Public Understanding of Climate Science, Extreme Weather and Climate Attribution

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Rachel L. Dryden Steratore
B.S., Environmental Sciences, Park University
M.Sc., Geography, McGill University

Carnegie Mellon University
Pittsburgh, PA

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Abstract

Experts in the geophysics community have understood the role of greenhouse gases in shaping the earth's climate for over a century and have grown increasingly confident and concerned about the risks of climate change. Studies conducted since the early 1990s have observed several changes in public understanding of the causes and consequences of climate change. The aim of this thesis is to explore public understanding and perceptions of various aspects of climate science, climate change, and its impacts. This work provides an update on the climate change perceptions literature, identifying new and persistent knowledge gaps, as well as characterizing the belief-driven undercurrent that consistently predicts support for immediate climate action across my studies.

In Chapter 2, I employ a local mail-out survey and a national online survey to explore the extent to which people understand the important differences between common air pollution and carbon dioxide (CO_2). This work focuses especially on the very different atmospheric residence times of both—and what drives public support to abate climate change now. I find that people do not understand this fundamental difference, dramatically underestimate how long CO_2 remains in the atmosphere and continues to change the climate, and the policy implications of long-lived CO_2 in the atmosphere. However, this misunderstanding does not deter respondents from showing strong support for immediate climate action.

While Chapter 2 focuses on drivers of climate change, in Chapter 3, I evaluate public perceptions of one of the most salient impacts of climate change: an increase in the frequency of extreme weather. In a two-part study comprised of a convenience sample of face-to-face interviews followed by a national study, I assess when, and to what extent, laypeople attribute extreme events to climate change and whether and how their beliefs are predictive of their decision thresholds, sensitivities, and support for immediate climate action using signal detection theory. I find that prior climate change beliefs are significant drivers that influence how people make decisions in attributing extreme events to climate change and in their self-reported support for immediate action in response to climate risks. I also find that simple spinner boards are effective tools in communicating non-stationary processes, such as attribution, to laypeople.

In Chapter 4, I focus on public perceptions of what can be done on the part of individuals to reduce CO_2 emissions and how laypeople view the efficacy of individual versus collective actions in a two-part study, starting with a convenience sample of face-to-face interviews and followed by a national study. I find that respondents believe that individuals have higher response-efficacy than what is likely to be attainable from individual actions alone, i.e. apart from any broader societal or governmental action. However, respondents view individual and governmental actions as having the same response-efficacy.

Finally, Chapter 5 discusses this work's contribution to the literature and the implications for the development of risk communications revealed in Chapters 2 through 4. Findings in all chapters show strong support for immediate action against climate risks. Climate change beliefs are significant predictors for decision thresholds and sensitivities in identifying hurricane frequencies as evidence of climate change (Chapter 2) and for support for immediate climate action across my studies (Chapters 2 and 3). These, and other findings reported in the thesis, can inform—and offer opportunities for—the development of improved risk communications, as well as alternative decision-making strategies when it comes to long-term risks and educational interventions.

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Glossary of Acronyms

AC	Allegheny County
AP	Air Pollution
AUC	Area Under the Curve
CO_2	Carbon Dioxide
EPA	Environmental Protection Agency
IPCC	Intergovernmental Panel on Climate Change
IPCC AR5	Intergovernmental Panel on Climate Change Fifth Assessment Report
KMO	Kaiser-Meyer-Olkin (measure of sampling adequacy)
MTurk	(Amazon) Mechanical Turk
NAS	National Academy of Sciences
PA	Pennsylvania
PCA	Principal component analysis
pdf	Probability density function
PEA	Probabilistic Event Attribution
POR	Period-of-record
RAER	Reasonably achievable emissions reduction
ROC	Receiver Operating Characteristic (curve)
SDT	Signal Detection Theory
U.S.	United States
VIF	Variance inflation factor

Table of Variables

Label	Variable	Appearance in Thesis
c	Decision Threshold Criterion	Chapter 3
FAR	False-Alarm Rate	Chapter 3
HR	Hit Rate	Chapter 3

1. Introduction

Burning coal, oil, and natural gas adds carbon dioxide (CO_2) to the atmosphere. When CO_2 is released as a byproduct of energy production and other human activity, some of it is absorbed by the oceans or is taken up by plants, but much of what is left stays in the atmosphere for hundreds of years, since there are no other natural processes that quickly remove it.[1] Indeed, some of the CO_2 in the atmosphere today is the result of burning coal in British factories during the Industrial Revolution. Over the past several centuries, global emissions have continued to increase—driven by population growth, technological advancement, and economic growth—particularly in industrialized countries.[2] With those increased emissions, atmospheric concentrations of CO_2 have continued to rise.[3-5]

As a greenhouse gas, CO_2 warms the planet, which causes the climate to change. Experts in the geophysics community have understood the role of greenhouse gases, like CO_2, in shaping the earth's climate for over a century[6,7] and have increasingly warned about the risks of anthropogenic forcing.

Studies conducted since the early 1990s have observed a number of changes in public understanding of the causes and consequences of climate change.[8-10] While Americans' knowledge of climate change has improved somewhat over the years,[8] gaps still exist in that understanding with respect to causes, consequences, and the most effective solutions.[11] Many Americans do understand that burning fossil fuels causes the climate to change,[8] and that a transition to renewable energy and other forms of low-emission technology is one of the important solutions.[11] Misunderstandings of the causes of climate change, however, can lead to support for ineffective or counterproductive solutions, such as ending the use of nuclear power or minimizing the use of aerosol spray cans.

Responding to climate change requires people—particularly those living in industrialized countries—to take both collective and individual responsibility for addressing the problem.[2] Individuals have two important roles in the effective management of greenhouse gas emissions to mitigate climate change: (1) support emissions abatement legislation and regulations, and (2) change lifestyles and consumer behavior to reduce one's own carbon footprint.[12] While knowledge regarding the causes of climate change alone do not necessarily lead to changes in behavior,[12] such changes are an important part of tracking and predicting public support in addressing climate risks.[13-15]

The aim of this thesis is to explore public understanding and perceptions of various aspects of climate science, climate change, and its impacts. This work updates the climate change perceptions literature, identifies an important, new gap in public understanding with respect to the atmospheric residence time of CO_2, and characterizes consistent beliefs that predict policy support and intention to act across my studies.

Thesis organization

This thesis includes findings from three main studies that I conducted with an overarching aim to explore public understanding and perceptions of various aspects of climate science, climate change, and its impacts. In Chapter 2, I employ a local and national survey to evaluate whether, and to what extent, people treat long-lived CO_2 the same as common air pollutants and how this is associated with their support for action in response to climate change. Chapter 3 details findings from two studies evaluating when, and to what extent, laypeople attribute extreme events to climate change, whether they understand non-stationary processes with the aid of simple spinner boards, and how their beliefs influence their intentions to act. Here, I begin with a set of interviews to inform a larger national study using signal detection theory. In Chapter 4, I evaluate public perceptions of what can be done on the part of individuals to reduce CO_2 emissions and how these actions are viewed compared to broader, societal action. Finally, Chapter 5 summarizes these studies and discusses their contributions to the literature on climate change perceptions and attribution, as well as their implications for the development of risk communications, alternative decision strategies for long-term risk, and educational interventions.

2.[1] Public perceptions of how long air pollution and carbon dioxide remain in the atmosphere

Abstract

The atmospheric residence time of carbon dioxide is hundreds of years, many orders of magnitude longer than that of common air pollution, which is typically hours to a few days. However, randomly selected respondents in a mail survey in Allegheny County, Pennsylvania (PA; N = 119) and in a national survey conducted with Amazon Mechanical Turk (MTurk; N = 1,013) judged the two to be identical (in decades), considerably overestimating the residence time of air pollution and drastically underestimating that of carbon dioxide. Moreover, while many respondents believe that action is needed today to avoid climate change (regardless of cause), roughly a quarter hold the view that if climate change is real and serious, we will be able to stop it in the future when it happens, just as we did with common air pollution. In addition to assessing respondents' understanding of how long carbon dioxide and common air pollution stay in the atmosphere, I also explore the extent to which people correctly identify causes of climate change and how their beliefs affect support for action. With climate change at the forefront of politics and mainstream media, informing discussions of policy is increasingly important. Confusion about the causes and consequences of climate change, and especially about carbon dioxide's long atmospheric residence time, could have profound implications for sustained support of policies to achieve reductions in carbon dioxide emissions and other greenhouse gases.

2.1 Introduction

Experts in the geophysics community have understood the role of greenhouse gases in shaping the earth's climate for over a century.(6,7) In the latter half of the 20th century, scientists grew increasingly confident and concerned about the risks of climate change.(16) Despite scientific consensus on the need to dramatically reduce greenhouse gas emissions now, political discourse and media coverage have grown ever more confusing and contentious.(17) This may be attributed, at least in part, to intentional efforts to keep people confused.(18)

Studies conducted since the early 1990s have observed a number of changes in public understanding of the causes of climate change. (8-10,19) Other studies have explored how perceptions of climate change are related to knowledge, cultural, and political orientation, among other factors.(11,13,20-32) While most Americans believe that climate change is real, they do not

[1] A version of this chapter has been published as Dryden, R., Morgan, M.G., Bostrom, A. and Bruine de Bruin, W., 2018. Public perceptions of how long air pollution and carbon dioxide remain in the atmosphere. *Risk Analysis*, *38*(3), pp.525-534.

fully understand its causes. Past communication efforts have been developed to address many of these misconceptions and to promote a more complete scientific understanding. [33-35]

In my view, public understanding of two facts is an essential ingredient to informed public discourse about climate change:

1. The primary cause of climate change is carbon dioxide that is added to the atmosphere when coal, oil and natural gas are burned; and,
2. Unlike conventional air pollutants—defined here as pollutants like smog, oxides of sulfur and nitrogen, organic gases, and fine particles—which remain in the atmosphere for only a few hours or days, once carbon dioxide enters the atmosphere, much of it remains there for hundreds of years.

Although the literature on public understanding demonstrates that considerable progress has been made on the first of these points,[8] the literature on public understanding is largely silent on the second. One study that did found that a third of Americans thought ceasing carbon dioxide emissions would cause an immediate decrease in carbon dioxide concentrations in the atmosphere; and when asked, "On average, how long does carbon dioxide stay in the atmosphere once it has been emitted?" two thirds responded that they did not know.[11] Another study found that people who hold a pollution mental model often blame environmental harms, like air pollution from toxic chemicals, for changes in the climate.[13] As a result, people may falsely conclude that if climate change is real and gets serious enough, it can be fixed relatively quickly by cutting emissions, just as was done with air pollution.

Once it enters the atmosphere, air pollution is quickly removed by a number of natural processes.[36] This is not true for carbon dioxide. When carbon dioxide is added to the atmosphere, some of it is absorbed by the oceans or is taken up by plants, but much of what is left stays in the atmosphere for hundreds of years, since there are no other natural processes that quickly remove it.[1] Indeed, some of the carbon dioxide in the atmosphere today is the result of burning coal in British factories during the Industrial Revolution.

To the extent that there is public confusion about the difference between common air pollution and carbon dioxide (as well as other long-lived greenhouse gases), it may be exacerbated by advocates and policy makers who refer to carbon dioxide as "pollution"—perhaps to gain initial momentum toward combatting climate change. For example, the United States' Supreme Court ruled that the Environmental Protection Agency (EPA) has authority to regulate emissions of carbon dioxide as an "air pollutant" under the Clean Air Act.[37,38] More recently, the Obama Administration's Clean Power Plan leveraged support for reducing carbon dioxide emissions by presenting it as an air pollutant.[2]

In this thesis chapter, I explore the extent to which Americans understand the fundamental difference in atmospheric residence time between common air pollutants and carbon dioxide. I also examine beliefs about causes of climate change and how these views influence willingness to act against climate change. I ask:

1. To what extent do people understand the difference in atmospheric residence times between common air pollution and carbon dioxide, as well as the sources of each?
2. To what extent do people correctly identify causes of climate change?
3. To what extent do these beliefs affect people's support to take action against future serious changes in the climate?

2.2 Method

2.2.1 Survey procedure

I administered a mail survey (with an optional online version) in Allegheny County, PA, and a national online survey with Mechanical Turk (MTurk).[39] I extend the efforts of previous research that have documented public understanding of climate change and its surrounding issues in Pittsburgh, PA.[8-10] Two parallel questions were included in a related national survey, for comparison. I employed a mail survey, because many people do not have easy access to the Internet. For example, almost one million PA residents lack Internet entirely.[40] Even if they have access, many elderly people, and people who are very busy, do not participate in online surveys.[41] Rookey and co-authors[42] report that mail studies may "improve the overall accuracy of survey results." The mail survey did include instructions on how to complete the same survey online, if desired (but none of the PA participants chose this response method).

