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LONG-TERM TREND ANALYSIS OF CLIMATIC FACTORS INFLUENCING AUTUMN-WINTER MIGRATION OF MALLARDS IN THE MISSISSIPPI FLYWAY

By

Christina Elizabeth Zimmerman

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LONG-TERM TREND ANALYSIS OF CLIMATIC FACTORS INFLUENCING AUTUMN-WINTER MIGRATION OF MALLARDS IN THE MISSISSIPPI FLYWAY

By

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Anecdotal evidence suggests that increased numbers of waterfowl are remaining at northern latitudes throughout winter in the Mississippi Flyway. A calculated weather severity index (WSI), based on temperature and snow data, determined that local mallard abundance decreases when a WSI of 8 is reached. In mapping the WSI 8 line, mallard movement can be estimated. A fifty year trend analysis of the climatic factors driving duck migration for various locations within the Mississippi Flyway was used to determine whether climatic shifts have occurred, finding that although there are sinusoidal temperature trends throughout those years, the past decade has a longer and overall warmer trend. In examining the role of El Niño Southern Oscillation, it was found that in La Niña there is a more severe WSI, and El Niño correlates with a less severe WSI. A neutral Oceanic Niño Index caused a very high or very low WSI (was inconclusive).

Key words: mallard migration, climate, El Niño Southern Oscillation

DEDICATION

I would like to dedicate this research to my family. First and foremost, my parents, Robert and Melissa Zimmerman, and my sister, Natalie, for all they have provided me with and for making me the person I am today. Also, to my extended family, who has always provided me with endless love, support, and encouragement.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

CHAPTER

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Recent observations suggest increased populations of waterfowl throughout winter at northern latitudes (Browne and Dell 2007, Link et al. 2006, Abraham et al. 2005, Petrie and Schummer 2002) possibly as a result of fewer ducks migrating southward into traditional wintering areas such as the Lower Mississippi Alluvial Valley (LMAV) (Greene and Kremetz 2007, Pearse 2007, Reineke et al. 2006). There are multiple hypotheses for these observed changes in waterfowl distribution, including the availability of foraging, sanctuary, and other habitats; climate; breeding populations and recruitment; harvest and harvest distribution; and anthropogenic influences (Browne and Dell 2007, Greene and Kremetz 2007, Pearse 2007, Reinecke et al. 2006, Stafford et al. 2006). Seasonal changes in temperatures directly affect waterfowl migration; warmer autumn and winter seasons mean waterfowl do not have to travel as far south to find ample amounts of food and open water. Open water at higher latitudes begins to freeze in November. Thus, if criteria of food and water are met waterfowl will often remain at higher latitudes (Browne and Dell 2007, Bellrose 1980). Changes in waterfowl habitat can be caused by changing weather patterns, and/or conversion of wetlands into cropland or human habitat (i.e., landscape change; Browne and Dell 2007). While many influences on autumn-winter distributions of waterfowl have been studied, little information exists regarding effects of weather on waterfowl migration.

In the last century (1906-2006), the mean global surface temperature has risen by approximately 0.74 °C (IPCC 2007). Many scientists suspect this temperature change has influenced the location of suitable climatic conditions for many species, altering the distribution of organisms (Seavy et al. 2008, Mustin et al. 2007, Parmesan 2007, Root et al. 2003, Walther et al. 2002). By studying if weather conditions known to influence egress of waterfowl from northern latitudes (i.e., temperature and snow cover) have changed over the past fifty years, interpretations regarding changes in waterfowl abundance at southern latitudes (e.g., LMAV) can be made. Further, information on weather factors influencing autumn-winter waterfowl migration could be used to make predictions about future migration patterns and waterfowl distributions.

While there are many influences of weather on waterfowl migration, research suggests that ducks at mid-latitude migrational staging areas react strongly to the combined effect of below freezing temperatures and snow cover by migrating to more southerly locations (Schummer et al., *unpublished manuscript*, Newton 2008, Bellrose 1980, Bellrose and Sieh 1960). Therefore, changes in climate may have influenced changes in autumn-winter distributions of waterfowl in the Mississippi Flyway in North America (Browne and Dell 2007). Currently available climate summaries are not useful at examining influences of finer-scale daily temperature and snow trends on waterfowl migration. Thus, the primary objectives of this study were to determine if timing and severity of autumn-winter weather events known to cause egress of waterfowl (Schummer et al., *unpublished manuscript*) have changed in the past fifty years throughout mid-latitude staging areas of the Mississippi Flyway. Mallard ducks are the only type of waterfowl examined in this study. Further, to aid in forecasting of waterfowl migration during autumn-winter this study also tested for a relationship between severity of autumn-winter weather and annual intensity of the El Niño Southern Oscillation (ENSO).

In a typical El Niño year, the polar jet typically remains to the north of the United States. Therefore, the central U.S. and Midwest will experience warmer conditions, while the southern and northeastern U.S. are cooler. The southern U.S. receives more precipitation during the fall and winter seasons. During La Niña years, the autumn and winter seasons bring overall warmer temperatures across the southeastern U.S. The polar jet stream lowers into the eastern U.S., bringing cold, polar air blasts down into the northern half of the Mississippi Flyway (Sellinger 2009). The upper Midwest and southwestern U.S. are dry, while the lower part of the Mississippi Flyway receives more precipitation than normal (Sellinger 2009, $NOAA_2$ 2008, O'Brien 1997).

The relationship between waterfowl migration and autumn-winter weather events will aid in demonstrating the effect winter weather severity has on mallard migration. Then, by comparing the fifty year trend in severity with ENSO events, it can be determined what type of relationship exists between ENSO and waterfowl migration. Information resulting from this study will improve our understanding of waterfowl migration and aid in proper distribution of funds to conserve and manage waterfowl habitat.

Objectives and Hypotheses

Objectives

1. Aid in the development and evaluation of models to predict large-scale migration of waterfowl during fall-winter
2. Using model(s) developed in Phase 1, determine if timing and severity of autumn-winter weather events in the Mississippi Flyway have changed from 1949-50 through 2007-08.
3. Determine if relationships exist between ENSO events and developed autumn-winter severity model(s).

Null Hypotheses

1. Severity of autumn-winter weather events (as they influence duck migration) did not change between 1949-50 and 2007-08 in the Mississippi Flyway of North America.
2. Severity of autumn-winter weather events and ENSO events are not correlated.
3. Autumn-winter severity model(s) are not related to ENSO events.

CHAPTER II

LITERATURE REVIEW

Mississippi Flyway

Migration routes by birds are individual lanes of travel from specific breeding areas to wintering area latitudes. Flyways include multiple related routes (US FWS 2009). In North America four major flyways are recognized: Atlantic, Mississippi, Central, and Pacific Flyways. While separate, the flyways do not have specific borders (Birds and Nature 2001). The Atlantic Flyway extends from Alaska, across the Canadian prairies, and down along the Allegheny Mountains eastward. The Pacific Flyway also extends from Alaska, but continues south along the Pacific coast through Mexico, going as far east as Idaho and Nevada. The Central Flyway occurs across the U.S. between the Rocky Mountains and the Mississippi River, and is also called the “Great Plains” Flyway (US FWS 2009, Birds and Nature 2001). The flyway used in this study was the Mississippi Flyway. The Mississippi Flyway crosses the U.S. from North to South, generally following the Mississippi River. It stretches as far north as Alaska and as far south as Patagonia. Its eastern U.S. boundary begins in Michigan, runs through Indiana to the Mississippi River, and then follows the river to the Gulf of Mexico. The western boundary enters the U.S. in North Dakota but does not have a precise border, and merges with the Central Flyway in eastern Nebraska and western Missouri, tracking along Louisiana to the Gulf of Mexico (Birds and Nature 2001). The Mississippi Flyway contains the longest migration route in the Western Hemisphere (Birds and Nature 2001). With low elevations, plenty of water, and wetland area, this region provides mallards with the ideal habitat (US FWS 2009). Changes in foraging, sanctuary, climate, breeding populations, harvest and harvest distribution, and increased anthropogenic influences are mechanisms that have resulted in mallards wintering at higher latitudes. Some recent studies indicate that more ducks are remaining at these higher latitudes for the winter, or simply not migrating as far south in the LMAV as in previous years (Inkley et al. 2004) (Link et al. 2006, Abraham et al. 2005, Petrie and Schummer 2002, Švažas et al. 2001). However, it should be noted other studies have shown little or no change in waterfowl migratory population (Greene and Kremetz 2008, Otis 2004).

Mallards

Mallards (*Anas platyrhynchos*) are the ancestor of most breeds of duck (Drilling and McKinney 2002). They are a member of the waterfowl family Anatidae, which contains 45 genera and 157 species of ducks, swans, and geese (Digimorph 2009).

Males have a chestnut-colored chest, grey sides, dark brown to black tails, and blue underside wing feathers. Their body is separated from their bright green heads by a white neckband. Females are mottled brown with purple underside wing feathers (NGS 2009, DU, Inc. 2009). Both have yellow bills and coral-red legs and feet. Full-grown males weigh about 2.7 pounds, while females weigh approximately 2.4 pounds, but either sex can grow to be up to 3 pounds (DU, Inc. 2009, NGS 2009, Bellrose 1976). They grow to be 20 to 26 inches long, males on average being a bit longer. Their average wingspan is 32 to 37 inches wide (NGS 2009, Drilling and McKinney 2002), allowing them to fly at speeds of 26 to 60 miles per hour (Palmer 1976). The male emits a softer, raspy grunt while the female is more vocal and emits the louder, repeated quacks (DU, Inc. 2009, NGS 2009, Drilling and McKinney 2002).

Mallard ducks are thought to be the most abundant, and most recognized, duck in the world (NGS 2009, Drilling and McKinney 2002). They are found across Eurasia and throughout the North American continent. They are the most widespread duck in the U.S., the majority of the population residing between the Appalachian and Rocky mountain ranges (DU, Inc. 2009). Their main habitat is made in fields, wetlands, marshes, parks, and forested wetlands. Although the most heavily hunted, they remain the most abundant (Drilling and McKinney 2002). The ducks choose their mates in the fall, courting all winter. The pairs are usually monogamous, but males also pursue other females and sometimes multiple males mate with one female (Drilling and McKinney 2002). Mallards breed in the summer months at higher latitudes. Their breeding ground extends across the northern U.S., Canada, and Alaska, making it one of the most extensive breeding ranges of any duck in North America (DU, Inc. 2009, Drilling and McKinney 2002). The prairie pothole region of Saskatchewan, Alberta, Manitoba, and North Dakota provides the most ideal conditions for breeding and holds the highest population density of mallards during the summer (DU, Inc. 2009, NGS 2009, Drilling and McKinney 2002). The nest is made in tree holes or nest boxes, or in a depression scraped in the ground. It will usually be within 100 meters (330 feet) of water, and lined with vegetation and down from the breast of the female (DU, Inc. 2009, Drilling and McKinney 2002, Bellrose 1976). After the female lays the eggs the male leaves. Incubation lasts 23 to 30 days, and the eggs are a cream to light green buff color. The clutch size can be up to 13, but the average is 9 (DigiMorph 2009, DU, Inc. 2009, Drilling and McKinney 2002). After 26 to 28 days, the chicks hatch, and leave the nest approximately 13 to 16 hours later. They are independent anywhere from 52 to 72 days after hatching (Drilling and McKinney 2002).

Mallards are considered omnivores, their diet on land consisting of insects and larvae, acorns, grains, seeds, and plants. They also eat aquatic plants, such as bulrushes, pondweeds, and saw grass. Approximately ninety percent of the mallard's diet is vegetable material (Palmer 1976, Martin et al 1961, Bent 1923). The other ten percent is animal material, and includes insects and larvae, small fish and their eggs, and aquatic invertebrates which they upend in the water to catch (NGS 2009, Drilling and McKinney 2002, Palmer 1976).

About 32 to 45 percent of chicks die their first year (Drilling and McKinney 2002). On average, mallards only live one-and-a-half to two years, rarely living longer than five (Palmer 1976). While there are waterfowl diseases, the most likely cause of mortality is shooting by hunters. Nest failure is also common, whether by destruction or predators. Typical destruction is caused by mowing, flooding, and plowing of the nest. Predators include skunks, rats, coyotes, raccoons, opossums, gulls, crows, and magpies (Bellrose 1976). The mallard population is closely monitored by wildlife agencies and there are ongoing conservation projects (DU, Inc. 2009, NGS 2009, Drilling and McKinney 2002).

Climate

Climate is defined by the Intergovernmental Panel on Climate Change (IPCC) as the "average weather," or "the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years" (IPCC 2001). The typical period used by the World Meteorological Organization is thirty years.

Climate elements include surface temperature, precipitation, and wind (AMS 2009). The climate of a specific location is determined by its' latitude, terrain, elevation, proximity to mountains and oceans, surface cover, and surface meteorological components (AMS 2009). There are three main schemes to classify climate types. Wladimir Koeppen developed the Thornthwaite classification in 1948. It uses the concept of evapotranspiration to monitor the portion of precipitation over a certain location used for vegetation (Thornthwaite 1948). The second type is the Köppen classification, which divides climate zones based on the vegetation type (McKnight and Hess 2000). The third major scheme is the Bergeron classification. It describes air mass movement using three letters which correspond to moisture, thermal characteristics, and stability of the air mass (AMS_2 2009). The Spatial Synoptic Classification system is based on the Bergeron classification (AMS_2 2009).

The climate of the Mississippi Flyway in North America is considered subarctic across Alaska and Canada, meeting humid continental across the northern 2/3 of the U.S., with the lower 1/3 being humid subtropical. Subarctic climate is characterized by little precipitation, continuous permafrost, and six months of temperatures below freezing (Ritter 2006). Humid continental is found in the mid-latitudes. It has variable weather patterns and markable seasonal temperature differences (Ritter 2006). Humid subtropical is located between twenty and forty degrees from the equator and does not have as much seasonal temperature variance as humid continental. These locations receive their rainfall from storms moving east across the continent and tropical cyclones (Ritter 2006).

In knowing the definition of climate, then climate change can be understood as a statistically significant change from the average, for at least a decade (IPC 2001). The American Meteorological Society (AMS) states that climate change may be due to natural forces, such as a change in solar emission or the climate system processes, or due to human activity (AMS 2009). The United Nations Framework Convention on Climate Change goes a step further, attributing climate "change" to human activities and uses the term climate "variability" for changes in climate due to natural causes (IPC 2001).

In the last 100 years (1906-2006), mean global temperature has risen by approximately 0.74 °C according to the IPCC (IPCC 2007), or by about 1.3 °C according to NOAA (EPA 2009). Also, the warmest eight years since 1850 have all occurred in the last decade, 2005 being the warmest of those eight (EPA 2009). Changes are evident in North America, as long-term climate data show rising temperatures and reduced snow cover across much of the continent (Johnson et al. 2005, Houghton et al. 2001). Studies have shown that between 1955 and 2005, the annual mean air temperature increased across North America, with the highest increases occurring in winter (Hengeveld et al. 2005; Karl et al. 1996, 2005). Statistics such as these provide scientists with evidence of global warming. The U.S created a policy in 2002 in order to address the subject of climate change and to reduce the amount of greenhouse gases emitted by humans, which is believed to increase the rate at which the earth warms. The strategy consists of three components: “slowing emission growth; strengthening science, technology, and institutions; and enhancing international cooperation” (EPA 2009). Global warming can contribute to changes in global climate patterns, which can effect the way everything on Earth lives.

