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Climate Change in the American Southwest

Lightning Strike Predictions

An Interactive Qualifying Project Report

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by

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Abstract

This project dealt with the problem with the water supply due to rapid population and commercial agricultural growth in the American Southwest. With the Colorado River water being utilized over such a range of purposes, periodic droughts are of great concern in its neighboring communities that so heavily depend on it. The purpose of this project was to try and predict climatic changes that seem certain to reoccur. Methods of climate prediction have been made in the report to analyze the future of the water supply in the American Southwest.

Introduction

The American Southwest has been a region, for a long time, of low rainfall and little water. The supply of water available will always be limited in this region. The future seems to be even more problematic as the population in this region will continue to grow through local immigration, a high birth rate, increasing property values, increasing land use and many other reasons. With population continuing to grow as rapidly as it has and with growth increasing steeply, there is certain to be an increasingly alarming challenge with the supply of water.

Land in the South West is used for two main purposes: for urban use and agricultural farming. Urban water consumption per person has been increasing steadily as in most parts of the United States but not nearly as much as the water consumption in the farmlands. Agriculturally, land was largely unutilized and undeveloped but with more and more land being used for agricultural purposes, water consumption is skyrocketing these days. A certain quota of water is given to urban and rural areas with such constant water scarcity. There has been competition among the big money investors, centralized farm owners and the city councils. For example, Arizona largely depends on water from the Colorado River for it fast growing communities and to supply its real estate explosion. However with much of the water from the Colorado going to the farmlands in its upper section, water has become more of a valuable commodity. Water used for agricultural purposes is largely not returned back into the system as it is with urban uses. Due to water use by the irrigational methods of Colorado River farmers, much of the water is lost through evapotranspiration.

In evapotranspiration, water is lost into the atmosphere as water vapor, both from plants and through open spray irrigational methods. In the Middle East and other areas of the world with advanced irrigational methods, water is used much more efficiently to provide for the nurturing of the drops. Methods like drip irrigation and underground water feeding reduce the amounts of water required to create a regular harvest. Almost 55% of the water is lost in the air when it is sprayed as a mist over the crops in the American Southwest. This spraying methodology, both with pipes that go over crops and with timed underground sprays, more water is required for the regular harvest. It is estimated that almost 200 gallons of water is required to produce a single tomato with the use of such methods whereas only 75 or so gallons of water is used to produce the same product with drip farming. [1]

The water vapor created by evapotranspiration is carried over the Rocky Mountains and into other rivers and ultimately into the Gulf of Mexico and eastwards by the wind currents of this region. Much of it does not re-enter the Colorado River again unfortunately and is lost within the cycle. Water loss in this manner, along with the many dams in the river had caused the river to cease its original flow into the natural delta in Baja California.[2]

One problem that is faced with the region today is the water consumption that the exploding population needs. More and more efficient techniques will be required in order to supply the sufficient water and electricity needs of the Southwest. Much of the water is already being used several times over in the region and in being over-utilized. This way, animal life within the river has suffered with the lack of water at times and too much at

[1] http://bioengr.ag.utk.edu/Extension/ExtProg/Vegetable/year/VegInitReport02/28hydroponic_tomato_production_in_.htm - Hydroponics Growth of Tomatoes
[2] *A River No More*, Fradkin, Philip L.

other times. Better irrigational methods would help immensely to cut down the amount of water utilized in the region, as well as a more careful, resourceful consumption by the general population.

With the economy of the region having such reliance on water, it is certain that it can not get by with a shortage of water. In order to succeed, the economy will require that water and lots of it. Water in the region is provided largely by the Colorado River however some is diverted from the Rio Grande and other smaller tributaries. The Colorado is the main source that builds the structure to pump dollars in this area's economy. In that way, the river has been largely abused.

Many dams have various sections closer to the source, including the first to be built and most famous, the Hoover Dam. This is the primary source of electricity to the surroundings areas of Nevada, Utah, Arizona, and California (among others) and during the Great Depression; it was a source of inspiration and a symbol of success in a newly developing America. But that idea of utilizing the wide range of resources has led to the over-utilization of the Colorado River. More than 15 dams use the river to form a floodplain for irrigation purposes and to draw hydroelectric power through the many hydraulic turbines. Water has been stuck in such reservoirs behind these dams and allowed to flow only in limited amounts. Over the years, many areas have been overrun by water in these man-made reservoirs, many Anasazi ruins and trekking trails now lie beneath the surface of the river.

