Correlation Between

Wildfires and Global Warming

By:

Tommy Oliver

For:

Huidae Cho

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University of North Georgia - Gainesville

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Abstract

This research analysis dives into the topics of global warming and wildfires and how to programmatically analyze data. Global warming and wildfires are crucial topics that do not receive enough attention. The two portions of this study are demonstrating the relationship between wildfire frequencies and rising temperatures and creating a toolbox in ArcGIS Pro – using Python language - that allows the operator to analyze 9 band (minimum) raster imagery. The findings about global warmings correlation to wildfire frequencies within this research are unsatisfactory due to a lack of data analysis, however it is believed that with a larger sample the correlation could be concluded. Also, a toolbox containing two analysis tools were created successfully. This is relevant because it allows the operator to visually display the size and magnitude of the damages done by a fire within minutes.

Introduction

Climate Change

The importance of climate change in relation to wildfire and the subsequent well-being of human society cannot be overemphasized. The world's leading dictionary publisher - Oxford dictionary - defines climate change as "a change in global or regional climate patterns, in particular a change apparent from the mid to late 20th century onwards and attributed largely to the increased levels of atmospheric carbon dioxide produced by the use of fossil fuels" (*Climate Change*, 2020). NASA claims that the Earth's climate has slowly increased throughout its lifetime and estimates that in the last 650,000 years, there have been seven cycles of glacial advancements and retreats; the final one being the end of the last ice age (approximately 11,700 years ago), marking the beginning of the modern climate era and human civilization (*Climate Change Evidence*, 2020). These climate changes derived from fractional variations in Earth's orbit that changed the amount of solar energy our planet received; although, the current warming trend is quite different from the rest (*Climate Change Evidence*, 2020). Most of the warming that has occurred since the mid-20th century is the result of increased greenhouse gases (i.e. carbon dioxide, methane, water vapor, nitrous oxide) and the greenhouse effect. They declare that "scientists attribute the global warming trend observed since the mid-20th century to the human expansion of the 'greenhouse effect' — warming that results when the atmosphere traps heat radiating from Earth toward space (*Climate Change Causes*, 2020)." Lastly, NASA points out that the Intergovernmental Panel on Climate Change, a group of 1,300 independent scientific experts from countries all over the world under the support of the United Nations, concluded in their Fifth Assessment Report that "there's a more than 95 percent probability that human activities over the past 50 years have warmed our planet" (*Climate Change Causes*, 2020). The industrial activities of our modern civilization have increased carbon dioxide levels in the atmosphere 134 parts per million in the last 50 years alone, from 280 parts per million to 414 parts per million (*Climate Change Causes,* 2020). The panel also concluded there's a 95+ percent probability that human-produced greenhouse gases (such as carbon dioxide, methane and nitrous oxide) have caused much of the observed increase in Earth's temperatures over the past 50 years (*Climate Change Causes*, 2020).

Even though warming has not been even across the planet, the upward trend in the global average temperature proves that more areas are warming than cooling (Lindsey & Dahlman, 2020). According to the NOAA 2019 Global Climate Summary, land and ocean temperatures have risen at an average rate of 0.07°C (0.13°F) per decade since 1880 and since 1981, the average rate has more than doubled, to 0.18°C (0.32°F) (Lindsey & Dahlman, 2020). The top 10 warmest years ever recorded have occurred since 1998, and 9/10 have occurred since 2005 (Lindsey & Dahlman, 2020). A common theme has been discovered, which is: as a new year is added to the historical record, it is also added to the top 10 warmest years of all time. Ultimately, as the "top 10" window shifts forward in time, the older years are replaced.

Wildfires - California

Fires are natural and many ecosystems have evolved to burn regularly. Although, Alejandra Borunda with National Geographic, claims that since the 1980's, the magnitude and intensity of fires have been trending upward (Borunda, 2018). For example, in California, 15 of the 20 largest fires in history have occurred since the year 2000 (Borunda, 2018). Borunda writes that the last two decades have consisted of most of California's hottest and driest years as well (Borunda, 2018). Also, the national Environmental Protection Agency states on their website that California's average temperature has warmed by roughly 3 degrees Fahrenheit over the past century, which is the proximate cause for drought because the extra warm air sucks water out of plants and soils (EPA, 2016). This leaves the trees, shrubs, and grasslands of the state dry and primed to burn (EPA, 2016). In Borunda's article, she references Daniel Swain, a climate scientist at the University of California, Los Angeles, and his perspective on the vegetation-drying effect. Swain explains that the vegetation-drying effect compounds with every degree of warming, which basically means that plants lose their water quicker today than they did before climate change drove California's temperatures up (Borunda, 2018). This has led to the increase in size of wildfires and since the 1980's, climate change has contributed to the burning of an extra 10 million acres in western forests - an area about the size of Massachusetts (Abatzoglou & Williams, 2016).

