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Over the last century nighttime minimum temperatures have been increasing at a faster rate than daily maximum temperatures. This warming trend has caught the attention of climatologists and agricultural scientists as they attempt to address the potential effects of elevated nighttime minimum temperatures on the health of these crops, which are so important to the U.S. economy. In this study, ten sites represent the Corn Belt of the United States. Those sites are spread across an area in which the average minimum nighttime temperatures for each of the three primary growing months of the year (June, July, August) increased from 1950-2011. Since this is a relatively new phenomenon, the effects of increased nighttime temperatures are not well understood. The main variables that can affect the growth of crops under elevated nighttime temperatures are: a shift in agro climatic zones resulting in an introduction of new pests formerly foreign to the crops, deviation from prime respiration temperatures and lastly the subsequent change in the properties of air associated with warmer air that would likely exist in a changing climate. Warmer nighttime temperatures raise the respiration rate of corn plants to levels above the optimum rate. This leads to "wasteful respiration,"

which often compromises the plant structure (leading to “stalk cannibalization”), negatively affects the overall health of the plant, and jeopardizes maximum production. Most crop simulation models and experimental results used in climate and agriculture studies were not designed well enough to quantify multiple stress effects associated with this research. The complexity and input requirements of a reliable agro ecosystem model are such that the predictive capacity of the simulation models represents a much smaller area than desired, decreasing the validity of a large-scale application. More research needs to be conducted comparing differing agro environments (since each environment contains a different set of target variables like soil type, rainfall, plant species, and climate events). Such research is necessary to help untangle climate effects from other factors affecting maximum crop yield.

INTRODUCTION

“Agriculture, especially crop production, is fundamentally linked to climatic conditions, so any changes in climate will necessarily affect agriculture.” –Juha Siikamaki

One of the strongest impacts of a changing (warming) climate is its impact on nighttime temperatures. “In the past century, daily minimum nighttime temperature increased at a faster rate than daily maximum temperature in association with a steady increase in atmospheric greenhouse gas concentrations.” (Peng et al., 2004). Following the heat wave that hit Europe in 2003, research has shown that nighttime temperatures have been trending upward. As a result, temperatures have had a direct impact on human discomfort and morbidity. In August 2003, a lethal heat wave scorched Europe claiming approximately 35,000 lives (Larson, 2003). Although the impacts of a changing climate on humans are relatively predictable, the impacts on crop production are not well understood.

Since the growth of crops is dictated by weather, it is difficult to predict the response of crops to a changing climate which contains many variables. Scientists conclude that predictions of the effects of climate change on agriculture depend heavily on underlying assumptions regarding adaptation to new climatic conditions and regulatory regimes, technological change, and alternative land uses (Siikamaki, 2008). As the climate changes, so too should our farming management practices. It is important to monitor the health of crops to ensure maximum production and high efficiency as we continue to live in a world where energy efficiency remains a hot topic.

The purpose of this study is to document whether there is a trend toward higher nighttime temperatures in the Corn Belt; if so, in what location and to what magnitude does the trend exist. It will then be necessary to conduct research on the primary crops within the Corn Belt, specifically Corn (maize), regarding its response to elevated nighttime temperatures.

Temperature is an important factor for the health of these valuable crops and a large population depends on this commodity. The health of the crops produced in the Corn Belt plays a crucial role in the local, national, and even global economy. In 2011, Corn production in the United States was valued at $76.5 billion, the Soybean crop was valued at about $35.8 billion, and the Wheat crop was valued at approximately $14.4 billion (USDA 2011). The United States' crop production plays an important role in the global grain market as well as providing commodities for our own country. Therefore, it is important to understand the relationship between a changing climate and crop productivity to ensure a steady grain market and a dependable supply of commodities.

A changing climate directly impacts agriculture in the Corn Belt of the United States. Since this is a relatively new phenomenon, the effects of increased nighttime temperatures are not well understood. However, it is apparent that a number of processes can contribute to a less healthy crop. I will discuss several of the main variables which can affect the growth of crops under elevated night time temperatures, including: a shift in agro climatic zones resulting in an introduction of new pests formerly foreign to the crops, deviation from prime respiration temperatures, and the subsequent change in the properties of air associated with warmer air that would exist in a changing climate.

Because plants have evolved to be dependent on a relatively fixed climate, it is important to understand how a changing climate will affect the general health of a crop. The crops' response to a changing climate can vary, but generally includes changes in: plant physiology, productivity and growth and species distribution and abundance primarily due to migration and range shifts (Midgley et al., 2002). As the average global temperatures rise, ecosystems and individual organisms tend to shift pole-ward, or up in elevation toward a cooler and more desired climate where they have evolved in order to flourish.