Figure 1: Major Dams of the Colorado River

The main problem here is that the population growth and the growth of the usage of land for agricultural purposes not only has created stiff competition between water usage quotas, but also where the water supply will come from in the future. There is competition not only between the urban and rural areas for water but also between the landowners who in many cases farm right up to the river against regulations.

Here lies the nature and purpose of this project. In order to calculate the water requirement and the effort required to source water in the future, we need to know how the water cycle operates in the region. The climatic changes that threaten to affect the future are critical to planning the future of the region, both subsistently and with its commercial economy. Ways of tracking the weather patterns and the cycle of wet and dry

years need to be addressed in order to predict future climates. This report will cover these particular climatic predictions.

The Ancestral History of the Colorado River and Region, From the Anasazi to Recent Times

The Anasazi, who are actually ancestors of the present Pueblo, dominated the upper Colorado Basin, particularly Utah, during the earlier part of North American history.

Figure 2: Anasazi Ruins (Mesa Verde)

Copyright of Anasazi Historical Society

The other significant Native American tribes that occupied the area during that time include the Utes and Southern Paiutes. Although the Anasazi only live as the Pueblos today, there are still pure Utes and Paiutes on the several reservations scattered along the River. These two tribes were hunters and gatherers[3] and they soon were cast into insignificance. The tribes in the southern part of the river practiced farming and they dominated the area for a much longer time than the rest of the tribes. This farming was partly facilitated by the fact that there was a wide flood plain in the regions around Yuma, Arizona.

[3] From the expressions used in Guns, Germs and Steel, Jared Diamond.
He thoroughly explains the significance of societies to switch from hunting and gathering to farming in order to succeed and avoid being conquered by more advanced societies.

Figure 3: The Mouth of the Colorado

This satellite picture shows the flood plain on which the Yuman tribes might have farmed. Copyright of Desert USA.

"Yuman tribes practiced more extensive patterns of floodplain farming and hunting on the Colorado, which was too large and variable for canal irrigation."
-A.R. Royo, Desert USA

Ecological change in the river only came with the Europeans. This ecological change affected the farming methods of the Native American tribes and they struggled to maintain their ancestral farming methods. The first European to reach the river was Francisco de Ulloa. He reached the upper Gulf of California in 1539 and saw the mouth of the river. The first European to sail up the river came by a year later in 1540 when Hernando de Alarcon led an unsuccessful attempt to explore the river. Garcia Lopez de Cardenas of Coronado led the first successful attempt up the Colorado. He became the first European to discover the Grand Canyon. The first person to call the river 'the

Colorado' was Francisco Garces (for the redness of the river's mud) who was a missionary in the region in the late 18th Century.

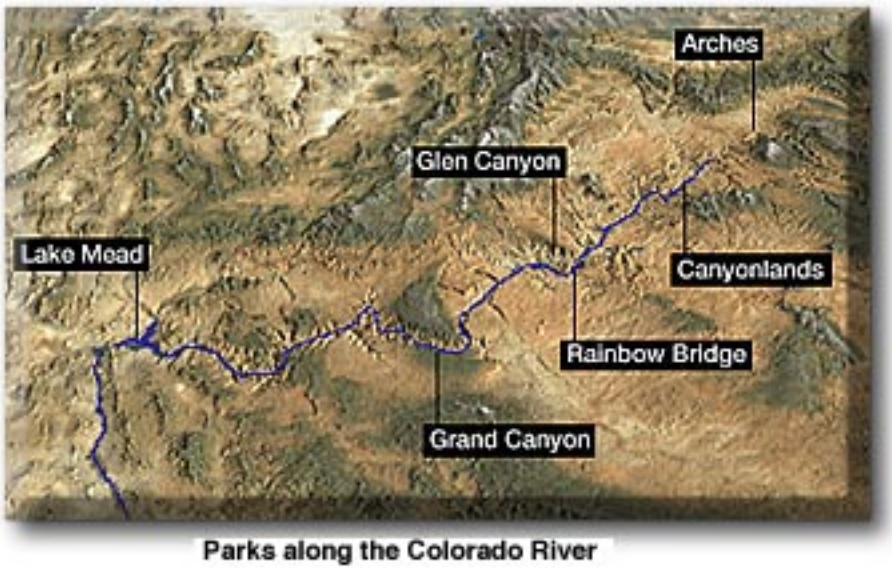

Figure 4: The Upper Colorado River

The area up the river which the Spanish explorer discovered. Copyright of Glendale NRA.

