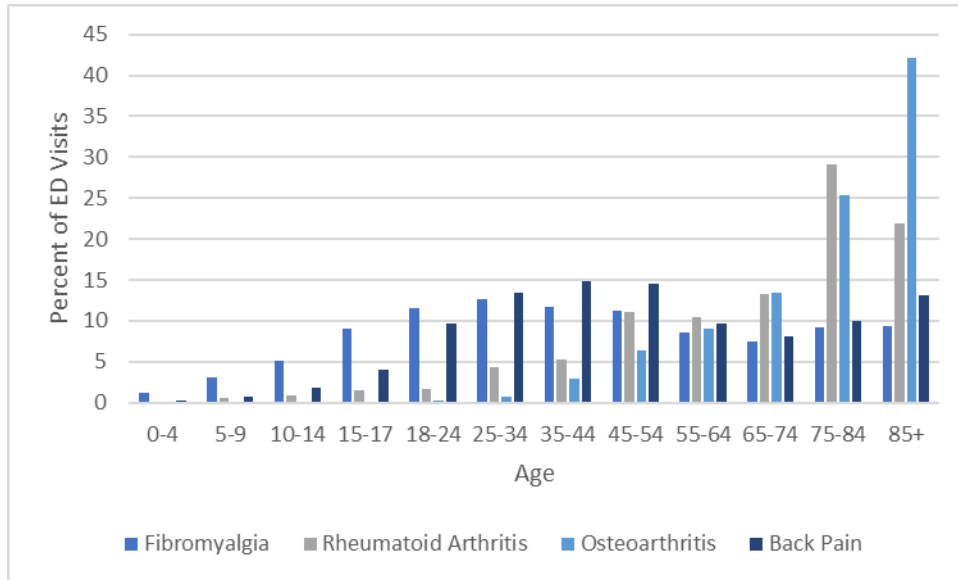
Figure 1.2   RDU age distribution of ED patients for the different conditions of interest from 2007-2013
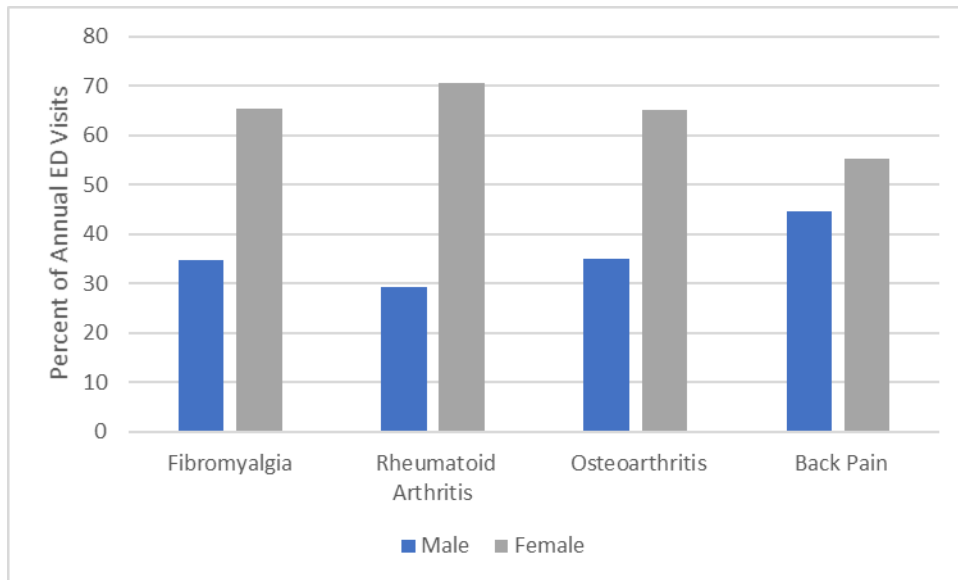
Figure 1.3   RDU gender distribution of ED patients for the different conditions of interest from 2007-2013

23
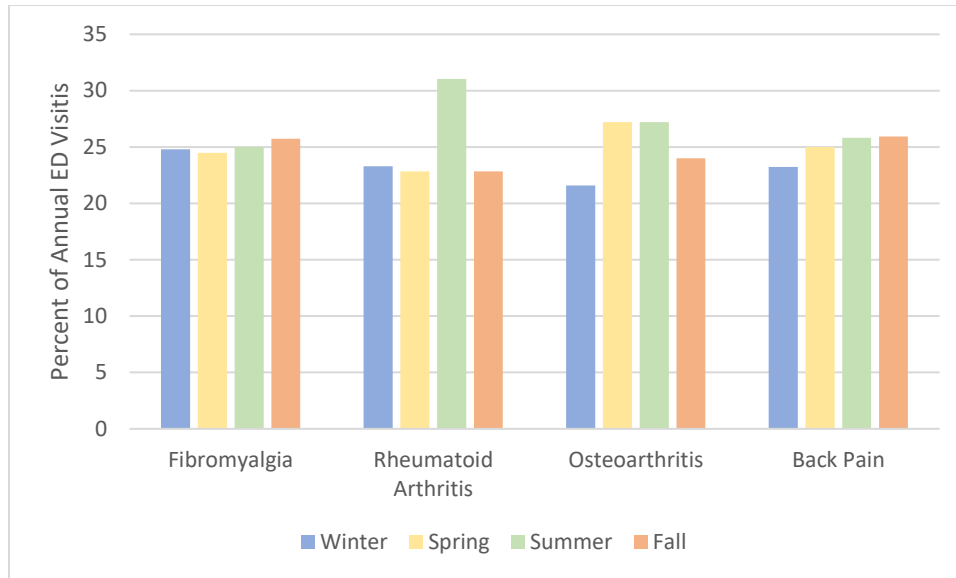
Figure 1.4   RDU seasonal distributions of ED patients for the different conditions of interest from 2007-2013

The seasonal distribution of each air mass (SSC) type is provided in Table 1.3. Tropical air masses (moist and dry) were more common during the spring and summer, while the frequencies of both polar air masses were highest in winter and fall months. Moderate air masses were more broadly distributed throughout the year. Transitional air masses, typically associated with frontal passages, occurred most often in winter and spring when the jet stream and associated weather systems frequently traverse the region.

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Table 1.3   Seasonal counts of air mass types from 2007-2013

Air Mass	Season				Total
	Winter	Spring	Summer	Fall	
Dry Moderate	182	170	145	220	717
Dry Polar	137	78	8	56	279
Dry Tropical	45	91	124	93	335
Moist Moderate	65	74	77	90	306
Moist Polar	54	21	3	31	109
Moist Tropical	43	74	205	80	402
Transitional	69	52	24	46	191

1.4.2   Bootstrapping Results

1.4.2.1   Mean Bootstraps

Table 1.4 shows that the mean number of daily ED visits for each condition were similar across the different air mass types. However, there were some statistically significant differences.

Figures 1.5-1.8 show the 95% confidence interval bootstrap plots associated with the mean number of daily ED visits for each air mass type from the RDU. Each of these figures is associated with one of the conditions of interest. The quantile values associated with these plots are provided in Tables 1.5-1.8.

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Table 1.4   RDU average number of ED visits from 2007-2013

Air mass	Fibromyalgia	Rheumatoid Arthritis	Osteoarthritis	General Back Pain
Dry Moderate	1.8173	0.2524	0.7336	28.4923
Dry Polar	1.8817	0.2401	0.6057	26.5161
Dry Tropical	1.7195	0.2521	0.6261	28.4561
Moist Moderate	1.9641	0.2451	0.6438	29.3170
Moist Polar	1.7156	0.1468	0.6606	27.7706
Moist Tropical	1.9055	0.3035	0.7786	30.7090
Transitional	1.7225	0.2408	0.6440	27.8639

MT and MM air masses were associated with the highest numbers of visits to the ED for fibromyalgia, while DT and MP air masses corresponded to the fewest visits (Figure 1.5 and Table 1.5). The difference in ED visits between DT and both MT and MM air masses was statistically significant at the 95% confidence level.

Similar results were noted for RA, as MT air masses resulted in the greatest number of ED visits and MP air masses led to the fewest (Figure 1.6 and Table 1.6). The difference in ED visits for RA between these two air masses was statistically significant. In fact, the number of ED visits associated with MP air masses was significantly lower than all other air mass types.

MT air masses were also associated with the greatest number of ED visits for OA, followed closely by DM air masses. In fact, the difference in ED visits between MT and four of the other air mass types (DP, DT, MM, and TR) was statistically significant. Interestingly, the difference was not statistically significant when compared to MP air masses, which corresponded to the lowest number of ED visits for the other two conditions (Figure 1.7 and Table 1.7).

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With regard to general back pain, MT air masses were once again associated with the highest number of ED visits (Figure 1.8 and Table 1.8). In fact, the number of general back pain ED visits associated with MT air masses was statistically significantly higher than the number of visits for all other air mass types. For general back pain, both types of polar air masses (DP and MP) led to the lowest numbers of ED visits. The difference in ED visits for back pain is most notable when comparing the tropical air masses to the polar air masses, as MT (DT) air masses were associated with a statistically higher number of ED visits than MP (DP) air masses.

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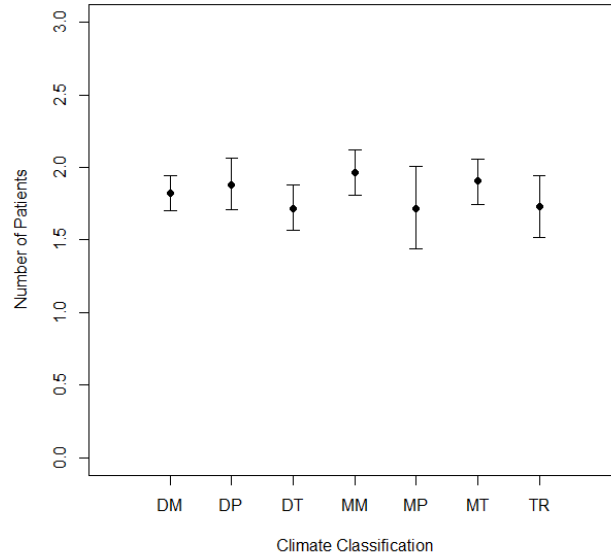
Figure 1.5   Bootstrap confidence intervals of the mean number of daily fibromyalgia ED visits from the RDU area for each air mass, 2007-2013

Table 1.5   Bootstrap quantile values of the mean number of daily fibromyalgia ED visits from the RDU area for each air mass, 2007-2013

	Quantile Values		
Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	1.7015	1.8173	1.9303
Dry Polar	1.6953	1.8853	2.0717
Dry Tropical	1.5637	1.7181	1.8754
Moist Moderate	1.8039	1.9641	2.1242
Moist Polar	1.4404	1.7156	2.0091
Moist Tropical	1.7537	1.9030	2.0572
Transitional	1.5236	1.7277	1.9373

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Figure 1.6   Bootstrap confidence intervals of the mean number of daily rheumatoid arthritis ED visits from the RDU area for each air mass, 2007-2013

Table 1.6   Bootstrap quantile values of the mean number of daily rheumatoid arthritis ED visits from the RDU area for each air mass, 2007-2013

	Quantile Values		
Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	0.2162	0.2524	0.2929
Dry Polar	0.1828	0.2401	0.3011
Dry Tropical	0.2011	0.2521	0.3031
Moist Moderate	0.1928	0.2451	0.3007
Moist Polar	0.0826	0.1468	0.2202
Moist Tropical	0.2512	0.3035	0.3557
Transitional	0.1780	0.2408	0.3089

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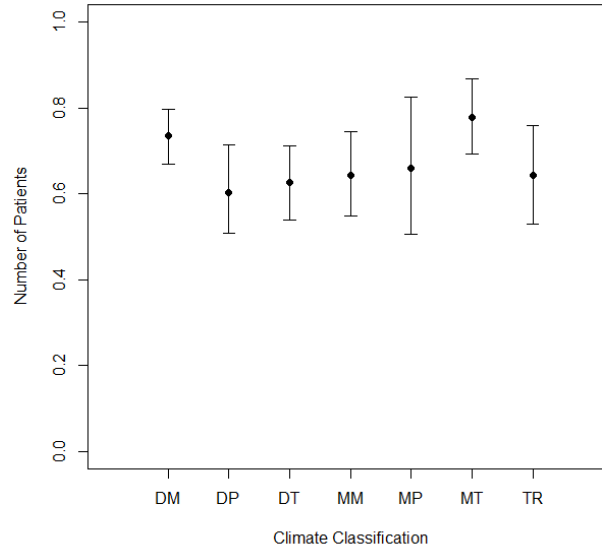
Figure 1.7   Bootstrap confidence intervals of the mean number of daily osteoarthritis ED visits from the RDU area for each air mass, 2007-2013

Table 1.7   Bootstrap quantile values of the mean number of daily osteoarthritis ED visits from the RDU area for each air mass, 2007-2013

| | **Quantile Values** | | |
Air Mass	2.5 %	50 %	97.5 %
Dry Moderate	0.6722	0.7350	0.7978
Dry Polar	0.5054	0.6022	0.7097
Dry Tropical	0.5439	0.6261	0.7111
Moist Moderate	0.5490	0.6438	0.7418
Moist Polar	0.4954	0.6514	0.8349
Moist Tropical	0.6891	0.7761	0.8731
Transitional	0.5393	0.6440	0.7592

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Figure 1.8   Bootstrap confidence intervals of the mean number of daily general back pain ED visits from the RDU area for each air mass, 2007-2013

Table 1.8   Bootstrap quantile values of the mean number of daily general back pain ED visits from the RDU area for each air mass, 2007-2013

	Quantile Values		
Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	27.8075	28.5007	29.2092
Dry Polar	25.3655	26.4839	27.7206
Dry Tropical	27.4588	28.4731	29.4846
Moist Moderate	28.2810	29.3366	30.3497
Moist Polar	25.9083	27.7431	29.5780
Moist Tropical	29.8381	30.7214	31.6742
Transitional	26.4708	27.8665	29.1939

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1.4.2.2 Standard Deviation Bootstraps

The bootstrap confidence intervals of the standard deviation of daily ED visits for each of the conditions of interest are presented in Figures 1.9-1.12. In general, there were very few statistically significant differences in the variability of ED visits for each condition across the different air mass types. For fibromyalgia, the variability in ED visits associated with MT air masses was significantly greater than the variability associated with MM air masses. For RA and OA, similar relationships were found among the bootstrap confidence intervals, except when it came to MP air masses. For RA, a drop in the variability of ED visits was noted for MP air masses. This drop led to TR air masses having significantly greater variability in ED visits for RA compared to MP air masses. For OA, there was no statistically significant differences between the variability in ED visits between TR and MP air masses. No statistically significant differences were noted in the variability of general back pain ED visits across any of the air mass types.
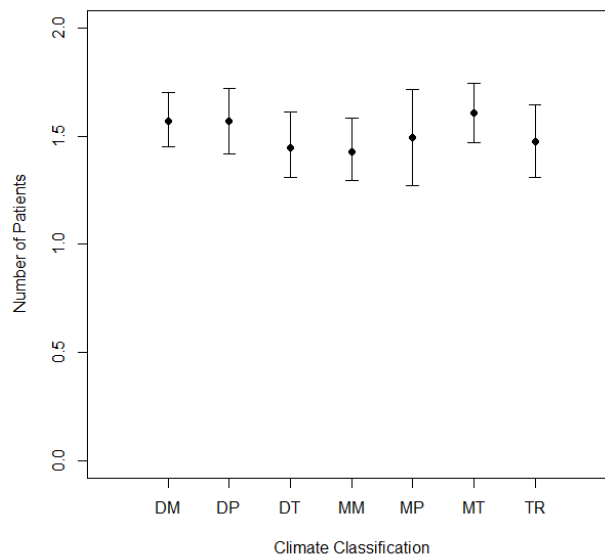
Figure 1.9   Bootstrap confidence intervals of the standard deviations of daily fibromyalgia ED visits from the RDU area for each air mass, 2007-2013

32
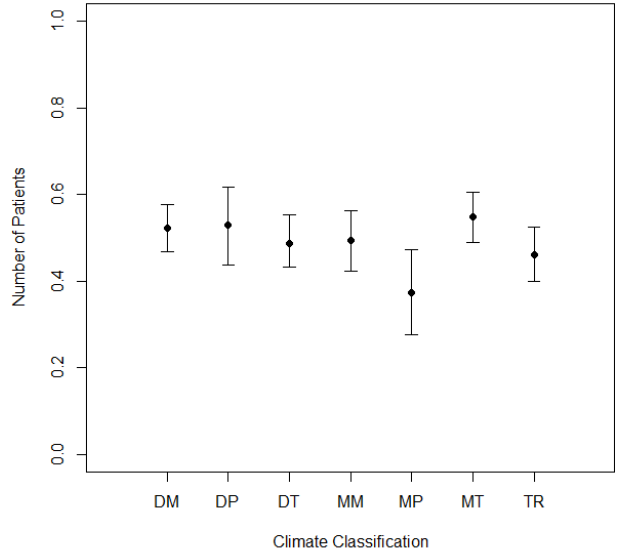
Figure 1.10   Bootstrap confidence intervals of the standard deviations of daily rheumatoid arthritis ED visits from the RDU area for each air mass, 2007-2013
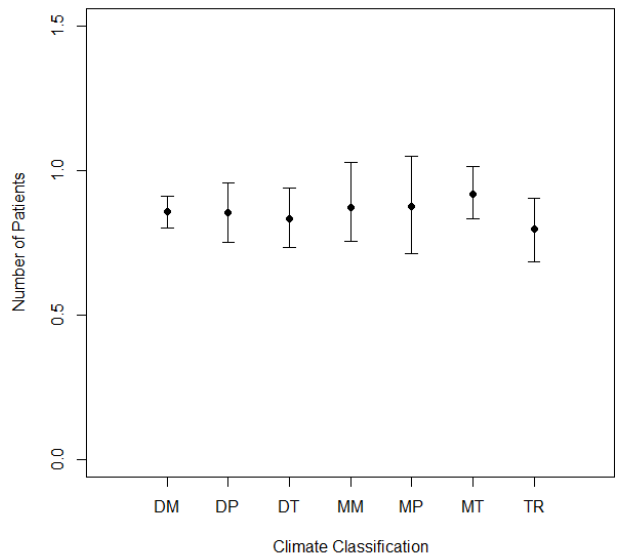
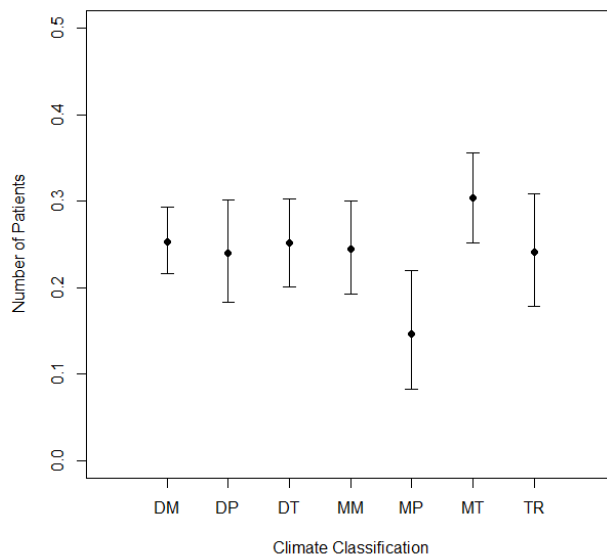Figure 1.11   Bootstrap confidence intervals of the standard deviations of daily osteoarthritis ED visits from the RDU area for each air mass, 2007-2013

33
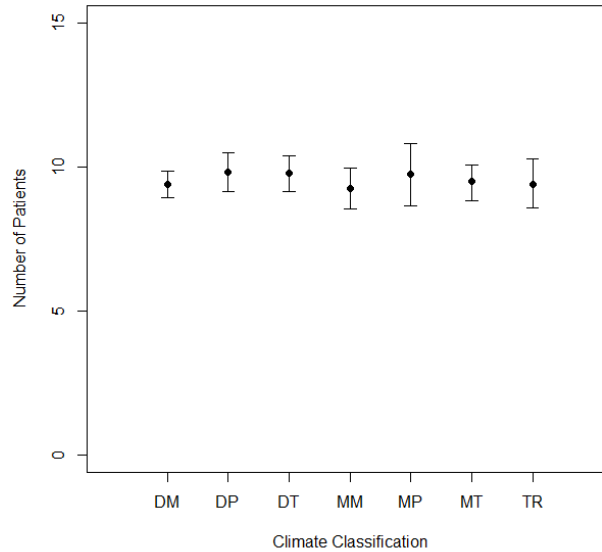
Figure 1.12   Bootstrap confidence intervals of the standard deviation of daily general back pain
ED visits from the RDU area for each air mass, 2007-2013

1.4.2.3   Seasonal Mean Bootstraps

Figures 1.13-1.16 show the 95% confidence interval bootstrap plots associated with the

mean number of daily ED visits for each air mass type during the different meteorological

seasons (winter, spring, summer, and fall). Each of these figures is associated with one of the

conditions of interest. Due to the low number of days in summer characterized by a MP air mass

(only 3 days over the seven-year study period; Table 1.2), seasonal comparisons with those

bootstraps were avoided.

Using Figures 1.13-1.16, seasonal relationships between average daily ED visits and the

seven air mass classifications were determined. Interestingly, for three of the four conditions

(rheumatoid arthritis, osteoarthritis, and general back pain), the spring season resulted in little to

no statistically significant differences in ED visits between the different synoptic classification

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types. The other three seasons frequently exhibited relationships analogous to what were found for the study period as a whole (Figures 1.5-1.8).

