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DROUGHT IMPACT ON THE COLORADO RIVER BASIN

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By

Derek Jodoin

Carlos Arias

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Approved:

Professor Theodore C. Crusberg, Advisor

ABSTRACT:

Colorado has had several major droughts in the past 130 years. Thanks to one of the droughts, 1983 was recorded as the driest year in some of the major cities. Scientists ask themselves what causes droughts. Many believe sunspots have an effect on the climate, but it is a subject that has not been studied enough to come to a conclusion. This IQP tries to find a correlation between droughts and sunspots.

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INTRODUCTION

The Colorado River basin was one of the last areas of the United States to be explored and populated. This is due to the fact that its 242,000 square miles are so rural and untamed. Due to the river and the climate the area could become extremely flooded at times and then at other times to be severely dry. Still today the weather can fluctuate and cause severe weather conditions from floods to severe drought.

The Colorado River forms in the mountains in the northern part of Colorado and runs southwest to the Gulf of California, traveling more than 14000 miles. Seen in below in Figure 1. The Colorado River basin is defined by the Colorado River as well as its main tributaries, the Green River, the Gunnison River, the San Juan River, the Virgin River, the Little Colorado River, and the Gila rivers. Much of the southwestern United States, as well as parts of Mexico rely on the Colorado River. Today, Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming all depend on it.

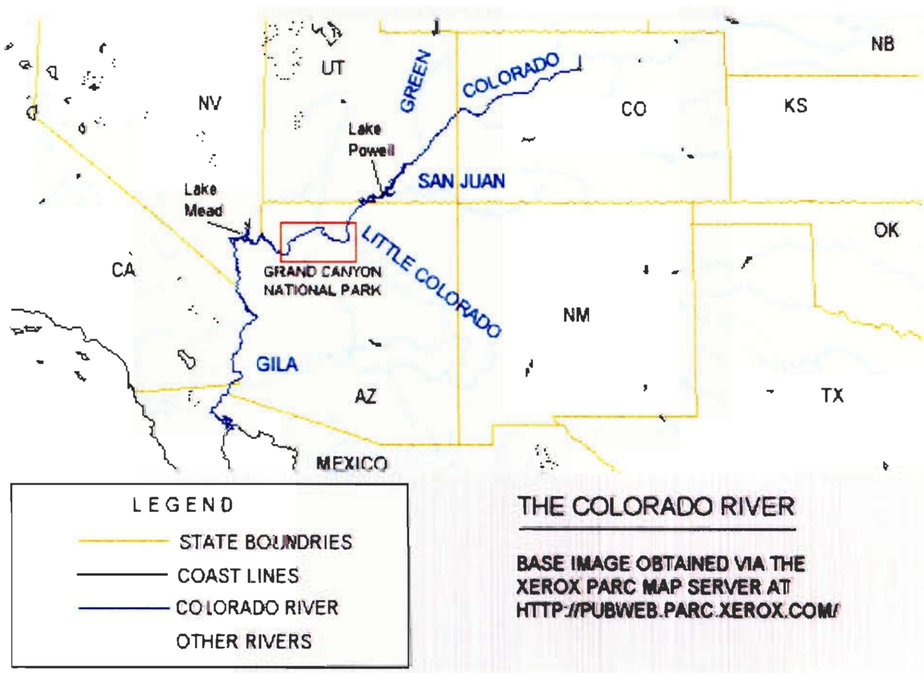


Fig. 1: Map of the Colorado River
(http://www.kaibab.org/misc/gc_coriv.gif)

However, this was not always true. At one point the river was completely uncharted and wild. Ever since people were living in and around the Colorado River Basin they wanted to control the river. Some, like the Anasazi Indians, wanted to harness this water to help them water their crops. While, today the river is used in many ways, including, drinking water in the form of reservoirs and electricity in the form of hydroelectric power.

EARLY DEVELOPMENT OF THE RIVER

The Anasazi Indians, of the American southwest, were some of the first people to control the waters of the Colorado River. Water was extremely important and the Indians even made rules to conserve water. Also children were taught the rules about water and to be careful with every drop they used. Obliviously water was very precious to the Anasazi due to the extremely dry conditions of the desert where they lived. So when it did rain, the Anasazi would store water in ditches. They built gates at the end of the ditches that could be raised and lowered to let water out. They used this to water crops in their field. (Southwest culture) Not only did they use canals to collect rainwater but they also built very primitive dams. These dams were used to try and control the water of the Colorado and its tributaries. These dams while being primitive worked for the Anasazi to get water to flow into their fields and irrigate their crops.

As can be seen from the information above agriculture was no easy feat for the Anasazi. Rainfall came sporadically between droughts, some of which lasted for years. There are several theories as to why the Anasazi left their homes. Some speculate that the Anasazi left because of a severe draught, which destroyed their crops and caused all of the animals to migrate. (Cridli)

The next group of people to rely on the Colorado River was the Spanish Missionaries. In the mid-1500's the set up and built missions in the basin and along the river. The missionaries also had to rely on the Colorado River for water. They needed the water for drinking water for themselves as well as they animals they had. The also, like the Anasazi Indians, needed the water to irrigate their crops. In the mid-1800's the Mormons (Church of Jesus Christ of Latter Day Saints) moved into the Colorado River

Basin. They established themselves in Utah near the Green and Virgin Rivers. Just like their predecessors, Anasazi Indians, and Spanish Missionaries, the Mormons used these tributaries to collect water for irrigation as well as consumption.

Up to this point there had been a few groups of people who lived in the Colorado River Basin and on the river. There was still almost no information known about the Colorado River. Then in 1869 someone decided they wanted to change this. A geologist named John Wesley Powell wanted to explore and map the river. He led ten men with four boats down the river. Along the way he lost two boats and most of his supplies, plus half of his crew left because they felt if they stayed they would have died trying to finish. During the exploration they ran into many problems, they had to get out of the boats and float them on ropes or even take them out of the water and portage around dangerous rapids. Three months after they started, the one-armed leader and five men, which was all that was left of his crew, got to the mouth of the Virgin River. This expedition not only proved it was possible to traverse the Colorado River, but also gave us a lot of information and data on the Colorado River and its basin.