The river wasn't completely mapped or even completely explored until 1869. The first person to actually charter through the Grand Canyon and record the geographical data was Major John Wesley Powell.[4] The documents and journals he recorded are still available today. He described the perilous journey through the Grand Canyon in excruciating detail along with the 'wonders of the desert' (A.R. Royo). He reached the Great Salt Lake in Utah.

[4] http://www.jacksoncountyohio.org/jw/live/powell/powell05011997.htm - Journal can be found here

Figure 5: The Salton Sea

Copyright of Glendale NRA.

After some force by the US military (of which Powell was part of) during the late 1800's, the Mexicans and the Indians lost rights of the land around the Colorado.

Figure 6: The Colorado River in the Grand Canyon

Figure 7: The Colorado River

These pictures of the Grand Canyon show the difficulty of attempting to go through this terrain. Mapping it must have been even harder. Copyright of Glendale NRA.

The first developments on the river were dams. The first of the dams were placed in the early 20th Century. Some of the dams were constructed during the Great Depression for electricity and also a way to solve the local unemployment problems. The river has the potential to produce over 9 million KW of power but only about 1.5 million is utilized. Partly due to the many dams on the river (over 20), the river almost never reaches the intended mouth at the Gulf of California.

"The Morelos Diversion Dam, located on the Mexico-Arizona border is the southernmost dam on the Colorado. It sends virtually all of the remaining water to irrigation canals in the Mexicali Valley and to the towns of Mexicali and Tijuana.

The Colorado River system was the first drainage basin in which the concept of the multipurpose dam was employed."
-Desert USA

The Colorado basin remains a controversy due this lack of water in the river today, and increasing amounts of federal laws are being placed to keep a stiff check on any activities, whether irrigational or environment-based.

"In 1963 a decision of the U.S. Supreme Court made explicit the amount of water apportioned among the lower-basin states, as well as the amounts that had been implicitly "reserved" for Indian tribes and federal public lands."

-Glendale NRA

Significance of Thunderstorms

Of the many ways possible to predict and determine future climatic patterns, rainfall in particular, thunderstorms are a key to what deductions we can make. Rainfalls patterns hold the key to what will and won't pass over the region in the coming years. Tracking these rainfall patterns will deem many ideas on which we can determine various climatic changes from.

The tracking of rainfall patterns can be achieved in many ways. One of the more accurate and widely utilized methods is by tracking thunderstorms and major precipitation disturbances. Thunderstorms can be tracked in several ways. They can be tracked through the amounts of rainfall recorded at each survey station, by recording the number of annual thunderstorms pass through the region, and through lightning strike data.

Registering the amounts of rainfall shows the varying pattern of precipitation throughout the surveyed region. It is done using rain gauges and other equipment in several hundred surveying stations littered through the Southwest in every state. This data is usually transformed into a statistical model that shows various measurements taken in a climatological report that is filed to the federal government by each state every year. Many graphical and pictographical maps inhibit the reports that show the transition of rainfall across the state.

When the number of thunderstorms that hit each surveying station through the year is counted, the average amount of rainfall in each thunderstorm throughout the year, usually recorded on a weekly basis in most states but monthly in others, is calculated and

the thereby offers slightly more sophisticated data to draw statistical models from. Since recording the data to offer the most visible and data-loaded information is the feature of most of the statistical models, much data is gathered in this manner. They occur mostly in the summer during June and July.

Lightning strike data is the first accurate way to tracking a particular rainfall pattern without having to measure amounts of rainfall or calculate models from. It offers simple clear thunderstorm data without the requirement of much of the equipment found in surveying stations. Much lightning data is gathered to show the most relevant thunderstorms that passed through the region. This way we can easily but clearly see the source and path a thunderstorm takes, how much it pours over the area it passes over and where it ultimately ends up. This is the data that I will be investigating in particular.

Lightning Strikes

Introduction

The so-called Four Corners, or the adjoining edges of the four states of New Mexico, Arizona, Utah and Colorado, is the main regions in determining the rainfall patterns that affect the Colorado River. Everything to the East of the Colorado River goes off into the Mississippi River and the Gulf of Mexico. This region is the main source of the water coming into the Colorado as all the clouds that goes in the Rockies pass over this region. In order to predict climatic conditions contributing to the water cycle of the Colorado River and its watershed, the Four Corners region will have to be analysis in particular.

