First Street

The 10th National Risk Assessment
Atrocious Air

February 12, 2024

California West Hollywood and Santa Monica

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The data data behind First Street's Air Quality Model and all of First Street's climate risk models can be licensed through a wide variety of formats.

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RISK FACTOR

First Street makes data accessible on its Risk Factor tool through a variety of products. Please visit www.riskfactor.com for more information.

Disclaimers

First Street's climate change risk estimates are based on one or more models designed to approximate risk and are not intended as precise estimates, or to be a comprehensive analysis of all possible climate change risks.

ARUP

To estimate indoor air quality at the property level, First Street collaborated with Arup in order to leverage their expertise as a leader in the environmental engineering and resilience space.

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Executive Summary

Since the middle of the last century, the United States has witnessed significant changes in air quality, driven by industrialization, technological advancements, regulatory measures, and public awareness. The most important of these interventions was the Clean Air Act of 1963, which served as the first federal legislation addressing air quality concerns. However, it lacked enforceability, and the subsequent Air Quality Act of 1967 strengthened federal involvement in research and regulation, laying the groundwork for future legislation. Following this foundational legislation, the Clean Air Act of 1970 established the Environmental Protection Agency (EPA) and set National Ambient Air Quality Standards (NAAQS) for six major pollutants; namely O3, Particulate Matter (10 and 2.5 micron PM, PM10 and PM2.5, respectively), Carbon Monoxide (CO), Sulfur Dioxide (SO2), Nitrogen Dioxide (NO2), and Lead (Pb). Perhaps the most well-known product related to the EPA's work in this area is the Air Quality Index (AQI), which is a numerical scale which presents the level of air pollution in an easy to understand way, and may be used to better understand the associated health impacts.

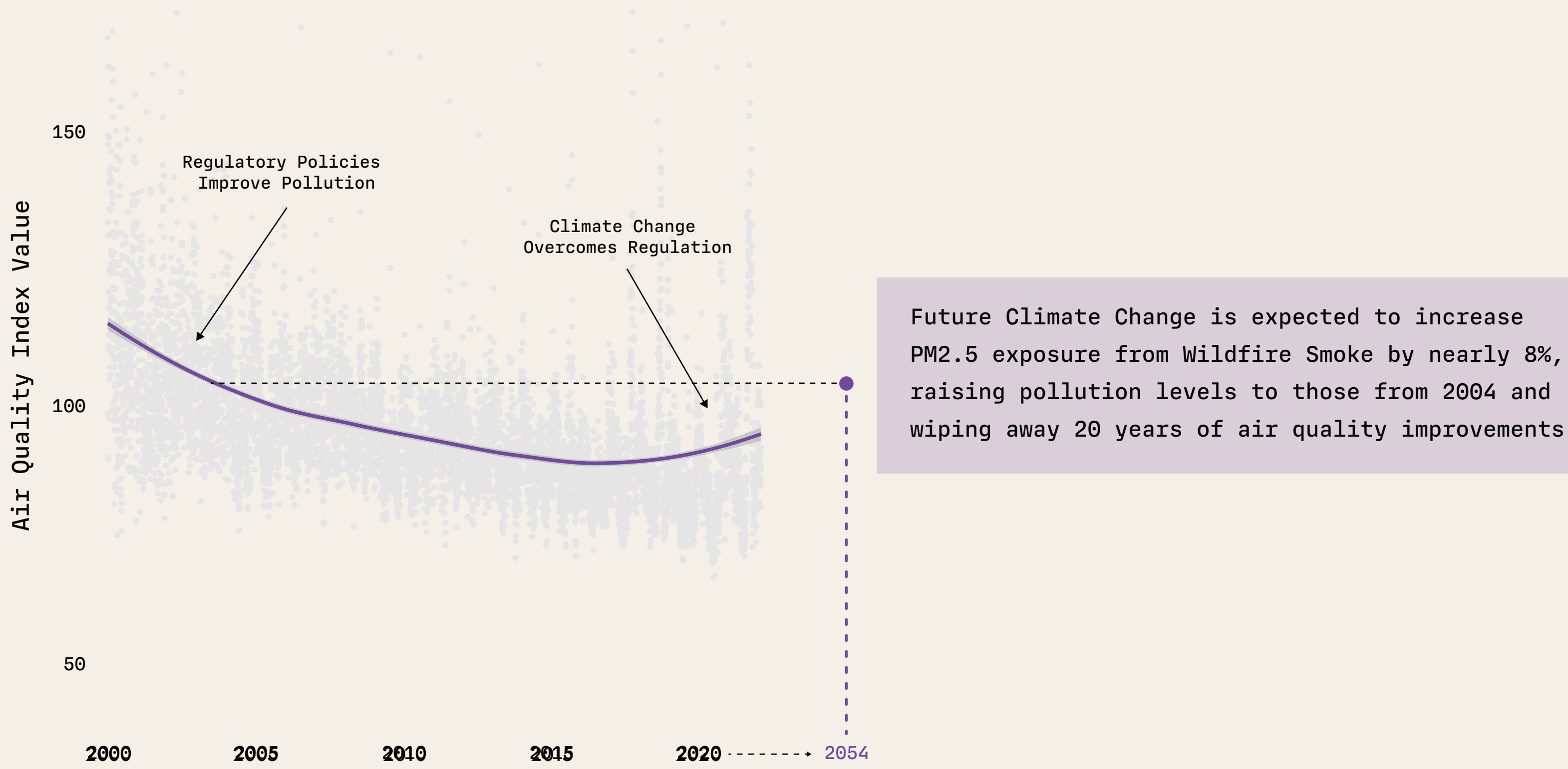


Figure 1. While anthropogenic emissions decrease, climate impacts such as PM2.5 concentrations will worsen (EPA: Hourly PM2.5 non FRM/FEM Mass)

Executive Summary

While air quality has significantly improved from the first half of the 20th century, there are growing concerns that climate change impacts are undoing some of the progress the US has made through regulations and policy. This trend has been referred to as a "climate penalty", whereby changing environmental conditions are inducing negative effects which erase some of the progress made through federal and local regulatory policies. Changes in environmental conditions, such as extreme heat, drought, and wildfires, are contributing to the increase in the levels of pollutants (O3 and PM2.5, specifically), often to concentrations above safe levels in much of the country. Even with significant cuts in anthropogenic emissions over the past decades, some research has projected that PM2.5 pollution will increase by as much as 50% over the next 3 decades in the Western United States. Moreover, while the majority of smoke impacts local and regional populations, some wildfire smoke can travel great distances, affecting communities far beyond the immediate vicinity of the fire. For example, the smoke from the Canadian wildfires in June of 2023 resulted in New York City breaking its previous air pollution record by 126 AQI points and, at the time, ranking as the worst air quality in the world.

The "climate penalty" is not felt equally across the country, with some of the most dramatic effects seen in recent upticks in PM2.5 from wildfire smoke in the West, and growing pockets of extreme O3 exposure. For instance, the western region of the US has already experienced higher levels of air pollution than other regions of the country due to a combination of factors, including emissions from transportation, industry, and wildfires; and geographical factors such as topography and weather patterns. Additional research suggests that PM2.5 pollution will increase by as much as 50% over the next 3 decades in the region. As a result, historic station data from the EPA demonstrates that between 2000 and 2021, in the West, the number of Orange Days has increased by 477%, Red Days by 459%, Purple Days by 318%, and Maroon Days by 381%. In California alone, the average number of Green Days seen across the state has decreased from 136 to 93 (-32%), and the average number of Yellow Days has decreased from 200 to 146 (-27%). Subsequently, the average number of Orange Days has increased from 15 to 55 (+267%), Red Days increased from 10 to 16 (+60%), Purple Days increased from 1 to 17 (+1,600%), and Maroon Days from 3 to 38 (+1,167%). Using the newly created First Street - Air Quality Model (FS-AQM), this report finds continued exposure as well as climate-related increases in poor air quality due to the growing incidence of wildfires, extreme heat events, and their negative interactions with other environmental and anthropogenic conditions. The results show that there are approximately 14.3 million properties (~10% of all properties) in the US that are estimated to have a week or more (7+ days) of unhealthy air quality days solely from PM2.5 in the current climate conditions. Of those, almost 5.7 million properties (~4%) may experience two or more weeks (14+ days) annually of smoke-driven unhealthy air quality days. The areas with the most extreme levels of exposure are in the western US, but pockets of this extreme exposure also exist in the Southeast (from wildfire smoke-drivenPM2.5) and in the Midwest and Northeast (from heightened O3 exposure). Projecting that exposure to both PM2.5 and O3 out by 30 years, there are expected to be an additional 1.7 million properties across the US with exposure to 10 or more days a year, growing from under 12 million to over 13 million over that time period. Additionally, some of the most at-risk areas include large population centers such as Seattle, San Francisco, and Sacramento. It is important to understand the nature of this hazard, its link to climate, and the growing impact it will have on areas across the US into the future, including the growing negative effects on human health, labor force productivity, and even migration patterns.

Top 10 Key Takeaways

1. The United States has witnessed improvements in air quality, driven by regulatory measures such as the Clean Air Act and the subsequent founding of the Environmental Protection Agency (EPA).

2. There is growing evidence of the emergence of a "climate penalty" associated with changing environmental conditions due to climate change, reversing of some of the progress that the US has made through regulatory policy.

3. The "climate penalty" is not felt equally across the country, with the most dramatic effects seen in the recent upticks in PM2.5 from wildfire smoke in the West.

4. In the western US, EPA station data demonstrates that between 2000 and 2021 the number of poor air quality days (Orange days) grew by as much as 477%.

5. In California, between 2000 - 2021 the average number of Green Days across the state has decreased from 136 to 93 (-32%) while the average number of Maroon Days has increased from 3 to 38 (+1,167%).

6. First Street developed a new Air Quality Model (FS-AQM), a probabilistic risk model estimating the amount of days of poor air quality at AQI-specific thresholds, across the country, for today and projected out 30 years into the future with climate change.

7. Approximately 14.3 million properties (~10% of all properties) in the US are estimated to have a week or more of unhealthy air quality days solely from PM2.5 today, with almost 5.7 million properties (~4%) experiencing two or more weeks annually of smoke-driven unhealthy air quality days.

8. Some areas like Fresno, CA, for example, are expected to see over 2 months (82 days) worth of poor air quality days in a bad year under the current environmental conditions, growing to over 3 months worth annually over the next 30 years.

9. The share of properties experiencing 10 or more poor air quality days a year from the combined effect of PM2.5 and O3, is expected to increase by nearly 15%, growing from under 12 million properties to over 13 million properties over the next 30 years.

10. Significant numbers of days with poor air quality will impact large population centers such as Sacramento, Fresno, Seattle, and suburban San Francisco. For context, these areas alone represent nearly 10 million people across their metropolitan areas with persistent and frequent risk.

Air Quality in the US Context

History of Air Quality in the US and Federal Legislation Responses

Since the middle of the last century, the United States has witnessed significant changes in air quality, driven by industrialization, technological advancements, regulatory measures, and public awareness. Prior to the 1970's, the United States was marked by rapid industrialization and the widespread use of coal, which led to increased emissions of sulfur dioxide (SO2) and particulate matter (PM). During this period, air quality in many regions was characterized by high levels of pollutants, resulting in notable social and health implications, including respiratory disease, cardiovascular disease, urban smog, and occupational health concerns (Dockery et al 1993; Nemmar et al 2002). As the scientific community's understanding of these health impacts deepened over time, the nation began to develop environmental regulations and public health interventions aimed at improving air quality.

The most important of these interventions was the Clean Air Act of 1963, which served as the first federal legislation addressing air quality concerns. However, it lacked enforceability. The subsequent Air Quality Act of 1967 strengthened federal involvement in research and regulation, laying the groundwork for future legislation. Following this foundational legislation, the Clean Air Act of 1970 established the Environmental Protection Agency (EPA) and set National Ambient Air Quality Standards (NAAQS) for six major pollutants; namely O3 (O3), Particulate Matter (10 and 2.5 micron PM, PM10 and PM2.5, respectively), Carbon Monoxide (CO), Sulfur Dioxide (SO2), Nitrogen Dioxide (NO2), and Lead (Pb).

In the later decades of the 20th century, rapid technological advancements, such as catalytic converters in automobiles, contributed to reduced emissions. However, the persistence of urban smog and concerns over acid rain prompted further amendments to the Clean Air Act in 1990, addressing new challenges and emphasizing market-based approaches. The 2000s witnessed increased attention on fine particulate matter (PM2.5) and ground-level O3. Stricter standards for these pollutants were implemented, highlighting the particularly harmful adverse health effects associated with exposure to these pollutants (EPA 2006). Most recently, the increased understanding and awareness of the drivers of air quality have increasingly taken into account concerns over impacts from climate change. Directly tied to the impact of climate, the Clean Power Plan (2015) is one of the most recent pieces of Federal legislation aimed at improving air quality and highlights the nation's growing awareness around the interconnectedness of air quality, the changing climate, and emissions (EPA 2015). As a result of major Federal legislation and related policies since the 1960s, air quality across the United States has markedly improved across many factors and is better today than even what was experienced at the beginning of the 21st century.

