Forecasting Wildfires and Examining the Extent of Global Climate Change

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Executive Summary:

Extending into late November 2008, fires continued to burn in California causing the evacuation of homes and the destruction of property. The western region of the continental United States continues to see an increase in devastating fires, especially over the last decade. The United States Environmental Protection Agency (USEPA) is interested in this increase in wildfires, the possible causes, and the emissions released from these fires. One important factor to consider in conjunction with an increase in wildfires is an increase in temperature. The Northern Hemisphere has shown an increase in temperature anomalies steadily over the last thirty to forty years. Similarly, over the last forty years there has been a positive trend in national temperature as well as western and northwestern regional temperatures. At the same time, there has been an increase in the acres burned nationally and an increase in the acres burned per fire on average. When compared over the last twenty-four years, we have observed an increase from approximately two million acres burned per year in 1983 to eight million acres burned per year as of 2007. In addition, in this period we have seen an increase from 1983 of around thirty to forty acres burned per fire to now seeing over one hundred acres burned per fire in 2007. Similarly, over this span of years, 1983 to 2007, there has also been an increase of about two to two and half degrees. This demonstrates that over this period as temperature has increased a drastic increase in acres burned and acres per fire is also observed. Because not all regions in the United States have the same climatic problems and geological make-up, it is important to analyze trends in regions separately. When we are able to analyze these regions, we can construct prediction models for conditions and factors effecting the number and intensity of wildfires in a particular region. It is our goal to develop a model to forecast wild fires for the Western United States and predict a potential impact from future global climate change. Hopefully, the USEPA will be able utilize our results to improve future State Implementation Planning for fine particulate matter and increase our understanding of possible impacts of global climate change. Our work should also be useful for future revisions to national wildfire policies.

Introduction/Background:

Over the past decade, wildfires have become an increasing problem for many regions of the United States, particularly the west coast. Wildfires are fires that occur only from natural causes, not prescribed burns where land is burned to be cleared for use or to prevent larger fires, arson related fires that are started with intent, or accidental fires caused by unnatural events. The environmental aspect of harmful emissions from these fires is important to the USEPA's Office of Air Quality Planning and Standards (OAQPS), which lead to our research for Dr. Linda Chappell of the USEPA. Our faculty advisor is Dr. William F. Hunt, Jr. with the Department of Statistics at North Carolina State University. Our research team is made up of Stephanie Bruns, Jason Leone, Jamie Pearce and Kristen Gore. Our approach is to use exploratory statistical analysis on wildfire emissions data along with historical meteorological, geographical, and ecological data in order to provide a forecasting model to predict wildfires. Our team intends to answer the question of whether a trend of global warming would result in an increase of wildfires in the western United States, as well as across the nation. A pertinent focus of the project is to compare the temperature trends in the western areas of the United States to the increasing temperatures in the Northern Hemisphere as predicted by the United Nation's Intergovernmental Panel on Climate Change (IPCC). Other variables will be examined to determine their correlation with this rising temperature trend over time in causing an increase in wildfires. The data was collected from four separate sources; the USEPA's National Emissions Inventory, the IPCC and affiliated sites such as the National Climatic Data Center, the National Interagency Fire Center (NIFC) and the Northwest Geographic Area Coordination Center. The USEPA National Emissions Inventory data are currently problematic, especially concerning the variable 'acres blackened' that depicts a repeating, unexplained value. However, the inventory's data once corrected or purged will provide a look at multiple hazardous chemicals produced by fires from different sites across the nation, and would have significant policy implications for the USEPA OAQPS as they examine states like California. The IPCC provides historical meteorological data for variables over time such as temperature, precipitation, drought indicators, etc. This data, when examined along with the acres burned data and other emissions variables, can indicate specific trends in areas where wildfires have occurred and could provide predictions as to when and where to expect fires, which factors lead to more wildfires, and also if wildfires are a growing problem which is spreading. The NIFC data sets include national data for number of fires and acres burned per year. The Northwest Geographic Area Coordination Center (GACC) provides fire information for fires in both the States of Oregon and Washington.

Objectives:

This research project began with a question concerning a recent warming trend that is seen across the Northern Hemisphere. Does the warming trend have an effect on the frequency and extent of wildfires that are occurring throughout the United States? Using historical climatic and meteorological data in association with the wildfire data, our objective is to determine which variables predict wildfires and determine if there is a connection between increasing temperature trends in the Northern Hemisphere and in the increasing trend in wildfires. From these factors, we can determine a forecasting model for regions of the nation with indicator variables to provide insight into where fires might occur and what can be done to prevent damage and destruction caused by the fires. Other variables that are of interest include insect damage, amount of burnable material in the area, fire-fighting resources, annual precipitation, number of days above ninety degrees, wind, drought indicators, and soil moisture. In addition to a national overview, we will focus on an analysis of two States – Oregon and Washington.

Methods and Analysis:

Our research consists of using exploratory statistical methods to analyze the trends between variables. Some methods include linear regression, distribution analysis, use of contour plots, and use of scatter plots. Based upon evaluation of the data we will present statewide models for forecasting wildfires.

