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Mediated and Public Perception of Hazards, Impacts, and Actions About Wildfire Smoke Exposure

ANDREW FOX[1]
Institute for Public Policy Research & Analysis, University of Oklahoma, USA

ZOEY ROSEN
Fordham University, USA

KUHIKA GUPTA
JOE RIPBERGER
ABBY BITTERMAN
HANK JENKINS-SMITH
Institute for Public Policy Research & Analysis, University of Oklahoma, USA

Exposure to wildfire smoke has serious health implications, highlighted by public and media attention each fire season. This study combines datasets from newspaper archives, social media, and a national survey to assess how hazards, impacts, and protective actions are discussed across different types of media. We found protective actions are underdiscussed in traditional and social media, especially in information-seeking contexts. The survey indicated the public would benefit from more wildfire smoke information. Results show how media and public data can help describe the risk communication environment surrounding hazards like wildfire smoke.

[1] Andrew Fox: asfox@ou.edu
Zoey Rosen: zrosen1@fordham.edu
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Continual expansion of the wildland-urban interface and increasing occurrence of drought have been accompanied by a surge in wildfire events. These wildfire events have grown in size, intensity, and frequency over the past decade, exacerbating the risks associated with prolonged exposure to wildfire smoke (Burke et al., 2021; 2022). Wildfire smoke can travel great distances, creating downstream effects on communities thousands of miles from an actual fire. Moreover, wildfire smoke has been documented as having negative effects on human health because of particulate matter, toxic pollutants, and other irritants released during combustion. These health impacts range across both short-term and long-term issues that can alter quality of life, including birth weights, higher rates of asthma, infertility, and chronic respiratory and heart diseases (Wu et al., 2020). It is anticipated that these negative health effects will increase in the coming decades as more particulate matter is predicted to come from wildfire smoke, subsequently increasing early mortality rates attributable to wildfire smoke exposure (Xu et al., 2020).

In response to the persistent and growing threat posed by wildfires, risk communicators face significant challenges in effectively informing the public about the adverse effects of wildfire smoke. In the past, traditional forms of media such as television, radio, and newspaper influenced exposure to public health messages about issues such as wildfire smoke (e.g., Sugerman, et al., 2012, Cisneros & Schweizer, 2018, Heaney et al., 2021). The Internet and social media have created an information and communication environment that not only incorporates traditional media, but also makes it possible to send and receive messages in real-time through a complex virtual ecosystem. Social media platforms speed the spread of information, which then has broader effects on how people engage and act on potential hazards (Ripberger et al., 2014; Morss et al., 2017). Trends in communication preferences during natural disasters like fires have also shown that different generations seek their information through different channels, like social media

sites for younger cohorts and more traditional mediated channels for older cohorts (Heaney et al., 2021). Increasing public reliance on social media as environmental hazards threaten human health means that while an abundant amount of information is available, individuals are also vulnerable to constantly changing, inconsistent, or conflicting messaging that can amplify uncertainty about what protective actions to take (Hughes & Palen, 2009; Vos et al., 2020).

Although much has been studied about risk communication for short-term threats, such as extreme weather or disease outbreaks, research has focused less on longitudinal risk communication designed to warn the public about chronic, lingering health threats, such as wildfire smoke. The protracted nature of wildfire smoke exposure poses a challenge to risk communicators seeking to warn the public and provide them with enough information to take appropriate protective actions. The modern information environment, which includes both traditional media and social media platforms, like Twitter2, is often characterized by fragmented communication, short attention spans, polarization, skepticism, and high levels of uncertainty that combine to make risk communication about long-term threats more difficult (Sutton et al., 2021a). To overcome these challenges, we must begin by understanding the information landscape (i.e., what is the current state of wildfire risk communication?) and then subsequently designing strategies that address the gaps, needs, and concerns related to longitudinal risk communication given the current public health crisis caused by wildfire smoke.

This study focuses on risk communication about the dangers of wildfire smoke exposure to the public in the context of the modern information environment. The current state of risk communication about wildfire smoke on traditional and social media over the same period of time remains understudied, but there is growing agreement that platforms like Twitter play an increasingly important role in communicating about hazards to human health (Morss et al., 2017). Drawing on established best practices for risk communication,

[2] Twitter was rebranded as X following the collection of data for this study. We refer to the platform as Twitter throughout.

we theorize that risk perceptions, intended protective actions, and perceived efficacy are likely influenced by the presence of information about the hazard, its potential impacts, and the recommended protective actions (Mileti & Peek, 2000; Weyrich et al., 2018; Potter et al., 2018; Sutton et al., 2021b). Therefore, we want to descriptively trace how these three risk communication elements (hazard, impact, and actions) are included across traditional and social media channels.

In this paper, we provide empirical evidence that describes the current state of the information environment in which risk communication takes place regarding wildfire smoke. Using a combination of three complimentary datasets from newspaper archives, social media, and a national survey of US adults, we examine the extent to which hazards, impacts, and protective actions are mentioned on traditional and social media, and the degree to which inclusion of these risk communication elements influences understanding and decision-making in offline settings. By examining both traditional and social media and public attitudes, this paper provides triangulated insight into how to better communicate about the risks related to exposure to wildfire smoke and its potentially detrimental effects on human health.

Relevant Literature

The dynamic nature of the modern information environment, which now includes both traditional media and social media, enables individuals to send and receive information via formal and informal channels. In this space, a new ecology of risk communication has emerged alongside an increased awareness of the social nature of human behavior and decision-making (Balog-Way, McComas, & Besley, 2020). Researchers and practitioners recognize that risk communication about environmental hazards, such as wildland fires and smoke, involves the exchange of information in multiple directions between authorities to the public, between members of the public, between authorities, and from the public to authorities (Robinson et al., 2019). While there has been an increasing attention being paid to the communication between these groups,

more research is needed to understand what messages are being passed between the public and authorities before, during, and after a wildfire smoke event (e.g., Remenick, 2018; Vien et al., 2024). Different sources have different challenges for wildfire smoke communication with their audiences, so it is important to know who is messaging in addition to what channels.