Recent and on-going research suggests that duck migration is correlated to below freezing temperatures and days of snow cover. Therefore, studies are needed to determine how the combined effect of temperature and snow cover has changed over the past fifty years and whether large-scale climate events, such as El Niño Southern Oscillation (ENSO) events, could be related to waterfowl migration.

El Niño Southern Oscillation

El Niño refers to the ocean current bringing warm water from West to East across the Pacific Ocean and occurs every two to ten years (Miller 1999). The other part of the cycle, La Niña, occurs when the ocean current is traveling from East to West across the Pacific Ocean (Miller 1999). ENSO events cause changes in ocean and land temperatures and rainfall amounts in different areas around the world. In a typical El Niño year, the polar jet typically remains to the north of the United States. Therefore, the central U.S. and Midwest will experience warmer conditions, while the southern and northeastern U.S. are cooler than normal. The southern U.S. receives more precipitation during the fall and winter seasons. During La Niña years, the autumn and winter seasons bring overall warmer temperatures across the southeastern U.S. The polar jet stream lowers into the eastern U.S., bringing cold, polar air blasts down into the northern half of the Mississippi Flyway (Sellinger 2009). The Midwest and southwestern U.S. are dry, while the lower part of the Mississippi Flyway receives more precipitation than normal (Sellinger 2009, $NOAA_2$ 2008, O'Brien 1997).

Correlation Between Mallards and Climate

Anecdotal evidence indicates that mallards are wintering at higher latitudes, but although researchers have begun to investigate the correlation, little information currently exists on the relationship between climate and duck migration. It is important to study the relevance of large-scale climate events to duck migration in the Mississippi Flyway because the Mississippi Alluvial Valley is one of the most important wintering areas for mid-continent mallards (MDC 2009).

CHAPTER III

METHODOLGY

Data Collection and Summary

Waterfowl data was obtained from the Missouri Department of Conservation (MDC). MDC conducts aerial or ground surveys every two weeks from October through early January, although survey dates may deviate due to weather or staffing issues. The Julian date will be used to organize the migration patterns. The study examined count data from 1995 through 2005, and locations where data does not exist for the full study period were eliminated. The meteorological data was collected from the United States Historical Climatology Network (HCN). Minnesota, Iowa, Missouri, Wisconsin, and Illinois were divided into three equal sections based on latitude. The HCN station closest to the middle latitude of each section was chosen to collect weather data from, provided a complete data set exists for the data needed. If the data set is incomplete, the nearest station will be used, alternating North or South of the original. Daily snowfall, snow depth, and mean temperature were found for each station from October 1949 through February 2008. A formula of –(mean daily temperature in °C) + number of consecutive days of mean temperature < 0 °C + snow depth in cm $* 0.394$ + number of consecutive days ≥ 2.54 cm of snow produces a waterfowl weather severity index (WSI) capable of predicting autumn-winter dabbling duck (*Anas* spp.) migration (Schummer et al., *unpublished manuscript*). A negative was placed infront of the mean daily temperature in order to ensure that a higher WSI value indicated a higher weather severity. For mallards, the WSI threshold is 7.2, but for this study the number 8 was used for simplification purposes. Therefore, when a WSI value of 8 is reached, local and regional mallard abundance would be expected to decline. The threshold may be reached in multiple ways. First, the WSI could be driven by temperature. For example, if the temperature is -4 °C for four consecutive days and there has not been any snow, the formula would be -(-4) + 4 + 0 + 0, giving a cumulative WSI of 8. Conversely, the threshold may be met having been mainly derived from the snow data. An example of how this may occur is if the temperature is -1 °C for a couple days, 1 inch of snow falls on day 1, and 2 more fall on day 2. This would fit into the formula as -(-1) + 2 + 3 + 2, giving the resulting cumulative WSI a value of 8.

When temperature data were missing a temporal interpolation was employed between two dates for which data exists. If snow depth data was missing, snowfall and temperature data were used to produce an estimate. To estimate snow depth (ESTIMATE) the following criteria were used: 1) If snow depth data was missing, snowfall data was used from the same day at a 1:1 ratio to estimate the snow depth, unless, 2) the snow depth was greater than zero on the day preceding the day with missing snow depth data, then the snowfall of the current day was added to snow depth of the preceding day to estimate snow depth, however, 3) if mean daily temperature was >0ºC on the day with missing snow data, it was assumed the snow had melted and the snow depth was estimated as zero. Potential bias in snow depth estimates was tested by randomly selecting 200 existing snow depth data points (ACTUAL) and used a paired t-test to compare ACTUAL to ESTIMATE (df = 199, p = 0.5, *r* = 0.97) (Schummer et al., *unpublished manuscript*).

It should be noted that when discussing a specific winter season, it is described using the year that season ended (i.e. the season of 1950 includes October 1949 through February 1950).

Objective 1: Trend analyses of the waterfowl weather severity index (WSI) during autumn-winter 1950 through 2008

The daily WSI was calculated, as well as the monthly mean WSI and maximum WSI for each of the fifteen weather stations, October through February, 1950 through 2008. Long-term (1950-2008) and decadal trends in mean WSI and maximum WSI for each station on a monthly basis were examined. Further, the departure from the long-term WSI mean for each period for each weather station was found to determine if frequency of severe weather events had changed for each month (October – February). The monthly and annual average WSI values were also found. Using departure from mean (Figs. 5-9), the severity change can be seen by examining the departure from the normal curve for each month. Therefore it was determined how the severity of weather has increased or decreased in the past fifty years. Also the station ID number, its' latitude and longitude, and the daily WSI for each month were plotted in GIS creating maps showing the monthly average WSI by year from 1950-2008 (Figs. 1-4). ArcMap was then used to produce a line depicting the latitude of when the WSI is equal to 8 by month November through February. An October map was not produced because the WSI 8 line did not appear on the October map; it was too far to the North. A chart was made of the percentage of days by decade by month when the WSI was 8 or above for each of the fifteen stations (Tables 1-5). Also, for each month the years were ordered by average WSI, then being divided into a top quarter, a middle half, and a bottom quarter, creating quantile tables (Table 6). Graphs were also made from these charts for visual effect (Figs. 10-13).

Objective 2: Annual timing of Mallard weather severity index threshold (Mallard WSI)

It is already known from previous research that the Mallard WSI threshold (when egress of waterfowl to southern latitudes occurs) is 8 (Schummer et al., *unpublished manuscript*). A trend analysis was completed for Mallard WSI to see how the date when the WSI is reached has changed for each station in the past fifty years. The most visual indicator of how the timing of the WSI for mallards has changed is seen in the ArcMaps. However, the GIS maps show decadal trends, along with the table of percents. Specific years can be examined in the quantile tables and in the departure from mean graphs.

Objective 3: Relationship between WSI and ENSO events during autumn-winter 1950 through 2008

ENSO was designated into three categories based on the Oceanic Niño Index (ONI): neutral, negative (La Niña), and positive (El Niño). The ONI used was the average for December, January, and February, because they are the most important months in the study examining the mallard's movement. A table (Table 7) was created showing the WSI verses the ONI for each year. The ONI and WSI were then graphed in a scatterplot (Fig. 14). While NOAA assumes the neutral zone of the ONI to be between

-0.5 and 0.5, after visually assessing the graph more of the outlying points near zero can be captured in the neutral zone if the arbitrary neutral zone is expanded. For this study, it was assumed regarding the ONI that La Niña is considered less than -0.7, El Niño is considered more than 0.7, and in between -0.7 and 0.7 is neutral. An analysis of variance (ANOVA) test was run (Table 8) (dF = 1, F = 5.62, p = 0.03), proving there is a difference among means if the neutral zone is between -0.7 and 0.7.

CHAPTER IV

DISCUSSION

Mallards

As stated previously, it is assumed that individual mallards migrate southward because the abundance of mallards begins to decline beyond a threshold of 8 (Schummer et al., *unpublished manuscript*). It is known that mallards are omnivores, their diet consisting mostly of plants, seeds, and insect larvae. They forage by grazing on land or up-ending in shallow waters. Also, they nest near open water in order to provide their young with access to food. If adequate amounts of food and open water are available, the ducks have no reason to leave. Mallards will remain at higher latitudes until it becomes more energetically costly to stay rather than migrate southward (Alerstam 1990, Newton 2007). In the Mississippi Flyway, however, all mallards must migrate southward at some point during the winter season, as cooler temperatures and snow cover cause food and open water to diminish. This usually occurs from November to January, depending on the latitude at which the mallards originate. As temperatures drop below freezing shallow water begins to freeze. The precipitation type will also change from rain to snow, covering any of the food that may still be available. Without food and open water, the mallards will migrate southward. For this reason, the WSI is calculated using temperature and snow depth, and the number of days each occurs consecutively. Using the formula described previously in Methods, this study used a WSI of 8 to determine when mallards leave a location.

Climate

It was found that there is a large amount of variability in the climate between decades. Overall, the 1970's were found to be cooler, while the 2000's tended to be a bit warmer than normal. This is evident on the maps created in ArcMap (Figs. 1-4), the table of the percents by stations (Tables 1-5), the departure from mean graphs (Figs. 5-9), and the quantile distributions (Table 6, Figs. 10-13).

First, the maps give a visual view of the decadal monthly average WSI. Since the line represents the threshold point of winter severity at which mallards' abundance begins to decrease locally, it can be assumed that the weather is more severe above, or to the north, of the line than below, or to the south, of the line. Therefore, if the WSI 8 line is pushed more to the south, the severe winter weather is therefore pushing the mallards further south as well. As previously stated, the variables which have the most effect on the mallards leaving an area are the temperature and snow depth, and the number of consecutive days temperatures are below freezing and/or there is an inch or more of snow cover. As would be expected, the WSI 8 line moves toward the south throughout the fall/winter season, located too far north to appear on the map in October. The 1950's, black, line begins in November in southern Minnesota, moving to mid-Iowa in December, then to almost central Missouri in January, before moving back North to northern Missouri in February. In comparison to the other decades, this line did not differ as much in latitude throughout the season. This would indicate long winters in that

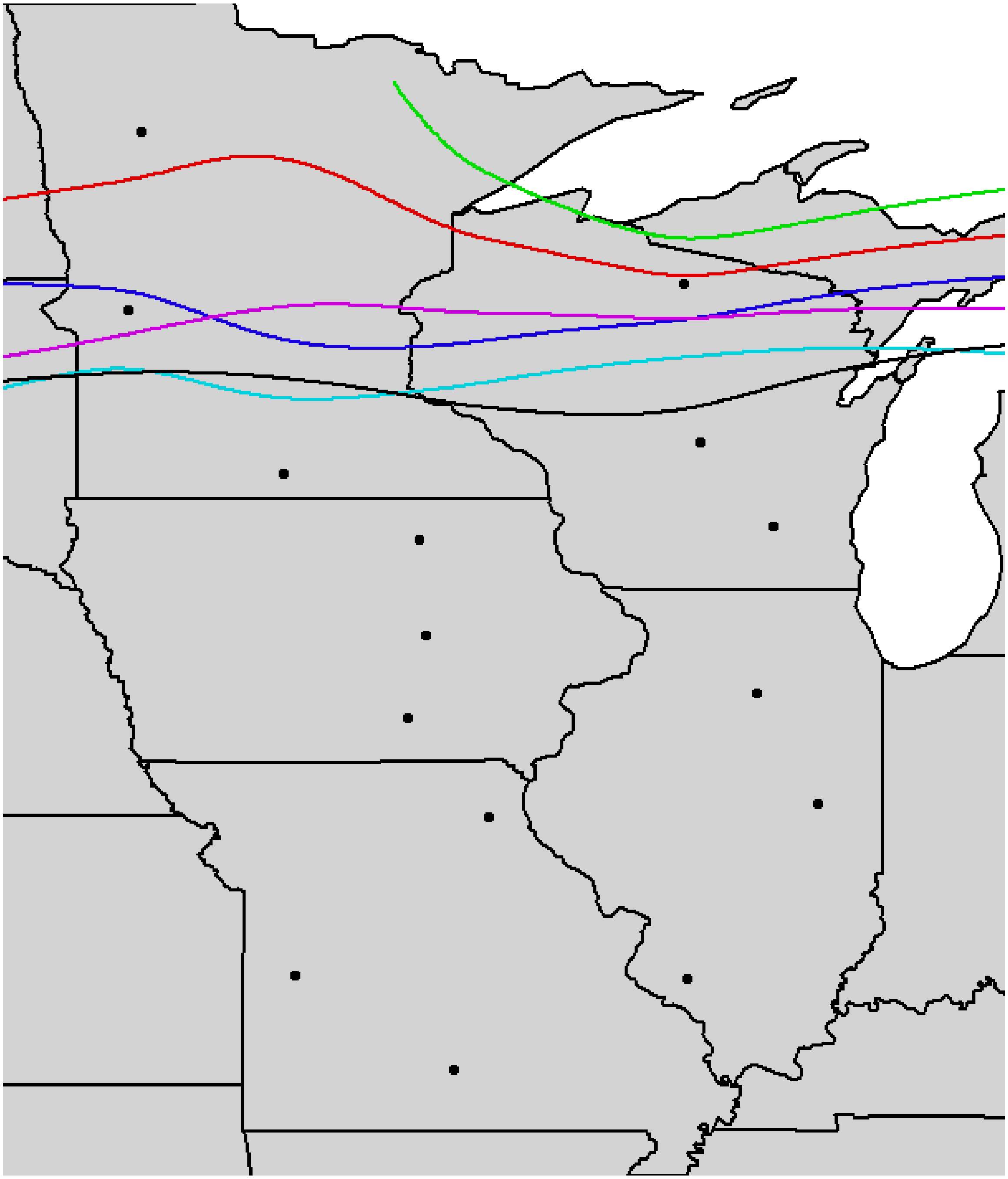

Figure 1 Average Latitude of Threshold WSI for Mallards in November by Decade, 1950-2008

1950's – black, 1960's – green, 1970's – pink, 1980's – blue, 1990's – aqua, 2000's – red