Previous Works and Analyses

Anthony Westerling, professor of Management of Complex Systems at the University of California, and Benjamin Bryant, professor at Stanford University, conducted a study and analysis of wildfire risks that are described as a function of climatic variables – such as temperature and precipitation, and hydrologic variables simulated using temperature and precipitation (2007). The study region included

California, Nevada, and "parts of neighboring states on a 1/8° grid contained within 124.5625° to 113.0625° West Longitude and 31.9375° to 43.9375° North Latitude" (Westerling & Bryant, 2007). Westerling and Bryant developed a logistic regression model with precise-wise polynomials to estimate the probabilities of fires that exceed an arbitrary threshold of 200 hectares – approximately 500 acres – occurring in any given month as function of climatologic, hydrologic, and topographic variables (2007). This regression model was estimated using the following data as a baseline, ranging from 1980 - 1999: large fire frequency, precipitation, temperature, simulated hydrologic variables (soil moisture, snow) and elevation (Westerling & Bryant, 2007). Westerling and Bryant used the 1980 - 1999 period because this was the longest period for which all of those data were available (2007). Following, they then used the model to investigate how large fire risks could change under four scenarios for future climate: "business as usual" (A2) and "transition to low greenhouse gas emissions" (B1) in two different global climate models: "Geophysical Fluid Dynamics Laboratory" (GFDL) and "Parallel Climate Model" (PCM) (Westerling & Bryant, 2007). A2 corresponds to a high-emission scenario where CO_2 concentration is 3x the pre-industrial level, while B1 corresponds to a low-emission scenario where CO_2 concentration is only 2x the pre-industrial level (Westerling & Bryant, 2007). A brief version of the results of this study are that by 2070–2099, increases ranged from just over +10% to just under +40% overall in large fire risk over the whole region (Westerling & Bryant, 2007). For California only, changes by the end of the century ranged from an increase of +12% to +53% (Westerling & Bryant, 2007). This elaborate study showcases what seems to be quite an accurate visualization and depiction of the future of the planet in reference to climate change and risks of fire. Westerling and Bryant provide an incredible amount of data, information, and knowledge complied over years of research and data collection.

Objective

The importance of climate change and its relation to wildfires is a serious topic that does not receive enough exposure. The first objective of this analysis is to visually present the correlation between global warming and the frequency of wildfires. The second objective of this research is to use python scripting to programmatically create a Custom Python Toolbox in ArcGIS Pro that mathematically evaluates the size and severity of fires.

Materials & Methods

Materials

This research will look at point data from the California Department of Forestry and Fire Protection, also known as "CAL FIRE," to present the history of California's fires. The following data was collected by the Fire and Rescue Assessment Program within the CAL FIRE program. This data comes from a multi-agency statewide database of fire history (CAL FIRE, 2020). CAL FIRE requires the following minimum acres for a fire to be included in this dataset: timber fires 10 acres or greater, brush fires 30 acres and greater, and grass fires 300 acres or greater are included (CAL FIRE, 2020). For the United States Forrest Service, there is a 10 acre minimum for fires since 1950 (CAL FIRE, 2020). This dataset contains wildfire history, prescribed burns and other fuel modification projects (CAL FIRE, 2020). This data set was updated in May 2020 and includes fire data from 1878-2019 (CAL FIRE, 2020). In this research, we will look at data from 1980-2019 because the temperature dataset, described in the following paragraph, only goes back to the 1980's.

This study will also look at raster data from the PRISM Climate Group, which is a northwest alliance group for computational science and engineering. The PRISM Climate Group attests on their website that they gather climate data from a wide range of monitoring systems, apply sophisticated quality control measures, and develop spatial climate datasets to reveal short and long – term climate patterns (PRISM, 2020). PRISM incorporates a variety of modeling techniques and have multiple spatial/temporal resolutions available as well (PRISM, 2020). The dataset pulled into this research falls under PRISM's "Recent Years" category. PRISM states that daily and monthly observations become stabilized after 6 months and are then posted under their "Recent Years" category (PRISM, 2020). Once the time series datasets are posted in this section, they also post the annual values computed at the end of each year (PRISM, 2020). This data will be inserted into a map, alongside the CAL FIRE data, and observed.

Additionally, Landsat 8 imagery will be summoned from the U.S. Geological Survey (USGS) Earth Explorer to present 2014 (before) and 2015 (after) imagery of a wildfire that occurred in Montana's Glacier National Park.

Methods

The first portion of this analysis will consist of observing the CAL FIRE and PRISM data overlayed. The goal of this is to show the correlation between the temperature of California and the number of fire occurrences for the corresponding year. The time frame of this data will be across nearly 4 decades, from 1981-2019.

