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Relationship between Air Mass Type and Emergency Department Visits for Migraine Headache across the Triangle Region of North Carolina

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By

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An estimated 240 million people worldwide suffer from migraines. Migraines have disruptive capabilities, therefore, understanding the mechanisms that trigger them is crucial for effective prevention and treatment. Air mass types and migraine induced emergency department (ED) visits in select North Carolina counties were collected over a seven year period in order to determine a potential relationship. Barometric pressure changes associated with Transitional air masses were also analyzed for potential trends. Bootstrapping showed that Tropical air masses resulted in greater numbers of migraine ED patients, while Polar air masses led to fewer. Moist Polar air masses in particular were found to correspond with the fewest number of migraine ED patients. On Transitional air mass days, the numbers of migraine ED patients fell between those of Tropical air mass days and Polar air mass days. With regards to barometric pressure changes associated with Transitional air masses, no trends were found.

DEDICATION

I would like to dedicate this research to my family and friends who have supported me and my goal of becoming a successful meteorologist. I would not be where I am today without the encouragement they have provided me.

ACKNOWLEDGEMENTS

I would like to express my thanks to my thesis advisor, Dr. Christopher Fuhrmann, and to my committee members, Dr. Andrew Mercer and Dr. Robert Davis, for their assistance in completing this project. I would also like to thank my family and friends for the constant support.

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CHAPTER I

INTRODUCTION

Head pain plagues many around the world. In the United States alone, 45 million people each year seek medical attention for head pain (Jefferson University Alumni, 2015). Many of these head pain cases are diagnosed as a migraine. Migraines are a common form of headache which causes sufferers to experience head pain, sensitivity to light, nausea, visual disturbances, and other neurological symptoms. Research indicates that roughly nine percent of the United States population suffers from migraines (Lofland, 2007). People who suffer from migraines, known as “migraineurs“, can have their daily lives altered significantly due to their disabling effects.

Migraines can cause a person to be inactive for hours at a time, which can be very detrimental to the productivity of an individual. Due to inactivity, the economic impacts of migraines are thought to be large, and a few studies have specifically considered the economic implications of migraines. Clarke et al. (1996) looked at the impact migraines have on the economy of the UK. An anonymous self-administered questionaire, filled out by 1,903 employees of a Trust Hospital, was used for this study. One hundred and fifty eight of the respondents were identified as migraineurs. Sufferers estimated two work days missed per year as a result of migraines. Along with full days missed, the migraineurs also estimated 5.5 days per year lost due to reduced effectiveness at work. In total, it was found that lost productivity cost the Trust Hospital approximately 50,000 pounds (75,000 US dollars) per year (Clarke et al. 1996). Similar costs exist in other regions of the world as well. For example, it is estimated that migraines cost United States‘ employers approximately 13 billion dollars per year (Lofland, 2007).

Due to the disabling nature and economic costs of migraines, it is important to understand what triggers them. Understanding potential triggers of migraines and other head pains is important because it allows individuals to avoid triggering conditions and to take other preventative measures. Many different triggers are thought to cause the onset of a migraine. Some triggers include diet, lack of sleep, stress, and physical stimuli. According to medical professionals, weather is one of the physical stimuli potentially responsible for migraine onset.

Weather may be defined as "the meteorological day-to-day variations of the atmosphere and their effects on life and human activity" (NOAA, 2014). In particular, weather can have an important effect on human health. In the context of migraines, research has been conducted to determine how weather and migraine frequency are related. Many of these studies looked at individual weather variables to see if they had an effect on migraine frequency, however, the results were generally inconclusive. Other studies have been able to identify significant relationships between specific weather patterns, such as those associated with Chinook winds, and migraine frequency (Cook et al. 1997 and Piorecky et al. 1997). Indeed, humans and other elements of the biosphere do not necessarily respond to single weather variables, but instead respond to multiple variables acting synergistically on the environment. This type of approach, known as the synoptic or air mass approach, has been adopted in numerous environmental and human health studies (Hondula et al. 2014); however, to the author's knowledge, it has not been applied specifically to the study of migraines. Therefore, the goal of this research is to determine if air mass types are a trigger for migraine headaches.

An air mass can be thought of as a large volume of air over a location at given time. It is formally defined as “a large body of air that has similar horizontal temperature and moisture characteristics” (NOAA, 2014). Therefore, at any given time the air mass of a location can be determined based on temperature and moisture observations. These large volumes of air have distinct weather conditions associated with them. A common air mass classification scheme is the Spatial Synoptic Classification (SSC), which was originally developed by Lawrence Kalkstein and colleagues in the early 1990s and later revised by Scott Sheridan in 2002 (Sheridan, 2002). The current Sheridan methodology characterizes the daily surface weather at various locations around the world into one of seven types: dry polar, dry moderate, dry tropical, moist polar, moist moderate, moist tropical, and Transitional. 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 et al. 2014).

In this study, the relationship between air mass type and the occurrence of migraine headaches was examined across three counties in central North Carolina (i.e. the Triangle region encompassing Orange, Durham, and Wake counties). The frequency of migraine headaches in these counties was assessed using daily emergency department (ED) 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 first-order weather station at the Raleigh-Durham International Airport. The specific objectives of this research were to (1) determine if there was a relationship between air mass type and the frequency of ED visits with a primary diagnosis of migraine headache, and (2) determine if the frequency of these ED visits was related to the direction and magnitude of pressure change associated with the Transitional SSC category.

CHAPTER II

REVIEW OF LITERATURE

Weather is known to impact humans in many ways. Specifically, weather has been discovered to have an influence on human health. Koppe et al. (2013) identified weather's influence on health in Germany. When compared to the results of a similar study conducted in 2001, it was found that weather sensitivity still affects about 50 percent of the country. While this study only looked at Germany, weather impacts human health around the globe.

In the report, "A Human Health Perspective On Climate Change," weather's impacts on various medical conditions are mentioned. The report identifies weather's influence on conditions such as: asthma, respitory allergies, airway diseases, cancer, cardiovascular diseases, stroke, and neurological diseases. The role that weather plays with each of these conditions vary. For example, higher temperatures are found to increase volitalization of chemicals that can lead to cancer, while high precipitation rates increase mold that can cause airway diseases.

With regard to human health, doctors have considered weather as a potential trigger for migraines. Surveys, based on headache sufferors' perceptions, have further identified weather as a possible trigger. Turner et al. (1995) observed migraine headache in a general population of Mexican-Americans living in San Diego County and found that weather was one of the reported triggers from both males and females. Kelman (2007) also argues that weather is a trigger for migraines. This study used 1,207 International Classification of Headache Disorders-2 patients to determine migraine triggers. A survey asked patients to rank how often a variable triggers a migraine. Patients identified a number of variables, including weather, as triggers for their headaches. Interestingly, weather was noted as one of the biggest triggers of migraines. Approximately 53 percent of the migraineurs identified weather as an occasional trigger. Only stress, hormones, and lack of food were reported more often as an occasional trigger. From July 2011 to December 2011, Wang et al. (2011) conducted a survey in the neurological clinic of a tertiary care hospital in Chongqing, China. Three hundred and ninety four patients surveyed were migraine patients, while 344 were tension type headache (TTH) patients. 80.2 % of the migraine patients and 67.4 % of the TTH patients reported triggers and changes in weather were one of the most common triggers reported.

Since the 1970's, research has been conducted in order to determine specifically how weather affects migraine frequency. Such studies have compared various meteorological variables, such as barometric pressure, temperature, humidity, cloud cover and opacity, precipitation type, as well as the occurrence of lightning, to the incidence and frequency of migraine headaches. In general, studies have had difficulty establishing a relationship between specific weather variables and head pain or migraine frequency. Table 2.1 shows the results from many of these studies. Based on the table, the results in some cases are actually contradictory.

Martin et al. (2013) observed lightning and its relationship with headache frequency. Participants who met the diagnostic criteria for International Headache Society-defined migraine were chosen for this study. Twenty three of the subjects came from Ohio and 67 came from Missouri. They recorded headache activity in a daily diary for three to six months. Then, a generalized estimating equations (GEE) logistic regression determined the odds ratio (OR) of headaches on lightning days compared to non-lightning days. The study suggests that lightning represents a trigger for headaches in migraineurs.

Villeneuve et al. (2006) observed the relationship between weather and migraine headaches in Ottawa, Canada. This study looked at several weather variables, including barometric pressure, relative humidity, temperature, wind speed, cloud opacity, and precipitation type. The study used a case-crossover design and identified 4,039 ED visits for migraine between 1993 and 2000. Once these visits were identified, the weather conditions that existed during the 24 hours preceding each visit were determined. Linear regression models were used to determine the nature of the relationship between the selected weather variables and ED visits for migraine. However, the findings showed little support for the hypothesis that ED visits for migraines are related to weather conditions.

Hoffmann et al. (2011) was another study that looked at the association between certain weather components and the onset and severity of migraine attacks. Headache diaries of 20 migraineurs from Berlin, Germany were analyzed in four-hour intervals to see if correlations existed with different weather variables. The diaries were completed over a 12 month period from January 2006 through December 2006. Absolute values and relative changes within the preceding 24 hours were also analyzed. The analysis process did not find a significant association between many of the variables and the beginning of new migraine periods. However, it was found that decreases in temperature and increases in relative humidity were associated with high intensity migraine attacks. In an earlier study, Osterman et al. (1980) looked at 73 head pain patients in Upsalla, Sweden over the course of four weeks from September 1976 to October 1976. Relationships were found between migraine frequency and some of the weather variables. Highly significant correlations were found between headache frequency and the atmospheric pressure recorded 32 to 120 hours later. Specifically, higher pressures were associated with greater headache frequencies. Lower temperatures 32 to 120 hours later were also associated with greater headache frequencies.

When it comes to the impact of weather on migraine frequency, barometric pressure is the variable most often studied. For instance, Schulman et al. (1980) focused solely on how barometric pressure impacts migraine frequency. The study looked at 75 people from the Boston, MA area who had sought help for migraines. Starting in March 1975, each person kept a headache diary for one month. Barometric pressure data were also collected throughout the month. Based on the collected data, only a minimal relationship between the two variables was found. Mukumal et al. (2009) also looked at how barometric pressure affects migraine frequency. A case crossover study of 7,054 patients seen in a single ED in Boston, MA between May 2000 and December 2007 was used. Each of these patients had a primary discharge diagnosis of a headache. To a small extent, a lower barometric pressure occurring 48 to 72 hours before hospitalization was found to be associated with an increased risk of a headache requiring an emergency department evaluation.

A different relationship with barometric pressure was found by Zebenholzer et al. (2010). The study was conducted in Vienna, Austria from 2002 to 2003. The diaries of

238 patients were used in this study. Through univariate and multivariate analyses, it was found that the presence of a ridge of high pressure appeared to increase the risk of headache. An earlier study by Cull (2005) also found that higher barometric pressure was associated with an increase in migraine frequency. Forty-four adult patients, who all suffered from classical or common migraines, were observed. The patients recorded the dates of their migraine attacks over periods of six months. Barometric pressure on the day of attacks, as well as changes in barometric pressure before the attacks, were correlated with the frequency of migraine attacks. This study found that the frequency of migraine attacks was significantly less when pressure at 06:00 hours was less than 1005 mb compared with pressures between 1016 and 1025 mb. In terms of changes in barometric pressure, the study concluded that a rise in barometric pressure of more than 15 mb over the preceding 24 hours was associated with a reduced frequency of migraines.

Prince et al. (2004) also examined the impact of barometric pressure changes and pressure in general on migraine occurrences. Seventy-seven human test subjects, 18 years of age or older, provided migraine calendars for the study. The subjects were from the states of New York and Connecticut. The daily migraine calendars covered the period from February 1997 to January 1999. Using a linear regression model, it was found that 39 out of the 77 subjects (51 percent) were found to be sensitive to weather variables. Of these 39 subjects, 10 had migraines that were related to changes in barometric pressure. In another study, Kimoto et al. (2011) looked at 28 migraine patients who lived within 10 km of the Utsunomiya Local Meteorological Observatory in order to determine how changes in pressure impacted migraine frequency. The patients kept a headache diary from April 2008 to March 2009. Correlation tests found that the frequency of migraine occurrences did not depend on the barometric pressure on the day of the headache. Rather, they found that migraine occurrences increased when the barometric pressure fell more than 5 mb between the day of the headache and two days after. The study also found that the frequency of migraine occurrences dropped when the barometric pressure rose more than 5 mb between the day of the headache and two days after.

Another approach to examining migraine frequency is the use of medication sales. Ozeki et al. (2014) used the proportion of sales of loxoprofen, commonly used to treat headache disorders, to other over the counter drug sales from a drug store chain in Japan to determine the relationship between headaches and weather. The study took place between April 1, 2011 and March 31, 2012. Linear regression was used to determine the relationship between loxoprofen sales and various weather conditions. The results showed that sales increased when there was a decrease in barometric pressure. The results from this study confirm those from Cull (2005) and Kimoto et al. (2011).