For fibromyalgia, the relationships found during the summer and fall matched what was found over the course of the entire study period as MM and MT air masses were associated with the greatest numbers of daily ED visits (Figure 1.5 and 1.13). For RA, the relationships during the summer matched the trends found over the seven-year period as increases in daily ED visits accompanied days with MT air masses (Figure 1.6 and 1.14). With OA, three of the four seasons (winter, summer, and fall) had relationships that matched those for the whole study period with DM and MT exhibiting greater numbers of ED visits (Figure 1.7 and 1.15). For general back pain (Figure 1.8 and 1.16), similarities to the study period were seen during the winter and fall seasons, but subtle differences were noted for each. In the winter season, MT air masses still resulted in greater numbers of general back pain ED visits compared to MP; however, statistical differences between DP and DT were not seen. In the fall, the DP and DT air mass comparisons were statistically significant, with the former being associated with fewer ED visits, but no statistically significant trends were found between MT and MP air masses. The results for the various conditions indicate that the overall relationships between air mass types and ED visits often hold true regardless of seasonality.
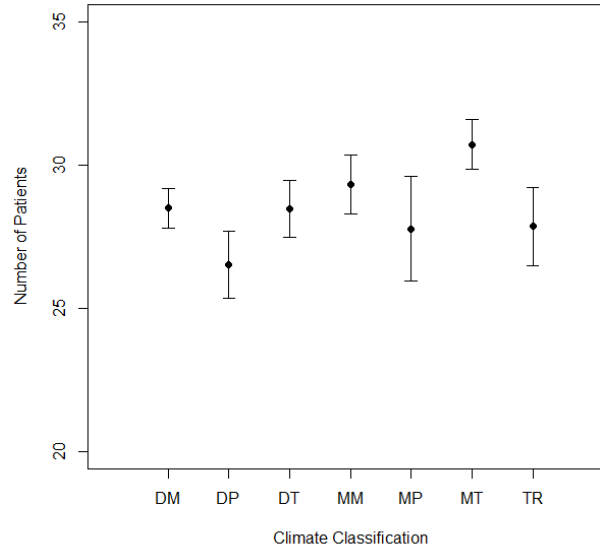
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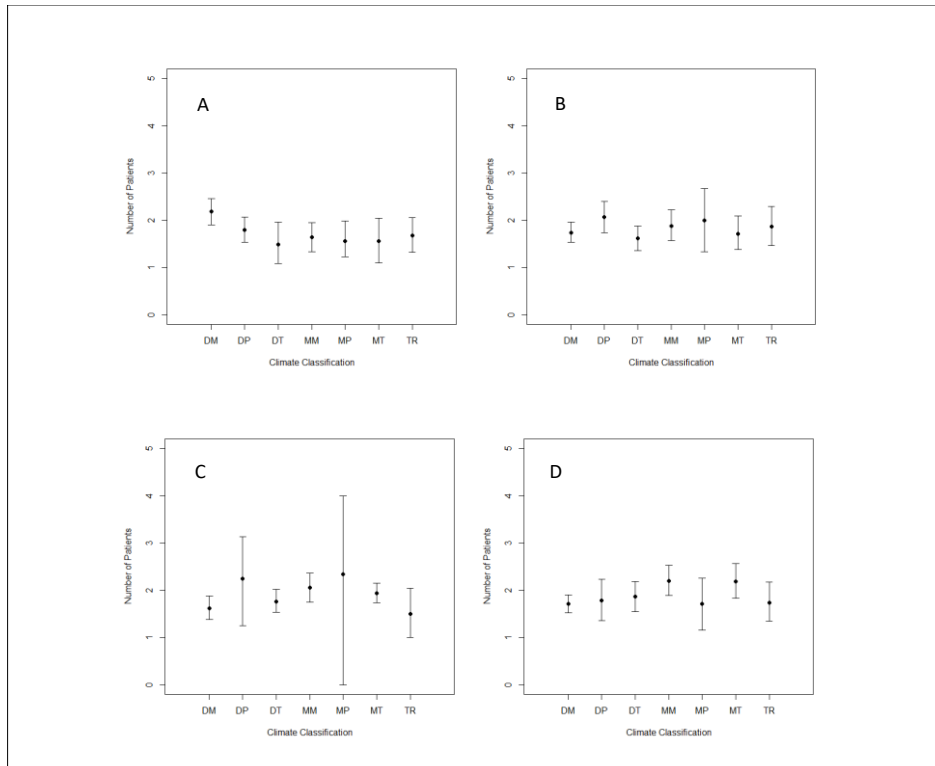
Figure 1.13   (A) Winter, (B) Spring, (C) Summer, and (D) Fall bootstrap confidence intervals of the mean number of fibromyalgia ED visits from the RDU area for each air mass, 2007-2013
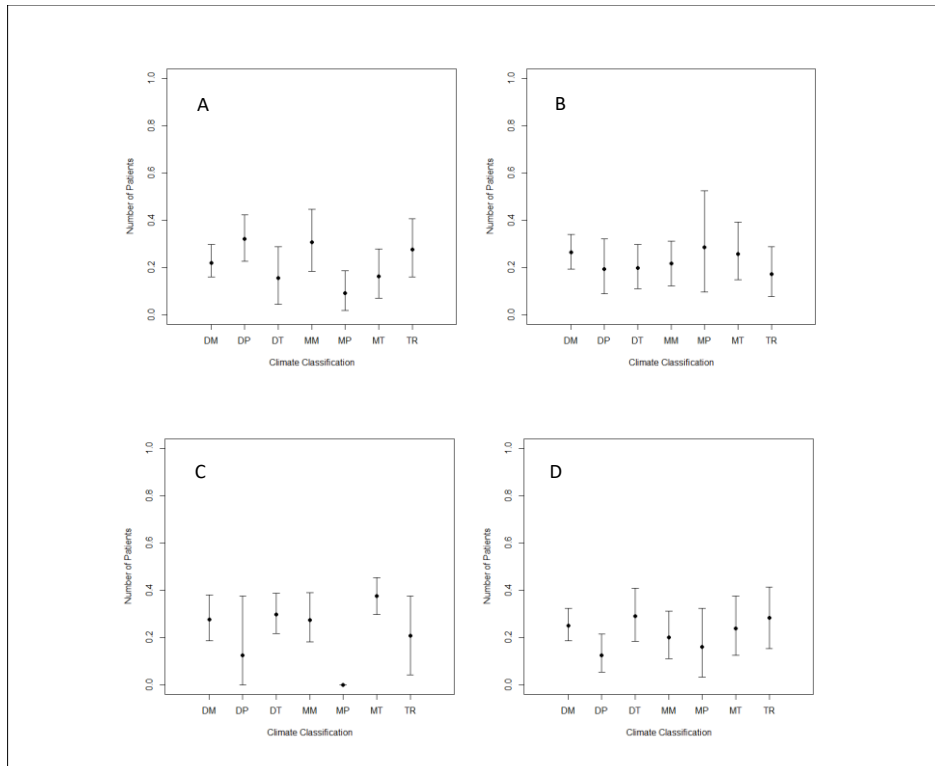
Figure 1.14   (A) Winter, (B) Spring, (C) Summer, and (D) Fall bootstrap confidence intervals
of the mean number of rheumatoid arthritis ED visits from the RDU area for each
air mass, 2007-2013
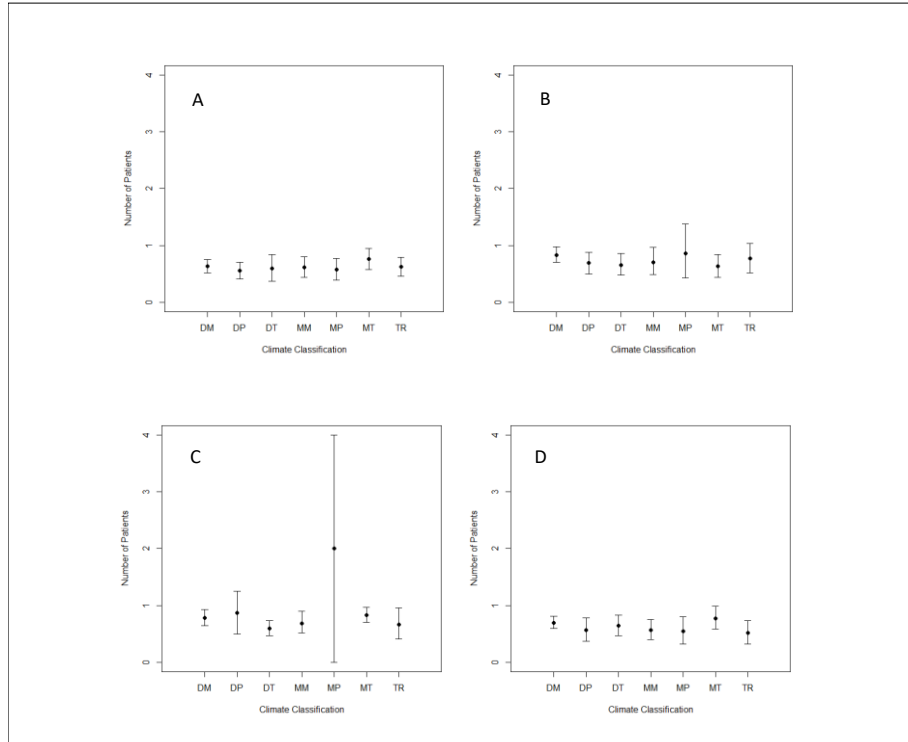
Figure 1.15   (A) Winter, (B) Spring, (C) Summer, and (D) Fall bootstrap confidence intervals of the mean number of osteoarthritis ED visits from the RDU area for each air mass, 2007-2013

38
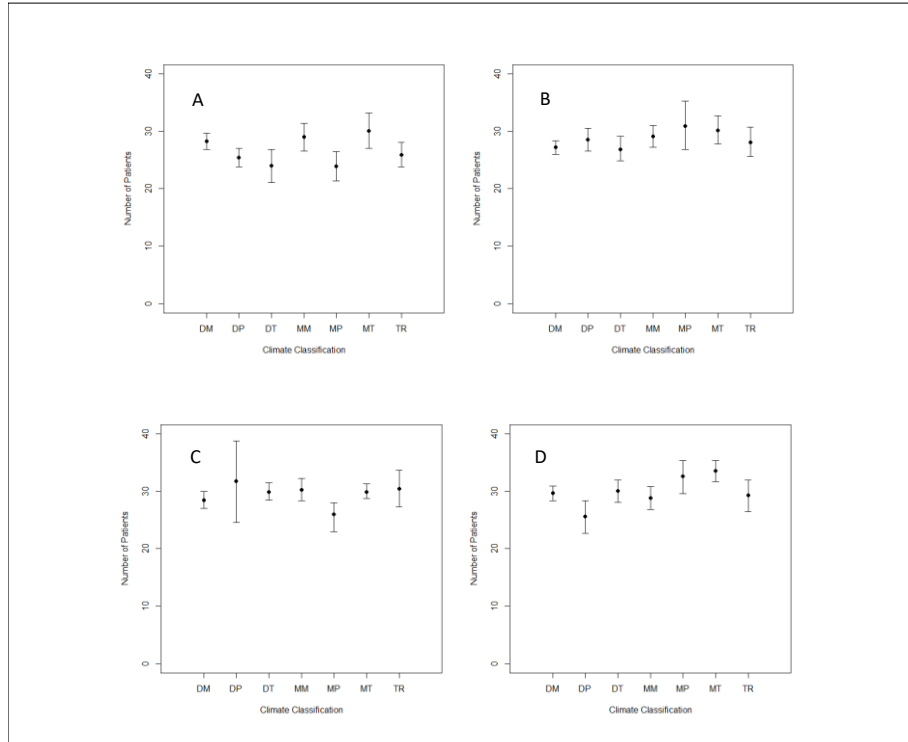
Figure 1.16   (A) Winter, (B) Spring, (C) Summer, and (D) Fall bootstrap confidence intervals of the mean number of general back pain ED visits from the RDU area for each air mass, 2007-2013

1.4.2.4   Lag Mean Bootstraps

The persistence of each classification type, or the number of consecutive days with the same air mass, was determined to better understand potential lag relationships (Table 1.9). On average, the classifications were found to last between one and two days. The most common scenario was that a classification type would last for only one day, with the following day experiencing a new air mass. TR air masses were unique in that they were never classified more than two days in a row. This was expected as multiple frontal passages are uncommon over a short duration due to the synoptic forcing mechanisms involved.

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Table 1.9   Spatial Synoptic Classification average persistence, 2007-2013

Spatial Synoptic Classification	Occurrences of days in a row with the same classification type								Average Persistence
	1	2	3	4	5	6	7	8	
Dry Moderate	191	106	49	20	8	3	4	0	1.8793
Dry Polar	89	48	19	5	1	2	0	0	1.7012
Dry Tropical	99	52	16	11	4	4	2	0	1.8777
Moist Moderate	126	48	16	2	3	1	0	0	1.5533
Moist Polar	51	19	5	0	1	0	0	0	1.4342
Moist Tropical	143	50	16	9	4	2	5	1	1.7478
Transitional	151	20	0	0	0	0	0	0	1.1170

Figures 1.17-1.20 show the 95% bootstrap confidence intervals for each air mass type and lag period. Each figure corresponds to one of the conditions of interest. Overall, only a few significant lag relationships were found between mean daily ED visits and air mass type, and these relationships varied by condition.

For fibromyalgia, a statistically significant increase in ED visits was noted 3 days following a TR air mass, while a decrease in ED visits was noted 3 days following a DT air mass (Figure 1.17). Of all the conditions examined, RA exhibited the greatest number of significant lag relationships. Specifically, a decrease in ED visits for RA was noted 2 days following either a MP or MT air mass (Figure 1.18). As with fibromyalgia, TR air masses also resulted in a significant lag effect for RA, except the increase in ED visits was noted 5 days following the air mass. In addition, the day following a MM air mass exhibited a significantly lower number of ED visits for RA; however, this relationship may not actually be associated with a lag. Based on Table 1.8, this air mass type persisted for 1.5533 days on average. Therefore, the relatively low ED counts could still be associated with the day of this air mass.

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Only one significant lag relationship was identified for OA and general back pain. In the case of OA, there was a significant increase in ED visits in the day following a DP air mass (Figure 1.19), while the day following a MP air mass exhibited a significantly greater number of ED visits for general back pain (Figure 1.20). As was the case for the relationship between MM air masses and RA, the relationship between DP air masses and OA may not be lagged either. Based on Table 1.8, DP air masses persisted for just under two days (1.7012) on average during the study period. Thus, this increase may be associated with the day of this air mass type; however, elevated daily ED visits during DP days were not noted in the mean bootstrap analysis (Figure 1.7).

For both OA and general back pain, regardless of lag period, comparisons between air masses resulted in similar relationships to those seen in Figures 1.7 and 1.8. For example, as was the case on the day of, the 1 to 5 days following a MT air mass resulted in more ED visits compared to the 1 to 5 days following any of the other air mass types. Additionally, for general back pain, the 1 to 5 days following a DP air mass led to fewer ED visits compared to that time period following any of the other classifications.

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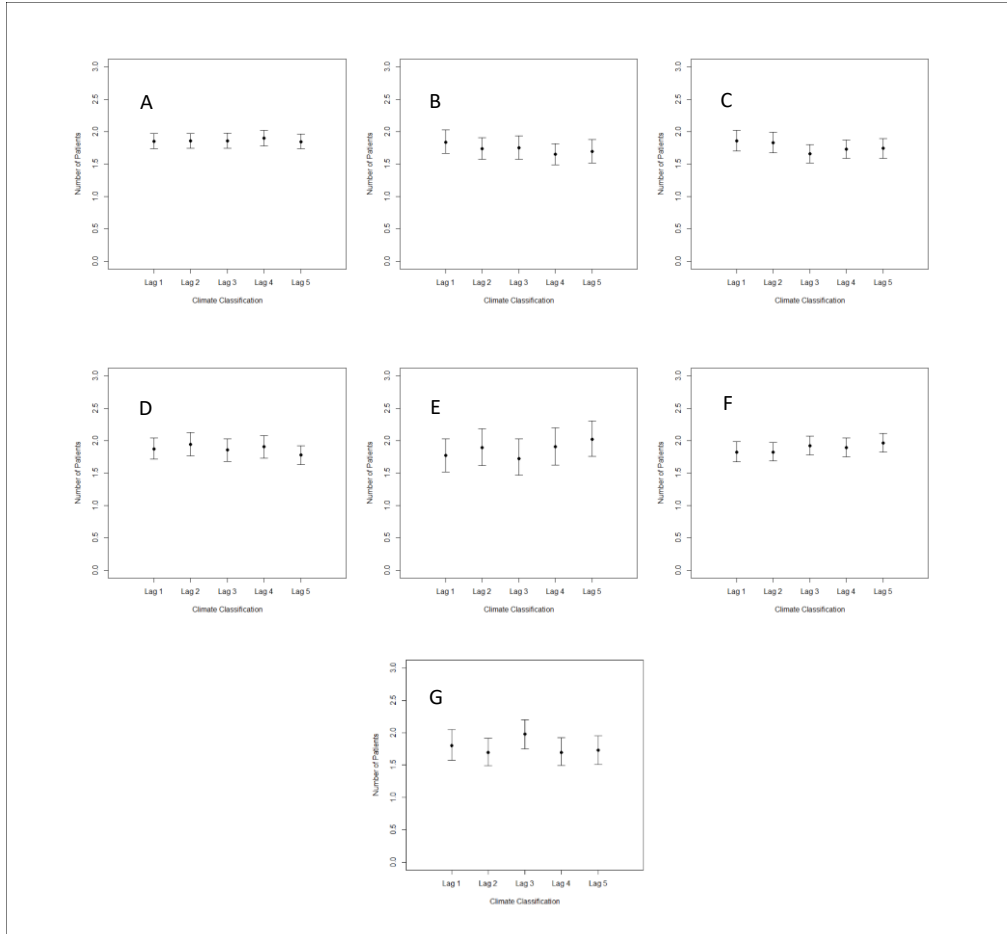
Figure 1.17   (A) DM, (B) DP, (C) DT, (D) MM, (E) MP, (F) MT, and (G) TR one to five day lag bootstrap confidence intervals of the mean number of daily fibromyalgia ED visits from the RDU area, 2007-2013
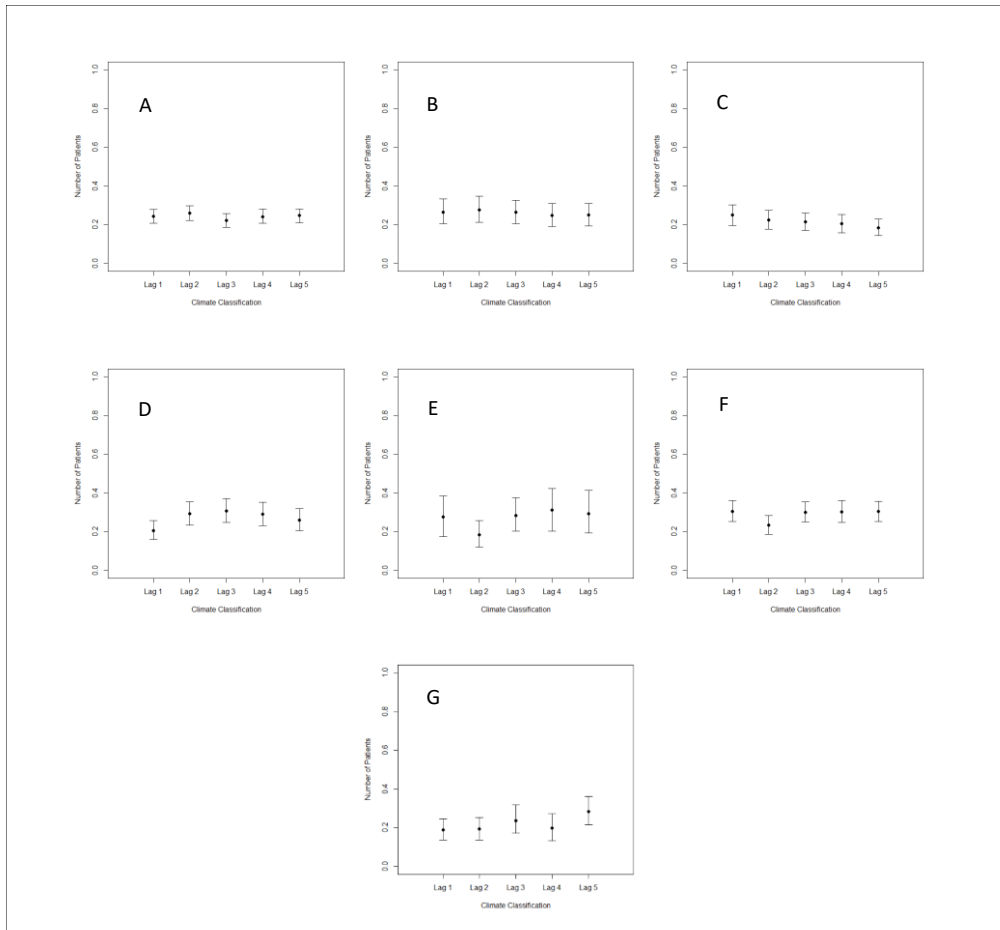
Figure 1.18   (A) DM, (B) DP, (C) DT, (D) MM, (E) MP, (F) MT, and (G) TR one to five day lag bootstrap confidence intervals of the mean number of daily rheumatoid arthritis ED visits from the RDU area, 2007-2013
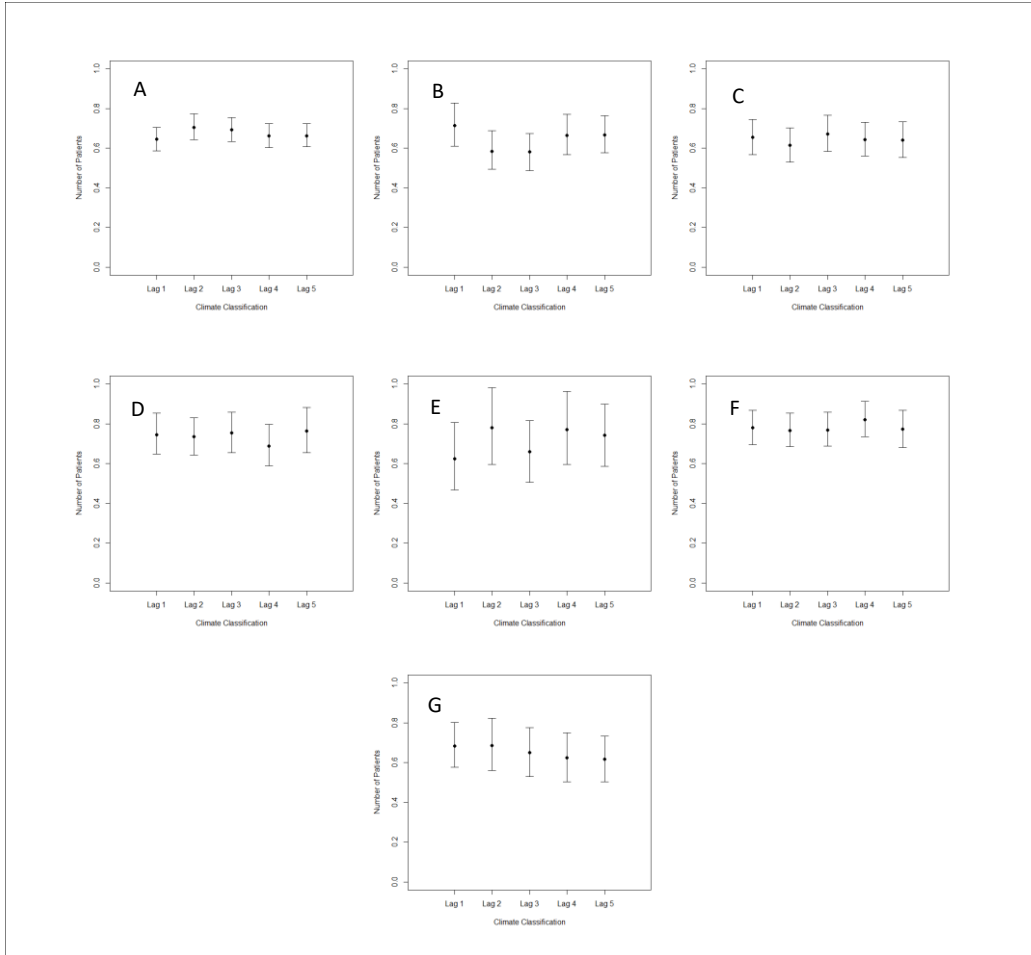
Figure 1.19   (A) DM, (B) DP, (C) DT, (D) MM, (E) MP, (F) MT, and (G) TR one to five day
lag bootstrap confidence intervals of the mean number of daily osteoarthritis ED
visits from the RDU area, 2007-2013

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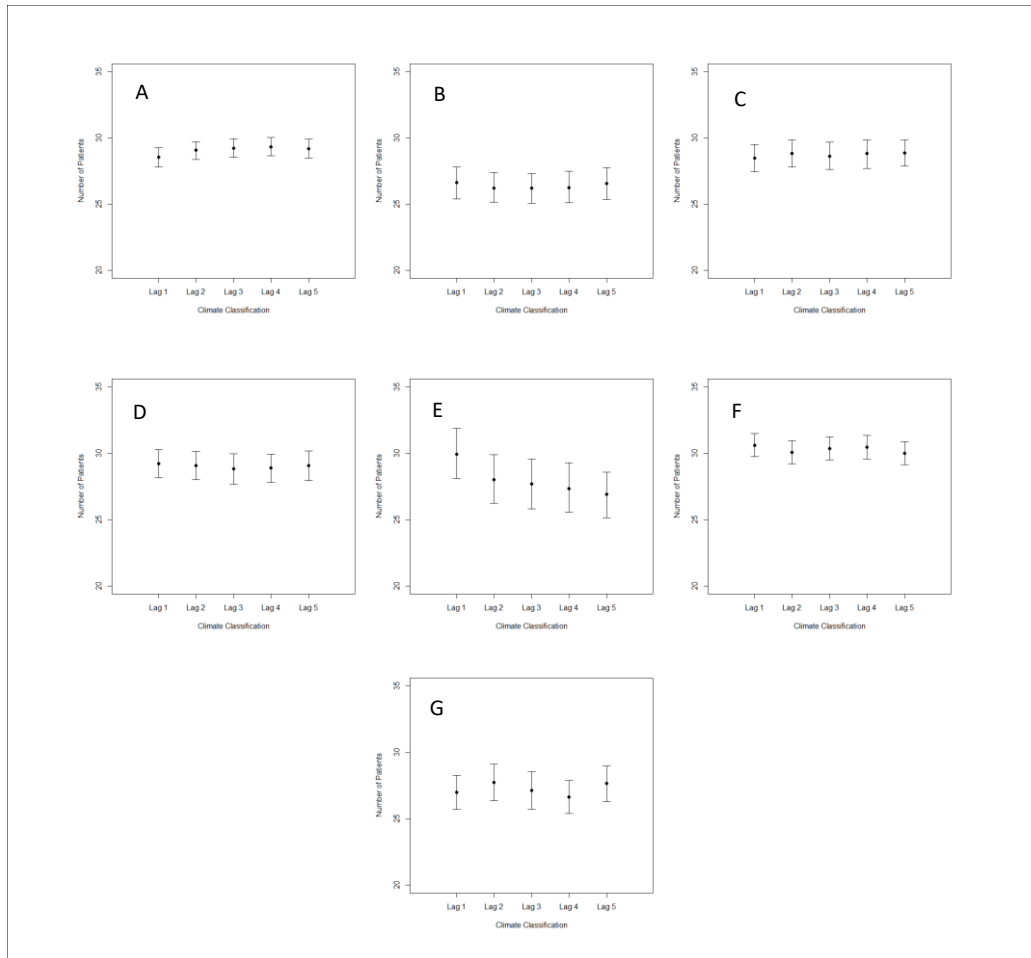
Figure 1.20 (A) DM, (B) DP, (C) DT, (D) MM, (E) MP, (F) MT, and (G) TR one to five day lag bootstrap confidence intervals of the mean number of daily general back pain ED visits from the RDU area, 2007-2013

1.4.2.5 Transitional Pressure Change Bootstraps

Bootstrap confidence intervals of mean ED visits for each condition were calculated on TR air masses exhibiting either a positive (increasing) pressure change (e.g. cold frontal passage) or negative (decreasing) pressure change (e.g. warm frontal passage or approaching low pressure system). These confidence intervals are illustrated in Figures 1.21-1.24.

