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Global Warming in the Colorado Plateau
An Interactive Qualifying Project Report

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By

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Executive Summary

In this Interactive Qualifying Project, also known as an IQP, the effects of Global Warming in the Colorado Plateau were studied and evaluated. Previous studies of precipitation changes, acid deposition, and human influences that affected this region's environment were major influences in our research.

The data collected included precipitation percentages, nutrient deposits, temperature changes and other factors that may limit or harm the water supply and ecosystems in this area. Acid deposition is one of the phenomena resulting from temperature changes in the Colorado Plateau. Wet deposition results from chemical and electrical wastes from different smelters and coal factories depositing SO2 and NOx into the clouds. They then fall into the earth after the precipitation has taken its toll. With the precipitation changes in the Colorado Plateau region, a drought is inevitable for the current time period and due to previous circumstances the drought is expected to be the worst in centuries. Humans play a vital role in the future of global warming in the Colorado Plateau. The role of humans in the current warming trend and in future warming events was also discussed. Due to the arid temperatures the Colorado Plateau makes an ideal study site for the effects of Global Warming. However, the future cannot be concluded because the affects of Global warming cannot be measure in severity as of now.

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1. Introduction

The Colorado Plateau is centered in northeastern Arizona, and includes the adjacent Four Corner region of Utah, Colorado and New Mexico. Due to the popularity of the National Parks and Monuments in the Great Basin and Colorado Plateau, over six million people are estimated to visit the area every year. Over the past eighty years, fire suppression has lead to the accumulation of fuels and the introduction of invasive species that are slowly draining the rivers (Covington 1994).

Humans are changing the environment beyond the boundaries of natural variability and thus causing us to venture into the unknown of anthropogenic climate change. Preliminary data suggests that warming trends will affect global air and water cycling that will eventually lead to changes in not only global but regional precipitation regions (Houghton et al 2001). Changes such as these will especially affect the Colorado Plateau because this is an arid to semiarid region; arid and semiarid regions of the world are highly vulnerable to climate and precipitation changes. Karl and Trenbeth authors of Modern Global climate change emphasize that climate change is a global issue due to air cycling all over the world. They explain that humans have not necessarily caused a large temperature change, only 0.2°C in the first half of the 20^{th} century however there have been large changes in natural energy flows. David Karoly et al in the article Detection of a Human Influence on North American Climate provides graphs and simulation models of temperature anomalies for the 20^{th} century. This author explains that temperature changes from 1950 to 1999 were unlikely due to natural variability.

With the increase of temporal conditions come precipitation changes. Drought is one possible outcome of these temperature changes and the vegetation is in danger, ultimately affecting the entire ecosystem. The pinion-pine juniper ecosystem in such areas as Arizona, New Mexico, Colorado, and Utah has been studied to show how such vegetation is slowly draining the water supply. From 2002-2003, droughts led to a decline of more than ninety percent of the trees in the southwestern deserts because once the trees are weakened, the insects can subsequently cause the death of the vegetation. The same results occurred in other vegetative species such as the *Boutelua gracilis, Juniperus monosperma* and *Pinus ponderosa*, also concentrated in the southwestern deserts, which provide the survival needs for small animals and birds (Breshears et al). Evaporation and precipitation rates are vital in the survival of suitable soil for vegetative life. The growth rate of oceanic vegetation is also affected by temperature increases because respiration increases parallel temperature increases. Since the temperature is increasing, cloud coverage is decreasing, which is vital for primary production in plankton and deep algae. Some of the vegetative life surrounding the Colorado Basin is also draining the water, such as the exotic Salt Cedar, making an already scarce resource even in more danger. In the Colorado Delta region, half the water flow is allocated to agriculture and ten percent towards natural vegetation, and this leaves very little towards the human residents of the area, and the demand for water will only increase as the delta depletes in size (Carpenter et al, 2006).

In the American West the mean temperature change of 0.2°C of the Northern United States is somewhat higher, 0.8°C. Snow pack levels in the Rocky Mountains have dropped considerably due to this warming trend. In Oregon and California snow packs have shrunk 25% whereas in the Rockies they have shrunk 15% in a 47yr period. Snowmelt contributes 75% of all water in the streams throughout the west. Therefore increasing temperature will have profound effects on precipitation experienced in this region. The amount of water stored by snow will decrease by 30-70% over the next fifty years. Most regions on the coast have already experienced a 60% decrease of their snow packs in the past 50 years. Numbers like this would be detrimental to the Mid-west causing an increase in drought and wildfire. Wildfire rates have increased from a four-fold to a six-fold since the 1980s and have managed to double in size over the eleven states they concentrate in.

Other environment affects such as erosion and sedimentation that result from heavy rain and an excessive amount of precipitation is also a plausible concern. The content of the soil is changed by gases such as sulfur dioxide and nitrogen oxide which chemically change to sulfuric acid and nitric acid in the atmosphere and fall to the earth as acid rain or snow. This process is called acid deposition which eventually contaminates the water and soil, harming aquatic and terrestrial life. Acid deposition harms aquatic and terrestrial life through direct contact and by changing the chemistry of surface water and soils (Pfaff, 1996). The product of acid deposition is acid rain, which is usually a problem in areas surrounded by lakes and lakes themselves (Environment Canada Website). In general, surface waters and watersheds of the Colorado Plateau are resistant to chemical change due to low levels of acidic deposition. Although acid deposition does not appear to be a threat at the present time in the Great Basin, it should be noted that all the lakes in the park probably would be highly susceptible to acidification, should acid deposition occur. Monitoring of effects of deposition (both wet and dry) on surface waters needs to be continued or expanded. No estimates of rates of dry deposition are currently available for the Colorado Plateau.

2. Global Warming

Global warming has been detrimentally effecting the environment for years in conjunction with the actions of Earth's superior inhabitants, humans. Human actions are the causes for the increased concentrations in the atmosphere of greenhouse gases; carbon dioxide release from coal, oil and gas combustion (Easterling et al, 2006). Carbon dioxide in combustion is not the most abundant fossil fuel; however it is the most significant in human affects (O'Donnell et al, 2006). Three-quarters of human generated greenhouse gases comes from energy activity in the US requiring the burning of fossil fuels. Half of the greenhouse gas emission is from power plants and a third is from transportation devices, the other percentages are filled from industrial businesses. In 2004 alone, the United States released over seven billion metric tons of greenhouse gases (EPA, 2006). Prior to the Industrial Revolution, carbon dioxide levels were 280 ppmv and the current levels are 370 ppmv. With such a drastic increase in such a short period of time, the IPCC Special Report on Emission Scenarios has determined carbon dioxide concentrations to vary from 490 ppmv to 1260 ppmv by the end of the twenty-first century (Easterling et al, 2006).

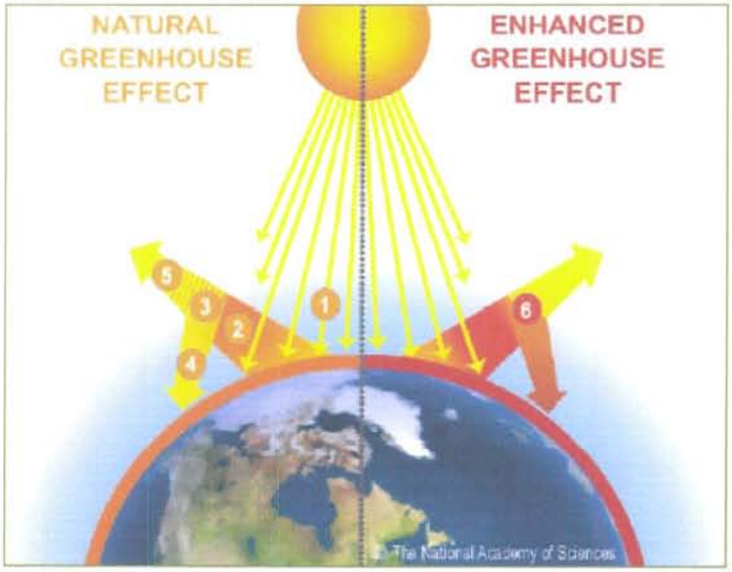


Figure 1. Greenhouse effect illustration. Sunlight first goes through the atmosphere without being absorbed. Once the sunlight has come to Earth it is (1) absorbed and converted to heat Earth's surface. Then the surface (2) releases the infrared radiation to the atmosphere. From there some of it is (3) absorbed by greenhouse gases and (4) re-emitted toward the surface. The infrared radiation not trapped by greenhouse gases is (5) released into space. Human activity releases excess greenhouse gases into atmosphere that (5) increase the amount of infrared radiation that gets absorbed before going into space. Element number five is what enhances the greenhouse effect that is causing global warming (Marian Koshland Science Museum of the National Academy of Sciences, 2002).