Based on the limited succes of looking at weather variables individually, some studies have decided to look at broader weather patterns in relation to migraine frequency. In Yang et al. (2011), headache diaries of 52 patients were collected from August 7, 1997 through December 31, 1997. The study found that headaches appeared to have a relationship with changes in weather, particularly during the cold season. Cold fronts were identified as a potential trigger for headaches, including migraines, due to the changing conditions associated with their passage. Specifically, the increased headache occurrence was linked to the increase in temperature and sunshine duration that typically occur during the aftermath of a cold front passage.

Chinook winds are one of the weather features that have been looked at in great detail with regards to their impact on migraine frequency. Piorecky et al. (1997) wanted to determine if warm/dry chinook weather conditions in the Calgary area increased the probability of headache attacks in migraine sufferers. Meteorological summaries from Environmental Canada during the period January through June 1992 were analyzed and times of chinook wind onset were identified. Chinook wind events included the day chinook winds were present as well as the day preceeding their onset. For this study, 13 migraine patients were analyzed using headache diaries. The probability of migraine headache onset was greater on days with chinook weather than on non-chinook days. Cooke et al. (2000) also looked at the relationship between chinook winds and migraine frequency in the Calgary area. The study used 75 patient diaries from the University of Calgary Headache Research Clinic. Regression models showed similar results to Piorecky et al. (1997), as migraine onset increased on days with chinook winds. The regression models also showed that the probability of migraine onset increased on pre-chinook days.

In light of the results from Cook et al. (2000) and Piorecky et al. (1997), other weather features, which encompass numerous weather variables, should be examined with respect to migraine frequency. While chinook winds represent a small scale weather feature, synoptic scale weather features with many variables may also impact migraine frequency. Accordingly, the goal of this research is to determine if synoptic air mass type is a trigger for migraine headaches.

Table 2.1 Previous Literature Results

Study	**Variable Found to Trigger Migraines**						
	High Pres.	**Low Pres.**	**Temp.**	**Pres. Increases**	**Pres. Decreases**	**Lightning**	**None**
Martin et al. (2013)						✓	
Villeneuve et al. (2006)							✓
Hoffmann et al. (2011)							✓
Osterman et al. (1980)	✓		✓				
Mukumal et al. (2009)		✓					
Zebenholzer et al. (2010)	✓						
Cull (2005)	✓				✓		
Kimoto et al. (2011)					✓		
Ozeki et al. (2014)					✓		

CHAPTER III

DATA AND METHODS

3.1 Study Region and Study Period

The study region is comprised of Durham County, Orange County, and Wake County, North Carolina (Figure 3.1). These counties comprise one of the most populated regions of North Carolina. In order to observe how air mass type impacts migraine frequency, the study location should experience many different air mass types. In central North Carolina, where these counties are located, a variety of air mass types can be found throughout a given year. This is mainly due to the region's midlatitude location, where air masses of polar, tropical, continental, and maritime origin often intersect. The study period spans from January 1, 2007 to December 31, 2013. This period was chosen based on the availability of migraine data described below.

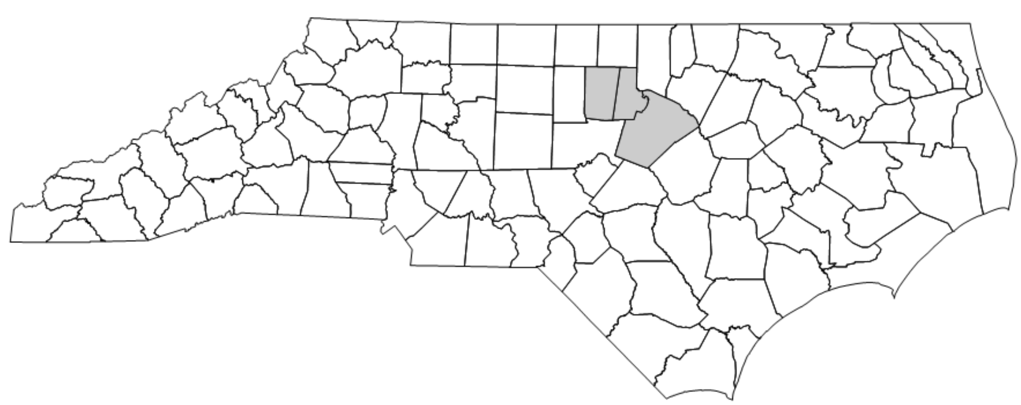

Figure 3.1 Durham County, Orange County, and Wake County, North Carolina

3.2 Migraine Frequency Data

Two sets of data were used in this research. The first dataset involves daily migraine frequency, which is based on the number of emergency department (ED) visits with a primary diagnosis of a migraine. Daily records of ED visits across the selected North Carolina counties for the period 2007–2013 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 a migraine could be found. The ICD-9 code for migraine is 346.xx. Sub-codes of migraines include: Migraine with aura (346.0), Migraine without aura (346.1), Variants of migraine, not elsewhere classified (346.2), Hemiplegic migraine (346.3), Menstrual migraine (346.4), Persistent migraine aura without cerebral infarction (346.5), Persistent migraine aura with cerebral infarction (346.6), Chronic migraine without aura (345.7), Other forms of migraine (346.8), and Migraine unspecified (346.9). All sub-codes of migraine were included in this study, including menstrual migraines, which only accounted for three percent of the total migraines in the dataset.

3.3 Air Mass Data

The second dataset for this research includes the daily type of air mass over central North Carolina. The Spatial Synoptic Classification (SSC), which identifies the synoptic meteorological characteristics of a location, was used to identify daily air mass type. The SSC is a hybrid classification scheme that utilizes both automated and manual processes (Sheridan, 2002). The SSC first identifies weather type manually based on climatological knowledge. As the character associated with these weather types changes from season to season, typical days in each type, known as “seed days”, were picked for each station for different times of the year. Then, algorithms develop hypothetical seed days for each day of the year. Actual conditions on each day can be compared to the seed days. This allows a day to be classified based on the classification type it most closely resembles (Spatial Synoptic Classification, 2015). The Raleigh-Durham International Airport in Morrisville, North Carolina (Wake County) was used as the base location for air mass classification due to its close proximity to the selected counties. The code for the selected weather station is “RDU.” Using the SSC, air mass types were determined for each day of the study period using the selected weather station code.

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 classification types mirror the classic air mass types developed by the Bergen School of Meteorology (Sheridan, 2002). Dry Polar classifications are synonymous with continental polar air masses. These air masses are typically 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). A Moist Polar classification is representative of a Maritime Polar air mass. These air masses can be the result of frontal overrunning or be advected inland from a cool ocean. These air masses lead to cloudy, humid, and cool conditions (Spatial Synoptic Classification, 2015). Dry Tropical classifications are similar to Continental

Tropical air masses. These air masses can be advected from desert regions or produced by rapidly descending air. The hottest and driest conditions found at any location are typically found with these air masses (Spatial Synoptic Classification, 2015). Moist Tropical classifications are analogous to Maritime Tropical air masses. They are often found in warm sectors of mid-latitude cyclones, but can also be found in a return flow on the western side of an anticyclone. Warm and humid conditions are found with these air masses. As you approach the equator, the frequency of this air mass increases (Spatial Synoptic Classification, 2015). Two "oppressive" sub-sets of the Moist Tropical air mass are defined as those days where the apparent temperature exceeds the MT seed day mean. Due to their infrequent occurrence across the study region, however, they are not considered in this study.

During Transitional days, one classification type yields to another, leading to changes in pressure, dew point, and wind over the course of the day (Spatial Synoptic Classification, 2015). A Dry Moderate classification does not have a traditional analog. This classification type is found with zonal flow in the middle latitudes, especially in the lee of mountain ranges. Additionally, they can occur when traditional air masses are advected far away from their source regions. Mild and dry conditions are associated with this type of classification (Spatial Synoptic Classification, 2015). Moist Moderate is another classification without a traditional analog. This classification type is typically found equatorward of Moist Polar air masses. They can occur when cloudy conditions suppress the temperature of a traditional Maritime Tropical air mass. Mild and humid conditions are typically found with this classification type (Spatial Synoptic Classification, 2015).

3.4 Data Organization

In order to complete the objectives of this study, the data had to first be organized. With regards to the first objective, identifying the potential relationship between air mass type and migraine frequency, Microsoft Excel spreadsheets were created to organize the daily migraine and air mass data collected from 2007-2013. Information in the spreadsheets included the date, number of migraine ED visits, and air mass type. A spreadsheet was made for each of the three selected counties. Furthermore, a Microsoft Excel spreadsheet combining the counties was created.

Information from the created spreadsheets was then placed in the statistical software program “R” (The R Project for Statistical Computing, 2015). Data vectors were created for each air mass type. At first this was done for each county individually. In this case, each value in the vector represented the number of migraine ED visits, for that county, during a day with a particular air mass type. Later, additional vectors were created to display combined values. With these vectors, each value represented the number of migraine ED visits, for all counties combined, during a day with a particular air mass type. In all cases the mean of a vector represented the average number of daily migraine ED visits for an air mass type.

To complete the second objective of this study, determining how pressure changes associated with Transitional air masses relate to migraine frequency, days with a Transitional air mass were first identified. Once found, a Microsoft Excel spreadsheet was created to organize the data. The spreadsheet included the date, combined number of migraine ED visits from the selected counties, 4am (LST) pressure, 10pm pressure, and the 4am to 10pm pressure change. The pressure information was obtained from hourly weather observations at RDU. These observations were retrieved through the Applied Climate Information System (ACIS), which is maintained by NOAA's Regional Climate Center Program. Information from this spreadsheet was then placed in "R" where data vectors were created for positive pressure changes and negative pressure changes. Each value in the vector represented the number of migraine ED visits, for all counties combined, on a day with a Transitional air mass.

3.5 Statistical Methods

Chi-Square tests determined that migraine ED visits were not normally distributed in all of the vectors. Based on the results of the Chi-Square tests, bootstrapping was utilized for this study. Bootstrapping is a non-parametric technique that does not require datasets to be normally distributed or to have the same distribution. Bootstrapping uses resampling, with repetition, to generate quantile values for statistical measurements, such as the mean. Based on vector sizes, which ranged from 61 to 717, quantile values in this study were generated by resampling the data 2,000 times.

Bootstrapping was first used to determine if statistically significant differences existed between the mean number of daily migraine ED visits for each air mass type. Ninety-five percent bootstrap confidence intervals of mean daily migraine ED visits, for each of the chosen air mass types, were created. This was done for each county individually as well as together. 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 in order to see if the null hypothesis could be rejected. Additionally, for the combined counties, standard deviation bootstraps were created. This was done to compare the variability in daily migraine ED visits between the different air mass types.

Bootstraps were also created to identify potential lag relationships between air mass type and migraine frequency. One to five day lags were looked at, where the daily number of migraine ED visits were compared to the air mass type that occurred one to five days prior. For each lag, ninety-five percent bootstrap confidence intervals of mean daily migraine 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.

Bootstrapping was also used to determine if a statistically significant difference existed between the average number of daily migraine ED visits during Transitional air mass days with a positive 4am to 10pm pressure change and Transitional air mass days with a negative 4am to 10pm pressure change. Positive 4am to 10pm pressure changes on Transitional air mass days are usually indicative of a cold front passage, while negative 4am to 10pm typically identify an approaching low pressure system or warm front passage. Ninety-five percent bootstrap confidence intervals of mean daily migraine 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. The confidence intervals were compared in order to see if the null hypothesis could be rejected.

Pearson correlation tests were also conducted on the Transitional air mass data to determine if there was a relationship between the magnitude of the pressure change and migraine frequency. Specifically, two correlations tests were completed. The first correlation test compared the positive 4am to 10pm pressure change magnitude to the number of migraine ED patients on those days. The second correlation test focused on Transitional air mass days with a negative 4am to 10pm pressure change. In this case, negative 4am to 10pm pressure change magnitudes were compared to the number of migraine ED patients on those days.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Data Characteristics

A total of 16,930 ED visits for migraine were recorded across the three counties from 2007-2013. Out of these visits, 4,640 were from Durham County, 1,451 were from Orange County, and 10,839 were from Wake County. The age distributions for Durham County, Orange County and Wake County (Figures 4.1, 4.2, 4.3) show that the highest rates of ED visits for migraines were found between the ages of 25 and 54. The rates of migraine ED visits were smaller between the ages of 0 and 18. Smaller rates were also found with age groups 74 and older. In terms of gender, there was a large difference between the rates of female patients and male patients. The gender distributions for each county (Figures 4.4, 4.5, 4.6) show that rates of female ED patients was greater than the rates of male ED patients in all cases. Overall, approximately 83 percent of the ED visitors in this study were female.

