



How the experience of California wildfires shape Twitter climate change framings

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Received: 25 January 2023 / Accepted: 12 December 2023 / Published online: 15 January 2024
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Abstract

Climate communication scientists search for effective message strategies to engage the ambivalent public in support of climate advocacy. The personal experience of wildfire is expected to render climate change impacts more concretely, pointing to a potential message strategy to engage the public. This study examined Twitter discourse related to climate change during the onset of 20 wildfires in California between the years 2017 and 2021. In this mixed method study, we analyzed tweets geographically and temporally proximal to the occurrence of wildfires to discover framings and examined how frequencies in climate framings changed before and after fires. Results identified three predominant climate framings: linking wildfire to climate change, suggesting climate actions, and attributing climate change to adversities besides wildfires. Mean tweet frequencies linking wildfire to climate change and attributing adversities increased significantly after the onset of fire. While suggesting climate action tweets also increased, the increase was not statistically significant. Temporal analysis of tweet frequencies for the three themes of tweets showed that discussion increased after the onset of a fire but persisted typically no more than 2 weeks. For fires that burned for longer periods of more than a month, external events triggered climate discussions. Our findings contribute to identifying how the personal experience of wildfire shapes Twitter discussion related to climate change, and how these framings change over time during wildfire events, leading to insights into critical time points after wildfire for implementing message strategies to increase public engagement on climate change impacts and policy.

Keywords Climate change · Climate change communication · Wildfire · Extreme weather events · Framing · Twitter · Engagement

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1 Background

1.1 Wildfires in California

Wildfire incidents in California have seen an increasing trend in both frequency and intensity. In 2021, there were 8835 wildfire incidents, yielding 3629 damaged/destroyed structures and three deaths. Besides burning over 2.5 million acres of land (California Department of Forestry and Fire Protection 2022), these wildfires also worsened air quality, set off drinking water crises, affected local economies, and increased human mortality (Ebi et al. 2018; Intergovernmental Panel on Climate Change 2021; Watts et al. 2019). Climate change heightens the risk of larger and more intense fires (National Academies of the Sciences 2016; Zhuang et al. 2021). California Department of Forestry and Fire Protection (2022) outlook for 2022 stated that extended dryness was expected to continue in California. Coupled with little precipitation and above-normal temperature, the lower-than-normal fuel moisture level would increase the potential for wildland fire activity. In an analysis of the social vulnerability of people exposed to wildfires in the West Coast states of the USA, the researchers found that 90% of the half million people directly exposed to wildfires in the West Coast from 2000 to 2021 were in California. Exposure per unit area burned was also over seven times greater in California (5.95 people/km²) compared to Washington (0.78 people/km²), and over 11 times greater compared to Oregon (0.51 people/km²) (Modaresi Rad et al. 2023).

In fact, wildfire is not a phenomenon specific to California. In the United Nations' recent scientific assessment of the risks of wildfire, it is estimated that by the end of this century, highly devastating wildfires could increase by 57% due to effects brought on by climate change (United Nations Environment Programme 2022). The worst wildfire season Canada has experienced on record in 2023 is the most recent example. Since the start of the 2023 fire season, there have been 1062 wildfires, burning a well-above seasonal average of 1.26 million hectares of land across British Columbia (Public Safety Canada 2023).

1.2 Anthropogenic climate change and wildfire

According to the National Academies of the Sciences (2016), wildfire is considered to have a low attribution to climate change (i.e., in contrast to extreme heat and drought) for wildfire's multifaceted nature. Even though weather conditions such as temperature, wind, and humidity are major drivers of wildfires, the fact that ignitions of wildfire are primarily by lightning and humans makes the attribution of climate change more controversial in public space. On the other hand, recent evidence based on advanced modeling tools has ascertained that the more recent widespread burning, such as the record-setting fire season in the western USA in 2020, are the results of unprecedented atmospheric aridity, of which anthropogenic climate change is a significant contributor (Higuera and Abatzoglou 2020). Not only does scientific evidence points to anthropogenic warming as the cause of increased fire activities, from fire ignition to the spread and intensity of fires (Kirchmeier-Young et al. 2019), Williams et al. (2019) posited that anthropogenic climate change contributed to an eight-time increase in forested burned area in California in the past 50 years through aggravated atmospheric aridity.

As for the outlook of wildfires in relation to climate change, researchers found through a recent review of trends and drivers of fire that in most world regions, climate change has

increased the occurrences of fire weather, and climate models projected that fire weather would become both more frequent and intense under future warming (Jones et al. 2022). All in all, there is a strong consensus among the scientific community about anthropogenic climate change's contribution to the increased frequency and intensity of wildfires occurring globally.

1.3 The public's recognition of climate change

Despite the detrimental effects of anthropogenic climate change affirmed by the scientific community, there are still considerable gaps between the scientific consensus and the public's recognition of the issue. Based on data from 2021, only 57% of Americans believe global warming is caused mainly by human activity (Marlon et al. 2022). The same survey estimated that while 64% of Americans believe global warming will harm people in the USA to a great/moderate amount, only 47% of Americans believe that global warming will harm them personally to the same level. These estimates of Americans' risk perceptions are alarming considering the imminent destructive impacts of climate change predicted by the scientific community worldwide.