Recent work on recommendations for wildfire messaging such as Vien et al.'s (2024) scoping literature review has found that it is best to communicate through a combination of channels, including traditional media sources (e.g., radio, television, phone lines, local papers, mass media) and newer digital media sources (e.g., internet, social media, social networks) to effectively disseminate information about the threat and encourage behavior change (Burns et al., 2010; Heaney et al., 2021; Sugerman et al., 2012; Fish et al., 2017; Olsen et al., 2014). Research into short-term crisis events has begun to incorporate social media data related to natural hazards, such as severe weather, wildfires, earthquakes, and disease outbreaks. For example, Twitter messages from government officials on public health threats from Ebola have allowed researchers to assess short-term outcomes of risk communication (Vos et al., 2020). There is a longer documented history of analyses of newspaper coverage for short-term crises, such as environmental risks like wildfire smoke (e.g., Wakefield & Elliott, 2003; Cisneros & Schweizer, 2018; Linnenluecke & Marrone, 2021). While traditional media outlets have historically been recognized to reflect public interest, social media users have had an increasing influence on gatekeeping and agenda setting around news topics (Meraz, 2009; Meraz and Papacharissi, 2013). Previous work in the disaster space has in particular found that social media, such as Twitter, influences television coverage more so than the other direction (Valenzuela et al., 2017). Thus, to more fully understand the risk communication information environment around natural hazard crises like wildfire, the messages from both traditional and social media sources should be studied.

Effective risk communication depends on individual risk perceptions of the threat, which in turn, have a direct influence on decision-making and response to hazards. Risk

perception has been defined as "the subjective assessment of risk," which is informed by contextual, social, institutional, and cultural factors (Slovic, 1987; Slovic, 2000; Glik, 2007; Stoutenborough, Vedlitz, & Liu, 2015). While actual risk describes objective likelihood and impact of a hazard, perceived risk is subjective, meaning that it is shaped by the individual and their experiences (Freudenburg, 1988; Champ & Brenkert-Smith, 2016). Research has demonstrated that risk perception is multidimensional, often depending on several different but interrelated factors, including factors such as understanding or knowledge of a hazard, media coverage, and emotion (Slovic, 2000; Weberling et all., 2011). In the wildfire domain, a relationship between perceived and objective wildfire smoke risk has been found, finding that while the two are comparable, perceived risk tends to be higher than actual risk (Kaval et al., 2009; Buchanan et al., 2024). Especially for a hazard that is dangerous to health and welfare, capturing risk perception around wildfire smoke exposure through their media consumption could have important implications on public decision-making and response.

Individuals' understanding of the risk information and has been found to be associated to their likelihood for performing actions in response (Mileti & Peek, 2000). Researchers have used a variety of theories and frameworks to study protective action during crises and disasters. Among the most common are the Protective Action Decision Model (PADM) (Lindell & Perry, 2012; Lindell, 2018; Johnson, 2019) and Protection Motivation Theory (PMT) (Floyd, Prentice-Dunn, & Rogers, 2000; Ling & Mullan, 2019; Wang et al., 2019). Although the specifics of PADM and PMT can vary, these two theories generally agree on core features of the decision-making process. Both frameworks share the idea that motivations for protective action stem from a combination of threat perceptions and protective action (coping) perceptions (beliefs about the efficacy and costs of action). They also agree that information from a variety of sources plays a key role in orienting these perceptions; individuals draw on the information they receive to appraise the nature of the threat and assess the benefits and costs of response options.

Public response to hazards not only depends on individual and environmental factors, but also risk communication, which must undergo a process of personalization by

recipients prior to protective action decision-making (Lindell & Perry, 2012). At a basic level, risk messages seek to convey a warning to audiences and prompt a response that results in avoiding or mitigating the negative consequences of a threat. The response process begins with hearing the information from a warning message. Previous research has identified five specific elements essential to creating effective warning messages (Mileti & Peek, 2000). Essential elements include the type of hazard, location of the situation, emergency response guidance, time, and source of the warning messages (Mileti & Sorensen, 1990; Mileti & Peek, 2000; Wood et al., 2018). Research has also linked specific mention of potential impacts and behavioral recommendations as additional elements key to effective risk communication (Ripberger et al., 2015; Weyrich et al., 2018; Potter et al., 2018; Sutton et al., 2021b). In general, the use of specific impact information has been found to have a positive effect on individual risk perceptions, making it easier to understand the potential effects of a hazard (Potter et al., 2018) and leading to a higher likelihood of taking intention to take protective actions (Ripberger et al., 2015). The addition of behavioral recommendations provides even greater benefit to audiences (Weyrich et al., 2018). The integration of information about hazards, impacts, and actions into wildfire messaging should therefore be common practice; however, in practice, communication strategies often fall short (Vien et al., 2024).

In sum, research into risk communication has often focused on the implications of short-term threats, particularly when accounting for the changing information environment that now includes social media as well as traditional media outlets. However, the question remains how well these insights apply to long-term, chronic risks like wildfire smoke in an evolving information environment (Sutton et al., 2021a). Given what we know from the existing body of knowledge on risk communication, we aim to capture where sources of information, across which channels, include information in their messages that have been found to have positive effects on risk perception and protective behavioral intention, such as hazards, impacts, and actions.

Research Design and Methods

To better understand the modern information environment and the current state of risk communication about wildfire smoke, we used a three-part research design that relied on complementary data from traditional media (newspaper articles), social media, and a national survey. We first examined the nature of risk communication about wildfire smoke on social media during the 2021 summer fire season. This period, beginning June 1 and ending September 30, 2021, captured several significant wildfire events in the United States, including the Telegraph, Rafael, Bootleg, Dixie, and Caldor fires that burned thousands of acres in the Western U.S and blanketed much of the country in wildfire smoke. We then paired the social media analysis with a content analysis of newspaper articles archived from Lexis-Nexis that were published in U.S. newspapers in the same fire season as the social media analysis (June 6, 2021 to June 6, 2022). Lastly, the findings are complimented with data from a national survey fielded at the beginning of the 2022 fire season.

Analysis of the data focused on four key questions:

1. What types of users are providing information about wildfire smoke on Twitter?
2. How do social media users describe the risks associated with wildfire smoke?
3. To what extent are newspaper articles describing risks about wildfire smoke, and do they reflect social media posts in the same time period?
4. How are social and traditional media sources including information about hazards, impacts, and actions in their messages?

Social Media

In Part 1 of this study, we began by collecting and analyzing Twitter messages about wildfire smoke. As a first step in this process, we spent considerable time experimenting with a combination of words and phrases that return tweets about wildfire smoke from Twitter's API. There are two considerations that require balance when

selecting these key words/parses. First and foremost, the set of words/phrases must be broad enough to capture most, if not all, relevant messages. But on the other hand, the words/phrases cannot be so broad that they capture too many irrelevant messages. For example, using the word "smoke" alone might capture a large proportion of relevant tweets, but it is also likely to capture a considerable amount of irrelevant information, such as tweets about smoking tobacco or other products. In machine learning, these concepts are called recall (the fraction of relevant instances that were retrieved) and precision (the fraction of relevant instances among the retrieved instances).