Figure 4.7 shows the monthly distributions of the rate of migraine visits for the combined counties from 2007-2013. Based on this figure there is no major trend in seasonality with regards to the rate of migraine visits. Each month had a similar rate of migraine induced ED visits over the course of the study period.

Figures (4.8, 4.9, 4.10) show the day of week distributions for each county during the study period. In all three counties, there is a decrease in the rate of visits on Fridays, but otherwise there is no discernable pattern with regards to the rate of ED patients on different days of the week.

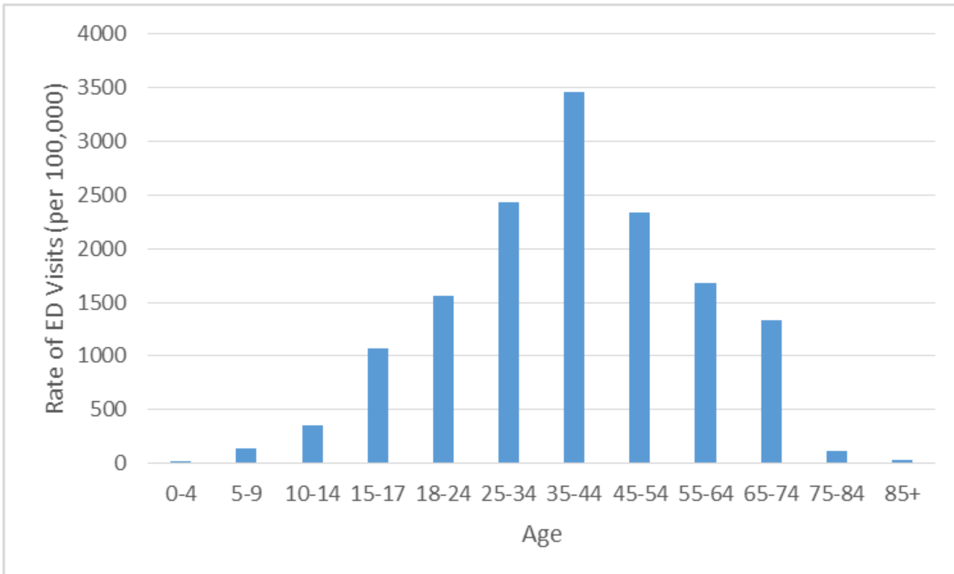

Figure 4.1 Durham County age distribution of migraine ED patients from 2007-2013

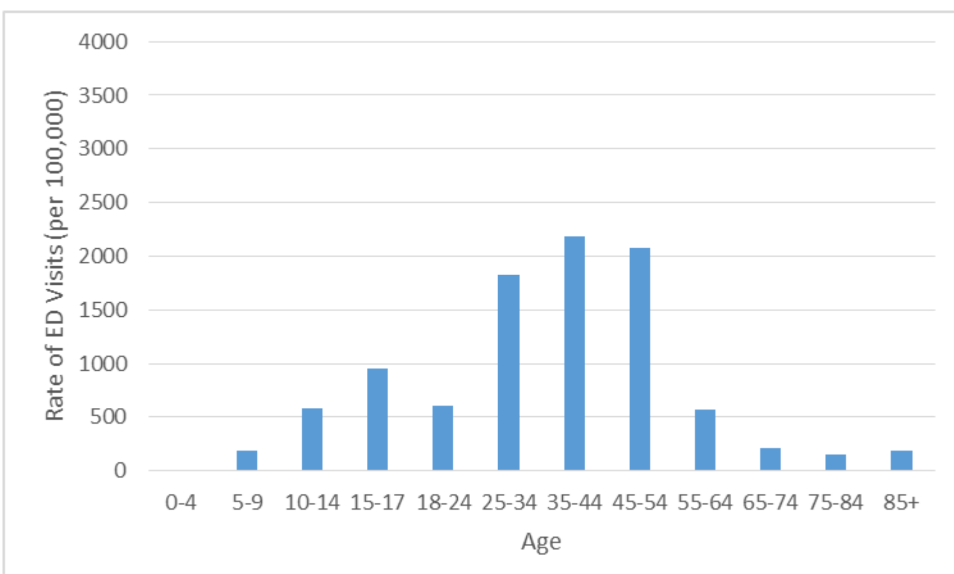

Figure 4.2 Orange County age distribution of migraine ED patients from 2007-2013

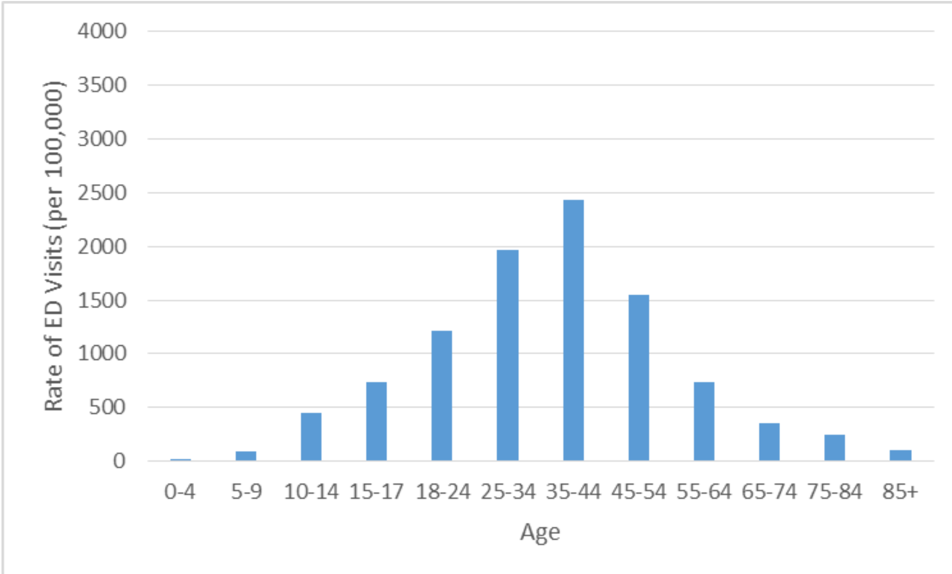

Figure 4.3 Wake County age distribution of migraine ED patients from 2007-2013

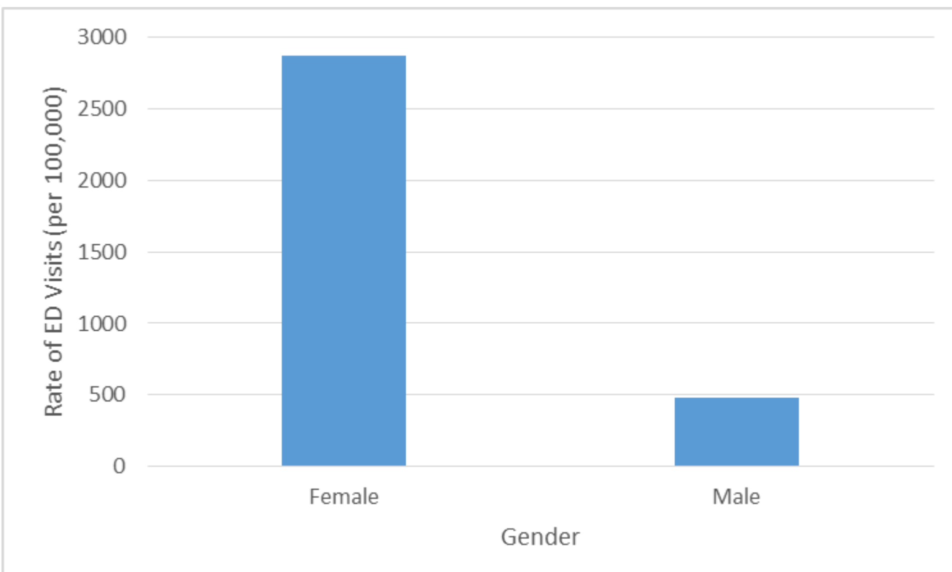

Figure 4.4 Durham County gender distribution of migraine ED patients from 2007-2013

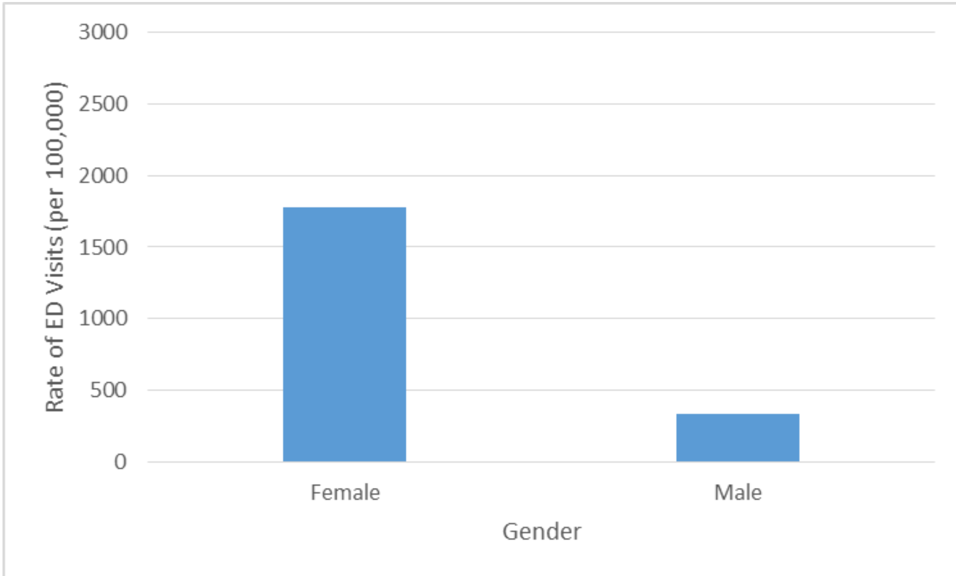

Figure 4.5 Orange County gender distribution of migraine ED patients from 2007-2013

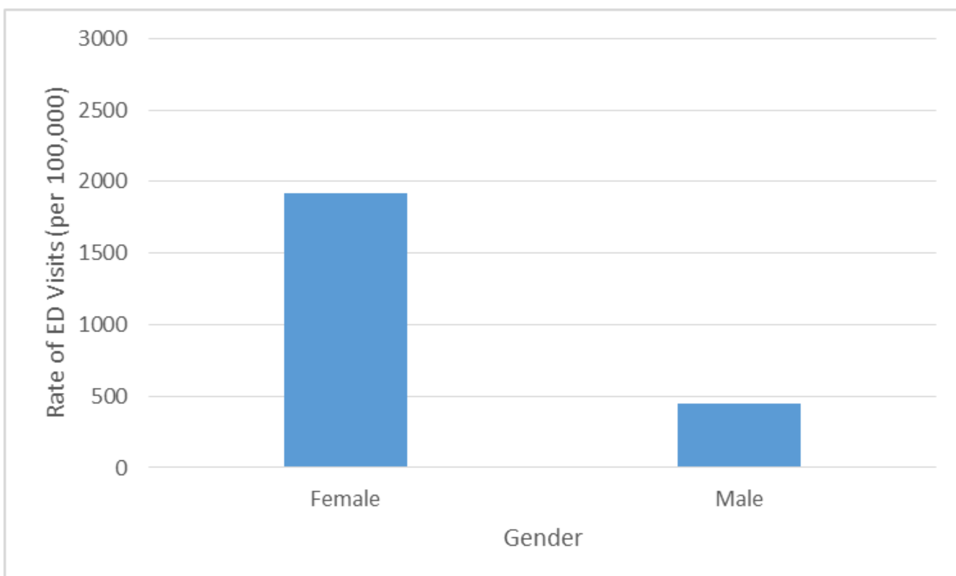

Figure 4.6 Wake County gender distribution of migraine ED patients from 2007-2013

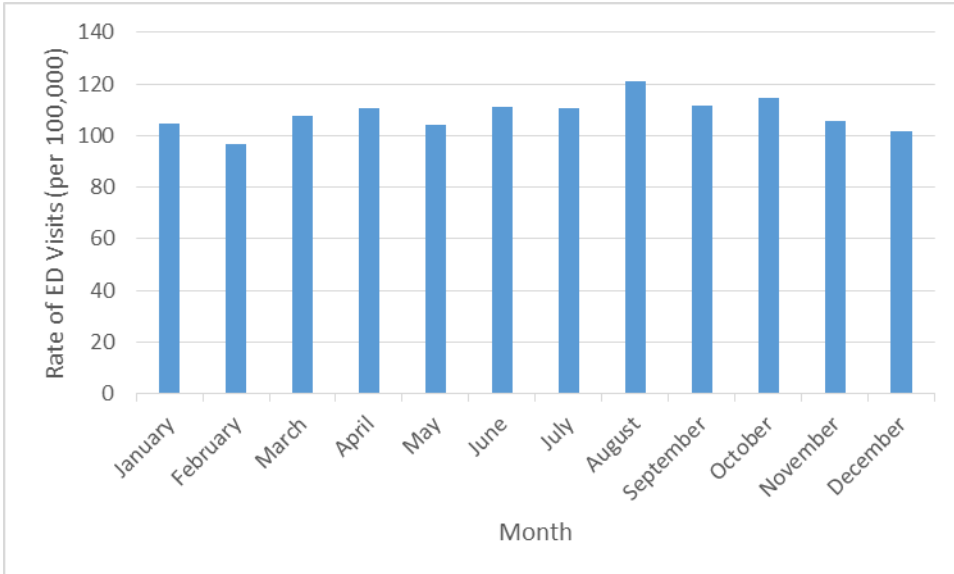

Figure 4.7 Monthly distribution of the rate of migraine ED visits per 100,000 people for the Triangle region of North Carolina from 2007-2013

