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Developing Tornado Climatology in the Southern Great Plains per Phases of Prominent Oceanic Oscillations

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DEVELOPING TORNADO CLIMATOLOGY IN THE SOUTHERN GREAT PLAINS PER PHASES OF PROMINENT OCEANIC OSCILLATIONS

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Meteorologists are continually working toward a greater understanding of which atmospheric environments are most conducive for tornado development. This Capstone project analyzed tornado occurrences across Texas, Oklahoma, Arkansas and Louisiana during the period 1950 through 2009 to determine if any correlation exists between the location and frequency of tornado activity and the phases of the El Nino-Southern Oscillation, the Atlantic Multidecadal Oscillation and the Pacific Decadal Oscillation. While it was determined that no phase of any of the oscillations studied was significantly more dominant over the other(s) concerning frequency, this project does identify some spatial shifts in tornado activity depending on the phase. By establishing basic tornado climatology, this project also provides the basis for continued research in a number of related topics.

TABLE OF CONTENTS

LIST OF ACRONYMS .... **iv**

INTRODUCTION **1**
- **Background** 1
- **Statement of Problem** 3
- **Goals and Objectives of this Project** 3

LITERATURE REVIEW **5**
- **El Nino-Southern Oscillation (ENSO)** 5
- **Atlantic Multidecadal Oscillation (AMO)** 6
- **Pacific Decadal Oscillation (PDO)** 7
- **Storm Surveys & Past Issues with Tornado Documentation** 7

DESIGN AND IMPLEMENTATION **9**
- **Software Requirements** 9
  - ***ESRI ArcGIS™ Desktop v9.3.1*** *9*
  - ***PHP*** *10*
  - ***Microsoft® Excel™ 2007*** *10*
  - ***Shapelib v1.2.9*** *10*
- **Hardware Requirements** 11
- **Creating a Shapefile of Tornado Tracks** 12
- **Preparing Data for Analysis** 13
- **Statistical Analysis Methodology** 14

RESULTS **16**
- **ENSO Winter** 16
- **ENSO Spring** 17
- **AMO Winter** 18
- **AMO Spring** 19
- **PDO Winter** 20
- **PDO Spring** 20

DISCUSSION **22**

AREAS OF FURTHER RESEARCH **24**
- **Analysis Strategy** 24
- **Hotspot Analysis** 24
- **Tornado Record Integrity** 25

BIBLIOGRAPHY **26**

APPENDIX 1: FIGURES **28**

APPENDIX 2: TABLES **38**

APPENDIX 3: EQUATIONS **50**

APPENDIX 4: PHP CODE TO GENERATE A TORNADO TRACKS SHAPEFILE **54**

LIST OF ACRONYMS

AMO:	Atlantic Multidecadal Oscillation
ENSO:	El Nino-Southern Oscillation
ESRI:	Environmental Systems Research Institute®
GIS:	Geographic Information System
NOAA:	National Oceanographic and Atmospheric Administration
NSSL:	National Severe Storms Laboratory
NWS:	National Weather Service
PDO:	Pacific Decadal Oscillation
SSTs:	Sea Surface Temperatures

INTRODUCTION

Background

Weather plays a critical role in our everyday lives. It does everything from influence the global economy to influence which clothes we dress in before leaving the house. Weather mesmerizes us with its beautiful, but sometimes deadly displays of power. One of weather's most spectacular displays is the tornado. So spectacular, in fact, that it has even served as main storyline in several Hollywood movies. Every year, hundreds of scientists, photographers and hobbyists spend up to several weeks at a time driving back and forth across the central United States to "chase" tornadoes. But while it's true that these storms capture our fascination, tornadoes are also one of nature's most violent and often most unpredictable phenomena.

A tornado is a violently-rotating column of air which descends from the base of a large thunderstorm and contacts the ground. Statistics kept by the National Oceanic and Atmospheric Administration (NOAA) indicate that hundreds of tornadoes occur every year across the United States, damaging or destroying nearly all objects in their path and causing an average of 1.1 billion dollars in property damage. In addition, tornadoes kill an average of 80 people annually while injuring roughly 1,500 nationwide.

The National Severe Storms Laboratory (NSSL, 2006) has stated that, under ideal atmospheric conditions, tornadoes are capable of forming nearly anywhere in the world, and have been documented on every continent except Antarctica. However, the Great Plains of the central United States has earned the reputation for the greatest amount of tornado activity in the world. The Great Plains is a location where cool dry air descending from Canada meets warm, moist air moving northward from the Gulf of Mexico. Low pressure systems, exiting the Rocky Mountains to move eastward across the Great Plains, usually serve as the trigger for the development of strong thunderstorms. Tornadoes sometimes develop within the most intense of these thunderstorms. And as the topography of the Great Plains varies little, ranging from flat land to gently rolling hills, there are no barriers to inhibit these airmasses from meeting one another from central Texas through the Dakotas.

The Great Plains by far records the most tornado occurrences of anywhere in the world, and has earned the nickname "Tornado Alley" (Figure 1).

One characteristic of the southern portion of the Tornado Alley is that it lies in close proximity to the Gulf of Mexico. The Gulf of Mexico is a large semi-tropical body of water which remains warm all year. During the winter, the Gulf of Mexico provides abundant moisture and warm air to the southern Great Plains, serving as the fuel and catalyst for strong thunderstorm development when a low pressure system approaches. As a result, while much of the rest of the United States is experiencing weather conditions generally too cold for tornado activity, the southern portion of Tornado Alley still has the potential to experience tornado activity, making this a year-round threat.

It is therefore of great interest to meteorologists to accurately forecast the development of thunderstorms which spawn tornadoes. Weather forecasters rely on a variety of tools which allow them to create better weather forecasts. These tools include WSR-88D Doppler weather radar, which allows a forecaster to detect the rotation of a tornado inside of a thunderstorm. Forecasters also rely on an ensemble of weather forecast models, which are a series of complex computer programs that project the movement of weather features along a path over the course of the upcoming 7 to 10 day period.

Another tool that weather forecasters have found to be increasingly useful is tornado climatology. Tornado climatology is the documented history of tornado occurrences for an area over an extended period of time. Unlike short-term forecasting tools such as Doppler radar and most forecast models, tornado climatology is most useful as a long-term analysis and planning/preparedness tool. Meteorologists can use tornado climatology to put the occurrence of tornado activity into historical perspective by comparing it to previous occurrences in the same area. And by referring to tornado frequency analysis for a certain time of year, meteorologists and emergency managers can plan to distribute resources and funding as appropriate for better preparation and improved response time.

Tornado climatology can provide details such as the average length and width of tornado paths for an area, the intensity distribution of past tornadoes, the average number of injuries and fatalities related to tornado activity, and a record of the type of damage that tornadoes have caused. Such information would be useful when considering improvements to building codes.

However, climatology is of little use to a meteorologist during a tornado outbreak. Because of their unpredictable nature, each tornado occurrence must be treated as unique. Meteorologists are required to rely on current atmospheric observations, the structure of thunderstorms as indicated by radar imagery, and reports from trained storm spotters and emergency personnel to gauge the nature of tornado activity during an event. Meteorologists must also remain eternally vigilant as well. While tornadoes may be climatologically unlikely during a certain time of day or certain time of year, they have been known to develop in seemingly unfavorable environments, taking those in the storm's path and meteorologists alike by surprise.

Statement of Problem

As stated previously, while tornadoes can occur almost anywhere, some locations are more prone to tornado activity than others. Possible factors which influence tornado activity are the oceanic oscillations in the Atlantic and Pacific Oceans. Several oscillations have been identified, and three in particular have been known to influence the weather pattern of the United States. These oscillations are the El Nino-Southern Oscillation, the Atlantic Multidecadal Oscillation and the Pacific Decadal Oscillation. These oscillations, measured typically as either warm phases or cool phases, are represented by the difference between the observed and average sea surface temperatures (SSTs) in the region where the oscillations occur. While it remains unknown the forces which drive these oscillations, it is clear they influence the weather pattern by shifting the locations of large high-pressure and low-pressure systems in the northern hemisphere. The placement of these high and low pressure systems, in turn, influence the jet stream, which often serves as the mechanism for transporting the low pressure systems which can generate tornado activity. This leads to the question: does a correlation exist between the phase of the above-mentioned oscillations and the frequency and location of tornado activity in the southern portion of Tornado Alley?

Goals and Objectives of this Project

The goal of this Capstone project is to provide meteorologists with a more complete understanding of the tornado climatology of the southern Great Plains/western Gulf of Mexico region as it relates to the phases of the above-mentioned oceanic oscillations. To accomplish this goal, this project will make use of a geographic information system (GIS) to perform spatial analysis of sixty years worth of tornado data across the states of Texas, Oklahoma, Louisiana and Arkansas. Analysis will include a comparison of the phases of each oscillation to determine if the frequency of tornado activity in one phase is significantly different than the frequency of the other(s). This study will also determine if there is any spatial shift in the location of tornado activity depending on phase. This project will conclude by identifying topics of future research which can build upon or benefit from the findings presented in this research.

It should be noted that, while most tornado climatology studies perform analysis to determine which time of day and which months are most active for tornado occurrences, that analysis is not one of the goals of this project. Several climatology studies have already concluded that the late afternoon/early evening hours are the peak time of day for tornadoes to occur, and most studies conclude that the months of March or April are the peak time of year in the study area.

LITERATURE REVIEW

El Nino-Southern Oscillation (ENSO)

An oscillation known to significantly influence global weather patterns (McLean et al. 2009) (Climate Prediction Center #2) is the El Nino-Southern Oscillation of the equatorial Pacific Ocean. El Nino is characterized by a weakening of the easterly equatorial trade winds which normally push warm water from along the coast of South America toward the western Pacific Ocean. This coincides with observed lower-than-normal atmospheric pressure in Tahiti, while atmospheric pressure is found to be higher-than-normal in Darwin, Australia (Climate Prediction Center #2).

The counterpart of El Nino is La Nina, which is characterized by stronger than normal equatorial trade winds over the Pacific Ocean. The stronger easterly trade winds push warm water from off the coast of South America further westward than normal. The displaced warm water is replaced by cooler, nutrient-rich water from beneath. Also opposite to El Nino, atmospheric pressure is observed to be higher-than-normal in Tahiti during a La Nina event while lower-than-normal atmospheric pressure is observed in Darwin Australia. For the purpose of consistency, the terms ENSO warm phase will replace the term El Nino and ENSO cool phase will replace La Nina through the remainder of this project.

ENSO is characterized by three phases: warm, cool and neutral (Climate Prediction Center #1). The warm phase is defined as a period when the three-month running-mean of SSTs in the Nino 3.4 region (Figure 2) of the central and eastern equatorial Pacific remains at least 0.5º C above the long-term normal for a period of five consecutive months. The opposite is the ENSO cool phase, which is defined as a period when the three-month running-mean of SSTs in the Nino 3.4 region of the central and eastern equatorial Pacific remains at least 0.5º C below the long-term normal for a period of five consecutive months. The final phase of ENSO is the neutral phase, which occurs when the conditions for neither the warm phase nor cool phase are met, which is typical during the transition from cool phase to warm or warm phase to cool. The Climate Prediction Center has observed that warm phases typically last for 9 to 12 months, while cool phases can persist for 1 to 3 years, although these time periods may vary. In most instances, but not always, a warm phase will follow immediately after a cool phase (or vice versa) to complete an ENSO cycle. ENSO cycles repeat on average every 3 to 5 years, but occasionally may repeat anywhere from 2 to 7 years (Climate Prediction Center #2). See Figure 3 of the Appendix for a timeline of the ENSO phases from 1950 through early 2010.

ENSO can have a significant impact on the track that storms take while crossing the United States (Figure 4). During the warm phase, the jet stream remains stronger and shifts southward, resulting in an increased number of storm systems and rainfall for the southern half of the United States, while weather conditions are drier than normal in the northern half of the nation (Marzban et al. 2000). However, during the ENSO cool phase, the jet stream is weaker and shifts over the northern half of the United States leading to increased rainfall in that region, while drier conditions are experienced over the southern half of the nation (Marzban et al. 2000).

Atlantic Multidecadal Oscillation (AMO)

Identified in 2001 during research to better understand the frequency of Atlantic hurricanes (Goldenberg et al. 2001), the AMO is a pattern of variability in sea surface temperatures in the North Atlantic Ocean. The period for the AMO cycle is the longest of the three oscillations analyzed in this project. While the time required to complete a full cycle of a warm phase and cool phase varies for each occurrence, observations over time have determined that full cycles of the AMO occur most commonly every 50 to 70 years (Dijkstra et al. 2006). This oscillation was only recently defined, and a great deal of research on its impacts to global weather patterns is on-going. As such, there are only a few weather patterns where a well-defined correlation to the AMO has been identified.

One pattern that has been identified is that an inverse correlation exists between the phase of the AMO and the amount of rainfall in the United States (Enfield et al. 2001). More rainfall and storminess is observed in the United States during a cool phase of the AMO, while less rainfall and storminess is observed when the AMO is in a warm phase (Dijkstra et al. 2006). Also observed is that the phase of the AMO has a strong correlation to hurricane frequency and intensity. Hurricanes tend to form in environments of relatively low atmospheric shear, which are the same type of environments which inhibit the development of tornadic thunderstorms. As such, hurricanes tend to occur with more frequency and greater intensity during the warm phase of the AMO. See Figure 5 of the Appendix for a timeline of the AMO phases from 1856 through 2009.

Pacific Decadal Oscillation (PDO)

Similar to the ENSO, the PDO is another oscillation found in the Pacific Ocean. However, this oscillation requires a period of nearly 30 years required to complete both a warm and cool phase. Also, whereas the ENSO is most prevalent in the equatorial waters of the Pacific, the PDO is most influential in the northern Pacific Ocean. Recent studies have found that there is a strong correlation between the PDO and the track of storm systems across the United States. During a warm phase of the PDO, the jet stream will dip farther south over the United States, allowing storm systems to pass more frequently across the area, leading to increased rainfall and storm activity in the southern United States. Conversely, during a cool phase of the PDO, the jet stream will be found farther to the north, resulting in reduced storm activity and drier conditions across the southern United States (Ting 1997). See Figure 6 of the Appendix for a timeline of the PDO phases from 1900 through September 2009.

Storm Surveys & Past Issues with Tornado Documentation

The National Weather Service (NWS) is the official agency in charge of performing storm surveys to categorize and document tornado occurrences. Today, the NWS has many tools at its disposal to quickly identify an area potentially affected by a tornado.

Primarily, NWS meteorologists make use of WSR-88D Doppler Weather Radar to interrogate the structure of thunderstorms and determine if any rotation is occurring. If rotation is detected, the NWS may issue a tornado warning indicating the direction and speed that the possible tornado is moving in. However, while Doppler radar is good at detecting rotation, it cannot confirm that a tornado is in contact with the ground.

For assistance during a severe weather event, the NWS relies heavily on a network of storm spotters, local government officials and emergency managers, most of who have been trained by the NWS identify characteristics of severe weather. NWS meteorologists relay to these spotters the location and intensity of storms in an area as indicated by Doppler radar or automated weather observing stations. In turn, members of the spotter network relay real-time observations of the storm or report any damage that was caused by the storm.

The general public also plays an important role in locating storm damage. As the population of the United States continues to grow, it is becoming increasingly difficult for a tornado to occur without somebody noticing the damage. The local NWS forecast office sometimes learns about damage when an insurance claim for repairs is submitted. In addition, many cell phones today are equipped with built-in cameras and GPS units, leading to a significant increase in the number of tornadoes caught on film. The GPS provides a specific location as to where the tornado occurred.

All of these factors increase the NWS's ability to locate storm damage and perform a storm survey. During a storm survey, NWS meteorologists will trace the path that a storm followed to analyze the pattern of damage, and will determine whether the damage was caused by a tornado or by straight-line winds. The extent of damage to trees and/or various structures will be analyzed to rate the tornado's intensity based on the Enhanced Fujita scale. Finally, the meteorologist will calculate the tornado path's length and width.

Improved communication and enhanced technology have recently led to a far more complete record of tornado occurrences. However, the documentation of tornado occurrences has come a long way over the years. One factor which complicated tornado documentation was the use of less-powerful weather radars during the early half of the study period. While these older weather radars were still very useful, they did not have quite the range that current weather radars do, which resulted in more "blind" areas in the radar coverage network.

Another complicating factor was a lower population density. With fewer people and a greater amount of unpopulated areas, it is highly likely that several tornadoes went undetected regardless of what the storm's intensity was. Communication between the NWS and local officials from the surrounding region was also not as consistent early in the study period as it is today. While a tornado may have been detected, details of the storm sometimes were not passed to the NWS for documentation. In other instances, the NWS would receive details about a tornado strike at a location, but receive no details as to the length or width of the tornado's path. Still in other instances, untrained members of the media would perform their own storm survey and send the NWS a copy of the newspaper article. Having a survey performed by somebody who was not properly trained introduces the possibility that the damage was improperly classified as tornado damage when it was actually caused by straight-line winds, or vice versa. It also introduces the possibility that the tornado was assigned a greater intensity than it deserved.

DESIGN AND IMPLEMENTATION

Software Requirements

ESRI ArcGIS™ Desktop v9.3.1

The Environmental Systems Research Institute® (ESRI) ArcGIS™ Desktop v9.3.1 is an expansive GIS software package. This package is made up of several components, including ArcMap™, ArcToolbox™ and ArcCatalog™, all of which will be required in this Capstone project.

ArcMap™ is the interface that allows a user to view and analyze geospatial data (ESRI ArcGIS Desktop 9.3 Help #2 2009). While data is often imported into ArcMap™ in the form of a shapefile or feature class, ArcMap™ will also support several other file structures. ArcMap™ has the ability to display multiple data layers at once and the user has the ability to turn on or off these layers as needed. Details of a shapefile may be viewed in the attribute table. Several tools are available which allow a user to perform a simple data search, to perform statistical analysis on an attribute field, or to perform calculations on the data. Once data is manipulated as needed, ArcMap™ makes use of an advanced graphical display to produce professional-grade maps of the data.