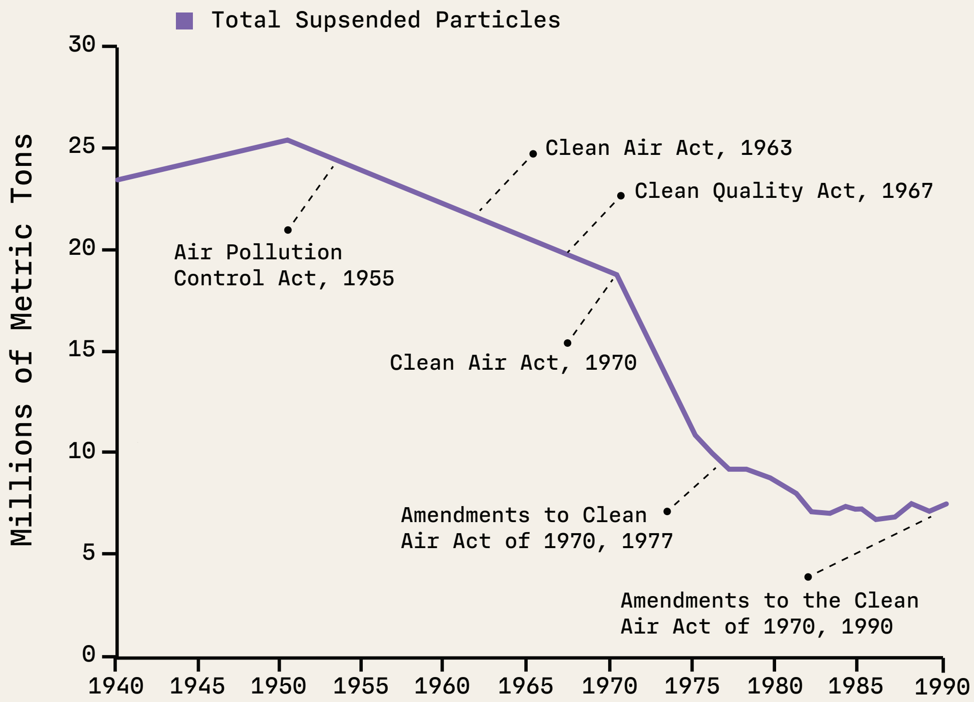


Figure 2. Trends in Major Air Pollutants Milestones, (Council on Environmental Quality)

Air Quality in the US Context

Communicating Air Quality with the Air Quality Index (AQI)

The Air Quality Index (AQI) is the primary metric used in the United States to understand the degree to which the atmosphere is carrying pollutants. The AQI is a numerical scale which presents the level of air pollution in an easy to understand way based on concentration thresholds for five "criteria pollutants" that include ground-level O3, particulate matter, carbon monoxide, nitrogen dioxide, and sulfur dioxide. As mentioned above, these pollutants are known to have harmful effects on human health and are regulated in the US under the Clean Air Act and National Ambient Air Quality Standards. Reducing air pollution is therefore an important public health priority, and efforts to reduce emissions and improve air quality can have significant benefits for public health and wellbeing.

Each AQI breakpoint is associated with a specific color, which is used in the EPA's 'Air Now' system and other public messaging to indicate daily air quality safety levels. The six AQI categories and corresponding colors are as follows: good (green), moderate (yellow), unhealthy for sensitive groups (orange), unhealthy (red), very unhealthy (purple), and hazardous (maroon). Under the AQI categories, the EPA offers broad guidelines for physical activity levels for both the general population and sensitive groups. The term "sensitive groups" pertains to populations that may encounter exacerbated symptoms due to exposure to air pollutants. These groups include individuals with cardiovascular or respiratory conditions such as asthma and COPD, children, teenagers, older adults, expectant mothers, individuals with diabetes or obesity, and outdoor workers, among others. Throughout the remainder of the report, each day in which an AQI threshold is crossed is referred to as a day of poor air quality aligning with the specific color associated with the AQI value.

AQI Color	Level of Concern	Index Value	Description of Air Quality
Maroon	Hazardous	> 300	Health Warning of emergency conditions; everyone is more likely to be affected
Purple	Very Unhealthy	201 - 300	Health alert: The risk of health effects is increased for everyone.
Red	Unhealthy	151 - 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Orange	Unhealthy for Sensitive Groups	101 - 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Yellow	Moderate	51 - 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Green	Good	0 - 50	Air quality is satisfactory, and air pollution poses little to no risk.

Table 1. The Air Quality Index includes AQI categories and colors, corresponding index values and potential health consequences (EPA)

Air Quality in the US Context

Recent Trends in Air Quality and the Emerging "Climate Penalty"

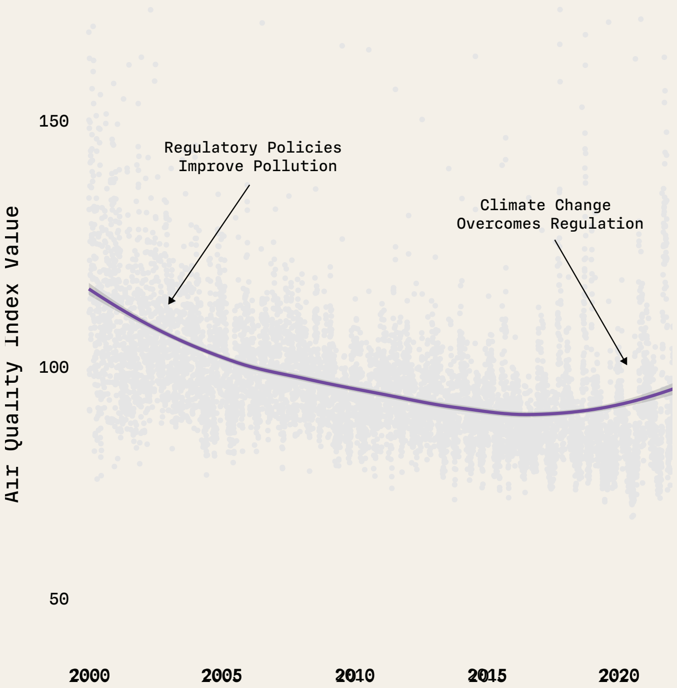


Figure 3. While anthropogenic emissions decrease, climate impacts such as PM2.5 concentrations will worsen (EPA: Hourly PM2.5 non FRM/FEM Mass)

While air quality has improved much from the first half of the 20th century, there are growing concerns that climate change impacts are undoing some of the progress the US has made through regulations and policy. This trend has been referred to as a "climate penalty", whereby changing environmental conditions are inducing negative effects and erasing progress made through federal and local regulatory policies. Changes in environmental conditions, such as extreme heat, drought, and wildfires, are influencing the levels of specific pollutants (O3 and PM2.5, specifically) which are gradually increasing, often to concentrations above safe levels in much of the country. The implications of these increasing rates of O3 and PM2.5 have been linked to respiratory and cardiovascular diseases, including asthma, chronic bronchitis, and cardiovascular problems (Dockery et al., 1993; Brook et al., 2010). As climate change continues to produce conditions conducive to the development of O3 and PM2.5 pollutants, the expectation is that these public health implications will likewise continue to grow.

Wildfires Make up a Significant Component of Worsening AQ Through Smoke

Even with significant cuts in anthropogenic emissions over the past decades, some research has projected that PM2.5 pollution will increase by as much as 50% over the next 3 decades in the Western United States (Inside climate news). Moreover, while the majority of smoke impacts local and regional populations, some wildfire smoke can travel great distances across the continent, affecting communities far beyond the immediate vicinity of the fire. So while most large wildfires occur in the West, the smoke from those fires is increasingly impacting other parts of the country.

Recently, the eastern United States has experienced a number of historically bad air quality days due to a combination of factors, including smoke from wildfires, heat events, and anthropogenic emissions. Smoke from Canadian wildfires had been particularly bad for air quality in the Northeast in 2023, where smoke caused the AQI to reach unhealthy levels in some cities. In fact, in early June of that year, the smoke from the Canadian wildfires was so bad that New York City broke its previous air pollution record by 126 AQI points, and had the worst air quality in the world (NBC News). Bad air quality days of that magnitude, while relatively uncommon on the East Coast, are projected to become more frequent in the future due to climate change, and the increasing likelihood of wildfires thousands of miles away (Inside climate news).

As such, the reversal of the regulatory-driven gains made by improved air quality standards in some areas of the US has largely been due to the increased significance of wildfires as a source of PM2.5 through the increased production of smoke (Burke et al. 2023). As climate change has led to hotter and drier conditions in many areas, wildfires have increasingly found the ideal conditions to ignite and spread. A recent First Street-led study (Kearns et al. 2022) found that the number of wildfires and thus the number of acres burned annually is likely to increase over the next 30 years in a changing climate due to impacts on wildfire fuel state, though those wildfires that do ignite will not necessarily be more severe or larger in size. As such, the prevalence of smoke has increased over recent years, and another study has shown that smoke emissions are expected to continue to increase with climate change (Melecio-Vazquez 2023).

Air Quality in the US Context

The impact of the increase in wildfire smoke emissions is especially apparent when comparing the trends of the mean and maximum concentrations of PM2.5 over the past two decades. Using historic station data from the EPA across the CONUS, Figure 3 shows that the trend of daily mean PM2.5 (hourly measurements) over the last 20 years has generally decreased due to the increased efficacy of air quality standards, and policy-driven changes such as the National ultra low sulfur diesel fuel requirement. However, in recent years this trend in concentrations has reversed, at least partially due to increases in the occurrence of severe wildfires (Burke et al., 2023). While the average of PM2.5 concentrations has mostly decreased since 2000, except for the recent uptick, the maximum values from PM2.5 have consistently worsened over the same time period. Figure 4 shows the trend of daily max measurements (hourly) and indicates that while the average levels of PM2.5 have generally improved, the peak levels of PM2.5 during specific events, such as wildfires, have continuously become more severe over the years. In fact, the figure shows that at the beginning of the current century, the average maximum value across CONUS was a borderline Orange AQI Day.

However, today the average maximum value across the country is a Red AQI Day. Simply using the qualitative scale associated with those AQI categories, the average air quality has gone from being classified as "Acceptable" to "Unhealthy" in just over 20 years of time.

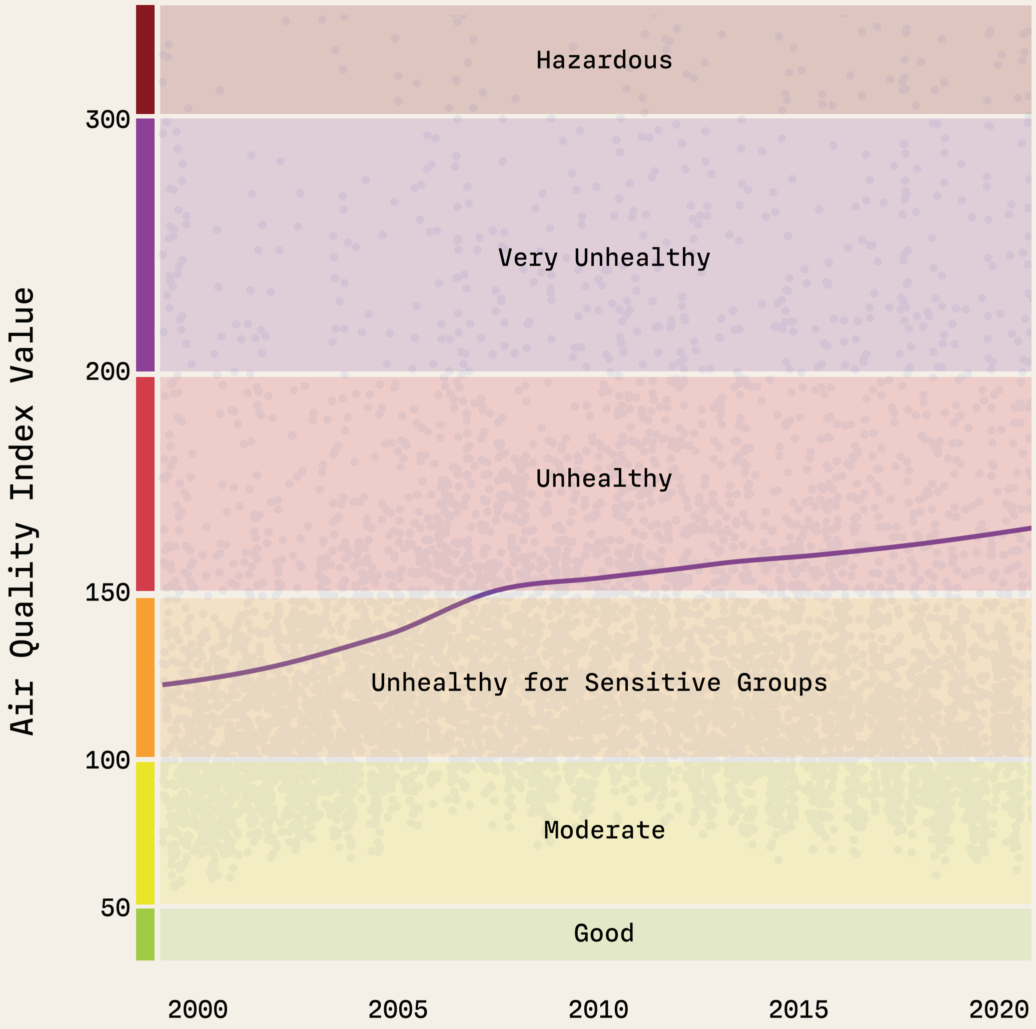


Figure 4. Time series of Max Particulate Matter (PM2.5) concentrations, 2000 - 2021 (EPA: Hourly PM2.5 non FRM/FEM Mass)

Air Quality in the US Context

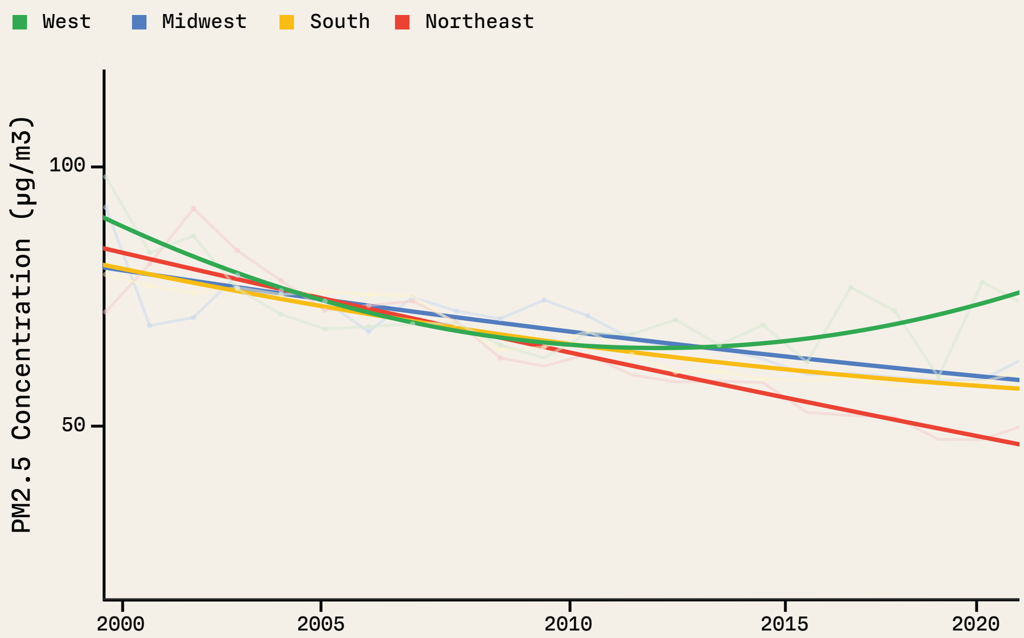


Figure 5. Regional trends in Particulate Matter PM2.5 concentrations, 2000 - 2021 (*EPA: Hourly PM2.5 non FRM/FEM Mass*)

Climate change, which is leading to hotter and drier conditions in many regions of the US, is also expected to impact the state of wildfire fuels and thus increase the frequency and extent of wildfires in the future (Abazgalou et al, 2021). This is particularly true in regions that are prone to frequent wildfires, such as parts of the western United States. The air quality in the western region of the US since 2000 varies widely depending on the specific location and time of year. However, in general, the western region of the US had higher levels of air pollution than other regions of the country due to a combination of factors such as emissions from transportation, industry, and wildfires, as well as geographical factors such as topography and weather patterns. While national air pollution levels have been increasing since 2015, they are not as poor as they were in previous decades. But, this trend upwards is not as easily controllable due to the fact that environmental factors are now more directly contributing to this increase (versus more chronic anthropogenic factors).