The second portion of this analysis evaluates the two Landsat 8 images. Using ArcGIS Pro 2.6 and Python scripting, a Custom Python Toolbox will be created that contains the Normalized Burn Ratio (NBR) to show the intensity of fires. The NBR was designed to quantitatively highlight burned areas and estimate the severity of fires over time (HSU, 2020). The NBR formula mathematically compares the near-infrared (NIR) and shortwave-infrared (SWIR) wavelengths (HSU, 2014). The formula is presented below:

$$NBR = \frac{NIR-SWIR}{NIR+SWIR}$$

When looking at a map produced by the NBR equation, the healthy vegetation will have very high near-infrared reflectance and moderately low reflectance in the shortwave infrared portion of the spectrum. On the other hand, areas that have been recently burned, will have relatively low near-infrared reflectance and high shortwave infrared reflectance (HSU, 2014). Typically, the NBR is used on pre-fire imagery to standardize the wellness of the vegetation prior to fire ignition, and then it is used on imagery taken shortly after the fire to see what the area looks like after all is said and done – in regards to the fire (HSU, 2014). The pre-fire NBR is then subtracted from the post-fire NBR to find the difference, or the ΔNBR (dNBR) (HSU, 2014). This eliminates the similarities between the two images and leaves an estimates of on the size, severity and damages done by the fire (HSU, 2014).

Results & Discussion

Results

Figures 1-5 depict the results of the first portion of this analysis. Displayed are the average temperatures for the years 1981, 1991, 2001, 2011, and 2019, as well as the number of fires that occurred in the corresponding year.

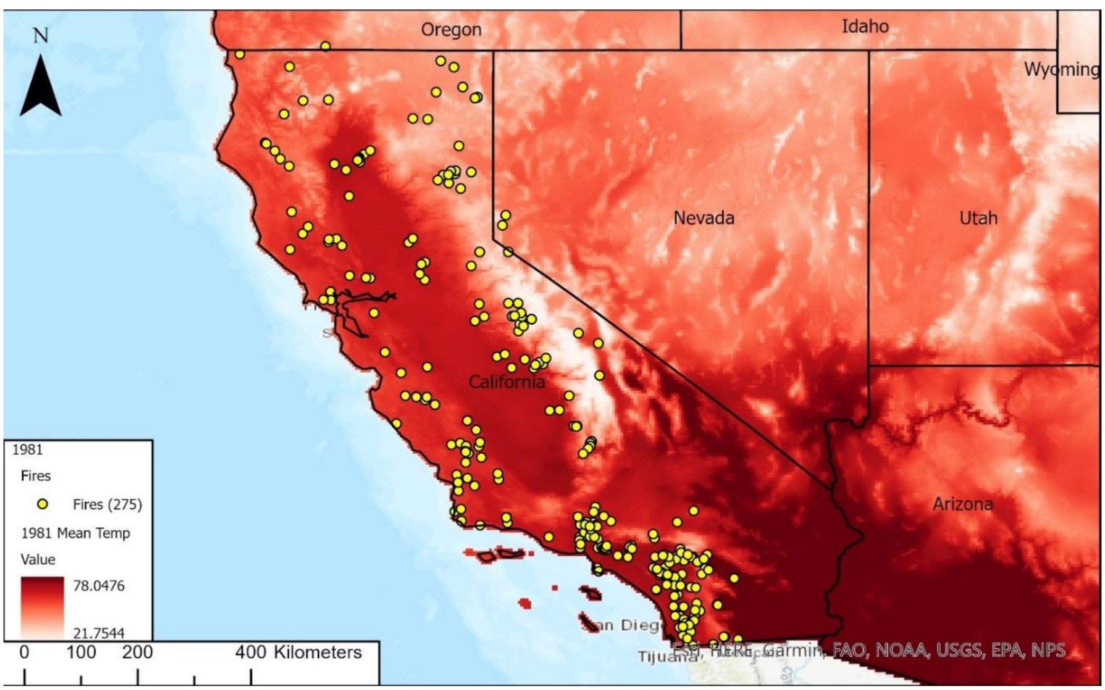

Figure 1. The image above represents California's Mean Temperature in 1981 along with the number of fire occurrences that year.