Within the TR air mass days, the mean number of ED visits for fibromyalgia, RA, and OA were higher on days with pressure decreases than on days with pressure increases (Figures 1.21-1.23). In contrast, the mean number of ED visits for general back pain was higher on days with pressure increases than on days with pressure increases (Figure 1.24). However, all of these differences were not statistically significant.
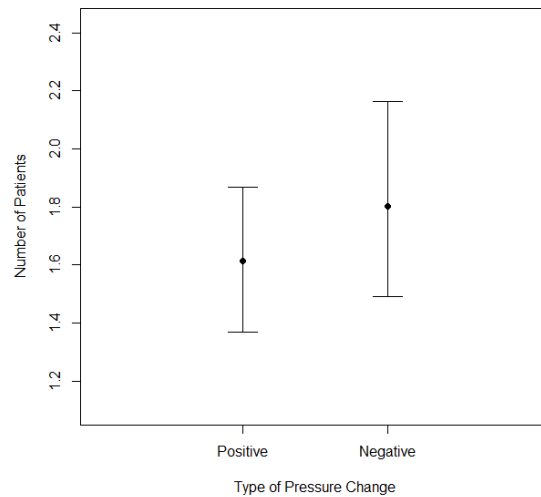
Figure 1.21   Bootstrap confidence intervals of the mean number of daily fibromyalgia ED visits from the RDU area for positive and negative pressure changes during Transitional air masses, 2007-2013

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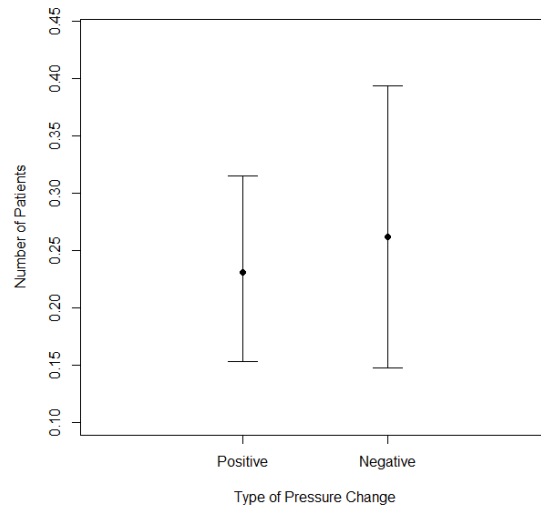
Figure 1.22   Bootstrap confidence intervals of the mean number of daily rheumatoid arthritis
ED visits from the RDU area for positive and negative pressure changes during
Transitional air masses, 2007-2013
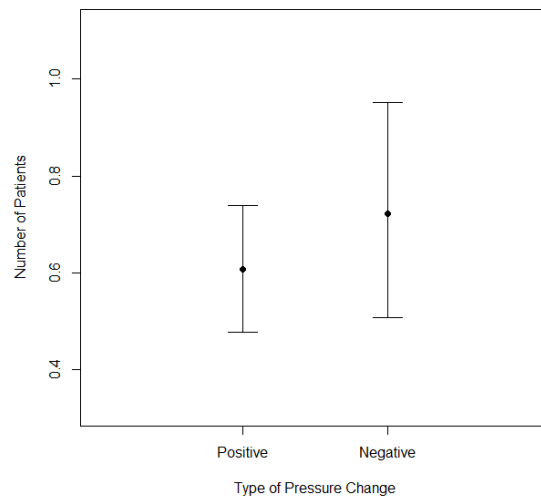
Figure 1.23   Bootstrap confidence intervals of the mean number of daily osteoarthritis ED visits
from the RDU area for positive and negative pressure changes during Transitional
air masses, 2007-2013
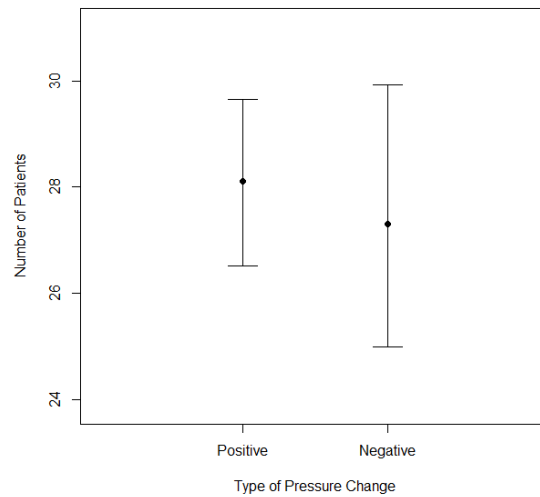
Figure 1.24   Bootstrap confidence intervals of the mean number of daily general back pain ED visits from the RDU area for positive and negative pressure changes during Transitional air masses, 2007-2013

1.4.3   Correlation Results

Pearson correlation coefficients were calculated to determine if relationships existed between the magnitude of the pressure change on TR days and the number of ED visits for each of the conditions of interest. These relationships are illustrated using simple scatterplots of pressure change and ED visits (Figure 1.25), while the correlation coefficients are provided in Table 1.10.

Generally poor and statistically insignificant relationships were found between the magnitude of pressure change (either increasing or decreasing) and the number of ED visits for each condition. For fibromyalgia, RA, and general back pain, the correlation coefficient on TR air mass days associated with an increase in barometric pressure was negative, indicating that as the increase in barometric pressure became larger, the frequency of ED visits for these conditions

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decreased. For OA, the correlation coefficient was positive, indicating that as the increase in barometric pressure became larger, the frequency of ED visits increased. On TR air mass days when the pressure decreased, the correlation coefficients for all conditions except fibromyalgia were positive. While the coefficients for pressure decreases were somewhat stronger than those for pressure increases, they were not statistically significant.
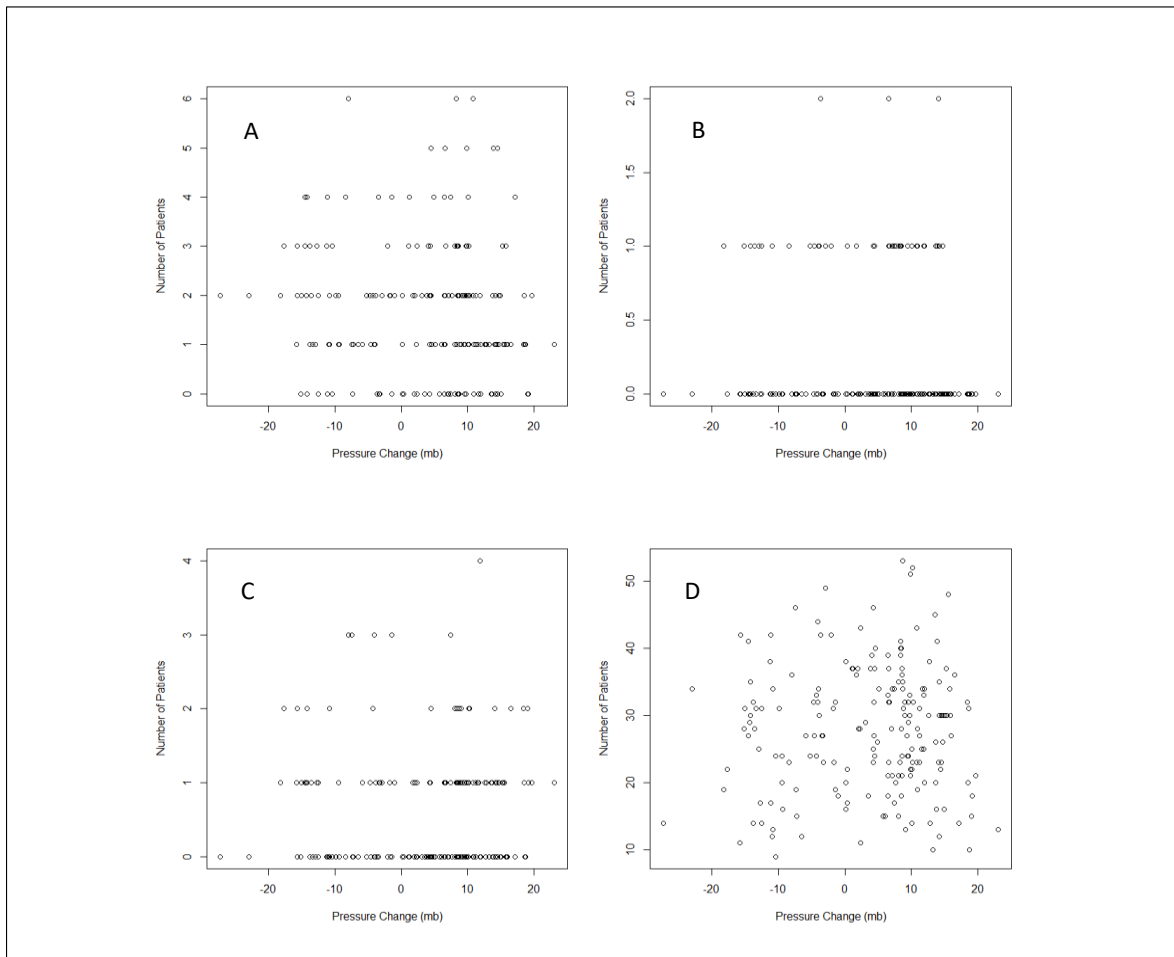
Figure 1.25   (A) Fibromyalgia, (B) Rheumatoid Arthritis, (C) Osteoarthritis, and (D) General Back Pain daily ED visits on Transitional air mass days with different pressure change magnitudes from the RDU area, 2007-2013

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Table 1.10   Transitional air mass pressure change magnitude and daily ED visit correlation
                coefficient values for the RDU area, 2007-2013

Condition	Pearson Correlation Coefficient	
	Positive Pressure Change	Negative Pressure Change
Fibromyalgia	-0.0731	-0.1026
Rheumatoid Arthritis	-0.0709	0.1012
Osteoarthritis	0.1939	0.1042
General Back Pain	-0.1501	0.1445

1.5   Discussion and Conclusion

In this chapter, the relationships between air mass type and the number of ED visits for

different types of pain were examined over a seven-year period in the Triangle region of North

Carolina. The age and gender distributions for these conditions are supported by the literature. In

particular, the elderly population suffers most frequently from RA and OA, while ED visits for

the other conditions are spread more evenly across the middle age groups.

The results from this chapter suggest that the occurrence of several types of pain are

linked to the synoptic environment. General back pain, in particular, exhibited the strongest

relationship with the prevailing air mass setting. While some relationships were identified with

fibromyalgia, RA, and OA, they were not as strong. It is likely that the weaker associations with

these conditions were due to lower counts of ED visits compared to general back pain. Since

only primary diagnoses were considered, the ED visits examined here represent the primary

reason an individual visits the ED and does not consider secondary diagnoses or any underlying

health conditions. Therefore, the ED may be a less common access point for individuals seeking

medical attention for fibromyalgia and both forms of arthritis. Furthermore, people who have

been diagnosed with these conditions may have ways to self-treat, thus limiting their need to go

to the emergency room.

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Bootstrapping analyses revealed that MT air masses resulted in the highest number of ED visits for all pain conditions examined, while MP air masses resulted in the fewest number of visits. Similar results were noted in the author's previous research on migraines (Elcik et al. 2017).

Seasonal trends in ED visits were thought to potentially have led to these relationships as MT air masses were one of the most common air mass types in the summer, which was often the season with the greatest number of ED visits. Furthermore, MP air masses were frequently experienced in the winter, which was often the season with the least number of ED visits. The seasonal analysis done in this study support these relationships not being caused by underlying trends in the ED visit data. This is because the relationships for both MT and MP air masses were observed across multiple seasons for each of the conditions looked at.

Given the results of previous studies, the increase in ED visits with MT air mass types is surprising, particularly for fibromyalgia and both arthritis types. Strasberg et al. (2002), Gorin et al. (1999), and Aikman (2004) found that low temperatures, high pressure, and high humidity led to increases in pain frequency in those who suffer from fibromyalgia and different types of arthritis. These conditions most closely resemble those found with MP air masses, which were in fact associated with the lowest numbers of pain-related ED visits in this study.

As was the case with migraines (Elcik et al. 2017), few lag relationships were found between the other pain conditions and the different air mass types. With regards to the pressure changes associated with TR air masses, pressure decreases were associated with a higher number of ED visits for fibromyalgia and both arthritis types. For general back pain, pressure increases were associated with a higher frequency of ED visits, which is consistent with the author's prior research on migraines. However, as was the case with migraines, none of these relationships

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were statistically significant. Furthermore, the magnitude of pressure change also did not have

any noticeable impact on pain frequency, as only low correlations were found.

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CHAPTER II

GEOGRAPHICAL VARIABILITY IN THE RELATIONSHIP BETWEEN AIR MASS TYPE

AND EMERGENCY DEPARTMENT VISITS FOR PAIN ACROSS NORTH CAROLINA

2.1   Introduction

In Chapter I, the relationships between synoptic air mass types and the incidence of various forms of pain were examined for one region in North Carolina (the Triangle region). Comparisons were also made to results from the author's prior work in this region on migraine headache (Elcik et al. 2017). This chapter expands on the research conducted in these two studies by examining air mass-pain relationships across *multiple regions* in North Carolina. The associations between weather and human health are known to vary geographically, particularly in response to variations in prevailing weather patterns. North Carolina is a climatologically diverse state that can be divided into three main regions: Appalachian Mountains, Piedmont Plateau, and Coastal Plain (Bobyarchick et al. 2000). The geographic characteristics of these regions could potentially modify the relationships found in Chapter I in a variety of ways. For example, a coastal population may be more acclimated to Maritime Tropical air masses due to their proximity to a warm body of water. On the other hand, mountainous regions typically exhibit greater variability in weather patterns due to elevation and topography. Going up one mile in elevation is roughly equivalent to traveling a thousand miles towards the nearest pole. Therefore, individuals in mountainous regions may be less susceptible to the influence of air mass type on their health, as they likely experience a wider range of meteorological conditions.

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The variability in climate across North Carolina provides an opportunity to identify how the air mass characteristics associated with these regions influence the relationships identified in Chapter I and Elcik et al. (2017). Therefore, the objective of this chapter was to assess regional differences in the relationship between air mass type and pain frequency.

2.2 Data and methods

2.2.1 Study Region and Study Period

Relationships between air mass types and the incidence of pain-related health outcomes were examined from 2007-2013 across the three physiographic regions of North Carolina: Appalachian Mountains, Piedmont Plateau, and Coastal Plain (Figure 2.1). Only a subset of counties in each region were chosen for this research. Variations in elevation across these regions, as well as the relative proximity to the warm waters of the Atlantic Ocean, result in much climatological diversity. As demonstrated in Chapter I and Elcik et al. (2017) for the Triangle region (located in the Piedmont Plateau), the position of North Carolina in the mid-latitudes results in numerous air mass types of varying characteristics (warm, cold, humid, dry) occurring throughout the year. It is hypothesized that numerous air mass types also intersect across the Mountains and Coastal Plain; however, the frequency of air masses in these regions may be different, thereby resulting in different air mass-pain relationships.
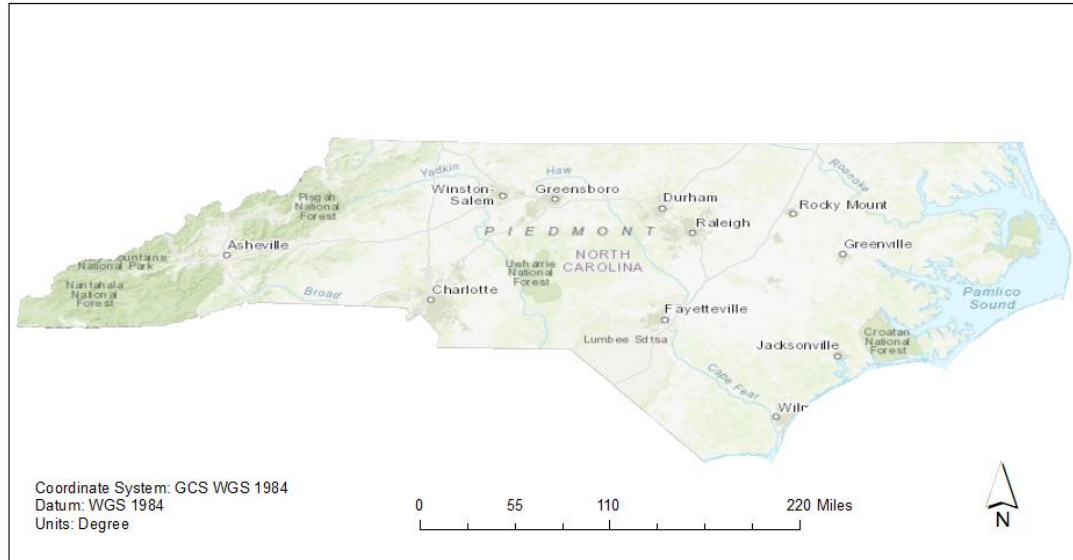
Figure 2.1   North Carolina topography

2.2.2   Data Collection

As in Chapter I, the frequency of pain-related health conditions was determined using daily counts of emergency department (ED) visits from the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT) for the period 2007 to 2013. The same conditions examined in Chapter I were also examined in this chapter (i.e. fibromyalgia, rheumatoid arthritis (RA), osteoarthritis (OA), and general back pain). In addition, ED visits with a primary diagnosis of migraine (ICD-9-CM code 346) were also examined in this chapter.

The Spatial Synoptic Classification (SSC) was again used to determine the daily air mass type. The location of weather stations in North Carolina with available SSC data determined the counties from which the ED data were acquired (Figure 2.2). Air mass types for the Mountain region were obtained from the Asheville Regional Airport station (AVL), while corresponding ED data were obtained from Buncombe and Henderson counties. Air mass types for the Plateau

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region were obtained from the Piedmont Triad International Airport station (GSO), while corresponding ED data were obtained from Guilford, Forsyth, Davidson, Alamance, and Randolph counties. Finally, air mass types for the Coastal region were obtained from the Wilmington International Airport station (ILM), while corresponding ED data were obtained from New Hanover and Brunswick counties. A SSC distribution analysis, over the 2,557 day study period, found that the AVL and GSO stations had the same SSC weather type 55% of the time, while the GSO and ILM station were the same 46% of the time. The AVL and ILM stations, which were the furthest apart, had the same SSC weather type 42% of the time. Furthermore, all three stations had the same classification during 30% of the days in the seven-year study period. Based on this, small study areas were required to ensure that the SSC weather types observed were representative of the counties where ED data were being collected. Ultimately, the selected counties either had a weather station within their border or are directly next to a county that did. Moreover, the stations were relatively central to the counties selected.
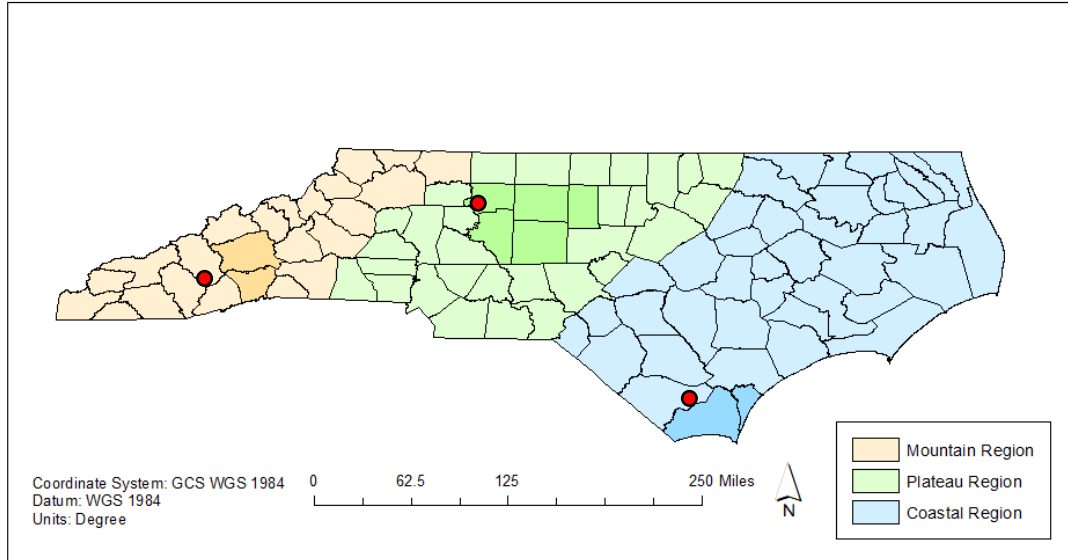
Figure 2.2   Geographical regions of North Carolina by county

Selected counties in each region are highlighted in darker shades and the three airports (AVL, GSO, ILM) are denoted as red dots.

2.2.3   Statistical Methods

Similar to Chapter I, chi-square (χ^2) tests revealed that ED visits for all types of pain were not normally distributed. Therefore, bootstrapping was again used to determine if statistically significant differences existed between the mean number of daily ED visits for each pain-air mass combination. Since the primary objective of this chapter was to assess regional differences in pain-air mass relationships, per capita rates of ED visits for each pain type were calculated using county-level population estimates from the 2010 U.S. Census. Next, 95% bootstrap confidence intervals of mean daily rates of ED visits for each air mass type were created. The null hypothesis was that the means were equal, while the alternative hypothesis was that the means were not equal. The confidence intervals were then compared to see if the null hypothesis could be rejected.

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2.3 Results

2.3.1 Data Characteristics

For each region, the raw counts of ED visits are shown in Table 2.1. The Plateau region had the greatest number of ED visits for each observed condition. This was expected due to the size of this region's population. Based on the 2010 United States Census, the two counties making up the Mountain region had a total population of 345,058, the five counties making up the Plateau region had a total population of 1,294,837, and the two counties in the Coastal region had a total population of 310,098 (United States 2010 Census, 2019). Interestingly though, the Coastal region experienced more ED visits for migraines and back pain compared to the Mountain region, despite the population of the former being smaller. There were consistent trends with regards to the magnitudes of ED visits for each condition; however, one exception was found. For the Plateau and Coastal regions, the number of migraine ED visits was greater than the number of fibromyalgia ED visits, but this was not the case for the Mountain region.

Table 2.1   ED visits in the selected regions of North Carolina, 2007-2013

Condition	Mountain Region	Plateau Region	Coastal Region
Migraines	1,498	30,010	4,832
Fibromyalgia	2,045	5,781	2,009
Rheumatoid Arthritis	586	885	274
Osteoarthritis	1,094	4,227	765
General Back Pain	13,223	98,487	21,497

Adjustments based on population differences were also made through the calculation of ED visit rates (per 100,000 persons), allowing for further comparisons between the three regions. A bootstrapping analysis was completed to see if any statistically significant differences existed.

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Figure 2.3 shows the 95% confidence interval bootstrap plots associated with the mean rate of ED visits from the three geographical regions of North Carolina.

Statistically significant differences in the daily rates of ED visits were found between the different regions. For fibromyalgia and RA, the Plateau region had the lowest rates of daily ED visits out of the regions looked at. With fibromyalgia, the Coastal region had the greatest rates of ED visits, whereas the Mountain region had the greatest rates for RA. Regionality affected the magnitude of migraine and general back pain ED visit rates similarly. For both conditions, the Mountainous region of North Carolina experienced the lowest rates. These regional differences in magnitude likely resulted from various socio-economic factors; however, weather could have also contributed.