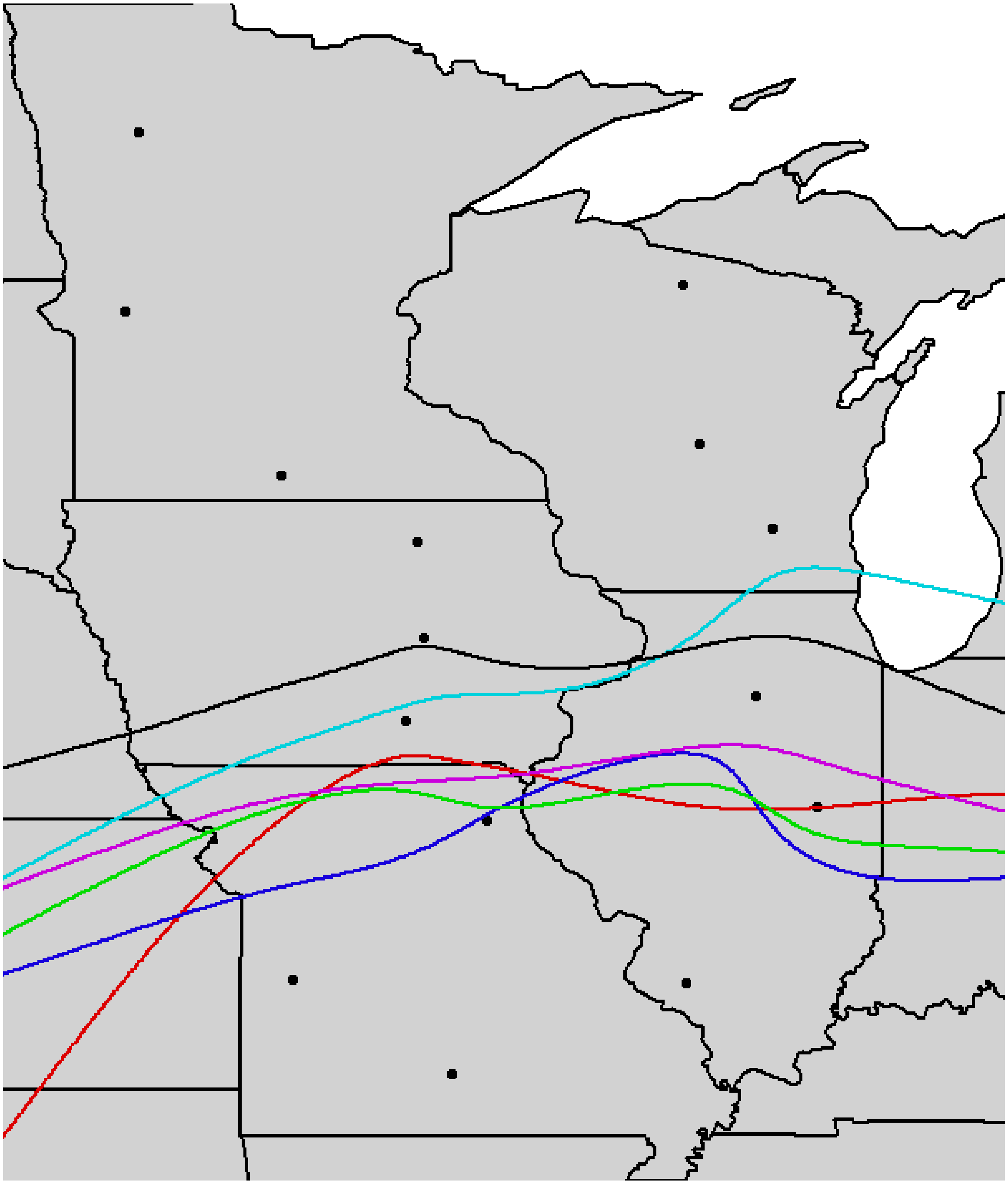

Figure 2 Average Latitude of Threshold WSI for Mallards in December by Decade, 1950-2008

1950's – black, 1960's – green, 1970's – pink, 1980's – blue, 1990's – aqua, 2000's – red

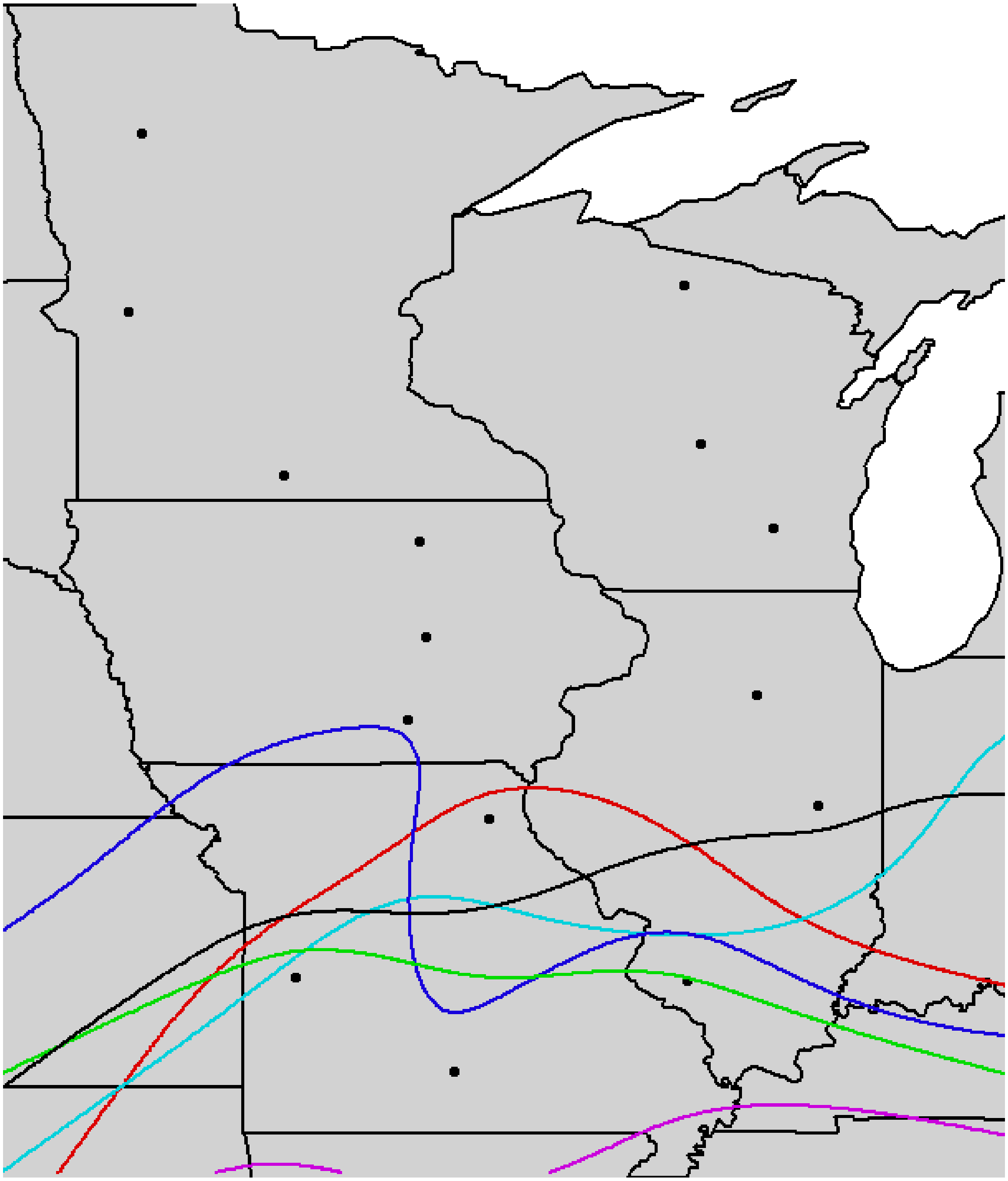

Figure 3 Average Latitude of Threshold WSI for Mallardsin January by Decade, 1950-2008

1950's – black, 1960's – green, 1970's – pink, 1980's – blue, 1990's – aqua, 2000's – red

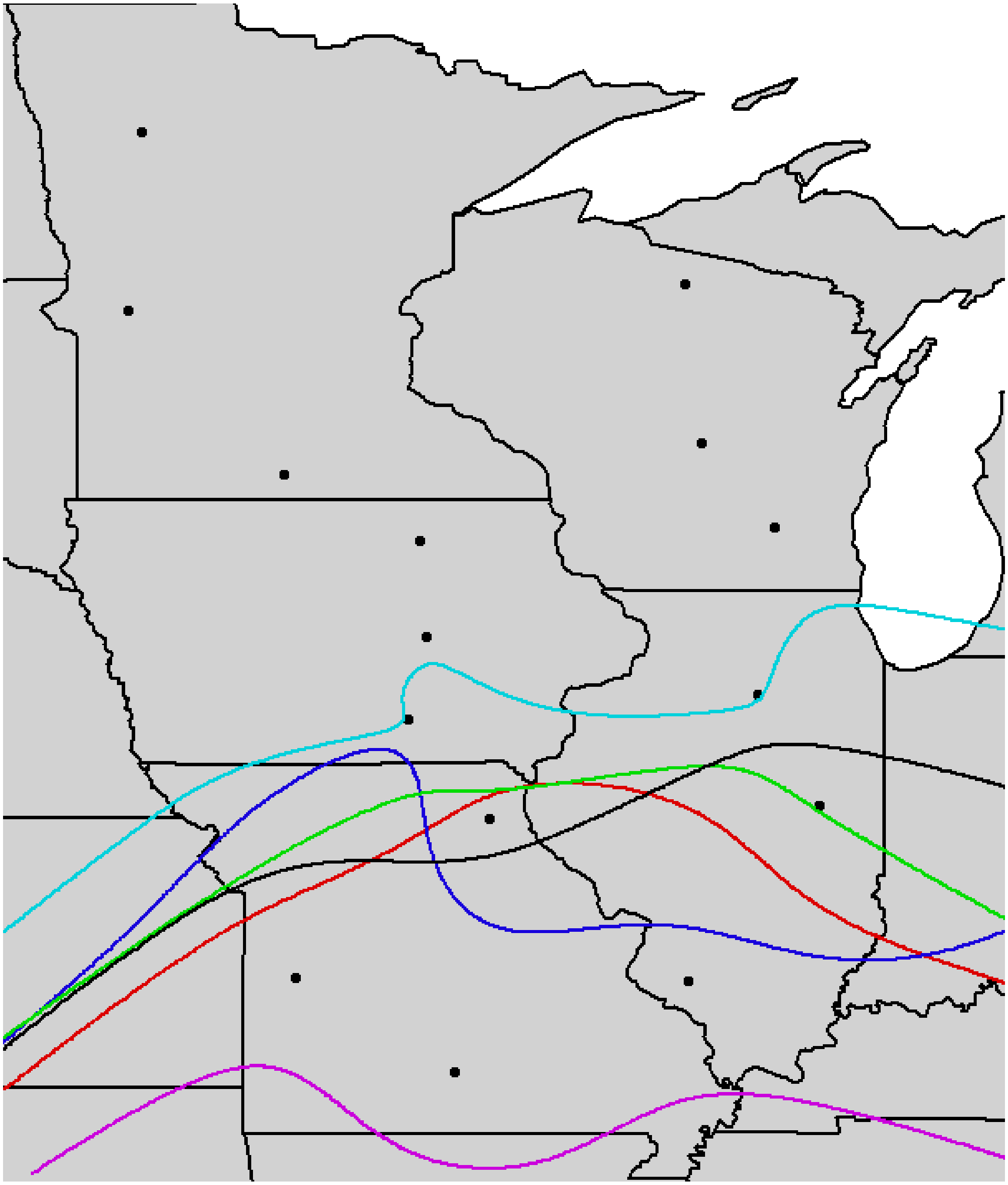

Figure 4 Average Latitude of Threshold WSI for Mallards in February by Decade, 1950-2008.

1950's – black, 1960's – green, 1970's – pink, 1980's – blue, 1990's – aqua, 2000's – red

decade and that there was not as much variation among months in the severity of the winter weather throughout the 1950's, especially compared to the 1970's, where the weather severity greatly increased during the season. The 1970’s, pink, was another long-winter decade. Although the line moved from central Minnesota in November to northern Missouri in December, it then moved further South to southern Missouri/northern Arkansas for January and February. The line stays near the middle or far to the south compared to the other decadal lines. Therefore, since the line represents a declining number of ducks to the north of that latitude, in that decade it was much more likely to have mallards living at lower latitudes compared to other decades. The 1960’s, green, also stayed relatively farther to the south, trending more towards the north in January and February, possibly indicating a relatively early but short winter. The other most notable trend is the location of the red and aqua lines, representing the two most recent decades. The aqua line, representing the 1990’s, begins in southern Minnesota, moving south to mid-Missouri, until moving back towards the north (mid-Iowa) in February. In February, it is by far at the highest latitude compared to the other decadal lines. The 2000’s line, red, begins in northern/mid-Minnesota and moves into northern Missouri, staying at relatively the same latitude for January and February. This would suggest that throughout the past decade it has stayed warmer longer into the season, and over the past two decades the severe winter weather period has been shorter and that winters have been ending earlier than in previous decades included in this study. These results correlate well with the table of percents.

The tables of percents by stations lists the exact percentage of days in each month when the WSI was 8 or above at each station. Since the stations are listed by latitude from the highest to the lowest, it makes sense that the highest percentages of days will also run top to bottom. In examining this table, the 1970’s had very high percentages of days when the WSI was 8 or above. In contrast, a lower percentage of days during the 1990’s and 2000’s had a WSI of at least 8. Therefore, during these two decades mallards may not have been pushed as far south as in past decades.

Table 1

Percentage of days in October with a WSI ≥ 8

Station ID	State	Lat	Long	2000	1990	1980	1970	1960	1950	Mean	00 St. Dev	90 St. Dev	80 St. Dev	70 St Dev	60 St Dev	50 St Dev
212916	MN	47.57	-95.7	3.58	2.58	2.87	2.26	0.36	0.65	2.05	1.53	0.53	0.82	0.21	-1.69	-1.40
475516	WI	45.89	-89.7	5.02	1.94	4.19	2.58	1.29	0	2.50	2.52	-0.56	1.69	0.08	-1.21	-2.50
215638	MN	45.59	-95.9	0.36	1.29	1.43	1.29	0.32	0.32	0.84	-0.48	0.46	0.60	0.46	-0.52	-0.52
473405	WI	44.12	-89.5	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
219046	MN	43.77	-94.2	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
478919	WI	43.19	-88.7	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
131402	IA	43.05	-92.7	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
138296	IA	41.99	-92.6	0	0.32	0	0	0	0	0.05	-0.05	0.27	-0.05	-0.05	-0.05	-0.05
116526	IL	41.34	-88.9	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
130112	IA	41.07	-92.8	0	0.65	0.72	0	0	0	0.23	-0.23	0.42	0.49	-0.23	-0.23	-0.23
118740	IL	40.11	-88.2	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
238051	MO	39.97	-91.9	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
230204	MO	38.21	-94.0	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
118147	IL	38.17	-89.7	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
235834	MO	37.16	-92.3	0	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00

Table 2

Percentage of days in November with a WSI ≥ 8

Station ID	State	Lat	Long	2000	1990	1980	1970	1960	1950	Mean	00 St. Dev	90 St. Dev	80 St. Dev	70 St Dev	60 St Dev	50 St Dev
212916	MN	47.57	-95.7	40.74	73.67	55.42	54	39.67	46.67	51.70	-10.96	21.98	3.73	2.31	-12.03	-5.03
475516	WI	45.89	-89.7	37.41	59.53	50.33	45.33	45.67	45.33	47.27	-9.86	12.26	3.06	-1.94	-1.60	-1.94
215638	MN	45.59	-95.9	28.52	55.67	39.67	45	30.67	38	39.59	-11.07	16.08	0.08	5.41	-8.92	-1.59
473405	WI	44.12	-89.5	14.07	28.67	20.67	26	16	33	23.07	-9.00	5.60	-2.40	2.93	-7.07	9.93
219046	MN	43.77	-94.2	17.78	39.33	32.67	28.33	23.33	33	29.07	-11.29	10.26	3.60	-0.74	-5.74	3.93
478919	WI	43.19	-88.7	6.3	19.63	12.37	14.07	9.33	19.67	13.56	-7.26	6.07	-1.19	0.51	-4.23	6.11
131402	IA	43.05	-92.7	12.59	25.33	25.33	18.67	12.67	25.67	20.04	-7.45	5.29	5.29	-1.37	-7.37	5.63
138296	IA	41.99	-92.6	11.48	17.67	12	16.67	9.69	18.67	14.36	-2.88	3.31	-2.36	2.31	-4.67	4.31
116526	IL	41.34	-88.9	1.85	6.67	1.33	5	4.67	9.33	4.81	-2.96	1.86	-3.48	0.19	-0.14	4.52
130112	IA	41.07	-92.8	5.19	13	7.04	11	7	10.67	8.98	-3.79	4.02	-1.94	2.02	-1.98	1.69
118740	IL	40.11	-88.2	1.85	7	2	5.33	4	10.67	5.14	-3.29	1.86	-3.14	0.19	-1.14	5.53
238051	MO	39.97	-91.9	1.48	4	2.67	6.67	3.33	7	4.19	-2.71	-0.19	-1.52	2.48	-0.86	2.81
230204	MO	38.21	-94.0	0.37	2.33	0.67	3.33	1.03	3.67	1.9	-1.53	0.43	-1.23	1.43	-0.87	1.77
118147	IL	38.17	-89.7	0	1.67	1	3.33	1.33	3.67	1.83	-1.83	-0.16	-0.83	1.50	-0.50	1.84
235834	MO	37.16	-92.3	0	3.33	2.33	4.33	1.33	5.33	2.78	-2.78	0.56	-0.45	1.56	-1.45	2.56

