Could the exception become the rule? ‘Uncontrollable’ air pollution events in the US due to wildland fires

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Abstract

Exceptional events occur when air pollution in a specific location exceeds the National Ambient Air Quality Standards (NAAQS) due to an event that cannot be reasonably attributed to human activities, such as a wildland fire. Ground-level ozone (O3) and particulate matter (PM) are Environmental Protection Agency (EPA) criteria pollutants regulated under the NAAQS. Smoke from wildland fires can increase PM and O3 concentrations downwind of fire and impact air quality, visibility, and health. Our analysis shows that the frequency of exceptional event reporting for PM with aerodynamic diameters smaller than 2.5 µm or 10 µm (PM2.5 and PM10) had increased since 2007 when the air quality standards became more stringent. We also show that wildland fires and windblown dust drive many exceptional events in several EPA regions. We note the importance of growth in the number of exceptional event days due to wildfire smoke in the future due to climate change and point to possible changes to the NAAQS and implementations.

1. Introduction

The US Federal government sets the National Ambient Air Quality Standards (NAAQS) for six criteria pollutants. States and tribal lands are required to attain these health-based standards. If they do not, the US Environmental Protection Agency (EPA) designates the region as being in ‘nonattainment.’ Nonattainment designsations can result in restrictions on federal transportation funding or new-source permitting in the affected regions. The Exceptional Events Rule (EER) was codified by Title 40 of the Code of Federal Regulations (CFR) Parts 50.1, 50.14, and 51.930 and promulgated in 2007 by the US EPA. The EER provides a way for states to flag pollutant exceedances that could be omitted from the NAAQS attainment determination. The state, local, and tribal agencies responsible for implementing the EER must document the exceptional event and submit the ‘demonstration’ to the EPA for approval to avoid liability for events beyond their control. The EER defines those events to be: (a) ‘a clear causal relationship between the specific event and the monitored exceedance or violation’; (b) ‘not reasonably controllable or preventable’; and/or (c) ‘caused by human activity that is unlikely to recur at a particular location.’ The EPA Office of Air Quality Planning and Standards sets the guidelines for Exceptional Event Demonstrations (EED), and the states and tribal lands apply for such exemptions when warranted. When a clear causal relationship showing that a NAAQS exceedance was due to causes beyond their control is proven, the EPA approves exceptional events. The exceedances are often due to a natural cause (e.g. wildfire emissions, windblown dust, and stratospheric ozone intrusion) or specific human activities such as emissions from prescribed fires and fireworks. These EPA approved exceptional events are then removed from consideration of NAAQS attainment for that region.

This paper focuses on three NAAQS pollutants: PM2.5 (the mass concentration of particulate matter with aerodynamic diameters smaller than 2.5 µm), PM10 (the mass concentration of particulate matter with aerodynamic diameters smaller than 10 µm), and O3. There are daily and annual mean NAAQS for PM2.5, which were revised in 2013. Currently, the annual standard for PM2.5 is 12 µg m−3 averaged over
3 years, and the daily PM$_{2.5}$ standard is 35 µg m$^{-3}$, evaluated as the 98th percentile of 24 h averages for 3 years. The PM$_{10}$ standard, set in 2006, is 150 µg m$^{-3}$ for 24 h not to be exceeded more than once per year on average for 3 years. According to the O$_3$ standard set in 2015, the annual fourth-highest daily maximum 8 h concentration, averaged over 3 years, cannot exceed 70 ppb (140 µg m$^{-3}$). Carbon monoxide (CO) is also a criteria pollutant with a 1 h (35 ppm) and 8 h (9 ppm) NAAQS that should not be exceeded more than once in a year. We have not considered CO in our analysis because its concentration rarely exceeds the NAAQS during exceptional events (e.g. wildfires). The CO concentrations beyond the immediate vicinity of the fires have been shown to be low. For example, the Canadian wildfire smoke impacted O$_3$ and PM$_{2.5}$ across the northern mid-Atlantic states of the US during 9–12 June 2015 (Dreessen et al 2016). In Maryland, the event led to an exceedance of the O$_3$ NAAQS and the highest daily average PM$_{2.5}$ concentrations of 32.5 µg m$^{-3}$. The highest 1 h averaged CO concentrations exceeded 0.50 ppm, which was lower than the range of CO enhancements (0.525–1.025 ppm) observed during the Quebec fires of 2002 (DeBell et al 2004). Mallia et al (2015) found that during intense wildfire smoke episodes in Utah and central Idaho, the CO concentrations in Salt Lake City increased by 0.25 ppm in 3 h, below the CO NAAQS. To our knowledge, there have been no EEDs based on CO concentration exceedances in the US.