1.4 Personal experience of extreme weather and climate change perception

The public's lukewarm perception of the issue has motivated a growing body of literature exploring the relationship between extreme weather event experiences and people's climate change concerns. Of such, local temperature has been examined most extensively. Krosnick et al. (2006) found that change in local temperature was a significant factor in the American public's climate change beliefs. This finding is echoed by a later study investigating the link between local temperature trends, media coverage, and an American public opinion poll on climate change (Donner and McDaniels 2013). At the same time, some studies found significant effects of temperature changes on people's belief in climate change but with caution. Egan and Mullin (2012) found that although abnormally high or low temperatures both had a significant impact on people's beliefs about climate change, the effect was fleeting, that climate change attitudes were unaffected by temperature changes that occurred more than a week ago. Deryugina (2012) showed that while longer periods of abnormal temperature had small effects on climate change beliefs, there was no discernible effect with short-term changes in temperature. There are also studies that found no significant association between temperature changes and people's concerns about climate change (Brody et al. 2008; Brulle et al. 2012).

Studies of personal experience of floods (Whitmarsh 2008; Spence et al. 2011; Demski et al. 2016) and extreme cold weather (Capstick and Pidgeon 2014; Shao and Goidel 2016) both found contradicting results on people's experience and the resulting climate change perceptions, concerns, and actions. Instead of looking at a single weather event, other researchers examined a mix of weather events. Konisky et al. (2015) used records of extreme weather events and data that includes information on individuals' perceptions of climate change with their detailed geospatial data. Respondents expressed a higher level of concern about climate change when they had experienced more climate-related extreme weather in the month prior to the survey. In this study, the severity of the weather events had an admissible effect on individuals' climate change concerns, which echoed the findings from an earlier study that considered weather event attributes (Brody et al. 2008), as well as a follow-up study (Sisco et al. 2017).

1.5 Wildfire experience on climate change perceptions

Of the limited studies on how wildfire experience was associated with climate change concerns, Hazlett and Mildenerger (2020) examined voting behavior on costly climate-related policies following the occurrence of wildfires. They found that support for costly pro-environmental policies increased by 5–6 percentage points for those living within 5 km of a recent wildfire, with the effect decreasing to nearly non-existent beyond a 15 km distance from areas affected by wildfire. This effect was almost exclusive to democratic-voting areas. Zanocco et al. (2018) included two tornadoes and two wildfire events in their query on climate change attitudes. Data from the two wildfire events showed diverging results—while 49.0% of respondents from California expressed increased concerns toward climate change, this increase was only reported by 21.4% of respondents from Arizona. The authors made similar notes regarding the impact political ideology might have on climate change attitudes. Nonetheless, the varying findings from these studies are not adequate in speaking to the association between personal experience of wildfires and the public's perception of climate change.

1.6 Gauging climate change perception through Twitter

The total number of Twitter active users has grown from 110 million in 2017 to 217 million in 2021 (Aslam 2022). There are 77.75 million Twitter users in the USA placing it at the top, followed by Japan, India, Brazil, and the UK (Aslam 2022). Research utilizing Twitter data to understand public perception of climate change covers a plethora of dimensions, including demographic differences in climate change communication (Holmberg and Hellsten 2015), sentiment analysis (Cody et al. 2015; Dahal et al. 2019), linguistic strategies and choices employed in climate change discussions (Anderson and Huntington 2017; Yeo et al. 2017), the flow and communication networks of climate change discussion (Burgess and Bruns 2012; Kirilenko and Stepanenkova 2014; Pearce et al. 2014); and crisis communication during weather events (Demuth et al. 2018; Kryvasheyeu et al. 2016; Sutton et al. 2015), etc.

Studies exploring the relationship between extreme weather event experience and individual climate change concerns have turned to Twitter data for insights given its real-time nature. Sisco et al. (2017) examined people's attention to climate change following a personal experience of extreme weather events and found an increase in attention to climate change after experiencing coastal floods, strong winds, extreme cold, excessive heat, drought, wildfires, hail, and heavy snow, while changes in attention were not found after flash floods and tornadoes. Roxburgh et al. (2019) found an increase in attention to climate change after hurricane and snowstorm events when financial damages and deaths were high. On the other hand, disparate literature regarding the personal experience of extreme weather events and belief in climate change remains (Capstick and Pidgeon 2014; Shao and Goidel 2016).

Despite the rise in using Twitter data among the research community, no study to date has exclusively examined how personal experience of wildfire is associated with people's climate change perceptions.

1.7 Current study and research questions

The current study responds to existing gaps in the literature by investigating how the public expresses personal experiences of geographically and temporally proximal wildfire on Twitter in relation to climate change across 20 wildfires over five years, with the following overarching research question:

RQ1: How is the experience of a wildfire expressed in climate tweets during California wildfires across 20 fires over the period of 2017–2021?

In addition, this study aims to gain insights into the framing of public climate discussion over the course of wildfires. Therefore, the following research questions were written after an initial manual coding of tweets, before any analyses were conducted, to both better define the scope of the study and to guide analyses (see method section on process).

On linking wildfires to climate change:

RQ2: Does the frequency of tweets linking wildfire to climate change differ comparing the periods before and after a wildfire started?

RQ2a: If so, what is the temporal dynamic of Twitter discussions linking wildfire to climate change over the course of a wildfire?

RQ2b: In what ways do Twitter users link wildfires to climate change during peak times of discussion?

On suggesting climate actions:

RQ3: Does the frequency of tweets suggesting climate actions differ comparing the periods before and after a wildfire started?

On attributing other adversities beyond wildfire to climate change during wildfires:

RQ4: Does the frequency of tweets attributing other adversities beyond wildfire to climate change differ comparing the periods before and after a wildfire started?

2 Data and methods

2.1 Data sources

2.1.1 Selection of wildfires

CAL-FIRE's record provides information on the start and contained dates of each fire, location of the fire in latitude and longitude, counties involved, number of structures destroyed/damaged, fatalities, etc. California wildfires between 2017 and 2021 meeting the following criteria were included in the study: 1) the most destructive wildfires each year defined by damaged structures, and fatalities, in addition to land coverage, and 2) wildfires occurring in wildland urban interface (WUI) areas, which is the zone of transition between unoccupied land and human development, resulting in 29 fires (Table 1).

