Wildfires Carbon: A Statistical Investigation of the Link Between Wildfires and Aerosols in the US 1994-2022

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Introduction

There is a positive feedback between wildfires and climate change. A warmer and drier climate increases wildfire risk, which further warms the climate by polluting the atmosphere with aerosols. Because of this effect, many climate factors such as precipitation and humidity are correlated with wildfire (Shi & Touge , 2023). On the other side of the cycle, wildfires' main contribution to climate change is the addition of aerosols to the atmosphere (Chen et al, 2014) Aerosols affect the heating and cooling of the atmosphere in two main ways: scattering shortwave radiation back down to the Earth, and suppressing cloud formation (Chen et al., 2014). Since these smaller droplets have a lower chance of forming, aerosols can lead to a reduction in precipitation levels. Overall, the effects of aerosols on climate change are hard to estimate precisely because there is no exact pre-industrial data on aerosol quantities or properties, but it is clear that their effect is likely to be significant (Bellouin et al, 2020).

Although climate change and wildfires are global issues, this paper will focus on how these two phenomena are interacting in Alaska in a cause-effect cycle. Numerous studies have found that the aerosols from wildfires are exacerbating climate change in the US. For example, after studying atmospheric composition at different altitudes in the immediate aftermath of major wildfires in the Southeastern US during November of 2016, Guan et al. (2016) found that wildfires may contribute 40 micrograms per cubic meter of PM2.5 during an event, which is an average of a 45% increase from the average. This paper will seek to build off this finding to further understand the relationship between fires and different aerosol levels by analyzing their relationship in Alaska.

To understand how wildfires affect climate change, it is important to understand the properties of some of its most significant aerosols: black carbon (BC) and brown carbon (BrC). The aerosols emitted from wildfires are less than 3% BC (Chakrabarty et al, 2023), but it has been considered one of the more dangerous environmental influences of wildfires for years (Chen et al, 2014). BC is a particularly potent chemical in the greenhouse gas effect, and it has a high mass absorption cross section (MAC), which means it reflects a large amount of shortwave radiation for its size (Moteki, 2023). Wildfires emit much more BrC than BC, but the effects of BrC have been considered negligible for years due to its low MAC (Moteki, 2023). A recent study, however, has found that this assumption of negligibility is not necessarily true (Chakrabarty et al 2023). Within the category of BrC, is a kind of aerosol referred to as dark brown carbon (D-BrC). D-BrC has a more than negligible MAC, which makes it a significant greenhouse gas when multiplied by the sheer quantity of D-BrC that wildfires release into the atmosphere (Chakrabarty et al, 2023). Aerosols can also suppress cloud formation by acting as nuclei for water condensation. As air cools to form clouds, water vapor condenses aerosols, and create water droplets (Chen et al, 2014).

On the other side of the wildfire and climate change feedback loop, climate change has increased fire risk in many areas within the US. The US as a whole has seen an increase in fire severity in the past 20 years (Fig 1 C). In their 2023 paper, Shi and Touge analyze six different variables in terms of their relation for fire occurrence: daily precipitation, daily maximum temperature, drought code, fine fuel moisture code, duff moisture code, and fire severity index. Fine fuel moisture code combines daily precipitation, relative air humidity, wind speed, and air temperature data to estimate the moisture of the ground fuel such as pine needles that would lay scattered across the forest floor. Duff moisture code is a similar combination of statistics taken at midday to indicate the moisture of larger fuel. Most of the factors analyzed by Shi and Touge other than temperature are closely related to precipitation and humidity, and the authors found all factors to be closely correlated to fire severity. Temperature had a significantly weaker association along the equator, but all factors studied had a relatively similar and strong correlation to wildfires within the US (Shi & Touge). Heat and drought frequency are widely agreed to be the main factors responsible for the uptick in wildfires in the Western US (Wehner et al, 2017). In Alaska especially, where extreme wildfires have been historically uncommon, the warming climate has made its tundra much more burnable. Alaska has seen a 50% increase in fire risk over the past decades, and its fire season is projected to lengthen with shortening winters (Wehner et al, 2017). Global warming is changing many parts of our climate from season lengths to storm or drought occurrences, and most of these changes are affecting wildfire frequency.