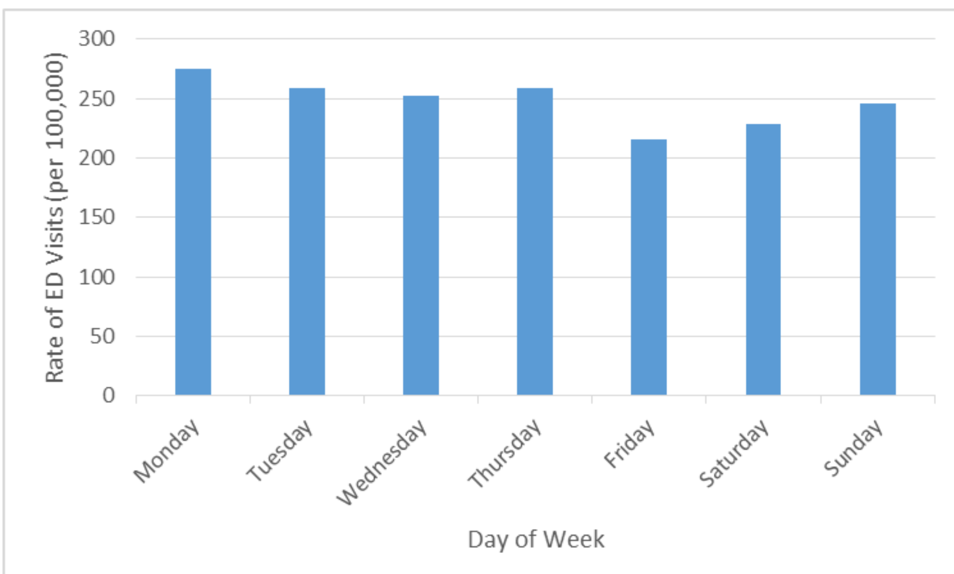

Figure 4.8 Durham County day of week distribution of migraine ED visits from 2007-2013

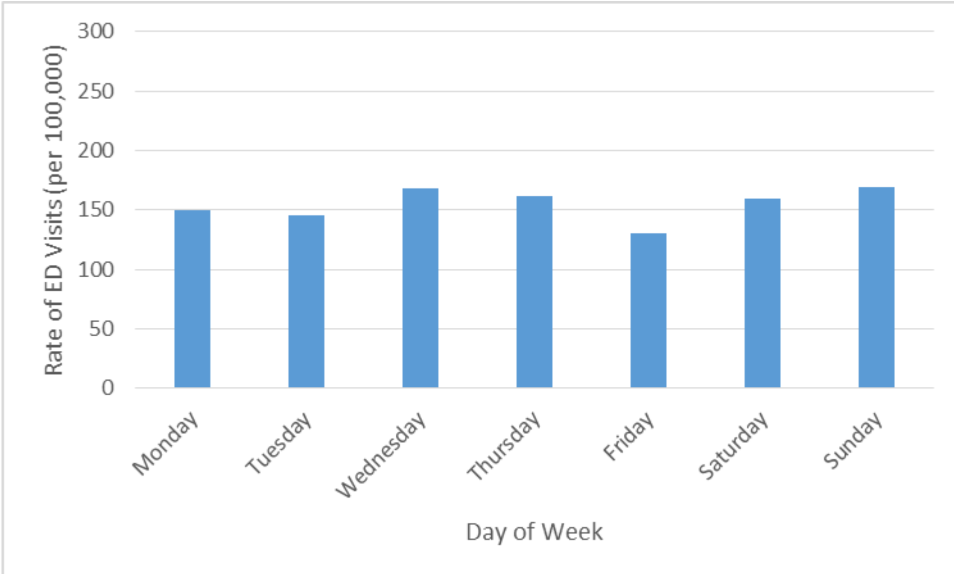

Figure 4.9 Orange County day of week distribution of migraine ED visits from 2007-2013

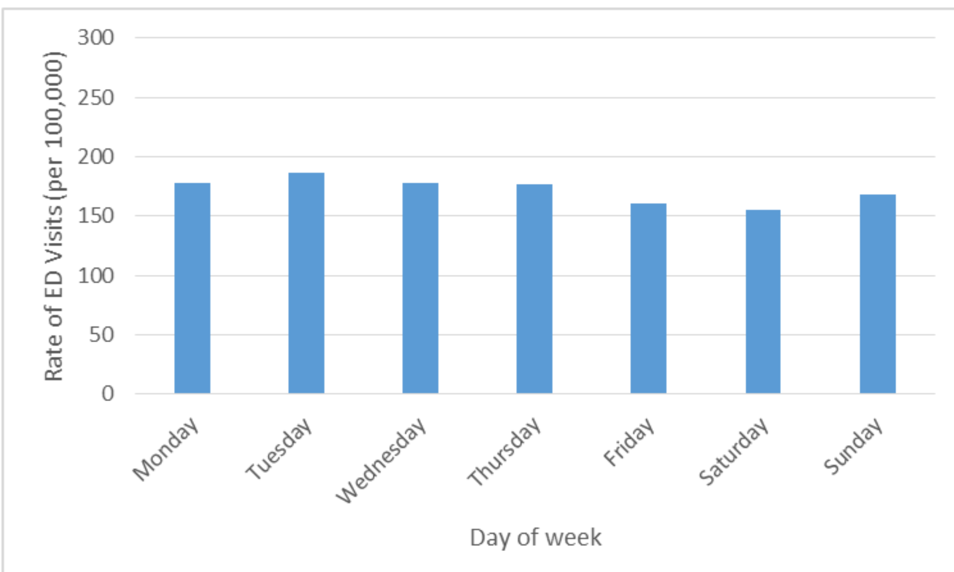

Figure 4.10 Wake County day of week distribution of migraine ED visits from 2007-2013

4.2 Bootstrapping Results

Table 4.1 shows how the mean number of migraine ED patients was similar for each air mass type. This was the case for each county individually and when the daily number of visits from each county were combined. Despite similar values, the bootstrap confidence intervals identified many statistically significant differences.

Durham County, Orange County, and Wake County all had similar patterns with regards to their bootstrap confidence intervals of the mean number of migraine ED visits for each air mass type. Therefore the counties shared a similar relationship between air mass type and migraine frequency.

Figure 4.11 shows the bootstrap confidence intervals of each air mass type for Durham County. Table 4.2 displays the quantile values, associated with the 95 percent confidence interval, for each bootstrap. In general, Polar air masses corresponded to fewer migraine ED visits when compared to days with Tropical air masses. Furthermore, days with a Dry Tropical air mass resulted in the highest number of patients arriving to the ED for migraines. The difference between Dry Tropical air masses and the other types was statistically significant in all cases but two. The first case was between Dry Tropical air masses and Moist Tropical air masses. The other case, where the difference in the number of migraine ED visits was not statistically significant, was between Dry Tropical air masses and Dry Moderate air masses. Moist Polar air masses resulted in the fewest number of visits to the ED for migraines. The difference between this air mass and the others was statistically significant in all cases but one. Only when compared to Dry Polar air masses was the difference not statistically significant. The confidence intervals also showed a statistically significant difference between Moderate air mass days and

Polar air mass days. Days with a Moderate air mass led to more visitors to the ED for migraines compared to Polar air mass days. Additionally, the confidence interval for Transitional air masses fell between those of Tropical and Polar air masses.

Figure 4.12 shows the bootstrap confidence intervals of each air mass type for Wake County, while Table 4.3 displays the bootstrapping quantile values associated with the 95 percent confidence interval. The bootstrap confidence intervals for Wake County were very similar to the ones found in Durham County. Just like with Durham County, Polar air masses resulted in fewer migraine ED visits, while Tropical air masses had more. Just like with Durham County, Moist Polar air masses were associated with the fewest ED visits for migraines. In fact, as was the case for Durham County, the difference between this air mass and the others was statistically significant in all cases but one. Only when compared to Dry Polar air masses was the difference not statistically significant. In Wake County, Moist Tropical air masses, rather than Dry Tropical air masses, were found to correspond to the highest number of migraine ED patients. This was one of the largest discrepancies between Durham and Wake County.

Figure 4.13 shows the bootstrap confidence intervals of each air mass type for Orange County. Table 4.4 displays the quantile values, associated with the 95 percent confidence interval, for each bootstrap. The defined pattern identified in the other counties is not as visible in Orange County. Also, due to the pattern not being as prominent, no statistically significant differences exist.

When the daily number of migraine ED visits for each county are combined, the resulting bootstrap confidence intervals reveal similar relationships to those found earlier. Figure 4.14 shows the bootstrap confidence intervals of each air mass type for the combined counties, while Table 4.5 displays the bootstrapping quantile values associated with the 95 percent confidence interval. Once again a difference existed between Polar air masses and Tropical air masses. Both Dry Polar and Moist Polar air masses had statistically significant differences when compared to Tropical air masses. Like before, it was found that Polar air masses resulted in fewer ED visits for migraines, while Tropical air masses resulted in more. With the combined counties, Moist Tropical air masses were associated with the highest number of patients arriving at the ED for migraines, while Moist Polar air masses were associated with the fewest. Both Dry Moderate and Moist Moderate air masses had statistically significant differences when compared to Polar air masses. Specifically, days with Moderate air masses resulted in more migraine ED patients than days with Polar air masses. The confidence interval for Transitional air masses again fell in between those of Tropical and Polar air masses. Figure 4.15 shows the standard deviation bootstraps, for each air mass type, when the daily number of migraine ED visits for each county are combined. Based on the bootstrap plots, the variability of daily migraine ED visits seems to be similar between the different air mass types.

Figures 4.16, 4.17, 4.18, 4.19, and 4.20 show the various lag bootstrap confidence intervals, for each air mass type, when the data from all three counties are combined. Tables 4.6, 4.7, 4.8, 4.9, and 4.10 display the bootstrapping quantile values, associated with the 95 percent confidence interval, for the different lags. With some exceptions, the confidence intervals show that one to five day lags have similar relationships to those found earlier. Just like on a day with a Tropical air mass, the one to five days after tend to result in more migraine ED visitors compared to the days following Polar air masses.

Also, similar to the day of a Moist Polar air mass, the one to five days following seem to be associated with the fewest visitors to the ED for migraines.

Figure 4.21 shows the bootstrap confidence intervals for Transitional air mass days with positive and negative pressure changes. Table 4.11 shows the quantile values, associated with the 95 percent confidence interval, for each bootstrap. Based on the bootstraps, there is no statistically significant difference between the number of migraine ED visits during Transitional air mass days with positive 4am to 10pm pressure changes and Transitional air mass days with negative 4am to 10pm pressure changes.