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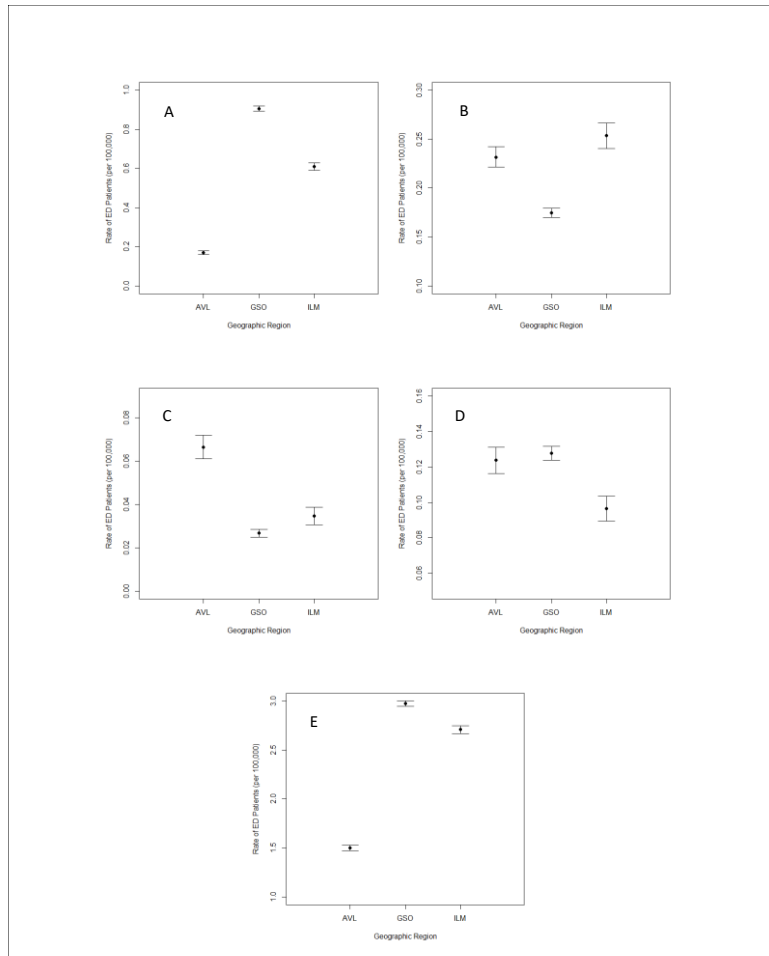
Figure 2.3   (A) Migraines, (B) Fibromyalgia, (C) Rheumatoid Arthritis, (D) Osteoarthritis, and
               (E) Back Pain bootstrap confidence intervals of the mean daily number of ED
               visits for each region, 2007-2013

Rates of ED visits by age group for each pain type and region are shown in Figures 2.4-2.8. The highest rates for migraines were found among mostly middle age adults (25-44 years of age) across all three regions, with fewer visits among the young (0-9) and elderly (65+). Rates of ED visits for fibromyalgia were also common among middle age adults, particularly in the Mountains and Coastal Plain. In contrast, the highest rates for both types of arthritis were found among the elderly (65+), particularly in the Mountain region. The age group distribution for

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general back pain visits was similar to that for fibromyalgia, but with higher rates among the elderly (65+), particularly in the Plateau and Coastal regions. Rates of ED visits for all pain types across all regions were highest among females (Figures 2.9-2.13).
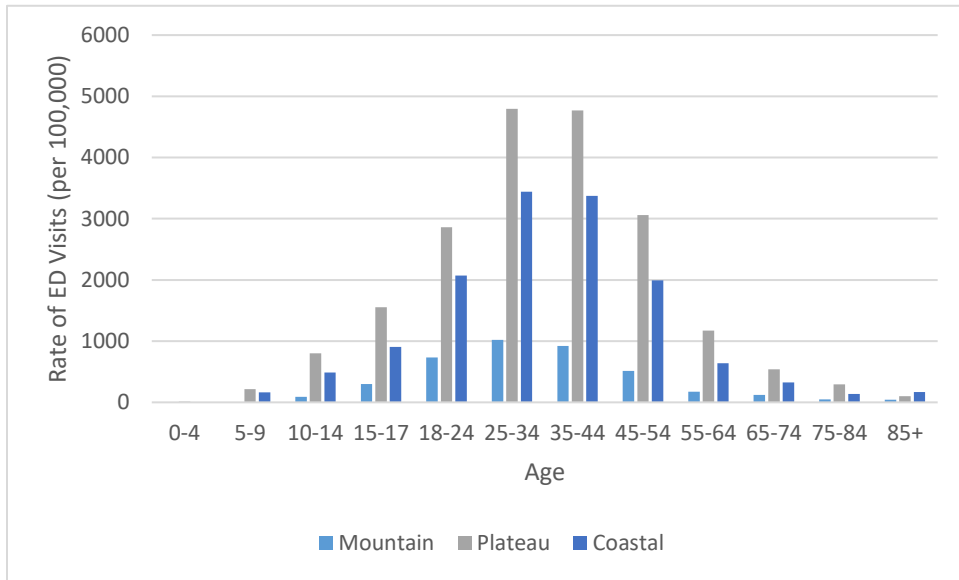
Figure 2.4   Age distributions of migraine ED patients for the mountain, plateau, and coastal regions from 2007-2013
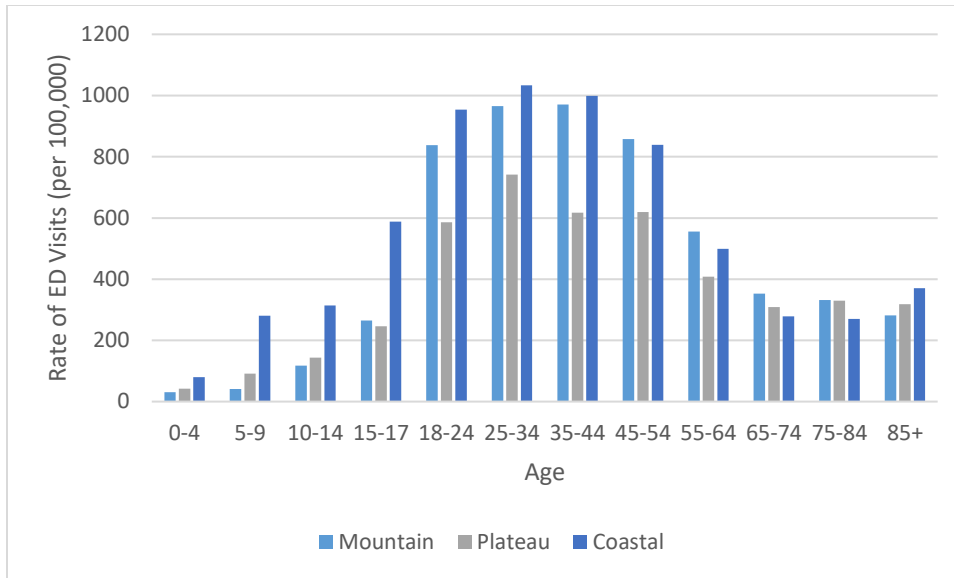
Figure 2.5   Age distributions of fibromyalgia ED patients for the mountain, plateau, and coastal regions from 2007-2013
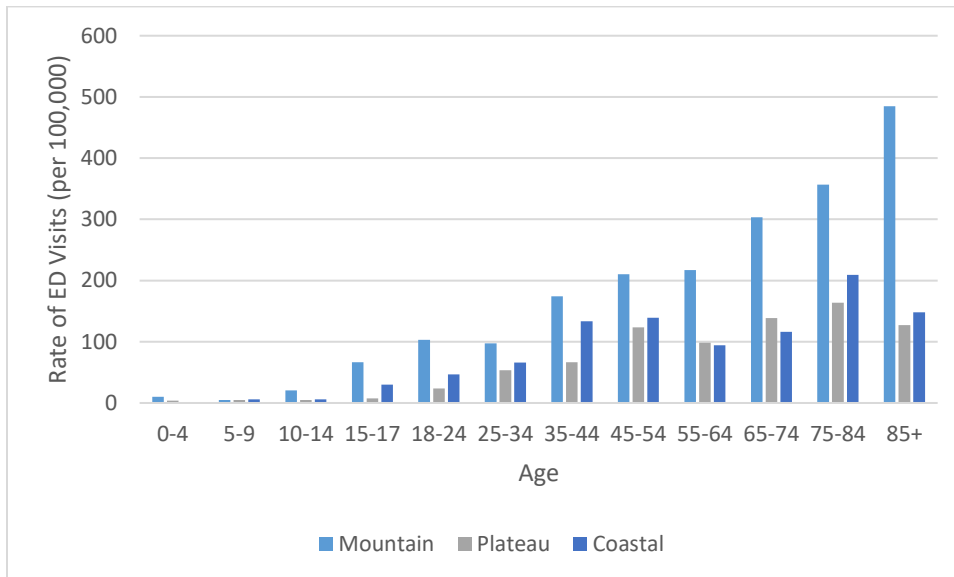
Figure 2.6   Age distributions of rheumatoid arthritis ED patients for the mountain, plateau, and coastal regions from 2007-2013

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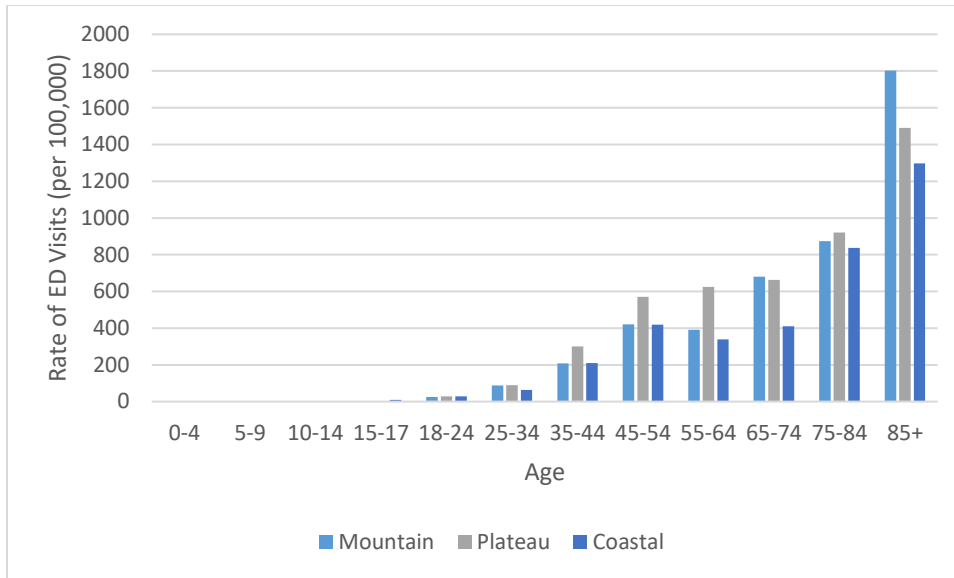
Figure 2.7   Age distributions of osteoarthritis ED patients for the mountain, plateau, and coastal regions from 2007-2013
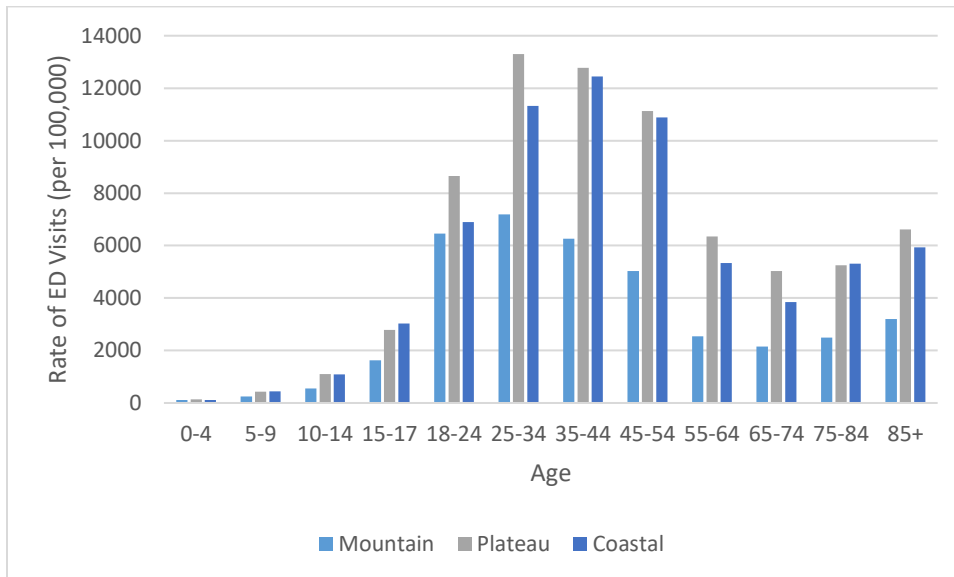
Figure 2.8   Age distributions of general back pain ED patients for the mountain, plateau, and coastal regions from 2007-2013

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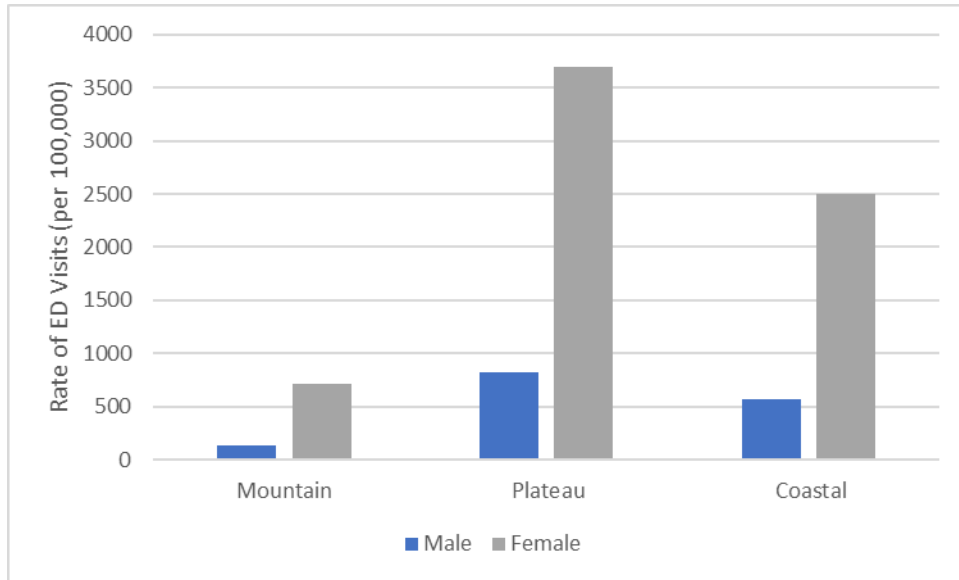
Figure 2.9   Gender distributions of migraine ED patients for the mountain, plateau, and coastal regions from 2007-2013
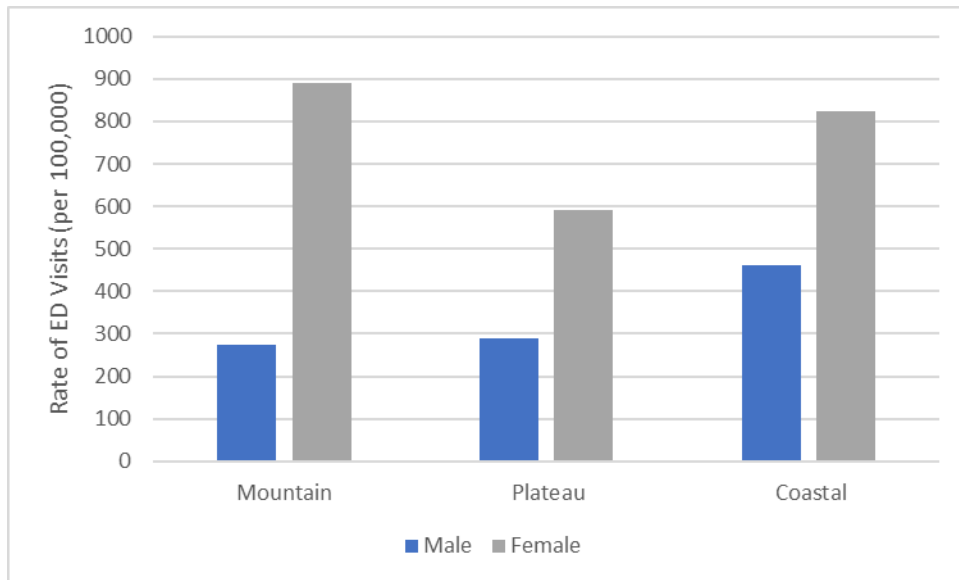
Figure 2.10   Gender distributions of fibromyalgia ED patients for the mountain, plateau, and coastal regions from 2007-2013
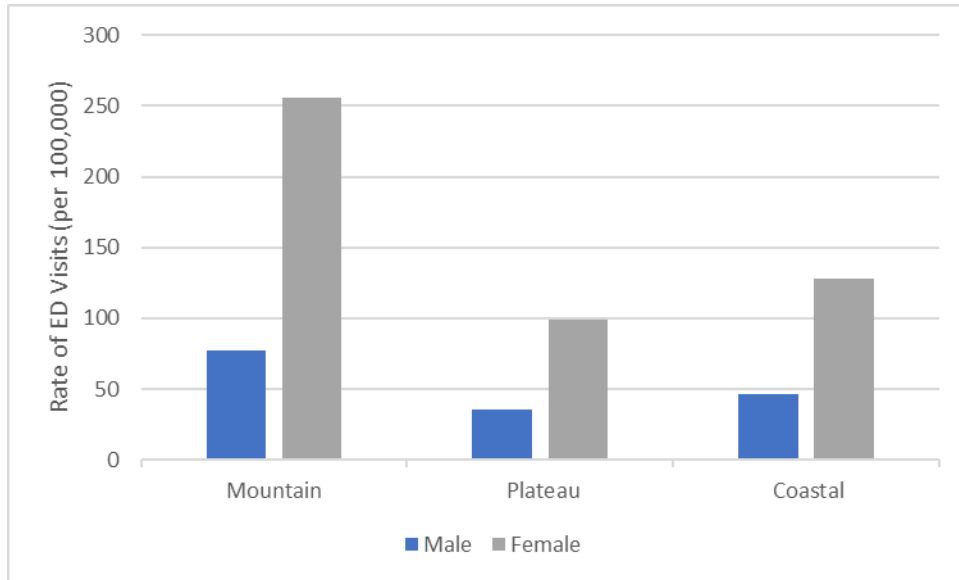
Figure 2.11   Gender distributions of rheumatoid arthritis ED patients for the mountain, plateau, and coastal regions from 2007-2013
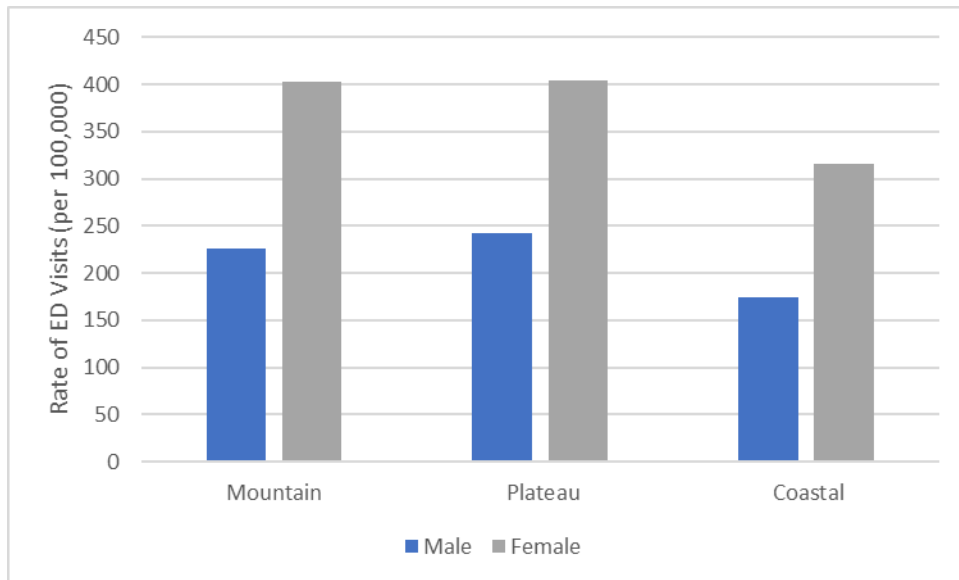
Figure 2.12   Gender distributions of osteoarthritis ED patients for the mountain, plateau, and coastal regions from 2007-2013

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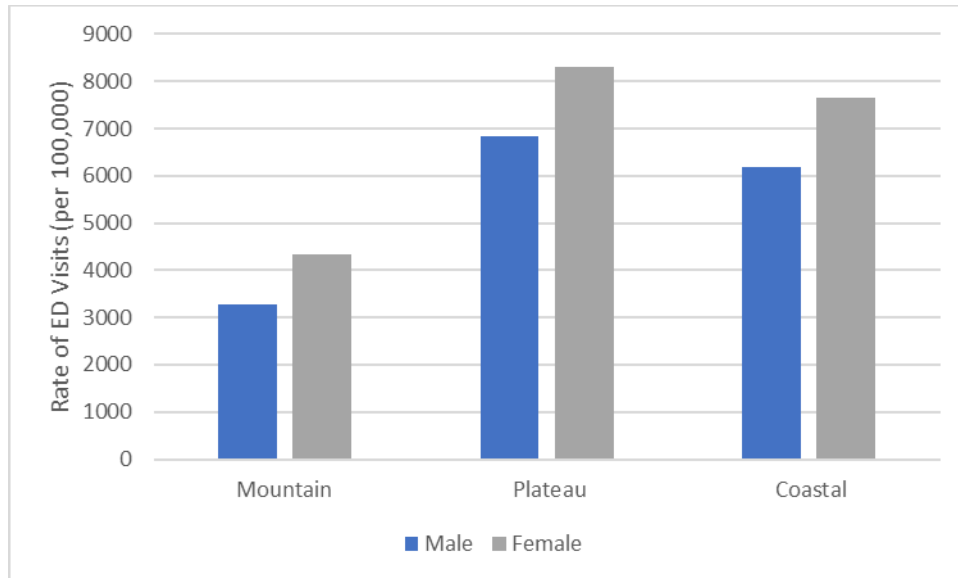
Figure 2.13   Gender distributions of general back pain ED patients for the mountain, plateau, and coastal regions from 2007-2013

Figures 2.14-2.16 illustrate how ED visits for the different conditions in each region varied by meteorological season. In general, ED visits were most frequent in summer and least frequent in winter. One notable exception was a winter peak in RA visits in the Coastal region. Of the conditions examined, both arthritis types exhibited the most seasonal variability across the three regions, while fibromyalgia and general back pain exhibited the least amount of seasonal variability.

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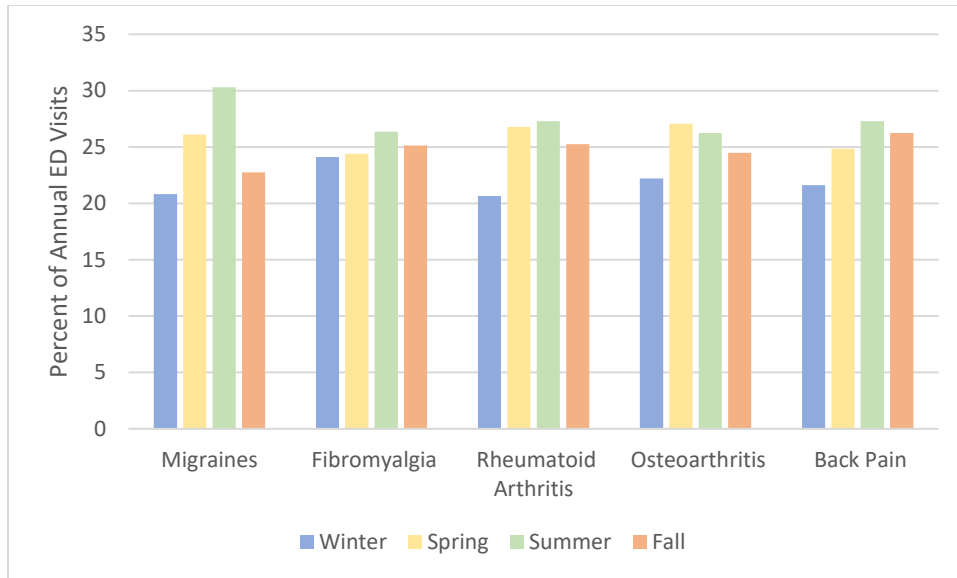
Figure 2.14   AVL seasonal distributions of ED patients for the different conditions of interest from 2007-2013
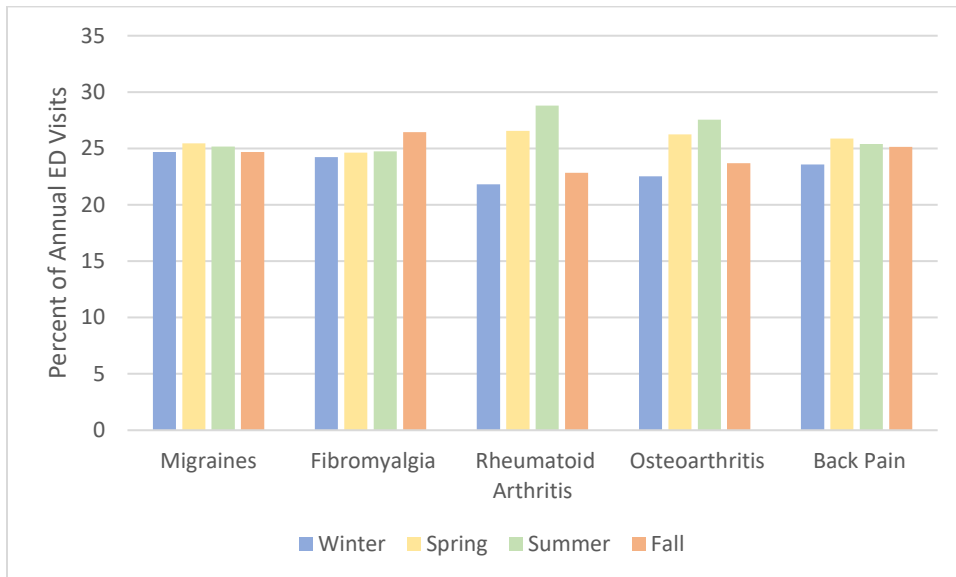
Figure 2.15   GSO seasonal distributions of ED patients for the different conditions of interest from 2007-2013

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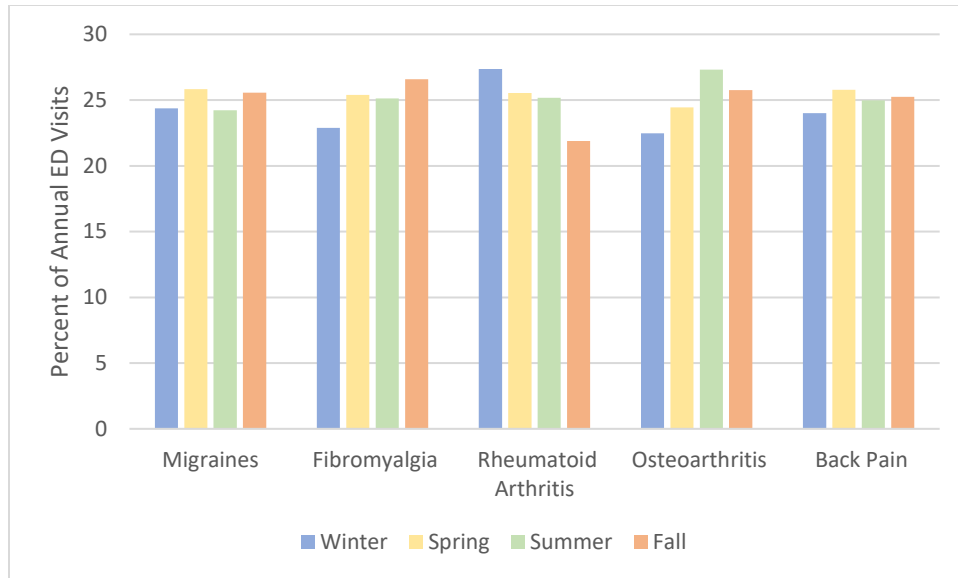
Figure 2.16   ILM seasonal distributions of ED patients for the different conditions of interest from 2007-2013

Based on Figures 2.17-2.20, the SSC displayed some seasonal trends. For the Mountain, Plateau and Coastal regions, Polar air masses (moist and dry) reached their peak frequencies in the winter. With regards to Tropical air masses, the MT classification had its highest frequency in the summer for each of the regions. Interestingly though, only in the plateau did the DT air mass experience its maximum frequency in the summer. For the Mountain and Coastal regions, this air mass reached its peak frequency in the spring and fall seasons, respectively. Moderate air masses were less susceptible to seasonality; however, some slight changes did occur. DM air masses typically maximized in the fall, while MM air masses commonly spiked in the summer months.