Smoke from wildland fires impacts every EPA region in the US. (Brey et al 2018b). From 1984 to 2015, the western US has accounted for approximately 40% of the burned area (Abatzoglou and Williams 2016, Schoennagel et al 2017). Wildland fire smoke is a significant source of elevated particulate matter (PM$_{2.5}$ and PM$_{10}$) and O$_3$ precursors (Jaffe and Wigder 2012, Brey and Fischer 2016, O’Dell et al 2019). When the wildfire smoke elevates PM$_{2.5}$ and O$_3$ at EPA Air Quality System (AQS) monitoring sites, it sometimes increases the concentration of these pollutants above the NAAQS (Brey and Fischer 2016, Liu et al 2016, Kaulfus et al 2017); such increases can be counted towards exceedances. Smoke plumes can originate from fires in regions beyond the border of the jurisdiction of the PM$_{2.5}$ and O$_3$ NAAQS violations (Lindaas et al 2017, Brey et al 2018b). The windblown dust also leads to violations of the PM standards (Sharratt and Edgar 2011). Several environmental trends will likely increase the number of exceptional events driven by smoke and windblown dust (as discussed below).

Over the last decade, numerous well-documented wildfires severely degraded the US air quality from local to national scales (Wiedinmyer et al 2006, Saide et al 2015, Val Martin et al 2015, Baker et al 2016, Brey and Fischer 2016, Ford et al 2017, Lassman et al 2017, Brey et al 2018b). Liu et al (2016) showed that 71% of days that exceed PM$_{2.5}$ regulatory concentrations in the western US could be attributed to wildfires. McClure and Jaffe (2018) showed that, since 1988, most of the US experienced a reduction in PM$_{2.5}$ concentrations except for the wildfire-prone regions in the western US. Similarly, O’Dell et al (2019) show that wildfires are hindering improvements in average PM$_{2.5}$ in the US Pacific Northwest. There is evidence that urban areas also experience increased O$_3$ mixing ratios on days impacted by wildfire smoke (Brey and Fischer 2016, Gong et al 2017). Such air quality concerns are not limited to the western states. Brey et al (2018b) and Rogers et al (2020) showed that smoke plumes from the western US wildfires routinely travel thousands of kilometers and influence air quality in the eastern states.

Humans have changed the abundance of fire worldwide, including in North America. Native Americans used fire for cultivating food, game management, and travel (Abrams and Nowacki 2008, Ryan et al 2013). After the European settlement of North America, forest re-growth after heavy logging in the late 19th century and massive suppression of wildfires during that period led to biomass accumulation (more fuels) resulting in more wildfires (Allen et al 2002, Schoennagel et al 2004). The US wildfires are variable and driven by natural environmental changes such as climate variability and human influences such as the anthropogenic climate change, legacy of wildfire suppression, land management priorities, and availability of wildfire ignition sources (Westerling et al 2006, Pechony and Shindell 2010, Westerling et al 2014, Abatzoglou and Williams 2016, Balch et al 2017). Relationships between wildfire burn area and regional meteorology (temperature, precipitation, and relative humidity) have been demonstrated (Abatzoglou and Kolden 2013, Morton et al 2013, Riley et al 2013, Barbero et al 2014, Cansler and McKenzie 2014, Westerling et al 2014, Williams et al 2015, Yoon et al 2015, Abatzoglou et al 2016, Hallar et al 2017, Brey et al 2018a). Assuming that historical relationships between wildfire activity and meteorology are unchanged and that fuel is not the limiting factor, there will likely be more wildfire activity and associated air quality deterioration in the future with climate change (Abatzoglou and Williams 2016). Fires ignite more easily and spread faster in warm, dry wildland environments (Rothermel 1972, van Wagner 1977, Albini and Stocks 1986, van Wagner 1998, Alexander and Cruz 2006, Schaaf et al 2007). These predispositions apply to both lightning and human-ignited wildfires (Brey et al 2018a). Therefore, the total area burned will likely increase in a warmer world.

