Climate Change in the American Southwest

An Interactive Qualifying Project Report

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Abstract

This project was necessitated by concern over the water supply problem due to rapid population increase in our nations Southwest that experts fear may be on the horizon. Future climatic effects, as well as technological advances and conservation methods will determine the impact of such problems on water supply. This project has examined and made speculations on different climate prediction techniques. Several methods for predicting this regions possible climate in coming years are presented and described in the project report.

Introduction

The Southwestern region of the United States may be facing serious water supply problems in the near future. The population in this region has been following a trend of rapid growth and experts suspect that if this trend continues, and many believe it will, it will increase the demand upon the already strained water supply in this region. With continuing population growth mostly in urban and sub-urban areas in the Southwest, the competition between agricultural and urban use for the limited water supply will only become stronger. At present, water used for agriculture in this region is largely consumed, meaning it is not returned to the water supply after it is used. The water used for agriculture in this region comes mostly from rivers, the most predominant being the Colorado River. The majority of the water used for irrigation in the Southwest is transpired by crops and then released into the atmosphere during irrigation in a process which is termed "evapotranspiration". This water is not returned to the Southwest; in fact much of this water vapor is carried away from this region by wind currents. In the future water must be used more efficiently in this region if it is to accommodate the growing population.

The population of the Southwestern United States grew by 1500% during the period between 1900 and 1990. This is nearly 7 times the average growth rate of the United States as a whole during that time period (14). In the time since 1990 the trend has certainly continued. Since then Nevada has had the fastest growing population in the country, with an increase by more than 50% between 1990 and 1999 (15). It is reasonable to suspect that this trend of population growth in the Southwest will continue in the future. Plans must be made to accommodate this growing population with utilities such as water, natural gas and electricity. So far the Southwest has been able to accommodate the rapidly growing population. This may become increasingly difficult in the future.

Today the Colorado River provides water to nearly 25 million people, and the economy of the Southwest relies heavily on this steady source of fresh water. Irrigation of the river is used on 1.8 million acres of land in the Southwest. (16) It has been said that the Colorado River is the "lifeblood of the Southwest". Irrigation agriculture in the Southwest has the most consumptive use of water in that region. Most of the water used for agriculture evaporates from the crops and earth into the atmosphere, rather than being reused. (17) Water can be diverted for irrigation uses by the damming of rivers which causes the areas behind these dams to flood. This water can then be more easily used for irrigation. (17)

Some experts suspect that the usage of the Colorado River is currently at capacity, and if the population of the Southwest continues to grow as it has been there may soon be water supply problems. At present the Colorado River no longer reaches the ocean except during particularly wet years. One idea being considered is the redistribution of water right from agricultural use to the general public. Such redistribution of water supply could have serious consequences such as the loss of many farming communities. Such propositions have been strongly opposed by Southwest farmers, but as the population of the Southwest continues to grow and the rights to water usage become more valuable the competition for this water will become stronger. (18)

The most important factor for gauging the future water supply of an area is the climate in that region and what predictions can be made about the future of that climate.

The goal of this project is to speculate on ways of predicting the future climate in the Southwest, and several new methods of climate prediction are proposed in this report.

Climate Change

One factor that certainly affects the Southwestern United States and the Great Basin as well as many other parts of the world is the phenomenon known as El Nino Southern Oscillation (ENSO). This phenomenon is caused by the water on the surface of the Pacific Ocean acting together with the atmosphere in the Pacific. The website listed with this paragraph as a reference has an excellent animation which demonstrates the oscillating pattern of El Nino and La Nina effects in the United States over the past 130 years. It is shown that drier climates in the Southwest have typically corresponded to La Nina effects, while El Nino corresponds to wetter conditions in this region. These two phenomenon occur in oscillation with one another and when one is occurring in the western pacific the other is occurring in the eastern pacific. (25)

Dendrochronology and Climate Change

Looking at the rings that have been formed on the cross sections of tree trunks, a science which is known as dendrochronology, is one way of gathering climate data for time periods prior to human records. By looking at these rings experts can gauge what type of precipitation was occurring during certain years. Years of higher precipitation and better growing conditions are accompanied by wide tree rings, and conversely years of intense cold or drought, poor growing conditions, correlate strongly to tight tree rings.

Below, wide tree rings can be seen in Figure 1, and tight tree rings in Figure 2.