Table 4.1 Average Number of Migraine ED visits

Air mass	**Durham County Average**	**Orange County Average**	**Wake County Average**	**Combined Average**
Dry Moderate	1.864714	0.5467225	4.232915	6.644351
Dry Polar	1.555556	0.5734767	4.021505	6.150538
Dry Tropical	2.008499	0.5949008	4.23796	6.84136
Moist Moderate	1.833333	0.5718954	4.30719	6.712418
Moist Polar	1.431193	0.5229358	3.688073	5.642202
Moist Tropical	1.88806	0.5870647	4.422886	6.898010
Transition	1.638743	0.5759162	4.162304	6.376963

Table 4.2 Bootstrap Quantile Values for Durham County Air Masses

Air Mass	2.5 %	50 %	97.5 %
Dry Moderate	1.757322	1.865411	1.967992
Dry Polar	1.405018	1.555556	1.716846
Dry Tropical	1.849858	2.008499	2.169972
Moist Moderate	1.679657	1.836601	2.003268
Moist Polar	1.192661	1.431193	1.706422
Moist Tropical	1.743719	1.888060	2.037313
Transition	1.434555	1.638743	1.853403

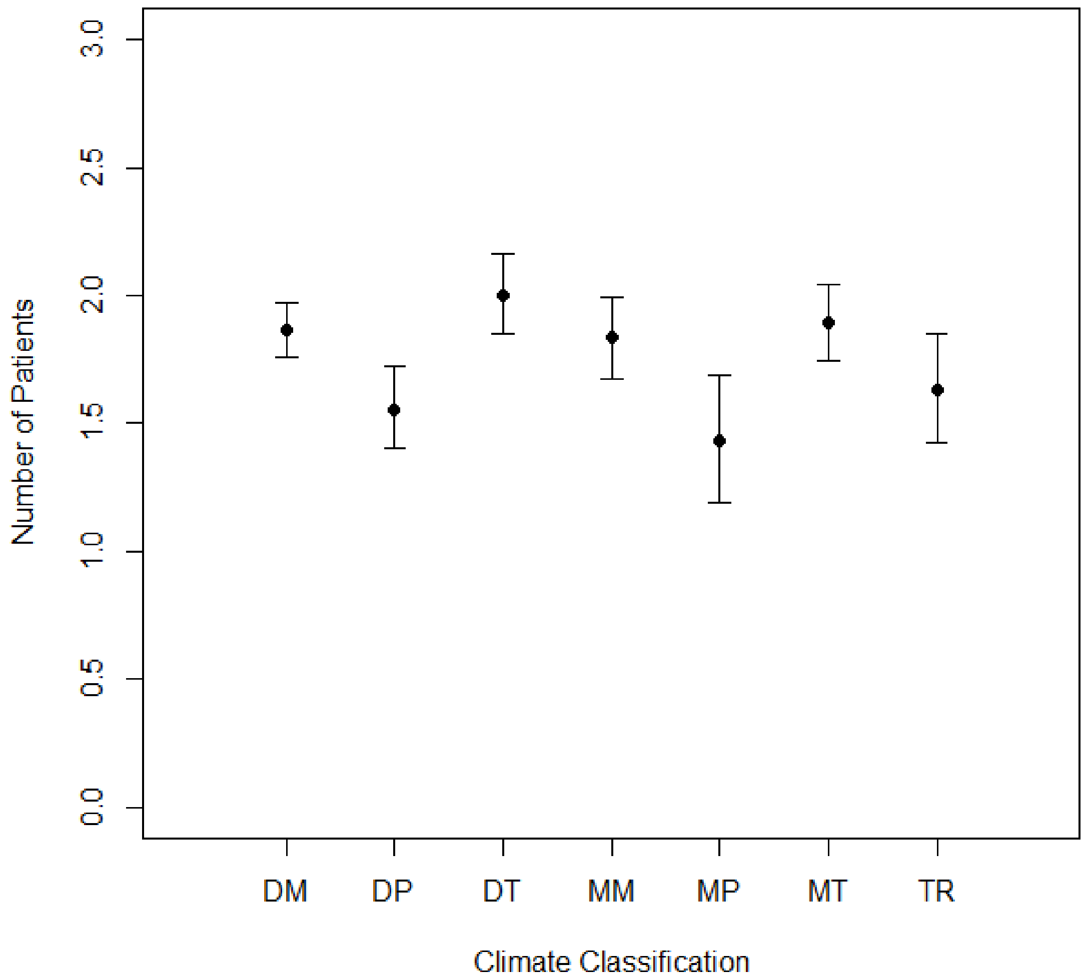

Figure 4.11 Bootstrap confidence intervals of the mean number of migraine ED visits from Durham County for each air mass from 2007-2013

Table 4.3 Bootstrap Quantile Values for Wake County Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	4.066911	4.232915	4.396130
Dry Polar	3.777778	4.014337	4.268817
Dry Tropical	3.997167	4.237960	4.461756
Moist Moderate	4.065359	4.310458	4.552288
Moist Polar	3.293578	3.688073	4.091972
Moist Tropical	4.201493	4.420398	4.626866
Transition	3.837696	4.162304	4.492147

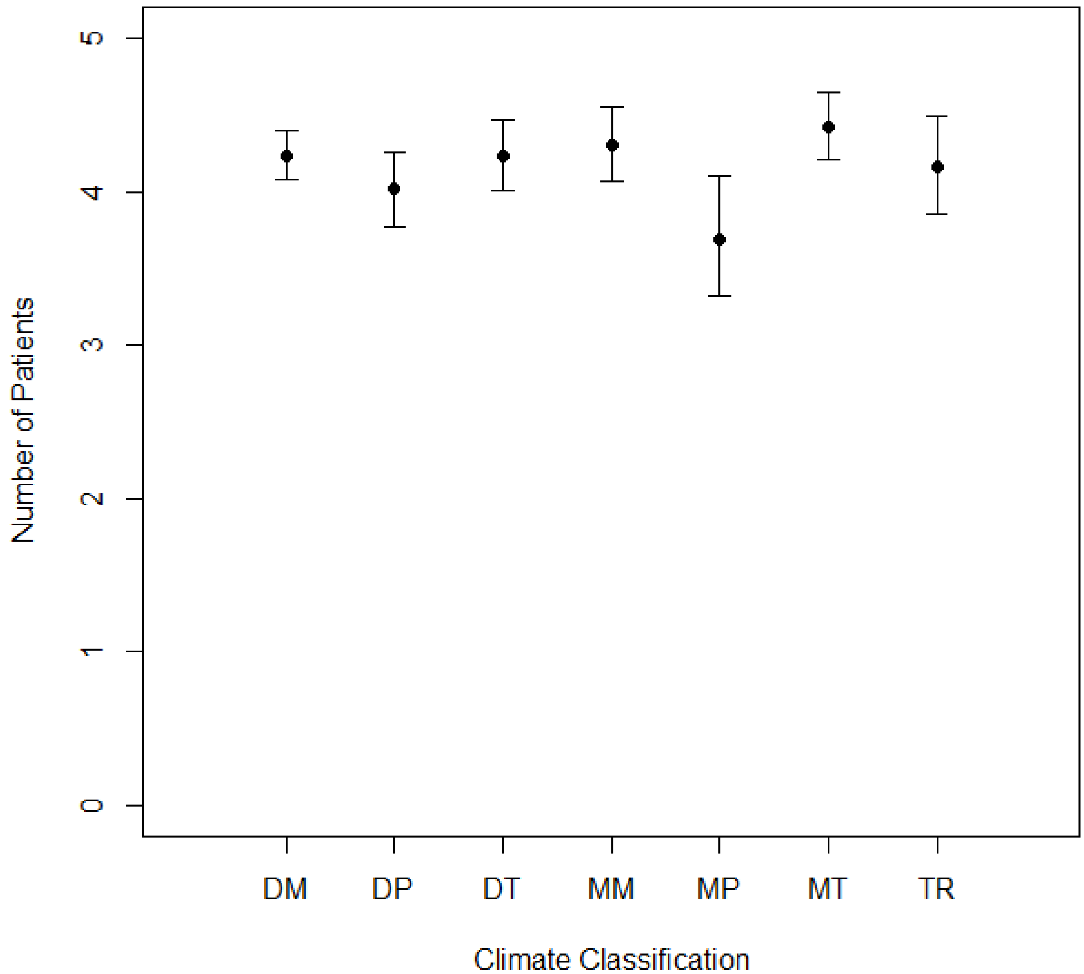

Figure 4.12 Bootstrap confidence intervals of the mean number of migraine ED visits from Wake County for each air mass from 2007-2013

Table 4.4 Bootstrap Quantile Values for Orange County Air Masses

Air Mass	2.5 %	50 %	97.5 %
Dry Moderate	0.4909344	0.5467225	0.6011158
Dry Polar	0.4874552	0.5734767	0.6559140
Dry Tropical	0.5127479	0.5920680	0.6742210
Moist Moderate	0.4803922	0.5718954	0.6633987
Moist Polar	0.3944954	0.5229358	0.6697248
Moist Tropical	0.5099502	0.5845771	0.6666667
Transition	0.4554974	0.5759162	0.7068063

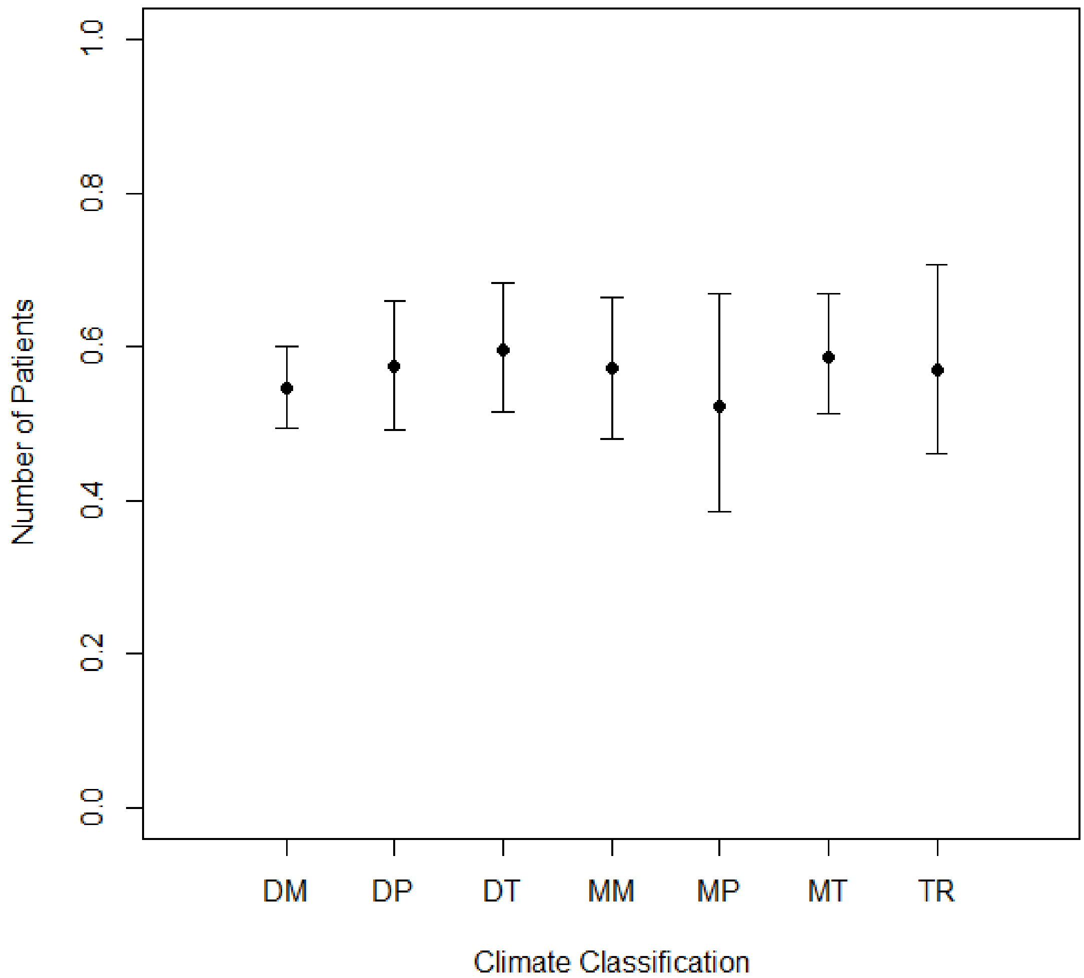

Figure 4.13 Bootstrap confidence intervals of the mean number of migraine ED visits from Orange County for each air mass from 2007-2013

Table 4.5 Bootstrap Quantile Values for the Combined Counties Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	6.439296	6.647141	6.856381
Dry Polar	5.842204	6.154122	6.473118
Dry Tropical	6.541076	6.838527	7.133144
Moist Moderate	6.392157	6.707516	7.045833
Moist Polar	5.155963	5.642202	6.137844
Moist Tropical	6.624378	6.895522	7.208955
Transition	5.989529	6.376963	6.774869

