THE EFFECT OF WILDFIRES ON AIR QUALITY AND PUBLIC HEALTH

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In consultation with the Government Accountability Office

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EXECUTIVE SUMMARY

In the U.S., wildfires are widely recognized as a major contributor to air pollution. Moreover, the adverse health effects associated with exposure to wildfire smoke produce public health and clinical challenges.

This report aims to examine the following research questions by conducting a literature review and a case study analysis in four U.S. states: California, Montana, North Carolina, and Texas.

1. What are the effects of wildfires on air quality and public health?
2. What efforts are states making to mitigate air quality pollutants from wildfires and reduce public exposure to air quality pollutants from wildfires?

The findings conclude that among wildfire pollutants, particulate matter (PM2.5) which are tiny particles or droplets in the air that are two and one half microns in width is considered the most harmful to health because it can affect heart and lung function and lead to serious health effects. A positive association exists between exposure to wildfire smoke and wildfire particulate matter PM2.5 and mortality and respiratory morbidity. Respiratory morbidity includes asthma, chronic obstructive pulmonary disease, bronchitis and pneumonia.

We also found that for the three wildfires in each state we researched, the average change in air quality index (AQI) and PM2.5 in California and Montana were significant, whereas, these changes in North Carolina and Texas were not significant as expected. However, the lower changes in AQI and PM2.5 in North Carolina and Texas might be misleading due to limited data availability.

Moreover, by observing the real-time air quality monitoring website https://airnow.gov, we found that within few days wildfire smoke can travel hundreds of miles away from the fire itself. There are four major indicators that determine how significantly and how rapidly smoke will be dispersed: the atmospheric stability, mixing height, terrain, and transport wind.

In terms of states' efforts, all four states studied are making efforts to monitor air quality, provide access to air quality and wildfire information, and educate the public to protect themselves from wildfire smoke exposure. In other words, state agencies are focused on reducing the public's exposure to the pollutants. Because the pollutants of wildfires (namely PM2.5) come from various sources in addition to wildfires, by implementing these strategies, relevant agencies are not necessarily targeting wildfire air pollution but overall air pollution from any cause. To mitigate wildfire pollution specifically, it is the responsibility of fire departments to forecast, suppress, and mitigate the occurrences of wildfires. Some fire departments show concern over air pollution from wildfires and partner with other agencies but, more often, mitigating air pollutants is not their priority because their goal is extinguishing wildfires as soon as possible.

INTRODUCTION

Pollution imposes large costs on human well-being and wildfires are wildly recognized as major contributors to air pollution. According to the findings of the researchers at the University of Illinois at Urbana-Champaign, wildfires contribute approximately 15 percent of total U.S. particle emissions each year, which is more than the combined emissions from power plants and the transportation sector (Miller et al. 2017). The major impact of wildfire smoke comes from two factors. First, wildfire smoke can travel hundreds or thousands of miles and remain in the atmosphere for days or weeks, and it is very hard to mitigate the effects of smoke once it is in the atmosphere. Second, wildfire smoke exposure causes a number of health risks to human being. Wildfire smoke is a mixture of gases and fine particles from burning trees and other plant material. The gases and fine particles can be dangerous if inhaled. In wildfires, carbon monoxide is mainly a risk to people (like firefighters) who work near smoldering areas. Smoke can irritate human's eyes and respiratory system, and worsen chronic heart and lung diseases. The amount and length of smoke exposure, as well as a person's age and degree of susceptibility play a role in determining if someone will experience smoke-related health problems. Wildfire smoke also increase infant and elderly mortality.

Wildfires are not a new phenomenon, but in many regions of the United States, particularly the western region, wildfires are becoming larger and longer-lasting. The National Interagency Fire Center has data on the total number of wildfires and acres burned for each year going back to 1926. In 1990, 4.6 million acres burned. In 2000, it was 7.4 million acres. In the year of 2015, the record was broken: 10.1 million acres were burned. The reason that total acreage is increasing is because the fires are getting larger. Throughout the 1980s and 1990s, the average wildfire burned anywhere from 40 to 80 acres. In 2010s, the average acres burned per year by wildfires increased to more than 100 acres.

Based on such background, our report seeks to answer two questions: first, ***what are the effects of wildfires on air quality and public health?*** Second, ***what efforts are states making to mitigate air quality pollutants from wildfires, and what efforts are states making to reduce public exposure to air quality pollutants from wildfires?***

To examine the effects of wildfires on air quality and public health, we:

1. based on the literature review, answered the question of what air pollutants wildfires emit and what pollutant has the most significant impact on public health;
2. based on data analysis, addressed the question of how the air quality index (AQI) and the level of fine particles (PM2.5) are affected by wildfires; and
3. used mapping tools to answer the question of how far pollutants spread and how populations are exposed to the spread of wildfires smoke.

To answer the second question, we collected information from the websites of state agencies involved and listed programs and tools that are being used on the state level.

LITERATURE REVIEW

Wildfires in the U.S.

Historical Trends

In contrast with prescribed fire, which is a planned and controlled fire used to manage fire and vegetation in consideration of the safety of the public and fire staff, weather, and probability of meeting the burn objectives (National Park Service, 2017), a wildfire, also called a wildland fire or forest fire, is an uncontrolled fire that occurs in wildlands. Depending on the land-cover type and the region where it occurs, a wildfire is sometimes more specifically described as a brush fire, bushfire, desert fire, forest fire, grass fire, hill fire, peat fire, vegetation fire, and veld fire (Britannica Academic, 2017).

Over the last three decades, the United States has experienced an increasing trend in public lands consumed by wildfires (Moeltner, Kim, Zhu, & Yang, 2013). In the 1980s, close to three million acres burned in an average year. This number increased to 3.6 million in the 1990s, and to over 6.5 million in the 2000s (National Interagency Fire Center, 2012). In 2018, according to the National Interagency Fire Center (NIFC), there were 58,083 wildfires in the U.S., totaling 8,767,492 acres burned. Of total wildfires reported, significant wildfires represented about 2%. The U.S. Forest Service, part of USDA, noted that forest fires had already become more intense and that the forest fire season had expanded by 2009 (U.S. Forest Service, 2009). By 2015, fire seasons were 78 days longer than in the 1970s (USDA, 2015). In the same year, the Intergovernmental Panel on Climate Change (IPCC) anticipated that climate change will lengthen the window of high summertime forest fire risk in North America by 10-30%, and result in increased frequency of forest fires in coming decades (Liu, Pereira, Uhl, Bravo, & Bell, 2015).

Geographic Distribution

In the U.S., wildfires are disproportionately distributed in the southern and western regions. The Geographic Area Coordinating Group (GACG) divides the United States and Alaska into 11 geographic areas for the purpose of emergency incident management. A national assessment of wildfire risk in the United States based on GACG identified regions (with the slight modification of combining Southern and Northern California, and the West and East Basin) indicates that California and the Southern Area are the geographic areas with the highest wildfire risk with 50.22% and 15.53% risk respectively.

Wildfires are most common in the western states where heat, drought, and frequent thunderstorms create perfect wildfire conditions. Montana, Idaho, Wyoming, Washington, Colorado, Oregon, and California experience some of the worst conflagrations. In California, wildfires are often made worse by the hot, dry Santa Ana winds, which can carry a spark for miles (National Geographic, 2017). In 2017, 9,560 wildfires burned more than 1.2 million acres of land in California. That same year, fire seasons in Washington and Oregon extended nearly three weeks longer than ever recorded. Meanwhile, with more than 88 million acres classified as the wildland-urban interface (WUI), the South (including Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, and Puerto Rico) consistently has the highest number of wildfires per year. Since the 1970s, the region's average temperatures have steadily increased, in part due to rising populations and human development in the region. Adding a huge drought and high-speed winds to the mix have made the region particularly vulnerable to fire. According to NIFC, in 2017, 17,548 wildfires were reported with a total of more than 2 million acres burned in the South.

Wildfire Smoke Pollutants

Wildfire smoke is composed primarily of carbon dioxide and water vapor. Pollutants include greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), photochemically reactive compounds (e.g., carbon monoxide (CO)), and fine and coarse particulate matter (PM) (Urbanski, Hao, & Baker, 2008). Among the components, PM, nitrogen dioxide (NO_2), CO, and ozone (O_3) are the National Ambient Air Quality Standard (NAAQS) criteria pollutants regulated under the Clean Air Act, and the health impacts of these pollutants are well established (Cascio, 2018).

Wildland fire emissions contribute to air pollution by increasing the atmospheric levels of pollutants that are detrimental to human health and ecosystems. They may also degrade visibility, leading to hazardous or general nuisance conditions. The air quality impacts occur through the emission of primary pollutants (e.g., PM, CO, NO_x) and the production of secondary pollutants (e.g., O_3) (Urbanski et al., 2008).

PM is the pollutant of greatest concern from wildfire smoke. PM are particles suspended in the air, typically as a mixture of both solid particles and liquid droplets. Particle pollution includes “coarse particles”, also known as PM 10-2.5, with diameters from 2.5 to 10 micrometers and “fine particles,” also known as PM 2.5, with diameters that are 2.5 micrometers and smaller (EPA, 2016). Wildfires have been found to be a major contributor (over 15%) to ambient PM 2.5 levels in the U.S. (Jia Coco Liu et al., 2016).

Another pollutant of concern is CO. It is a colorless, odorless gas. CO levels are highest during the smoldering stages of a fire, especially in very close proximity to the fire (EPA, 2016). Other air pollutants, such as acrolein, benzene, and formaldehyde, are present in smoke, but in much lower concentrations than particulate matter and carbon monoxide that are too low to cause detectable health effects.

Dispersion of Wildfire Smoke

Almost all of the weather elements can affect the dispersion of smoke, such as winds, relative humidity, temperature, atmospheric stability, mixing height, the stage of fire, terrain. There is an index called the dispersion index that uses a numerical indicator to measure how well and how rapidly smoke will be dispersed. It utilizes atmospheric stability, mixing height, and transport wind as major fact.

There is vertical as well as horizontal motion in the atmosphere. Stability is an indication of how rapidly vertical mixing is taking place. The more unstable the atmosphere, the more quickly smoke is lifted and dispersed. The atmosphere is usually most unstable during the afternoon. This is because of the heating of the earth's surface during the day. The air just above the surface becomes heated and expands. In turn, it begins to rise, resulting in vertical movement in the atmosphere ("Atmosphere, Climate & Environment Information Programme," n.d.)

Mixing height is the maximum height that rapid vertical mixing takes place in the atmosphere. The more unstable the atmosphere, the higher the mixing height is. The higher the mixing height, the higher the smoke will rise.("Design For Environment," n.d.)

Transport wind is defined as the wind that determines the direction and speed with which smoke is transported away from its source. This is the wind that moves smoke out of an area and helps to disperse it in the atmosphere ("Wildfire Smoke,"n.d.).

Wildfire Smoke and Public Health

Human Health Effects of Wildfire Smoke

The U.S. Forest Service recognizes forest fire smoke as a hazard to human health. Wildfire smoke can trigger a variety of adverse health effects as a major contributor to a deterioration in air quality (Moeltner et al., 2013). Overall, wildfire smoke exposure, as measured by proxies such as criteria air pollutants, were consistently associated with mortality and respiratory morbidities. The effects of smoke range from eye and respiratory tract irritation to more serious disorders, including reduced lung function, bronchitis, exacerbation of asthma and heart failure, and premature death (EPA, 2016). Respiratory-related effects of wildfire smoke included increases in the risk of hospitalization, use of respiratory medication, cough, wheeze and eye irritation (Jia C. Liu, Pereira, Uhl, Bravo, & Bell, 2015).

The smoke is likely to be especially deleterious to human health because of exposure to very high levels of PM (Jia Coco Liu et al., 2016). Studies have found that short-term exposure (days to weeks) to fine particles are linked with increased premature mortality and aggravation of preexisting respiratory and cardiovascular disease (EPA, 2016). PM10 and especially PM2.5 are considered the most harmful to health because they can affect the heart and lungs (Moeltner et al., 2013) (Jayachandran, 2009).

A study shows that for each 10 μg/m3 increase in PM10 concentration, the risk of total non-accidental mortality increased by 0.36%, the risk of mortality due to cardiovascular disease increased by 0.36%, and the risk of mortality due to respiratory disease increased by 0.42%. For each 10 μg/m3 increase in PM2.5 concentration, the risks were 0.40%, 0.63%, and 0.75% respectively (Lu et al., 2015).

NO2 is a respiratory tract irritant that causes a spectrum of adverse respiratory health effects, depending on the dose of exposure. Scientific evidence links short-term NO2 exposures, ranging from 30 minutes to 24 hours, with adverse respiratory effects including airway inflammation in healthy people and increased respiratory symptoms in people with asthma. For a 10-μg/m3 increase in NO2 concentration, the investigators found a 0.30% increase in total mortality, 0.41% increase in cardiovascular disease mortality, and 0.34% increase in respiratory disease mortality (Chen, Kuschner, Gokhale, & Shofer, 2007a). Studies also show a connection between short-term exposure and increased emergency room visits and hospital admissions for respiratory illnesses. NO2 levels are appreciably higher in close proximity to pollution sources. Health effects associated with NO2 are much less likely farther away from these pollution sources (EPA, 2011).

CO enters the bloodstream through the lungs and reduces oxygen delivery to the body's organs and tissues. Acute and chronic CO exposure has been found associated with headaches and death (Chen et al., 2007a). Evidence shows significant associations of CO with total and cardiovascular mortality. An increase per 1 mg/m3 in CO was associated with 1% increase in total mortality (Samoli et al., 2007). CO concentrations typical of population exposures related to wildfire smoke do not pose a significant hazard, except to some sensitive individuals and to firefighters very close to the fire line. Individuals who may experience health effects from lower levels of CO are those who have cardiovascular disease; they may experience chest pain or cardiac arrhythmias. At higher levels, CO exposure can cause headache, weakness, dizziness, confusion, nausea, disorientation, visual impairment, coma, and death, even in otherwise healthy individuals (EPA, 2016).

O3 exposure causes acute decreases in lung function in both healthy and asthmatic subjects. Exposure to O3 is associated with various respiratory symptoms including dyspnea, upper airway irritation, coughing, and chest tightness. An increase of 10 μg/m3 in the 2-day average of O3 levels was associated with a 0.45% increase in total non-accidental mortality and 0.53% increase in cardiovascular mortality (Chen, Kuschner, Gokhale, & Shofer, 2007b).

In terms of risk of cancer or of other chronic health conditions (such as heart disease) from short-term exposure to wildfire smoke, it is well characterized that smoke contains carcinogenic components with polycyclic aromatic hydrocarbons (PAHs) comprising the largest percent, and to a lesser extent, benzene and formaldehyde. People exposed to these toxic air pollutants at sufficient concentrations and durations may have a slightly increased risk of cancer or of experiencing other chronic health problems. However, in general, the long-term risks from short-term smoke exposures are quite low. Short-term elevated exposures (i.e., over days to weeks) to carcinogens found in wildfire smoke are also small relative to total lifetime exposures to carcinogens in other, more common combustion sources (EPA, 2016).