With increased greenhouse gases comes the greenhouse effect, involving the regulation of the temperature on Earth. The greenhouse gases- water vapor, carbon dioxide and other trace gases- are responsible for absorbing heat (Figure 1), setting the precedent heat of 14°C instead of -18°C that would exist without the gases. However, human involvement poses a threat to an increase in the gases and thus an increase in heat absorption leading to higher overall temperatures. Climate changes over time coincide with the physical factors that are external to the climate system that has an increase or decrease of heat as a whole (Hansen, Sato et al, 2005). Internal climate variability where heat is transported by winds or ocean currents has no change in total heat such as the El-Niño-Southern Oscillation (Hansen, Nazarenko et al, 2005). There is evidence that

Earth's temperature has increased over the past century coinciding with the Industrial Revolution, an increase of 0.6°C since the late-19th century and 0.2 to 0.3°C since 1980 (Figure 2) has thus far been recorded. This is not a uniform change for the globe, some countries did cool over the century, but the temperature increases have been concentrated in the more industrial countries such as North America, Europe and Asia. It has also been estimated that the temperature will increase an additional 1.5 - 4°C over the next century, from calculations derived from the past few centuries (Easterling et al, 2006). It has been found that twenty of the twenty-one hottest years recorded have been in the last twenty-five years, and the hottest of all thus far has been found to be 2005 (O'Donnell et al, 2006).

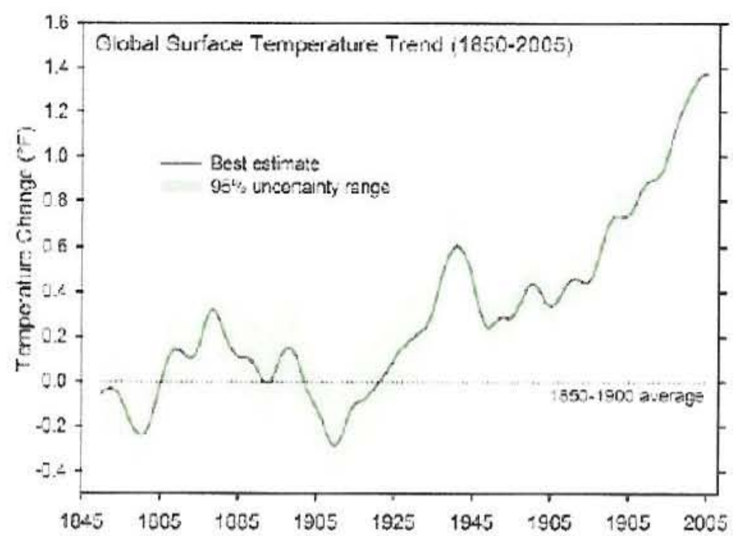
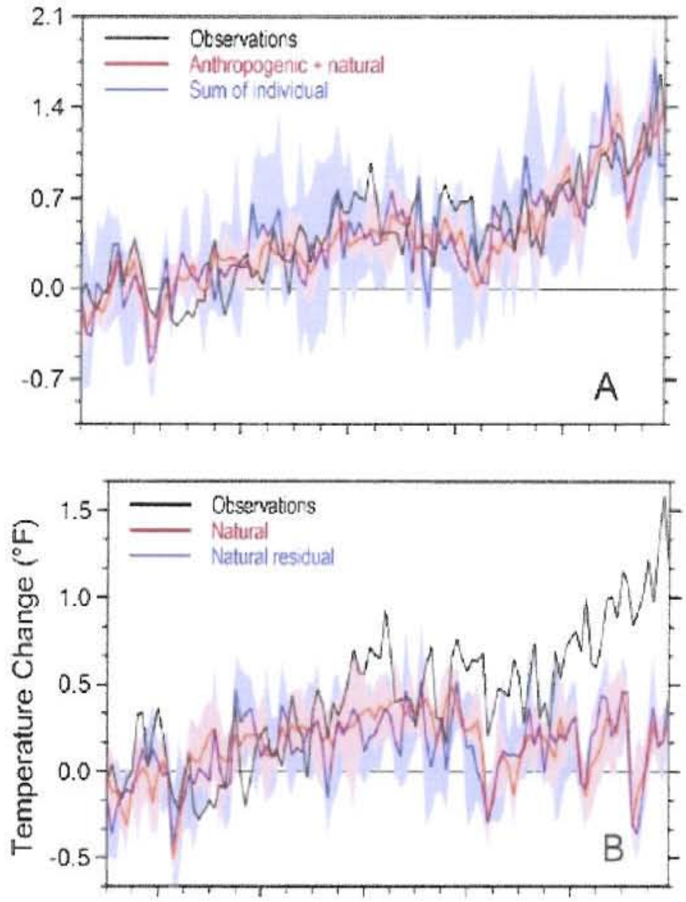


Figure 2. Average global surface temperature (Brohan et al. 2006; © Crown copyright 2006, data by Met Office)

The beginning of the twentieth-century had a warming trend at the earth's surface during the period from 1910-1940, then began a moderate cooling from 1940-1975 and a larger scale warming from 1975 to present day. (Figure 2) Through the study of natural (solar radiation and volcanic particles) and man-made (greenhouse gases and sulfate aerosols) have forced the climate change (Meehl et al, 2004). The changes in surface temperatures for each forcing or combination of forcings or the conditions causing climate to change towards a certain distinction compared to the surface temperatures can be coupled and compared for the twentieth century. (Figure 3) There are several ways this can be displayed from overall forcings compared to temperature change (Figure 3A), natural forcings dominating the change during the beginning of the century (Figure 3B), and man-made greenhouse gases dominating the change after 1975 (Figure 3C). With the greenhouse effect absorbing more heat in the lower atmosphere comes the cooling of the higher atmosphere region because the heat is not passing through. Such an example is the data collected after the eruption of Mt. Pinatubo in 1991, where the temperature in the troposphere was recorded as cool and the stratosphere was warmer. Over 50% of the global land regions have experience what is called reduced diurnal temperature range which is defined as the difference between the high and low daily temperatures and with this has come increased cloud coverage. The maximum daily temperature difference from the studied period (1950-1993) was found to be 0.1°C/decade and the minimum was 0.2°C/decade producing a negative diurnal temperature range of -0.1°C/decade. Other factors that show evidence of warming trends are snow cover and glacial recession with changes in snowcap elevation and glacier length, such changes also allow for data of changing temperatures in higher atmospheres to be collected. From 1973 to 1996, Artic sea ice had decreased at a rate of -2.8 +/- 0.3%/decade; however Antarctic ice has shown little change, even a possible increase, in the same period, these conditions have yet to be determined if they are the results of warming but ongoing studies are being done to determine if they are for certain linked or not (Easterling et al, 2006). Oceans have region with the exception of Russia but there has also been a decrease of -0.3%/decade in tropical regions. Precipitation rates are given by changes in stream flow, lake levels and soil moisture because it is too hard to obtain workable data otherwise involving precipitation. The northern region of the world has also experienced a decrease in snow cover since 1987; it has decreased 10% since 1966. Cloud coverage was shown to have increased over these areas in the 1980s, but that has changed since the early 1990s and now a decrease in cloud coverage can be observed (Easterling et al, 2006).

Global warming has not shown dramatic changes in the world as a whole and is not evident until regional calculations are compared solely to one another. Depending on the region's climatic conditions, the intensity of precipitation changes are increasing, droughts are worse and excessive moisture has increased. Increased precipitation is largely due to the increase of extreme precipitation events- hurricanes- rather than an increase in normal precipitation activity- longer rainy periods. Extreme precipitation events are actually representing a decrease in precipitation if the drastic weather events had not taken place, such as an increase of tropical cyclone activity over the last half of the twentieth century in the northern hemisphere and a decrease of such in the southern hemisphere. This behavior of storm exchange described as El Niño and La Niña have not been directly related to Global warming however, it has been linked to a decadal-interdecadal fluctuation where the regions exchange weather characteristics. The sea level has also shown to have raised 1 to 2 mm/year over the past 100 years overall due to the thermal expansion of the upper 100 meters. With such a dramatic increase it has been projected that it will increase from 0.09-0.88 meters from 1990 to 2100 (Easterling et al, 2006).

natural temperature change cycles where some areas cool while others warm which is called internal variability. By identifying which areas are exchanging heat, several institutions have found that the oceans along the equator have warmed drastically over the past fifty years by the enhancement of greenhouse gases (Barnett et al, 2005). Through these observations the oceans have been warming from the surface downward (Figure 4- all red dots), representing heat transfer from the atmosphere. Internal variability with or without solar and volcanic forcings that would have vertical warming (Figure 4A) but human-induced forcings combined with the two did (Figures 4B).



