THE GLOBAL CLIMATE CHANGE AND ITS IMPACTS: CURRENT ASSESSMENT AND FUTURE PROSPECTS

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Abstract

Global climate change is one of the most important issues that human faces in the 21st century. Its impact on food supply, human health, natural and environmental systems, and social and economic developments, though difficult to measure, would be enormous. For instance, in a US-EPA commissioned study of world food supply and trade, agricultural scientists from 18 countries used International Benchmark Sites Network for Agro-technology Transfer Model simulated potential changes in national grain crop yields. Overall, world crop yield is projected to reduce by 27% when CO_2 fertilization effect is not considered and 5% when CO_2 fertilization effect is considered in a global warming situation. Worse yet is that the stability of the weather system seems also questionable. The frequency of floods and droughts that were observed in recent years indicates to a likely scenario, that is, the weather system is becoming less stable worldwide. Effects of the extreme weather conditions, such as the 1998 Mitch hurricane in middle Atlantic; the 1998 flood in south China; and the 1999 Oklahoma tornado in the US are profound and devastating. If the weather system is becoming less stable the impact of these record-breaking phenomena on human and earth systems would be dramatically greater than the global warming. Therefore, the question of whether there is a fundamental change of global climate? and if so, what is the nature of the change? requires a careful evaluation and investigation. The potential impacts of climate change on agriculture are reviewed. Important areas of future research with respect to climate change, particularly, those concerns relevant to local and regional lives are suggested.

Global Climate Change

The earth's average surface temperature in 1998 is the highest since people first began to measure it with thermometers in the mid-19th century. Indeed, seven of the 10 warmest years on record have occurred since 1990. The cause of the warming is often linked to the increase of trace gases in the atmosphere (IPCC, 1997). A wide variety of human activities contribute to the trace gases increase such as burning of coal, oil, and natural gas releases. Worldwide, About 6 billion tons of carbon are released into the atmosphere each year. Burning and logging of forests contributes another 1-2 billion tons annually by reducing the storage of carbon by trees (USGCRP, 1999). The result is that atmospheric level of CO_2 has been increased from 280 to 360 parts per million (ppm) in the past 150 years. The overall emissions of greenhouse gases from industry and agriculture are still growing at about 1 percent per year.

There has been a clear correlation between CO_2 levels and the global temperature record. over the last 160,000 years (USGCRP, 1999). Other findings such as glacier retreats (Oerlemans, 1994) also suggest the warming. Schneider (1994) and Hansen at el. (1998) declared that the record of the last century provided sufficient evidence of global warming. In order to quantify the effects of greenhouse gases on climatic systems, the Global Climate Models (GCMs) have been developed to calculate the dynamic temporal and spatial transports and exchanges of heat, moisture, and momentum throughout the earth's atmosphere and its surface, including the continents and oceans (Rosenzweig and Hillel, 1998). However, due to incomplete understanding in climate, oceanic and biological systems, let alone their complex interactions, predictions obtained from GCMs runs are often inconclusive (Hanssen-Bauer and Forland, 1998), or even questionable (Idso, 1998; Gray, 1998).

Climate Change Impact on World Agriculture In an attempt to assess the potential impact of climate change on food production, the US EPA commissioned a study that involved agricultural scientists from 18 countries and used IBSNAT (International Benchmark Sites Network for Agrotechnology Transfer) crop models to simulate potential changes in national grain crop yields (Rosenzweig and Hillel, 1998). Table 1 presents a summary of the average impact estimated from the 3 GCM scenarios on cereal crops in the world. When climate change is considered without the direct fertilization effects of CO_2, wheat yields declined by 24%, rice by 25% and maize by 26%. When all cereals were combined, a 27% reduction was estimated. The same reduction was also predicted by the models when all crops are combined. This reduction could be a very serious problem given that the world population is still increasing. The estimated hunger population could increase by almost 1 billion, if these climate change scenarios were realized. The predicted negative impact persisted even when potential positive effects of CO_2 were considered in the crop simulation model. However, the impacts would not be uniform across countries and regions. Positive yield changes are possible in regions at middle and high latitudes, where the growing season may be extended by warming and the CO_2 fertilization effect is added. In contrast, in regions of low latitude, further temperature increase shortens the growing season and adds heat and water stress, which may not be compensated for by CO_2 enrichment. It should be noted, however, that the coefficients of variation (CV) of the predictions among the model scenarios are high; ranging between 22 to 61% when CO_2 effect is not included and between 24% to over 1851% when CO_2 effect is considered. These large CVs reflect the uncertainty of the predictions. The differential impact on agriculture between areas of high and low latitudes also coincides with economic disparities between developed and developing countries. The potential reduction in agricultural productivity in developing countries could further increase the risk of hunger in those countries.