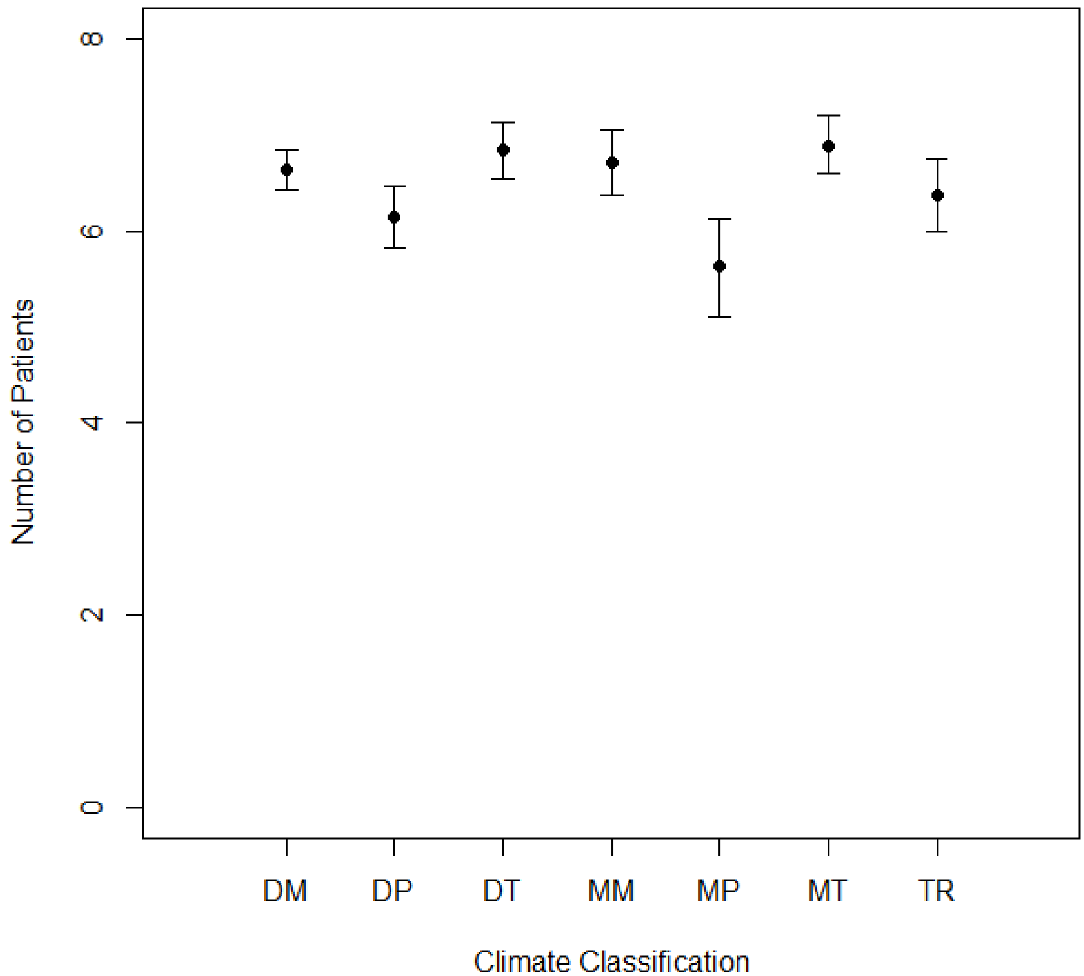

Figure 4.14 Bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for each air mass from 2007-2013

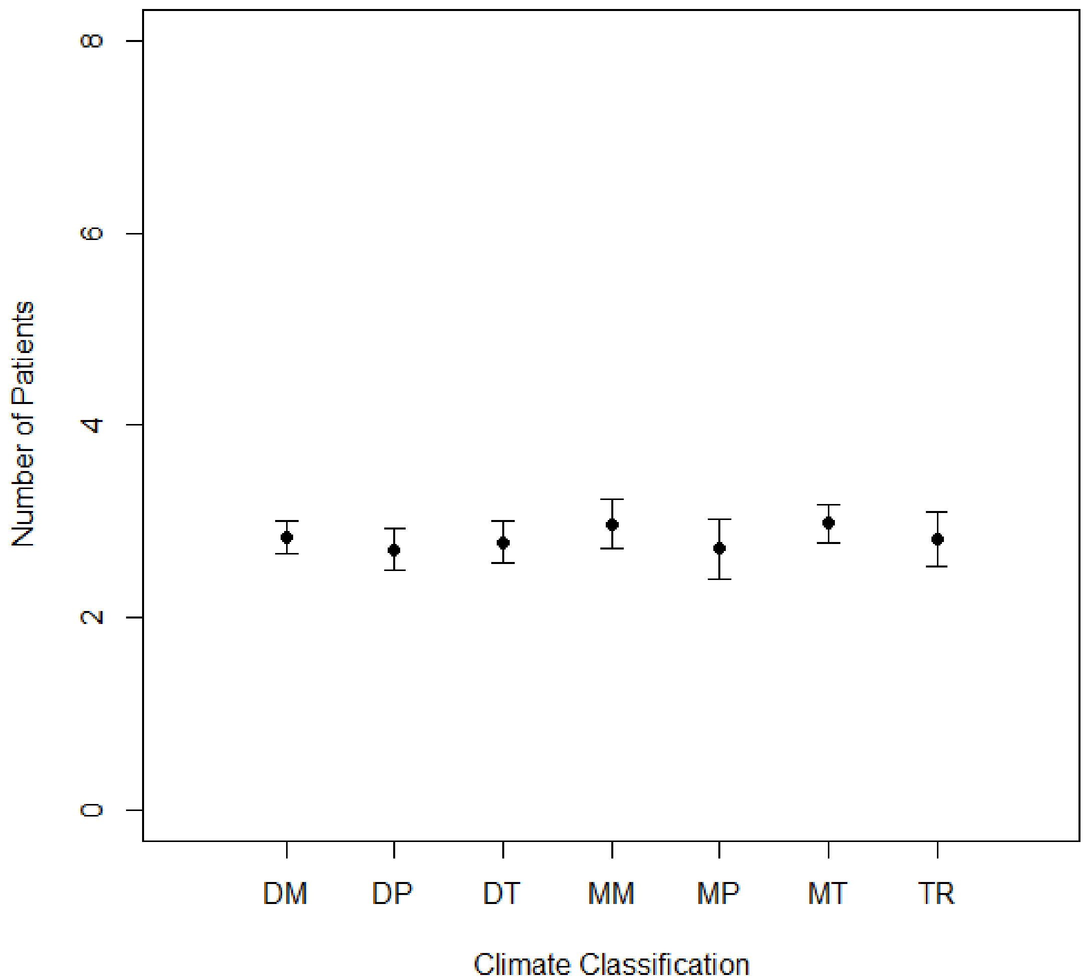

Figure 4.15 Bootstrap confidence intervals of the standard deviations of migraine ED visits from the entire study area for each air mass from 2007-2013

Table 4.6 Lag 1 Bootstrap Quantile Values for the Combined Counties Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	6.377060	6.581006	6.798918
Dry Polar	5.939068	6.275986	6.605735
Dry Tropical	6.322875	6.589235	6.869688
Moist Moderate	6.490196	6.810458	7.133987
Moist Polar	5.651376	6.165138	6.697248
Moist Tropical	6.605397	6.890819	7.181203
Transition	5.947644	6.356021	6.780105

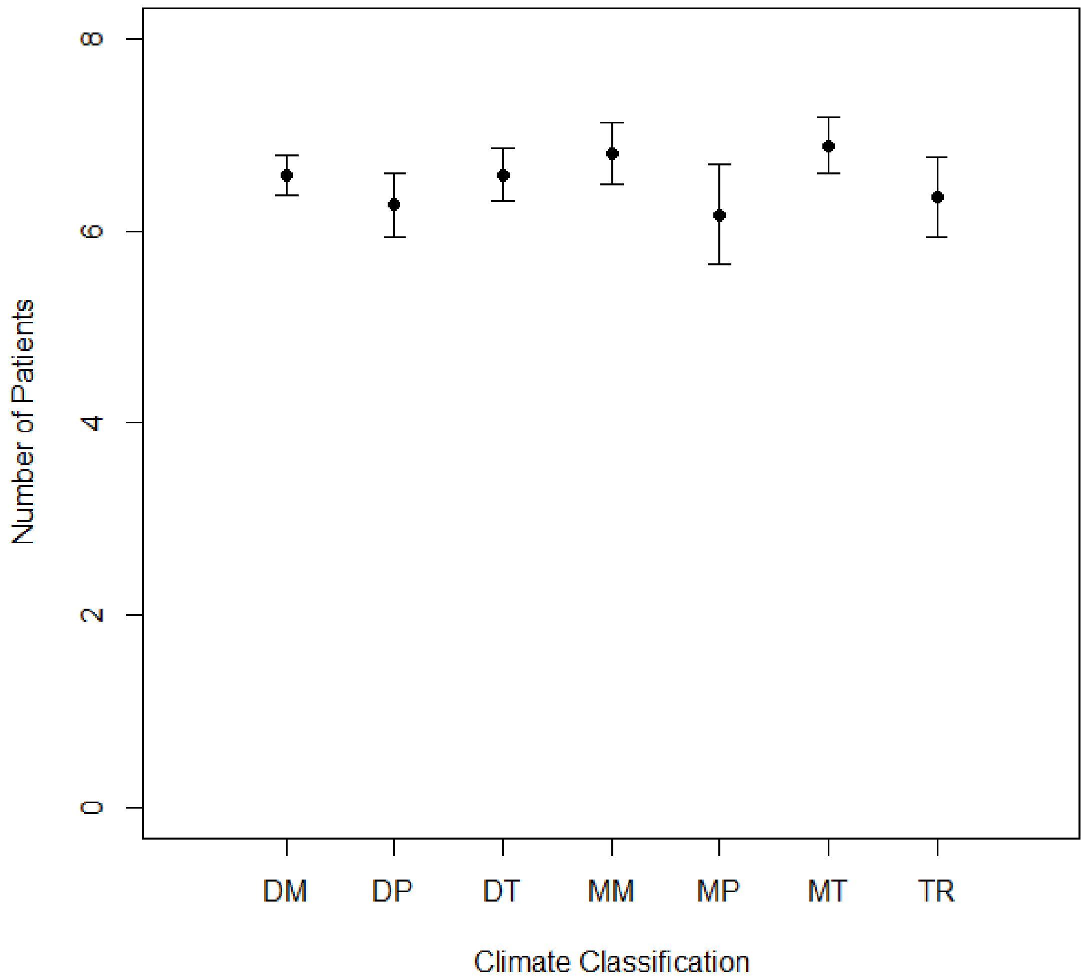

Figure 4.16 Lag 1 bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for each air mass from 2007-2013

Table 4.7 Lag 2 Bootstrap Quantile Values for the Combined Counties Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	6.395251	6.592179	6.800279
Dry Polar	5.924642	6.272401	6.612993
Dry Tropical	6.362535	6.645892	6.932082
Moist Moderate	6.295000	6.600000	6.90500
Moist Polar	5.577982	6.119266	6.642431
Moist Tropical	6.528474	6.813896	7.106700
Transition	6.544372	6.942408	7.361257

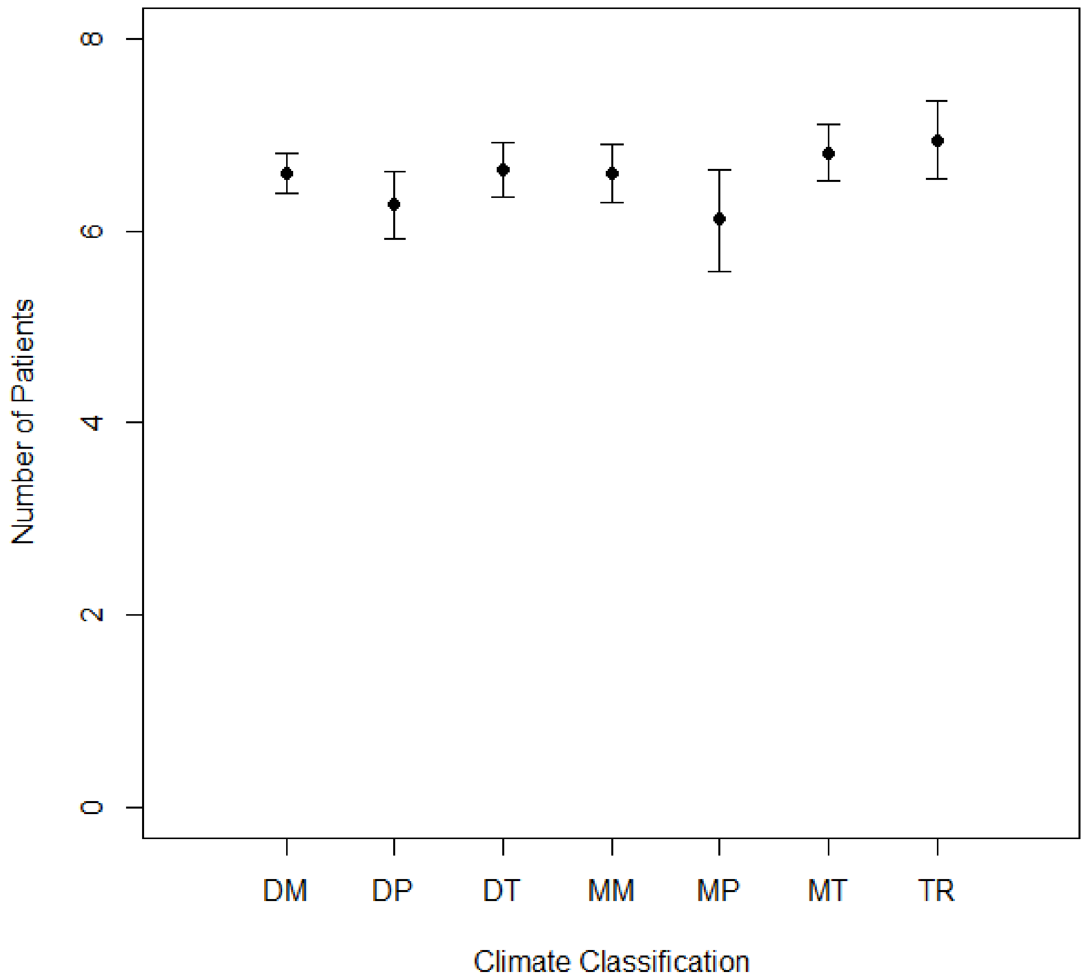

Figure 4.17 Lag 2 bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for each air mass from 2007-2013