The first analysis performed with our project was temperature trends. We hoped these analyses would show an increase in temperature over recent years. We created a scatter plot of the Northern Hemispheric annual temperature anomalies from 1880-2007, as shown in **Figure 1**.

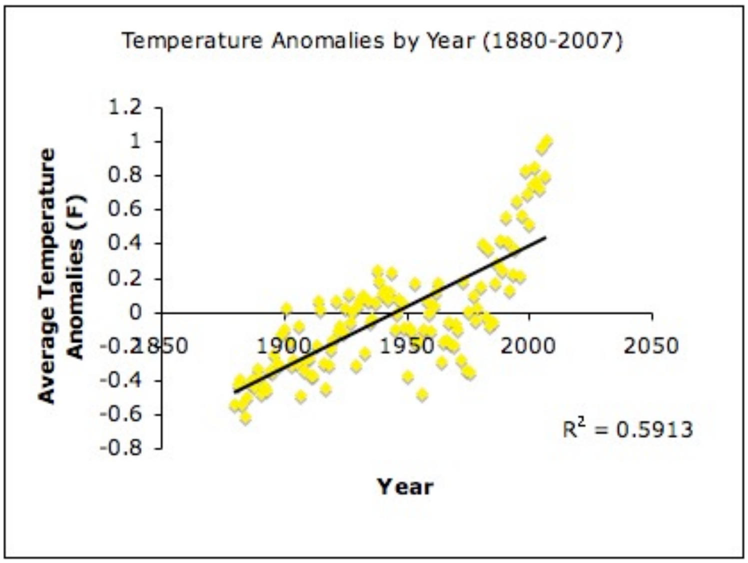


Figure 1: Northern Hemisphere Temperature Anomalies

These anomalies are the deviation from a long standing mean of the temperature values. As seen above, there is a significant increase in the values on the chart around 1980. Note the positive correlation coefficient R squared is 0.5913, which suggests a strong positive correlation between year and temperature anomaly. In accordance with the NIFC data, which claims to be accurate back to 1983, we also plotted the values from 1983-2007 shown below in **Figure 2**. These values are the upper tail that takes a significant shift above the center line of zero. It is important to note that almost all corresponding values in this plot represent a value above the normal mean of temperature.

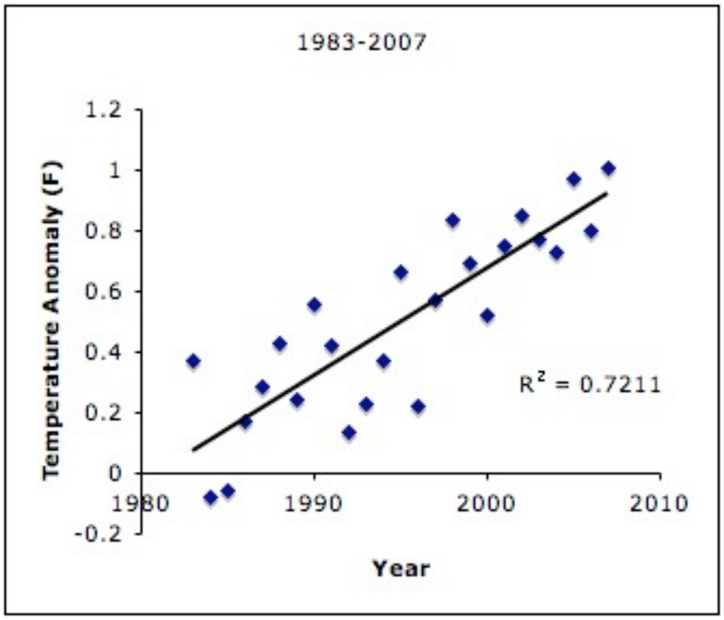


Figure 2: Anomalies for 1983-2007

In order to better understand this warming trend, the temperature anomaly data were examined on a seasonal basis. Seasonal annual averages and graphed in an overlay plot to show the relationship of each season and concurrent temperatures. This is seen below in **Figure 3**.