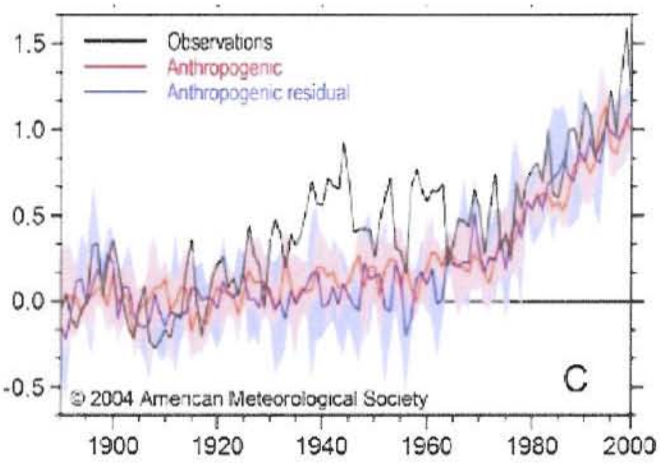


Figure 3. Modeling of global surface temperature change). (A) All forcings in comparison to temperature change. (B) Natural forcings effecting temperature change during the beginning of the century. (C) Man-made facings effecting temperature change after 1975(Meehl et al, 2004)

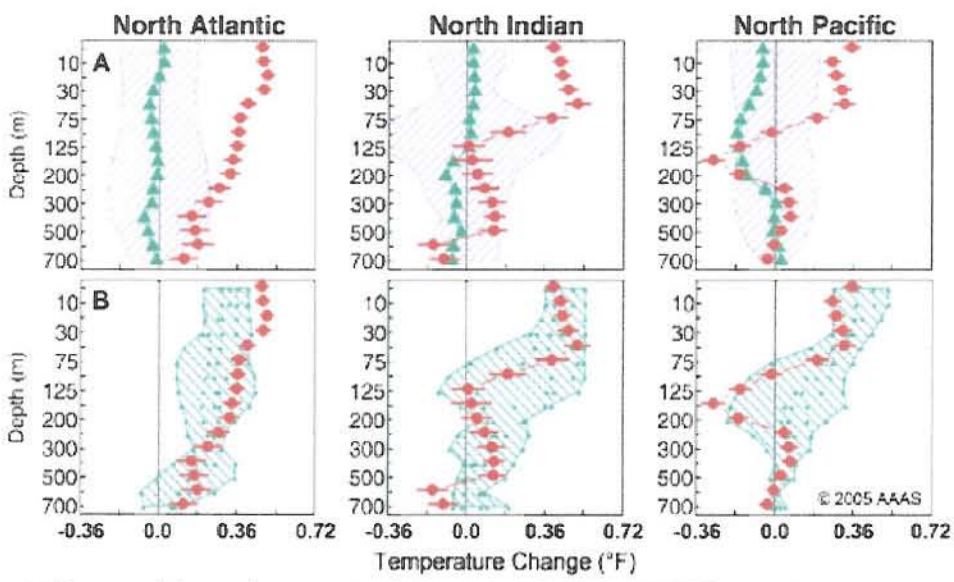


Figure 4. Observed heat changes in three ocean basins. (A) Blue region represents 90% confidence of natural internal variability from heat exchange. The red dots are the observed temperature changes. Green triangles have little to no agreement with climate trend. (B) Human-induced forcings from greenhouse gases and sulfate aerosols (green area) and red dots show heat variables (Barnett et al, 2005).

Precipitation levels have increased by about 2% since 1900 overall; however this does not include the globe as a whole. A 0.5-1.0%/decade has been shown in the northern

The actions taken by the government so far to prevent further dramatic precipitation and temperature changes are slowing the growth of emissions, strengthening science, technology and institutions so that data can be organized and composed more accurately, and relating internationally to work on the problem with then world. A strategy devised to reduce the greenhouse gas intensity, measurement of greenhouse gases emitted per unit of economic activity, by eighteen percent was put into effect by the United States in February of 2002 and expire in 2012. In order for the greenhouse gas intensity to be reduced by eighteen percent, the prevention of over 100 million metric tons (all carbon based elements) annually must be met or the minimum of 500 million metrics tons cumulatively (EPA, 2006).

3. The Colorado Plateau

The Colorado Plateau is a huge basin surrounded by highlands. It spreads across southeastern Utah, northern Arizona, northwestern New Mexico and western Colorado (see Figure 5). It covers 130,000 square miles of land. Being over 500 million years old, the Colorado Plateau has remained quite stable geographically. Surrounded by the remnants of volcanic eruptions, the Plateau consists of many layers of sedimentary rock. Two rivers run across its deserts that have enough water to supply millions of people in all four states. On the other side, snow covered mountains rise about the desert carrying artic-alpine biota. Pools of water, flowered gardens and springs in the desert can also be found. Since the Colorado Plateau has remained untouched for 5 million years, it houses layers of fossil life forms each descending from earlier epochs, such as dinosaurs, camels, mammoths and sloths. The Plateau also serves as a great shelter for over 80 plants that are listed as endangered species.

Figure 5. A map of the Colorado Plateau, showing the states it covers. The white outline is the outer borders of the Colorado Plateau (http://www.cpfieldinstitute.org/images/cpinfo/colorado_plateau.jpg).

When two teams of geologist were asked by the National Park Service to identify "National Landmarks", 110 sites were nominated. "In no other province in America", they explained, are the relationships between morphology and geology more clearly or graphically revealed." There is some bad news concerning the Colorado Plateau. The National Park Service protects only 5 million acres making up only 7% of the land of the Plateau. This is a threat because the rest of the land in managed by the Bureau of Land Management which is in charge of land development.

Since the 1930's there have been multiple attempts to maintain the wilderness of the Colorado Plateau. Today, most of the Plateau is maintained as a wilderness through the efforts of the National Park Service and other nature enthusiasts. Environmental organizations have proposed several protection plans some of which have involved creating "monuments" of vast amounts of wilderness acreage. Developers have also proposed many ambitious projects involving the Colorado Plateau. These projects have included coal mining and burning, using the plateau as a waste dump and the building of hydroelectric dams on the Colorado River. Differing views between environmentalist and developers have led to many confrontations. However, since the Colorado Plateau is one of the last, vast natural ecosystems left in the United States, there was a public demand for conservation. This demand overruled the growing needs for energy as was evident by the defeat of proposals to damn Glen Canyon in the 1960's and 70's

Today the people of Utah recognize the invaluable asset that they have on their hands and are taking steps to protect it. The Governor of Utah and other state officials are changing their points of view. Many of them now realize that the potential economic benefits of tourism in the long run, outweigh the economic benefits of destroying the wilderness for industry. However, the beauty of the Colorado Plateau should intrinsically inspire protection, not the economic value alone.

4. Acid Deposition in the Colorado Plateau

Acid deposition occurs when sulfur dioxide (SO_2) and nitrogen oxide (NOx) gases chemically change to sulfuric acid in the atmosphere and fall to the earth with rain and snow (wet deposition), or with dust and microscopic particles (dry deposition). For the purpose of our IQP, we were focusing on wet deposition on the Colorado Plateau (Pfaff, 1996). Acid deposition harms terrestrial life through direct contact with the plant tissue itself and with the earth, and by changing the chemistry of surface waters and soils once in contact. It is predicted that if no action is taken, the Great Basin will have a 44% loss of mammalian species, 23% loss of butterfly species, 30% loss of perennial grasses, and 17% loss of shrub species (National Wildfire Action, 2006). Acid rain, the process by which acids with a pH normally below 5.6 are removed from the atmosphere in rain, snow or hail, is the result of wet deposition. It has a sour taste that is characterized by the ability to react with a base to form a salt. Strong acids burn your skin. Acid rain is usually a problem in areas surrounded by lakes because lakes and soils resting on granite bedrock, for instance, cannot neutralize precipitation (Environment Canada Website 2005). All lakes in the dry West probably would be highly susceptible to acidification. Some Western lakes are granitic but not many. Natural rainwater with normal CO_2 levels in the atmosphere has a pH of 5.5 due to the reaction $CO_2 + H_2O = H^+ + HCO_3^-$. Most of the West has a limestone base which helps in the neutralization of acids. The granitic and quartzic basins occupied by these lakes leave them with very little capacity to neutralize acidic pollutants (Pfaff, 1996). The average annual precipitation of the Colorado Plateau ranges from 136 to 668 mm/yr with a median of 300 mm/yr (see Figure 6). This data is based on daily records from ninety-seven weather stations, where the precipitation levels varied substantially over the century.

