HOW EL NINO AFFECTS ENERGY CONSUMPTION: A STUDY AT NATIONAL AND REGIONAL LEVELS

A Thesis

by

KATHLEEN JO COLLINS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2007

Major Subject: Atmospheric Sciences

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Approved by:

Chair of Committee, R. Saravanan
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ABSTRACT

How El Niño Affects Energy Consumption:
A Study at National and Regional Levels. (August 2007)
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Chair of Advisory Committee: Dr. R. Saravanan

El Niño is typically viewed as an episode of destructive weather anomalies that can last from a few months to several years. The majority of research looks at the negative impacts of this event. However, not all impacts of El Niño are necessarily bad. This study outlines areas of the United States that are most highly impacted by anomalous temperature and rainfall during El Niño years and determines whether these anomalies affect energy consumption. These effects will be examined on both a national and regional scale.

Areas of the northwestern and southeastern United States exhibit anomalous temperatures during El Niño years. The southern US and Great Plains area receives positive anomalous precipitation during El Niño years while an area of the east central US experiences negative anomalous precipitation. Natural gas consumption in the northwestern US is reduced by the El Niño/Southern Oscillation (ENSO). During an ENSO event consumers actually save money because less is spent on natural gas for home heating purposes. Hydroelectricity may also be affected by ENSO in the southeastern US but the results at this time are inconclusive. At the national level, ENSO influences the consumption of nuclear electricity.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

Page

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

1. INTRODUCTION

Anomalous temperature and rainfall amounts consistently occur in many areas of the United States during most El Niño events (Beller-Simms, 2004). If it was better understood how El Niño affects energy use different areas of the US, it would possible for better energy load forecasts to be made. More accurate energy load forecasts mean the potential for decreased energy generation prices for the production company. A reduction in generation costs will lead to a reduction in the consumption costs incurred by energy companies' customers.

Temperature and energy consumption go hand and hand. The northwestern United States shows a decrease in energy consumption during the winter months because during an El Niño event the winter is not as harsh as it is during non-El Niño years. It is possible that other areas of the US that are impacted by temperature anomalies during an ENSO event may also experience a change in energy consumption.

This study will analyze the consumption of energy in the US during El Niño and non-El Niño years. The goal is to determine whether consumption is impacted by El Niño conditions in regions of the country that exhibit definitive temperature and precipitation changes with regard to El Niño. Areas of the United States that are most highly impacted by anomalous temperatures and rainfall during El Niño events will be outlined. Anomalous energy consumption in these impacted areas will be considered to determine if there is a coherent increase or decrease in energy consumption during El

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Niño events. Once it is understood how El Niño impacts these areas it will be possible for energy companies to tailor their forecasting methods to incorporate the nuances introduced by El Niño.

2. BACKGROUND INFORMATION

The information provided in this section is meant to create a foundation upon which this study will take place. Climate and energy data will play equally important roles in this analysis. It is therefore pertinent that a good understanding of both is achieved.

a. El Niño/Southern Oscillation

El Niño/Southern Oscillation (ENSO) is one of the most widely studied weather events in the world because of its far-reaching impacts around the globe. Every 2-7 years this phenomenon captures the attention of the globe with the threat of severe drought, extensive floods, and loss of life and property, depending on location. These potential hazards have driven much of the ENSO research to date (Glantz, 2001).

The El Niño phenomenon was first noted by Peruvian fishermen who observed a pronounced shift in the availability of fish around the end of the calendar year. Warm water was pushed eastward, creating an environment in which fish were not able to find enough food to sustain the population. Thus, the fish moved away from the coast of South America towards a cooler, more conducive feeding environment. An increase in precipitation was also noted to occur around the same time of year as El Niño. The El Niño phenomenon was given its name by these fishermen because of its occurrence around Christmas time each year (Glantz, 2001).

Gilbert Walker and Jakob Bjerknes are given credit for discovering ENSO from a scientific standpoint. Walker identified a seesaw of atmospheric pressure between the southeast Pacific subtropical high (Tahiti) and the low-pressure region of Australia (Darwin) in the 1920's. He termed this seesaw of pressure as the Southern Oscillation (Walker, 1923) (Fig. 1). In the 1960's, Bjerknes identified the mechanism by which this pressure difference occurs. In short, he linked El Niño and the Southern Oscillation together. He showed that fluctuations in sea surface temperatures (SSTs) and anomalous rainfall go hand in hand with the pressure differences noted by Walker (Bjerknes, 1966). They are associated with the large-scale variations in the equatorial trade wind system (Rasmusson and Wallace, 1983).

Whether ENSO begins because of an increase in sea-surface temperatures (SSTs) or due to a strong shift in pressure between Darwin, Australia and the South Pacific island of Tahiti causing wind stress at the ocean's surface is still the subject of much debate among scientists (Rasmusson and Wallace, 1983; McPhaden, 1999). Tahiti tends to lead a change in sign for monthly sea surface pressure at least 1 to 3 seasons ahead of the sea surface pressure at Darwin (Trenberth and Hoar, 1996). SSTs during El Niño events become warmer than usual (by approximately 2°C) in the eastern Pacific during the late fall through early winter (McPhaden, 1999).

When these warm SST's are situated further east they cause a breakdown of the Walker Circulation, which results in a weakening of the easterlies. Convection is increased in horizontal extent over the warm Pacific waters. The thermocline, a layer of water in the ocean separating the warmer layer above from the colder layer below, becomes flat beneath the Pacific where this warm anomaly is observed (Fig. 1). When these conditions are in place, anomalous temperature and precipitation regimes are noted

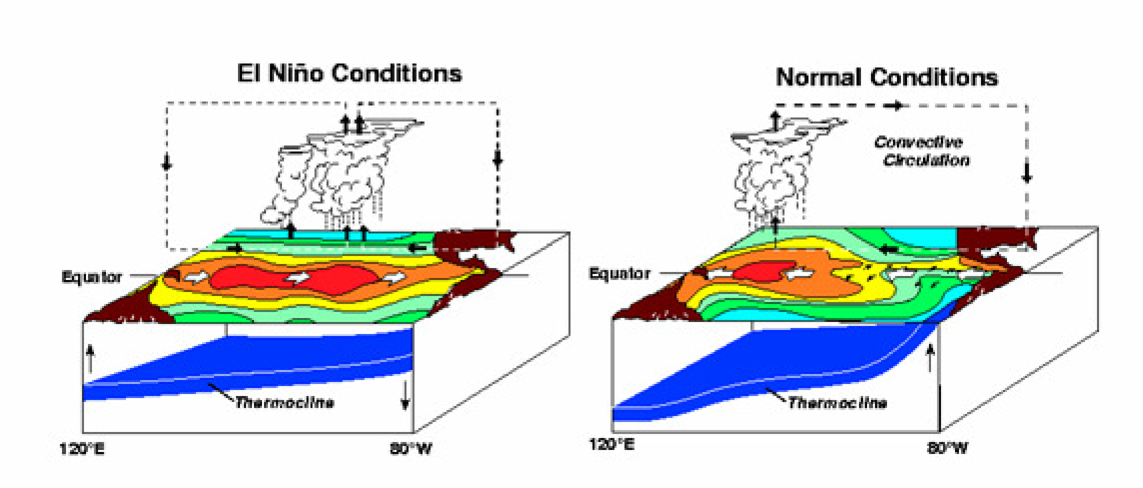


FIG 1. El Niño vs normal conditions in the Pacific Ocean. El Niño causes weakening trade winds, which result in the reversal of flow along the equator, moving area of warmer SSTs and convection eastward. The thermocline flattens out beneath the surface during an El Niño (Source: NOAA/PMEL/TAO Project Office, Michael J. McPhaden, Director).

around the world. An El Niño event can last anywhere from a few months to several years (McPhaden, 1999).

b. ENSO's Global Effects

It has been estimated that 35 in every 1000 people world wide are affected by a natural disaster in El Niño years. That is four times the average number of people affected during non-El Niño years (Kovats et al, 2003). A multitude of different weather events occur around the globe during ENSO years. For the most part, droughts and floods are the main disasters experienced due to ENSO events (Fig. 2).

During El Niño events, fewer Atlantic Hurricanes occur (Changnon, 1999). It is speculated that this is due to stronger upper-level westerlies and lower-level easterlies. As warmer than usual SSTs during an ENSO episode increase deep cumulus convection, divergence is enhanced in the upper atmosphere while convergence is enhanced at the lower levels and vertical wind shear is increased. This makes the environment over the Atlantic unfavorable for tropical storm development and enhancement (Vitart and Anderson, 2001). However, Typhoons are more likely to occur in the Pacific Ocean during ENSO events. They typically track towards the Marshall Islands during these events because the storm tracks in the Pacific are located further west at this time (Kovats et al, 2003).

In some areas, El Niño means catastrophic floods are likely. It is important to note that only 20%-30% of land areas experience statistically significant rainfall anomalies as a result of El Niño (Goddard and Dilly, 2005). However, in areas of the

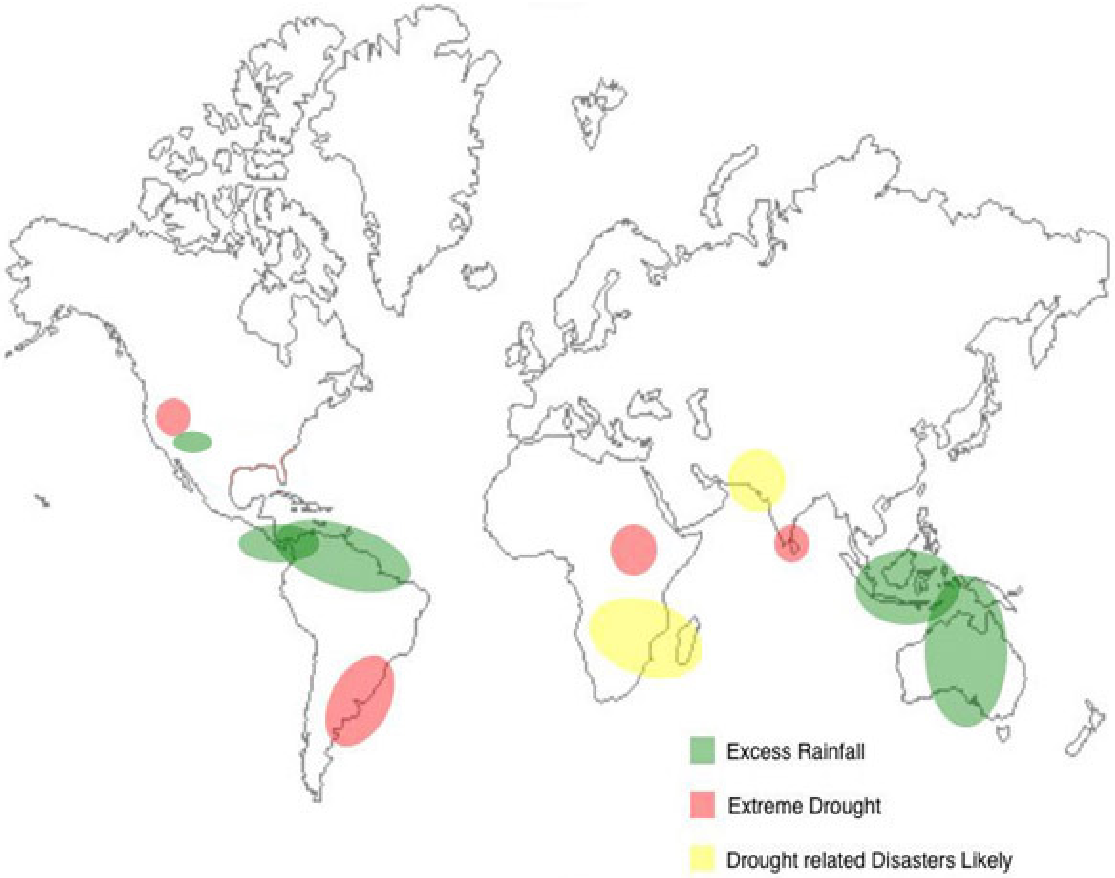


FIG. 2. ENSO extremes from around the world. Graphic adapted from information from Kovats et al (2003).

world where no mitigation plan is in place, it is very likely that loss of life and spread of diseases, such as malaria, will ensue. Flooding in Ecuador during the 1997-1998 El Niño cost the lives of 286 people and left approximately 30,000 people homeless (Vos et al, 1999). In Peru, the same ENSO event spawned floods and landslides that destroyed over 100,000 homes and left more than a half a million people without the resources to maintain healthy living conditions (Reyes, 2002). Hundreds of flood related deaths during the 1982-1983 and 1997-1998 El Niños also occurred in Colombia and Bolivia (Kovats et al, 2003).

Over the past 65 years, it has been shown that fatalities as a result of floods have been increasing, especially within the most recent 25 years. This could be due to the fact that there have been more frequent ENSO episodes over the past 30 years. The 1990's have seen a particular upswing in flood related deaths around the globe (Kunkel et al, 1999). The longest El Niño on record spanned from 1991-1995 (Trenberth and Hoar, 1996). One of the strongest El Niños on record occurred over a period from 1997-1998 (McPhaden, 1999). This may explain why the 1990's exhibited such a hike in flood related deaths.

Drought related catastrophes are also common during ENSO events. In 1992 almost 80% of crops being grown in South Africa were destroyed. Fortunately, the government had been aware of this possibility from previous El Niño events (most recently, the strong 1982-1983 El Niño event) and had allotted funds to purchase foodstuffs in case the crops were destroyed. In areas of South America and Australia, drought resistant crops are now planted when an ENSO event is imminent. In the past, these areas have also suffered significant agricultural losses as a result of droughts (Kovats et al, 2003).

Diseases are also more likely to spread during El Niño events. A relationship between ENSO and the spread of diseases has been identified in at least 18 countries. Malaria transmission due to El Niño has specifically been found in areas of Venezuela and Colombia. Cholera transmission in Bangladesh is prevalent during ENSO events (Kovats et al, 2003).

The manner in which these diseases spread varies by the weather event taking place with respect to El Niño. In flood prone areas, it becomes a breeding ground for mosquitoes carrying malaria. In areas affected by drought, insects and rats may carry the diseases into the homes of the areas inhabitants. Famine and malnutrition are often a result of both flood and drought and make those living in the affected areas more prone to disease. As people migrate, they carry these diseases to other parts of their country and often infect those around them (Kovats et al, 2003).

c. How ENSO Affects the United States

It has been estimated that there have been $500 billion in losses due to natural disasters in the US during the period of 1980-1999. Approximately 80% of natural hazard losses from this time period can be attributed to climatological events (Beller-Simms, 2004). It has been estimated that the 1997-98 El Niño event cost the US $25 billion in economic losses alone (Hernandez, 2002). While ENSO events may vary in magnitude and extent, climatological data shows general characteristics associated with

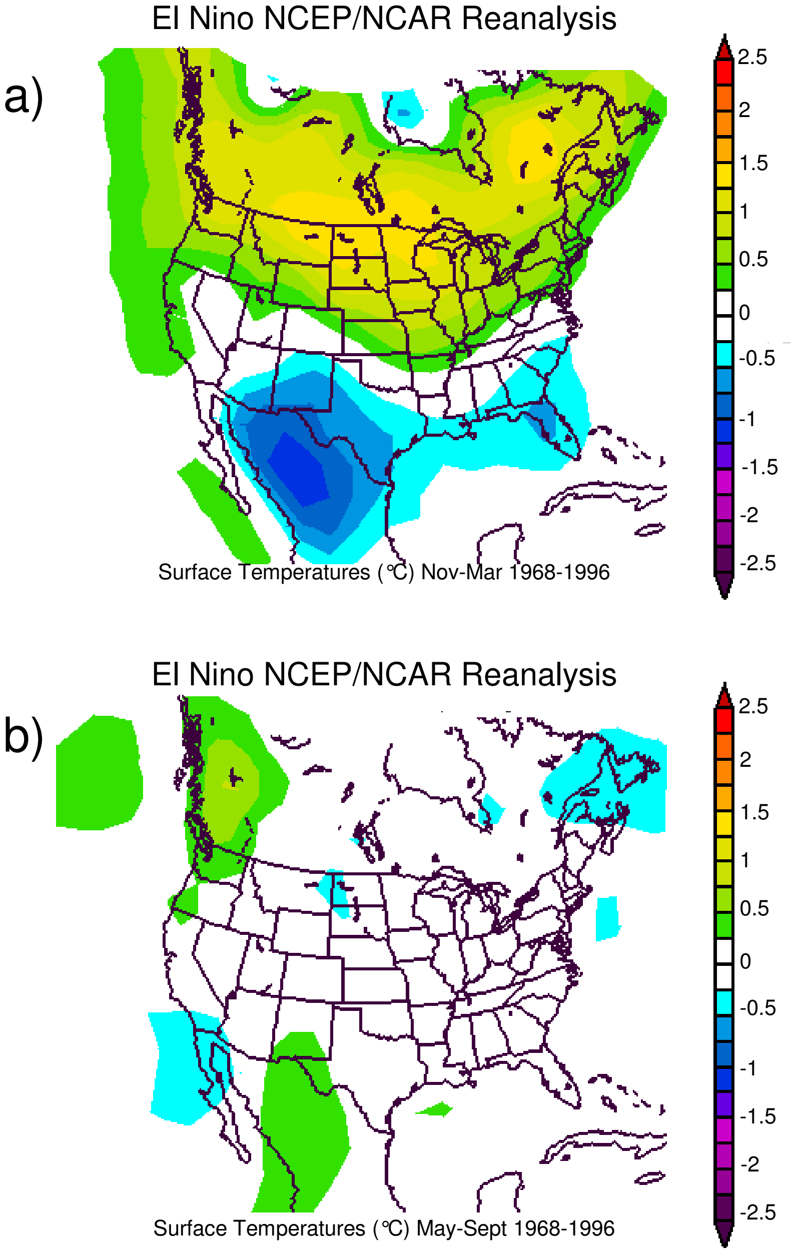


FIG. 3. Maps displaying temperature anomalies common during the winter (a) and summer (b) seasons of an El Niño event. Maps generated using the Earth System Research Laboratory's ENSO response software.

