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Comparing public and scientific extreme event attribution to climate change

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Abstract
Extreme event attribution is an active area of scientific research, but public attribution of extreme events to climate change is not well understood – despite its importance to climate change communication and policy. We surveyed a representative sample of the U.S. population ($n = 1071$) to measure the public's confidence in attributing five event types to climate change – wildfire, heat, rainfall/flooding, tornadoes, and hurricanes. Our respondents had the highest confidence in attributing wildfires and extreme heat to climate change, and the lowest confidence for hurricanes and tornadoes. Respondent characteristics, such as education level, age, race/ethnicity, political affiliation, and self-reported extreme event impacts, were linked to attribution confidence. Overall, those reporting negative impacts from extreme events had higher levels of attribution confidence. While Republicans on average had lower levels of attribution confidence, we found that self-reported negative event impacts had a moderating effect on attribution confidence among Republicans. Republicans who were more negatively impacted by extreme events had higher levels of attribution confidence compared to Republicans who were less impacted. We also compared the public's attribution confidence to scientific assessments, developing a measure of *attribution alignment*. We found that respondents aligned with scientific event attribution for an average of 2 out of 5 extreme event types. While respondent characteristics were less consistently related to attribution alignment overall, Democrats on average had lower alignment. Our study suggests that the public is connecting climate change to extreme weather and making distinctions in attribution levels, but politics and experiences with extreme weather matter. We recommend that scientists and climate change communicators reflect this discernment in discourses about extreme events, climate change, and policy.

Keywords Extreme event attribution · Climate change · Public opinion · Extreme weather · Science communication

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1 Introduction

The attribution of extreme weather events to anthropogenic climate change is an area of active scientific research and scholarly debate. For some extreme weather hazard types – such as extreme heat events – their relationship to climate change is becoming clearer with every passing year, while for other event types – such as tornadoes – the influence of climate change is less certain (NASEM 2016). These scientific efforts to understand the connection between extreme weather events, and human-caused climate change, have led to an emerging field known as extreme event attribution (EEA), which seeks to understand if "…climate change [has] influenced the frequency, likelihood, and/or severity of individual extreme events" (pg. 523) (Swain et al. 2020). While EEA is an emerging field, it is increasingly important for assessing the global impacts of climate change via extreme events, now and in future periods (Clarke et al. 2022; Strauss et al. 2021).

EEA does not seek, however, to establish a simplistic causal link between climate change and extreme weather. It instead strives to distinguish among several possible factors that influence the likelihood of an event (Swain et al. 2020). Establishing causal links is confounded by climate and weather being incommensurate, with climate measures spanning much longer time horizons. Instead, EEA considers the influence of climate change on the likelihood or probability that extreme weather has become more severe, frequent, or likely to occur. The National Academies of Sciences, Engineering, and Medicine (NASEM) report on extreme event attribution, produced by a committee of climate experts, placed certain extreme event types on a scale of confidence in the scientific ability to link them to human-caused climate change (NASEM 2016). According to this NASEM report, extreme heat events have among the highest levels of attribution confidence, followed by droughts and extreme rainfall with mid-level confidence, and then hurricanes, wildfires, and tornadoes with lower levels of confidence. We use the NASEM report as our primary source for scientific assessments of extreme event attribution but acknowledge on-going scientific research on this topic (e.g., Clarke et al. 2023, 2022; Swain et al. 2020).

In parallel to this scientific debate about extreme event attribution, a similar discussion is occurring in the public sphere. Public discussions about extreme weather often center around recent events and their intensity and/or frequency compared to past lived experiences or historical recollections, although if and how a connection is made to climate change varies across time period, event, and context, both in the U.S. and internationally (Hopke 2020; Noviello et al. 2022; Painter et al. 2021; Roxburgh et al. 2019). Often these connections between extreme weather and climate are made via the media's coverage of events, with examples ranging from record breaking heat waves in 1988 (Shabecoff 1988) to Hurricane Sandy in 2012, which at the time was directly connected to climate change by politicians and national news media in a broadly publicized manner (Goldenberg 2012). However, for some events, such as Hurricane Katrina just seven years prior, there was far less coverage of climate change related topics (Cody et al. 2017). Moreover, with respect to community discussion, an examination of 15 high impact extreme weather events that occurred between 2012 and 2015 found that discussions about climate change occurred in over half the cases, although it was more likely to occur in Democratic-leaning communities and when the attribution of the event to climate change had higher scientific confidence (Boudet et al. 2020). This suggests that both the political context and the characteristics of the event can influence public discussions about its connection to climate change.

In terms of how the public perceives the relationship between extreme events and climate change, previous studies have often focused on either a single impactful extreme event, multiple events of the same type, or overall attribution of extreme weather generally (Boudet et al. 2020; Capstick and Pidgeon 2014; Hai and Perlman 2022; Ogunbode et al. 2019; Osaka and Bellamy 2020). Recent polling in the U.S. indicates that two-thirds of Americans (67%) report extreme weather events are happening more often (Funk and Tyson 2021) and a majority (63%) believe the climate change is affecting the weather, with most indicating that it contributes to environmental problems, including extreme heat, wildfires, droughts and rising sea levels (Leiserowitz et al. 2022). Additionally, polling has found that Republicans are less likely to report community experience with extreme events overall, and among those that report community experience, Democrats are more likely to believe that climate change contributed to the event (Leppert 2022). These findings are consistent with Democrats having higher levels of belief in anthropogenic climate change and being more likely to view climate change as a major threat to the U.S. (Poushter et al. 2022).