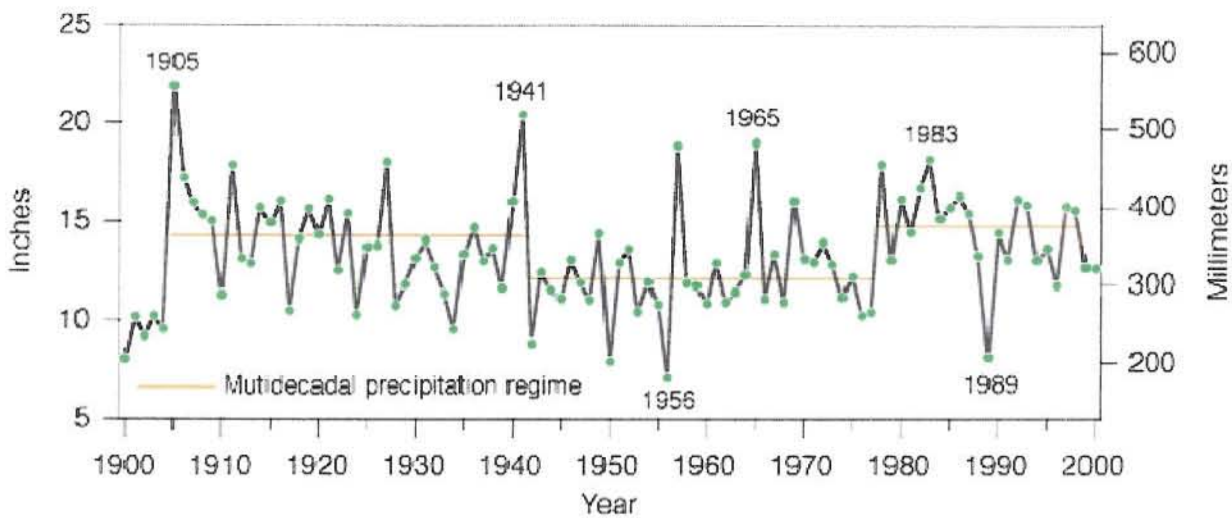


Figure 6: The average annual precipitation levels recorded on the Colorado Plateau from 1900 to 2000. The years that are of unusual wet or dry concentration are labeled as so and the horizontal lines represent the average precipitation for three multidecadal precipitation times (Hereford, 2005).

From 1985 through 1994, the precipitation-weighted mean of pH of rain and snow at the Great Basin was 5.4 which are within the normal pH range of 4.8 to 6.0. During this ten year period, the lowest valid weekly sample was 4.34 and the highest was 8.00. In that same period, the average concentration of sulfate in precipitation was 0.8 mg/l, and the average annual deposition of sulfate was 2.5 kg per hectare. Nitrate concentrations were 1.1 mg/l, and the annual wet deposition of nitrate was 3.3 kg per hectare. During the summer of 1993, the wet concentration of sulfate and nitrate at Red Rock Canyon were somewhat higher than before, because the site is strongly affected by the emissions of nearby Las Vegas (Pfaff, 1996).

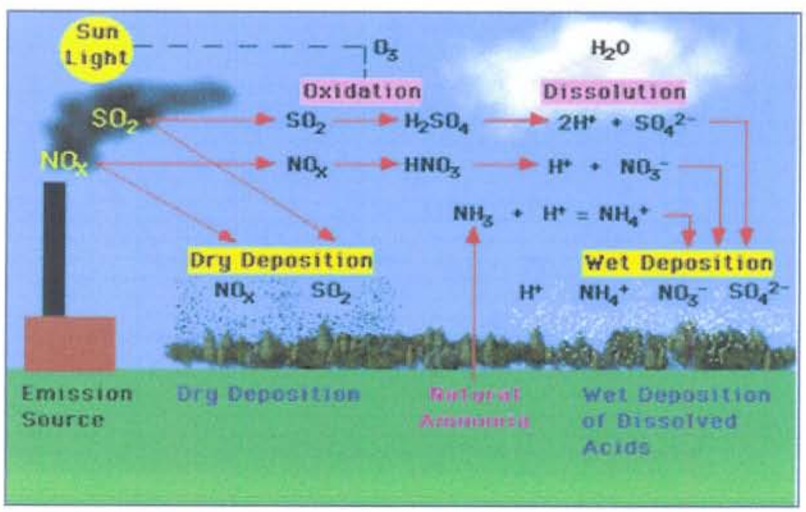


Figure 7: An overview of the cycles of wet and dry deposition (www.gippsland.monash.edu.au/.../project22.shtml).

Coal-fired power plants and smelters are the main sources of SO_2 emissions. In the United States, 67% of emissions are from electric utilities. For example, in 2000 U.S. SO_2 emissions reached 14.8 million tons. Automobiles and electric utilities are the main sources of NOx emissions. United States' NOx emissions for 2000 amounted to 21 million tons (Green Lane, 2005).

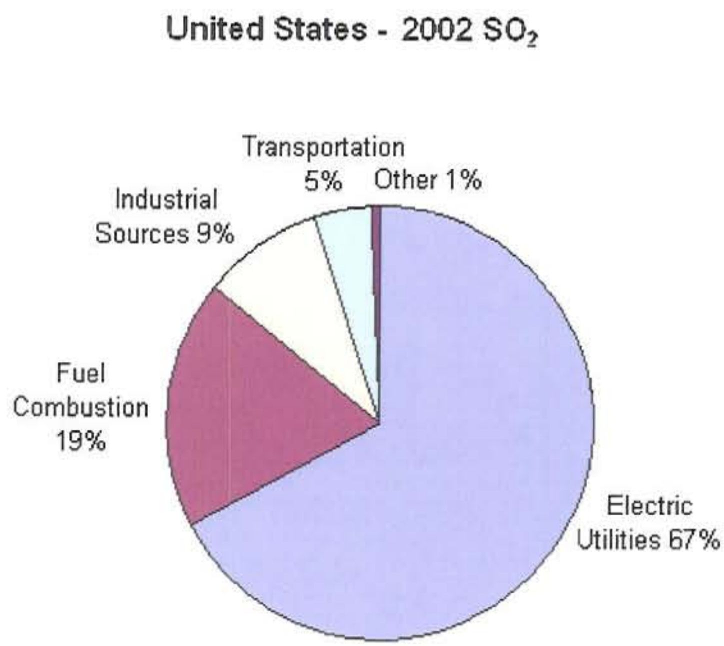


Figure 8: The biggest source of SO_2 comes from Electric Utilities at 67%, following to Fuel Combustion at 19%, then Industrial Resources and Transportation making up the last 25% (Green Lane, 2005).

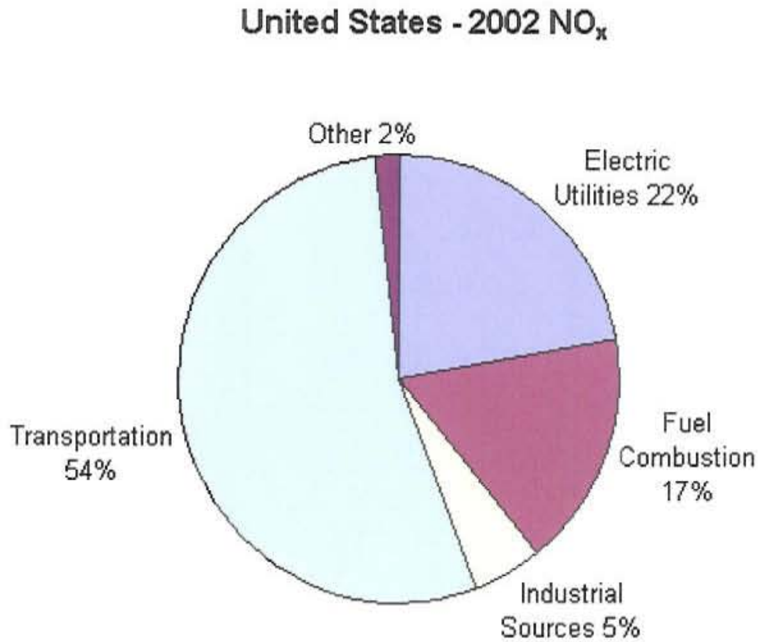


Figure 9: The biggest source of NOx comes from Transportation at 54%, following with Electric Utilities at 22%, then Industrial Resources and Fuel Combustion making up the last 24% (Green Lane, 2005).