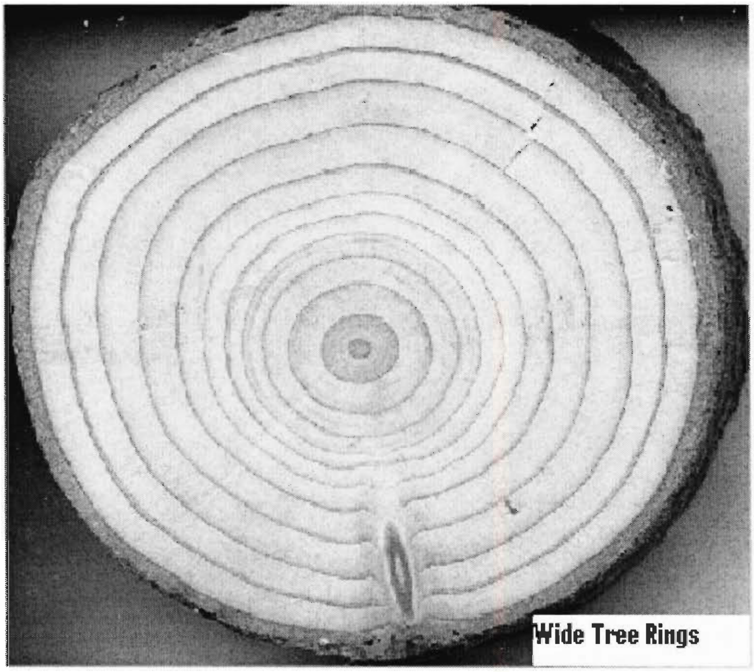

Figure 1: Wide Tree Rings (12)

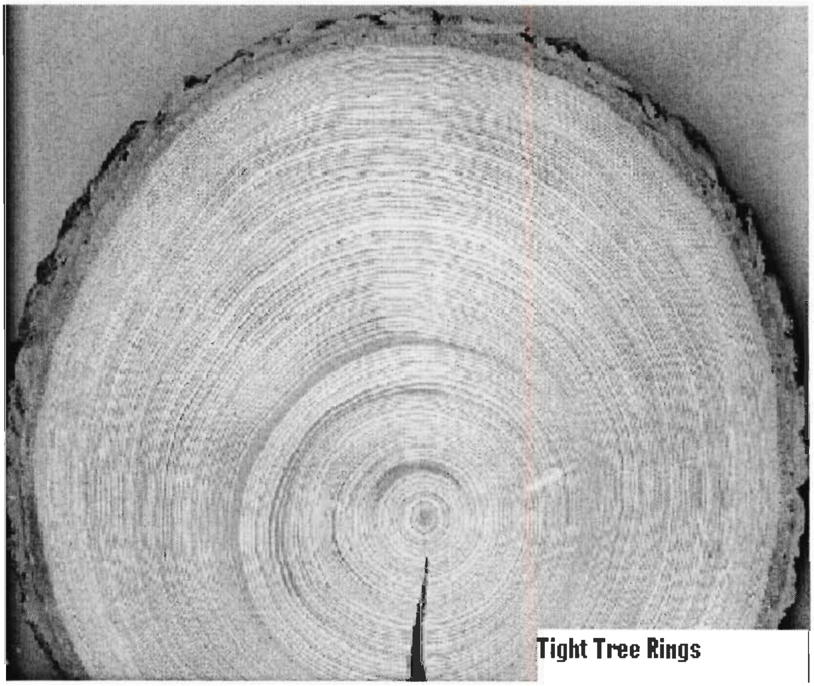

Figure 2: Tight Tree Rings (12)

By examining these tree ring patterns dendrochronologists (those who study tree rings) have successfully been able to generate a general idea of climate patterns in the Southwest over the past 1000 years. This is especially useful to us because the more we know about the climate history of a particular region the more we can understand the potential climate changes in the future of that region. (1)

These tree ring data are valuable because we know that the most limiting factor in tree ring growth is the amount of moisture (as rainfall) that a tree encounters. Therefore tree ring data will reflect rainfall data more accurately than it will reflect other growth factors such as air pollution or temperature. To gain an accurate collection of data dendrochronologists must look at many trees from one site and many sites from a region; they then must look for any patterns that exist between these tree rings. This process will limit the variability which would occur when examining a single tree. Site selection is also important because if dendrochronologists studying past drought look at sites which are in particularly wet regions such as near to a river or lake, they will not get as accurate picture of past drought as they would if they examined trees in drier areas. This is because trees in drier areas would be more responsive to any additional rainfall, whereas additional rainfall would make less of a difference for trees existing in wet regions which are acclimated to heavy precipitation. Another important aspect of dendrochronology is to select trees that exist in large quantities throughout the region in study. This is simply because the more samples that can be obtained of a tree, the more accurate the data will be that is generated. If only a few tree samples are examined the accumulated data would be subject to greater coincidental variability. (3)