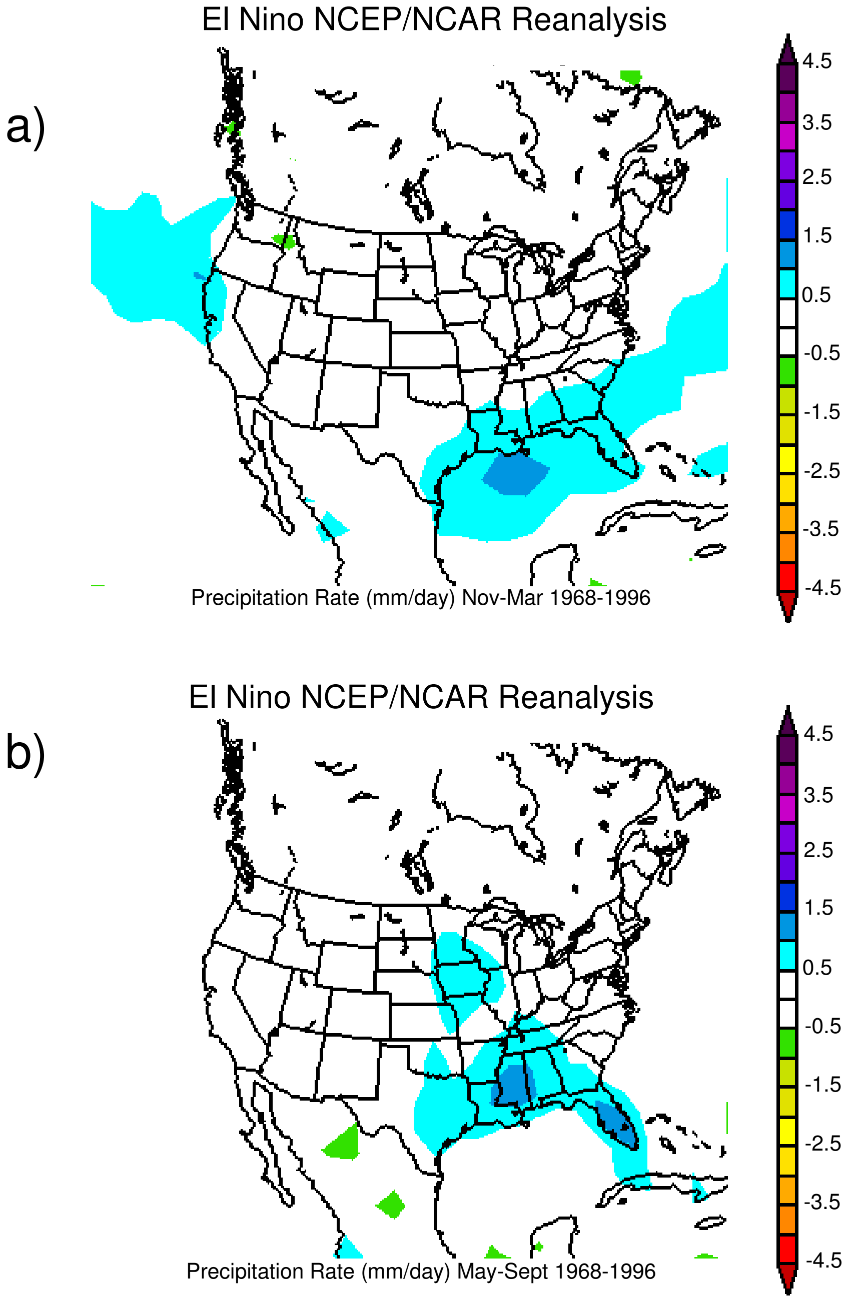


FIG. 4. Maps displaying precipitation anomalies common during the winter (a) and summer (b) seasons of an El Niño event. Maps generated using the Earth System Research Laboratory's ENSO response software.

El Niño that repeatedly occur within the United States during these events (Fig. 3 and Fig. 4).

Increased precipitation is a common characteristic of the Southwestern United States during an El Niño event (Beller-Simms, 2004). Additional areas of the US that exhibit above average rainfall are the Great Plains region and the East Coast (Ropelewski and Halpert, 1986). Drought conditions are typical of the Midwestern states but the extent of the drought often varies (Kunkel et al, 1999) (Fig. 5).

In the northwestern United States and Canada temperatures are warmer, thus there are fewer winter weather related deaths (Fig. 6). Warmer weather results in an increase in sales of merchandise, homes, and services. It has also been noted that milder conditions in the NW US will decrease energy consumption during the winter (Changnon, 1999). In the southwest US there is an observed decrease in average temperature (Ropelewski and Halpert, 1986).

The US typically does not suffer the same extent of losses as a result of ENSO events. The catastrophes experienced in less developed areas of the world are usually a result of poor mitigation planning. This is not to say that the extent of the losses in the US are not significant to the inhabitants of the affected areas and to the economy on both national and local levels.

Losses in crops due to drought may occur if the drought is extensive enough to warrant the mandatory conservation of water. During extreme drought events, an irrigation ban may be put in place on a local level. Mandatory water conservation was

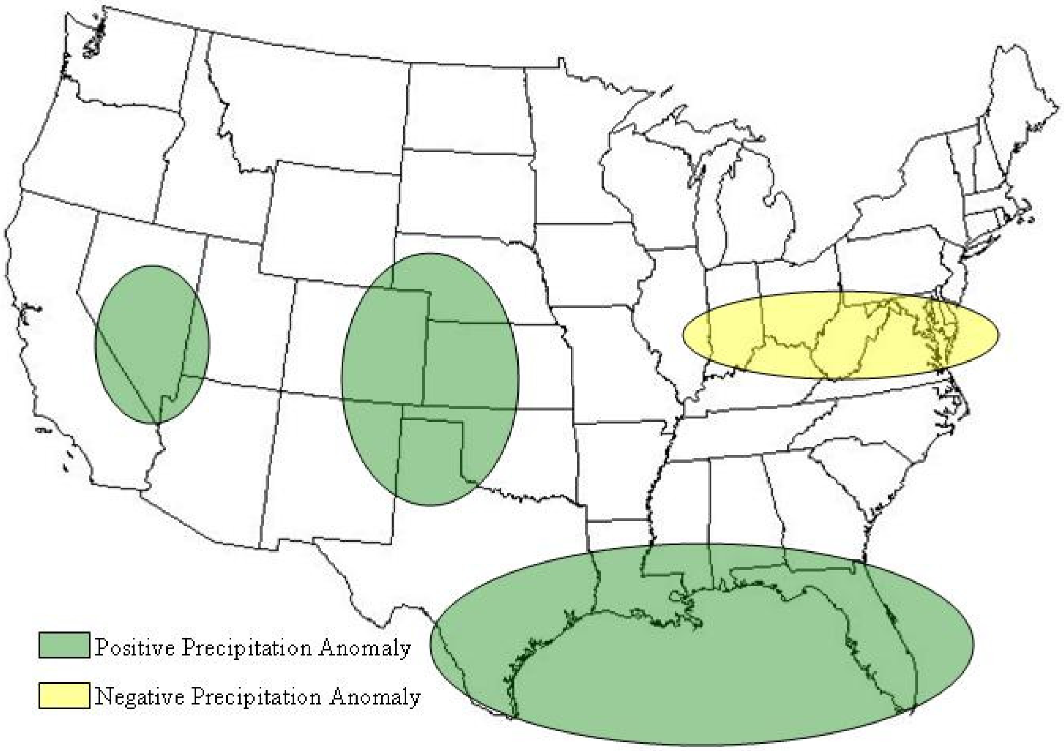


FIG. 5. Areas of the US that experience anomalous precipitation during ENSO events.

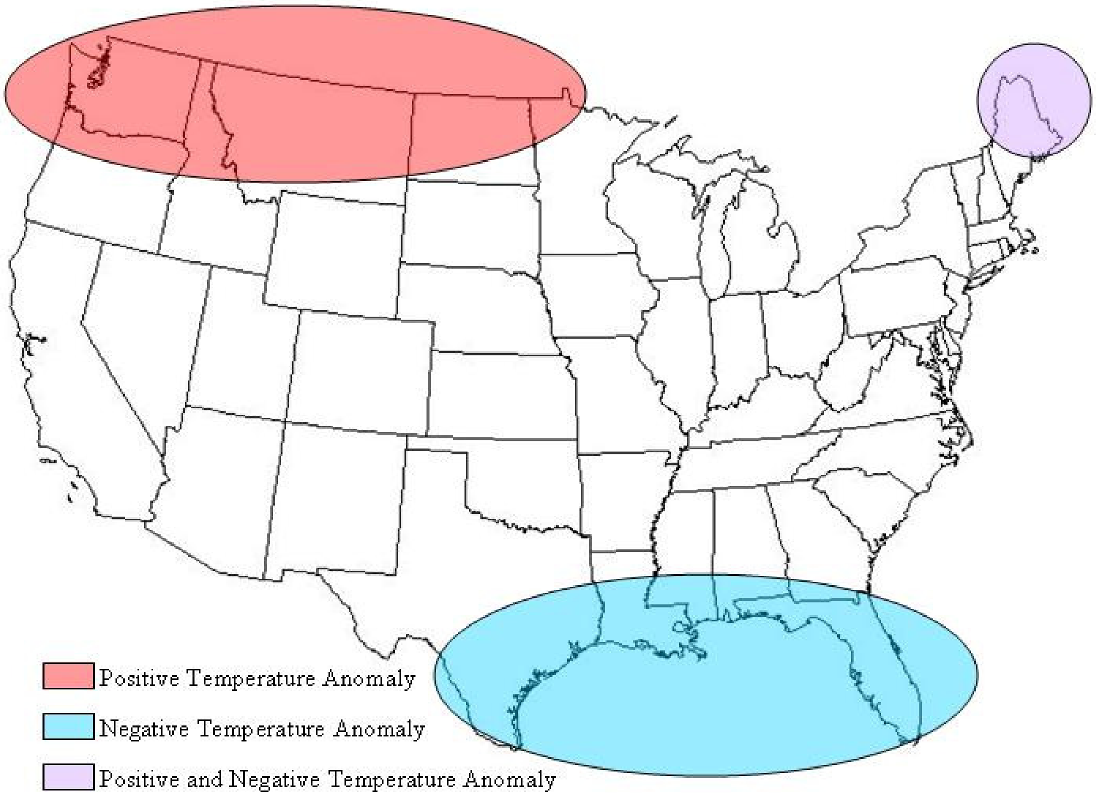


FIG. 6. Areas of the US that experience anomalous temperatures during ENSO events.

implemented in Iowa during the 1977 El Niño and resulted in the loss of a substantial portion of crops grown in that area (Lee, 1981).

Wildfires are often more extensive during ENSO events in the US. Areas with a noted decrease in precipitation during ENSO years are often more extensively burned by wildfires. In previous cases, the Federal Emergency Management Agency (FEMA) has worked with mitigation leaders to create liaisons between nearby counties and states in case they are needed to help battle blazes in Arizona, Oklahoma, and northern Texas. Residents of homes in affected areas were evacuated until the fires were under control (Beller-Simms, 2004). Though this is not unique to El Niño events, during these periods it is more likely that additional help will be needed in the affected areas.

In flood prone areas, drainage systems have been put in to place, bridges have been built, and retaining walls or dams erected. Numerous measures have been taken by the local government to guard life and property from damage due to flooding. These measures are especially important during El Niño years in places where the likelihood of severe flooding increases (Beller-Simms, 2004).

d. Implications of ENSO on Energy Consumption

A study conducted by Northern Illinois University's (NIU) meteorology program illustrated that based on temperature forecasts, the school would not need as much natural gas to warm the buildings during the 1997-1998 El Niño year as it would during non-El Niño years. Based on the results from the SST ENSO model they created to specifically show the local impact of El Niño, they were able to present their findings to the university's heating plant manager. The manager decided to go with a natural gas package that saved NIU approximately $500,000 (Changnon et al, 1999).

If the impacts of certain repeatable El Niño characteristics can be identified, as they were in the case at NIU, it will be possible for entities that consume energy to plan ahead. If energy production companies are aware how much consumption may be likely in a given time period, they can better prepare to meet their consumers' energy demands. These preparations will help keep the cost of energy production down, which will benefit both the production company and their customers.

e. Climate Forecasts

Various techniques have been used to predict climate. The simplest technique for predicting climate is the annual cycle; cold during the winter, hot during the summer. However, even the annual cycle is not so cut and dried. Variations with the annual cycle determine just how cold it may be during the winter and how warm it may get during summer months. Larger scale oscillations on periodic or quasi-periodic scales impact the climate in ways that may alter the weather from seasonal normals. The coupled ocean-atmosphere event known as El Niño is one of the most well-known quasi-periodic events (Glantz, 2001).

Climate forecasts are potentially more skillful during ENSO events than during non-ENSO events. Precipitation forecasts become especially skillful towards the ENSO event's peak in magnitude. The chance of a particularly skillful forecast doubles during ENSO extremes as relative to neutral conditions. This is because the signal, which is caused by boundary forcing due to changes in SST patterns, becomes more discernable through the general chaotic influences of the atmosphere's dynamics, or "noise" (Goddard and Dilley, 2005).

This El Niño signal is defined by the ability of climate models to pick up on the anomalies associated with an El Niño event. Forecasters who are familiar with the resultant anomalies introduced by El Niño can pick out this signal. By knowing what the repeatable characteristics of an El Niño event are for a certain area, it will make forecasters more likely to create accurate forecasts as long as the signal is indicated in the climate models.

However, climate forecasts are only significantly skillful over areas that exhibit significant repeatability in precipitation response to ENSO. It has been noted that only 20-30% of total land areas experience statistically significant repeatability in precipitation anomalies during ENSO events (Mason and Goddard, 2001). The same can be said for repeatability of temperature forecasts during El Niño episodes. Certain areas of the globe consistently experience temperature anomalies during ENSO. As shown by Ropelewski and Halpert, (1986), certain areas of the United States show a coherent temperature increase or decrease during an El Niño event.

f. Energy Load Forecasts

Energy load forecasts are used to predict how much energy demand there will be on a given day. Commonly, energy companies will employ meteorologists and statisticians to provide comprehensive analysis of future weather forecasts and the amount of energy that is likely to be consumed as a result of the weather. The forecasts specifically aimed at the amount of energy that will be consumed in the immediate future are done with a lead-time of several days. Additional forecasts may be made months in advance in order to give an energy production company an idea of the quantity of energy that will be necessary to meet the energy demand in future seasons (Katz and Murphy, 1997).

If an energy load forecast is too low, the energy generators must be readied in a short amount of time, which leads to higher production costs and higher prices for the end user (Teisberg et al, 2005). Additional fuel and maintenance costs will also be incurred when a short lead-time is given. The production company could run into the issue of an insufficient amount of resources available to produce the necessary energy to meet the demand. If given a long enough lead-time, lower cost energy sources could have been used to produce the power. The methods used to produce electricity from these lower cost energy sources require a longer lead-time in order to produce an adequate amount to meet demand. The use of these energy sources depends heavily on the availability of the source. If the source is not readily available, a more expensive energy source will be utilized to meet the demand. Some companies enter into sale commitments, which means that the energy is sold at a fixed price. A blown forecast in this situation can mean a serious loss of revenue for the company (Hobbs et al, 1999).

Conversely, if the load forecast is too high, too much energy may be generated which leads to energy “waste” (Teisberg et al, 2005). In the case of over-forecasting, the monetary losses are due to the expenditure of the company to produce more energy than is necessary to meet the demand. Again, additional fuel and maintenance costs would be incurred because of the additional time spent generating energy that was not needed (Hobbs et al, 1999).

For operational purposes, time-series analyses using non-seasonal Auto-Regressive Integrated Moving Average (ARIMA) models or other spectral methods are good at forecasting energy loads in the short term. Typically, these methods are producing only 1-2% errors, which mean that short-term forecasts are fairly accurate. Medium range forecasts using this method however are not as accurate but they do provide a basis for planning energy loads for future weeks (Bunn, 2000).

Many companies have implemented the practice of hourly or half hourly load forecasts. It has been shown that using individual regression models for each hour actually out-performs the less advanced approaches for forecasting energy loads (Ramanathan et al, 1997). Using these individual hourly regressions has allowed for the implementation of this method into a more computationally intensive strategy that could lower the amount of error in the forecasts even further (Bunn, 2000). A reduction of error by even just 1% is estimated to save hundreds of thousands to even millions of dollars (Hobbs et al, 1999).

Neural networks have become popular for making energy load forecasts. These highly parameterized, general purpose models learn complex input and output relationships. Because the load data is systematic and has few structural changes, the results issued by the neural network are very reliable. In 1999, the second version of the Electric Power Research Institute's (EPRI) artificial neural network short-term load forecaster (ANNSTLF) was reportedly adopted by 40 North American utility companies (Bunn, 2000).

g. Heating Degree Days and Cooling Degree Days

Heating degree days (HDDs) and cooling degree days (CDDs) are measurements used in the energy industry to determine what demand for a certain commodity may be. HDDs occur when the average daily temperature is below 65°F (18°C). They are called HDDs because it is assumed that when the temperature drops below 65°F people will turn on their furnaces. Conversely, CDDs occur when the average daily temperature is above 65°F. As the temperature rises above 65°F, the assumption is made that people will turn on their air conditioners (Ahrens, 2007).

A simple calculation is needed to find the number of HDDs or CDDs for a certain period of time. Equation (1) is used when the average temperature for the area under consideration is larger than 65°F and equation (2) is used for average temperature values less than 65°F.

$$\text{Average Temperature} - 65 = \text{CDDs} \tag{1}$$

$$65 - \text{Average Temperature} = \text{HDDs} \tag{2}$$

The term “days” is somewhat confusing. For example, if the average temperature for May 22 in College Station, Texas is 77°F, the CDDs value for that day is 12. The larger the CDD value becomes, the more power that will be necessary to cool a property located in College Station. The same is true for HDDs. The larger the HDD value is, the more power that will be necessary for heating.

Sensitivity is found to be greater with respect to HDDs than CDDs (Valor et al, 2001). Errors may be + or – 2% when predicting electricity demand associated with cooling, while errors are on the order of + or – 4% with regard to heating. In most parts of the US there are more HDDs than CDDs in a given year. More energy will be expended on heating than on cooling in these areas. It is therefore likely that there will be more forecast error based on the number of days a forecast will be needed for HDDs versus CDDs.