Table 3

Percentage of days in December with a WSI ≥ 8

Station ID	State	Lat	Long	2000	1990	1980	1970	1960	1950	Mean	00 St. Dev	90 St. Dev	80 St. Dev	70 St Dev	60 St Dev	50 St Dev
212916	MN	47.57	-95.7	60.57	63.55	64.84	77.42	59.35	56.13	63.64	-3.07	-0.09	1.20	13.78	-4.29	-7.51
475516	WI	45.89	-89.7	95.34	94.98	98.39	99.03	97.42	97.1	97.04	-1.70	-2.06	1.35	1.99	0.38	0.06
215638	MN	45.59	-95.9	84.95	86.77	89.68	97.42	89.68	89.35	89.64	-4.69	-2.87	0.04	7.78	0.04	-0.29
473405	WI	44.12	-89.5	67.38	80.97	81.29	91.61	76.13	87.1	80.75	-13.37	0.22	0.54	10.86	-4.62	6.35
219046	MN	43.77	-94.2	67.38	85.81	85.16	92.58	73.23	80.65	80.80	-13.42	5.01	4.36	11.78	-7.57	-0.15
478919	WI	43.19	-88.7	58.42	64.52	64.19	80.32	61.61	70.32	66.56	-8.14	-2.04	-2.37	13.76	-4.95	3.76
131402	IA	43.05	-92.7	59.14	81.94	78.06	88.71	66.13	80.32	75.72	-16.58	6.22	2.34	12.99	-9.59	4.60
138296	IA	41.99	-92.6	93.15	93.87	95.16	97.74	94.19	95.16	94.88	-1.73	-1.01	0.28	2.86	-0.69	0.28
116526	IL	41.34	-88.9	46.95	39.35	36.77	53.55	43.55	36.45	42.77	4.18	-3.42	-6.00	10.78	0.78	-6.32
130112	IA	41.07	-92.8	47.67	43.87	41.53	55.81	44.52	47.42	46.80	0.87	-2.93	-5.27	9.01	-2.28	0.62
118740	IL	40.11	-88.2	37.28	30.32	33.87	37.74	39.35	30.32	34.81	2.47	-4.49	-0.94	2.93	4.54	-4.49
238051	MO	39.97	-91.9	30.47	30.65	30.97	39.68	39.03	33.55	34.06	-3.59	-3.41	-3.09	5.62	4.97	-0.51
230204	MO	38.21	-94.0	24.73	20	22.9	13.87	22.26	15.48	19.87	4.86	0.13	3.03	-6.00	2.39	-4.39
118147	IL	38.17	-89.7	20.79	19.68	15.48	17.92	15.48	12.9	17.04	3.75	2.64	-1.56	0.88	-1.56	-4.14
235834	MO	37.16	-92.3	22.58	20	20	16.13	15.48	10	17.37	5.22	2.64	2.64	-1.24	-1.89	-7.37

Table 4

Percentage of days in January with a WSI ≥ 8

Station ID	State	Lat	Long	2000	1990	1980	1970	1960	1950	Mean	00 St. Dev	90 St. Dev	80 St. Dev	70 St Dev	60 St Dev	50 St Dev
212916	MN	47.57	-95.7	95.7	99.35	100	100	100	100	99.18	-3.47	0.17	0.83	0.83	0.83	0.83
475516	WI	45.89	-89.7	99.64	100	100	100	100	100	99.94	-0.30	0.06	0.06	0.06	0.06	0.06
215638	MN	45.59	-95.9	94.98	100	98.06	100	98.71	98.39	98.36	-3.38	1.64	-0.30	1.64	0.35	0.03
473405	WI	44.12	-89.5	83.87	92.26	96.77	97.1	95.48	98.71	94.03	-10.16	-1.77	2.74	3.07	1.45	4.68
219046	MN	43.77	-94.2	88.89	94.19	91.76	100	95.48	96.13	94.41	-5.52	-0.22	-2.65	5.59	1.07	1.72
478919	WI	43.19	-88.7	72.76	80.65	86.45	92.26	80.97	88	83.52	-10.76	-2.86	2.94	8.75	-2.55	4.49
131402	IA	43.05	-92.7	75.27	88.39	93.23	98.06	94.84	94.52	90.72	-15.45	-2.33	2.51	7.34	4.12	3.80
138296	IA	41.99	-92.6	70.61	82.58	78.71	88.71	80.65	76.45	79.62	-9.01	2.96	-0.91	9.09	1.03	-3.17
116526	IL	41.34	-88.9	59	70	64.16	74.84	64.19	55.48	64.61	-5.61	5.39	-0.45	10.23	-0.42	-9.13
130112	IA	41.07	-92.8	62.01	64.84	52.81	76.77	70.65	68.39	65.91	-3.90	-1.07	-13.10	10.86	4.74	2.48
118740	IL	40.11	-88.2	48.03	56.45	61.94	69.35	61.61	41.61	56.50	-8.47	-0.05	5.44	12.85	5.11	-14.89
238051	MO	39.97	-91.9	36.2	54.84	49.35	72.76	59.68	50	53.81	-17.61	1.04	-4.46	18.96	5.87	-3.81
230204	MO	38.21	-94.0	33.33	40.32	35.16	52.9	36.45	27.42	37.60	-4.27	2.72	-2.44	15.30	-1.15	-10.18
118147	IL	38.17	-89.7	30.82	36.13	30.32	54.48	35.48	16.77	34.00	-3.18	2.13	-3.68	20.48	1.48	-17.23
235834	MO	37.16	-92.3	29.39	32.9	39.68	52.9	30.97	19.35	34.20	-4.81	-1.30	5.48	18.70	-3.23	-14.85

Table 5

Percentage of days in February with a WSI ≥ 8

Station ID	State	Lat	Long	2000	1990	1980	1970	1960	1950	Mean	00 St. Dev	90 St. Dev	80 St. Dev	70 St Dev	60 St Dev	50 St Dev
212916	MN	47.57	-95.7	95.92	90.36	95.24	100	98.93	98.21	96.44	-0.52	-6.08	-1.20	3.56	2.49	1.77
475516	WI	45.89	-89.7	100	100	100	100	100	100	100.00	0.00	0.00	0.00	0.00	0.00	0.00
215638	MN	45.59	-95.9	91.67	93.21	89.64	99.29	93.93	97.14	94.15	-2.48	-0.94	-4.51	5.14	-0.22	2.99
473405	WI	44.12	-89.5	90.36	91.79	92.86	97.5	88.93	95	92.74	-2.38	-0.95	0.12	4.76	-3.81	2.26
219046	MN	43.77	-94.2	89.68	81.43	81.75	89.29	92.5	86.43	86.85	2.83	-5.42	-5.10	2.44	5.65	-0.42
478919	WI	43.19	-88.7	84.13	60	70.71	89.64	88.21	78.02	78.45	5.68	-18.45	-7.74	11.19	9.76	-0.43
131402	IA	43.05	-92.7	89.68	85.36	81.79	87.86	87.5	78.93	85.19	4.49	0.17	-3.40	2.67	2.31	-6.26
138296	IA	41.99	-92.6	73.02	49.6	62.86	71.79	79.29	56.79	65.56	7.46	-15.96	-2.70	6.23	13.73	-8.77
116526	IL	41.34	-88.9	59.52	37.86	59.64	55	59.29	37.5	51.47	8.05	-13.61	8.17	3.53	7.82	-13.97
130112	IA	41.07	-92.8	61.51	36.07	50.45	61.07	62.7	46.79	53.10	8.41	-17.03	-2.65	7.97	9.60	-6.31
118740	IL	40.11	-88.2	44.84	27.86	56.07	49.64	47.14	26.43	42.00	2.84	-14.14	14.07	7.64	5.14	-15.57
238051	MO	39.97	-91.9	30.56	22.86	49.29	54.76	42.5	28.57	38.09	-7.53	-15.23	11.20	16.67	4.41	-9.52
230204	MO	38.21	-94.0	20.33	16.43	33.57	32.5	18.93	15.71	22.91	-2.58	-6.48	10.66	9.59	-3.98	-7.20
118147	IL	38.17	-89.7	28.57	10.71	31.07	32.14	20.71	10.36	22.26	6.31	-11.55	8.81	9.88	-1.55	-11.90
235834	MO	37.16	-92.3	18.25	12.14	36.43	29.64	17.14	11.07	20.78	-2.53	-8.64	15.65	8.86	-3.64	-9.71

The departure from mean graphs (Figs. 5-9) also support these conclusions. In creating these graphs, it was found that the 1970's had a very high positive departure from mean. A positive departure from mean represents a more severe winter than average. Therefore, since the 1970's had an unusually high positive difference from the mean, that decade had more winter weather affecting the WSI than normal. While examining decades, it must be understood that there is a large amount of variation between each season, and also each month within each season. These variations are also visibly shown on graphs representing the departure from mean of the monthly WSI for each year. (Negative numbers represent a less severe than average WSI). For example, 2000-2001 was very severe, compared to 2001-2002 which was less severe. It could be thought that the 2001 season was cooler than normal, while the 2002 season was warmer. There are obvious sinusoidal trends in the WSI throughout the decades. However, the timing of the waves has changed. In the past, these cycles swung from more to less than average severe winter weather seasons in approximately 1-3 year trends. This study shows that the most recent decade has longer and overall less severe winters, or warmer than average, trends.