After much experimentation, we developed 5 query strings that maximize the balance between recall and precision. The strings are shown in Table 1. To assess recall, the team collected a random sample of 4,585 tweets from 30 accounts that commonly post risk communication messages about wildfire smoke (for example: accuweather, AirResources, CAL_FIRE, EPAresearch, sfchronicle, forestservice, KQED, NWCleanAir, IQAir, AIRNow, EPAregion9, EPAair). The queries returned 91% of the relevant messages from these accounts, suggesting that they are broad enough to capture most messages about wildfire smoke on Twitter. To assess precision, the team analyzed a random sample of 2,000 tweets from any account that match the queries in Table 1; 82% of them related to wildfire smoke, indicating that the queries are not so broad that they capture a large fraction of irrelevant messages.

Table 1. Query Strings from social media and newspaper analyses.

String	Number of Tweets
("wildfire") AND ("smoke" OR "particulate" OR "ash" OR "mask" OR "dust" OR "inhale" OR "breath" OR "haze" OR "air quality" OR "health" OR "air filter" OR "air cleaner" OR "hvac")	53,644
("smoke map" OR "smoke plume" OR "smoke forecast" OR "smoke model" OR "smokesense" OR "smoke 2.5")	4,639
("smoke") AND ("air quality" OR "outlook" OR "advisory" OR "advisories" OR "airquality" OR "hrrr" OR "exposure" OR "pollut" OR "pm2.5")	28,586
("smoky") AND ("air" OR "sky" OR "skies" OR "weather" OR "conditions" OR "morning" OR "afternoon" OR "night")	15,621
("fire") AND ("air quality" OR "airquality" OR "air pollution" OR "airpollution")	8,924
Total (Unique)	**111,414** **(98,864)**

Satisfied with the balance of recall and precision, we used the queries to collect every matching tweet from June 1 - September 30, 2021 through Twitter's Application Programming Interface (API). In total, this produced a dataset of 98,864 unique tweets. In addition to the text of each tweet, the dataset includes information about the users responsible for the message (for example: username, description, followers) and the "attention" to the message (for example: retweets and likes). It also includes all links or images that were part of the message. Figure 1 plots the number of unique tweets each day during the data collection period.

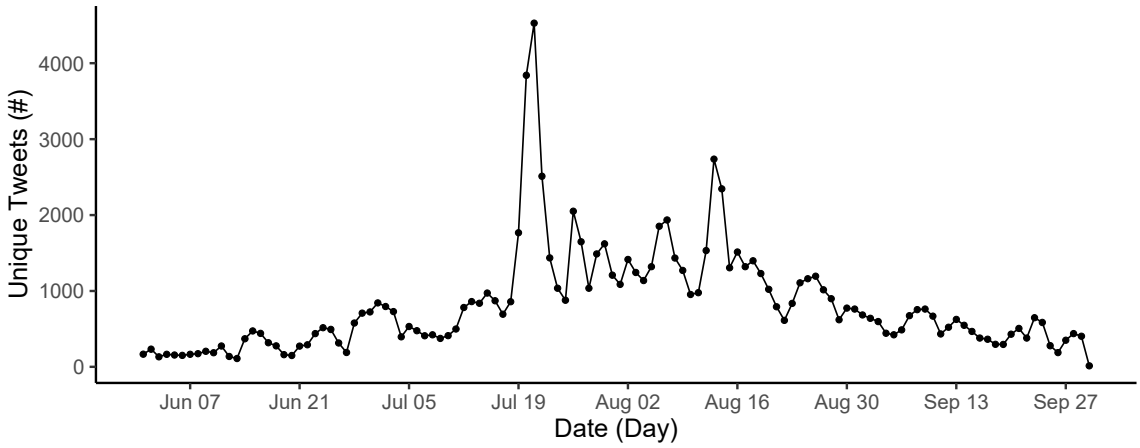

Figure 1. Tweets about Wildfire Smoke by Day from June 1 - September 30, 2021.

Newspaper Content Analysis

In Part 2 of this study, we collected 253 news articles from Lexis-Nexis Articles published in US newspapers during the study period of June 6, 2021 to June 6, 2022. While most of the articles were published during the summer when most of the wildfires were burning, we collected articles for the full year to be exhaustive of the information landscape. The query terms used to collect the articles were the same as the social media analysis (Table 1). Metadata on the date published and location of newspaper were included in the Lexis-Nexis database. Mentions of locations, evidence or direct quotes, hazards, impacts, and actions were coded for with two independent coders. To test intercoder reliability for the study sample, approximately 10% of the articles at-random were coded, which equates to 26 articles. Cohen's κ values were between 0.91 and 1.00 for each variable captured in analysis, signally a reliability in the coding of the data.

Online National Survey

In Part 3 of the study, we used an online national survey of English-speaking adults from across the US (n = 3,000) to collect data about risk perceptions, intended actions, and perceived efficacy when exposed to messages that included different levels of information

about hazards, impacts, and protective action recommendations. We worked with Qualtrics (a company that maintains a large list of people who agree to complete online surveys) to recruit a demographically representative sample of people to complete the survey. Respondents matched the target population on multiple dimensions, such as age, race, sex, income, and education in line with the most recent US Census data. We then calculated and used post-stratification weights to adjust for slight discrepancies and enhance the demographic representativeness of the samples and generalizability of the results. Table 2 provides an overview of the key demographic categories.

Table 2. Key Demographics of Survey Respondents.

Gender	
Male	45%
Female	55%
Ethnicity	
Hispanic	17%
Non-Hispanic	83%
Race	
White	75%
African American	14%
Other Race	11%
Age	
18-34	32%
35-59	36%
60+	32%
Education	
No College Degree	49%
College Degree	51%
Income	
Less than $50k	43%
$50-$100k	31%
More than $100k	26%

Results

The results of both the media analyses (social media tweets and newspaper articles) and survey data provide complementary data sources that can inform risk communicators seeking to warn the public about the dangers associated with exposure to wildfire smoke. Specifically, the data provide insight into how the threat is being talked about on social media and whether risk messages should include additional information, such as potential impacts and recommended protective actions. The following sections summarize key findings from both social media, traditional media (newspapers), and the national survey.