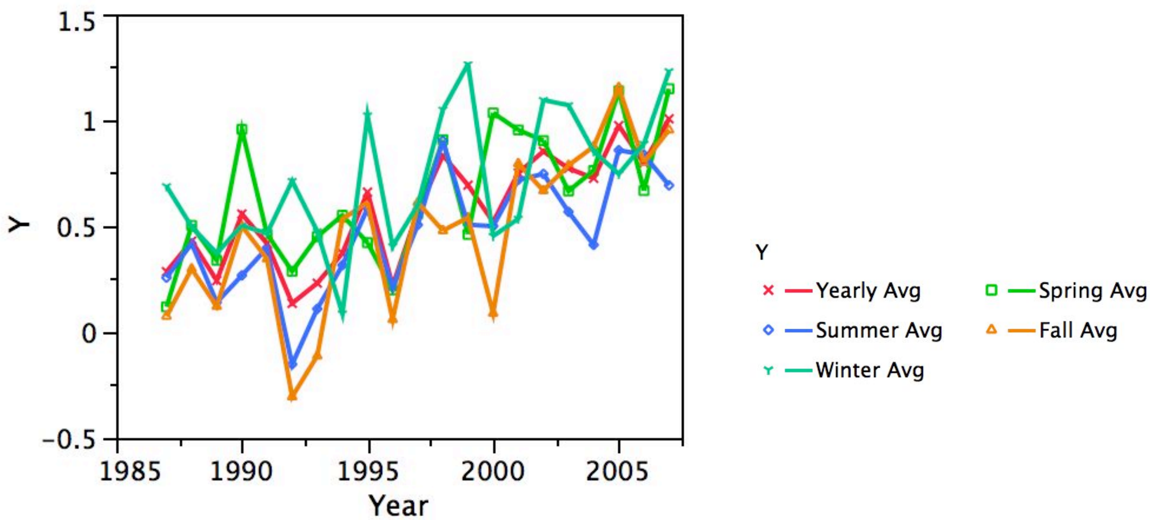


Figure 3: Seasonal Anomalies Overlay Plot

Figure 3 shows that each season is progressively getting warmer. In fact, the green and teal lines, representing spring and winter months respectively, have the highest temperature anomaly for most of the years shown above. On the other hand, the summer months have seen a steady increase and as time has progressed we are now seeing warmer seasons across the nation. The warmer seasons would represent a positive correlation for the average national and regional temperatures. **Figures 4a, 4b,** and **4c** are all scatter plots of temperatures over the last forty years for the nation, northwestern region (Washington, Oregon, Idaho, and Montana), and western region (California, Nevada, Arizona, and New Mexico). Again, with these scatter plots of temperature data, it is important to note that all three of these plots have positive correlations indicating that the temperature is rising in these areas over time.

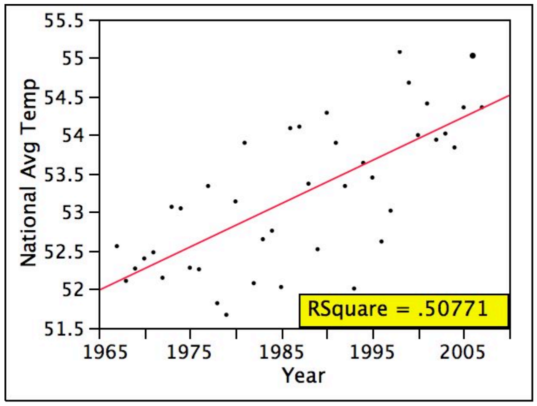


Figure 4a: National Temperature

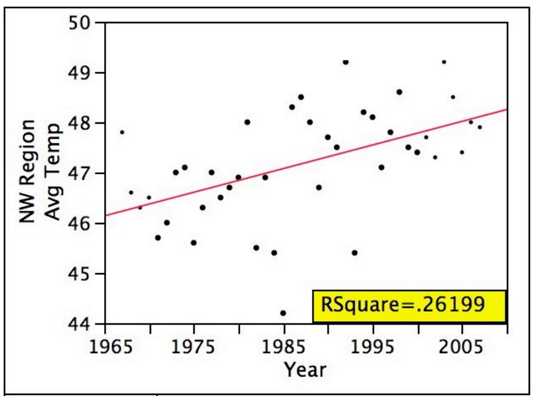


Figure 4b: Northwest Region

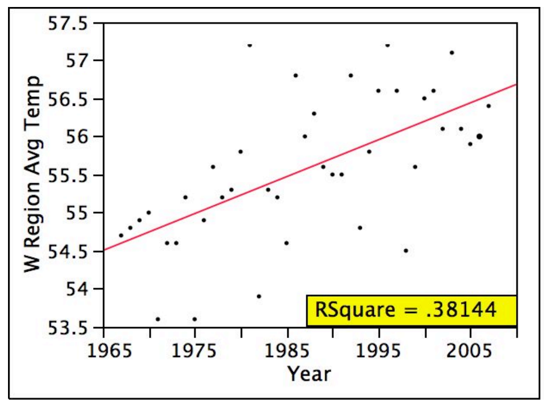
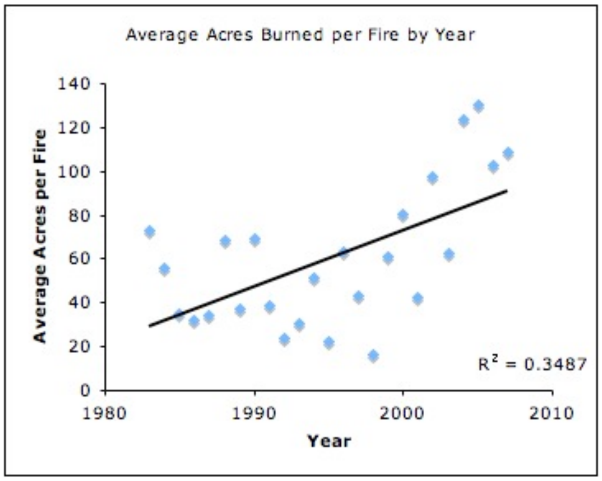


