FLASH FLOOD RESEARCH AND PREDICTION MODEL

Research Paper

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ABSTRACT OF THE RESEARCH

Flash Flood Research and Prediction Model

According to the National Weather Services (NWS), a flash flood is defined as a flood that develops in under six hours, though they can form in a matter of minutes. It is important to understand flash floods which is responsible for 80% of weather-related deaths in the United States. When rain falls rapidly on saturated or dry soil with very low absorption ability, then the run-off that is caused gains tremendous force and becomes a gushing river which takes down almost everything in its path. It can sweep all kinds of debris downstream in just a few seconds. Sometimes these run-offs could also join with other low lying water or streams and cause an even more devastating impact.

Our research goal was to have a clearer understanding of the factors causing flash floods in California, by studying the past flash flood data. This analysis was then applied to the data collected over the ten years period from August 2003 to August 2013 for our geographical areas of interest in California, in order to understand the likelihood of flash floods occurrence in these areas.

We studied the methods adopted by National Weather Services (NWS) and National Oceanic and Atmospheric Administration (NOAA), and gathered data using Data-enhanced Investigations for Climate Change Education (DICCE-GIOVANNI) tool developed by Stanford Research Institute and National Aeronautics and Space Administration (NASA). We then used Microsoft Excel software application to help with time series data analysis.

We developed a hypothesis that, increased temperature leads to increase of flash floods. In order to test our hypothesis, we first narrowed down the list of parameters based on our findings from studying the methods adopted by the meteorologists. We then used the Excel data graphing tool to investigate the parameters and correlations for Mohave Desert for the known timeframes when flash floods had occurred during the past ten years period. We used overlaying of parameters onto a single graph technique to test our hypothesis for these known timeframe data points, and came up with a prediction model and trends for flash floods.

Next, we applied the same procedure used for the Mohave Desert for our other geographical areas of interest in California, and investigated the data for similar parameter correlations and trends to conclude the likelihood of flood floods occurrences in those areas.

This eight months research work has given us a clearer understanding of the factors that causes flash floods, and we hope that there would be future opportunities to further our research to develop solutions to protect and prepare our towns against the catastrophic impacts of flash floods.
INTRODUCTION

Flash floods are floods caused by a sudden surge of water which usually happens in a very short amount of time, usually six hours. These surges of water are generally caused by overflowing streams or rivers, or heavy rains. They generally occur in tropical places, or in the western United States where the soil might be too dry for water to be absorbed. Flash Floods cause about 3 trillion dollars’ worth of damages worldwide.

We have three basic needs for our project. The main need is to help predict when flash floods might happen, so people can evacuate out of the area in danger more quickly. The second reason is to help provide information about the effects of climate change on flash floods, so that we might be able to prepare and adapt our cities and mitigate the devastating impacts of flash floods. The final need for this project is to set the example for more flash flood oriented research, and to inspire others to use the tools that we used.

This project's results could lead to many benefits and solutions. One such future solution could be a creation of an online system using the prediction model we formulated and applying it to the daily live data of weather parameters, and be able to produce live predications for flash floods.

QUESTION AND HYPOTHESIS

Question: Does increased temperature leads to increase in the frequency of flash floods?

We think that increased temperature will lead to increase of flash floods. We think this because in recent times there has been more prevalence of flash floods, and we believe that this could be attributed to the increase in earth’s surface temperature caused by climate change.

Hypothesis: Increased temperature leads to increase of flash floods.
DATA AND METHOD

Testing of Hypothesis

In order to test our hypothesis, we did research to understand the factors that cause the flash floods.

Flash floods can occur for many reasons, depending on the location. Typically, heavy precipitation during the rainy season on saturated ground leads to flooding. Back to back storms in this season often saturate the ground, leading to runoff and flooding. In desert and dry regions, where soil is hard and clay like, precipitation is not absorbed by the ground. Small amounts of precipitation in this region can cause flash flooding with the water runoff. Flash floods occur in mountainous regions with large amounts of snow because an unusual warm weather can melt the snow and create “spring runoff”. Depending on the water load, these creeks and rivers can cause flooding. Finally, logging and clear cutting has been noted to contribute to flash flooding. Tree roots hold soil in place, reducing the top soil runoff and thereby, shrinking the river channel downstream. Also, breaks in levees and in dams can cause flash floods. The impact of flash flooding depends on where it occurs, in rural, urban, or natural settings.