Social Media Results

While many of the most visible tweets in the dataset were from national and international news agencies, these agencies were only a small fraction of the users who shared information about wildfire smoke. The 98,864 unique tweets in the dataset were published by 51,143 different users, re-tweeted or quoted 255,485 times, and "liked" 850,495 times. 38% of the original tweets in the dataset came from users who posted only once; 37% came from users who posted 2-10 tweets; and 26% were from users who posted more than 10 times in the 4-month study window. Initial exploration of the data was dedicated to understanding this group of routine users or "information producers." For example, we identified the routine users who were providing information to the widest audience during the study period. Overall, data indicate that most people who were using Twitter to get information about wildfire smoke were likely getting that information from mainstream media/news organizations or meteorologists. Some people were also relying on accounts that specialize in providing information about air quality, but these accounts had significantly smaller followings than the larger media outlets.

Taking a random sample of 11,880 tweets from the dataset for in-depth analysis, we studied the types of actors present in the data as well as the content of their messages, focusing on tweets that were meant to convey information about the risk of wildfire smoke.

Research in risk communication indicates that messages are most effective when they include information about hazards, impacts, and actions (Mileti & Sorensen, 1990; Shen & Bigsby, 2013). In this context, this means that messages ought to warn the audience that wildfire smoke is affecting or may affect their area, explain how it might impact their health or the environment, and what they can do to protect themselves or the environment from this impact.

To better understand users, we first developed categories to identify the types of users who tweeted about wildfire smoke hazards. Using trained human coders, we began by identifying Twitter accounts according to specific types of actors, which included categories for individuals, local, state, and federal government, academic and scientific accounts, public health agencies, private companies, nonprofit organizations, news media outlets, emergency management agencies, departments of environmental quality, meteorologists, the National Weather Service, and the EPA.

The data (Table 3) revealed that 64% of users in the analytic sample consisted of accounts run by individual members of the public. This was followed by news media representatives (including reporters and organizations) who made up 16% of users who posted messages during the study period. Meteorologists (6%), representatives of for-profit companies (3%), academic and science (3%), public health (2%), nonprofit organizations (2%), emergency management (1%), National Weather Service (1%), local government (1%), state government (0.5%), federal government (0.5%), departments of environmental quality (0.4%), and the US EPA (0.05%) comprised the remainder of the data. A breakdown of actor types and messages revealed that most Twitter users in the analytic sample made little mention of hazards, impacts, and actions (only 34.14% of the total sample mentioned all three elements).

Table 3. Actor Types from social media data. All actor types had messages that discussed hazards, impacts, or actions. Only about one-third of messages included information about all three topics.

Actor Type	Messages	Hazards (H)	Impacts (I)	Actions (A)	H + I + A
Individuals	64%	53.97%	57.04%	32.63%	0.49%
News media	16%	18.91%	16.40%	8.42%	0.57%
Meteorologists	6%	6.92%	4.28%	15.79%	2.90%
For profit companies	3%	3.39%	3.92%	2.11%	0.74%
Academic and science	3%	2.98%	3.63%	None	None
Public health	2%	3.55%	6.24%	10.53%	3.77%
Nonprofit organizations	2%	2.05%	2.98%	4.21%	2.60%
Emergency management	1%	1.17%	0.80%	4.21%	4.60%
National Weather Service	1%	1.92%	0.94%	2.11%	1.40%
Local government	1%	1.15%	0.94%	6.32%	6.98%
State government	0.50%	0.51%	0.58%	1.05%	2.63%
Federal government	0.50%	1.01%	0.80%	1.05%	1.33%
Departments of environmental quality	0.40%	2.31%	1.23%	11.58%	6.40%
US EPA	0.05%	0.16%	0.22%	None	None
Total	*100%*	*100%*	*100%*	*100%*	*34.41%*

Actor types that included all three elements of risk communication were often organizations directly concerned with the dangers of wildfire smoke, such as local government entities, departments of environmental quality, emergency management officials, public health agencies, and meteorologists. These accounts made mention of hazards, impacts, and actions between 3-6% of the time. In contrast, federal government agencies, for profit companies, news media, academics, individuals made the least use of risk messaging elements while producing a higher volume of tweets.

Closer examination of the content of the data revealed that 74% of the tweets (8,804 messages) in the analytic sample contained relevant risk communication content about wildfire smoke (the hazard). The remaining 26% of tweets were found to contain non-relevant content that failed to describe wildfire smoke as a hazard, including messages that focused on the fact that smoke was merely present or artistic photographs of smokey skies. In most cases, the relevant messages were often vague, simply alerting people that wildfire smoke was in the area or affecting air quality and thus posing a danger. Analysis revealed content focused on wildfire smoke across a broad spatial scale that included local, regional, and national concerns about wildfire smoke. Perhaps unsurprisingly, there were several messages that pointed to the danger of wildfire smoke near ongoing fires. For instance, there were tweets that mentioned wildfire smoke in California and Nevada, informing residents about poor air quality. Examples of this type of message included: "California Wildfire Smoke Prompts Air Quality Advisory in 3 Southern Counties"; "Air quality advisory issued for Monday in Bay Area due to wildfire smoke"; "Lake Tahoe air quality reaches 'hazardous' levels from wildfire smoke".

Concern, however, was not limited to the areas closest to active fires. Places as far away as Arkansas and New York were reported to be dealing with the effects of wildfire smoke. For example, Twitter users mentioned that "Wildfire smoke is reducing air quality throughout most of Oregon and southern Washington"; "Midwesterners Are Breathing Smoky Air from California Wildfires"; "The wildfire smoke has thinned out some today across the Tulsa area. The thickest smoke is over Missouri and Arkansas this afternoon"; "The wildfire smoke over AR should be better today but looks to increase again for Friday"; "New York City air quality was among the worst in the world as cities across the eastern US were shrouded in smoke from wildfires raging thousands of miles away on the country's west coast"; and "Wildfire Haze from Out West Could Be Worse Than Many Nyers Realize." Still, other messages framed the impact of wildfire smoke as an issue of national concern. Example messages of this category included: "Wildfire smoke is hazardous no matter where in the US you live"; "Wildfire smoke blowing across the U.S. is more toxic than we thought"; "Growing wildfire dangers create a hazardous haze across

the U.S. as smoke from massive blazes spreads"; "You don't need to be in the immediate area of a #wildfire to be affected by one. Air Now's Fire and Smoke Map shows plumes covering nearly the entire country".