Lightning strike data will be collected here and we will be able to deduce climatic conditions in the future accordingly with the rainfall patterns. We will see in what ways the data is recorded and after looking at its methods and use, we can determine relevant information from it. We can come up with methodology that form be useful in predicting climatic changes in the region and uses of lightning strike data.

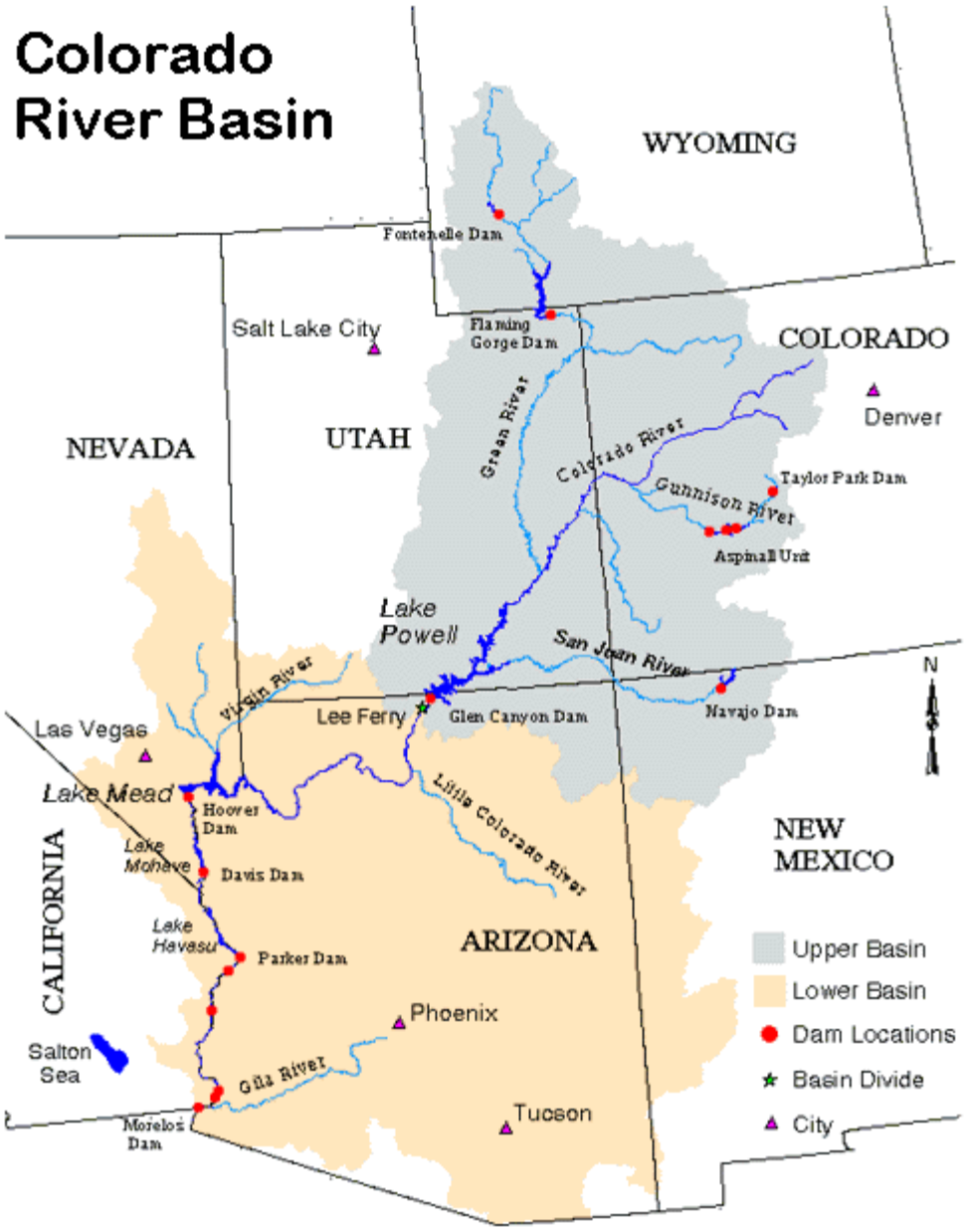

Figure 8: The Colorado River Basin and the Four Corners Region

The Significance of Lightning Strike Data

The main reason that lightning strike data is important is the availability of easy tracking methods that it enable us to have. We can see things that can't be seen using only rainfall topology.