The dust emissions are influenced by precipitation, soil management (including agricultural practices), and surface wind speed (Pu and Ginoux 2017). However, models do not reproduce observed dust variability over North America (Mahowald et al 2010). The primary natural dust sources in the US are
the Mojave, Sonoran, and Chihuahuan deserts (Pu and Ginoux 2017). Dust emissions in the Great Plains and the inland Pacific Northwest are associated with wind erosion of farmland (Sharratt and Edgar 2011, Pu and Ginoux 2017) and desert (van Wagner 1977). Dust can degrade air quality, and such occurrences may be more frequent in the future. Achakulwisut et al (2017) showed that fine dust concentrations have increased in the Southwest US from 2002 to 2015 and that these trends are associated with warmer and drier conditions as well as increased trans-Pacific transport. Vegetation and biological soil crusts impact soil erosion by wind (Marticorena and Bergametti 1995, Belnap and Gillette 1998) and, thus, dust levels. We note that dust is one of the least well-characterized sources of PM$_{2.5}$ and PM$_{10}$.

We analyze EED and EPA AQS data together over the recent 18 year period (2000–2017). We are restricted to this period because the pollutant data and simultaneous details on exceptional events and EED submitted are available during these 18 years. Furthermore, the PM$_{2.5}$ network was started by the EPA in early 1999 to understand trends in PM$_{2.5}$; earlier data are deemed not suitable for compliance evaluations. Our goal in analyzing these data was to address the following two questions: (a) how has the number of annual exemptions requested changed during this period? (b) Have changes to the number of exemption requests been associated with changes in standards or pollutant concentrations?

To achieve our goal, we (a) identified the number of days that PM$_{2.5}$, PM$_{10}$, and O$_3$ levels had exceeded the NAAQS due to exceptional events over the ten EPA regions; (b) examined how many exemptions requests were made by states in the ten EPA regions; (c) compiled data on how many requests were granted by the EPA; and (d) identified any trends in these requests. We also discuss the implications of granting exception event waivers to protecting human health in the future.

2. Data and methods

We used the O$_3$ mixing ratios and PM$_{2.5}$ and PM$_{10}$ concentrations archived by the EPA AQS (US Environmental Protection Agency 2017) over the 18 years (2000–2017). The AQS contains data on NAAQS criteria pollutant concentrations collected by EPA, state, local, and tribal agencies from more than 4000 monitoring stations. Many counties are not represented because they do not have air pollution monitors. When a monitoring site location and/or its monitoring frequencies change, the network is deemed robust and sufficient for compliance purposes as long as each criteria pollutant has a reference method and a measurement principle. The AQS compiles hourly, 8-hourly, daily, and annual concentrations of pollutants.

The EER provides an avenue whereby states may flag pollutant concentrations resulting from an exceptional event in the AQS database. The measurements attributed to exceptional events are flagged in the AQS data in four categories: (a) ‘No events’, which denotes that no exceptional events occurred; (b) ‘Included’, which means exceptional events occurred and the data from them are included; (c) ‘Excluded’, which means that exceptional events occurred and data from them are excluded; and (d) ‘Concorded’, which means that events occurred, but only EPA concurred exclusions are removed. These categories (CFR Parts 50.1, 50.14, and 51.930 and promulgated in 2007 by the US EPA) are used here. It should be noted that AQS data do not provide information on the specific type of exceptional event for which the data are flagged.