ArcCatalog™ is the data management component of ArcGIS™ Desktop (ESRI ArcGIS Desktop 9.3 Help #1 2009). Among its other capabilities, ArcCatalog™ is the function by which geodatabases are created. A geodatabase allows the data stored within to be portable and remain organized. This Capstone project will make use of a personal geodatabase for storing tornado track data, as well as any statistical analysis performed on these tracks.

According to ESRI, ArcToolbox™ is an interface for accessing and organizing a collection of geoprocessing tools, models and scripts (ESRI ArcGIS Desktop 9.3 Help #3 2009). Among other capabilities, the functions in ArcToolbox™ will allow a user to merge data from multiple shapefiles into a single shapefile, clip out unnecessary data from a shapefile, or redefine the projection of a shapefile. ArcToolbox™ also contains tools which measure the density of features in a layer, as well as measure the average distance between features and analyze patterns. Some of the tools available ArcToolbox™ will be used extensively in this Capstone project.

PHP

PHP, also known as PHP: Hypertext Processor, is a robust computer-scripting language capable of being run on most operating systems (Achour et al. 2010). Originally designed to be embedded inside HTML code to create dynamic webpages, it now is more commonly used as a general-purpose language for performing functions on a server, which allows it to be run from the command line and to work with databases. PHP software was originally developed by Rasmus Lerdorf in 1995, and the language has been continually developed ever since by the PHP Group. The source code for PHP is open, and available for download free of charge.

Microsoft® Excel™ 2007

Microsoft® (MS) Excel™ 2007 is a spreadsheet application which is part of the Microsoft Office™ 2007 application package (Microsoft Office Website, 2010). MS Excel™ spreadsheets use a grid of cells to store data. Each cell is referenced by the column and row that it resides in, providing each cell a unique identification. The software also has an array of built-in commands which allows for a variety of statistical calculations to be performed on the data. Also, among its other capabilities, MS Excel™ 2007 has the ability to automatically import data an external file the user chooses, greatly reducing the time required to perform data analysis. Originally released in 1987 for MS Windows, MS Excel™ 2007 can be run on both MS Windows and Macintosh operating systems. The software is proprietary, and a license must be purchased to use the software.

Shapelib v1.2.9

Shapelib v1.2.9 (Shapelib hereafter) is a set of executable commands that can read, create and update ESRI® shapefiles (Shapefile C Library Website 2008). These commands can be called to execute at the command line interface, or in a script. The software has the ability to shapefiles as points, multipoints, arcs (polylines) or as polygons.

To create a new, blank shapefile, a user calls on two commands: *shpcreate*, which will develop the vertex (.shp) portion of the shapefile, and *dbfcreate*, which develops the database (.dbf) portion that stores the attribute data. In the *dbfcreate* command, the user will define the nature of the attributes, such as the size of the data field and whether they are numeric or alphanumeric. Executing these two commands will also create an index file (.shx) which relates the data in the .shp to that in the .dbf file.

The user next calls on the *shpadd* and *dbfadd* commands, both of which populate the shapefile with data. The *shpadd* command passes the coordinate data (longitude and latitude) to the shapefile in the form of decimal degrees. The *dbfadd* command populates the attribute table with the appropriate data. For shapefiles with small amounts of data, the required coordinate and attribute data can be supplied directly at the command line interface. However, for shapefiles holding larger amounts of data, a script is used to loop through a table containing the coordinate and attribute data, and then call on the above-mentioned commands.

Care must be taken when supplying the software with attribute data. Shapelib does not tolerate blank values for attribute fields, and the software is very limited in its ability to report errors. A single blank value in the attribute table will cause a mismatch in the number of attributes and the associated vertex data. The result is that the shapefile will not open when imported into a GIS.

Shapelib is open-source software and is available for download free of charge. The software was originally developed by Frank Warmerdam in 1998, but several others have contributed to this software's development since.

Hardware Requirements

The only hardware required to complete this Capstone project was a personal computer with a minimum of 1 gigabyte (GB) of memory, as required to operate the ArcGIS™. This project was completed on a computer with 1 GB of memory, 60 GB of hard-drive space and a 1.66 gigahertz (GHz) processor, which proved to be more than sufficient to perform all analysis in this project.

Study Area

The study area for this project is the four states which make up the southern Great Plains/western Gulf of Mexico region. These states are Texas, Oklahoma, Arkansas and Louisiana (Figure 7). This study area was chosen for several reasons. First, due to the study area's proximity to the Gulf of Mexico, tornadoes are possible during the winter as warm moist air from the Gulf can interact with polar airmasses arriving from the north. Farther northward, tornado activity is reduced to zero in the winter, and only picks up as warmer weather arrives. Second, the size of the study area was an important consideration. It was important to choose a multi-state study area because, as Turcotte (2003) concluded, spatial occurrences of tornadoes which correlate to the phases of oscillations may not be obvious in an area as small as a single state. This study area was also chosen because these four states have similar climates, where wintertime is characterized by a series of warm spells intermixed with cool spells, and spring usually sets in by early March. Finally, it was decided to limit the size of the study area so that any trends discovered would apply to the southern Great Plains/western Gulf of Mexico region, rather than being muted by or absorbed into the trends of a much larger study area such as the eastern half of the United States. A shapefile of the states and the counties/parishes for the study area will be obtained from the United States Census Bureau website.

Creating a Shapefile of Tornado Tracks

The original plan was to use a shapefile obtained from the Storm Prediction Center which contained all documented tornado occurrences in the continental United States between 1950 and 2009. However, when inspecting the data within the shapefile, it quickly became obvious that there were several errors with the tornado records. In several instances, tornado tracks in ArcMap did not match up with the corresponding metadata in the attribute table. For example, when performing a search by location to identify all tornado tracks in Oklahoma, ArcMap also highlighted several tornado tracks located well outside the state. Additionally, several tracks inside the state were omitted from the search. Inspecting the attribute table revealed that the coordinates of the tornado tracks were not consistent with those that would properly place the storm in relation to the location of Oklahoma. Several other searches provided similar results. An attempt was made to delete the erroneous records, however there were simply too many errors within the shapefile for the data to be useful. It was decided to discard this shapefile, and build one from scratch using raw historical data for tornado tracks.

Raw data for historical tornado tracks from 1950 through 2009 for the United States was obtained from the WCM webpage on the Storm Prediction Center website. The data was contained in several comma-delimited files, most files containing a decade’s worth of historical information, while some contained only a few years worth. All files were downloaded, and were combined so that all tornado data from 1950 through 2009 was contained in one file. This file, named All_Tracks.cvs, contains more than 54,000 records.

Next, observed monthly readings for the ENSO (Table 1), AMO (Table 2) and PDO (Table 3) were obtained and stored in separate text files. Each year, listed in ascending order, was assigned its own row and the monthly observed values for each year were also delimited by commas.

In order to build a shapefile that contained the correct location of tornado tracks as related to the metadata, as well as contain the observed ENSO, AMO and PDO readings at the time of the each tornado's occurrence, a simple program was written in the PHP programming language. The program first read through and ingested the text files containing ENSO, AMO and PDO data and then assigned each monthly value a unique identification number.

The program next called on Shapelib software to create a blank shapefile and associated database. The program then ingested the raw data from the All_Tracks.cvs into an array, and then passed each tornado track record and associated metadata, one at a time, to the Shapelib software to populate in the shapefile. As each tornado track was populated, Shapelib also added as part of the metadata the observed values of the ENSO, AMO and PDO that correlated with the time of the tornado's occurrence. A copy of the PHP code that ingested the data and built the shapefile is included at the end of this project.

Preparing Data for Analysis

In preparing the data, the first step was to remove all tornado tracks that occurred outside of the study area. This was accomplished in ArcMap by using the "select by location" function to identify all tracks that intersected any of the four states that make up the study area. The tracks which did intersect the study area were separated into a new layer.

In the next step, it was decided that only tornadoes occurring during the months of December through May will be analyzed. This step will remove all tornadoes that possibly resulted from tropical cyclones. It has been noted that tropical cyclones tend to be more frequent and stronger during years of an ENSO cool phase and/or an AMO warm phase, and weaker and less frequent during years of an ENSO warm phase and/or an AMO cool phase (Turcotte 2003). Analyzing tornado data from the months of June through November in the dataset will likely add bias to the data, making for less accurate results even though this step may also remove several tornadoes which did not result from a tropical cyclone.

The next step in preparing the tornado data is to remove all tornadoes which are rated zero or one on either the Fujita Scale or the Enhanced Fujita Scale for tornadoes after February 2007 ((E)F0 or (E)F1). See Table 4. There are several reasons for this exclusion. One reason is that the ability to detect weak tornadoes of F0 or F1 intensity is greater after 1988 than it was in years prior. This likely coincides with the National Weather Service transitioning to the use of WSR-88D radar, the Doppler radar currently used today (Turcotte 2003), which has a greater ability to detect weak tornadoes. Other reasons include inconsistent storm survey methods and a lack of trained storm spotters prior to the 1990s (Akyuz et al., 2004), which may have allowed damage from weak tornadoes to have gone undetected or unreported, especially if it occurred in a remote location. Also, damage caused by strong thunderstorm straight-line winds is sometimes reported as damage having occurred due to a weak tornado (Carrin 2003).

The next step was to remove any tornadoes which did not occur on a tornado outbreak day. While the definition of a tornado outbreak day has been altered in some studies, it is generally defined as a calendar day in which 6 or more tornadoes occurred within the same storm system (Galway 1977). For the purposes of this study, tornadoes from the next calendar day will be included with those of an outbreak day if they are all found to have occurred in the same general area, indicating that they are all part of the same storm system. The reason that only tornadoes which occurred as part of an outbreak will be analyzed in this project is to focus on those which developed as part of a large-scale storm system. This strategy will eliminate those tornadoes which may develop due to local or regional effects, such as tornadoes which form in a line of sea-breeze thunderstorms. Figure 8 is a map of the tornado tracks in the study area after this step.

Statistical Analysis Methodology

The next step in data preparation was to create separate layers of tornado tracks depending on the phases of the oscillations. Seven different subsets of data were created on which analysis was performed:

1. Tornadoes which occurred during an ENSO warm phase.
2. Tornadoes which occurred during an ENSO neutral phase.
3. Tornadoes which occurred during an ENSO cool phase.
4. Tornadoes which occurred during an AMO warm phase.
5. Tornadoes which occurred during an AMO cool phase.
6. Tornadoes which occurred during a PDO warm phase.
7. Tornadoes which occurred during a PDO cool phase.

Each oscillation phase was subdivided again for tornado occurrences in wintertime seasons and occurrences in springtime seasons. Wintertime seasons were defined as the months of December (of the prior year), January and February. Springtime seasons were defined as the months of March, April and May. To simplify the analysis, each season was assigned the average of the three monthly observed SSTs, and was therefore categorized to only one oscillation phase.

In performing statistical analysis, each oscillation was analyzed independent of the other oscillations. A simple ratio test was performed for each oscillation to determine the number of tornado outbreaks per phase. This test will help identify if any one phase is more dominant over its counterpart(s) concerning the number of outbreaks in the study area.

An unpaired Student’s t-test was used to determine if there is a significant difference (at the 95% confidence level) in the number of tornadoes per outbreak depending on the phase. Student's t is preferred because it is designed for spatial analysis of a small number of samples (Gonick and Smith, 1993), up to a few hundred, as opposed to other statistical analysis methods which depend on a larger set of samples. The unpaired version of the test was used because the datasets are independent of one another.

Kernel Density Analysis was performed to simply identify locations where tornado activity has been concentrated over time. Kernel Density was chosen because of its ability to smooth data. This allows tornado activity to be estimated over sparsely-populated areas, based on nearby documented tornado activity. Kernel Density is also useful as output cell size and search radius are adjustable in ArcMap™, which allows the density coverage to be adjusted for uncertainty in the tornado record.

RESULTS

ENSO Winter

During the sixty-year study period, a total of 120 tornadoes of (E)F2 intensity or greater were documented as a result of outbreaks during the winter seasons (Table 5). Twenty-one winters were influenced by a cool phase of ENSO. During these cool phases, 8 outbreaks occurred, resulting in 78 documented tornadoes. This equates to 61% of the total number of outbreaks and nearly 65% of resultant tornadoes. The average number of tornadoes per ENSO cool season outbreak is 9.8, with a standard deviation of 3.1 tornadoes. The maximum number of tornadoes occurred in 1999, with 30 documented storms over 2 outbreaks. Several seasons occurred in which there was no documented tornado outbreak.

Twenty-two winters were influenced by a neutral phase of the ENSO, in which 1 outbreak occurred, resulting in 10 documented tornadoes. This equates to 8% of the total number of outbreaks and nearly 8% of resultant tornadoes. During these seasons, the average number of tornadoes was 10 with a standard deviation of 0.0 tornadoes (because of only 1 outbreak).

Seventeen winters were dominated by a warm phase of ENSO. 17 winters were influenced by a warm phase of ENSO. During these warm phases, 4 outbreaks occurred, resulting in 32 documented tornadoes. This equates to 31% of the total number of outbreaks and 27% of all tornadoes. During the study period, the average number of tornadoes per season was 8.0, with a standard deviation of 0.0 tornadoes. All four outbreaks were observed in 1983.

Kernel Density analysis of documented tornado tracks resulting from winter-time outbreaks has indicated a slightly greater tendency for tornado outbreaks to affect east Texas and southern Oklahoma during the cool phase of the ENSO (Figure 9). Tornado outbreaks appear to be mostly confined to portions of Arkansas and Louisiana during the warm and neutral phases (Figures 10 & 11).

Student's-t Test comparisons were performed to determine if there is a significant difference between the number of tornadoes per outbreak which occur between the warm, cool and neutral phases of the ENSO during the winter seasons. Student's-t Test analysis has concluded that a difference of **2.0 ± 0.0** tornadoes exists between the neutral and warm phases (Equation 5). This marks a significant difference in the number of tornadoes per outbreak. However, analysis concludes that a difference of **0.2 ± 9.4** tornadoes exists between the neutral and cool phases (Equation 3), and a difference of **1.8 ± 4.9** tornadoes exists between the cool and warm phases (Equation 4). Since it is possible that the ± error of these difference values may make the total value less than 0, it is concluded that there is no significant difference between the cool and warm or the cool and neutral phases at the 95% confidence level.

ENSO Spring

In the spring season of the study period, a total of 773 tornadoes were documented during outbreaks (Table 6). Ten spring seasons were under the influence of an ENSO cool phase. Twelve outbreaks occurred, resulting in 96 documented tornadoes. This equates to 15% of the total number of outbreaks and 12% of resultant tornadoes. The average number of tornadoes per outbreak during the cool phase was 8.0, with a standard deviation of 1.4 storms. Of these 10 cool phase seasons, the maximum number of tornadoes documented in a season was 44, spread over 5 outbreaks in 1957.

Thirty-seven spring seasons were influenced by a neutral phase of ENSO. 497 tornadoes were documented during 50 outbreaks in these seasons, which accounts for 64% of all spring-time tornadoes and 62% of the total number of outbreaks in the record. The average number of tornadoes per outbreak during neutral phases was 9.9 tornadoes, and the standard deviation was 2.1 tornadoes. A maximum of 60 tornadoes was documented in 1982, spread over 6 outbreaks.

Thirteen spring seasons were influenced by ENSO warm phases, in which 180 tornadoes were documented over 19 outbreaks. This equates to 24% of all spring time tornadoes and 23% of all outbreaks. During these seasons, the average number of tornadoes was 9.5 with a standard deviation of 2.7 tornadoes. A maximum of 45 tornadoes was documented in 1999, which occurred during 3 outbreaks.

Kernel Density analysis of the tornado tracks documented during spring-time tornado outbreaks has indicated a significant difference in the spatial distribution of tornado outbreaks during the ENSO. Outbreaks during the warm phase (Figure 14) are far more sporadic than those observed during the cool or neutral phases (Figure 12 & 13), with the greatest amount activity observed in the northern half of Texas and the southern half of Oklahoma. Very little activity is observed in Arkansas.

During the neutral and cool phases however, tornado outbreak activity is most concentrated in across portions of Oklahoma and Arkansas.

Student's-t Test comparisons were performed to determine if there is a significant difference between the number of outbreak tornadoes which occur between the warm, cool and neutral phases of the ENSO during the spring months. Student's-t Test analysis has concluded that there is a difference of **1.9 ± 1.9** tornadoes between the neutral and cool phases (Equation 8). A difference of **0.4 ± 2.0** tornadoes exists between the neutral and warm phases (Equation 10). Finally, a difference of **1.5 ± 2.7** tornadoes exists between the cool and warm phases (Equation 9). Since it is possible that the ± error of these difference values may make the total value equal to 0 for any of these values, it is concluded that there is no significant difference between any of the three phases at the 95% confidence level.

AMO Winter

In performing analysis for the AMO during winter seasons (Table 7), it was found that 35 winter seasons were influenced by the cool phase. During the cool phases, a total of 76 tornadoes were documented during 9 outbreaks. This equates to 63% of all winter-time tornadoes and 69% of all outbreaks. The average number of tornadoes per outbreak was 8.4, with a standard deviation of 1.6 tornadoes. The maximum number of tornadoes documented during a season was 32 in 1983, which was spread out over 4 outbreaks.

Twenty-five seasons were influence by the warm phase of the AMO during the study period. During these phases, 44 tornadoes were documented during 4 outbreaks, which equates to 37% of all winter-time tornadoes and 31% of all wintertime outbreaks. The average number of tornadoes per season was 11.0, and the standard deviation was 4.0 tornadoes. A maximum of 30 tornadoes was documented during the 1999 season, resulting from 2 outbreaks.