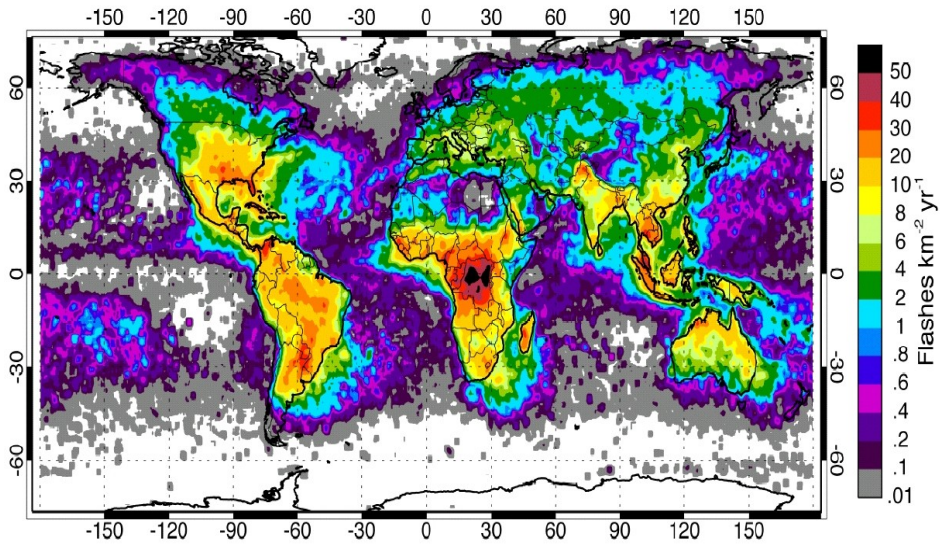

Figure 9: Global Frequency and Distribution of Lightning as Observed from Space by the Optical Transient Detector

Figure 9 above shows that most of the lightning in the world occurs within the continents themselves especially between and in the tropics. Although this does correlate in many ways with the rainfall that falls within those regions, it also shows us the few regions that have rainfalls and not as much lightning and vice versa. This enables us to predict the amounts of rainfall that hit the region fairly accurately. Lightning can be used as a monitor for other things like forest fire activity, the amount of nitrogen oxides and nitric oxides in a certain region (lightning is the primary source of natural N_xO and NO_x), and many other significant facts outside of precipitation levels.

How Lightning Strike Data is Recorded

Lightning strike data is recorded in many ways, of which the most common is from space through weather satellites. Lightning data is also recorded in some cases from electrical build-up sensors located at the larger weather station located in some states. However electrical activity in easier to locate and analyze with the data received by what satellites pickup over their allocated regions. Much of the data collected by weather stations on the earth are only presumed accurate with data collected during the day.

Many weather satellites are loaded with a wide array of sensors that detect and record many different climatic events from precipitation patterns to wind current movements. Each one of these events is recorded by various sections of the satellite specializing in record just that. The main feature of the particular system that analyzes and catalogs lightning strike data is known as the Optical Transient Detector.

Figure 10: Optical Transient Detector

The device detects momentary changes in an optical scene that show lightning occurring in the particular area between scenes. The OTD is extremely accurate in picking up these transitions over a wide area. Since many OTDs nowadays enable for a higher density

resolution in the scene transition radius, they are also very accurate in there data over the most minute of areas too. The primary advantage with OTDs, as expensive as they maybe, is the ability to record accurate data both during the night as well as during the day. The other advantages include accuracy, durability and sourcing of data for statistical analysis. Data Retrieval Algorithms process the data collected by this system in the satellite and produce the statistical figures and databases that inbihit lightning strike information to the government today.

The other device on the weather satellites that is of key importance is the Lightning Imaging Sensor which actually records the data. The basic idea here is that the sensor uses a very high-speed camera, in effect, to take pictures every 777 nanoseconds and search for key differences that may presume the occurance of a lightning strike.

The sensor upon the satellite may not have clear imaging in local areas as ground-based radio frequency sensors, such as within a 10-mile radius, but is predominantly used to oversee lightning over general regions like the American Southwest or the Four Corners region.

Figure 11: Lightning Imaging Sensor

Actual Lightning Strike Data

Now we know the relevance and how lightning strike data is collected, we can start looking at actual examples of lightning strike data collected over the region we are analyzing.