This increase in fire occurrence cannot be attributed to one change in climate conditions, but rather a culmination of several different conditions that can all be linked to human activities or climate change. For example, ignition patterns – how the fires actually start – can now be something as simple as a discarded lit cigarette or unattended campfire rather than just natural forms of ignition such as an eruption or a lightning strike. As mentioned above, drought and generally dry conditions contribute to fire severity and likelihood. More broadly, fire weather, which is defined as any “weather conditions directly affecting fire behavior” (Pausas et al, 2021) includes any strong winds that can influence the shape and size of the fire as well as increase the rate of evapotranspiration in an area, which decreases the vegetation moisture levels. Fire weather is not usually directly associated with climate change, but there is evidence of a link between global warming and an increase in large oceanic windstorms that can worsen a fire event in a coastal region (Pausas et al, 2021).

This paper investigates the link between wildfires and organic carbon as well as the link between wildfires and general aerosols. The state of Alaska, with its rapidly increasing fire risk, serves as a case study for these relationships. The connection between aerosols and wildfires is important because wildfires are increasing in intensity and frequency across the globe (Shi & Touge, 2023) even as the world moves to phase out fossil fuels. Because wildfires emit a much higher organic carbon to black carbon ratio than fossil fuels we may see an increase in proportional organic carbon aerosols in the atmosphere (Moteki, 2023) so we need to understand how much of each kind of aerosol to expect in our atmosphere.

Data and Methods

Two databases were used to analyze the relationship between wildfires and aerosols. Organic carbon levels in the atmosphere in Alaska were extracted from the Environmental Protection Agency's (EPA) yearly Air Quality System (AQS) database.[1] The AQS database also provided daily data on total $PM_{2.5}$ in Alaska. Regional fire data was sourced from the Incident Management Situation reports within National Interagency Fire Center (NIFC).[2] Yearly data was extracted from these reports by taking the "Year to Date" data of the last report of each year, which would be released on either December 29th or 30th.

The relationship between organic carbon and wildfires were analyzed in Alaska by year. The NIFC's fire reports were based on a ten region system. Their region map is displayed in Figure 2. Because the AQS data was split by state. Converting the entire AQS data set to the NIFC's regional system would have had some imperfections. For example, Idaho is split across two NIFC regions, which means any of the AQS data from Northern Idaho will be associated

[1] https://aqs.epa.gov/aqsweb/airdata/download_files.html
[2] https://famprod.nwcg.gov/batchout/IMSRS_from_1990_to_2022/

with the Great Basin Region. The NIFC regions also count Northern California and Hawaii as the same region while considering Southern California a separate reason. Because of these inconsistencies in how these two databases divided geographic data, Alaska was the only region that could be perfectly converted. The NIFC counted Alaska as its own region, separate from all other states. Alaska is also an ideal case study because it is reported to be one of the areas in the US experiencing a severe increase of 50% in its fire risk (Wehner et al, 2017).

The AQS database has yearly data on many different aerosols since 1980. In this time frame, there were just under 2.2 million rows of data on over 1,000 different aerosol categories. Only 4,078 rows regarded organic carbon. This is because the EPA employs a variety of different equipment and methods for measuring different aerosols throughout the US. The EPA used the Interagency Monitoring of Protected Visual Environments (IMPROVE) network from 2005 onwards. Before 2005, it appears the EPA has no record of what method was used as their "Method Name" is labeled "unknown" in all organic carbon data preceding 2005. Each datum was collected over a 24 hour period, but the EPA did not report what device they used to find the organic mass of aerosols. The organic carbon was measured only in terms of particles less than 2.5 micrometers in diameter ($PM_{2.5}$). Its quantity was measured in micrograms per cubic meter. The daily $PM_{2.5}$ data, meanwhile, quantified all $PM_{2.5}$ particles with a wide variety of methods including broadband spectroscopy and sequential air sampler.