2.2.1.1 Mail survey

The mail survey covered five topics: 1) source and atmospheric residence time of common air pollution (3 items); 2) source and atmospheric residence time of carbon dioxide (4 items); 3)

[2] In 2018, the Clean Power Plan was replaced with the Affordable Clean Energy rule by the Trump Administration. The Affordable Clean Energy rule eliminates target reductions put in place by the Clean Power Plan and gives states the authority to decide how much to cut emissions from power plants absent a national target.

basic facts about electricity production in the United States (6 items); and 5) causes of and responsibility for climate change and what, if anything, can and ought to be done about it (11 items). A number of the questions adopted wording from previous studies on public understanding of climate change.[8-10] Other questions were pre-tested in a small study using randomly distributed mail-back postcards.

The order of questions about air pollution and carbon dioxide was reversed in half of the mail surveys. No order effects were found ($p > .05$). Demographic questions (educational attainment, income, age, gender, political affiliation, and religion) were placed at the end of the survey so as to not influence responses.

The section on "common air pollution" began by defining the term as, "pollutants like smog, oxides of sulfur and nitrogen, organic gases and fine particles." It asked respondents to rank order (1-4) four sources of common air pollution in their region in terms of their "best guess of how much each contributes to air pollution in the region where you live:" 1) all kinds of industry and factories; 2) power plants making electricity; 3) residential and commercial sources (for example, furnaces and water heaters in homes, stores and office buildings); and 4) all kinds of transportation (airplanes, cars, trains, trucks, ships, etc.). Subsequent questions asked if less than a few percent of common air pollution here in the United States comes from thousands of miles away (answered on a 5-point, degree of belief scale comprising "true," "probably true," "don't know," "probably false," and "false"; abbreviated T, ~T, ?, ~F, and F in subsequent sections).

A "don't know" option was included to cue participants that having no information is an acceptable response.[43] The final question about common air pollution read: "Imagine that the world's modern factories, transportation and power plants all stopped emitting **common air pollution** now. How long would it take for the amount of pollution in the air to fall back to what it was before those modern factories, transportation and power plants existed?" Respondents answered using a 6-point scale, ranging from "hours to days" to "never."

Questions about carbon dioxide followed a parallel structure. Participants were first asked to assign 100 points across five sources to estimate "where the carbon dioxide (CO_2) the United States puts in the atmosphere comes from." They were then asked to rank order (1-4) the relative emissions from four regions (China; the European Union; India; and the United States), followed by the same question about contributions to the concentration of CO_2 in the United States coming from other countries. The section concluded with wording that was identical to the air pollution question: "Imagine that the world's modern factories, transportation and power plants all stopped emitting **carbon dioxide** (CO_2) today. How long would it take for the amount of carbon dioxide (CO_2) in the air to fall back to what it was before those modern factories, transportation and power plants existed?"

Respondents in the mail survey answered questions about causes of climate change, including nuclear power and aerosol spray cans (both of which are <u>not</u> significant causes of climate change). These questions read: "Nuclear power is a significant cause of climate change;" and "Using aerosol spray cans today is a significant cause of climate change." Respondents answered on a 5-point, degree of belief scale (T, ~T, ?, ~F, and F).

Respondents in the mail survey answered a series of additional questions about electricity and climate change on 5-point degree-of-agreement or true-false scales. A full copy of the mail survey instrument is available in the Appendix of this chapter (Appendix A.1).

2.2.1.2 Online survey

Using the same wording, the two questions about the atmospheric lifetime of common air pollution and of carbon dioxide were included in a study conducted using MTurk. Parallel questions for nuclear power and aerosol spray cans were also included in the MTurk survey (Appendix A.2). The Results section reports on the mail survey and the online survey when analyzing these questions (*2.3.1* and 2.3.2.2). The remaining analyses focus on the mail survey only unless noted otherwise.

2.2.2 Respondents

The mail-based study in this thesis chapter targeted members of the general public in the Greater Pittsburgh Area. I obtained a list of all addresses by zip code across Allegheny County, PA, and randomly selected 400 households, including two from each zip code, to comprise this convenience sample. Postcards were mailed to all selected households to notify residents that they had been randomly selected to participate in a survey conducted by Carnegie Mellon University. The aim was to increase the response rate, which is generally lower for mail-out surveys compared to other recruitment methods.[44] A few days after the post card was sent, survey packages were mailed. These included a $2 financial incentive for completing the survey and a pre-paid, pre-addressed envelope to mail back the response. Because responses were returned without identifiers, they were completely anonymous, and I have no information on those who did not respond. One hundred and nineteen responses were received from the mail survey (response rate of 30%).

Fifty-five percent of the sample from Allegheny County (AC) are female, compared to 52% of the AC population that is female. Ages in this sample range from 18 to 93, and the mean age (56 ± 17) was statistically higher than Allegheny County's mean age of 41. Mail survey respondents were well educated compared to the U.S. population: 96% had finished high school [U.S. = 88%], 44% had completed college [$U.S._{some}$ = 59%; $U.S._{all}$ = 33%], and 21% had completed graduate training [U.S. = 12%]. Fifty-five percent of the mail survey respondents were Democrats [AC = 60%]; 28% Republicans [AC = 27%]; and 17% Independent or other [AC = 13%]. The results from the mail-based study are biased toward older, educated Democrats.

The national MTurk study in this thesis chapter represents a convenience sample of 1,013 respondents. Forty-nine percent of the sample from MTurk are female, compared to 51% of the U.S. population that is female. The mean age for the MTurk sample was 36.6, compared to 36.8 for the U.S. population. Forty-six percent of MTurk respondents were Democrats, [U.S. = 47%]; 19% Republicans [U.S. = 41%]; and 35% Independent or other [U.S. = 12%]. The results from the MTurk study are biased toward those who self-identify as Independents or other.

The mail-based, local study had a higher composition of female, older, and Democrat respondents compared to the national MTurk study.

2.3 Results

2.3.1 To what extent do people understand the difference in atmospheric residence times between common air pollution and carbon dioxide, as well as the sources of each?

Our primary objective was to assess whether people understand the different atmospheric residence times of common air pollution and carbon dioxide. The analyses suggest that they do not. Figure 1 provides a histogram of how long respondents believed it would take for common air pollutants to disappear in the atmosphere once all emissions stop and how long it would take for carbon dioxide to disappear from the atmosphere once all emissions stop. For each time interval, the two dark bars on the left are the results for air pollution, and the two light bars on the right are for carbon dioxide. The solid bars are results from the Allegheny County, PA mail survey; air pollution is the dark solid bar, and carbon dioxide is clear. The pattern and magnitude of average Allegheny County responses showed no statistically significant difference between common air pollution and carbon dioxide (paired *t*-test, $t = 0.25$, $df = 116$, $p = 0.80$, 95% *CI* [-0.12, 0.15]).[3] The two stippled bars in each time interval are the analogous results for the MTurk study (paired *t*-test, $t = -0.97$, $df = 1{,}012$, $p = 0.34$, 95% *CI* [-0.07, 0.02]).[3]

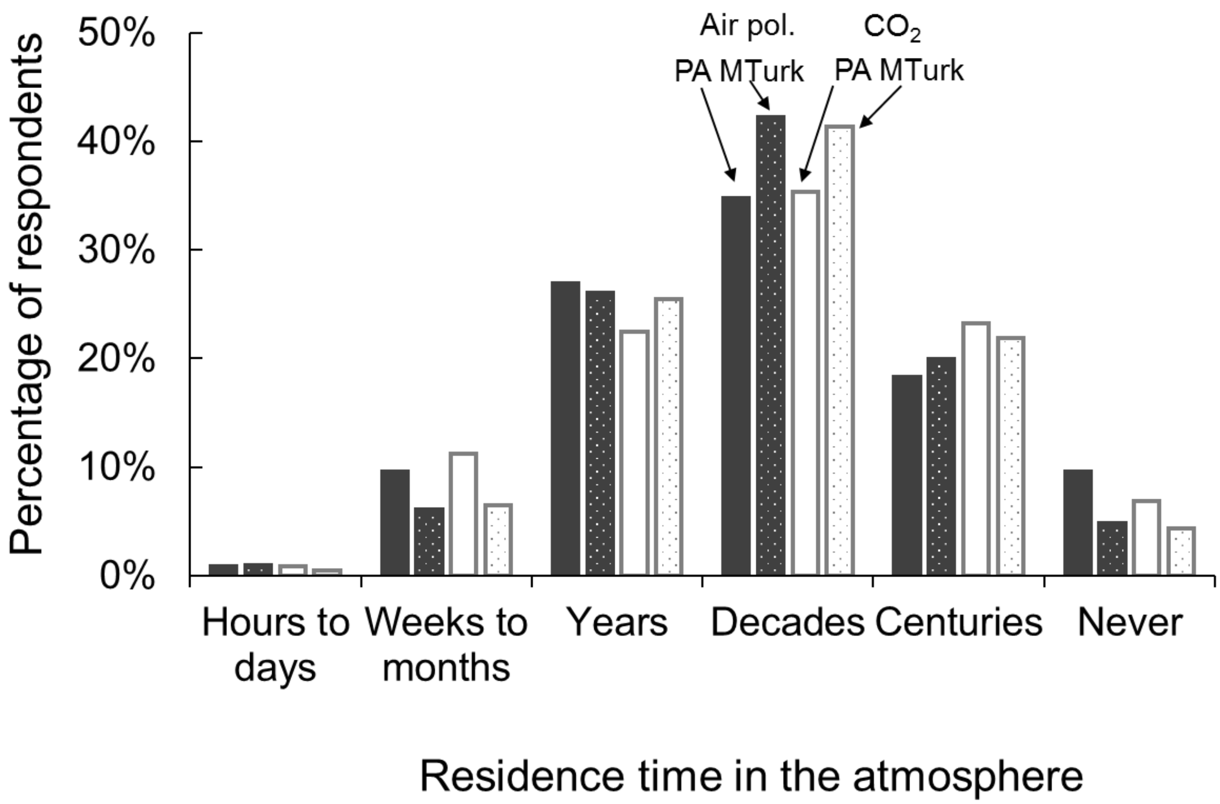

Figure 1: Histogram of responses to the parallel questions, "Imagine that the world's modern factories, transportation and power plants all stopped emitting [**common air pollution/carbon dioxide**] today. How long would it take for the amount of [**common air pollution/carbon dioxide**] in the air to fall back to what it was before those modern factories, transportation and power plants existed?" For each time interval, the two dark bars on the left are results for air pollution, leftmost from the Allegheny County, PA mail survey ($N = 116$), and the adjacent stippled dark bar is the analogous result for the MTurk study ($N = 1{,}013$). For each time interval, the two lighter bars on the right are results for CO_2, the left from the Allegheny County, PA mail survey, and the adjacent stippled light bar is the analogous result for the MTurk study. The pattern and magnitude of average responses shows no statistically significant difference.

[3] Wilcoxon Signed-Ranks Test was also conducted and yielded the same result ($Z = -0.22$, $p = 0.83$ for the Allegheny County survey; $Z = 0.97$, $p = 0.33$ for the MTurk survey).

These results indicate that, on average, respondents did not differentiate between the atmospheric residence time of common air pollutants—which is typically hours to a few days—and the residence time of carbon dioxide—much of which remains in the atmosphere for centuries. Further, Figure 2 shows that, on a respondent-by-respondent basis, more than 70% of respondents believed that there was no difference in atmospheric residence time for common air pollution and carbon dioxide. The mean, median, and modal perceived atmospheric residence time for both is in decades.