DEVELOPMENTS OF DAMS ON THE RIVER

As more and more people began moving west they realized something needed to be done to use the river. Then,

> "In 1922, after a lengthy debate over how best to tame Colorado, Arthur Powell Davis, Director of the Bureau of Reclamation ... confidently handed the government a comprehensive proposal to quit the raging river and make it useful. At its heart was a soaring dam, higher by three hundred feet than anything on earth."(Ward, 59)

The Hoover Dam, shown at right, named for ex-President Herbert Hoover, was finished in 1935 on the Nevada-Arizona border. It was the first and largest of the dams to ever be built on the Colorado River.

These dams and the reservoirs they create make life in many dry regions possible. If not for the water in the Colorado River Basin cites like Las Vegas, Phoenix, and Los Angeles would never have been able to grown to anywhere near the size they are now. Not only does the river provide the most essential ingredient for life, water, but it also supplies electric power to most of the surrounding areas. This electricity is provided through hydroelectric power created by the dams.

Currently there are 18 dams on the Colorado River. They include those listed below in Table 1.

Table 1: DAMS IN THE COLORADO RIVER WATERSHED

Arizona
Davis Dam, Bullhead City;
Glen Canyon Dam, Page;
Palo Verde Diversion, Ehrenberg;
Parker Dam, Parker;
Imperial Diversion, north of Yuma;
Laguna Dam, north of Yuma

Colorado
Blue Mesa Dam, Gunnison;
Dixon Canyon Dam, Ft. Collins;
Flatiron Dam, Loveland;
Granby Dam, Granby;
Olympus Dam, Estes Park;
Rifle Gap Dam, Rifle;
Sugar Loaf Dam, Leadville

Nevada
Hoover Dam, Boulder City

New Mexico
Navajo Dam, Farmington

Utah
Deer Creek Dam, Heber;
Flaming Gorge Dam, Dutch John;
Moon Lake Dam, Duchesne

Wyoming
Fontenelle Dam, La Barge

When one considers Las Vegas for instance, before the Hoover Dam was built it was a tiny strip of casinos. While the dam was being built it became the entertainment center for the builder of the dam as well as tourists. "Hoover was the catalyst in the transformation of a small strip of casinos into a water-sucking desert nightmare."(Ward, 66) Without the development of the Hoover Dam, Las Vegas would never been able to grow to anywhere near the size it is today.

REGULATION OF THE WATER

Today, the basin's 250,000 square miles is usually divided into 2 parts, the upper basin and the lower basin, as shown by Figure 2. Lees Ferry is thought to be the middle of the river and is used to divide the Colorado River Basin in its 2 parts. The Upper Basin, which is all parts that the water drains into the Colorado River above Lees Ferry, Arizona. This includes parts of Arizona, Colorado, New Mexico, Utah, and Wyoming. The Lower Basin, which is all parts that the water drains into the Colorado River below Lees Ferry. This includes parts of Arizona, California, Nevada, New Mexico, and Utah. A map of the river basin can be seen below in Figure 2.

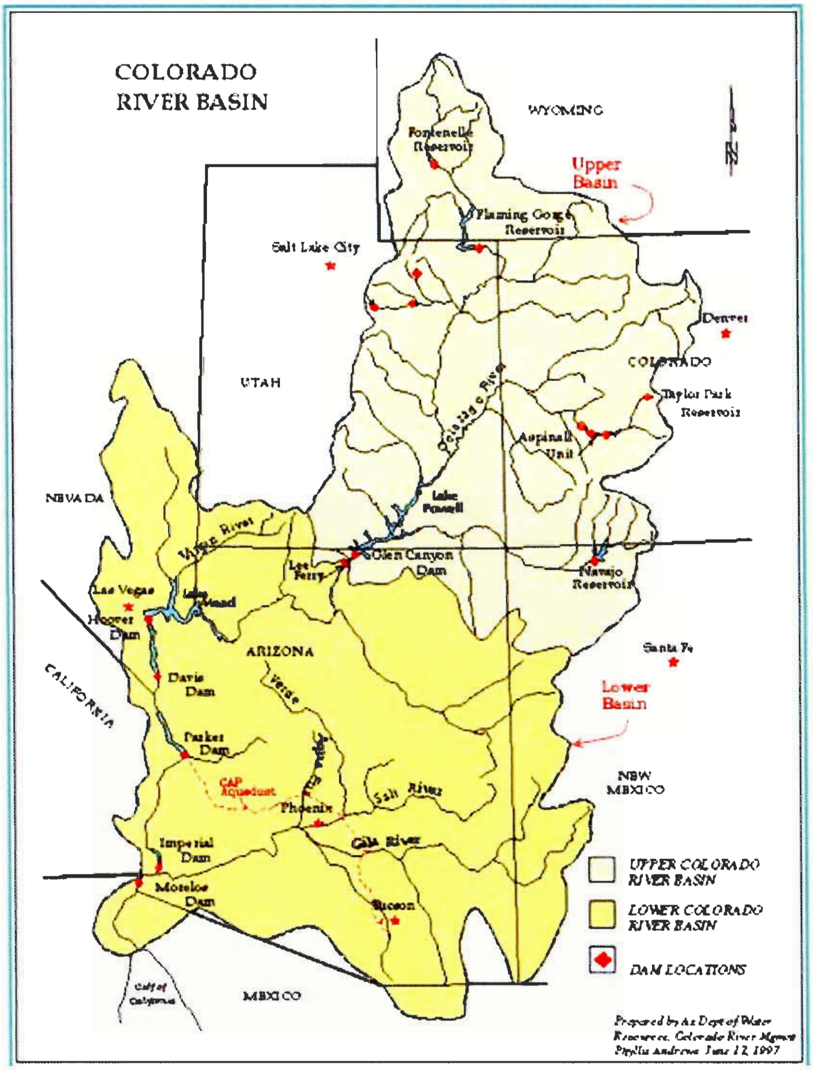


Fig. 2: Map of the Colorado River Basin
(http://www.gsfc.nasa.gov/gsfc/earth/pictures/2003/0210snowpack/colorado-river-basin.jpg)

In order to make sure that everyone gets water from the Colorado River, it has been divided via special legislation. First off the Upper and Lower Basins are prearranged to get 7,500,000 acre-feet of water per year. One acre-foot equals 326,000 gallons of water. Then the states of the Upper basin got together and came up with a plan to appropriate water to each. They decided that, Arizona would get to use 50,000 acre-feet, Colorado would get to use 3,855,000 acre-feet, New Mexico would get to use 838000 acre-feet, Utah would get to use 1700000 acre-feet, and Wyoming would get to use 1000000 acre-feet.