Kernel Density analysis of the tornado tracks documented during winter-time tornado outbreaks has indicated that there is little spatial difference in the occurrence of tornado activity during the winter months between the cool (Figure 15) and warm (Figure 16) phases of the AMO. A greater amount of short tornado tracks is observed across portions of east Texas and southern Oklahoma. In addition, a greater number of tornado tracks are observed across northwest Louisiana.

A Student's-t Test comparison was performed to determine if there is a significant difference between the number of outbreak tornadoes which occur during the warm phase and the cool phase of the AMO during the winter months. Student's-t Test analysis has concluded that there is a difference of **2.6 ± 4.7** tornadoes between the two phases (Equation 1). Since it is possible that the ± error may make the total value equal to 0, it is concluded that there is no significant difference between the warm and cool phases at the 95% confidence level.

AMO Spring

After analysis for the AMO during the spring seasons (Table 8), it was found that 32 seasons were under the influence of the warm phase. There were 372 tornadoes documented during these warm phases over 36 outbreaks, which accounts for 48% of all spring time tornado occurrences and 44% of all outbreaks. An average of 10.3 tornadoes occurred during each outbreak, with a standard deviation of 2.4 tornadoes. A maximum of 48 tornadoes was documented in 1960 as a result of 4 outbreaks that season.

Twenty-eight seasons were influenced by the cool phase of the AMO. 401 tornadoes were documented during these seasons over the course of 45 outbreaks. This accounts for 52% of all spring-time tornadoes in the record and 56% of all outbreaks. The average number of tornadoes per outbreak was 8.9, and the standard deviation was 1.8 tornadoes. A maximum of 60 tornadoes was documented in 1982, which was a result of 6 outbreaks that season.

Kernel Density analysis of the tornado tracks documented during spring-time tornado outbreaks has indicated a greater tendency for tornado outbreaks to affect central and eastern Arkansas during a warm phase (Figure 18) of the AMO versus during a cool phase (Figure 17). Analysis also indicates a greater tendency for tornado outbreaks to affect portions of central and western Texas. There is little spatial difference in the occurrence of tornado activity between warm and cool phases elsewhere in the study area.

A Student's-t Test comparison was performed to determine if there is a significant difference between the number of outbreak tornadoes which occur during the warm phase and the cool phase of the PDO during the spring months. Student's-t Test analysis has concluded that there is a difference of **1.4 ± 0.2** tornadoes between the two phases (Equation 6). Since this value remains positive, it is concluded that there is a significant difference between the warm and cool phases at the 95% confidence level.

PDO Winter

After analysis of the PDO during winter months (Table 9), it was found that 28 season were under the influence of the warm phase. During these warm phases, 39 tornadoes were documented over 5 outbreaks, which accounts for 33% of all winter-time tornadoes and 38% of all outbreaks. The average number of tornadoes per outbreak was 7.8, with a standard deviation of 0.4 tornadoes. A maximum of 32 tornadoes was documented in 1983, all of which occurred over 4 outbreaks that season.

It was also found that 32 winter seasons were under the influence of the cool phase of the PDO. During these phases, 81 tornadoes were documented during 8 outbreaks, which accounts for 67% of all tornadoes and 62% of the outbreaks. The average number of tornadoes during these cool-phase outbreaks was 10.1, and the standard deviation was 3.0 tornadoes. A maximum of 30 tornadoes was documented during the 1999 season, which occurred during 2 outbreaks.

Kernel Density analysis of documented tornado tracks resulting from winter-time outbreaks has indicated there is little spatial difference in the occurrence of tornado activity between cool (Figure 19) and warm (Figure 20) phases of the PDO. Analysis indicates a cluster of tornado tracks in northwest Louisiana during the cool phase, in addition to a greater number of short tornado tracks across the eastern half of Texas and in southern Oklahoma.

A Student's-t Test comparison was performed to determine if there is a significant difference between the number of tornadoes which occur during the warm phase and the cool phase of the PDO during the winter months. Student's-t Test analysis has concluded that there is a difference of **2.3 ± 4.3** tornadoes between the two phases (Equation 2). Since it is possible that the ± error may make the total value equal to 0, it is concluded that there is no significant difference between the warm and cool phases at the 95% confidence level.

PDO Spring

After performing analysis of the PDO during the spring months (Table 10), it was found that 31 seasons, slightly over half in the study period, were under the influence of a warm phase. During these warm-phase seasons, 400 tornadoes were documented over 42 outbreaks. This accounts for 52% of all spring-time tornadoes and 52% of all outbreaks. The average number of tornadoes per outbreak was found to be 9.5, while the standard deviation was 2.4 tornadoes. A maximum of 48 tornadoes was documented in 1960, which occurred over 4 outbreaks.

Twenty-nine seasons were under the influence of the cool phase of the PDO, in which 373 tornadoes were documented during 39 outbreaks. This accounts for 48% of all spring-time tornadoes for this oscillation d 48% of all outbreaks. The average number of tornadoes per cool-phase outbreak was found to be 9.6, while the standard deviation was 1.9 tornadoes. A maximum of 60 tornadoes was documented in 1982, which occurred as a result of 6 outbreaks.

Kernel Density analysis of the tornado tracks documented during spring-time tornado outbreaks has indicated that there is little spatial difference in the occurrence of tornado activity between the cool (Figure 21) and warm (Figure 22) phases of the PDO. A similar distribution pattern is evident across nearly all of the study area.

A Student's-t Test comparison was performed to determine if there is a significant difference between the number of tornadoes that occur during the warm phase and the cool phase of the PDO during the spring months. Student's-t Test analysis has concluded that there is a difference of **0.1 ± 0.2** tornadoes between the two phases (Equation 7). Since it is possible that the ± error may make the total value equal to 0, it is concluded that there is no significant difference between the warm and cool phases at the 95% confidence level.

DISCUSSION

Kernel Density analysis of the winter season ENSO phases does not reveal a significantly different pattern in the location of tornado activity, although more outbreaks are noticed across portions of east Texas and even southern Oklahoma. This is not very surprising as warmer-than-normal temperatures are known to occur in the southern Great Plains and western Gulf of Mexico region during and ENSO cool phase. These warmer temperatures would allow intense thunderstorm activity to develop further north and west than normal during the winter, which would correspond with the spatial occurrences of these tornadoes. It would also explain why 8 of the 13 tornado outbreaks occurred during the cool phase. It may be interesting to see what pattern would be revealed if tornadoes of (E)F1 intensity were added to the analysis.

The location and density of tornado tracks during the warm phase of ENSO during the spring seasons reflect the more southern track that the jet stream takes as indicated in Figure 4. The cooler temperatures across the study area associated with the warm phase appear to limit the number of tornado outbreaks, and the more west to east track of the jet stream bring an increased amount of tornado activity to the panhandle and Permian Basin regions of west Texas. A greater amount of tornado activity is observed in Arkansas during the neutral phase than the cool phase. It is possible that, as the jet stream shifts farther to the north during the cool phase, tornado activity shifts northward as well, out of the study area in this case.

Kernel density and Student's-t analysis both make an interesting observation of the AMO during the spring season across Arkansas. The density of tornado activity is significantly greater during the warm phase across most of Arkansas than what is documented during the cool phase. As this increased density of tornado activity appears to extend to the northeast of the study area, a future study would probably benefit from an enlarged study area which includes the mid-Mississippi River Valley. It is also noted that several "bulls-eyes" appear in the kernel density analysis which coincide with larger cities in the region. It would be beneficial to investigate these high density areas to determine if any bias has been introduced into the tornado record because of these more-populated areas.

Analysis of the PDO reveals that, while the cool phase during the winter season appears to be more dominant in both the number of tornadoes and the number of outbreaks, there appears to be very little difference in activity between the phases during the spring season. The number of documented tornadoes and documented outbreaks are nearly split down the middle. And while there are minor differences in the density pattern of tornado occurrences, the patterns on the whole are very similar. This leads to a conclusion that, on its own, the PDO has little influence on tornado activity within the study area. Because of these results, analysis of the PDO should be performed on a larger study area to better understand its influence on tornado activity.

AREAS OF FURTHER RESEARCH

Analysis Strategy

When considering future tornado climatology research concerning oceanic oscillations, perhaps one consideration to take into account is the size of the study area. As already established, oceanic oscillations are known to have an impact on global weather patterns. Depending on the guiding principle of the study, perhaps more meaningful results would be achieved from a regional study (a study area the size of a few states, for example), when the same type of analysis has been performed on a national or continental scale.

The approach would be similar to a weather forecasting process that meteorologist call "the forecasting funnel". When developing a weather forecast, many meteorologists employ a strategy where they first analyze the weather pattern on a national or continental scale. Once they are familiar with weather pattern, meteorologists will then focus closer to the forecast area, paying increasing attention to the finer details of the weather pattern directly surrounding the area.

Analysis of tornado climatology might benefit from taking a similar approach: by identifying the pattern of tornado occurrences on a national or continental scale first, and then scaling down to a regional study area in a more detailed analysis. One benefit would be that it allows climatology analysis on a regional scale to be put into perspective with analysis results from a much larger area. Another benefit would be that national or continental scale analysis may reveal similar trends in tornado activity in other areas to those found in the main study area.

Hotspot Analysis

The establishment of tornado climatology can serve as the starting point for other, more specific research topics. Further analysis should be performed in certain areas of the study region to determine if population density is playing a role in the number of documented tornadoes. For example, Kernel Density analysis revealed a high concentration of tornado activity across portions of southwest and central Arkansas. These high density areas appear to be near the cities of Texarkana and Little Rock, respectively. The question is: Are the increased number of documented tornadoes in these areas directly related to the higher populations of nearby cities, or is reason more meteorological in nature?

One possible solution would be to perform a decade-by-decade analysis, comparing the documented tornado occurrences of each decade with census data. If the highest density of tornado tracks corresponds mainly with the highest density population centers, it could be argued that the record of tornado occurrences is biased toward these population centers. However, if it is discovered that a significant number of tornado occurrences were documented also in scarcely-populated areas, it could be concluded with greater confidence that the reason for these occurrences is meteorological. Possible reasons could be topography-related, where the terrain in the areas of these hotspots may be more favorable for tornado development than surrounding areas.

Tornado Record Integrity

Another area of potential research would be a study to verify the integrity of the tornado record. It was suggested by Akyuz et al. (2004) that the number of tornadoes which are F2 or greater on the Fujita Scale may have been exaggerated prior to 1977. This was the year that the NWS initiated a service-wide policy to perform surveys of all weather-related damage when possible. Prior to this policy, storm surveys were performed, but mostly on an inconsistent basis. As a result, many tornado documentations were the result of second-hand reports, often from local media or town officials with little to no training in how to perform a storm survey.

While performing another study, Akyuz et al. suspected that the record of F2 or greater tornadoes in the central Great Plains prior to 1977 was overestimated compared to record since 1977. By applying a mathematical correction to the data, Akyuz et al. found that the new value of F2 or greater tornadoes was closer to the normal distribution. Akyuz et al. admits that this is an artificial calculation, and it does not take into account possible climate change which resulted in the decrease in F2 or greater tornadoes.

Nevertheless, the possibility of overestimation in the record of F2 or greater tornado occurrences exists in the southern Great Plains as well. If comparison of mean annual values before and after 1977 reveals a discrepancy, further research should be performed to identify the source of the discrepancy and determine if it is reasonable to apply a correction to the data.

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APPENDIX 1: FIGURES

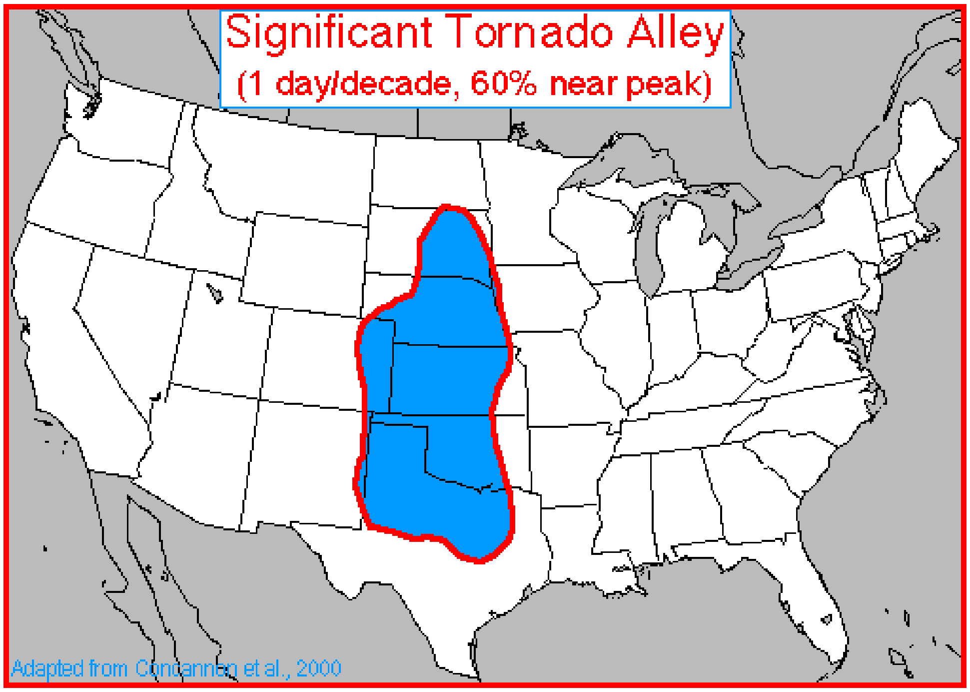

Figure 1: Tornado Alley
Source: National Weather Service National Climate Data Center
http://www.ncdc.noaa.gov/img/climate/research/tornado/stalley.gif

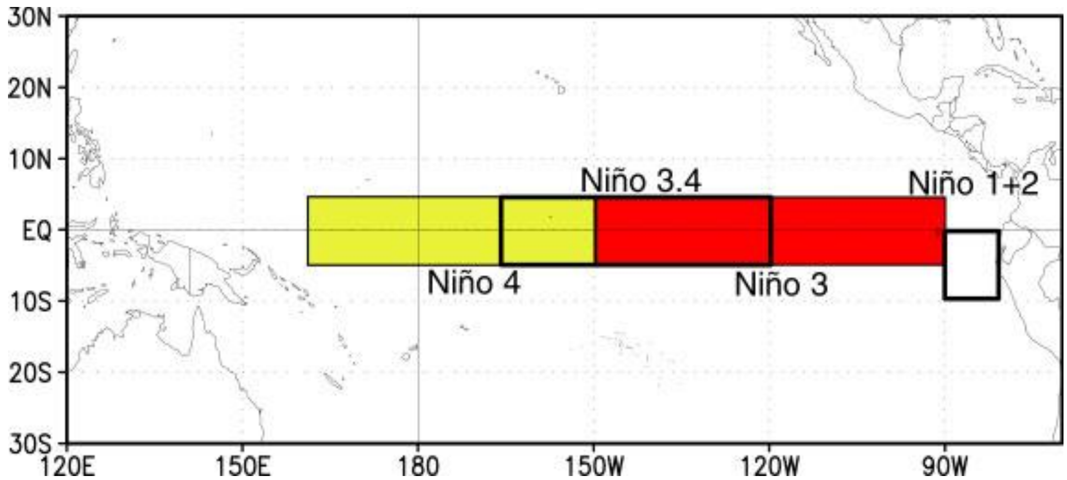

Figure 2: Graphical Depiction of the Four Niño Regions
Source: National Weather Service Climate Prediction Center
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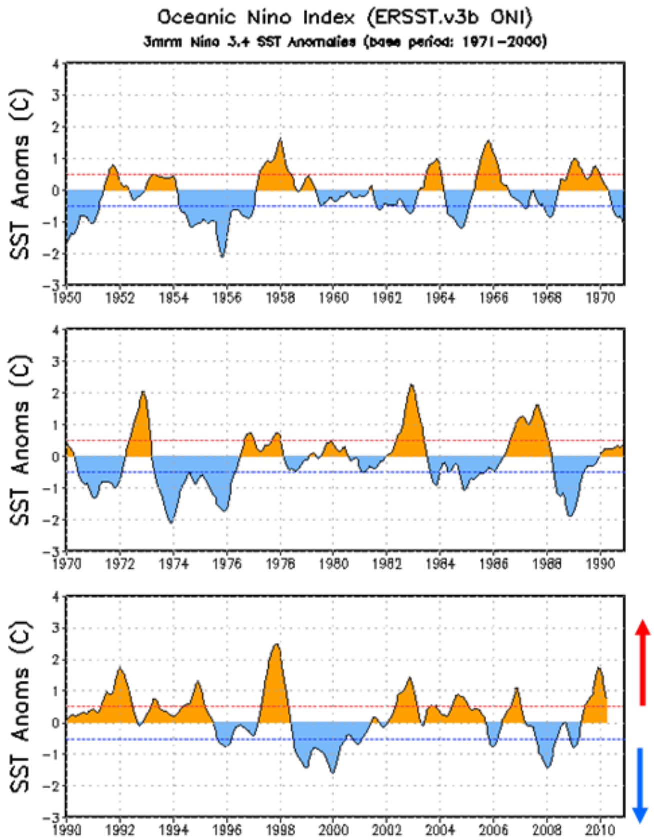

Figure 3: Oceanic Nino Index, 1950 – 2010
Source: National Weather Service Climate Prediction Center
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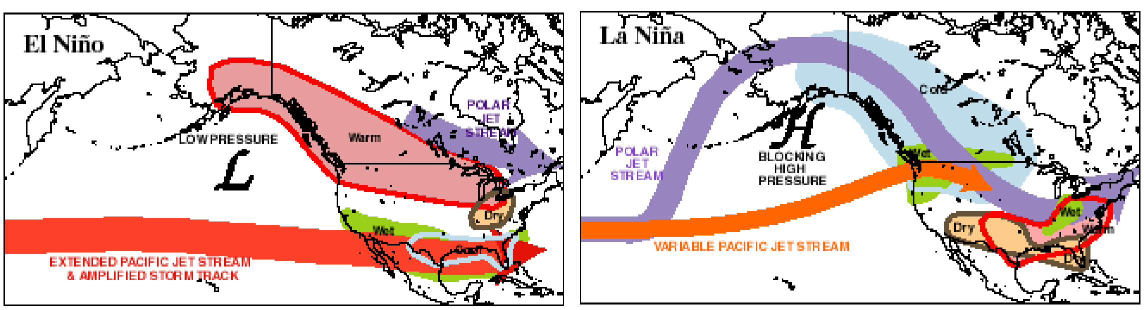