The objective for our research was to gather data at least for the past ten years from 2003 to 2013, and observe the rainfall occurrences at high temperatures, and to make observations of data for the timeframes on some of the reported past flash flood occurrences during that timeframe. These observations and analysis would lead to clear understanding of the conditions when flash floods occur, and help us in predicting future flash floods.

During this research, we hoped to learn and analyze the various factors that cause flash floods along with its correlation to temperature, and come up with the trend-analysis model for predicting the likelihood of flash flood which could then be applied to data from other geographical areas, and also use this opportunity to learn the advanced tools and technologies developed by SRI and NASA to help us obtain our required data, and to perform data analysis.

While testing, we might come across flash floods that might have occurred during lower temperatures too. However, we still hope to find more flash floods at peak temperatures, which could be easily identified when we do trend-analysis using the time-series graphs method.

We discussed the above mentioned factors causing flash floods, with Dr. Zalles from Stanford Research Institute (SRI) and learned about the data parameters that we could use in this research, and extract data for those parameters using the “Data-enhanced Investigations for Climate Change Education (DICCE-GIOVANNI)” tool developed by Stanford Research Institute and National Aeronautics and Space Administration (NASA).
Below are the nine parameters initially identified for this flash floods research:

i. Rainfall rate
ii. Snowfall rate
iii. Accumulated rainfall
iv. Ground station precipitation
v. Land temperature (day time)
vi. Water temperature
vii. Vegetation
viii. Atmosphere CO₂
ix. Cloud cover (cloud fraction)

As our next step in understanding flash floods in greater detail, we decided to gather data for the past ten years from August 2003 to August 2013. Then, investigate the data for Mohave Desert, for the known timeframes within this ten years period, in order to identify the trends and correlation between the parameters, and formulate a model for predication. We choose Mohave Desert area for our investigation and for creating the prediction model because this place was known for flash floods occurrences. We were also hoping that our conclusions from this trend analysis would clearly confirm our hypothesis.

The geographical areas of interest was chosen based on high population density, agricultural and industrial development. The geographical areas in California that would face devastating humanitarian and economic crisis if impacted by Flash Floods are:

a. Bay Area
b. Sacramento
c. Los Angeles
d. San Diego

We proceeded to the next stage to study the analysis and predication methods adopted by meteorologists from National Weather Services (NWS) and National Oceanic and Atmospheric Administration (NOAA). We learned that the meteorologists were using graphing tools and were analyzing the data for the following three parameters; so we also narrowed down our focus to those three parameters as listed below:

1. **Land Temperature**: how hot the “surface” of the Earth would feel to the touch in a particular location.
2. **Rainfall rate**: A measure of the average intensity of rainfall by calculating the amount of rain that would fall in each rainfall event if each event that month had the same intensity.

3. **Cloud Fraction**: Cloud fraction is the percentage of each pixel in satellite imagery or each grid box in a weather or climate model that is covered with clouds.

**Method (Procedure):**

D.I.C.C.E stands for Data-enhanced Investigations for Climate Change Education. This tool is also known as DICCE-GIOVANNI. It helps students in middle schools and high schools across the nation to predict our planet's environmental change. We can go to DICCE-Giovanni and query its archives, and later we can save our results as map images, time series plots, vertical profiles and data tables.

Here are the step by step procedures we used to extract data from DICCE-Giovanni tool, and the creation of graphs for parameters analysis:

1. Draw a box on points of interest by using cursor coordinates.
2. Select a Parameter and choose the start and end time

3. Then transport the files to Notepad, so then it can be put onto excel (Use the ASC format), so we can observe the data
4. Open Notepad, the data should look like the below picture

In excel we then go to Data and press insert from Text
5. Then we press fixed width and made sure that we chose date
6. The Spreadsheet should now look like the below picture

![Spreadsheet screenshot]