3. DATA

Multiple data sources were necessary to complete this study. Energy data are available on a limited basis to the public. Basic energy statistics are accessible on an annual basis, but not on a monthly basis, which would have been best for this study. Climate data were much easier to find via the government entities that catalogue such data for public use.

a. Energy Data

The Energy Information Administration (EIA) provides official energy statistics approved by the US Government. Annual information offers a complete climatological (30-year) data set while monthly data is only available for a recent 3-year time period (January 2004- December 2006). This study will focus on the consumption of energy for the purposes of heating and cooling in residential, commercial, and industrial settings.

National data regarding the consumption of individual fuel sources and a general overview of consumption is available dating back to 1949. However, complete, consecutive yearly data are not available until 1970. Not all energy data sets have information available after 2000. Therefore the time period of 1970-2000 will be considered since 30 years worth of consecutive data are needed for a valid climatological analysis. This study will focus on coal, natural gas, and both hydroelectricity and nuclear electricity consumption.

Yearly consumption data by state are available from 1960-2003 and yearly pricing and expenditure data are available from 1970-2003. State data also offers consumption information for individual energy sources. The same types of energy will be considered at this level. State data for Washington, Montana, Texas, and Florida will be examined. The reason for the selection of these states is explained in section 4b. Listings of the exact sources for the energy consumption data are located in Appendix A. Data concerning electricity generation imports and exports was also used to examine the flow of electricity between neighboring states.

Data from the EIA are quality controlled by the US Department of Energy. All energy data are collected via surveys which are typically handled by the Census Bureau. Two supervisors under the Office of Management and Budget (OMB), the Sponsoring Office Director and a Statistics and Methods Group (SMG) Director, must agree on the collection methods, processing requirements, and dissemination procedures. All of the data that are collected and analyzed must be approved by the OMB before it is made available to the public. A full listing of the requirements can be accessed via the websites listed in Appendix A.

b. Temperature Data

Temperature data for this study will be obtained from the NOAA Climate Diagnostic Center (CDC). The CDC provides a wide range of climatological data that covers an extensive period from 1895 to present. The majority of the data options are available for consecutive time periods beginning in 1948. This includes daily, monthly, and yearly data sets. Based on the available data concerning energy forecasts, temperature data will be needed from 1970 to 2000 to complete this analysis.

Temperature data needed for each state are available using the CDC US Climate Division data. This option allows for the creation of monthly or seasonal time series of temperature averaged over the whole area of the selected state. The temperature information has been bias corrected by each state climatic division. This includes removing any anomalous readings resulting from instrument malfunction, correcting the values for readings taken at different times of the day; etc. National plots were created to display the average annual temperature of each state. Also, the difference between the average annual temperature and the average El Niño year temperature were plotted to illustrate any associated anomalies.

Heating degree day (HDD) and cooling degree day (CDD) data were made available by the National Climatic Data Center (NCDC). Monthly HDDs and CDDs could be looked at per state and census division. The state data will be used to correspond to those states chosen for the study. Each state was chosen based on where the strongest temperature anomalies occur in the US.

c. Precipitation Data

State precipitation data were also obtained using the bias corrected data available through the CDC. The same control method was applied to this data by the state climatic divisions to account for any biasing. State and national precipitation averages were computed using same method that was applied to the temperature data.

d. El Niño Data

Temporal El Niño information from the NOAA Climate Prediction Center (CPC) will be used for the period of 1970-2000. The periods of time defined as El Niño events were determined by the CPC using a threshold of 0.5°C above average sea surface temperature (SST). SST measurements were taken in the NINO 3.4 region which is located between 5°N-5°S and 120°-170°W (Fig. 7). The Oceanic Niño Index (ONI) is based on the 3-month running mean of SST values from within this region of the tropical Pacific. The warm anomaly must be in place during five consecutive 3-month periods to constitute as an El Niño (www.CPC.noaa.gov). The bold values on Table 1 indicate the seasons considered to be experiencing an El Niño event, italicized values indicate a La Niña and numbers normal text indicate neutral periods.

NINO 3.4 Index values were obtained from the National Center for Atmospheric Research's (NCAR) Earth-Sun Systems Laboratory's (ESSL) Climate and Global Dynamics (CGD) division. In this area, shifts in the local SSTs are important for shifting large regions of rainfall. In this case, NINO 3.4 is used because the shift in the location of rainfall influences the atmospheric circulation (IRI, 2007).

The values of this index indicate how much above or below normal SSTs are in the region. The values are available on a monthly basis. For the purpose of this project the monthly values were averaged so that they could be used on an annual basis with the energy data. Sources for the climate data can be found in Appendix B.

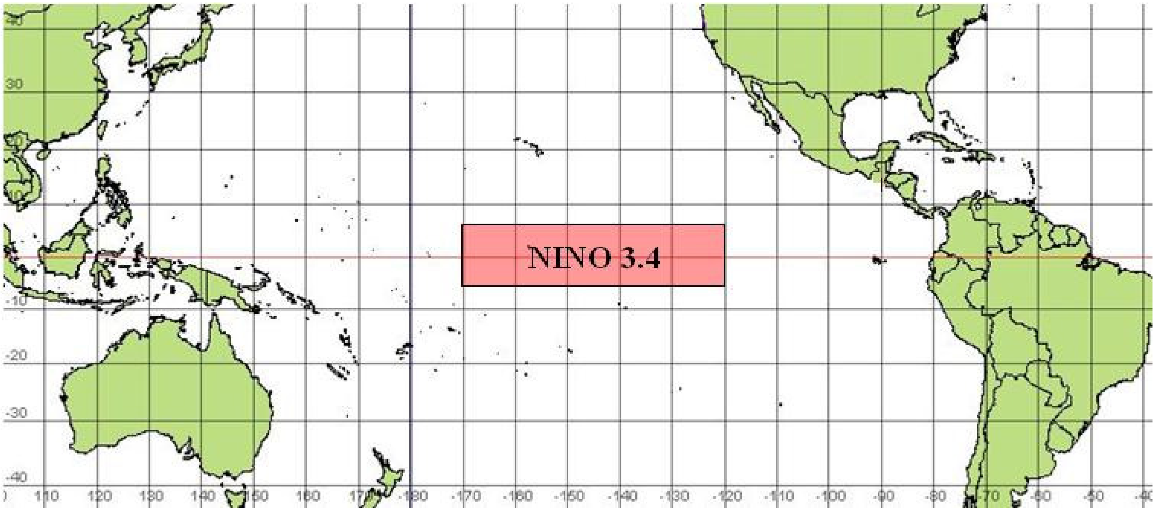


FIG. 7. The NINO 3.4 region, located in the Pacific Ocean, is bounded by 120°W-170°W and 5°S- 5°N.

TABLE 1. El Niño conditions (in bold) and La Niña conditions (in italics) based on SST values from the NINO 3.4 region in the Pacific Ocean. Five or more consecutive seasons of SST departures greater than or equal to 0.5°C qualify as an ENSO event.

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1970	**0.5**	0.3	0.2	0.1	-0.1	-0.4	*-0.6*	*-0.8*	*-0.8*	*-0.8*	*-0.9*	*-1.2*
1971	*-1.4*	*-1.4*	*-1.2*	*-1.0*	*-0.8*	*-0.8*	*-0.8*	*-0.8*	*-0.9*	*-0.9*	*-1.0*	*-0.9*
1972	*-0.7*	-0.3	-0.0	0.3	**0.5**	**0.8**	**1.1**	**1.3**	**1.5**	**1.8**	**2.0**	**2.1**
1973	**1.8**	**1.2**	**0.5**	-0.1	*-0.5*	*-0.8*	*-1.1*	*-1.3*	*-1.4*	*-1.7*	*-1.9*	*-2.0*
1974	*-1.8*	*-1.6*	*-1.2*	*-1.1*	*-0.9*	*-0.7*	*-0.5*	-0.4	*-0.5*	*-0.7*	*-0.8*	*-0.7*
1975	*-0.6*	*-0.6*	*-0.7*	*-0.8*	*-1.0*	*-1.1*	*-1.3*	*-1.4*	*-1.6*	*-1.6*	*-1.7*	*-1.8*
1976	*-1.6*	*-1.2*	*-0.9*	*-0.7*	*-0.5*	-0.2	0.1	0.3	**0.5**	**0.7**	**0.8**	**0.8**
1977	**0.6**	**0.5**	0.2	0.1	0.2	0.3	0.3	0.4	**0.5**	**0.7**	**0.8**	**0.8**
1978	**0.7**	0.4	0.0	-0.3	-0.4	-0.3	-0.4	-0.5	-0.5	-0.4	-0.2	-0.1
1979	-0.1	0.0	0.1	0.2	0.1	0.0	0.0	0.2	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	0.0	0.0	-0.1
1981	-0.3	-0.4	-0.4	-0.3	-0.3	-0.3	-0.4	-0.3	-0.2	-0.1	-0.1	-0.1
1982	0.0	0.1	0.2	0.4	**0.6**	**0.7**	**0.8**	**1.0**	**1.5**	**1.9**	**2.2**	**2.3**
1983	**2.3**	**2.0**	**1.6**	**1.2**	**1.0**	**0.6**	0.2	-0.2	*-0.5*	*-0.8*	*-0.9*	*-0.8*
1984	*-0.5*	-0.3	-0.2	-0.4	-0.5	-0.5	-0.3	-0.2	-0.3	*-0.6*	*-1.0*	*-1.1*
1985	*-1.0*	*-0.8*	*-0.8*	*-0.8*	*-0.7*	*-0.5*	-0.4	-0.4	-0.4	-0.3	-0.2	-0.3
1986	-0.4	-0.4	-0.3	-0.2	-0.1	0.0	0.2	**0.5**	**0.7**	**0.9**	**1.1**	**1.2**
1987	**1.3**	**1.2**	**1.1**	**1.0**	**1.0**	**1.2**	**1.5**	**1.6**	**1.6**	**1.5**	**1.3**	**1.1**
1988	**0.8**	**0.5**	0.1	-0.3	*-0.8*	*-1.2*	*-1.2*	*-1.1*	*-1.3*	*-1.6*	*-1.9*	*-1.9*
1989	*-1.7*	*-1.5*	*-1.1*	*-0.9*	*-0.6*	-0.4	-0.3	-0.3	-0.3	-0.3	-0.2	-0.1
1990	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.4
1991	0.5	0.4	0.4	0.4	**0.6**	**0.8**	**0.9**	**0.9**	**0.8**	**1.0**	**1.4**	**1.7**
1992	**1.8**	**1.7**	**1.6**	**1.4**	**1.1**	**0.8**	0.4	0.2	-0.1	-0.1	0.0	0.1
1993	0.3	0.4	**0.6**	**0.8**	**0.8**	**0.7**	**0.5**	0.4	0.4	0.3	0.2	0.2
1994	0.2	0.3	0.4	**0.5**	**0.6**	**0.6**	**0.6**	**0.6**	**0.7**	**0.9**	**1.2**	**1.3**
1995	**1.2**	**0.9**	**0.7**	0.4	0.2	0.1	0.0	-0.3	*-0.5*	*-0.6*	*-0.7*	*-0.8*
1996	*-0.8*	*-0.7*	*-0.5*	-0.3	-0.2	-0.2	-0.1	-0.2	-0.2	-0.2	-0.3	-0.4
1997	-0.4	-0.3	0.0	0.4	**0.9**	**1.4**	**1.7**	**2.0**	**2.3**	**2.4**	**2.5**	**2.5**
1998	**2.4**	**2.0**	**1.4**	**1.1**	0.4	-0.1	*-0.8*	*-1.0*	*-1.1*	*-1.1*	*-1.3*	*-1.5*
1999	*-1.6*	*-1.2*	*-0.9*	*-0.7*	*-0.8*	*-0.8*	*-0.9*	*-0.9*	*-1.0*	*-1.2*	*-1.4*	*-1.6*
2000	*-1.6*	*-1.5*	*-1.1*	*-0.9*	*-0.7*	*-0.6*	-0.4	-0.3	-0.4	*-0.5*	*-0.7*	*-0.7*

4. METHODS

The determination of whether the El Niño/Southern Oscillation has an influence on energy consumption in the United States was a two-scale study. This analysis first considered national data to determine if there was an ENSO signal in the consumption of coal, natural gas, or electricity. Then the same analysis method was applied to regions of the United States exhibiting a coherent response in either temperature or precipitation to ENSO episodes. A limited amount of national monthly data was also used to determine how the seasonal cycle is important in the consideration of each energy type.

a. National Study Area

First, energy and temperature data was examined for the continental United States. A national overview of energy consumption during El Niño and non-El Niño years was performed. These results gave a broad overview of what the continental US typically experiences in terms of energy usage trends during an El Niño year.

A five-year running average was applied to energy data from 1970-2000. This takes into account the natural consumption increase with time (i.e. population growth). Seven and nine-year running-averages were also considered but using a longer averaging period did not significantly change the results of the analysis. Coal, natural gas, and electricity (nuclear and hydrological) were treated separately at first. Once the running-average of the data was determined, the difference between the averaged data and the raw data was calculated to deduce the deviations in consumption per year, or the “anomalous consumption.”

Once we deduced a value for the anomalous consumption it was plotted against the NIÑO 3.4 Index to determine if there was a positive or negative correlation in consumption of a specific energy type. Plots of average temperature versus power consumption were also generated. This same process was repeated for all energy types together to determine if there is an overall trend in US energy consumption.

The standard deviation for all consumption data was calculated to determine the typical departure of the data from the mean consumption value. A compositing technique was also applied to El Niño and non-El Niño years. It is through this technique that it was possible to assign a dollar amount to the change in consumption from El Niño years to non- El Niño years. It was not possible to apply this same procedure to hydro-electricity and precipitation data because monetary values for the price of hydro-electricity are not available.

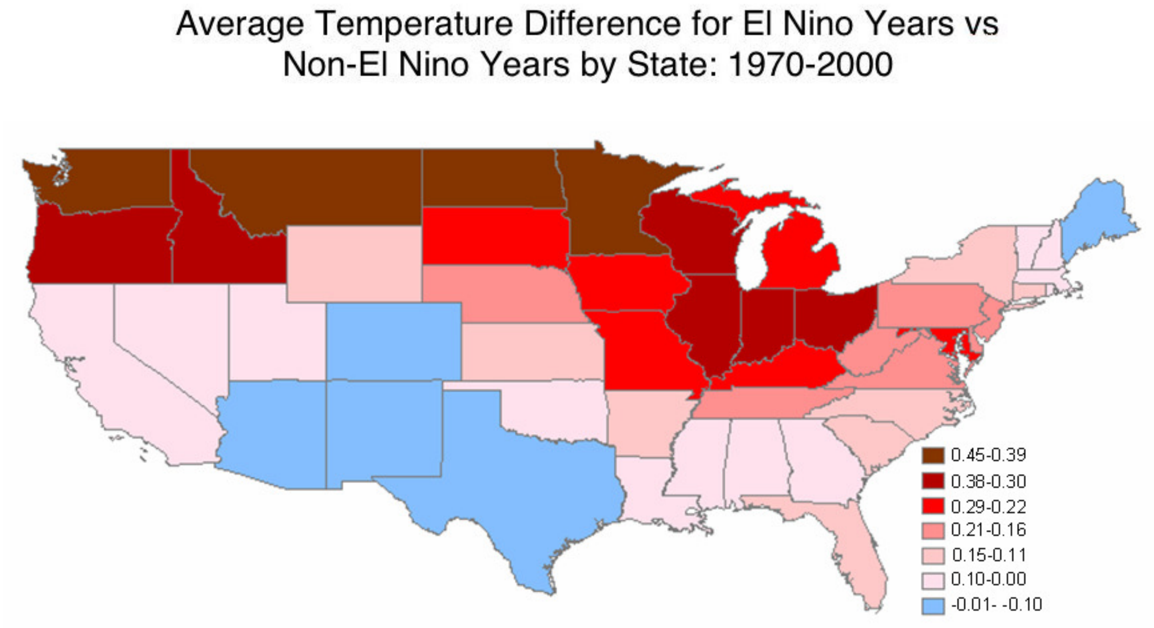
b. Regional Study Area

Once the trends at the national level were examined, energy data was analyzed for several specific regions. First, plots of temperature and precipitation anomalies associated with El Niño events were created for the study period of 1970-2000. The initial regions of the US chosen for this study originated from this analysis. Several regions were identified as exhibiting a coherent climate anomaly during an ENSO event. Some areas exhibit anomalous temperature fluctuations while others show a response in precipitation amount.

Four areas of the United States were identified as having a robust temperature response to El Niño (Fig. 8). They are 1) Southeast United States (SEUS) which includes Louisiana, Mississippi, Alabama, Georgia, and Florida, 2) Southwestern United States which includes Texas, New Mexico, Arizona, and Colorado, 3) Northwest United States (NWUS) which includes Washington, Montana, North Dakota, and Minnesota, and 4) Northeastern United States (NEUS) which includes the New England states.

It is important to note that the NEUS does not show a definitive negative or positive temperature departure (Ropelewski and Halpert, 1986). However, Figure 8 shows that Maine has experienced a negative temperature anomaly during ENSO years for this study period. Since it is likely the data may be skewed by one or two very strong negative temperature episodes in that region associated with strong ENSO events, states from this region will not be analyzed on the regional scale.

The NWUS shows a definite positive departure in temperature during El Niño events while the SEUS and SWUS show a definite negative departure. States were chosen from these defined regions based on Figure 6 and the results of the temperature analysis for the period 1970-2000 (Fig. 9). From the NWNA region, Montana and Washington will be used. Florida will represent the SEUS and Texas will represent that SWUS. These states represent the areas of the US whose temperatures are most greatly affected by El Niño. Another reason Texas has been chosen is because this study is based out of Texas A&M University.



Average Temperature Difference for El Nino Years vs Non-El Nino Years by State: 1970-2000

FIG. 8. El Niño temperature difference map made using state temperature data from 1970-2000. Blue indicates a negative temperature anomaly during an El Niño event and red indicates a positive temperature anomaly during an El Niño event.