Table 1 Most destructive California wildfires between 2017 and 2021

| Year | Fire name | County(s) involved |
|------|------------------------|---|
| 2017 | Atlas fire | Napa |
| | Tubbs fire | Napa and Sonoma |
| | Lilac fire | San Diego |
| | Redwood Valley fire | Mendocino |
| | Thomas fire | Santa Barbara and Ventura |
| | Creek fire* | Los Angeles |
| | Skirball fire* | Belair and Los Angeles |
| | Rye fire* | Santa Clarita |
| 2018 | Mendocino Complex | Colusa, Glenn, Lake, Mendocino |
| | Carr fire | Shasta and Trinity |
| | Donnell fire | Tuolumne |
| | Camp fire | Butte |
| | Woolsey fire | Los Angeles and Ventura |
| 2019 | Mountain fire | Shasta |
| | Sandalwood fire | Riverside |
| | Kincade fire | Sonoma |
| | Saddle Ridge fire* | Los Angeles |
| | Tick fire* | Los Angeles |
| | Getty fire* | Los Angeles |
| 2020 | CZU Lightening Complex | Santa Cruz and San Mateo |
| | LNU Lightening Complex | Napa, Sonoma, Lake, Yolo, Solano |
| | August Complex | Mendocino, Humboldt, Trinity, Tehama, Glenn, Lake, Coluse |
| | North Complex | Plumas and Butte |
| | Glass fire | Napa and Sonoma |
| 2021 | Beckwourth Complex | Plumas |
| | Dixie fire | Butte, Plumas, Shasta, Lassen, Tehama |
| | River fire | Nevada and Placer |
| | Caldor fire | El Dorado, Amador, Alpine |
| | Fawn fire | Shasta |

*Denotes wildfires in wildland urban interface (WUI) areas, the zone of transition between unoccupied land and human development

2.1.2 Tweet extraction

Tweets from each wildfire were extracted using a three-step process.

Step 1: Extract tweets from the Twitter API with filters (Twitter 2022a, b). The Twitter API allows the use of keywords and returns only tweets containing specified keywords. A list of climate change-related keywords was compiled to retrieve tweets related to climate change (Appendix A). Next, a spatial filter was added to retrieve tweets from the state of California only, followed by a date filter to retrieve tweets

from four weeks prior and eight weeks after the onset of each wildfire, totaling a 12-week period. Duplicated tweets were subsequently removed.

Step 2: Determine the location of each tweet. Tweets retrieved in step 1 did not contain granular information on the location beyond the state of California. Each tweet came with a place id attribute. We wrote a program for Twitter API to retrieve geocoding information for each place id. The API returns a bounding box, which is a rectangle that encloses a space between two latitudes and two longitudes corresponding to each place id. Lastly, we joined the geocoding information dataset and the tweet dataset on the place id column to get the bounding box for each tweet.

Step 3: Identify tweets proximal to the wildfire location. Since the current study's purpose is to examine the association of personal experience of wildfire with climate change discussions, tweets were collected from locations where people were likely affected by the wildfires included in the study. Following step 2, each tweet is tagged with a bounding box based on its latitude and longitude. With the information on the center of each wildfire from CAL-FIRE, we computed the distance between the center of each tweet's bounding box and the center of a wildfire. A filter condition was then added on this distance to only include tweets from within a 25- to 150-mile radius from the center of each fire. The specific radius varied based on the size of the fire.

The three-step retrieval process resulted in tweets that originated within 25–150 miles of the wildfires, as well as within the time duration of four weeks prior and eight weeks after the onset of each fire. Because some fires had overlapping timelines and were near each other, we created a unified dataset for these instances. Tweet datasets from these fires were merged with duplicates removed. Fires with under 300 tweets for the 12-week period were dropped since the number was negligible for analysis. The merges left the analysis with a total of 12 datasets reflecting 20 fires. Table 2 shows the tweet numbers from each dataset totaling 14,457 tweets from 9464 unique users for the analysis.

Table 2 Number of geo-tagged climate change-related tweets from each dataset

| Dataset | Tweets | Unique users |
|--|--------|--------------|
| Tubbs and Atlas fires 2017 | 1111 | 791 |
| Thomas and Creek fires 2017 | 1169 | 848 |
| Lilac fire 2017 | 356 | 260 |
| Mendocino Complex and Carr fires 2018 | 2055 | 1221 |
| Camp fire 2018 | 1154 | 757 |
| Woolsey fire 2018 | 2019 | 1215 |
| Saddle Ridge, Getty, and Tick fires 2019 | 1706 | 1174 |
| Kincadee fire 2019 | 1007 | 844 |
| August and North and LNU Complex 2020 | 1588 | 1068 |
| CZU Lightning Complex 2020 | 432 | 315 |
| Glass fire 2020 | 402 | 256 |
| Dixie and Caldor fire 2021 | 1458 | 715 |
| Total | 14,457 | 9464 |

2.2 Manual and automated coding of tweets

2.2.1 Initial manual coding and themes identification

A random sample of 800 tweets across five years was manually coded by two coders. Coders came up with code names that captured the linguistic nature of the tweets. Given our theoretical interest in understanding how users geographically and temporally proximal to the wildfires expressed climate change-related attitudes, we took a deductive approach and identified three ways in which tweets most commonly expressed the proximal experience of wildfire in relation to climate change: 1) linking wildfires to climate change, 2) suggesting climate actions, and 3) attributing climate change to adversities besides wildfire. Tweets not coded as one of the three were marked “not relevant,” meaning they were not relevant to the parameter defined for this study. Each climate tweet could be coded for expressing one or more of the three themes, or as not relevant. A codebook was developed for interpreting tweets’ inclusion and exclusion criteria (Appendix B). Cohen’s kappa for intercoder reliability was 0.85 (O’Connor and Joffe 2020).