Figure 4: El Nino & La Nina Jet Stream Patterns
Source: NASA Goddard Space Flight Center
http://www.nasa.gov/centers/goddard/news/topstory/2008/elnino_winter.html

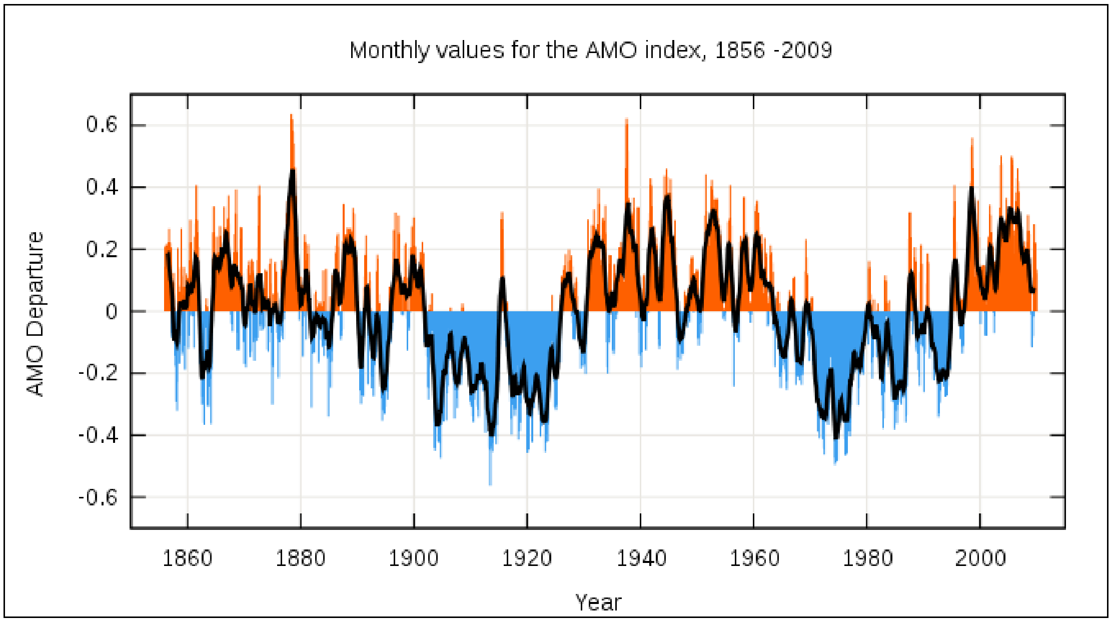

Figure 5: Monthly AMO Index, 1856 – 2009
Source: NOAA Earth System Research Laboratory
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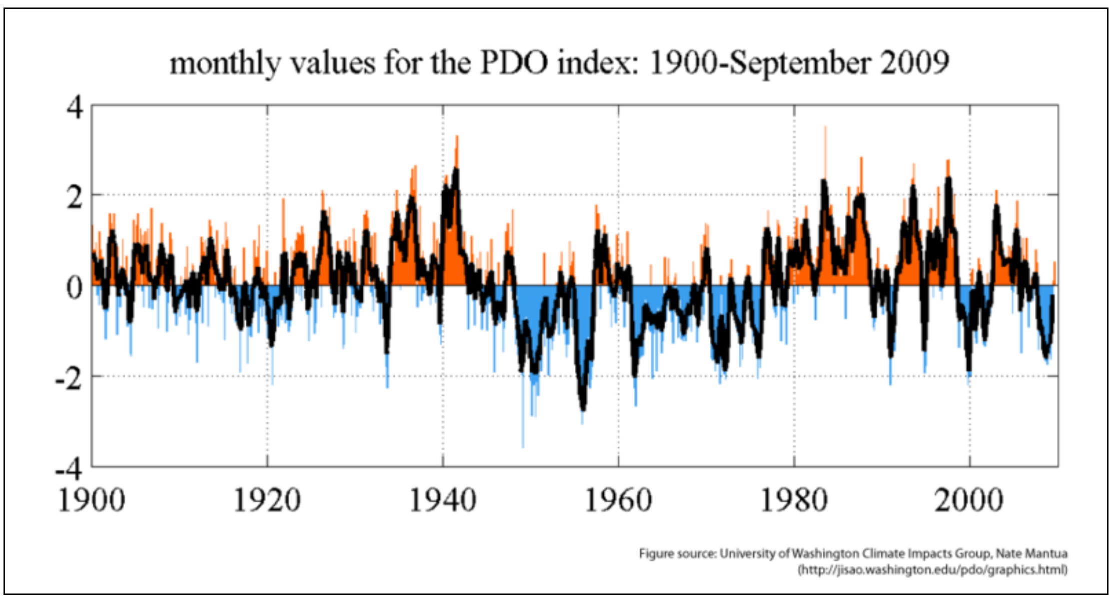

Figure 6: Monthly PDO Index, 1900 – September 2009
Source: Joint Institute for the Study of the Atmosphere and Ocean
http://jisao.washington.edu/pdo/img/pdo_latest.png

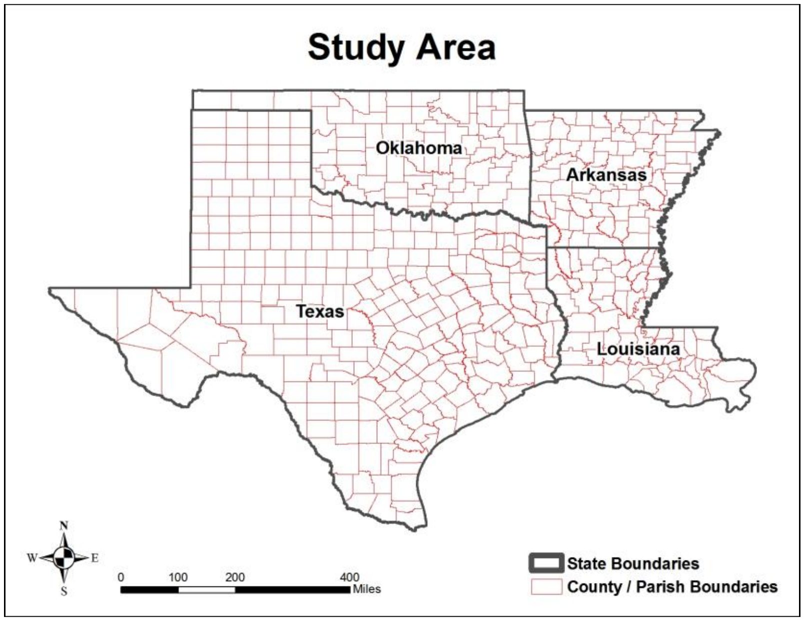

Figure 7: A map of the Study Area
Source: United States Census, 2000
http://www2.census.gov/cgi-bin/shapefiles2009/national-files

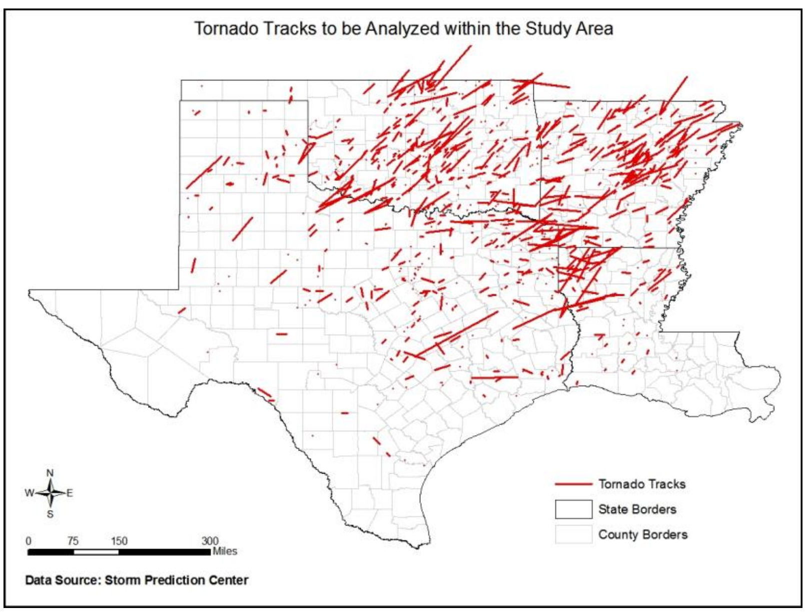

Figure 8: Tornado Tracks to be Analyzed within the Study Area
Source: NWS Storm Prediction Center
http://www.spc.ncep.noaa.gov/wcm/

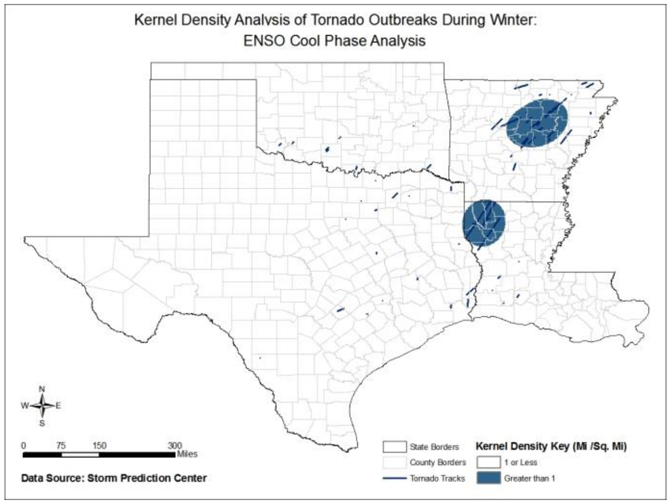

Figure 9: Kernel Density Analysis of ENSO Cool Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

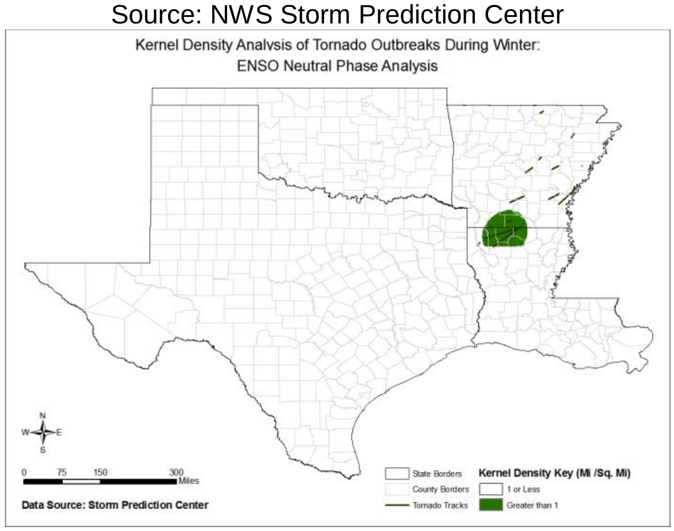

Figure 10: Kernel Density Analysis of ENSO Neutral Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

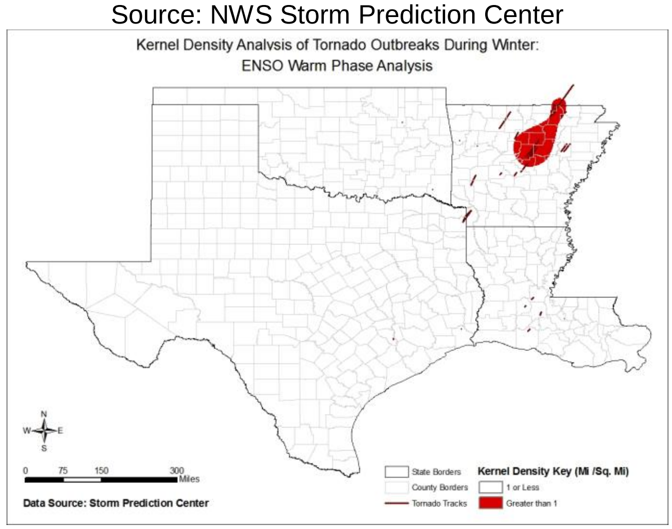

Figure 11: Kernel Density Analysis of ENSO Warm Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

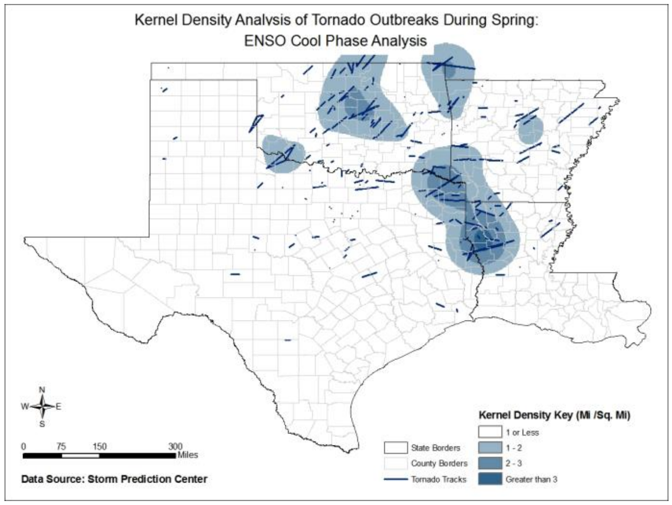

Figure 12: Kernel Density Analysis of ENSO Cool Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

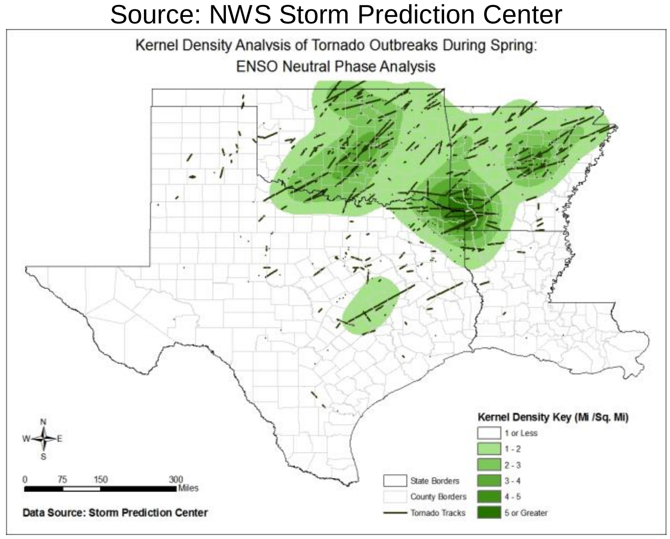

Figure 13: Kernel Density Analysis of ENSO Neutral Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

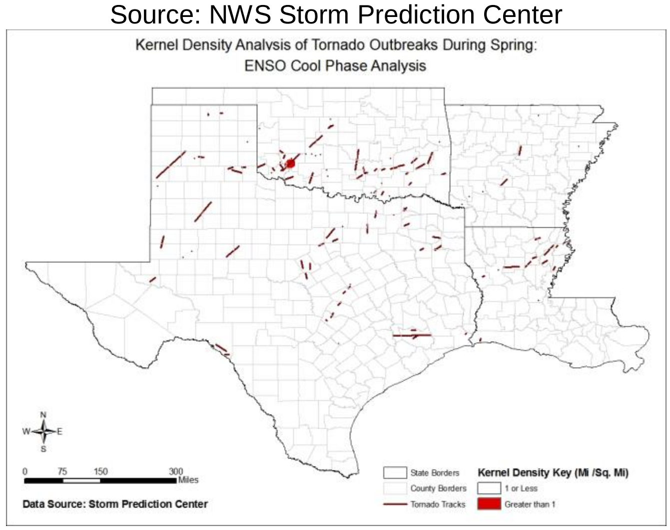

Figure 14: Kernel Density Analysis of ENSO Warm Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

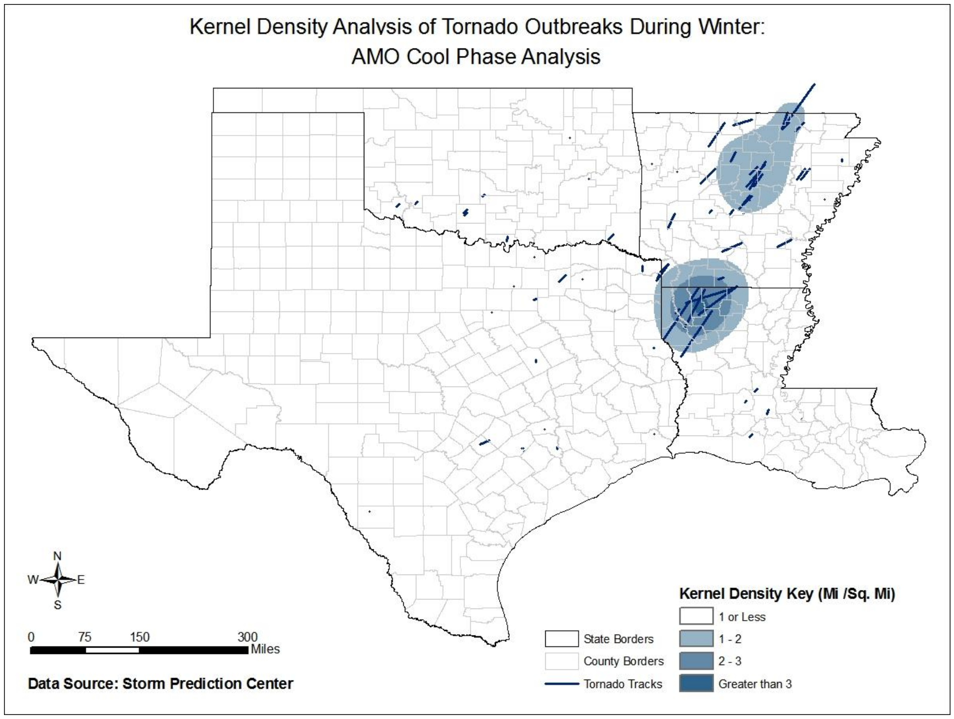

Figure 15: Kernel Density Analysis of AMO Cool Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