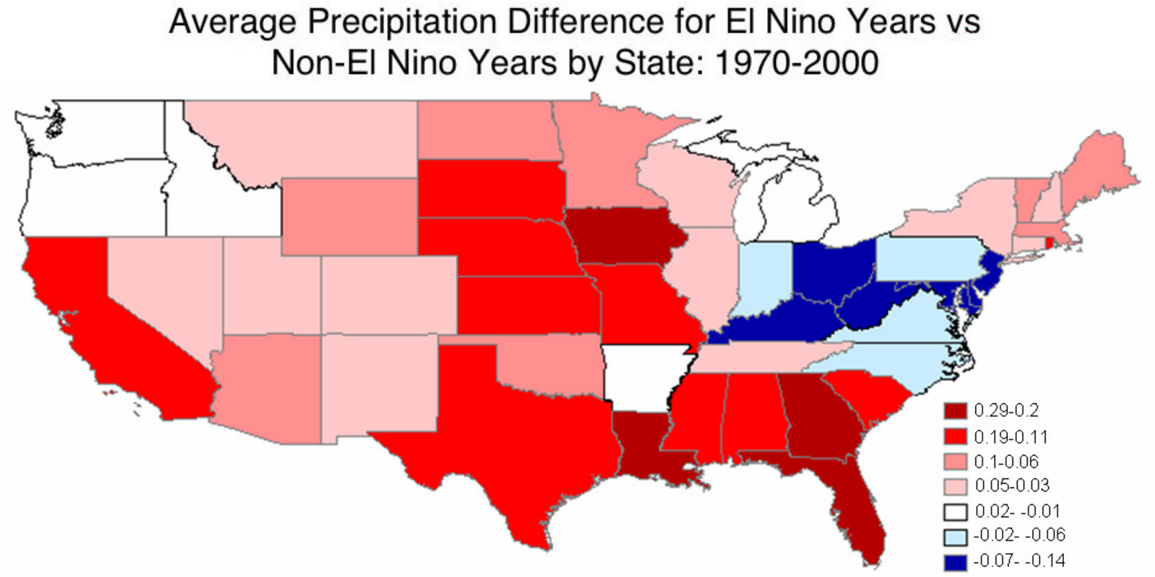


FIG. 9. El Niño precipitation difference map made using state precipitation data from 1970-2000. Blue colors indicate monthly negative anomalous rain fall amounts and red colors indicate monthly positive anomalous rainfall amounts.

Heating degree days (HDDs) and cooling degree days (CDDs) were examined at both annual and monthly scales by state. Florida, Montana, Texas, and Washington HDDs and CDDs were analyzed for the period of 1970-2000 because these were the states chosen that showed a coherent temperature fluctuation during ENSO events. The HDDs and CDDs were plotted against the NINO 3.4 Index to determine whether an ENSO signal was prevalent amongst the data on an annual scale or during certain months of the year.

Areas were also identified that had a coherent precipitation response to El Niño. From the graphics created using precipitation data from 1970-2000, it is evident that the SEUS and Great Plains also receives an increase in precipitation during El Niño events. In Ohio, Kentucky, and West Virginia there is a precipitation deficit during these events.

The states chosen to examine how precipitation affects energy consumption were Florida, Kansas, Nevada, Texas, and West Virginia. Hydroelectricity data for these particular states were examined to determine if an electricity generation signal was present during El Niño years. The same quantitative processes used on the national data were applied to the state data.

5. RESULTS

The results of this study focus on findings at the national and regional level. The following is an overview of the findings from this analysis of temperature, precipitation and energy data. Additional information can be found in the figures associated with this section or in the appendices indicated throughout the text.

a. National

The energy consumption signals on a monthly scale for the national data were considered. This was done so that the pattern of consumption for each energy type could be better understood. Since monthly energy data is not available on a climatological time-scale, the few available years were graphed to look at the positive and negative extrema in usage for each energy type. By observing the trends illustrated by the graphs, the typical energy footprint for each type of fuel can be identified within the seasons of the year. These trends are also complemented by the HDD and CDD graphs, which show the peak months of the year for heating and cooling of homes and businesses (Fig. 10 and Fig 11).

Coal exhibits peak usage in the continental US in August. A secondary peak is present in January and December. The main peak in coal usage corresponds to the peak usage time for air conditioners. The secondary peak occurs around the holidays when people will be using additional electricity and will be in need of heat for their homes. The lowest usage of coal occurs in April with a secondary low in October and

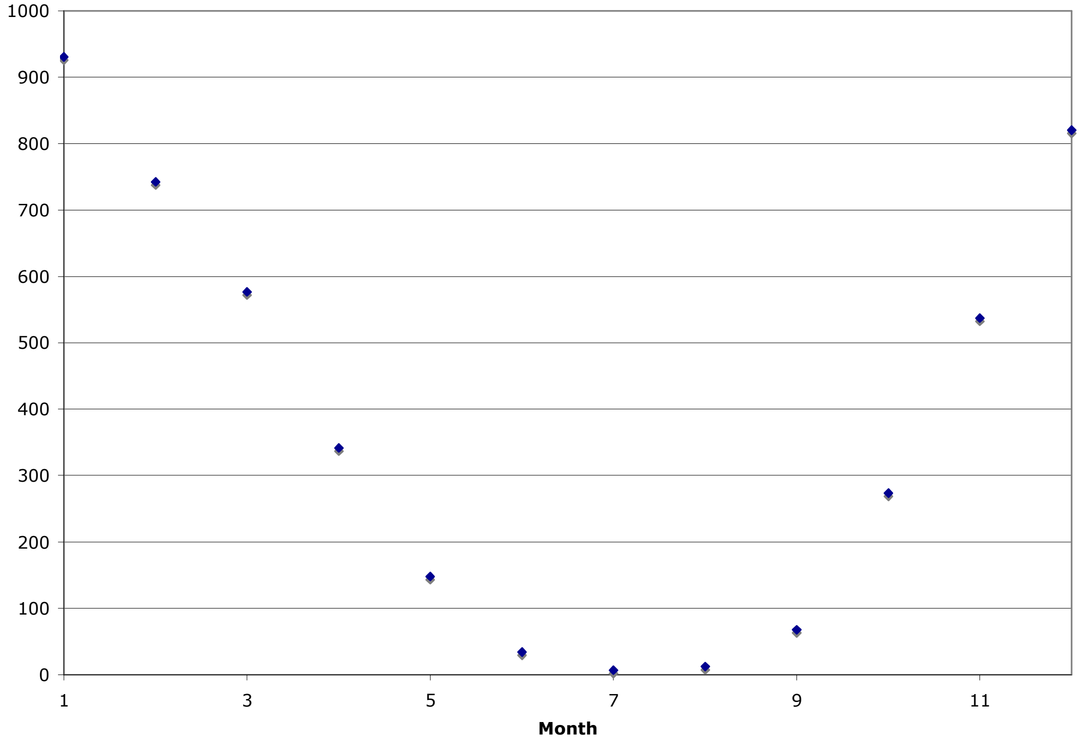


FIG. 10. Average monthly population weighted HDDs at the national level as a function of calendar month.

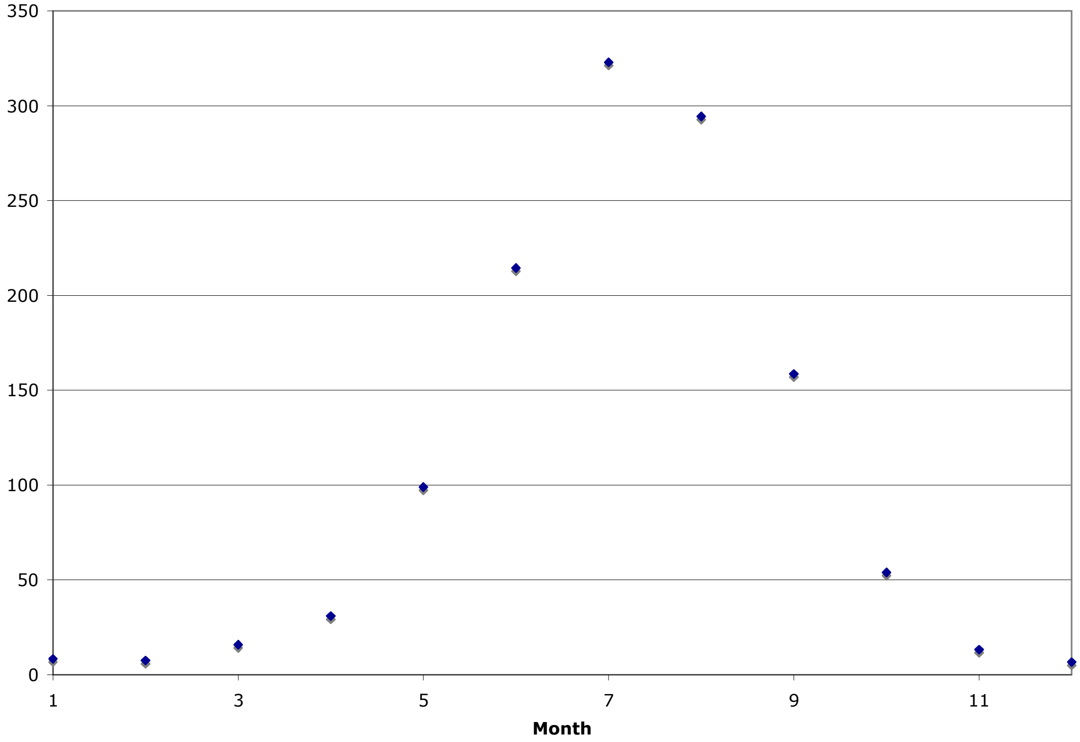


FIG. 11. Average monthly population weighted CDDs at the national level as a function of calendar month.

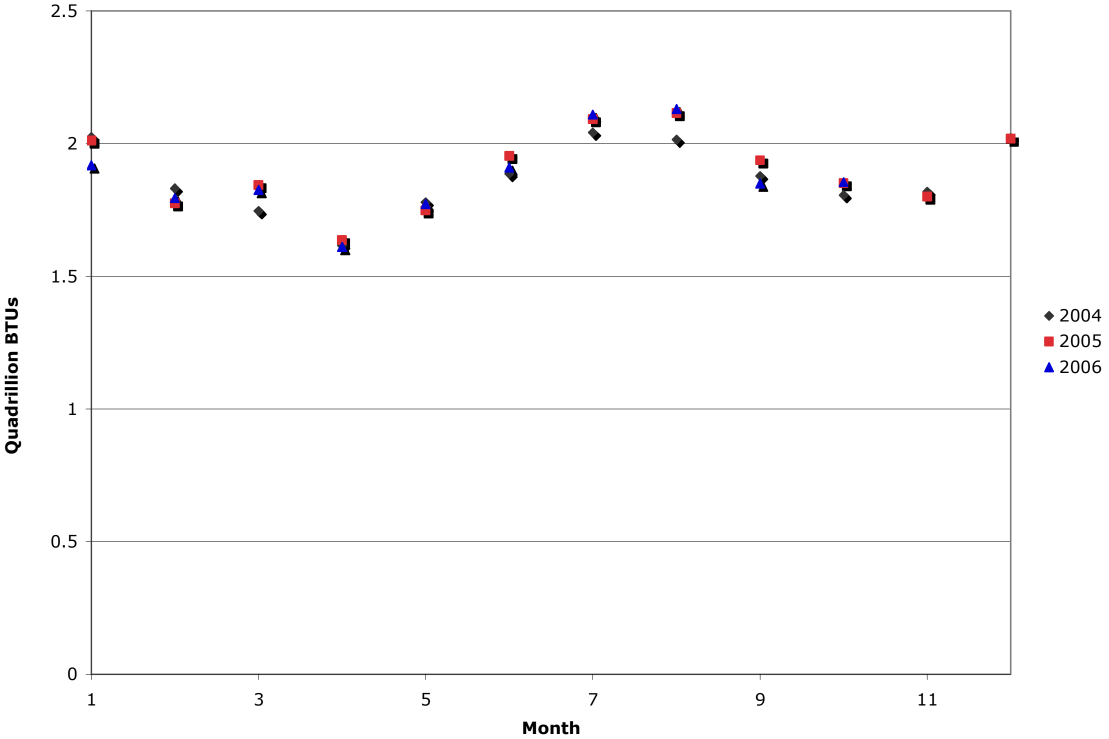


FIG. 12. Monthly coal consumption on a national scale.

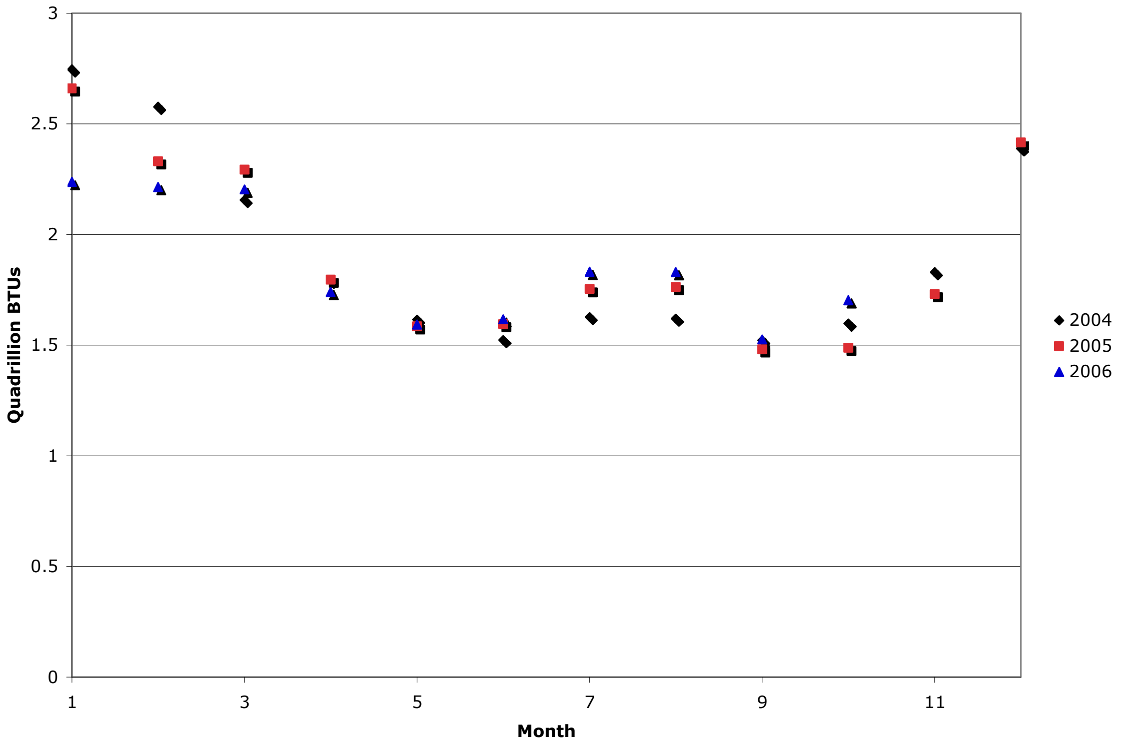


FIG. 13. Monthly natural gas consumption on a national scale.

November. This is because these are not months in which air conditioners and heaters are typically necessary (Fig. 12).

As a typical fuel used for heating homes, it is no surprise that annually natural gas has its peak usage during December, January, and February. The lowest consumption typically occurs from May-October each year (Fig. 13). This minimum in consumption is due to the fact that temperatures during the months of May-October do not necessitate home heating.

Nuclear electricity has two peaks. The first, in December and January, is due to the fact that people spend more time inside during these months meaning more electricity is consumed due to the additional use of lights, electronics, appliances, etc. One of the key factors contributing to this increase in usage during these winter months is the use of nuclear electricity as a source for home heating during these months. The second peak occurs in July and August, resulting from increased use of nuclear electricity to cool commercial and residential buildings. The lowest usage months for this commodity are April and October, which climatologically exhibit milder temperatures (Fig. 14) (EIA - see Appendix A).

Hydroelectricity, which is dependent on rainfall amounts to drive its production, peaks in May, with a secondary peak in January. Springtime in the Northwestern US is associated with snowmelt. This would supply companies producing hydroelectric power with the means to produce more. Rain would also add additional water for generating hydroelectricity. The lowest consumption values occur in September and October when there is little to no snowmelt to drive stream flow (Fig. 15) (NCDC 1 - see Appendix B).

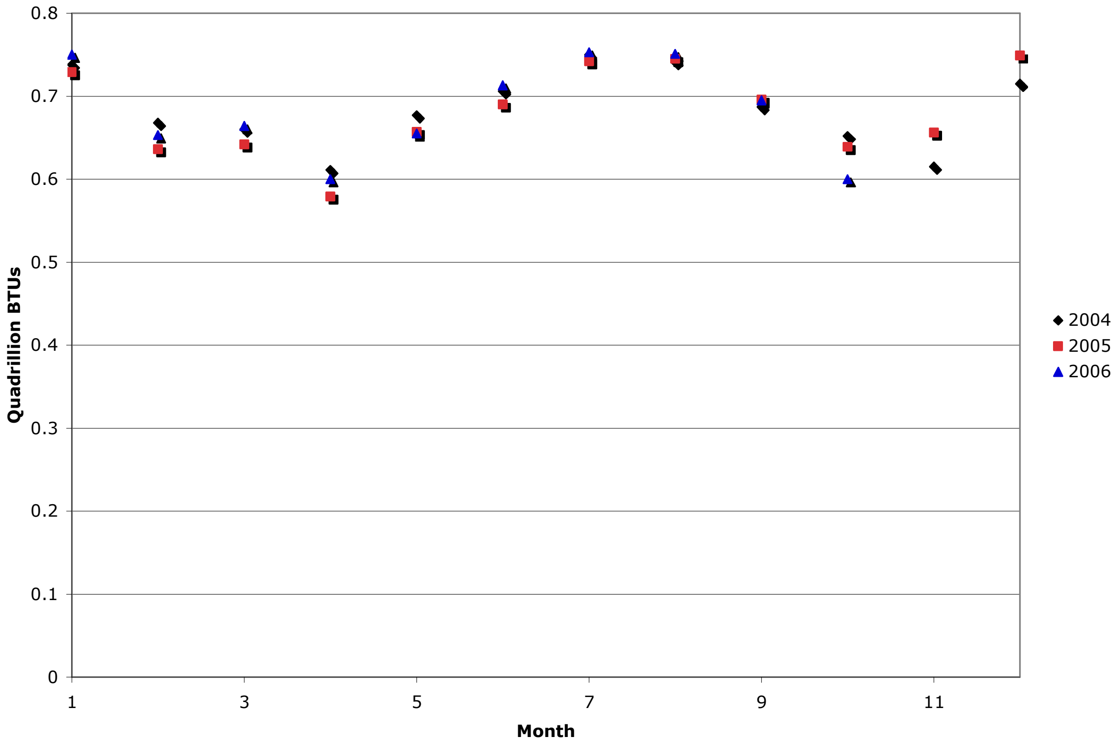


FIG. 14. Monthly nuclear electricity consumption on a national scale.