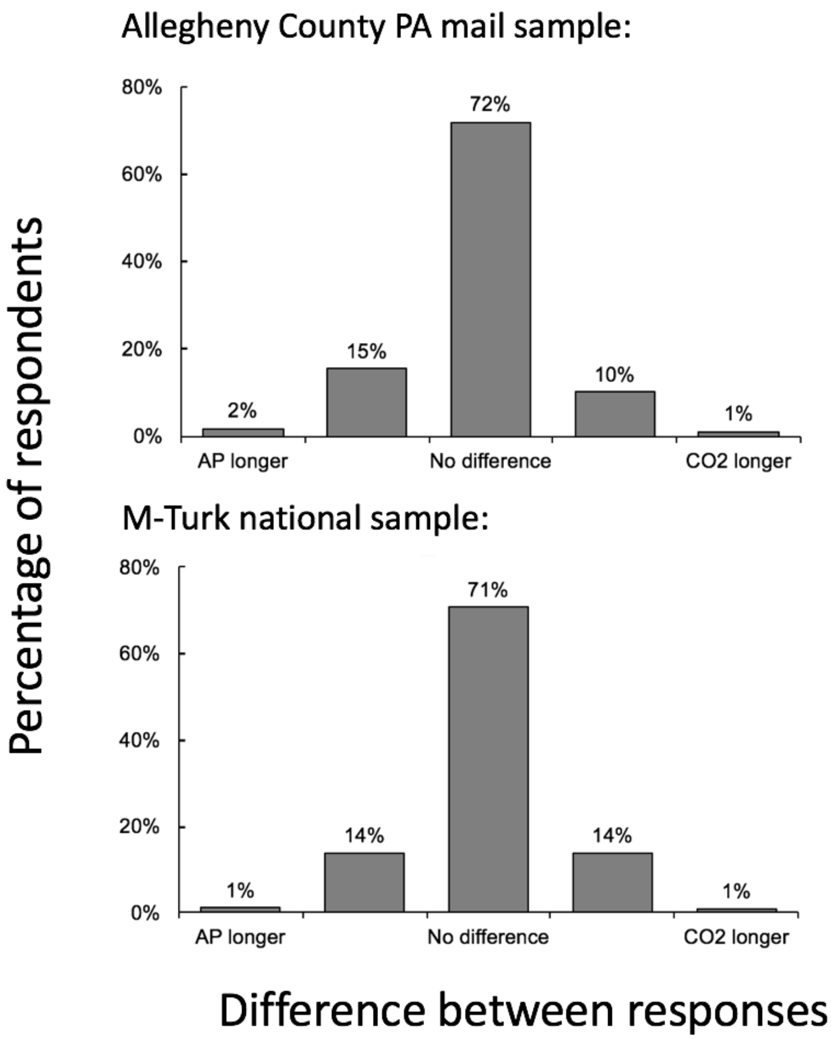

Figure 2: Respondent-by-respondent distribution of difference in atmospheric residence time between common air pollution and carbon dioxide. Results for the mail survey in Allegheny County, PA are above (N = 119) and the National MTurk study are below (N = 1,013). Total percentage for MTurk is greater than 100% due to rounding. Most respondents in both studies report no significant difference.

In the mail survey, I also asked respondents to assess the geographic source of common air pollution and carbon dioxide (i.e., whether the majority of **common air pollution/carbon dioxide** here in the United States comes from places that are thousands of miles of away). The results, summarized in Figure 3, showed no statistically significant difference between responses for common air pollution and carbon dioxide (paired *t*-test, $t = 0.98$, $df = 117$, $p = 0.33$, 95% *CI* [-0.10, 0.31]).[4] The results do not allow me to make statements about what fraction of common air pollution in the United States respondents believed originates abroad, only that over half believed that fraction to be more than a few percent.

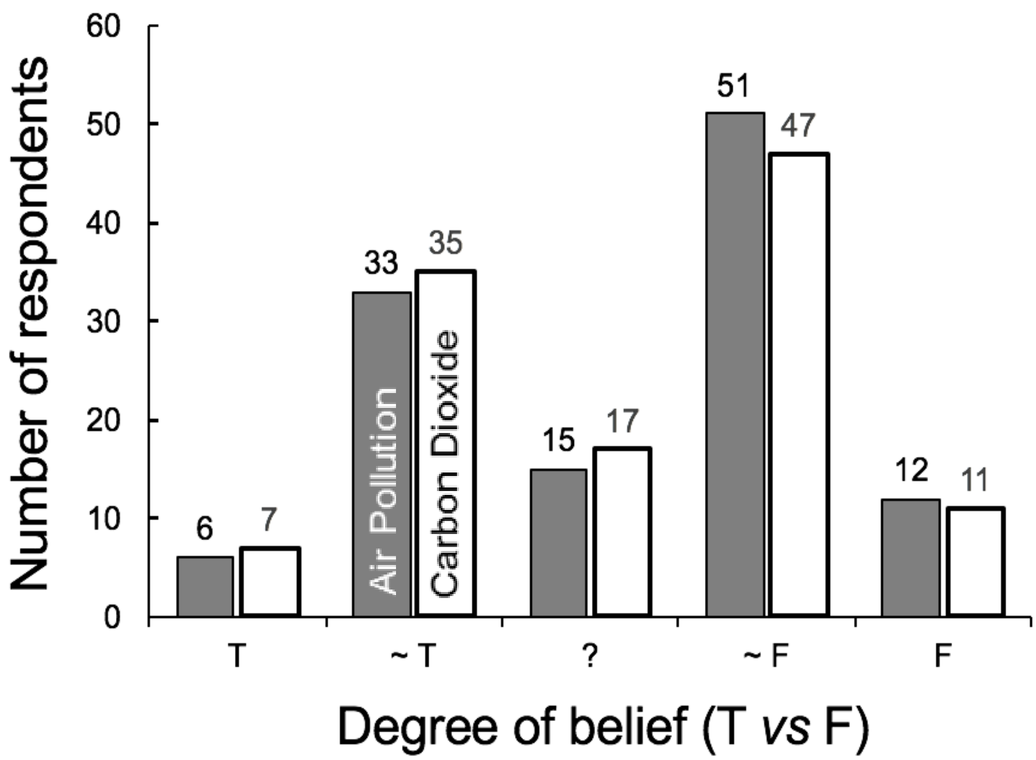

Figure 3: Distribution of responses in the Allegheny County, PA mail survey to the statement that, "Less than a few percent of **the common air pollution/carbon dioxide** that is in the atmosphere here in the United States has come from places that are thousands of miles away." Solid bars on the left are air pollution; open bars on the right are carbon dioxide. The y-axis shows the frequency for each response category. The x-axis represents degree of belief comprising "true," "probably true," "don't know," "probably false," and "false" from left to right (abbreviated T, ~T, ?, ~F, and F).

[4] Wilcoxon Signed-Ranks Test was also conducted and yielded the same result ($Z = -0.96$, $p = 0.34$).

2.3.2 To what extent do people correctly identify causes of climate change?

2.3.2.1 Natural vs Human-Caused climate change

A key research question is whether people can identify important causal agents of climate change. Two groups emerged in the survey results: (1) those who believed that climate change is mainly natural (37%), and (2) those who believed that climate change is mainly caused by human activity (63%). More than one-third of respondents incorrectly cited natural causes as primary drivers of recent changes in the climate.

2.3.2.2 Nuclear power and aerosol spray cans

Beliefs that nuclear power and beliefs that aerosol spray cans are significant causes of climate change were positively correlated (Spearman's $\rho = 0.41$; $p < 0.01$; also see Bostrom *et al*, 2012). Fifty-six percent of respondents either did not know or incorrectly believed that nuclear power is a significant cause of climate change; 60% did not know or incorrectly believed that aerosol spray cans are a significant cause of climate change.

The distributions of responses for nuclear power are more similar across natural versus human-causation beliefs than the distributions of responses for aerosol spray cans (Table 1). Of the 41 respondents who believed that climate change is mainly natural, 27% correctly judged as false, the statement that nuclear power is a significant cause of climate change. Fifty-six percent did not know or incorrectly believed that nuclear power is a significant cause of climate change.

A smaller proportion—44%—did not know or incorrectly believed that aerosol spray cans are a significant cause of climate change, χ^2 (1, $n = 41$) = 1.67, $p = 0.20$. A statistically significant correlation was found between natural climate change beliefs and belief that aerosol spray cans are a significant cause of climate change ($\rho = -0.22$; $p = 0.02$). Only 8 of the 41 (20%) were confident that aerosol spray cans are not a significant cause of climate change (i.e., judged this statement false).

Of the 69 respondents who believed that climate change is mainly caused by human activity, 20% correctly indicated that nuclear power is not a significant cause of climate change. Fifty-seven percent either did not know or falsely believed that nuclear power is a significant cause of climate change. This result suggests that no matter whether people think that climate change is natural or human-induced, they are equally likely to hold the incorrect belief that nuclear power is a significant cause of climate change (56% and 57% respectively). This trend does not hold for aerosol spray cans. Seventy percent of those who recognized that humans have caused climate change either did not know or incorrectly believed that aerosol spray cans are a significant cause of climate change. Only 2 of the 69 (3%) were confident that aerosol spray cans are not a significant cause of climate change. This is proportionally lower than the 20% of natural climate change believers who were confident that aerosol spray cans are not a significant cause of climate change, χ^2 (1, n = 115) = 42.2, $p < 0.01$.

TABLE 1: Distributions of responses according to (1) peoples' degree of belief in nuclear power and aerosol spray cans as causes of climate change (both of which are not significant causes) and (2) natural versus human-caused climate change beliefs

	(2)	Climate change is mainly caused by?	
(1)		Natural causes (n = 41)	Human causes (n = 69)
Nuclear power is a significant cause of climate change. (n = 110)	True, Probably True	29%	32%
	Don't know	27%	25%
	False, Probably False	44%	43%
Using aerosol spray cans today is a significant cause of climate change. (n = 110)	True, Probably True	22%	54%
	Don't know	22%	16%
	False, Probably False	56%	30%

The parallel questions for nuclear power and aerosol spray cans in the MTurk survey revealed similar results; a majority of those in the national sample who were randomly assigned to receiving the question thought that these were significant contributors to global warming or reported that they did not know (61% for nuclear power and 71% for aerosol spray cans, N = 524). However, for the small subset of these MTurk respondents who thought that human activities have not contributed to global climate change (n = 33), a majority answered correctly that nuclear power (79%) and aerosol spray cans (69%) are not major causes of global warming.

2.3.2.3 What can and should be done about climate change?

Sixty percent of Allegheny County respondents disagreed that we will be able to stop future changes in the climate, if they are occurring and ever get serious. Of these, nearly all (91%) believed that the only way to avoid possible future serious changes in the climate is to take action to stop them now. Eighty-one percent of Allegheny County respondents agreed that the only way to avoid possible future serious changes in the climate is to take action to stop them now.

Allegheny County respondents who thought that climate change is primarily caused by natural causes tended to disagree that, “If the climate is changing, there is not much people *can* do about it” (66% responded disagree/strongly disagree), but were less likely to do so than those who thought that climate change is primarily caused by human activities (66% vs 94%), χ^2 (1, n = 115) = 7.26, $p < 0.01$. Further, of those who thought that climate change is primarily caused by natural processes, 41% responded disagree/strongly disagree that if changes in the climate are occurring, and these changes ever get serious, we will be able to stop them in the future, as compared to 71% for those who think climate change is primarily caused by human activities, χ^2 (1, n = 121) = 22.0, $p < 0.01$.

Despite this, only 7% (3 of 41) of those who viewed climate change as primarily caused by natural processes thought that we should not do anything about it, similar to the less than half a percent (3 of 69) of those who saw climate change as primarily caused by humans. Sixty-three percent of natural climate change believers indicated that they agree or strongly agree that the only way to avoid possible future serious changes in the climate is to take action to stop them now (as compared to 91% of those who believed that climate change is primarily caused by human activities), χ^2 (1, n = 115) = 16.0, $p < 0.01$. The distribution of responses for the statement, “If the climate is changing, and those changes ever get serious, we’ll be able to stop them in the future when they happen,” is provided in Figure 4 for all respondents.