The rapid increase in the maximum PM2.5 values in the western region of the Contiguous United States (CONUS) illustrates how the increased prevalence of severe wildfire affects regional air quality. In recent years, the western region of the CONUS has experienced more wildfire-driven losses, driven by a combination of factors, including climate change, land management practices, and human activity. A study published in Environmental Research Letters found that wildfires were responsible for more than 25% of PM2.5 pollution in the western US between 2008 and 2012 (Fann et al., 2018). In comparison, the Northeastern region of the US has consistently decreased in PM2.5 concentration over this time period, while the Midwest and South are just starting to show signs of an emerging "climate penalty". Figure 5 shows that while all regions of the country had relatively similar poor air quality at the turn of the century, and actually saw simultaneous increases in air quality through the first decade of the 2000's, the western US has seen a sharp decline in air quality and is directly responsible for much of the climate penalty identified at the national level.

Furthermore, when focusing on the extreme levels of exposure (maximum hourly near ground surface readings each day), it is clear that the most extreme exposure has increased at a rate not seen in the average data.

Air Quality in the US Context

As evidence, one study published in 2021 (Childs et al.) found that there has been a 27-fold increase over the past decade in the number of people experiencing an "extreme smoke day," defined as air quality deemed unhealthy for all age groups. In 2020 alone, nearly 25 million people across the country were affected by dangerous levels of smoke from wildfires.

Ozone: The Emergence of Another Climate Penalty Associated With Air Quality

Along with PM2.5 from wildfire smoke, recent trends in the maximum levels of O3 indicate that there is an emerging "climate penalty" related to the most extreme cases of O3 concentrations across the US which can also be linked to the changing environment. From a climatological standpoint, increased air temperatures, i.e. heat, with associated changes in vapor pressure deficit (a measure of humidity) are expected to cause an increase in ground-level O3 levels, as heat and sunlight are essential for the formation of ground-level O3 (Wilson et al, 2022). With increased heat, there will be an increasing amount of reactions with any existing pollutant precursors, such as nitrogen oxides (NOx) and volatile organic compounds (VOCs), which creates conditions conducive to the increased potential for O3 formation in those regions that also have high levels of these precursor pollutants. These existing pollutants primarily are found in high concentrations in urbanized areas, as they are driven by anthropogenic emissions. Even if pollution levels of NOx and VOCs were to hold constant, increases heat and vapor pressure deficits from climate change are expected to cause O3 levels to increase significantly in many of those areas across the US. While O3 levels may decrease in some areas where anthropogenic input pollutants decrease, areas that see large increases in heat may still see higher levels of O3. Furthermore, the propensity for the necessary precursors to exist in urban areas means that more densely populated areas are potentially more likely to see these increases in exposure to O3 moving into the future. Figure 6 highlights these relationships and demonstrates a consistent, declining rate of mean annual O3 concentrations since the beginning of the 21st century. However, for maximum levels of annual O3, the emergence of increasing O3 concentrations, a "climate penalty", since the end of the last decade. This growth in maximum O3 levels indicates that the most severe levels of O3 are happening more often and are more severe when they do occur. Figure 7 highlights the fact that the levels of O3 across the country are dramatically different by region of the country. Similar to the distribution of PM2.5, the O3 rates are highest in the Western region of the country, where the average daily maximum values have consistently risen since the beginning of the century. In the rest of the country, the average maximum daily values are decreasing, although they are leveling off in the Midwest.

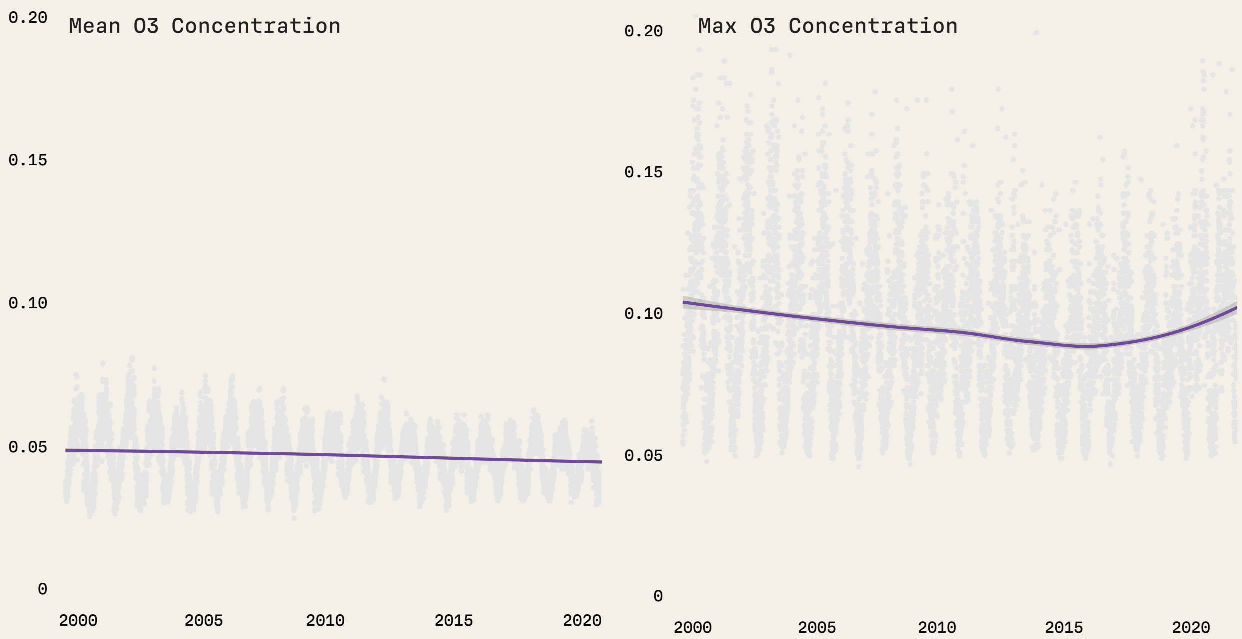


Figure 6. Time series of Ozone (O3) concentrations, 2000 - 2021

Air Quality in the US Context

Case Study: Air Quality Trends and Patterns in the Western US

Historic changes in the rates of PM2.5 and O3 concentrations across the US are being felt differently in different regions of the country. However, in both cases the severity of the risk associated with the pollutant is most pronounced when looking at the most extreme cases (maximum concentrations) in the West. The time series graphs above indicate that extreme cases of high concentrations of both pollutants are becoming more common, and, to varying degrees, are reversing the downward trend of concentrations that had been a positive outcome of Federal regulation, through the Clean Air Act and other initiatives. From these data, it is also evident that the most impacted region of the country is the West, where there is a sharp reversal of early century decreases in PM2.5 and consistently higher levels of O3. These historic results indicate that while the impacts of increasing concentrations of these pollutants is going to be more severe in a warming climate, impacts are likely to be regionally variable and affect some parts of the country more than others. As a direct result of these recent increasing rates of extreme exposure, higher rates of dangerous days are being reported via the AQI in the most impacted region (Western US). The raw data behind Figure 8 shows the increase in poor air quality days by AQI category since the year 2000. In each case the frequency of occurrence has increased, with the largest increases occurring among the worst category. From the figure it is evident that while Orange Days increased by about 1.8 times their rate in 2000, the increase was relatively flat given the higher occurrence early in the time series. On the other hand, we have seen dramatic increases in Maroon (Hazardous) and Purple (Very Unhealthy) Days over the time period. These more dramatic increases in the trend lines are associated with the more gradual increases in exposure over the 2 decade period of interest.

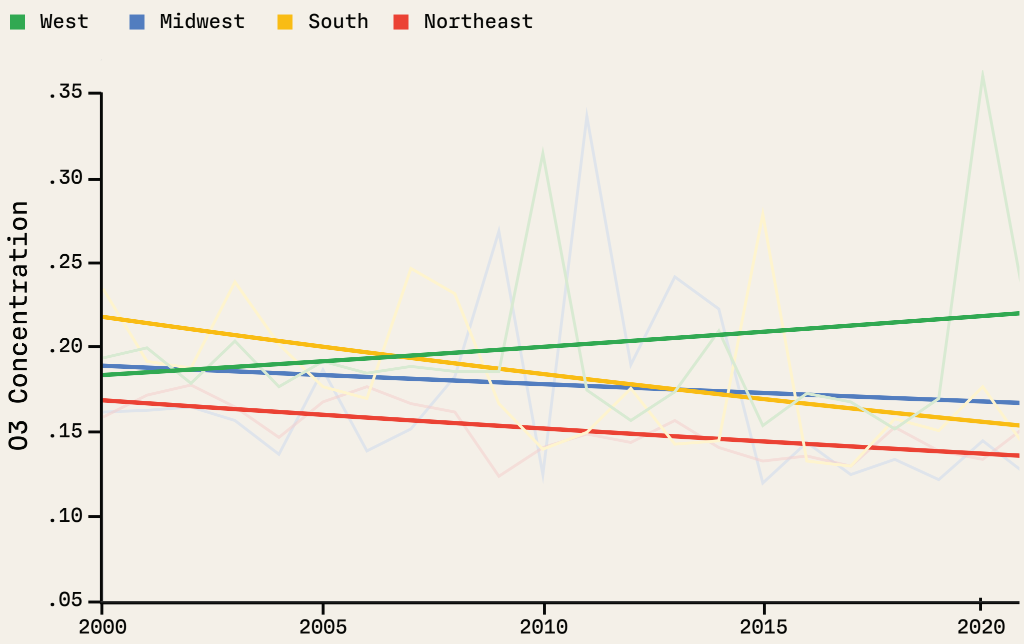


Figure 7. Regional trends in Ozone (O3) concentrations, 2000 - 2021

Air Quality in the US Context

Is California our Potential Future Under Climate Change?

Within the West region, California is perhaps "ground zero" when examining the impact of increasing PM2.5 driven by the changing environment and the increasing likelihood of wildfires. Within the state, the EPA station data demonstrate that the most extreme air quality days are happening more often, and that what was once a relatively rare event is now becoming more frequent and commonplace. From the historic record of maximum daily concentrations across the state, the previously-rare Purple and Maroon days are emerging as expected conditions at least a handful of times per year.

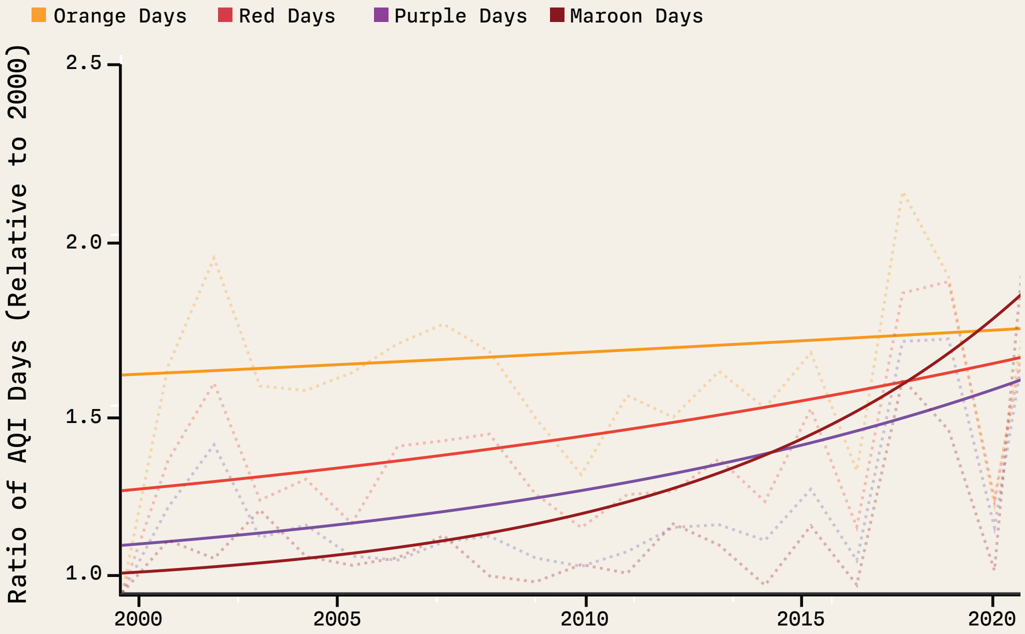


Figure 8. Regional trends in AQI days by risk category, 2000 - 2021

1.8x	1.7x	1.6x	1.9x
ORANGE DAYS	RED DAYS	PURPLE DAYS	MAROON DAYS
1.8 TIMES MORE THAN 2,000	1.7 TIMES MORETHAN 2,000	1.6 TIMES MORE THAN 2,000	1.9 TIMES MORE THAN 2,000

Air Quality in the US Context

This is alarming, as Purple and Maroon days were almost unheard of just 15 years ago, and now they occur annually and with a fairly regular cadence. Additionally, the increase in Red, Purple, and Maroon Days has come at the loss of more "moderate" Yellow and "good" Green Days. In fact, between 2010 - 2021 Green Days have decreased from 136 to 93 (-32%), Yellow Days have decreased from 200 to 146 (-27%), Orange Days have increased from 15 to 55 (+267%), Red Days have increased from 10 to 16 (+60%), Purple Days have increased from 1 to 17 (+1,600%), and Maroon Days have increased from 3 to 38 (+1,167%).

The occurrence of poor air quality in California is closely linked to the increase in wildfire risk, especially when concerning the most extreme poor air quality days within the last decade. In Figure 10, the spikes associated with those most extreme cases and the distribution seen in the previous figure (Figure 9) are closely tied to wildfires from 2017 through 2022. Although other spikes are apparent throughout the time series, it is clear that the risk has trended upward over time, drawn higher by the extreme concentrations from the increasing size, intensity, and occurrence of wildfire events.