New disease complexes may arise in a particular location if warmer temperatures cause a pole ward shift of agro climatic zones. Likewise, some diseases may cease to be economically important as host plants migrate into new agro climatic regions (Coakley et al., 1999). This shift in agro climatic zones can have both positive and negative effects, depending on specific situations. Warmer weather can extend farther north the range for acceptable copland, however, by the same token it can shrink certain areas. Regardless of the effect, species displacement has been observed and can present additional health problems to the plant.

The process of a general shift in the range of a particular species may introduce new pathogens and fungi into the Corn Belt that have never before been seen. Because the climate dictates which species thrive in certain locations, it has the potential to modify host physiology and resistance, and can alter stages and rates of development of the pathogen itself (Coakley et al., 1999). This occurrence doesn't pertain only to agricultural crops; the migration of other vegetation also brings its own set of pests that could be harmful to the crops in the area. Although this shift in species has the potential to damage crops, new biotechnology and the use of genetically modified organisms, accompanied by the use of pesticides and fungicides, will play a crucial role in defending the crops and protecting their health.

Based on the general properties of an air parcel, as it warms, its ability to hold moisture and energy increases. Therefore, it is likely that we will observe a climate with more moisture in the air, resulting in more available energy for storm-like events to occur. The Intergovernmental Panel on Climate Change conducted a survey and concluded that a five degree Fahrenheit temperature increase will result in an eight percent increase in precipitation (Mendelsohn et al.,1994). However, this effect may not be applicable on a global scale and it is possible that such an effect may only be seen regionally. Likewise, temperature trends can exist on a regional scale, not just a global scale.

Although elevated temperatures can affect crops, it's also important to take into consideration the potential changes in precipitation patterns and the relationship to crops. Many climate change projections suggest an intensification of the hydrological cycle. Higher evaporation rates are associated with warmer weather, along with higher air humidity and subsequently higher precipitation. At first glance, the idea of more precipitation as a possible result of global climate change seems wonderful, largely benefitting the crops grown on the western Corn Belt where precipitation is the most common limitation to maximum yields. However, higher temperatures in areas that experience a summer drought may aggravate the situation. While many climate models are preoccupied with temperature calculations, sometimes they overlook the changes in precipitation- which have more pronounced effects on the development of a variety of plant diseases, specifically those caused by fungi (Coakley et al., 1999).

Deviation from prime respiration temperatures is an important variable that affects crops. It is perhaps the most threatening as it affects the growth and development of the organism. Generally speaking, the growth of a plant is broken down into two processes: photosynthesis and respiration. During photosynthesis, the plant uses the Sun's energy to form chemical bonds; during respiration, the plant breaks down these chemical bonds and provides that energy to the plant. Up until a certain point, warmer temperatures are actually beneficial to plants during the photosynthesis process while the respiration rate increases as temperatures rises (Evans).

The primary threat to the health of the plant with regards to elevated nighttime temperatures lies in the respiration process. A large diurnal fluctuation in temperature during the growing-season (which have warm days and cool nights) is beneficial for plant growth because sunny, hot daytime conditions increase the photosynthetic rate. At night, when it gets cooler, the respiration rate is reduced (Fulu et al., 2006). When nighttime temperatures remain high, the plant respires at a much faster rate than if the temperature was cool. This is referred to as "wasteful respiration." Plants are sensitive to the temperature at night, as the rate of respiration increases rapidly as the temperature increases. For each 13 degree Fahrenheit increase, the rate of respiration approximately doubles (Thomison, 2010).

As such, these higher nighttime temperatures often lead to wasteful respiration. Ultimately, the plant is working hard to distribute the sugars provided by photosynthesis to the developing plant, sometimes trying to distribute more sugars than photosynthesis provided. In corn, the plant expends so much energy sending sugars to the developing ear that the plant actually eats away at its structure searching for more nutrients, leading to stalk cannibalization. Maximum grain yields are jeopardized because there is less available energy to fill developing kernels while maintaining a solid plant structure (Thomison, 2010). The stalk is then more vulnerable to the environment and can break, causing it to fall over, deeming it unharvestable. In association with wasteful respiration, the temperature effects can be explained by assuming inactivation of an enzyme(s) or loss of membrane structure as the temperature rises (Cridder et al., 1997).