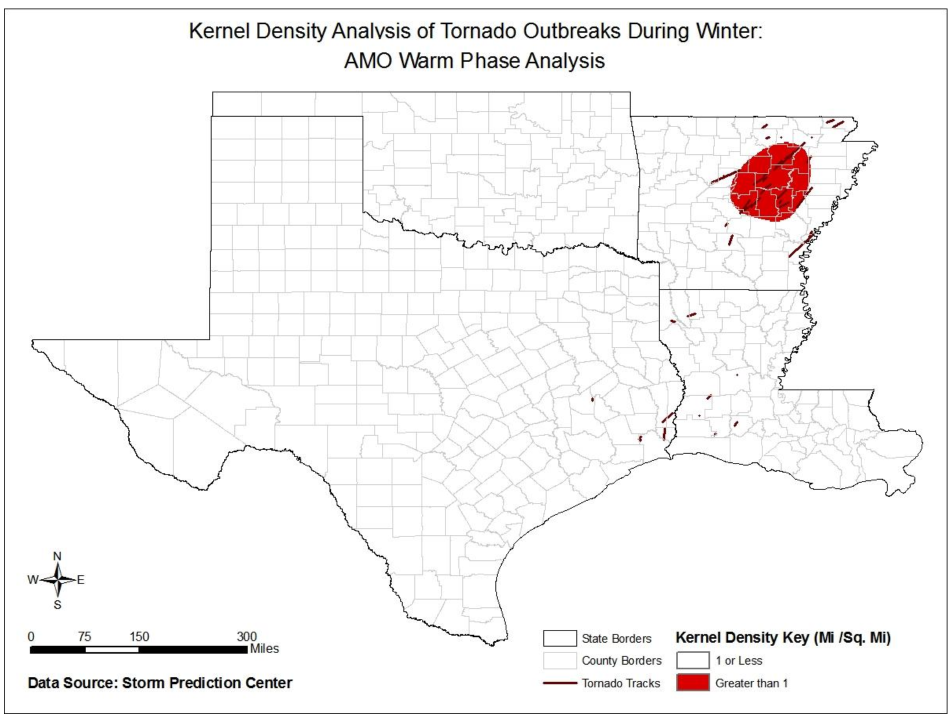

Figure 16: Kernel Density Analysis of AMO Warm Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

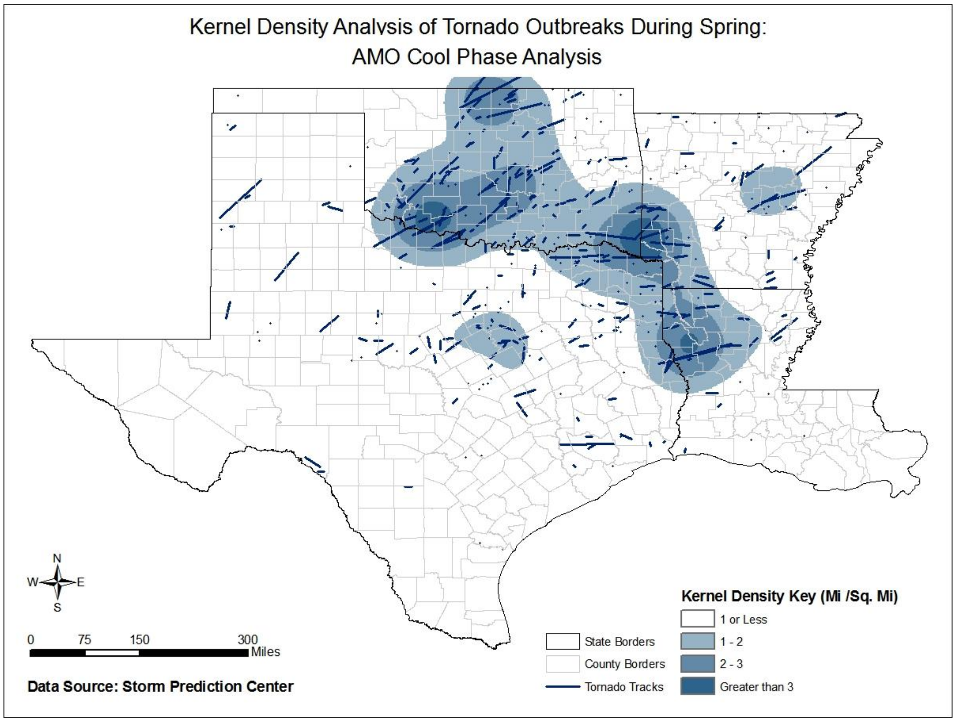

Figure 17: Kernel Density Analysis of AMO Cool Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

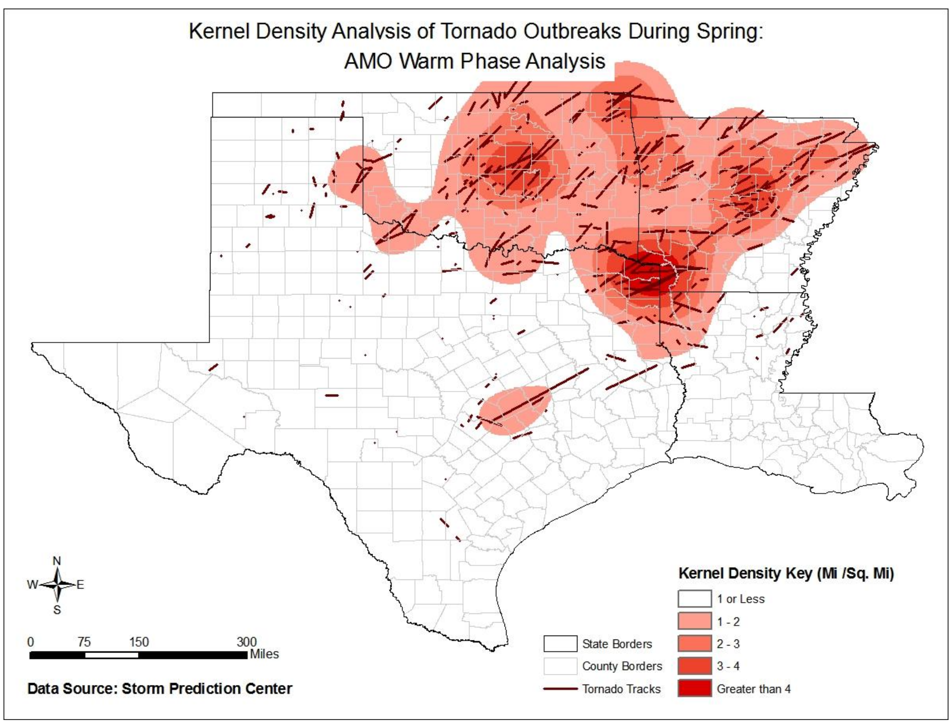

Figure 18: Kernel Density Analysis of AMO Warm Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

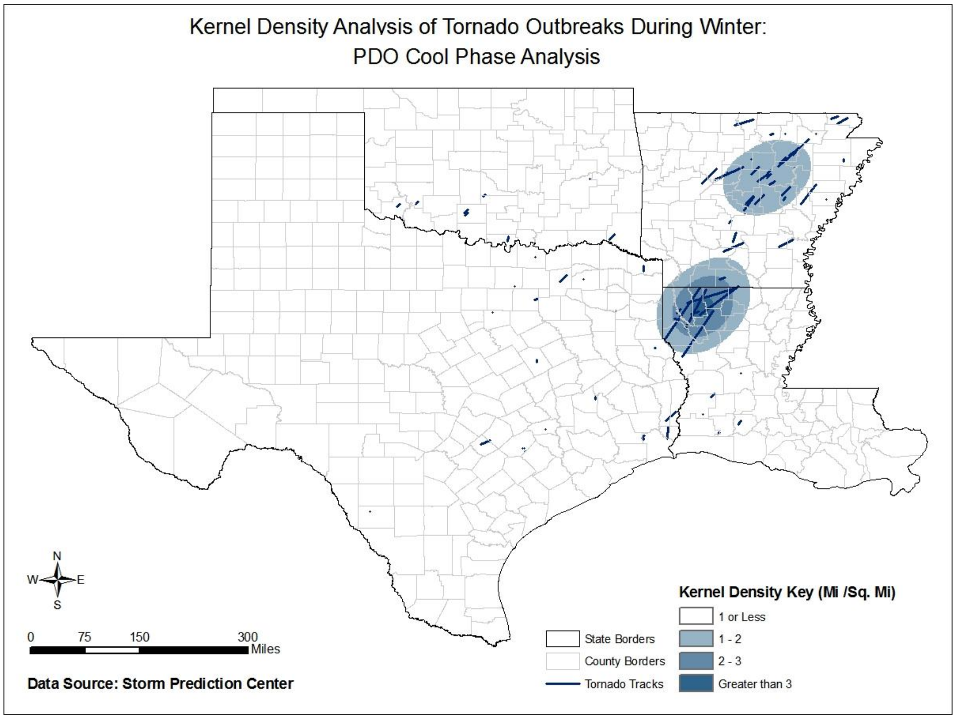

Figure 19: Kernel Density Analysis of PDO Cool Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

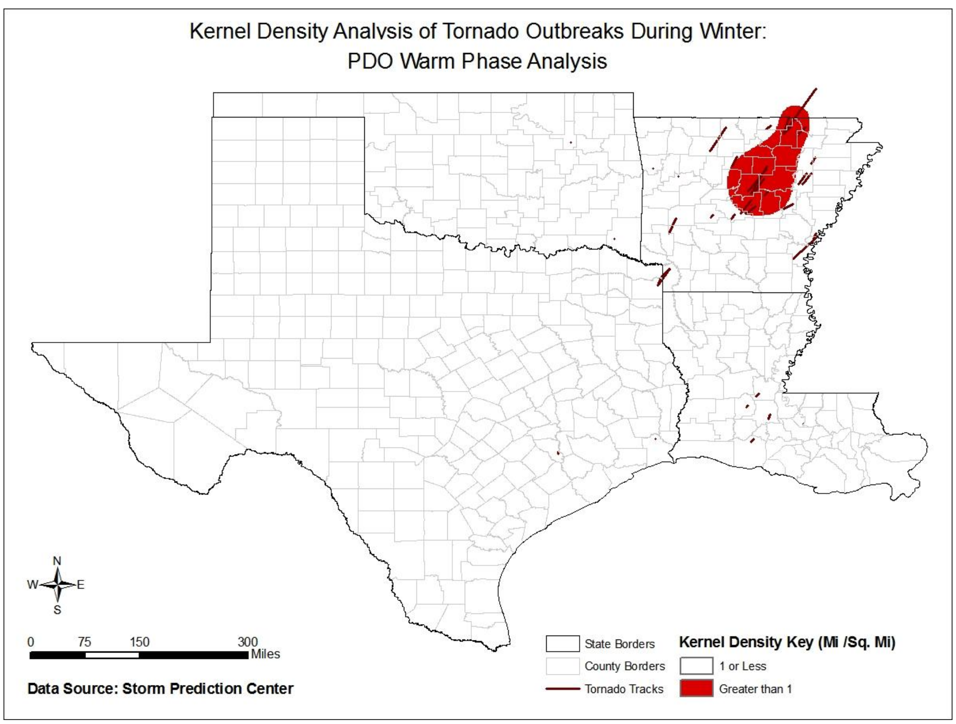

Figure 20: Kernel Density Analysis of PDO Warm Phase Winter Tornado Outbreaks
Source: NWS Storm Prediction Center

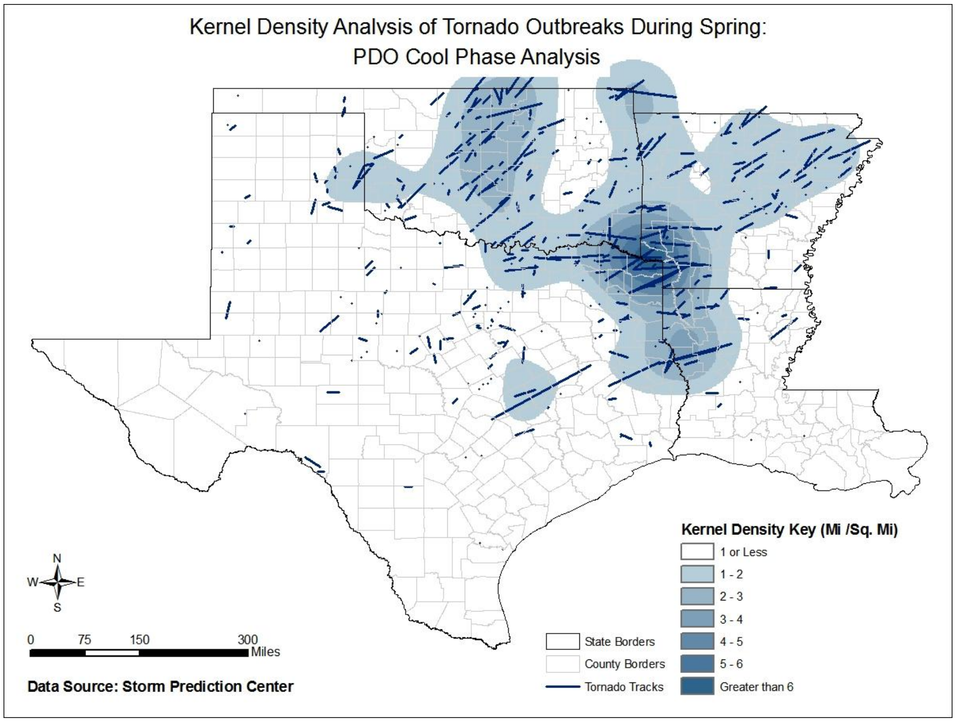

Figure 21: Kernel Density Analysis of PDO Cool Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

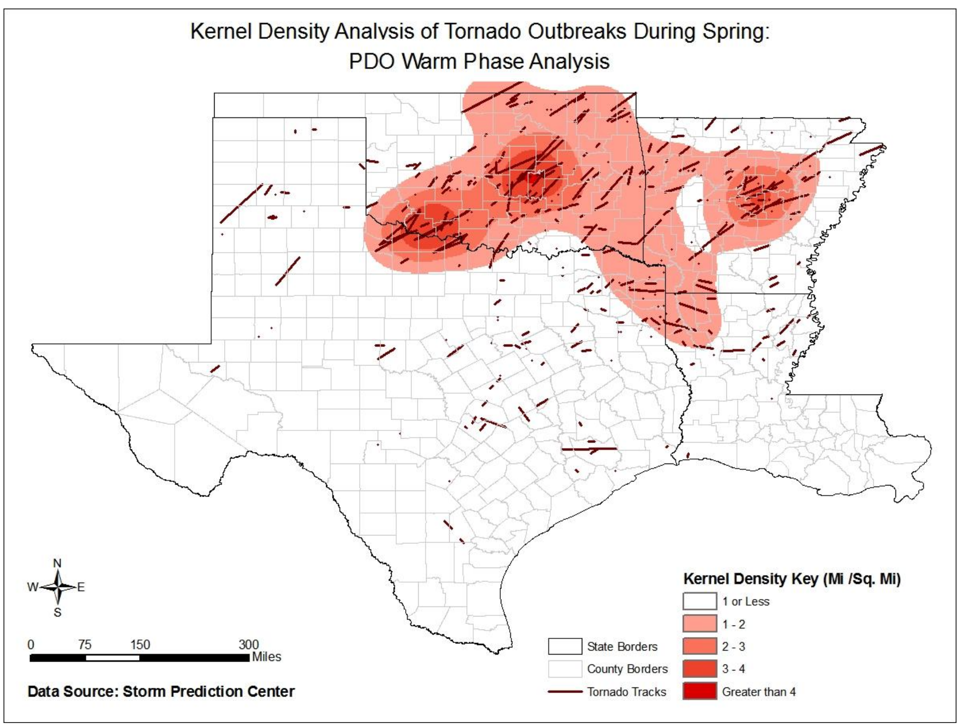

Figure 22: Kernel Density Analysis of PDO Warm Phase Spring Tornado Outbreaks
Source: NWS Storm Prediction Center