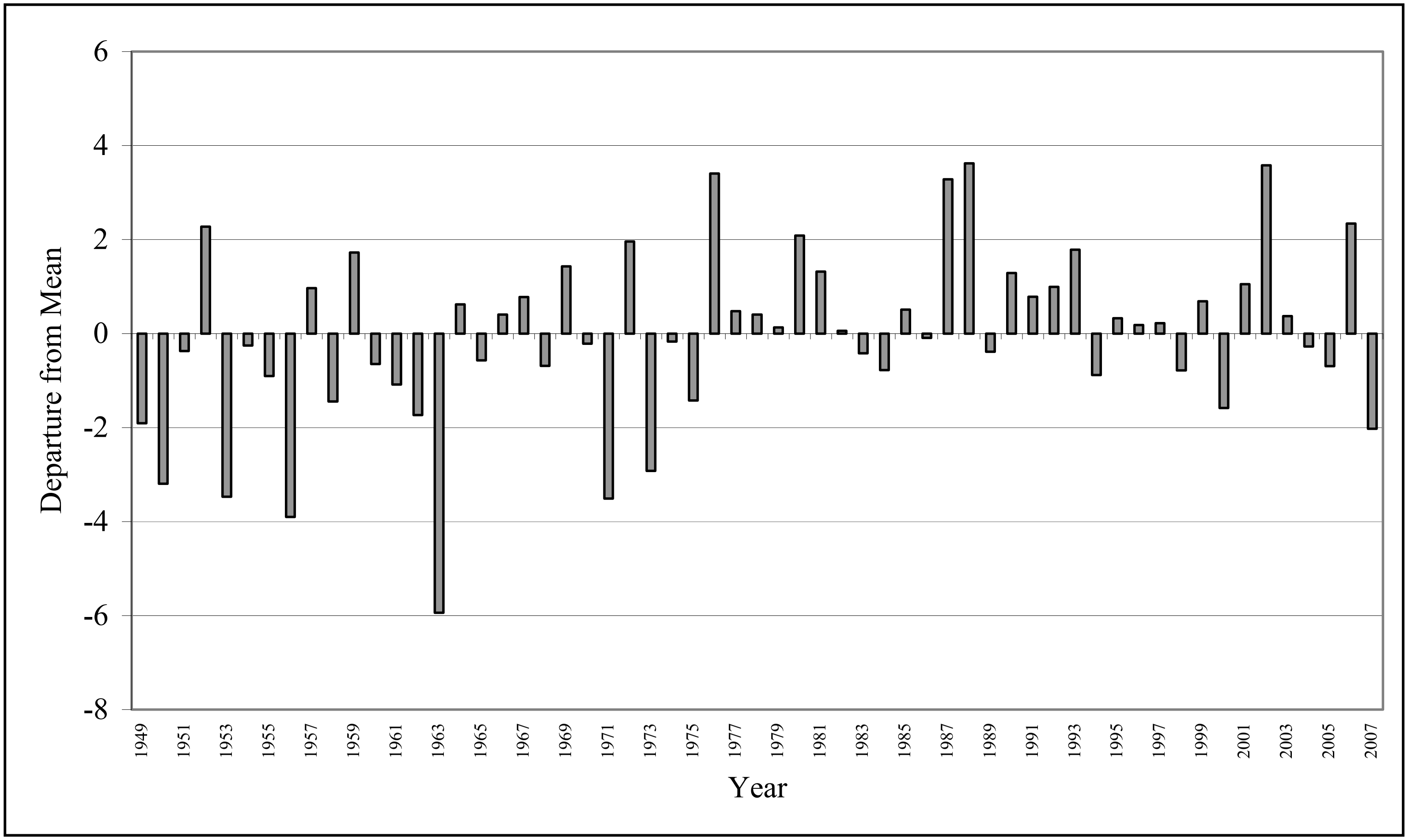

Figure 5 October WSI Departure from Mean, 1950-2008

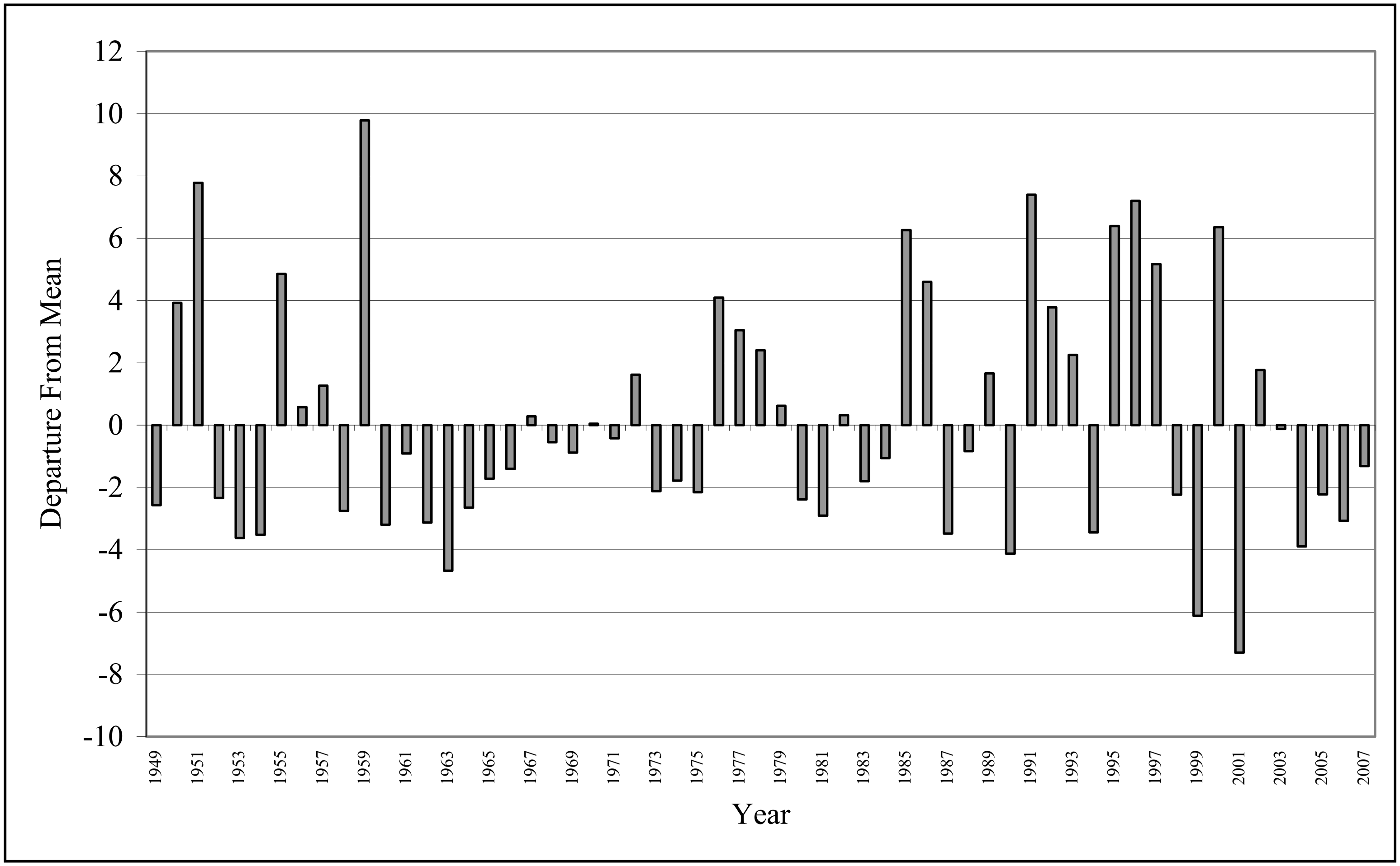

Figure 6 November WSI Departure from Mean, 1950-2008

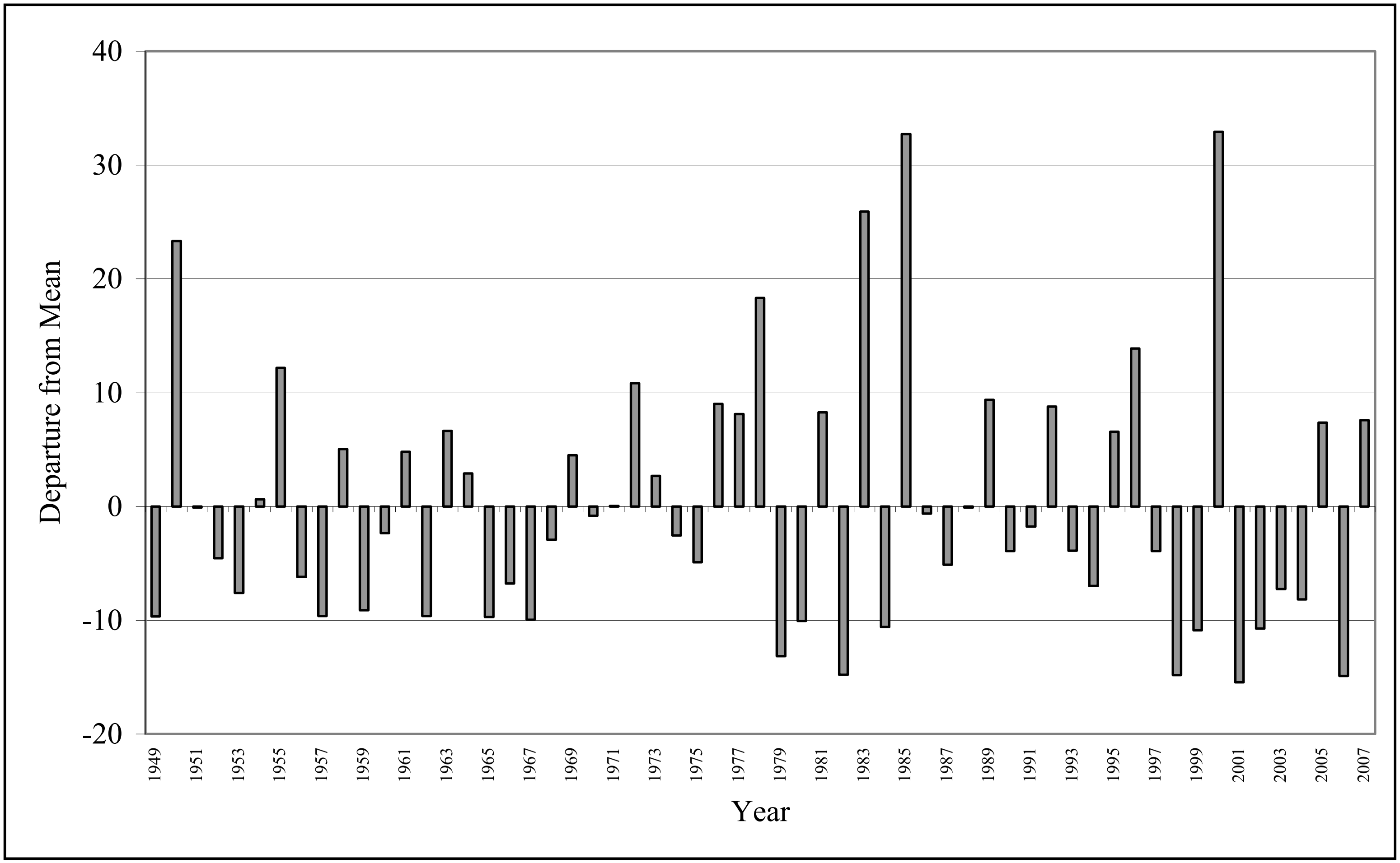

Figure 7   December WSI Departure from Mean, 1950-2008

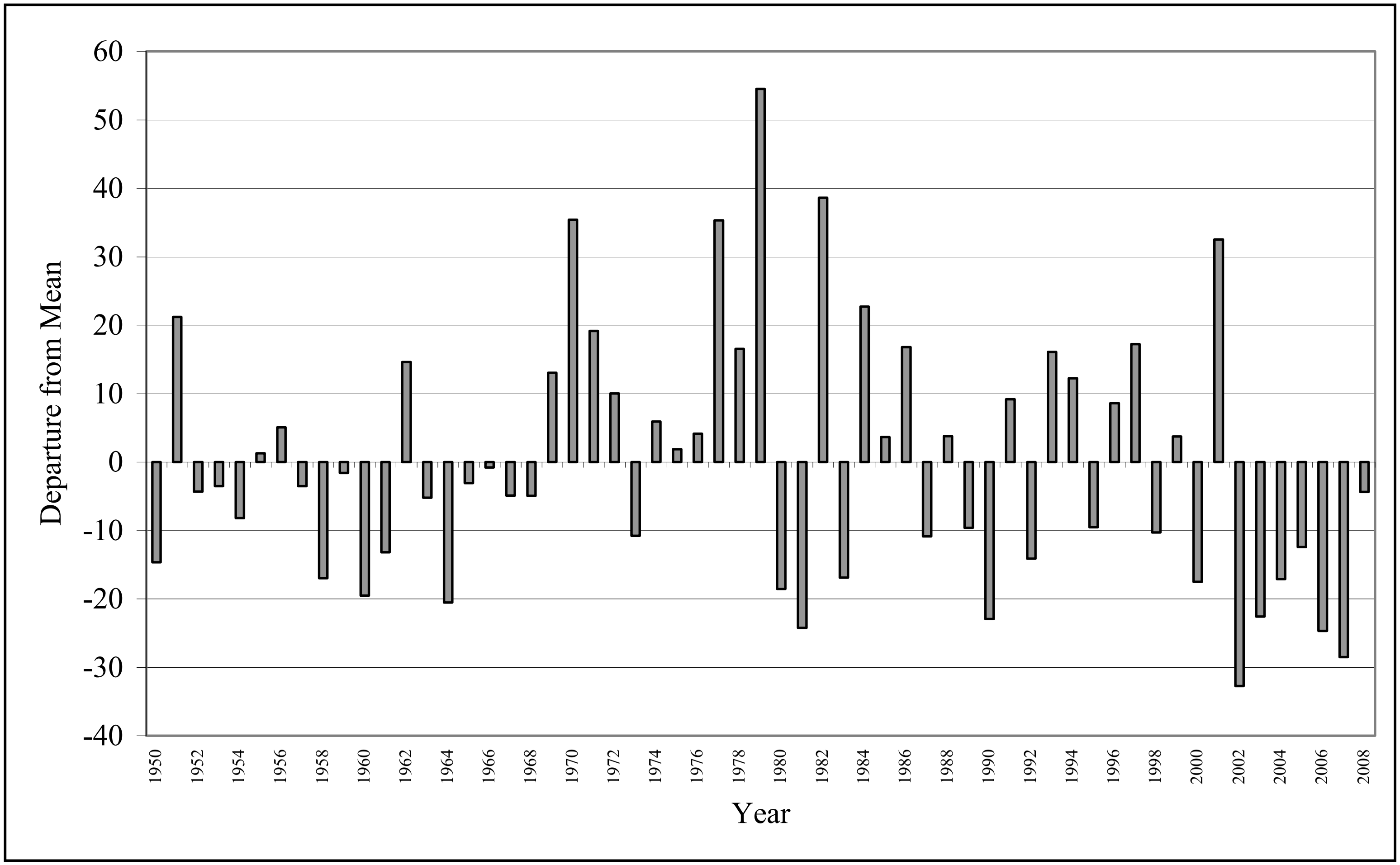

Figure 8 January WSI Departure from Mean, 1950-2008

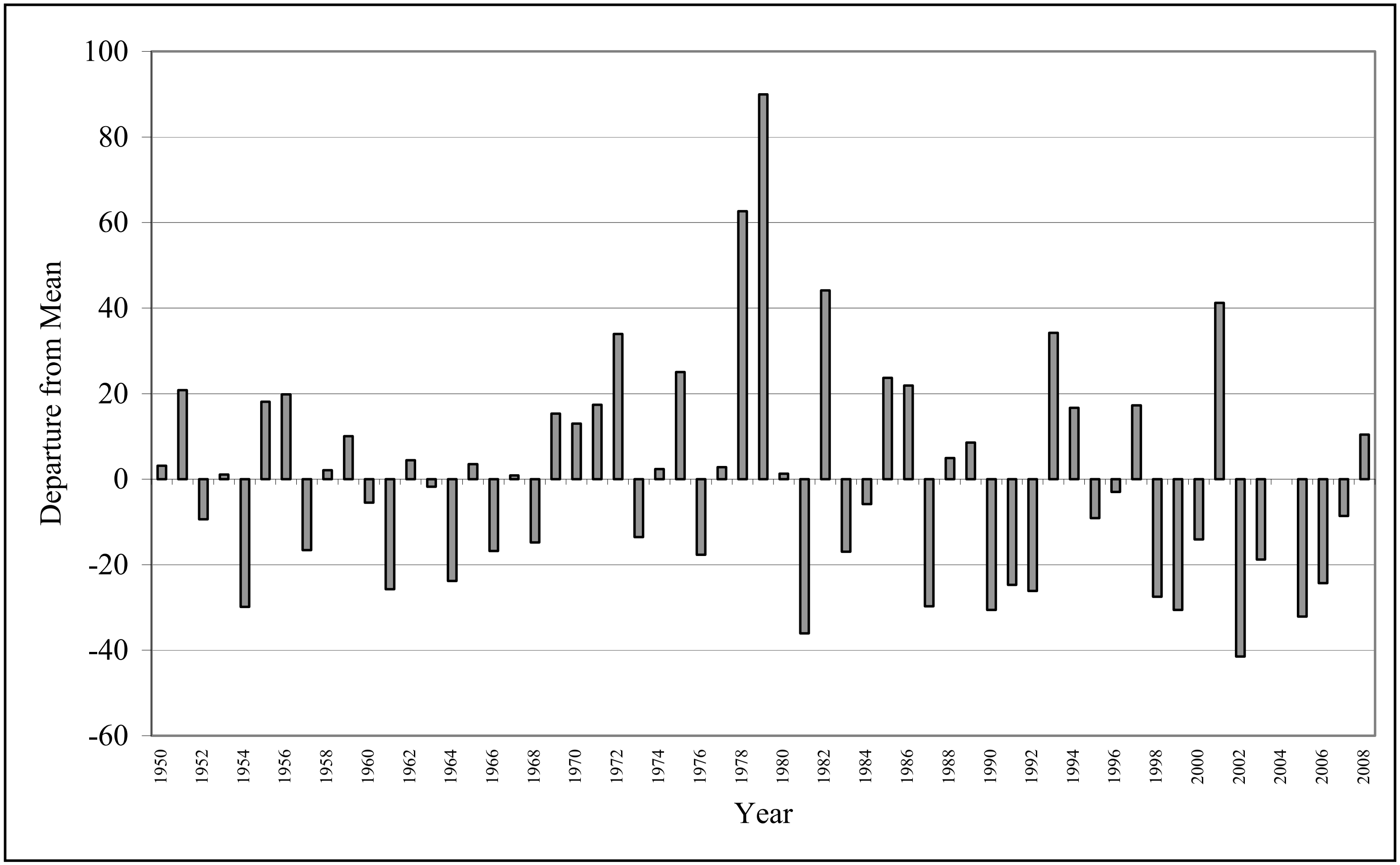

Figure 9   February WSI Departure from Mean, 1950-2008

The quantiles, or north and south tables and graphs are the last example supporting the conclusions reached above. For length purposes, only the table of January was included as an example. The table was divided into the top quarter, middle half, and lower quarter, these divisions represented by bold lines. The stations were ordered from the northernmost through the southernmost, and then the years were ordered by WSI for each station (lowest to highest). The graphs for each month follow, providing a visual representation of how many years had an average WSI of 8 or above for that month for each station. As expected, the most northernmost, located in Minnesota and Wisconsin, had much higher WSI values. Also expected, these stations saw WSI values above 8 earlier in the season than the southernmost ones, located in Missouri and Illinois (Iowa located in the middle). The seasons since, and including, 2000 have occurred quite frequently in the top 25 percent of the lowest WSI values. The 2000 and 2001 seasons occur in the top quarter at 11 stations in October, 15 in November, and 13 in December. The 2007 season also appears at 13 stations in October. In January and February, more of the most recent years appear in the top quarter. During January, each season except 2001 was in the top quarter at 3 or more stations. The obvious years were 2002, occurring at 12 stations; 2006, at 11 stations; and 2007, occurring at 9 stations. In February, each season except 2008 appeared at least once in the top 25 percent. The most notable years were 2005, occurring at 12 stations, and 2002, at 10 stations. Considering a total of approximately fifty years in this study, to have so many recent years occurring in the top quarter is remarkable. Since the years were ranked by the average WSI from lowest to highest, this means that in the top quartile the least severe winter weather was occurring that season. Therefore, it can be concluded that the past eight seasons overall have seen the least severe winter weather in comparison to other decades.