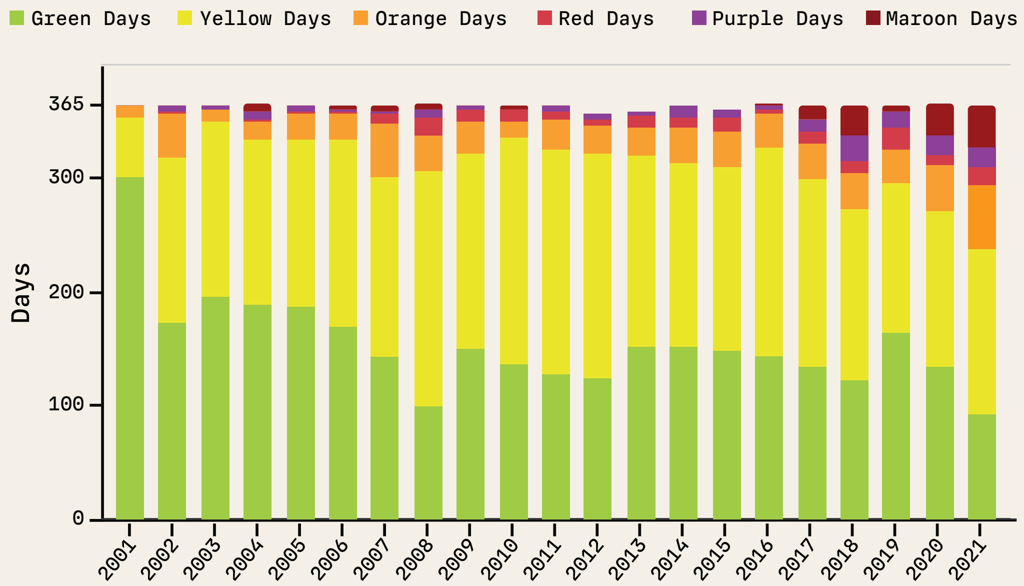


Figure 9. Distribution of max AQI reading across the state of California's EPA stations, 2000-2020

-32%	-27%	+267%	+60%	+1,600%	+1,167%
GOOD	MODERATE	UNHEALTHY FOR SOME	UNHEALTHY FOR ALL	VERY UNHEALTHY	HAZARDOUS
GREEN DAYS HAVE DECREASED FROM 136 TO 93	YELLOW DAYS HAVE DECREASED FROM 200 TO 146	ORANGE DAYS HAVE INCREASED FROM 15 TO 55	RED DAYS HAVE INCREASED FROM 10 TO 60	PURPLE DAYS HAVE INCREASED FROM 1 TO 17	MAROON DAYS HAVE INCREASED FROM 3 TO 38

Air Quality in the US Context

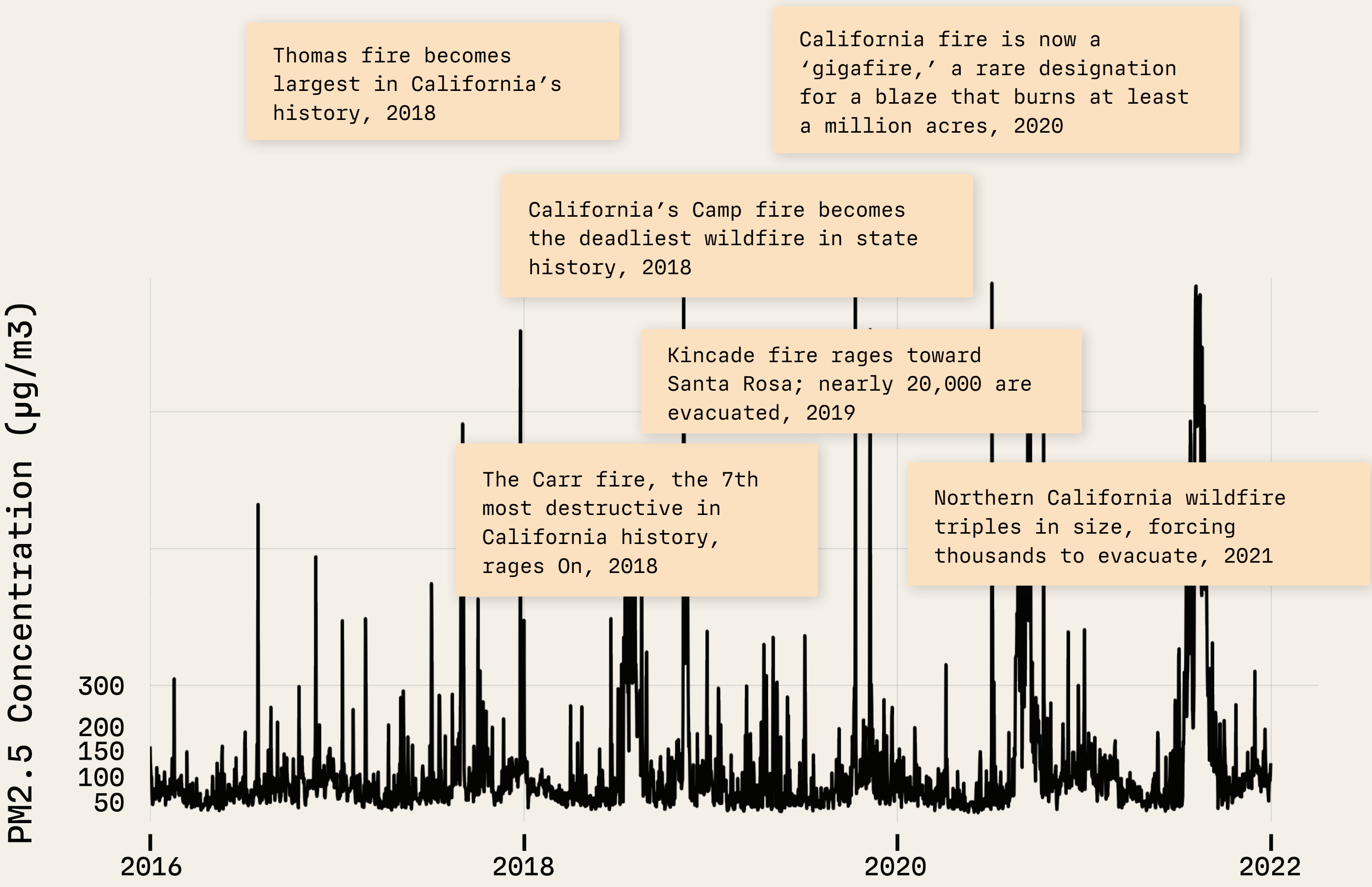


Figure 10. Time series of max PM2.5 concentrations in California, 2016-2022

Modeling the Impacts of Poor Air Quality Today and Into the Future

To understand how exposure to poor air quality will be impacted by climate change, this report introduces the First Street - Air Quality Model (FS-AQM). The FS-AQM is a probabilistic, high-resolution risk model that estimates the likely exposure to poor air quality conditions at AQI-specific thresholds, and projects changes in that exposure over the next 30 years with climate change.

Air Quality in the US Context

The FS-AQM allows for the analysis and comparison of risk now and 30 years into the future. The same hazard modeling approach for the current environment is employed in the development of future Air Quality hazard layers, which may be evaluated against current metrics to estimate the effect of a changing climate.

The FS-AQM uses open science methodologies, open data provided by the US Federal government, and additional information and support provided by state and local governments to enable the creation of valuable new information products.

As with all of the climate hazard models developed by the First Street Foundation, these data are publicly available through the Risk Factor™ website for any property in CONUS, in line with the First Street's goal of making climate risk accessible, easy to understand, and actionable for citizens, government, and industry. Property-level Air Factor™ assessments are readily available by address search to help resolve the asymmetry in access to high-quality climate risk information in the United States. Most significantly, this hyper-local resolution allows for an extremely granular understanding of risk from poor air quality, empowering communities, states, and national government actors to take steps to address current and evolving risk.

The Novel Contributions of the FS-AQM Include

High Resolution Current Risk Estimates: A national-scale, high-resolution (10km horizontal resolution) Air Quality risk model is achieved through the intersection of high-resolution hazards modeling baseline PM2.5, PM2.5 emissions from wildfire, and O3 concentrations, with property-specific statistics provided for the contiguous United States.

Future-Facing Risk: The FS-AQM allows for the analysis and comparison of risk now and 30 years into the future. The same hazard modeling approach for the current environment is employed in the development of future Air Quality hazard layers, which may be evaluated against current metrics to estimate the effect of a changing climate.

Methodology

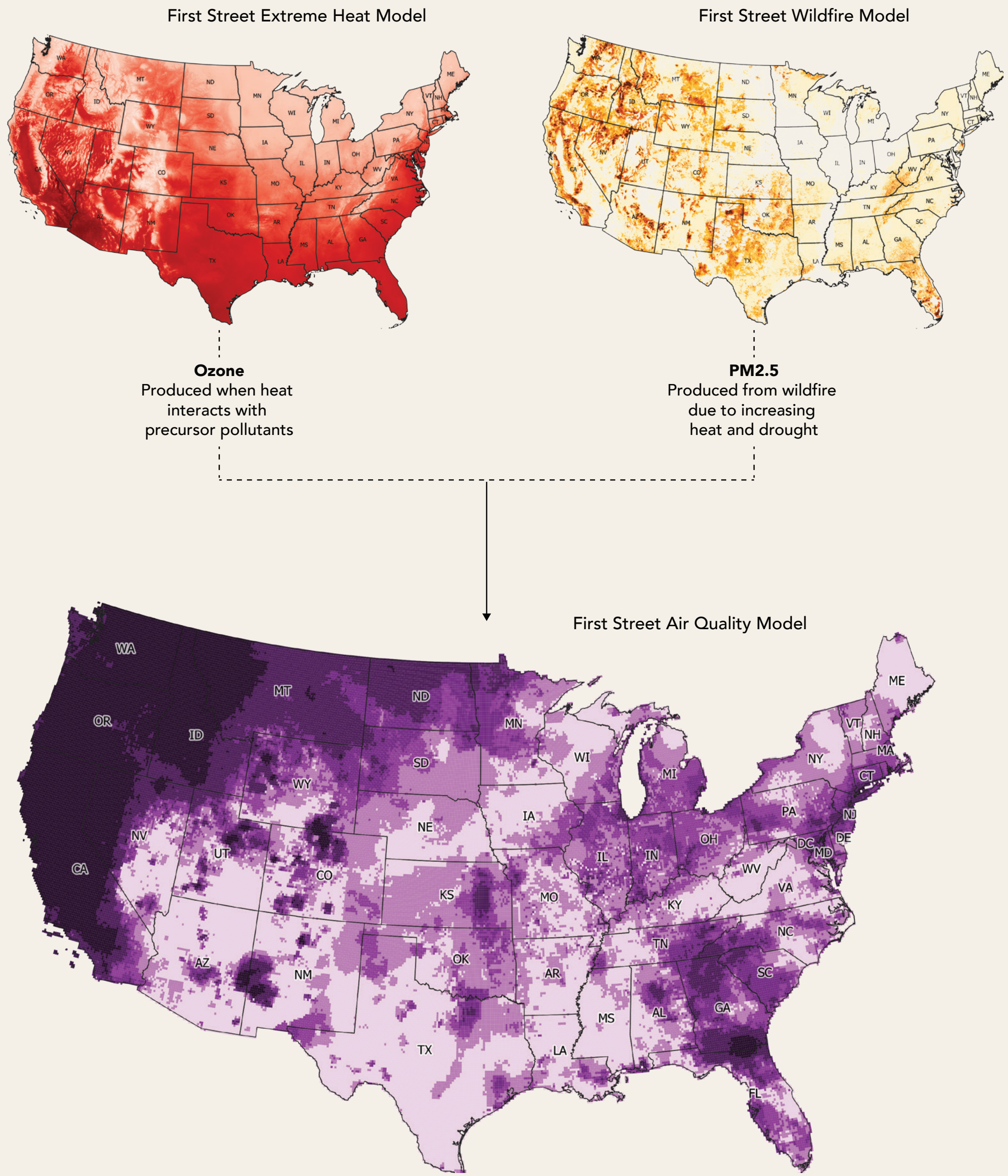
Building the First Street Foundation - Air Quality Model

In order to build the First Street - Air Quality Model (FS-AQM), multiple sources of data were compiled, analyzed, and synthesized to create a single integrated model at a high resolution. The FS-AQM is driven by concentrations of the two pollutants whose variability is most clearly linked to climate change in the scientific literature, PM2.5 (from increasing wildfire smoke) and O3 (changes in air temperature and humidity). The model also includes a baseline level of anthropogenic PM2.5 to account for high levels of risk from anthropogenic sources like high density manufacturing, power plants, automobiles, and other drivers of non-climate related PM2.5 levels (EPA, 2023). The following section documents the collection, analysis, and integration of the data describing the variability of these sources of pollutants into the FS-AQM.

PM2.5 from Wildfire Smoke

Wildfire emissions, along with other anthropogenic and biogenic emissions, are represented in the EPA's Air Quality Time Series (EQUATES) Project modeled PM2.5 concentrations alongside O3. However, there are known limitations in modeling wildfire smoke in climate chemistry models. As a result, climate chemistry model output of wildfire PM2.5 can differ significantly from ground observations.

Therefore in the FS-AQM, with a focus on proper attribution of wildfire PM2.5, the daily gridded wildfire smoke PM2.5 concentration dataset from Childs et al. (2022) is used in combination with simulated ELMFIRE fire emissions (Kearns et al. 2022; Melecio-Vázquez et al. 2023) to characterize current and future impacts to air quality conditions for CONUS due to PM2.5. The Childs et al. (2022) data, which are openly available via Github, were produced using a machine learning model that combines ground, satellite, and reanalysis data sources. The data are calculated on a 10 kilometer grid across CONUS between the years of 2006 and 2020.