7. Repeat steps 1-4 for all parameters
8. Find previous flash flood locations
10. Copy the data from “Temperature of Land” which is in unit K (Kelvin) onto Column A in the Final sheet
11. Copy “Cloud Fraction” to Column B in the final sheet
12. Copy “Rainfall rate” to Column C in the final sheet
13. From “Temperature of Land” sheet, copy the “month” to column D in the final sheet
14. Column E in the final sheet, we will be converting temperature to Fahrenheit, using the formula:
15. \[ F = K \times \frac{9}{5} - 459.67 \]
16. \[ =A4*9/5 - 459.67 \] – this is the spreadsheet formula
17. Fill “down” so it is calculated for all the rows
18. Column F in the final sheet, we will be multiplying “cloud fraction” by 100
19. \[ =B4*100 \] – this is the spreadsheet formula
20. Column G in the final sheet, we will be multiplying “Rainfall rate” by 10000000
21. \[ =C4*10000000 \] – this is the spreadsheet formula
22. The reason we are doing this is to overlay on the same Y-axis. It still keeps to the same trend of original data
23. Now, to create the graph, select all the data on columns D, E, F, G including the headings.
From the “Insert” menu, select the 2D line graph as marked below:

25. The graph produced is the overlay graph of all the three required parameters.
26. Stretch the graph and make it bigger, so you could see the details clearly
27. Now, add the dates that you obtained from Step 1 above on the “Rainfall Rate” as shown in the key legend as “Flash Flood”. I just used the cloud shape to mark this (you can find it from the Insert menu – Shapes)
28. You can also add the dates as shown below on the graph, it just makes it easy visually, pointing to the approximate temperature for that flash flood date.
29. We need to do all of these steps for all the Points of Interest

The picture below shows the overlay of parameters for Mohave desert with all the data needed for investigation in one graph.
We also did individual parameter analysis. This means we found patterns and analyzed them separately, before we looked at the final overlaid graph. While doing this, we observed many interesting weather patterns and took notes of what we found. Before, we looked at the date points in the graph, we also made predictions of the scenarios for flash floods. After this, we then looked at the overlaid graph with date points, in order to see if our previous observations matched, and our hypothesis that “Increase of Temperature Leads to Increase of Flash Floods,” were correct. We did this for every point of Interest.
Results and Analysis

Data, graphs, and analysis

Mojave Desert

The Mojave Desert has a very warm and dry climate, with extremely high temperatures.

Figure 1: Temperatures in Mojave Desert from 2003-2013

As shown by the graph, the temperatures are very high during the summer but, drop during the winter. When the temperature increases, the ground becomes drier. This means the higher the temperature, the drier the ground. Since the temperatures in the desert can be extremely high during some periods of the year, the ground will become drier making it less capable of absorbing water. Because of this the rain will just become run-off, and the more the rainfall rate, the higher the chance of a flash flood. For example, if there was a lot of rain in August 2012 then according to our analysis, there should be a flash flood. So, by looking at this temperature pattern, we can assume that most of the flash floods will happen during the peak summer time, like in the months of July and August, should there be any rainfall during that time.
Figure 2: Rainfall in the Mojave Desert from 2003-2013

This graph shows the amount of rainfall in the Mojave Desert. The rainfall rate is very small in the Mojave Desert. At first, when we looked at the data we thought that a flashflood would have happened on February, 2011, as the rainfall rate was extremely high. But, by applying more thought we were able to conclude that it would not be possible as February is during the winter, and the temperatures are low. Winter, is a cold time of year, even in the desert. Since, the ground is now able to absorb water, and it is not too dry any more, the heavy rainfall during this winter month was just absorbed into the ground and turned into ground water. This pattern can be observed throughout the winter months of the graph, such as February 2005, and February 2008.

Figure 3: The Cloud Fraction in Mojave from 2003 to 2013
Cloud Fraction shows us the pixilation of the clouds. Rainfall occurs even with lower cloud fraction. However, the rainfall rate increases with increase in cloud fraction, as thicker clouds would increase the rainfall rate. Cloud Fraction also has a direct impact on surface temperature, as thicker clouds reflect more of the sun’s rays and prevent it from hitting the land, resulting in lower surface temperature. Monitoring the cloud fraction can help us predict the impact of the flash flood, should rainfall occur. The thicker the cloud fraction, the more rain falls and when it falls rapidly could cause devastating impacts.

After observing our parameters individually, we then put them all together in one graph in order to see if our analysis and hypothesis were true. In order to do this, we also took previous Flash Flood dates and marked those points on the graph to test our theories.