2.2.2 Automated coding of wildfire tweets

Machine-learning language models using BERT (Devlin et al. 2018) were developed to perform the classification of the rest of the extracted tweets into the three themes identified in the initial manual coding. For a given label, a single BERT model was trained to recognize whether a tweet belonged to that label by presenting tweets that either had a positive or negative label, where positive implies that the label applies to the tweet, and negative implies that the label does not apply to the tweet. The model converged at approximately 400 labeled instances for the labels “attributing climate change to other adversities,” “linking wildfires to climate change,” and “suggesting climate actions,” while the “not relevant” label required training with a larger dataset to converge (Appendix C). Table 3 provides accuracy metrics on the model’s performance.

2.3 Data analysis

With the study’s aim to examine whether and how the personal experience of wildfire is associated with climate change-related discussions on Twitter, we took a mixed-method approach to gain optimal insights into each research question raised.

Table 3 The F1-score and accuracy metrics for the model trained on each label

| Label | F1 | Precision | Recall | Accuracy |
|---|-------|-----------|--------|----------|
| Linking wildfires to climate change | 76.52 | 78.58 | 74.58 | 95.54 |
| Suggesting climate actions | 63.16 | 57.14 | 70.59 | 90.76 |
| Attributing climate change to other adversities | 55.17 | 61.54 | 50.00 | 89.27 |
| Not relevant | 87.44 | 89.50 | 85.46 | 83.83 |

Precision is the ratio of the number of true positive-predicted data points to all positive-predicted data points (includes both true and false positives); Recall is the number of true positive-predicted data points to all true positive data points (includes both true positives and false negatives); F1 is a function of the precision and recall metrics.

2.3.1 Qualitative analysis

Two parts of the study involved qualitative analyses. First, after the inaugural extraction of climate-relevant tweets during wildfire periods from locations likely impacted by wildfires, an initial round of manual coding, as described in Sect. 2.2.1, was performed to identify themes as parameters of the study. Second, in the examination of the temporal dynamic of discussion linking wildfire to climate change over the course of a wildfire, tweets during times when the volume of this theme of tweets peaked were qualitatively examined, to gain a better understanding of what drove the increased volume of discussion as well as framings used to express the connection between wildfire and climate change.

2.3.2 Quantitative analysis

Frequencies of tweets were computed for the three themes of tweets across the 12 datasets. To examine whether tweet frequencies change over the course of a wildfire, one-way ANOVA tests were performed using SAS version 9.4 for RQ2a, RQ3, and RQ4. Wildfire time periods were determined as four weeks prior to the onset of a wildfire (time 1), weeks 1–4 after the onset of a wildfire (time 2), and weeks 5–8 after the onset of a wildfire (time 3). Line graphs based on the frequencies of tweets from the theme linking wildfire to climate change were generated to examine temporal trends since the focus of the study is to understand the association between personal experience of wildfire and climate change-related perceptions.

3 Results

RQ1: How is the experience of a wildfire expressed in climate tweets during California wildfires across 20 fires over the period of 2017–2021?

To answer this overarching research question of the study, we started by manually reading a random sample of the extracted tweets and identified three themes that most commonly integrated the notion of climate change:

- 1) Linking wildfire to climate change: Climate tweets linked wildfire to climate change by describing climate change as a direct or indirect contributor to wildfires, as well as asserting that climate change exacerbates the spread of wildfires. Tweets expressed the consequences of wildfires such as bad smell, ashes in the atmosphere, bad air quality, dark skies, disruption to daily life, etc., and attributed these negative experiences to climate change as the cause.
- 2) Suggesting climate actions: Climate tweets suggested actions to alleviate anthropogenic climate change effects. Tweets expressed actions in both general and specific ways. General expressions included tweets that did not mention specific actions but expressed that actions were needed. Specific climate actions suggested ranged from individual behavior change such as consuming less meat, voting for those who support climate action, driving electric vehicles, to policy-related actions, such as transiting to renewable energy and promoting climate change education.