Understanding public perceptions of extreme event attribution is important to climate change communication and policy (McClure et al. 2022). Social scientists have long argued that experience with extreme weather could shift public concern *and* potentially individual and policy action on climate change (Brügger et al. 2021; Weber 2016). Discussions about extreme event attribution have been found to promote public engagement with climate change related-issues and can make the topic of climate change more concrete by relating it to personal experiences (Ettinger et al. 2021; Weber 2006, 2016). Research has also suggested that attribution of extreme events to climate change is a crucial link between extreme weather experience and support for climate change mitigation responses (Ogunbode et al. 2019; Thaker and Cook 2021), as there is only mixed evidence that weather experience alone shapes climate opinion (Howe et al. 2019). There are, however, potential drawbacks to the public attributing extreme weather events to climate change even when the scientific connection is less certain. A tendency to *over*-attribute weather events to climate change can divert public attention away from other, non-climate related factors that exacerbate event impacts, such as socio-economic conditions and policy decisions that increase risk and vulnerability (Lahsen and Ribot 2022). Much remains unknown about the public's extreme event attribution and how it compares to that of the scientific community. Measurement of public event attribution is therefore critical to inform both science communication strategies and identify differences in EEA between the public and scientific community (McClure et al. 2022).

We seek to develop a more comprehensive understanding of the public's perceptions of extreme event attribution, as well as the factors that may be associated with these perceptions. Our research inquiry is thus guided by two questions: (1) To what extent is the public attributing different types of extreme weather events to climate change? (2) How does the public's attribution of extreme weather event types to climate change compare to the scientific community's? To answer these questions, we surveyed a representative sample of the U.S. public ($n = 1071$) in Fall 2021 about their confidence in linking the increasing frequency and severity of different types of extreme weather events (extreme heat, tornadoes, wildfire, etc.) to human-caused climate change.

2 Data and methods

2.1 Data

Our data was collected as part of the AmeriSpeak Omnibus panel, a recurring bi-weekly survey of the U.S. public funded and operated by NORC at the University of Chicago. AmeriSpeak uses probability-based sampling of residential addresses to recruit a representative sample of participants. NORC's sampling methodology follows established scientific practices in survey research, and its panels are frequently used by national news media and academic researchers to conduct U.S. public opinion polling (Holman et al. 2020; McGinty et al. 2020). For detailed information about the AmeriSpeak panel, including a full description of its methodology, see NORC (2021).

Study participants were surveyed from September 10–12, 2021, with a total sample size of 1071 and a margin of error of +/- 3.93% points at the 95% confidence level. The questionnaire was administered both online and by phone to participants who were 18 years of age or older. In addition to standard sociodemographic information, the survey also included questions about extreme weather experiences and the attribution of extreme weather events to climate change.

2.2 Survey measures

To measure respondent attribution of extreme weather events to climate change, we asked: "How confident are you that the increased frequency and severity of the following types of weather events can be linked to human-caused climate change?" Five response items included different extreme event types / event type combinations all situated on the same response scale from 1="Not at all confident" to 5="Extremely confident". The five extreme event items included: "Extreme heat" (mean = 3.05; sd = 1.52); "Extreme rainfall / flooding" (mean = 2.91; sd = 1.51); "Hurricanes" (mean = 2.86; sd = 1.54); "Wildfires" (mean = 3.26; sd = 1.45); and "Tornadoes" (mean = 2.73; sd = 1.53).

We also asked respondents about negative impacts from the same five event types: "How negatively impacted were you by the following extreme events in the past three years?" with responses situated on a scale from 1="Not at all impacted" to 5="Extremely impacted". Negative impacts from these five event types included: "Extreme heat" (mean = 2.48; sd = 1.26); "Extreme rainfall / flooding" (mean = 1.81; sd = 1.06); "Hurricanes" (mean = 1.55; sd = 0.98); "Wildfires" (mean = 1.68; sd = 1.11); and "Tornadoes" (mean = 1.44; sd = 0.91). We further combined these five event type impacts into a single mean composite index (mean = 1.79; sd = 0.77). We also considered how responses to these questions related to sociodemographic characteristics, including respondent age, educational attainment, household income, race/ethnicity, gender, political party affiliation, as well as geographic area (urban/rural) of the participant. See Table 1 for a summary of the survey measures applied in our study, as well as a comparison to national population statistics collected by the US Census Bureau.

2.3 Mapping public attribution to scientific attribution

To form a comparison between public and scientific assessments of extreme event attribution, we developed a strategy for mapping our survey questionnaire to levels of scientific EEA confidence (from NASEM (2016), see Table 2). Subsequent comprehensive assessments of

EEA for various event types (e.g., Seneviratne et al. 2021) have not substantially changed the general assessment of confidence. As an example of how we scored alignment, for 'extreme heat' – which was attributed with 'high' confidence to climate change in the NASEM report – a respondent would be considered in alignment with scientist assessments if they responded to our survey question on extreme heat that they were either 'extremely' or 'very confident' that increases in its frequency and severity were linked to climate change. Table 2 provides the percentage of respondents aligned with scientific assessments for each event type.

Our event type survey items were selected for consistency with negative extreme event impact reporting and designed so that a layperson could respond to them without causing undue fatigue (e.g., asking questions about confidence in increased *frequency* for each event type, then confidence in increased *severity* for each event type, etc.). Given these considerations, a direct alignment to scientific extreme event attribution was not always clear. Moreover, uncertainty in levels of scientific event attribution confidence also hampered our efforts to directly link public and scientific assessments.

Due to these challenges, we also developed an alternative category mapping distinct from that presented in Table 2 that widened survey confidence mapping for extreme rainfall / flooding and wildfire events (see Supplemental Information Table S7 for this alternative mapping). When applied in analysis, there were no substantive differences compared to the findings presented in the main text (see Supplemental Information Table S8 for alternative EEA mapping results).