DATA METHODOLOGY

The Effect of Wildfires on Air Quality

To determine the effects of wildfires on air quality, the team selected a sample of wildfires in four states to compare the air quality index (AQI) and PM2.5 level during the wildfire to the baseline period (the average of one-month pre and one month post of the wildfire). To conduct this analysis, the team collected annual wildfire statistics data from the National Interagency Fire Center, daily air quality (AQI) and particulate matter (PM2.5) data from the U.S. Environmental Protection Agency, and specific wildfire information in California, Texas, North Carolina, and Montana from the California Department of Forestry and Fire Protection, Texas Commission on Fire Protection, North Carolina Forest Service, and Northern Rockies Coordination Center, respectively. For each state, the team analyzed three wildfires with specific information available about the location and the duration of the fire.

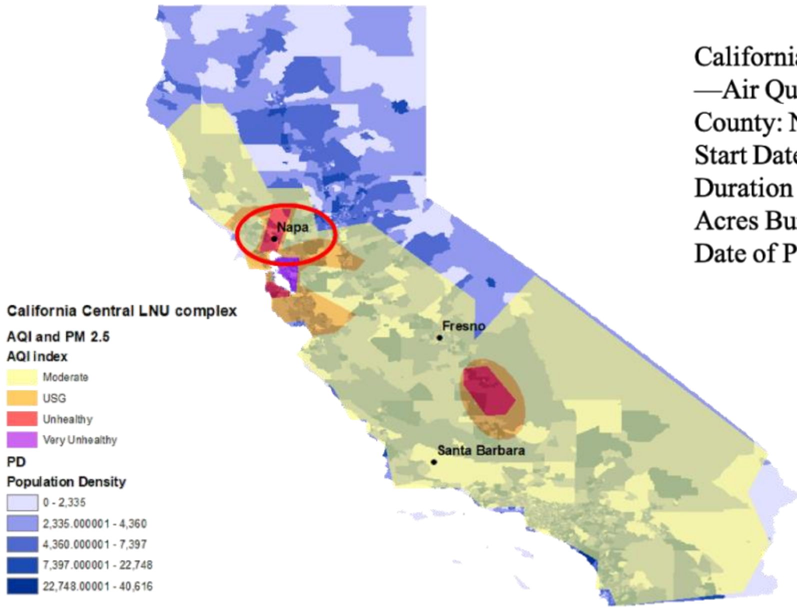
Mapping Data

To determine how wildfire smoke spreads and the size of areas exposed to wildfire smoke, we visualized the AQI and PM 2.5 index on a map. We used time-series analytical techniques and overlaid population density data on the map.

Due to the data limitations, we were unable to extract Texas's wildfire data and other two wildfire data in North Carolina and Montana. The team made maps for 7 wildfire events to demonstrate the information of the geographical distribution of AQI and PM 2.5 index, and the information of population density of the state. Moreover, the map demonstrates the AQI and PM 2.5 on the day that has the highest AQI during the wildfire in the county in which the wildfire broke out. Some of the wildfire events have two maps, one for AQI index and another for PM 2.5 index. Other wildfire events only have one map because AQI and PM 2.5 index are the same in terms of the geographical distribution and level.

Specifically, our map has two layers. One layer uses 2016 U.S. census tracts GIS data, which includes the population density information as the background which uses the gradient color to illustrate the population density, the darker the color, the higher population density. The layer above the background layer uses AQI and PM 2.5 data from EPA, which illustrates the geographical distribution of AQI and PM 2.5 in different level that reflected by different colors.

In sum, the map includes information of the name of wildfire events, geographical distribution of AQI and PM 2.5, population density. The sample is shown below.



California Central LNU complex wildfire
—Air Quality Impacts & Affected population
County: Napa
Start Date:10/8/2017
Duration of Fire: 12 days
Acres Burned: 110,720
Date of Peak: 10/13/2017

<u>Movement of Wildfire Smoke</u>

The team analyzed the movement of wildfire smoke based on the information in AIRnow, which provides information about daily geographical distribution change of AQI and PM 2.5 on the map for each state from 2012 to 2019. The movement of smoke can be captured by these indicators. Then, we explained how wildfire smoke spreads and how severe the AQI can be during the wildfire. When analyzing the spread of smoke, we will focus on AQI which is identified as “unhealthy” or above. Because when AQI is equal or above this level, the smoke will have a significant impact on public health.

<u>State Mitigation Efforts</u>

The team collected information about state efforts by looking to websites of involved state agencies. We only considered information on government official websites to make assure its reliability. We focused on efforts on the state level so local programs in counties were not taken into consideration. We limited our research to programs and activities that explicitly address wildfire smoke pollution and the public exposure to it.

FINDINGS

The Effect of Wildfires on Air Quality

Table 1 provides comparisons of air quality based on factors that have been shown to increase risk from air pollution. The higher the AQI and PM2.5 level value, the greater the level of air pollution and the greater the health concern.

Table 1. The level of health concern with the index values of AQI and PM2.5 level.

AQI Range	PM-2.5 in μg/m³ LC	Level of health concern
301 - 500	250.5 - 500.4	Hazardous
201 - 300	150.5 - 250.4	Very Unhealthy
151 - 200	55.5 - 150.4	Unhealthy
101 - 150	35.5 - 55.4	Unhealthy for Sensitive Groups
51 - 100	12.1 - 35.4	Moderate
0 - 50	0 - 12.0	Good

Source: EPA

When AQI values are between 101-150 and PM2.5 level values are between 35.5-55.4, or code orange, members of sensitive groups may experience health effects. This is because they are more likely to be affected at lower air quality levels than everyone else. For example, children and older adults, people with lung disease, and people who are active outdoors (outdoor workers) are at greater risk from exposure to ozone. Older adults and children, and people with heart or lung disease are at greater risk from exposure to particulate pollution. Everyone is more likely to be affected when the AQI values exceed 150 and PM2.5 level values are above 55.4, or code red and higher.

To answer our research question, the team looked at NIFC data and randomly selected wildfires in each region among wildfires with complete information records including location, start date, duration and average change in AQI and PM 2.5. Table 2 illustrates the specific information about each of 12 wildfires that are used in the analysis, such as location, start date, and duration, as well as the average change in AQI and PM2.5 level due to each wildfire. For instance, on December 04, 2017, the wildfire Thomas occurred in Ventura and Santa Barbara counties, California. The duration of this wildfire was 16 days and it burned in total 270,000 acres. Excluding the baseline, the average change in AQI and PM2.5 level due to Thomas were 179.4 and 70.3, respectively. Both of these changes exceed the “code red” situation discussed above and triggers serious health concerns.

Table 2. Information and mean change in AQI and PM2.5 level duet to the wildfires.

States	County	Name of Fire	Date	Duration of Fire	Acres burned	Δ in AQI	Δ in PM2.5
California	Ventura, Santa Barbara	Thomas	12/4/2017	16 days	270,000	**179.4**	**70.3**
	Fresno	Rough	7/31/2015	3.5 months	151,623	**33.5**	**1.0**
	Napa, Sonoma	Central LNU complex	10/8/2017	12 days	110,720	**114.3**	**49.8**
Montana	Ravalli	Valley Complex	8/1/2000	25 days	292,070	**99.2**	**91.7**
	Missoula	Lolo Peak Fire	7/15/2017	3 months	53,902	**171.7**	**30.5**
	Lewis and Clark	Alice Creek	7/22/2017	2 months	29,252	**45.8**	**19.8**
North Carolina	Dare, Hyde, Beaufort, Tyrrell, Washington	Evans Road Fire	6/1/2008	5 months*	41,534	**17.3**	**6.1**
	Swain	Maple Spring Fire	11/4/2016	23 days*	7,788	**48.4**	**22.8**
	Henderson, Rutherford	Party Rock	11/5/2016	22 days	7,200	**51.0**	**24.7**
Texas	Brewster	Schwartz and Iron Mt.	5/7/2011	1.5 months*	173,400	**21.9**	**11.6**
	Cass, Marion (Harrison)	Bear Creek	9/5/2011	24 days	43,000	**44.7**	**2.6**
	Travis	Horseshoe and Moon-glow	8/15/2011	3 weeks	100	**33.5**	**2.7**

*Note: * represents that the information about the duration of the wildfire is from informal source.*

We found that for the three wildfires in each state we researched, the average change in air quality index (AQI) and PM 2.5 level in California and Montana were significant, whereas, these changes in North Carolina and Texas were not significant as expected. As illustrated in Table 3, we can see that the average change in AQI and PM2.5 levels in California and Montana exceed the “code orange” situation for health concern. However, it is fair to highlight that these average changes do not represent the changes in AQI and PM2.5 level in the entire state, but only the changes in the counties where the wildfires occurred.

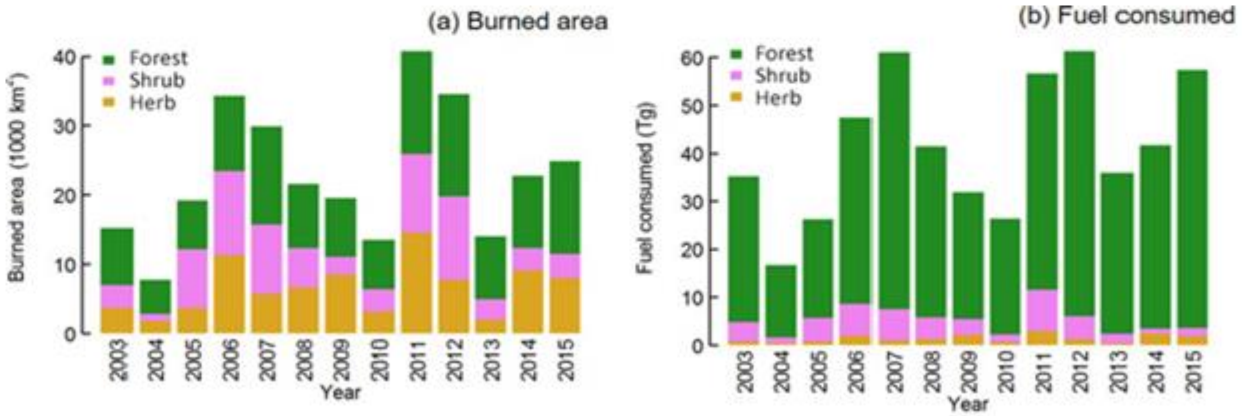
Table 3. The average changes in AQI and PM2.5 level in each state due to 3 wildfires.

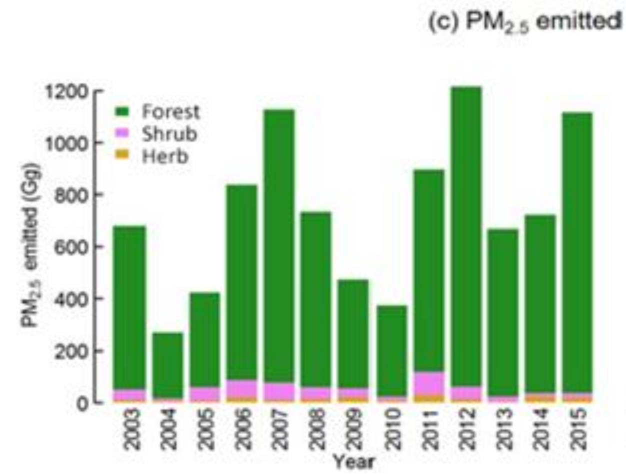
States:	Average change in AQI	Average change in PM2.5
California	(53.0)+109.06 =162.06	(11.2)+40.35=51.55
Montana	(38.4)+105.57=143.97	(5.7)+47.34=53.04
North Carolina	(30.1)+38.92=69.02	(7.8)+17.86=25.66
Texas	(45.3)+30.8=76.1	(15.6)+5.62=21.22

Note: The number in parentheses represents the AQI and PM2.5 during the baseline period. And the color of the numbers are consistent with the level of health concern of Table 1.

Given the number of acres burned during the wildfires Schwartz and Iron Mountain in Texas were significant, both the change in AQI and PM2.5 levels were relatively counterintuitive in our result. However, according to the results of U.S. wildland fire emission estimates during 2003-2015, wildfire emission level heavily depends on the composition of biomass and fuel (Shaw P. Urbanski et al, 2018). The authors used multiple datasets of fire activity and burned areas in the U.S., a newly developed wildland fuels map and an updated emission factor database.

Graph 1. Annual burned area, fuel consumed, and PM2.5 emitted for 2003-2015; U.S forestry map





Source: Contiguous U.S. wildland fire emission estimates 2003-2015.(Shawn P. Urbanski et al.)

From the map on the bottom right of Graph 1, we can see that the forested areas of Texas and North Carolina are much smaller than in California and Montana. Forest wildfires emit considerably more PM 2.5 than grassland wildfires (shrubs and herbs). For instance, in 2011, burned areas of the herb were close one-third of total burned areas, whereas, the PM2.5 emission level due to burned herbs were less than 3 percent. Because forests have relatively more per acre fuels(biomass) than grasslands, the corresponding emission level of forest are significantly higher than grassland fires.

Moreover, the burned area has a bimodal distribution with peaks in April and August. Summer and spring accounted for 49 percent and 31 percent of the burned area, respectively. The ratio of herb and shrub to forest burned area was similar for summer and spring but differed considerably between the peak months of April and August. August was the most significant month for emissions, accounting for 32 percent PM2.5 emitted, more than twice the share of the next highest month, which was July at 15 percent. While April had the third highest burned area (15 percent of total), it accounted for only 6.7 percent of PM2.5 emitted (see Appendix 1). The geographic distribution of emissions also varies considerably by season (see Appendix 2). On a regional basis, southwest emissions peaked during June (46 percent) and during August in both the northwest (59 percent) and California (40 percent). Northwest emissions were concentrated in July to

September (95 percent), while California emissions were spread symmetrically across June to October (see Appendix 3).

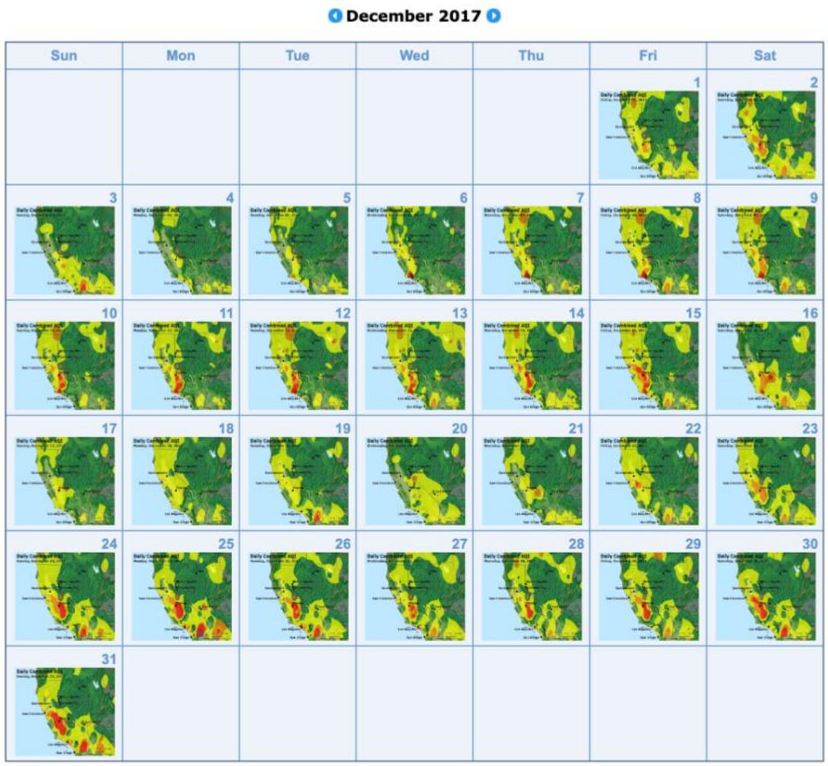
However, the lower changes of AQI and PM 2.5 in North Carolina and Texas might be misleading due to limited data availability. More detailed explanations regarding the limited data are discussed in the Limitations section below.