Table 4.8 Lag 3 Bootstrap Quantile Values for the Combined Counties Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	6.379324	6.584379	6.800558
Dry Polar	5.921057	6.265233	6.612993
Dry Tropical	6.422096	6.711048	7.019830
Moist Moderate	6.351974	6.638158	6.934293
Moist Polar	6.073394	6.568807	7.036927
Moist Tropical	6.330025	6.598015	6.875931
Transition	6.371597	6.759162	7.178010

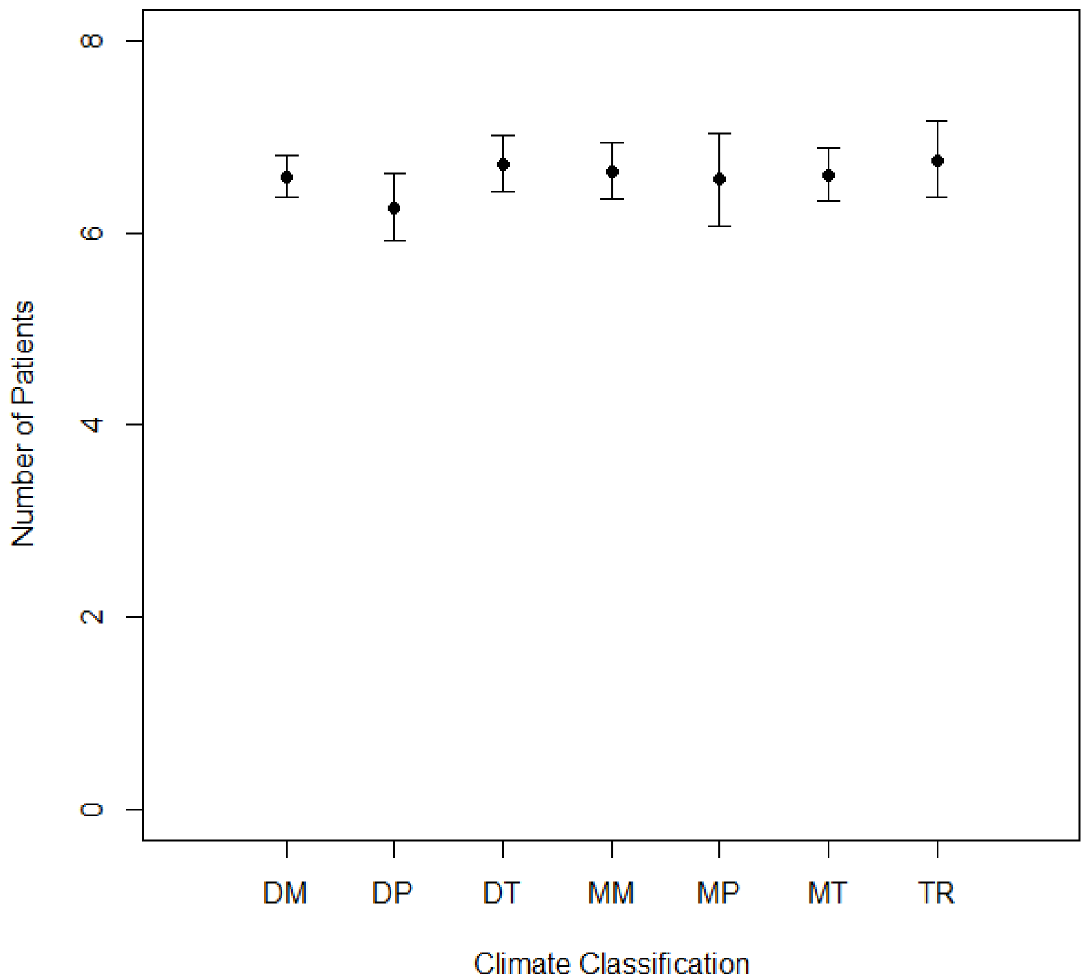

Figure 4.18 Lag 3 bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for each air mass from 2007-2013

Table 4.9 Lag 4 Bootstrap Quantile Values for the Combined Counties Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	6.372385	6.578801	6.781102
Dry Polar	6.025090	6.344086	6.659498
Dry Tropical	6.388031	6.705382	7.031161
Moist Moderate	6.460526	6.776316	7.115132
Moist Polar	5.669495	6.137615	6.614908
Moist Tropical	6.342432	6.610422	6.878474
Transition	6.450262	6.869110	7.282723

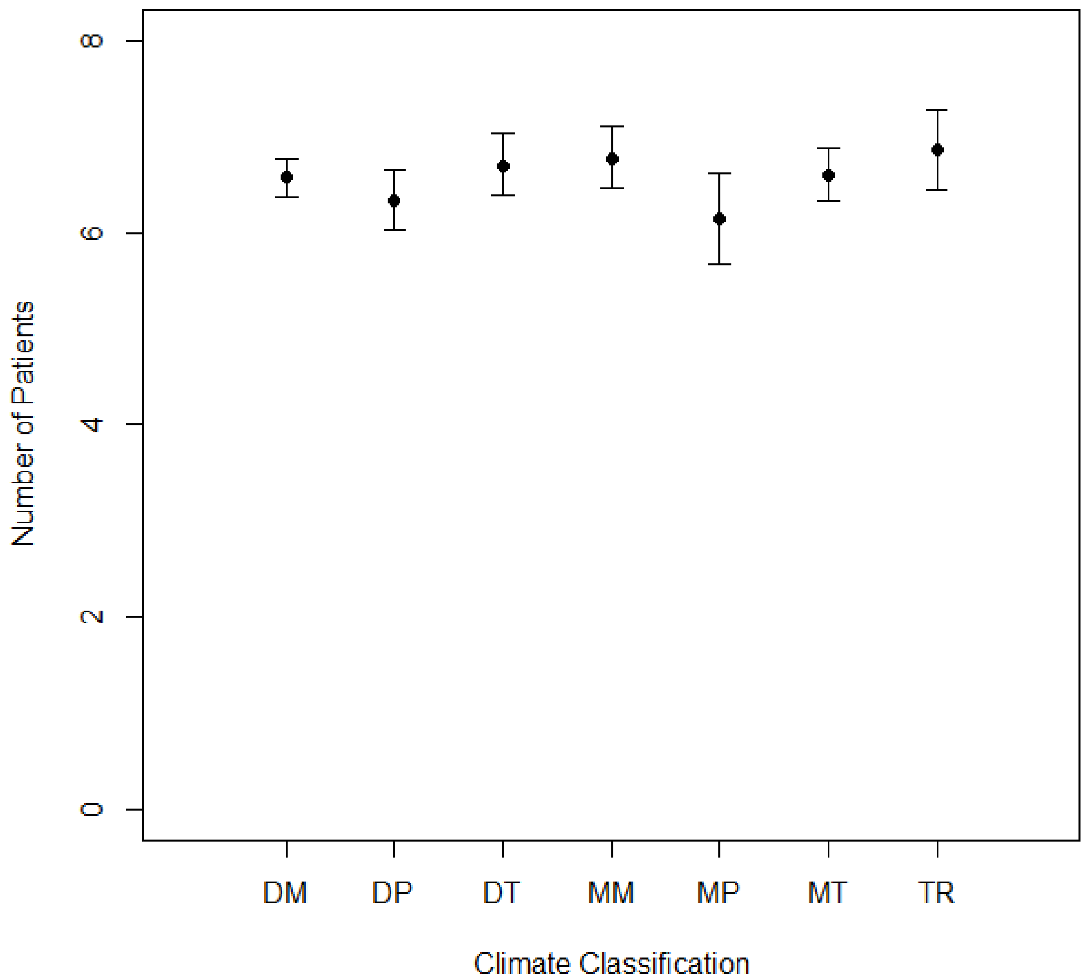

Figure 4.19 Lag 4 bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for each air mass from 2007-2013

Table 4.10 Lag 5 Bootstrap Quantile Values for the Combined Counties Air Masses

Air Mass	**2.5 %**	**50 %**	**97.5 %**
Dry Moderate	6.419735	6.619247	6.836855
Dry Polar	5.946237	6.263441	6.584319
Dry Tropical	6.368272	6.677054	7.000000
Moist Moderate	6.375000	6.713816	7.046053
Moist Polar	5.559633	6.064220	6.550459
Moist Tropical	6.456576	6.736973	7.019851
Transition	6.125654	6.554974	6.984293

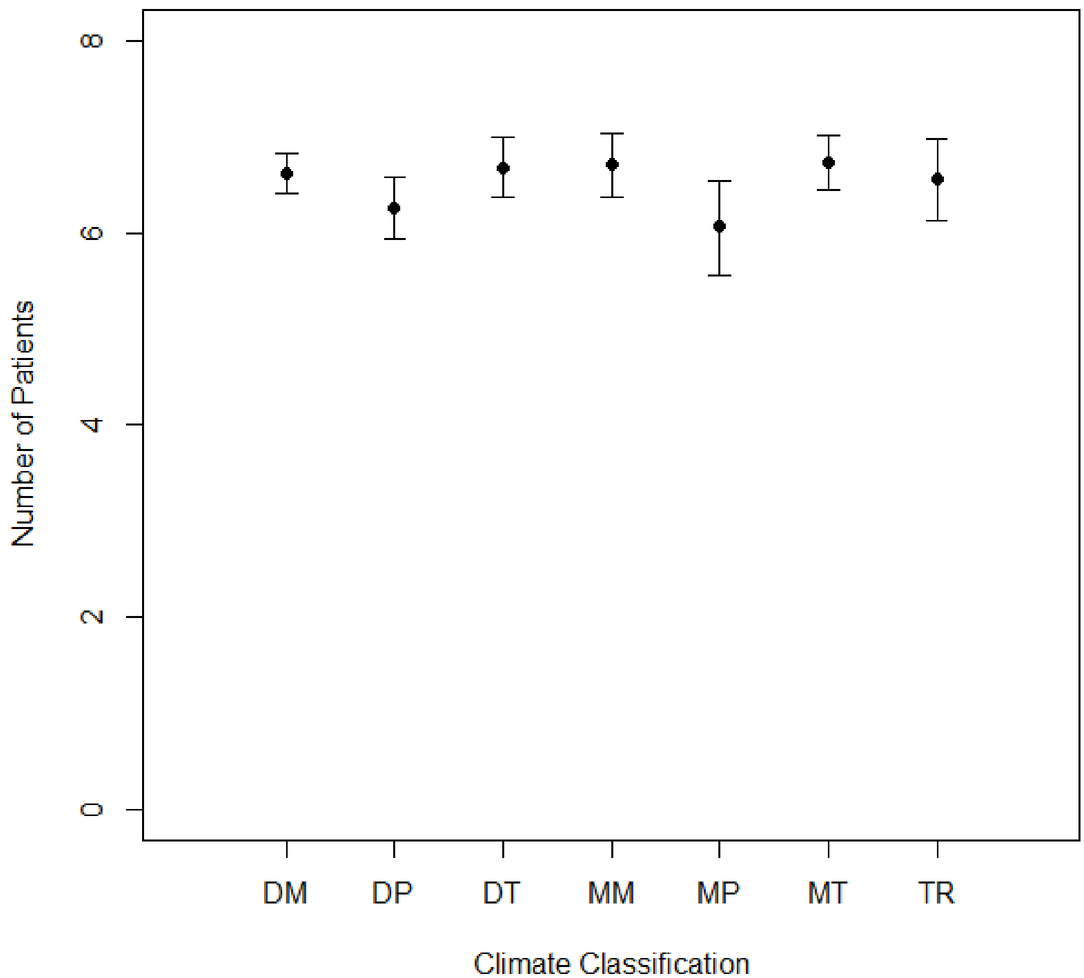

Figure 4.20 Lag 5 bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for each air mass from 2007-2013

Table 4.11 Bootstrap Quantile Values for Pressure Changes Associated with Transitional Air Masses

Pressure Change Type	**2.5 %**	**50 %**	**97.5%**
Positive	6.122885	6.615385	7.084615
Negative	5.180328	5.901639	6.622951