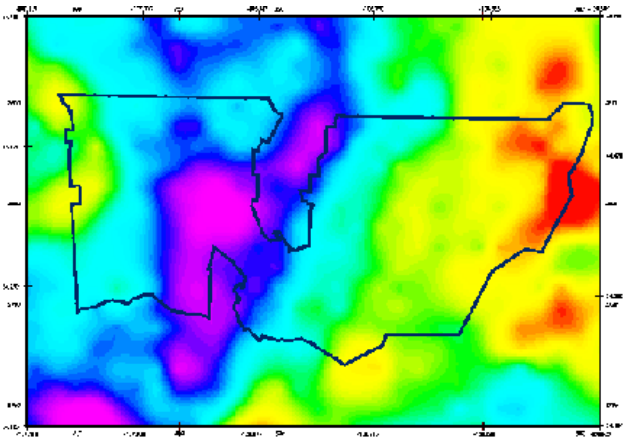

Figure 12: A Precipitation Graph Example

First of all, I started to analyze the theory that we can predict the anticipation of rainfall knowing the wind direction and speed and comparing it with that day's precipitation. Then we can tell, according to lightning strike data, if our predictions were correct.

Looking at the precipitation below on August 30th 1994 in New Mexico, we can see that there seems to be a pattern arriving from the South. The most intense parts of the precipitation seem to be centered within the system. I choose this example as it is a strong level of precipitation and it is clearly defined as to where it is coming from.

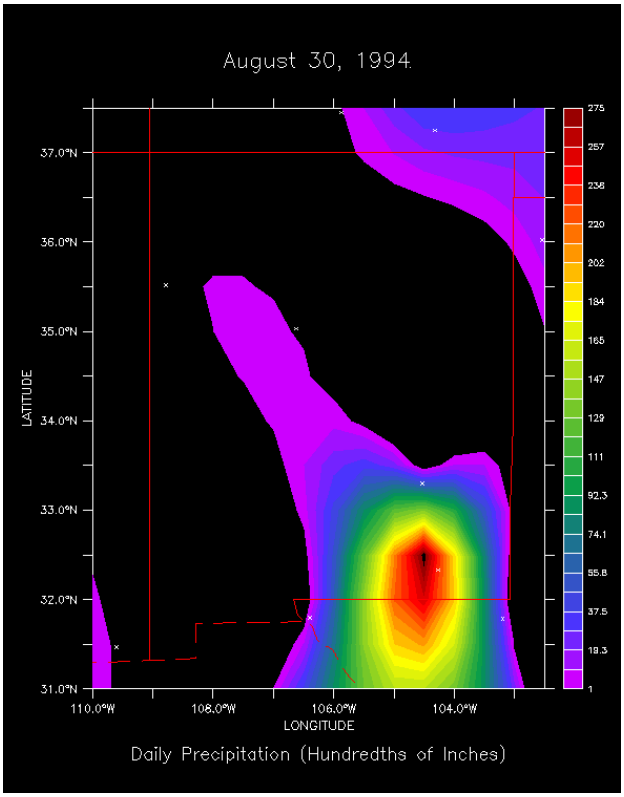

Figure 13: Precipitation in New Mexico, August 30th 1994

Now we can look at the wind direction and speed during the same day and see if we can predict where the most intense parts of the precipitation will be the next day.