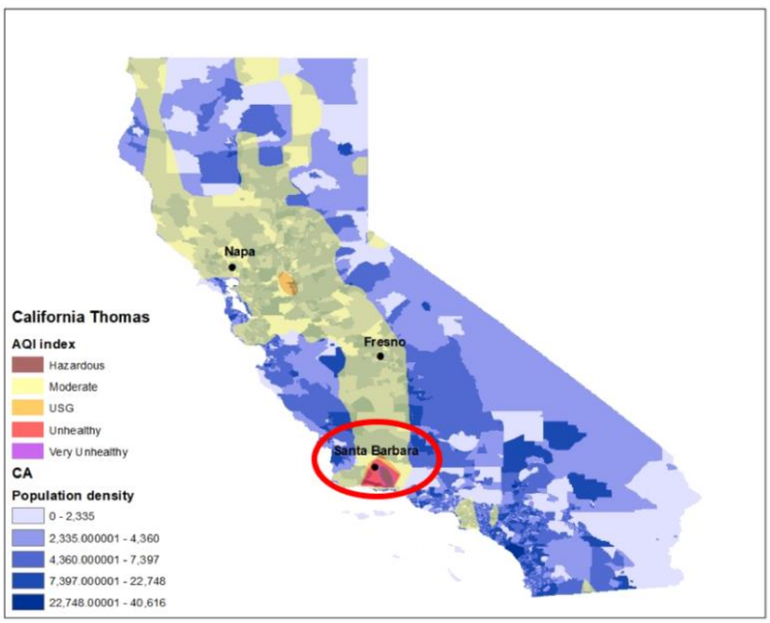
Spread of Wildfires Smoke

In this part, based on the information provided by AIRnow, we will analyze the movement of each wildfire smoke to understand how it spreads across the state and how severe the AQI can be during the wildfire.

In this part, for each wildfire event, we will exhibit several graphs. One demonstrates the movement of the smoke during the wildfire event, the other demonstrates the geographical distribution of AQI and PM 2.5 on the day that has the highest AQI during wildfire events.

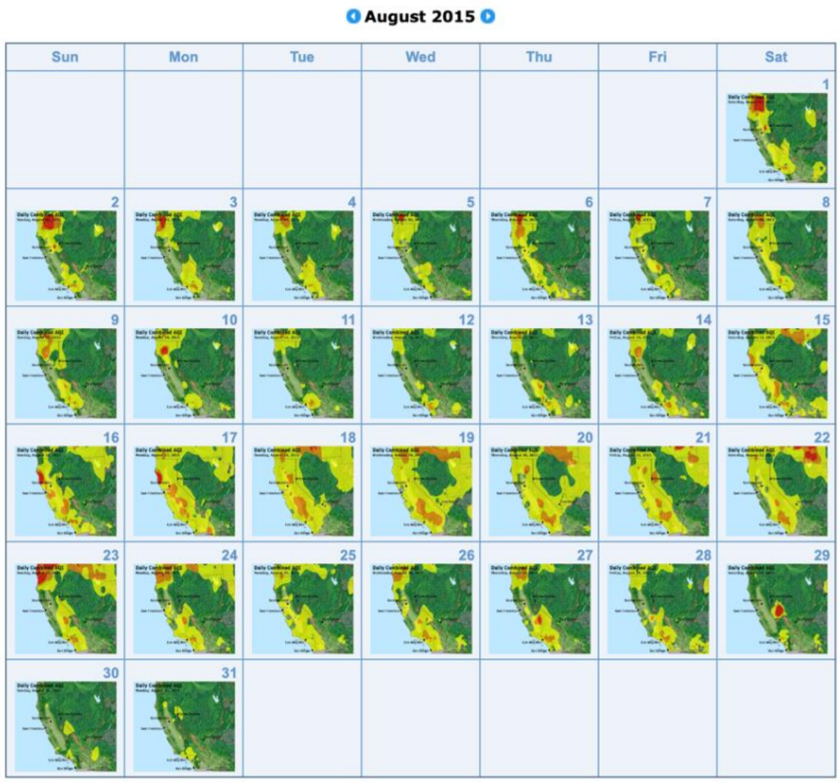
A. California wildfire events
1. Name of the fire: Thomas
County: Ventura, Santa Barbara
Start date:12/4/2017
Duration: 16 days
Acres burned: 270,000
Date of peak (highest AQI): 12/7/2017
Description: two days after the fire began, the AQI was at "moderate" level around areas of Santa Barbara and Fresno. Suddenly, on December 6, the AQI rose rapidly up to "very unhealthy" around Santa Barbara and the high AQI continued to December 16. Then, it dropped to "moderate" level on 17th until 23 rd on which AQI increased to "USG" again until 31 st. Meanwhile, the smoke kept spreading to the north and reached to the northern boundary of California. From December 8 to 16 and 23 to 31, the smoke maintained at "USG" or higher lingering around central California.



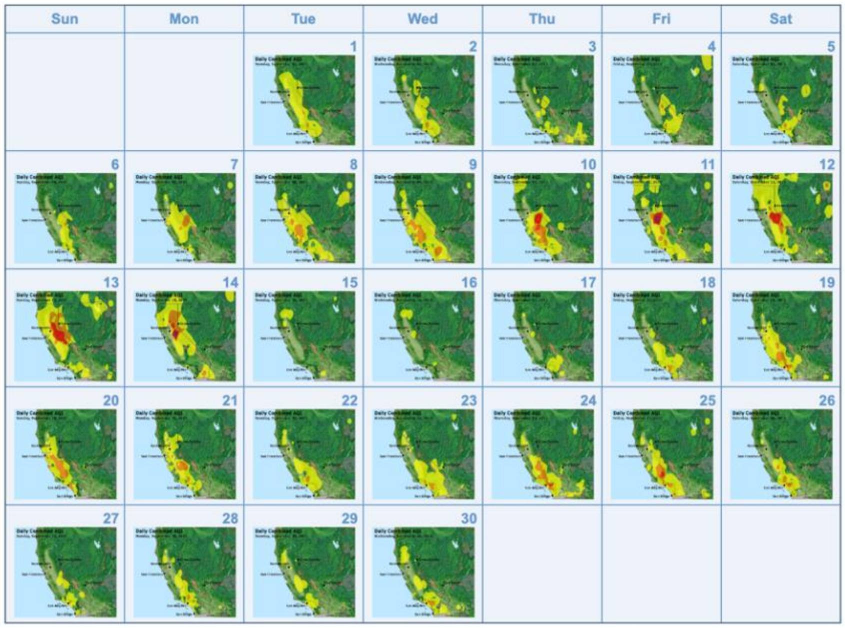


2. Name of the fire: Rough
County: Fresno
Start date: 7/31/2015
Duration: 3.5 months

Acres burned: 151,623
Date of peak (highest AQI): 9/10/2015
Description: Rough fire lasted for a very long time, during this time, the most severe AQI occurred on September 10 to 14. Although it may be caused by other reasons besides Rough wildfire, from August 15 to 28, for a half month, most areas in California were affected by at least "moderate" AQI.



September 2015



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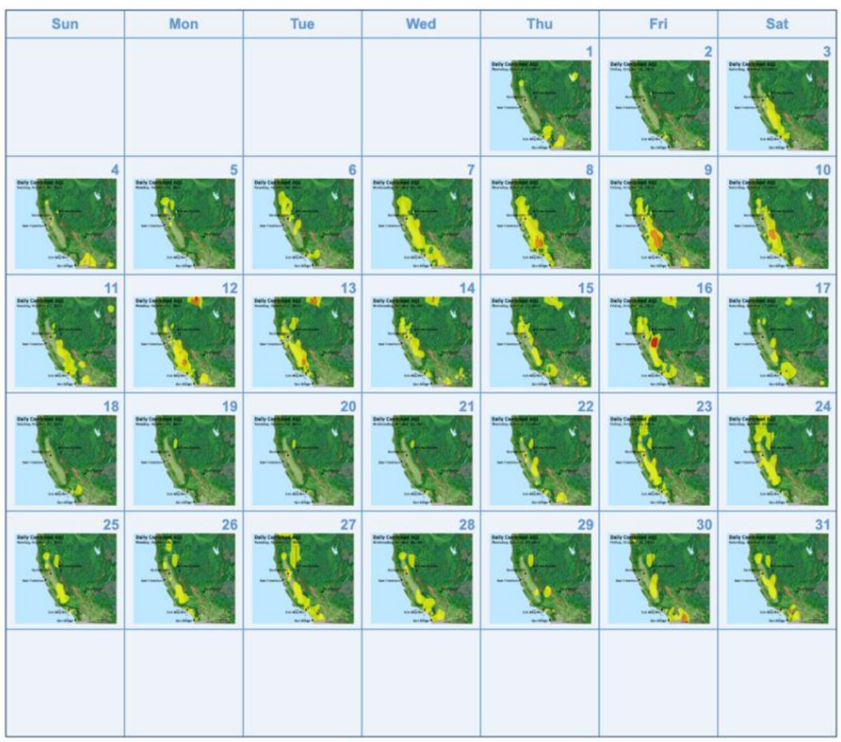
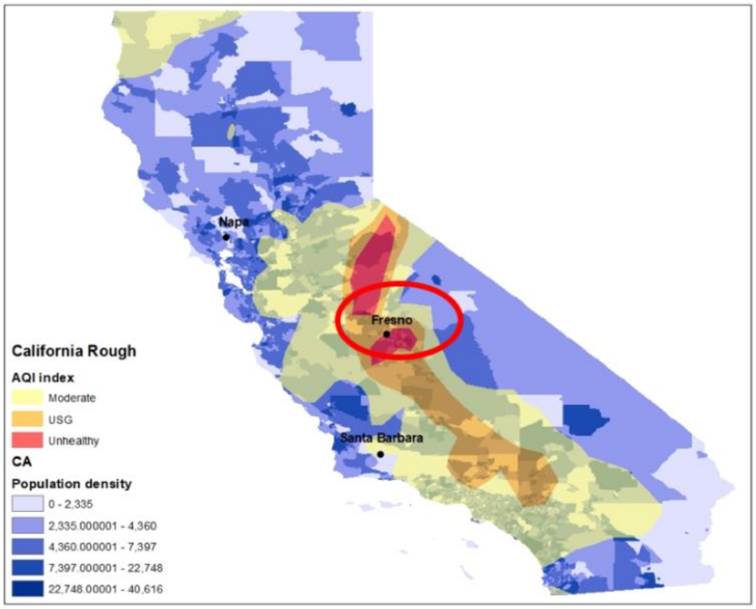
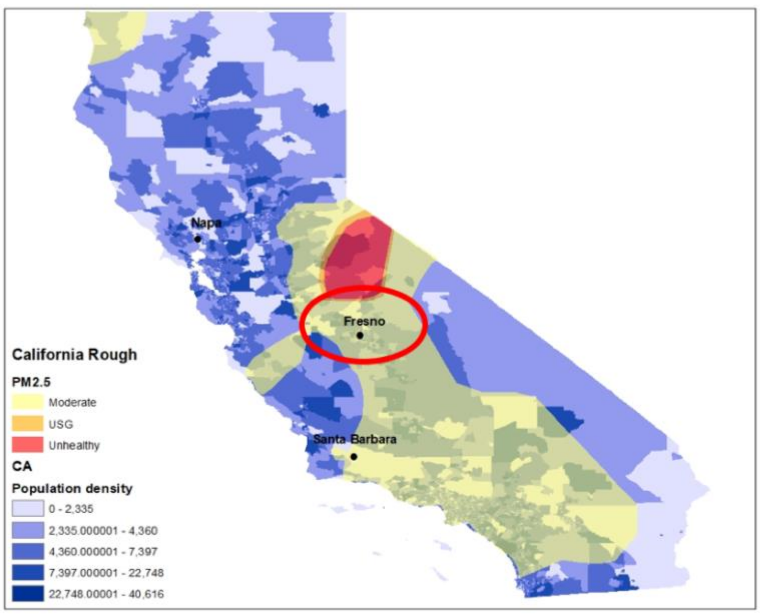
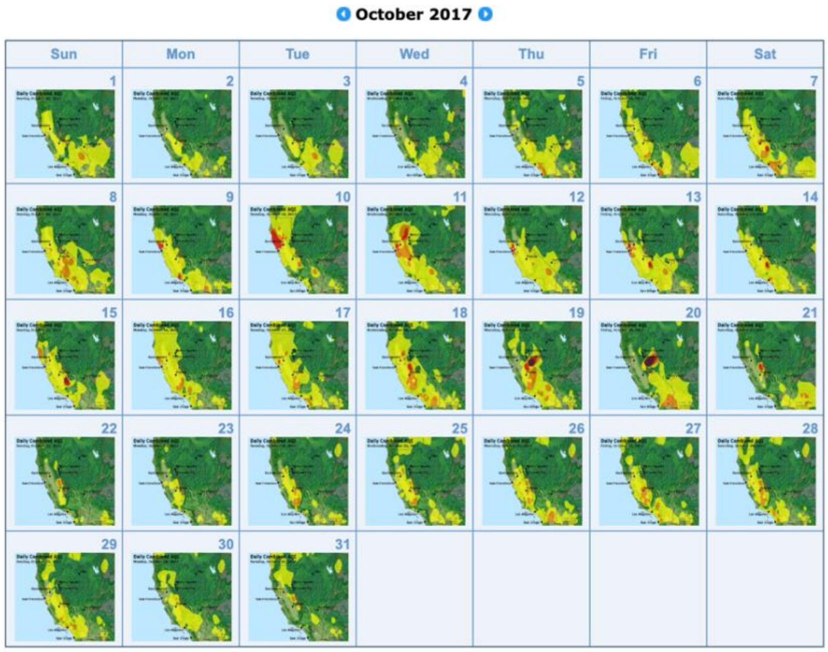


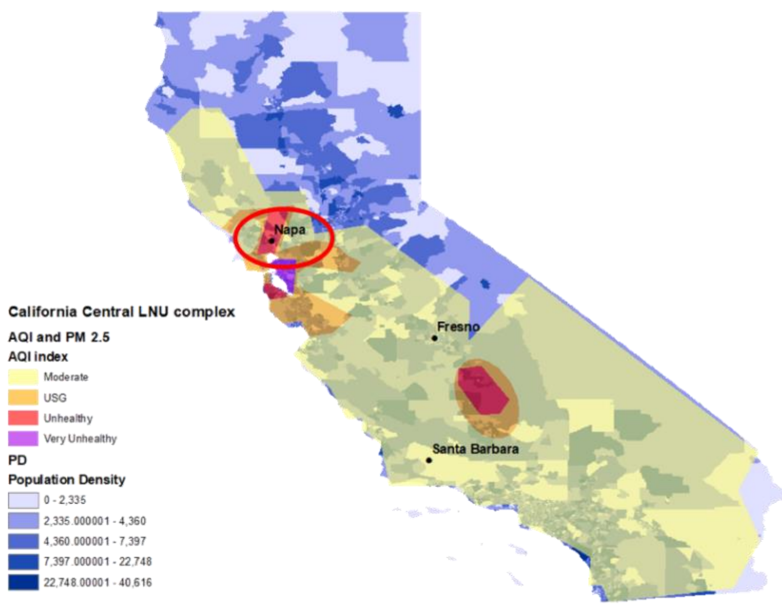




3. Name of the fire: Central LNU complex
County: Napa
Start date: 10/8/2017
Duration: 12 days
Acres burned: 110,720
Date of peak (highest AQI): 10/13/2017
Description: within two days, the smoke was surrounding areas in Napa. From 12th to 18th, the AQI level dropped to "moderate" in areas in Napa, the air quality seemed becoming good. However, from 19th to 20th, in the east of Napa county, on the boundary between California and

Nevada, the AQI was up to “Hazardous”. This was probably because the smoke was transferred by some weather conditions to the boundary and lasted for two days before it dissipated.