In this study, we used the daily (24 h) files of O$_3$, PM$_{2.5}$, and PM$_{10}$, along with the 8 h file for O$_3$. The daily and 8 h data files were downloaded from the website: https://aqs.epa.gov/aqsweb/airdata/download_files.html. The data files have information on the site, including state, county, and monitor location (site number and latitude and longitude information). The AQS reports 8 h values only when at least 75% of the data are available within a given day. The daily 8 h maximum O$_3$ value that had exceeded the standard was determined from the 8 h files, and the daily (24 h) O$_3$ files were used to examine if an exceptional event impacted O$_3$ on those days. The 8 h files do not have information on the exceptional event other than for the count of the number of observations that were influenced by an event. The daily (24 h mean) files were used for PM$_{2.5}$ and PM$_{10}$. We determined the number of days when O$_3$ and PM exceeded the standards and were also flagged for an exceptional event in the AQS database. The O$_3$ and PM exceedances compiled in this study consider the change in standards during the study period.

We connected the identified day(s) with a specific event (e.g. a particular wildland fire, high wind period, stratospheric O$_3$ intrusion, agricultural or prescribed burn) by mining data from state monitoring websites (if available), blogs focused on major US air quality events (e.g. http://alg.umbc.edu/usaq/hosted by the University of Maryland, Baltimore County and http://nmborderaq.blogspot.com/, hosted by the New Mexico Department of Health), the Western States Air Resources Council exceptional event tracking table (www.westar.org/exceptional_events.html), and NOAA satellite smoke text product (www.ssd.noaa.gov/PS/FIRE/smoke.html).

State, local, and tribal agencies submit an EED for data that will or may influence the initial designation of an area (as specified in 40 CFR 50.14) to the EPA when a given pollutant exceeds the NAAQS (for one or multiple monitors), and it is attributed to an exceptional event. We gathered information on the number of EEDs along with the total number of days

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Figure 1. The number of exceedance days for O$_3$, PM$_{2.5}$, and PM$_{10}$ due to an exceptional event over the ten EPA regions for the period 2000–2017. The y-axis shows the number of days. The contributions to the exceedance day are broken down in terms of various causes noted in the top left.

3. Results and discussion

Figure 1 shows a summary of the number of days that O$_3$, PM$_{2.5}$, and PM$_{10}$ exceeded the NAAQS and attributed to exceptional events for each EPA region. Over these 18 years (2000–2017), western EPA Regions 8, 9, and 10 documented the most exceptional event days. EPA Region 4 (Southeastern US) also recorded a similar number of exceptional events driven by elevated PM$_{2.5}$, but this region documented many fewer PM$_{10}$ events than the western regions. Wildland fires were the primary driver for PM$_{2.5}$ exceptional events. Though the total numbers vary over two orders of magnitude between regions, every EPA region documented many fewer PM$_{10}$ events than the western regions. Wildland fires were the primary driver for PM$_{2.5}$ exceptional events. Though the total numbers vary over two orders of magnitude between regions, every EPA region documented many fewer PM$_{10}$ events than the western regions. Wildland fires were the primary driver for PM$_{2.5}$ exceptional events. Though the total numbers vary over two orders of magnitude between regions, every EPA region documented many fewer PM$_{10}$ events than the western regions. Wildland fires were the primary driver for PM$_{2.5}$ exceptional events. Though the total numbers vary over two orders of magnitude between regions, every EPA region documented many fewer PM$_{10}$ events than the western regions. Wildland fires were the primary driver for PM$_{2.5}$ exceptional events.

However, the total numbers of exceedances were small, and the sum of agricultural and prescribed burns account for a larger fraction of the exceptional events in Region 7. However, exceptional event requests are more frequent for the wildland fires than for the prescribed burns. Interestingly, in Regions 5 and 7, fireworks emissions along with wildland fires contribute equally to exceptional event days. It is worth noting that firework emissions are entirely under human control.

Wildland fires are also large sources of O$_3$ precursors. The O$_3$ production can occur over various timescales (Alvarado and Prinn 2009, Alvarado et al 2015). Its production in the boundary layer often cannot be understood in isolation from other O$_3$ precursors. For example, enhanced O$_3$ has been observed when (a) smoke plumes interact with urban air masses (Singh et al 2012) and/or (b) the emissions from wildfires mix with the emissions from biogenic sources near the surface (Bossio et al 2012). However, fires do not always enhance O$_3$; some smoke plumes show evidence for O$_3$ reduction (Jaffe and Wigder 2012).