APPENDIX 2: TABLES

Table 1: El Nino 3.4 Three-Month Running Mean Values
Source: Climate Prediction Center
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1950	-1.7	-1.5	-1.3	-1.4	-1.3	-1.1	-0.8	-0.8	-0.8	-0.9	-0.9	-1.0
1951	-1.0	-0.9	-0.6	-0.3	-0.2	0.2	0.4	0.7	0.7	0.8	0.7	0.6
1952	0.3	0.1	0.1	0.2	0.1	-0.1	-0.3	-0.3	-0.2	-0.2	-0.1	0.0
1953	0.2	0.4	0.5	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
1954	0.5	0.3	-0.1	-0.5	-0.7	-0.7	-0.8	-1.0	-1.2	-1.1	-1.1	-1.1
1955	-1.0	-0.9	-0.9	-1.0	-1.0	-1.0	-1.0	-1.0	-1.4	-1.8	-2.0	-1.9
1956	-1.3	-0.9	-0.7	-0.6	-0.6	-0.6	-0.7	-0.8	-0.8	-0.9	-0.9	-0.8
1957	-0.5	-0.1	0.3	0.6	0.7	0.9	0.9	0.9	0.9	1.0	1.2	1.5
1958	1.7	1.5	1.2	0.8	0.6	0.5	0.3	0.1	0.0	0.0	0.2	0.4
1959	0.4	0.5	0.4	0.2	0.0	-0.2	-0.4	-0.5	-0.4	-0.3	-0.2	-0.2
1960	-0.3	-0.3	-0.3	-0.2	-0.2	-0.2	-0.1	0.0	-0.1	-0.2	-0.2	-0.2
1961	-0.2	-0.2	-0.2	-0.1	0.1	0.2	0.0	-0.3	-0.6	-0.6	-0.5	-0.4
1962	-0.4	-0.4	-0.4	-0.5	-0.4	-0.4	-0.3	-0.3	-0.5	-0.6	-0.7	-0.7
1963	-0.6	-0.3	0.0	0.1	0.1	0.3	0.6	0.8	0.9	0.9	1.0	1.0
1964	0.8	0.4	-0.1	-0.5	-0.8	-0.8	-0.9	-1.0	-1.1	-1.2	-1.2	-1.0
1965	-0.8	-0.4	-0.2	0.0	0.3	0.6	1.0	1.2	1.4	1.5	1.6	1.5
1966	1.2	1.0	0.8	0.5	0.2	0.2	0.2	0.0	-0.2	-0.2	-0.3	-0.3
1967	-0.4	-0.4	-0.6	-0.5	-0.3	0.0	0.0	-0.2	-0.4	-0.5	-0.4	-0.5
1968	-0.7	-0.9	-0.8	-0.7	-0.3	0.0	0.3	0.4	0.3	0.4	0.7	0.9
1969	1.0	1.0	0.9	0.7	0.6	0.5	0.4	0.4	0.6	0.7	0.8	0.7
1970	0.5	0.3	0.2	0.1	0.0	-0.3	-0.6	-0.8	-0.9	-0.8	-0.9	-1.1
1971	-1.3	-1.3	-1.1	-0.9	-0.8	-0.8	-0.8	-0.8	-0.8	-0.9	-1.0	-0.9
1972	-0.7	-0.4	0.0	0.2	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.1
1973	1.8	1.2	0.5	-0.1	-0.6	-0.9	-1.1	-1.3	-1.4	-1.7	-2.0	-2.1
1974	-1.9	-1.7	-1.3	-1.1	-0.9	-0.8	-0.6	-0.5	-0.5	-0.7	-0.9	-0.7
1975	-0.6	-0.6	-0.7	-0.8	-0.9	-1.1	-1.2	-1.3	-1.5	-1.6	-1.7	-1.7
1976	-1.6	-1.2	-0.8	-0.6	-0.5	-0.2	0.1	0.3	0.5	0.7	0.8	0.7
1977	0.6	0.5	0.2	0.2	0.2	0.4	0.4	0.4	0.5	0.6	0.7	0.7
1978	0.7	0.4	0.0	-0.3	-0.4	-0.4	-0.4	-0.4	-0.4	-0.3	-0.2	-0.1
1979	-0.1	0.0	0.1	0.1	0.1	-0.1	0.0	0.1	0.3	0.4	0.5	0.5
1980	0.5	0.3	0.2	0.2	0.3	0.3	0.2	0.0	-0.1	-0.1	0.0	-0.1
1981	-0.3	-0.5	-0.5	-0.4	-0.3	-0.3	-0.4	-0.4	-0.3	-0.2	-0.1	-0.1
1982	0.0	0.1	0.1	0.3	0.6	0.7	0.7	1.0	1.5	1.9	2.2	2.3
1983	2.3	2.0	1.5	1.2	1.0	0.6	0.2	-0.2	-0.6	-0.8	-0.9	-0.7
1984	-0.4	-0.2	-0.2	-0.3	-0.5	-0.4	-0.3	-0.2	-0.3	-0.6	-0.9	-1.1
1985	-0.9	-0.8	-0.7	-0.7	-0.7	-0.6	-0.5	-0.5	-0.5	-0.4	-0.3	-0.4
1986	-0.5	-0.4	-0.2	-0.2	-0.1	0.0	0.3	0.5	0.7	0.9	1.1	1.2
1987	1.2	1.3	1.2	1.1	1.0	1.2	1.4	1.6	1.6	1.5	1.3	1.1
1988	0.7	0.5	0.1	-0.2	-0.7	-1.2	-1.3	-1.2	-1.3	-1.6	-1.9	-1.9
1989	-1.7	-1.5	-1.1	-0.8	-0.6	-0.4	-0.3	-0.3	-0.3	-0.3	-0.2	-0.1

1990	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.4
1991	0.4	0.3	0.3	0.4	0.6	0.8	1.0	0.9	0.9	1.0	1.4	1.6
1992	1.8	1.6	1.5	1.4	1.2	0.8	0.5	0.2	0.0	-0.1	0.0	0.2
1993	0.3	0.4	0.6	0.7	0.8	0.7	0.4	0.4	0.4	0.4	0.3	0.2
1994	0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.9	1.2	1.3
1995	1.2	0.9	0.7	0.4	0.3	0.2	0.0	-0.2	-0.5	-0.6	-0.7	-0.7
1996	-0.7	-0.7	-0.5	-0.3	-0.1	-0.1	0.0	-0.1	-0.1	-0.2	-0.3	-0.4
1997	-0.4	-0.3	0.0	0.4	0.8	1.3	1.7	2.0	2.2	2.4	2.5	2.5
1998	2.3	1.9	1.5	1.0	0.5	0.0	-0.5	-0.8	-1.0	-1.1	-1.3	-1.4
1999	-1.4	-1.2	-0.9	-0.8	-0.8	-0.8	-0.9	-0.9	-1.0	-1.1	-1.3	-1.6
2000	-1.6	-1.4	-1.0	-0.8	-0.6	-0.5	-0.4	-0.4	-0.4	-0.5	-0.6	-0.7
2001	-0.6	-0.5	-0.4	-0.2	-0.1	0.1	0.2	0.2	0.1	0.0	-0.1	-0.1
2002	-0.1	0.1	0.2	0.4	0.7	0.8	0.9	1.0	1.1	1.3	1.5	1.4
2003	1.2	0.9	0.5	0.1	-0.1	0.1	0.4	0.5	0.6	0.5	0.6	0.4
2004	0.4	0.3	0.2	0.2	0.3	0.5	0.7	0.8	0.9	0.8	0.8	0.8
2005	0.7	0.5	0.4	0.4	0.4	0.4	0.4	0.3	0.2	-0.1	-0.4	-0.7
2006	-0.7	-0.6	-0.4	-0.1	0.1	0.2	0.3	0.5	0.6	0.9	1.1	1.1
2007	0.8	0.4	0.1	-0.1	-0.1	-0.1	-0.1	-0.4	-0.7	-1.0	-1.1	-1.3
2008	-1.4	-1.4	-1.1	-0.8	-0.6	-0.4	-0.1	0.0	0.0	0.0	-0.3	-0.6
2009	-0.8	-0.7	-0.5	-0.1	0.2	0.6	0.7	0.8	0.9	1.2	1.5	1.8

Table 1 (Continued): El Nino 3.4 Three-Month Running Mean Values
Source: Climate Prediction Center
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Table 2: Atlantic Multidecadal Oscillation Values
Source: NOAA Earth System Research Laboratory
http://www.esrl.noaa.gov/psd/data/correlation/amon.sm.long.data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1950	0.13	-0.02	-0.09	-0.11	-0.04	-0.03	-0.04	0.04	0.03	-0.07	0.10	0.11
1951	0.12	0.02	0.03	0.19	0.19	0.31	0.44	0.32	0.27	0.28	0.19	0.19
1952	0.19	0.20	0.25	0.21	0.20	0.40	0.39	0.42	0.38	0.37	0.27	0.36
1953	0.28	0.20	0.16	0.33	0.36	0.29	0.36	0.28	0.30	0.17	0.26	0.28
1954	0.25	0.11	0.12	0.01	0.09	0.12	-0.03	0.00	0.01	-0.01	-0.01	-0.03
1955	0.10	0.06	0.06	0.11	0.20	0.21	0.29	0.19	0.22	0.30	0.41	0.28
1956	0.21	0.11	0.03	0.08	-0.04	-0.25	-0.07	-0.08	-0.07	-0.02	-0.07	0.04
1957	-0.06	-0.09	0.00	-0.06	-0.10	0.01	0.06	0.22	0.24	0.17	0.10	0.10
1958	0.07	0.21	0.36	0.37	0.22	0.24	0.18	0.18	0.23	0.17	0.20	0.24
1959	0.12	0.13	-0.01	0.02	0.03	-0.04	-0.01	0.03	0.15	0.13	0.07	0.13
1960	0.20	0.24	0.11	0.12	0.32	0.34	0.29	0.36	0.23	0.32	0.27	0.16
1961	0.08	0.10	0.17	0.25	0.21	0.05	0.00	0.06	0.02	0.05	0.09	0.23
1962	0.17	0.17	0.19	0.11	0.04	-0.05	0.01	-0.04	0.03	0.09	0.07	0.21
1963	0.18	0.19	0.15	0.13	-0.06	-0.03	-0.02	-0.05	-0.18	-0.05	-0.04	-0.04
1964	-0.06	0.04	0.06	-0.13	0.06	0.03	-0.12	-0.21	-0.20	-0.25	-0.15	-0.10
1965	-0.18	-0.16	-0.06	-0.08	-0.08	-0.11	-0.17	-0.19	-0.20	-0.23	-0.26	-0.10
1966	-0.06	0.03	0.01	0.06	0.02	-0.02	-0.03	-0.02	0.02	0.04	0.02	0.10
1967	0.10	0.11	-0.01	0.01	-0.17	-0.24	-0.21	-0.14	-0.08	-0.08	-0.21	-0.13
1968	-0.23	-0.18	-0.19	-0.14	-0.10	-0.24	-0.21	-0.19	-0.13	-0.09	-0.09	-0.11
1969	-0.04	0.13	0.23	0.17	0.03	0.05	0.12	-0.08	-0.09	-0.16	-0.10	-0.01
1970	0.01	-0.03	0.04	0.04	-0.02	-0.16	-0.18	-0.12	-0.12	-0.17	-0.22	-0.19
1971	-0.22	-0.27	-0.29	-0.39	-0.30	-0.34	-0.33	-0.41	-0.34	-0.21	-0.22	-0.29
1972	-0.30	-0.36	-0.42	-0.30	-0.45	-0.47	-0.35	-0.36	-0.28	-0.26	-0.25	-0.33
1973	-0.35	-0.37	-0.32	-0.24	-0.14	-0.15	-0.08	-0.11	-0.11	-0.19	-0.19	-0.21
1974	-0.25	-0.26	-0.38	-0.50	-0.48	-0.42	-0.49	-0.44	-0.48	-0.48	-0.40	-0.34
1975	-0.25	-0.31	-0.29	-0.32	-0.36	-0.27	-0.25	-0.16	-0.31	-0.33	-0.32	-0.30
1976	-0.36	-0.42	-0.47	-0.40	-0.46	-0.46	-0.28	-0.16	-0.17	-0.27	-0.39	-0.41
1977	-0.36	-0.31	-0.16	-0.19	-0.14	-0.08	-0.08	-0.12	-0.21	-0.20	-0.12	-0.18
1978	-0.08	-0.12	-0.13	-0.17	-0.18	-0.31	-0.25	-0.20	-0.16	-0.18	-0.09	-0.16
1979	-0.17	-0.12	-0.20	-0.21	-0.09	-0.01	-0.07	-0.09	-0.08	-0.06	-0.06	-0.03
1980	0.03	-0.05	-0.11	0.03	0.16	0.14	0.08	0.05	0.02	-0.03	-0.17	-0.22
1981	-0.15	-0.15	0.04	-0.06	-0.05	-0.03	-0.06	-0.08	0.00	-0.15	-0.10	0.02
1982	-0.05	-0.05	-0.05	-0.15	-0.16	-0.15	-0.19	-0.27	-0.27	-0.33	-0.38	-0.35
1983	-0.27	-0.07	0.11	0.10	-0.01	-0.02	0.02	-0.12	-0.18	-0.16	-0.12	0.03
1984	-0.07	-0.05	-0.09	-0.12	-0.14	-0.29	-0.24	-0.20	-0.17	-0.30	-0.39	-0.28
1985	-0.32	-0.29	-0.32	-0.37	-0.31	-0.09	-0.12	-0.24	-0.21	-0.21	-0.26	-0.30
1986	-0.31	-0.24	-0.26	-0.28	-0.20	-0.22	-0.21	-0.23	-0.18	-0.28	-0.36	-0.34
1987	-0.25	-0.18	0.00	0.06	0.09	0.23	0.31	0.32	0.23	0.09	-0.04	0.08
1988	-0.01	-0.08	0.03	0.09	0.17	0.20	0.16	0.03	-0.05	-0.13	-0.12	-0.14
1989	-0.19	-0.13	-0.22	-0.24	-0.11	0.12	0.21	0.15	-0.05	-0.09	-0.12	-0.12
1990	-0.26	-0.13	-0.14	-0.07	-0.03	-0.02	0.02	0.09	0.18	0.15	-0.01	0.00

1991	-0.16	-0.08	-0.03	-0.09	-0.13	-0.10	-0.08	-0.07	0.00	-0.22	-0.23	-0.19
1992	-0.16	-0.07	-0.06	-0.15	-0.20	-0.12	-0.19	-0.35	-0.33	-0.26	-0.30	-0.26
1993	-0.21	-0.16	-0.22	-0.14	-0.14	-0.15	-0.25	-0.20	-0.13	-0.20	-0.28	-0.26
1994	-0.26	-0.27	-0.25	-0.16	-0.17	-0.19	-0.19	-0.19	-0.10	-0.01	0.02	-0.06
1995	-0.03	0.00	0.06	0.11	0.30	0.40	0.35	0.22	0.09	0.14	0.16	0.07
1996	0.02	0.00	-0.03	0.04	-0.03	-0.09	-0.07	0.03	0.04	-0.11	-0.14	-0.12
1997	-0.05	0.00	0.04	0.04	0.07	0.05	0.10	0.05	0.14	0.18	0.08	0.16
1998	0.17	0.33	0.36	0.33	0.41	0.53	0.53	0.56	0.46	0.43	0.36	0.32
1999	0.09	0.09	0.11	0.09	0.20	0.23	0.24	0.35	0.23	0.07	0.00	0.06
2000	-0.05	0.00	0.14	0.08	0.14	0.02	0.11	0.14	0.14	0.00	-0.01	-0.08
2001	-0.08	0.02	0.06	0.03	0.03	0.24	0.18	0.23	0.34	0.31	0.20	0.25
2002	0.22	0.21	0.19	0.07	-0.01	-0.07	-0.02	0.15	0.13	0.16	0.06	0.05
2003	0.09	0.02	0.15	0.12	0.19	0.25	0.33	0.47	0.50	0.47	0.27	0.27
2004	0.25	0.25	0.20	0.15	0.04	0.22	0.27	0.36	0.28	0.29	0.27	0.23
2005	0.15	0.16	0.32	0.34	0.33	0.37	0.50	0.49	0.47	0.28	0.18	0.26
2006	0.16	0.11	0.10	0.24	0.35	0.38	0.43	0.46	0.41	0.38	0.32	0.21
2007	0.21	0.25	0.17	0.20	0.15	0.13	0.18	0.10	0.15	0.21	0.22	0.15
2008	0.07	0.17	0.20	0.09	0.21	0.31	0.26	0.22	0.25	0.15	0.05	0.07
2009	-0.01	-0.12	-0.12	-0.09	-0.02	0.17	0.28	0.20	0.10	0.22	0.12	0.13

Table 2 (Continued): Atlantic Multidecadal Oscillation Values
Source: NOAA Earth System Research Laboratory
http://www.esrl.noaa.gov/psd/data/correlation/amon.sm.long.data

Table 3: Pacific Decadal Oscillation
Source: Joint Institute for the Study of the Atmosphere and Ocean
http://jisao.washington.edu/pdo/PDO.latest