Several regional differences in the seasonal frequency of air mass types were discovered based on these figures. One of the biggest differences involved MT air masses. During each season, the Coastal region experienced this air mass type more frequently compared to the other

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two regions. In fact, during the summer, the coastal region's most common air mass type was MT (54 percent of summer days being given this classification). Another regional difference in the seasonal frequency of air mass types involved DT classifications. The Plateau region had these air masses more often than the Mountain or Coastal regions.

One of the major similarities between the three regions was that the DM air mass was one of the more common types during each season. In fact, for all three geographical regions looked at, the DM air mass was the most common type during three of the four meteorological seasons (i.e. winter, spring, and fall).
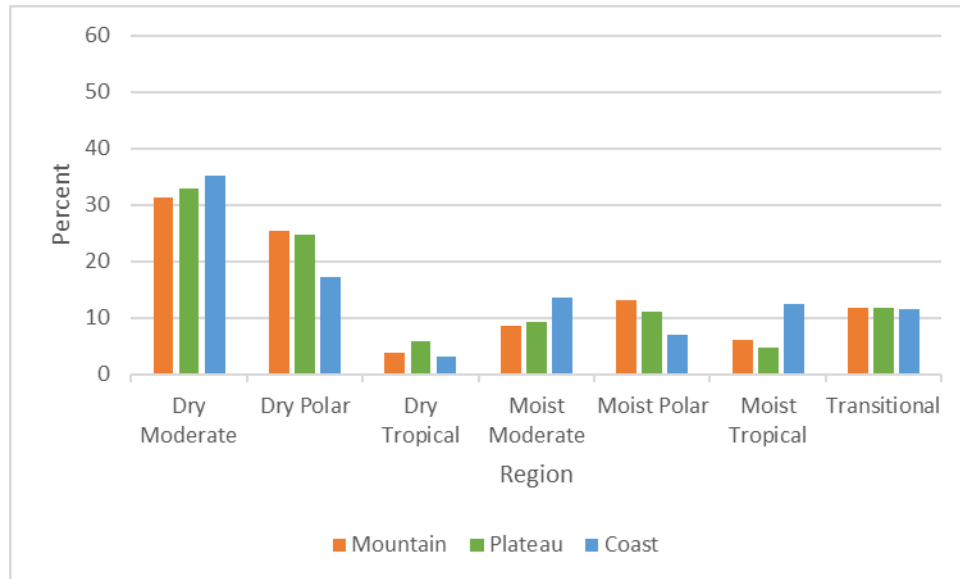
Figure 2.17   Distribution of Spatial Synoptic Classifications during the winter for the selected regions of North Carolina from 2007-2013
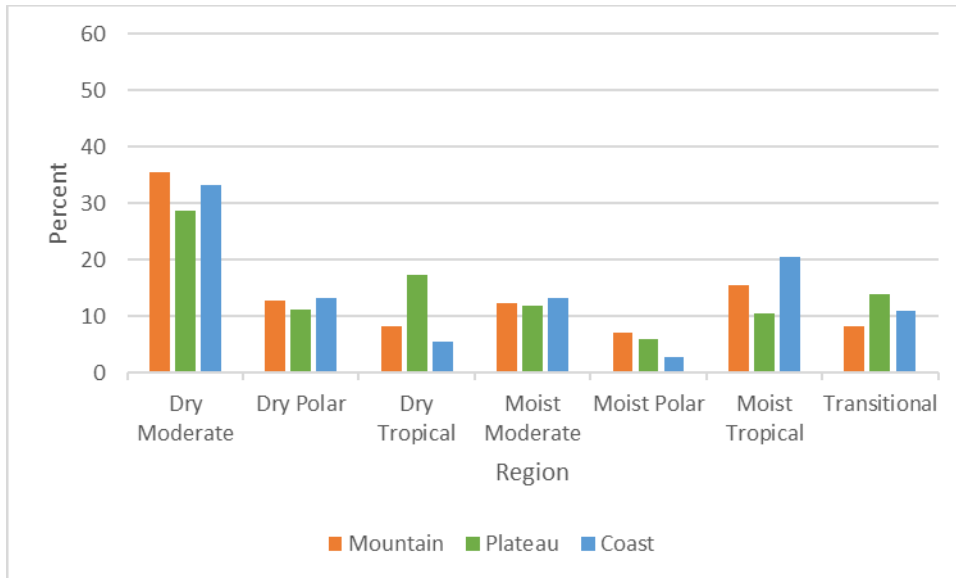
Figure 2.18   Distribution of Spatial Synoptic Classifications during the spring for the selected regions of North Carolina from 2007-2013
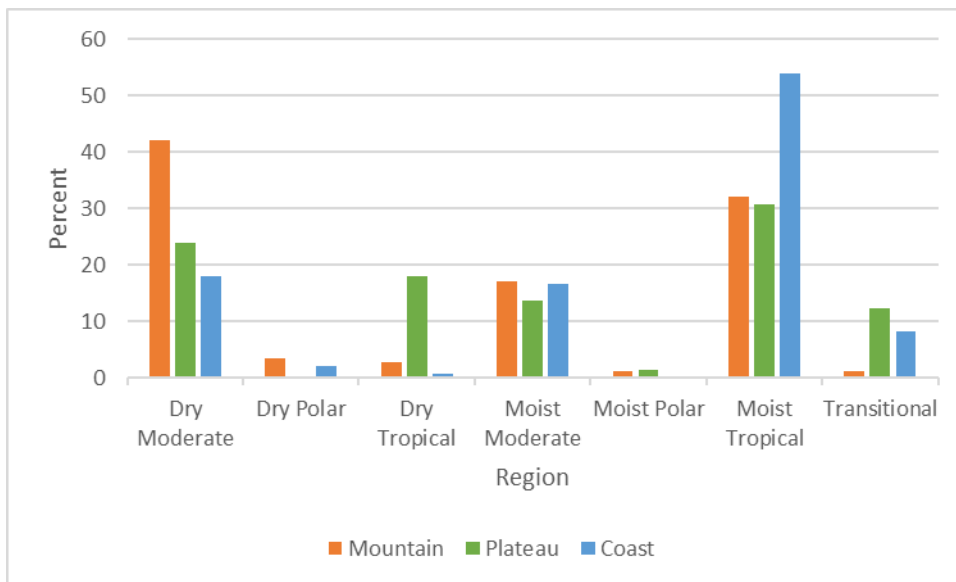
Figure 2.19   Distribution of Spatial Synoptic Classifications during the summer for the selected regions of North Carolina from 2007-2013

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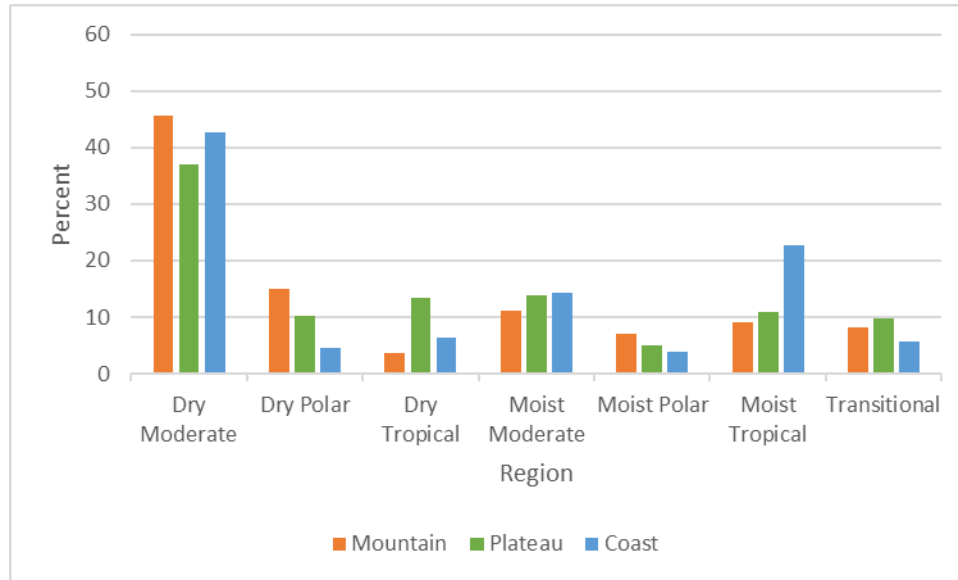
Figure 2.20   Distribution of Spatial Synoptic Classifications during the fall for the selected regions of North Carolina from 2007-2013

2.3.2   Bootstrapping Results

2.3.2.1   Mean Bootstraps

Figures 2.21-2.25 show the 95% confidence interval bootstrap plots of the mean per capita rate of daily ED visits associated with each air mass by region. Each figure corresponds to one of the conditions of interest. Based on these plots, several relationships between air mass types and pain-related conditions were revealed.

2.3.2.1.1   Migraines

In the Mountain region, MT air masses were associated with the highest rates of ED visits for migraine. These rates were statistically significantly higher than those associated with DM, DP, and MP air masses. In the Plateau region, both MT and DT air masses were associated with the highest rates of ED visits for migraine, while MP and DP air masses were associated with the fewest visits. The differences in ED visits between MT and MP air masses, and between DT and

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DP air masses, were statistically significant. DT air masses were also associated with high rates of ED visits for migraine in the Coastal region, while DP air masses were also associated with the lowest rates. The differences in ED visits between these two air masses were statistically significant. In contrast to the other two regions, MT air masses were not associated with an increase in ED visits for migraine in the Coastal region. Interestingly, while MP air masses were associated with the lowest rates of ED visits in the Mountains and Plateau regions, they were associated with the highest rates of ED visits in the Coastal region.

Figure 2.21   (A) Mountain, (B) Plateau, and (C) Coastal region bootstrap confidence intervals of the mean rate of daily migraine ED visits for each air mass, 2007-2013

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2.3.2.1.2   Fibromyalgia

Relationships between air mass type and ED visits for fibromyalgia were generally weak in the Mountain region. One exception was for MM air masses, which exhibited statistically higher rates of ED visits than DP and MP air masses. In the Plateau region, MT and MM air masses resulted in the highest rates of ED visits for fibromyalgia, while DP, DT, and TR air masses resulted in the fewest visits. The differences in ED visits between these air mass types were statistically significant. Similar relationships were found in the Coastal region; however, the confidence intervals associated with the MP and DT air masses were large. These large confidence intervals resulted in fewer statistically significant relationships.

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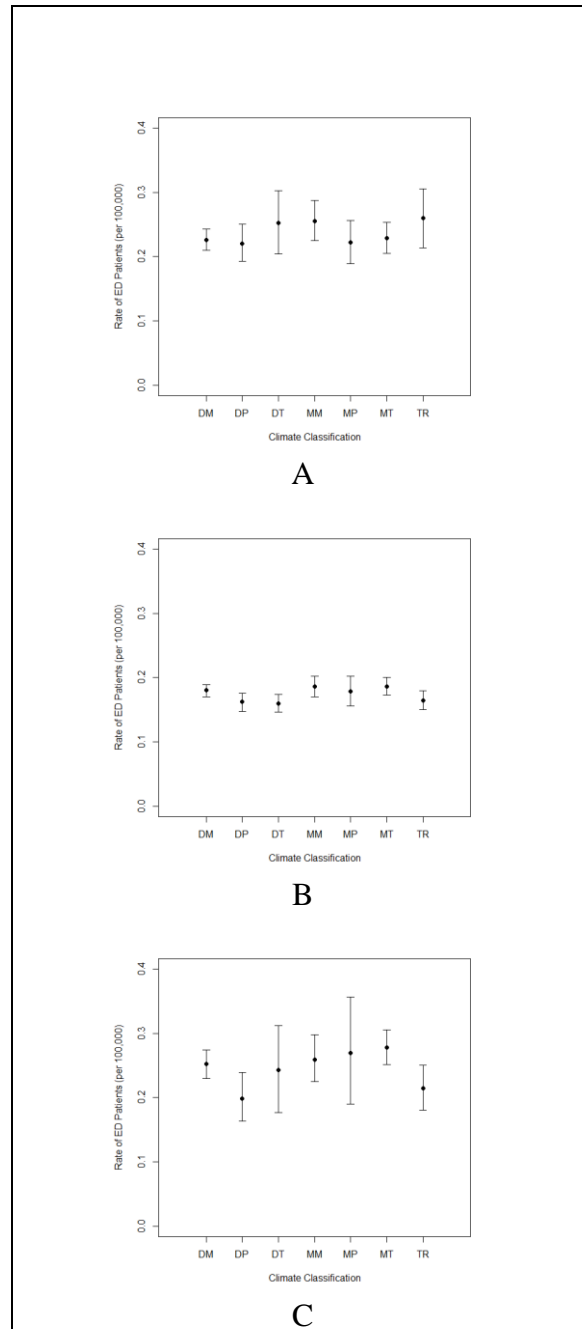
Figure 2.22   (A) Mountain, (B) Plateau, and (C) Coastal region bootstrap confidence intervals of the mean rate of daily fibromyalgia ED visits for each air mass, 2007-2013

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2.3.2.1.3   Rheumatoid Arthritis

In the Mountain region, rates of ED visits for RA were highest among MM and MP air masses. These rates were statistically significantly higher than those associated with many of the other air mass types. The lowest rates for RA were found among DT air masses. In fact, the differences in ED visits between DT and all other air masses were statistically significant. In the Plateau region, MT and MM air masses were associated with the greatest rates of ED visits. These rates were statistically significantly higher than those associated with all other air mass types. Interestingly, while MP air masses exhibited high rates of ED visits in the Mountain region, they were associated with the lowest rates in the Plateau region. Relationships between ED visits for RA and air mass types were weakest in the Coastal region. MT and TR air masses exhibited the greatest number of ED visits, while DM air masses exhibited the fewest. The differences between these air masses was statistically significant.

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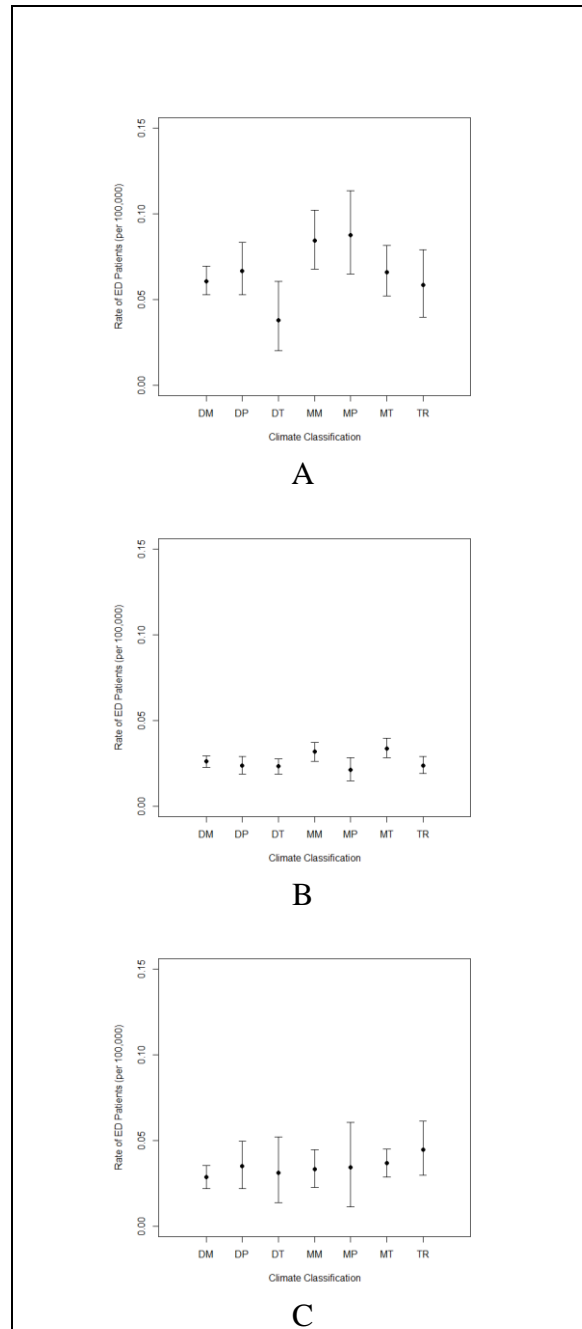
Figure 2.23   (A) Mountain, (B) Plateau, and (C) Coastal region bootstrap confidence intervals of the mean rate of daily rheumatoid arthritis ED visits for each air mass, 2007-2013

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2.3.2.1.4   Osteoarthritis

Relationships between ED visits and air mass types for OA were very similar to those for RA, particularly in the Mountain and Plateau regions. As was the case with RA, DT air masses in the mountain region resulted in a drop in ED visits for OA. Furthermore, like with RA, MP air masses resulted in high rates of OA ED visits in the Mountain region and low rates of OA ED visits in the Plateau region. Generally speaking, in both the Mountain and Plateau regions, MT air masses resulted in higher rates of ED visits for OA compared to many of the other air mass types. In contrast, no statistically significant relationships were found in the Coastal region.

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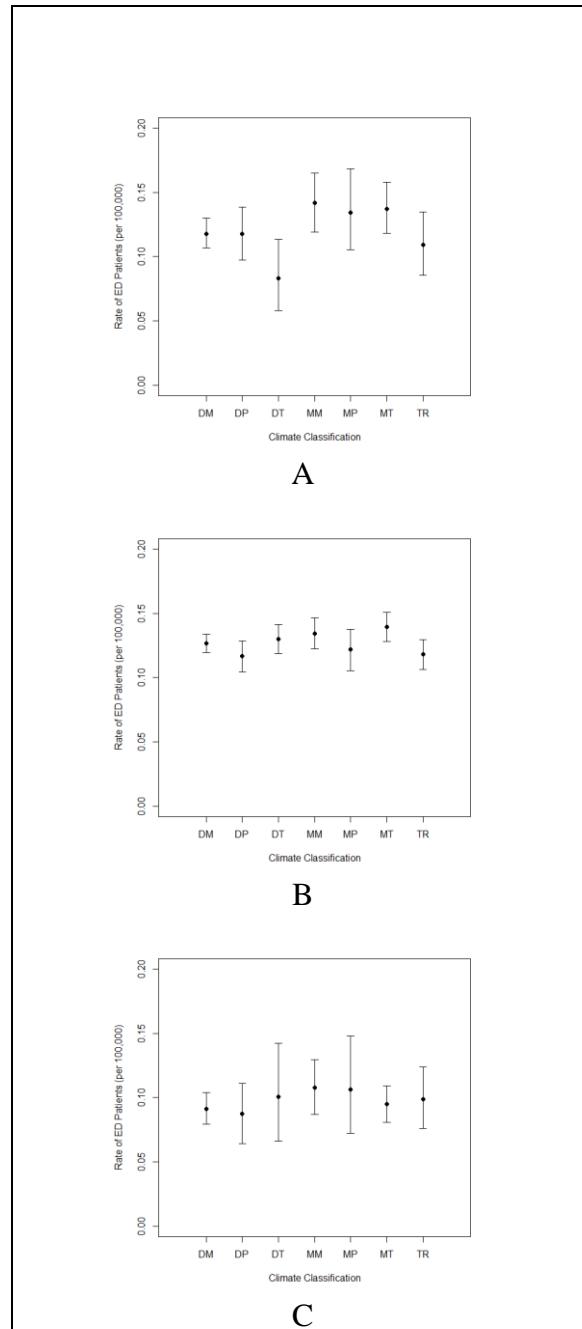
Figure 2.24   (A) Mountain, (B) Plateau, and (C) Coastal region bootstrap confidence intervals
of the mean rate of daily osteoarthritis ED visits for each air mass, 2007-2013

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2.3.2.1.5   General Back Pain

In the Mountain region, MT and MM air masses were associated with the highest rates of ED visits for general back pain, while both polar air masses (DP and MP) as well as TR air masses were associated with the lowest rates. The differences between MT and MP air masses were statistically significant. Another significant difference was noted between DT and DP air masses, with the warm, dry air mass associated with a higher visit rate. MT and MM air masses were also associated statistically higher ED visit rates for back pain the Plateau region, while MP air masses were associated with the fewest visits. Unlike the Mountain region, ED visits associated with DP air masses were not much lower than the other air mass types. As was the case with OA, no statistically significant differences in ED visits for back pain were found between air mass types in Coastal region.
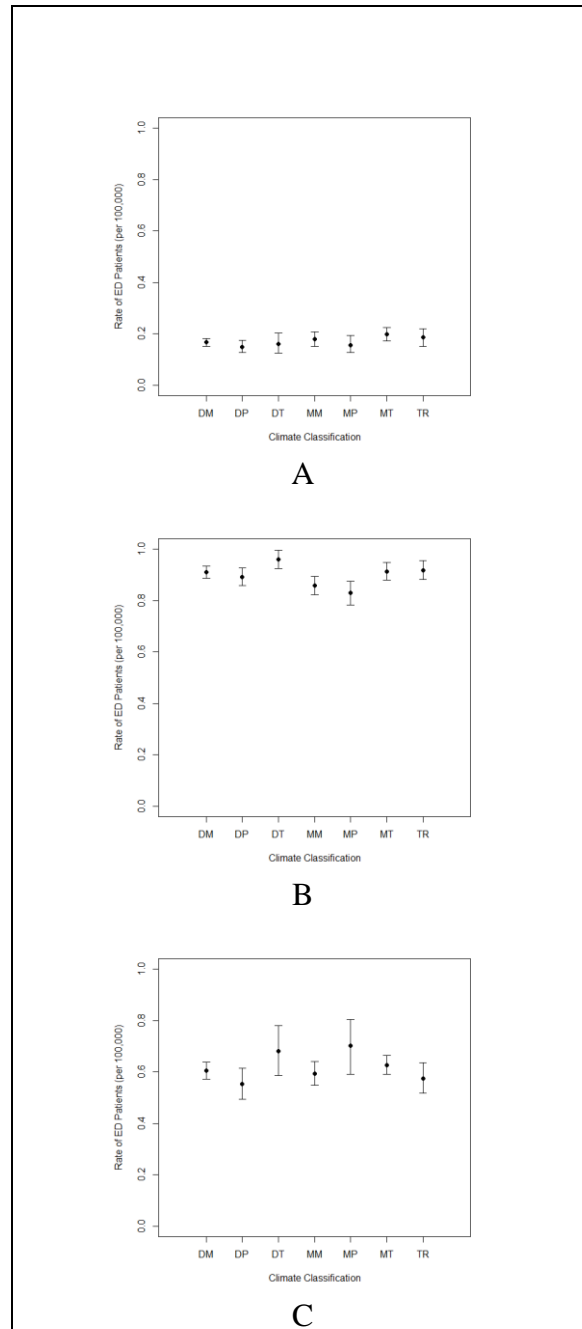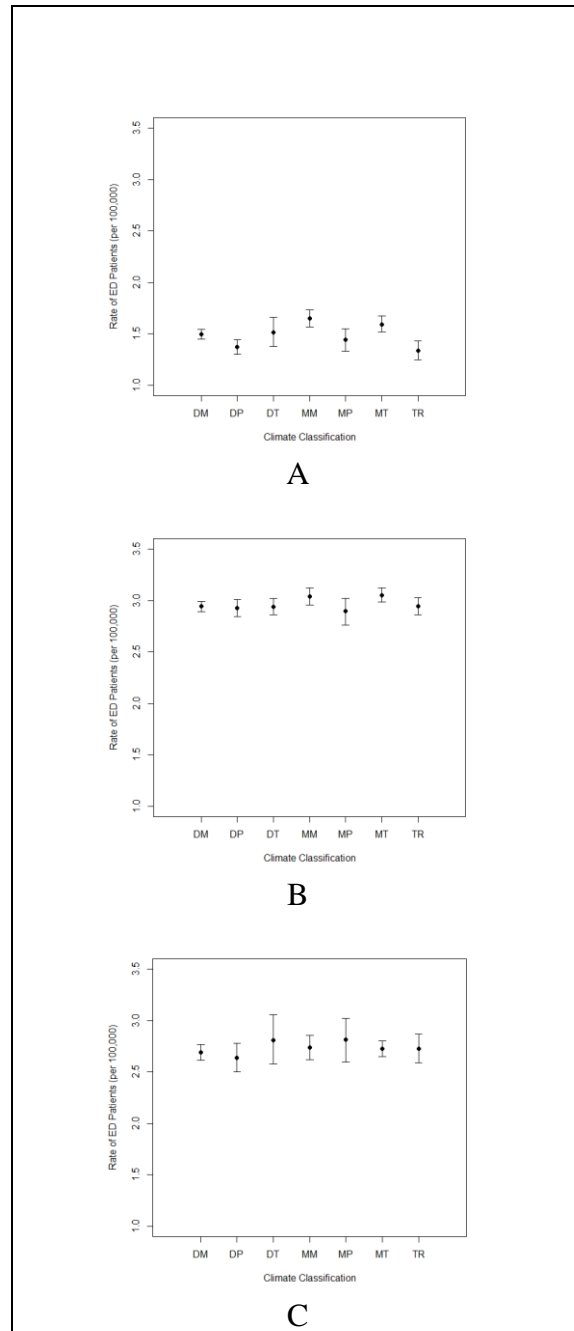
Figure 2.25   (A) Mountain, (B) Plateau, and (C) Coastal region bootstrap confidence intervals of the mean daily rate of general back pain ED visits for each air mass, 2007-2013

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2.3.2.2　　Standard Deviation Bootstraps

Figures 2.26-2.28 show the standard deviation bootstrap plots of daily ED visits for each condition and air mass type. Each figure represents one of the three regions. In general, there were few statistically significant relationships. For migraines, the variability in ED visits associated with MT air masses was significantly greater than the variability associated with MP air masses in both the Mountain and Plateau regions. For fibromyalgia, the variability in ED visits associated with TR air masses was significantly greater than the variability associated with all other air mass types in the Mountain region, while in the Coastal region, the variability associated with TR air masses was significantly less. For RA, the variability in ED visits associated with MT air masses was significantly greater than the variability associated with all other air mass types in the Plateau region. In the Mountain region, the variability in ED visits was lowest among DT air masses for both arthritis types. For general back pain, the variability in ED visits was significantly lower on TR air mass days than on all other air mass days in the Mountain region.