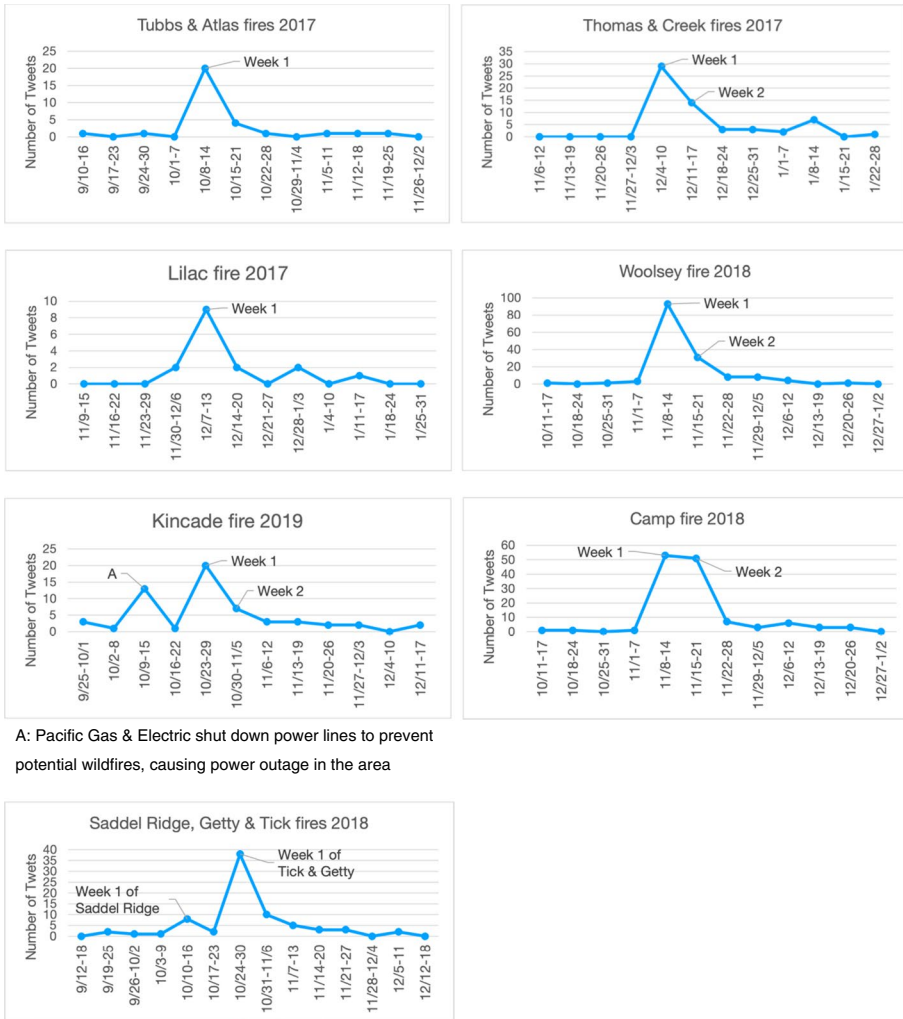
- 3) Attributing climate change to adversities besides wildfires: Climate tweets made reference to adversities unrelated to wildfires to climate change. Most referred to weather-related events such as unusually hot or cold temperatures, hurricanes, and drought; but users also expressed non-weather adversities such as a poor economy, poor harvest of crops, and disruption to daily life. There were also tweets that did not mention specific adversities but carried the connotation that climate change brought negative consequences.

RQ2: Does the frequency of tweets linking wildfire to climate change differ comparing the periods before and after a wildfire started?

We quantitatively examined the change in frequencies of tweets linking wildfire to climate change across three time periods (4 weeks prior to fire (time 1), weeks 1–4 after the onset of a wildfire (time 2), and weeks 5–8 after the onset of a wildfire (time 3)) with one-way ANOVA test. There were significant differences in mean tweet frequency for the three time periods across the 12 datasets ($F = 10.87$, $p = 0.0004$). Post hoc contrast analysis showed that the number of tweets significantly increased during time 2 compared to time 1 ($p = 0.0005$) and significantly decreased from time 2 to time 3 ($p = 0.0047$). This means that tweets linking wildfire to climate change significantly increased during weeks 1–4 of a wildfire compared to before the fire started. However, this increase was not sustained, as the number of tweets significantly decreased during weeks 5–8 compared to weeks 1–4 after a fire started.

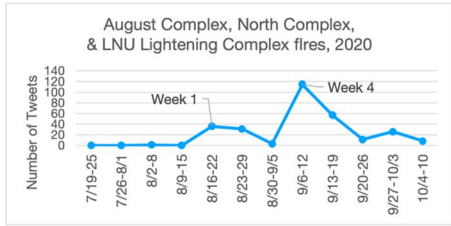
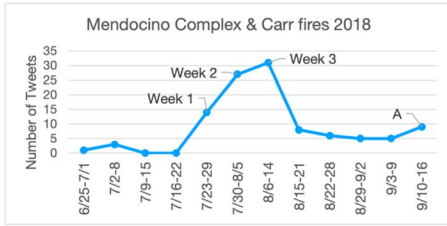
RQ2a: What is the temporal dynamic of Twitter discussions linking wildfire to climate change over the course of a wildfire?

To examine the temporal dynamic of discussion, a line graph was generated on each dataset for a visual representation of the changes in tweet frequencies as a function of time throughout the course of wildfires. Out of the 12 datasets, seven datasets showed a peak in the volume of tweets during the first week following the onset of the fire(s) (Fig. 1). For the other five datasets, the volume of tweets peaked at different times (Fig. 2). Overall, no consistent pattern was observed for when discussions linking wildfires to climate change peaked following the onset of fires. The spike in volume of wildfire discussions likely depended on wildfire characteristics (e.g., some fires did not have dramatic progress until a few weeks after the ignition, while some burned fiercely at the start) and external events, such as climate conferences, power shutdowns, politicians speech related to wildfires/climate change, etc., as seen in graphs of Mendocino Complex and Carr fires, Glass fire, and Dixie and Caldor fires in Fig. 2. Furthermore, the observed time trend of wildfire discussions showed that regardless of when the peak of discussion occurred during a wildfire, the increases were short lived, persisting for only a week or two in most cases.