Figure 4c: West Region

This data confirms that there is apparent warming going on through the regions of the United States where our initial focus is on this problem with wildfires. It is important to note that each red trend-line on the plots above represents about a two degree increase in temperature over approximately forty years, which means the country could be getting a degree hotter every twenty years. Showing that the temperature is increase does not necessarily mean that fires are increasing along with it. However, **Figure 5a** and **Figure 5b** are side-by-side scatter plots of average acres burned by year next to average national temperature by year. The correlations shown on both graphs are nearly identical R squared values of 0.3487 and 0.3406 respectively over the same period, 1983-2007.



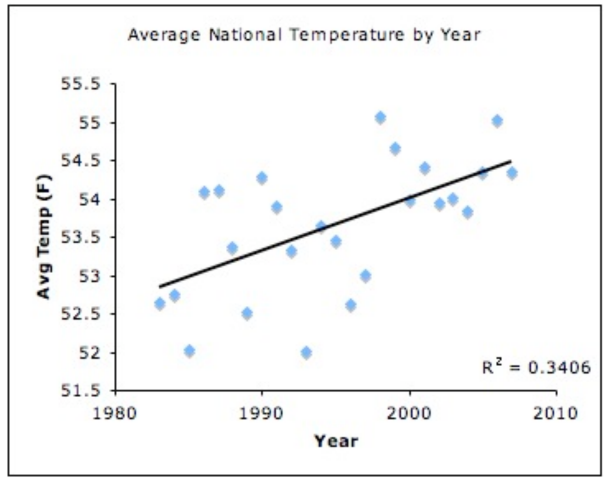


Figure 5a: Average acres burned by year **Figure 5b**: Average national temperature

This suggests that over the last 24 years there is a similar positive trend in both of these data sets. To compare the two together, a contour plot was utilized as seen in **Figure 6a**. Another contour plot of acres per fire is displayed in **Figure 6b.**

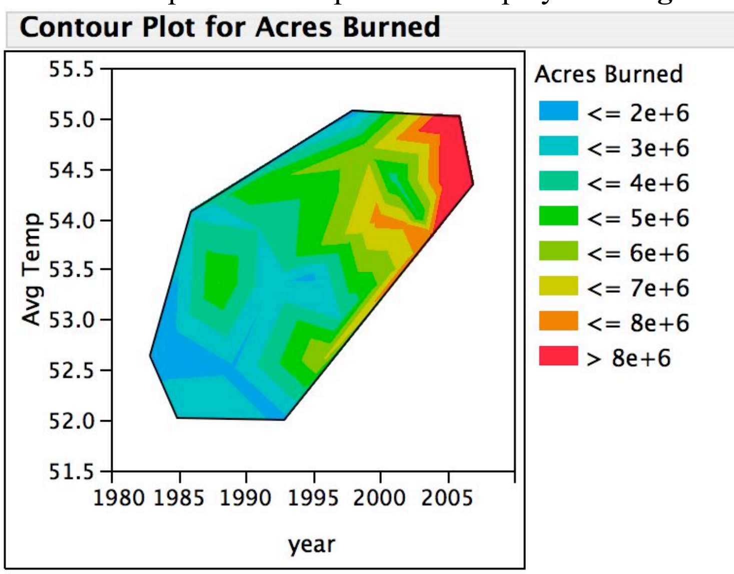


Figure 6a: Contour plot of total annual national acres burned, by temperature by year

To interpret this contour plot one must notice that there are three variables represented. Year is shown on the X –Axis from 1983-2007, while average national temperature is shown on the Y-Axis from 51.5 to 55.5 degrees Fahrenheit. Finally, there are acres burned nationally spanning from under two million to over eight million depicted in color. In **Figure 6a,** we see that in 1985, the nation saw an average temperature of around 52.5° F and around two to three million acres burned a year. As time passes, we begin to see values of around five million acres burned with an annual average temperature of approximately 53.5° F. The trend continues and from 2005 on we record temperatures two degrees above the 1985 average with acres burned being eight million or higher, four times higher than observed 1985. **Figure 6b** below plots the average acres burned per fire each year in the United States along with temperature in the same manner.