The O$_3$ exceedances driven by wildland fire smoke are more complex to demonstrate for several reasons: (a) O$_3$ is a secondary pollutant generated in the atmosphere; (b) measurements of a comprehensive suite of O$_3$ precursors are not available in many regions (for each EED) submitted by each state (on a county-by-county basis) from the state monitoring websites and other sources to compile the statistics. We also include details on whether an EED was concurred to or declined by EPA. This entire archived data set will be publicly available.
urban areas; (c) smoke can change the meteorology that drives \( \text{O}_3 \) formation; and (d) models do not reproduce observed \( \text{O}_3 \) enhancements even in relatively well-characterized smoke plumes (Singh et al. 2012, Alvarado et al. 2015). These factors point to the need for further research into quantifying the role of wildland fire effluents on surface \( \text{O}_3 \). In contrast, the case for wildfire-driven \( \text{PM}_{2.5} \) exceedances is clear. Unlike the situation for wildfire-driven changes in surface \( \text{O}_3 \), the influence of stratospheric intrusions was more evident. Only Region 8, with mountainous terrain, had a substantial fraction of potential \( \text{O}_3 \) NAAQS exceedances attributable to this factor.

Figure 2. The black bars correspond to the exceedance days flagged for exceptional events (EE) in the EPA’s air quality system data files. The red bars represent the days when each county applied for an exceptional event demonstration (EED). The blue bars correspond to the days that were concurred by EPA as an exceptional event. The dashed lines in panels (a) and (b) correspond to a change to stricter NAAQS for \( \text{O}_3 \) and \( \text{PM}_{2.5} \) that lowered the exceedance thresholds. The \( \text{O}_3 \) and \( \text{PM} \) NAAQS during the study period are also shown in the figure. The large increases seen subsequent to changes in the NAAQS points to counties not coming into compliance with the stricter standards and asking for exemptions.

In figure 2, the black bars correspond to the exceedance days flagged for exceptional events for each county in the EPA’s AQS data files. The red bars correspond to days when each county applied for an EED. (Note: more than one county may submit an EED for the same exceptional event.) The blue bars correspond to the total days that were concurred by EPA as an exceptional event. Figure 2 shows that exceptional event reporting frequency changed dramatically in 2007, mainly for \( \text{PM}_{2.5} \) and \( \text{PM}_{10} \). The new EER became effective in May 2007. Before this, the EPA provided guidance on how to address data influenced by natural or exceptional events based on three documents: (a) the Exceptional Events Policy; (b) the \( \text{PM}_{10} \) Natural Events Policy; and (c) the Interim Air Quality Policy on Wildland and Prescribed Fires, Memorandum from Richard D. Wilson. In 2007 more days became eligible as exceptional events because wildfires were considered natural events and prescribed fires could be considered exceptional events on a case-by-case basis. The EPA finalized revisions to the 2007 EER in September 2016. While the 2007 EER applied only to \( \text{PM} \) and \( \text{O}_3 \), the rule now applies to all NAAQS. It is also clear that more days were designated as exceptional soon after the standard changed, and such concurrences have decreased significantly since then. The inclusion of wildfire smoke and the new standards had marked changes in the EERs. However, the number of EPA approved exceptional events dropped quickly after the changes, suggesting that most requests were not granted. The exceptional event accounts for 19% ± 10% of \( \text{PM}_{2.5} \) exceedances averaged for 2007–2017 while it was less than 2% before 2007. For \( \text{PM}_{10} \), exceptional events account for 28% ± 10% of the exceedances during 2000–2017. PM exceedances were more prevalent in the Western regions than the Eastern regions of the country, where elevated \( \text{O}_3 \) is a common issue.