B. Montana wildfire events

1. Name of the fire: Alice Creek

County: Lewis and Clark

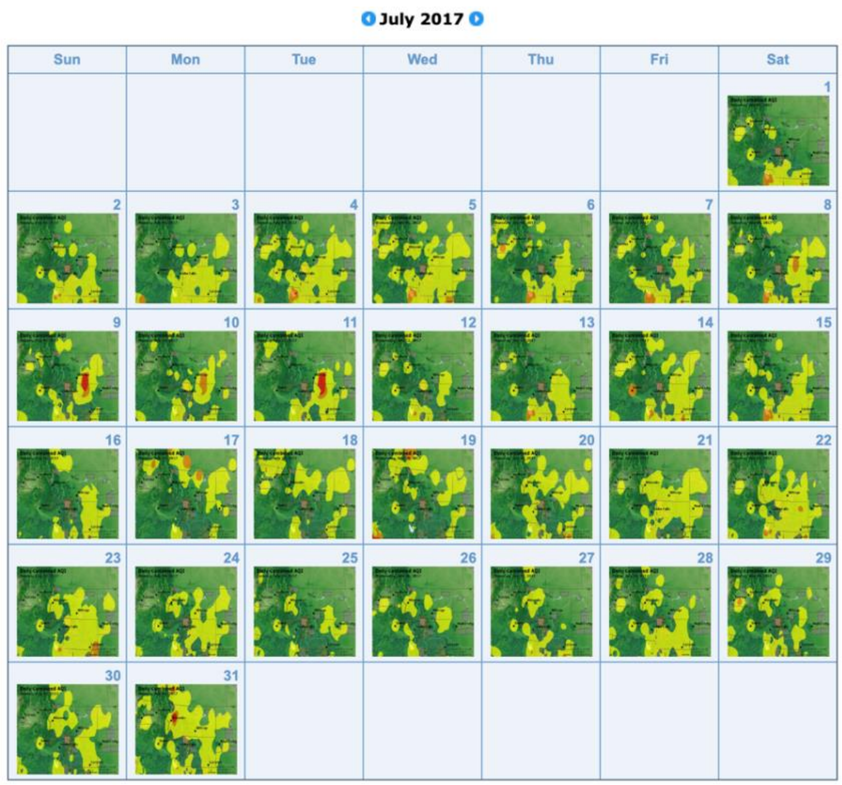
Start date: 7/22/2017

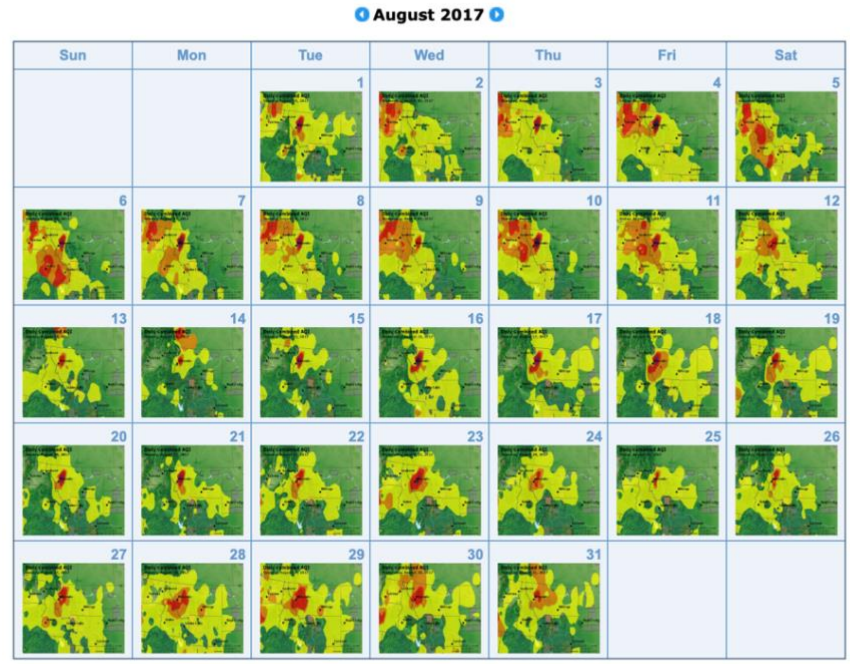
Duration: 2 months

Acres burned: 29,252

Date of peak (highest AQI): 8/29/2017

Description: at the beginning of the fire, the smoke concentrated in a very small area. Then, it began to grow up but still highly concentrated on the areas near Lewis and Clark county for the whole August. During this time, the AQI level kept raising until 23 rd , then the AQI level stared to decrease. Entered into September, the areas that were affected by smoke were bigger and the smoke was gradually moving towards northwestern corner of Montana. On September 4, the smoke was suddenly covered the whole areas of northwestern Montana, meanwhile, the level of AQI was rapidly increased to a very high level and remained until 13 th.

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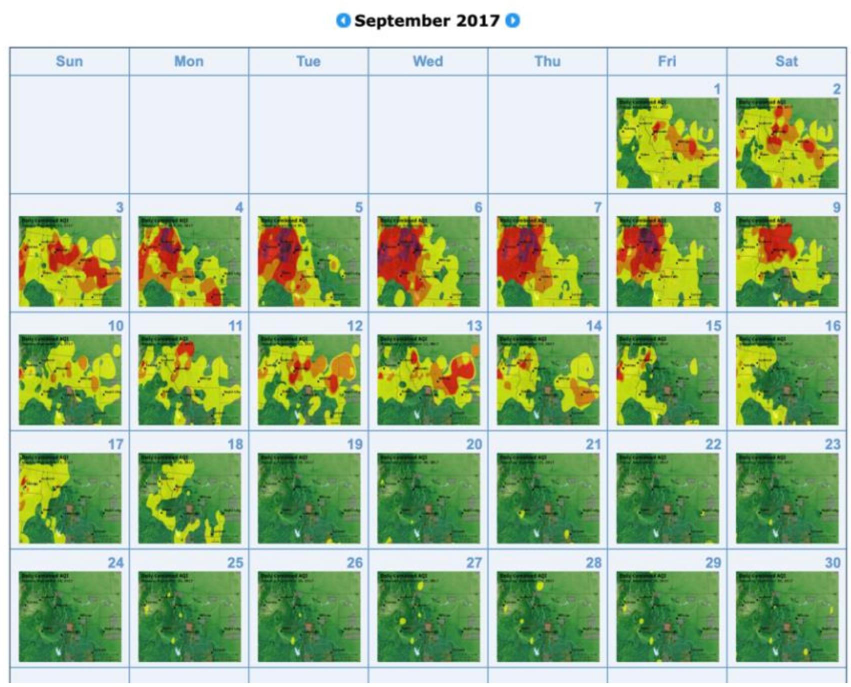
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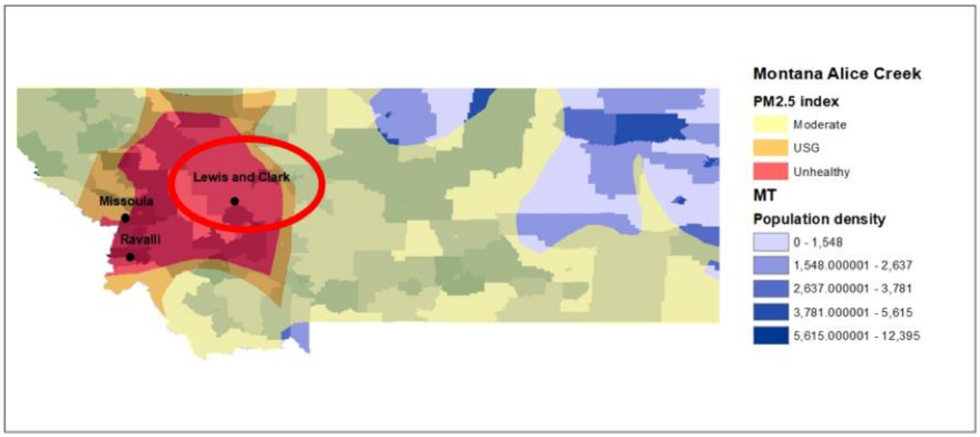
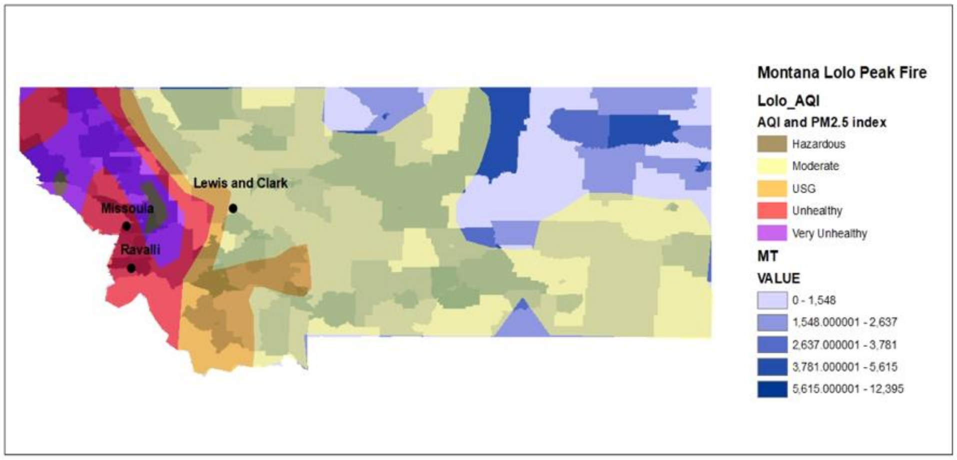


2. Name of the fire: Lolo Peak
County: Missoula
Start date: 7/15/2017
Duration: 3 months
Acres burned: 53,902
Date of peak (highest AQI): 9/6/2017
Description: the Lolo Peak had overlap with Alice Creek in terms of the start date and duration. Also, the location of the two wildfires was close to each other. Therefore, it was hard to clearly identify the distinguish the smoke caused by two different wildfires.



C. North Carolina wildfire events

1. Name of the fire: Party Rock

County: Henderson

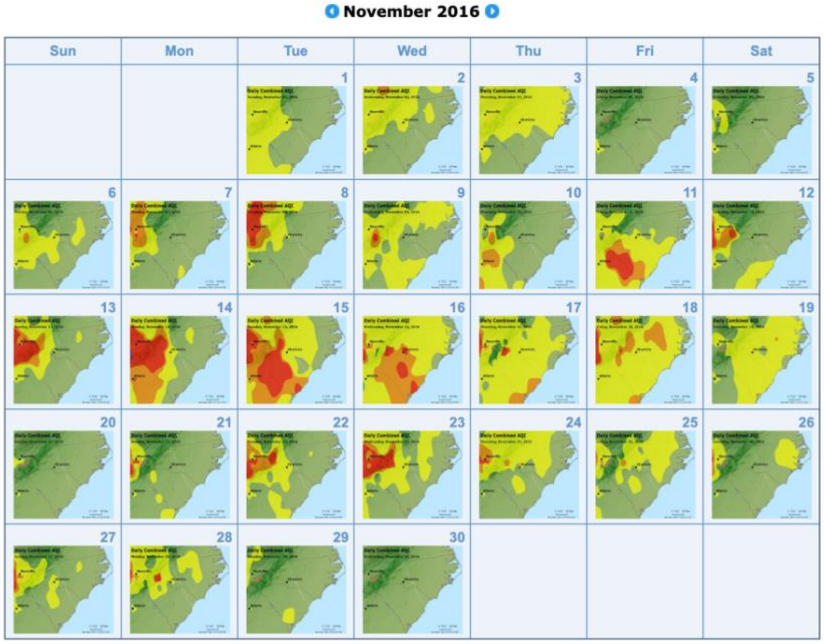
Start date: 11/5/2016

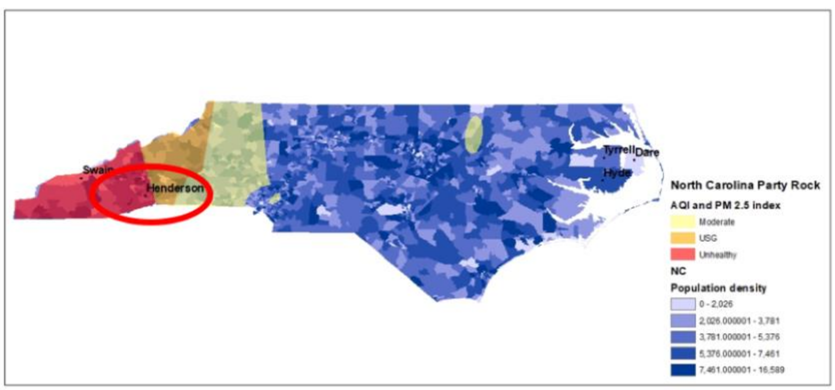
Duration: 22 days

Acres burned: 7,200

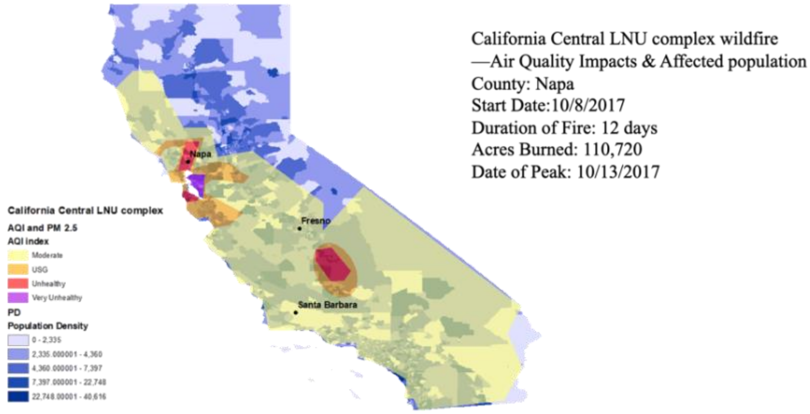
Date of peak (highest AQI): 11/13/2016

Description: at the beginning of the fire, the smoke covered the southwestern corner of North Carolina. As time changed, the smoke was gradually expanding vertically towards north and south and kept becoming fatter and fatter horizontally. On November 19, most areas in North Carolina was covered by smoke and it disappeared on 20th. On 21st, the smoke had appeared again and occupied most of the western and central areas. The highest AQI occurred on 13th, 14th, and 15th in western areas.