Impacts of Climate Change on US Agriculture. Barry and Geng (1992, 1995a) used weather outputs from GCM for both current CO_2 and double CO_2 scenarios to evaluate climate change impacts on wheat and rice productions in the US. The model outputs information by grid, and each grid point is the center of a 4 degree latitude by 5 degree longitude "box". For each grid point the model simulates number of wet days/month, monthly total precipitation, and monthly maximum and minimum temperature. These monthly averages, adjusted for doubling of CO_2, were then used as inputs into SIMETO for the US wheat and rice simulation studies. When CO_2 is doubled, rainfall will decrease by between 8 and 37% in wheat growing regions in the US, and annual mean minimum temperature will increase by between 3°C and 8°C. As a result, wheat yields will decrease by between 8 and 61%, depending on the location (Figure 1). Adjustments in planting dates and alternative cultivars were tested and in most cases the adjustments did not significantly improve yields. Their rice study indicated that rice yields decrease by between 14 and 24% in the Gulf Coast states and between 11 and 21% in California, with a US average reduction of 19% (Figure 2). In all cases, the decrease in rice yields was due primarily to the large increase in summer temperatures. On the other hand, dry-land fall planted spring wheat yields in California increase by 62% and 125%. This is due to increased rainfall and temperatures during the winter months in California.

In their study, Barry and Geng performed a cluster analysis to evaluate the differences among locations for their yield and rainfall variations. Four clusters of locations are formed based on the yield and rainfall data. The CV of total rainfall and CV of yield increase concurrently. A small increase in CV of rainfall is accompanied by a large increase in CV of yield. For example, at Ellsworth, which is located in central Kansas, the CV of total rain is 23% and the CV of yield is 47%. At Syracuse, in western Kansas, the CV of total rain is 29% and the CV of yield is 76%: a six unit increase in CV of rainfall is accompanied by a 29 unit increase in CV of yield. Similar patterns were obtained for Oklahoma, Texas and Nebraska. Results of the study showed clearly that wheat yield variation is greatly intensified and exacerbated by weather variation.

Impacts of Climate Change on China's Agriculture Brandstetter and Geng (1999) used a regression model to evaluate the impact of meteorological variables on winter wheat production in China. Data used as input to the model included yield data from 23 provinces, obtained from various Chinese publications, and weather data from the World Meteorological Organization. Meteorological variables included mean temperature, temperature sum, mean rainfall per day, and rainfall sum. In addition, "biometeorological" variables were calculated based on knowledge of wheat's response to temperature. For example, adjusted temperature during germination was computed based in using an optimal range for germination of between 20 and 25°C, and a range of between 4 and 37°C under which wheat will germinate. Meteorological and biometeorological variables were computed for each of six stages of the wheat life cycle: stand establishment, fall growth, winter dormancy, spring growth, heading, and grain filling. A typical or average start and finish date for each growth stage was used for each province. The most important weather identified by the model were fall growth temperature, winter temperature, spring growth rainfall, and grain filling temperature. Figure 3 shows the current wheat yield levels and Figure 4. depicts the simulated changes in yields for each province. The model predicts that the greatest decrease in yields (25 to 54%) will occur in all of the highest-yielding provinces. Most of these high-yielding provinces (Liaoning, Hebei, and Shandong) are in the North. Close examination of the regression model revealed that in these provinces, it is primarily a positive impact of temperature during stand establishment that will result in higher yields. The model predicts that yields will decrease in most coastal provinces, and increase in most inland provinces. Along the South coast (Zhejian, Fujian, Guangdong, and Guangxi), the regression model predicts that higher temperatures during fall will cause lower yields. Just inland from these provinces (in Anhuei, Hubei, Jiangxi and Hunan), the regression model predicts that higher temperatures during grain filling are the primary cause of increased yields. Further inland

(Sichuan, Guizhou, and Yunnan), there is still some benefit to increased temperature during grain filling, but higher temperature during stand establishment also contributes to increased yields. However, in this model, water is not considered limiting because the yield data used in the model development were taken from irrigated wheat. If the water effect is considered, the impact of climate change could reduce yields of many inland provinces.