From these data, experts can determine when periods of heavy precipitation or intense drought may have occurred. The study of tree rings has revealed that in the past there have been several periods of drought lasting five to ten years in the Southwest. The most telling tale of the tree rings however seems to be an extremely intense drought in the region which lasted for a period of about 40 years. The existence of this drought is further proven by the records of some early European settlers. Unfortunately however, not much more is known about this drought except that it did happen. The most important question regarding this mega drought is if it could happen again. Experts speculate that a possible cause of the drought may have been the existence of colder than normal ocean currents, an effect that is presently known as La Nina. If this is the case such a drought could certainly happen again because La Nina is a phenomenon which affects the Southwest at a regular frequency. (1) We can only imagine the devastating effect that such a drought might have upon the growing population, agriculture, and economy of this region if it were to occur now. Further investigation into the causes of this drought and what might prevent or curb the intensity of such a drought would be strongly beneficial to the future of southwest.

The tree ring data goes back 1000 years and according to these data there have been several intense droughts with the worst occurring in the 1500's. In recent years however there has been an anomaly in the correlation between tree ring data and precipitation data for trees in high elevation areas of Arizona and New Mexico. There have been growth surges in these trees during the time period proceeding from 1976 that are far greater than would be expected for the amount of rainfall that has occurred in these areas (2). As can be

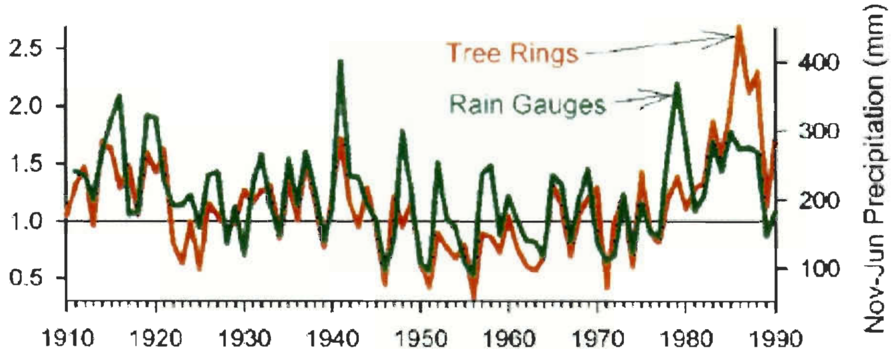

Figure 3: Tree Ring Growth vs. Precipitation (2)

seen in Figure 2 tree ring growth for recent years has far outweighed the accompanying amount of rainfall, a correlation which has not been true in the past. There are two likely possibilities here; there may be a phenomenon occurring in these areas that we are unaware of, or there is a flaw in the correlation of tree rings to the amounts of precipitation in these high elevation areas. Either way, it is important to know why growth rates of trees are so much greater than would be expected in this region. If this phenomenon is occurring it might be worthwhile investigating the potential of agriculture in these higher elevation areas of these states during drought years.

The phenomenon of global warming has demonstrated a trend of increased activity since 1976. The averaged temperature of the United States has shown a dramatically increasing trend in the 28 years since 1976, which can be seen in Figure 3.

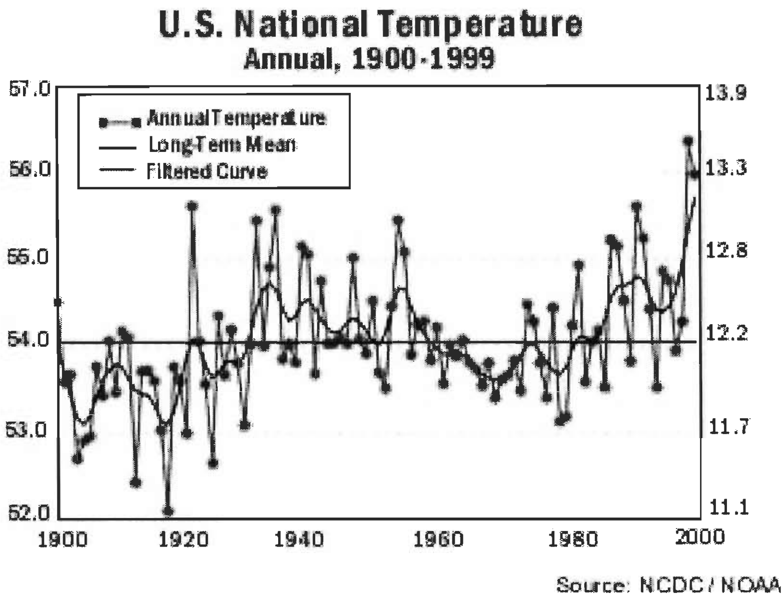

Figure 4: National Annual Temperature (10)

Researchers gauge that in the years since 1976 the rate of temperature increase on the national scale can be estimated as approximately 4 degrees Celsius per century. (10) It is suspicious that this trend of increasing temperature began in the same year as the anomalous growth of tree rings in high elevation areas. It is strange that tree growth and temperature would increase in an area while average rainfall would not. However, the temperature increase is on a national scale while the tree ring growth is specific to areas of high elevation in the Southwest so it is possible that these changes could be completely coincidental to one another.