Unlike the Upper basin states, the Lower basin states could not reach an agreement on their own. So the United States Supreme Court stepped in and made a ruling. Of the first 7,500,000 acre-feet of mainstream water in the Lower Basin, California is entitled to 4,400,000 acre-feet, Arizona 2,800,000 acre-feet, and Nevada, 300,000 acre-feet. Also the United States Government and the Mexican Government came to an agreement and decided Mexico is entitled to 1,500,000 acre-feet of Colorado River water annually.

DROUGHT

Drought can be simplified into a simple supply and demand curve, as shown at right. When the demand for water exceeds the supply of water you have a drought. The government officially defines drought as "a period of insufficient rainfall for normal plant growth, which begins when soil moisture is so diminished that vegetation roots cannot absorb enough water to replace that lost by transpiration." This is a good definition for areas that depend on rainfall for their moisture, but, in Colorado Basin, 80 percent of the surface water supplies come from the melting of snow pack. A better definition for drought in the Colorado Basin might read: "A period of insufficient snow pack and reservoir storage to provide adequate water to urban and rural areas."(Moellenberg)

The snow pack collects in the mountains around the Colorado River Basin during the winter months, between October and April, as shown at right. Annual snow pack in Colorado averages about 17 inches statewide. It then starts melting soon after. This melting snow pack is absorbed into the ground for use by plant life as well as going into the Colorado River and its many tributaries. With the use of dams and reservoirs this water is collected and stored so it can be used to support human life.

How would a sever drought effect the Colorado River basin? Obviously some things and people will be affected much more or less than others. The people that rely on their farms or ranches will be some of the most effected by a drought. They need large amounts of water to irrigate their crops or to keep their animals hydrated. So obliviously agriculture will suffer first and most severely, whenever there is a drought.

Drought can also affect the economy for many different reasons. Tourism is one of Colorado's biggest income providers but less snow pack would cut down on the amount of skiers, less fishing and boating would occur with lower water levels, fires can impact both camping and visiting of parks. All of these things as well as other can tremendously cut down on tourism profits. Agriculture is the other huge economic issue influenced during the drought. Because agriculture accounts for 48 percent of the state's land area, there is much to be lost in a drought.

Much of this was seen during the drought of 1977. Data from the 1977 drought show that ski lift ticket sales declined by 2.3 million tickets, approximately 40 percent. In addition, employment at the ski areas declined by 15 percent. Moreover, it is estimated that the revenue loss to resort communities was approximately $76.8 million in uninflated dollars; commercial airlines lost approximately $15 million; retail sales declined by $7 million; and restaurant and hotel visits declined 29 percent. (Hart) Usually the impact of a drought is extremely difficult for agriculture. Thanks to the monetary help the government provided for the farmers, these issues were not felt as strongly in 1977.

Another huge problem that can arise because of drought is forest fires, something that can be seen in the drought of 2002. Snow pack data for this can be seen below in Figure 3. Snow pack data is gathered using snow pits, and measuring the amount of fresh snow on top of the old snow fall. An example of this is shown at right. During the months of April, May, and June Colorado had extremely low snow pack levels, at 52% of average, 19% of average, and 2% of average, respectively. During these months the southwest had a huge

problem with forest fires. The fires, ranging up to about 40 fires cost well over 150 million dollars. Below is shown a map of some of the fires in Figure 4.

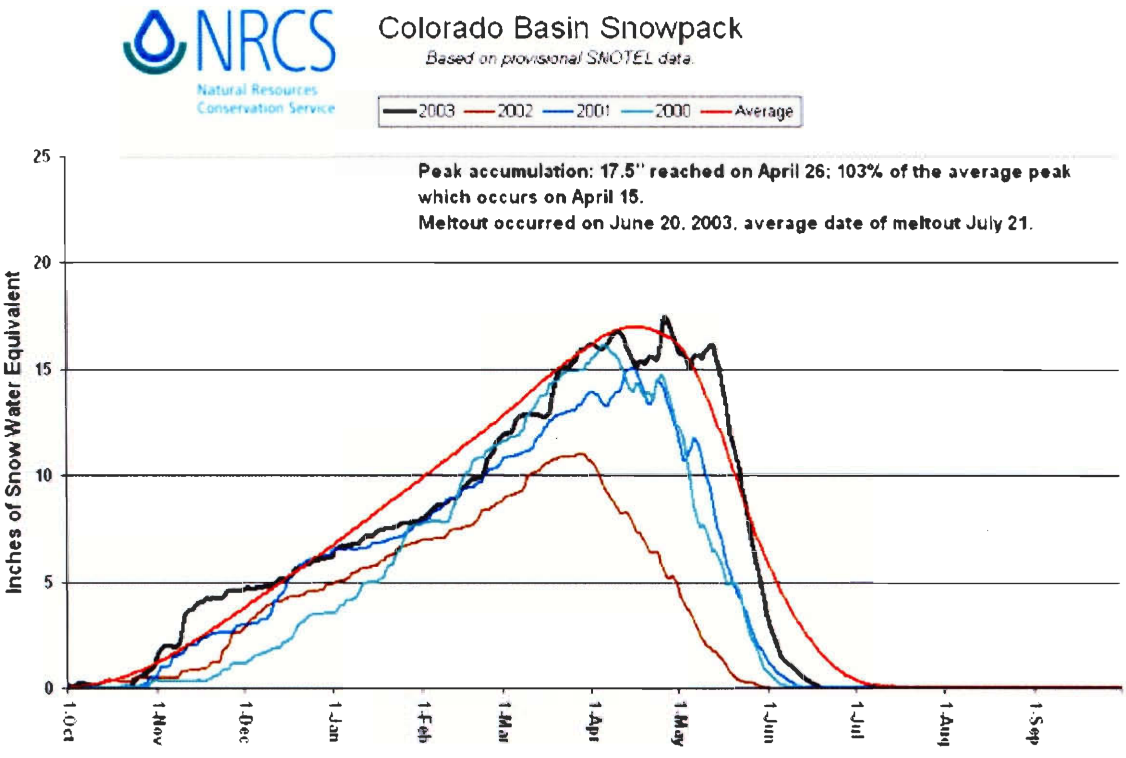


Fig. 3: Colorado Basin Snow pack
(http://www.co.nrcs.usda.gov/snow/data/basinplotco03.html)