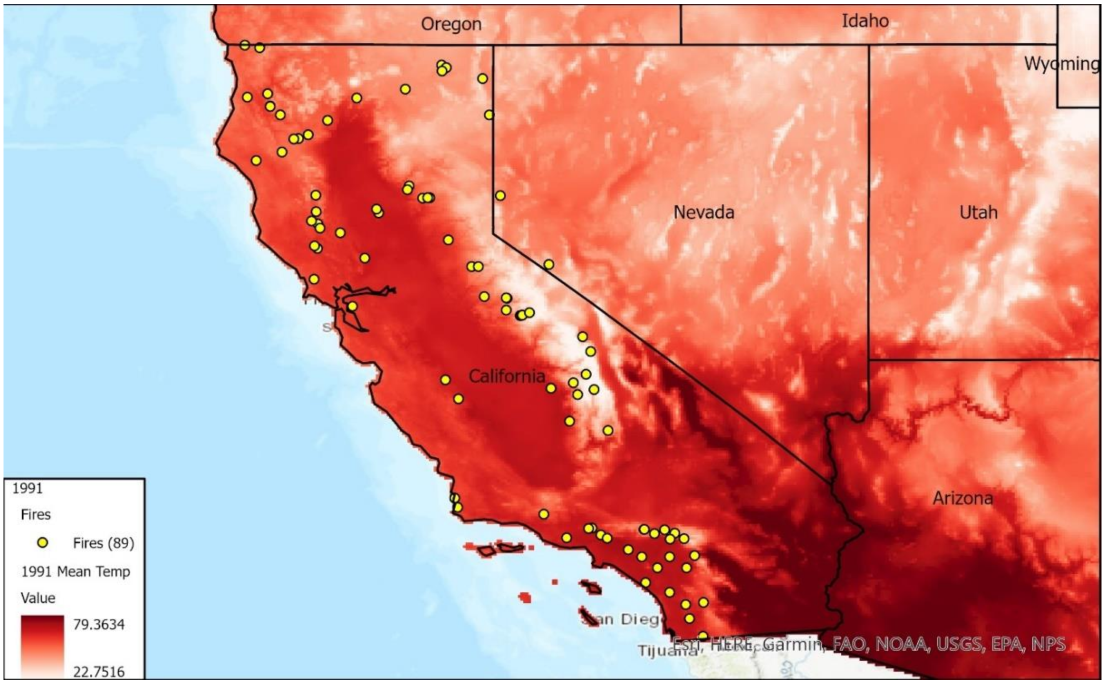

Figure 2. The image above represents California's Mean Temperature in 1991 along with the number of fire occurrences that year.

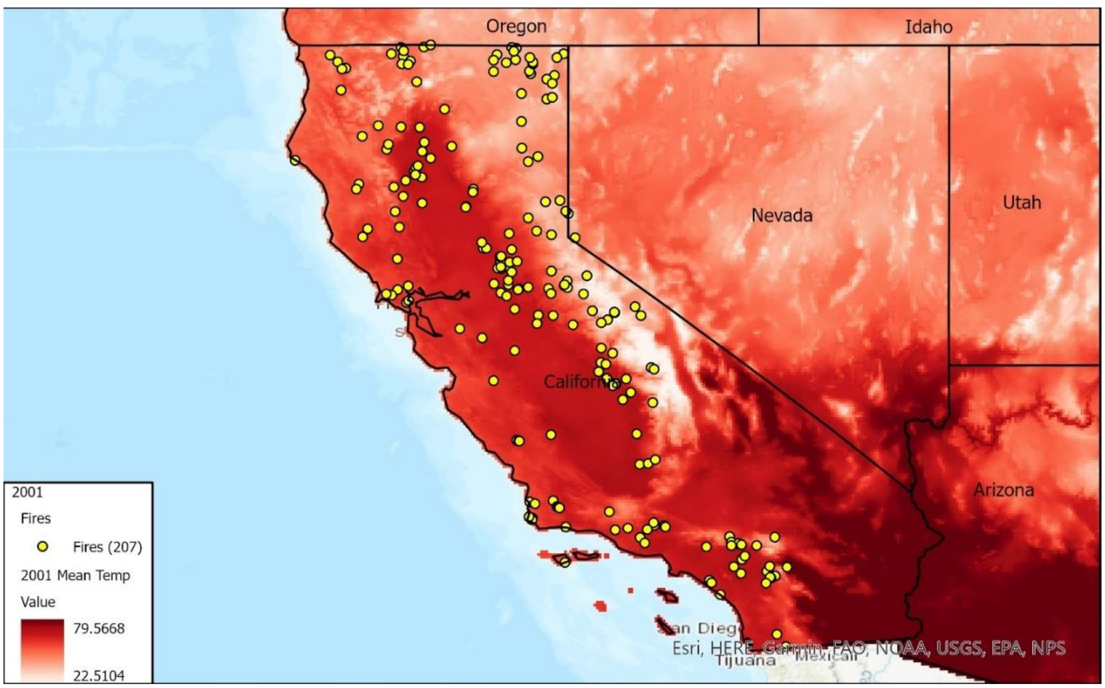

Figure 3. The image above represents California's Mean Temperature in 2001 along with the number of fire occurrences that year.