Now that acid deposition is defined, here are some forms that scientists use to figure out in what shape are ecosystems when it comes to acid deposition. Pollution in an ecosystem is categorized either as a critical load or a target load. A critical load is a measure of how much pollution an ecosystem can tolerate. Ecosystems that can tolerate acidic pollution have high critical loads, while sensitive ecosystems have low critical loads. Scientists have defined the critical load of aquatic ecosystems as the amount of wet deposition that protects 95% of lakes from acidifying to a pH level of less than 6. A target load is the amount of pollution that is deemed achievable and politically acceptable when other factors like ethics and social and economic effects are balanced with environmental concerns. Scientists have predicted that acid deposition will continue to be a problem unless a 75% reduction of SO_2 emissions takes place (The Green Lane, 2005).

One network that is supported by EPA monitors acid rains pH and the chemicals that cause acid rain. The National Atmospheric Deposition Program (NADP, 2007) measures wet deposition and developed maps of rainfall pH and other important precipitation chemistry measurements. According to the National Atmospheric Deposition Program, annual wet and dry deposition has been going down in the period of 10 years. For example, sulfate deposition has gone down from 3.66 kg/ha in 1997 to 2.29 kg/ha in 2007. Nitrate deposition has also gone down from 1.48 kg/ha in 1997 to 1.16 kg/ha in 2007.

Currently, ambient concentrations of SO2 are far below thresholds for impacts on sensitive plants. In general, surface waters and watersheds of the Colorado Plateau are resistant to chemical change due to low levels of acid deposition and the nature of the region's hydrogeology. The current pH of rainfall in the plateau is not low enough to cause any direct acidification problems. Wet deposition of nitrogen is also very low across the Plateau. It is unlikely that such low rates could increase nitrogen availability enough o significantly change plant populations (Covington et al, 2001)

Monitoring of effects of wet deposition on surface waters needs to be continued and expanded. No estimates of rates on dry deposition are available for the Colorado Plateau; therefore an attempt should be made. Also a series of experiments should be developed to tackle the impact of reasonable exposures to air pollutants and deposition. As far as pollution goes, the United States needs to have a limit on the use of fossil fuels and start investing in alternative ways for energy sufficiency such as renewable technologies (National Wildlife Action, 2006).

5. Changes in Precipitation in the Colorado Plateau

Recently, the U.S. Geological Survey (USGS) and other scientists suggested that in the next twenty to thirty years the Colorado Plateau will become drier. It is expected that the new drought will be similar to the drought that took place from 1942 to 1977. Since the mid-1950s, the population of the region has increased four times likely making such a drought have far more severe consequences than the previous. Changes in drier climate regions such as the Colorado Plateau, particularly reduced winter rainfall, would have dramatic effects of the ecosystems. Reduced winter rainfall would result in reduced groundwater recharge, lower base flow in perennial streams, increased amounts of dust storms and strong winds, weakened soil crusts, reduced plant cover and changes in species composition, movement of sand from once stable dunes, and increased forest and range fires. Based on the changes in precipitation of the twentieth century in the Colorado Plateau, it is possible to conclude future patterns and global effects on the Plateau currently (Hereford, 2005).

The average annual precipitation of the Colorado Plateau ranges from 136 to 668 mm/yr with a median of 300 mm/yr (see Figure 6). These data are based on daily records from ninety-seven weather stations, where the precipitation levels varied substantially over the century. The precipitation levels can be sorted into distinct periods of precipitation changes. These data show a wetter period from 1905 to 1941 but it followed a severe drought that had taken place over eleven years and continued five years into the twentieth century. These data also showed a drier period from 1942 to 1977 and was described as the worst drought the southwest had experienced in the past four hundred years, although precipitation rates began increasing after 1956. Finally, 1978 to 1998 was a wetter period, restoring the nutrients needed for habitation in the land and increasing the population and visitation rates. Currently, the region has been re-introduced to the drought conditions with decreased rainfall, although survival is still maintained (See Figure 10). The wet years were defined as having precipitation levels higher than that of the median in the twentieth century and droughts were considered when moisture was below the norm (Hereford, 2005). The early part of the twenty-first century has produced the most severe drought in terms of flow deficit in over a century. The average MAF from 2001-2003 has been a mere 5.4. The Dust Bowl from 1930-1937 had an MAF of 10.2. The Colorado River Basin is the main source of water for the Western region of the United States and the recent drought has been hypothesized as the worst drought since the 1500s by studying the tree rings of shrubbery in the vicinity of the river. Even in comparison to last year, drought conditions have increased dramatically. (see Figure 11) The drought conditions have increased the susceptibility for the fire season (USGS, 2004).

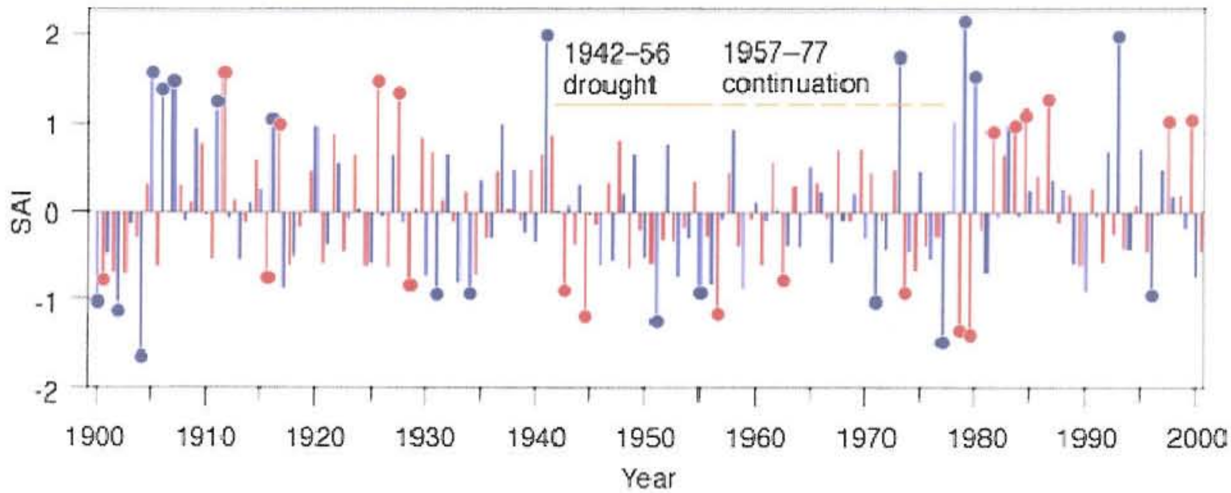


Figure 10: The standardized anomaly index, also known as SAI, of seasonal precipitation for the Colorado Plateau. The blue lines represent cool seasons and the red lines represent warm seasons. The solid circles are the top ten wettest and driest seasons from 1900-2000. (Hereford, 2005)

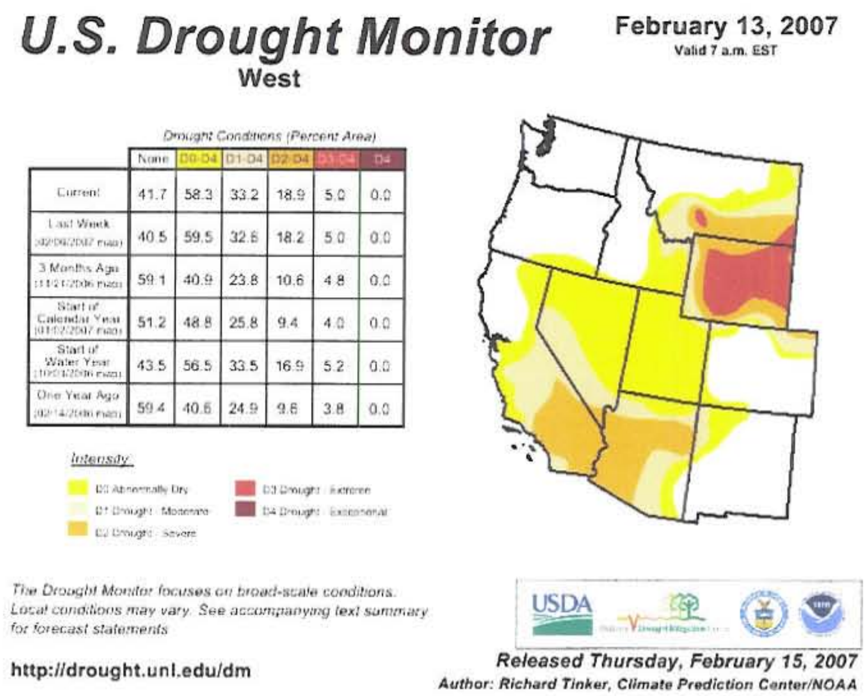


Figure 11: Current drought conditions in the Western region of the United States as of February 15, 2007. (Tinker, 2007)