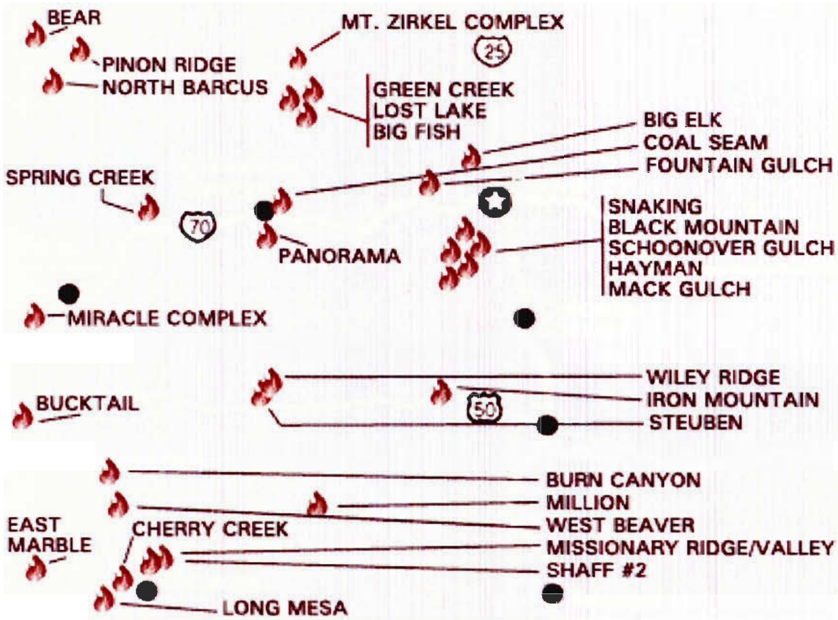


Fig. 4: Map of Fires During 2002 Drought.
(http://www.dola.state.co.us/oem/PublicInformation/firebans/CO_Fires1.pdf)

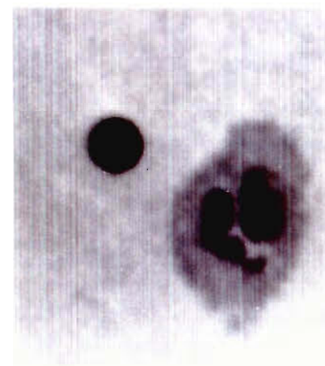
DROUGHT CYCLES

Previously, the only way to determine if a drought had occurred was to look at the rings in a tree. These facts, called tree ring data, can be used to determine if drought occurred and approximately when. While this information can help us understand drought cycles and what they do to the environments, it is limited. First, this is not a precise tool for measuring time so it can only be interpreted somewhat accurately. Second, these records can only date back as long as the tree had lived, which in most instances, is not enough data. This is one of the reasons that drought and snow pack data does not have data dating far back. Records pertaining to drought are now being kept. These records date back a little over a hundred years. The data is collected daily at hundreds of stations in the mountains of Colorado.

SUNSPOTS

Sunspots are dark areas that appear occasionally on the surface of the sun and measure typically about 10,000 kilometers across, but can be larger in size.

They can usually be seen during sunrise and sunset. Sunspots have been observed for over 2000 years. Civilizations that have studied the phenomena include ancient Chinese observers, Indian astronomers and the Greeks. Galileo and many other astronomers first observed the sun through telescopes around 1610 and realized that sunspots could exist in large numbers. After telescopes were used, astronomers could observe between 20 to 30 sunspots daily for about 18 years. From 1650 to 1670 a very small number of sunspots could be found and between 1676 and 1684 none could be seen. This period was named the Maunder Sunspot Minimum, which coincided with the extreme cold period on Earth. Before the Maunder Minimum, other similar periods of low solar activity have occurred: the Spoerer Minimum (1420-1530), the Wolf Minimum (1280-1340), and the Oort Minimum (1010-1050). Periods as these led to speculations that sunspot activity can affect the earth's climate.



SUNSPOT CYCLES

Before explaining the sunspot cycles, one must understand several facts about the sun and its sunspots: the sun is composed mostly of ionized hydrogen. In order for us to see the sun “shine”, thermonuclear reactions at the core must take place. There, the temperatures reach millions of degrees Kelvin. This heat is carried from the core to the outer layers of the Sun by a process called radiative transport and it takes a photon hundreds of thousands of years to travel from the core to the outer layers.

Sunspots have strong magnetic fields, which keep the hot, ionized gases from reaching the surface and releasing their heat below the sunspots. To be more specific, the outside of a sunspot has only gas pressure, which depends on the temperature. The inside of a sunspot has both gas pressure and magnetic field pressure combined and in order for this pressure to be balanced, the magnetic pressure inside the sunspot must allow the gas pressure to remain lower than in the areas outside of the sunspot. Since the heat cannot reach the surface, the total temperature is lower in comparison to the surrounding photosphere (lowest layer of the solar atmosphere). The temperature of a sunspot is about 4000K, while the rest of the sun’s temperature is about 5700K. Thanks to the difference in temperature, sunspots seem darker compared to the rest of their surrounding photosphere. They still are very bright: if we take an average sized sunspot and compare it to the moon, its brightness would be similar.

Sunspots are made of a dark, central disk called the umbra and an outer lighter colored area called the penumbra. This can bee seen below in Figure 5. Both words are from Latin and mean “shade” and “almost shade” respectively.

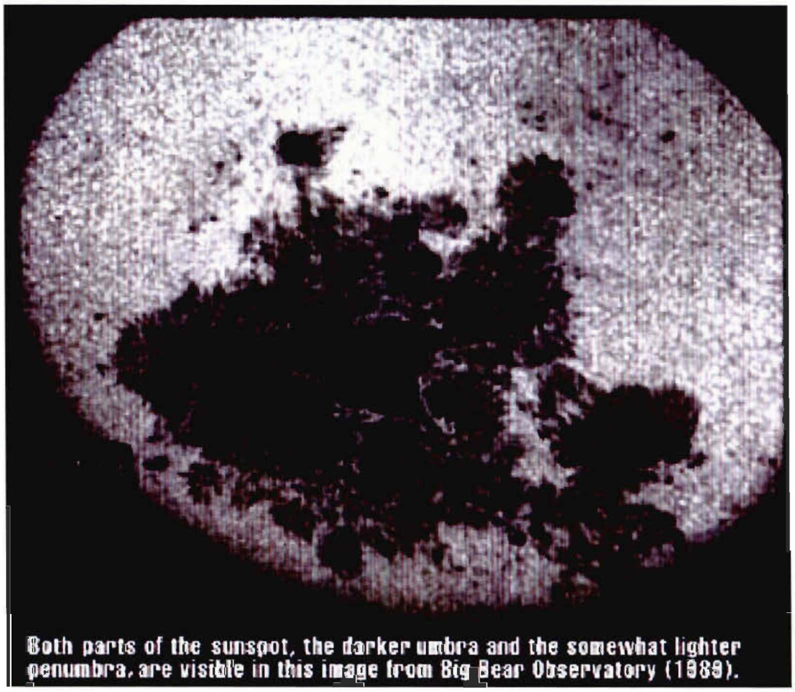


Fig. 5: Composition of a Sunspot
(http://www.exploratorium.edu/sunspots/research3.html)