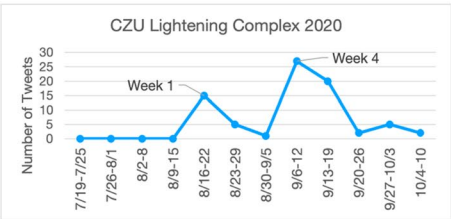
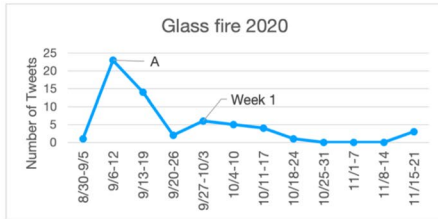


A: Pacific Gas & Electric shut down power lines to prevent potential wildfires, causing power outage in the area

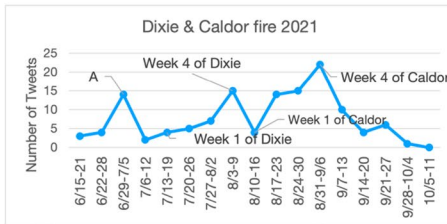
Fig. 1 Trend graphs of data sets with peaks of volume of discussion linking wildfire to climate change during the first week of fires



A: 2018 Global Climate Action Summit took place in San Francisco, near the two fires in Northern California



A: Other large -scale fires burning near -by



A: Preside Biden made a statement about climate change's effect on wildfires

Fig. 2 Trend graphs of data sets with peaks of volume of discussion linking wildfire to climate change during the weeks 3 to 4 of fires

RQ2b: In what ways do Twitter users link wildfires to climate change during peak times of discussion?

To answer this research question, qualitative analyses were carried out to examine tweets “linking wildfires to climate change” during time points where volume of this theme of tweets peaked in each dataset. Three framings were identified:

I. People’s firsthand experiences of wildfire.

First, most tweets associate climate change with people’s firsthand experiences of wildfires, such as having their cars covered by ashes, having classes canceled, being affected by bad air quality, etc. A portion of tweets mentions other climate events happening simultaneously with the wildfire, drawing a link between these events to climate change alongside the wildfires:

- Harvey. Irma. Maria. Now this #napafire/#sonomafire. #Climatechange is here and rearing its ugly head. (Tubbs and Atlas fires 2017 dataset)
- From my kitchen window I can see the Malibu fires. Some scary sh*t. Hurricanes, fires, Global warming is real ...#lookitup @West Hollywood, California (Woolsey fire 2018 dataset)

II. Comments directed at politicians.

The second major type of tweet was made up of responses to statements made by politicians. For example, during the August Complex, North Complex, and LNU Complex fires in 2020, the largest volume of tweets linking wildfires to climate change came up during the fourth week of the fires. A significant portion of tweets from this week were in response to former President Trump's statement that the spread of the fires was due to poor forest management:

- *I am in the midst of the California wildfires and I am sick of Trump trying to blame us. Due to man caused climate change we had 5 years of drought, millions of trees died and then we had record high temperatures, high winds and lightning. No one takes the forest you moron!*
- *@JunkScience @realDonaldTrump @GavinNewsom Is Gavin managing California's forests? Isn't the land on fire managed by the US Forest Service? How should the forests be managed? There have been droughts, but each year has been the hottest ever recorded. If you think this isn't global warming, take another hit.*

III. External events concurrent with the wildfires.

The third major type of tweet is related to external events happening concurrently with wildfires. For example, two weeks prior to the onset of the Kincadee fire in 2019, the number of tweets that linked wildfires to climate change increased noticeably as a result of power lines shut down to prevent a potential wildfire. Tweets mention the shutdown, attributing climate change as the cause of heightened fire risks:

- *Dryer annual seasons prompted huge fire risk. So basically climate change is why 800 k+ people are at risk of multi-day power outages*
- *A glimpse into our future, when a public utility @PGE4Me can send a notifying text of "we may shut off your power" to prevent a potential fire disaster. I'm all for safety precautions but this is NOT the answer for global warming. Let's figure this sh*t out @WhiteHouse @UN*
- **RQ3: Do the frequencies of tweets suggesting climate actions differ comparing the periods before and after a wildfire started?**

The one-way ANOVA test comparing the number of tweets from the three time periods showed no significant difference in the frequencies of tweets suggesting climate actions ($F=0.57$, $p=0.57$).

RQ4: Does the frequency of tweets attributing other adversities beyond wildfire to climate change differ comparing the periods before and after a wildfire started?

The one-way ANOVA test comparing frequencies of tweets from the three time periods was statistically significant ($F=7.20$, $p=0.0036$). Post hoc analyses showed that the mean frequency of tweets in time 2 significantly increased compared to time 1 ($p=0.0075$), and the frequency of tweets significantly decreased in time 3 compared to time 2 ($p=0.0095$). The difference between pre-fire (time 1) and weeks 5–8 after the onset of fires (time 3) was not statistically significant ($p=0.66$). This means that this theme of tweets (attributing other adversities beyond wildfire to climate change) significantly increased during the first four weeks of wildfire, and the volume of discussion dropped to a level similar to pre-fire beyond the 4th week after a wildfire started.

4 Discussion

The current study fills existing literature gaps on three fronts. First, we characterized three themes in Twitter discussions during wildfire events most frequently integrating the notion of climate change. Second, we sought to understand the relationship of wildfire experience on the volume of climate change-related discussions on Twitter. Lastly, we qualitatively contextualized tweets that explicitly linked wildfire to climate change for a more substantive understanding of the framing of such discussions, as well as to gain insights on factors associated with heightened volume of discussions.

4.1 Wildfire experience and attention to climate change

Of the three themes identified in climate change-related discussions during wildfire events, we found that tweets linking wildfire to climate change and attributing climate change to other adversities besides wildfires significantly increased after the onset of wildfires, while tweets suggesting climate actions did not. The quantitative result showing an increased frequency of discussion linking wildfires to climate change affirms the findings of several studies that found a significant positive association between experience of extreme weather events and climate change belief (Donner and McDaniels 2013; Kirilenko and Stepchenkova 2014; Konisky et al. 2015; Krosnick et al. 2006; Roxburgh et al. 2019; Sisco et al. 2017). On the other hand, literature contextualizing real-time wildfire discussions on social media is nascent (Kuligowski et al. 2023). The current study reveals through Twitter data that people attribute climate change to wildfire to a greater degree after the onset of geographic and temporally proximal fires. Furthermore, by examining trends of wildfire discussions across 20 fires over five years during California's most intense and destructive fires, the current study confirms the consistency of this association across wildfire events and that it is not only unique to some wildfire incidents.