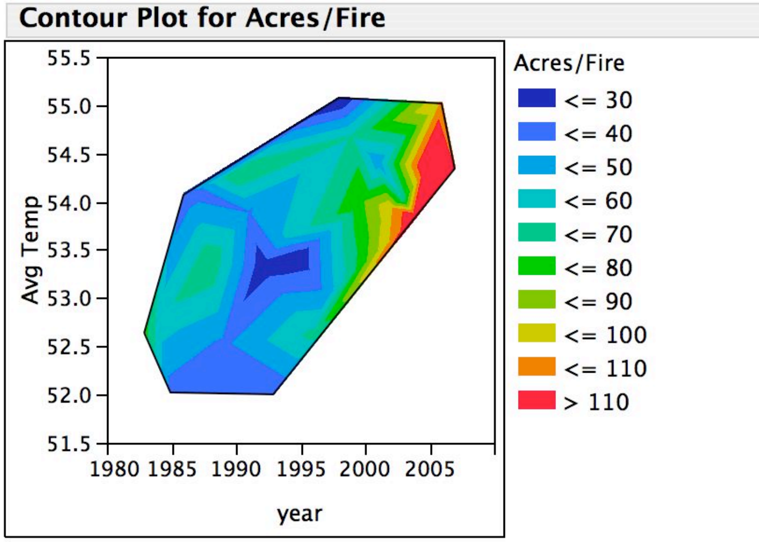
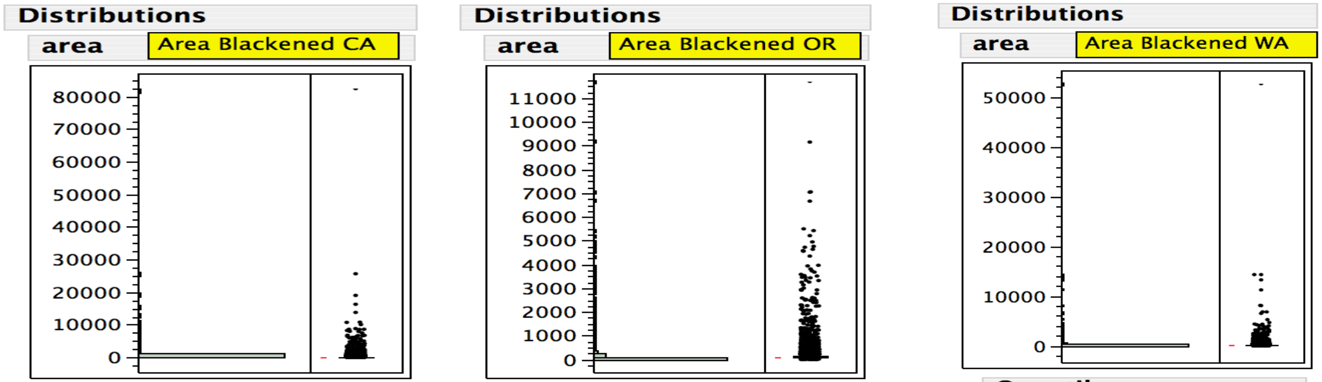


Figure 6b: Contour plot of annual national acres per fire, by temperature by year

Plotted similarly to the chart in **Figure 6a**, the data here reveals a similar trend in the amount of acres per fire burned per year in the United States. In 1985 we record values around 52.5 F and see forty or fifty acres burned per fire. It is not until 1998 when we see a significant shift in acres burned per fire when we see temperatures of 53.5 F and see about eighty acres burned per fire. The trend continues and the amount of acres burned per fire increases to over one hundred and ten acres once we get to 2005. However, with the exception of **Figure 4a, 4b,** and **4c**, this data is either for the Northern Hemisphere or for the United States. We examined this further with a regional analysis to see which areas have more wildfire problems than others.

Figure 4b and **4c** show the average regional temperatures of interest for our initial study because many of these states included California, Oregon, and Washington because naturally occurring forest fires are more probable in western regions of the United States. However, we received a data set from the USEPA that was extremely large including locations and emissions data for wildfires all across the nation. The data set included approximately sixty-three variables with seventy thousand observations. This became problematic as our team did not have the resources at hand to process this size of a data set. However, Stephanie was able to run the data set by a coworker at the SAS Institute who was able to produce for us smaller data sets for just a few of the states. Shown below in **Figure 7** are the distributions of those states data sets. Notice that in these distributions, up to the third quartile in each of the data sets are values of 100, which are rounded up from 99.999586.



Quantiles (Area Blackened CA)

100.0%	maximum	82442
99.5%		2372
97.5%		858
90.0%		317
75.0%	quartile	100
50.0%	median	100
25.0%	quartile	100
10.0%		100
2.5%		30
0.5%		4
0.0%	minimum	1

Quantiles (Area Blackened OR)

100.0%	maximum	11707
99.5%		1658
97.5%		565
90.0%		228
75.0%	quartile	100
50.0%	median	100
25.0%	quartile	100
10.0%		100
2.5%		100
0.5%		45
0.0%	minimum	1

Quantiles (Area Blackened WA)

100.0%	maximum	52680
99.5%		2444
97.5%		801
90.0%		307
75.0%	quartile	100
50.0%	median	100
25.0%	quartile	100
10.0%		100
2.5%		100
0.5%		10
0.0%	minimum	1

Figure 7: Distributions of Area Blackened variable from California, Oregon, and Washington data set from left to right.

This value of 99.999586 was first assumed to be a small fire under one hundred acres default value, but upon inspection we found that there are values listed below the 99.999586, such as, forty-five in Oregon and 10 in Washington at the 0.5 percentile. A value like this causes us to reevaluate data set we have and our interpretation of the high frequency of 99.999586. We need to get this resolved. However, you could infer from the nation data versus the regional data in **Figure 4(all)**, that the temperature is rising in those areas as well.