More scientific experiments conducted in the field are necessary in order to investigate the magnitude of disease infestation with respect to warming nighttime temperatures. So far, the few experiments that were conducted have been in controlled laboratory settings, which limit the validity of large-scale field applications. Aside from controlled experiments, some observations have been made regarding nighttime temperatures and corn yield. Previous research conducted at the University of Illinois shows that corn grown at night temperatures in the mid-60s out yields corn grown at nighttime temperatures in the mid-80s (Thomison, 2010).

Each crop is affected differently since they are ultimately different species. Variation of plant metabolism with temperature as a variable determines the growth rate of each species. Morphological differences aside, plant growth and survival of each individual species are dictated by their metabolism (Cridder et al., 1997). With this in mind, it is important to take into account all growth factors which affect the health of crops when conducting research to determine if a changing climate is responsible for jeopardizing maximum production of important agricultural commodities produced in the Corn Belt, and to what magnitude.

MATERIALS AND METHODS

In order to fully understand the magnitude at which the agricultural crops will be affected in the Corn Belt of the United States, it would be necessary to research the effects of elevated nighttime temperatures on the health of the crops. Not much research has been conducted on this topic since it is a relatively new phenomenon. With this in mind, it will be important for me to analyze my own climate data and draw conclusions on existing research from scholarly sources on the topic.

I will gather climate data from a controlled access database called XMACIS. XMACIS is developed and maintained by the National Oceanic and Atmospheric Administration (NOAA) Regional Climate Centers of the United States. This database provides professional climatologists accurate climate data in hundreds of locations across the United States. To represent the Corn Belt accurately, I chose ten different locations to asses: Fargo ND, Sioux Falls SD, Grand Island NE, Des Moines IA, Topeka KS, Quincy IL, Madison WI, Fort Wayne IN, Louisville KY, and Columbus OH. These locations are on average 250-350 miles apart from each other, sufficiently representing the area of study. At each site, I will document the monthly average of minimum nighttime temperatures in the primary growing months of the year: June, July and August, and plot them on a chart. It is important to document a sufficiend period of time in order to illustrate a trend in changing minimum temperatures. And in order to find a significant trend, I will assess the minimum temperatures from 1950-2011.

RESULTS

It has been observed that minimum nighttime temperatures have increased throughout my entire region of study over my period of study. Figures 1-10 depict the warming trends that have been present from 1950-2011. Each of the ten sites I chose to examine experienced a warming trend in each of the three months of the primary growing season.

Table 1 represents the information displayed by the trend lines observed in each of the month's average temperature (Fahrenheit) for each site (as seen in figures 1-10).

CONCLUSION/DISCUSSION

Although the scientific community has advanced and expanded its understanding of the climate effects on crop growth, the availability of valid quantitative estimates of the impact of a climate change scenario on a particular agro ecosystem are often slightly out of reach because regional scale predictions are too vague and uncertain due to the plethora of variables at play. It is clear that there have been an increase in nighttime minimum temperatures over the last 62 years (figures 1-10) and its important that scientist and climatologists consider a more diversified approach to tackle this issue. More research is needs to be conducted comparing differing agro environments (which contain a different set of target variables like soil type, rainfall, and plant species) to untangle climate effects from other factors effecting maximum crop yield.

Most crop simulation models and experimental results used in climate and agriculture studies were not designed well enough to quantify multiple stress effects. For example, since it's hard to predict the role that genetic diversity plays in the potential for adaptation, it is rarely taken into account. The complexity and input requirements of a reliable agro ecosystem model are such that the predictive capacity of the simulation models represents a much smaller area than desired, decreasing the validity of a large-scale application (Rotter, Van De Geijn 1999).

One thing is for certain: the future is unpredictable. Adaptation potential of agriculture technologies, coupled with advances in biotechnology, could offset any changes in growing conditions humans are sure to encounter in the future. On the contrary, nature is powerful and can be uncontrollable. As scientists look into the future and formulate policies that target reduction in energy demand and the like, they will also need to look into research and development of agricultural practices aimed at reducing the vulnerability of crops or entire ecosystems to climate related risks.