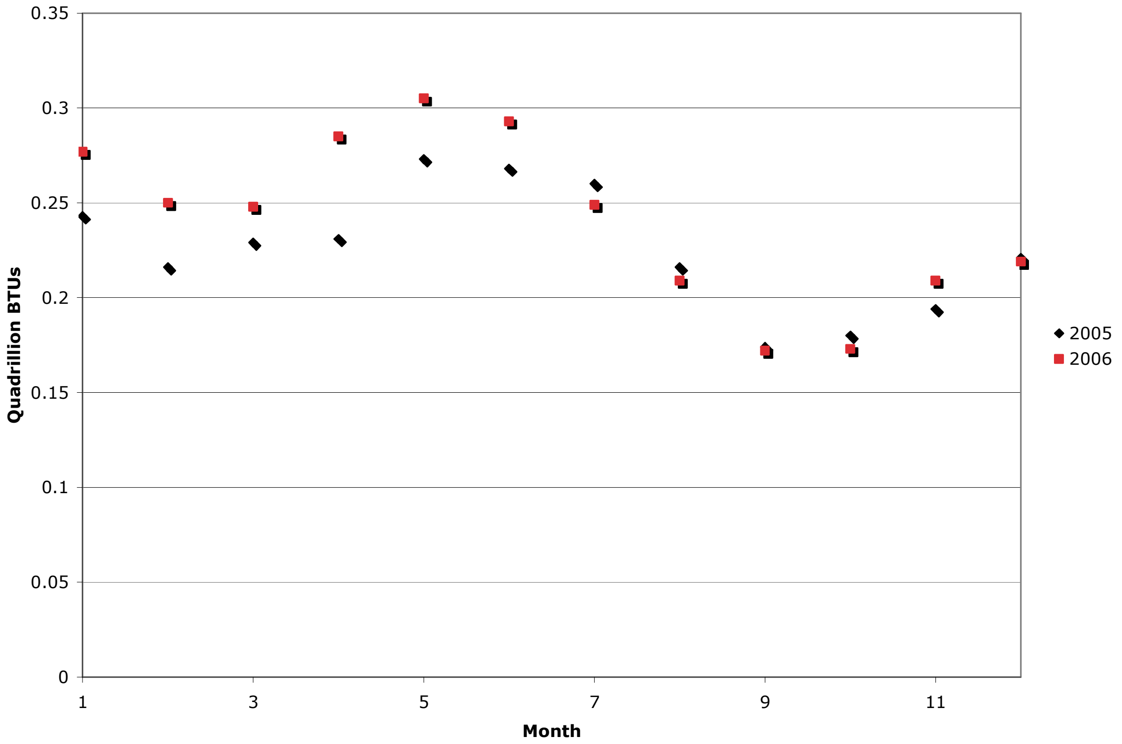


FIG. 15. Monthly hydro-electricity consumption on a national scale. Data only available from 2005-2006.

The annual average temperature for the continental US is 52°F and the mean annual rainfall is 30.22 inches per year (NCDC 2 - see Appendix B). The national energy data reflects this average; meaning detecting discrete responses to El Niño may be more difficult using annual national data. However, even with all the noise from the states that are not significantly impacted by temperature or precipitation anomalies during ENSO events, there are still significant results within the national data.

Using a 95% confidence interval for 31 years worth of data indicates that squared-correlation (r^2) values greater than or equal to 0.13 are statistically significant. If the values are less than 0.13 this indicates that there is a more than 1 in 20 chance that the assumption that the response can be attributed to El Niño will be wrong. This chance of being incorrect increases the further below 0.13 the value becomes. However, if the r^2 value is greater than 0.13, there is a greater than 95% chance that the assumption made will be correct.

The squared-correlation between anomalous national consumption from all energy sources and the NINO 3.4 Index is 0.04, which is not significant. The slope for national anomalous consumption is negative. This means that as the NINO 3.4 Index values increase, anomalous consumption decreases (Fig. 16). However, this value (r^2=0.04) is not statistically significant.

Coal, natural gas, and hydroelectricity consumption at a national level do not reflect significant anomalous usage. However, nuclear electricity does show a coherent response to the NINO 3.4 Index. Nuclear electricity has an r^2 value of 0.14, which means

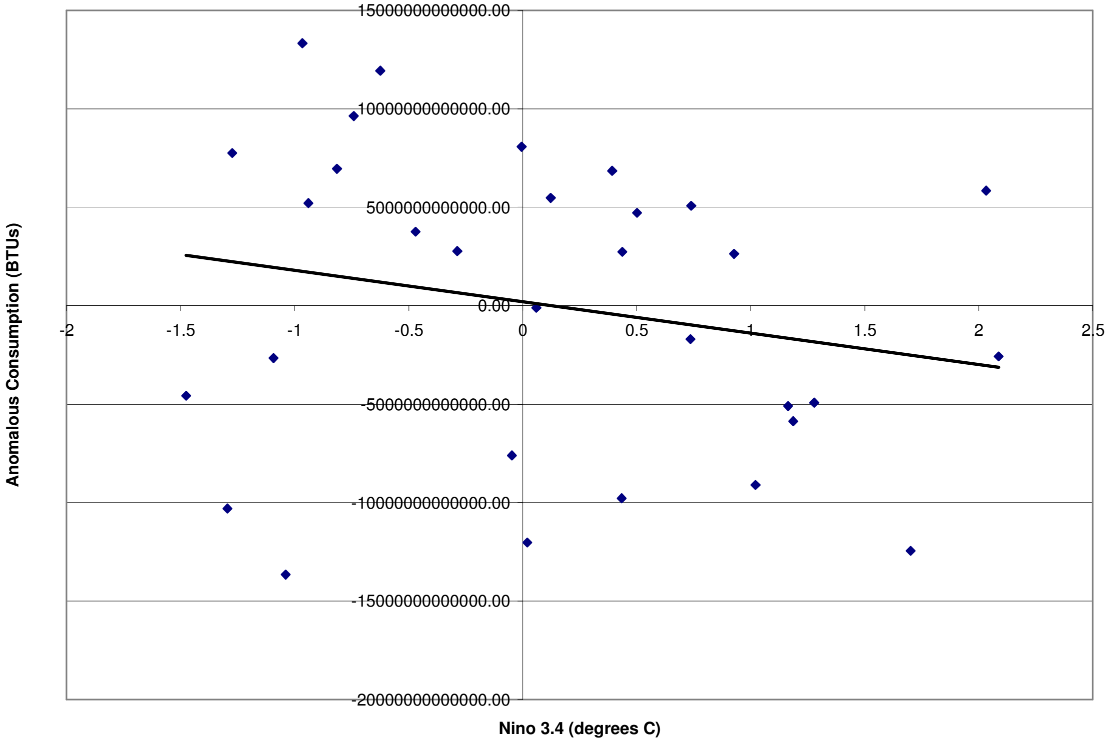


FIG. 16. Relationship between NINO 3.4 Index and anomalous consumption of all energy types at a national level. (r^2=0.04)

14% of the variance in anomalous consumption can be attributed to the NINO 3.4 Index. This negative correlation indicates that as the NINO 3.4 Index increases, the anomalous consumption of nuclear electricity decreases (Fig 17). For all r^2 values obtained at the national level in this study, see Appendix C.

b. Regional

Coal, natural gas, nuclear electricity, and hydroelectricity were analyzed in the states chosen based on temperature anomalies. The energy information was analyzed for each of these states to gain an idea of how the temperature and precipitation anomalies experienced during El Niño years affect consumption. For each state chosen based on temperature, the following energy sources were considered: coal, natural gas, nuclear electricity, and hydro electricity. The states chosen to represent the Northwestern US are Montana and Washington, while the states representing the Southeastern US are Texas and Florida.

It was also important to make sure the chosen states were at least mostly self-contained in their electricity generation. Being self-contained means that the majority of the electricity used in the state was produced in the state. Some states will produce additional electricity to be exported to nearby states that do not have the means by which to produce enough to meet the demands of its residents. It would be exceedingly difficult to pick up the ENSO signal in the generation values if a large amount on the electricity generated is either leaving the state or being brought into the state.

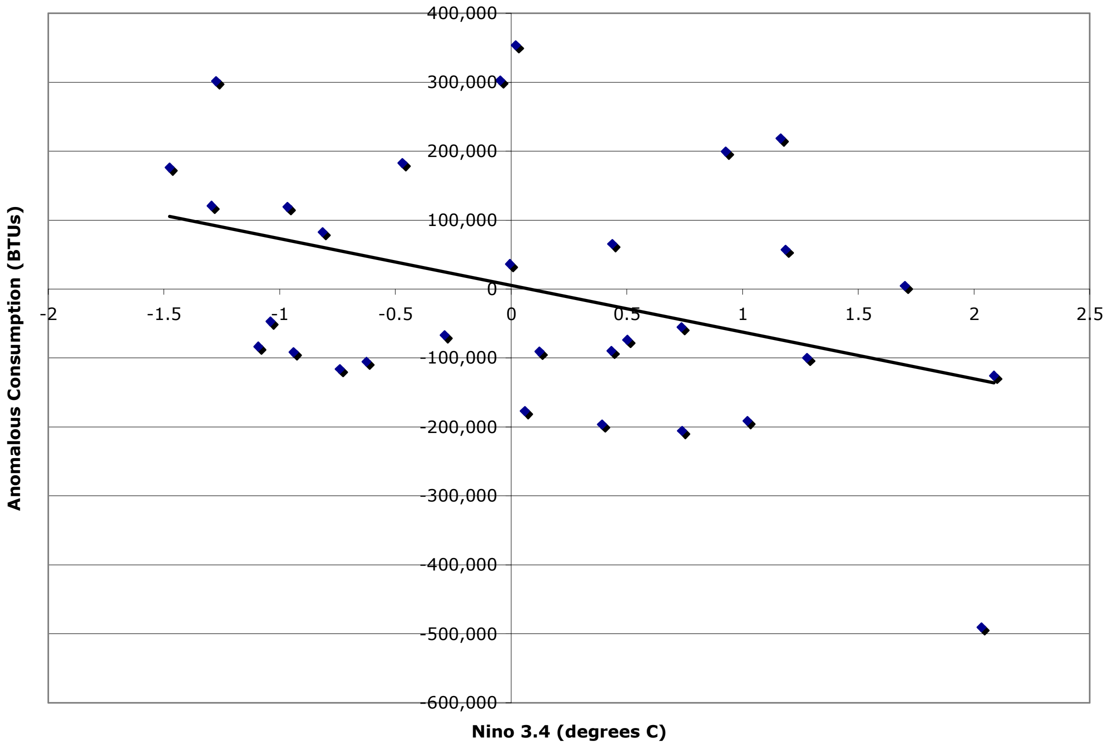


FIG. 17. Relationship between NINO 3.4 Index and anomalous consumption of nuclear electricity at a national level. (r^2=0.14)

Florida and Texas both have to have electricity imported from neighboring states to meet the consumption needs of their residents. Texas imports 2% of its total annual electricity based on power sector estimates in 2004, while Florida imports 16% of its total annual electricity. Montana and Washington are entirely self-supported. However they export 50% and 11% of their generated electricity to neighboring states respectively (EIA).

In the states chosen based on precipitation anomalies, only hydroelectricity was considered. The chosen states for hydroelectricity analysis under El Niño conditions follow: Florida, Texas, Kansas, Nevada, and West Virginia. A table with all regional temperature and precipitation (r^2) values and information on whether the correlation was positive or negative can be found in Appendix C.

c. State Data Based on Temperature Anomalies

In Montana, natural gas consumption data indicates that 17% of anomalous consumption can be attributed to El Niño conditions (Fig. 18). Since wintertime temperatures tend to be warmer in this area during El Niño events, the necessity for using large amounts of energy to heat homes decreases. Since natural gas makes up 59% of Montana's heating sources, it is not surprising to see a correlation between warmer temperatures and reduced consumption of this source. The amount of electricity generated from natural gas is now negligible (Fig. 19). In 1970, 3% of electricity was generated from natural gas and 8% was generated by coal. By the year 2000, electricity generation from coal jumped to 48%. However, coal shows almost no correlation with

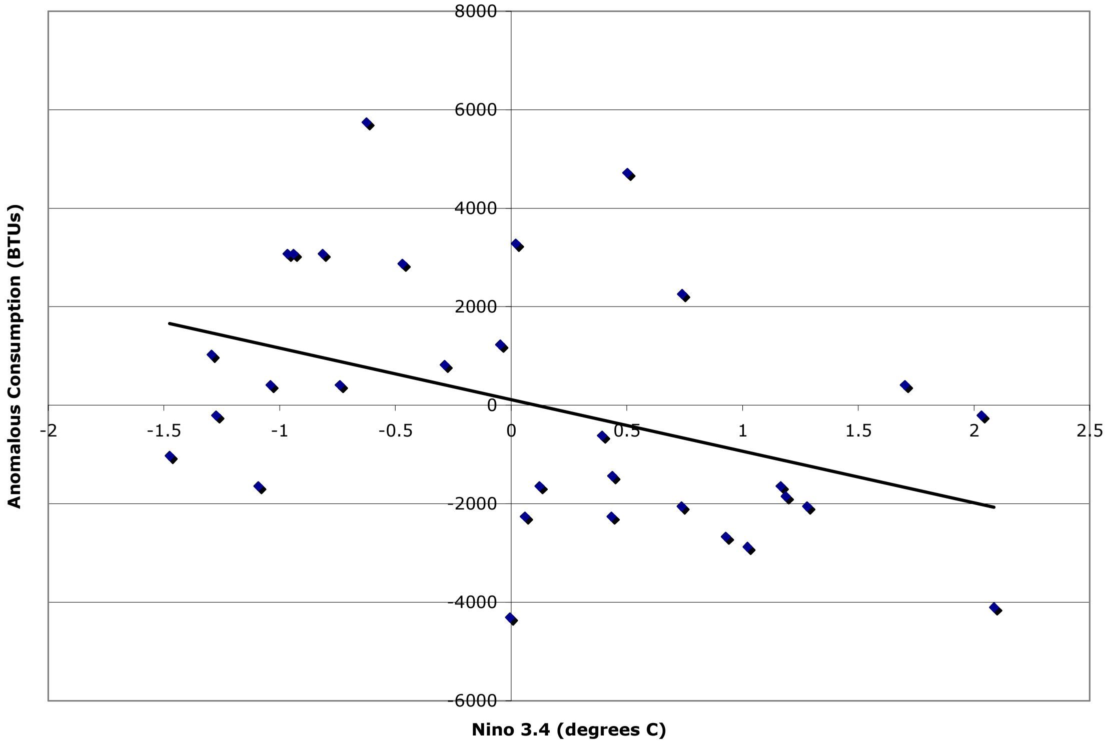


FIG. 18. Statistically significant negative correlation between NINO 3.4 Index and anomalous consumption of natural gas in Montana. (r^2=0.17)

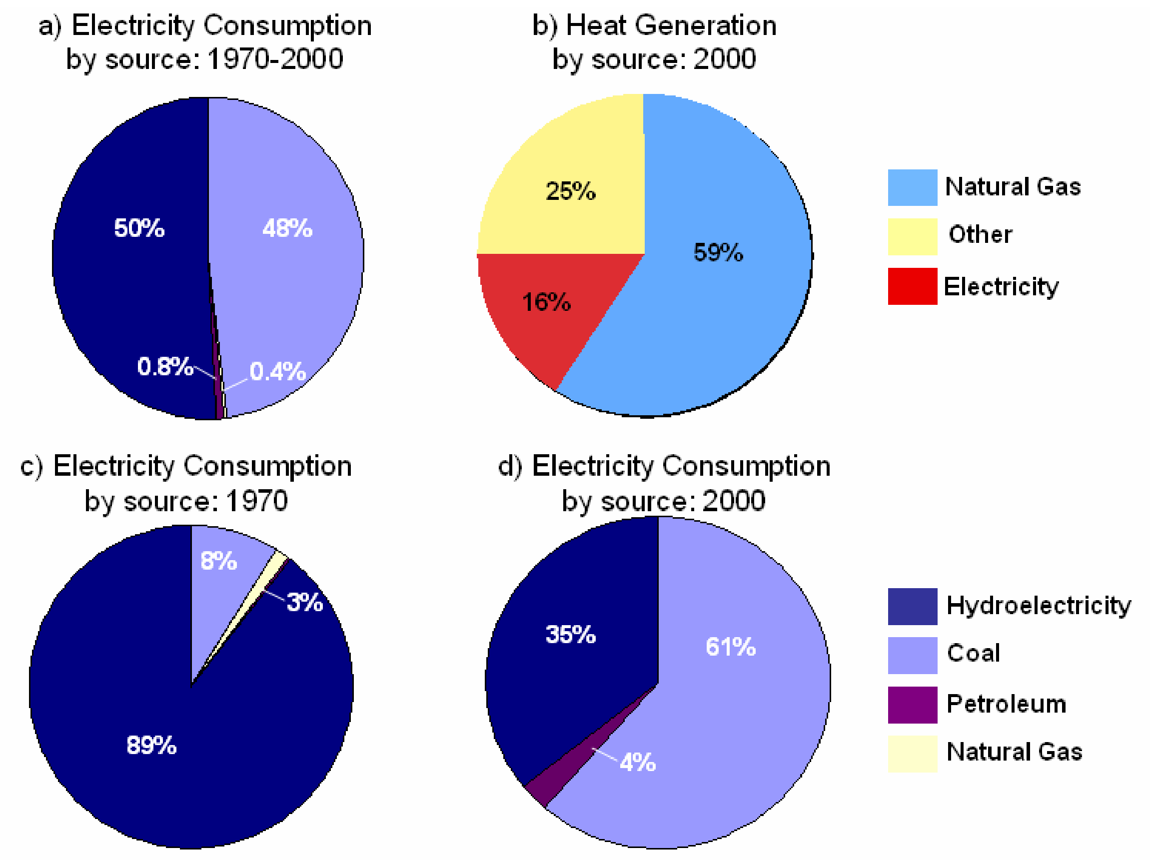


FIG. 19. Electricity consumption and home heat generation charts showing what percentage of each energy type is used in Montana. a) shows the average amount of each electricity source type used between 1970-2000, b) shows the sources of home heat generation based on data from 2000, c) shows the consumption of energy by source in 1970, and d) shows the consumption of energy by source in 2000.