Weather Variability

Although it is debatable whether GCM-predicted warming is part of natural variation or a long-term climatic change, extreme weather events are clearly felt by people in many parts of the world. The 1998 flood in south China was considered the most devastating in China's recent history. Heavy rainfalls in summer weeks of 1998 (June to August), across most parts of the Yangze River region, caused the loss of hundreds of lives and thousands of hectares of crops. Mitch, the deadliest Atlantic hurricane since 1780, brought a death toll of over 11,00 people in Honduras and Guatemala. The economies of these countries were pulled back for decades.

The possible increase in frequency and intensity of extreme weathers, however, may be related to the warming scenario. One hypothesis (The New York Times, May 18, 1999) relates the warming to the frequent appearances of El Nino. Since the time interval between El Nino formations depends on the time it takes to recharge the tropical system by re-accumulating heat at the sea surface, global warming may enable the system to recharge more rapidly, thereby making El Nino appear more often. Based on the list compiled by Quinn (1993), Geng (1998) calculated that a total of 119 El Nino events happened during the last 474 years, including the recent one of 1997-98. Among these 119 El Nino events, 10 are classified as very strong. If the frequency and the intensity of the El Nino were uniformly distributed over time, one would expect to see one very strong El Nino in every 47 years. It turns out that 4 of the very strong El Nino were observed in the last 100 years and 2 of them have happened since 1980s: 1982-83 and 1997-98. This result seems to support the theory that weather variation has increased in recent decades.

In searching for evidence of weather variability and its impact on world food production from real data, Geng (1998) performed a residual analysis of the time series data of global temperature and world cereal yield from 1961 to 1995. He found both temperature mean anomalies and standard deviations of the anomalies are significantly different statistically ($p < 0.05$) between the time periods of 1960s and 80-90s. Similarly, the absolute residuals of yield data from the fitted technological lines were also increased 300%. Thus, the variation of cereal yields has increased at the same time while the variation of mean temperature has also increased in the last 35 years. Though it does not prove that there is a cause-effect relationship, the results do present a plausible hypothesis that the global climate is increasingly more variable and, aggregately, world cereal yields are responsive in a way that is also becoming less stable. If this is true, it will have serious repercussions on world food security.

Weather Variability in the US and China. Karl et al. (1996) used two indices to quantify climate changes in the US: a Climate Extremes Index (CEI) and a U.S. Greenhouse Climate Response Index (GCRI). The CEI is based on an aggregate set of climate extreme indicators, and the GCRI is composed of indicators that measure changes in the climate of the U.S. that have been projected to occur as a result of increased emissions of greenhouse gases. Their results supported the notion that the climate of the U.S. has become more extreme in recent decades, but they can't exclude other factors than greenhouse gases that may have been the cause of the amplified variation. Though it is extremely difficult to prove beyond doubt that the weather is becoming more variable in the US, the evidence is strongly indicative toward that direction.

China is also vulnerable to natural disasters. Annually, China has about 20% cropland that will suffer a yield reduction by at least 30%. The main problem is the uneven distribution of rainfall. Along the Yangze river watershed, where rice is the predominant crop, flood is often the main cause of disasters. While in north China, wheat and corn are the main crops, water is the limiting factor even under normal conditions, and drought is particularly damaging. If the projected climate change is realized, then the temperature will raise more in higher latitudes. As a result, the evapotranspiration (ET) will increase: this condition would exacerbate the water shortage problem in northern and western China. On the other hand, the increased extreme weather conditions due to climate change could further intensify the frequent storms that often occur in south China summers, which is also unfavorable to south China's agriculture. China feeds 22% of the world population with 7% of the world's arable land; the agriculture system has to be very productive. China's increase in cereal yields is truly remarkable - about 100 kg/ha a year since 1961, or an annual growth rate 3.8%. The total cereal production in China approached 463 million tons in 1999 (FAO estimates). In order to feed its population of an estimated 1.6 billion in 2030, China would need to produce an additional 177 million tons. Current average yield of the cereal crops is 4,961 kg/ha in China (compared to 5,671 kg/ha in the US). To meet the food demand without additional crop land for cereal production or imports from foreign markets means the average yield in China will have to be raised to 6,858 kg/ha:

a national record that so far has not been observed anywhere in the world. It is probably a fair assessment that this record can not be achieved if the weather conditions are less than optimal.