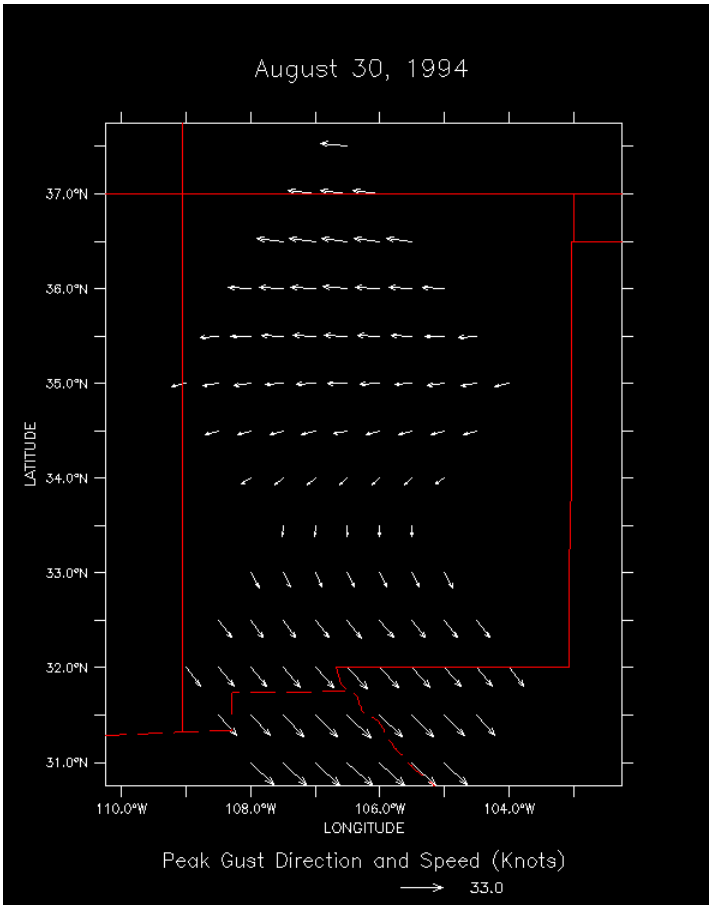

Figure 14: Wind Gusts and Direction in New Mexico, 30th August 1994

Wind gusts are coming primarily from East to West within the state and since the thunderstorm is coming from the South East, it should spread across the entire Western portion of the state and the most intense part should occupy the middle of the state in a defined boundary as there are some gusts moving South at the bottom of the state along that predicted line. Since the gales are coming from the East that portion of the state should be more calm, and perhaps even clear of thunderstorms or lightning. We can look at the lightning strike data on the next day to see if our predictions are correct. The purple dots represent a single strike of lightning at that point during that day.