2. Name of the fire: Maple Spring
County: Missoula
Start date:11/4/2016
Duration: 23 days
Acres burned: 7,788
Date of peak (highest AQI): 11/23/2016
Description: the fire almost simultaneously broke out with Party Rock fire, and the location was very close. The smoke that was caused by the fire was hard to differentiate with Party Rock fire.



State Mitigation Efforts

In this section, the team mainly researched information on government websites of relevant state agencies of the four states (CA, TX, NC, MT). During the research, we focused on state-level tools and programs that are carried out specifically to address wildfire smoke pollution and individuals' exposure to it. Because the source of PM 2.5 and other major pollutants in the air cannot be distinguished between wildfire smoke and other causes, some of the approaches discussed in this section are also applied for mitigating air pollution in general. As long as the program explicitly considered the mitigation of wildfire smoke pollution as a goal in its design or implementation, we counted it as part of the effort within our project scope.

According to our findings, all of the four states are taking approaches to monitor air quality and public messaging and education. Among the four states, California shows the most significant efforts, with respect to cross-agency collaboration, the number of agencies involved, and the variety of actions. The relevant response efforts from each agency within the four state governments we studied are included below.

California

California Environmental Protection Agency- California Air Resources Board (CARB)

1. Monitoring Air Pollution

During wildfire events, CARB and other agencies deploy additional monitors to measure PM2.5 so the public has information to make health-based decisions and reduce exposure. CARB and local air districts constantly monitor criteria pollutant ambient air concentrations in real time. Location-specific data are posted online several times per day.

California maintains extensive air monitoring networks, with more than 250 monitors collecting data on a wide range of pollutants. There are a number of existing community air monitoring systems throughout California to provide data for and support community specific actions. Community air monitoring data uses can range from providing localized air quality information that may help an individual make decisions to reduce their personal exposure to informing local mitigation and regulatory strategies.

These existing community air monitoring systems utilize a variety of air monitoring approaches and technologies to address community-specific air quality concerns. New monitoring technologies (air sensors and satellite measurements) are providing additional air quality data in areas that do not have traditional air monitors.

Incident Air Monitoring Section (IAMS)

In 2009, CARB assembled the IAMS official emergency response program to "address the mounting concern for public health in the wake of wildfires and other air emergencies." The scope of the program includes efforts to:

- Provide emergency air monitoring support to help protect the public from acute exposure hazards of major unplanned air contaminant releases and other emergencies with air quality impacts.
- Maintain and improve emergency preparedness through training sessions and exercises.
- Represent CARB in developing Board-mandated and interagency response plans.
- Collaborate with other emergency response entities and local air districts for optimum technical and operational effectiveness during emergency events.

The program was initially designed to deploy air monitoring instruments during emergency events, carried out by the Office of Emergency Response (OER) in CARB, but now has evolved to incorporate all types of air monitoring. With the passage of Assembly Bill 617 in 2017 (more details below) and CARB's efforts to establish a more comprehensive community air monitoring capabilities, OER became IAMS at the end of 2017 and is orienting its program to include air monitoring for other non-routine air emission and incidents. While IAMS has broadened its scope to include multiple types of incident monitoring, emergency response will remain a primary focus.

The 2017 annual report of IAMS comprehensively introduced their wildfire response in detail including wildfire response activities, equipment readiness, wildfire outreach, coordination, and training, and wildfire situational awareness.

As part of wildfire response activities, IAMS actively monitors for wildfires and respond to requests from air districts for monitoring support and services and closely coordinates with the California Office of Emergency Services (CalOES) to enable CalOES track CARB resources and enable CARB and local agencies to pursue disaster reimbursement. Once a major wildfire occurs, IAMS establishes communication with client agencies and air districts. IAMS maintains multiple coordination activities as a source of open dialogue between district, state, and federal representatives. During wildfire season, IAMS submits reports of the daily situation, response, fire summaries, public website blog updates, and air monitoring and health advisory information provided to local health officials as requested.

In terms of equipment readiness, in addition to purchasing more instruments to satisfy the increasing need, IAMS also explores low-cost PM sensors seeking to expand and improve the smoke monitoring networks. IAMS also runs an Equipment Cache Program which includes three cache locations for the equipment supply in remote areas. More staff at the air district has been trained to deploy monitoring equipment which has increased the efficiency of IAMS.

*Note: Annual report of IAMS was last updated in 2017 and the 2018 report was not located by the team.

*AB 617: Approved by Governor Brown in July 2017, AB 617 aims to establish a new community-scale emissions abatement program by making use of new air pollution monitoring technologies capable of detecting elevated exposures at a much more granular scale than the conventional ambient air quality monitors. AB 617 requires CARB to develop a monitoring plan for the state and then select the highest priority locations to deploy community air monitoring systems. Considerations in setting the priority locations include the presence of sensitive receptors like schools and hospitals, whether the community is disadvantaged, and whether there is a high degree of exposure to toxic air contaminants and criteria air pollutants. By July 1, 2019, air districts containing selected locations would be required to deploy monitoring systems in the selected locations, with data to be published on the CARB website.

2. Public Messaging and Education

California Smoke Information Blog

The California Smoke Blog is a voluntary effort by city, county, state, tribal and/or federal agencies to coordinate and aggregate information for California communities affected by wildfire smoke. The blog has a plethora of information ranging from air quality standards and the air quality index, information and links to current wildfire locations, and predictive services that can provide a forecast for air quality potential for two to seven days.

There are also links to fact sheets and information about the health effects of smoke, and how to protect oneself, family, friends, and community. There is information regarding advice to resident amid smoke, how wildfire smoke can affect human health, and physical activity during smoky conditions, etc.

California Smoke on Twitter

In addition to the California Smoke Blog, there is a California Smoke Twitter Account, which is another voluntary effort by city, county, state, tribal and/or federal agencies to coordinate and disseminate information to public stakeholders affected by wildfire smoke. The account started in September 2014. All tweets relay users back to the specific wildfire or health information located on the California Smoke Blog. So far, the twitter account has posted nearly 1,500 tweets and has 549 followers.

Air Quality and Meteorological Information System (AQMIS)

AQMIS provides real-time monitoring data of O3 and PM2.5 concentrations in over 150 cities across California and is available on both website and mobile device. Residents can use AQMIS to check for wildfire smoke impacts.

3. Outreach and Coordination

California Air Response Planning Alliance (CARPA)

Formed in 2016, CARPA is a network of local, state, federal air and public health agencies and resources joined together to improve coordinated response to major air releases and emergencies with air quality impacts (https://www.arb.ca.gov/carpa/carpa-charter.pdf). The mission of the alliance is "to provide actionable incident response information to protect public health and the environment from the impacts of accidental or deliberate releases of hazardous compounds into the air."

CARPA Participating Agencies include:

- Agency for Toxic Substances and Disease Registry (ATSDR)
- Bay Area Air Quality Management District
- California Air Pollution Control Officers Association (CAPCOA)
- Office of Environmental Health Hazard Assessment (OEHHA)
- California Department of Public Health (CDPH)
- California Air Resources Board (CARB)
- Governor's Office of Emergency Services (Cal OES)
- National Park Service
- USDA Forest Service
- EPA Region 9 (Pacific Southwest)
- Sacramento Metropolitan Air Quality Management District

CARPA provides a forum for air districts, environmental and public health professionals, emergency response agencies, and public information officers to facilitate increased response coordination and capabilities for major hazardous air release incidents with the goal of protecting public health in California. In particular, CARPA's charge is to improve air quality assessments, making them useful for emergency response. Inherent in the charge is to provide public health officials with 'actionable' information.

Other areas CARPA addresses include raising awareness among California's emergency response community of existing and potential capabilities, improving cooperation and coordination among all levels of government and across disciplines, and enhancing, cataloging, developing, and disseminating information on credible response methods and practices. The main emphasis of CARPA's preparedness and planning efforts is on downwind communities impacted by hazardous air releases.

CARPA is structured as an ad hoc alliance of representatives from federal, state, local, and tribal government agencies and supporting entities governed by a Steering Committee and subcommittees. The subcommittees are organized according to the three themes:

- Data: focuses on the analytical aspects of airborne releases including emergency air monitoring, sampling, modeling, meteorology, and data management.
- Data to Message: focuses on developing, standardizing, and applying public health guidance for making rapid decisions about health and safety during emergencies.
- Message to Audience: focuses on training and tools for messaging and emergency communication during an airborne release.

*Note: CARPA is still active currently but information about CARPA Meetings & Emergency Response Training Opportunities were last updated in March 2012.

Department of Forestry and Fire Protection (CalFire)

CAL FIRE regularly updates the Statewide Incidents Map with details about fires burning in California.

Vegetation Management Program (VMP)

Started in 1980, the goal of the VMP is to reduce the chance of large, damaging wildfires by reducing fire hazards on wildlands in California. It allows public and private landowners to participate in wildland fuel reduction projects to establish fuel breaks and eliminate heavy fuel accumulations in many areas of the state. Although it uses prescribed fire as the primary tool, one of the 14 sub-goals of the program is to improve air quality over the long term, and acres treated have declined significantly in recent years since 1999 partly due to the concern of air quality issues.

California Climate Investments (CCI) Grant Programs

CalFire administers grant programs using funds provided by the Greenhouse Gas Reduction Fund for CCI. Through these programs, CalFire funds and implements project partly for the purpose of minimizing the loss of forest carbon from large, intense wildfires.

One of the current three grant programs is Fire Prevention, through which CalFire aims to reduce the risk of wildfires to habitable structures and communities while maximizing carbon sequestration in healthy wildland habitat and minimizing the uncontrolled release of emissions emitted by wildfires. Projects and activities of the program include 1) hazardous fuel reduction and removal of dead, dying, or diseased trees, 2) fire prevention planning, and 3) fire prevention education. Roadside Fuels Reduction Project in Yuba County is an example of a project that reduces the potential for a large and damaging wildfire which would also reduce hazardous greenhouse gasses due to the wildfires.

Department of Industrial Relations Division of Occupational Safety and Health (Cal/OSHA)

Worker Safety and Health in Wildfire Regions

When employees are working outdoors where the air is affected by wildfire smoke, employers are required by Cal/OSHA's standards on Control of Harmful Exposure to Employees and Respiratory Protection (2012) to determine if the outdoor air is a "harmful exposure" to employees. Exposure is harmful when the pollution or contaminants in the air cause (or are likely to cause) injury, illness, disease, impairment or loss of function. Cal/OSHA provides guidance for employers and workers on working safely in conditions with heavy smoke caused by the wildfires, including information for protecting outdoor workers, details on how to protect indoor workers from outdoor air pollution, worker safety and health during fire cleanup, and safety and health of workers rebuilding after wildfires.

1. Protecting Outdoor Workers Exposed to Smoke from Wildfires

When employees are working outdoors where the air is affected by wildfire smoke, employers are required by Cal/OSHA's standards on Control of Harmful Exposure to Employees and Respiratory Protection to determine if the outdoor air is a "harmful exposure" to employees.

When outdoor workers are exposed to air quality that is designated “Unhealthy”, “Very Unhealthy” or “Hazardous” by local air quality management districts, employers are required to provide filtering respirators such as masks labeled N95 and certified by the National Institute for Occupational Safety and Health (NIOSH). These masks filter at least 95 percent of airborne particles but do not protect against gases or vapors. On Cal/OSHA’s website, information is provided of the distribution locations of N95 respirator masks and frequently asked questions about N95 masks.

When exposure to wildfire smoke is considered harmful, employers are required to take the following measures to protect workers:

• Implement feasible modifications to the workplace to reduce exposure. Examples include providing enclosed structures or vehicles for employees to work in, where the air is filtered.

• Implement practicable changes to work procedures or schedules. Examples include changing the location where employees work or reducing the amount of time they work outdoors.

• Provide proper respiratory protection equipment, such as disposable respirators, if the previous measures are not feasible or do not prevent harmful exposures.

2. Protecting Indoor Workplaces from Wildfire Smoke with Building Ventilation Systems and Other Methods

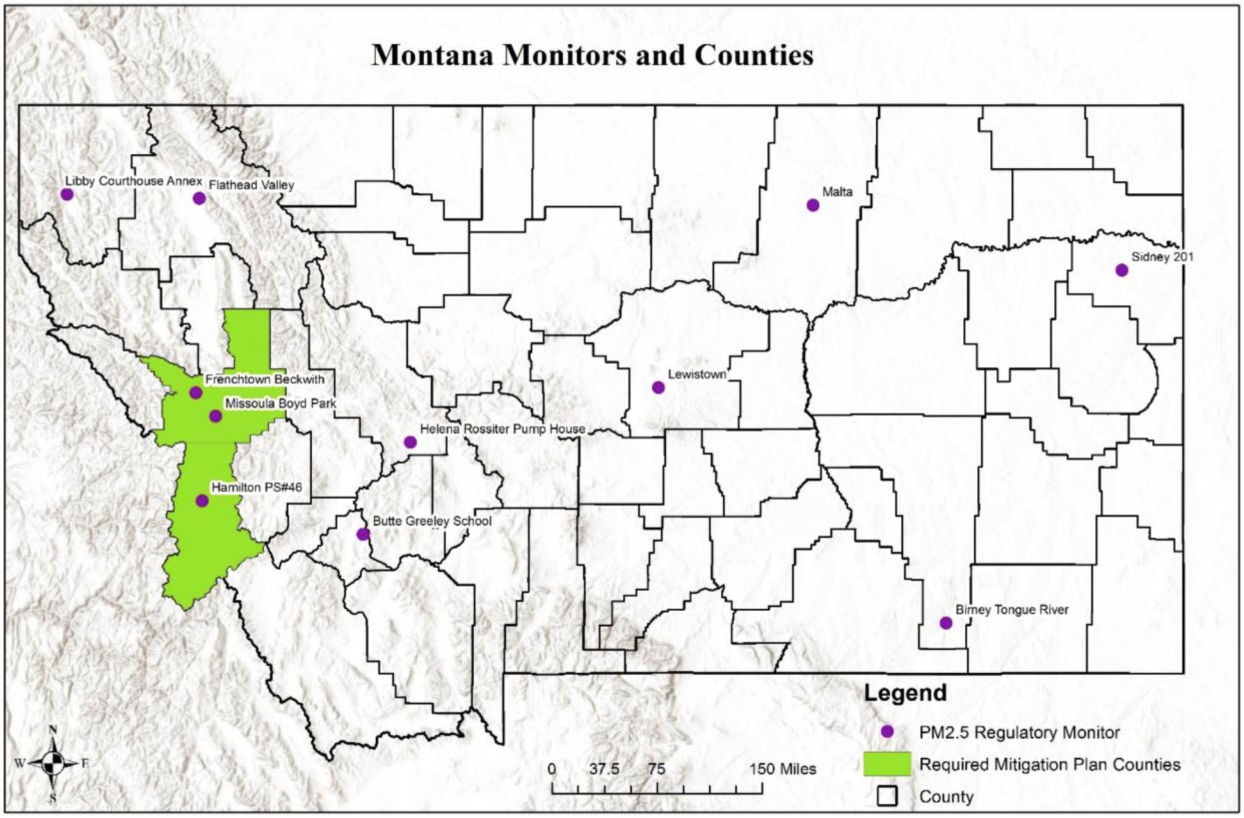
Guidance and details are provided about using the HVAC system and other methods to protect building occupants from wildfire smoke. Employers are required to ensure that **h**eating, **v**entilating and **a**ir **c**onditioning (HVAC) systems are maintained and operated to provide the minimum quantity of outdoor air required by the State Building Standards Code in effect at the time the building permit was issued.