2.4 Analytical strategy

We pursued two analytical strategies using regression modeling. Our first strategy involved modeling characteristics associated with respondent level of attribution of extreme event types. Using linear regression, we predicted level of attribution confidence for each event as a separate model, with covariates including sociodemographic characteristics, self-reported impacts from the event types, as well as geographic region fixed effects. In our second analytical strategy, we used binary logistic regression to predict attribution alignment (0 = does not align; 1 = aligns) for events. Using linear regression, we also predicted extreme event attribution alignment index (i.e., an average measure of alignment across all event types), with the index of negative extreme weather event impacts included as a covariate. In the Supplemental Information we present full outputs for all models included in the main text (Supplemental Information Table S1 & S3), as well as modeling that applies different demographic categories (Supplemental Information S2 & S4), interaction models (Supplemental Information Tables S5 & S6), and an alternative formulation of attribution alignment measures that do not substantially differ from the main results presented here (Supplemental Information Table S7 & S8). As an alternative to our extreme event attribution alignment index, we also modeled respondent alignment across all five events using binary alignment indicators (e.g., four or more align vs. three or less, three or more align vs. two or less, etc.) and observed no notable patterns in covariate estimates (Supplemental Information Table S9). Finally, because it is plausible that respondents who believe in climate change and its connection to extreme weather events will tend to report a higher level of exposure to extreme events (Howe and Leiserowitz 2013), we considered two other relationships – (1) the relationship between actual event exposure and self-reported negative extreme weather experience by US region, reported in Zanocco et al. (2022) (2) the relationship between self-reported negative extreme weather experience and political affilia-

Table 1 Summary of survey measures, description, descriptive statistics, and variables

Measure	Description	Descriptive Statistics	Comparison to selected Census Bureau 2020 American Community Survey (5 year estimates) (Census Bureau 2020)	Variable
Gender [a]	Respondent gender	Male = 53.6% Female = 46.4%	Male = 49.2% Female = 50.8%	Female (vs. male)
Age [b]	Age of the respondent in years	Mean = 49.2 Median = 49 Range = 18–92	Median = 38.2	Age (in years)
Household income	Household income of the respondent	Ranging from categories 1 = "Less than $5,000" to 18 = "$200,000 or more" Mean = 9.77 Median = 10 or "$50,000 to $59,999"	Median household income = $64,994	Income
Education	Education level of the respondent	Bachelor's degree or better = 35.5%	Bachelor's degree or better = 33.0%	Bachelor's degree (vs. no bachelor's degree)
Race/ethnicity	Race/ethnicity of the respondent	White, non-Hispanic = 64.6% Black, non-Hispanic = 11.5% Other, non-Hispanic = 1.1% Hispanic = 16.5% Two or more categories, non-Hispanic = 3.5% Asian, non-Hispanic = 2.9%	White, non-Hispanic = 60.1% Black, non-Hispanic = 12.3% Other, non-Hispanic = 1.4% Hispanic = 18.2% Two or more categories, non-Hispanic, 2.4% Asian, non-Hispanic: 5.6%	White (vs. nonwhite)
Urban/rural	A measure of urban or non-urban location of respondent	Metropolitan = 82.0% Non-metropolitan = 18.0%	Urban population = 80.7%	Non-metro area (vs. metro area)
Political affiliation	Political party affiliation of the respondent	Republican = 35.5% Democrat = 47.2% Independent / other / none = 17.3%	n/a	Republican (vs. Independent/other/none) Democrat (vs. Independent/other/none)

Table 1 (continued)

Measure	Description	Descriptive Statistics	Comparison to selected Census Bureau 2020 American Community Survey (5 year estimates) (Census Bureau 2020)	Variable
Extreme event attribution confidence	Attribution of extreme weather event to climate change	Question: "How confident are you that the increased frequency and severity of the following types of weather events can be linked to human-caused climate change?" 1= "Not at all confident" 2= "Slightly confident" 3= "Moderately confident" 4 = "Very confident" 5= "Extremely confident" Extreme heat (mean=3.05; sd=1.52); Extreme rainfall / flooding (mean=2.91; sd=1.51); Hurricanes (mean=2.86; sd=1.54); Wildfires (mean=3.26; sd=1.45); Tornadoes (mean=2.73; sd=1.53)	n/a	Extreme heat confidence Extreme rainfall / flooding attribution confidence Hurricane attribution confidence Wildfire attribution confidence Tornado attribution confidence
Extreme event negative impacts	Self-reported negative impacts from extreme weather events	Question: "How negatively impacted were you by the following extreme events in the past three years?" 1= "Not at all impacted" 2= "Slightly impacted" 3= "Moderately impacted' 4= "Very impacted" 5= "Extremely impacted" Extreme heat (m=2.48; sd=1.26); Extreme rainfall / flooding (m=1.81; sd=1.06); Hurricanes (m=1.55; sd=0.98); Wildfires (m=1.68; sd=1.11); Tornadoes (m=1.44; sd=0.91)	n/a	Extreme heat impacts Extreme rainfall / flooding impacts Hurricane impacts Wildfire impacts Tornado impacts

[a] The American Community Survey questionnaire (Census Bureau 2020) does not include sexual orientation or gender

[b] This study's survey was administered to respondents 18 years or older

Table 2 Mapping of survey response categories to scientific extreme event attribution (EEA) for all event types included in the survey