The NIFC data is much more straightforward. They reported the number of non-prescribed fires of each year, and used satellite data to calculate the total acreage burned. The yearly data only goes back to 1994, however, which proved to be the limiting factor range for a historical data analysis.

Discussion

At this stage in research, few results have been generated. The NIFC data is split into a separate file for each year in pdf format, which means nearly 600 cells of data have to be put into a real spreadsheet manually before any analysis can be done on the data. Averaging the organic carbon data to produce one number for each region in each year is also a time-intensive task that has yet to be completed.

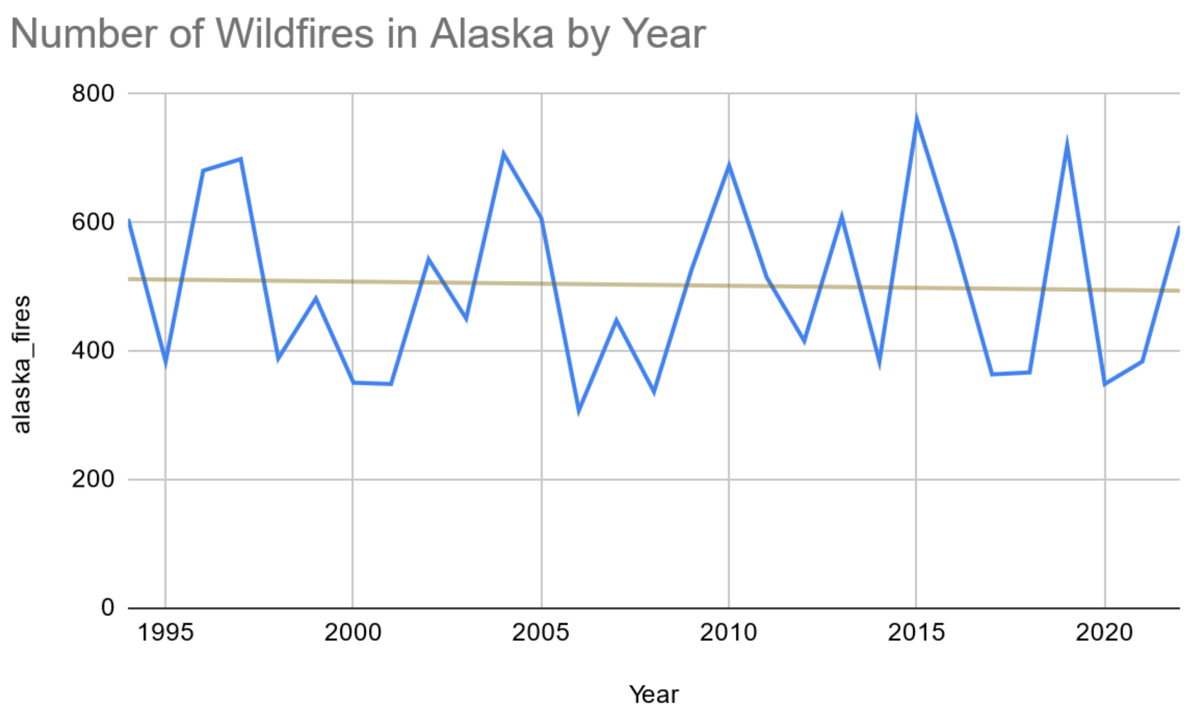
Conclusions

Although I do not yet have my final results, I am not optimistic about finding a strong statistical correlation between wildfires and organic carbon in the data in most of the US because of how massive the regions are. I believe, however, that some regions will have a much stronger correlation than others. Alaska for example, could show a pure correlation since it is both a state and its own region, which means its geographic area is exactly the same in both datasets.