Climate Models

The spectrum of this project is also concerned with water supply in the future of the Southwest. It is important to note however that higher temperatures in the future of the Southwest may not necessarily mean a drier climate in the region. The USNA (United States National Assessment of Climate Change Impacts on the United States) has produced two models showing precipitation predictions for the 21st century based on the predicted greenhouse effects. A picture including both of these models as well as model of observed precipitation in the 20th century can be seen in Figure 4.

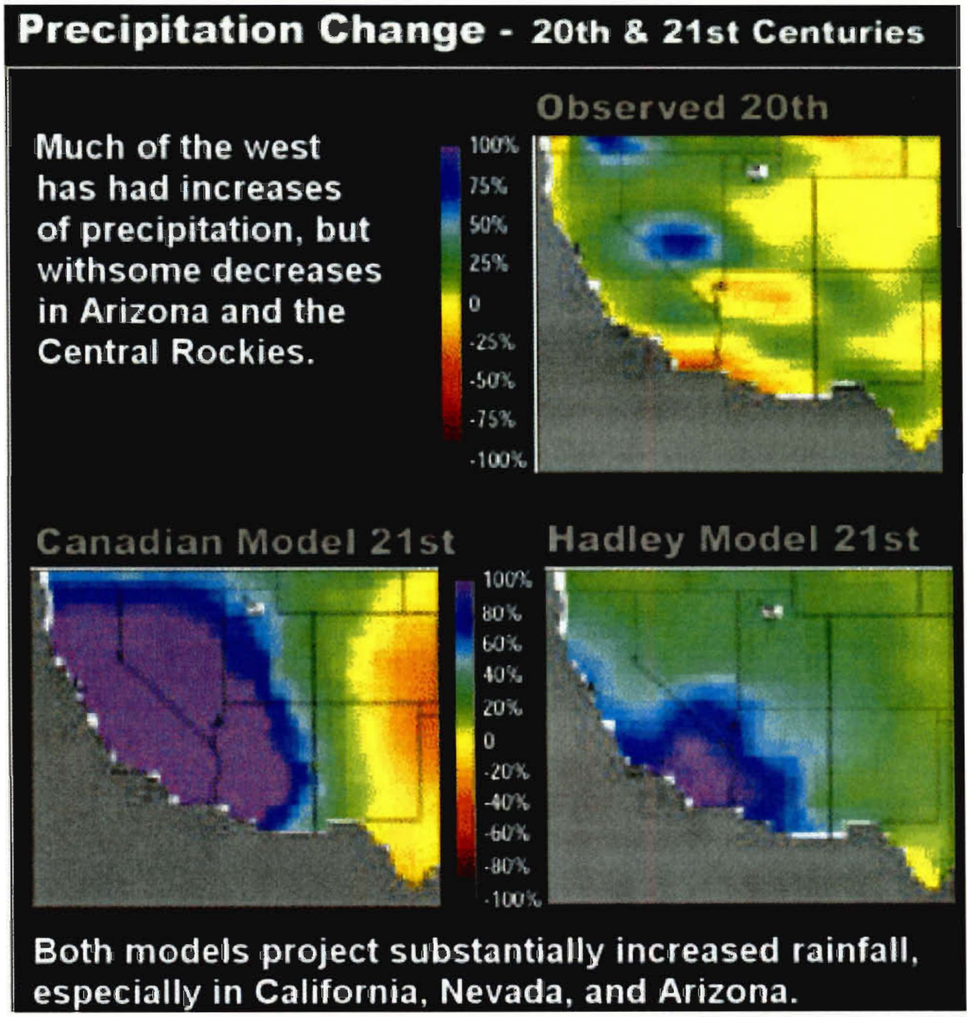

Figure 5: Predicted 21st Century Rainfall Models (13)

As can be seen, both of these models predict greenhouse effects to greatly increase precipitation in the southwestern states of California, Arizona, and Nevada. This increased precipitation in that region could possibly have the positive effect of increased water supplies, resulting in a lower demand for the limited water available from the Colorado River and ease the competition for water between agricultural and urban purposes. It is difficult to predict exactly how an increase in precipitation could affect the

Southwest but it is likely it would affect the currently strained water supply in this region. (13).