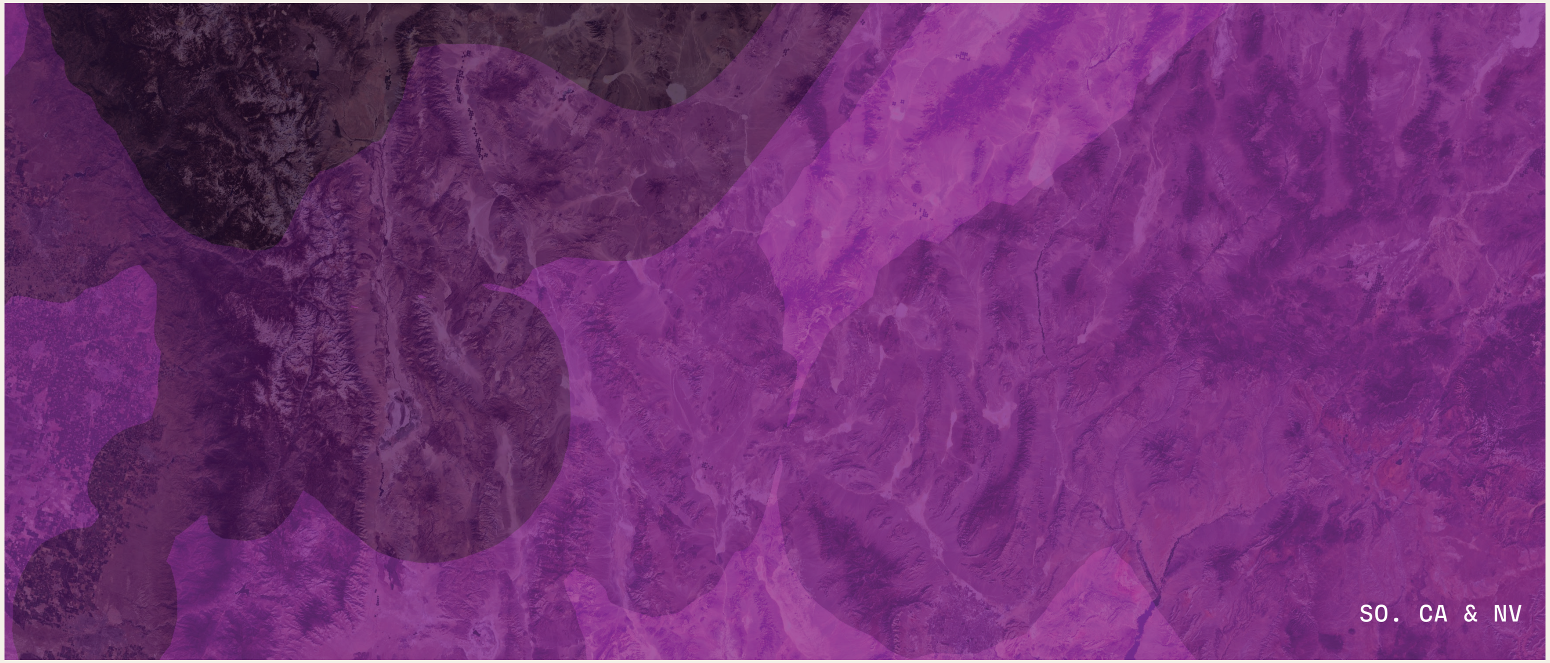
Methodology

To calculate annual Orange+ Days using the Childs et al (2022) data, the daily concentration data is first processed with a gaussian filter. Baseline anthropogenic concentrations are then added to the daily smoke PM2.5 estimates and the number of total number days above the Orange Day threshold for each year are summed. This accounts for the fact that the AQI is calculated off total PM2.5, not just the wildfire smoke contributing portion, and should thus also consider non-smoke sources. From this annual count of Orange+ Days per year due to PM2.5, the average and maximum number of Orange+ Days annually are derived across the entire time range. The 'maximum' year is a helpful additional characterization in this context because wildfire time series have a high frequency of zero concentration days, and Orange+ Days tend to be heavily concentrated in specific years with heightened fire activity.

To estimate how air quality due to wildfire-driven PM2.5 may evolve with climate change in the future, the FS-AQM model leverages the output from First Street's wildfire modeling effort. The wildfire modeling used a Monte Carlo simulation approach to drive a wildfire behavior model at 30m horizontal resolution (Kearns et al. 2022). Simulations were also conducted using future atmospheric conditions. For each simulated wildfire, information on the PM2.5 mass emitted was retained to allow for estimated changes in current and future conditions.
To model potential changes in poor air quality days at ground-level from the larger number of fires anticipated in the future, a "change factor" approach using the ratio of future emissions to current emissions was used. To calculate the change factor, small fires that are less likely to have a large effect on Orange+ day occurrence were filtered out. The remaining fires were aggregated in 48 km bins defined by the underlying fire model and used to calculate the average mass of PM2.5 released in current (2024) and future (2054) simulations. In doing so, these average masses of emitted PM2.5 focus on local wildfire effects and do not incorporate any advection in or out of adjacent 48 km bins. This focus recognizes the dominance of local fires on ground-level PM2.5 conditions and is aligned with other studies that indicated that 80% of wildfires' emissions are injected into the local atmospheric boundary layer instead of reaching higher layers at which advection over larger distances may occur.

Ozone Concentrations

The FS-AQM's O3 component concentrates on extreme O3 concentrations, which are calculated under the O3 Maximum Daily Average 8-hour (MDA8) National Air Quality Standards (NAAQS). The MDA8 values are the highest eight-hour mean O3 concentration recorded during a day.



Methodology

To simulate O3 concentrations, a non-stationary Point Process Extreme Value Theory model is utilized, which relates extreme O3 levels to meteorological conditions. The model sources O3 concentration data from two locations: reference air quality stations involved in the EPA Air Quality System (AQS) data program and EPA Community Multiscale Air Quality (CMAQ) modeling results from EQUATES (EPA's Air Quality Time Series Project).

CMAQ is an advanced modeling platform that uses atmospheric science and air quality modeling to track pollution movement over time and measure pollutant concentrations across spatially continuous grid cells and vertical layers. However, there have been noted biases in the CMAQ model results. To address this, FSF combined station observations and climate-chemistry model output into a consistent daily gridded O3 concentration estimates adjusted to ground-level observations to remove any biases in the model outputs. These data sources are then combined with a statistical model.

The FS-AQM O3 component uses a consistent set of daily meteorological covariates from the University of Idaho Gridded Surface Meteorological Dataset (GridMET), which have a spatial resolution of approximately four kilometers (Abatzoglou, 2013). Based on prior work establishing meteorological relationships with O3 formation (Wilson et al., 2023), maximum temperature, minimum humidity, and vapor pressure deficit data were used for model fitting. Daily observations were downloaded for the years which match the O3 observations and resampled onto a 10 km grid using a weighted average of each covariate value. A model was then trained using the meteorological relationships identified above at the site of the in-situ station observations, which were then used to extrapolate O3 concentrations continuously across the US.

Projecting O3 and Particulate Matter 2.5 with Future Climate Conditions

In order to project O3 and PM2.5 into the future, the FS-AQM relied on existing future smoke projections and downscaled Global Climate Models (GCMs). For the projection of PM2.5, the extrapolation requited the application of the ratio of future to current emissions as a multiplier to the daily PM2.5 wildfire concentrations from Childs et al. (2022) to create a representative 2050s time series, and repeated the summation of Orange+ AQI days to estimate the likely number of such days under future climate conditions. The future O3 projections were created by generating mid-century (~2054) O3 weather by statistically adjusting the 2006-2019 GridMET data to reflect the distribution changes between current and future conditions across an ensemble of 12 downscaled GCMs. Modeled projections are corrected by adjusting them with statistical scaling factors derived between current and future model output. This process preserves the underlying variability in the current time series while shifting the overall trend towards a future climate.

Baseline Particulate Matter 2.5

Finally, while wildfire smoke is increasingly a significant contributor to PM2.5 concentrations, PM2.5 also forms due to anthropogenic sources such as industrial facilities and transportation which poses a significant health risk. To communicate risk from anthropogenic (baseline) PM2.5, historical CMAQ output data and gridded smoke estimates are jointly processed to calculate average PM2.5 concentrations across CONUS exclusive of wildfire smoke days.

First, to process the data a cap is implemented on daily PM2.5 concentrations at 1,400 µg/m3 to account for a known error in wildfire ignitions in CMAQ output. The CMAQ output is then combined with EPA station observations to reduce biases in underlying CMAQ model output. "Smoke days," defined by non-zero values in the Childs et al dataset are matched to the CMAQ grid to be excluded from the fused CMAQ output. This removed a majority of wildfire activity, but some clear fire activity remained due to methodological differences between the two data products. To account for this, a median filtering process is applied to the daily data to remove the remaining large spikes. The remaining PM2.5 values are smoothed across pixels. The output is then used to calculate a yearly baseline PM2.5 concentration and the number of Orange+ Days.

This baseline PM2.5 data is held constant throughout present day and future projections, and is added to the modeled smoke caused PM2.5 and O3 data for the current year and 30 years in the future. On its own, baseline PM2.5 may reach Orange Day conditions relatively frequently in some areas across the United States, but does not commonly reach Red Day conditions. In combination, the modeled baseline PM2.5, smoke-derived PM2.5, and O3 hazards create the components of the full FS-AQM.

National Trends in Poor Air Quality Exposure

Variations in the Type of Air Quality Risk

All parts of the country are impacted by poor air quality at least occasionally. Figure 11 maps the dominant pollutant in each area based on the maximum level of pollutant-specific concentrations. Across the western and most southeastern portions of the United States, PM2.5 is the dominant air pollutant, with most of those areas seeing the greatest impacts from wildfire smoke. Throughout the middle and eastern portions of the country, O3 is the primary pollutant for many areas due to the high amounts of precursor anthropogenic pollutants and the high level of vulnerability to extreme heat events. Additionally, many urban areas report higher risk to poor air quality from O3 than PM2.5, including Atlanta, Charlotte, Houston, Dallas, and much of the Northeast urban corridor from Washington DC to Boston. In other areas, like Chicago, Memphis, Nashville, and St. Louis there exist equal levels of risk to poor air quality from both sources. Finally, there are areas throughout Iowa, Texas, the Mississippi-Arkansas-Louisiana area, and the Appalachian Mountain states where the models do not find a predominant poor air quality contributor.

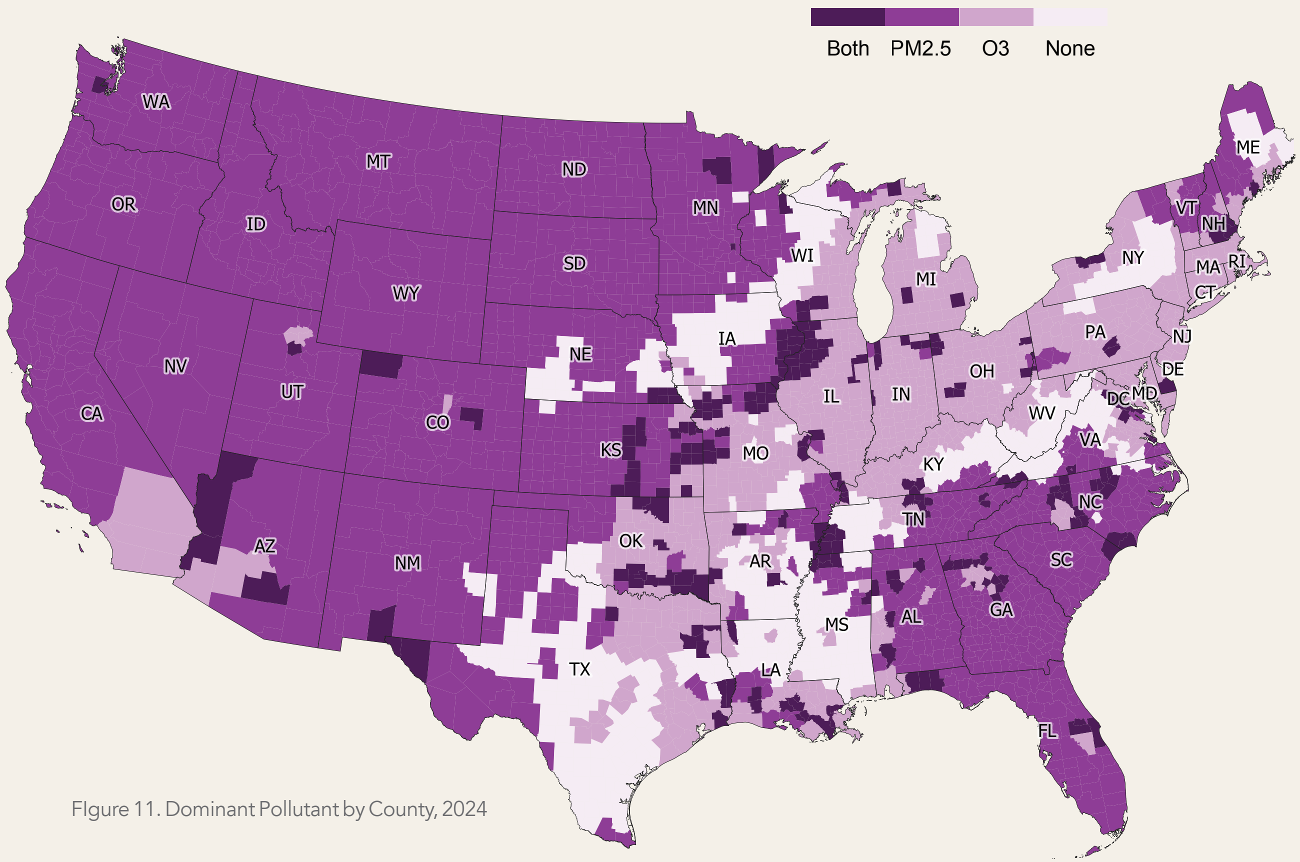


FIgure 11. Dominant Pollutant by County, 2024

National Trends in Poor Air Quality Exposure

In the places with the most frequent occurrence of risk from Orange+ Days, PM2.5 is the predominant driver of poor air quality. However, where there are low maximum annual counts (~less than a week) of potential Orange+ Days, more properties nationwide are impacted by O3 than PM2.5. Some of this discrepancy has to do with the character of the two pollutants and the conditions required to produce them. While O3 concentrations are driven by precursor pollutants and atmospheric conditions over longer time periods, PM2.5 is driven by wildfire events that are highly episodic and often severe in their impact on air quality. Figure 12 highlights the fact that a large number of properties see low to moderate poor air quality risk from both O3 and PM2.5, but there also exists a significant number of properties with exposure to more persistently bad air quality lasting for over a week or more. In total, there are almost 14.3 million properties in the US that the FS-AQM estimates to have a week or more of Orange+ Days today, solely from PM2.5 in the current climate conditions. This makes up almost 10% of all properties across the US. Of those, almost 5.7 million properties may experience two or more weeks (14+ days) annually of smoke driven Orange+ Days (or about 4% of all properties in the US). In comparison, there are about 2 million properties which may experience a week or more of O3 driven Orange+ Days (1.4% of all properties) with over 859,000 properties may experience two or more weeks annually of Orange+ Days due to O3 alone (about 0.6% of all properties).