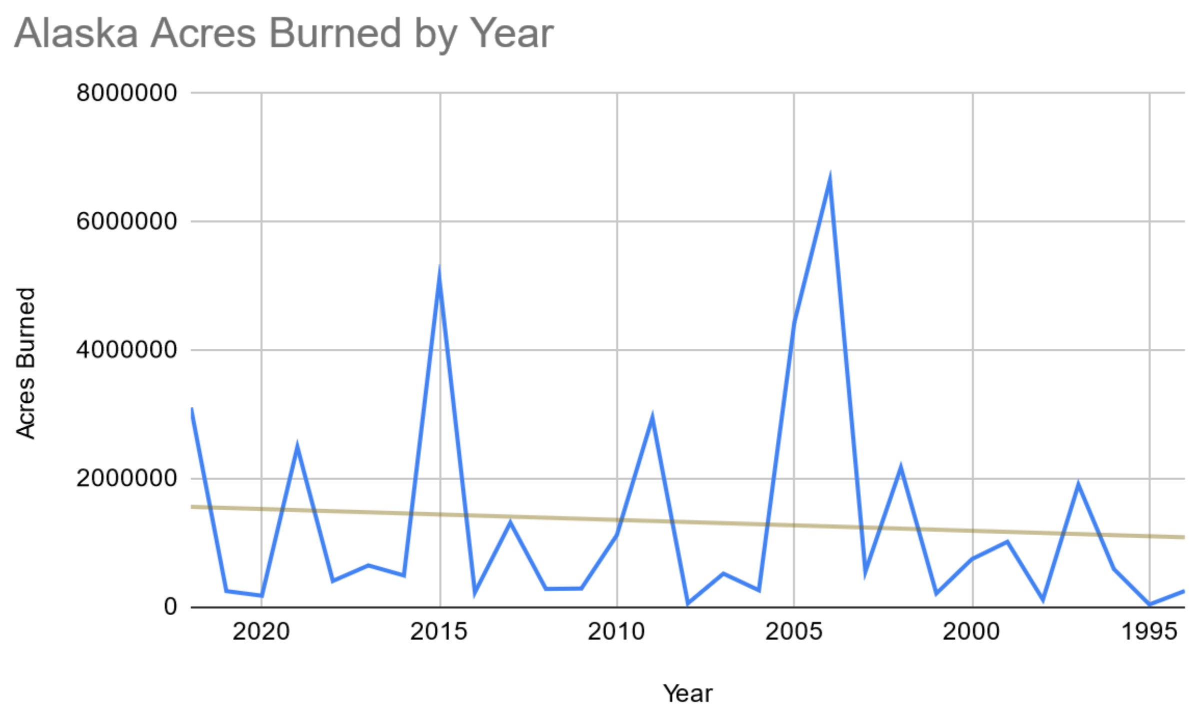
Figures & Tables

Figure 1

A



B


Alaska Acres Burned by Year
8000000
6000000
4000000
2000000
0
Acres Burned
2020
2015
2010
2005
2000
1995
Year