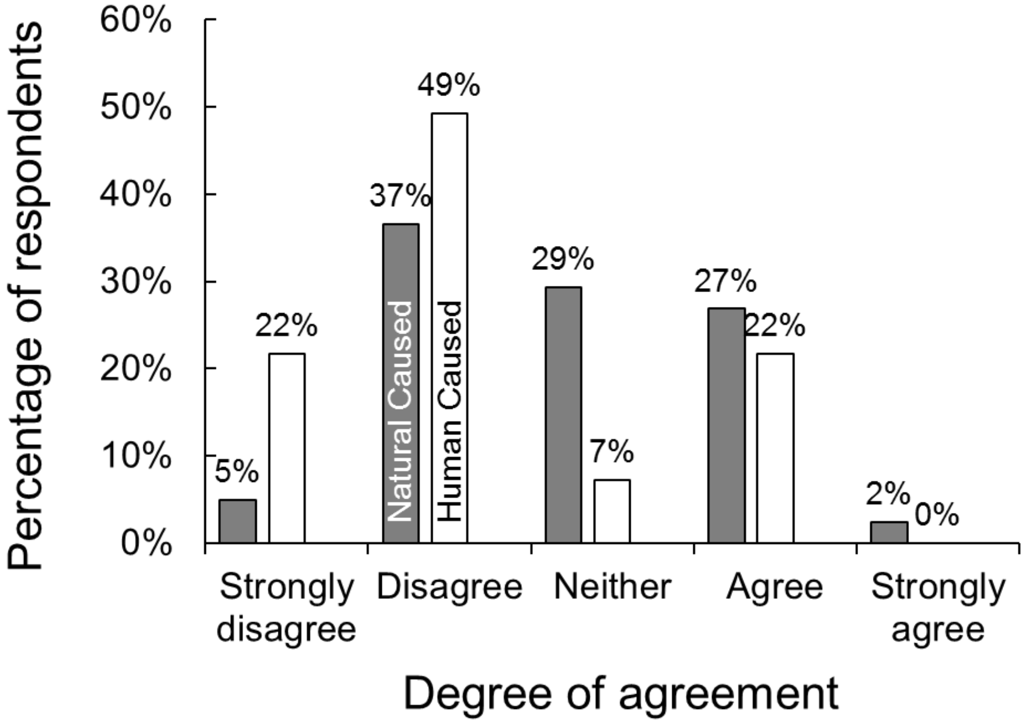

Figure 4: Distribution of responses in the Allegheny County, PA mail survey to the statement that, "If the climate is changing, and those changes ever get serious, we'll be able to stop them in the future when they happen." Responses are separated by natural-caused (solid bars on the left) and human-caused (open bars on the right) climate change beliefs. The y-axis shows the frequency for each response category. The x-axis represents degree of agreement comprising "strongly disagree," "disagree," "neither disagree nor agree," "agree," and "strongly agree" from left to right.

2.3.3 To what extent do these beliefs affect people's support to take action now against future serious changes in the climate?

To address the third research question, I conducted a logistic regression in which the binary dependent variable reflected responses to: "The only way to stop future serious changes in the climate is to take action to stop them now." Those who agreed or strongly agreed with this statement were coded as '1,' and those who disagreed or strongly disagreed with this statement were coded as '0.'I estimated support for this statement as a function of beliefs about climate change, while controlling for political party (Table 2).

TABLE 2: Summary of variable parameters and significance levels for logistic models

	Model 1 (n = 103)		Model 2 (n = 91)	
Variables	Odds Ratio (95% CI)	*p*-value	Odds Ratio (95% CI)	*p*-value
Democrat	7.71 (1.55, 38.36)	0.01	104.53 (2.94, 3715.28)	0.01
Residence Time	1.20 (0.44, 3.27)	0.72	0.37 (0.09, 1.60)	0.20
Indiscriminate Green Beliefs	-	-	212.23 (7.12, 6330.36)	< 0.01
Distant Source	-	-	0.28 (0.04, 2.20)	0.23
Electricity Source	-	-	4.31 (0.61, 30.35)	0.14
Constant	3.79	< 0.01	0.21	0.45
Nagelkerke R^2	0.17		0.66	
Wald Model Evaluation	$\chi^2(2) = 8.87, p = 0.01$		$\chi^2(5) = 31.97, p < 0.01$	
Hosmer-Lemeshow Goodness of Fit	$\chi^2(3) = 2.56, p = 0.47$		$\chi^2(8) = 4.72, p = 0.79$	

Then, I conducted a variance inflation factor (VIF) multicollinearity test. There was some indication of multicollinearity (VIFs ranged from 1.27 to 2.71), and high correlations were present in a pairwise correlation matrix (Fig. A.3.1). Next, I conducted a factor analysis [Kaiser-Meyer-Olkin (KMO) = 0.58] to reduce the number of intercorrelated independent variables.[5]

A total of five reliable factors were found (see scree plot in Appendix A.3): (1) Democrat; (2) Indiscriminate Green Beliefs (3 items; Cronbach's α = 0.59); (3) Residence Time (2 items; Cronbach's α = 0.88); (4) Distant Source (2 items; Cronbach's α = 0.69); and (5) Electricity Source (2 items; Cronbach's α = 0.78). For each multi-item factor, I therefore created a new variable (Appendix A.3).

[5] When all items were included as individual predictors in the regression, we found some indication of multicollinearity (variance inflation factors ranged from 1.27 to 2.71), and none of the individual parameter estimates were significant (*p* >.99 for all).

Model 1 includes two factors: Democrat and Residence Time (i.e., the misunderstanding of atmospheric residence time of common air pollution and carbon dioxide (Table 2). Pseudo R^2 for model 1 approximates 0.17 (Nagelkerke). Only Democrat is statistically significant (p = 0.01). Model 2 includes all five independent variables. Pseudo R^2 for model 2 approximates 0.66 (Nagelkerke). In model 2, Democrat and Indiscriminate Green Beliefs are statistically significant ($p = 0.01$ and $p < 0.01$, respectively). Of note is that the Residence Time factor was not significant in either model (Table 2). In other words, atmospheric residence time beliefs were not related to support to take action, as part of the logistic regression.

The Indiscriminate Green Beliefs factor combined responses to three related survey questions. If people held "Indiscriminate Green Beliefs," they met at least one of the following requirements: (1) answered true or probably true that nuclear power is a significant cause of climate change; (2) answered true or probably true that aerosol spray cans are a significant cause of climate change; or (3) answered true or probably true that renewable forms of energy (like solar and wind) could reliably supply United States electricity demands. If any of these requirements were met, the respondent received a coding of '1,' signifying that they had Indiscriminate Green Beliefs. All other respondents were coded as '0.'

Of respondents who self-identified as Democrats, 48 had Indiscriminate Green Beliefs.[6] For those who held Indiscriminate Green Beliefs and were Democrats, the probability of believing we should act now to combat climate change is virtually 100%. For the 13 Democrats who did not have Indiscriminate Green Beliefs, the probability of believing that we should act now to combat climate change was 95%. Of those respondents who self-identified as Republicans, 29 had Indiscriminate Green Beliefs. For those who held Indiscriminate Green Beliefs and were Republicans, the probability of believing we should act now to combat climate change was 98%. For the 11 Republicans who did not have Indiscriminate Green Beliefs, the probability of believing we should act now to combat climate change is 17%.

2.4 Conclusion

Previous studies of educated laypeople revealed a variety of public misunderstandings about the causes of climate change[(8-10)] but did not systematically explore whether people understand the very long (>100 years) residence time of carbon dioxide once it enters the atmosphere. This

[6] (N = 101) for the IGB analyses, as sample size varied slightly due to item non-response.

thesis chapter found that people did not differentiate between the residence time of common air pollution (which they dramatically overestimated) and carbon dioxide (which they dramatically underestimated). Such a belief in a short residence time could lead people to the false conclusion that if and when the effects of climate change ever get serious, those effects could be reversed in just a few decades or less by reducing emissions of CO_2. However, that is not the case: Once CO_2 enters the atmosphere, much of it remains there and contributes to warming for many centuries. In addition, overestimating the residence time of short-lived air pollutants could lead to misapplication of abatement solutions over a wider policy window than is necessary or effective. Thus, a communication strategy that continues to link CO_2 with air pollution may be unwise, if it perpetuates these misunderstandings.

While many people accept that changes in the climate are occurring, misconceptions persist about the cause of those changes. Results obtained in the Pennsylvania sample suggest that despite efforts to correct a variety of misunderstandings over the last decade, gaps still exist.

Knowledge deficits are rarely the primary drivers of policy support.[45] Hence, it is unlikely that support for climate abatement is determined by personal views about atmospheric residence time. However, specific knowledge sometimes does explain meaningful differences in policy support.[46] Further, it is arguable that voters and policy makers will be able to make more informed decisions about which policies to support if they understand that successful climate policy will require consistent attention to reducing CO_2 emissions over the course of many decades, due to the long-lived nature of CO_2 and its persistent impact on climate.

While in some respects discouraging, my results do offer two signs of hope. The first is that, compared to an earlier survey,[8] a considerably higher proportion of survey respondents now understand that burning fossil fuels releases carbon dioxide and that changes the climate. Perhaps that means that with well-designed, tested analogies—such as filling bath tubs that have large faucets and very small drains [47,48]—wider understanding of the long atmospheric residence time of carbon dioxide and its fundamental policy implication can be achieved both in the general public and among members of the media, opinion leaders, and decision makers. The second is the strong support for action *now*, although this appears to result primarily from Indiscriminate Green Beliefs rather than an understanding of the long-lived problem that continued emissions creates.

3. Public perceptions of climate attribution

Abstract
Increased frequency or severity of extreme weather events is arguably one of the most important consequences of anthropogenic climate change, due to the immediate and salient impacts. A number of recent extreme events, like Hurricane Harvey, incited public discourse surrounding the role of anthropogenic climate change in amplifying, or otherwise modifying, these events. Over the last decade, scientists have made significant strides in climate attribution to identify probabilistic links between climate change and extreme weather events. While prior studies have mapped mental models of climate attribution for decision-makers, lay perceptions of this issue have yet to be adequately explored. I build upon this body of research by focusing on the cognitive mechanisms by which beliefs and experience affect interpretations of extreme weather events. Specifically, in two related studies, I explore whether and how laypeople attribute extreme weather events to climate change and the circumstances under which they make this connection. Mapping these lay perceptions should help us to better understand what motivates support for immediate climate action and whether and to what extent climate beliefs drive differences of interpretation of extreme weather events.

3.1 Introduction

Both public and scientific discourse is growing about whether and how anthropogenic climate change may affect the frequency and intensity of extreme weather events. For example, in the U.S., *The Washington Post* reports that the "majority of Americans now say climate change makes hurricanes more intense."[49] Within the scientific community, recent years have witnessed considerable progress on "climate attribution"—the use of statistical techniques to assess the probability that climate change may have played a role in influencing the character of an extreme event.[45, 50-54]

The extent to which climate change affects any individual weather event involves a variety of natural and anthropogenic factors (e.g., large-scale circulation, anthropogenic climate change, aerosol effects, etc.). By definition, extreme events are rare, which means that at any given location, there are typically only a few examples of past events. Despite this, several methods exist for climate attribution. Some approaches use historical comparisons of long-term averages and model simulations of climate and weather with and without climate change.[45] A study done in the aftermath of Hurricane Harvey suggests that rainfall may have been increased by 40%.[55] Another study synthesized a suite of climate models, finding that, as a result of climate change, the return period of Harvey-like rainfall events could change from a 1-in-2,000-

year event to a 1-in-100-year event.[56] These and other studies argue that, because the temperature of the ocean surface waters that drive hurricanes is rising, they can be expected to intensify in the future.[1,57]

Previous research finds that laypeople tend to use their experiences with daily weather and certain extreme weather events as evidence of climate change.[50,58] In other words, the public often links their assessment of whether there is climate change to local weather.[50,59] The nature of the causal connections laypeople make varies with a range of demographic factors and beliefs. Individuals holding different beliefs may also have different interpretations of extreme weather due to diverse knowledge and experience or altogether different interpretations of extreme events.[20,32] Specifically, there may be a motivational distortion in interpreting extreme weather events as evidence of climate change.[50] This process of judgment can create problems in interpreting and applying climate attribution, since various locations experience different hazards, and laypeople may have differing interpretations of the evidence the same events provide for climate change.[60,61] For example, asserting that an abnormally hot day or an individual hurricane is clear evidence of climate change may not be defensible. Such attribution of specific events can create challenges in garnering sustained support for climate abatement—especially during cold spells or notable snow storms that some might argue (falsely) provide evidence *against* global warming.

Since personal experience motivates one's concern for short- and long-term hazards (e.g., a hurricane and climate change, respectively) and willingness to act to lessen its adverse effects,[62] such experience can motivate some people to support mitigative action more than others.[12] As a result, it is necessary to evaluate what drives differences of interpretation of the same extreme weather event across individuals. Several things may influence interpretations of experience across individuals, including various levels of perceptual ability (e.g., strong climate change beliefs may lead to more inferences drawn between global warming and extreme weather) or proportional differences in how bad extreme weather, like a hurricane, must get before it is considered evidence of climate change.