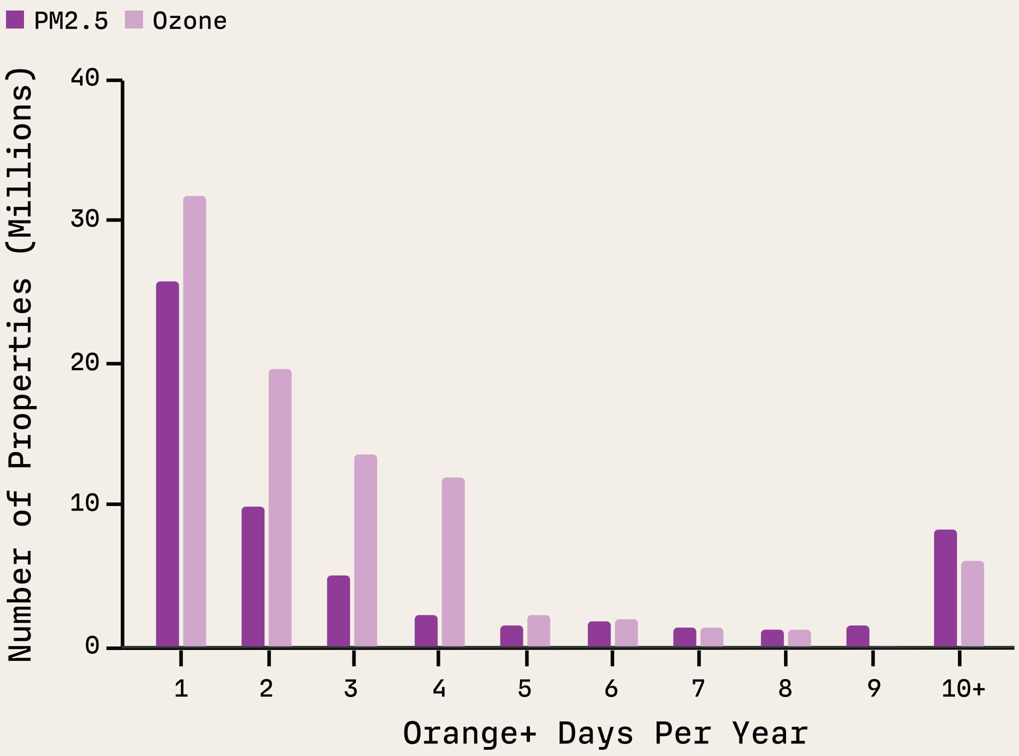


FIgure 12. Number of properties by number of Orange+ Days, 2024

National Trends in Poor Air Quality Exposure

Smoke (PM2.5) Risk Across the US

Given the propensity for the most persistent exposure to be driven by wildfire-sourced PM2.5, Figure 13 displays the average number of Orange+ Days, by county, that are estimated based on the current climate conditions (2024). The spatial distribution highlights the fact that many areas along the West Coast, from California through Oregon and Washington are most at risk of seeing persistent and frequent exposure to high numbers of unhealthy air quality days. Additionally, there are pockets in Idaho, Montana, and along the Colorado-Wyoming border where as much as three weeks worth of high PM2.5 exposure can be expected in today's climate. Outside of the West, there are pockets throughout the Southeast where there is a potential for a high frequency of Orange+ Days. The most pronounced is along the Florida-Georgia state border on the east side of both states. This area is similar to the West in the sense that it has a history of relatively frequent wildfires, the primary source for these PM2.5 concentrations.

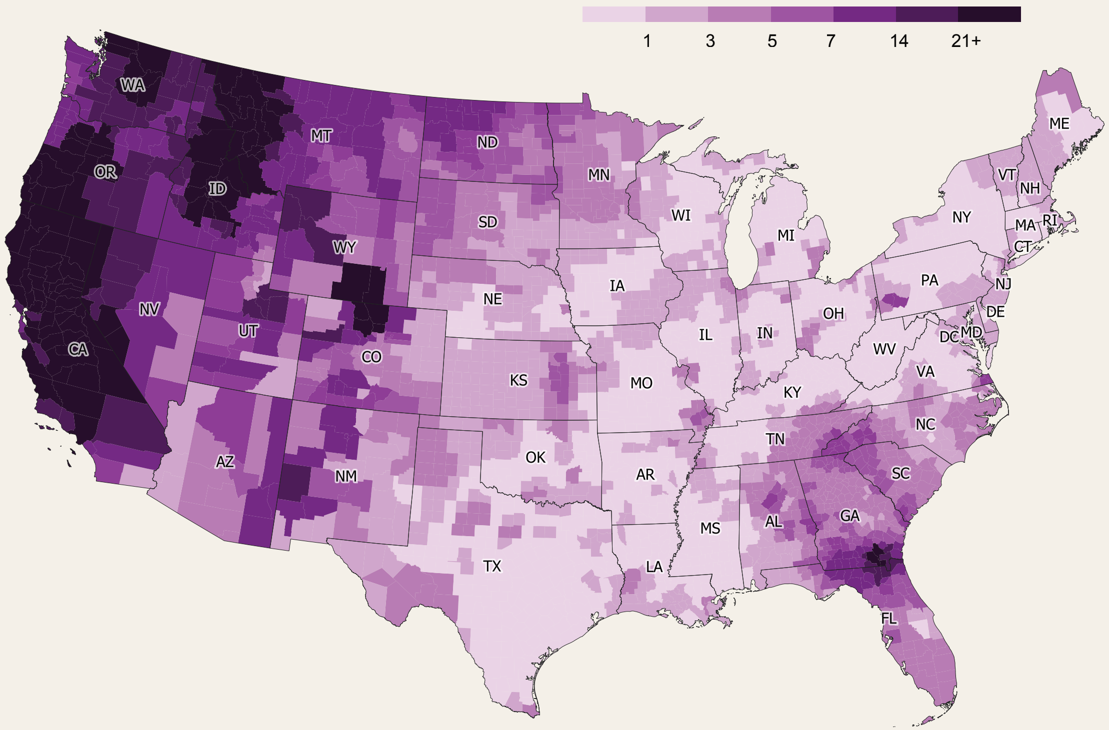


Figure 13. Orange Plus Days from Wildfire Induced Smoke (PM2.5), 2024

State	County	Orange+ Days 2024	Orange+ Days 2054	Difference
CA	Fresno	66	69	3
CA	Tulare	66	67	1
CA	Kern	40	40	0
CA	Sonoma	36	37	1
OR	Marion	35	38	3
CO	Larimer	34	36	2
OR	Deschutes	33	34	1
OR	Lane	33	33	0
CA	Placer	32	34	2
CA	El Dorado	31	34	3

Table 2. Top counties by current (2024) number of smoke Orange+ Days
* Counties with at least 100k Properties

National Trends in Poor Air Quality Exposure

Again, the areas with the most risk in terms of the highest estimated number of PM2.5 driven Orange+ Days under the current climate and future climate projections (in 30 years) are concentrated in the West, with the top ten counties all within California, Oregon, and Colorado (when limiting to counties with at least 100,000 properties). The counties expected to see the most Orange+ Days in today's environment are topped by Fresno, CA (66 days) and Tulare, CA (66 days). This indicates that these two counties will see over 2 months of poor air quality today due only to PM2.5. Other CA counties making the top 10 list include Kern (40), Sonoma (36), and Placer (32), and El Dorado (31) Counties. Each of these counties is expected to see over 30 days in which at least one hour of the day reaches the threshold for a poor air quality day, categorized as an Orange+ Day. In the most extreme cases, Fresno and Tulare Counties are expected to see this level of poor air quality nearly 20% of the year, or over two months' worth of days. The spatial patterns associated with the growing risk exposure to poor air quality over the next 30 years highlights the most growth in the northwestern parts of the country. In particular, the states of Washington, Oregon, Idaho, Montana, Nevada, and Wyoming are expected to see some of the largest increases in Orange+ Days into the future due to the projected increase in wildfire exposure in the area. This is particularly true given other related climatological expectations in the regions where temperatures are expected to continue to increase and drought is expected to persist. It's also worth noting the increases in risk that show up in the Southeastern portions of the CONUS due to projected increases

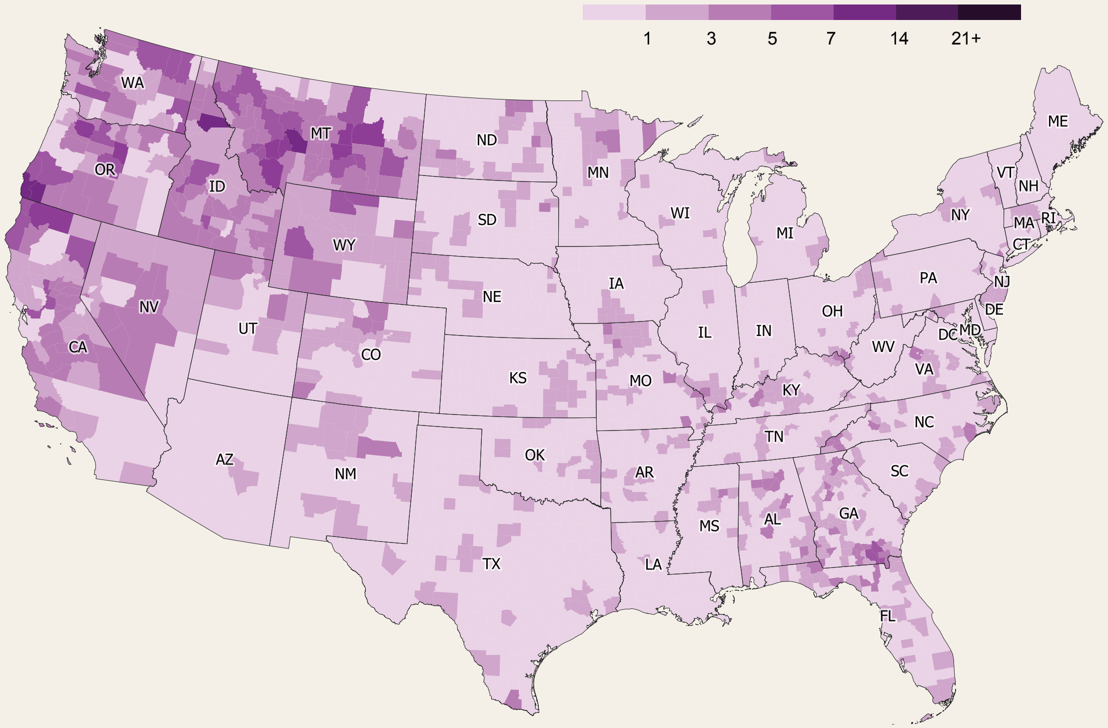


Figure 14. Difference in Orange Plus Days from Wildfire Induced Smoke (PM2.5), 2024-2054

State	County	Orange+ Days 2024	Orange+ Days 2054	Difference
OR	Clackamas	22	28	6
CA	Sacramento	27	31	4
CA	Contra Costa	19	23	4
WA	Pierce	21	24	3
CA	Fresno	66	69	3
CA	El Dorado	31	34	3
WA	King	19	22	3
WA	Whatcom	31	34	3
CO	Boulder	22	25	3
OR	Marion	35	38	3

Table 3. Top counties by increase in number of smoke Orange+ Days
*Counties with at least 100k Properties

National Trends in Poor Air Quality Exposure

in wildfire in those areas as well. In fact, the Southeastern US is both the 2nd most fire prone region historically and the area most expected to see increases in that risk outside of the West.

Among places with at least 100,000 properties, the counties which are expected to experience the greatest increase in the number of Orange+ Days over the next 30 years due solely to PM2.5 from wildfire smoke include Clackamas County, OR (+6), Sacramento County, CA (+4), Contra Costa County, CA (+4), Pierce County, WA (+3), Fresno County, CA (+3), El Dorado County, CA (+3), and King County, WA (+3). Each of these counties contains a significant population and are expected to see nearly one-week of additional poor air quality in the worst cases. Of particular note here is the fact that some of these areas contain large population centers, including Sacramento, Fresno, Seattle, and suburban San Francisco.

These cities are all likely to see increasing exposure and the potential downstream effects on human health, labor force productivity, and even migration patterns. Learning to live with wildfires, or suppressing their activity, is going to be paramount to the quality of life in many of these communities into the future.