4.2 Implications on the gap between the public and the scientific community on climate change concerns

4.2.1 A narrower gap

Although the scientific community has long recognized climate change's impact on both the increased frequency and intensity of wildfires (Abatzoglou and Williams 2016;

Kirchmeier-Young et al. 2019), in prior decades, persistent discussion about belief in climate change emphasized uncertainty and promoted inaction or status quo with respect to climate policy. As the media landscape evolved, unsolicited discussions on social media platforms not only have become increasingly important in gauging how policy issues are discussed, but these discussions could also shape public perceptions of whether a policy warrants prioritizing (Anderson and Huntington 2017). While there have been expressions of climate skeptics, the result from this study where users explicitly link wildfire to climate change during their personal experience of wildfires suggests that public opinion might be changing to readily accept climate change, at least in the context where individuals have personally experienced an extreme weather event, which is becoming a more familiar experience for many. On a similar note, based on existing literature on extreme weather events and climate change communication, Ettinger (2023) postulates that at times of extreme weather events where people's psychological distance to climate change is shortened, it is most fitting to bring up climate change-related conversations.

Communication on social media platforms has a central role in provoking a response to climate change and related policy (Ettinger and Painter 2023). With expressions increasingly acknowledging the link between more intense and frequent wildfires and climate change, this communication on social media signals a shift in the public's adoption of this belief long acknowledged by scientific communities. Social media can be critical in provoking a collective response to build support for departing from status quo policies.

4.2.2 Framing of climate change discussion

The quantitative analyses of the current study showed that in conjunction with linking wildfires to climate change, there was also a significant increase in discussion that linked adversities besides wildfire to climate change during people's experience of wildfire events. This evidence may speak to the nuance of integrating other climate-related adversities in climate communication during extreme weather events to emphasize the devastating impacts of climate change outside of one's personal experience.

Furthermore, the current study found that the volume of climate change discussions during wildfire events varied based on multiple factors. The qualitative analyses on the framing of discussion revealed that besides personal experience of negative impacts brought about by wildfires, external climate-related events happening concurrently such as local or international climate summits, power shutdown, and politicians' comments related to the wildfires were also major drivers of climate change discussions during wildfire events. This finding resonates with Roxburgh et al.'s (2019) study that took a comparative approach to Twitter discussions during two hurricanes and a snowstorm. Compared to Hurricane Irene, Hurricane Sandy resulted in a much larger number of tweets related to climate change because of high-profile public figures speaking about the issue, such as Al Gore, Ian Somerhalder, and the Mayor of New York City. Publications of climate campaign groups also contributed to the boost of climate change-related tweets during Sandy.

En masse, these insights on framings embroiled in the public's climate change real-time discussions on Twitter could direct climate change communication strategies for better public engagement on the topic, as nowadays, social media platforms are the most prominent space for the spread of information.

4.2.3 Timing of climate change communication

The temporal dynamic of climate-related discussion during wildfire events observed in the current study adds to the limited insights into the fleeting relationship between personal experience of extreme weather events and attention to climate change. Although several studies have reported an increase in climate change-related discussion during extreme weather events, data from these studies were limited to a few days or a week at most (Kirilenko and Stepchenkova 2014; Sisco et al. 2017). Of the few studies that investigated the persistence of the increased attention to climate change based on personal experience of extreme weather events, authors often pointed out the ephemeral nature of this heightened attention (Egan and Mullin 2012). The current study extended the extraction of tweets to a total of 12 weeks and observed the same fleeting nature of the increased volume of climate change-related discussion. Researchers in the past have repeatedly raised the same issue and suggested that more longitudinal studies are necessary to disentangle this relationship (Reser et al. 2014; Borick and Rabe 2017). This could potentially speak to the gap between the public and the scientific community in the recognition of climate change. The fact that the public seems to maintain a lukewarm attitude toward the issue while the scientific community evidently affirms the detrimental effects of anthropogenic climate change could be the result of climate change being an abstract, intangible concept, except for when individuals personally experience the negative effects from it. However, these personal experiences are usually short lived for the majority of the public, e.g., heatwaves that last a few days and wildfires that cause bad air for a week. After all, only a relatively minuscule portion of the public experience the most catastrophic impacts of these extreme weather events, such as losing their homes or loved ones in wildfires.

This sheds light on the importance of timing in climate communication. Although literature reveals that when extreme weather events take place, the public, especially those affected by the events, tend to be more engaged in the topic of climate change, this engagement fades quickly. In order to optimize communication efforts around public engagement brought on by climate events, actions need to be taken swiftly, in a matter of one to two weeks following the start of an extreme weather event. Sending timely messages about climate change when people are feeling the tangible effects before this memory fades could potentially help narrow the space between the public and the scientific community on actions needed to tackle the issue.

4.3 Personal experience of wildfire and climate action intention

During the initial manual coding of tweets, tweets suggesting climate actions were among the most frequent framings of climate-related tweets and thus was included as one of the three themes as the parameter of the study. There was an increasing albeit statistically insignificant number of tweets suggesting climate actions after the onset of a fire. Our findings suggest that although personal experience of wildfire may heighten climate-related discussion, it may not translate into intention for climate actions. This finding is consistent with Hornsey et al. (2016) meta-analysis that the association between climate change beliefs and the willingness to act in climate-friendly ways is slight.