While prior work has focused on decision-makers' views on climate attribution,[54,63,64] lay perceptions of this issue have yet to be adequately explored. I build upon this body of research by focusing on the cognitive mechanisms by which beliefs and experience affect interpretations of extreme weather events. Specifically, in two related studies, I explore whether and how laypeople attribute extreme weather events to climate change and the circumstances under which they make this connection. Mapping these lay perceptions should help us to better understand what motivates support for immediate climate action and whether and to what extent climate beliefs drive differences of interpretation of extreme weather events.

First, in a small face-to-face study, I explore peoples' understanding and perceptions of the issue and the use of spinner boards as a vehicle to communicate with the public about non-stationary, rare events (i.e. extreme weather).

In a larger study using Amazon Mechanical Turk (MTurk), I replicate the efforts of Broomell and co-authors (2017), who applied signal detection theory to analyze judgements of daily temperatures as evidence of global warming and exposed sources of perceptual biases. The goal of this study was to assess to what extent people perceive certain extreme weather events as abnormal, and if these perceptions are influenced by certain beliefs or demographics. First, I conduct an extreme event attribution task for multiple extreme weather events; I then perform a signal detection task for hurricanes only, alternating the frequency and intensity for each judgement. However, the goal is not to test laypeople's understanding of historical hurricane data. Rather, I use signal detection theory to quantify the tendency of people to identify hurricanes as abnormal and how their performance is influenced by their beliefs. Specifically, I ask:

1. How do individuals' beliefs about climate change affect their interpretation of hurricane frequencies?
2. What drives personal perceptual abilities (sensitivity) and decision thresholds in hurricane judgments?
3. How well do individual difference measures (such as climate change beliefs and experience) predict support for immediate climate action?
4. To what extent is the use of spinner boards an effective communication tool for these non-stationary, rare events?

3.2 Study 1: Face-to-face study including the use of spinner boards

3.2.1 Participants

For the first study, a convenience sample of 28 face-to-face interviews were conducted through Carnegie Mellon's Center for Behavioral and Decision Research in Allegheny County (AC), Pennsylvania (PA). The ages of respondents in this sample ranged from 18-76 years old (mean = 31.0, median = 26). This convenience sample, on average, was younger than both the AC and U.S. populations (41 and 37, respectively). This sample was well educated compared to the U.S. population: 28 (100%) had finished high school [U.S. = 88%], 17 (61%) had completed college [$U.S._{some}$ = 59%; $U.S._{all}$ = 33%], and 12 (43%) had completed graduate training [U.S. = 12%]. Of the total sample, 20 (71%) identified as liberal [AC = 60%, U.S. 47%], and 15 (54%) were female [AC = 52%, U.S. = 51%]. The results are biased toward younger, educated liberals. The full demographic composition of the sample is displayed in Table 3.

TABLE 3: Demographic distribution of interview sample ($N = 28$)

Demographics	Frequency	Fraction
Gender		
Female	15	0.54
Male	13	0.46
Political ideology		
Extremely Liberal	2	0.07
Liberal	10	0.36
Slightly Liberal	8	0.29
Moderate / Middle of the Road	5	0.18
Slightly Conservative	1	0.04
Conservative	1	0.04
Extremely Conservative	0	0.00
None Response	1	0.04
Education		
Some high school	0	0.00
High school graduate	2	0.07
Some four-year college, junior college or trade	8	0.29
school	1	0.04
Junior or trade school graduate	5	0.18
Four-year college graduate	7	0.25
Graduate school in a non-technical field	5	0.18
Graduate school in a technical field		

3.2.2 Procedure

On average, the semi-structured interviews lasted about 30 minutes. Participants were compensated $5.00 for their time. The interview protocol adopted wording from previous studies on public understanding of climate change.[(8-10,65)] Additional questions were pre-tested in a set of pilot interviews. The interview protocol was comprised of three sections: 1) trends in the weather; 2) meaning, examples, and perceptions of the causes of extreme weather events; and 3) questions surrounding climate attribution.

The section on trends in the weather began with three questions: 1) “In your personal experience, over the past few years, have you noticed any changes or trends in the weather where you live?”; 2) “In your experience, have average temperatures where you live been rising, falling or staying about the same as in previous years?”; and 3) “In your experience, has the amount of rain or snowfall where you live been rising, falling, or staying about the same as previous years?". These core questions were followed by a series of neutral prompts, contingent on the unique response from each participant.

The next section asked participants what the phrase "extreme weather events" meant to him/her. Following a series of neutral prompts, participants were then asked to provide examples of extreme weather events. Using an event that was mentioned, the participant was asked to explain what might have caused that event. A couple of questions followed regarding what the participant believed caused specific types of events, as well as what the participant thought caused a specific event: "Please tell me what sorts of things you think make extreme rainfall happen"; and "What sorts of things do you think made Hurricane Harvey happen?" The section concluded with a series of questions about what the connection may be, if any, between what is in our air and weather trends (as well as the connection with extreme weather). Specifically, participants were asked, "Could adding carbon dioxide to the atmosphere change [**weather patterns/extreme weather**]?" If the participant indicated that adding CO_2 to the Earth's atmosphere might change the patterns and kinds of weather that happen, he/she was asked to describe what he/she thought those changes might be. If the participant indicated that adding CO_2 to the Earth's atmosphere would (probably) not change the patterns and kinds of weather that happen, he/she was asked to explain why he/she thought there would not be any changes.

The last section introduced "climate" into the dialogue. Participants were asked, "In your view, what is the difference, if any, between 'weather' and 'climate'?" The interview then moved from broad prompts to more specific examples: "What type of evidence, if any, would show that [**California's summer droughts/hurricanes (like Harvey or Irma)**] are more likely to happen due to climate change?" Participants were then asked about the likelihood of occurrence and strength of extreme weather events with the aid of spinner boards. This portion of the interview protocol warrants further explanation.

A standard way of communicating about the return period of rare events is to talk in terms of an *N*-year event. For example, USGS speaks of 100-year floods and produces maps of the 100-year floodplains (2018). In such a case, the annual event probability is $p_{\text{annual}}(E) = 0.01$. More generally, $p_{\text{annual}}(E) = P/(365.25)$, where P is the expected value of the number of events that will occur in a year of 365.25 days.[7] This study sought to explain such processes to laypeople by using spinner boards (Fig. 5) in which the odds of the event occurring are equal to the chance that a spinner will land on a colored segment of the wheel, whose width is (P/365.25)*360°. To explain the effect of climate change on the annual probability of an extreme weather event, I showed respondents a second wheel, in which the colored wedge had gotten a bit wider. Very different types of spinner boards than these have been used by MIT's Global Change group to describe the uncertainty of future climate predictions with and without policy intervention.[(66)]

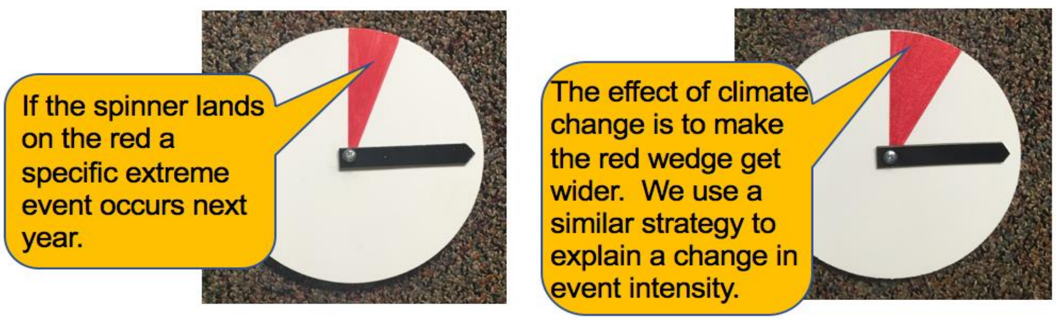

Figure 5: Example of spinners used to explain climate event attribution. The chance that the spinner will land on the red segment in the left wheel is the chance that the extreme event will occur next year, absent climate change. The right wheel shows the same thing with climate change.

While there is not a specific body of research on the use of spinner boards, similar methods have been used in decision analysis studies and tasks[(67)] using the same underlying assumption. It is implied that in tasks such as these, people can perceive the changes in the red slice (Fig. 5) and know that if it is bigger, that signifies a higher chance; if the red slice is smaller, that signifies a smaller chance. The only time this assumption would not hold is if the change in the size of the red slice was below the detection threshold, and therefore, people could not tell if it increased or decreased in size.[(68)]

Thus, I assessed the extent to which participants could explain the probabilistic features of event attribution using spinner boards. Specifically, I evaluated whether or not participants could correctly answer questions such as, "If climate change makes it more likely that an extreme event will occur, how would the spinner board change, and what would this difference

[7] There is of course no reason why the formulation needs to be made in terms of events per year. Any period of time can be used. However, for rare events, a year (or longer) is an interval that is easily understood.

mean?" The fact that a "100-year flood" can happen two years in a row was explained by the fact that in two successive spins, there is a chance that the spinner will land twice in a row on the narrow red slice (which, in the 1-in-100 case, would be only ~3.7° wide). If the process was non-stationary, that simply meant the width of the red slice changed over time. In the case of climate-related extreme weather events, that change would typically result in a growth of the width of the red slice as time goes by. Climate and other models can be used to estimate how rapidly the width of the slice grows. While the simplest case would be growth that occurs at a constant rate in time, for many climate-related events, the growth rate is likely to be some increasing function of time.

The audio recordings were transcribed verbatim and coded in ATLAS.ti based on thematic patterns. Because the issues raised were quite straight-forward, I did not have a second person code the responses, although I will do so before preparing the results for publication. Some broad themes I examined included climate change and extreme weather beliefs, the presence of pro-environmental attitudes, and understanding of causality and probabilities. General findings and response statistics are described below.

3.2.3 Results

In general, participants took notice of weather trends and changes where they resided. Participants noted changes in temperatures and precipitation patterns; a 76-year-old male participant summarized the temperature changes as generally more extreme: "…the summers are hotter; winters are colder and much more long-lasting." In relation to extreme weather events, he stated, "I think there are many more storms, and the northern part of the country is getting an enormous amount of hurricanes, snow, and rain. Much more than in the past." Other participants described extreme weather as anything "beyond normal" or that disrupted the basic functionality of cities or human lives (i.e. a more impact-based outlook). Summary response statistics for the question of whether people have noticed changes in the weather where they live are displayed in Table 4.

TABLE 4: Distribution of the most common responses to the question of whether participants have noticed changes in the weather where they live (*N* = 28)

Response	Frequency	Fraction
(Yes) noticed changes in the weather	28	1.00
Warmer temperatures	28	1.00
Wider range in temperatures	20	0.71
Hotter summers	17	0.61
Colder winters	11	0.39
Wider range in precipitation	10	0.36
More rain	18	0.64
Less rain	10	0.36
More snow	17	0.61
Less snow	11	0.39
More extreme weather	28	1.00
More intense extreme weather	14	0.50
More floods	18	0.64
Weather more unusual	19	0.68
Mentioned climate change	11	0.39

When asked to provide examples of extreme weather events, hurricanes were the most cited example (86%), followed by heavy rainfall (68%), and flooding (64%). This question was posed before asking about Hurricane Harvey, specifically, to avoid priming participants. These participants believed that hurricanes would increase in frequency and severity in the future. Nearly all participants also cited events *not* driven by weather patterns, like earthquakes and volcanic eruptions. One Texan participant mentioned the Zika virus as an example of an extreme weather event. Even regarding actual extreme weather events—e.g. tornadoes and hurricanes—most participants misunderstood or responded that they did not know what caused these extreme weather events. One participant judged that, "more clouds in the sky is causing the change in weather."

When asked what changes in weather could happen because of CO_2 being added to the atmosphere, all participants (100%) cited more extreme weather and global warming / warmer temperatures. Summary response statistics for this question are displayed in Table 5.

Table 5: Distribution of the most common responses to the question about what changes in weather could occur due to CO_2 being added to the atmosphere (N = 28)

Response	Frequency	Fraction
Global warming / warmer temperatures	28	1.00
More extreme weather	28	1.00
Negative impacts to society	19	0.68
More unusual weather	19	0.68
More rain	19	0.68
Melting ice caps	18	0.64
Create holes in the ozone layer	13	0.46
Sea level rise	13	0.46
Warmer oceans	11	0.39
Wider range in precipitation	10	0.36

More broadly, and in agreement with previous findings, participants confused “weather” and “climate.” Some confused the definition of each, while others believed weather and climate to be essentially the same thing or didn’t know the difference (80%). Perhaps the fact that people conflated weather and climate is related to their response that changes in the climate could also cause changes in extreme weather events.