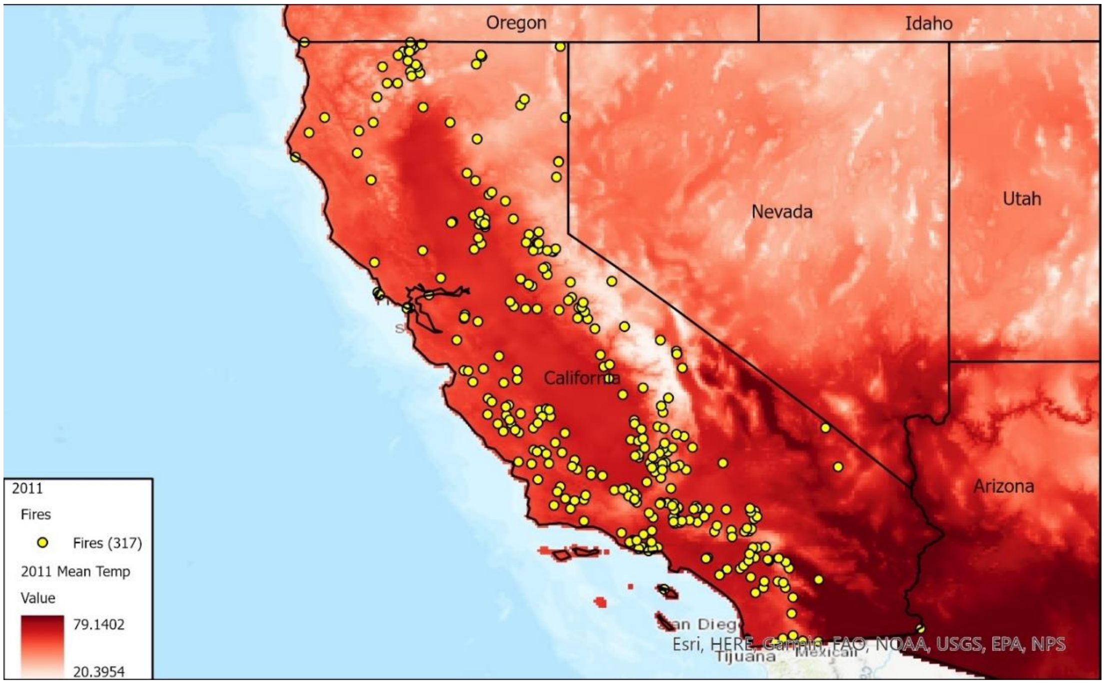

Figure 4. The image above represents California's Mean Temperature in 2011 along with the number of fire occurrences that year.

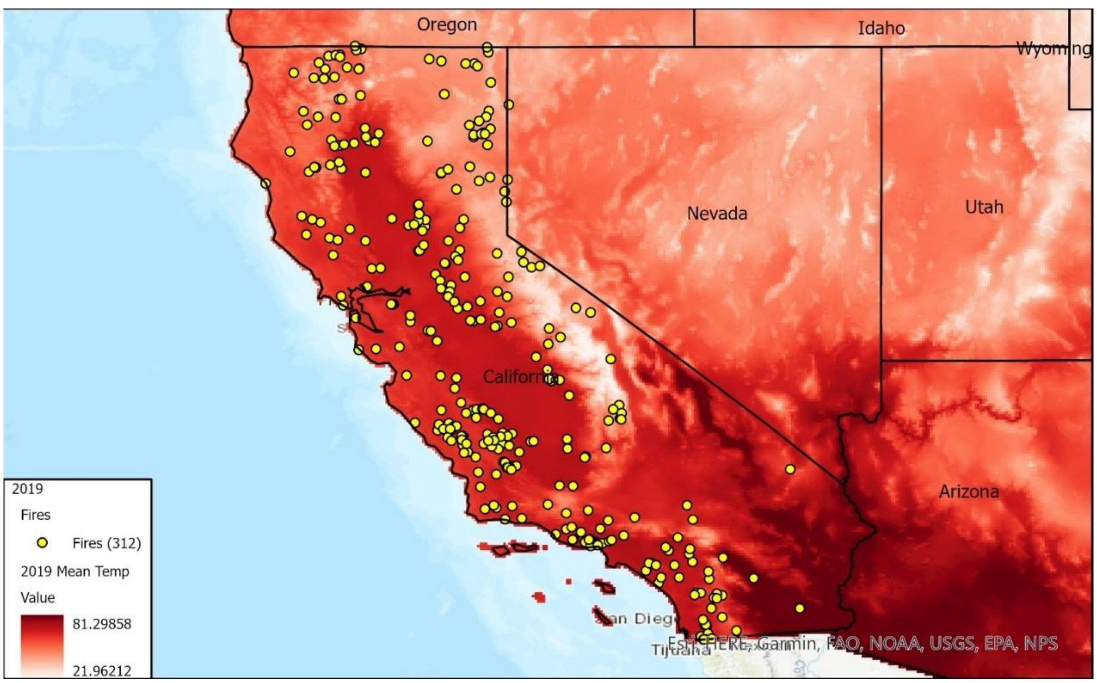

Figure 5. The image above represents California's Mean Temperature in 2019 along with the number of fires that occurred that year.