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1950	-2.13	-2.91	-1.13	-1.20	-2.23	-1.77	-2.93	-0.70	-2.14	-1.36	-2.46	-0.76
1951	-1.54	-1.06	-1.90	-0.36	-0.25	-1.09	0.70	-1.37	-0.08	-0.32	-0.28	-1.68
1952	-2.01	-0.46	-0.63	-1.05	-1.00	-1.43	-1.25	-0.60	-0.89	-0.35	-0.76	0.04
1953	-0.57	-0.07	-1.12	0.05	0.43	0.29	0.74	0.05	-0.63	-1.09	-0.03	0.07
1954	-1.32	-1.61	-0.52	-1.33	0.01	0.97	0.43	0.08	-0.94	0.52	0.72	-0.50
1955	0.20	-1.52	-1.26	-1.97	-1.21	-2.44	-2.35	-2.25	-1.95	-2.80	-3.08	-2.75
1956	-2.48	-2.74	-2.56	-2.17	-1.41	-1.70	-1.03	-1.16	-0.71	-2.30	-2.11	-1.28
1957	-1.82	-0.68	0.03	-0.58	0.57	1.76	0.72	0.51	1.59	1.50	-0.32	-0.55
1958	0.25	0.62	0.25	1.06	1.28	1.33	0.89	1.06	0.29	0.01	-0.18	0.86
1959	0.69	-0.43	-0.95	-0.02	0.23	0.44	-0.50	-0.62	-0.85	0.52	1.11	0.06
1960	0.30	0.52	-0.21	0.09	0.91	0.64	-0.27	-0.38	-0.94	0.09	-0.23	0.17
1961	1.18	0.43	0.09	0.34	-0.06	-0.61	-1.22	-1.13	-2.01	-2.28	-1.85	-2.69
1962	-1.29	-1.15	-1.42	-0.80	-1.22	-1.62	-1.46	-0.48	-1.58	-1.55	-0.37	-0.96
1963	-0.33	-0.16	-0.54	-0.41	-0.65	-0.88	-1.00	-1.03	0.45	-0.52	-2.08	-1.08
1964	0.01	-0.21	-0.87	-1.03	-1.91	-0.32	-0.51	-1.03	-0.68	-0.37	-0.80	-1.52
1965	-1.24	-1.16	0.04	0.62	-0.66	-0.80	-0.47	0.20	0.59	-0.36	-0.59	0.06
1966	-0.82	-0.03	-1.29	0.06	-0.53	0.16	0.26	-0.35	-0.33	-1.17	-1.15	-0.32
1967	-0.20	-0.18	-1.20	-0.89	-1.24	-1.16	-0.89	-1.24	-0.72	-0.64	-0.05	-0.40
1968	-0.95	-0.40	-0.31	-1.03	-0.53	-0.35	0.53	0.19	0.06	-0.34	-0.44	-1.27
1969	-1.26	-0.95	-0.50	-0.44	-0.20	0.89	0.10	-0.81	-0.66	1.12	0.15	1.38
1970	0.61	0.43	1.33	0.43	-0.49	0.06	-0.68	-1.63	-1.67	-1.39	-0.80	-0.97
1971	-1.90	-1.74	-1.68	-1.59	-1.55	-1.55	-2.20	-0.15	0.21	-0.22	-1.25	-1.87
1972	-1.99	-1.83	-2.09	-1.65	-1.57	-1.87	-0.83	0.25	0.17	0.11	0.57	-0.33
1973	-0.46	-0.61	-0.50	-0.69	-0.76	-0.97	-0.57	-1.14	-0.51	-0.87	-1.81	-0.76
1974	-1.22	-1.65	-0.90	-0.52	-0.28	-0.31	-0.08	0.27	0.44	-0.10	0.43	-0.12
1975	-0.84	-0.71	-0.51	-1.30	-1.02	-1.16	-0.40	-1.07	-1.23	-1.29	-2.08	-1.61
1976	-1.14	-1.85	-0.96	-0.89	-0.68	-0.67	0.61	1.28	0.82	1.11	1.25	1.22
1977	1.65	1.11	0.72	0.30	0.31	0.42	0.19	0.64	-0.55	-0.61	-0.72	-0.69
1978	0.34	1.45	1.34	1.29	0.90	0.15	-1.24	-0.56	-0.44	0.10	-0.07	-0.43
1979	-0.58	-1.33	0.30	0.89	1.09	0.17	0.84	0.52	1.00	1.06	0.48	-0.42
1980	-0.11	1.32	1.09	1.49	1.20	-0.22	0.23	0.51	0.10	1.35	0.37	-0.10
1981	0.59	1.46	0.99	1.45	1.75	1.69	0.84	0.18	0.42	0.18	0.80	0.67
1982	0.34	0.20	0.19	-0.19	-0.58	-0.78	0.58	0.39	0.84	0.37	-0.25	0.26
1983	0.56	1.14	2.11	1.87	1.80	2.36	3.51	1.85	0.91	0.96	1.02	1.69
1984	1.50	1.21	1.77	1.52	1.30	0.18	-0.18	-0.03	0.67	0.58	0.71	0.82
1985	1.27	0.94	0.57	0.19	0.00	0.18	1.07	0.81	0.44	0.29	-0.75	0.38
1986	1.12	1.61	2.18	1.55	1.16	0.89	1.38	0.22	0.22	1.00	1.77	1.77
1987	1.88	1.75	2.10	2.16	1.85	0.73	2.01	2.83	2.44	1.36	1.47	1.27
1988	0.93	1.24	1.42	0.94	1.20	0.74	0.64	0.19	-0.37	-0.10	-0.02	-0.43
1989	-0.95	-1.02	-0.83	-0.32	0.47	0.36	0.83	0.09	0.05	-0.12	-0.50	-0.21
1990	-0.30	-0.65	-0.62	0.27	0.44	0.44	0.27	0.11	0.38	-0.69	-1.69	-2.23

1991	-2.02	-1.19	-0.74	-1.01	-0.51	-1.47	-0.10	0.36	0.65	0.49	0.42	0.09
1992	0.05	0.31	0.67	0.75	1.54	1.26	1.90	1.44	0.83	0.93	0.93	0.53
1993	0.05	0.19	0.76	1.21	2.13	2.34	2.35	2.69	1.56	1.41	1.24	1.07
1994	1.21	0.59	0.80	1.05	1.23	0.46	0.06	-0.79	-1.36	-1.32	-1.96	-1.79
1995	-0.49	0.46	0.75	0.83	1.46	1.27	1.71	0.21	1.16	0.47	-0.28	0.16
1996	0.59	0.75	1.01	1.46	2.18	1.10	0.77	-0.14	0.24	-0.33	0.09	-0.03
1997	0.23	0.28	0.65	1.05	1.83	2.76	2.35	2.79	2.19	1.61	1.12	0.67
1998	0.83	1.56	2.01	1.27	0.70	0.40	-0.04	-0.22	-1.21	-1.39	-0.52	-0.44
1999	-0.32	-0.66	-0.33	-0.41	-0.68	-1.30	-0.66	-0.96	-1.53	-2.23	-2.05	-1.63
2000	-2.00	-0.83	0.29	0.35	-0.05	-0.44	-0.66	-1.19	-1.24	-1.30	-0.53	0.52
2001	0.60	0.29	0.45	-0.31	-0.30	-0.47	-1.31	-0.77	-1.37	-1.37	-1.26	-0.93
2002	0.27	-0.64	-0.43	-0.32	-0.63	-0.35	-0.31	0.60	0.43	0.42	1.51	2.10
2003	2.09	1.75	1.51	1.18	0.89	0.68	0.96	0.88	0.01	0.83	0.52	0.33
2004	0.43	0.48	0.61	0.57	0.88	0.04	0.44	0.85	0.75	-0.11	-0.63	-0.17
2005	0.44	0.81	1.36	1.03	1.86	1.17	0.66	0.25	-0.46	-1.32	-1.50	0.20
2006	1.03	0.66	0.05	0.40	0.48	1.04	0.35	-0.65	-0.94	-0.05	-0.22	0.14
2007	0.01	0.04	-0.36	0.16	-0.10	0.09	0.78	0.50	-0.36	-1.45	-1.08	-0.58
2008	-1.00	-0.77	-0.71	-1.52	-1.37	-1.34	-1.67	-1.70	-1.55	-1.76	-1.25	-0.87
2009	-1.40	-1.55	-1.59	-1.65	-0.88	-0.31	-0.53	0.09	0.52	0.27	-0.40	0.08

Table 3 (Continued): Pacific Decadal Oscillation
Source: Joint Institute for the Study of the Atmosphere and Ocean
http://jisao.washington.edu/pdo/PDO.latest

The Fujita Scale and the Enhanced Fujita Scale			
Fujita Scale		Enhanced Fujita Scale	
F Number	3-second gust (mph)	EF Number	3-second gust (mph)
0	45 - 78	0	65-85
1	79 - 117	1	86-110
2	118 - 161	2	111-135
3	162 - 209	3	136-165
4	210 - 261	4	166-200
5	262 - 317	5	Greater than 200

Table 4
Source: Enhanced F Scale for Tornado Damage, 1 February 2007
National Weather Service Storm Prediction Center
http://www.spc.noaa.gov/efscale/ef-scale.html

Table 5: ENSO Winter Season (December, January & February) Outbreak Analysis

1950 - 2009

Cool			Neutral			Warm		
Year	Tornado	Outbreaks	Year	Tornado	Outbreaks	Year	Tornado	Outbreaks
1950	7	1	1952	0	0	1958	0	0
1951	0	0	1953	0	0	1964	0	0
1955	0	0	1954	0	0	1966	0	0
1956	7	1	1957	0	0	1969	0	0
1963	0	0	1959	0	0	1970	0	0
1965	0	0	1960	0	0	1973	0	0
1968	0	0	1961	0	0	1977	0	0
1971	7	1	1962	0	0	1978	0	0
1972	12	1	1967	0	0	1983	32	4
1974	0	0	1979	10	1	1987	0	0
1975	8	1	1980	0	0	1988	0	0
1976	0	0	1981	0	0	1992	0	0
1985	0	0	1982	0	0	1995	0	0
1989	0	0	1984	0	0	1998	0	0
1996	0	0	1986	0	0	2003	0	0
1999	30	2	1990	0	0	2005	0	0
2000	0	0	1991	0	0	2007	0	0
2001	7	1	1992	0	0			
2006	0	0	1994	0	0			
2008	0	0	1997	0	0			
2009	0	0	2002	0	0			
			2004	0	0			
# of Seasons:		21	# of Seasons:		22	# of Seasons:		17
# of Tornadoes:		78	# of Tornadoes:		10	# of Tornadoes:		32
# of Outbrakes:		8	# of Outbrakes:		1	# of Outbrakes:		4
Avg. # Tornadoes Per Outbreak		9.8	Avg. # Tornadoes Per Outbreak		10.0	Avg. # Tornadoes Per Outbreak		8.0
Standard Deviation:		3.1	Standard Deviation:		0.0	Standard Deviation:		0.0

Table 6: ENSO Spring Season (March, April & May) Outbreak Analysis
1950 - 2009

Cool			Neutral			Warm		
Year	Tornado	Outbreaks	Year	Tornado	Outbreaks	Year	Tornado	Outbreaks
1953	10	1	1951	0	0	1950	0	0
1957	44	5	1952	14	1	1955	18	2
1958	0	0	1954	30	2	1956	10	1
1966	0	0	1959	20	3	1968	6	1
1969	0	0	1960	48	4	1971	12	2
1983	25	4	1961	41	4	1974	8	1
1987	6	1	1962	0	0	1975	10	1
1992	11	1	1963	0	0	1976	28	3
1993	0	0	1964	0	0	1985	7	1
1998	0	0	1965	12	2	1989	0	0
			1967	16	2	1999	45	3
			1970	0	0	2000	17	1
# of Seasons:		10	1972	0	0	2008	19	3
			1973	35	4			
# of Tornadoes:		96	1977	10	1			
			1978	7	1			
# of Outbrakes:		12	1979	34	2			
			1980	19	2			
			1981	30	4			
Avg. # Tornadoes Per Outbreak		8.0	1982	60	6			
			1984	0	0			
			1986	0	0			
Standard Deviation:		1.4	1988	0	0			
			1990	33	4			
			1991	19	2			
			1994	0	0			
# of Seasons:		37	1995	8	1	# of Seasons:		13
			1996	6	1			
# of Tornadoes:		497	1997	31	2	# of Tornadoes:		180
			2001	0	0			
# of Outbrakes:		50	2002	0	0	# of Outbrakes:		19
			2003	0	0			
			2004	0	0			
Avg. # Tornadoes Per Outbreak		9.9	2005	0	0	Avg. # Tornadoes Per Outbreak		9.5
			2006	0	0			
			2007	11	1			
Standard Deviation:		2.1	2009	13	1	Standard Deviation:		2.7

Table 7: AMO Winter Season (December, January & February) Outbreak Analysis

1950 - 2009

Warm			Cool		
Year	# Tornadoes	# Outbreaks	Year	# Tornadoes	# Outbreaks
1950	7	1	1957	0	0
1951	0	0	1964	0	0
1952	0	0	1965	0	0
1953	0	0	1966	0	0
1954	0	0	1968	0	0
1955	0	0	1969	0	0
1956	7	1	1970	0	0
1958	0	0	1971	7	1
1959	0	0	1972	12	1
1960	0	0	1973	0	0
1961	0	0	1974	0	0
1962	0	0	1975	8	1
1963	0	0	1976	0	0
1967	0	0	1977	0	0
1996	0	0	1978	0	0
1998	0	0	1979	10	1
1999	30	2	1980	0	0
2000	0	0	1981	0	0
2002	0	0	1982	0	0
2003	0	0	1983	32	4
2004	0	0	1984	0	0
2005	0	0	1985	0	0
2006	0	0	1986	0	0
2007	0	0	1987	0	0
2008	0	0	1988	0	0
			1989	0	0
			1990	0	0
			1991	0	0
			1992	0	0
			1993	0	0
			1994	0	0
			1995	0	0
			1997	0	0
			2001	7	1
			2009	0	0
# of Seasons:		25	# of Seasons:		35
# of Tornadoes:		44	# of Tornadoes:		76
# of Outbreaks:		4	# of Outbreaks:		9
Avg. # Tornadoes Per Outbreak:		11.0	Avg. # Tornadoes Per Outbreak:		8.4
Standard Deviation:		4.0	Standard Deviation:		1.6

Table 8: AMO Spring Season (December, January & February) Outbreak Analysis
1950 - 2009

Warm			Cool		
Year	# Tornadoes	# Outbreaks	Year	# Tornadoes	# Outbreaks
1951	0	0	1950	0	0
1952	14	1	1957	44	5
1953	10	1	1964	0	0
1954	30	2	1965	12	2
1955	18	2	1967	16	2
1956	10	1	1968	6	1
1958	0	0	1971	12	2
1959	20	3	1972	0	0
1960	48	4	1973	35	4
1961	41	4	1974	8	1
1962	0	0	1975	10	1
1963	0	0	1976	28	3
1966	0	0	1977	10	1
1969	0	0	1978	7	1
1970	0	0	1979	34	2
1980	19	2	1981	30	4
1983	25	4	1982	60	6
1987	6	1	1984	0	0
1988	0	0	1985	7	1
1995	8	1	1986	0	0
1997	31	2	1989	0	0
1998	0	0	1990	33	4
1999	45	3	1991	19	2
2000	17	1	1992	11	1
2001	0	0	1993	0	0
2002	0	0	1994	0	0
2003	0	0	1996	6	1
2004	0	0	2009	13	1
2005	0	0			
2006	0	0			
2007	11	1			
2008	19	3			

Warm		Cool	
# of Seasons:	32	# of Seasons:	28
# of Tornadoes:	372	# of Tornadoes:	401
# of Outbreaks:	36	# of Outbreaks:	45
Avg. # Tornadoes Per Outbreak:	10.3	Avg. # Tornadoes Per Outbreak:	8.9
Standard Deviation:	2.4	Standard Deviation:	1.8

Table 9: PDO Winter Season (December, January & February) Outbreak Analysis
1950 - 2009

Warm			Cool		
Year	# Tornadoes	# Outbreaks	Year	# Tornadoes	# Outbreaks
1958	0	0	1950	7	1
1959	0	0	1951	0	0
1960	0	0	1952	0	0
1961	0	0	1953	0	0
1970	0	0	1954	0	0
1977	0	0	1955	0	0
1978	0	0	1956	7	1
1980	0	0	1957	0	0
1981	0	0	1962	0	0
1982	0	0	1963	0	0
1983	32	4	1964	0	0
1984	0	0	1965	0	0
1985	0	0	1966	0	0
1986	0	0	1967	0	0
1987	0	0	1968	0	0
1988	0	0	1969	0	0
1992	0	0	1971	7	1
1993	0	0	1972	12	1
1994	0	0	1973	0	0
1996	0	0	1974	0	0
1997	0	0	1975	8	1
1998	0	0	1976	0	0
2001	7	1	1979	10	1
2003	0	0	1989	0	0
2004	0	0	1990	0	0
2005	0	0	1991	0	0
2006	0	0	1995	0	0
2007	0	0	1999	30	2
			2000	0	0
			2002	0	0
			2008	0	0
			2009	0	0

Warm		Cool	
# of Seasons:	28	# of Seasons:	32
# of Tornadoes:	39	# of Tornadoes:	81
# of Outbreaks:	5	# of Outbreaks:	8
Avg. # Tornadoes Per Outbreak:	7.8	Avg. # Tornadoes Per Outbreak:	10.1
Standard Deviation:	0.4	Standard Deviation:	3.0

Table 10: PDO Spring Season (December, January & February) Outbreak Analysis
1950 - 2009

Warm			Cool		
Year	# Tornadoes	# Outbreaks	Year	# Tornadoes	# Outbreaks
1957	44	5	1950	0	0
1958	0	0	1951	0	0
1960	48	4	1952	14	1
1961	41	4	1953	10	1
1965	12	2	1954	30	2
1970	0	0	1955	18	2
1977	10	1	1956	10	1
1978	7	1	1959	20	3
1979	34	2	1962	0	0
1980	19	2	1963	0	0
1981	30	4	1964	0	0
1983	25	4	1966	0	0
1984	0	0	1967	16	2
1985	7	1	1968	6	1
1986	0	0	1969	0	0
1987	6	1	1971	12	2
1988	0	0	1972	0	0
1990	33	4	1973	35	4
1992	11	1	1974	8	1
1993	0	0	1975	10	1
1994	0	0	1976	28	3
1995	8	1	1982	60	6
1996	6	1	1989	0	0
1997	31	2	1991	19	2
1998	0	0	1999	45	3
2000	17	1	2001	0	0
2003	0	0	2002	0	0
2004	0	0	2008	19	3
2005	0	0	2009	13	1
2006	0	0			
2007	11	1			

Warm		Cool	
# of Seasons:	31	# of Seasons:	29
# of Tornadoes:	400	# of Tornadoes:	373
# of Outbreaks:	42	# of Outbreaks:	39
Avg. # Tornadoes Per Outbreak:	9.5	Avg. # Tornadoes Per Outbreak:	9.6
Standard Deviation:	2.4	Standard Deviation:	1.9

APPENDIX 3: EQUATIONS

$$S_{Pool} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

$$SE(\overline{X}_1 - \overline{X}_2) = S_{Pool}\left(\sqrt{\frac{1}{n_1}} + \sqrt{\frac{1}{n_2}}\right)$$

$$\mu_1 - \mu_2 = \overline{X}_1 - \overline{X}_2 \pm t_{\frac{\alpha}{2}} SE(\overline{X}_1 - \overline{X}_2)$$

Equation 1: AMO Winter Cool vs. Warm Phase Outbreak Analysis

$\overline{X}_{\text{WARM}} = 11.0$, $S_{\text{WARM}} = 4.0$, $n_{\text{WARM}} = 4$

$\overline{X}_{\text{COOL}} = 8.4$, $S_{\text{COOL}} = 1.6$, $n_{\text{COOL}} = 9$

1) $S_{Pool} = \sqrt{\frac{(9-1)1.6^2 + (4-1)4.0^2}{9+4-2}} = 2.5$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.5\left(\sqrt{\frac{1}{9}} + \sqrt{\frac{1}{4}}\right) = 2.1$

3) $\mu_1 - \mu_2 = 11.0 - 8.4 \pm (2.23)(2.1)$ = **2.6 ± 4.7**

Not significant at the 95% confidence level.