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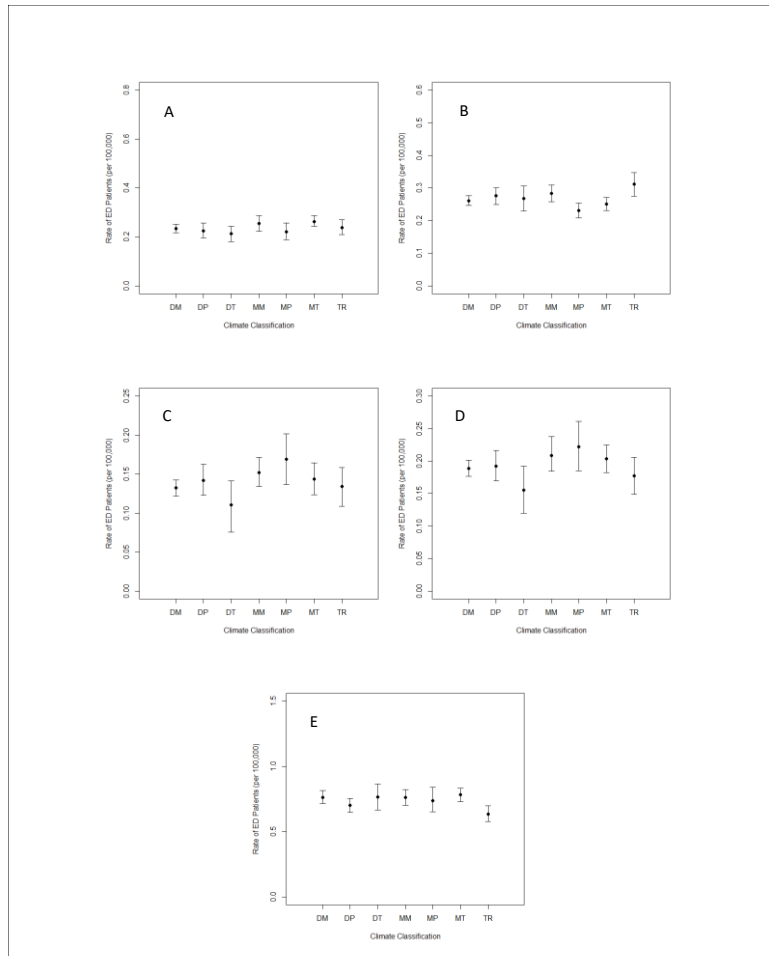
Figure 2.26   (A) Migraine, (B) Fibromyalgia, (C) Rheumatoid arthritis, (D) Osteoarthritis, and (E) Back Pain bootstrap confidence intervals of the standard deviation of ED visits for each air mass from the AVL area, 2007-2013
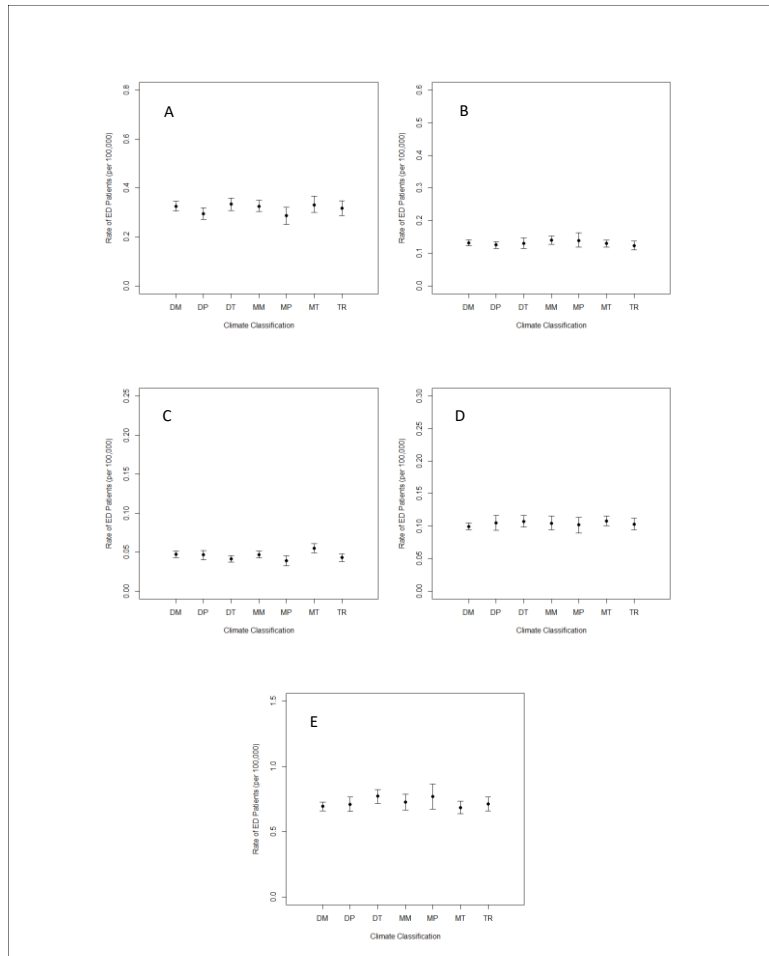
Figure 2.27   (A) Migraine, (B) Fibromyalgia, (C) Rheumatoid arthritis, (D) Osteoarthritis, and
(E) Back Pain bootstrap confidence intervals of the standard deviation of ED visits
for each air mass from the GSO area, 2007-2013
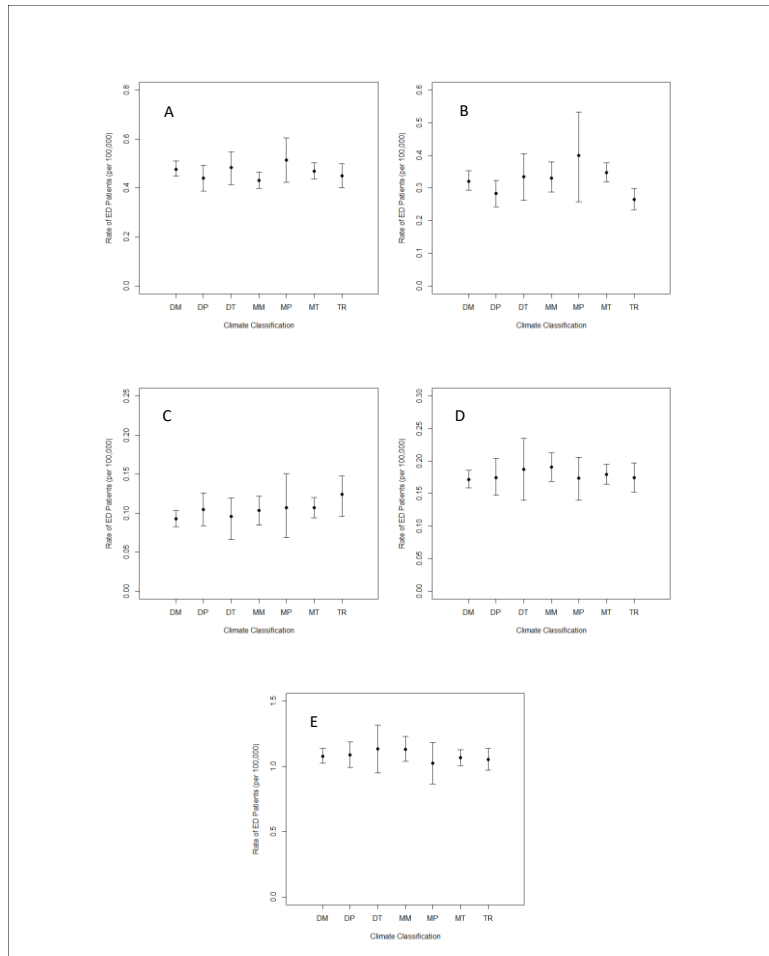
Figure 2.28   (A) Migraine, (B) Fibromyalgia, (C) Rheumatoid arthritis, (D) Osteoarthritis, and (E) Back Pain bootstrap confidence intervals of the standard deviation of ED visits for each air mass from the ILM area, 2007-2013

2.4   **Discussion and Conclusion**

In this chapter, the relationships between air mass type and pain frequency for multiple

conditions were examined across the three primary physiographic regions of North Carolina

from 2007-2013. The Spatial Synoptic Classification (SSC) was used to determine daily air mass

type, while the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC

DETECT) and population estimates were used determine per capita rates of ED visits for

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migraine, fibromyalgia, RA, OA, and general back pain. The objective of this chapter was to determine if the relationships between air mass and pain demonstrated regional variability across climatologically diverse locations. As expected, the relationships found between air mass type and pain in the Plateau region were similar to those found in Chapter I (the relationships for migraine headache were also similar to those found in Elcik et al. 2017). However, in this chapter, differences were noted between the Plateau, Mountains, and Coastal regions.

Both MT and MM air masses were frequently associated with the highest rates of ED visits for all the conditions examined, while MP and DP air masses were often associated with the fewest rates of visits. This was certainly the case in the Plateau region, but several conditions also exhibited similar relationships with these air mass types in the Mountains, particularly OA and general back pain. Exceptions to this were found with ED visits for migraine and fibromyalgia, where fewer statistical relationships were noted in the Mountain region. This may be due to the greater microclimatic variability in the mountains, which was a hypothesis proposed earlier in this chapter. Due to variability in meteorological conditions with elevation, the broader synoptic environment may not have a significant influence on the incidence of migraine or fibromyalgia.

While several significant associations were found between air masses and pain in the Plateau and Mountain regions, very few relationships were identified in the Coastal region. In fact, in some cases (e.g. OA, general back pain), no statistically significant associations were found. While MT air masses were frequently associated with the highest number of ED visits for most conditions in the other regions, they were often associated with lower counts of ED visits in the Coastal region. This could be the result of the maritime climate of the coastal region. The maritime aspect of the region's climate would lessen the physical differences between each air

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mass type, thus potentially altering the impacts on pain. Moreover, persistent exposure to this air mass type, due to living near its source region, may be another explanation. Due to more frequent exposure, those who are susceptible to pain may become acclimated to any negative physiological impacts of the MT air mass type.

The relationships between air mass types and some forms of pain may be able to be explained physiologically. In the case of migraine headache, warm temperatures associated with tropical air masses could result in vasodilation (i.e. expanding blood vessel). When the body is thermally stressed, vasodilation can increase blood flow to the skin. This enables heat to be dissipated from the surface of the skin via conduction, convection, and the evaporation of sweat (Charkoudian, 2010). The dilation of blood vessels increases pressure in the body, including the cranium, therefore potentially resulting in increased risk for head pain. During cold conditions, vasoconstriction occurs in the blood vessels, which slows down the flow of blood to the skin and reduces heat exchanges with the environment (Charkoudian, 2010). By constricting the blood vessels in the body, the pressure in the cranium would be reduced, potentially resulting in reduced risk for head pain.

It is worth noting that there is literature that both supports and refutes the notion that vasodilation plays a role in migraine attacks. For example, Asghar et al. (2011) used a high-resolution direct magnetic resonance angiography imaging technique to measure the arterial circumference of the extracranial middle meningeal artery (MMA) and the intracranial middle cerebral artery (MCA). Dilation was found in both the MMA and MCA, suggesting dilation is an integral part of the migraine pathophysiology. An earlier study, Nagata et al. (2009), also looked at the behavior of the MMA during a migraine. The change of the MMA was measured on the axial brain images of a 42-year-old woman using MATLAB for three phases (attack-free period,

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during an attack, a period after medication) (Nagata et al. 2009). While some changes in the artery were identified, they were not considered statistically significant. Therefore, the study concluded that vasomotion may not be associated with migraine pathophysiology.

A review of the literature fails to provide a physiological explanation for the relationships found with MT and MP air masses for the other conditions examined in this study. One possibility is that the presence of a particular air mass type may lead to an increase or decrease in physical activity and pain-related symptoms. The presence of an MT air mass, for instance, may increase the likelihood that an individual will seek outdoor activities (e.g. golf) that are linked to increased risk for back pain (Hosea et al. 1996). A corollary to this is that individuals may be less likely to engage in outdoor activities during cold and humid days, which may explain why MP air masses resulted in fewer ED visits for many of the conditions of interest.

CHAPTER III

PERCEPTIONS OF WEATHER-BASED PAIN FORECASTS AND THEIR EFFECT ON

DAILY ACTIVITIES

3.1   Introduction

Weather information includes, but is not limited to, temperature, humidity, pressure, probability of precipitation, and cloud cover. People obtain routine weather information from many different sources, including television, radio, print/newspapers, cell phone applications, internet websites, word of mouth, and social media (i.e. Facebook and Twitter).

The source that people turn to for their weather information can vary based on a variety of factors. One factor is age. In a 2018 survey, the Pew Research Center found that only about one-third of those 65 years of age and older in the U.S. use the internet in their daily lives (Pew Research Center, 2018). However, Hilt et al. (2010) found that of the elderly who do use the internet, most use it as a source of news. In particular, the individuals in their study frequently used popular search engines like Google and Yahoo to access information, including weather information.

Community type has also been found to influence how people receive information, including weather information (Pew Research Center, 2012). Research from 2012 found that urban populations used a wide range of platforms to obtain news and information, though most relied mainly on technologic devices, especially cell phones. Suburban residents, on the other hand, received most of their information from the radio. This is not surprising, as suburban

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residents have long been associated with longer commute times than urban or even rural residents.

Regardless of the source, weather information is often provided via a forecast, which indicates how meteorological variables (e.g. temperature, humidity, pressure, wind speed/direction, cloud cover) may change over time, usually over a period of up to five days. Lazo et al. (2009) conducted a study of about 1,500 individuals in the U.S. to assess where, when and how often people obtain weather forecasts, how they perceive forecasts, how they use forecasts, and the value they place on current forecast information. They found that the average adult obtains a weather forecast approximately 115 times per month, which equals more than 300 billion forecasts annually. Survey results indicated that the public was highly satisfied with weather forecasts, though their confidence decreased with longer-range forecasts. Lazo et al. (2009) estimated the annual value of weather forecast information at 31.5 billion dollars per year to US households. This is a remarkable value when considering that the costs associated with producing weather forecasts is approximately 5.1 billion dollars per year (Lazo et al. 2009).

Results of the Lazo et al. study also revealed that people use weather forecasts to make decisions across a range of sectors (e.g. transportation, agriculture, energy). While many decisions are made within the standard five-day forecast period, there has been an increasing demand for longer-range forecasts (e.g. 7-10 day forecasts). Several of these forecasts are concerned with how different weather variables lead to an environmental response. Examples include flood and drought forecasts, which are issued by agencies such as the National Weather Service (NWS) and Climate Prediction Center (CPC).

The need for weather information has also led to the development of specialized forecasts. One type of specialized forecast is a weather-based human health forecast, which uses

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weather variables to predict a human-health response. The earliest weather-based health forecasts involved measures of "apparent" temperature, such as the heat index and wind chill. These indices were initially developed in the 1970s, and modified versions, which provide a "real feel" temperature for outdoor conditions, are still used today by a number of weather service providers (e.g. local meteorologists, The Weather Channel, AccuWeather, and Weather Underground). More complex thermal comfort indices have also been developed, such as the Physiological Equivalent Temperature (Hoppe 1999). While thermal comfort indices have existed for several decades, their use in operational forecasting has been rather limited. More recently, weather-based predictions for other health conditions, such as the flu, common cold, and respiratory stress (sinus, pollen, dust, and dander), have been developed and are disseminated by many weather-related media sources, such as AccuWeather and The Weather Channel.

One of the newest types of weather-based forecasts are those that are focused on different types of pain (i.e. meteoropathy). As discussed in Chapter I, numerous studies have sought to determine potential relationships between weather and pain. While earlier research that focused on individual weather variables largely failed to find consistent relationships, more recent synoptic-based approaches have yielded more robust results (Cooke et al. 2000; Elcik et al. 2017; Piorecky et al. 1997). Much of this research was conducted with forecasting applications in mind. Weather-based pain forecasts may give sufferers some notice for when to take preventative measures (i.e. medication). The weather media company AccuWeather provides two types of daily weather-based pain forecasts, one for arthritis pain and one for migraine headache. These forecasts categorize the daily weather as either beneficial (i.e. weather conditions that reduce the risk of pain), neutral, at risk, high risk, or extreme (i.e. weather will significantly impact the risk of pain) (AccuWeather, 2018). Information about the conditions

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used in the creation of these forecasts, or how they are made (i.e. models or human-created) is not publicly available. Nevertheless, these products represent an expanding suite of weather-based human health forecasts.

Forecasting ability will continue to improve as knowledge about the relationships between weather and pain increases. Further improvements will eventually lead to more widespread adoption of pain forecasting by other weather media agencies. Therefore, it is important to know how those who suffer from pain respond to weather-based pain forecasts. While research has examined how weather forecasts (Morss et al. 2010) and severe weather watches (Gutter et al. 2018) affect an individual's decision-making process, the author is unaware of any research on how pain sufferers use and are influenced by weather-based pain forecasts. Therefore, the objectives of this research were to (1) determine if people who suffer from migraines or pain-related conditions are receptive to weather-based pain forecasting and (2) determine how these forecasts impact the daily activities of those who use them.

3.2   Data and Methods

3.2.1   Survey

A survey was constructed to complete both objectives of this study. The survey was generated using Qualtrics, a private online survey tool, and distributed using various social media platforms (i.e. Facebook and Twitter). The survey was shared by broadcast meteorologists from around the country, as well as professors, friends, and family. The target audience were those in the general public who suffer from migraines or some type(s) of pain-related condition(s). The survey contained a total of 40 questions, which were mainly a mix of multiple choice (Appendix A.1). A small subset of these multiple choice questions were Likert-type, where respondents used multiple choice selections to indicate their likelihood of some action.

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Some of the questions also provided the option to write-in an answer. Prior to taking the survey, potential respondents were asked a preliminary question to participate in the survey. This preliminary question provided information about the study including the title of the research, the procedures, contact information in case of questions, age requirements, and that participation is voluntary. The survey was reviewed and approved by the Institutional Review Board at Mississippi State University (IRB-18-260).

The survey itself consisted of three main parts. The first section included three questions, which were used to gather basic demographic information (age, sex, and state of residence). The second section focused on those who suffer from migraines. The goal of this section was to gain information about each respondent's migraines including frequency, symptoms, and triggers. If weather was identified as a trigger, follow-up questions were asked to determine more specifically how weather affected each respondent's migraines. Respondents were then asked to respond to various scenarios involving hypothetical weather-based pain forecasts. Two of the questions utilized a Likert-type scale where respondents rated their likelihood of taking preventative measures (i.e. medication) based on two different forecasts. The first question used a "high risk" forecast for migraines (i.e. weather will significantly impact the risk of migraines), while the second question used a "moderate risk" forecast for migraines (i.e. weather will have less of an impact on the risk of migraines). Additionally, two other questions utilized a similar scale for respondents to rate their likelihood of continuing activities of various lengths based on the same two migraine forecasts. The activity lengths considered were 30 minutes, 1 hour, 2 hours, and 3+ hours. The third section of the survey was constructed similarly to the second, except that the questions were related to the pain experienced from rheumatoid and other pain-

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related conditions. The total number of questions a participant was asked depended upon whether they identified themselves as someone who suffers from migraines, rheumatoid diseases, or both.

3.2.2   Statistical Methods

In order to determine the effects of weather-based pain forecasts on the decision-making process, hypothesis testing was utilized to compare the responses when under the different hypothetical forecasts. For the questions involving a respondent's likelihood of taking preventative measures, a numerical value (1 through 7) was given to each of the Likert-type categories. In this case, lower numbers were indicative of the categories where a person was likely to take preventative measures, whereas higher numbers corresponded to those where a person was unlikely to take preventative measures. For the questions involving a respondent's likelihood of changing their daily activities, a similar process was taken with numerical values (1 through 5) assigned to each of the Likert-type categories. For these questions, lower numbers represented categories where a person was likely to continue their activity, while higher numbers were for categories where a person was unlikely to continue their activity. Non-parametric hypothesis tests were used in this study as they do not require a specific distribution type. Furthermore, these tests do not require the datasets being tested to follow the same distribution. The null hypothesis was that there is no difference in the likelihoods, while the alternate hypothesis was that there was a difference in the likelihoods. A 95% confidence interval was used, with a rejection region (alpha) of 0.05.

The non-parametric method utilized in this study was the permutation technique. With this technique, the means of two datasets are determined. After calculating the difference between these means, the datasets are pooled together. Two mutually exclusive samples are then created from this pool, with replacement, and the difference in means is calculated. If the

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difference in means of the samples are found to be greater than the original, it is "counted". This is done repeatedly in order to calculate a p-value, which is found by taking the number of pools with a larger difference in means and dividing it by the number of trials. For this study, 2,000 trials, or permutations (not including the original) were created for each analysis. Small p-values are indicative of a situation where the null hypothesis can be rejected, while large p-values prohibit the null hypothesis from being rejected. P-values were calculated to compare the likelihoods of taking preventative measures based on different weather-based pain forecasts. P-values were also calculated to compare the likelihood of continuing activities of various time lengths given different weather-based pain forecasts.

3.3 Results

3.3.1 Data Characteristics

The survey garnered a total of 6,262 responses. Of these, 1,631 (26%) were removed from analysis as they were either incomplete or the respondents answered "No" to both "Do you suffer from migraines?" and "Do you suffer from a rheumatoid disease?". Therefore, the number of usable responses was 4,631. Of these, 1,458 (32%) indicated that they suffer solely from migraines, 1,623 (35%) indicated that they suffer from a rheumatoid disease, and 1,550 (33%) reported that they suffer from both. When considering those respondents who suffer from both, the total number of migraine and pain-related condition sufferers were 3,008 and 3,173, respectively.

Responses were gathered from all across the United States (US). In fact, at least one respondent from 44 out of the 50 states completed the survey (Only Delaware, New Hampshire, New Mexico, North Dakota, Nevada, and Vermont were not represented). Impressively, 83.7% (3,870) of the 4,631 respondents listed Alabama as their state of residence. This Alabama bias

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was the result of prominent broadcast meteorologist, James Spann, sharing the survey to his followers on social media. Based on the National Centers for Environmental Information (NCEI) defined climate regions (Karl et al. 1984), a majority of responses came from the Southeast region (89.7%), largely due to the Alabama bias. Other responses came from the South (3.8%), Central (3.3%), Northeast (1.0 percent), East North Central (0.8%), Southwest (0.4%), West (0.3%), West North Central (0.2%), and Northwest (0.2%) regions. The remaining responses (0.3%) came from Hawaii, Alaska, or those who selected "other". Respondents selecting "other" are either located in the District of Columbia (DC), a US territory, or another country entirely.