Table 6

Yearly average WSI for each station for January

212916	MN	475516	WI	215638	MN	473405	WI	219046	MN	478919	WI	131402	IA	138296	IA
Year	WSI	Year	WSI	Year	WSI	Year	WSI	Year	WSI	Year	WSI	Year	WSI	Year	WSI
2007	**27.5**	2007	**36.5**	1987	**20.6**	2006	6.0	1990	**13.6**	2006	3.3	2002	**9.4**	2006	4.6
2002	**31.2**	2002	**50.8**	2007	**22.4**	2002	**16.1**	1958	**14.1**	1992	7.3	2006	**11.5**	2002	7.1
1958	**38.5**	2003	**77.4**	2002	**23.6**	2007	**16.3**	1964	**16.1**	1950	7.5	1990	**12.1**	1992	**8.2**
2001	**39.0**	1961	**79.5**	1958	**26.6**	1990	**18.1**	1981	**16.7**	1990	**11.2**	1981	**12.3**	1990	**10.6**
2003	**46.3**	1983	**84.8**	1964	**28.5**	1960	**20.7**	1987	**17.3**	1973	**12.4**	2003	**12.7**	1981	**10.9**
2006	**50.7**	2008	**88.3**	2003	**31.0**	2003	**20.8**	2002	**17.3**	1956	**14.1**	1989	**17.2**	1983	**11.0**
1995	**52.3**	1999	**91.1**	1981	**31.5**	1995	**22.3**	2003	**19.0**	2002	**14.5**	1964	**18.5**	1964	**11.5**
1960	**54.6**	1965	**92.2**	1957	**35.1**	1980	**22.3**	1959	**26.2**	1983	**16.0**	2004	**19.3**	1950	**11.6**
1980	**58.4**	1967	**93.7**	2004	**38.1**	1961	**26.9**	1980	**26.7**	1989	**16.1**	1954	**19.4**	1989	**11.6**
2008	**72.9**	2005	**94.5**	1963	**38.5**	1950	**27.7**	2005	**30.4**	1961	**17.0**	1960	**19.5**	1980	**14.0**
1963	**74.1**	1952	**96.9**	2000	**40.2**	1983	**32.6**	1957	**30.6**	2003	**17.7**	2007	**20.2**	1952	**14.5**
2004	**75.8**	1981	**97.5**	1961	**45.0**	1965	**33.9**	2004	**31.2**	2007	**17.9**	1973	**23.5**	1973	**14.6**
1992	**77.2**	1963	**99.9**	1990	**48.8**	1998	**37.4**	1960	**35.1**	1987	**18.2**	1980	**24.9**	1987	**16.2**
2000	**77.5**	2000	**101.4**	1980	**52.4**	1973	**37.7**	1998	**39.4**	1960	**18.2**	1955	**25.0**	1954	**16.8**
1988	**78.6**	1985	**102.9**	1955	**52.6**	1981	**40.0**	2007	**41.1**	2000	**18.7**	1992	**25.3**	1976	**17.0**
1990	**83.8**	2004	**103.5**	1960	**55.8**	1964	**41.2**	1963	**44.4**	1980	**19.6**	1959	**27.0**	1998	**17.1**
1991	**85.8**	1966	**105.8**	1998	**63.6**	1989	**41.3**	1954	**44.7**	1993	**20.0**	1950	**27.1**	2003	**18.1**
1973	**88.1**	1991	**106.0**	2005	**64.0**	2000	**41.5**	2000	**45.1**	1997	**22.5**	1983	**27.3**	1961	**18.4**
1957	**88.2**	1978	**106.4**	1999	**69.8**	2005	**42.5**	1950	**46.3**	1953	**22.5**	1998	**29.4**	2004	**19.5**
1983	**90.0**	1968	**107.3**	1968	**70.2**	2004	**46.0**	2006	**48.4**	1954	**22.7**	1968	**30.2**	1975	**19.5**
1999	**90.1**	1953	**107.7**	1962	**72.6**	1954	**47.5**	1989	**49.8**	1968	**22.8**	2000	**31.5**	1997	**19.6**
1968	**93.7**	1973	**107.9**	1971	**75.8**	1985	**49.1**	1985	**51.2**	1965	**23.3**	1965	**32.0**	1967	**19.7**
1985	**96.6**	1974	**110.1**	1992	**76.2**	1992	**50.0**	1995	**52.0**	1975	**23.3**	1996	**35.1**	1958	**19.8**
1964	**99.7**	1964	**110.6**	1966	**76.7**	2008	**52.2**	1966	**52.0**	1998	**23.5**	1958	**39.3**	1956	**20.2**
2005	**100.6**	1995	**110.8**	1950	**78.2**	1966	**52.9**	1961	**53.5**	1995	**23.6**	1985	**40.0**	2000	**20.5**
1953	**102.1**	1954	**111.9**	1983	**79.5**	1968	**54.9**	1983	**55.9**	1974	**26.8**	1963	**40.2**	1955	**21.0**
1976	**103.4**	1989	**114.7**	2006	**80.7**	1958	**57.2**	1968	**57.7**	1964	**27.5**	1976	**40.4**	1951	**21.4**
1952	**107.9**	1960	**115.0**	1991	**83.4**	1972	**57.4**	1976	**60.2**	2008	**27.8**	2005	**41.6**	1957	**21.7**
1970	**114.0**	1962	**115.8**	1959	**85.2**	1959	**58.0**	1973	**65.1**	2004	**28.7**	1956	**46.0**	1965	**21.8**
1962	**118.6**	1969	**123.5**	1985	**89.0**	1953	**58.4**	1967	**69.2**	1958	**31.4**	2008	**46.2**	1960	**22.3**
1998	**119.2**	2006	**124.5**	1953	**89.5**	1967	**59.4**	1999	**73.4**	2005	**32.0**	1967	**48.7**	1953	**22.8**
1975	**119.3**	1950	**126.2**	1995	**90.9**	1963	**61.3**	1962	**76.5**	1988	**32.5**	1966	**48.9**	1968	**23.2**
1961	**120.3**	1984	**131.6**	1975	**92.8**	1974	**65.3**	1992	**78.2**	1966	**33.1**	1961	**55.6**	2007	**23.7**
1955	**121.1**	1988	**132.7**	1984	**96.8**	1952	**70.5**	1978	**78.4**	1952	**34.5**	1957	**56.3**	1972	**24.1**
1967	**122.5**	1992	**133.1**	1956	**102.2**	1978	**79.4**	1988	**82.1**	1972	**35.8**	1972	**56.6**	1996	**25.1**
1974	**129.1**	1975	**134.2**	1952	**103.6**	1962	**79.8**	1974	**82.8**	1996	**36.3**	1975	**62.4**	1959	**26.4**
1977	**130.5**	1959	**135.0**	1974	**108.5**	1976	**80.0**	1975	**88.6**	1967	**37.0**	1952	**65.5**	1988	**28.6**
1950	**131.8**	1970	**135.4**	1954	**110.1**	1999	**83.3**	1991	**89.2**	1984	**37.9**	1977	**66.0**	1985	**30.5**
1978	**134.1**	1955	**135.9**	1967	**112.3**	1994	**84.0**	1952	**89.4**	1981	**40.5**	1962	**73.8**	1974	**32.7**
1969	**134.3**	1958	**137.7**	2008	**115.5**	1988	**85.9**	1977	**92.9**	1986	**42.3**	1999	**77.4**	1966	**33.1**
1984	**140.6**	1980	**140.4**	1996	**116.7**	1993	**87.6**	1969	**95.3**	1999	**45.8**	1995	**78.9**	1995	**35.4**
1959	**146.9**	1976	**142.6**	1970	**117.0**	1996	**89.6**	1997	**97.3**	1991	**46.5**	1994	**79.3**	2008	**37.0**
1951	**147.1**	1971	**143.5**	1969	**117.7**	1997	**89.8**	1971	**99.8**	1959	**50.1**	1974	**79.8**	1963	**38.8**
1965	**148.5**	1982	**145.3**	1988	**120.7**	1987	**90.9**	1996	**104.1**	1985	**52.1**	1978	**80.1**	2005	**41.0**
1972	**148.6**	1996	**146.4**	1973	**120.8**	1956	**92.4**	1993	**107.6**	1994	**56.3**	1953	**80.7**	1993	**41.3**
1982	**151.1**	1993	**146.8**	1951	**123.5**	1969	**93.3**	1994	**108.4**	1957	**56.4**	1987	**86.4**	1977	**43.4**
1989	**153.2**	1957	**146.9**	1978	**131.0**	1975	**101.0**	1953	**109.7**	1963	**57.8**	1997	**87.1**	1984	**44.8**
1954	**157.8**	1956	**148.3**	1965	**131.4**	1957	**102.7**	1965	**110.5**	1976	**59.1**	1988	**88.4**	1986	**49.9**
1986	**158.9**	1972	**148.7**	1977	**131.6**	1982	**103.2**	1984	**111.5**	1978	**60.5**	1969	**90.2**	1999	**53.8**
1956	**159.3**	1990	**151.3**	1989	**134.0**	1991	**106.5**	1955	**112.0**	1969	**62.2**	1991	**104.1**	1991	**55.3**
1994	**161.5**	1951	**151.9**	1976	**142.1**	1986	**106.7**	2008	**115.8**	1955	**67.7**	1971	**105.8**	1969	**57.2**
1971	**163.4**	1986	**152.2**	1972	**143.6**	1971	**115.5**	1956	**120.5**	1962	**69.3**	1986	**110.8**	1971	**58.0**
1996	**165.3**	1998	**153.5**	1994	**145.8**	1955	**116.6**	1970	**121.2**	2001	**73.4**	1982	**113.9**	1994	**58.0**
1979	**167.2**	1987	**157.3**	1982	**147.2**	1977	**120.1**	1972	**122.1**	1982	**78.2**	1970	**117.8**	1978	**60.8**
1966	**169.5**	2001	**157.3**	1993	**149.6**	1970	**122.8**	1951	**138.3**	1977	**99.5**	1993	**118.6**	1979	**69.2**
1993	**172.7**	1997	**157.5**	2001	**153.2**	1984	**124.4**	1982	**152.0**	1970	**100.7**	1984	**123.9**	1962	**71.4**
1997	**175.8**	1977	**160.3**	1979	**156.0**	2001	**137.3**	2001	**156.4**	1971	**101.9**	1951	**126.6**	1982	**76.7**
1981	-	1979	**163.7**	1986	**157.7**	1951	**145.0**	1979	**159.4**	1951	**106.8**	2001	**127.5**	2001	**85.5**
1987	-	1994	-	1997	**174.1**	1979	**146.6**	1986	-	1979	**125.3**	1979	**154.6**	1970	**106.2**

Table 6 continued

116526	**IL**	**130112**	**IA**	**118740**	**IL**	**238051**	**MO**	**230204**	**MO**	**118147**	**IL**	**235834**	**MO**
Year	**WSI**	**Year**	**WSI**	**Year**	**WSI**	**Year**	**WSI**	**Year**	**WSI**	**Year**	**WSI**	**Year**	**WSI**
2006	0.3	2006	0.2	2006	-3.0	2006	-4.0	2006	-5.4	1990	-6.2	2006	-5.3
2000	0.8	1990	0.4	1990	-1.8	1990	-3.0	1990	-4.8	1989	-5.0	1950	-4.1
1950	2.4	1989	0.9	1950	-0.3	1989	-2.2	1989	-3.7	2006	-4.6	1952	-3.4
1990	3.1	1992	1.9	1989	1.2	1992	-0.3	1986	-1.9	1950	-3.9	1990	-3.4
1983	3.2	1964	3.7	2002	1.2	2002	0.3	1964	-1.7	1952	-3.5	1953	-3.2
1964	4.2	2002	5.3	1953	2.1	1950	1.1	1953	-1.3	1953	-1.7	1967	-3.0
1975	4.5	1983	7.5	1954	2.8	1986	2.2	1975	-0.8	1967	-1.6	1965	-2.5
1954	4.7	1975	7.5	1998	2.9	1951	3.2	1992	-0.8	1986	-1.3	1964	-2.1
1973	5.0	1981	7.5	1973	3.6	2000	3.2	1967	-0.6	1992	-1.2	1975	-2.0
1989	5.1	1950	7.6	1992	3.7	2005	3.5	1950	-0.5	1951	-0.7	1998	-1.6
2002	5.8	1987	7.6	1975	3.8	1952	3.7	2004	-0.5	1954	-0.6	1951	-1.0
1960	6.6	1998	**11.2**	1967	4.0	1954	3.9	1965	-0.4	2007	-0.6	2005	-0.9
1956	7.0	1972	**11.2**	1952	4.5	1983	3.9	1951	-0.1	2005	-0.5	1992	-0.7
1953	7.2	1976	**11.5**	1983	4.6	1998	4.7	1952	-0.1	1960	-0.2	1955	-0.7
2007	7.2	1980	**12.2**	1986	4.9	2008	4.9	1955	0.1	1955	-0.2	1986	-0.6
1992	**8.2**	1954	**12.3**	1960	5.8	1964	4.9	1954	0.5	2002	-0.1	1989	-0.4
1981	**8.4**	1961	**12.5**	1958	6.4	1975	5.2	1980	0.8	1965	0.7	1958	-0.3
2005	**9.3**	1956	**12.8**	1964	6.5	2004	5.3	2005	1.1	1964	0.7	1972	0.3
1980	**9.9**	2000	**12.9**	1951	7.1	2007	5.4	1983	1.3	1958	0.8	1981	0.5
1965	**10.6**	1988	**13.0**	2007	7.2	1953	5.9	1998	1.5	1973	0.8	1959	0.5
1952	**10.8**	1965	**13.5**	1955	7.7	1967	6.5	1976	2.0	1983	1.0	1969	0.5
2008	**11.1**	1973	**14.2**	1972	**7.9**	1965	7.5	1981	2.1	1998	1.3	1954	0.8
1995	**11.3**	1951	**14.2**	2008	**8.2**	1956	7.6	1960	2.3	1980	1.4	1960	0.8
1972	**12.1**	1993	**14.5**	1980	**8.3**	1980	7.7	2008	2.5	1969	1.9	1980	1.0
1961	**12.3**	1955	**14.7**	2005	**8.6**	1981	**8.1**	1972	2.6	1972	1.9	1976	1.4
1951	**12.6**	1958	**16.2**	1965	**8.8**	1996	**8.1**	1961	2.8	1981	2.5	2002	1.4
1955	**13.5**	1995	**16.4**	1956	**9.5**	1973	**10.0**	2000	2.9	1959	2.6	2004	1.5
1967	**15.1**	2007	**17.6**	1995	**10.1**	1960	**10.0**	2002	3.1	1993	2.7	2008	1.8
1993	**15.6**	1997	**17.9**	2004	**10.2**	1966	**10.2**	1971	3.8	1971	2.7	1971	1.9
1987	**15.7**	1957	**18.2**	1971	**10.7**	1961	**10.2**	1956	4.9	1976	2.8	2007	2.1
1996	**16.0**	1952	**18.5**	1993	**11.1**	1955	**10.5**	1958	5.1	1987	3.0	1961	2.4
2004	**16.8**	1960	**19.1**	2000	**12.9**	1988	**10.8**	1969	5.3	2000	3.2	2000	2.6
1958	**17.3**	2003	**19.3**	1994	**13.5**	2003	**11.0**	2007	5.8	1988	3.4	1999	3.1
1974	**17.7**	2004	**20.4**	1957	**14.6**	1976	**12.3**	1966	6.1	2008	3.8	1995	3.8
2003	**21.0**	1984	**20.6**	1959	**14.8**	1984	**12.6**	1999	6.1	1995	4.1	1957	3.9
1998	**21.0**	1967	**21.4**	1988	**14.9**	1987	**12.8**	1994	6.4	1974	4.2	1993	4.2
1997	**21.5**	1953	**23.0**	1991	**14.9**	1958	**13.6**	1973	6.7	1956	4.6	1963	4.7
1957	**21.8**	1966	**23.4**	1981	**15.1**	1995	**13.9**	1982	6.9	1957	5.1	1956	4.9
1971	**23.2**	2005	**24.0**	1966	**16.8**	1993	**14.4**	1959	**7.9**	1961	5.7	2003	5.2
1969	**24.4**	1996	**24.2**	1996	**17.3**	1957	**14.9**	1996	**7.9**	2004	6.0	1966	5.3
1988	**24.4**	1986	**24.3**	1969	**18.2**	1997	**15.1**	1988	**8.1**	1966	7.2	1973	6.0
1966	**25.5**	1994	**24.3**	1987	**18.3**	1994	**16.5**	1957	**8.7**	1991	7.7	1983	6.4
1959	**25.7**	2008	**24.5**	1961	**18.4**	1968	**16.8**	2003	**9.1**	1984	**8.0**	1994	6.5
1968	**27.2**	1959	**25.3**	2003	**20.0**	2001	**18.4**	1995	**9.3**	1996	**8.1**	1987	6.6
1991	**31.6**	1968	**26.3**	1976	**23.5**	1969	**18.7**	1987	**9.7**	1963	**9.5**	1996	7.1
1985	**31.9**	1969	**31.6**	1997	**25.2**	1999	**19.3**	1970	**10.2**	1982	**9.5**	1974	7.7
1963	**33.2**	1963	**33.2**	1974	**25.4**	1974	**19.4**	1997	**12.1**	1994	**9.6**	1962	**9.0**
1994	**34.6**	1991	**34.1**	1999	**27.7**	1971	**19.8**	1993	**12.4**	1999	**10.4**	1968	**9.4**
1978	**39.1**	1978	**34.4**	1962	**28.0**	1991	**20.1**	1963	**12.8**	2003	**10.6**	1997	**9.6**
1976	**41.8**	1999	**34.7**	1963	**28.3**	1959	**22.2**	1962	**12.9**	1997	**11.6**	1988	**10.6**
1999	**48.2**	1971	**39.6**	1978	**28.4**	1963	**23.2**	1984	**13.9**	1968	**12.0**	1982	**13.0**
1984	**57.2**	1974	**42.5**	1985	**33.5**	1978	**25.8**	2001	**14.6**	1962	**14.3**	1984	**14.4**
1982	**57.3**	1977	**48.3**	1968	**37.1**	1962	**28.3**	1974	**15.3**	2001	**20.5**	1991	**14.7**
1962	**57.4**	2001	**56.6**	1970	**44.1**	1985	**37.8**	1968	**15.3**	1979	**22.1**	2001	**17.4**
1970	**59.3**	1970	**58.8**	2001	**45.7**	1970	**47.3**	1991	**15.9**	1985	**25.0**	1978	**21.2**
1977	**63.3**	1979	**66.4**	1979	**52.5**	1979	**55.8**	1978	**21.1**	1978	**25.7**	1985	**22.8**
2001	**63.4**	1962	**69.8**	1982	**59.9**	1977	**56.1**	1985	**21.3**	1970	**27.8**	1970	**26.3**
1979	**78.0**	1982	-	1977	**64.4**	1982	**59.7**	1979	**42.2**	1977	**46.2**	1979	**36.5**
1986	-	1985	-	1984	**80.4**	1972	-	1977	**43.2**	1975	-	1977	**42.2**