Extreme weather event types from survey	Scientific EEA sourced from National Academies of Sciences (2016)	Scientific EEA mapped to survey categories	Attribution alignment (i.e., % of respondent assessments that align with scientific EEA)
Extreme heat	High	Extremely confident OR Very confident	43.6%
Extreme rainfall / flooding	Medium	Moderately confident OR Slightly confident	34.7%
Hurricanes	Medium	Moderately confident OR Slightly confident	33.3%
Wildfire	Low	Slightly confident OR Not at all confident	30.9%
Tornadoes	Low	Slightly confident OR Not at all confident	47.7%

Extreme event attribution alignment index: median alignment = 2 events (out of 5); mean alignment percentage = 38.0%

tion – due to the partisan nature of views on climate change. While we did not find evidence of such relationships in either case, we cannot draw any definitive conclusions as the coarse spatial resolution of our data is not well-suited for testing more nuanced effects, such as the role of extreme event proximity in shaping respondent perceptions (e.g., Zanocco et al. 2018). See Zanocco et al. (2022) and Supplemental Information Table S10 for more information.

3 Results

3.1 Public extreme event attribution confidence

We first examined the public's attribution of extreme events to climate change (Fig. 1). We found that the public has the highest levels of confidence in wildfire attribution (with 47.4% reporting either very or extremely confident), followed by extreme heat (41.8%), extreme rainfall / flooding (37.2%), hurricanes (35.5%), and finally tornadoes (33.2%). Comparing this ordination of public attribution to the NASEM report, we see that there is overall good alignment between public and scientific assessments, with the greatest divergence in wildfire attribution, which was highest among the public but on the lower end of the spectrum in terms of scientific attribution. Overall, only 16.8% of respondents reported they were "Not at all confident" that climate change was increasing the frequency and severity of any of our five event types, with the remainder of respondents reporting some level of confidence in climate change attribution for at least one event type. Also to note from Fig. 1 is that across all event types, the widest variation in responses occurs for the "Not at all confident" (18.9 – 33.6%) categories while the "Slightly confident" (11.1 – 13.3%) has the least variation.

We further examined levels of confidence in attribution using respondent characteristics and self-reported negative impact from extreme weather events in regression modeling (Fig. 2). Across each event type, some patterns emerged in relationships to sociodemographic characteristics. We found that White respondents (vs. non-White) and those with bachelor's degree or higher (vs. no bachelor's degree) reported significantly higher levels ($p < 0.05$) of attribution confidence for extreme heat, extreme rainfall / flooding, and hur-

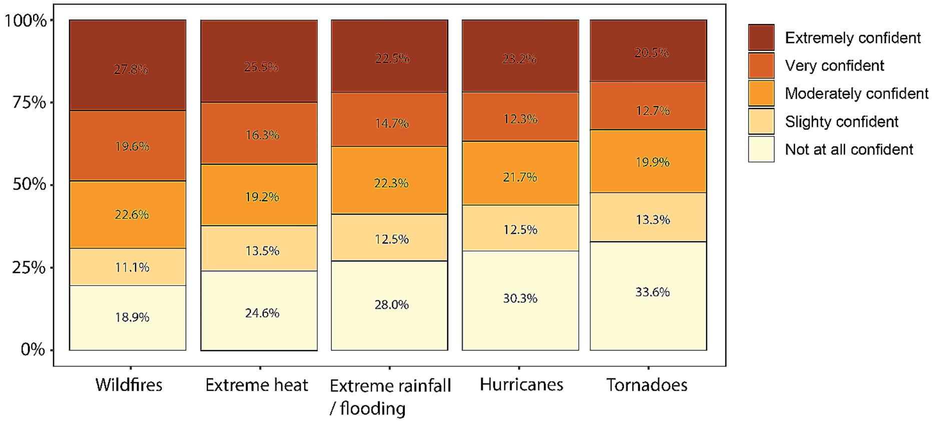

Fig. 1 Public confidence in the relationship between climate change and the increased frequency / severity of each extreme weather event type

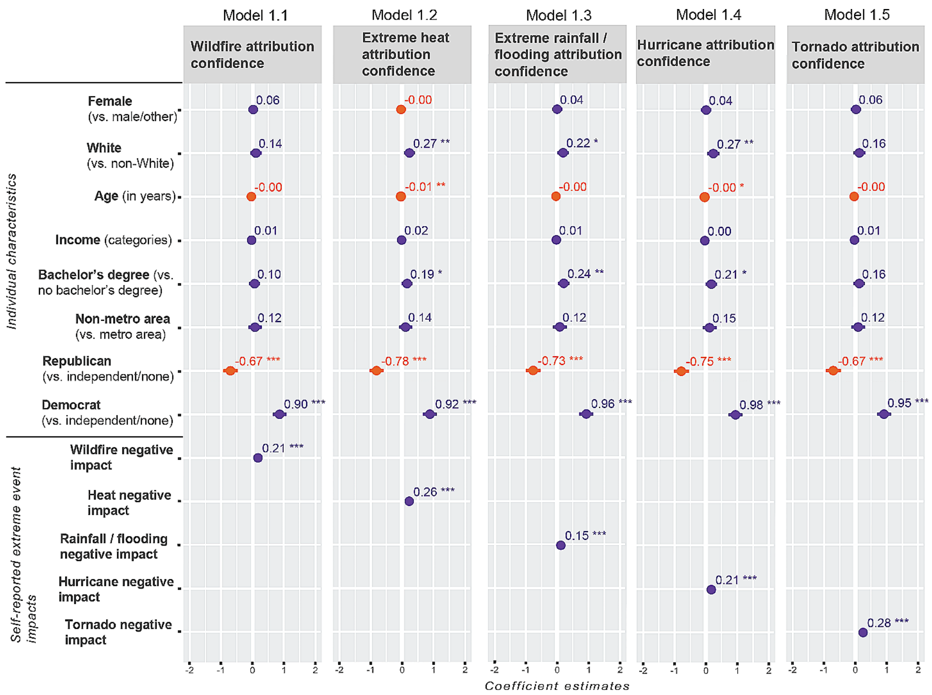

Fig. 2 Linear regression models predicting attribution confidence for event types (Model 1.1 – Model 1.5). Purple labels indicate a positive association with attribution confidence, orange a negative association. Significance levels are: *p<0.05; **p<0.01; ***p<0.001. Each model contains geographic region fixed effects but are not displayed here. Model r-squared ranges from 0.271– 0.343. See Supplemental Information Table S1 for full model outputs