Regional Effects

Global climate change, if it occurs as projected, will have serious consequences on agriculture and food production. The most detrimental aspect of the climate change will be the increased frequency and intensity of extreme weather events. This type of weather event is very difficult to predict, but when it happens it brings enormous destruction. It may be debatable whether these changes are a part of the natural system or due to anthropogenic activities, however, these issue will be most relevant if they are demonstrated and discussed at the regional or local levels.

For example, because logging and burning have replaced large tracts of forest with grasslands, which cannot transpire as much water as lush vegetation or crops do, the tropical forest has become spotted with hot, dry patches. Michael Glantz, a senior scientist at NCAR, estimated that temperatures are about 1 degree Celsius higher and precipitation up to 30% lower in large deforested patches. Similar effects have been seen in deforested regions of sub-Saharan Africa. For the same reason, Cousin (1999) reported that overgrazing on the Mexican side has raised temperature as much as 4^0C on some afternoons than in the United States, just a few dozen meters away. We have experienced similar regional climate changes in California. Figure 5 shows the Sacramento maximum and minimum temperatures for the last 47 years and Figure 6 shows the temperatures of Five Points, California. In Sacramento, the population has grown at least 3 fold in the last 47 years. Currently the population for the Sacramento greater area has exceeded 1 million. The night temperature has increased more than 1.5^0F probably due to the energy use and traffic increase of the urban growth effect. While Five Points has expanded its cotton production and irrigation area rapidly in the last 50 years. The maximum temperature, particularly in summers, has decreased, perhaps due to irrigation. The night temperature is still rising, and may have to do with the urban growth effect of the Fresno County, where Five Points is located. These types of regional effects are much more important to the local and regional populations. Researchers are only now begin to measure and to understand the impacts of agriculture, deforestation, and economic development on regional and local climate.

Conclusion

Climate change will have a wide range of direct and indirect impacts on agriculture. The direct impact on crop production in China and the US, on balance, would be negative. The indirect impact on agriculture will be mostly through the climate change effects on water systems. In the US, water supply problems in several river basins and regions, such as the Missouri, Arkansas, Texas Gulf, Rio Grande, Lower Colorado and California will be increased. The water shortage problem in northern and western China will be exacerbated and painfully felt by the local populations. In these regions, the evapotranspiration is expected to increase due to warming, and at the same time agriculture will be pushed to its limit to produce even more to feed the still increasing population in China. The compounded pressure from scarce water resource and heavy inputs could render Chinese agricultural systems extremely vulnerable to natural disasters. Climate change could also dramatically alter the geographic distributions of vegetation types in the US and China. Many species may no longer be adaptable to the changed environment, leading to a reduction of biological diversity that provides fundamental benefits to the health of humans and ecosystems.

Global climate change, if it occurs as projected, will have serious consequences on agriculture and food production, particularly for developing countries. The most detrimental aspect of the climate change, however, will be the increased frequency and intensity of extreme weather events. Future research must emphasize the changes in climatic variability and the forecasting techniques of extreme weather events. In addition, relevant regional and local studies are needed to realistically relate the impact of climate change to people's lives.

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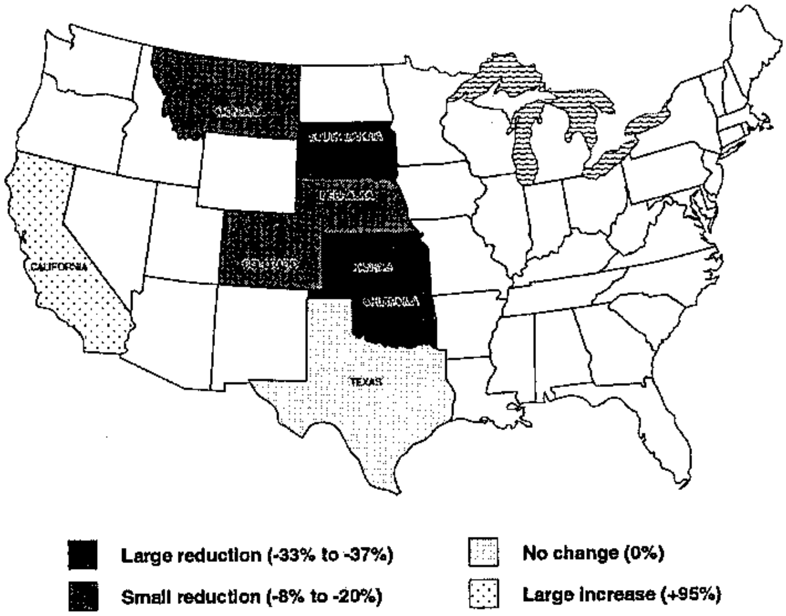