Radiocarbon Dating

Another possible use of the rings created in trees is what we can learn from the amount of carbon 14 that exists in the tree rings. Solar activity, including the variation of sunspots, has a direct affect on the amount of carbon 14 produced in the atmosphere. The relationship is that the greater the solar activity the less carbon 14 is produced in the atmosphere, and therefore less carbon 14 is absorbed into the trees. Studies in Oman and northeastern Mongolia have shown evidence for the correlation between the amounts of carbon 14 existing in tree rings and the corresponding amount of solar activity. When these data sets were compared to the precipitation records for Mongolia there were significant correlations seen between amounts of rainfall, solar activity, and carbon 14 in tree rings. (4).

Sunspots and Climate

It is believed that the amount of solar activity, including the occurrence of sunspots, might directly affect the number of precipitation produced in the earth's atmosphere at those times. Sunspots appear as dark irregular areas that sometimes occur in groups on the sun's surface. They are actually dark magnetic loops which protrude out from the sun's surface. The amount of sunspots which a person might see depends largely on how the sun is being looked at, more sunspots will be seen based on the order of magnification with which the sun is viewed. A telescopic view will see many more sunspots than can be seen with the naked eye. Sunspots must be observed through a *camera obscura* through which the suns image can be projected onto a surface. Although there may have been some ancient sightings of sunspots by naked eye observers, the first to see them through a telescope was the astronomer Galileo. Edward Walter Maunder was the first astronomer to observe sunspot cycles and one of the first sunspot minimums was named after him. There is a fairly accurate record for sunspots from 1610 to 1645 but after that some sunspots were noticed but they were not accurately recorded again until about 1710. (5)

A system of recording sunspots was developed by Rudolph Wolf and it was to calculate a sunspot number based on daily observation. The sunspot number is found by an equation relating observed sunspot groups, individual sunspots and a variable scaling factor depending on the method of observation. There are records of sunspot numbers going back to 1610 and they have been put into yearly averages and plotted in figure 5. (6)

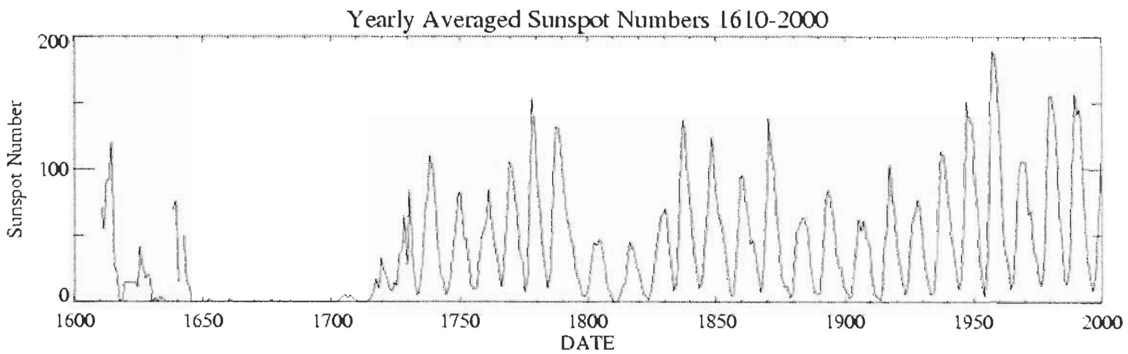

Figure 6: Recorded Sunspot Numbers (6)

The sunspot number, which seems to operate on an eleven year cycle between maximums, has shown a strong correlation when compared to temperature data for the northern hemisphere over the last 100 years. The data for globally averaged sea surface temperature has many features in common with the mean sunspot number and its running 11 year cycle. This 11 year cycle is not constant, long term variations in this cycle have been observed. The cycle seems to be shorter during periods of high solar activity and longer during periods of low solar activity (8). Sunspots and the trend of their correlation to the climate are one factor which we must consider when making predictions for the future climate of the Southwest.