Figures 6-8 depict the results of translating the NBR equation into the Python language to create a Custom Python Toolbox in ArcGIS Pro 2.6. These figures display what the Custom Python Toolbox – and the tools within it – look like to the operator.

Figures 9-10 are the 2014 pre-fire True Color imagery and 2015 post-fire True Color imagery, respectively.

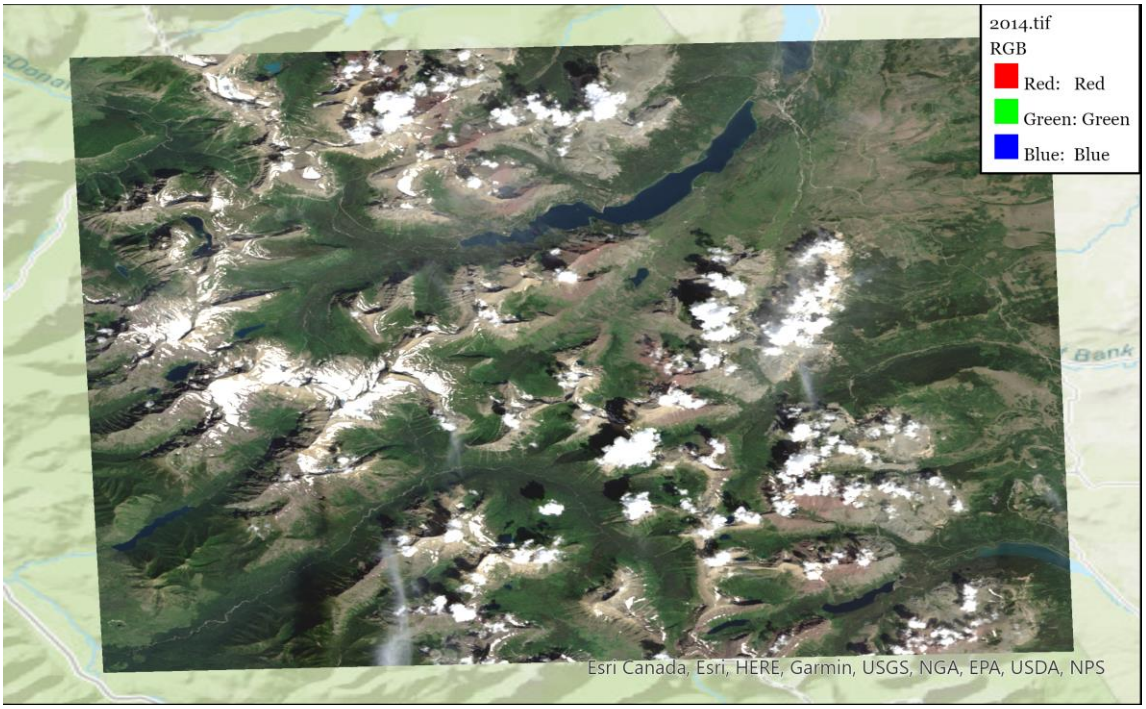

Figure 9. Glacier National Park 2014 (Pre-Fires)

Figure 10. Glacier National Park 2015 (Post-Fires)

Figures 11-12 show the produced rasters, for the 2014/2015 data respectively, after they have been processed by the Normalized Burn Ratio tool.