Figure 1. The US Wheat Yield Changes under Climate Change Scenarios Without CO2 Direct Effect

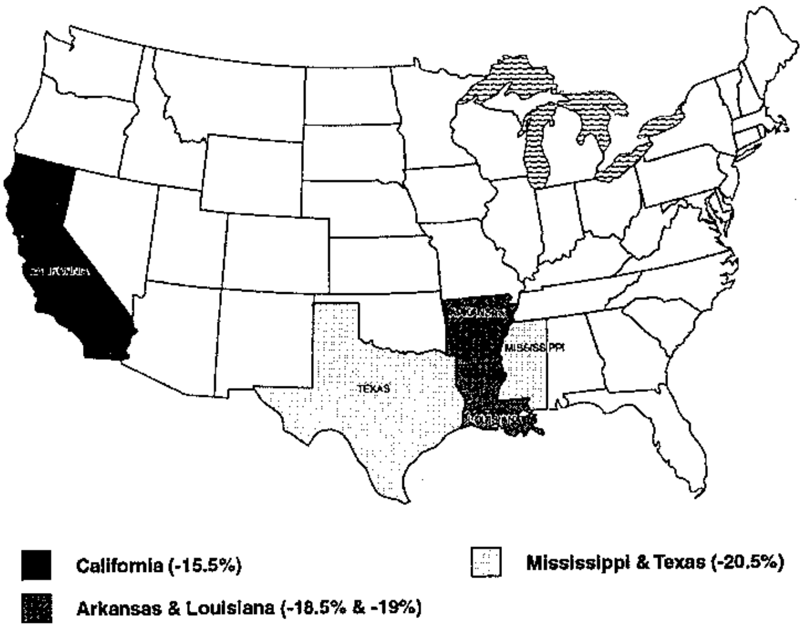

Figure 2. The US Rice Yield Changes under Climate Change Scenarios Without CO2 Direct Effect

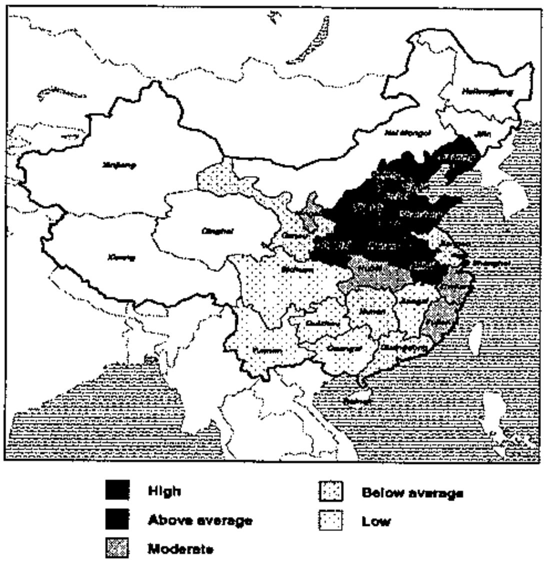

Figure 3. China's Wheat Yield Base Map Under Current Conditions. (High: 3,600 kg/ha and more; Above: average 3,000 - 3,500; Average:2,000 - 2,900; Below average: 1,400 - 1,900; Low: 1,300 and less)