By looking at this combined data for the points where there has been recorded flash floods, we found out that our hypothesis was correct. We were able to clearly see that flash floods occurred when the land temperature was at peak, during which even a lower cloud fraction and lower rainfall rate resulted in flash flood.
An example of a time, was during July, 15th, 2012, when there was recorded flash flood in the Mohave. During this time, the temperature was extremely high, at about 110 degrees Fahrenheit.

We can see many more of these same weather patterns during the other Flash Flood months as well. An example is August 17th, 2010.

The Mohave Desert gets summer storms that originate in the Gulf of Mexico but those storms usually don’t go far west enough or far north enough to affect the other California locations in our study.

Making observations and investigating the data of Mohave, helped us to clearly see the correlation of the parameters, and apply these analysis to the other data points of known flash floods to confirm our prediction model.

We are now ready to apply this prediction model and analysis to our four areas of interest in California.

Bay Area

The Bay Area is a coastal region with a mild climate and with lots of rainfall.

Figure 5: Rainfall rate in Bay area from 2003 to 2013
As you can see by the graph, Bay Area has lots of rainfall in the winter, especially in December. We can conclude from Mojave, that most flash floods will occur in the summer, as the temperatures are usually high. But, in order for a Flash Flood to occur there must be rain. The amount of rainfall in the summer is extremely low in the Bay Area. Most of the time, the rainfall rate is close to 0. This means that there is not enough rainfall to have a flash flood, since there needs to be some rain occurring rapidly for flash floods to occur during peak temperatures. However, there always can be a Flash Flood even with less precipitation when it falls rapidly, and when the ground is extremely dry.

![Temperature Graph](image)

*Figure 6: Temperature in Bay Area from 2003 to 2013*

This graph shows the temperature in the Bay Area. The temperatures are fairly mild in the Bay Area, unlike the extremely high temperatures in Mojave. So, there hasn’t been a Flash Flood during 2003 to 2013 due to these milder temperatures. But, if the weather conditions change to longer periods of high temperatures, it would cause drought, and the ground would be unable to hold water due to extreme dryness. So, temperature plays a big role in the occurrence and frequency of Flash Floods as it is also a major factor that affects the ground’s ability to absorb water.
As we stated before, “The thicker the cloud fraction, the more rain falls and when it falls rapidly it could cause devastating impacts.” So, we use Cloud Fraction, which shows the amount of pixels in the clouds, to help us determine the impact of a Flash Flood, when there is one. For example, by looking at the graph we can see that February 2010 had an extremely high cloud fraction. So, if there was a corresponding high temperature at that time, it could have led to a devastating flash flood. We believe that continually monitoring cloud fraction along with the surface temperature, is very important in the predication of the impacts of potential flash floods, and will provide an opportunity to be prepared to save lives from crisis.
Figure 8: Bay Area - Overlay of all 3 parameters

After we observed all the parameters individually we then combined them to see if our theories and hypothesis were true. By overlaying all three parameters on one graph, it helps to see a much clearer picture on the inter-dependencies of these parameters. In the past data from 2003 to 2013 for Bay Area, we can clearly see that whenever there was peak temperatures, the rainfall rate was almost negligible, thus we have not experienced a flash flood in this region during this time frame. The high rainfall rates have been occurring during winter timeframes for these past ten years. So, we can make conclusion from these data that Bay Area is still not at high risk for flash floods. However, we have to closely keep monitoring for changing weather conditions, such as increased periods of high temperatures, cloud fraction, and the rain fall rate.
Sacramento has a warmer climate, and sometimes can have extreme high temperatures during summer.

This is a Graph of the Temperatures in Sacramento. As you can see by the graph, Sacramento receives most of its peak temperatures during the summer. An example is June and July months of 2006 and 2009, when the temperature crossed over 100 degrees Fahrenheit. So, there is a potential for flash floods occurrence during this time, should there be any rainfall.
Figure 10: Amount of Rainfall in Sacramento

Here is the rainfall rate for Sacramento. The rainfall rates for the time frame 2003 to 2013 clearly shows that the summer time rainfall rates have been mostly low. It is important that we understand the difference between little rainfall and no rainfall. During times of little rainfall, there is still a possibility of a Flash Flood as we discussed before.