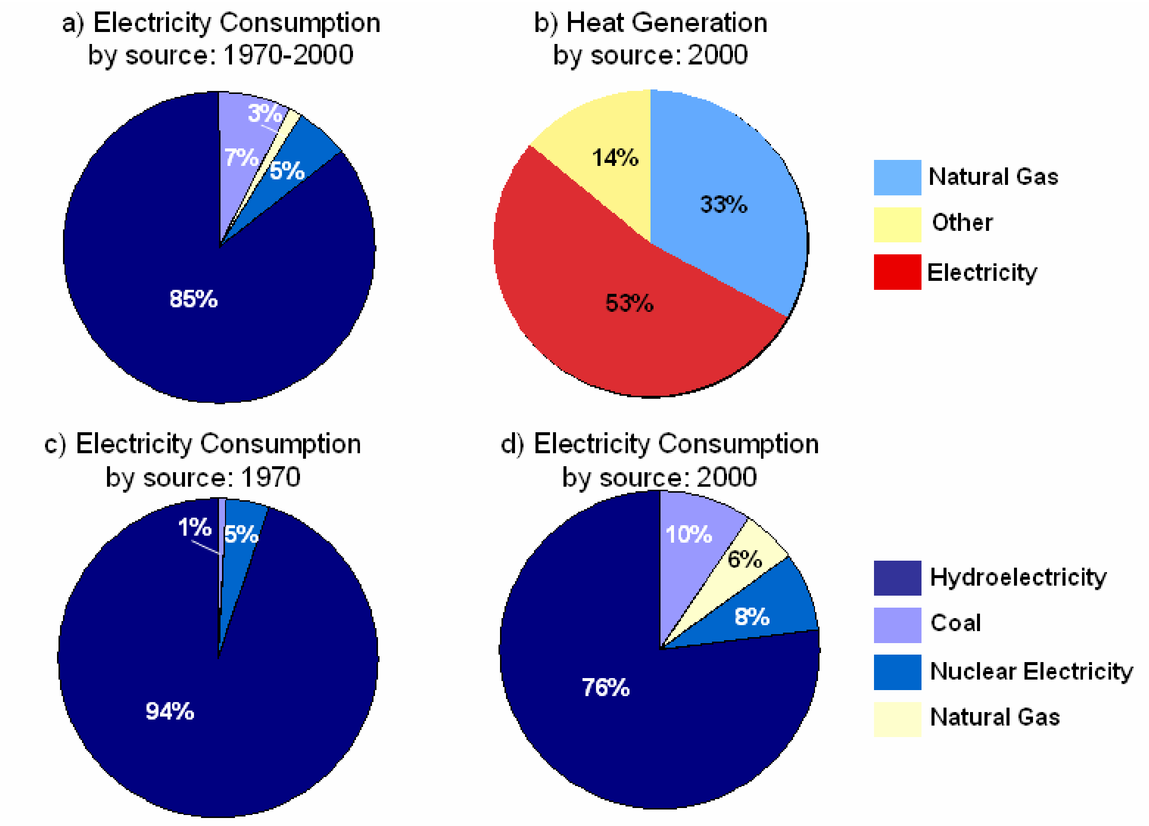


FIG. 20. Electricity consumption and home heat generation charts showing what percentage of each energy type is used in Washington. a) shows the average amount of each electricity source type used between 1970-2000, b) shows the sources of home heat generation based on data from 2000, c) shows the consumption of energy by source in 1970, and d) shows the consumption of energy by source in 2000.

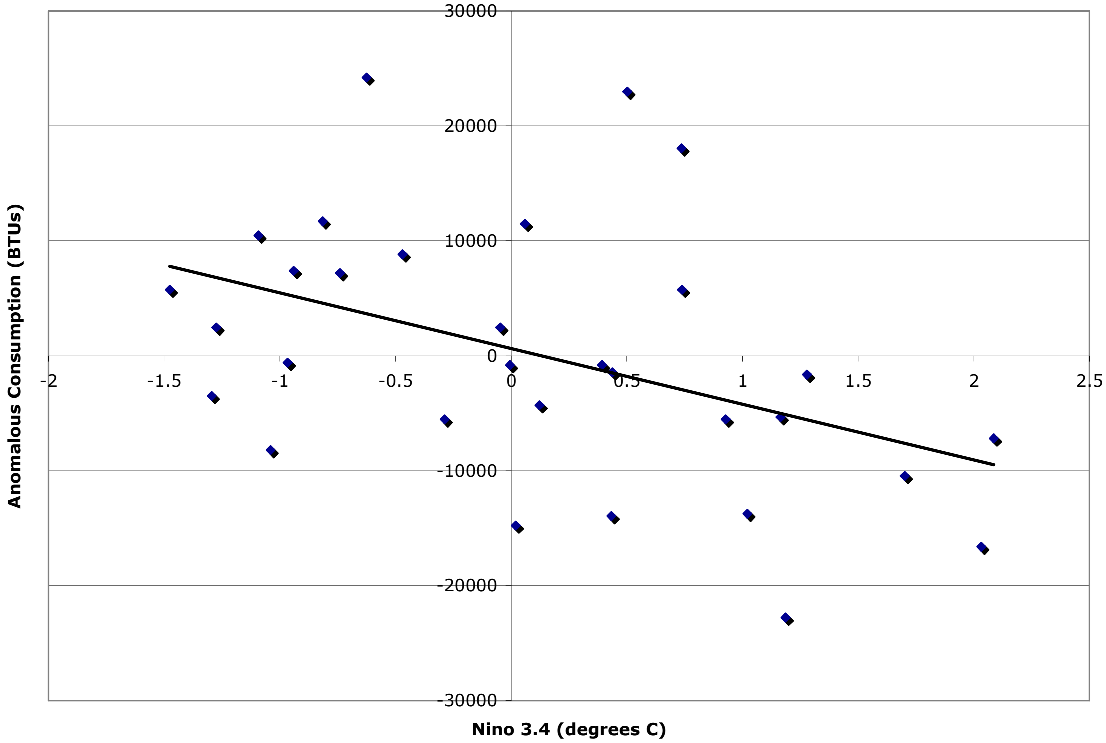


FIG. 21. Statistically significant negative correlation between NINO 3.4 Index and anomalous consumption of natural gas in Washington. (r^2=0.187)

anomalous consumption. Nuclear energy data for this state was not available while hydroelectricity, like coal, showed practically no correlation.

In Washington, natural gas, which is used to create 3% of electricity and 33% of heat generation for the state on average, also shows a correlation to the ENSO signal (Fig. 20). In 1970, natural gas was not used in the generation of electricity for Washington. However, by 2000, 6% of electricity generation could be attributed to natural gas. 19% of the anomalous consumption of natural gas in Washington for the study period can be explained by the decrease in natural gas usage as temperature due to El Niño increase (Fig. 21). The decreases in natural gas usage can be linked to the warmer winters typically experienced in this region during and El Niño event. Coal, nuclear electricity, and hydroelectricity do not show a significant correlation to the NINO 3.4 index.

In Texas, the energy sources from coal, natural gas and nuclear electricity show little to no correlation to the NINO 3.4 index. While natural gas accounts for 56% of electricity generation and 43% of home heating generation, this commodity does not show anomalous consumption like that seen in the Northwestern US (Fig. 22). This is most likely due to the fact that in Texas, winters are already mild. Even though Texas experiences an average temperature decrease of 2.2°C during ENSO events (based on temperature data from the CDC), it would not be enough to significantly alter the anomalous consumption. Texas did show a slight increase in anomalous consumption of natural gas (r^2=0.05) during ENSO events, though this is not considered statistically significant.

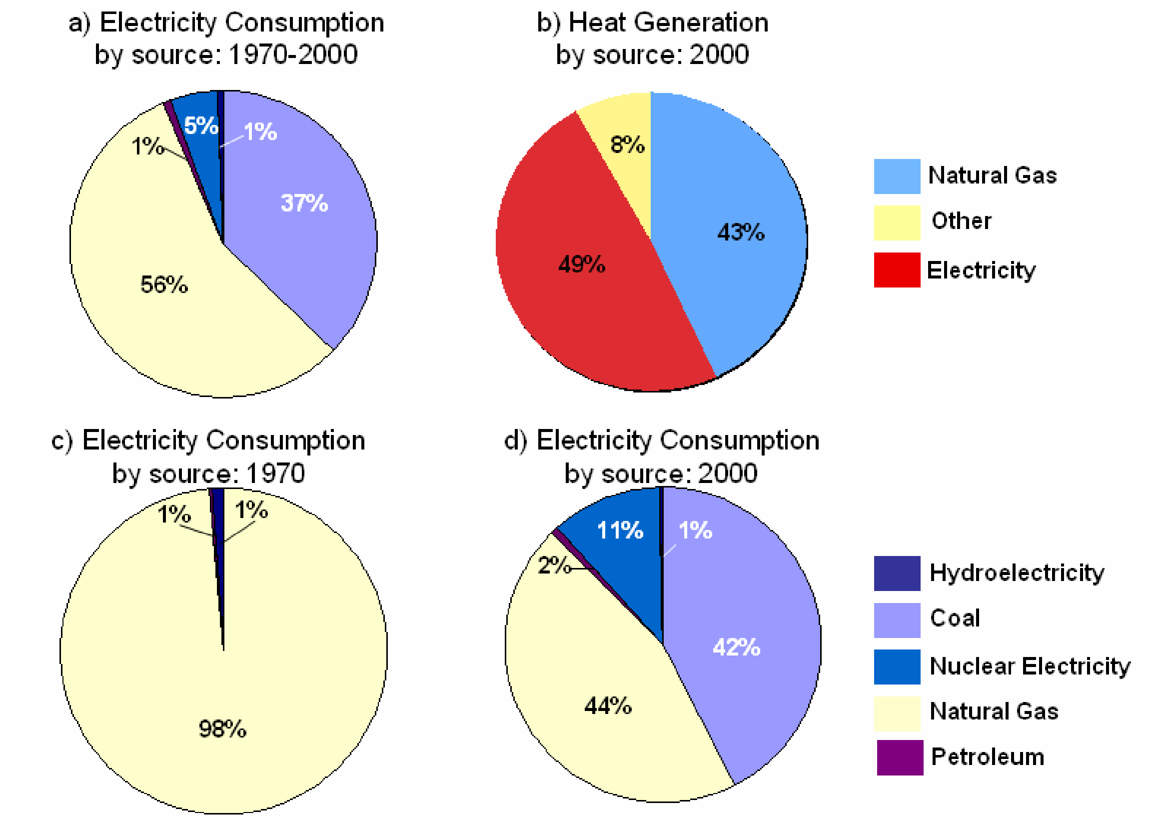


FIG. 22. Electricity consumption and home heat generation charts showing what percentage of each energy type is used in Texas. a) shows the average amount of each electricity source type used between 1970-2000, b) shows the sources of home heat generation based on data from 2000, c) shows the consumption of energy by source in 1970, and d) shows the consumption of energy by source in 2000.

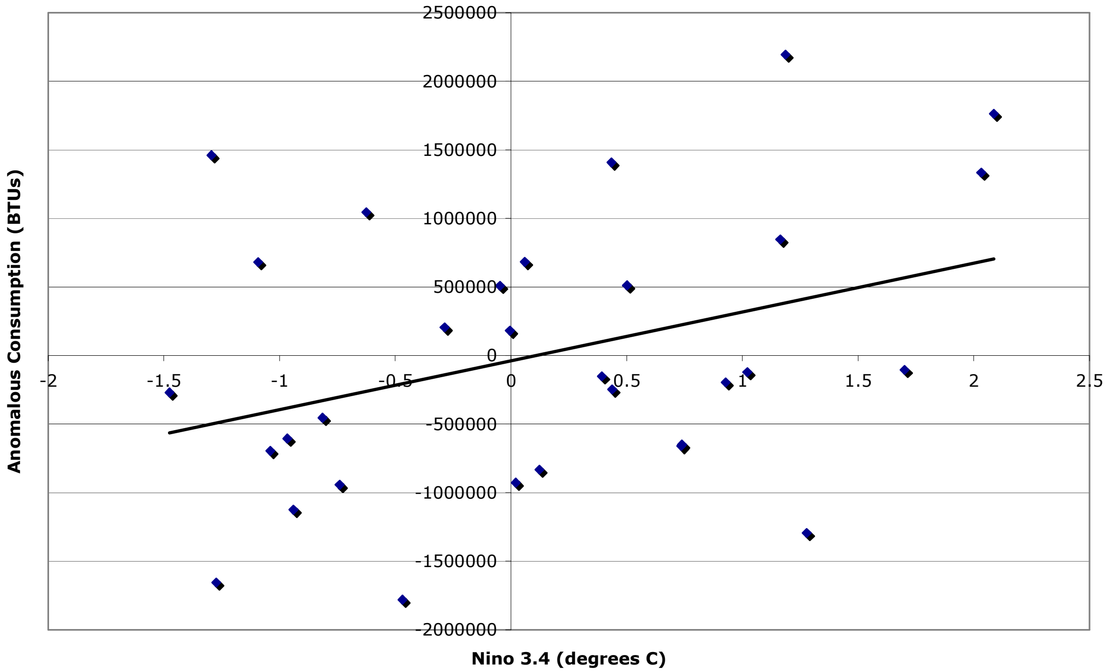


FIG. 23. Statistically significant positive correlation between NINO 3.4 Index and anomalous consumption of hydro-electricity in Texas. (r^2=0.13)

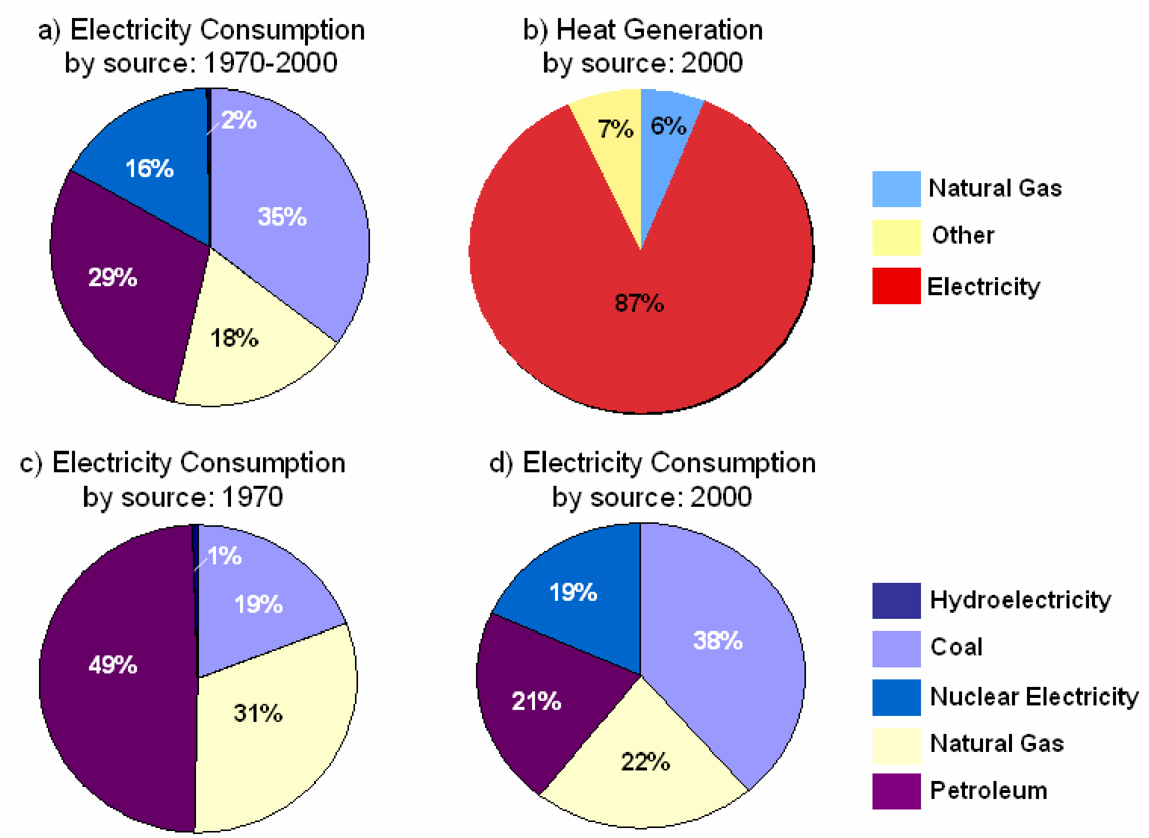


FIG. 24. Electricity consumption and home heat generation charts showing what percentage of each energy type is used in Florida. a) shows the average amount of each electricity source type used between 1970-2000, b) shows the sources of home heat generation based on data from 2000, c) shows the consumption of energy by source in 1970, and d) shows the consumption of energy by source in 2000.

Hydroelectricity however does show a statistically significant correlation in Texas. 13% of anomalous consumption can be linked to episodes of El Niño (Fig. 23). This positive correlation illustrates that as the NINO 3.4 index increases, so does the incidence of anomalous consumption of hydroelectricity. The reason for this increase will be discussed in the next section.