After a discussion with Mr. Dan O'Brien at the North West GACC, we were able to obtain and decipher forest fire burn numbers for the states of Washington and Oregon over the years from 1990 to 2008. Because of the topographical differences around the nation, the separate data for each state helps us control the area we are looking at, and while this would provide a crude outlook based on an entire state, this data is not as crude as comparing the fires of the entire nation. Also, in examining each state, there are a few apparent trends in the data given. **Figure 8** below shows side by side overlay plots for the total number of fires and total number of acres burned in Oregon and Washington respectively. The first thing that is noticeable about these plots is that while Oregon tends to have more total fires each year than Washington, there are not many years where the number of acres burned are very significantly different. There are a few exceptions where you see peaks in the Oregon plot (2001-2003) or the year 1996 with a large differential. Also, another trend to point out is there seems to be a large drop off in total acres burned after a higher number of acres were burned the year before. Lastly, while experiencing peaks and higher years than others, there does not seem to be a very strong correlation either in the number of fires or acres burned, in fact there is a slight be a decreasing trend in the total number of fires in Washington.

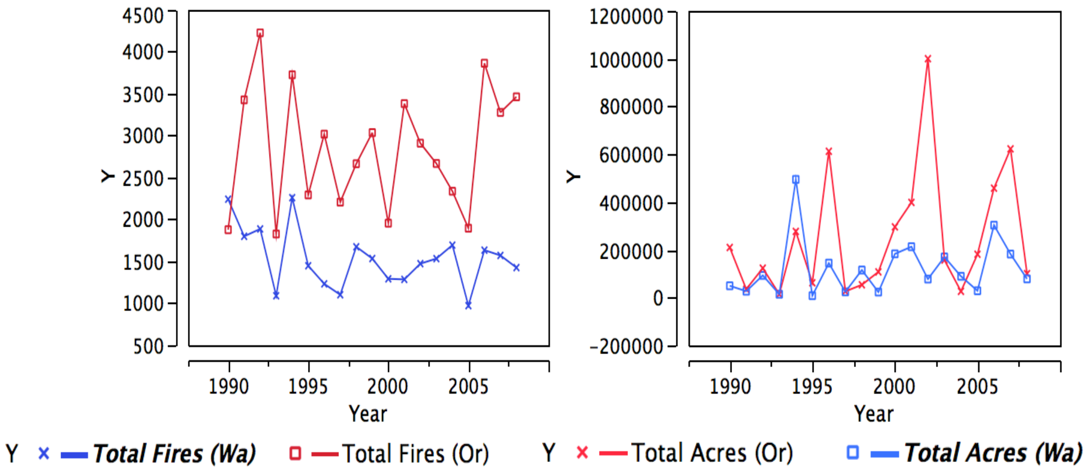


Figure 8: Side by side overlay plots of Total Fires (Left) and Total Acres (Right) for Oregon and Washington.

Taking a step back to now look at the total values over this 18-year period, we see that Oregon saw 54,057 fires and 4,761,702 acres burned. Where as for Washington, the state sat 31,160 fires resulting in 2,354,937 acres burned. This information alone suggests that the states experience a difference in wildfires, and leads to our methodology of examining each state separately. In preparation for our construction of predictive models for each of these states, there was exploratory variable analysis and comparison done by the contours plots seen here in **Figure 9** directly below and **Figure 10** further down the page. The trends in question were what were happening to the amount of fires in each state while either temperature or annual levels of precipitation fluctuate.

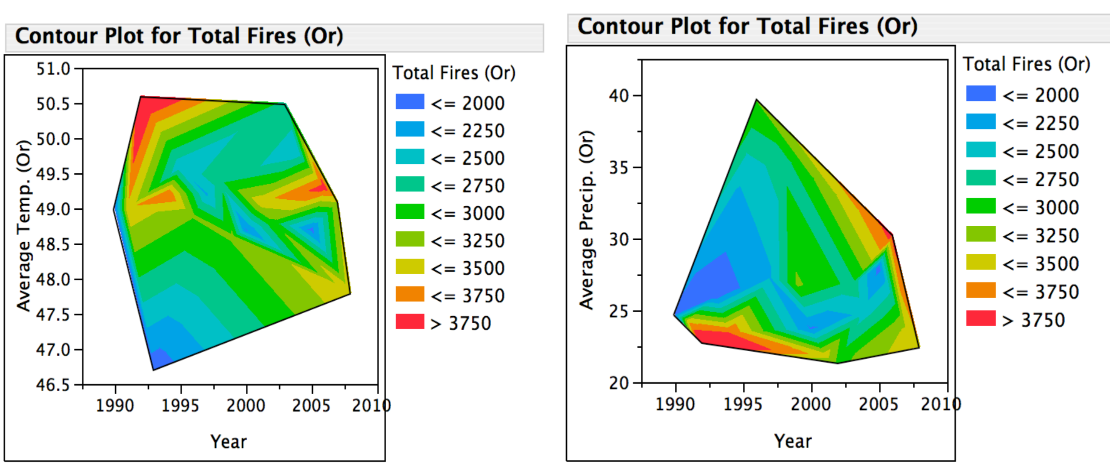


Figure 9: Contour plots for Total Fires in Oregon by temperature by year (Left) and by precipitation by year (Right).