But, there is another aspect of flash flood which is human caused flash floods that we also need to keep watch of, like breakages of dams and levees. During high temperature times, and when the land has been extremely dry to be able to absorb moisture, any leakage from dams and other human caused accidents could cause flash flood with devastating impacts.
Figure 11: Cloud Fraction in Sacramento

Cloud Fraction is a good way to discover the impact of a Flash Flood if there is one. As we can see by the graph the Cloud Fraction is usually high in Sacramento, as it is a valley region. We can clearly see the cloud fraction peaking during winter timeframe and low during the summer.

It is also important to note that when there is less cloud fraction like in Aug 2013 in this graph, it could also correspond to a rainfall that might have happened before that time, hence the cloud has released most of its water, which would result in lower cloud fraction data. So, that is why we need to overlay the parameters to understand the corresponding correlation with the rainfall rate.
The graph above shows the overlay of the three parameters to observe the correlation. In Sacramento there was a reported Flash Flood in July 2013. Like we stated before, a Flash Flood can happen when there is not that much rainfall. So, July 2013 is an example of such a situation. The temperature was at its peak slightly above 100 degree Fahrenheit. The ground was too dry to absorb the rainfall that occurred during that time thus resulting in a flash flood.

If we look at the graph carefully, we can clearly observe that July 2013 was the only time when there was a rainfall at peak temperature occur over the past ten year’s period of this data collection.

This observation further proves our hypothesis that the increase in temperature leads to more flash floods. A rainfall during peak temperatures can be more dangerous than heavy rainfalls at low temperatures.
Los Angeles

Los Angeles is situated in the Mohave Desert, where it is very dry with longer periods of dry weather, and has limited rainfall.

![Temperature graph for Los Angeles](image)

*Figure 13: Temperature for Los Angeles*

As it is shown in the graph above, temperature rises in spring and peaks in summer, and stays high almost until Fall season. The temperature starts to fall again in October, and becomes its lowest in December. Sometimes, in summer, the temperature crosses the triple digits (Fahrenheit), due to the fact that is located in the desert. The chance of a flash flood is quite high in this period of time, if our hypothesis is correct. The ground is also dry because of the sustaining temperature, making it un-absorbent. So, there does not need to be too much rainfall in order for the flash flood to occur. Also, in theory, our hypothesis says that summer time is an ideal time for flash floods to occur.
In summer, there is little to no rainfall, due to the fact that Los Angeles is in a desert region. For example, in June through August 2007, there are extremely high temperatures, but no flooding occurs. This is because the rainfall rate is at zero, so there is no water buildup. There has never been a flood in Los Angeles because of that very region's characteristics, little to no rain. In winter, there is lots of rain, but since the temperatures are lower, the ground can actually absorb the water.
Cloud fraction in Los Angeles is relatively low, this directly correlates with the fact that the region gets little rain during the summer. This means that impact of the Flash Flood would not be too costly. There is a trend where once cloud fraction increases, rain spikes almost instantaneously.

Los Angeles has not had a flash flood during our time frame. The graph clearly shows that Los Angeles has high temperatures in the range of 100 degrees Fahrenheit from spring to Fall seasons, which results in very long periods of dry weather, and making the land extremely dry to absorb water. However, during this time, there has not been a significant rain fall rate, resulting in no flash flood. We can also observe that high winter rainfalls did not result in flash floods because of the low temperatures. However, during 2014, Los Angeles has had lot of warnings, and severe threats, since the temperature is increasing, and sustaining even longer, as California is in a drought. This fact proves our hypothesis, that increase in temperature will increase the frequency of the Flash Floods.
San Diego

San Diego is located on the southwest coast of California and is just above the border of Mexico.