5.1. Small Scale Precipitation Influences

Due to the arid conditions of the Colorado Plateau region, precipitation is biseasonal. Most of the precipitation responsible for moisture in this region occurs during the cool and warm seasons, respectively October 16 to April 15 and June 15 to October 15. Cooler season precipitation is brought on by the North Pacific Ocean through frontal systems and the warmer season rainfall coincides with the South American monsoon. The South American monsoon is classified as a season related reversal of the circulation in the atmosphere that is responsible for the transportation of moisture from the Gulf of Mexico and the Gulf of California. Seasonal precipitation is expressed in standardized anomaly index (SAI). SAI shows all figures near zero to be of normal precipitation, values above zero represent wet periods and values below are representative of dry periods. Seasonal precipitation is very similar to annual precipitation because it too is broken into three periods where a drought is sandwiched between two wet periods (Hereford, 2005).

5.2. Large Scale Precipitation Influences

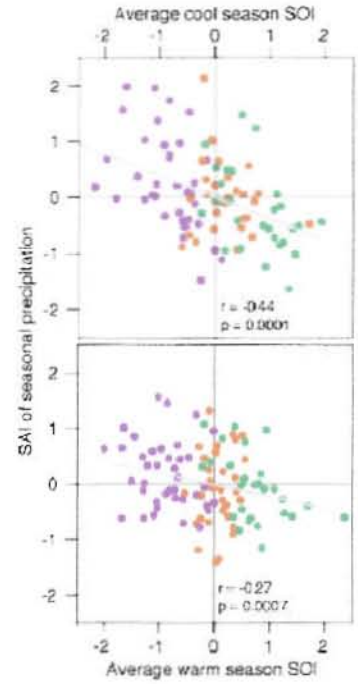


Figure 12: Seasonal precipitation for the Colorado Plateau is classified by the ENSO or non-ENSO or non- ENSO influences as a function of the SOI. Purple, light green and orange symbols represent El Niño, La Niña, and non-ENSO, respectively. The SOI in this case was averaged off of a 7 month seasonal period. (Hereford, 2005)

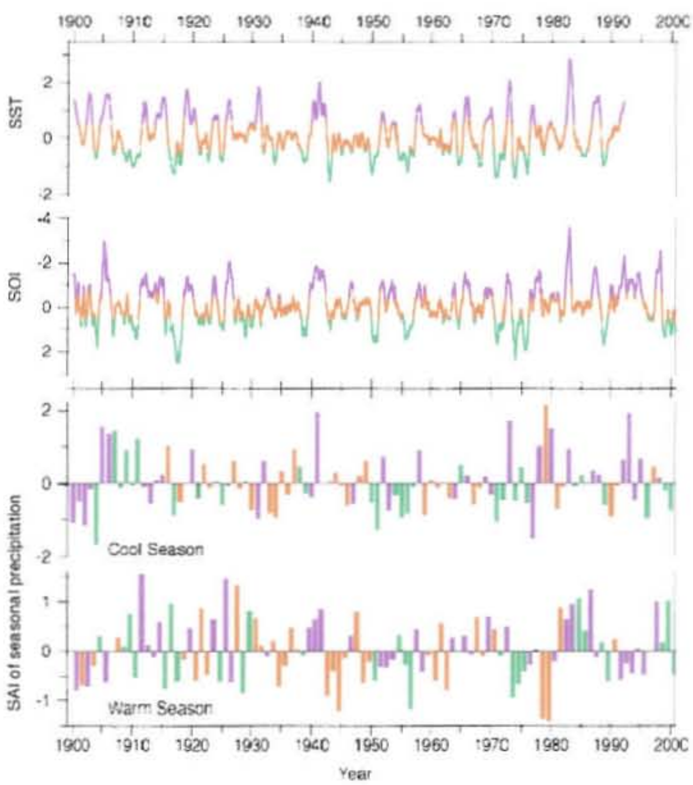


Figure 13: This figure displays seasonal precipitation (SAI) for the Colorado Plateau in comparison with the El Niño-Southern Oscillation (ENSO) chronology of sea-surface temperature and the SOI. The color pattern has the same meaning as in Figure 11. The SST and SOI were averaged over a 5-month period with the ENSO conditions for SST of 0.4 and –0.3°C and SOI threshold of ±0.5 standard deviation. (Hereford, 2005)

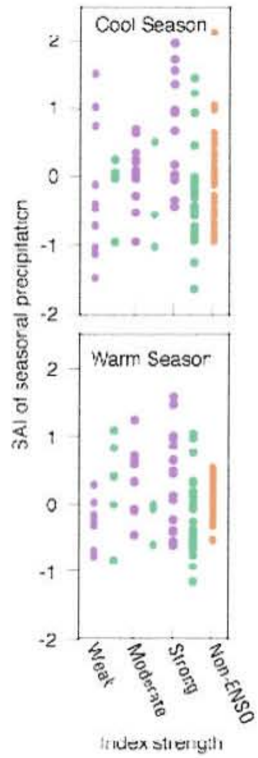


Figure 14: This figure displays the seasonal precipitation anomalies for the Colorado Plateau as described by strength of the ENSO activity. The color pattern is once again the same as Figure 11 describes. (Hereford, 2005)

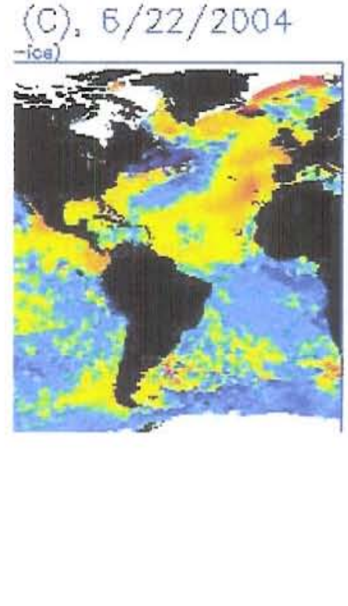


Figure15: This is a map showing the temperature anomalies for the Atlantic Ocean. The orange and red shades represent water that is from 2 to 5 degrees warmer than average. (Hereford, 2005)

Precipitation changes in the Colorado Plateau are due in part to the temperature changes that take place over the tropical Pacific and the northern Pacific Ocean. Climate changes are the resultants of sea-surface temperature fluctuations, atmospheric pressure and atmospheric circulation patterns. There are two variations of climate change studied- short term and long term variations. Short term climate variants are based on El Niño and La Niña activity represented by the Southern Oscillation Index (SOI) (see Figure 12) and equatorial sea-surface temperature which last on average from four to seven years. The SOI is the difference between the sea-level atmospheric pressure in Darwin, Australia and Tahiti. If the SOI is kept at a negative value it is represented of a warmer sea-surface temperature in the tropical eastern Pacific Ocean which is representative of an El Niño and conditions in opposition represent a La Niña. The comparison between the atmosphere and the ocean on climatic effects is called El Niño- Southern Oscillation or ENSO (see Figure 13). Such conditions are representative of wetter winters in the Southwest and an increase in stream flow in mishaps with storm tracks where drought is a possibility and La Niña conditions are normally defined as dry winters. Seasonal precipitation, as defined previously, in the Colorado Plateau is negative in representation of the SOI. ENSO activity (see Figure 14) in the Colorado Plateau is based on the SOI, the sea-surface temperature in the equatorial region of the Pacific Ocean at 5°N to 5°S, 90° to 150° W (known as the Niño3 region) and the data of Trenberth in 1997, Ropelewski in 1999 and the Climate Prediction Center in 2001. (Hereford, 2005) The sea-surface temperature, also known as SST, is consistent with the warming of the ocean (see Figure 15) and the rapid shrinking of the Arctic ice caps. If such conditions persist this could result in American living in uninhabitable regions and surviving off of river and land water that is continuously depleting. (USGS) The Colorado Plateau bases its seasonal precipitation in accordance to the ENSO classification from the middle and up to six months after a season has begun. The El Niño has an increase of cool-season precipitation and La Niña tends to have lower precipitation rates. The strengths of precipitation are also variably dependent in the observation of climate change also though causing weaker versions to show opposite results and an increase of each makes seasons that would normally lack due to the situation show climate levels similar to that of its counter-part (Hereford, 2005).