In contrast to mentions of hazards, only 20% (1,788 tweets) of relevant messages included some type of warning explaining how the wildfire smoke might impact people or the environment. Most (89%) of these messages focused on the health impacts of wildfire smoke and air pollution. Some messages focused on the general health effects while others drew attention to specific risks. For example, "Unhealthy, even hazardous air from wildfire smoke has been all too routine this summer in Reno area. 24-hour average of 251 AQI on Sunday set a new record"; "Breathing wildfire smoke can affect the brain and sperm as well as the lungs"; "Wildfire smoke weakens immune system, increases susceptibility to COVID-19 infections: Harvard study."; "Breathing wildfire smoke during pregnancy raises risk of premature birth, study finds".

A few (12%) messages in this category focused on the environmental impact of wildfire smoke. Some Twitter users pointed out the potential impacts of wildfire smoke on the weather, expressing concerns that smoke would lead to less rainfall and more drought. For example, one user pointed out that "wildfire smoke is transforming clouds, making rainfall less likely" while other users referenced that a "study shows wildfire smoke makes clouds drop less rain" to argue that "wildfire smoke can reduce raindrops to meaningless drizzle…further exacerbating drought conditions". Environmental concerns, however, went beyond the impact of wildfire smoke on weather. The data also revealed perceived uncertainties about the potential effects on animals and crops. Some messages expressed concern for broader impacts on animals in general while others were worried about pets and/or livestock. For example: "We don't know much about how the haze that comes with wildfires impacts animals"; "Just as wildfire smoke is dangerous for humans, it can also adversely impact pets and livestock"; "Preliminary results in an Idaho study show that wildfire smoke damages dairy cow milk production and immune cells."; "Could more US wildfires mean less milk from Oregon's huge dairy herd?". Other messages expressed

concern about the impact of wildfire smoke on agricultural products. For example, several users posted messages related to wine. Tweets in this category include: “Wildfire Smoke: An Emerging Threat to West Coast Wines”; “Wildfire smoke is the West Coast wine industry’s greatest threat”.

Approximately 1% of the messages that included a warning about wildfire smoke noted the actions that people could take to protect themselves or the environment from negative impacts. Moreover, about one-third of messages that contained recommendations made mention of multiple recommendations, such as limiting outdoor activity and wearing a mask, while other tweets contained a single recommendation like using an air filter. The most common (68%) recommendation in these messages was to stay indoors or limit outdoor activities. For example: “During a wildfire, protect yourself from smoke. Stay inside and close windows and doors.”; “Probably better off staying inside in parts of Minnesota where wildfire smoke is resulting in ‘very unhealthy’ and ‘hazardous’ air quality”; and “Officials are advising those in the Bay Area and the San Joaquin Valley to limit their time outside as wildfire smoke and ash fills the air”.

The next most common recommendation for protective action (23%) advised people to wear a mask when outdoors. Some examples of this type of message include: “Folks, get your N95s now. The wildfire smoke is here already. The outdoors is tinted orange and its nearly midday”; “Just a reminder that today's Air Quality Advisory is in effect due to the smoke from active wildfires. If you need to go outside, wear a N95 mask to block breathing in unhealthy particles”; and “California is experiencing unhealthy air quality in many parts of the state. Be sure to take necessary precautions like using N95 masks and avoid breathing smoke to stay safe”.

The third most common recommendation (21%) was to use an air filter while indoors. For example, “Invest in an air purifier with a true-HEPA filter that’s robust enough to filter out wildfire smoke”; “During smoky times, keep your indoor air cleaner by closing your windows and using an air cleaner”; “How can you prepare for an #airquality advisory

during #wildfire season? Consider buying a portable air cleaner that uses HEPA filtration"; and "During times of wildfire smoke, keep your indoor air cleaner by closing your windows, recirculating air through a forced air system, and using an air cleaner".

In sum, if you had checked Twitter to get information about wildfire smoke during the study period, it is likely that you would have seen a message warning you about smoke. Unless you looked for it, it is less likely that you would have seen information about the possible impact of wildfire smoke on your health or the environment and even less likely that you would have seen information about the protective actions you could have taken to reduce your risk. In other words, the risk messages from routine users in this sample frequently mentioned the existence/presence of wildfire smoke but provided little information about why it is harmful and what people can do to reduce the harm. Our analysis further suggests that the users who were most likely to provide valuable information about impacts and actions were less visible than the users who were not providing this information. For example, messages from individuals made up the bulk of tweets during the study period, but they rarely included information about impacts and actions. Messages from less visible users (such as local governments, departments of environmental quality, public health agencies, and emergency management officials) were more likely to include this information, but Twitter users were less likely to see it because these users were generally less visible. Traditional media emerged as one of the most influential actors stemming from the social media conversation. Behind individuals, media outlets were some of the most frequent disseminators of wildfire smoke information on Twitter during this study. Previous work on mass media outlets like traditional news agencies, while not the only voice on social media, have a major topical influence in these spaces as well (Meraz, 2009). Additionally, while hazards, impacts, and actions did not appear frequently in social media posts in this study, many of those posts linked to external articles. The question arises whether the longer-form articles included more information about hazards, impacts, and actions, which motivated extending the social media analysis of actors to the traditional media content analysis.

Traditional Media (Newspaper) Results

Of the 253 articles in the 2021 fire season, the majority of articles were published in newspapers from the Western United States (78.7%). Articles about wildfire and wildfire smoke were also published from papers in the Northeast (7.11%), Midwest (11.86%), and South (6.32%). Most of the articles (92.09%) discussed the western region, though 7.91% (20 of 253) of the articles talked about impacts on the Northeast, 4.74% on the Midwest, and 3.16% on the South. Almost one-fifth of the articles (19.76%) talked about a region that was not located where the article was published (e.g., discussing the West when the article was published in the Northeast). Lastly, 6.32% articles discussed wildfire smoke in general, without directly mentioning a specific location.

We were curious who the authors of each article were quoting directly within their articles. 89.33% of the articles directly quote government personnel or organization websites (e.g., EPA's AirNow site, National Weather Service meteorologists, or information officers from state Departments of Environmental Quality). This was the most quoted evidence source, followed by quotes from people in academia like university professors (30.43%), private sector organizations such as independent air filter companies (26.48%), activist organizations such as the American Lung Association (13.44%), assorted community members (7.91%), hospital employees (6.32%), or other media networks (1.58%).