The energy types considered in Florida had to be modified because of the state's consumption profile (Fig. 24). "Other" is almost entirely petroleum. However, petroleum shows no anomalous consumption with respect to the NINO 3.4 Index. In fact, the only type of energy that warrants mention in Florida is electricity.

Both hydroelectricity and nuclear electricity show ~10% of their anomalous usage can be attributed to the NINO 3.4 index (Fig. 25 and Fig. 26). 87% of all home heating energy generation comes from electricity (Fig. 24). This information is not broken down into nuclear vs hydro. During normal years, the price for electricity is approximately $1.72 per million BTU. If it is an El Niño year, prices on average have been $1.67 per million BTU. Essentially, electricity users in Florida could expect to save $0.05 per million BTU during El Niño events if this was statistically significant.

d. State Data Based on Precipitation Anomalies

As mentioned above, Texas and Florida both show weak positive anomalous consumption of hydroelectricity during years affected by ENSO. As shown in Figure 9, Texas and Florida receive an increased amount of precipitation during El Niño events. On average they receive 2.3 and 4.5 inches per month respectively but during El Niño

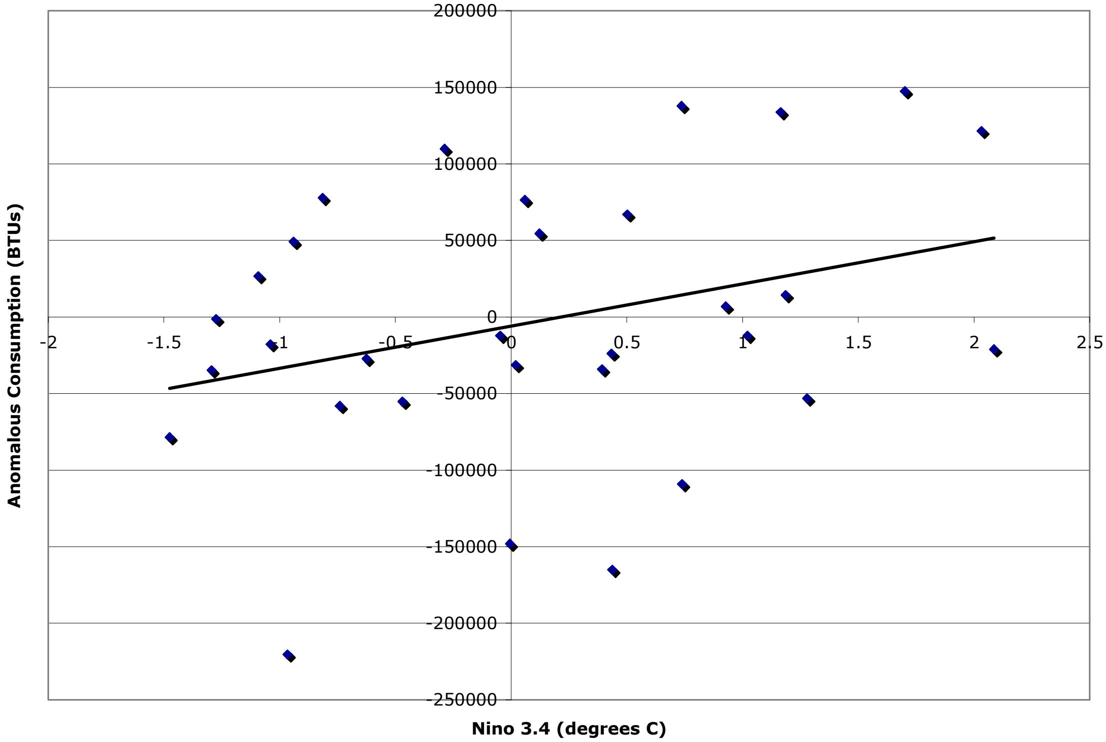


FIG. 25. Relationship between NINO 3.4 Index and anomalous consumption of hydroelectricity in Florida. (r^2=0.10)

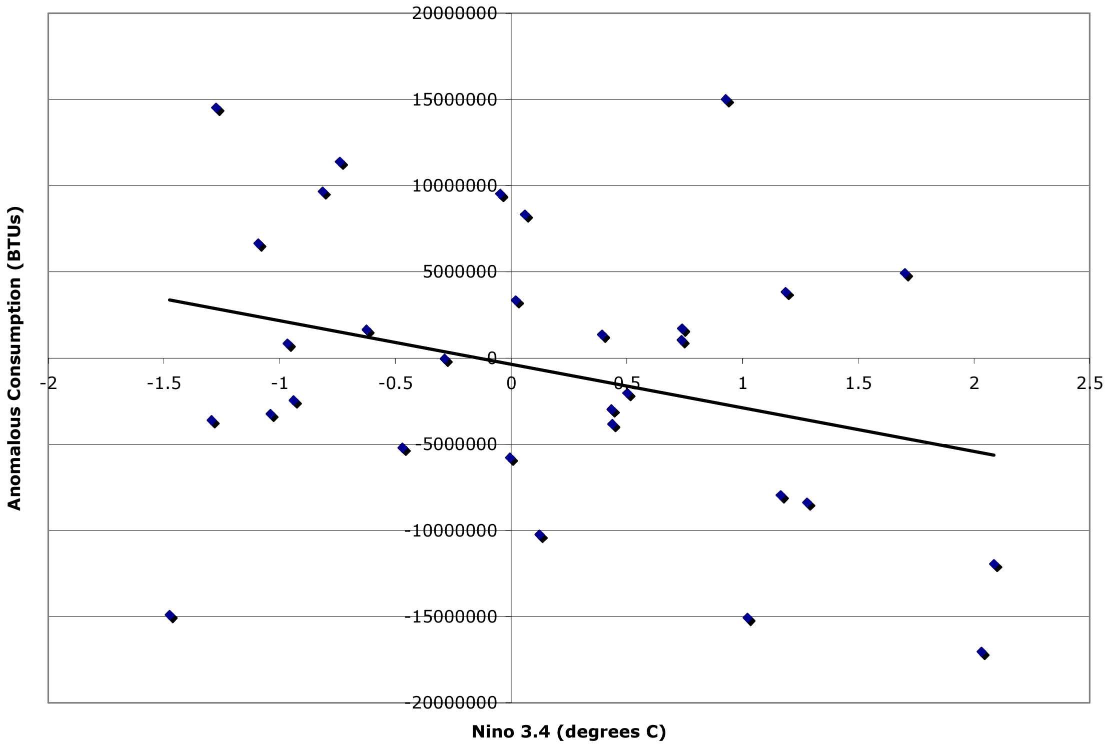


FIG. 26. Relationship between NINO 3.4 Index and anomalous consumption of nuclear electricity in Florida. (r^2=0.10)

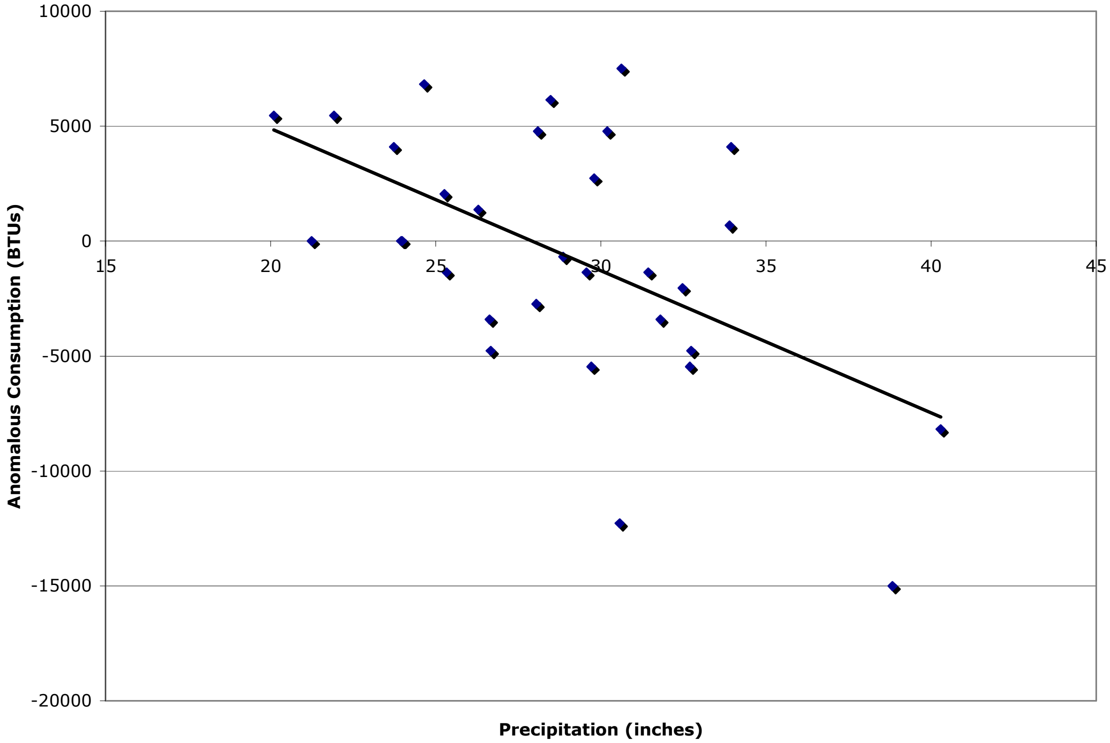


FIG. 27. Statistically significant negative correlation between precipitation amount and anomalous consumption of hydroelectricity in Kansas. (r^2=0.29)

years Texas averages 2.5 inches per month while Florida receives 4.8 inches. This increase in precipitation leads to additional water available for hydroelectricity production. Since hydroelectricity is a low-cost energy source, energy companies will produce as much as possible.

In Kansas, the opposite appears to be true. As precipitation increases, the 29% of anomalous consumption that can be attributed to El Niño actually decreases (Fig. 27). Thus, the more rain they receive, the less hydroelectricity they consume. This may be due to rainfall amount or due to the fact that production of hydroelectricity is not prevalent throughout the state. Like much of the plains region, Kansas focuses renewable energy projects on wind power (EIA – see Appendix A).

Nevada receives 0.73 inches per month of rainfall on average but during ENSO events the state receives 0.78 inches. In the case of this state, there are no significant correlations. The highest value results from 6% of the average increase in precipitation being related to El Niño conditions.. The precipitation increase in this area of the US is not highly pronounced in the data from the time period of 1970-2000. This is most likely why the data doesn't show any significant correlation to hydroelectricity consumption.

In West Virginia, drought conditions are common during ENSO episodes, particularly when the episode is very strong. There is a high positive correlation (r^2 =48.5%) between an increase in precipitation and the anomalous consumption of hydroelectricity (Fig. 28). Because of the drought conditions that occur during an El Niño year, the correlation between anomalous hydro-electricity consumption and the NINO 3.4 Index is negative. As NINO 3.4 increases, anomalous consumption decreases.

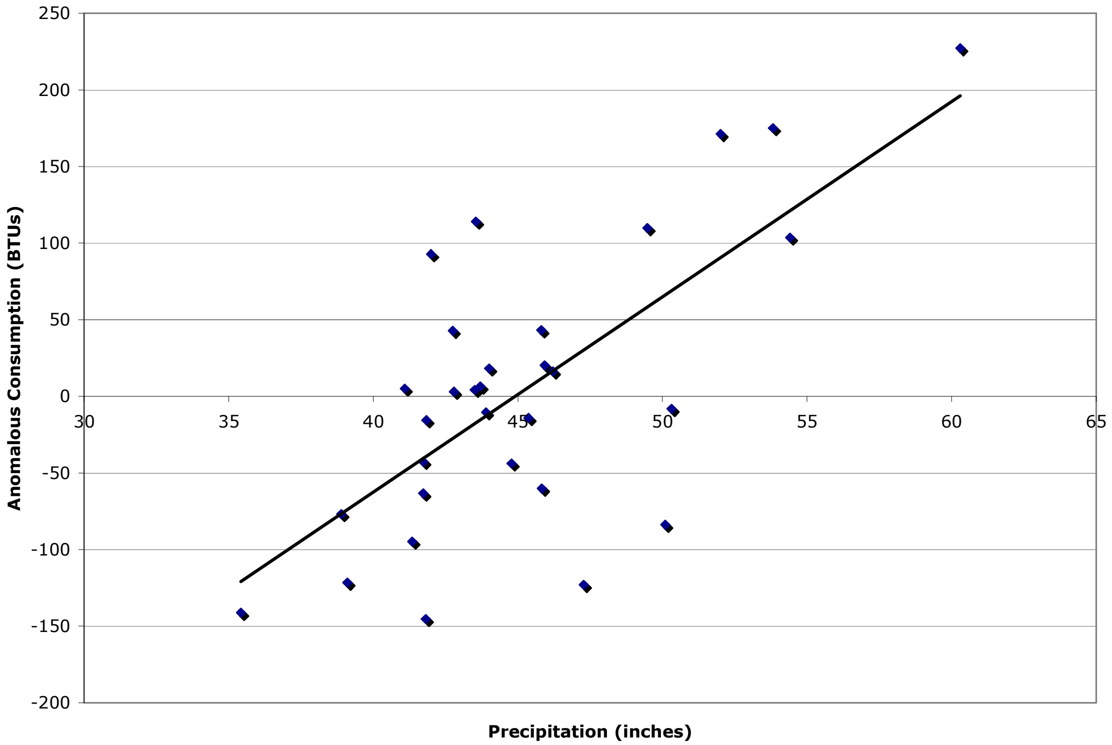


FIG. 28. Statistically significant positive correlation between precipitation and anomalous consumption of hydroelectricity in West Virginia. (r^2=0.485)

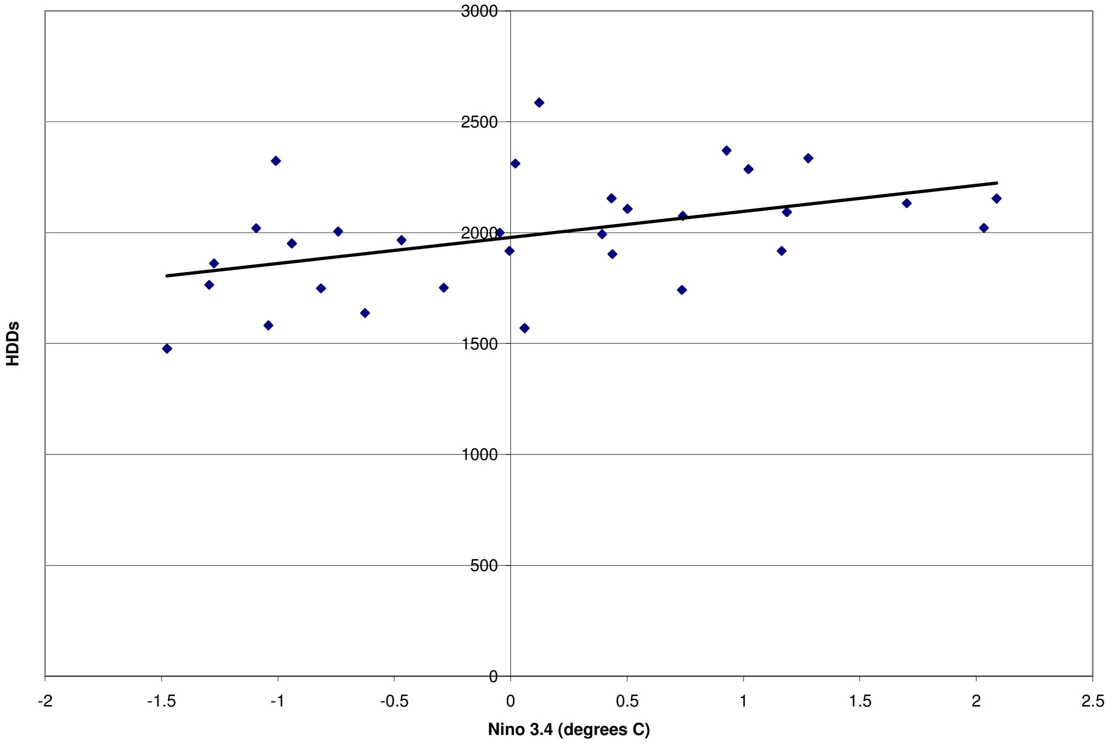


FIG. 29. Positive correlation between NINO 3.4 Index and annual heating degree days in Texas. (r^2=0.21)

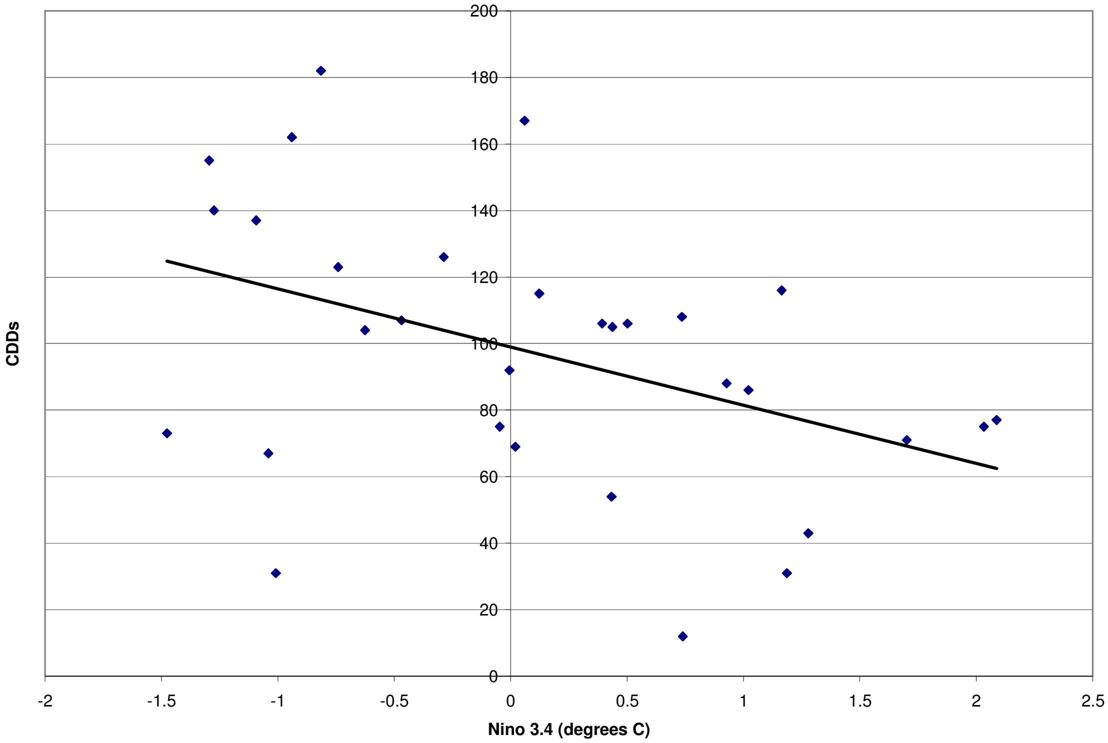


FIG. 30. Negative correlation between NINO 3.4 Index and cooling degree days in July in Montana. (r^2=0.18)

However, for the period of study, the amount by which the anomalous consumption decreases is not statistically significant.

e. Heating and Cooling Degree Days

The heating degree days (HDDs) and cooling degree days (CDDs) for the Contiguous US were examined over the period of 1970-2000. The states considered were Florida, Montana, Texas and Washington. While Florida did not show a significant correlation between HDDs/CDDs and the NINO 3.4 Index, the other states being analyzed did.