O3 Risk Across the US

While not as well-known as PM2.5 exposure to wildfire smoke, O3 driven Orange+ Days are also a serious health concern and a driver of significant poor air quality in some parts of the country. Spatially, the risk is less concentrated in the Northwest and spreads further across much of the Midwest and Northeast regions of the

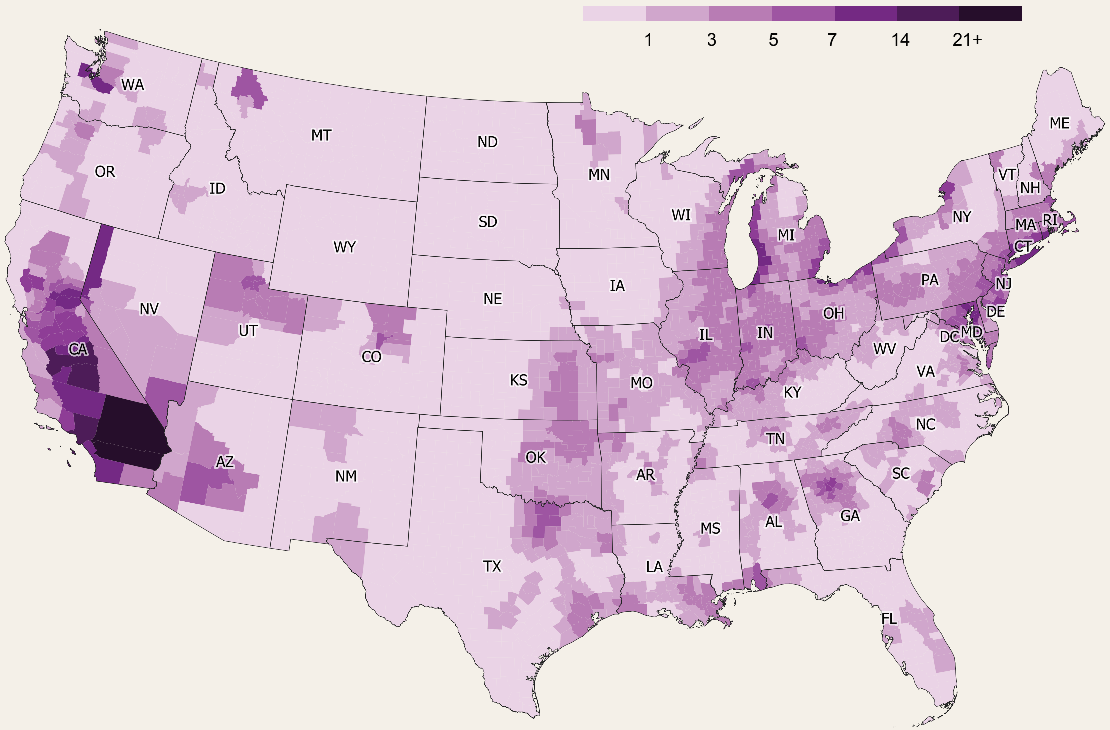


Figure 15. Orange Plus Days from Ozone (O3), 2024

State	County	Orange+ Days 2024	Orange+ Days 2054	Difference
CA	San Bernardino	27	36	9
CA	Riverside	26	33	7
CA	Los Angeles	21	27	6
CA	Tulare	17	23	6
CA	Fresno	16	21	5
CA	Kern	13	18	5
CT	Fairfield	13	18	5
NY	Suffolk	13	18	5
WA	Pierce	10	19	9
NV	Washoe	10	15	5

Table 4. Top counties by current number of Ozone (O3) Orange+ Days
*Counties with at least 100k Properties

National Trends in Poor Air Quality Exposure

country. That being said, the areas with the most at risk extreme level of poor air quality due to O3 exposure are in Southern California. In a bad year under the current climate conditions, some counties (San Bernardino) may experience as many as 27 O3 driven Orange+ Days. With increased heat conditions, this increases to as many as 36 potential O3 Orange+ Days in 30 years.

In fact, among those counties with the greatest number of Orange+ Days due to O3 exposure, the top 6 are all from California and include San Bernardino, Riverside, Los Angeles, Tulare, Fresno, and Kern Counties. For this group of counties, the projected exposure to poor air quality days from O3 ranges from about 2 - 3 weeks a year. Unlike PM2.5, O3 has a more geographically dispersed impact across the country with Fairfield County, CT (13 days) and Suffolk County, NY (13 days) also seeing significant impact among those counties with at least 100k properties. The overall geographic pattern further highlights the fact that the Midwest and Northeast have significant levels of risk of poor air quality from O3, along with pockets in the Great Plains, the Deep South, and the Gulf Coast.

The counties expected to see the greatest increase in the number of O3 driven Orange+ Days between the current year and 30 years in the future are also spread across the West, Midwest, and Northeast regions of the country. Additionally, there are 426 counties which may see air quality levels from O3 worsen enough to cause an Orange+ Day in the future that do not have any such risk in the current environment.

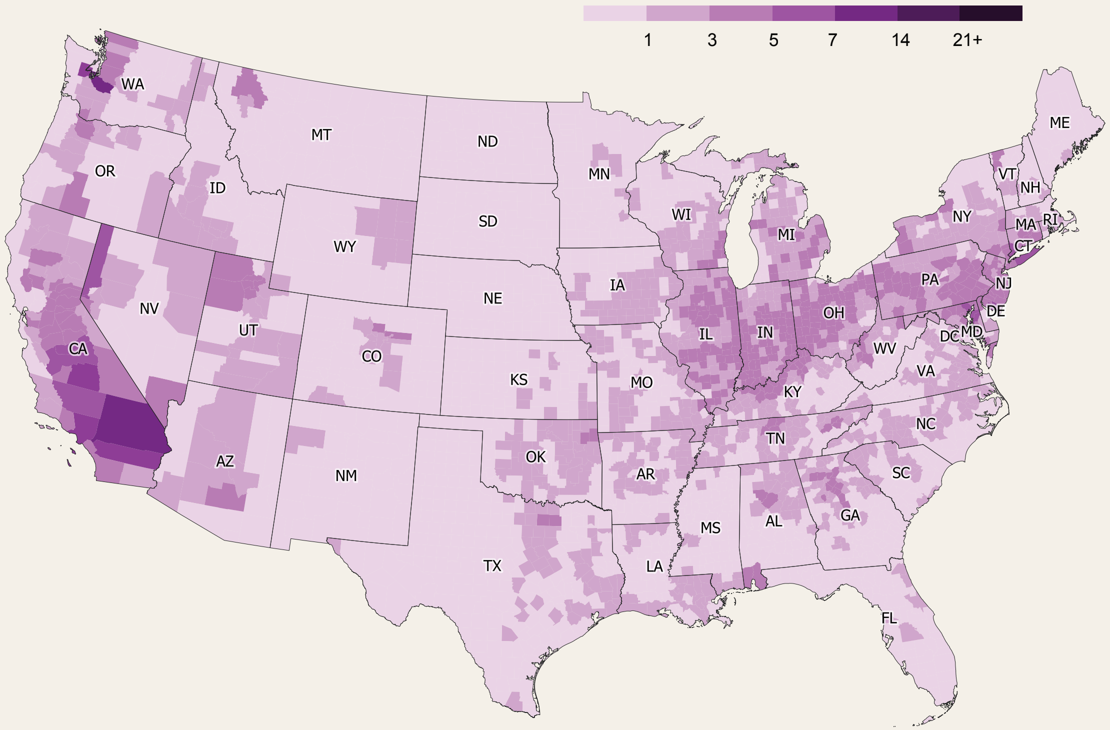


Figure 16. Difference in Orange Plus Days from Ozone (O3), 2024-2054

State	County	Orange+ Days 2024	Orange+ Days 2054	Difference
CA	San Bernardino	27	36	9
WA	Pierce	10	19	9
CA	Riverside	26	33	7
CA	Los Angeles	21	27	6
CA	Tulare	17	23	6
CA	Fresno	16	21	5
CA	Kern	13	18	5
CT	Fairfield	13	18	5
NY	Suffolk	13	18	5
NV	Washoe	10	15	5

Table 5. Top counties by increase in number of Ozone (O3) Orange+ Days
*Counties with at least 100k Properties

National Trends in Poor Air Quality Exposure

These single days of exposure generally do not pose much of a health risk, but do indicate the ubiquitous nature of poor air quality projections into the future and the fact that no part of the country will be immune from at least some risk.

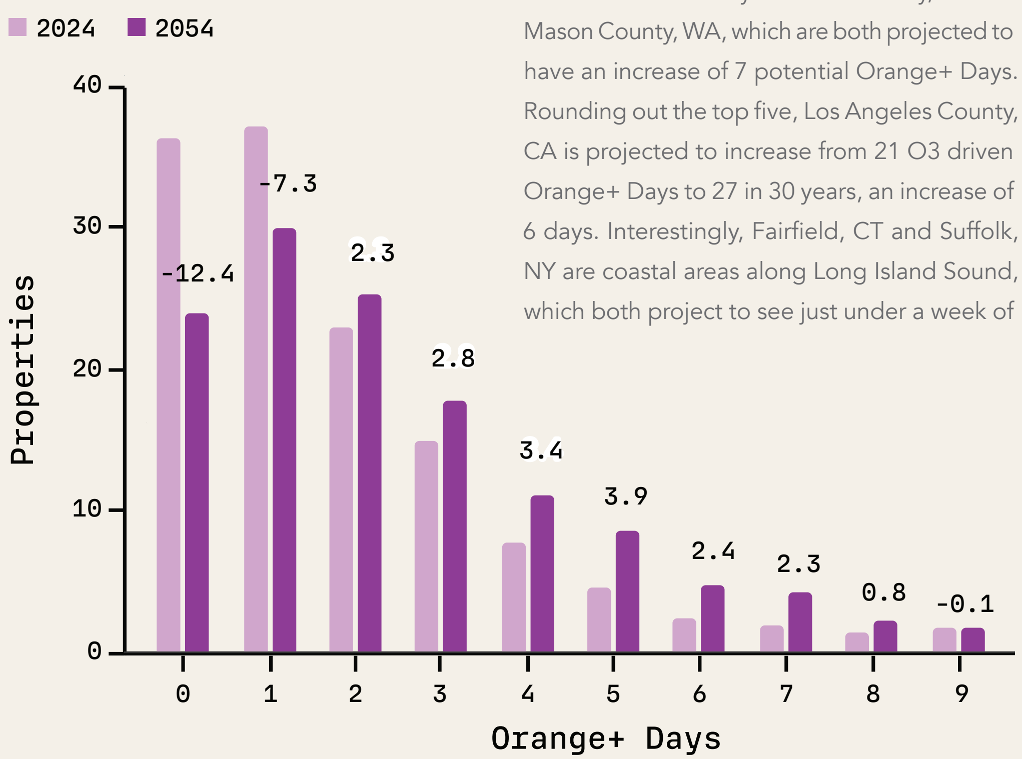


FIgure 17. Change in number of properties by number of Orange+ Days from all sources, 2024 - 2054

The top 10 counties with the greatest increase in O3 driven Orange+ Days are located in California, Washington, Connecticut, and New York. Topping the list, San Bernardino County, CA, and Pierce County, WA will both see a 9 day increase in the maximum amount of Orange+ Days from O3. This is followed by Riverside County, CA and Mason County, WA, which are both projected to have an increase of 7 potential Orange+ Days. Rounding out the top five, Los Angeles County, CA is projected to increase from 21 O3 driven Orange+ Days to 27 in 30 years, an increase of 6 days. Interestingly, Fairfield, CT and Suffolk, NY are coastal areas along Long Island Sound, which both project to see just under a week of additional poor air quality from O3 exposure. While the FS-AQM only projects out 30 years, the trends indicate that the Midwest and Northeast are areas of the country that are likely to see persistent issues further into the future from O3 exposure and increasing risk from poor air quality from that source.

Combined Risk (PM2.5 + O3) Across the US

While understanding the contributions and spatial distribution of risk from both PM2.5 and O3 is important, it is equally, if not more important to understand how these contribute to overall changes in air quality risk. Different parts of the country will see different impacts to air quality; areas with nearby wildfire risk will see increases in PM2.5 air pollution from smoke, and areas with increasing heat conditions will see increases in O3. Additionally, there are many parts of the country with mixed impacts which will see increases from both. Understanding how these individual risks for the current year and future year contribute to overall air quality levels, as well as how different regions change, is important for a holistic understanding of risk.

Projected Changes in Combined Risk Into the Future

When examining the change in the exposure of properties to poor overall outdoor air quality, categorized as Orange+ Days, over the next 30 years, the results indicate more frequent exposure. In fact, the share of properties at risk of zero Orange+ Days is estimated to decrease from over 36 million today to about 24 million over that time period, a decrease of about 34%. Similarly, those at risk of a single Orange+ Day is estimated to decrease from over 37 million to about 30 million, a decrease of almost 20%. On the other hand, that decrease indicates that most other categories will see an increase in the proportion of properties estimated to be exposed to poor air quality.

At the most extreme end of the distribution, the share of properties experiencing 10 or more Orange+ Days a year is expected to increase by nearly 15%, growing from under 12 million properties to over 13 million properties over the 30 year period.

National Trends in Poor Air Quality Exposure

That is, over this time period, over 1.7 million additional properties will experience poor air quality, and the negative effects associated with that exposure, at least a week and a half every year.

The counties with the greatest expected increases in the number of Orange+ Days are primarily driven by PM2.5, and are located in the West. While there are significant increases in some areas due to O3 over the next 30 years, O3 tends to be limited in how much it can increase due to the reliance on the presence of many precursor pollutants. In comparison, PM2.5 does not rely on those multiple precursors, and can be expected to see much more drastic increases in the number of Orange+ Days from wildfire smoke events. Similar to the results when examining PM2.5 and O3 independently, the highest levels of risk to poor air quality exist in the Western portion of the US and are disproportionately driven by exposure to PM2.5, often from wildfire smoke.

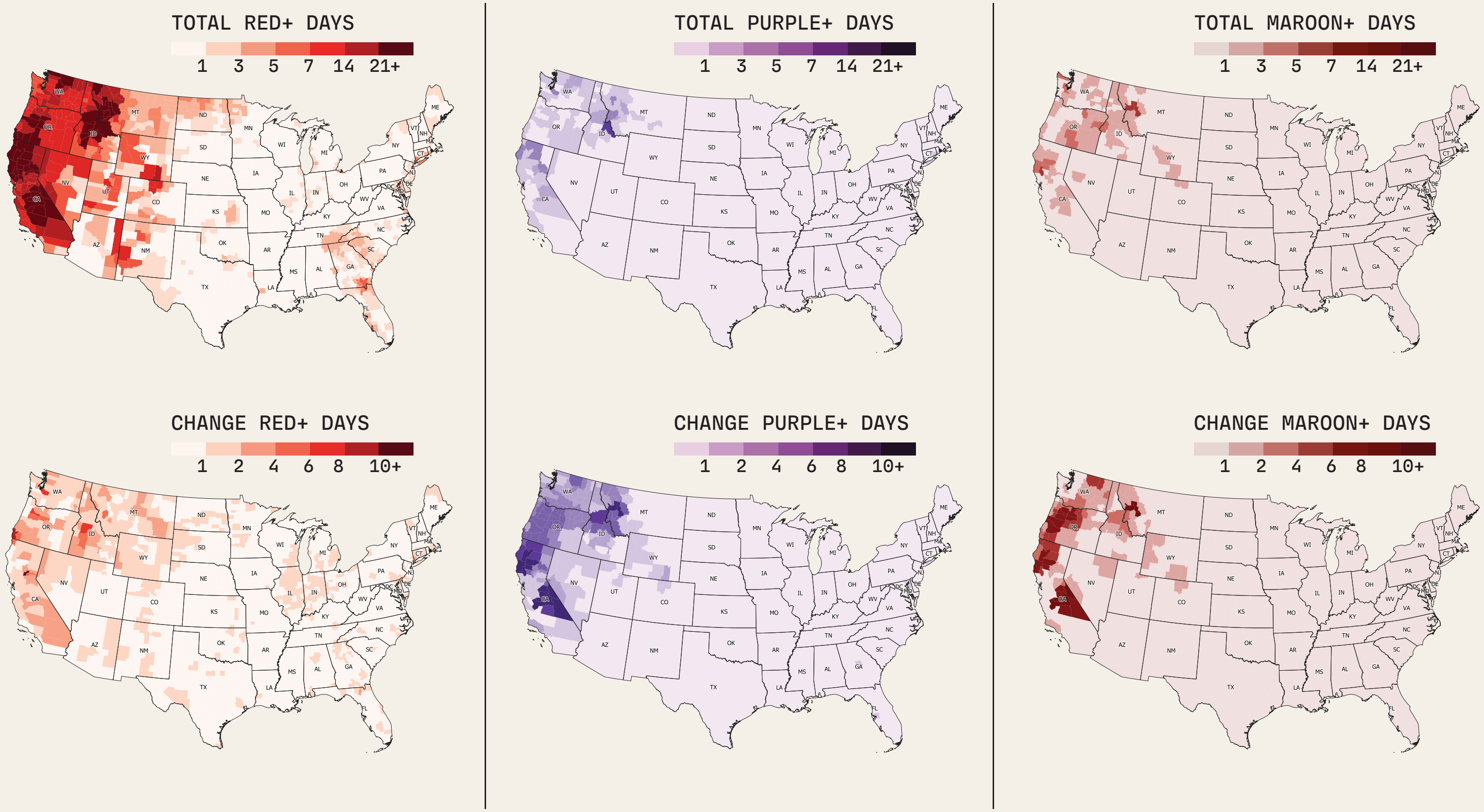


FIgure 18. Total number of days above AQI threshold, 2024-2054

National Trends in Poor Air Quality Exposure

This is further highlighted when examining Red+ Days (more severe than Orange+ Days) where the overall pattern of risk shifts from one that affects the entire country to one that is squarely centered on the West. There are pockets of risk in the Southeast, Northeast, and Midwest; they are almost lost in comparison to the dramatic risk that exists across the West. In fact the counties with the highest absolute risk today (Tulare, CA; 83 Orange+ Days), into the future (again Tulare County, CA; 90 Orange+ Days), and with the largest change (Pierce County, WA; +12 Days) highlight the region's exposure.