Generally, participants misunderstood aspects, or even the entire process, of how CO_2 emissions caused global warming, which could increase the probability of occurrence and strength of extreme weather events. Some understood that CO_2 somehow warmed the planet (43%); while others separately understood that global warming may influence the base rate and strength of extreme weather. However, no participant mapped out the entire process, i.e. the connection between CO_2 emissions to climate change to changes in extreme weather. In other words, their thought processes lacked transitivity.

Some participants were puzzled by the question: “What connection might there be, if any, between what’s in our air and extreme weather?” In these cases, participants replied, “I don’t know” or “I’d never thought about that.” When some of these connections were made, the causes and consequences were often conflated: “I think there’s a definite connection [between what’s in our air and extreme weather]. I think the plants and factories are causing smoke and smog…and the ozone layer is lessening, and we’re not being protected like we used to be.” Another participant explained that chemicals in the air affected the ozone layer, and that holes in the ozone layer contributed to global warming. When asked what type of evidence, if any, would show that hurricanes are more likely to happen due to climate change, one participant simply stated, “the fact that [these hurricanes] are happening.” The same participant continued that statistics would show that there were more hurricanes (of greater intensity and longer-lasting)[8] now than ever before. A few others discussed looking at historical trends of extreme weather and comparing them to current patterns to determine if extreme weather was worsening (which most believed to be true).

At the conclusion of each interview, I evaluated the extent to which the use of spinner boards was an effective communication tool for non-stationary, rare events.(66,67) When I asked respondents how they would explain this demonstration (of climate attribution) using spinner boards to a friend, they provided remarkably accurate explanations. Given that an event has occurred, I used a similar spinner board strategy to explain the severity of an event. As an example, I divided a wheel in proportion to the occurrence of the 1-5 Saffir–Simpson hurricane intensity values and changed their ratio (wedge widths) in the case of climate change to include more frequent hurricanes of greater severity.

All participants (100%) were able to accurately communicate the meaning of the spinner boards as it related to nonstationary, rare events. First, participants were shown the leftmost spinner board in Figure 5 and told that it represented the probability of getting an extreme storm next month. If the spinner landed on the red section, you got the storm; if the spinner landed on the white section, you did not get the storm. The participants were then asked, “If climate change makes it more likely for a storm to happen next year, how would this spinner board change to show that?” Every participant (100%) explained that the red section would get wider to represent a higher probability of occurrence of an extreme storm. This may suggest that the use of spinner boards could be an effective tool in communicating probabilities in this context. The same initial results were true in the interviews for spinner boards representing the strength of hurricanes.

From the interviews, I learned that people believed climate change affected extreme weather. However, it remained unclear when, how, and why laypeople attributed extreme events to climate change. The overall objective of the signal detection task in Study 2 was to tease out

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[8] The empirical evidence to date for the Atlantic is that they are becoming more intense, but not significantly more frequent.

what lines of evidence lay people follow when they attributed an event to climate change by explicitly treating type, frequency, and severity factors.

3.3 Study 2: MTurk study using signal detection theory

The theory of signal detection (SDT)[69] describes two influences on judgments that are elicited in the experimental setup: 1) sensitivity, i.e., the extent to which people can encode information from their personal experience with hurricanes; and 2) decision thresholds, or what type of event or how severe (or frequent) an event must occur if it is to be interpreted as evidence of global warming.

Sensitivity and decision thresholds are two important, theoretically independent, dimensions of judgment (Figure B.2.1 in Appendix B.2). Sensitivity, in this context, is the distance between the centers of the signal and noise distributions along the perceptual continuum of “evidence of global warming” (Figure 6). This distance reflects the objective difference between signal and noise and an individual’s ability to differentiate between the two. Estimates of sensitivity can serve as a measure of one’s perceptual ability and determine whether participants who do not believe in anthropogenic climate change differentiate these events from past events or identify them as similar (i.e. no increase in frequency or severity).

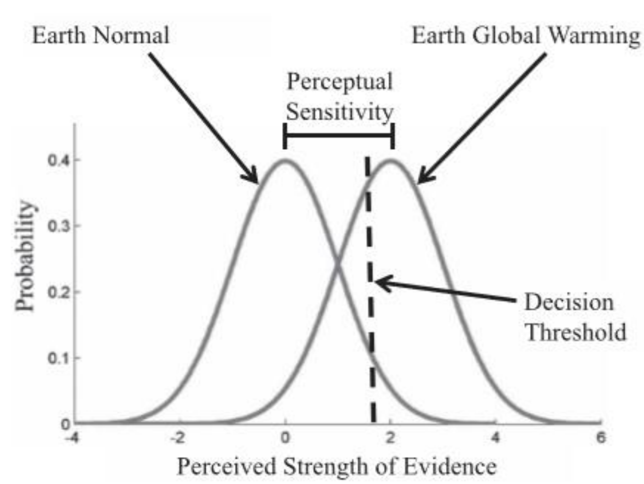

Figure 6: Earth Global Warming (signal) and Earth Normal (noise) distributions along the perceptual continuum of “evidence of global warming.” Image has been reproduced from Broomell, Winkles & Kane (2017). Note that the actual change in the probability density function (pdf) is both a shift in the mean and standard deviation, but pdfs have been simplified here for ease of viewing.

The second dimension is one's decision threshold, or the criterion for providing a given response. Also known as response bias, the detection threshold is a measure of relative frequency between false alarms (saying the signal is present when there is only noise) and correct hits (saying signal is present when a true signal is present). In the case of this study, the decision threshold measures one's decision strategy for classifying hurricane frequencies and can reveal if individuals who do not believe in anthropogenic climate change use different strategies for judging frequencies than individuals that do believe in climate change. In this example, the decision threshold represents how frequent a hurricane must be before a participant will classify the observation as being generated by a hypothetical Earth which includes anthropogenic climate change. The detection threshold can shift due to several factors, such as the base rate of events and the relative "value" of judgments, i.e. the ratio of the costs of misclassification versus the benefits of correct classification.

3.3.1 Participants

Participants for the signal detection task were recruited from a national, convenience sample (*N* =250) via MTurk. The ages of respondents in the MTurk sample ranged from 20-79 years old (mean = 35.4, median = 32). This convenience sample, on average, was younger than the U.S. population (mean = 37). In this sample, 100% had finished high school [U.S. = 88%], 57% had completed college [$U.S._{some}$ = 59%; $U.S._{all}$ = 33%], and 7% had completed graduate training [U.S. = 12%]. Of the total sample, 52% identified as liberal (U.S. 47%), and 38% of respondents were female (U.S. = 51%). The results are biased toward younger, liberal males. The full demographic composition of the sample is displayed in Table 6.

TABLE 6: Demographic distribution of survey sample (N = 250)

Demographics	Frequency	Fraction
Location		
Non-U.S. Coast	169	0.68
U.S. Coast	81	0.32
Gender		
Female	94	0.38
Male	156	0.62
Political ideology		
Extremely Liberal	26	0.10
Liberal	76	0.30
Slightly Liberal	30	0.12
Moderate / Middle of the Road	45	0.18
Slightly Conservative	25	0.10
Conservative	34	0.14
Extremely Conservative	14	0.06
Education		
Some high school	1	< 0.01
High school graduate	51	0.20
Some four-year college, junior college or trade school	43	0.17
Junior or trade school graduate	13	0.05
Four-year college graduate	124	0.50
Graduate school in a non-technical field	12	0.05
Graduate school in a technical field	6	0.02

3.3.2 Design

All participants completed two tasks: (1) *extreme event attribution*, where they classified 21 extreme events from a list containing both real (based on the IPCC AR5 report) and bogus examples of events attributable to anthropogenic climate change, and (2) *perception of hurricanes*, where they classified 45 hurricane frequencies projected over the next decade. I estimated each participant's sensitivity and decision threshold for the hurricane perception task using SDT.

To evaluate how people's beliefs may influence when, how, and why they attribute hurricanes to climate change, I compared performance across two groups. Participants in each group answered identical questions but with different framings, depending on random assignment. In the control group, participants were instructed to classify hurricane projections over the next decade as either normal (noise) or abnormal (signal), without making any mention of global warming. In the climate frame, participants were instructed to classify hurricane projections over the next decade as either not evidence of global warming (noise) or evidence of global warming (signal). After the main tasks, I asked about each participant's beliefs, ideology, and demographic characteristics. Based on prior findings, I predicted strong differences in people's sensitivity based on their personal experiences, emergency preparedness, and reported impacts from hurricanes[(59)] and that people's climate change beliefs would be predictive of their respective decision thresholds, or biases.[(50)]

3.3.3 Procedure

Potential participants read a short description of the task posted to MTurk. If interested, they were routed to an online survey (implemented through Qualtrics). Upon completion of the task, participants received unique confirmation codes to redeem $2.50 as compensation for their time. The task took less than 20 minutes to complete. To be eligible to participate in the study, participants had to be 18 or older, fluent in English, using a desktop computer, reside in the U.S., and have at least 95% approval rate and at least 500 previously approved tasks. I included four attention checks with obvious answers to assess whether participants were paying attention for the task duration.

First, the participants completed a short extreme event attribution task to measure their perceptions of extreme events that could be attributable to climate change. Table 7 displays a list of actual and bogus events attributable to climate change. The participants were shown these lists (in random order) and were asked to categorize each into one of two bins labeled, "Could be evidence of man-made climate change" and "Could NOT be evidence of man-made climate change."

TABLE 7: List of examples of events that could and could not be attributable to man-made climate change (to some degree) in the extreme event attribution task

Changes in events that could be linked to climate change in IPCC AR5:
Cold waves Droughts Floods Hail Heat waves Heavy rainfall Heavy snow Hurricanes Ice Ocean waves Tornadoes Winds Wildfires
Changes in events that could be indirectly linked to climate change (i.e. *via* precipitation and / or warming temperatures):
Avalanches Landslides Sinkholes
Bogus:
Earthquakes Gas eruptions from deep water lake (i.e. limnic eruptions) Holes in the ozone layer Solar flares Volcanic eruptions

After this sorting task, participants were randomly assigned to either the control or climate condition for classifying hurricane frequencies. Individuals assigned to the control condition read the following instructions:

> "Every year, some parts of the U.S. are hit by hurricanes. Whether that happens at a particular location depends on many uncertain factors.
>
> Hurricanes grow out of tropical storms that circle around a low-pressure system and are fueled by warm ocean waters. The National Hurricane Center categorizes hurricanes based on how fast their sustained winds are blowing. To do that, they use something called the Saffir-Simpson Scale. This scale assigns a 1 to 5 rating to storms based on their potential to cause property damage.

This table from the National Hurricane Center shows the range of windspeeds for each hurricane category. Category 1 hurricanes have the lowest windspeeds, and Category 5 hurricanes have the highest windspeeds:

Category	Sustained Winds	Danger Level
1	74-95 mph	Very dangerous
2	96-110 mph	Extremely Dangerous
3 (Major)	111-129 mph	Devastating
4 (Major)	130-156 mph	Catastrophic
5 (Major)	157 mph or higher	Catastrophic

We are interested in understanding how frequently the public expects to see hurricanes of different intensities during "normal" hurricane seasons in the U.S. in the future. In this study, we will show you hypothetical news headlines that describe experts' forecasts of the number of hurricanes expected to make landfall in the U.S. over the next decade.

We would like you to tell us whether you think the headline describes a **normal** or an **abnormal** number of hurricanes over the next decade. An abnormal hurricane season would mean that there are either **many fewer** or **many more** hurricanes than you would expect. For each number of hurricanes, we will ask you to also rate how confident you are about your decision."

It should be noted that although I did not make mention of global warming in the task instructions for the control group, it is possible that participants may have been influenced by the initial sorting task (i.e. assigning events as possible evidence of anthropogenic climate change).

Individuals assigned to the climate condition read identical instructions, except the wording of the final two paragraphs differed to reflect their unique response options. The final paragraphs for the climate condition read:

"We are interested in understanding what the public thinks could suggest evidence in the future of global warming during hurricane seasons in the U.S. In this study,

we will show you hypothetical news headlines that describe experts' forecasts of the number of hurricanes expected to make landfall in the U.S. over the next decade.
We would like for you to tell us whether you think the headline suggests evidence of global warming or does not suggest evidence of global warming during the next decade. For each number of hurricanes, we will ask you to also rate how confident you are about your decision."