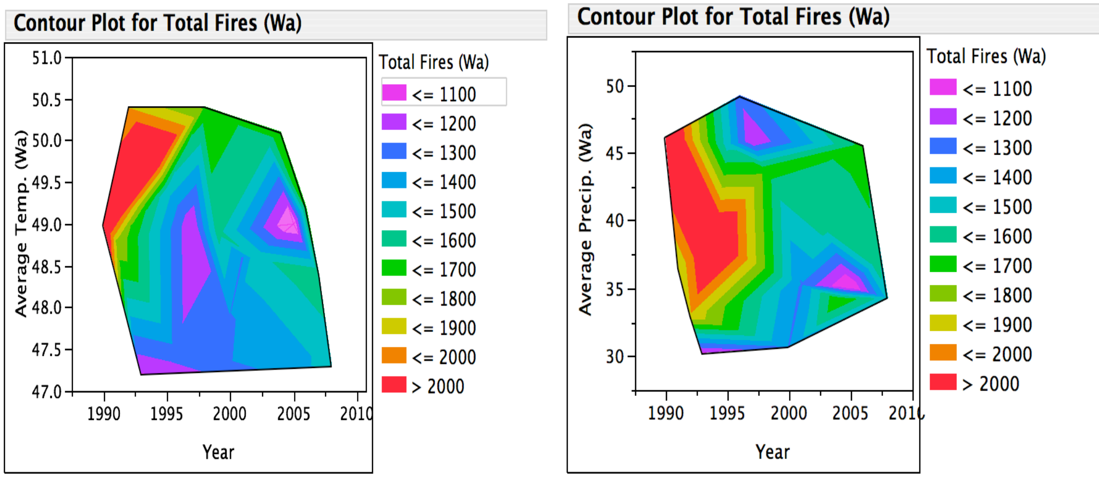


Figure 10: Contour plots for Total Fires in Washington by temperature by year (Left) and by precipitation by year (Right).

First, as expected from the overlay plots above, these contour plots prove to be different in their nature, which leads to analyzing the states separately because of difference in the effectiveness of each variable in questions. To being discussion with **Figure 9** and specifically Oregon there is some interesting data revealed by the plot. Between 1991 and 1996 there is clearly a trend where higher temperature values in combination with lower precipitation values yield the greatest number of fires indicated by the red areas on the graphs. Lower temperatures and higher precipitation resulting in fewer fires, as seen by the corresponding blue areas in the plot mirror this. As time progresses in the plots, we see an increase in green values and blue values, suggesting lower amounts of fires until around 2002. As we examine the outer edge of the contour plots we see evidence that now regardless of temperature or precipitation in 2005 and beyond, there appears to be a trend of over 3,750 fires per year in Oregon, represented by the orange and red values that line the outside right edge of the contour plot. As mentioned earlier, we see that the two plots do not resemble each other in shape or color, indicating some of the difference between them. However, similarly to **Figure 9**, **Figure 10** above also sees its highest values between 1991 and 1996 with red values corresponding to over 2,000 fires a year in Washington. Unlike the contour plots for Oregon there is not a heavy correlation between low values of precipitation and lower fire counts. In fact, during the early 5-year period, the middle and higher values of annual precipitation saw higher values of total fires than the lowest values of annual precipitation. Also, another difference is where there was a noticeable increase over the last few recent years, since 2005, there does not appear to be much of an increase for the number of fires in Washington. This is represented by the consistent blue or green values seen as time progresses along the contour plot.

<u>Conclusions:</u>

First, there were a few limitations in using the USEPA data. Specifically seventy-five percent of the USEPA data consisted of the same repeated value of 99.999586 for acres blackened, one of our most integral variables to our analysis. However, we were able to perform the national analysis from acres burned data from the NIFC data However, without the data from the USEPA or other data concerning regional acres burned and emissions data it becomes difficult to perform further regional analysis. While this is delaying any regional model building for forecasting wildfires, we were able to identify similar trends to answer the questions posed to us about global climate warming and increases in wildfires.

First, the temperature anomaly data shown in **Figure 1** and **Figure 2** confirm a positive trend in warming across our nation's region. Also, other scatter plots in **Figure 4(all)** and **Figure 5b** show a similar positive trend in the temperature data for either the nation or the western and northwestern regions of the nation. Lastly, to distinguish further from global climate change, **Figure 3** illustrates a near identical positive trend in seasonal temperature anomalies suggesting a uniform warming trend not only across the entire hemisphere but across the four seasons as well. This suggests a similar pattern in the IPCC temperature anomaly data for the Northern Hemisphere, and temperature trends in the western parts of the nation. From there we can continue to further examine this increasing temperature to the increase in wildfires that we see across the nation.