A recent trend that can be seen in solar activity exists in the last three solar cycles of sunspot numbers. The last three solar cycles, 21, 22, and 23, as referenced from the first in 1760, have had consistently high maximums. That is the peak cycle years for the last three cycles have had similarly high counts of sunspot numbers and can be seen in

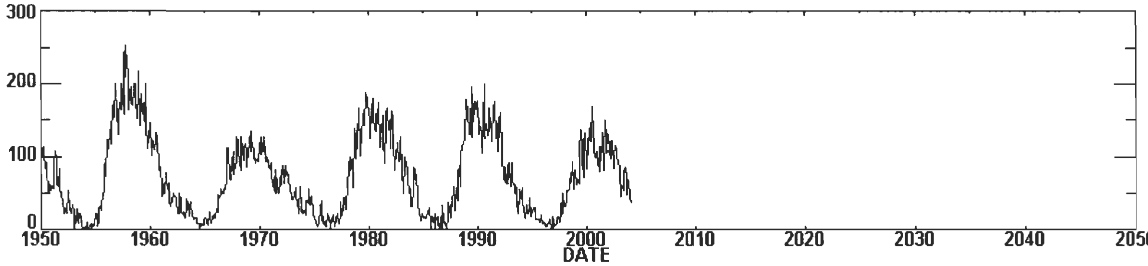

Figure 7: Sunspot Cycles 19-23 (11)

Figure 6. The plateau of subsequent solar cycles is not unusual, but this recent similarity in solar cycle peaks is peculiar in that it includes three solar cycles whereas previous cycles had not included more than two solar cycles with consistent maxima. Also notable is that this recent plateau in solar cycles involves higher peaks than any previous recorded plateau. Cycle 19 had a higher peak than any of cycles 21 through 23 but other than that no other recorded cycle exceeded the peaks of the last three cycles, nor have any three cycles been as consistently high. It is also notable that cycle 21 began around 1976, the same year that an accelerated rate of temperature increase began in the United States. This is interesting because it leads to the question of whether or not sustained solar activity could affect the rate at which the global temperature increases.

Cosmic Ray Flux and Climate

The interaction between the earth and the sun, and the suns effect on the earth's climate is more complicated than what the sunspot numbers alone can tell us. There is also the effect of the cosmic ray flux. This flux has decreased by about fifteen percent since the year 1900. The cosmic ray flux is inversely affected by the sun's geomagnetic field and the velocity of the solar wind, both of which have increased by a factor of 2 over the same time period (7). Scientists are unsure what exactly is causing these changes but they suspect that these solar changes might be having a larger effect on the phenomenon of global warming, which has also been occurring since about the year 1900, rather than the effects of greenhouse gases which are presently the leading suspects. Observations have also proven that cosmic ray flux has a strong effect on the earth's cloud cover. Some scientists believe that a greater cosmic ray flux causes an increase in cloud cover and a lower flux causes a decrease in cloud cover because the cosmic ray flux is a high source of ions in the upper atmosphere which play an important role in the formation of clouds. Clouds play an important part in the cooling of the earth's atmosphere, and a trend of lower cloud cover would result in a warming effect on the earth's atmosphere. The cosmic ray flux has decreased in recent years and the cloud cover has also decreased in this time (7). It is certainly a possibility that this phenomenon could be affecting the trend of observed global warming. Regardless of the cause, global warming is a phenomenon that is certainly occurring and must be considered in any future climate predictions. The sun itself certainly plays an important role in earth's climate and any solar effects or solar changes must also be considered. These considerations have effects on the climate of the entire planet rather than the much more specific region of the Southwestern United States that we are concerned with, but they do affect it nonetheless and cannot be omitted from the scope of this project.

Everything covered so far has had something to do with effects on earth's climate or comparing precipitation data to other sets of data. However the system for measuring precipitation in the Southwest is a flawed one. Much of the Southwest is a desert region and therefore much of it is uninhabited. Although there are some heavily populated cities in the Southwest such as Phoenix and Las Vegas these populations exist only in concentrated areas and relative to the size of the region the Southwest is a sparsely populated area. This fact comes into play when we consider the collection of precipitation data. There are consistent rainfall data sets for the populated areas of the Southwest, but there are many large uninhabited regions of the Southwest which certainly must be considered in climate studies for which there are no data at all. There is a system setup that records any and all lightening strikes in a given region. Lightening strikes often coincide with precipitation in the Southwest and therefore lightening data may prove useful in measuring precipitation. If an accurate approximation can be made for the ratio of total number of lightening strikes in an area to the amount of precipitation in an area for a given time, then this lightening strike data would be extremely valuable in finding precipitation measurements throughout the Southwest, rather than only in the populated areas of the region. There is a website which keeps a running tab on the current lightening strikes which can be viewed (9), unfortunately one company owns the sole rights to this lightening strike data and a history of the data is unavailable. For this reason it is impossible for us to attempt to get any actual precipitation amounts from lightening strike data in this project.