Table 1

	June			July			August		
SITE	Average temp at the beginning of the study period	Average temp at the end of the study period	NET:	Average temp at the beginning of the study period	Average temp at the end of the study period	NET:	Average temp at the beginning of the study period	Average temp at the end of the study period	NET:
Columbus, OH	58	62	+2	62	66	+4	60	65	+5
Fort Wayne, IN	58	60	+2	62	63	+1	60	61	+1
Louisville, KY	62	65	+3	67	70	+3	65	69	+4
Quincy, IL	61.5	62.5	+1	65	67	+2	63	65	+2
Madison, WI	54	57	+3	59	62	+3	56	59	+3
Des Moines, IA	60	62	+2	65	67	+2	62	65	+3
Topeka, KS	63	64	+1	66	69	+3	65	67	+2
Grand Island, Ne	59	60	+1	64	66	+2	62	63	+1
Souix Falls, SD	56	57	+1	61	63	+2	59	61	+2
Fargo, ND	53	56	+3	58	60	+2	56	57	+1
Monthly Average Over each of the ten sites:	+1.9 degrees F			+2.4 degrees F			+2.4 degrees F		

FIGURE 1

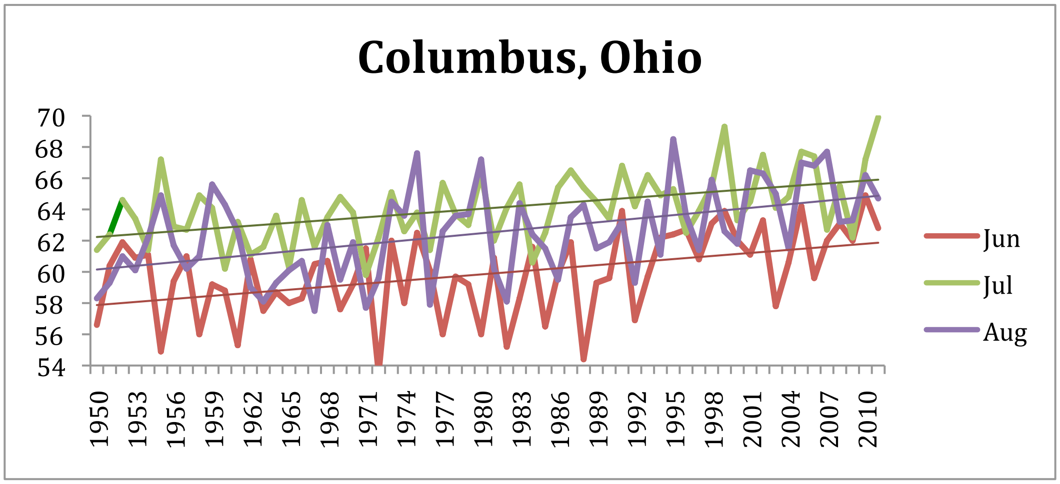


FIGURE 2

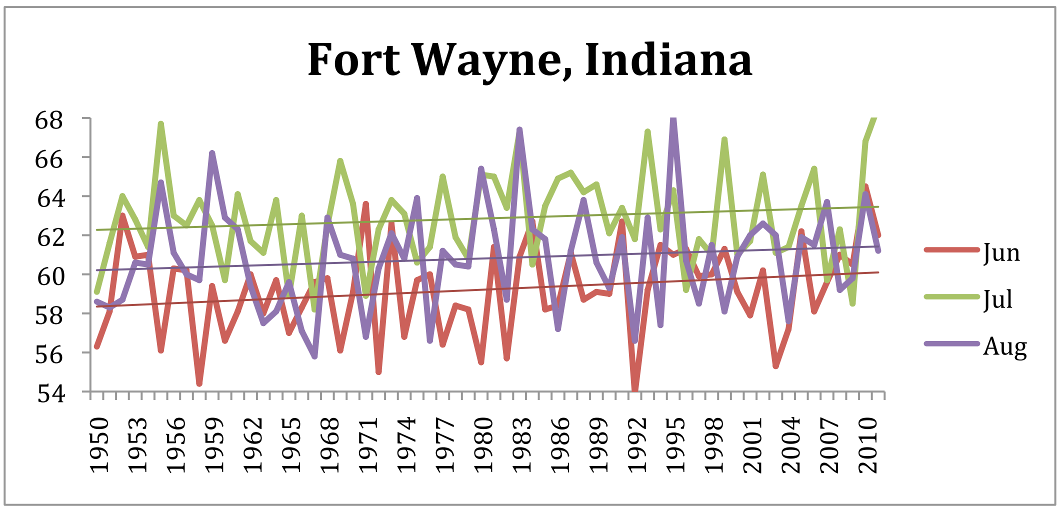


FIGURE 3

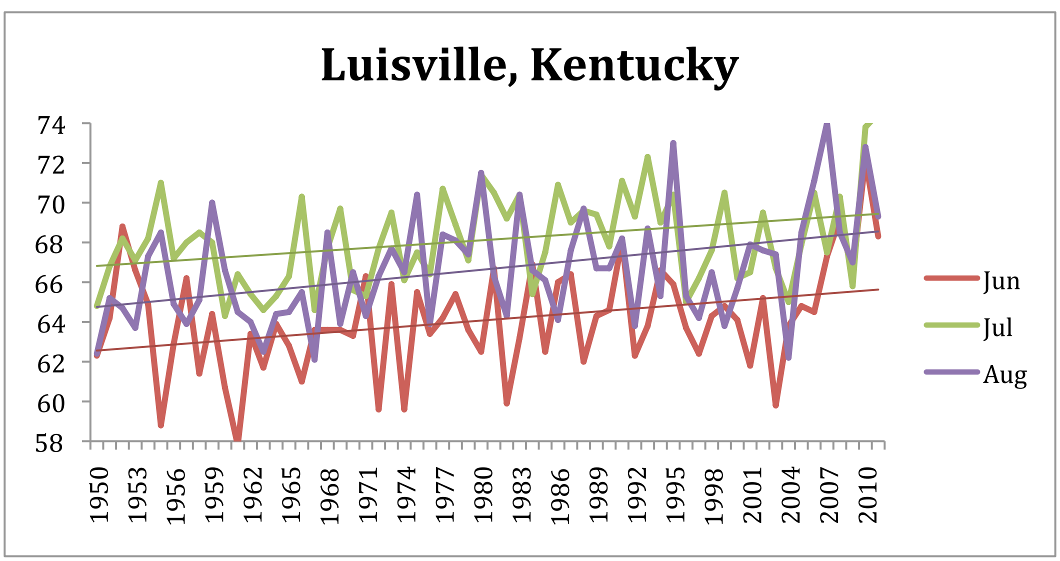


FIGURE 4

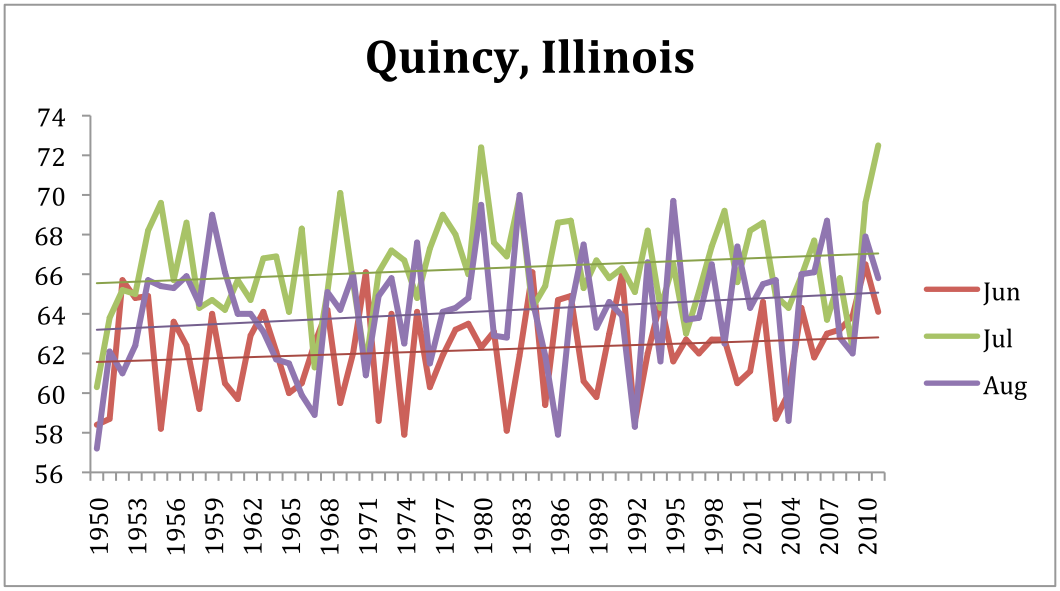


FIGURE 5

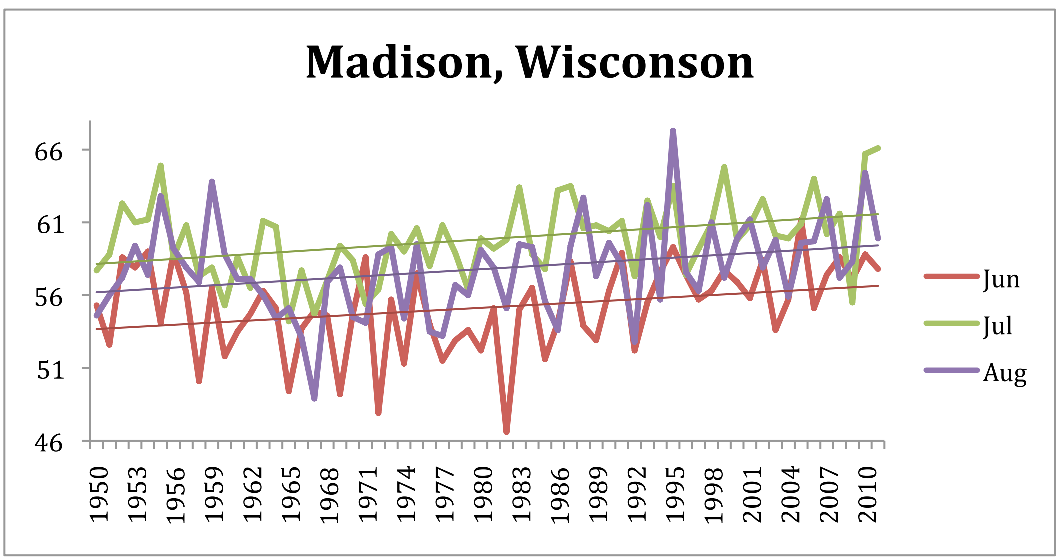


FIGURE 6

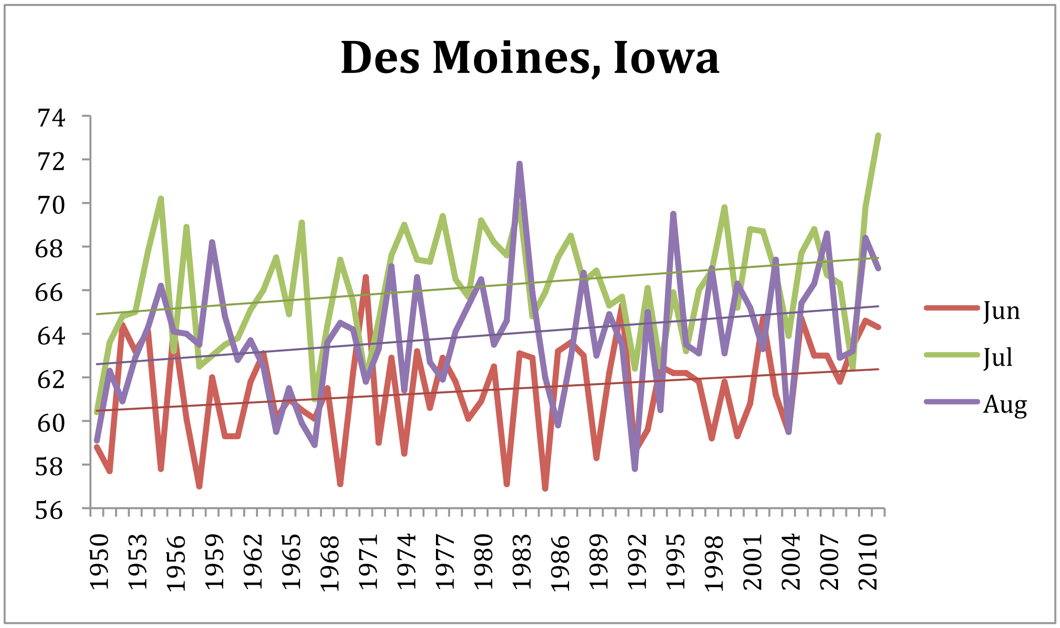