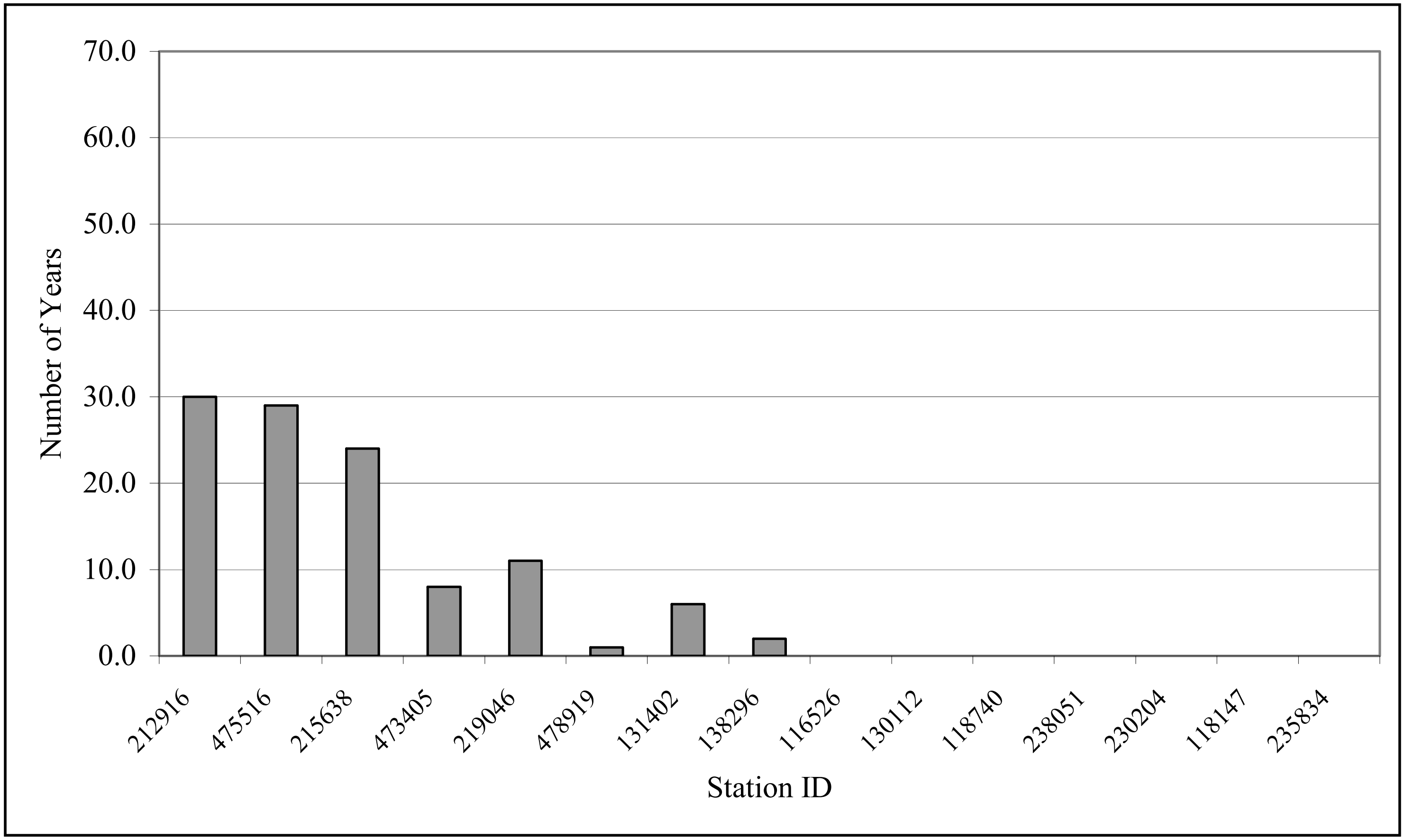

Figure 10 November Years of WSI ≥ 8 for Each Station, 1950-2008

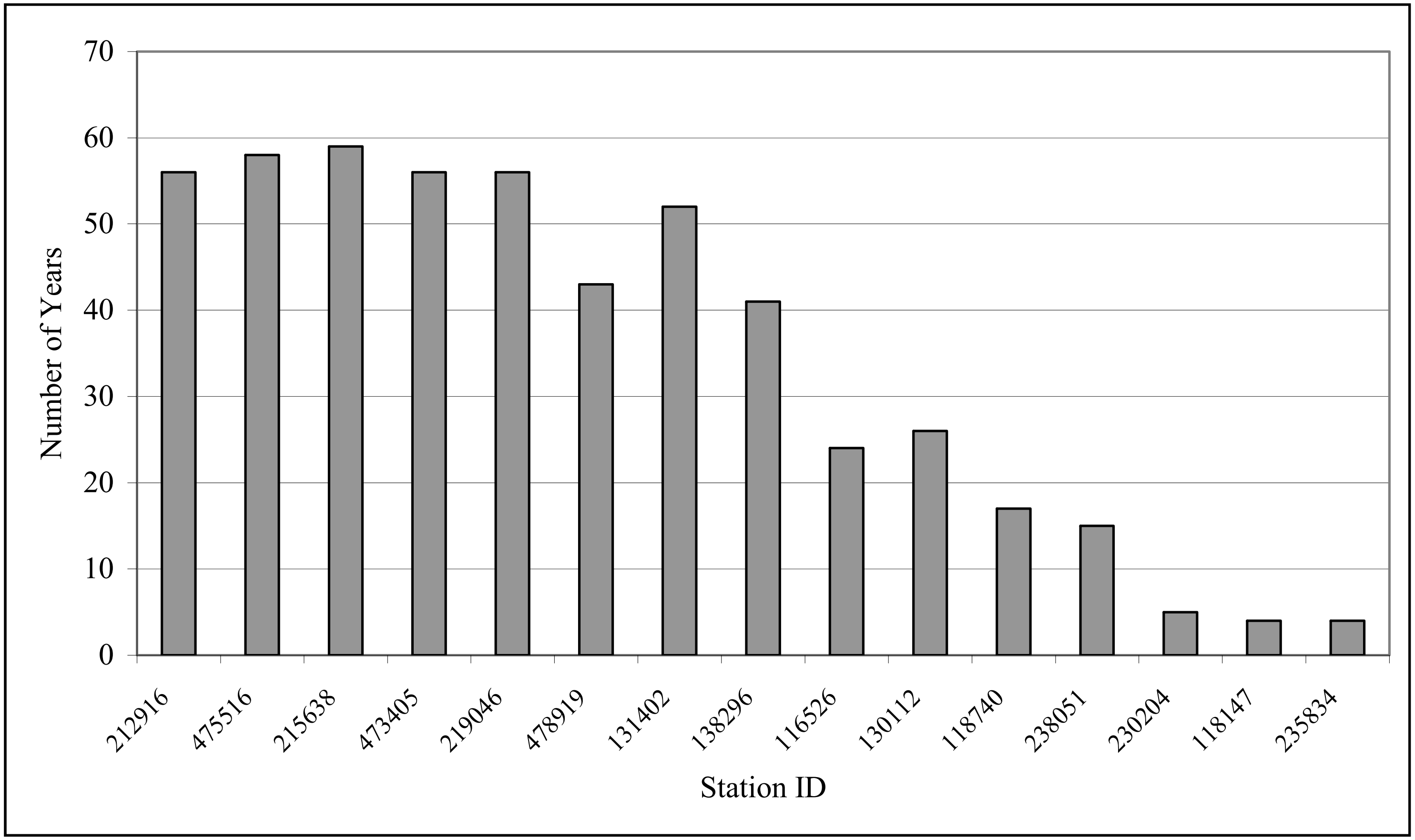

Figure 11 December Years of WSI ≥ 8 for Each Station, 1950-2008

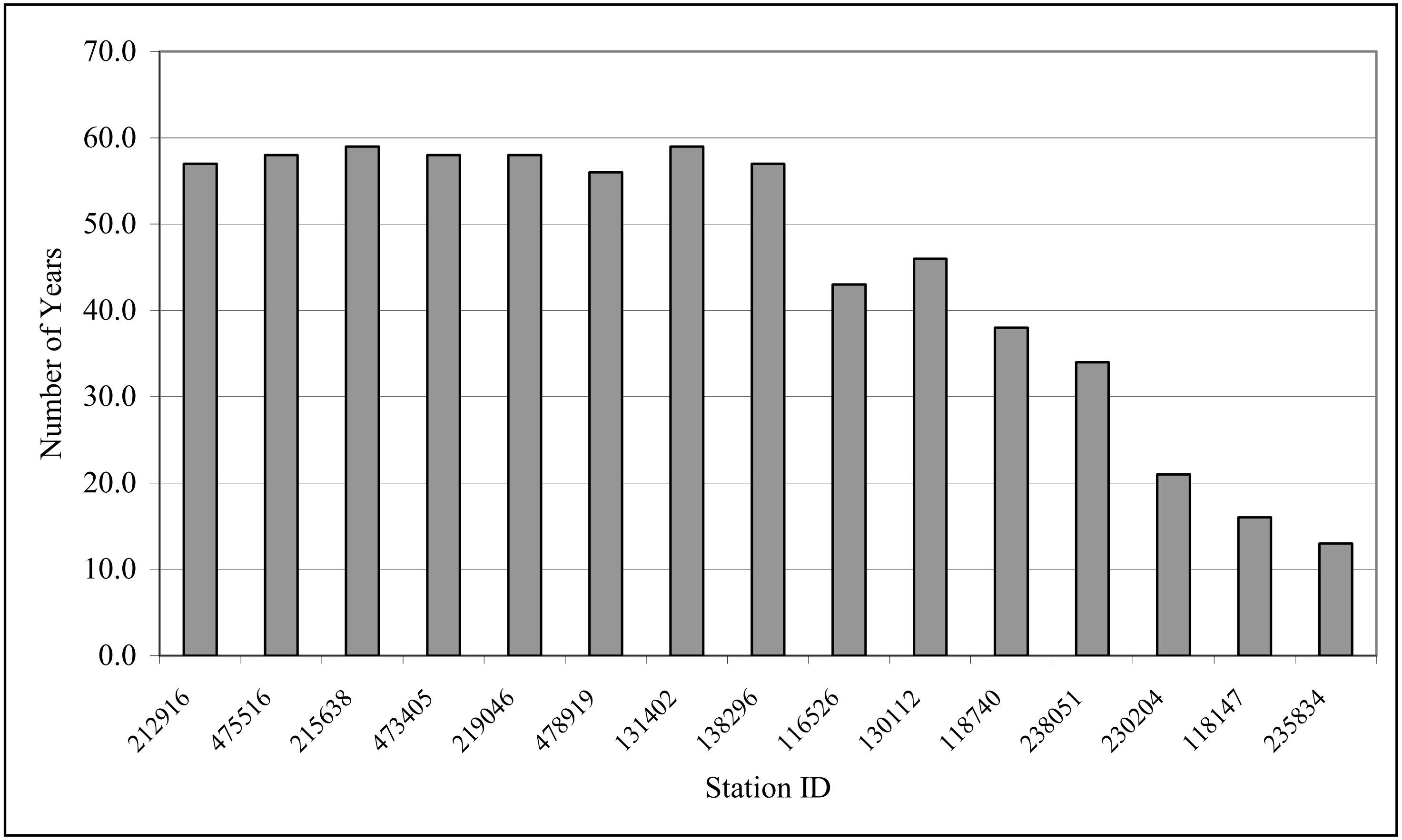

Figure 12   January Years of WSI ≥ 8 for Each Station, 1950-2008

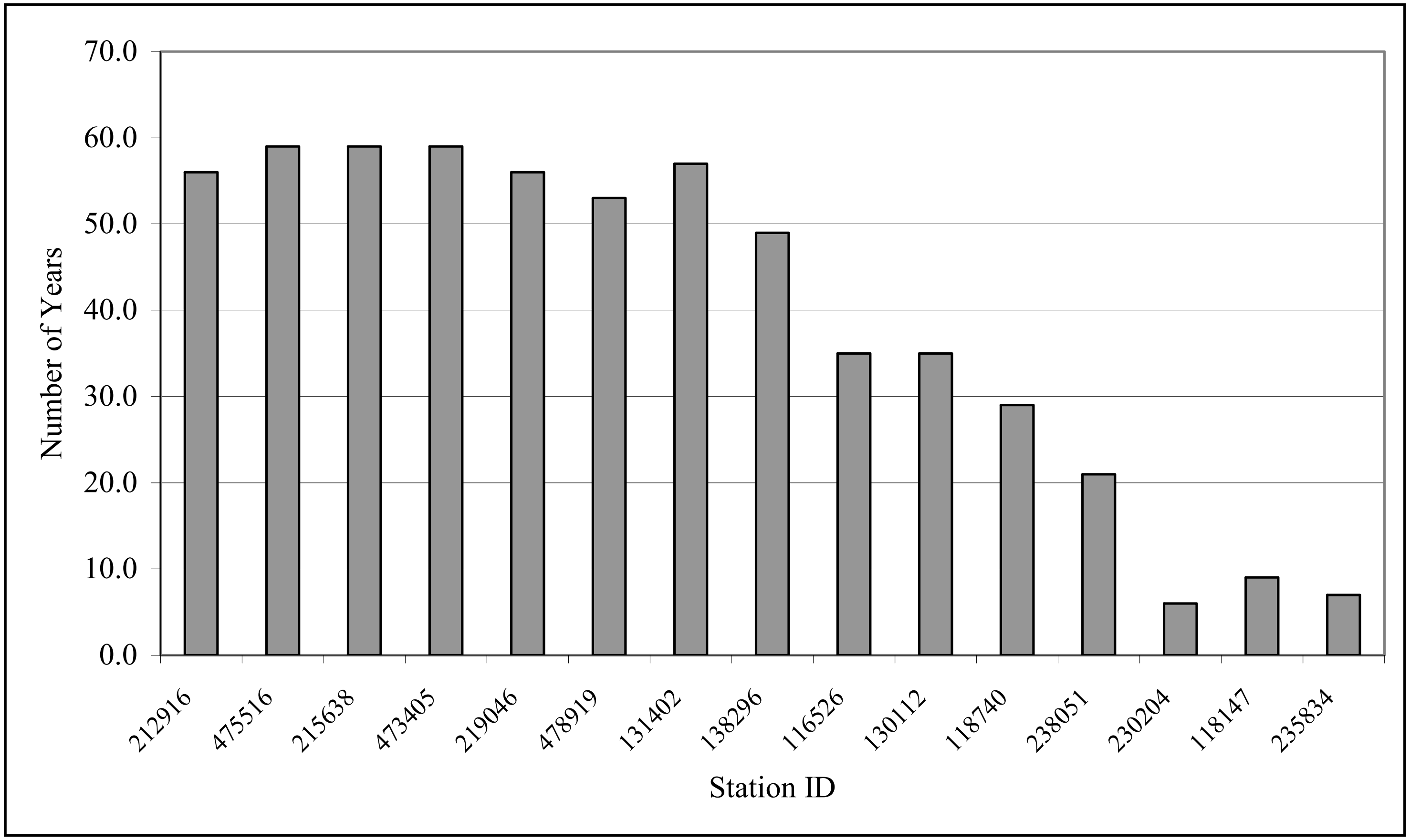

Figure 13 February Years of WSI ≥ 8 for Each Station, 1950-2008

Mallards and Climate

A colder climate with snow cover will cause a WSI of 8 to be reached faster, therefore mallards will leave the area earlier. The most obvious method of tracking the ducks movement is to examine where the WSI 8 line falls. The maps created in ArcMap clearly show how the line has moved during the migrational months over the past 5 decades. When the line is further south, such as the pink 1970's line, the mallards must have moved further south as well in order to survive away from the harsh winter conditions. In some instances, such as the red 2000's line, it remains further north. This demonstrates a decade when the winter conditions were milder and therefore the WSI 8 line did not reach as far south. It can then be determined that in the most recent years, mallards have not needed to travel as far south in the winter as in the past. Other tools to aid in examining duck migration timing are a probability table, a WSI standard deviation graph, and a quantile distribution table. The probability table helps in understanding which locations are most likely to have a WSI of 8 or greater each month. Clearly, the WSI will reach 8 at the northernmost stations before affecting the southern latitude locations, but one can examine these tables and graphs and make a general conclusion regarding where the mallards may still be, and where most likely they have already migrated from. For example, at station 116526's location (4 miles southwest of Ottawa, IL), there has never been a year when the WSI has reached 8 in November. Therefore, it is highly likely that mallards will remain in that area and also in locations further to the south. The ducks are less likely to be there in December, and it becomes more unlikely that there will be any mallards there in January and February. Actual percentages could also be found from the quantiles, such as determining that a WSI of 8 or more occurs at station 219046 (Winnebago, MN) in December 56 of the 59 seasons, or 90% of the time. Remembering that information, the average WSI for each year can then be examined to arrive at a final conclusion of when the mallards will most likely migrate from that area. Seeing as 6 of the past 10 seasons are in the top 25% of WSIs calculated for that station, it is likely that this year the mallards will move out in December as usual.

ENSO

As stated earlier, in a typical El Niño year, the polar jet typically remains to the north of the United States. Therefore, the central U.S. and Midwest will experience warmer conditions, while the southern and northeastern U.S. are cooler. This corresponds well with the lower WSI values, or the less severe winter weather. During La Niña years, the polar jet stream lowers into the eastern U.S., bringing cold, polar air blasts down into the northern half of the Mississippi Flyway. The autumn and winter seasons bring overall warmer temperatures across the southeastern U.S. (Sellinger 2009). The upper Midwest and southwestern U.S. are dry, while the lower part of the Mississippi Flyway receives more precipitation than normal (Sellinger 2009, NOAA$_2$ 2008, O'Brien 1997). This corresponds well to higher WSI values and more severe winter weather. As the cold air pushes into the northern part of the Mississippi Flyway, it will drop temperatures. With moisture available, there may also be more snow, and the snow may be able to last longer, as a cause of the cooler air being brought in by the jet. These elements combined will cause the WSI to have higher values. With warmer temperatures, food, and open water towards the south, it is likely the mallards will leave the area. Clearly, the ENSO period does correspond to mallard migration timing, as the WSI is formulated from climate variables that affect the ducks' movement. A table was created using the WSI and the Oceanic Niño Index (ONI) provided by NOAA (Table 7), and then used to produce a graph (Fig. 14).