The contour plots, **Figure 6a** and **Figure 6b**, connect the average national temperature to the number of acres burned by year nationally and the number of acres burned on average per fire by year respectively. The increasing trend is clear by the color change throughout both plots. For acres burned, over the last twenty-four years we have seen a jump from around two to three million acres burned to now over eight million acres burned a year with an approximate two degree increase in temperature. In terms of acres burned per fire on average, over the last twenty-four years we see a rise from under forty acres burned a fire to over one hundred acres burned a fire with the same two degree increase. If temperature continues to rise into the future, we can assume that the amount of acres burned and acres per fire will increase as well. However, temperature is not the only variable we have concluded could play a role in this increase in wildfires. Other than temperature change, variables such as annual rainfall, drought conditions, insect damage, and many other factors are being considered for further research in the regional models we hope to develop. Unfortunately, with the limitations on our data that we currently have, we are unable to perform analysis or reach many conclusions on which of these factors will play a significant role at this time.

Ass we move on from viewing the nation as a whole to analyzing Oregon and Washington as there own geographic region, **Figure 7** shows the necessity for contacting the NW GACC to find better wildfire burn data to begin our model and statewide analysis. The overlay plots in **Figure 8** represent the fact that the two states are not the same in terms of annual amount of fires and show similar trends in acres burned. First, as Oregon has a higher number of fires, that state is more at risk than Washington for fires occurring in either state. However, most years show that the acres burned is not significantly different, which might suggest that while Oregon has more fires, Washington has a harder time extinguishing or controlling the fires in their state. In coordination with building a model for these states, two variables were examined to determine their effect on total fires. **Figure** 9 and **Figure 10** show how temperature and precipitation react over time with the number of total fires in each state. In the early 1990's, Oregon showed that high temperature and low precipitation result in more fires, but experienced a drop in the amount of fires until the years past 2005 when they begin to increase. In the 1990's in Washington, the contour plots shows that high precipitation values do not correspond with low total fire values. Not only does this represent a difference between states, but also this suggests that precipitation might not be as much of a factor in the number of fires for Washington than it is for Oregon. Also, we do not experience the increase in fires past 2005 for Washington, showing another difference between the states which might suggest Washington is not as much of a problem area.

Overall, if each state could be analyzed in such a manner to determine which states in the country need more help controlling these wildfires and which states are more problematic, forestry departments could improve how they distribute resources to necessary areas for fire-fighting.

Recommendations/Further Research:

There are a few recommendations and a few insights into further research that can be gathered from this report. First, we strongly believe that having a student from a meteorology or forestry background would benefit this team tremendously. Dr. Hunt has contacted the chairs of both the Meteorology and Forestry Departments at NCSU for other students majoring in meteorology and/or forestry. These students would contribute by extending the teams knowledge of some of the important factors we must now begin to look at to perform sufficient regional analysis such as insect damage to forests, amount of burnable material, or weather patterns over California for example. Different eyes on this research would be of great benefit and provide additional perspectives. Second, another suggestion would be for the USEPA to help us better understand the repeated value of 99.999586. Because of its high frequency, it makes it difficult to connect these other factors with the acres burned variable in question. The last recommendation is for some sort of consolidation of data pertaining to wildfires. Ideally, a data set to monitor and track the state of all wildfires would be of great benefit as trends could be discovered and lives, property, and the environment could be protected. This would benefit the project in making further research on the topic easier to perform.

The next work we are currently undertaking is performing further exploratory analysis on variables and constructing predictive models for what conditions are more favorable for wildfires to occur in each state beginning with Oregon and Washington and then moving on to California. Also, following a question posed after the State of North Carolina Undergraduate Research and Creativity Symposium at Appalachian Stare University in Boone, NC, we would like to investigate a possibility of "solar warming". This would entail view variables such as total solar variance, or how much heat energy the sun is producing, over time to indicate the extent of the man-made contribution to global warming. If this solar radiance was in fact increasing, then this would question if we could control the amount of temperature increase or not, resulting in the increase of wildfires being a more natural phenomenon rather than humanly inhibited.

One suggestion is for a more uniform approach across the country for how to handle preparation and dealing with wildfires. In the Northwest GACC, they create 7-day prediction model based on climatic conditions and previous burn history for both Oregon and Washington. This model is then used to judge and predict when and where the fires might occur, helping the agencies that deal with the fire allocate resources to selected areas of need before the problem is out of control. If a method like this was used in every GACC, or for each state's forestry department, the nation would be better prepared for dealing with large wildfires and the number of acres burned a year would not be increasing at such a high rate.

Another suggestion is for a consolidation of burn data for the nation collectively. Since data like this can be used in important manners, such as the prediction models in the NW GACC, then it would be beneficial to make sure this data is accurate and available for each state or regions in a state. Not only just make the data available and accurate, but if possible, to make the data somewhat uniform so comparisons can be made and productive research can continue regarding the state of wildfires across the nation as the global climate changes.