Montana

Department of Environmental Quality's (DEQ)

1. Air Quality Monitoring

Montana DEQ actively monitors smoke impacts from wildfires and provides regular smoke updates during the wildfire season. Two counties, Missoula and Ravalli, are required to prepare mitigation plans for wildfire smoke pollution. Missoula and Ravalli counties were noted in the final exceptional events rule (81 FR 68272) as being subject to mitigation requirements for particulate matter of 2.5 microns (PM2.5) or less due to wildfire events.



[Helena AQ Webcam](#)

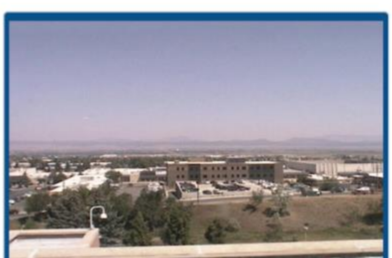
The webcam faces north towards the "Sleeping Giant" mountain, a well-known local landmark. The cam is located at DEQ headquarters and operates during daylight hours. It is used primarily as an indicator of air quality conditions. The Giant is 22 miles north of the camera and can be seen when the air quality in the Helena Valley is good to excellent. The dark band of trees in front of the Sleeping Giant is on the "North Hills" 12 miles away. As long as the North Hills are visible, the air quality in the valley is good. When they cannot be seen, the air quality is moderate.

The photo refreshes every 5 minutes. Occasionally someone will be driving the camera. The camera returns to the Sleeping Giant every 15 minutes.

[*Today's Air*]

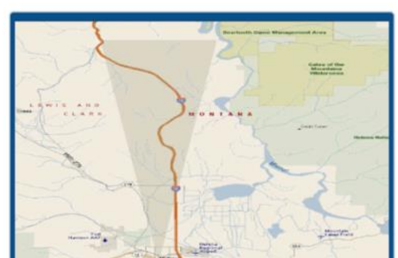
Good quality:

Poor quality:



Hazy Conditions

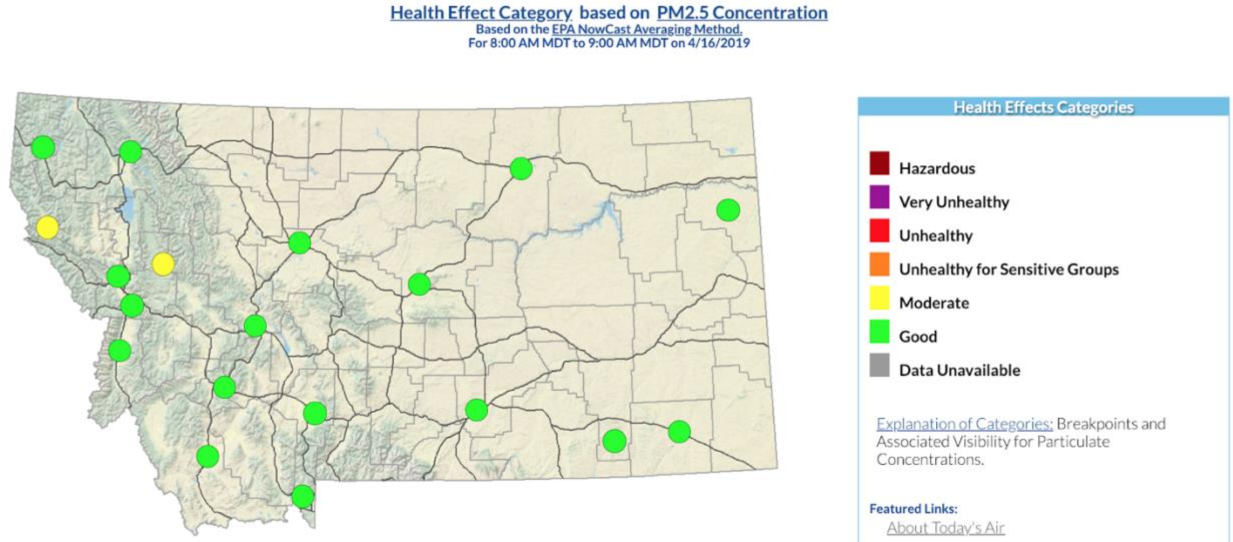
Good Air Quality



Camera Span

[*Today's Air*]

Today's Air website provides near real-time fine particulate-related air quality information to the public on an hourly basis. The website, first launched in 2006, has evolved over time to continually provide more up-to-date information in more user-friendly formats. Currently, Today's Air website updates at 15 minutes past the hour and provides PM2.5 concentrations from permanent and temporary monitoring stations running 24 hours a day and 365 days a year.



Each dot on the map represents an air monitoring station. The color of the dot is determined by the current local air quality and comparison to the health effects category table.

These stations are sited in accordance with regulatory obligations or have been installed at the discretion of the DEQ to represent a significant population area. On occasion the DEQ will place temporary monitors in response to an episodic event, typically to address wildfire impacts. Depending upon the nature and duration of a monitoring event a temporary station may be represented on the Today's Air web page.

Wildfire Smoke Update

The DEQ provides daily updates during times when air quality impacts are occurring across the state. These updates are divided into two categories: 1) wildfire smoke updates and 2) winter air quality updates. Wildfire smoke updates outline the cause of wildfire smoke in the state as well as a forecast for upcoming days. Every day's report, forecast, and summary are posted as well as satellite photos and locations and smoke conditions (PM2.5) of wildfires over the past 24 hours. Updates will not be available during times when air quality is good across the state, most commonly in springtime.

Additional Monitoring

When numerous fires in Montana cause hazardous air pollution in communities, additional monitors can be deployed to track the most significant impacts. During wildfire season, DEQ deploys monitors to track PM2.5 impacts on a case-by-case review of requests. These monitors were used to support the public in their effort to find cleaner air. Monitors deployed by DEQ show up on Today's Air website with the data reported at the same frequency as our permanent monitors. In past years, DEQ has also coordinated with the U.S. Forest Service to place additional monitors in vulnerable communities. These monitors can be used by schools, public health officials, and business to determine if activities should be canceled, rescheduled or moved based on the air quality. For example, in 2017 DEQ deployed monitors around the Seeley-Swan Valley to assist residents impacted by the large Rice Ridge Fire in identifying areas of improved air quality.

2. Public Notification and Education

Social Media

DEQ is running a twitter account started in 2010. The account has 1,179 tweets and 1,402 followers in total. It tweets to inform the public to protect their heart and lungs from poor air quality when wildfire season is approaching.

Wildfire Smoke Forecasts

During wildfire season, the agency issues wildfire smoke forecasts, which are disseminated across a variety of platforms. These forecasts include a summary of current air quality across the state, a review of current fires and anticipated future smoke impacts. These updates are posted on the state of Montana website, accessible through the Today's Air site, posted to social media, and distributed to interested parties via email. The interested parties list is open to anyone wanting to receive this information and commonly includes city and county environmental health officials, federal land managers, local news stations and newspapers, school nurses, athletic coaches, and members of the public.

Educational Videos

DEQ provides an educational video for explaining the information available on Today's Air website. This video explains what the color-coded health effect categories mean, how to navigate the site, where to find individual station information and the daily wildfire smoke update. The video also provides background on PM2.5 and the need for air quality standards.

3. Outreach and Coordination

The National Weather Service

At times during severe air quality events, DEQ issues Air Quality Alerts in coordination with the National Weather Service. The state of Montana initiates the alert process across the entire state. The Great Falls National Weather Service office then disseminates the alert to all affected offices automatically.

Department of Public Health & Human Services (DPHHS)

DEQ and DPHHS worked together to create recommendations for outdoor activities based on air quality for schools and child care facilities. This two-page document recommends activities that are appropriate and warns against those that are not for different health effect categories. This document was distributed to all schools through the Montana Office of Public Instruction, through the Montana Coaches Association, and in coordination with state and local health departments.

Montana-Idaho Interagency Smoke Management Coordination Strategy

DEQ participates in the Montana-Idaho Interagency Smoke Management Coordination Strategy for the mitigation of public health and welfare impacts caused by smoke from wildfires. This strategy focuses on three main aspects: contact, documentation, and information. Through these three focus areas DEQ and fire management agencies work together to inform and mitigate smoke impacts to the public. In the 2017 wildfire season, DEQ, the Missoula City County Health Department, and the USFS Air Resource Advisors initiated daily coordination calls to talk about current and future fire activity, the need for additional monitors, and public meeting messages. These meetings continued daily and grew to include more counties as smoke impacts spread until mid-September when wildfire activity subsided.

4. Smoke Management Plan

Wood burning during the wildfire season (June – October) is the main cause of PM2.5 in Montana. The exceptional events in Montana caused by wildfires do not overlap with the winter inversion season, when wood stove impacts are impacting western valleys. Therefore, prescribed burning is the main competing source of PM2.5 that could increase PM2.5 concentrations during exceptional events. For this reason, open burning in Montana is regulated at the state and local level to prevent additional PM2.5 smoke impacts during wildfire season, and to protect NAAQS when wildfire activity subsides.

Disaster and Emergency Services (MDES)

Montana Wildfire Event Action Plan for the Mitigation of Public Health Impacts Caused by Smoke from Wildfire Events

As part of the Multi-Hazard Mitigation Plan prepared by MDES, the action plan focuses on the monitoring and notification actions to be taken by the State for air quality during wildfire events. The issue of public information and suggested actions such as staying indoors etc. is addressed. Additional integration of mitigation measures is not required. The Wildfire Event Action Plan is maintained by the Montana DEQ, Air Resources Management Bureau, and actions in the plan have been introduced in the DEQ section above.

Department of Natural Resources and Conservation (DNRC)

DNRC does not engage in direct efforts to address the air quality impacts of wildfires.

Department of Public Health and Human Services (DPHHS)- Public Health & Safety Division

1. Public Messaging and Education

On the website, DPHHS provides health resources to the public including recommendations for avoiding prolonged exposure to harmful wildfire smoke, a guide to buying a High-Efficiency Particulate Air (HEPA) air purifier, recommendations for outdoor activities based on air quality, and other national resources.

2. Outreach and Coordination

Montana Wildfire Partners

The page also provides links to other wildfire partners of Montana which includes Today's Air, Ready and Safe Montana, Montana Office of Tourism and Business Development, American Lung Association, and Climate Smart Missoula county.

The American Lung Association works with DPHHS, DEQ, and local county health departments to get air filters into the most vulnerable populations across the state and purchase HEPA air purifiers for schools most heavily impacted by wildfire smoke.

North Carolina

Department of Environmental Quality (DEQ) - Division of Air Quality (DAQ)

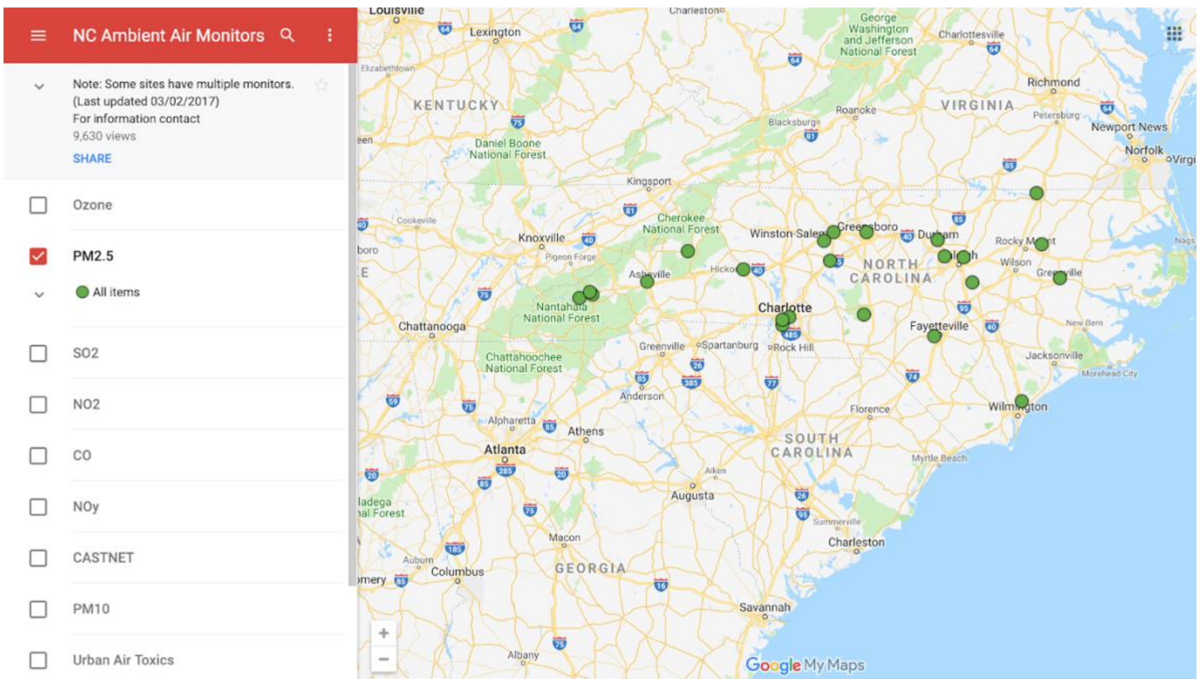
The DAQ operates a statewide air quality monitoring network to measure the level of pollutants in the outdoor air, develops and implements plans to meet future air quality initiatives, assure compliance with air quality rules, and educates, informs and assists the public with regard to air quality issues. The Division of Air Quality consists of five sections located in the central offices in Raleigh and seven regional offices located across the state.

Air Quality Monitoring

The DAQ operates a network of air quality monitors across the state. The network includes 75 monitors at multiple sites and measures the concentration of regulated pollutants in the ambient or outdoor air (including ozone, PM2.5, nitrogen oxides, sulfur dioxide and carbon monoxide which are also pollutants of wildfire smoke).