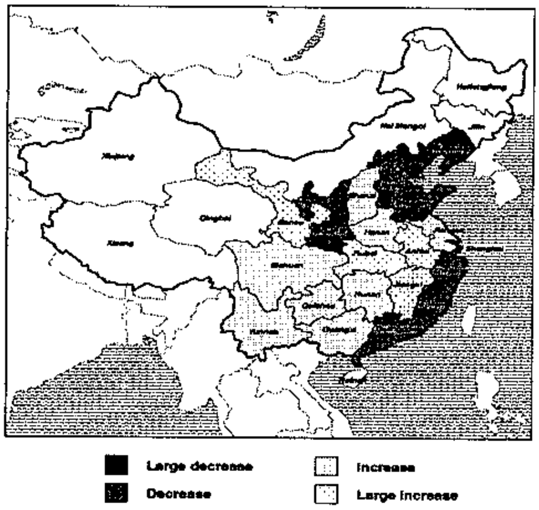

Figure 4. Estimated China's Wheat Yield Reduction Under Climate Change Scenarios (Large Decrease: -25% or less; Decrease: -1% to -24%; Increase: 0 to 24%; Large Increase: 25% or more)

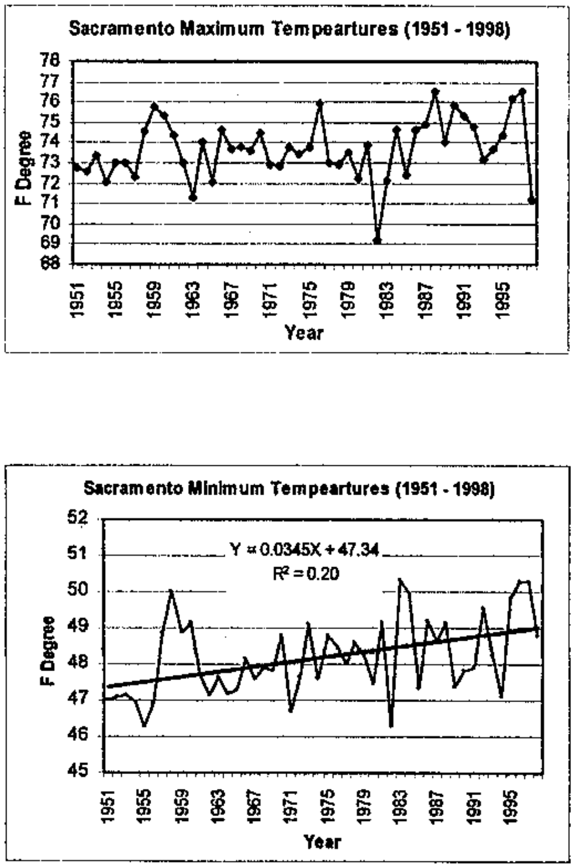

Figure 5. Sacramento (California, USA) Temperature Records

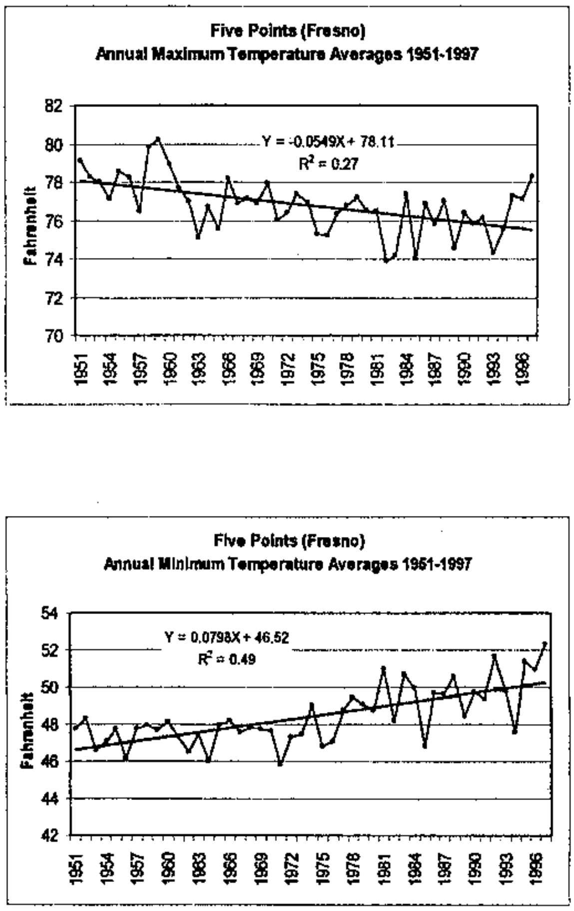

Figure 6. Five Points (California, USA) Temperature Records