FIGURE 7

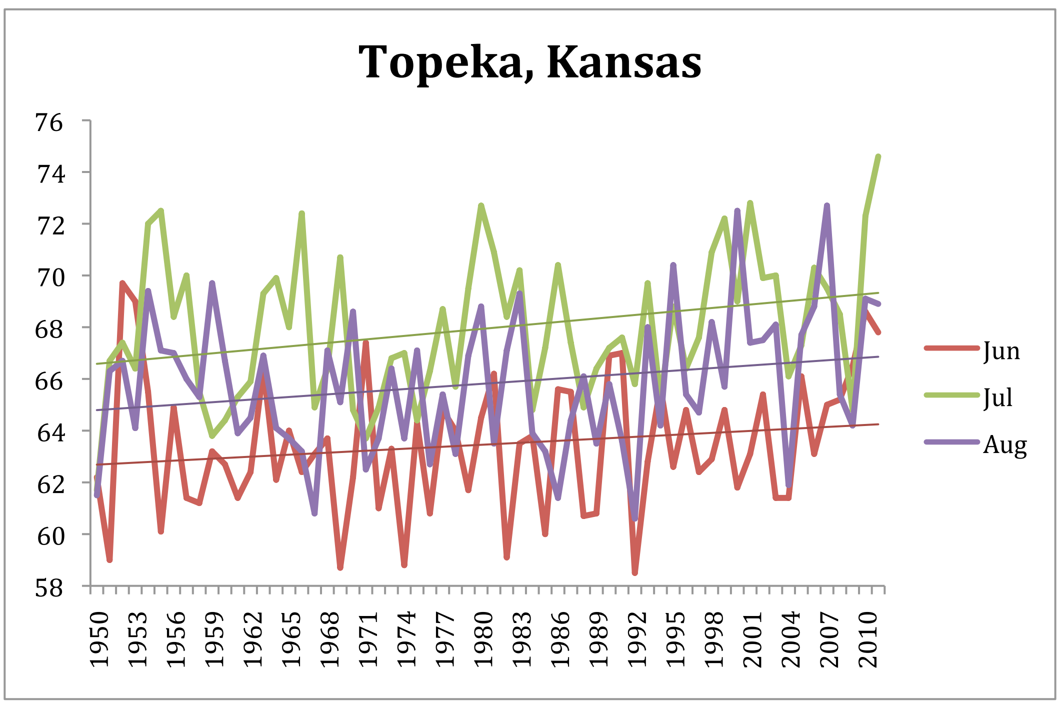


FIGURE 8

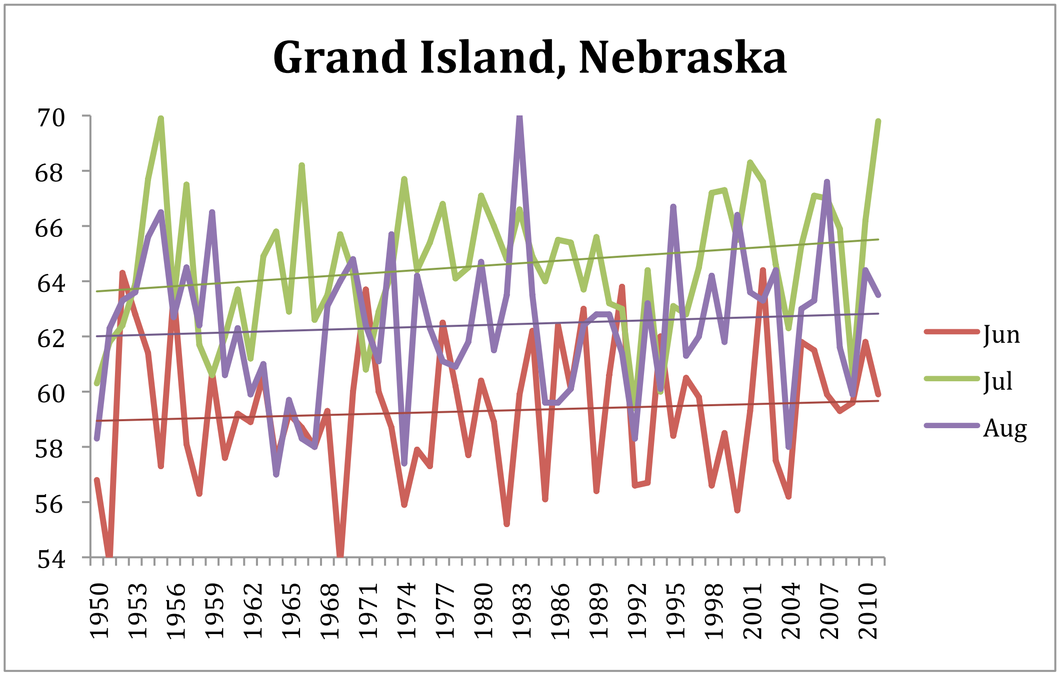


FIGURE 9

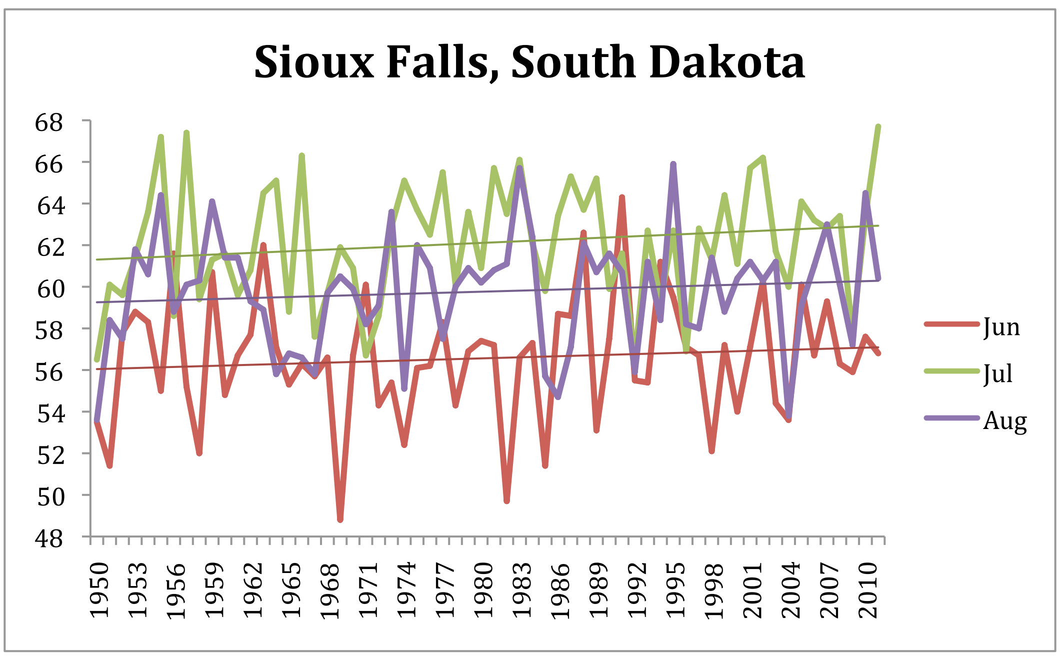
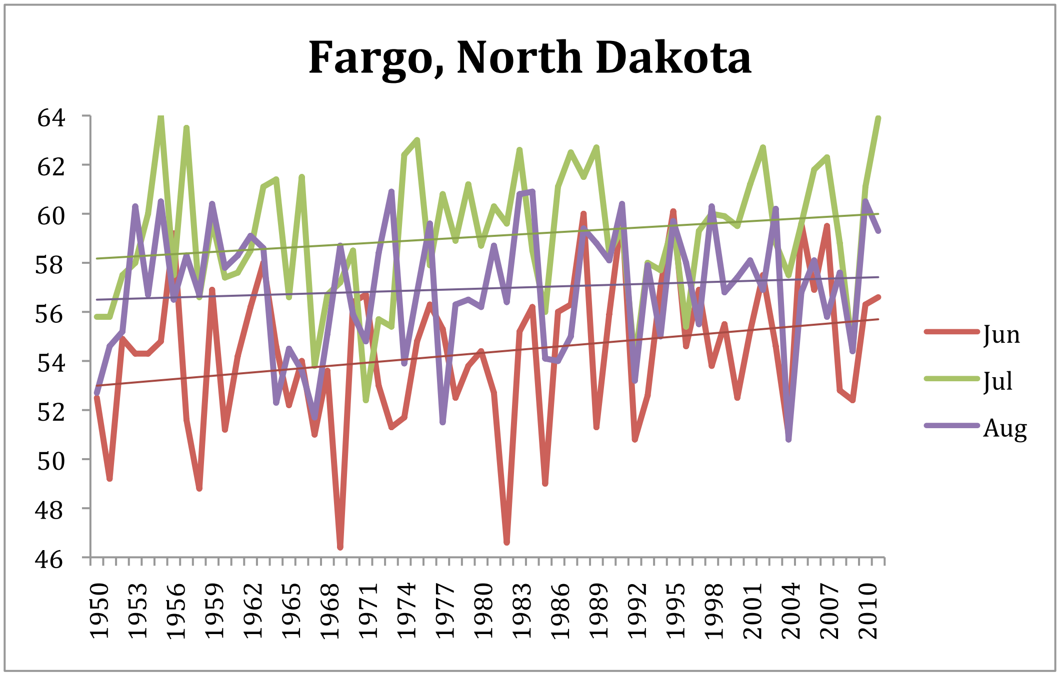


FIGURE 10


Fargo, North Dakota
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