![Temperature of San Diego](chart)

*Figure 17: Temperature of San Diego*

San Diego’s climate consists of temperatures in the high 90’s (Fahrenheit) in summer, and low 60s (Fahrenheit) in winter, but it can vary. San Diego has long dry weather pattern and its hottest month is August, and its coolest is December. If our hypothesis is applied, a flash flood would be most likely in summer, more specifically August. This also depends on cloud fraction and rainfall of course. Unlike, Los Angeles and Mojave, the temperatures have not reached hundred degrees even once over the ten years span of data we collected.
Rainfall rate in San Diego is the highest in December, and lowest in August, which is the hottest month of the year, on average. In December, the coldest month, it rains quite a bit. San Diego has not had a Flash Flood yet in summer, because of less to almost no summer time rainfall and because rainfall mostly occurs during low temperatures in winter.
Cloud fraction in San Diego peaks in winter, more specifically January/February months. San Diego has a more consistent amount of clouds in the sky. This leads to more rain during the year, and keeps the temperatures around 90 degree Fahrenheit, due to the fact that the sun rays are blocked by the clouds. However, because it stays dry for a longer period in summer, and is likely to have rain fall, it is still at high risk for flash flood.

![Figure 20: Overlay of 3 parameters for San Diego](image)

In San Diego, there have been no flash floods during the timeframe 2003 to 2013 of data we collected. Though the temperature is close to 90 degrees Fahrenheit for long periods, there were no rainfalls during the peak temperatures in this timeframe. It can also be noted that San Diego has had rainfalls mostly during the winter seasons, when temperatures are low. However, as per our predication model, because San Diego has long periods of dry weather pattern, if they have a rainfall at high-temperatures it could most likely result in a Flash Flood. As cloud fraction is directly related to the rainfall rate, it is important to constantly monitor the cloud fraction in San Diego especially during the dry seasons. When cloud fraction is very high, we know that it would result in rainfall.
CONCLUSION

Our hypothesis was: an increase in temperature leads to an increase in flash floods. As our data and results show, it turns out that our prediction is true! Studying the data from Mohave Desert’s past flash floods, helped us to create a model for prediction. When carefully observed, our time-series graphs clearly show that the temperature almost always peaks just right before a flash flood occurs. This happens because as temperatures peak, the ground becomes very dry and cannot absorb water fast enough, and just lets the water run-off. When rainfall occurred at peak temperatures, the data showed that it turned into a flash flood. This proves our hypothesis that an increase in temperature does increase the frequency of flash flood occurrences. Though temperature certainly is a major factor in the occurrence of flash floods, it is not the sole factor either.

At first we were surprised to see the consequences of rainfall and how different the impacts were when it occurred at different times of the year. Heavy rainfall during winter’s low temperature timeframes, were actually good for us, providing us with more fresh water resources.

But, during times of hot weather even at low rainfall, there were flash flood occurrences, which has been mostly causing damages.

So, this shows that we need to closely monitor our temperatures, and as we get to periods of peak temperatures we need to also very closely monitor cloud fraction and rainfall rates, as we now know that when there is an increase in temperature there is an increase in flash floods.

When we applied our prediction model to the data for our areas of interest in California, we were able to conclude the following:

- **Bay Area**: we can make conclusion from the data that Bay Area is still not at high risk for flash floods
- **Sacramento**: has had flash flood during peak temperature, and is likely to have more flash floods during summer times
- **Los Angeles**: Due to the long periods of dry weather pattern, Los Angeles is more likely to experience an increase of Flash Floods in the future.
- **San Diego**: has favorable conditions for flash floods, though it has not occurred yet. The risk is very high.

With the changes we are experiencing in our climate, and the increasing of earth’s surface temperature, we anticipate that there would be longer periods of high temperatures resulting in more frequent flash floods.
For further research we would like to create an online system that will utilize live data and using our prediction model to provide live predictions.

As the soil type and vegetation also are critical factors involved in the study of flash floods, we hope to also incorporate these parameters and their effects into our predication model.

The DICCE-Giovanni tool provides data about soil moisture and landscape greenness (i.e. vegetation). Our follow-up research would incorporate analyzing the relationship between the soil moisture and the greenness of the landscape. We know that surfaces that have been cleared of plant life are more likely to be flooded because plants’ root systems absorb water and hold the soil together. It would be interesting to study flash floods in other places in the United States and see if areas that have been cleared of vegetation have become more vulnerable to flooding.

Flash Floods are the number one natural disaster killer causing hundreds of deaths per year, so it is extremely important that we learn to predict and help evacuate the region in a timely manner to reduce humanitarian crisis.

We hope that our research will help further other Flash Flood research projects and move towards creating solutions to mitigate the devastating impacts of flash floods.
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