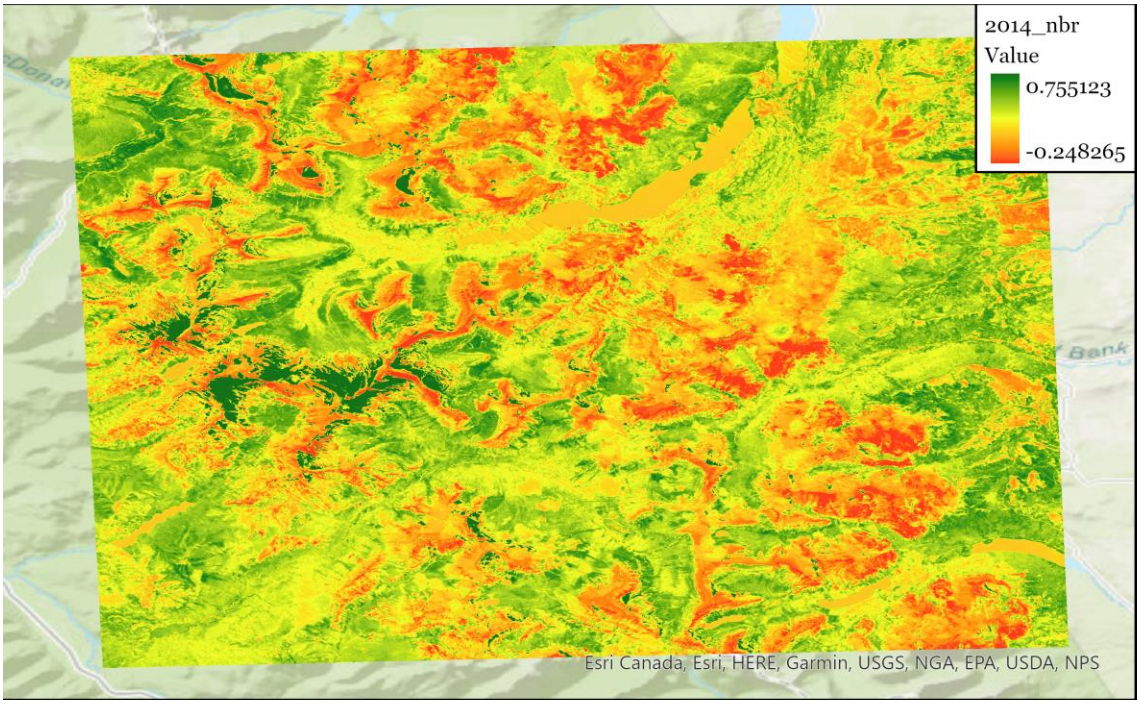

Figure 11. Post processed NBR image of Glacier National Park 2014 (Pre-Fires)

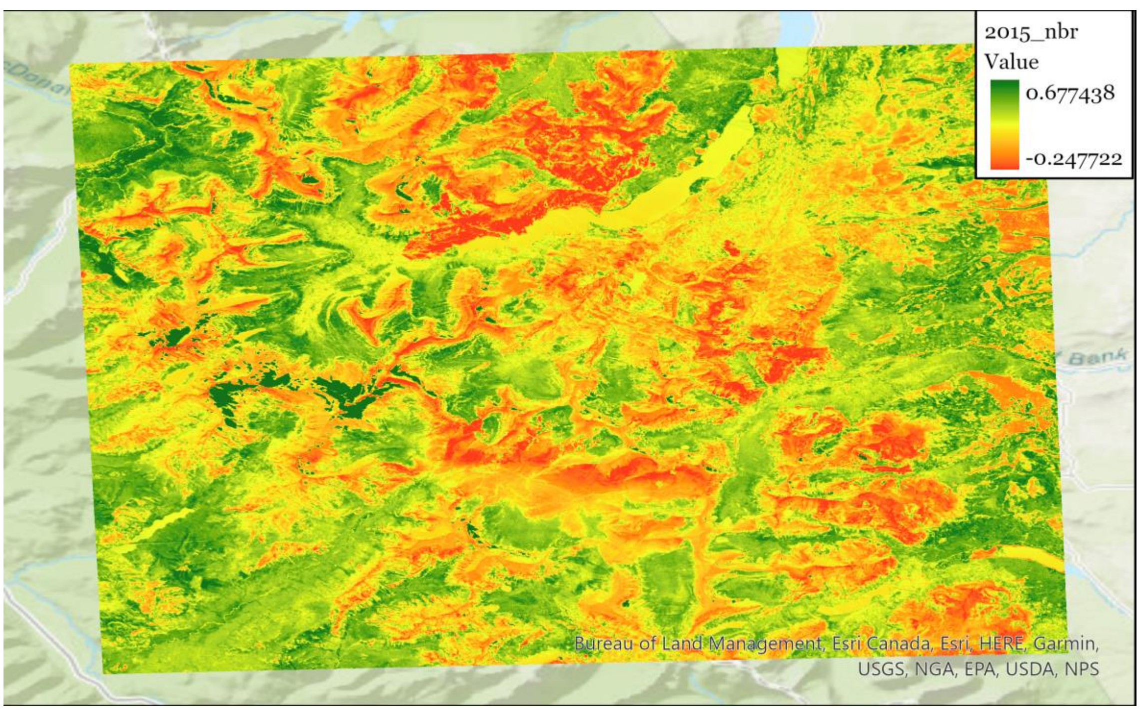

Figure 12. Post processed NBR image of Glacier National Park 2015 (Post-Fires)

Figure 13 shows the difference between the 2014 NBR raster and 2015 NBR raster. Both fires that occurred are clearly demarcated.