ricanes. Additionally, we found those who were older had lower levels of attribution confidence for two event types: extreme heat and hurricanes. In alternative modeling efforts, we included different categorizations of race/ethnicity (Black, Hispanic, and White/Other) and found that Black respondents overall had less confidence in attributing extreme weather events to climate change, while no statistically significant differences were noted for Hispanics (Supplemental Information Table S2).

We next considered the relationship between political affiliation and event attribution. We found that Republicans were significantly less confident in attributing extreme weather to climate change for all event types ($p<0.001$), while Democrats were more confident across all event types ($p<0.001$; Model 1.1 - Model 1.5). We then examined the relationship between self-reported negative impacts from each event type, and these impacts were associated with increased attribution confidence for all event types ($p<0.001$; Model 1.1 – Model 1.5).

In additional modeling (full results presented in Supplemental Information Table S5), we tested models with interactions terms for political affiliation and extreme event negative impacts, combining Democrat and Independent/None categories for ease of comparison. We found that negative extreme event impacts had a moderating effect on political affiliation, with Republicans reporting higher levels of negative impacts also having higher levels of event attribution confidence for all event types except extreme heat. Interaction effects between political affiliation and extreme event impacts are displayed for each event type in Fig. 3.

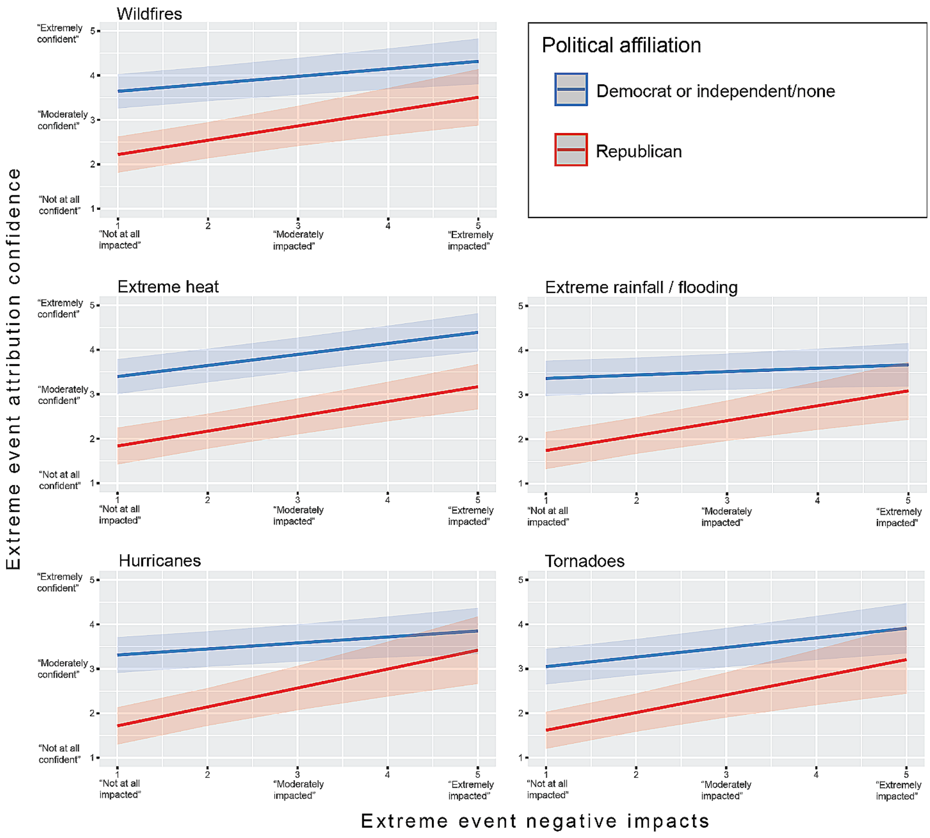

Fig. 3 Plot displaying the interaction between political affiliation and self-reported negative event impacts in predicting extreme event attribution confidence. For the model outputs used to generate this figure, see Supplemental Information Table S5

3.2 Alignment of public and scientific extreme event attribution

Comparing average respondent attribution confidence with scientific attribution confidence (NASEM 2016) reveals a generally positive relationship, albeit with wildfire as an outlier due to its high level of public attribution confidence (Fig. 4). To test this relationship more formally, we next applied our attribution alignment measure which compares respondent attribution confidence with scientific confidence (Table 2). Consistent with Figs. 1 and 4, we found the lowest attribution alignment for wildfires (30.9%). Wildfire had the highest attribution level by the public but was low in terms of scientific EEA confidence. Events falling in the middle of attribution alignment levels were hurricanes (33.3%) and extreme rainfall / flooding (34.7%), while the highest levels of attribution alignment were observed for extreme heat (43.6%) and tornadoes (47.7%). Overall, the median attribution alignment for survey respondents with scientific assessment was 2 out of 5 events, with an average alignment score of 38% across all event types.