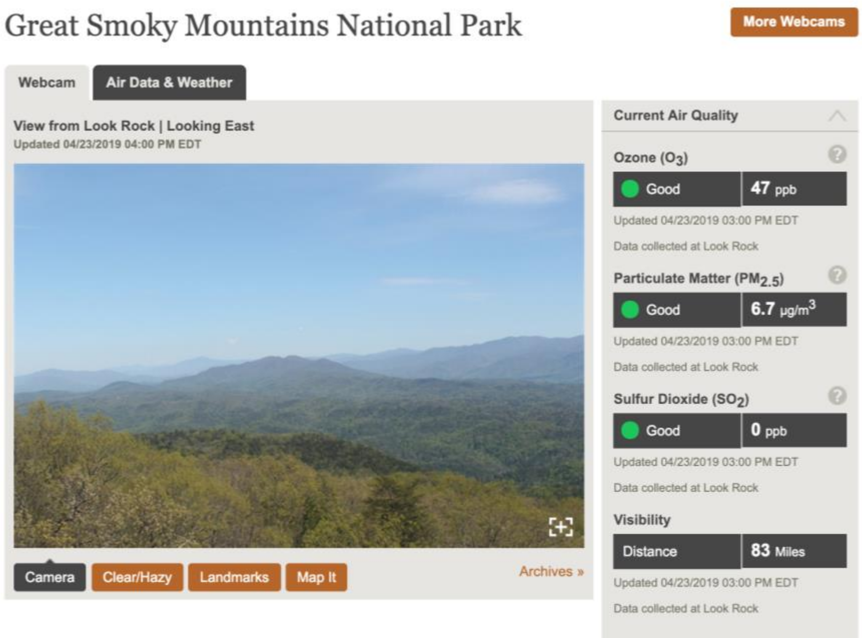
Blow (on the next page) is a screenshot of the distribution of PM2.5 monitoring stations (source). Monitoring locations of other pollutants can be selected and shown on the map.

The public can check monitoring data by pollutants and by sites. When wildfires occur, DEQ issues special air quality forecasts for areas affected by smoke from the large wildfires that are burning. In 2016, with wildfires burning across Western North Carolina, state air quality officials distributed a visibility guide for assessing health risks from smoke due to wildfires.



Haze Cams

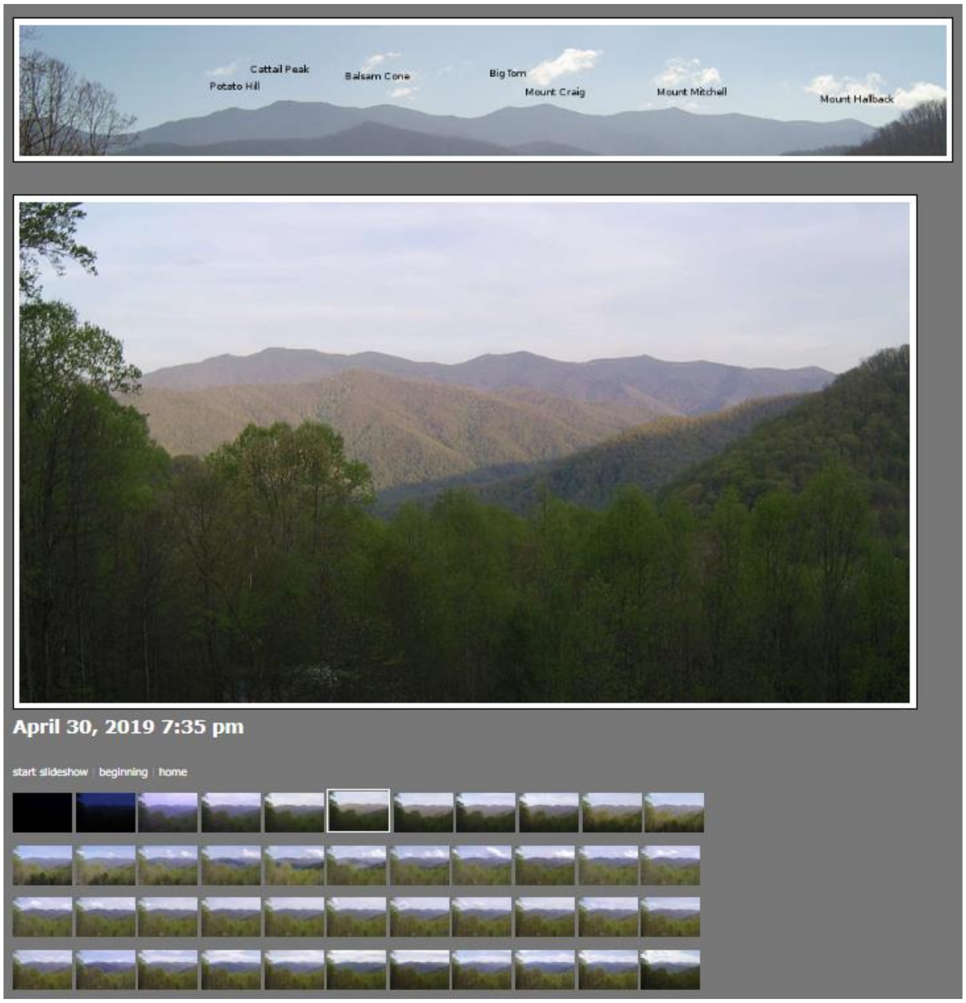
North Carolina haze cams present real-time images of 19 locations. The images are updated every hour. Nine out of the 19 camera sites are mountains or state parks where forests are concentrated. Some of the cams are run by the National Park Service (NPS). Below is an example of one cam located in a national park.



Good Visibility Day
Visual Range: 124 miles

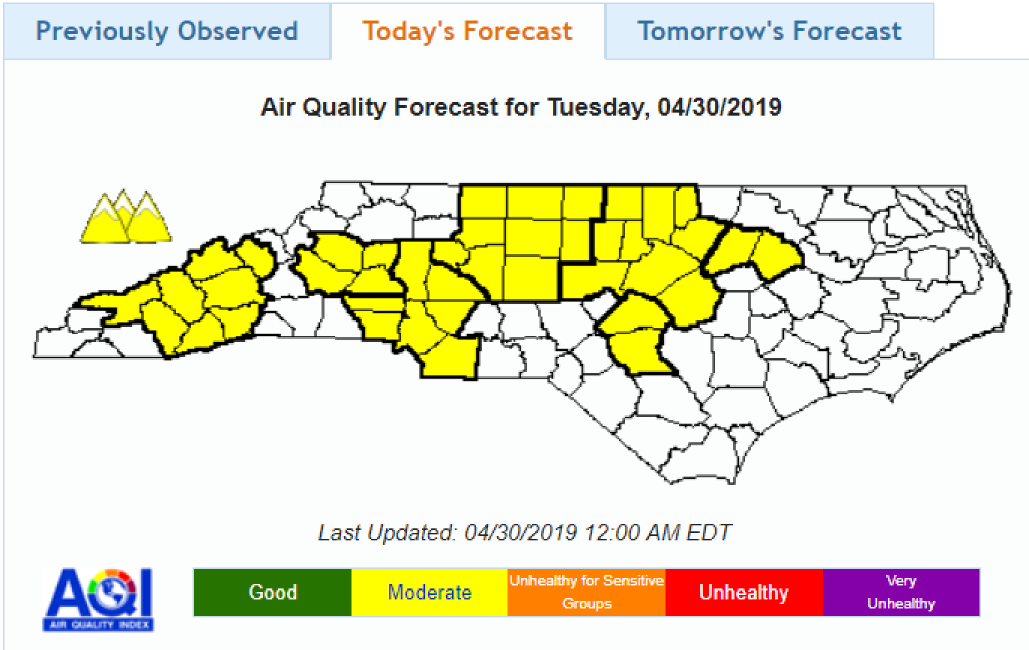
Bad Visibility Day
Visual Range: 26 miles

Cams other than those run by NPS do not provide detailed data about the monitoring sites as above. Below is an example of a cam in a state park.



[Air Quality Forecast Center]

The hub for finding air quality forecasts and related air pollution information, but it does not provide specific information about wildfires. There are seven air quality forecast twitter accounts run by different counties for the purpose of public messaging.



North Carolina Forest Service (NCFS)

Smoke Management Program (SMP)

SMP is a program whose primary purpose is to mitigate the effects of smoke from forestry related prescribed burning which is an effective tool used to reduce the risk of wildfire occurrence. The SMP and smoke management guidelines are part of North Carolina's effort to control PM2.5 and are intended to be used by burners to mitigate smoke from prescribed burns so that the PM2.5 standards are not exceeded.

Texas

Texas Commission on Environment Quality

The EPA adopted rules in 40 Code of Federal Regulation (CFR) §§50.14 and 51.930 to implement section 319, requiring states to adopt and implement mitigation plans in areas with historically documented or known seasonal events. Mitigation plans must include two components: first, public notification and education; second, steps to identify, study and implement mitigating measures.

1. Public Notification and Education

The TCEQ has a mechanism in place to forecast the future and monitor current air quality and to notify the public when exceptional air quality events occur. The exceptional air quality events are usually identified when air quality concentrations of criteria pollutants exceed or are expected to exceed an applicable short-term National Ambient Air Quality Standards (NAAQS). The notification will take place 48 hours in advance of the event if possible. To serve the affected or potentially affected communities, several programs are being conducted such as the following:

TCEQ Air Quality Index (AQI) report

This report is provided in the TCEQ website that displays the latest and historical daily AQI and its components information online for public access. The AQI is measured on 14 regions divided as a metropolitan area and non-metropolitan area --however, the report had several missing components.

Daily Texas Air Quality Forecast

This forecast website provides a four-day forecast information for air quality. Each day's forecast has been attached with description of wind pattern, smoke, which will give people details of how the smoke spread in Texas. The website also provides links to related data such as Air Quality Index (AQI) Report, Ozone: The Facts, Map of Current PM2.5 Levels, Texas Air Monitoring Data , Map of Current Ozone Levels, EPA AIRNow Air Quality Forecasts, Current Satellite Images, NOAA/EPA Ozone Model Forecasts, Real-Time Winds Aloft, NRL Aerosol Model Forecasts. The forecast is disseminated via email and available on the agency social media accounts.

2. Implement Mitigating Measures

Once TCEQ realizes that an exceptional event is highly possible to occur, and the forecast indicates that air quality conditions will be severe, additional measures to mitigate controllable sources that are emitting pollutants will be considered. Measures may include the efforts that encourage the public and businesses to help minimize emissions of pollutants by conducting actions such as: shift work schedules to allow employees to avoid morning rush-hour traffic, allow employees to work at home, carpool to lunch and meetings, etc.

The TCEQ employs mechanisms to consult with other air quality managers in the affected area regarding the appropriate responses to abate and minimize impacts. These include:

• Toxic Substances Coordinating Committee (TSCC). The purpose of the TSCC is to coordinate communication among member agencies concerning each agency's efforts to regulate toxic substances and harmful physical agents.

• Local Government Advisory Groups. The groups' responsibilities include helping the TCEQ implement legislation, developing rules, forming policies and procedures, and implementing plans to assist local governments.
• Air Quality Advisory Groups. Advisory groups' main job is to assist the agency with air quality issues.
• TCEQ regional air quality managers from the impacted area are periodically updated, and routinely interact with local partners regarding air quality issues.

LIMITATIONS

Methodology

It is difficult to isolate the effects of wildfires on air quality as may be seen in studies with regression analysis. Since our variables for air quality impacts are daily AQI and PM2.5, we are assuming that the change in AQI and PM2.5 level in the period and county studied occurred as a result of the selected wildfire. Thus, we have assumed other air pollutants or events are not intervening. Given the limited information about the wildfires in some of the states studied, such as duration (how many days), location (which counties are affected), and the number of acres burned, the team was limited in the wildfires that could be selected for a detailed analysis. We would like to emphasize that this analysis was especially difficult in Texas. For instance, according to the National Interagency Fire Center data, in 2011, there were 3,470 wildfires in Texas. However, only 12 wildfires had thorough information including duration, location, and the number of acres burned. Wildfires with missing information were not included in the list from which wildfires were randomly selected for detailed analysis. Moreover, the impact of the selected wildfire on AQI and PM2.5 level is only measured in the counties where the wildfire occurred, the impact on the neighboring counties are not measured.

Air Quality Index and PM2.5 Level Data

Since we are comparing the AQI and PM2.5 level during the wildfire to the baseline period, it is essential to have a daily AQI and PM2.5 level data for that particular county where the selected wildfire occurred. Otherwise, we cannot measure the effect of the selected wildfire on air quality. While the National Interagency Fire Center (NIFC) has extensive state-level data of overall numbers of fires and acres burned, the information regarding the exact location and date of the wildfires were very limited. In that regard, NIFC only has data (year, state, acres burned, and fire name) for 187 wildfires that burned more than 100,000 acres. Except for California, other state agencies also have very limited information on wildfires.

Regarding the daily AQI and PM2.5 level data from the U.S. Environmental Protection Agency, California had the most data available for our study, whereas, Montana, North Carolina, and Texas had very limited data available. In total, California has 58 counties and corresponding data was available for 52 counties; Montana has 56 counties but data was available for 16 counties; North Carolina has 100 counties but data was available for 27 counties; Texas has 254 counties but data was available only for 36 counties. Fortunately, for Montana, the selected 3 wildfires occurred in counties where we had available data. Whereas, in North Carolina and Texas, the wildfires mostly occurred in the counties where we had no available data. Thus, for the wildfires Party Rock Fire (Henderson and Rutherford counties, North Carolina) and Bear Creek Fire (Cass and Marion counties, Texas) we used desperate measures, such as capturing the effect of wildfires by the change in AQI and PM2.5 level in the nearby county (Buncombe, North Carolina and Harrison, Texas). Therefore, we believe that the lower changes of AQI and PM 2.5 in North Carolina and Texas might be misleading.

Mapping

There are several limitations of the mapping methodology. First, static mapping cannot reflect the daily change in the movement of wildfire smoke. Since the smoke can spread far away from the broke out point and the existence of smoke that is identified as USG or above can be durable. Therefore, to understand how the smoke spread across the state and what AQI level it can maintain over time are important. Due to the limitation of GIS, it is hard to make an animation that can reflect the movement of wildfire smoke. We were only able to demonstrate the one-day map of smoke.

Second, exact coordinates of acres burned by wildfire unknown. Due to the data limitation, although the total acres burned in each wildfire event is accessible, the information of the exact location of acres burned remains missing.

Third, it is very hard to clarify the movement of smoke. Since there are many factors that can emit smoke. Also, it is hard to differentiate the smoke caused by different wildfire, especially when wildfire events were geographically close to each other.

Fourth, due to data limitations, we were unable to map five wildfire events including Valley Complex fire in Montana, Evans Road fire in North Carolina, and all the wildfire events in Texas.

State Mitigation Efforts

Since the team relied on online searching to answer this question, any effort that is not documented and published on governments' website will not be identified by the team. In terms of available information, most of the programs are introduced as plans in place, however, their performance and how well they are executed remains uncertain.