Participants then proceeded to classify 45 hurricane observations. The 45 observations were composed of hypothetical news headlines projecting the potential number of hurricane landfalls and their intensity over the next decade. The headlines followed the form:

"Roughly [*frequency*] Category [*intensity*] Hurricanes could Strike the U.S. over the Next Decade, Study says"

The hurricane stimuli were generated for the U.S. from decadal means and standard deviations of hurricane landfall data from NOAA Hurricane Research Division from 1851 to 2017.[(70)] Since the hypothetical news headlines asked participants to judge observations "over the next decade," evaluating historical hurricane incidence by decade was appropriate. The mean number of landfalls, their highest intensity, and standard deviations were computed for each decade in the U.S. over the 166-year period-of-record (POR). Note that this POR cannot strictly be interpreted in this manner, since hurricane observation methods have changed over this time period and would lead to potential differences in frequency, intensity, or landfall records. An alternative formulation would be to extract stimuli from the POR when satellite observations were in operation (i.e. 1970s to present day). Summary statistics for each POR follow.

Based on the 166-year POR, the mean number of hurricane landfalls in the U.S. (per decade) was: 7 category 1 hurricanes (std. dev. = 2); 5 category 2 hurricanes (std. dev. = 2); 4 category 3 hurricanes (std. dev. = 2); 1 category 4 hurricanes (std. dev. = 1); and 0 category 5 hurricanes (std. dev. = 0). Based on a POR from 1971 to 2017, the mean number of hurricane landfalls in the U.S. (per decade) was: 6 category 1 hurricanes (std. dev. = 2); 3 category 2 hurricanes (std. dev. = 2); 3 category 3 hurricanes (std. dev. = 2); 1 category 4 hurricanes (std. dev. = 1); and 0 category 5 hurricanes (std. dev. = 0). The calculations and results to follow are based on the full, 166-year POR.

Given the greater incidence of category 1-3 hurricanes, frequencies ranged from 0 to 10 to adequately capture the mean number of hurricanes per decade, as well as frequencies above and below the mean. Category 4 and 5 hurricanes included a range from 0 to 5, due to the historically lower incidence of strong hurricanes in the database in both the full, 166-year POR and the POR from 1971 to 2017. The presentation of category 1-5 hurricanes was randomized, as well as random presentation of frequencies within each hurricane category. For each trial, participants were asked to rate their confidence in their decision (i.e. low, medium, or high). Detailed information about the hurricane stimuli is provided in the Appendix to this chapter (Appendix B.1).

After completing the two main tasks (i.e. extreme event attribution and hurricane perception tasks), participants were asked to indicate their age, gender, education political ideology, and state of residence. They also answered questions about their hurricane experience, interest and knowledge regarding weather and climate, level of emergency preparedness, primary news source, beliefs in climate change, and belief in the need for immediate climate action (see Appendix B.3 for full list of questions). Finally, they completed two standard instruments: (a) a seven-item weather salience questionnaire (short form) to gauge psychological significance of weather;[71,72] and (c) a five-item objective numeracy test[73] based on the proportion of questions answered correctly. I analyzed the dependent variables of sensitivity and decision threshold in hurricane perception as a function of (a) experimental condition (control or climate group) and location (non-coastal or coastal resident), (b) demographic variables, (c) the four scales measuring beliefs and experience, (d) extreme event preparation measures, and (e) numeracy, plus one knowledge question on whether people know a hurricane watch is less severe than a hurricane warning. I also analyzed the dependent variable of support for immediate climate action as a function of: (a) demographic variables, (b) the four scales measuring beliefs and experience, (c) extreme event preparation measures, and (d) numeracy. A full description of individual difference measures and personal questions are available in the Appendix to this chapter (Appendix B.3).

3.3.3.1 Estimating SDT parameters

I estimated two SDT parameters in this experiment: sensitivity and decision bias measures for people's hurricane interpretations. SDT estimates are calculated based on hit rates and false alarm rates. The hit rate is the proportion of trials where participants responded “signal” when the trial was a true signal. The false alarm rate is the proportion of trials where participants responded “signal” when the trial was noise (i.e. not a true signal). The hit and false alarm rates were calculated based on grading criteria for each experimental framing group, described next.

Defining Abnormal Hurricane Frequencies: Two calculation methods were explored in defining abnormality: (1) an examination of standard deviations and (2) the use of a Poisson arrival process (see Appendix B.1 for calculations). The standard deviation approach yielded a broader interval than the Poisson approach, and I decided the standard deviation approach is conservative but appropriate for defining abnormal hurricane frequencies. As a result, for the control condition, I classified landfall frequencies that were 1 (or more) standard deviations above or below the decadal mean as abnormal. All other trials were classified as normal.

Defining Evidence of Global Warming: For the climate condition, I estimated the SDT parameters based on the results from the 28 face-to-face interviews in Study 1, where all participants said that climate change caused hurricanes to be more frequent and more intense.[9] I classified frequencies that were higher than the decadal mean number of landfalls as representing evidence of global warming. This definition was not meant to represent the scientific community’s understanding of how climate change may influence (rather than *cause*) hurricanes—but rather—I adopted laypeople’s mental models in evaluating how they may understand “evidence” of global warming. Because participants stated that climate change would *increase* the severity and frequency of hurricanes, I concluded that anything below the mean (and the mean itself) would not be identified as evidence of global warming.

I estimated the sensitivity and decision threshold parameters by creating a receiver operating characteristic (ROC) curve for each participant. ROC curves were calculated using the Hit Rate (HR, or accurate signal detection based on my grading criteria), False Alarm Rate (FAR, or inaccurate signal detection), and self-reported confidence. The sensitivity parameter was estimated by the area under the ROC curve (AUC), while the decision threshold was calculated by the equation: $C = -0.5[\Phi^{-1}(1 - HR) + \Phi^{-1}(1 - FAR)]$ where Φ^{-1} is the inverse Gaussian cumulative density function.[(74)]

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[9] The empirical evidence to date for the Atlantic is that they are becoming more intense, but not significantly more frequent.

3.3.4 Results

3.3.4.1 Attribution of Extreme Events (Sorting Task)

Descriptive statistics: Table 8 shows responses to the extreme event attribution task, displayed as the proportion of participants indicating each event as potential "evidence" of climate change. These proportions show that participants classified several events incorrectly (i.e. their perceptions of which events were attributable to climate change did not reflect those listed in the IPCC AR5 report). The fraction of trials classified as "Could be evidence of man-made climate change" for Heavy snow (0.56), Tornadoes (0.53), Landslides (0.55), and Avalanches (0.45) were not significantly different than chance (i.e. 0.50; one-sample *t*-tests, $p > 0.05$ for all). Participants also identified some bogus examples as attributable to climate change (e.g. "holes in the ozone layer," 0.81). Table 8 also shows that participants perceived hurricanes as potential evidence of man-made climate change (0.64), following only heatwaves and wildfires (0.75), droughts (0.71), and floods (0.68), of the events on the IPCC list. This coincides with results from Study 1, where hurricanes were the most cited example of extreme weather (86%) and were believed to increase in both frequency and severity in the future.[58]

TABLE 8: List of examples of events that could and could not be attributable to man-made climate change in the extreme event attribution task. Values for "fraction of trials" should be above 0.5 for events linked to climate change and below 0.5 for bogus events. The situation for indirect effects is less clear. Fraction of trials significantly different than chance (i.e. 0.50) are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$. Fraction of trials for events **in bold** are not significantly different from chance.

Changes in events that could be linked to climate change in IPCC AR5:	Fraction of Trials Categorized as "Could be evidence of man-made climate change"
Heat waves	0.75***
Wildfires	0.75***
Droughts	0.71***
Floods	0.68***
Hurricanes	0.64***
Cold waves	0.58**
Heavy rainfall	0.57*
Heavy snow	**0.56**
Tornadoes	**0.53**
Hail	0.42*
Ice	0.42**
Winds	0.36***
Ocean waves	0.34***
Changes in events that could be indirectly linked to climate change (i.e. *via* precipitation and / or warming temperature):	
Landslides	**0.55**
Avalanches	**0.45**
Sinkholes	0.44*
Bogus:	
Holes in the ozone layer	0.81***
Gas eruptions from deep water lake (i.e. limnic eruptions)	0.39***
Earthquakes	0.32***
Solar flares	0.24***
Volcanic eruptions	0.20***

3.3.4.2 Attribution of Hurricane Frequency (Signal Detection Task)

Descriptive statistics: Figure 7 presents responses to the hurricane signal detection task, shown as the proportion of participants who described each hurricane frequency as abnormal (control group) or evidence of global warming (climate group) separately for each hurricane category. Responses for the control group tended to be bimodal (i.e. peaks at low and high hurricane frequencies); whereas responses for the climate group tended to be linear. Overall, 51% of control and 49% of climate participants judged the hurricane frequencies presented as abnormal.

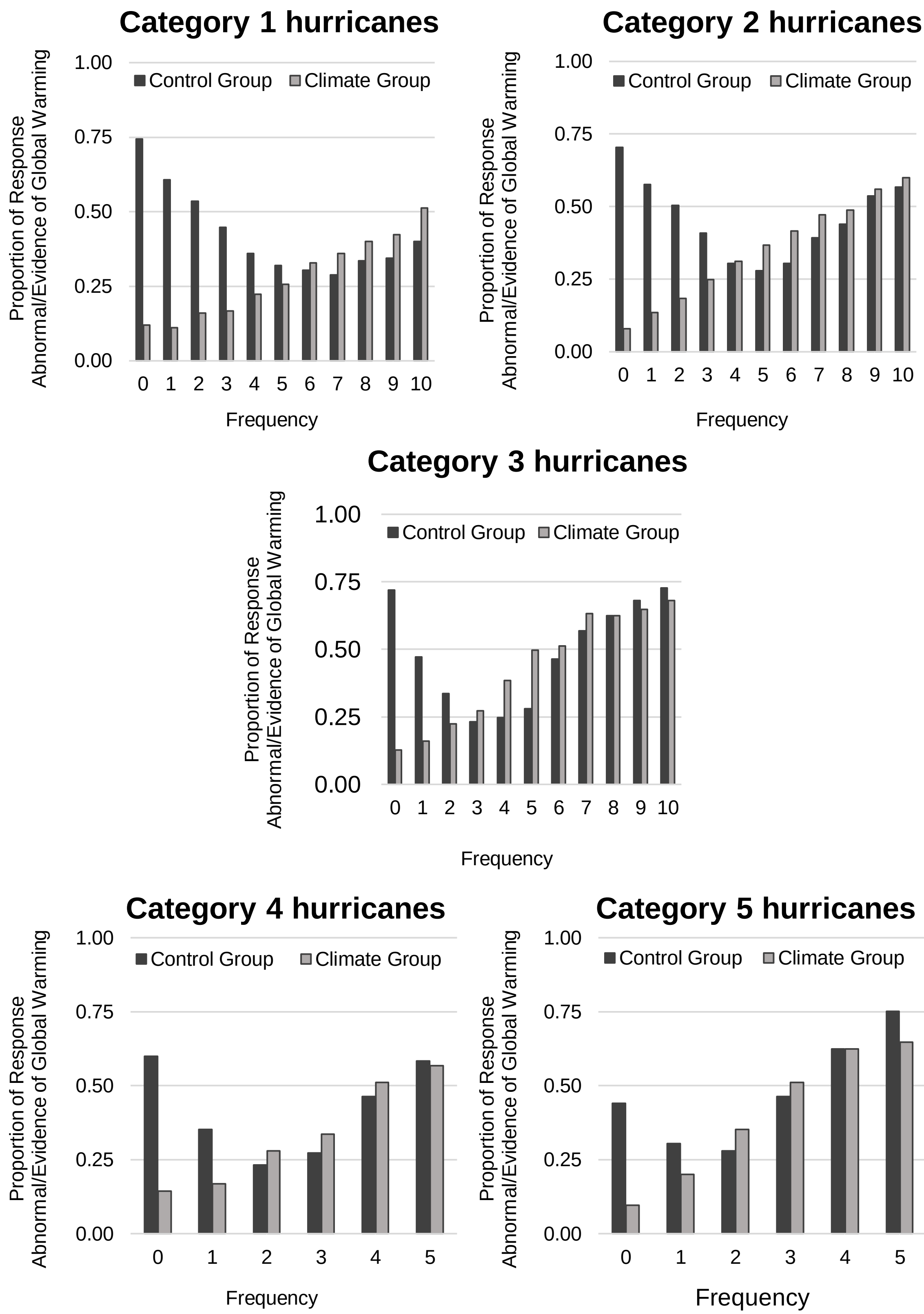


Figure 7: The proportion of responses in the control group (choosing abnormality) and the climate group (choosing evidence of global warming) as a function of hurricane frequency separately for each hurricane category.