Every single article mentioned the hazard of wildfire smoke (100%), though 14.23% of the articles also mentioned non-air related hazards with wildfire, for example containment or fire size and duration. Every article also directly mentioned at least one impact associated with the wildfire smoke. When broken up by type of impact, 100% mentioned a health impact and 10.28% mentioned an environmental impact, such as soil composition or water quality. Interestingly for long-form media such as an article (when compared to social media posted with character restraints), only 94.47% of the articles suggested an action for the reader to take. When broken up by type, 90.51% were protective

actions. The most common protective actions written about in the articles included running or installing air filters (HEPA, MERV, build-your-own box fan, etc.), masking (wearing an N95, not fabric), designating a “clean room”, staying indoors, and limiting indoor air pollution through actions such as avoiding vacuuming, not burning candles, etc. Authors of 43.48% of the articles suggested seeking additional information about the air quality or fire. 20.16% of the articles mentioned evacuation as an action to take from the threat of air quality, meaning to relocate to a less smoky area until the fire subsides. Lastly, 1.58% of the articles suggested waiting as an action to take in response to the wildfire impact, such as waiting to hear more information from local officials or until the event itself was over.

In sum, if you had read a newspaper article about wildfire during the study period, it is likely that you would have seen an article discussing the health impacts of the wildfire smoke. While it is likely that you would have seen information about the protective actions you could have taken to reduce your risk written in the articles, there would have been less messages provided to encourage seeking additional information. Many of the sources that message about wildfire and wildfire smoke on social media are directly quoted in traditional media forms like newspaper articles. While there are small regional differences where articles are published about the impacts of fire, for the most part the articles are relevant to the areas of impact. Overall, there are similarities between the traditional and social media messaging around wildfire smoke over the study period, such as which protective actions are recommended (when they are recommended). We then paired public perception data from a national survey collected at the same study period to these findings from the traditional news articles as a way to potentially provide an insightful way to trace where public perceptions may or may not reflect the overall media landscape.

Survey Results

Results from the survey indicate that the American public has relatively low risk perceptions and limited knowledge about wildfire smoke. Concern for outdoor air quality in general, which included auto and industrial emissions as well as wildfire smoke was low

with 58% of respondents answering that poor outdoor air quality posed either no or low risk to them and the people in their household. When asked specifically how they would rate the risk of wildfire smoke to you or your family; 54% of respondents indicated that wildfire smoke posed either no or only low risk. Just 20% considered wildfire smoke a high or extreme risk. In addition to relatively low risk perceptions, we observed mixed levels of self-reported knowledge about the impacts of wildfire smoke. For example, 18% of respondents stated they had very poor or poor understanding, and 37% said they had an adequate understanding. 44% believed they had a good or very good understanding. When asked if they had ever experienced wildfire smoke, 61% of respondents said no, and 62% believed that the area where they live would not be affected by wildfire smoke in the next twelve months. Together, results from the survey suggest that the public has a limited understanding of wildfire smoke and does not view it as an imminent threat to human health.

Discussion and Conclusions

Different types of information have been shown to matter in short-term risk communication, especially the inclusion of information about hazards, potential impacts, and protective action recommendations, but to what extent does this matter for chronic, lingering health threats? In this study, we examined both messages from Twitter, newspaper articles, and data from a national survey of US adults to better understand the information environment on traditional and social media channels, and the effects of incorporating best practices for risk communication into messages about wildfire smoke exposure.

The results from our social media analysis indicate that Twitter users encountered messages warning them about the dangers of wildfire smoke but little information about potential health risks or guidance on what to do in response. Approximately 74% of messages included some type of warning about wildfire smoke. Many of these tweets could be characterized as generic and crossed a broad spatial scale that highlighted local,

regional, and national exposure to wildfire smoke. Only 20% of messages that included a warning about wildfire smoke also provided information about how the smoke might impact human health. Just 1% of messages that included a warning about wildfire smoke noted actions that people could take to protect themselves from negative impacts.

The results from the content analysis of newspaper articles provided a look into regional patterns for where public exposure and concern about wildfire smoke may not coincide. While every article in the sample included information about hazards and impacts, there was still a paucity regarding discussing actions. While protective actions were included in 90.51% of the articles, under half (43.48%) recommend seeking additional information about the wildfire smoke event. It is important to increase our understanding of where wildfire smoke impacts communities, as well as how sources of information, like the news media, are discussing the hazards, impacts, and protective actions for wildfire smoke.

The findings from the survey, in tandem to the social media posts and traditional media articles, point to the importance of considering how risk messages about wildfire smoke are constructed and disseminated as well as the context in which they are shared with the public. While highlighting hazards like wildfire smoke no doubt helps raise awareness, it does not appear sufficient to meet the public's need for timely information. The American public has relatively low-risk perceptions and knowledge about wildfire smoke. Moreover, the information environment is dominated by specific sources and types of actors who tend to focus on the hazard posed by wildfire smoke without mention of its potential impacts or what protective actions might be taken to minimize the risk to human health. Providing additional information in messaging appears to be beneficial when the goal of risk communication is to get people to take protective actions and have confidence that their choices are effective. While additional information to the public can help, it often depends on what kind of information (e.g., inclusion of hazard(s), impacts, and protective actions) is provided.

This study is particularly relevant for risk communicators seeking to understand the diverse and dynamic nature of the modern information environment. Participatory risk communication characterized by multi-directional information flows between individuals and authorities has become the norm, which means that risk communicators need to consider a holistic view of the information landscape (Robinson et al., 2019). Methodologically, the approach used in this study demonstrates how social media can be used as a complementary data stream to more traditional sources like newspaper articles and survey data when careful attention is given to research design. Social media data enables direct observation of unsolicited views and comments from a significant portion of the public, providing a continuous real-time window into public understanding, perceptions, and preferences about threats to human health like wildfire smoke. The primary challenge of analyzing big data lies in the design and implementation of sampling strategies that overcome problems posed by access to the data, the volume of information, and identification of relevant information. In other words, researchers must find ways to separate signal from noise to be able to draw meaningful insight from large, dynamic data sources like Twitter. Through systematic data collection and processing protocols used in conjunction with machine learning tools, we can overcome these problems to identify relevant samples of data that give us clues about how a portion of the public understands and communicates about wildfire smoke. When combined with traditional media data, social media data can be used as an additional source to get a more comprehensive picture of the risk communication environment, especially around increasingly salient issues like wildfire smoke exposure.