The Sun's magnetic field's strength is very similar to that of the earth: the magnetic field lines emerge at the North Pole and re-enter at the South Pole (diagram: The Sun's and the Earth's Magnetic Fields page 18). The intensity of the Sun's magnetic field is about the same as that of the Earth: about 1 Gauss (unit of magnetic field strength). The sunspot's local magnetic field, however, can be several thousand times stronger. This can be explained thanks to the Zeeman Effect. The Zeeman Effect is the "splitting of a single spectral line into a group of closely spaced lines when the substance of producing the single line is subjected to a uniform magnetic field" (The Columbia Encyclopedia).

In 1844 Heinrich Schwab, an amateur astronomer, published a paper that explained the cycles of sunspots and that they occur about every 9.5 to 11 years, on average about every 10.8 years. When the Cycle reaches low sunspot activity, it is called a "solar minimum", when it reaches high activity, it is called a "solar maximum". What causes these cycles is still an unanswered question. Since sunspot cycles have been discovered, several scientists have tried to prove that they are caused by the influence of other planets. Jupiter, with its 11.86-year period is thought to be the most affecting. Even though there have been several correlations between sunspot cycles and other planet's periods in the past century, no one has been convinced. Below in Figure 6, sunspot cycles can be seen.

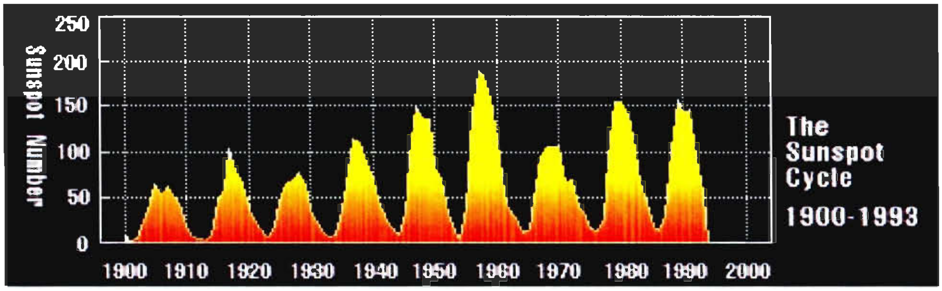


Fig. 6: The Sunspot Cycle from 1900 - 1993
(http://www.exploratorium.edu/sunspots/research4.html)

John P. Bagby introduced a new theory concerning solar-cyclic behavior. While he was looking for possible changes in the planets due to a tenth major planet or a dark massive solar companion, he found that the orbital points nearest to the Sun were being disturbed with an average period of 11.2 years, which is very close to the sunspot period. These cycles were and are still thought to be a trigger for cyclic volcanic and seismic activity on earth. This further proves the theory that there is a link between the Sun and the Earth.

John P. Bagby tried explaining it with two possibilities:

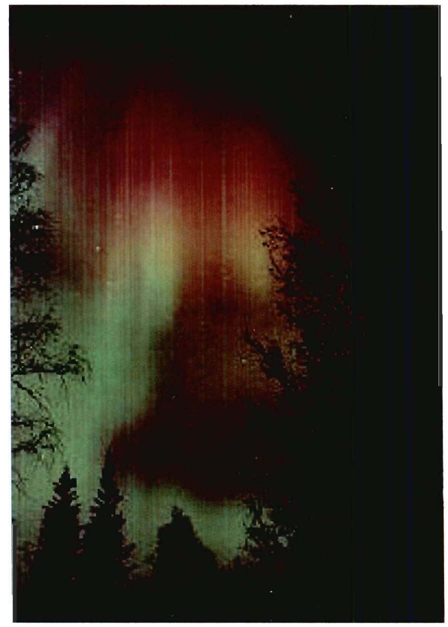
"1. Mutual resonance effects between the planets

2. The effects of a massive solar companion" (What causes the sunspot cycle?)

Moving back to sunspot cycles and the sun's magnetic field, astronomers in the past century have discovered that sunspot cycles are in reality 22 years long. There are two 11-year cycles of sunspots: one above the equator and an equal cycle right below the equator. As George Fischer, a solar astronomer at the University of California, stated: "the overall magnetic field structure changes in a way that is very interesting: It turns out that the magnetic fields primarily point from west to east in the Northern Hemisphere (of the sun), and from west to east in the Southern Hemisphere. In the next eleven-year cycle, the fields are reversed. So the cycle is really twenty-two years" (Sunspots: Modern Research, page 4).

Sunspots tend to appear in lower altitudes near the equator's sun. They usually appear between five and forty degrees north and south latitude. Sunspots will move constantly towards the equator, as the cycle progresses.

MAGNETIC FIELDS



As mentioned before, John P. Bagby tried to find a correlation between the sunspot cycles and other planets and an additional correlation between the Sun and the Earth while trying to find an explanation. We know that the Sun's energy has a large effect on earth; its energy provides us with energy for photosynthesis for plants and algae, which feed almost all live on Earth. The Sun can additionally affect Earth in a completely different way. The Earth's magnetic field protects the planet from any emissions coming from the Sun. Since during strong sunspot times the emissions are much stronger, the Earth's magnetic fields cannot protect as efficiently as during low sunspot activity. The emissions that hit earth are energetic particles, x-rays and magnetic fields. When this happens geomagnetic storms are created. Thanks to these storms, we are able to see the Aurora Borealis and the Aurora Australis, or also called Northern and Southern Lights.

As it can be seen in Figure 7 below, the Earth's magnetic field (the magnetosphere) does protect the planet from solar winds and other emissions coming from the Sun. The sun can be seen on the right of the picture, including its magnetic fields (yellow). As mentioned earlier, these do not hit Earth when their strength is at a normal level. When the strength is very high, they act as if a part of the Sun would have broken away from the star and hit Earth. These chunks are also visible in Figure 7.