Comparative Climatology

Another possible method of predicting the climate in the Southwest would be to compare its climate to other regions of the world with similar climates. Using the Koeppen climate classification map it can be seen that the Southwest has a similar climate classification to regions such as Central Asia, Australia and possible even the Southwestern corner of South America. These areas are characterized as "dry" regions, meaning that there is greater evaporation in these areas than there is precipitation in a given year. These regions can be seen on the Koeppen Climate Classification map below titled Figure 7, and you will notice that these regions are colored orange, indicating that they are dry regions. (19)

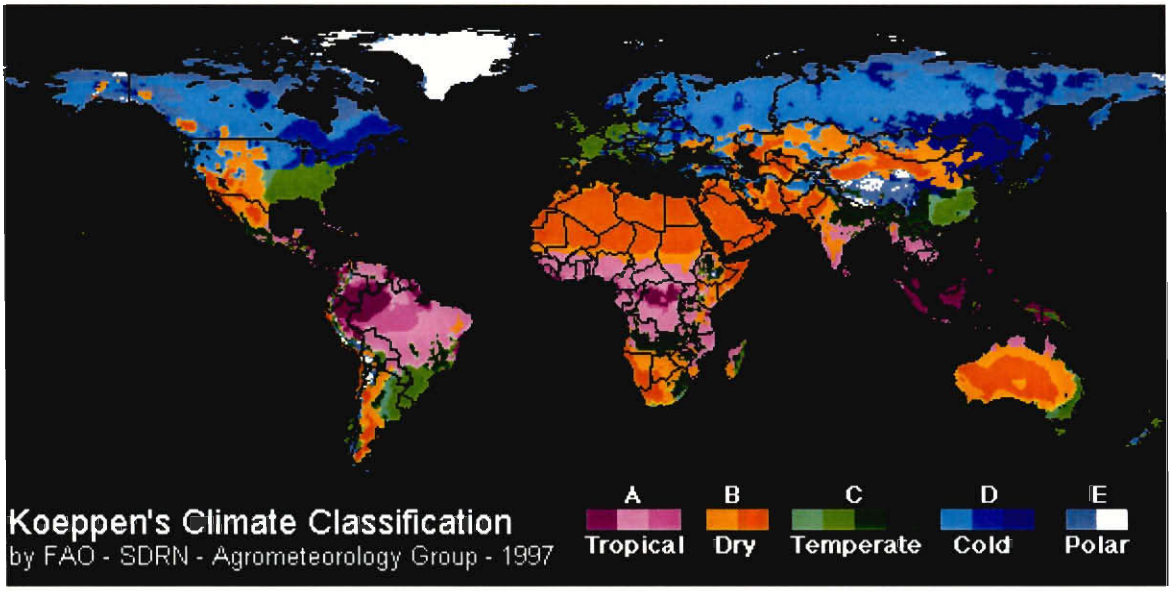

Figure 8: Koeppen Climate Map (19)

Let's first consider Australia. This lies in the Southern Hemisphere and therefore experiences an inverted order of seasons when compared to the Southwestern United States. Any comparisons made between these regions must take into account that Australia is experiencing its winter during the summer months of the Southwestern

United States and vice versa. Most of Australia is in a semiarid or desert climate, except along much of the coastline which experiences a tropical climate. The amounts of precipitation on the continent are as would be expected for the different climates, areas of central Australia may accumulate less than ten inches of annual precipitation while coastal regions may receive in excess of 150 inches. (20) Australia is considered a drought prone continent and has suffered through many droughts in the past. The worst recorded drought in Australia took place at the end of the 19th century and was known as the "Federation Drought". This drought lasted several years and was due to the occurrence of two very dry years immediately following a long period of below average rainfall. Another severe drought took place on this continent in the early 1990's and is believed to have been due to El Nino, southern oscillation effects. Both of these droughts had devastating effects upon the country's agriculture and livestock populations. The Southwestern United States has also had its share of droughts and some of them have had similar origins as those existing in Australia. ENSO, the southern oscillation phenomenon affects both of these regions and seems have caused droughts in both. Comparisons between the causes of drought in both of these regions could certainly be beneficial to both countries and help to make climate predictions in the future. The Australian people have come to accept erratic dry spells as part of life in Australia and are generally prepared to deal with moderate droughts. (21) One important difference to note between these regions is that the desert region of Australia lies in close proximity to tropical climates which exist on the Australian coast. The Australian continent is also surrounded by ocean. The desert region of the United States is not nearly so close to a tropical region and is bordered by only one ocean. These factors may cause significant differences in the climates between these regions and must certainly be taken into account when making any comparisons.