On the other hand, this result contradicts findings of significant positive shifts in people's attitudes and voting behaviors toward pro-environmental policies and pro-environmental politicians after personal experience with wildfires and hurricanes (Rudman et al. 2013; Hazlett and Mildemberger 2020). However, Hazlett and Mildemberger (2020) added

that the effect on voting behaviors was almost exclusively detected in democratic-voting areas only. The association between personal experience of extreme weather events and climate action intentions should be considered with caution, for the limited research on this front and other factors that are yet to be discovered.

4.4 Limitation

A limitation of this study is the representativeness of our sample of Twitter users. Since socio-demographic information of users is not available, we are uncertain how much our sample resembles the US population in terms of age, ethnicity, socioeconomic status, etc., which are factors that might be associated with people's perception of climate change. A report on Twitter users published by Pew Research Center in 2019 indicates that Twitter users are more likely to represent younger populations, more likely to identify as Democrats, are more highly educated, and have higher incomes (Wojcik and Hughes 2019). Our data therefore may underrepresent those living in rural areas, earning lower incomes, and who are more conservative. Since climate change has evolved into a politically charged topic in the USA, the experience of extreme weather events is likely to have diverging impacts on people with different political ideologies. Of the limited access to Twitter users' information, the current study is unable to further confirm these assumptions.

Another critical observation made in the qualitative analysis of tweets linking wildfire to climate change is that of the tweets that spoke of personal experiences of wildfire, they expressed the relatively less severe effects of wildfires, such as having their car covered in ashes and having school canceled due to poor air quality. We did not come across tweets that spoke about experiences of having to evacuate, having their house destroyed, losing a loved one in a fire, or having one's horses, cattle, or pets die in a fire. One speculation is that individuals facing immediate threats of wildfires (i.e., those who had to evacuate or lost their homes) may not have the luxury of time to post on social media. Thus, although this study aimed to examine the effects of personal experience of wildfires on engagement in climate change discussion, our data seemed to have captured the attitudes of those witnessing a fire yet still able to report about it. Nonetheless, there is an importance to this subset that we were able to examine—after all, the impacts of wildfire go beyond those that get their houses burned down. Although these effects are not as immediate, the poor air quality and smoke from large wildfires produce effects that remind a larger population of the prominence of climate change.

A few studies have used frequencies of climate change-related tweets as a proxy for climate change concerns or attention to climate change (Kirilenko and Stepchenkova 2014; Roxburgh et al. 2019; Sisco et al. 2017). For this study, since there is a lack of evidence in the literature that suggests the equivalency of the volume of tweets and climate change concerns/attention, we limit the interpretation of climate change-related tweet numbers to volume of discussion, instead of extrapolating the results to people's concerns/attention toward climate change. While it might be intuitive that when people are concerned about/have their attention drawn to something, they would discuss it more, including posting on social media platforms, we have reservations about whether the opposite holds true—when people do not discuss something, we cannot ascertain that they are not concerned with or are not paying attention to the issue, thus our decision to only refer to the number of tweets as volume of discussion.

5 Conclusion

The aim of this study is to examine a type of extreme weather event that has been understudied for its association with the public's engagement in climate change discussion. This is the first study that exclusively examined the relationship between personal wildfire experience and climate change concerns through real-time social media data. Consistent with previous studies, our findings in the context of wildfire suggest that the personal experience of extreme weather events contributes to increased climate change-related discussion on Twitter. Results from the study show that the personal experience of wildfire is related to increased frequency of tweets in two of the three themes defined as the parameter of this study—linking wildfire to climate change and attributing climate change to other adversities besides wildfires, while the frequencies of tweets suggesting climate actions did not change significantly across periods. This study of the three themes of tweets leads us to a rather nuanced insight—when people experience one type of extreme weather event, it induces the tendency to go beyond what they are experiencing and to bring in other adversities, linking them to climate change.

The result of this study suggests a possible narrower gap between the public's and the scientific community's consensus on anthropogenic climate change's contribution to extreme weather events. It has long been believed that the public was rather uncertain about the linkage. Data (i.e., tweets) from this study demonstrated otherwise—during wildfire events, tweets that attributed the increased frequency and intensity of wildfires to climate change were commonly seen.

The analysis of the persistence of increased Twitter discussion from the current study adds insight into the temporal dynamics of how the volume of discussion changes on Twitter during wildfire events. The key takeaway is that consistent with previous studies, the effect is short lived—even with the deadliest and costliest wildfire in California's history on record, types of climate change-related discussion did not last past two weeks.

Finally, the qualitative analysis of tweets linking wildfires to climate change adds to the understanding of the framing of climate change discussion during extreme weather events. Mirroring results from another study that examined the framing of tweets during weather events, the analysis shows that besides personal experiences of disturbances from wildfires, external factors, such as public figures' statements and climate-related initiatives happening during wildfires, were factors associated with increased discussion on climate change.

These findings should be considered in climate communications to better engage the general public in the eminent but overlooked issue of anthropogenic climate change.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s10584-023-03668-0>.

Author contribution The authors confirm contribution to the paper as follows: Jessie Ko: conceptualization, formal analysis, and writing—original draft; Shengquan Ni: data curation; Alexander Taylor and Xiusi Chen: software (tweets coding); Yicong Huang, Avinash Kumar, Sadeem Alsudais, Zuozhi Wang, and Xiaozhen Liu: software (data retrieval); Wei Wang: conceptualization, software (tweets coding), supervision, and funding acquisition; Chen Li: conceptualization, software (data retrieval), supervision, and funding acquisition; Suellen Hopfer: conceptualization, writing (review and editing), supervision, and funding acquisition. All authors read and approved the final manuscript.

Funding This work was supported by NSF (grant number IIS-2107150).

Data availability The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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