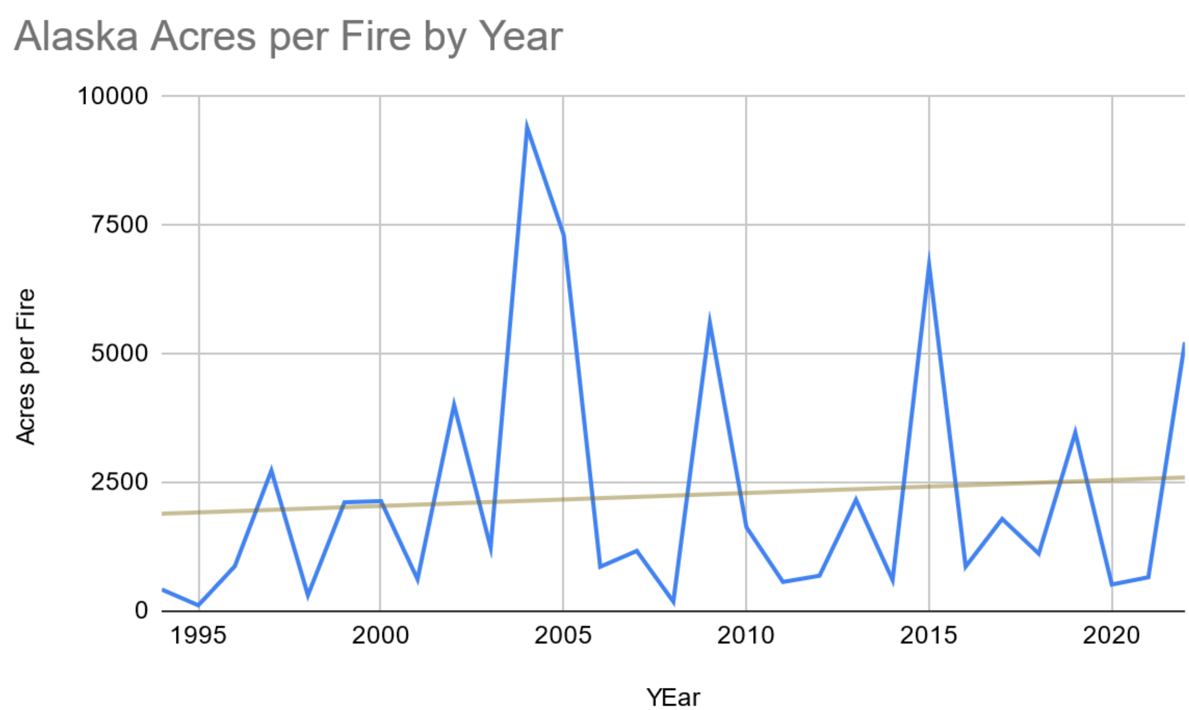

Alaska Acres per Fire by Year
10000
7500
5000
2500
0
Acres per Fire
1995
2000
2005
2010
2015
2020
YEar

Figure 2:

- (A) This graph will show a linear analysis between the total PM2.5 in the atmosphere and the number of wildfires per year in Alaska.
- (B) This graph will show a linear analysis between the total PM2.5 in the atmosphere and the number of acres burned per year in Alaska.