Equation 2: PDO Winter Cool vs. Warm Phase Outbreak Analysis

$\overline{X}_{\text{WARM}} = 7.8$, $S_{\text{WARM}} = 0.4$, $n_{\text{WARM}} = 5$

$\overline{X}_{\text{COOL}} = 10.1$, $S_{\text{COOL}} = 3.0$, $n_{\text{COOL}} = 8$

1) $S_{Pool} = \sqrt{\frac{(5-1)0.4^2 + (8-1)3.0^2}{5+8-2}} = 2.4$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.4\left(\sqrt{\frac{1}{5}} + \sqrt{\frac{1}{8}}\right) = 1.9$

3) $\mu_1 - \mu_2 = 10.1 - 7.8 \pm (2.23)(1.9)$ = **2.3 ± 4.3**

Not significant at the 95% confidence level.

Equation 3: ENSO Winter Cool vs. Neutral Phase Outbreak Analysis

$\overline{X}_{\text{NEUTRAL}} = 10.0,\quad S_{\text{NEUTRAL}} = 0.0,\quad n_{\text{NEUTRAL}} = 1$

$\overline{X}_{\text{COOL}} = 9.8,\quad S_{\text{COOL}} = 3.1,\quad n_{\text{COOL}} = 8$

1) $S_{Pool} = \sqrt{\dfrac{(8-1)3.1^2 + (1-1)0.0^2}{8+1-2}} = 3.1$

2) $SE(\overline{X}_1 - \overline{X}_2) = 3.1\left(\sqrt{\tfrac{1}{8}} + \sqrt{\tfrac{1}{1}}\right) = 4.2$

3) $\mu_1 - \mu_2 = 10.0 - 9.8 \pm (2.23)(4.2) =$ **0.2 ± 9.4**

Not significant at the 95% confidence level.

Equation 4: ENSO Winter Cool vs. Warm Phase Outbreak Analysis

$\overline{X}_{\text{WARM}} = 8.0,\quad S_{\text{WARM}} = 0.0,\quad n_{\text{WARM}} = 4$

$\overline{X}_{\text{COOL}} = 9.8,\quad S_{\text{COOL}} = 3.1,\quad n_{\text{COOL}} = 8$

1) $S_{Pool} = \sqrt{\dfrac{(8-1)3.1^2 + (4-1)0.0^2}{8+4-2}} = 2.6$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.6\left(\sqrt{\tfrac{1}{8}} + \sqrt{\tfrac{1}{4}}\right) = 2.2$

3) $\mu_1 - \mu_2 = 9.8 - 8.0 \pm (2.23)(2.9) =$ **1.8 ± 4.9**

Not significant at the 95% confidence level.

Equation 5: ENSO Winter Warm vs. Neutral Phase Outbreak Analysis

$\overline{X}_{\text{NEUTRAL}} = 10.0,\quad S_{\text{NEUTRAL}} = 0.0,\quad n_{\text{NEUTRAL}} = 1$

$\overline{X}_{\text{WARM}} = 8.0,\quad S_{\text{WARM}} = 0.0,\quad n_{\text{WARM}} = 4$

1) $S_{Pool} = \sqrt{\dfrac{(4-1)0.0^2 + (1-1)0.0^2}{4+1-2}} = 0.0$

2) $SE(\overline{X}_1 - \overline{X}_2) = 0.0\left(\sqrt{\tfrac{1}{4}} + \sqrt{\tfrac{1}{1}}\right) = 0.0$

3) $\mu_1 - \mu_2 = 10.0 - 8.0 \pm (2.23)(0.0) =$ **2.0 ± 0.0**

This is significant at the 95% confidence level.

$$S_{Pool} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

$$SE(\overline{X}_1 - \overline{X}_2) = S_{Pool}\left(\sqrt{\frac{1}{n_1}} + \sqrt{\frac{1}{n_2}}\right)$$

$$\mu_1 - \mu_2 = \overline{X}_1 - \overline{X}_2 \pm t_{\frac{\alpha}{2}} SE(\overline{X}_1 - \overline{X}_2)$$

Equation 6: AMO Spring Cool vs. Warm Phase Outbreak Analysis

$\overline{X}_{\text{WARM}} = 10.3$, $S_{\text{WARM}} = 2.4$, $n_{\text{WARM}} = 36$

$\overline{X}_{\text{COOL}} = 8.9$, $S_{\text{COOL}} = 1.8$, $n_{\text{COOL}} = 45$

$$S_{Pool} = \sqrt{\frac{(36-1)2.4^2 + (45-1)1.8^2}{36+45-2}} = 2.1$$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.1\left(\sqrt{\frac{1}{36}} + \sqrt{\frac{1}{45}}\right) = 0.1$

3) $\mu_1 - \mu_2 = 10.3 - 8.9 \pm (2.23)(2.0) =$ **1.4 ± 0.2**

This is significant at the 95% confidence level.

Equation 7: PDO Spring Cool vs. Warm Phase Outbreak Analysis

$\overline{X}_{\text{WARM}} = 9.5$, $S_{\text{WARM}} = 2.4$, $n_{\text{WARM}} = 42$

$\overline{X}_{\text{COOL}} = 9.6$, $S_{\text{COOL}} = 1.9$, $n_{\text{COOL}} = 39$

1) $S_{Pool} = \sqrt{\frac{(42-1)2.4^2 + (39-1)1.9^2}{42+39-2}} = 2.2$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.2\left(\sqrt{\frac{1}{42}} + \sqrt{\frac{1}{39}}\right) = 0.1$

3) $\mu_1 - \mu_2 = 9.6 - 9.5 \pm (2.23)(0.1) =$ **0.1 ± 0.2**

Not significant at the 95% confidence level.

Equation 8: ENSO Spring Cool vs. Neutral Phase Outbreak Analysis

$\overline{X}_{\text{NEUTRAL}} = 9.9$, $S_{\text{NEUTRAL}} = 2.1$, $n_{\text{NEUTRAL}} = 50$
$\overline{X}_{\text{COOL}} = 8.0$, $S_{\text{COOL}} = 1.4$, $n_{\text{COOL}} = 12$

1) $S_{Pool} = \sqrt{\dfrac{(50-1)2.1^2 + (12-1)1.4^2}{50+12-2}} = 2.0$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.0\left(\sqrt{\frac{1}{50}} + \sqrt{\frac{1}{12}}\right) = 0.9$

3) $\mu_1 - \mu_2 = 9.9 - 8.0 \pm (2.23)(2.1)$ = **1.9 ± 1.9**

Not significant at the 95% confidence level.

Equation 9: ENSO Spring Cool vs. Warm Phase Outbreak Analysis

$\overline{X}_{\text{WARM}} = 9.5$, $S_{\text{WARM}} = 2.7$, $n_{\text{WARM}} = 19$
$\overline{X}_{\text{COOL}} = 8.0$, $S_{\text{COOL}} = 1.4$, $n_{\text{COOL}} = 12$

1) $S_{Pool} = \sqrt{\dfrac{(19-1)2.7^2 + (12-1)1.4^2}{19+12-2}} = 2.3$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.3\left(\sqrt{\frac{1}{19}} + \sqrt{\frac{1}{12}}\right) = 1.2$

3) $\mu_1 - \mu_2 = 9.5 - 8.0 \pm (2.23)(1.2)$ = **1.5 ± 2.7**

Not significant at the 95% confidence level.

Equation 10: ENSO Spring Warm vs. Neutral Phase Outbreak Analysis

$\overline{X}_{\text{NEUTRAL}} = 9.9$, $S_{\text{NEUTRAL}} = 2.1$, $n_{\text{NEUTRAL}} = 50$
$\overline{X}_{\text{WARM}} = 9.5$, $S_{\text{WARM}} = 2.7$, $n_{\text{WARM}} = 19$

1) $S_{Pool} = \sqrt{\dfrac{(50-1)2.1^2 + (19-1)2.7^2}{50+19-2}} = 2.5$

2) $SE(\overline{X}_1 - \overline{X}_2) = 2.5\left(\sqrt{\frac{1}{50}} + \sqrt{\frac{1}{19}}\right) = 0.9$

3) $\mu_1 - \mu_2 = 9.9 - 9.5 \pm (2.23)(2.4)$ = **0.4 ± 2.0**

Not significant at the 95% confidence level

APPENDIX 4: PHP CODE TO GENERATE A TORNADO TRACKS SHAPEFILE

```
<?php
########################################
##This program will convert coordinates into a polyline or polygon.
##
##Written 7/2/2010 by Nick Fillo
##
##This code is free for anyone to use or modify as needed. However, please maintain the  ##credits
within this header.  Thank you.
########################################

$types = array("ENSO","AMO","PDO");


foreach ($types as $names)
{
	$triggerfile = $names.".txt";

	if (file_exists($triggerfile))
	{
		$fcontents = file($triggerfile); //loads the trigger file into an array
		for($i=0; $i<sizeof($fcontents); $i++)
		{
			$cleanup = trim($fcontents[$i]);
			$row = explode(",", $cleanup);

			for($j=1; $j<sizeof($row); $j++)
			{
				$id = $names.$row[0].$j;
				$holder[$id] = $row[$j];
//				print "holder$id is $holder[$id] \n";
			}
		}
	}
}

$triggerfile = "All_Tracks.csv";

if (file_exists($triggerfile))
{
	$line = trim($triggerfile);
	$name = explode(".", $line);
	$shapefilename = $name[0];

	system ("C:\\Shapelib\\shpcreate.exe ".$shapefilename." arc");	//You can choose from point,
arc (polyline), polygon or multipoint
//	system ("C:\\Shapelib\\dbfcreate.exe ".$shapefilename." -n OBJECTID 10 0, -s DATE 10, -n
YEAR 10 0, -n MONTH 10 0, -n DAY 10 0, -n CST 10 0, -s STATE 10, -n F_SCALE 10 0, -n
LENGTH_MI 10 2, -n WIDTH_YDS 10 0, -n WIDTH_MI 10 4, -n AREA_SQ_MI 10 4, -n AREA_LOG
10 4, -s AREA_CLASS 10, -n DPI 10 1, -n DEATHS 10 0, -n INJURIES 10 0, -n TDLAT 10 3, -n
TDLON 10 3, -n LIFTLAT 10 3, -n LIFTLON 10 3, -n ENSO 10 3");
	system ("C:\\Shapelib\\dbfcreate.exe ".$shapefilename." -n OBJECTID 10 0, -s DATE 10, -n
YEAR 10 0, -n MONTH 10 0, -n DAY 10 0, -n CST 10 0, -s STATE 10, -n F_SCALE 10 0, -n
LENGTH_MI 10 2, -n WIDTH_YDS 10 0, -n WIDTH_MI 10 4, -n AREA_SQ_MI 10 4, -n AREA_LOG
10 4, -s AREA_CLASS 10, -n DPI 10 1, -n DEATHS 10 0, -n INJURIES 10 0, -n TDLAT 10 3, -n
TDLON 10 3, -n LIFTLAT 10 3, -n LIFTLON 10 3, -n ENSO 10 3, -n AMO 10 3, -n PDO 10 3");
```

```
	$fcontents = file($triggerfile); //loads the trigger file into an array
	$titleline = trim($fcontents[0]);
	$titlesearch = explode(",", $titleline);

	for ($j=0; $j<sizeof($titlesearch); $j++)
	{
		if (trim($titlesearch[$j]) == "Date")
			{$Dateinfo = $j;}
		elseif (trim($titlesearch[$j]) == "Begin Date")
			{$Dateinfo = $j;}
		elseif (trim($titlesearch[$j]) == "Time")
			{$Timeinfo = $j;}
		elseif (trim($titlesearch[$j]) == "Begin Time")
			{$Timeinfo = $j;}
		elseif (trim($titlesearch[$j]) == "Year")
			{$year = $j;}
		elseif (trim($titlesearch[$j]) == "Month")
			{$month = $j;}
		elseif (trim($titlesearch[$j]) == "Day")
			{$day = $j;}
		elseif (trim($titlesearch[$j]) == "State")
			{$State = $j;}
		elseif (trim($titlesearch[$j]) == "Tornado F-Scale")
			{$Fujita = $j;}
		elseif (trim($titlesearch[$j]) == "Tornado Length (miles)")
			{$pathlengthmi = $j;}
		elseif (trim($titlesearch[$j]) == "Tornado Width (yards)")
			{$pathwidthyd = $j;}
		elseif (trim($titlesearch[$j]) == "Injuries")
			{$Injuries = $j;}
		elseif (trim($titlesearch[$j]) == "Direct Injuries")
			{$dirinjuries = $j;}
		elseif (trim($titlesearch[$j]) == "Indirect Injuries")
			{$indirinjuries = $j;}
		elseif (trim($titlesearch[$j]) == "Fatalities")
			{$Fatalities = $j;}
		elseif (trim($titlesearch[$j]) == "Direct Fatalities")
			{$dirfatals = $j;}
		elseif (trim($titlesearch[$j]) == "Indirect Fatalities")
			{$indirfatals = $j;}
		elseif (trim($titlesearch[$j]) == "Location #1 (Lat)")
			{$blatnum = $j;}
		elseif (trim($titlesearch[$j]) == "Location #1 (Lon)")
			{$blonnum = $j;}
		elseif (trim($titlesearch[$j]) == "Location #2 (Lat)")
			{$elatnum = $j;}
		elseif (trim($titlesearch[$j]) == "Location #2 (Lon)")
			{$elonnum = $j;}
		elseif (trim($titlesearch[$j]) == "Property Damage")
			{$PropDam = $j;}
	}

	##This loop will go through the trigger file line by line, and create polylines from the
coordinates.
//	for($i=1; $i<500; $i++)
	for($i=1; $i<sizeof($fcontents); $i++)
	{
```

```
			$line = trim($fcontents[$i]); //this command trims all of the extra white space from each
line in the array
			$arr = explode(",", $line); //this command breaks up the comma delimited file

			$time = explode(":", $arr[$Timeinfo]);
			$hour = $time[0];
			$minute = $time[1];
			$CST = $hour."".$minute;

			if ($arr[$elatnum] == 0)
				{$arr[$elatnum] = ($arr[$blatnum] + 0.001);}
			if ($arr[$elonnum] == 0)
				{$arr[$elonnum] = ($arr[$blonnum] + 0.001);}

			//This part does calculations to determine path size and coverage information
			$pathwidthmi = ($arr[$pathwidthyd] / 1760);
			$patharea = ($pathwidthmi * $arr[$pathlengthmi]);
			$arealog = log($patharea);

			if ($arealog > 2)
				{$areaclass = "DECAGIANT";}
			elseif ($arealog < 2 & $arealog >=1)
				{$areaclass = "GIANT";}
			elseif ($arealog < 1 & $arealog >=0)
				{$areaclass = "MACRO";}
			elseif ($arealog < 0 & $arealog >= -1)
				{$areaclass = "MESO";}
			elseif ($arealog < -1 & $arealog >= -2)
				{$areaclass = "MICRO";}
			elseif ($arealog < -2 & $arealog >= -3)
				{$areaclass = "DECIMICRO";}
			elseif ($arealog < -3)
				{$areaclass = "TRACE";}

			//This section will calculate the DPI, which is the track area multiplied by the Fujita
scale rating + 1.
			$Fscale = explode("EF", $arr[$Fujita]);
			$Fnumber = $Fscale[1];
//			$dpi = (($Fnumber + 1) * $patharea);
			$dpi = (($arr[$Fujita] + 1) * $patharea);

			$ENSO = "ENSO".$arr[$year].$arr[$month];
			$AMO = "AMO".$arr[$year].$arr[$month];
			$PDO = "PDO".$arr[$year].$arr[$month];

			system ("C:\\Shapelib\\shpadd ".$shapefilename." ".$arr[$blonnum]."
".$arr[$blatnum]." ".$arr[$elonnum]." ".$arr[$elatnum]."");
//			system ("C:\\Shapelib\\dbfadd ".$shapefilename.".dbf ".$i." ".$arr[$Dateinfo]."
".$arr[$year]." ".$arr[$month]." ".$arr[$day]." ".$CST." ".$arr[$State]." ".$arr[$Fujita]."
".$arr[$pathlengthmi]." ".$arr[$pathwidthyd]." ".$pathwidthmi." ".$patharea." ".$arealog." ".$areaclass."
".$dpi." ".$arr[$Fatalities]." ".$arr[$Injuries]." ".$arr[$blatnum]." ".$arr[$blonnum]." ".$arr[$elatnum]."
".$arr[$elonnum]." ".$holder[$ENSO]."");
			system ("C:\\Shapelib\\dbfadd ".$shapefilename.".dbf ".$i." ".$arr[$Dateinfo]."
".$arr[$year]." ".$arr[$month]." ".$arr[$day]." ".$CST." ".$arr[$State]." ".$arr[$Fujita]."
".$arr[$pathlengthmi]." ".$arr[$pathwidthyd]." ".$pathwidthmi." ".$patharea." ".$arealog." ".$areaclass."
".$dpi." ".$arr[$Fatalities]." ".$arr[$Injuries]." ".$arr[$blatnum]." ".$arr[$blonnum]." ".$arr[$elatnum]."
".$arr[$elonnum]." ".$holder[$ENSO]." ".$holder[$AMO]." ".$holder[$PDO]."");
```

```
			print "$i C:\\Shapelib\\shpadd ".$shapefilename.".dbf ".$arr[$year]." ".$arr[$month]." ".$holder[$ENSO]." ".$holder[$AMO]." ".$holder[$PDO]."\n";
		}
}

?>
```