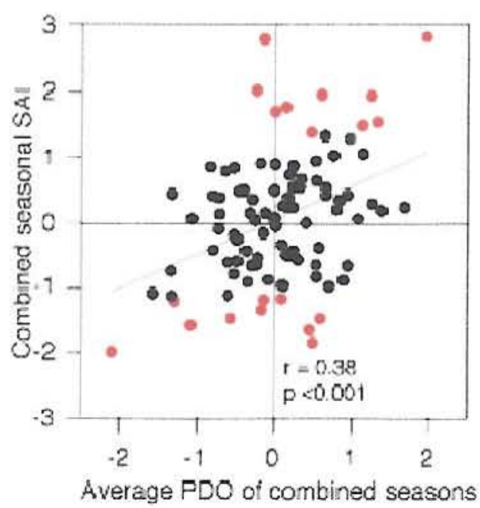


Figure 16: Displays the combined cool and warm season, from October 15-October 16, precipitation for the Colorado Plateau as PDO. The top ten driest and wettest years are shown in red. The PDO is averaged over 14 months. (Hereford, 2005)

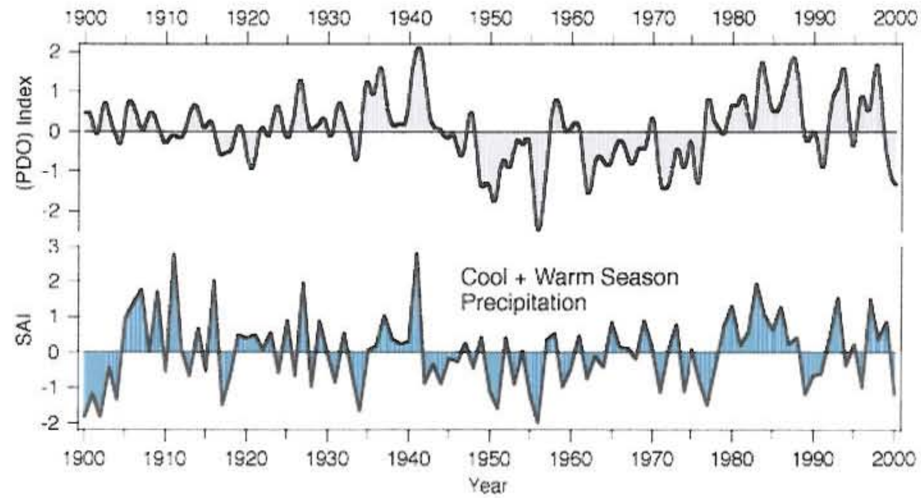


Figure 17: The PDO over a 15 month interval is represented in the upper region and the SAI in the lower region for the Colorado Plateau. (Hereford, 2005)

In contrast to short-term variation, long-term variation is based on a pattern of Pacific Decadal Oscillations known as PDO (see Figure 16). This is a far longer term of observation and has to do with the multidecadal climate explained in the drought and wetter periods. The PDO is related partially to the sea-surface temperatures and atmospheric pressure of the northern Pacific Ocean. Changes within these conditional factors trigger transitions from one climate to another which normally is the length of two to three decades. PDO and ENSO work together in climate variations. Precipitation in the Colorado Plateau area correlates with the PDO (see Figure 17). There are three precipitation regimes that represent these changes by the annual and seasonal precipitation changes. Annual and seasonal precipitation changes are in-phase with the PDO which was very evident in the behavior of precipitation during 1942 to 1977. But the conditions that have been of great controversy have been far more recent, as of 1999, with a downward shift in the PDO. This decrease has continued and is currently showing behavior similar to that of the severe droughts that have previously taken place (Hereford, 2005).

Precipitation in the Colorado Plateau region is highly variable due to the conditions of both the long-tern and the short-term implications. Since the current conditions are indicative of the drought from 1942 to 1977 that severely affected the region at the time, if such conditions continue for the next twenty years, which is expected, the region would lose its abundant supplies and have catastrophic consequences with such a high increase in population (Hereford, 2005).

6. Human Influences on Global Warming

There is no doubt that global warming is occurring. However, there are still questions as to what is causing global warming to occur. Karoly et al. in 2003 have shown through simulations performed by five different climate models that climate change in the North American region over the 20th century were due to "anthropogenic forcing from increasing atmospheric greenhouse gases and sulfate aerosols" (Karoly et al, 2003). Karoly et al have also shown with the use of several model simulations that it is unlikely that large scale global climate change is due only to natural variability (Karoly et al, 2003).

Humans are changing the environment at a rapid pace. In North American, carbon dioxide is up 31% since preindustrial times (280ppmv-370ppmv), Figure 18 shows that in the Grand Canyon and rebuffing proposals to build a coal mine and power plant on the Kaiparowits Plateau in 1976 (Wheeler, 2007) The damming of Glen Canyon which ruined183 miles of canyons proved to be one of the few exceptions. However, for the most part the citizens of Colorado Plateau realize that much of their livelihood is based on the natural resources of this region. Therefore much has been done to prevent the loss of natural ecosystems and to combat global warming.

Very often the negative effects of a warming trend are not directly attributed to global warming. Therefore very little is done to fight the real issue at hand. Communities and lawmakers only focus on the local issues while the global problems remain the same. A prevalent argument is that global warming is caused by natural variability and not by human influences. However, recent research done by the United Nations-sponsored Intergovernmental Panel on Climate Change (IPCC) states that "most of the observed warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations" not any natural changes. The panel states that carbon dioxide and other heat-trapping gases that humans have pumped into the environment are definitively the main cause of global warming. Richard Kerr summarizes the findings of the (IPCC) in his article "It's Official: Humans Are Behind Most of Global Warming" (Kerr, 2001). The panel which consisted hundreds of participating scientists and approved by 100 participating governments concluded that by the end of the century the world will warm from twice as much to ten times as much as it has in the previous century.

Sophisticated computer models and new research on global warming have lead to an estimation that by 2100 warming will be anywhere from 1.4°C to 5.8°C. If the emission trends are also increasing from about 0.5%-1% per year. (Karl & Trenbeth, 2003). This data is indicative of changes in other greenhouse gases and emphasize that

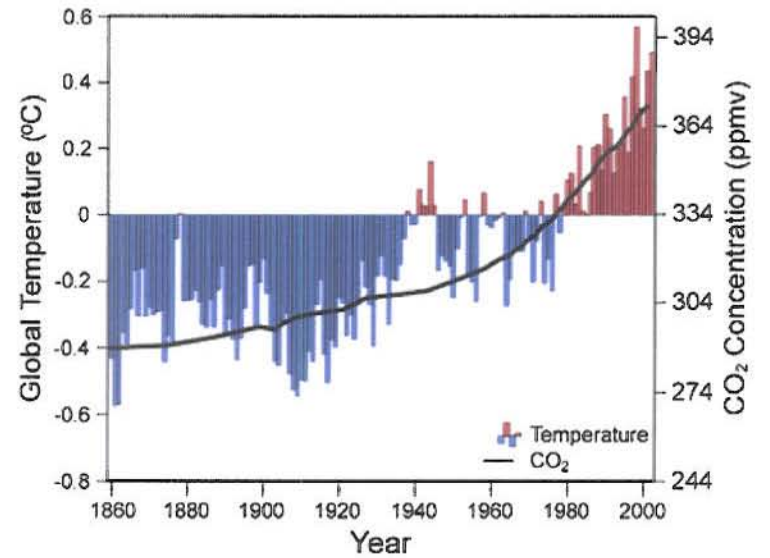


Figure 18. Time series of departures from the 1961 to 1990 base period for an annual mean global temperature of 14.0°C (bars) and for a carbon dioxide mean of 334 ppmv (solid curve) during the base period, using data fromice cores and (after 1958) from Mauna Loa (4). The global average surface heating approximates that of carbon dioxide increases, because of the cancellation of aerosols and other greenhouse gas effects, but this does not apply regionally (2). Many other factors (such as the effects of volcanic eruptions and solar irradiance changes) are also important (Karl & Trenbeth, 2003).

humans are changing the environment beyond the boundaries of natural variability causing us to venture into unknown of anthropogenic climate change.