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References

Balog-Way, D., McComas, K., & Besley, J. (2020). The evolving field of risk communication. *Risk Analysis, 40*(S1), 2240–2262. https://doi.org/10.1111/risa.13615

Buchanan, R., Ripberger, J., Fox, A., Carlson, N., Gupta, K., Silva, C., & Jenkins-Smith, H. (2024). Where there's smoke there's fire: the relationship between perceived and objective wildfire smoke risk. *Environmental Hazards*, *23*(4), 347–363. https://doi.org/10.1080/17477891.2024.2304192

Burke, M., Driscoll, A., Heft-Neal, S., Xue, J., Burney, J., & Wara, M. (2021). The changing risk and burden of wildfire in the United States. *Proceedings of the National Academy of Sciences*, *118*(2), e2011048118. https://doi.org/10.1073/pnas.2011048118

Burke, M., Heft-Neal, S., Li, J., Driscoll, A., Baylis, P., Stigler, M., Weill, J. A., Burney, J. A., Wen, J., Childs, M. L., & Gould, C. F. (2022). Exposures and behavioural responses to wildfire smoke. *Nature Human Behaviour*. https://doi.org/10.1038/s41562-022-01396-6

Burns R, Robinson P, & P. Smith (2010). From hypothetical scenario to tragic reality: a salutary lesson in risk communication and the Victorian 2009 bushfires. *Aust N Z J Public Health*. *34*(1):24–31. https://doi.org/10.1111/j.1753-6405.2010.00469.x

Champ, P. A., & Brenkert-Smith, H. (2016). Is seeing believing? Perceptions of wildfire risk over time. *Risk Analysis*, *36*(4), 816-830. https://doi.org/10.1111/risa.12465

Cisneros, R., & Schweizer, D. W. (2018). The efficacy of news releases, news reports, and public nuisance complaints for determining smoke impacts to air quality from wildland fire. *Air Quality, Atmosphere & Health*, *11*, 423-429. https://doi.org/10.1007/s11869-018-0545-9

Fish, J.A., Peters, M.D.J., Ramsey, I., Sharplin, G., Corsini, N., & M. Eckert (2017).

Effectiveness of public health messaging and communication channels during smoke events: a rapid systematic review. *J Environ Manage*. 193:247–56. https://doi.org/10.1016/j.jenvman.2017.02.012

Floyd, D. L., Prentice-Dunn, S., & Rogers, R. W. (2000). A meta-analysis of research on protection motivation theory. *Journal of Applied Social Psychology, 30*(2), 407–429. https://doi.org/10.1111/j.1559-1816.2000.tb02323.x

Freudenburg, W. R. (1988). Perceived risk, real risk: Social science and the art of probabilistic risk assessment. *Science*, *242*(4875), 44-49. DOI: 10.1126/science.3175635

Glik, D. C. (2007). Risk communication for public health emergencies. *Annual Review of Public Health, 28*(1), 33–54. https://doi.org/10.1146/annurev.publhealth.28.021406.144123

Heaney, E., Hunter, L., Clulow, A., Bowles, D., & Vardoulakis, S. (2021). Efficacy of communication techniques and health outcomes of bushfire smoke exposure: a scoping review. *International Journal of Environmental Research and Public Health*, *18*(20), 10889. https://doi.org/10.3390/ijerph182010889

Hughes, A. L., & Palen, L. (2009). Twitter adoption and use in mass convergence and emergency events. *International Journal of Emergency Management, 6*(3/4), 248–260. https://doi.org/10.1504/IJEM.2009.031564

Johnson, B. B. (2019). Americans' views of voluntary protective actions against Zika infection: Conceptual and measurement issues. *Risk Analysis, 39*(12), 2694–2717. https://doi.org/10.1111/risa.13378

Kaval, P. (2009) Perceived and actual wildfire danger: An economic and spatial analysis study in Colorado (USA), *Journal of Environmental Management*, *90*(5), pp. 1862-1867, ISSN 0301-4797, https://doi.org/10.1016/j.jenvman.2008.12.009.

Lindell, M. K. (2018). Communicating imminent risk. In H. Rodríguez, W. Donner, & J. E. Trainor (Eds.), *Handbook of Disaster Research*. pp. 449–477. Springer International Publishing. https://doi.org/10.1007/978-3-319-63254-4_22

Lindell, M. K., & Perry, R. W. (2012). The Protective Action Decision Model: Theoretical modifications and additional evidence. *Risk Analysis, 32*(4), 616–632. https://doi.org/10.1111/j.1539-6924.2011.01647.x

Ling, M., Kothe, E. J., & Mullan, B. A. (2019). Predicting intention to receive a seasonal influenza vaccination using Protection Motivation Theory. *Social Science & Medicine, 233*, 87–92. https://doi.org/10.1016/j.socscimed.2019.06.002

Linnenluecke, M. K., & Marrone, M. (2021). Air pollution, human health and climate change: Newspaper coverage of Australian bushfires. *Environmental Research Letters*, 16(12), 125003.

Meraz, S., & Papacharissi, Z. (2013). Networked Gatekeeping and Networked Framing

on #Egypt. *The International Journal of Press/Politics*, *18*(2), 138-166. https://doi.org/10.1177/1940161212474472

Meraz, S. (2009). Is There an Elite Hold? Traditional Media to Social Media Agenda Setting Influence in Blog Networks, *Journal of Computer-Mediated Communication*, Volume 14, Issue 3, Pages 682–707, https://doi.org/10.1111/j.1083-6101.2009.01458.x

Mileti, D. S., & Peek, L. (2000). The social psychology of public response to warnings of a nuclear power plant accident. *Journal of Hazardous Materials, 75*(2–3), 181–194. https://doi.org/10.1016/S0304-3894(00)00179-5

Mileti, D. S., & Sorensen, J. H. (1990). Communication of emergency public warnings: A social science perspective and state-of-the-art assessment (ORNL-6609, 6137387). https://doi.org/10.2172/6137387

Morss, R. E., Demuth, J. L., Lazrus, H., Palen, L., Barton, C. M., Davis, C. A., Snyder, C., Wilhelmi, O. V., Anderson, K. M., Ahijevych, D. A., Anderson, J., Bica, M., Fossell, K. R., Henderson, J., Kogan, M., Stowe, K., & Watts, J. (2017). Hazardous weather prediction and communication in the modern information environment. *Bulletin of the American Meteorological Society, 98*(12), 2653–2674. https://doi.org/10.1175/BAMS-D-16-0058.1