The number of exceptional event days per year varies and depend, in part, on the severity of the wildfire season. The largest number of exceptional
events for PM$_{2.5}$ occurred in EPA Regions 8, 9, and 10 over the period 2000–2017 (figure 1). These events are predominantly driven by wildland fire smoke. In 2012, there were massive wildfires in Colorado (Alman et al 2016) and Washington (Lassman et al 2017). In 2015, there were extreme wildfires in the Pacific Northwest that produced sufficient smoke to degrade air quality locally and in downwind states (Lindaas et al 2017). During 2012 and 2015, there were more than 100 potential PM$_{2.5}$ exceptional event days. The consequences of the EER from a large number of severe wildfires in California (in December 2017, July 2018, November 2018, and the summer of 2020) are not yet available; we expect a better assessment of the role of the mega wildland fires (more than 100,000 acres burned) when the EEDs are submitted to EPA.

The national patterns of exceptional events shed light on several issues. First, EEDs are a mechanism for affected locations to avoid enacting more comprehensive or additional air pollution control mechanisms since these events are deemed uncontrollable. While there are uncontrollable pollution events (e.g. stratospheric intrusions of O$_3$ rich air or windblown dust from deserts), the smoke from wildland fires is to some extent controllable, though not necessarily by the region affected (i.e. wildfires in one state may be beyond the control of the affected state/region/location). Second, some of the anticipated enhancements in smoke (and dust) will be due to human-caused climate change, again under human control, but not within the impacted jurisdiction. Climate change could also lead to changes in agricultural practices and abandonment of lands from agriculture, with associated changes to exceptional events. A small increase in the number of days with smoke and dust due to climate change can increase the number of exceptions disproportionately since such increases are likely to put states above the threshold for attainment. Our analysis also demonstrates that there are significant regional differences in EEDs submitted. Western states appear to experience far more wildland fires and stratospheric O$_3$ intrusions relative to other areas. Regions not significantly influenced by exceptional events are mostly in the Eastern US, where local ‘traditional’ pollution sources have historically been responsible for elevated pollution events. Recent research suggests that smoke and other pollutants from wildfires can indeed reach distant regions within the country (Rogers et al 2020). If the number of large fires continues to grow, the potential for exceedence days will also increase, for Western regions, the adjacent midsection of the country, and the distant Eastern US.

Finally, granting exceptional events due to wildland fires neither reduce the fires nor their health impacts. Indeed it may be contrary to the reasons and origin of the exceptional events regulations since the populations that are exposed to smoke will experience health impacts whether the exceedance days are exceptional event days or not. The allowance of exceptional events removes the threat of non-attainment for the NAAQS but does not void the nation’s responsibility to protect public health. Unfortunately, many wildland fires occur beyond the jurisdictions and controls of the affected states, thereby disabling a state’s implementation plan to deal with this issue. The number of both wildland fires and mega fires has increased over the past 50 years (Barbero et al 2015). This upward trend portends increases in the request for exceptions.

New policy approaches may need to be considered for fire and smoke management. Perhaps, EPA regions and combinations of regions most influenced by fires’ effects could cooperate and come up with coordinated implementation plans. Such a collaboration has to include the agencies with jurisdiction over the areas burned, i.e. the USDA/Forest Service, the Department of the Interior, and the Department of Defense, amongst others. The current coordination between agencies in research and fighting wildland fires are good signs for future collaborations on new policy instruments. Climate change will only exacerbate wildland fires and, hence, their impacts. This also highlights the need to deal with climate change and wildland fire effects together.

The above points are especially relevant for communities that are vulnerable and/or susceptible to health effects following acute pollution events (Liu et al 2017, Gan et al 2020) and the ones who cannot protect themselves. The health impacts are real, and it will be exacerbated by climate change. The recent coincidence of COVID-19 with the prolonged wildfire smoke episodes across much of the western states highlights the need to deal with multiple stresses and issues.

These findings point to emerging challenges: (a) how will society and policymakers deal with the new reality? (b) Are the health impacts of wildland fire smoke sufficiently well understood? (c) How will the smoke characteristics change when the built environment is a part of the wildland fire? (d) What actions will be feasible in the coming decades to deal with the increasing importance of wildland fire smoke? The answers to these challenges need further research at the intersection of air quality, climate, and health, as well as the use of exceptional event rules. However, actions may be feasible in the near future without waiting for research to be completed.

**Data availability statement**

The data that support the findings of this study are openly available at the following URL/DOI:  
http://dx.doi.org/10.25675/10217/210798 (David 2020).
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