Southwestern South America is another region that could potentially be compared to the Southwestern United States. This region also lies in the Southern Hemisphere and has inverted seasons. A desert that is perhaps drier than any other resides in this corner of the world. The Atacama desert is sometimes referred to as an "absolute desert" and may even be more comparable to the surface of mars than other deserts here on earth. (22) The Atacama is a truly barren landscape and accumulates hardly any rainfall. The only moisture that really exists in this desert comes in the form of fog. This desert is in a perpetual state of drought and is considered the driest place on earth. There was a period of drought in the Atacama which lasted about 400 years, ending with a very small amount of rainfall in the early 1970's. (23) The climate in the Southwestern United States is not nearly as severe as that of the Atacama and the two regions do have significant geographical differences. The Andes Mountains which run along the Western coast of South America prevents much of the moisture from the Pacific Ocean from entering the desert, while no such barrier exists in the Southwestern United States. However these two regions do have similar latitudinal locations in their respective hemispheres and are both arid desert regions. Comparison of droughts in the two regions would not be helpful because the Atacama is an extreme case, but it would be important to note any climate changes which might take place in this region of South America and compare them to the climate changes that take place in the Southwestern United States.

The region of the world that is perhaps the most similar to the Southwest is the Gobi desert of Central Asia which exists on the border between China and Mongolia.

This desert and the Mojave Desert in the Southwestern United States are both considered "temperate deserts" and get more precipitation in the summer months than other deserts, the temperature in these deserts are also in the same range. Both of these deserts also support wildlife in some capacity, and the Gobi desert is home to many mammal species. The geographies of these two regions have some differences and some similarities. The surface of the Gobi desert is characterized by sand dunes while the Mojave Desert consists of a flatter rockier surface. Both deserts are home to scattered mountain ranges. In recent years Central and Southwestern Asia has suffered a rather severe drought which has affected about sixty million people. Experts suspect that this drought may have been caused by La Nina effects in the Pacific Ocean in combination with warmer than normal temperatures in the Pacific Ocean. (24) This phenomenon of La Nina is what experts believe may have caused the mega drought in the American Southwest in the mid 16th century. It is entirely possible that the very same conditions in the Pacific Ocean could be affecting both of these regions simultaneously, and perhaps even in similar ways. For these reasons Central Asia may well be the region of the world most comparable to the Southwestern United States and may be the most helpful in making climate observations and predictions. One drawback however is that Central Asia is less technologically developed than the Southwestern United States and there may be insufficient or incomplete climate data for this region. For the purposes of this report climate data was more difficult to find for this region than the other two regions discussed.

It is important to note that the Southwest may be different than these other regions of the world because of the larger role of human impact in this area. Throughout its history the United States of America has followed the trend of increasing its population and making full use of its natural resources, even in regions such as the desert Southwest which may have been uninhabitable at one time. The rapidly increasing population and use of natural resources in the Southwest may be affecting the Southwestern climate in ways that other desert regions of the world are not affected. The Colorado River has certainly been utilized and irrigated more than any other desert river in the world and because of this there is far greater evapotranspiration in the Southwest than in other desert regions of the world. This greater presence of evapotranspiration in the Southwest may be affecting the climate in this area in significant ways, effects that would not be present in less populated deserts such as the Gobi and Atacama. This aspect of the climate in the Southwest must be kept in mind when making comparisons to other regions of the world. Large amounts of water entering the atmosphere in the Southwest could have unpredictable effects on the climate and this project should keep this factor in mind. The magnitude of this effect is also unknown, but it is present in the Southwest and cannot be ignored. If evapotranspiration effects in the Southwest are determined to be much larger than other regions of the world it could result in the Southwestern climate having an entirely unique climate. If this be the case it would render any comparisons to other regions of the world useless. This is a speculative report however and because the magnitude of evapotranspiration effects in the Southwest is not known we can make the current assumption that the Southwestern climate is not completely distinct from other desert regions and perhaps comparisons can be made.

Summary

There are many factors which must be considered when looking at the climate of the American Southwest and making predictions for the future. Some of these things, such as tree rings and solar effects, are well documented and comparisons have been made before. Others, such as lightening strike data and comparisons to other regions of the world, are new correlations which have not previously been looked into and few if any comparisons have been made. Past climate data and the ways in which it was measured, are probably the most important things we have looked at, because they will tell us about the future. New methods of measurement or ways of making climate predictions are also important, not because we yet have data sets to go by, but because they can be generated in the future, and these may well tell us more than the previous data sets. One extremely valuable example of this is any method of measuring climate data for which a record of the past has been kept but not looked into, such as the discovery that tree rings kept a general record of past climate and the mega drought of the 16th century which they revealed. All of these things are important to consider in our study of the climate in the Southwest and the prediction of future climate in this region.

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