Next, using the same covariates as in Fig. 2, we modeled attribution alignment and fit binary logistic regression models to account for the distribution of the dependent variable (0 = does not align; 1 = aligns) (Fig. 5). Compared to the previous regressions predicting confidence in event attribution (Model 1.1 – Model 1.5), far fewer sociodemographic characteristics were related to attribution alignment in our modeling (Model 2.1 – Model 2.6). Only for extreme heat (Model 2.2) were estimates for White (vs. non-White), bachelor's degree or higher (vs. no bachelor's degree), and income statistically significant and positively related to higher attribution alignment. In alternative attribution alignment modeling, we included different categorizations of race/ethnicity (Black, Hispanic, and White/Other) and found that Black and Hispanic respondents did not provide responses that were signifi-

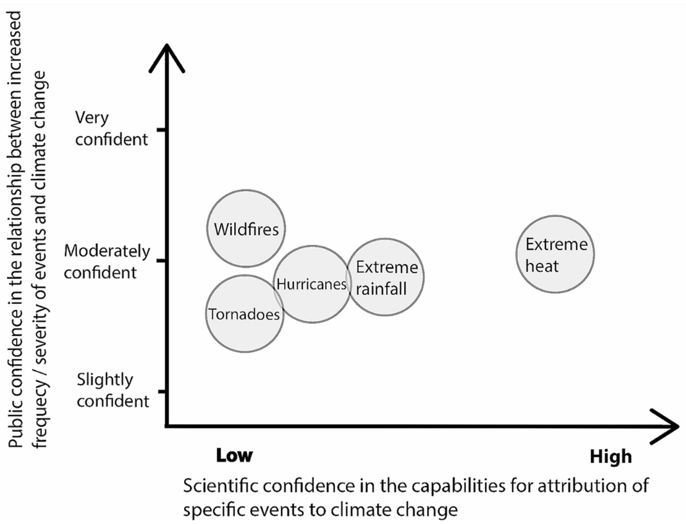

Fig. 4 Comparison of average public attribution confidence and scientific attribution confidence for selected extreme event types. Event types from our survey were assigned to the closest corresponding event types in NASEM (2016) and then were positioned using the scientific attribution confidence levels described in NASEM (2016)

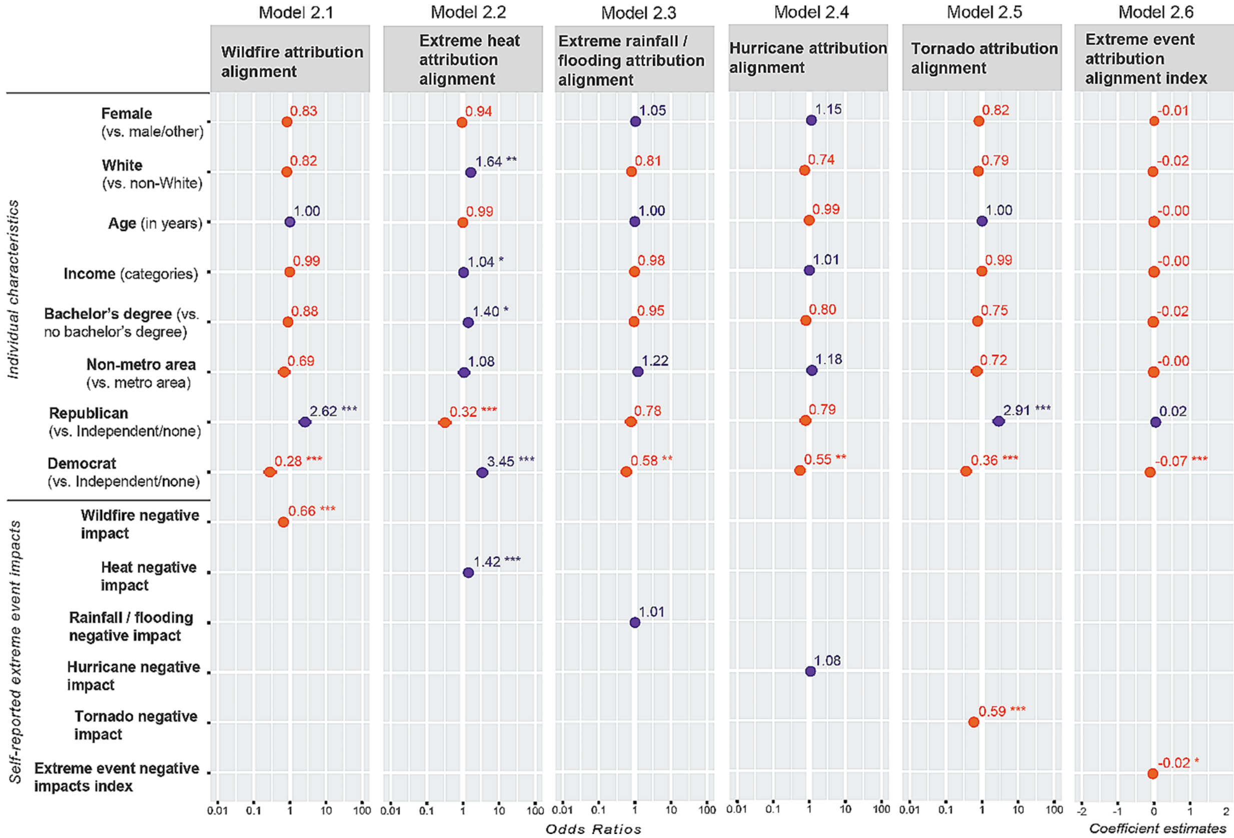

Fig. 5 Binary logistic regression models predicting attribution alignment for event types (Model 2.1– Model 2.5). Linear regression was used to model extreme event attribution alignment index (Model 2.6). Purple labels indicate a positive association with attribution alignment, orange a negative association. Significance levels are: *p<0.05; **p<0.01; ***p<0.001. Each model contains geographic region fixed effects but are not displayed here. See Supplemental Information Table S3 for full model outputs

cantly different for the attribution alignment index. See Supplemental Information Table S4 for more information.