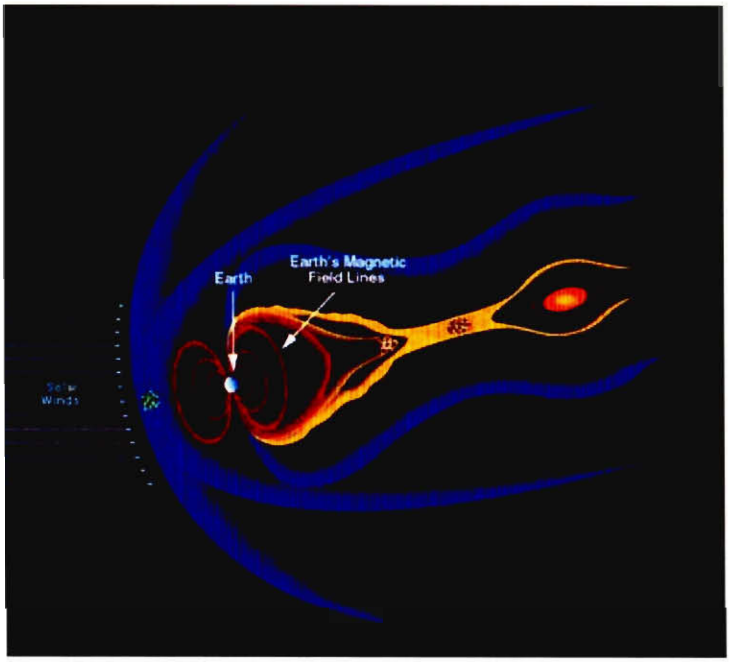


Fig. 7: The Sun's and the Earth's Magnetic Fields
(http://spaceflightnow.com/news/n0211/12electrons/)
Earth's magnetosphere (red), pushed and shaped by the impinging magnetic field of the sun (yellow). Solar winds are depicted in blue.

ISSUES WITH TECHNOLOGY

Problems can occur with technology, such as satellites, during high sunspot activity. Since the magnetic fields are pushed together to form the sunspots, more magnetic field is brought in. With the high amount of magnetic energy produced, magnetic tension can occur when there are magnetic fields running in two different directions; they can either move away from each other or become very close to one another. In several circumstances these fields connect and the electric currents are reduced, releasing high amounts of energy in the form of x-rays and particles of gas. Due to the energy, the gas' movement's speed rises making the gas particles 'interact' with the magnetic fields on earth. As these particles travel around the earth, they form current sheets. These current sheets are made of magnetic energy and can be either positively or negatively charged. When a satellite moves to a place that has one charge to a place that has a different charge, the surface of the satellite can change its polarity, allowing electric currents to flow into the satellite and damaging the hardware.

Particles that travel deeper into the Earth's magnetic field can be trapped in that field, making them oscillate back and forth between the poles. As mentioned earlier, these produce the Aurora Borealis and the Aurora Australis. In addition to the beautiful auroras, they create a lot of radio interference, which can be best heard at lower radio frequencies, making it difficult for us to make broadcasts.

CONTROVERSIES

A question that many astronomers and other scientists have been asking themselves since the times of Galileo and many other famous astronomers is: do sunspots affect the earth's climate? This is a question that is very hard to answer. As mentioned earlier, sunspots have a lower temperature than their surrounding photosphere. The dark spots in the Sun increase the total amount of energy emitted from the star. The ultraviolet radiation of the solar spectrum increases during sunspot activity. As we know for a fact, ultraviolet radiation is a very small part of the total energy emitted from the Sun; energy that we know can change the weather on Earth. Even though there is little radiation, the effect produced by the sunspots is enough to affect the energy balance and chemistry of the outer atmosphere. As clear as this might seem, the theory about sunspots affecting the weather on Earth is still very controversial. George Fischer, a solar astronomer at the University of California, believes that "it's controversial whether the solar cycle has an effect on the earth's climate. One thing that is known for sure is that solar activity, which is what we call the general feature of having magnetic fields on the sun, changes the sun's luminosity--that is, how much energy is coming out of the sun--on the level of a few tenths of a percent. That could change the earth's climate in this cyclical way, but it's controversial" (Modern Research 7 of 7). One of the few proofs that scientists have to explain their theory is the Maunder Minimum, a period of very low sunspot activity from 1645-1715. This period coincided with the period in which the temperatures were extremely low in places such as Europe. This period is often called the "Little Ice Age".

Moving back as to why the theory is very controversial, the main reason is the complexity of the earth's climate. The complexity is due to other forces that drive the

Earth's temperature, such as the Malkovich forcing of now, it is impossible to determine what makes the weather change. There is too much to think about. Let's take a look at global warming: it is thought that the green house effect triggers global warming, among other things. Many scientists try to disprove this theory due to the lack of reasonable proof. If it is true that global warming is caused by the green house effect, then scientists need to include this fact in their study, which will make it more difficult.

Global warming is not the only additional possible effect for climate change. There are many other climate cycles that one must think about. Thanks to studies we know that the Earth is oscillating between cooler and warmer cycles of about 100,000 years. Is it therefore correct to assume that the current high temperatures can be explained with global warming alone? The answer is no. In addition, scientists have found that during the Maunder, and the Dalton Minima, the temperature anomaly was -.04K in 1890, when the cycle was 11.7 years. In 1989, when the cycle was 9.8 years, the anomaly was 0.25K. This discovery has made critics doubt the theory, that the green house effect triggers global warming. Despite the contradictions, many scientists believe that green house gases do affect global warming. A recent study has shown that the "combined effects of sunspot-induced changes in solar irradiance and increases in atmospheric greenhouse gases offer the best explanation yet for the observed rise in average global temperature over the last century" (Sunspots and climate). Scientists build a global climate model based on energy conservation and constructed a profile of atmospheric climate that included solar irradiance and greenhouses gases. The years they concentrated on were between 1880 and 1993. They found that the "temperature variations predicted by their model accounted for up to 92% of the temperature changes actually observed over the period. Their results also suggest that the sensitivity of climate to the effects of solar irradiance is about 27% higher than its sensitivity to forcing by greenhouse gases" (Sunspots and climate). Although this study is not enough proof on this matter, later studies may prove this issue.

There are many other cycles that are thought to affect the Earth's climate, such as the 41,000-year and the 20,000-year glacial cycles, the 22-year solar magnetic polarity cycles, etc. The cycles run simultaneously and affect the Earth's temperature. Scientists have found a correlation between the 100,000-year magnetic cycles on the Sun and the 100,000-year climate cycles on our planet. Even though there is a correlation, it is uncertain how much the cycles affect the Earth's climate.