CONCLUSION

We found that for the three wildfires in each state we researched, the average change in air quality index (AQI) was highest in California, exceeding the “code red” situation or unhealthy for all population. Due to the relatively lower baseline level, the average change in AQI in Montana was slightly lower, but exceeded the “code orange” situation or unhealthy for sensitive groups. However, in North Carolina and Texas, the average changes in AQI were not significant, the “code yellow” situation or moderate level. Whereas, the average change in PM2.5 level was highest in Montana, slightly lower in California. However, both changes exceeded “code orange” situation for the health concern. In North Carolina and Texas, both changes were at moderate level. This finding could be misleading due to limited data availability, however, we also believe that the wildfire emission level heavily depends on the composition of fuel. Our finding was consistent with the previous literature findings of the U.S. wildland fire emission estimates 2003-2015.

Based on the map of wildfire events we studied, we concluded several findings about the movement of smoke and impact on populations. First, during the wildfire event, smoke that is on “moderate” AQI level seems to stay longer in the atmosphere than smoke that has AQI levels above “moderate”. In the wildfire events we studied, smoke that is identified as “very unhealthy” or “hazardous” usually lasted for only several days. Smoke that is on “moderate” AQI level lasted for weeks. Second, smoke that is on higher AQI level usually concentrated in a small area, while smoke that is on lower AQI level can cover a large range of areas. This finding implies that the longer the distance smoke travels, the lower the AQI level will be. The movement of smoke may decrease its density of pollutants. It also implies that a greater population will be affected by wildfire smoke that has “moderate” AQI for weeks or months and even though it is far away from the place in which wildfire occurred.

State governments of California, Montana, North Carolina, and Texas are aware of the serious threat of wildfire smoke on local air quality and public health. Among the four states, California and Montana have relatively more developed and comprehensive programs. The two states are advanced in terms of the number and diversity of the programs. All four states implemented air quality monitoring in the emergence of wildfires. Across-agencies cooperation were established for wildfire-smoke response preparation. Another action that is taken by all of the four states is public notification and education. State agencies are taking advantage of social media, websites, application on mobile devices, and an email subscription to notify residents of real-time air quality and appropriate activities during the days of poor air quality resulting from wildfire smoke. In addition to these methods, Cal/OSHA’s effort in protecting workers’ safety, including regulating employees and distributing N95 masks, stands out for reducing exposure of outdoor workers specifically. It is also interesting of Montana DEQ to coordinate with DPHHS and American Lung Association to distribute recommendations for schools and child care facilities and purchase HEPA air purifiers for schools most heavily impacted by wildfire smoke.

RECOMMENDATION

Observing the trends of wildfires in states California, Montana, North Carolina, and Texas for the last 15 years, we found that the increasing number of wildfires, as well as its severity (acres burned) were mainly due to the increasing level of droughtness caused by climate change. Given the current technological advancement allows us to forecast temperature, level of droughtness, level of rainfall, and wind patterns, the Federal Government of the U.S. can build a wildfire risk prediction model by combining above data with historical wildfires data by region and seasons. This model will support state and county authorities to prevent wildfires, mitigate its risk and allocate their resources efficiently.

Based on the expansion of programs in California, it is likely that air quality monitoring will be expanded to the community level in the state, i.e. every community is an air quality monitoring unit, when technology allows low-cost and easy-to-operate monitors. In this case, accurate data information about local air quality will be accessed by community officials and residents. This will better serve to make policy decisions and recommend residents' activities.

To mitigate public exposure to wildfire, more agencies with different functions should involve and coordinate to target different vulnerable groups. Cal/OSHA and Montana DEQ's coordination with DPHHS are good examples. Departments of environment, health, fire etc. and the media should work closely to provide health advice informing the public. During the incident, these agencies can make the public receive consistent messages of wildfire and smoke by mobile phones, emails, or local media. Moreover, based on the wildfire smoke forecast system, cities, towns, and villages on the way of wildfire smoke should be warned in advance.

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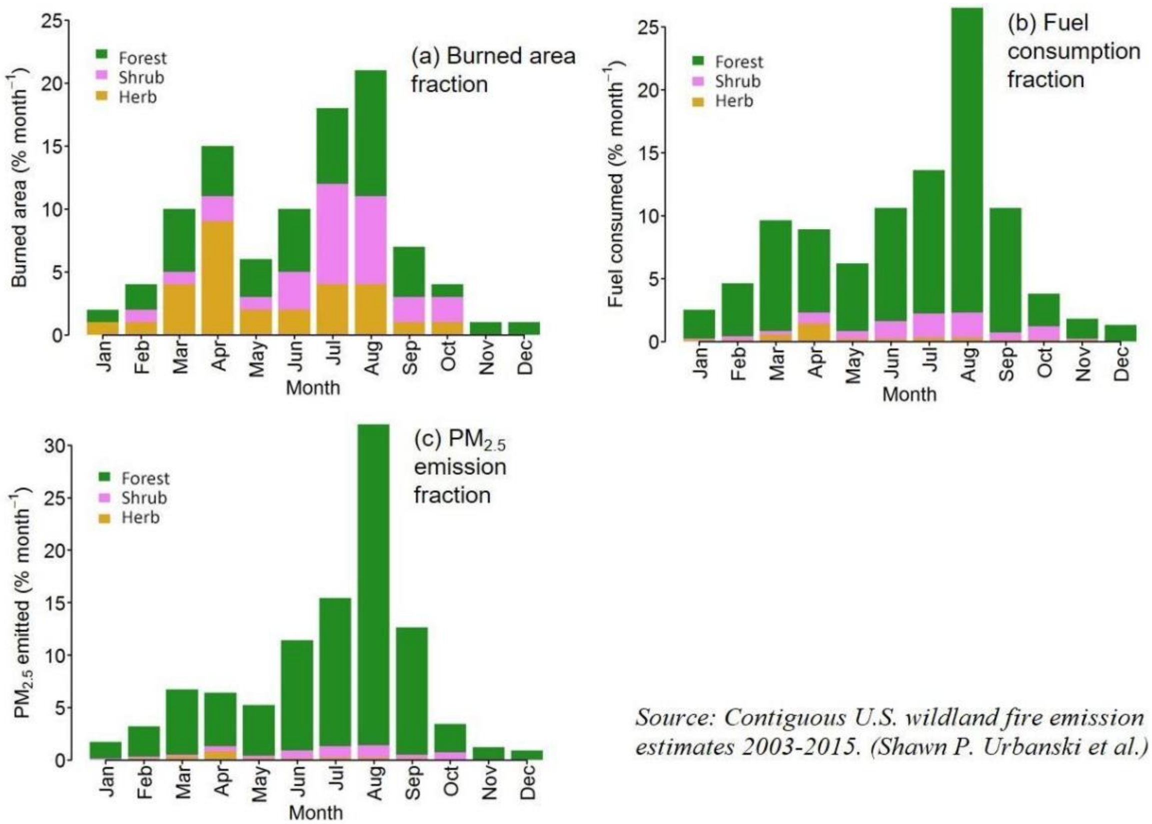
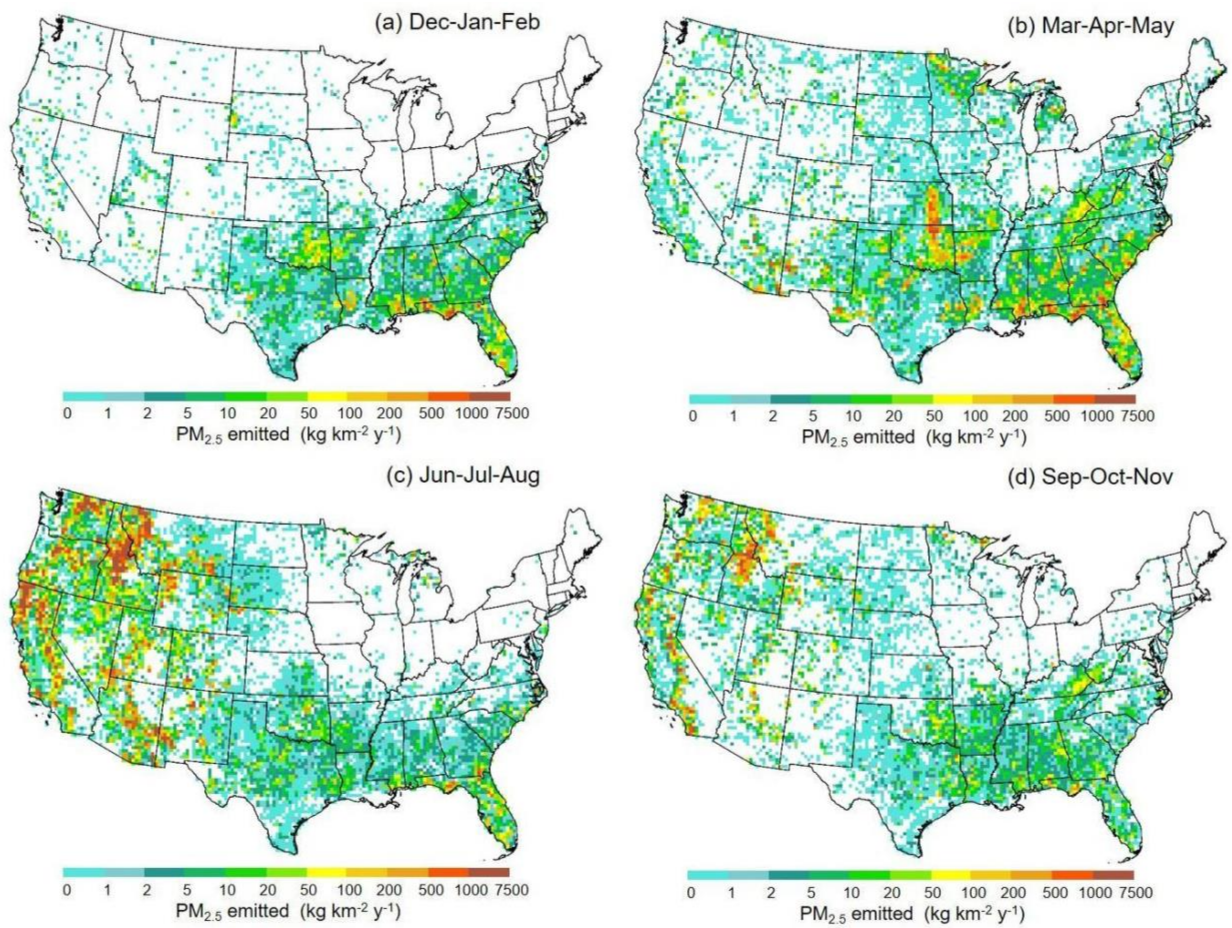
APPENDICES

Appendix 1. Monthly distribution of burned area, fuel consumption, and PM2.5 emitted over 2003-2015.



Source: Contiguous U.S. wildland fire emission estimates 2003-2015. (Shawn P. Urbanski et al.)

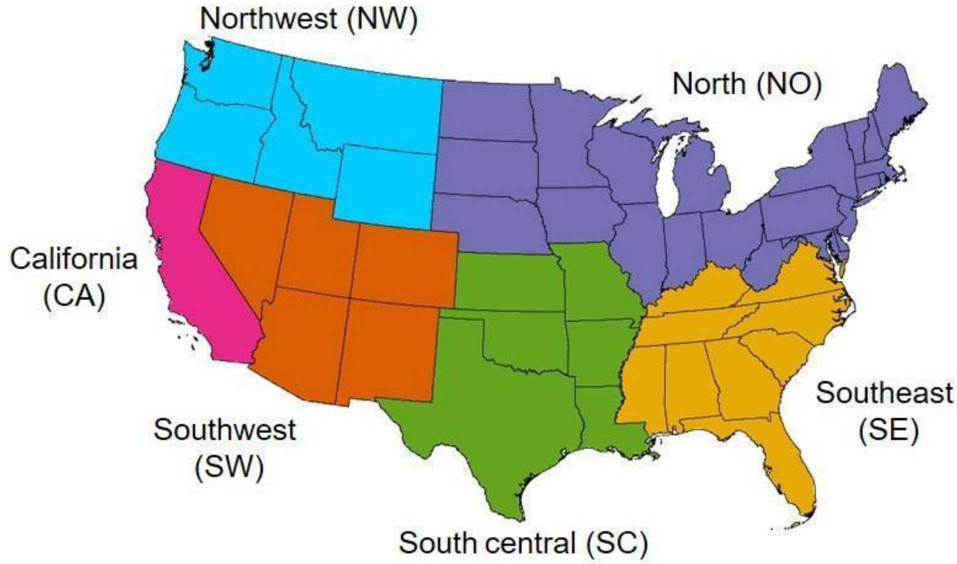
Appendix 2. Seasonal PM2.5 emitted average over 2003-2015.



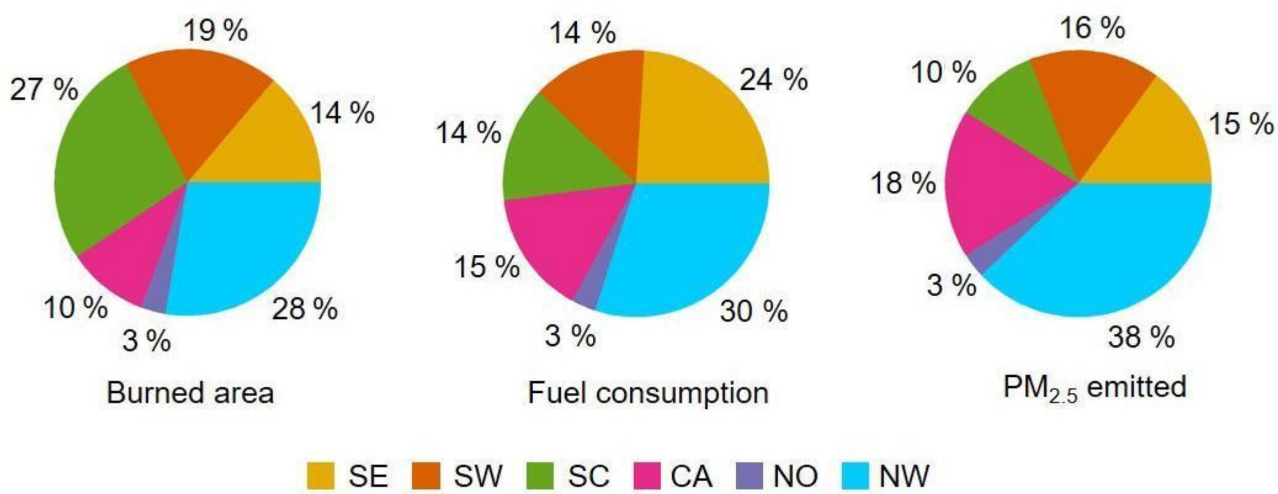
Source: Contiguous U.S. wildland fire emission eastimates 2003-2015. (Shawn P. Urbanski et al).

Appendix 3. Burned area, fuel consumption, and PM2.5 emitted by region over 2003-2015.

(a) Regions



(b) Fraction of burned area, fuel consumption, and $PM_{2.5}$ emitted over 2003–2015 by region



Source:Contiguous U.S. wildland fire emission estimates 2003-2015. (Shawn P. Urbanski et al).