When examining political affiliation measures for each event type, we found opposing directionality in attribution alignment. For example, Republicans had lower attribution alignment for extreme heat and higher alignment for tornado and wildfire. For Democrats the opposite was generally true, with higher levels of attribution alignment for extreme heat and lower alignment for all other event types. Similarly, when investigating the role of self-reported impacts from extreme events, we also found inconsistency in attribution alignment across event types. We found that while negative impacts from extreme heat were associated with increased attribution alignment, impacts from tornadoes and wildfires were associated with lower attribution alignment.

Lastly, when we modeled the index of attribution alignment (Model 2.6) – i.e., a respondent's average alignment across all event types – we found that White respondents, Democrats, and those who reported negative impacts from extreme events had lower overall attribution alignment. Interactions between political affiliation and extreme event negative impact index did not yield statistically significant results (Supplemental Information Table S6: Model 2.6i).

4 Discussion

We have provided a detailed picture of the U.S. public's attribution of extreme events to climate change by measuring the public's level of confidence in attribution across extreme event types, alignment of attribution confidence between the public and scientific assessments (attribution alignment), and the sociodemographic characteristics associated with attribution confidence level and alignment. We found that the public overall is relating the increased frequency / severity of extreme weather to climate change, with only 17% percent of the sample reporting "no confidence at all" for all event types. This suggests that 5 out of 6 Americans are at least making some connections between anthropogenic climate change and extreme weather event frequency / severity.

We also found that there are generally high levels of confidence in attribution among the U.S. public, especially for wildfire and extreme heat. These events are often mentioned in the context of climate change, especially in media coverage around the severity of particularly impactful, unusual, or otherwise noteworthy events (Muyskens et al. 2022; Sengupta 2023). For the public overall, we found the ranking of confidence in the connection between climate change and extreme events to be generally consistent with the ranking of events by the scientific community, albeit with some deviations. Most notably, this difference is in wildfires, where formal attribution science does not appear to be as confident in attribution as the public.

We posit two primary reasons for the disparity between public and scientific confidence in wildfire attribution. First, on the public side, wildfire produces high cognitive impact because wildfires engender memorable images of flames and destruction and have been extensively covered in the media (Flavelle and Kanno-Youngs 2021; Smith 2021), and our survey was fielded after a historic wildfire season. Moreover, some impacts of wildfire like smoke can extend thousands of kilometers beyond the event itself (e.g., smoke from fires in Alberta, Canada in June 2023 producing poor air quality in New York City). Second, on the scientific side, attribution science generally uses a specific causal framework that is inherently (but not intentionally) weaker for wildfire. NASEM (2016) assessed the confidence in wildfire attribution as low because (a) climate models have difficulty simulating wildfire, (b) physical mechanisms leading to changes in extremes because of climate change are poorly understood, and (c) the quality and length of the observational record are marginal. Wildfire behavior, even aggregated over large regions and seasons, is both nonlinear and stochastic. The total area burned, a common quantity in climate-related studies, depends on the stand-specific history of disturbance including previous fires; fuel moisture, which is influenced by the weather in the previous weeks or months; ignition sources, which include both natural and human; and weather favorable to fire spread, as well as other factors (e.g., McKenzie et al. 2004). All these factors vary spatially and throughout a season. Expecting both data and climate models to adequately represent these factors and their dependence on climate change inherently leads to low confidence in attribution.

Yet there is ample evidence for strong and direct connections between climate variations and area burned. For example, McKenzie et al. (2004), using state-level for 1916–2002, regressed log(area burned) against seasonal temperature and precipitation for 11 western US states and found significant correlations between summer temperature and annual area burned in all but CA and NV (Williams et al. 2019 later found strong connections in California). The strongest relationship was in Montana, where on average a 1 °C warmer summer was associated with 30% lower precipitation and a three-fold increase in area burned. Subsequent studies (e.g., Jones et al. 2022; McKenzie and Littell 2017) found even stronger climate-fire relationships for ecoregions, and (Abatzoglou and Williams 2016) estimated that a warming climate doubled the area burned in the western US between 1984 and 2015. Seneviratne et al. (2021) assessed a 'medium' level of confidence in attribution of *fire weather*. Thus, stepping outside NASEM's formal attribution framework, strong statistical relationships between climate and area burned offer scientific support to public perception.

When examining factors related to public attribution confidence, we found that some sociodemographic characteristics were related, namely education level, race/ethnicity, and age. However, sociodemographic factors were not as consistent in effects compared to political affiliation or measures of self-reported negative impacts from extreme weather. Similar to other polling about climate change perspectives, we found that Republicans had lower levels of attribution confidence, while Democrats had higher confidence (Leppert 2022). We also found that self-reported negative impacts from the event were related to higher levels of attribution for all event types. This suggests that negative impacts from extreme events can play a strong role in the public connecting the frequency and severity of an event type to climate change. Negative event impacts even had a moderating effect on political affiliation, where Republicans with higher impacts also had higher levels of attribution confidence, similar to research that found that extreme weather harm moderated the effect of political ideology on climate change mitigation policy support (Zanocco et al. 2019).