The only state that exhibited an annual significant correlation was Texas. This positive relationship indicates that 21% of the variance can be attributed to ENSO (Fig. 29). As the NINO 3.4 index increases, so does the number of HDDs. This makes since because Texas is cooler during an El Niño event and would therefore have more days on which the average daily temperature fell below 65°F.

During July in Montana 18% of the occurrence of CDDs can be attributed to ENSO (Fig. 30). This relationship indicates that as the NINO 3.4 Index increases, the number of CDDs decreases. This is only true for July. The surrounding months show very little correlation between ENSO and CDDs.

Washington also shows a significant correlation between the NINO 3.4 Index and CDDs (Fig. 31). In this case the significant relationship occurs in May. It indicates that 13% of the occurrence of CDDs during this month can be attributed to ENSO. This

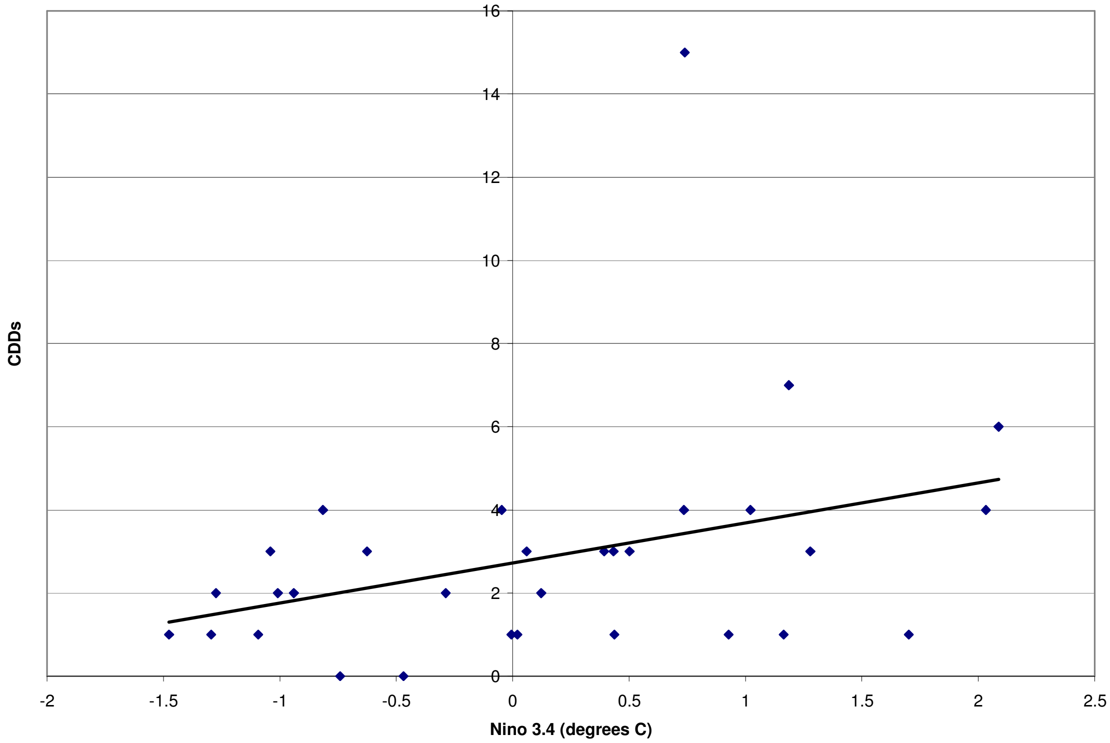


FIG. 31. Positive relationship between NINO 3.4 Index and CDDs in May in Washington. (r^2=0.13)

positive relationship shows that as the NINO 3.4 Index increases, so does the number of CDDs.

A significant relationship for both HDDs and CDDs is found during November in Texas (Fig. 32). For CDDs, as the NINO 3.4 Index increases, the number of CDDs decreases. 13% of the variance can be attributed to the ENSO signal. For HDDs during November in Texas the relationship is positive (Fig. 32). As the NINO 3.4 Index increases, so does the number of HDDs. Again, 13% of the variance points to ENSO.

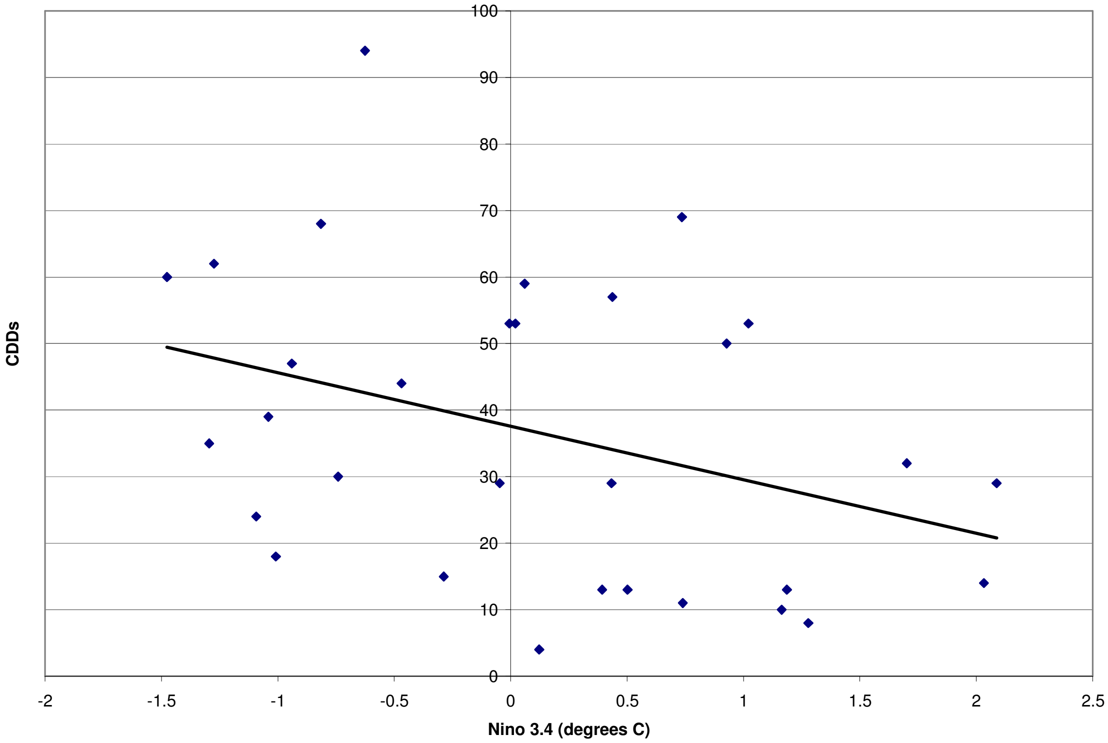


FIG. 32. Negative relationship between NINO 3.4 Index and CDDs in November in Texas. (r^2=0.13)

6. CONCLUSIONS

In the United States, ENSO events affect precipitation amounts and average temperatures in some parts of the country. The Northwestern United States shows a warm anomaly during ENSO events while the Southern US exhibits cooler temperatures. Precipitation is increased across the Southwestern US and throughout the high plains while some parts of the Midwest exhibit drought conditions.

Consumption of coal, natural gas, nuclear electricity and hydroelectricity were considered in this study. Consumption profiles at the national level show only a significant correlation between the NINO 3.4 index and nuclear electricity, indicating that 14% of anomalous consumption of nuclear electricity can be explained by El Niño. In this case, a negative correlation exists showing that as the NINO 3.4 index increases, the anomalous consumption of nuclear electricity decreases. This implies that warmer temperatures during ENSO have a damping effect on the national consumption of nuclear electricity and should lead to less money being spent on energy.

In the northwestern US, the main anomalous consumption factor can be attributed to natural gas. Because the northwestern US exhibits warmer winter time temperatures during ENSO events, it is not surprising that the amount of natural gas consumed during those years decreases. This is because natural gas is the main means of generating heat in this region. Thus less is necessary for consumption during ENSO events. Furthermore, approximately 17.5% of anomalous consumption of natural gas in the NW US can be attributed to the ENSO signal.

In Montana, $2.86 million is saved on natural gas during El Niño years, while Washington saves $47.2 million. Since the winter months are warmer during an ENSO event and natural gas is a primary home heating source, it can be expected that less natural gas will be consumed during these anomalously warm episodes. The difference in price can be attributed to the amount of natural gas each state consumes and the population of each state. Montana, which had a population of just over 900,000 people in 2000, uses only 0.3% of its natural gas for generating electricity and 59% for home heat generation. Washington, whose population was nearly 6 million in 2000, uses 6% natural gas for electricity generation and 33% for home heat generation. (Population statistics from the US Census Bureau www.census.gov.)

Also in the NW US, all correlations, no matter how small, are negative. This means as the NINO 3.4 values increase, the anomalous consumption decreases. This is not surprising because a large portion of electricity consumed annually is used for heating purposes. Only a small portion is used for cooling purposes since summer temperatures in this region are typically mild. Thus, consumption values would not increases significantly as the temperature increases.

Consumption of hydroelectricity is the energy type that receives the most influence from the ENSO signal in the southern US. In Texas, 12% of anomalous consumption can be attributed to El Niño. As NINO 3.4 increases, so does the anomalous consumption of hydroelectricity. The same is true for Florida with 10% of anomalous hydroelectricity consumption attributed to El Niño. This is most likely due to the increased precipitation both of these states receive during an El Niño. When more water is present, more hydroelectricity can be generated. However, the data still needs to be looked at to determine whether this increase in hydroelectricity production is actually a function of ENSO or if it has to do with precipitation that is not necessarily a result of an ENSO event.

While natural gas, nuclear electricity, and hydroelectricity all showed a statistically significant correlation at some level of this study, coal did not. In fact, the highest r^2 value exhibited by this electricity generation source was 4%, and that was based on national data. At the regional level, the squared-correlation between anomalous coal consumption and the NINO 3.4 index never reached over 3%. It can therefore be inferred that coal consumption is not significantly affected by the signal from ENSO.

HDD and CDD data were examined for the four states showing a coherent temperature response to El Niño events. A significant correlation in the annual Texas data was identified indicating that 21% of the variance results from the ENSO signal. Also, significant correlations were found during certain months in Montana, Washington, and Texas. No significant correlations were found in Florida.

Both states in the northwestern US region showed significant correlations. Montana exhibited a significant negative correlation for CDDs during July. 18% of the variance in the data are attributed to ENSO. For Washington, a positive significant relationship for CDDs was present in May. In this case, 13% of the variance results from the ENSO signal.

Only one state in the southeastern US exhibited a significant correlation. Texas showed a significant correlation (r^2=0.13) during November for both HDDs and CDDs.

The HDD correlations was positive, indicating that as the NINO 3.4 Index increases, so does the number of HDDs. Conversely, for CDDs it is illustrated that as the NINO 3.4 Index increases, the number of CDDs decreases.

The fact that the ENSO signal could be picked up in the annual data implies that it is possible that an even better understanding of anomalous consumption would come from analyses of energy data on a smaller temporal scale. Because monthly energy data is not available on a climatological time scale, it will be essential to gain access to a database containing monthly data. This may mean working directly with energy companies located throughout the US.

It is possible that a stronger consumption signal with respect to ENSO events lies within the electricity generation import and export data. During an ENSO event, areas that have cooler temperatures and rely on electricity for heating during the winter months will require more electricity during an ENSO event. Therefore they will either be exporting less electricity to have more for their own use or they will be importing more than usual.

The same goes for areas that experience warmer than average winter temperatures during ENSO events. There will be less electricity demand during ENSO events so the state will either be able to export more electricity to neighboring states or they will import less during these episodes. The same sort of signal may be evident during summer months when electricity for air conditioning is necessary.

Additionally, analysis on strong ENSO events would be beneficial. It would be interesting to see how these stronger events impact El Niño consumption values. Also, resolving the ambiguity introduced in the hydroelectricity and El Niño correlation will be key for determining if El Niño is truly causing anomalous consumption of hydroelectricity. By understanding the smaller scale affects of El Niño in the contiguous US it will be possible to understand how different region's energy profiles are affected by the occurrence of ENSO. This understanding could possibly lead to better energy forecasts during ENSO events. In turn, better energy forecasts could lead to money saving opportunities for both the energy production companies and customers.

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APPENDIX A

EIA Data Quality:
http://www.eia.doe.gov/smg/EIA-IQ-Guidelines.html#eiaquality
and
http://www.eia.doe.gov/smg/Standard.pdf

National:
Consumption: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_9.pdf

States:
Florida:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_fl.html
Pricing: http://www.eia.doe.gov/emeu/states/sep_prices/total/pr_tot_fl.html

Montana:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_mt.html
Pricing: http://www.eia.doe.gov/emeu/states/sep_prices/total/pr_tot_mt.html

Texas:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_tx.html
Pricing: http://www.eia.doe.gov/emeu/states/sep_prices/total/pr_tot_tx.html

Washington:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_wa.html
Pricing: http://www.eia.doe.gov/emeu/states/sep_prices/total/pr_tot_wa.html

Kansas:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_ks.html

Nevada:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_nv.html

West Virginia:
Consumption: http://www.eia.doe.gov/emeu/states/sep_use/total/use_tot_wv.html

Energy Conversions:
http://www.eia.doe.gov/basics/conversion_basics.html

APPENDIX B

Temperature Data:
http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/readme.html
and
http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html#dd

Precipitation Data:
http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/readme.html
and
http://lwf.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html#dd

ENSO year Data:
http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ensoyears.shtml

Niño 3.4 Data:
Information:
http://iri.columbia.edu/climate/ENSO/background/monitoring.html

Raw Data:
http://www.cgd.ucar.edu/cas/catalog/climind/TNI_N34/index.html#Sec5

HDDs and CDDs:
HDDs:
http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_21.pdf
CDDs:
http://www.eia.doe.gov/emeu/aer/pdf/pages/sec1_23.pdf

National Climatic Data Center (NCDC):
NCDC 1. May 2007: Annual Review-US Summary.
http://www.ncdc.noaa.gov/oa/climate/research/2004/ann/us-summary.html#Apcp

NCDC 2. May 2007: United States Climate Summary.
http://www.ncdc.noaa.gov/oa/climate/research/cag3/na.html

APPENDIX C

TABLE 2. r^2 values and sign of correlations for all national values found in this study.

Energy Type	r^2 Value	Correlation
Coal	0.0442	Negative
Natural Gas	0.0754	Negative
Nuclear Electricity	0.1421	Negative
Hydro Electricity	0.0062	Negative

TABLE 3. r^2 values and sign of correlations for all regional values found in this study.

State	Energy Type	r^2 Value	Correlation
Florida	Coal	0.0038	Negative
	Natural Gas	0.026	Negative
	Nuclear Electricity	0.0908	Negative
	Hydro Electricity	0.0.097	Positive
	Petroleum	None	None
Texas	Coal	0.0071	Negative
	Natural Gas	0.0586	Negative
	Nuclear Electricity	0.0219	Positive
	Hydro Electricity	0.1267	Positive
Montana	Coal	0.032	Negative
	Natural Gas	0.1711	Negative
	Nuclear Electricity	None	None
	Hydro Electricity	0.0113	Negative
Washington	Coal	0.0004	Negative
	Natural Gas	0.1876	Negative
	Nuclear Electricity	0.0199	Negative
	Hydro Electricity	0.0043	Negative

TABLE 4. r^2 values and sign of correlations for all hydroelectricity values found in this study.

Parameters	State	r^2 value	Correlation
NINO 3.4 vs avg precipitation	Texas	0.051	Negative
	Florida	0.0044	Positive
	Kansas	0.0324	Positive
	Nevada	0.0692	Positive
	West Virginia	0.0087	Negative
Avg precip vs anom consump	Texas	0.0644	Positive
	Florida	0.0264	Positive
	Kansas	0.2919	Negative
	Nevada	0.0087	Positive
	West Virginia	0.485	Positive
NINO 3.4 vs anom consump	Texas	0.1267	Positive
	Florida	0.097	Positive
	Kansas	0.0000002	None
	Nevada	0.0356	Negative
	West Virginia	0.0077	Negative

VITA

Biography

Kathleen Collins was born in Xenia, OH during a snow storm in December of 1981. She lived in Dayton, OH with her family until she graduated from high school in 2000. She then set out to attend Ball State University in Muncie, IN where she learned just how much she liked weather. She was active with the department extracurricular activities but enjoyed being a member of the Ball State Storm Chase Team most of all.

After receiving her B.S. in Operational Meteorology and Climatology in 2004, Kathleen began looking for a graduate program where she could gain a theoretical background. In August 2005, she moved to College Station, TX to begin work as a graduate student at Texas A&M University. While at Texas A&M, Kathleen worked as a graduate teaching assistant and was also Co-Coordinator of the Texas Aggie Storm Chase Team. Kathleen can be contacted through the Texas A&M University Department of Atmospheric Sciences, 3150 TAMU, College Station, TX 77843.

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M.S., Atmospheric Sciences, Texas A&M University, August 2007.