The age distribution for all respondents is shown in Figure 3.1. Most respondents were between the ages of 25 and 64, with a peak in the 35-44 age group. For those who suffer from migraines, most were between the ages of 35 and 44 (Figure 3.2). For other pain-related conditions, the average age of respondents was older, with the 45-54 age group exhibiting the greatest number of usable responses (Figure 3.3). This is consistent with the literature and results from the first two chapters, which show that many of these conditions (i.e. rheumatoid arthritis and osteoarthritis) are associated with older age groups. The vast majority of respondents who provided gender information (93%) were female.
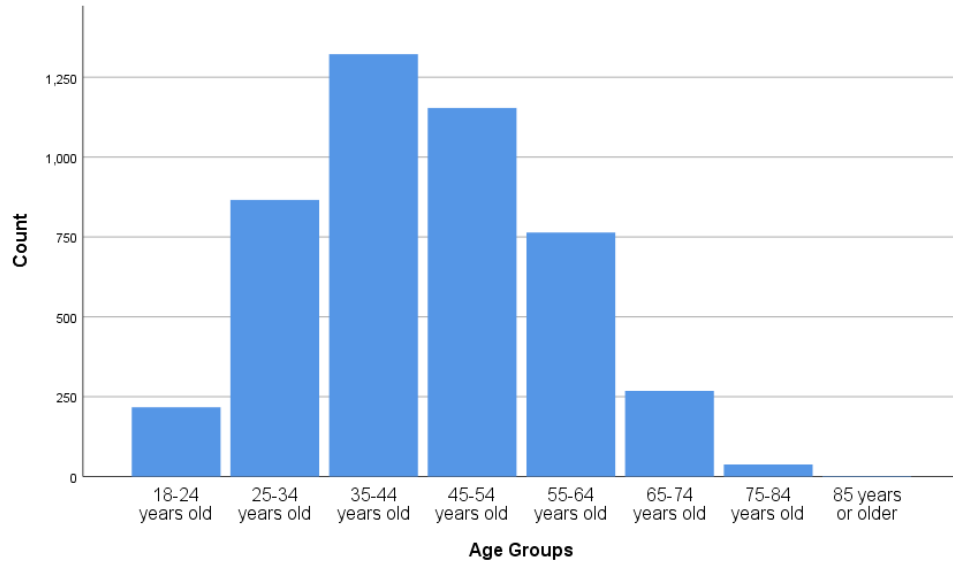
Figure 3.1   Age group distribution of all survey respondents
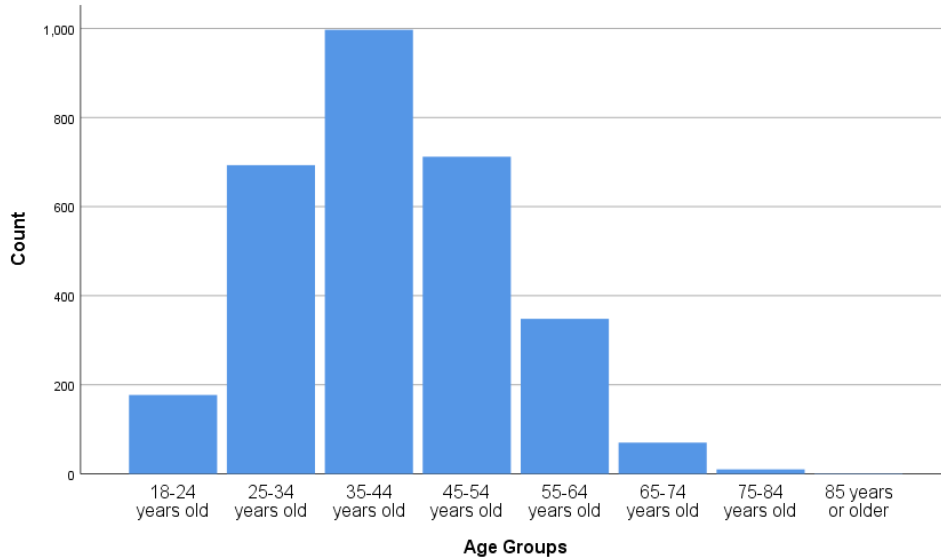
Figure 3.2   Age group distribution of survey respondents who suffer from migraines

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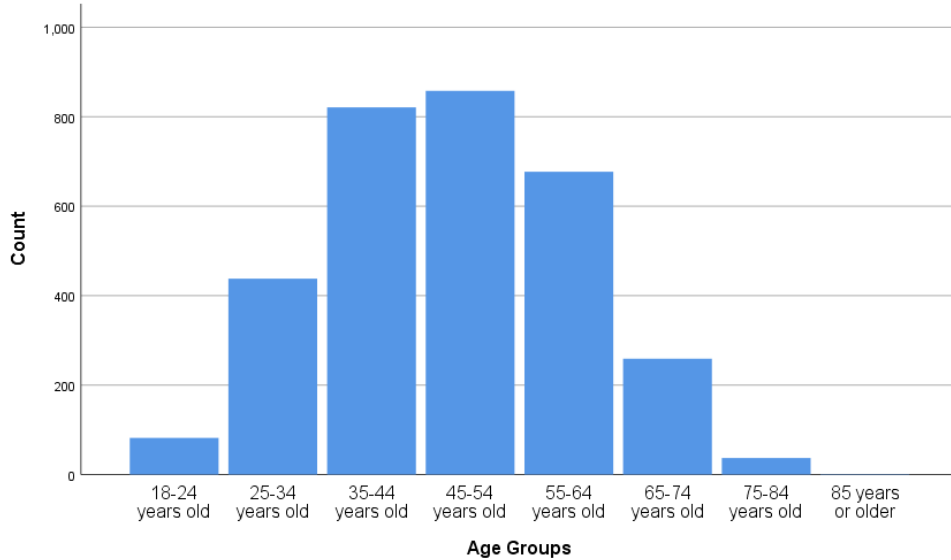
Figure 3.3   Age group distribution of survey respondents who suffer from a type of pain-related condition

3.3.2   Sources of Weather Information

Those who responded to the survey were asked to select their sources of weather information. The respondent's choices were local television meteorologist (television, website, social media, etc.), The Weather Channel (television, website, social media, app, etc.), internet sites (i.e. AccuWeather, Weather Underground), local National Weather Service (NWS) office, radio, newspaper, smartphone or tablet app, word of mouth, or other. A majority of the respondents (78%) reported that they obtain weather information from their local meteorologist (television, website, social media) (Figure 3.4). Smartphone apps were also listed as a frequent source for weather information, as 52% of respondents selected this option. The least common source for weather information was the newspaper, which was mentioned by less than 1% of respondents.

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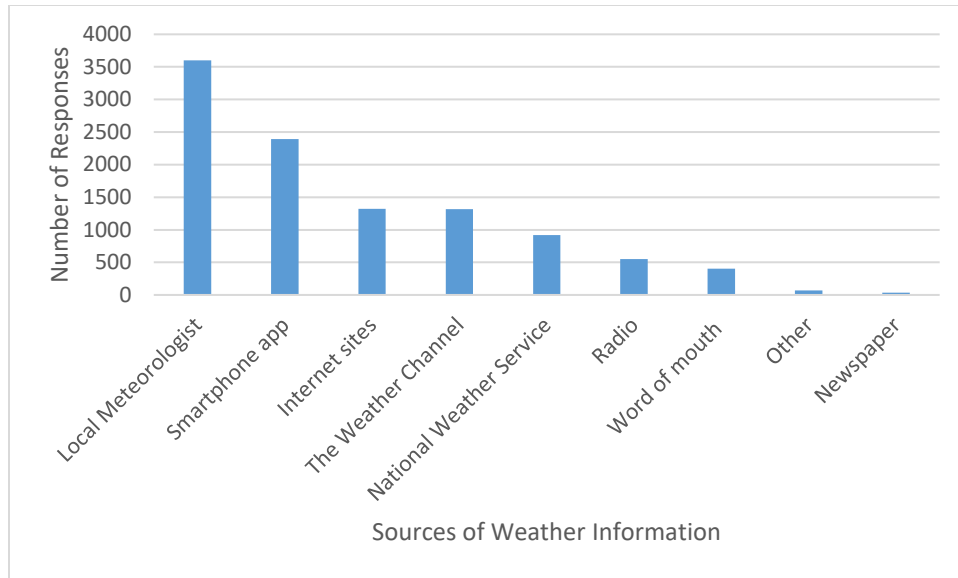
Figure 3.4   Weather information sources of survey respondents

3.3.3   Migraine and Pain Influencing Variables

Survey respondents were asked to identify those factors that had an impact on their migraines or other pain-related conditions. Options included stress, weather, hormones, food or drink, sleep patterns, and other. Of these options, weather was selected most often for migraines (89%) and other pain-related conditions (94%) (Figure 3.5). This result may be due to the emphasis of the survey on weather-based pain, which would naturally attract respondents who already consider the weather to be a factor on their pain. In addition to weather, stress was also frequently selected as a factor for both migraines (83%) and pain-related conditions (71%). Survey participants were also able to write-in a factor not included in the options given. For migraines, the most common response was "strange odors", while for pain-related conditions, the most common response was "increased activity".

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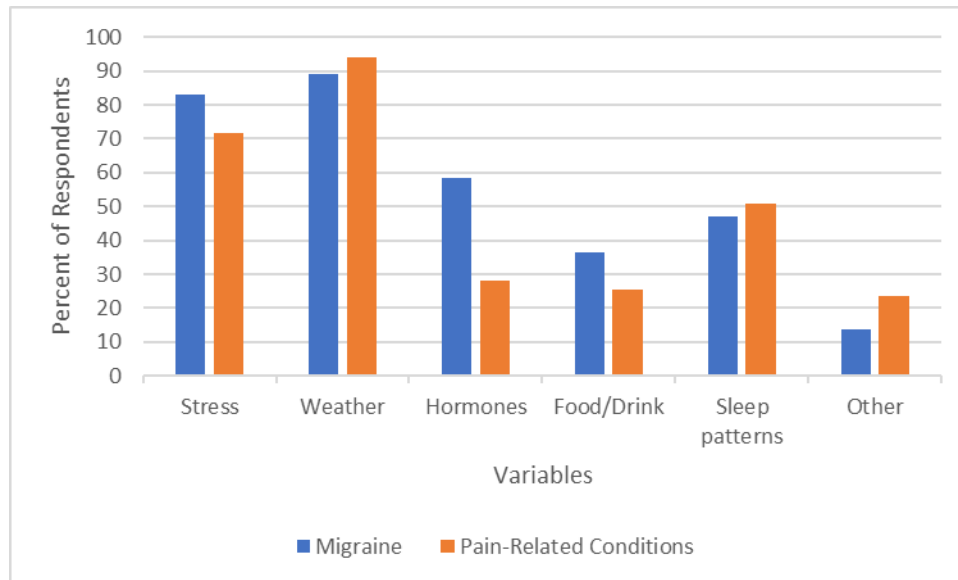
Figure 3.5   Reported variables to impact pain

Respondents who selected weather as a factor were then asked to indicate how weather affects their pain. The options were: weather triggers pain, weather changes pain intensity, weather changes pain duration, and not sure. Most respondents indicated that weather was a trigger for both migraines and other pain-related conditions (Figure 3.6). Interestingly, nearly 80% of respondents indicated that weather increased the intensity of pain-related conditions, while only about 40% indicated that weather increased the intensity of migraines. Relatively few respondents indicated that weather increased the duration of pain-related conditions or migraines.

www.manaraa.com
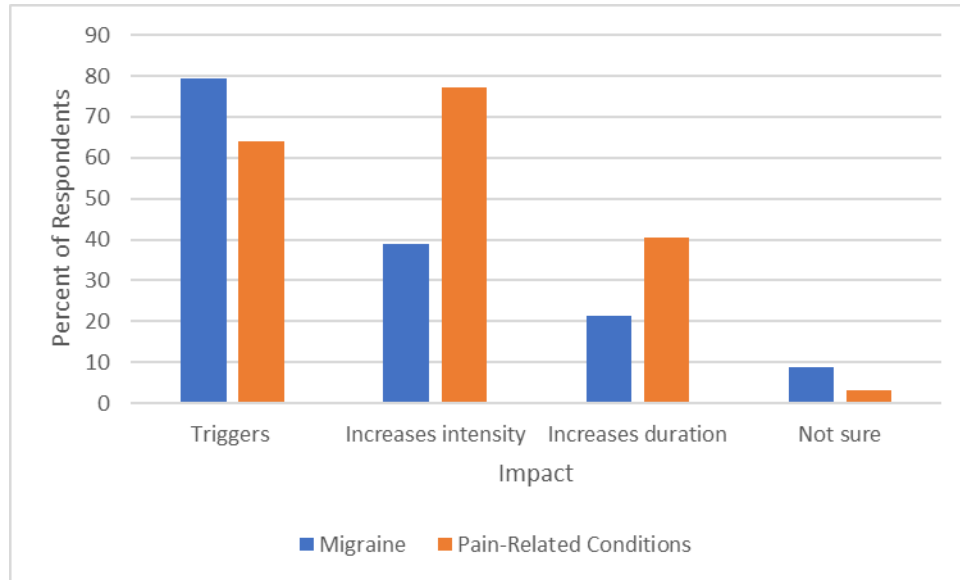
Figure 3.6   Weather's reported impact on pain

3.3.4   Permutation Results

3.3.4.1   Meteorological Variables

Respondents who indicated that weather affects their pain were asked to rate the impact of different meteorological variables on a scale of 0 (no impact) to 10 (greatest impact). For migraines, the meteorological variables of interest were pressure, temperature, moisture, wind, and sunlight. The same variables were provided for pain-related conditions, except for sunlight, as the literature indicates that the influence of sunlight is specific to migraines. Responses from all respondents were used to calculate an average rating for each variable for both migraines and pain-related conditions. Permutations were then used to see if differences in average ratings between meteorological variables were statistically significant for both migraines and pain-related conditions.

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The distribution of ratings for each meteorological variable for migraines is shown in Figure 3.7. The average ratings for each variable are given in Table 3.1. Average ratings for each variable were all above zero, indicating that respondents found these variables had at least some impact on migraine headaches. The mean differences in the ratings between each variable, as well as the results of the permutation analysis, are given in Table 3.2. Differences amongst all variables were statistically significant (i.e. less than the 0.05 rejection level). Most notably, survey respondents found pressure to be significantly more impactful to their migraines compared to the other variables, with the majority of respondents assigning a value of 10 (greatest impact). In contrast, the most frequently selected rating for temperature (21%), moisture (15%), wind (43%) and sunlight (19%) was zero (no impact). Since the average ratings for these other variables were greater than zero, these results suggest that there is considerable variability in ratings amongst all respondents. In other words, the perceived influence of certain weather variables on migraine headaches likely varies from person to person.
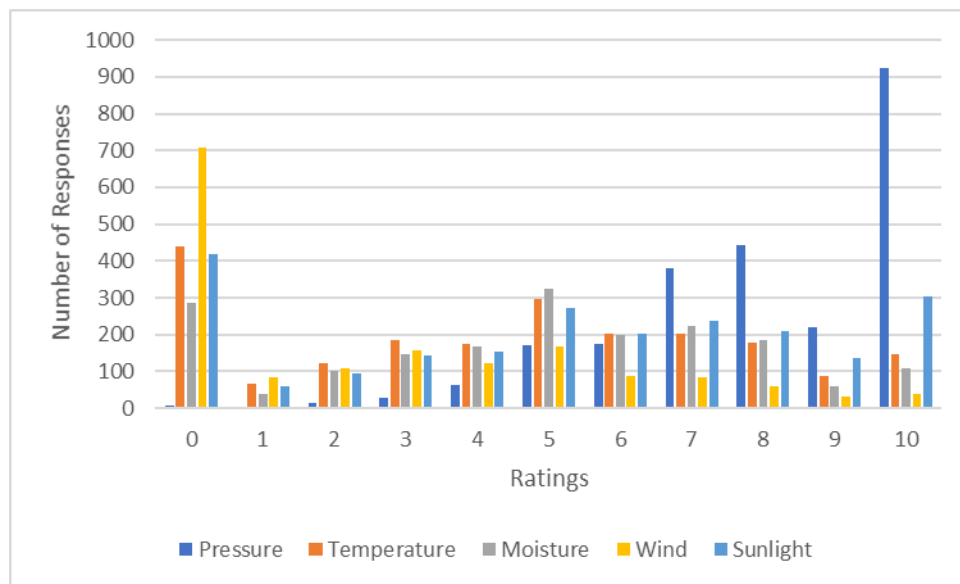
Figure 3.7   Estimates for weather variable impacts on migraines

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Table 3.1   Means estimates for weather variable impacts on migraine

Migraine Variable Average Ratings	
Variable	Mean
Pressure	8.1032
Temperature	4.4505
Moisture	4.8073
Wind	2.6396
Sunlight	5.1356

Table 3.2   Migraines weather variable permutation results

Migraine Variables Ratings			
Variable A	Variable B	Mean Difference (A-B)	P-Value
Pressure	Temperature	3.6527	<0.001*
	Moisture	3.2959	<0.001*
	Wind	5.4636	<0.001*
	Sunlight	2.9676	<0.001*
Temperature	Pressure	-3.6527	<0.001*
	Moisture	-0.3568	0.001*
	Wind	1.8109	<0.001*
	Sunlight	-0.6851	<0.001*
Moisture	Pressure	-3.2959	<0.001*
	Temperature	0.3568	0.001*
	Wind	2.1677	<0.001*
	Sunlight	-0.3283	0.002*
Wind	Pressure	-5.4636	<0.001*
	Temperature	-1.8109	<0.001*
	Moisture	-2.1677	<0.001*
	Sunlight	-2.4960	<0.001*
Sunlight	Pressure	-2.9676	<0.001*
	Temperature	0.6851	<0.001*
	Moisture	0.3283	0.002*
	Wind	2.4960	<0.001*

The asterisk next to a p-value indicates statistically significant differences

As was the case with migraines, the distribution and average of ratings for pain-related conditions were all greater than zero, indicating that each meteorological variable was influential (Figure 3.8; Table 3.3). Results of the permutation analysis also revealed significant differences in average ratings between all variables (Table 3.4). Similar to migraines, the variable with the

greatest impact on pain-related conditions was pressure. However, average ratings for temperature and moisture were higher for pain-related conditions than for migraine, suggesting that these variables have a greater influence on other types of pain. Moreover, ratings of zero (no impact) were less common for pain-related conditions than for migraine, except in the case of wind, which had little to no impact regardless of pain type.
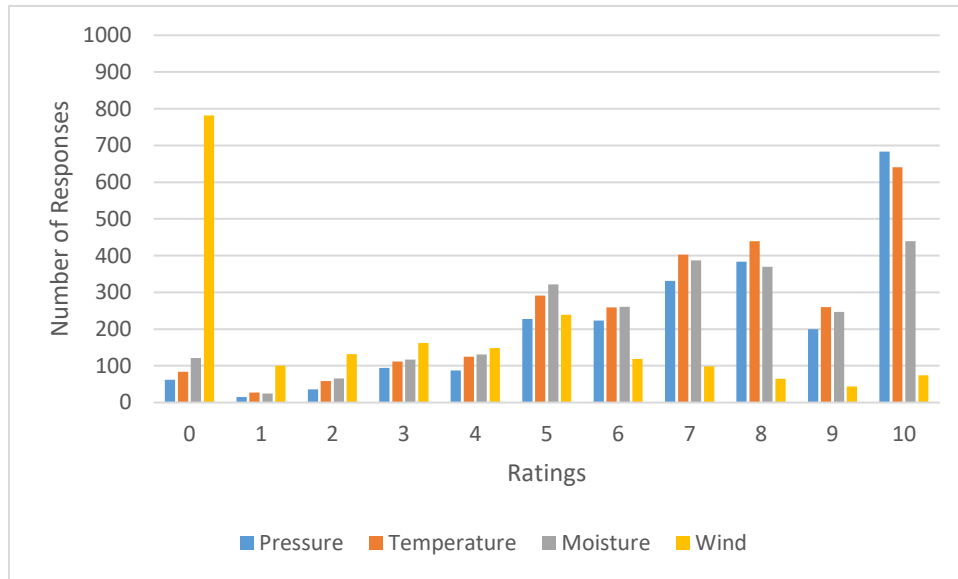

Figure 3.8   Estimates for weather variable impacts on pain-related conditions

Table 3.3   Means estimates for weather variable impacts on pain-related conditions

Pain Variable Average Ratings	
Variable	Mean
Pressure	7.3470
Temperature	7.0641
Moisture	6.6331
Wind	2.5149

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Table 3.4   Pain-related conditions weather variable permutation results

Pain Variables Ratings			
Variable A	Variable B	Mean Difference (A-B)	P-Value
Pressure	Temperature	0.2829	<0.001*
	Moisture	0.7138	<0.001*
	Wind	4.4448	<0.001*
Temperature	Pressure	-0.2829	<0.001*
	Moisture	0.4309	<0.001*
	Wind	4.1618	<0.001*
Moisture	Pressure	-0.7138	<0.001*
	Temperature	-0.4309	<0.001*
	Wind	3.7309	<0.001*
Wind	Pressure	-4.4448	<0.001*
	Temperature	-4.1618	<0.001*
	Moisture	-3.7309	<0.001*

The asterisk next to a p-value indicates statistically significant differences

3.3.4.2   Impacts of Weather-Based Migraine/Pain Forecasts

A majority of migraine sufferers (72%) and those suffering from other pain-related conditions (66%) indicated that they would alter their behavior in response to weather-based pain forecasts. In addition, 27% of migraine sufferers and 33% of those with pain-related conditions noted that they had used a migraine forecast. Respondents were then asked to respond to different scenarios to see if, in practice, they would alter their behavior.

3.3.4.2.1   Effects on Taking Preventative Measures

The distributions of responses to the Likert-type questions involving the likelihood of taking preventative measures (i.e. medication) for migraines and other pain-related conditions are shown in Figures 3.9-3.10, respectively. In both cases, most respondents stated that they would be "extremely likely" to take preventative measures in response to a high-risk forecast for migraines/pain. In contrast, the likelihood of taking preventative measures in response to a moderate-risk forecast was more evenly divided among "extremely likely", "moderately likely",

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and "slightly likely". Only a small number of respondents indicated that they would be unlikely

to take preventative measures in response to a high or moderate risk forecast.
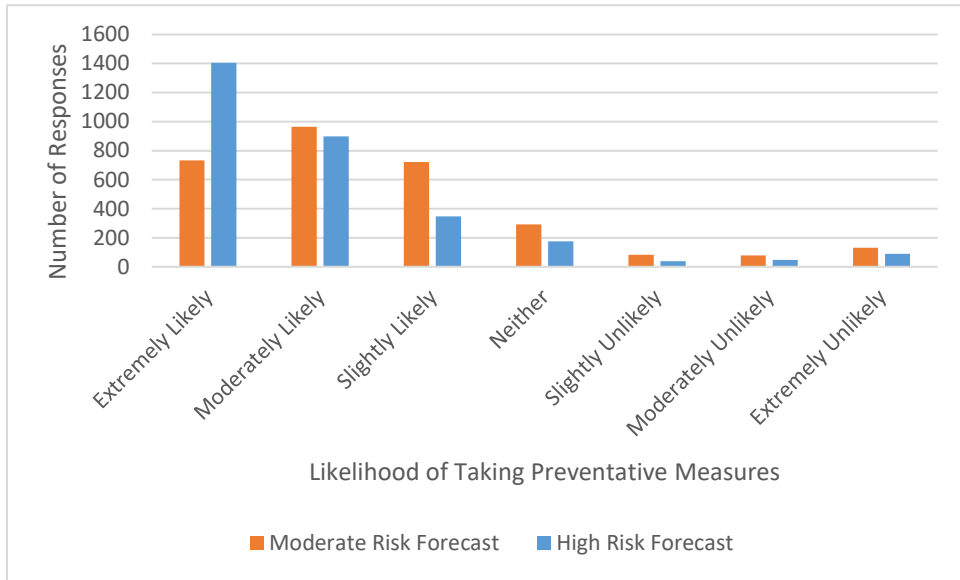

Figure 3.9   Likelihood of taking preventative measures for migraines
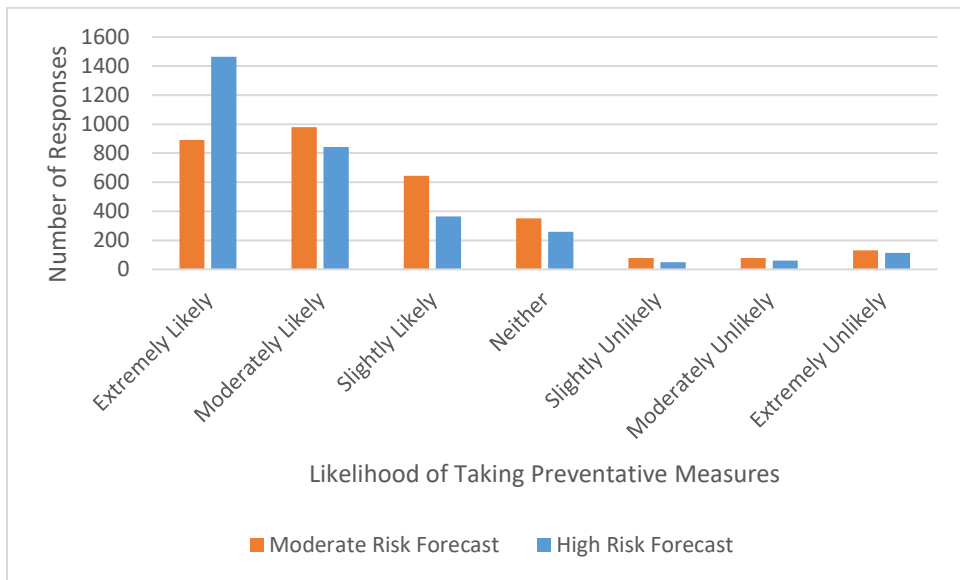

Figure 3.10   Likelihood of taking preventative measures for pain-related conditions

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To further examine the effect of forecast severity on taking preventative measures, averages of the likelihoods illustrated in Figures 3.9-3.10 were calculated for each forecast type (high-risk and moderate-risk). Smaller averages represented a higher likelihood of taking preventative measures, while larger averages corresponded to a higher likelihood of not taking preventative measures. The differences in these averages are shown in Table 3.5. The high-risk forecast led to lower averages compared to the moderate-risk forecast for both migraines and pain-related conditions, however, the differences in these averages were found to be relatively small. The results of the permutation analysis, also shown in Table 3.5, did reveal that these small differences were statistically significant. Thus, high-risk forecasts led to statistically significant increases in the likelihood of both migraine sufferers and those with pain-related conditions taking preventative measures. Ultimately, the large size of the datasets may have played a role in statistical significance being found.