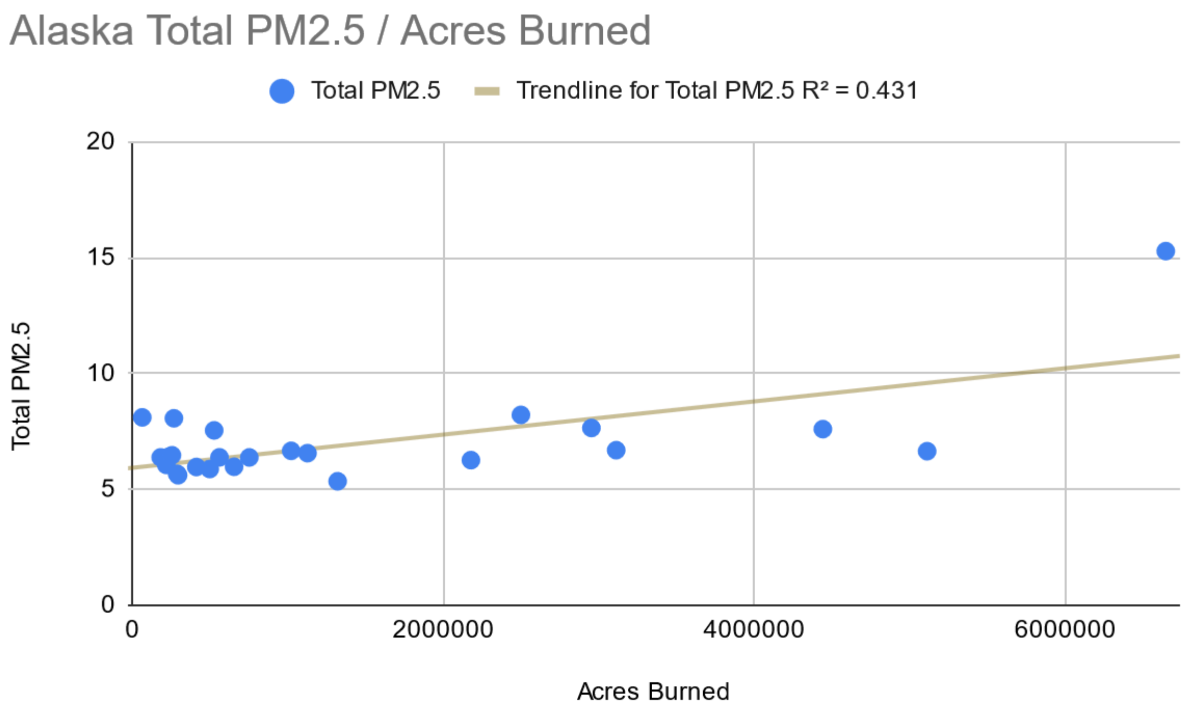


Figure 3:

- (A) This graph will show a linear analysis between the organic carbon in the atmosphere and the number of wildfires per year in Alaska.

- (B) This graph will show a linear analysis between the organic carbon in the atmosphere and the number of acres burned per year in Alaska.

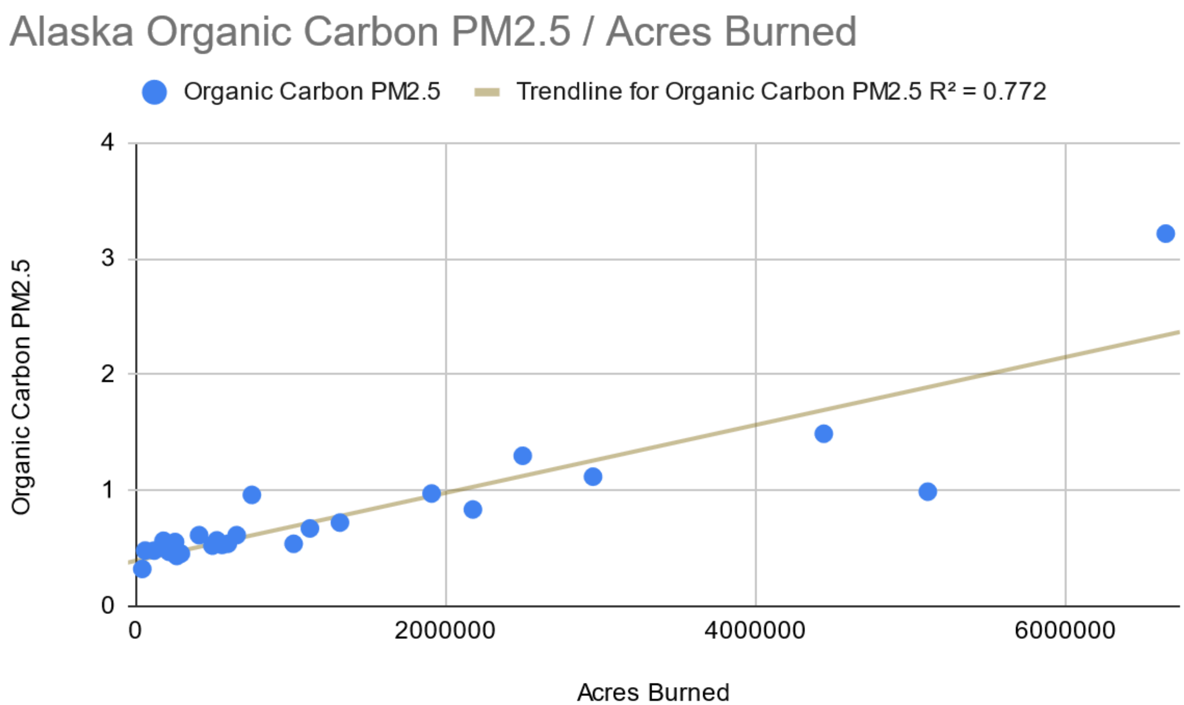


Figure 4:

- (A) This graph will show the real average amounts of total PM2.5 and organic carbon in Alaska.
- (B) This graph will show the proportional average amounts of total PM2.5 and organic carbon in Alaska.

Figure 5:

- (A) This will be a map of points where all the organic carbon data was observed within Alaska.
- (B) This will be a map of points where all the organic carbon data was observed within Alaska.

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