ANOVA was completed on the data, which provided significant results when designating an El Niño as greater than 0.7, and a La Niña as less than -0.7 (dF = 1, F = 5.62, p = 0.03). Therefore, a neutral ONI was assumed to be between -0.7 and 0.7. The graph visually demonstrates the correlation, which the ANOVA test then proves. It can be seen from the graph that a La Niña year will most likely mean a more severe weather season, a higher WSI value, and an El Niño will produce less severe conditions, or a lower WSI. A neutral ONI could not be correlated with a high or low WSI as it can result in either, providing inconclusive results. Further studies need to be completed in examining specifically the neutral zone in order to understand what causes the severity (or lack thereof) in the weather during a neutral ONI period.

Table 7

ONI and WSI for Each Year

Year	NOAA	WSI
55	-1.1	18.1
56	-1.9	29.2
57	-0.8	18.8
58	1.5	13.4
59	0.4	22
60	-0.2	15.5
61	-0.2	15.6
62	-0.4	28
63	-0.7	15.8
64	1	15.6
65	-1	20.9
66	1.5	17.7
67	-0.3	17.4
68	-0.5	17
69	0.9	25
70	0.7	35.6
71	-1.1	27.9
72	-0.9	24.3
73	2.1	22.4
74	-2.1	24
75	-0.7	20.4
76	-1.7	20.8
77	0.7	38
78	0.7	31
79	-0.1	46.9
80	0.5	11.4
81	-0.1	9.6
82	-0.1	35.5
83	2.3	11.4
84	-0.7	37.4
85	-1.1	19.1
86	-0.4	39.4
87	1.2	19.5
88	1.1	20.2
89	-1.9	18.3
90	-0.1	18.2
91	0.4	22.2
92	1.6	19
93	0.2	31.4
94	0.2	24.8
95	1.3	15.2
96	-0.7	29
97	-0.4	34.6
98	2.5	18.8
99	-1.4	17.4
2000	-1.6	10.3
2001	-0.7	45.6
2002	-0.1	3.3
2003	1.4	11.3
2004	0.4	13.7
2005	0.8	13.6
2006	-0.7	15.3
2007	1.1	6.3
2008	-1.3	22.5

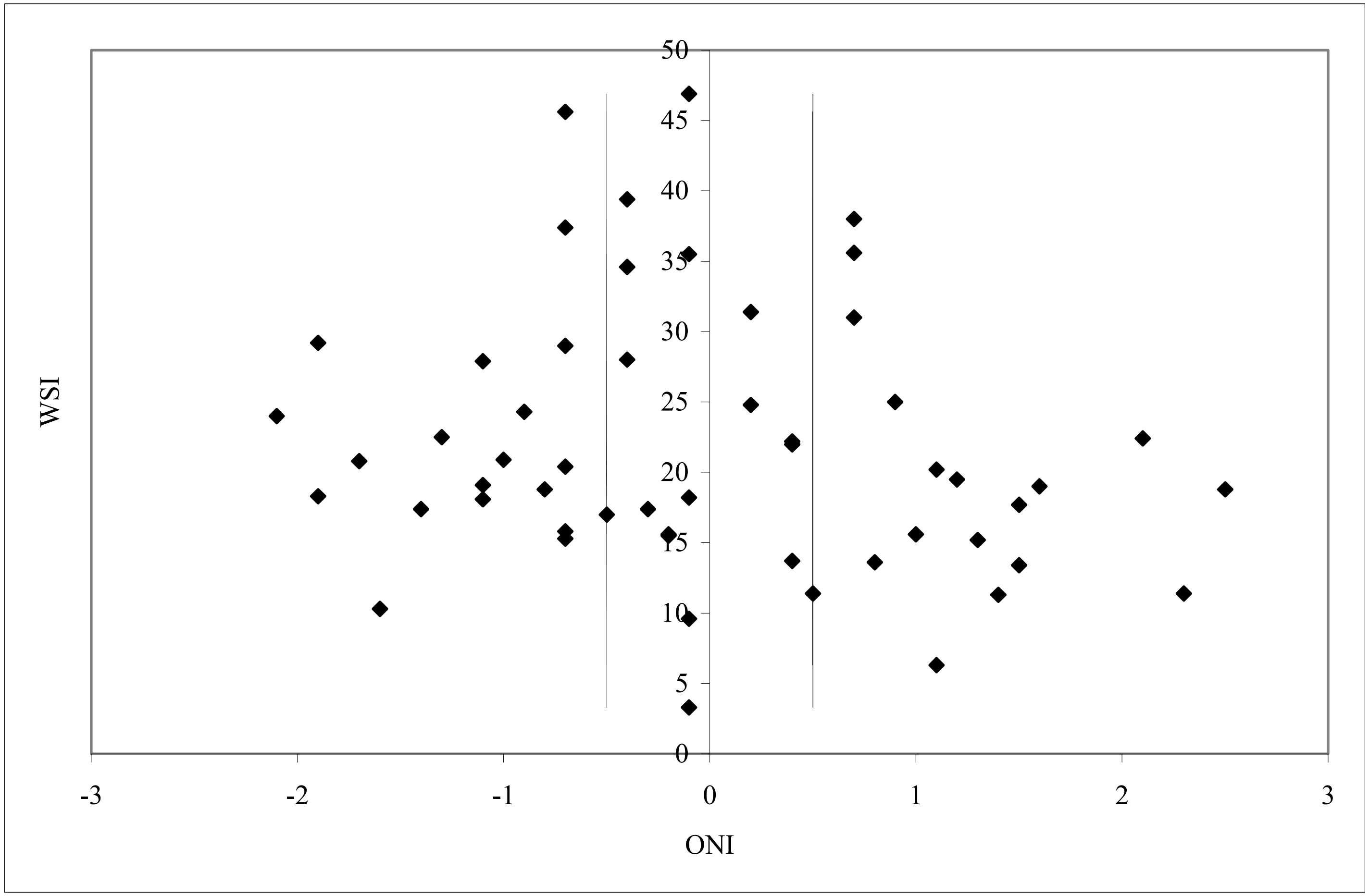

Figure 14 ONI vs. WSI with La Niña (-0.7) and El Niño (0.7) Marking Neutral Zone

Table 8

WSI and ONI Categories for ANOVA

WSI	ONI
24	LA
29.2	LA
18.3	LA
20.8	LA
10.3	LA
17.4	LA
22.5	LA
18.1	LA
27.9	LA
19.1	LA
20.9	LA
24.3	LA
18.8	LA
15.8	N
20.4	N
37.4	N
29	N
45.6	N
15.3	N
17	N
28	N
39.4	N
34.6	N
17.4	N
15.5	N
15.6	N
46.9	N
9.6	N
35.5	N
18.2	N
3.3	N
31.4	N
24.8	N
22	N
22.2	N
13.7	N
11.4	N
35.6	N
38	N
31	N

WSI	ONI
13.6	EL
25	EL
15.6	EL
20.2	EL
6.3	EL
19.5	EL
15.2	EL
11.3	EL
13.4	EL
17.7	EL
19	EL
22.4	EL
11.4	EL
18.8	EL

CHAPTER V

CONCLUSION

This research project had a goal of demonstrating if and how duck migration and weather are related. The results show a strong relationship between the two. Using a formula involving temperature and snow cover and their cumulative effects, it was determined that when the WSI reaches 8, there is a decrease in local mallard abundance. There is a large amount of variability from year to year and decade to decade. For example, the 1999-2000 winter season was warmer than average, while the following season was much colder. Also, the 1970's were an overall colder decade, pushing the mallards further south, while the 2000's have been more mild, permitting the ducks to remain at higher latitudes longer. In comparing the WSI with the ONI, it was found that the WSI may be very large or very small when the ONI is neutral. ANOVA results showed a significant difference in the weather severity between the ONI periods. When the ONI is neutral, results are inconclusive regarding how severe the winter weather will be that season. If the ONI is negative (La Niña) the WSI tends to be higher, meaning more severe winter weather, while if positive (El Niño) the WSI tends to be lower, meaning less severe winter weather. This correlates well, as with a La Niña there will be cold, polar air coming into the northern sections of the Mississippi Flyway, while an El Niño has milder temperatures across the area. With moisture available, there may also be more snow, and the snow may be able to last longer, during a La Niña as a cause of the cooler air being brought in by the polar jet. Clearly, ENSO affects the climatic variables that then affect the migration of mallards, and there is a correlation. The objectives of this project were to aid in the development and evaluation of models to predict large-scale migration of waterfowl during fall-winter, determine if timing and severity of autumn-winter weather events in the Mississippi Flyway have changed from 1949-50 through 2007-08, and to determine if relationships exist between ENSO events and the developed autumn-winter severity model(s). The null hypotheses in this project stated that the severity of autumn-winter weather events (as they influence duck migration) did not change between 1949-50 and 2007-08 in the Mississippi Flyway of North America, that the severity of autumn-winter weather events and ENSO events are not correlated, and that autumn-winter severity model(s) are not related to ENSO events. For this project, all objectives were met, and all of the null hypotheses were rejected as well.

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