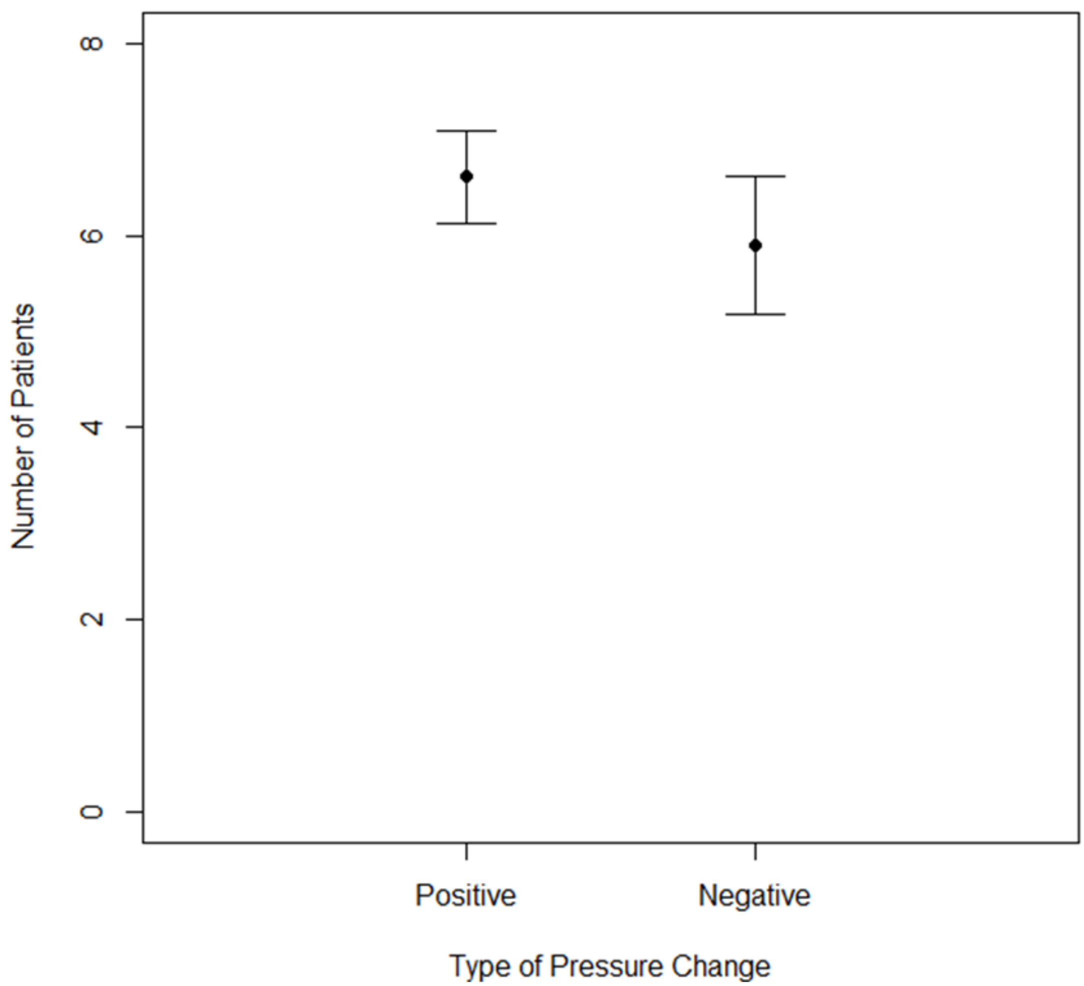

Figure 4.21 Bootstrap confidence intervals of the mean number of migraine ED visits from the entire study area for positive and negative pressure changes during Transitional air masses 2007-2013

4.3 Correlation Results

The scatter plot in Figure 4.16 shows the number of migraine ED patients associated with different 4am to 10pm pressure change magnitudes on Transitional air mass days. Based on this figure, there appears to be no distinct pattern with regards to migraine frequency and 4am to 10pm pressure change magnitude on Transitional air mass days. Correlation values further support the notion that no pattern exists between pressure change magnitude and migraine frequency. For Transitional air mass days, the correlation values were small between the magnitude of 4am to 10pm pressure changes and the number of migraine ED visits. This was the case with both positive and negative 4am to 10pm pressure changes.

For positive 4am to 10pm pressure changes, a negative Pearson correlation coefficient was found. This indicates that as the magnitude of positive pressure change increased, the number of patients going to the ED for migraines decreased. The value of the Pearson correlation coefficient was -0.24, indicative of a weak relationship. Negative 4am to 10pm pressure changes had a positive Pearson correlation coefficient. Therefore, increasingly negative pressure changes corresponded to fewer patients going to the ED for migraines. The actual Pearson correlation coefficient was 0.21, once again indicating a weak relationship. Despite the low correlation values, they both allude to larger magnitude pressure changes leading to fewer visits to the ED for migraines.

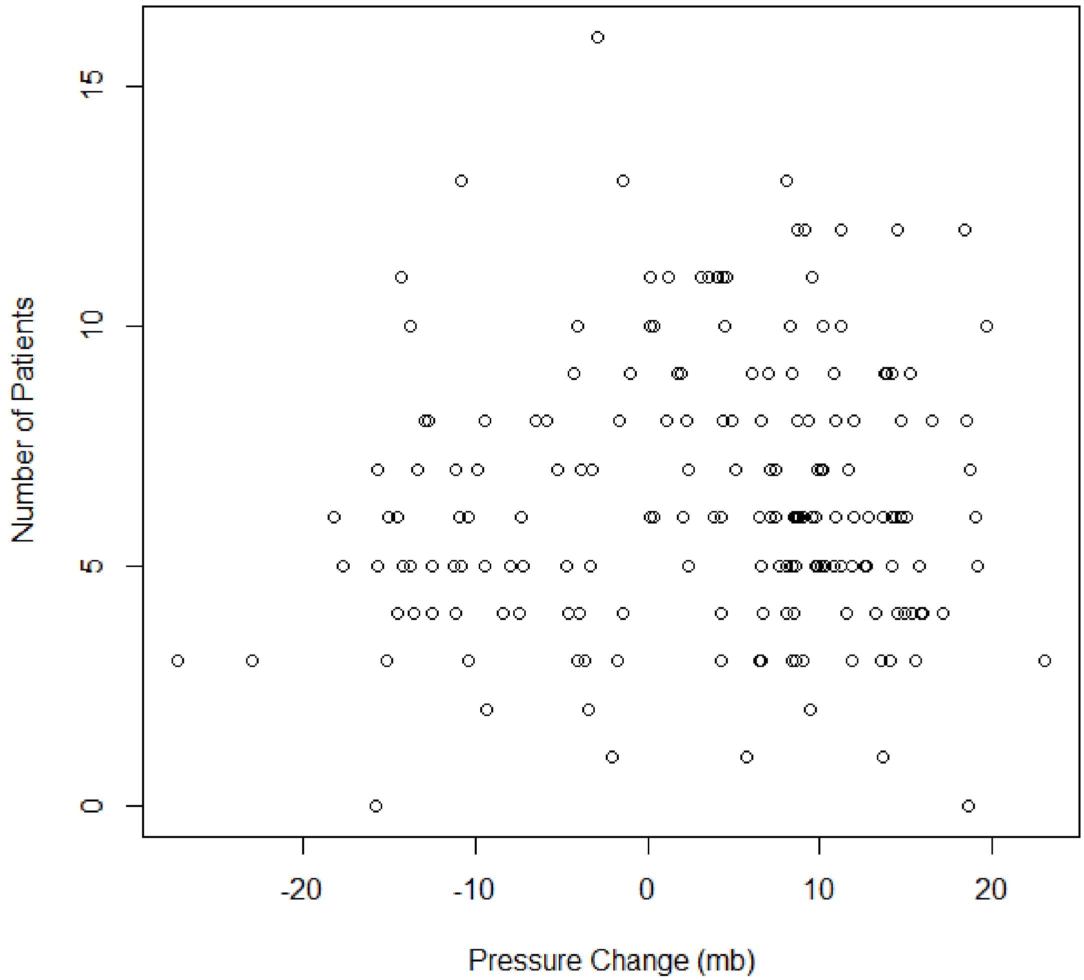

Figure 4.22 Migraine ED visits on Transitional air mass days with different pressure change magnitudes from 2007-2013

CHAPTER V

SUMMARY AND CONCLUSIONS

Migraines and other forms of headache plague many around the world. Migraines have numerous symptoms associated with them. These symptoms can alter the quality of life of those experiencing them. Due to their impacts, triggers of migraines must be understood. While research has identified weather as a potential trigger, an exact relationship has yet to be determined. Studies have looked at individual weather variables in order to determine how weather may impact migraine frequency. These studies have had limited success, due to contradicting results; however, a shift in focus towards larger scale weather features has led to stronger associations.

This research looked at the relationship between air mass types and migraine frequency in the triangle region of North Carolina from 2007-2013. This study also looked at the pressure changes associated with Transitional air masses in order to identify a potential relationship with migraine frequency. For this study, the Spatial Synoptic Classification (SSC) was used to determine daily air mass type from 2007-2013. Then, Emergency Department (ED) visits for migraines were collected in order to determine migraine frequency. The ED data were collected using the North Carolina Disease Event Tracking and Epidemiologic Collection Tool (NC DETECT). Bootstrapping and correlation tests were used to determine the statistical associations between air mass type and migriane frequency.

Durham County, Orange County, and Wake County all had similar patterns with regards to their bootstraps, thus indicating a consistent relationship between air mass type and migraine frequency. In all cases the average number of migraine ED patients appeared to be relatively similar between each air mass type, however, the bootstraps showed that statistically significant differences existed. The bootstraps indicated that Polar air masses generally resulted in fewer numbers of migraine ED patients, while Tropical air masses led to more. This relationship also was found when one to five day lags were looked at. The one to five days following Polar air masses also seemed to result in fewer ED visits for migraines compared to the one to five days following Tropical air masses. Moist Polar air masses were found to lead to the fewest number of migraine ED patients. When the data from all three counties were combined, Moist Tropical air masses coincided with the greatest number of migraine ED patients. Despite not being associated with the greatest number, Dry Tropical air masses still resulted in large numbers of migraine ED patients. This spike on days with Dry Tropical air masses supports the conclusions found by Cook et al. (2000) and Piorecky et al. (1997), since the warm/dry chinook winds also led to increases in migraine frequency. Both Dry Moderate and Moist Moderate air masses had statistically significant differences in the number of migraine ED patients when compared to Polar air masses. Specifically, days with Moderate air masses resulted in more migraine ED patients than days with Polar air masses. During days with a Transitional air mass, the average numbers of migraine ED patients fell between those of Tropical air mass days and Polar air mass days. When looking at the pressure changes associated with Transitional air masses, there was no statistical difference between the number of patients going to the ED for migraine during days with

4am to 10pm pressure increases and 4am to 10pm pressure decreases. This finding directly contradicts the results of other studies, which identified pressure falls as a migraine trigger. In terms of the magnitude of these pressure changes and their impact on migraine frequency, small correlation values were found, indicating no relationship.

A limitation to this research involved how migraine frequency was determined. Using migraine ED visits likely excluded less serious and debilitating migraine occurrences, since only those which lead an individual to the ED were recorded. Therefore, by focusing solely on ED visits, only a small percentage of the overall health burden associated with migraines was examined. Another limitation involved the statistical analysis technique chosen for this research. By comparing multiple bootstraps, the chances of making an error increased. This study began to look into the day of week trends of migraine ED visits, however, no statistical differences were tested for. Future research should see if statistically significant differences exist between the numbers of migraine ED visits on different days of the week. If statistically significant differences are found, then the results of this study would need to be adjusted. While this study focused on the relationship between migraines and air mass type from the Triangle region of North Carolina, similar research should be conducted for different areas so that comparisons can be made. Future work should also be done in order to determine how the seasonality of air mass types affects migraine frequency. This study examined the relationship between air mass type and migraines irrespective of season. However, differences could exist between a particular air mass if it occurred in the winter versus the summer. For example, a Dry Tropical air mass in the winter may lead to different results than a Dry Tropical air mass in the summer. Lag relationships were not a main focus of this research, but statistically significant differences were found between the number of migraine ED patients on the days following different types of air masses. Due to the existence of these statistically significant differences, future research should focus solely on these lag relationships in order to gain a better understanding of them.

This study identifies the role of large scale weather features on migraine frequency. While this work sheds some light on how different air mass types impact migraine frequency, it mainly serves as a foundation for future research on this topic. The relationships in this study could be used to help both migraineurs and migraine forecasters. Those who suffer from migraines, especially in the study area, can begin to understand how air mass type impacts them. Sufferers can also consider air mass type when they are trying to determine their potential for migraine headaches. Migraine forecasters now have information regarding air mass type that was previously not available. Such information could be beneficial to consider when forecasting migraine risk.

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