Before satellites, astronomers believed that as the number of sunspots increased, the temperatures would decrease. Recent research with satellites has disproved that fact: the more sunspot energy is delivered to the atmosphere, the more the temperatures will rise.

CORRELATION

As can be seen below in Figure 8, Colorado has had many periods of time, between 1890 and 1997, where the amount of drought was very high. These periods of drought are shown below by the green arrows. These years, in consecutive order, starting with the oldest, are: 1894, 1904, 1913, 1927, 1937, 1946, 1956, 1965, 1979, and 1991. These dates are roughly in a 10-year cycle. This cycle time is very close to the cycle time for sunspots, which is 11 years. One of the most convincing pieces of evidence is found when the cycle charts for drought (Figure 8) and sunspots (Figure 9). On the sunspot cycle chart below the green arrows correspond to the same years as on the drought cycle chart. When these to charts are compared it can be seen that when every there is a low number of sunspots there is a large amount of drought in Colorado. This shows that there is a pretty direct correlation between sunspots and drought.

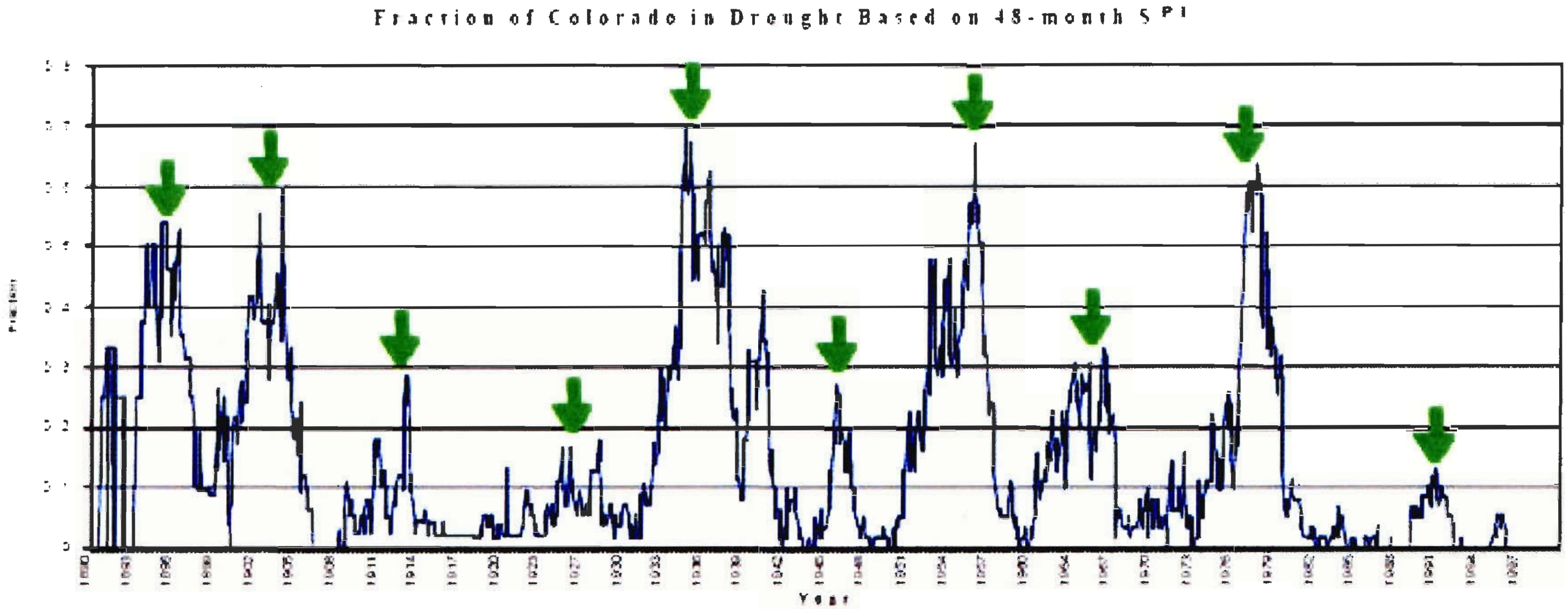


Fig 8: Cycles of Drought in Colorado
(http://cwrri.colostate.edu/pubs/balance/no.%209/wibno9rev2.pdf)
The blue lines, in this figure, show the fraction of Colorado that was in drought at a specific time period. The green arrows are the times when the sunspot count was at its lowest points.

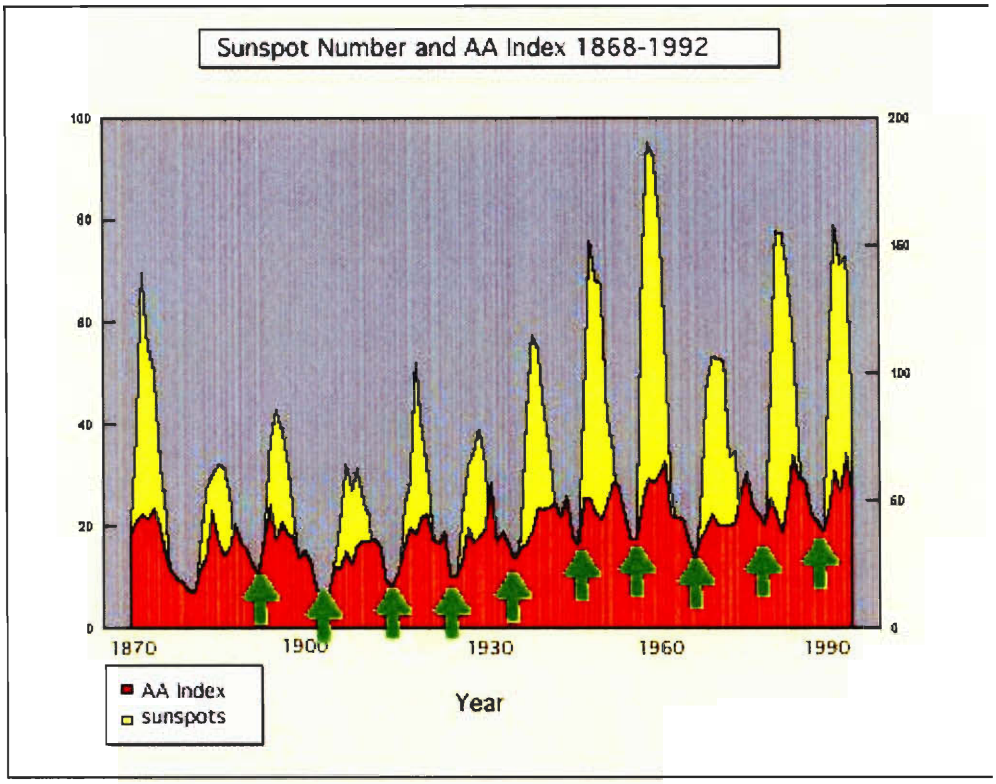


Fig 9: Cycles of Sunspots
(http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/aurora.gif)
The yellow sections, in this figure, show the sunspot number at a specific time period. The green arrows are the times when the fractions of Colorado in drought were at its highest points.