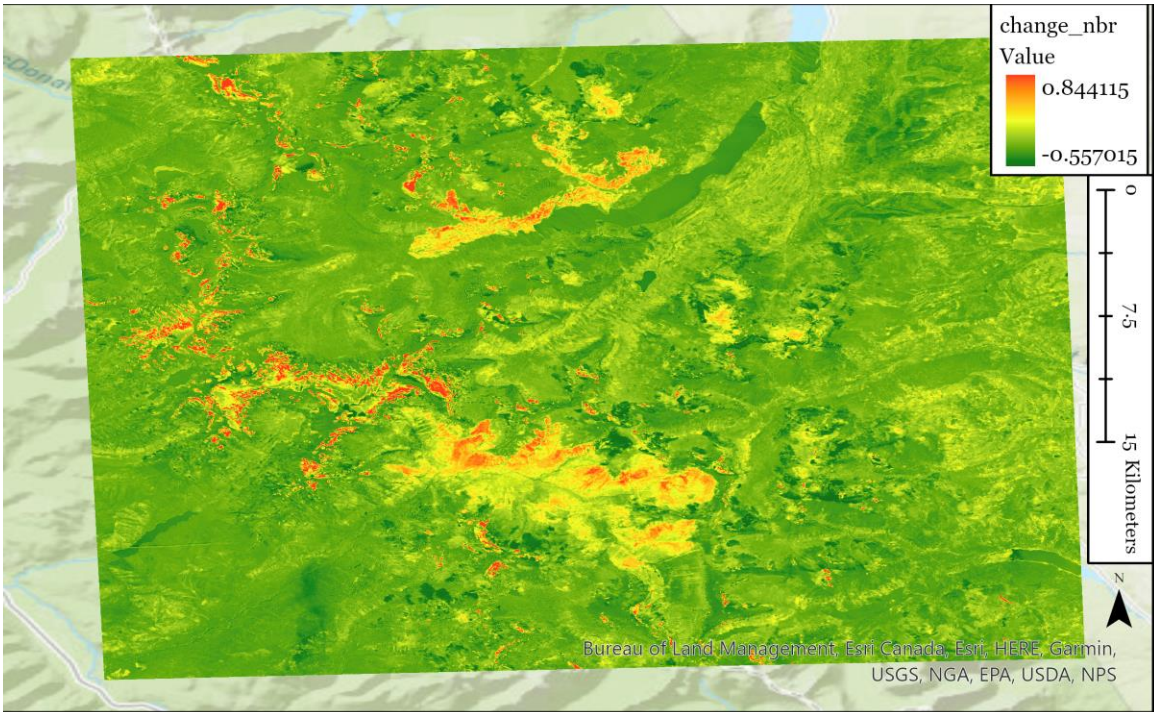

Figure 13. Post processed dNBR image of Glacier National Park

Figures 9-13: Green represents healthy vegetation; Yellow represents unhealthy vegetation; Red represents bare earth/no vegetation/burnt areas

Discussion

Based on Figures 1-5, it can be proven that the Earth's temperature is rising as time presses on. Each year analyzed portrays an increase in average temp, with the exception of 2011, which was atypically -.42°F from 2001. Although, the following decade was +1.73°F from 1991 and +2.15 from the anomaly year. From 1981 – 2019, the average rise in temperature per decade was approximately .65°F. Also based on these figures, there is not enough evidence to conclude any correlation between wildfire frequencies and the rise in temperature because there is too much inconsistency with the data used. For instance, 2011 had the most fire occurrences (317) and the second lowest average temperature (79.14°F, while 1991 had the least amount of fire occurrences (89) and the 3rd highest average temperature (79.36°F). This research acknowledges the fact that this point could not be proven due to lack of data analysis. This point could still potentially be proven if a larger group of data was analyzed.

Both of the tools within the Custom Python Toolbox work properly and produce the desired outcomes. The NBR tool executes the NBR mathematical equation accurately and the Change in NBR tool correctly eliminates the similarities between the NBR images – leaving an estimate of on the size, severity and damages done by a fire.

Conclusion

In short, global warming and its effects are an issue that does not receive enough attention. The findings from this research – in regards to global warming – is that the overall temperature of the Earth is rising over time. The findings about how wildfire frequencies are correlated to global warming are unconvincing. The data analyzed showed no correlation, however it is believed that if a larger dataset were to be examined, this thesis could still potentially be proven. Lastly, the NBR Toolbox – consisting of the NBR tool and the Change in NBR tool - works excellently. It possesses the ability to help a tremendous amount of people in the future. The toolbox can be used by analysts who are seeking to estimate the size of fires and the damage to the affected areas. In the future, with a sufficient amount of data, the NBR toolbox could be used to display how wildfires are increasingly becoming more intense over time.

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