The top ten counties with the most increase in Orange+ Days between the current climate conditions and 30 years in the future are mostly clustered on the West coast. These top ten counties are within Washington, California, Idaho, Oregon, and Nevada. Topping the list is Pierce County, WA which increases from 31 total Orange+ Days to 43 over the next 30 years (+12 days). This is followed by San Bernardino County, CA, with an increase of 9 days from 45 Orange+ Days in the current year. Tied with San Bernardino by most increase (+9 days) is Clearwater County, ID (from 24 days in the current year) and Mason County, WA (from 16 days). In each case these counties are expected to see an increase of 1-2 weeks of additional air quality when projecting out 30 years. Additionally, the vast majority of these counties have PM2.5 as the dominant pollutant type for the current year and in 2054. The only counties where PM2.5 is not the dominant pollutant are San Bernardino County, CA, where O3 is the dominant pollutant, and Mason County, WA. In Mason County, WA, O3 and PM2.5 currently both equally contribute to the total of 16 Orange+ Days, but O3 is projected to overtake as the dominant pollutant over the next 30 years.

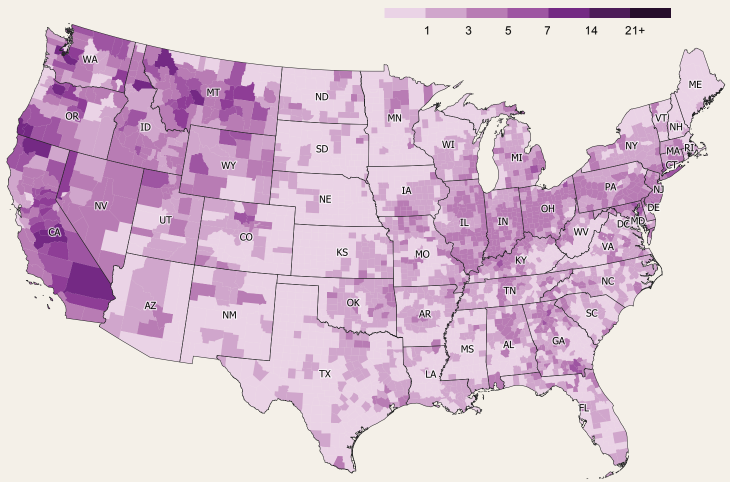


Figure 19. Difference in Orange Plus Days from Combined Smoke (PM2.5) and Ozone (O3), 2024-2054

State	County	Orange+ Days 2024	Dominant source, 2024	Orange+ Days, 2054	Dominant source, 2054	Change in Orange+ Days
WA	Pierce	31	pm	43	pm	12
CA	San Bernardino	45	oz	54	oz	9
CA	Fresno	82	pm	90	pm	8
OR	Clackamas	24	pm	32	pm	8
CA	Riverside	38	oz	45	oz	7
CA	Los Angeles	47	pm	54	both	7
CA	Tulare	83	pm	90	pm	7
NV	Washoe	35	pm	41	pm	6
CA	El Dorado	39	pm	45	pm	6
CA	Sacramento	33	pm	39	pm	6

Table 6. Top counties by increase in number of total Orange+ Days
*Counties with at least 100k Properties

National Trends in Poor Air Quality Exposure

Risk Exposure to the Worst Air Quality Levels, 2024 - 2054

In addition to the increases in poor air quality exposure from Orange+ Days, changes in the worst air quality are expected to increase exposure in the "Unhealthy" (Red), "Dangerous" (Purple), and "Hazardous" (Maroon) AQI categories over the next 30 years. Today, "Unhealthy" Red Days are already a risk for 212 counties across the US (~7% of all counties), but those counties disproportionately account for about 25% of the population across the US (83.1 million). In the future that exposure is expected to grow by about 50%, impacting over 125 million people across 317 counties. When looking at counties with over 100,000 properties, exposure to "Unhealthy" levels of air pollution is expected to be highest in the California counties of Fresno (56 days), Tulare (53 days), and Sonoma (26 days), with the biggest increases projected to occur in in Marion County, OR (+7 days), Pierce County, WA (+7 days), and Whatcom County, WA (+7 days).

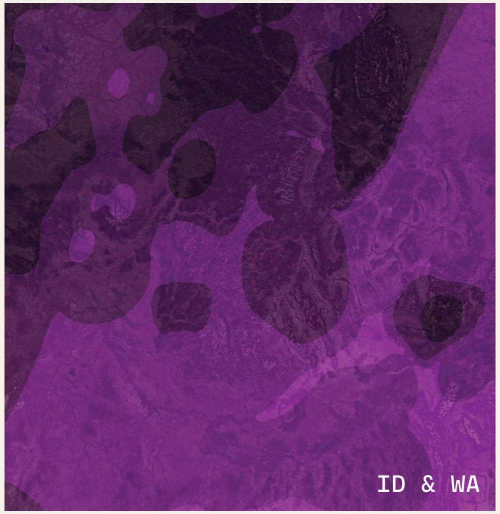
Even worse, exposure to "Dangerous" Purple Days will currently impact nearly 10 million people across 51 counties, but that exposure is expected to increase by 13% over the next 30 years, impacting 11.2 million people across 69 counties. Similar geographic patterns exist in regard to exposure to "Dangerous" levels of air pollution, which occur in many of the same counties as those exposed to "Unhealthy" days. The highest number of exposure to "Dangerous" days are again in Fresno (35 days) and Tulare (20 days), but there are also high levels of risk outside of California in Marion County, OR (11 days), with the largest increases projected in Pierce County, WA (+5 days).

Finally, the most extreme levels or poor air quality, "Hazardous" Maroon Days, are currently a risk for about 1.5 million people across 9 countries. Over the next 30 years, the exposure to the highest levels of air pollution are expected to grow by about 27%, affecting nearly 2 million people concentrated in 11 counties. Fresno County, CA is expected to see as many as three weeks worth of "Hazardous" air pollution days, with Thurston, WA expected to see the largest increase over the next 30 years (+3 days).

AQI Category	Counties exposed, 2024	Counties exposed, 2054	Population exposed, 2024	Population exposed, 2054
Red "Unhealthy" Days	212 (7%)	317 (+50%)	83.1 MM (25%)	125.2 MM (+51%)
Purple "Dangerous" Days	51 (2%)	69 (+35%)	9.9 MM (3%)	11.2 MM (+13%)
Maroon "Hazardous" Days	9 (<1%)	11 (+22%)	1.5 MM (<1%)	1.9 MM (+27%)

Table 7: Risk of exposure to the worst air quality levels, 2024 - 2054

Conclusions & Policy Implications



The First Street Foundation Air Quality Model (FS-AQM) represents a "first of its kind", climate-adjusted, smoke-driven PM2.5 and O3 air quality model calculated at the property level. The model gives property owners an objective view of their personal risk to potentially harmful air quality levels now and in the future, and can be used to make personal decisions around where to live, adaptation solutions, and property-hardening options against that risk. The model incorporates changing climate conditions as a way to predict changes in PM2.5 and O3 risk over the next 30 years based on probabilistic models. Understanding how air quality risks change over time with future environmental conditions at a high spatial resolution is important to know how financial, human, and community resources should be allocated efficiently. First Street's high-resolution model, which estimates air quality now and 30 years into the future under changing environmental conditions, empowers property owners by informing them of the necessary actions to protect their health, and for citizens, governments, and industry to fully understand and appropriately account for this risk. By considering the effects of climate change, the FS-AQM provides a unique understanding of future air quality trends and risks that can be leveraged for strategic planning and policymaking.

Over the last half-century, a tremendous amount of improvement has been made in the reduction of harmful anthropogenically-sourced pollutants. In fact, per the EPA, the combined emissions of criteria pollutants and their precursors have dropped by 78%. This trend provides clear empirical evidence that the Clean Air Act, and other policies geared towards the reduction of harmful air pollutants, have been effective. Furthermore, those reductions have occurred across a number of different pollutants, but have generally all had the positive benefit of reducing various health risks. The outcome has been a healthier environment, less pollutant exposure for the population, and an overall improvement in the quality of life across a number of different associated dimensions. The implications of these improvements are exceedingly important as exposure to high levels of O3 and PM2.5 have been consistently shown to be linked to greater threats to physical and mental health, at even low levels of occurrence.

Unfortunately for US communities, recent changes in the environment are also driving increases in the origins of those pollutants and some of the improvements that have been made under the Clean Air Act are coming undone per the "climate penalty". While the country is still vastly less exposed to high levels of O3 and PM2.5, the simple fact that the US is seeing a reversal at the national level is worrisome and worth the attention of scientists and policymakers. Moreover, this research shows that while the average "climate penalty" across the country is relatively small, in some areas the reversal is much more dramatic. First Street's research finds that the "climate penalty" into the future is on the order of one or two additional poor air quality days at ground-level for most of the US, increasing up to a week or even two weeks in the most severe locations. These increases are consistent with previous literature on the magnitude of the O3 climate penalty (Shen et al.) and are similar in magnitude to the increase in poor air quality days from wildfire smoke days over the past two decades (Childs et al., 2022; Burke et al., 2023). While these increases might appear modest, there is a growing body of evidence suggesting that even small increases in air pollution can negatively affect health outcomes, especially over longer time periods (Anderson et al., 2012). These results are particularly meaningful for the smaller proportion of areas across CONUS that see 7or greater Orange+ Days. For those properties, the increase in exposure is disproportionately driven by PM2.5 from wildfire smoke. An abundance of recent studies have focused specifically on the impacts of wildfire smoke on counteracting progress in reducing anthropogenic PM2.5 levels in the US (Kinney, 2018). With results showing upwards of 25% of progress has been undone, it is important to understand how these trends might continue into the future.

Furthermore, some research indicates that current "acceptable" levels of air pollution are possibly too high, and adverse health effects from air pollution can be observed down to very low concentrations (World Health Organization). In 2021, this led the World Health Organization to recommend lowering annual mean concentrations of PM2.5 to 5 µg/m3 and peak season

Conclusions & Policy Implications

MDA8 O3 concentrations to 60 µg/m3. Additionally, the EPA has proposed and may change the standards for "safe" concentrations of PM 2.5 from 12 µg/m3 to 9 or 10 µg/m3.
The EPA estimates that changing the standard could prevent up to 4,200 premature deaths per year and 270,000 lost workdays per year, resulting in as much as $43 billion in net health benefits annually. Using these standards would result in even more poor air quality days than estimated in this study, underscoring the importance of characterizing any climate-related impacts to air quality.

Broadly speaking, air quality generally improved nationwide during the height of the COVID pandemic, in part because emissions were lower due to the decrease in people driving. But as activities have gone back to normal, air quality nationally has been worsening accordingly. The EPA is proposing new vehicle emission standards which would limit the total number of vehicles which may be sold by automakers to not exceed strict emissions limits. It would be the federal government's most aggressive climate regulation and would propel the United States to the front of the global effort to slash both the emissions of greenhouse gasses and pollutants harmful to air quality generated by cars.

However, despite these efforts, the projected increase in asthma diagnoses and respiratory-related hospital admissions associated with air pollution is concerning. The health impacts of air pollution are expected to be most severe for vulnerable populations, including children, pregnant women, and the elderly. The impacts of wildfire smoke exposure in 2020, for example, resulted in large areas of the west coast experiencing hazardous air quality for extended periods. In the United States, the new asthma diagnoses associated with PM2.5 and O3 are projected to increase by about 34,500 with 2^{0}C, bringing with it an increase in Emergency Department visits and hospital admissions due to respiratory conditions (EPA kids health report). Additionally, there is likely to be an increase in infant mortality and adverse birth outcomes, such as preterm birth (EPA kids health report). Previous research has found an association between smoke exposure during pregnancy, especially when exposed late in the term, and low birth rates (Amjad et al., 2021).

The effects of smoke exposure can be very detrimental on quality of life. In 2020, for instance, due to wildfires, large areas of the west coast were exposed to hazardous air quality for several weeks. These decreases in quality of life, such as due to health impacts or the ability for people to engage in outdoor activities, may lead many Americans to consider moving away from areas with poor air quality, or avoid moving to those areas altogether. The economic and social impacts of such migration could be significant. It may lead to a decline in property values in areas most affected by wildfires and increase the demand for housing in areas with better air quality. Additionally, it could result in reduced tax bases for affected areas, decreasing their capacity to invest in infrastructure, adapt to the changing environment, and provide community services.