Although Fort Collins, Colorado is not in the Colorado River basin we also found a correlation between sunspots and drought there. At Fort Collins there have been five major droughts recorded in the past 130 years. In 1893 it was the driest year in Fort Collins recorded History at 7.13". In 1934 it was the hottest and driest year of the dustbowl. In 1854 there was severe drought and it was the hottest year in Fort Collins history, most temperatures of 100+ in recorded history. In 1966 was the most recent severe drought with only 7.34" of precipitation. 1977 was the last major drought for northern Colorado. (Doesken) Also another drought was recorded in the very early

1900's. When this information is compared to sunspot cycles, as shown below in Figure 10, it seems as though there is a pretty direct correlation here also.

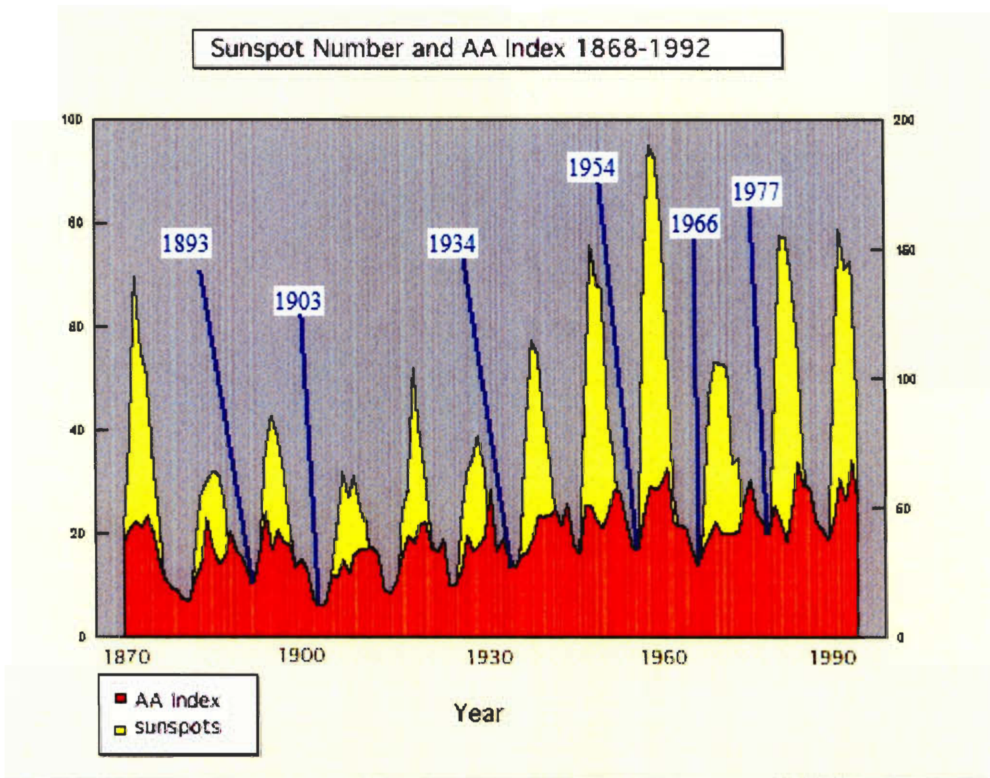


Fig. 10: Sunspot cycles when compared to droughts at Fort Collins Colorado (http://www-das.uwyo.edu/~geerts/cwx/notes/chap02/aurora.gif)
The yellow sections, in this figure, show the sunspot number at a specific time period. The blue dates are the times when Fort Collins, Colorado was in sever drought.

CONCLUSIONS

As it can be seen in our paper, there is no direct proof that there is causation between sunspots and drought. If we ask Andrew Odins, a scientist at the Texas A&M University, what he thinks about the issue of sunspots affecting the climate on earth, he responds: "There has been research done on subject of sunspots and our weather for at least 100 years, and the bottom line is that we still aren't sure. We know that the primary energy source that controls our weather is sunlight. And we know that sunspots - which release giant solar flares of energy - can often disrupt satellites and radio transmissions here on Earth. But a link between sunspots and the weather is still not certain. Galileo observed them 400 years ago and we know that sunspots seem to occur in a roughly 11-year cycle during which there can be just a few dozen or several thousand." (Sunspots and the weather). We know enough information about sunspots and their cycles, but we do not know how the phenomenon affects our planet and why it occurs.

When looking at data about sunspot cycles and drought, we have found some relationship between the two, but not enough proof to show a direct link. While we can see a relationship between sunspots and drought, we cannot actually show a correlation or causation. When trying to study this issue, we cannot only concentrate on sunspots. If we try to explain why there is a drought, we have to look at other Sun and Earth cycles. As it was mentioned before, the Earth has 100,000-year cycles of cold and hot weather. Unfortunately not enough research has been done in the area to prove or disprove how much this affects drought. Another factor that scientists should look out for is the green house effect, which has not been proven to trigger global warming. Even though it has not been proven, they should take into account, the possibility that a correlation exists.

When analyzing data, we came to the conclusion, that there is a relationship between sunspots and drought. How in depth this relationship is, is uncertain due to the lack of proven data. This possible correlation only exists when the amount of sunspots in a cycle is close to its minimum. Unfortunately we cannot conclude that there is causation: if we would want to calculate the amount of correlation or effect of the two, several theories would need to be proven: the green house effect triggers global warming, how much the Earth's 100,000-year cycles matter, etc.

Finally we feel as though we have shown a relationship between sunspots and drought in the Colorado River basin. This link can be shown to be correct as more data is gathered over the next hundreds of years. Although a relationship can be found, there is no way we can prove a correlation or causation. A correlation could be found much easier then trying to prove causation between sunspots and drought. In order to find a valuable answer, sunspots and the causes of drought must be researched much more in depth.

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