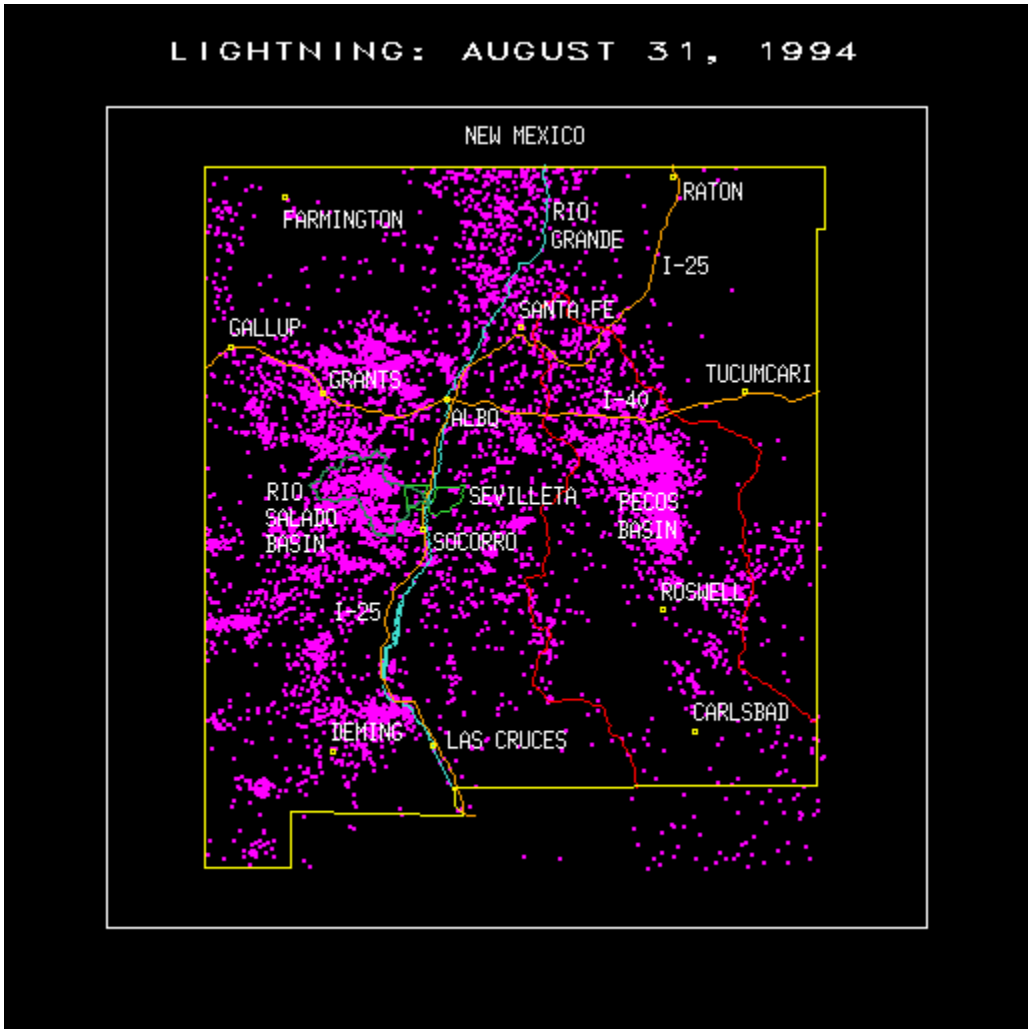

Figure 15: Lightning Strike Data in New Mexico, 31st August 1994

After analyzing the lightning strike data during that day, we can see that our prediction was approximately correct. There is a categorical line of lightning progressing across the middle of the state and there isn't much lightning at the Eastern portion of the state as predicted. The thunderstorm does seem to have moved across the state from the south upwards and across as the wind gusts predicted. Then there was that progression south as well. The center of the precipitation zone where we predicted the most activity seems to have created the line we were looking for.

Deductions from the Lightning Strike Data

Since our little experiment worked out almost exactly as predicted, we can see that predicting the pattern of rainfall over a short period of time is extremely simple, especially when using lightning strike data as a factor. We can also use lightning strike data over a period of time and follow it through with precipitation information over the same time and compare and contrast the results to predict the amounts of rainfall that may fall over an extensive period of time. Once we factor in the wind gust data into the compound, we can track the future of vapor directions into the water cycle of the Colorado River watershed. This link contains an animation of lightning strikes over a certain period of time:

http://sevilleta.unm.edu/research/local/climate/lightning/strikes/aug94-anim.html

I compared these data along with similar animations that I experimented on with precipitation graphs and found an almost certain match. It became especially evident that the data and system of prediction was particularly accurate with certain heavy amounts of rainfalls and with accordance to wind gusts. Although this system was less accurate with smaller amounts of rainfall, it was within an acceptable ratio.

I found this quote in the Sevilleta LTER site found it to be so pertinent to project that I had to quote it word for word:

"Typically, 50-70% of the total annual precipitation in New Mexico is produced by convective lightning/thunderstorms between June and September. These summer storms produce intense, spatially-variable rainfall, which is a critical factor influencing plant productivity, nutrient cycling, and herbivore activity. Knowledge of the timing, location and amounts of precipitation are important in planning or monitoring research activities and spatial modeling of the dynamics in this semiarid region. Technology exists for locating cloud-to-ground lightning strikes that has the potential to locate these intense precipitation events, quantify the volume of water associated with them and document the spatial and temporal variability of these phenomena over large areas. Near real-time analysis capability can identify areas receiving precipitation that will experience rapid vegetation growth in this semiarid region"

-Sevilleta LTER (http://sevilleta.unm.edu/research/local/climate/lightning/description)

Figure 16: Lightning as a Predictor of Precipitation

Basically the quote states that we can use lightning strike data as a valuable asset in determining such climatic patterns we are trying to identify in this project.

Concluding Lightning Strike Data

We can see the uses of lightning strike data now in predicting climatic conditions in the American Southwest. With this lightning data we find, it can be merged with rainfall/precipitation data to identify any similarities and differences, i.e. where rainfall was present but lightning wasn't and any inaccurate reading and false data can be narrowed down. There are other uses for lightning strike data as well including using enhanced technology to absorb electrical energy at sites that can be built in areas where lightning can be predicted to strike to this system of data.

Conclusion

In conclusion, after the predicted changes in land use and the effects of evapotranspiration the American southwest, we can use advanced technology to predict rain patterns in the future to work with the climatic changes that seem certain to dominate the region in the future.

Lightning strikes, certainly with the advanced technology used to detect them, provide this outlet to predicting rainfall patterns. I tried to analyze data on the SAS statistical modeling system using data gathered on rainfall and lightning strikes to observe the accuracy between the intensity and location to lightning strikes compared to the rainfall that could be predicted. Unfortunately SAS was not able to infer legitimate information from limited data and simple probability techniques for use in accurately depicting in the report. However it did seem possible that there could be a future venture in this area of statistical modeling to process all the various and much disintegrated data that is available into neat chunks of graphs and others models over a specific period of time comparing lightning strike data with precipitation patterns.

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