Even though humans have not caused a large temperature change, only 0.2°C in the first half of the 20th century we have caused large changes in natural energy flows through changes in atmospheric composition. Karl and Trenbeth in 2003 explain that changes in energy flows have more potential to interfere with global climate change than just an increase in temperature (Karl & Trenbeth, 2003). Carpenter expresses a similar view as Karl and Trenbeth which is that precipitation and increased temperatures throw off an important balance.

Even though humans are an important part of the climate system interaction processes it must be realized that small changes being made to an ecosystem can disrupt a delicate balance. Climate systems are composed of physical, chemical and biological components. Each of these components is connected by fluxes of mass, heat and momentum. There is no way to close any of these subsets from the others; all of these systems are interrelated. The atmosphere and oceans are strongly related in the hydrological cycle where condensation, cloud formation, precipitation and runoff all supply energy to weather systems (Inter-Governmental Panel on Climate Change, 2001). This is just one example of the complex interactions of the Climate system. Humans could very easily disrupt the hydrological cycle especially in semiarid regions like the Colorado Plateau where water resources are limited. Figure 19 shows that interactions of Climate systems can be complex and extensive. It is hard to discern what one small change whether natural of anthropogenic could have on climate change.

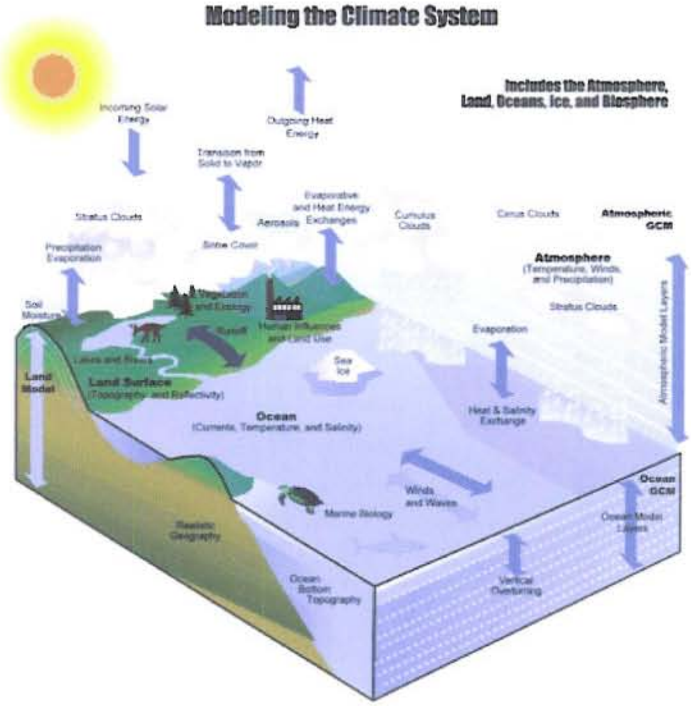


Figure 19. Components of the climate system and the interactions among them, including the human component. All these components have to be modeled as a coupled system that includes the oceans, atmosphere, land, cryosphere, and biosphere. GCM, General Circulation Model (Karl & Trenbeth, 2003).

Now that it is established that global climate change is occurring and that humans are part of this phenomena we begin to wonder what are the implications of large scale global climate change. Stephen Carpenter insists that temperature is expected to drop a minimum of 2-4°C over the next century (Carpenter, 2006). This change will corrupt the water balance because of its reliance on precipitation, soil moisture and potential evapotranspiration. There will be accelerated land-surface drying and increase atmospheric water vapor which increases the risks of intense precipitation events and the severity of droughts.

Change in climate alters the biomass, productivity and species composition of areas, slows down photosynthesis and increases respiration. Since air quality is also changing and vegetation rates will reduce, oxygen will begin depleting in overall air composition (Carpenter, 2006). Rapid and extreme shifts are also expected at ecotones, the boundaries between ecosystems, particularly those in semiarid landscapes like the Colorado Plateau where ecotones are most sensitive to changes in climate.

Humans are a driving force behind global warming but little is being done to reduce the impact that we are having on our environment. The reasons why global warming is ignored are diverse, many of the problems being connected to economics. There is also a component of uncertainty. There is a popular view that "global warming" means that the most noticeable effects will be an increase in temperature. The truth is that global warming may not cause a considerable increase in temperature as was discussed previously. Therefore the public may not notice a change in temperature and tend to dismiss the effects of global warming. What many people do not realize is that global warming is more of a change in circulation. The results may be a warmer climate in some places and colder in others or simply change in temperatures at different times of the year. It may also be wetter, drier, cloudier or sunnier in some places along with changes in extreme weather patterns.

6.1 Economics of Global Warming

The uncertainty associated with global warming leaves lawmakers in a difficult situation because there is an uncertainty of what effects will be had on humans and ecosystems. However what many people do not realize is that the negative effects of global warming will cost a considerable amount of money to resolve. An estimate in the 1990's calibrated in absolute dollar terms for the US economy at that time put the figure at approximately $6 trillion worldwide to combat the effects of global warming. Since global warming is truly a global issue the main problem is where are these resources going to come from to fight the effects of warming.

William Cline the author of The Economics of Global Warming states that agricultural losses from heat stress and drought, a particular problem in the Colorado Plateau, would be $18 billion annually with a 2.5°C warming rate in 1990 when the book was written (Cline, 1992). This approximate warming rate has occurred indicating that in today's currency to save agriculture from heat and drought stress alone would cost over the estimated $18 billion annually. The author also estimates $7 billion to fight damages from rising sea levels, $11 billion to cover the rising need for electricity requirements for air conditioning, $7 billion annually to compensate for the loss in water runoff and dollar amounts estimated in the billions to fight damages to industries and costs to repair damages due to natural disasters associated with the global warming phenomenon (Cline, 1992).

6.2 Human Influences in the Colorado Plateau

In the Colorado Plateau alone there have been at least 10 major confrontations between developers and conservationists. However, in the case of this region conservationists have won most of the legal battles preventing the building of two dams warming that occurs is closer to the 5.8°C range then we are looking at an upcoming climate disaster. However, scientists emphasize that changes in our behavior may be able to curve the effects of global warming. Small steps are being taken to fight the problem and we cannot predict what steps will be taken in the future. IPCC members believed that most countries will drastically cut emissions of sulfurous pollution that form a haze over many cities. Without the haze, cities will lose a protective cooling umbrella and temperatures will skyrocket. Scalding temperatures in the past few years have lead many everyday citizens to the realization that something out of the ordinary is happening. This realization has led to a new-found effort to combat the issues of global warming (Kerr, 2001).

Many organizations such as The World Wildlife Foundation, Sierra Club, Environmental Protection Agency and Environmental Defense are launching programs to counteract the problem. Websites like www.Stopglobalwarming.org give ordinary people the opportunity to keep up to date with current global warming issues and to donate to the cause. Companies are now offering consumers options such as hybrid vehicles, green buildings and energy saving light bulbs. Laws that require lower emissions for cars and NSR regulations for factories are also being implemented to combat the global warming issue. If things continue in this manner then the predicted negative outcomes of global warming may be curtailed.

7. Conclusions

It was deduced from the literature that humans are causing a definitive affect on temperature and precipitation changes. Multiple authors produce data confirming the hypothesis that global climate change is not a product of natural variability but of human interferences. Both previous data and current simulation models verify that temperature and precipitation changes are an issue especially in the arid to semiarid regions of the American west.

Although wet and dry deposition levels in the Colorado Plateau have been diminishing in the last decade, data shows that there are still concerns that acid deposition affects the ecosystem and its inhabitants. The main factors of acid deposition are still found in the ground due to factory activities in the West territories.

In turn precipitation and temperature changes affect vegetative growth, fire suppression tactics and the introduction of invasive species. The Colorado Plateau is a semi-arid region so the results of precipitation are the best values for Global Warming studies. As can be seen by the data collected, the Colorado Plateau has recently begun a severe drought period that is expected to last for a minimum of ten years. Although the changes in precipitation are common throughout the region's history, the severity of the drought periods have been seemingly increasing since the Industrial Revolution, leading to a conclusion that the two factors do coincide.

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