Olsen CS, Mazzotta DK, Toman E, Fischer AP. Communicating about smoke from wildland fire: challenges and opportunities for managers. *Environ Manage*. 2014;54(3):571–82. https://doi.org/10.1007/s00267-014-0312-0

Potter, S. H., Kreft, P. V., Milojev, P., Noble, C., Montz, B., Dhellemmes, A., Woods, R. J., & Gauden-Ing, S. (2018). The influence of impact-based severe weather warnings on risk perceptions and intended protective actions. *International Journal of Disaster Risk Reduction, 30*, 34–43. https://doi.org/10.1016/j.ijdrr.2018.03.031

Remenick, L. (2018). The Role of Communication in Preparation for Wildland Fire: A Literature Review. *Environmental Communication*, *12*(2), 164–176. https://doi.org/10.1080/17524032.2017.1346519

Ripberger, J. T., Jenkins-Smith, H. C., Silva, C. L., Carlson, D. E., & Henderson, M. (2014). Social media and severe weather: Do tweets provide a valid indicator of public attention to severe weather risk communication? *Weather, Climate, and Society, 6*(4), 520–530. https://doi.org/10.1175/WCAS-D-13-00028.1

Ripberger, J. T., Silva, C. L., Jenkins-Smith, H. C., & James, M. (2015). The influence of consequence-based messages on public responses to tornado warnings. *Bulletin of the American Meteorological Society, 96*(4), 577–590. https://doi.org/10.1175/BAMS-D-13-00213.1

Robinson, S. E., Pudlo, J. M., & Wehde, W. (2019). The new ecology of tornado warning

information: A natural experiment assessing threat intensity and citizen-to-citizen information sharing. *Public Administration Review, 79*(6), 905–916. https://doi.org/10.1111/puar.13030

Rogers, R. W., & Prentice-Dunn, S. (1997). Protection Motivation Theory. In *Handbook of health behavior research 1: Personal and Social Determinants* (pp. 113–132). New York: Plenum Press.

Shen, L., & Bigsby, E. (2013). The effects of message features: Content, structure, and style. In *The SAGE handbook of persuasion: Developments in Theory and Practice* (pp. 20–35). New York: Sage Publications, Inc.

Slovic, P. (1987). Perception of Risk. *Science*, *236*(4799), 280–285. http://www.jstor.org/stable/1698637

Slovic, P. (2000). *The Perception of Risk*. New York: Earthscan Publications.

Stoutenborough, J. W., Vedlitz, A., & Liu, X. (2015). The Influence of Specific Risk Perceptions on Public Policy Support: An Examination of Energy Policy. *The ANNALS of the American Academy of Political and Social Science, 658*(1), 102–120. https://doi.org/10.1177/0002716214556472

Sutton, J., Rivera, Y., Sell, T. K., Moran, M. B., Bennett Gayle, D., Schoch-Spana, M., Stern, E. K., & Turetsky, D. (2021a). Longitudinal risk communication: A research agenda for communicating in a pandemic. *Health Security, 19*(4), 370–378. https://doi.org/10.1089/hs.2020.0161

Sutton, J., Fischer, L., & Wood, M. M. (2021b). Tornado warning guidance and graphics: Implications of the inclusion of protective action information on perceptions and efficacy. *Weather, Climate, and Society*. https://doi.org/10.1175/WCAS-D-21-0097.1

Sugerman, D. E., Keir, J. M., Dee, D. L., Lipman, H., Waterman, S. H., Ginsberg, M., & Fishbein, D. B. (2012). Emergency health risk communication during the 2007 San Diego wildfires: comprehension, compliance, and recall. *Journal of health communication*, *17*(6), 698-712. DOI: 10.1080/10810730.2011.635777

Vien, M. H., Ivey, S. L., Boyden, H., Holm, S., & Neuhauser, L. (2024). A scoping review of wildfire smoke risk communications: issues, gaps, and recommendations. *BMC Public Health*, *24*(1), 312. https://doi.org/10.1186/s12889-024-17681-0

Valenzuela, S., Puente, S., & P.M. Flores (2017). Comparing Disaster News on Twitter and Television: an Intermedia Agenda Setting Perspective, *Journal of Broadcasting & Electronic Media*, *61*(4), pp. 615-637, DOI: 10.1080/08838151.2017.1344673

Vos, S. C., Sutton, J., Gibson, C. B., & Butts, C. T. (2020). #Ebola: Emergency risk messages on social media. *Health Security, 18*(6), 461–472. https://doi.org/10.1089/hs.2019.0158

Wakefield, S. E., & Elliott, S. J. (2003). Constructing the news: The role of local newspapers in environmental risk communication. *The Professional Geographer*, *55*(2), 216-226. DOI: 10.1111/0033-0124.5502009

Wang, J., Liu-Lastres, B., Ritchie, B. W., & Mills, D. J. (2019). Travellers' self-protections against health risks: An application of the full Protection Motivation Theory. *Annals of Tourism Research, 78*, 102743. https://doi.org/10.1016/j.annals.2019.102743

Weberling, B., Lovejoy, J., & Riffe, D. (2011). News coverage of environmental risks: Subjective knowledge, personal efficacy and perceived usefulness of different media. *Web Journal of Mass Communication Research*, 40.

Weyrich, P., Scolobig, A., Bresch, D. N., & Patt, A. (2018). Effects of impact-based warnings and behavioral recommendations for extreme weather events. *Weather, Climate, and Society, 10*(4), 781–796. https://doi.org/10.1175/WCAS-D-18-0038.1

Wood, M. M., Mileti, D. S., Bean, H., Liu, B. F., Sutton, J., & Madden, S. (2018). Milling and public warnings. *Environment and Behavior, 50*(5), 535–566. https://doi.org/10.1177/0013916517709561

Wu, X., Nethery, R. C., Sabath, M. B., Braun, D., & Dominici, F. (2020). Exposure to air pollution and COVID-19 mortality in the United States: A nationwide cross-sectional study [Preprint]. *Epidemiology*. https://doi.org/10.1101/2020.04.05.20054502

Xu, R., Yu, P., Abramson, M. J., Johnston, F. H., Samet, J. M., Bell, M. L., Haines, A., Ebi, K. L., Li, S., & Guo, Y. (2020). Wildfires, global climate change, and human health. *New England Journal of Medicine, 383*(22), 2173–2181. https://doi.org/10.1056/NEJMsr2028985