Attribution alignment was not as well predicted by respondent characteristics. In some cases, we found opposing directionality across event types. The most consistent factors were political, with Democrats having on average lower levels of attribution alignment with scientific assessments. Republicans appear to be more hesitant to connect certain types of events to climate change, such as tornadoes, while Democrats seem more willing to associate extreme events with climate change. This public misalignment with attribution science could have multiple, potentially diverging explanations. It could be that the public's lived experiences with extreme events are reflecting changes that are not yet well captured by attribution science *or* that the public is attributing events too readily to climate change when other explanations (e.g., increased development in the wildland-urban interface) deserve attention. Yet another explanation is that some of the same reasons that make scientific attribution more complex for certain event types, such as wildfires, could apply to public attribution. For example, the public could be making conjunctive attributions, or attributing multiple factors or causes to extreme events, not just climate change (McClure et al. 2022). Our research design does not allow us to assess to what degree, if any, the public is making single- or multi-cause attributions for certain event types, which presents an important area for future research.

While extreme event attribution to climate change among members of the U.S. public may increase support for climate-related policy action, 'over' attribution of events to climate change could prove problematic. Some scholars, for example, have argued that attributing extreme weather events mostly to climate change could lead policymakers and communities to ignore other factors contributing to disasters that deserve societal and political attention (e.g., forest management, poorly planned urbanization, social injustices that leave vulnerable communities at risk, inadequate investment in flood prevention). Moreover, policy changes related to these factors – as opposed to climate mitigation – may result in faster and more equitable fixes (Lahsen and Ribot 2022; Pearce 2022; Raju et al. 2022). Thus, we believe our study also has important implications for climate change communication. We show that the U.S. public is already making distinctions in attribution by event type and our work can allow science communicators to better account for these distinctions – and even correct misperceptions – when discussing climate change and extreme weather issues.

Due to design considerations, we only asked participants about a limited number of extreme events categories and had to combine or exclude some extreme event types. Relatedly, we chose to combine frequency and severity in the question stem, rather than ask about each separately for each event type, with the reasoning that repetition of very similar question wording would be tedious for respondents and could result in less thoughtful responses overall. However, this combination later led to challenges in directly matching responses from the survey to the scientific attribution literature which often views these as related but not identical. Another challenge is in the quantification of confidence and mapping of confidence from the survey responses to scientific EEA. While we demonstrated that our overall results were not highly sensitive to some of these category mapping choices (see Supplemental Information Table S7 & S8), we acknowledge that this is a source of uncertainty that cannot be completely overcome. Finally, our survey was conducted around the time of a historic wildfire season in Fall 2021 (Flavelle and Kanno-Youngs 2021), and the timing of this survey could have resulted in bias, potentially towards those events that were more temporally proximal, such as heatwaves and wildfires.

Future research could incorporate several additional design components to tease out more nuanced effects, perhaps most effectively applied to fewer extreme event types than what we included in our current study. First, while we asked about respondents' confidence in increased frequency *and* severity of the event, separating these two dimensions would provide additional insights into what, if any, distinctions are being made. Moreover, prior to asking about climate change attribution, respondents could first be asked if they thought events had increased in frequency or severity and then be offered multiple attribution factors (i.e., management decisions, emergency response, etc.) to choose from alongside climate change. This approach could more precisely identify respondent level of attribution to climate change (Shepherd 2016) by unpacking the role of event frequency and severity as well as other attribution sources potentially independent of, or combined with, climate change attribution. Our research relied on self-reported experiences with extreme weather events, and future research could consider how objective experience measured at a high spatial resolution, like exposure to hot dry days, may also influence attribution (Marlon et al. 2021). Qualitative approaches or computer-assisted text analysis strategies could be used to explore media narratives around the connection between climate change and extreme weather (Giordono et al. 2020), as well as the mental models members of the public are creating around this relationship (Stern and Raimi 2015; Wong-Parodi and Bruine de Bruin 2017). Furthermore, future research could test if a focus on extreme events that are more scientifically attributable to climate change and related to fewer other factors, such as heat events, could be more effective for communicating with skeptical audiences. Finally, our findings are not applicable outside the U.S., so another area for future research would be to conduct a similar survey study in different countries and contexts. This would enable comparisons to the U.S. public and establish similarities and differences in scientific alignment and the relationship to extreme weather event experience.

5 Conclusion

The overall willingness of a wide majority of our respondents to acknowledge some role of climate change in increased frequency / severity of extreme weather events, and that their self-reported negative impacts from events were related to this attribution level, suggests that people who report more negative event impacts are more likely to make connections between such events and climate change. Research has suggested that extreme event attribution is a critical link in bridging extreme event experience with climate mitigation policy support (Ogunbode et al. 2019). However, these attributions can also be problematic if they surpass event attribution science and allow policymakers to ignore other relevant factors contributing to disasters. The public's differentiation in level of climate attribution across event types also implies that connections to policy preferences could be more nuanced and requires further study. Our research argues that specific extreme weather event types and their impacts are important factors to consider and should be included in future research designs, perhaps alongside, or in replacement of, other questions that ask about extreme weather event attribution more generally. We think this event type focus is particularly important as it stays closer to scientific assessments – and allows for opportunities to engage and teach the public about the impacts of climate change in a more complex, and ultimately more accurate, way.

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Data availability De-identified versions of the data will be made available upon request from the authors.

Code availability Not applicable.

Declarations

Ethics approval This study was reviewed by the Oregon State University Human Research Protection Program (IRB-2019-0137) and received an exempt determination.

Conflicts of interest The authors declare no competing interests or conflicts of interest.

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