Table 3.5   Likelihood of taking preventative measures permutation results

Likelihood of Taking Preventative Measures				
Condition of Interest	Forecast Type (A)	Forecast Type (B)	Mean Difference (A-B)	P-Value
Migraines	High	Moderate	-0.5810	<0.001*
Pain-Related Conditions	High	Moderate	-0.4082	<0.001*

The asterisk next to a p-value indicates statistically significant differences

3.3.4.2.2   Effects on Daily Activities

Migraine sufferers and those with pain-related conditions also responded similarly to weather-based migraine/pain forecasts when it came to the likelihood of continuing an activity. The distribution of responses from migraine sufferers to the Likert-type questions involving the

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continuation of activities of various lengths are shown for moderate-risk forecasts (Figure 3.11) and high-risk forecasts (Figure 3.12). Responses for pain-related conditions are shown in Figures 3.13-3.14. The distribution of responses for both migraine and pain-related conditions indicates that the duration of the activity, as well as the intensity of the forecasted risk, had an impact on the likelihood of respondents continuing with the activity.
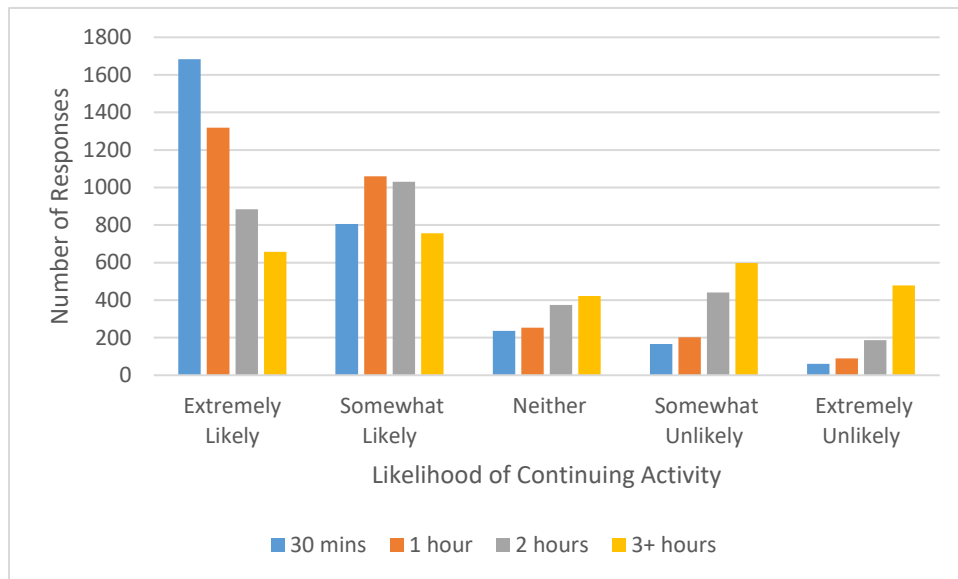

Figure 3.11   Likelihood of continuing an activity during a moderate-risk forecast for migraine
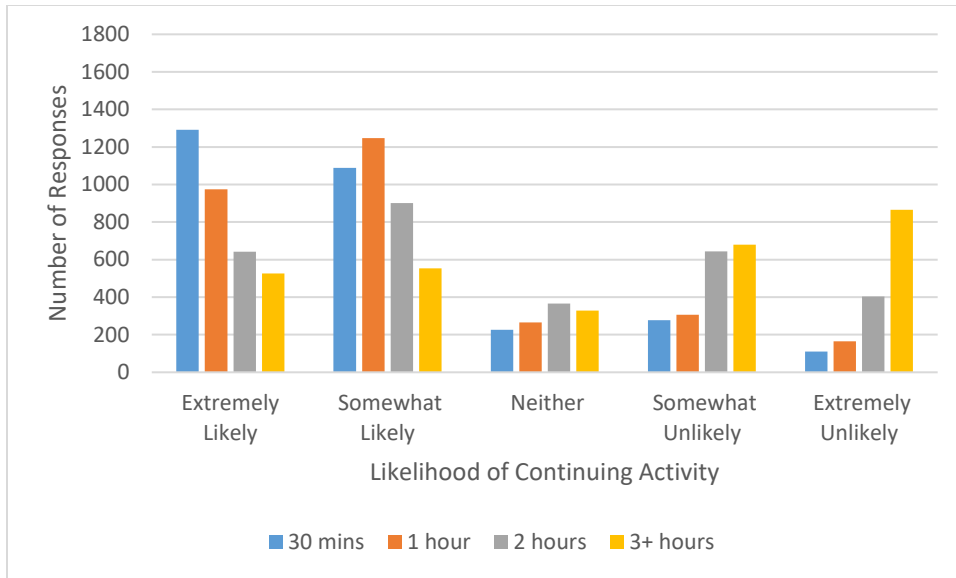
Figure 3.12   Likelihood of continuing an activity during a high-risk forecast for migraine
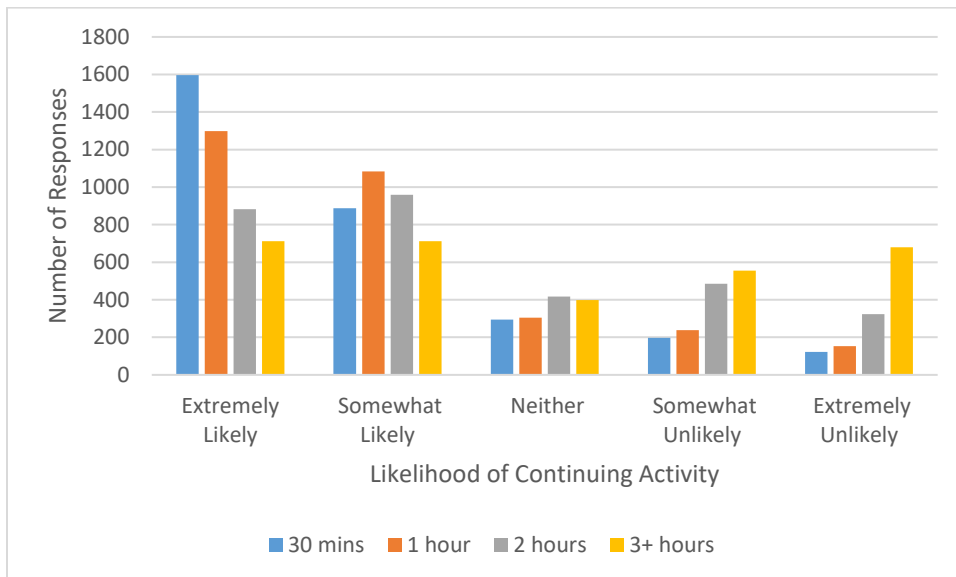
Figure 3.13   Likelihood of continuing an activity during a moderate-risk forecast for pain

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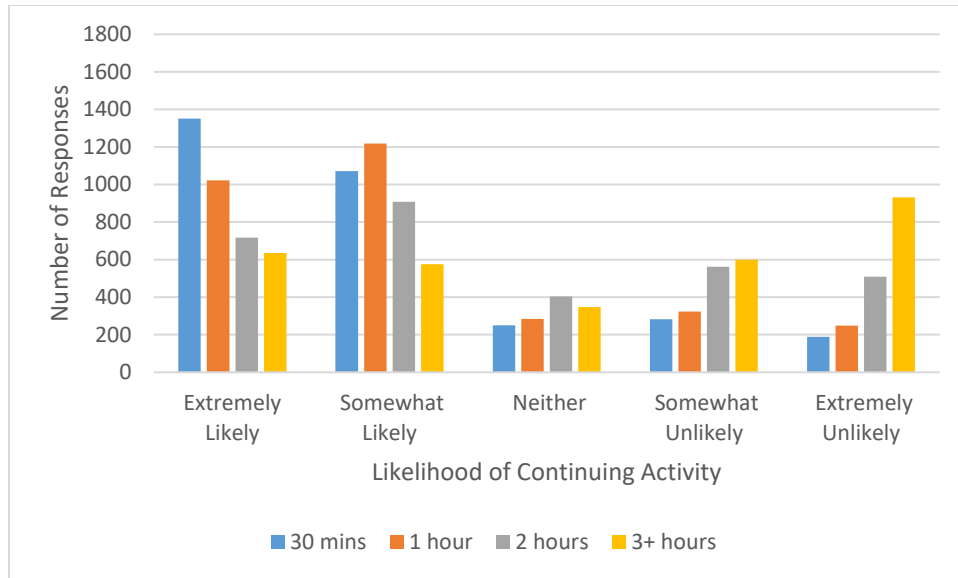
Figure 3.14   Likelihood of continuing an activity during a high-risk forecast for pain

To determine the statistical significance in the effects of activity length, means of the likelihoods were calculated for activities lasting 30 minutes, 1 hour, 2 hours, and 3+ hours. Smaller averages corresponded to a higher likelihood of continuing an activity, while larger averages were associated with a lower likelihood of continuing an activity. For moderate-risk forecasts and high-risk forecasts, the differences in means for both migraines and pain-related conditions are shown in Tables 3.6-3.7, respectively. These tables also include the p-values associated with the permutation analysis, which compared the means of the different activity lengths. In all cases, p-values were less than 0.05, allowing for the null hypothesis (i.e. likelihoods are equal) to be rejected. For both migraines and pain-related conditions, as activity length increased, the likelihood of continuing the activity decreased. This was the case for both moderate-risk and high-risk forecasts. Like the results for the likelihood of taking preventative measures, the differences in means were quite small in some cases, yet statistical significance was always found (Table 3.6-3.7). For example, the comparison between a 30 minute and 1 hour

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long activity in particular led to some of the smallest differences in means (i.e. always less than

0.21) (Table 3.6-3.7). The size of the datasets could have again played a role in statistical

significance.

Table 3.6   Activity length permutation results for moderate-risk forecasts

Moderate Risk Forecast				
Condition of Interest	Activity Time (A)	Activity Time (B)	Mean Difference (A-B)	P-Value
Migraines	30 minutes	1 hour	-0.1794	<0.001*
		2 hours	-0.6344	<0.001*
		3+ hours	-1.1363	<0.001*
	1 hour	30 minutes	0.1794	<0.001*
		2 hours	-0.4550	<0.001*
		3+ hours	-0.9569	<0.001*
	2 hours	30 minutes	0.6344	<0.001*
		1 hour	0.4550	<0.001*
		3+ hours	-0.5019	<0.001*
	3+ hours	30 minutes	1.1363	<0.001*
		1 hour	0.9569	<0.001*
		2 hours	0.5019	<0.001*
Pain-Related Conditions	30 minutes	1 hour	-0.1557	<0.001*
		2 hours	-0.6550	<0.001*
		3+ hours	-1.1020	<0.001*
	1 hour	30 minutes	0.1557	<0.001*
		2 hours	-0.4993	<0.001*
		3+ hours	-0.9463	<0.001*
	2 hours	30 minutes	0.6550	<0.001*
		1 hour	0.4933	<0.001*
		3+ hours	-0.4470	<0.001*
	3+ hours	30 minutes	1.1020	<0.001*
		1 hour	0.9463	<0.001*
		2 hours	0.4470	<0.001*

The asterisk next to a p-value indicates statistically significant differences

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Table 3.7   Activity length permutation results for high-risk forecasts

High Risk Forecast				
Condition of Interest	Activity Time (A)	Activity Time (B)	Mean Difference (A-B)	P-Value
Migraines	30 minutes	1 hour	-0.1946	<0.001*
		2 hours	-0.8114	<0.001*
		3+ hours	-1.3314	<0.001*
	1 hour	30 minutes	0.1946	<0.001*
		2 hours	-0.6168	<0.001*
		3+ hours	-1.1367	<0.001*
	2 hours	30 minutes	0.8114	<0.001*
		1 hour	0.6168	<0.001*
		3+ hours	-0.5110	<0.001*
	3+ hours	30 minutes	1.3314	<0.001*
		1 hour	1.1367	<0.001*
		2 hours	0.5110	<0.001*
Pain-Related Conditions	30 minutes	1 hour	-0.2010	<0.001*
		2 hours	-0.7446	<0.001*
		3+ hours	-1.1901	<0.001*
	1 hour	30 minutes	0.2010	<0.001*
		2 hours	-0.5436	<0.001*
		3+ hours	-0.9891	<0.001*
	2 hours	30 minutes	0.7446	<0.001*
		1 hour	0.5436	<0.001*
		3+ hours	-0.4455	<0.001*
	3+ hours	30 minutes	1.1901	<0.001*
		1 hour	0.9891	<0.001*
		2 hours	0.4455	<0.001*

The asterisk next to a p-value indicates statistically significant differences

To determine if the effects of forecast severity on the likelihood of continuing an activity were statistically significant, the mean likelihood for each activity length under the two forecasts (moderate-risk and high-risk) were compared. The difference in means and the associated p-values from the permutation analysis are provided in Table 3.8. While the differences in means were quite small, the p-values from the permutation tests once again indicated statistically significant differences in all cases for both migraines and pain-related conditions. Therefore, as the risk for migraine or pain increased, the likelihood of continuing an activity decreased for all

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four activity lengths (30 minutes, 1 hour, 2 hours, and 3+ hours). Once again, the size of the

datasets may have played a role in the identification of statistical significance.

Table 3.8   Likelihood of continuing an activity based on forecast type

Likelihood of Continuing an Activity					
Condition of Interest	Activity Time	Forecast Type (A)	Forecast Type (B)	Mean Difference (A-B)	P-Value
Migraines	30 minutes	High	Moderate	0.2545	<0.001*
	1 hour	High	Moderate	0.2697	<0.001*
	2 hours	High	Moderate	0.4314	<0.001*
	3+ hours	High	Moderate	0.4495	<0.001*
Pain-Related Conditions	30 minutes	High	Moderate	0.1835	<0.001*
	1 hour	High	Moderate	0.2287	<0.001*
	2 hours	High	Moderate	0.2730	<0.001*
	3+ hours	High	Moderate	0.2715	<0.001*

The asterisk next to a p-value indicates statistically significant differences

3.4   Discussion and Conclusion

In this chapter, survey respondents identified the meteorological variables that they

perceive to have an impact on their pain. Migraine sufferers indicated that atmospheric pressure

has the biggest effect on their pain, while sufferers of pain-related conditions indicated pressure,

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temperature, and moisture. Such perceptions are consistent to what has been found in other studies. Despite these perceptions, research has not consistently found pressure to have a clear impact on different types of pain. Interestingly though, temperature and moisture have been linked to pain. The results from Elcik et al. (2017) and Chapters I and II found that air masses, which have different thermal and moisture characteristics, impact the frequency of pain in those who suffer from migraines as well as pain-related conditions. In fact, some consistent trends were found, such as Moist Tropical air masses (i.e. hot and humid) being associated with increased frequencies of pain.

A major goal of this chapter was to determine if those who suffer from migraines or pain-related conditions are receptive to weather-based pain forecasting. The results of a survey determined that many are willing to utilize weather-based pain forecasting. Interestingly, some of the survey respondents indicated that they had used these types of forecasts before.

When provided with different scenarios involving weather-based migraine/pain forecasts, the behavior of respondents were altered to some degree. When the hypothetical forecast indicated that the weather was conducive to migraines or other types of pain, a large percentage of those surveyed indicated that they would likely take preventative measures. When the weather-based risk decreased, fewer respondents indicated that they would take preventative measures. Moreover, as forecast severity or activity length increased, respondents were less likely to continue with an activity. It is important to note that while statistical significance was found in this research, the underlying numbers indicated minimal behavioral changes.

The results from this chapter support the need to further develop human-health forecasts associated with migraines and other pain-related conditions. By affecting the decision-making

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processes of some respondents, these forecasts have the potential to be useful tools for those who suffer from migraines as well as pain-related conditions.

3.5   Limitations and Future Research

Several limitations to this study existed. For Chapters I and II, the largest limitation involved how pain frequencies were determined for the different conditions. By using ED visits, only the most serious and debilitating pain occurrences were identified. Therefore, only a small percentage of the total instances of pain were accounted for in this study. This likely had a large impact on fibromyalgia, RA, and OA as low daily ED counts were found. Perhaps sufferers of these conditions are less likely to go to the ED for their pain. The statistical analysis technique (i.e. Bootstrapping) chosen for Chapters I and II also resulted in limitations. By comparing multiple bootstraps, the odds of making at least one statistical Type-I error increased. In statistics, this is known as the "multiplicity issue". The Alabama bias in Chapter III also serves as a limitation. Based on the results of Chapter II, regionality likely plays a role in the various relationships between weather and pain. By having a large percentage of respondents from one state, the perceptions of sufferers were not adequately represented.

There are numerous opportunities for future research with this topic. Based on the results of Chapter II, future research should be conducted to look further into the role of geography on the relationships between air masses and pain. While data availability led this author to focus on North Carolina, research should be conducted in different regions of the United States to corroborate the findings from this study. Furthermore, in the future, the results from Chapters I and II and other existing literature should be used to develop synoptic weather-based pain forecasts.

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APPENDIX A

WEATHER-BASED PAIN FORECAST SURVEY

A.1 Survey

Pain Survey

We would like to ask you to participate in a research study. If you participate in this study, you will be asked a variety of questions about pain as well as the effects of weather-based pain forecasts on daily activities. We are looking for participants who suffer from migraines or some type of pain-related condition (i.e. arthritis, osteoarthritis, fibromyalgia). Please understand that your participation is voluntary. Your refusal to participate will involve no penalty or loss of benefits to which you are otherwise entitled. You may discontinue your participation at any time without penalty or loss of benefits. If you have any questions about this research project, please feel free to contact Christopher Elcik at 443-974-3521 and/or by email at cje143@msstate.edu. You must be 18 years or older to participate. If you are willing to participate in this research study and are at least 18 years old, please select yes. If not, please select no.

- o Yes
- o No

if No is selected, then skip to the end of the survey

1) How old are you?
    - o 18-24 years old
    - o 25-34 years old
    - o 35-44 years old
    - o 45-54 years old
    - o 55-64 years old
    - o 65-74 years old
    - o 75-84 years old
    - o 85 years or older
2) What is your sex?
    - o Male
    - o Female
3) What state do you currently live in?

4) Where do you get your daily weather information? (Select all that apply)
   o Local television meteorologist (television, website, social media, etc.)
   o The Weather Channel (television, website, social media, app, etc.)
   o Internet sites (accuweather, weather underground, etc.)
   o Local National Weather Service office (website, social media, etc.)
   o Radio
   o Newspaper
   o Smartphone or tablet weather app
   o Word of mouth
   o Other
5) Do you suffer from migraines?
   o Yes
   o No

If No is selected, then skip to question 24

6) How often do you get migraines?
   o 0-4 per year
   o 5-9 per year
   o 10-14 per year
   o 15+ per year
7) Have you dealt with migraines for a majority of your life?
   o Yes
   o No
8) Are your migraines associated with a pre-existing condition?
   o Yes
   o No
9) Which symptoms are associated with your migraine? (Select all that apply)
   o Head pain
   o Dizziness
   o Irritability
   o Nausea
   o Visual disturbances
   o Other
10) Have you found a successful way to reduce or eliminate your migraine symptoms? (i.e. medication)
   o Yes
   o No

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11) For the past year, estimate how many days of work/school you have missed due to migraines.
- o None
- o 1-4 days
- o 5-8 days
- o 9-12 days
- o 13+ days
- o I currently do not work or attend school

12) For the past year, estimate how many days you have attended work/school but had your productivity impacted due to migraines.
- o None
- o 1-4 days
- o 5-8 days
- o 9-12 days
- o 13+ days
- o I currently do not work or attend school

13) Approximately how many times have you gone to the emergency room (ER) because of migraines?
- o Never
- o 1-4 times
- o 5-8 times
- o 9+ times

14) What factors do you believe have an impact on your migraines? (Select all that apply)
- o Stress
- o Weather
- o Hormones
- o Food/drink
- o Sleep patterns
- o Other

If weather is selected, answer questions 15-17

15) Which of the following best explains how your migraines are affected by the weather? (Select all that apply)
- o Weather triggers migraine
- o Weather changes migraine intensity
- o Weather changes migraine duration
- o Not sure

16) On a scale from 0 (no impact) to 10 (highest impact), how do each of the following weather variables impact your migraine headaches? Please select "Not Sure" if you do not know how a variable impacts your migraine headaches.

Weather Variable	Ranking											
	Not Sure	0	1	2	3	4	5	6	7	8	9	10
Pressure	o	o	o	o	o	o	o	o	o	o	o	o
Temperature	o	o	o	o	o	o	o	o	o	o	o	o
Moisture	o	o	o	o	o	o	o	o	o	o	o	o
Wind	o	o	o	o	o	o	o	o	o	o	o	o
Sunlight	o	o	o	o	o	o	o	o	o	o	o	o
Other	o	o	o	o	o	o	o	o	o	o	o	o

17) When a weather front (i.e. warm front or cold front) moves through, does this have an impact on your migraine?
   o Always
   o Most of the time
   o About half the time
   o Sometimes
   o Never

18) Have you used a migraine forecast based on weather conditions before?
   o Yes
   o No

19) Would you be likely to alter your behavior based on a weather-based migraine forecast?
   o Yes
   o No

The next two questions give you a scenario to react to. Using the information below, please answer the questions as best you can.

Migraine weather-based forecasts can be:

   Highest risk for migraines

   Moderate risk for migraines

   Neutral risk for migraines

   Lower risk for migraines

   No risk for migraines

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20) You currently are not experiencing symptoms, but the forecast indicates "highest risk for migraines." How likely are you to take preventative measures (i.e. medication)?
- o Extremely likely
- o Moderately likely
- o Slightly likely
- o Neither likely nor unlikely
- o Slightly unlikely
- o Moderately unlikely
- o Extremely unlikely

21) You currently are not experiencing symptoms, but the forecast indicates "moderate risk for migraines." How likely are you to take preventative measures (i.e. medication)?
- o Extremely likely
- o Moderately likely
- o Slightly likely
- o Neither likely nor unlikely
- o Slightly unlikely
- o Moderately unlikely
- o Extremely unlikely

22) It is 10:00 am on a Saturday. You have an activity planned for 12:00 pm. The forecast indicates "highest risk for migraines." How likely are you to continue with your activity?

Activity Length	Extremely likely	Somewhat likely	Neither likely nor unlikely	Somewhat unlikely	Extremely unlikely
30 minutes	○	○	○	○	○
1 hour	○	○	○	○	○
2 hours	○	○	○	○	○
3+ hours	○	○	○	○	○

23) It is 10:00 am on a Saturday. You have an activity planned for 12:00 pm. The forecast indicates "moderate risk for migraines." How likely are you to continue with your activity?

Activity Length	Extremely likely	Somewhat likely	Neither likely nor unlikely	Somewhat unlikely	Extremely unlikely
30 minutes	○	○	○	○	○
1 hour	○	○	○	○	○
2 hours	○	○	○	○	○
3+ hours	○	○	○	○	○

24) Do you suffer from a pain-related condition (i.e. arthritis, osteoarthritis, fibromyalgia)?
- o Yes
- o No

if No is selected, then skip to the end of the survey

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25) How often do you experience pain?
- o 0-1 times per week
- o 2-3 times per week
- o 4-5 times per week
- o 6+ times per week

26) How long have you been dealing with a pain-related condition?
- o 0-5 years
- o 6-11 years
- o 12-17 years
- o 18+ years

27) Have you found a successful way to reduce or eliminate the pain associated with your condition? (i.e. medication)
- o Yes
- o No

28) For the past year, estimate how many days of work/school you have missed due to pain.
- o None
- o 1-4 days
- o 5-8 days
- o 9-12 days
- o 13+ days
- o I currently do not work or attend school

29) For the past year, estimate how many days you have attended work/school but had your productivity impacted due to pain.
- o None
- o 1-4 days
- o 5-8 days
- o 9-12 days
- o 13+ days
- o I currently do not work or attend school

30) Approximately how many times have you gone to the emergency room (ER) due to pain from your condition?
- o Never
- o 1-4 times
- o 5-8 times
- o 9+ times

31) What factors do you believe impact your pain? (Select all that apply)
- o Stress
- o Weather
- o Hormones
- o Food/drink
- o Sleep patterns
- o Other

32) Which of the following best explains how your pain is affected by the weather? (Select all that apply)
   o Weather triggers pain
   o Weather changes pain intensity
   o Weather changes pain duration
   o Not sure

33) On a scale from 0 (no impact) to 10 (highest impact), how do each of the following weather variables impact your pain? Please select "Not Sure" if you do not know how a variable impacts your pain.

Weather Variable	Ranking											
	Not Sure	0	1	2	3	4	5	6	7	8	9	10
Pressure	o	o	o	o	o	o	o	o	o	o	o	o
Temperature	o	o	o	o	o	o	o	o	o	o	o	o
Moisture	o	o	o	o	o	o	o	o	o	o	o	o
Wind	o	o	o	o	o	o	o	o	o	o	o	o
Other	o	o	o	o	o	o	o	o	o	o	o	o

34) When a weather front (i.e. warm front or cold front) moves through, does this have an impact on your pain?
   o Always
   o Most of the time
   o About half the time
   o Sometimes
   o Never

35) Have you used a pain forecast based on weather conditions before?
   o Yes
   o No

36) Would you be likely to alter your behavior based on a weather-based pain forecast?
   o Yes
   o No

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The next two questions give you a scenario to react to. Using the information below, please answer the questions as best you can.

Pain weather-based forecasts can be:

Highest risk for pain

Moderate risk for pain

Neutral risk for pain

Lower risk for pain

No risk for pain

37) You currently are not experiencing symptoms, but the forecast indicates "highest risk for pain." How likely are you to take preventative measures (i.e. medication)?
- o Extremely likely
- o Moderately likely
- o Slightly likely
- o Neither likely nor unlikely
- o Slightly unlikely
- o Moderately unlikely
- o Extremely unlikely

38) You currently are not experiencing symptoms, but the forecast indicates "moderate risk for pain." How likely are you to take preventative measures (i.e. medication)?
- o Extremely likely
- o Moderately likely
- o Slightly likely
- o Neither likely nor unlikely
- o Slightly unlikely
- o Moderately unlikely
- o Extremely unlikely

39) It is 10:00 am on a Saturday. You have an activity planned for 12:00 pm. The forecast indicates "highest risk for pain." How likely are you to continue with your activity?

Activity Length	Extremely likely	Somewhat likely	Neither likely nor unlikely	Somewhat unlikely	Extremely unlikely
30 minutes	o	o	o	o	o
1 hour	o	o	o	o	o
2 hours	o	o	o	o	o
3+ hours	o	o	o	o	o

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40) It is 10:00 am on a Saturday. You have an activity planned for 12:00 pm. The forecast indicates "moderate risk for pain." How likely are you to continue with your activity?

Activity Length	Extremely likely	Somewhat likely	Neither likely nor unlikely	Somewhat unlikely	Extremely unlikely
30 minutes	○	○	○	○	○
1 hour	○	○	○	○	○
2 hours	○	○	○	○	○
3+ hours	○	○	○	○	○