The sensitivity measure ranges from 0 (perfect reverse discriminability between signal and noise) to 1 (perfect discriminability between signal and noise) with a score 0.5 in the middle, representing chance. Sensitivity estimates from this sample ranged from 0.31 (minimum) to 0.97 (maximum). Decision threshold estimates ranged from -2.88 (lax thresholds resulting in more abnormal / evidence responses) to 2.88 (strict thresholds resulting in more normal / not evidence responses). The average sensitivity for the control condition [mean (M) = 0.62 , standard deviation (SD) = 0.12] was lower than the climate condition (M = 0.73, SD = 0.16), and participants in both conditions performed significantly better than chance in discriminating the hurricane frequencies with respect to my grading criteria (one-sample t-test, $p < 0.0001$). The average decision threshold for the control condition (M = 0.23, SD = 0.61) was less strict than the climate condition (M = 0.78, SD = 1.41). This means that individuals in the control group perceived the hurricane frequencies as overall more abnormal than the climate condition perceived them as being evidence of global warming, reflecting findings similar to those of Broomell and co-authors (2017).

Inferential statistics: Table 9 shows results of regression analyses predicting the SDT parameters in the hurricane task. Threshold and sensitivity were regressed onto five sets of predictors: (a) experimental condition (control or climate group) and location (non-coastal or coastal resident), (b) demographic variables, (c) the four scales measuring beliefs and experience, (d) extreme event preparation measures, and (e) numeracy, plus one knowledge question to determine whether people know a hurricane watch is less severe than a hurricane warning. The regression model includes an interaction term between experimental group and the individual covariates to allow for different slopes in each of the respective experimental conditions. Significant interactions represent differential effects of individuals predictors on perceiving abnormality in the control group versus perceiving evidence of global warming in the climate group.

Table 9 displays the coefficients estimated for both sensitivity and decision threshold. The predictors accounted for more variance in sensitivity ($R^2 = 0.46$) than in the decision threshold ($R^2 = 0.31$). The top of the table reveals significantly greater sensitivity and a stricter decision threshold in the climate group, compared to the control group. There was a significant effect for coastal residents ($p = 0.02$) for sensitivity, but no such effect was present for decision threshold. There were no other significant main effects for predicting sensitivity and decision threshold. However, two interaction effects were significant. The bottom of the table shows significant interaction effects for predicting sensitivity from the interaction of experimental group and climate change beliefs ($p = 0.001$), as well as the interaction of experimental group and numeracy ($p = 0.04$). These variables also had significant interactions with experimental group for predicting decision threshold ($p < 0.0001$ for climate change beliefs and $p = 0.02$ for numeracy).

TABLE 9: Coefficient estimates (and standard errors) for predicting decision threshold (criterion *C*) and sensitivity (area under the ROC curve) in classifying hurricane frequencies. Group is coded as Control = 0, Climate = 1; Location is coded as Non-coast = 0, Coastal = 1; Gender is coded as Male = 0, Female = 1. Politics is coded as Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), and Extremely Conservative (-3). The decision threshold for interpreting hurricanes is neutral at 0, with negative values indicating bias toward abnormal / evidence of global warning responses and positive values indicate bias toward normal / not evidence of global warming responses. Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Predictor	Decision threshold for hurricane frequencies (criterion *C*)				Sensitivity for hurricane frequencies (area under the ROC curve)			
	Estimate		Std. err.		Estimate		Std. err.	
Intercept	0.22		0.18		0.65***		0.02	
Design variables								
Climate group	0.44*		0.21		0.08**		0.03	
Coastal	0.08		0.15		-0.04*		0.02	
	Main effect (control group baseline slope)		Interaction effect (change in slope for climate group relative to control group)		Main effect (control group baseline slope)		Interaction effect (change in slope for climate group relative to control group)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Demographics								
Age	-0.05	0.10	0.09	0.14	0.01	0.01	-0.01	0.02
Female	-0.01	0.10	0.01	0.14	-0.01	0.01	0.02	0.02
Education	0.05	0.09	-0.07	0.13	0.01	0.01	-0.02	0.02
Politics	-0.01	0.11	0.04	0.15	0.01	0.01	0.00	0.02
Beliefs								
Climate Change	0.02	0.11	-0.67***	0.14	0.01	0.01	0.06***	0.02
Weather Salience	-0.04	0.10	-0.15	0.14	0.00	0.01	-0.02	0.02
Experience	0.06	0.15	0.10	0.21	0.02	0.02	-0.01	0.03
Impacts	-0.03	0.13	-0.22	0.21	-0.03	0.02	0.01	0.02
Preparation								
Shelter	-0.11	0.25	0.14	0.34	-0.01	0.03	0.03	0.04
Supplies	0.02	0.25	0.03	0.34	0.01	0.03	0.02	0.04
Knowledge								
Numeracy	-0.05	0.10	0.33*	0.14	0.02	0.01	0.03*	0.02
Knows Watch < Warning	0.00	0.10	0.11	0.14	0.01	0.01	0.02	0.02
R^2			0.31				0.46	

Figure 8 shows the theoretically relevant interaction between experimental group and climate change beliefs (Table 9; $p < 0.0001$). Individuals reporting higher climate change beliefs had a similar predicted decision threshold in the two groups. However, individuals reporting lower climate change beliefs had a less strict threshold for responding “abnormal” compared to responding “evidence of global warming.” This interaction provides support that climate change beliefs are associated with perceptual thresholds and are creating a perceptual bias.

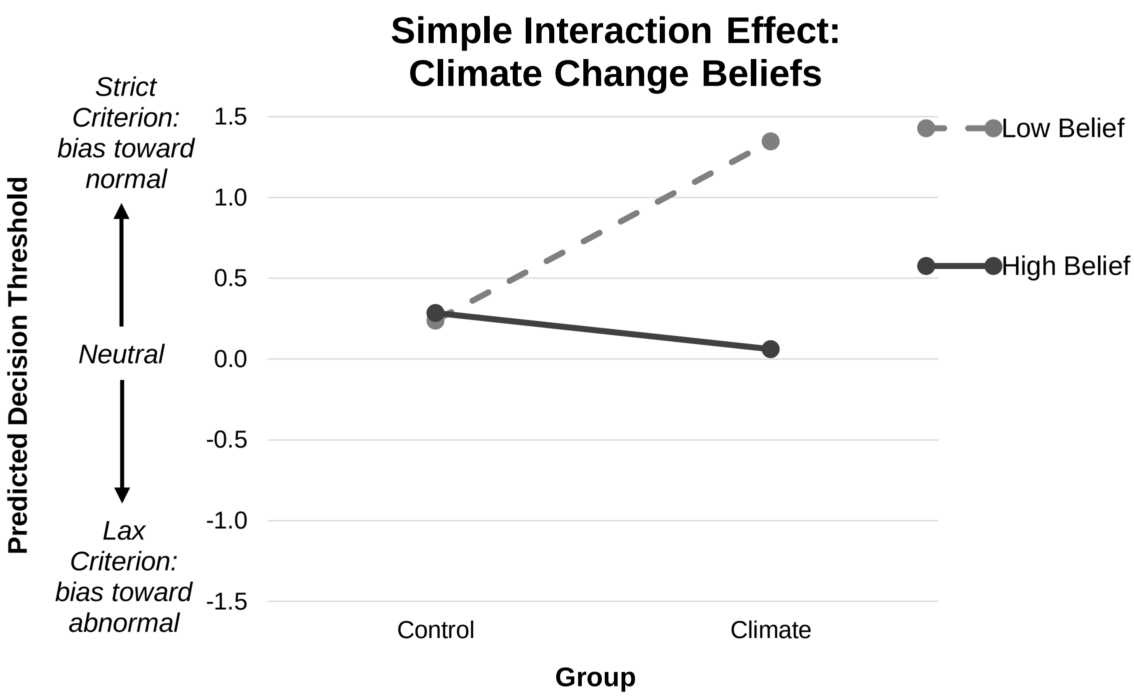


Figure 8: The simple interaction effect for predicting decision threshold of hurricane frequencies based on the interaction between condition assignment and climate change beliefs ($p < 0.0001$). This plot is generated by displaying the predicted mean decision threshold when using values for the predictor values that are one standard deviation above and below the mean, within each experimental group.

3.3.4.3 Analysis of Support for Immediate Climate Action

Descriptive statistics: Figure 9 shows the distribution of responses to the dependent variable: “The only way to avoid possible future serious changes in the climate is to take action to stop them now.” In both experimental groups, 78% of respondents agreed or strongly agreed with this statement. Compared to the control group, a higher percentage in the climate group disagreed or strongly disagreed with this statement (10% versus 14%), but this difference was not significant [χ^2 (1, n = 227) = 0.70, p = 0.40].

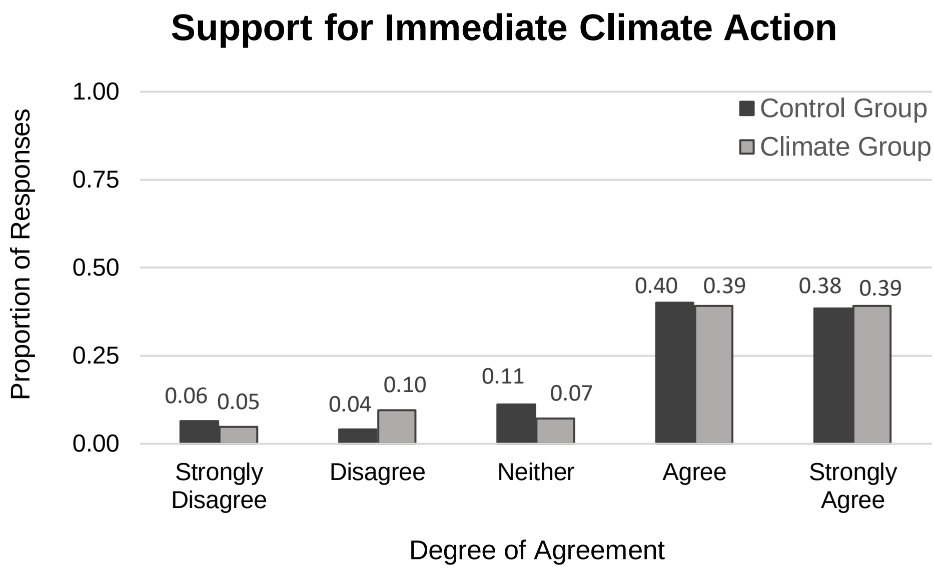


Figure 9: Distribution of responses to the statement: "The only way to avoid possible future serious changes in the climate is to take action to stop them now," separately for the control group (darker bars on the left) and climate group (grey bars on the right).

Inferential statistics: Table 10 shows results of regression analysis predicting support for immediate climate action. I regressed support onto four sets of predictors: (a) demographic variables, (b) the four scales measuring beliefs and experience, (c) extreme event preparation measures, and (d) numeracy.

TABLE 10: Coefficient estimates (and standard errors) for predicting support for immediate climate action: "The only way to avoid possible future serious changes in the climate is to take action to stop them now." Response options are coded as Strongly disagree (1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), and Strongly Agree (5). Gender is coded as Male (0), Female (1). Politics is coded as Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), and Extremely Conservative (-3). Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Predictor	Support for immediate climate action	
	Estimate	Standard Error
Intercept	4.03***	0.07
Demographics		
Age	-0.01	0.05
Female	-0.01	0.05
Education	0.04	0.05
Politics	0.13**	0.05
Beliefs		
Climate Change	0.79***	0.05
Weather Salience	0.10*	0.05
Experience	-0.03	0.07
Impacts	0.09	0.07
Preparation		
Shelter	0.12	0.12
Supplies	-0.20	0.12
Numeracy	0.06	0.05
R^2		0.63

Table 10 displays the coefficients estimated for support for immediate climate action. The predictors accounted for 63% of the variance. There were significant effects for political ideology ($p = 0.01$), climate change beliefs ($p < 0.0001$), and weather salience ($p = 0.04$). These results are similar to the findings in my logistic regression in Chapter 1 predicting the identical dependent variable.

3.4 Conclusion

This present study reports the first psychophysical investigation of climate attribution for hurricanes (Study 2), a topic of growing interest and attention in public and scientific discourse. The goal was to assess the extent to which people perceive certain extreme weather events as attributable to climate change and when they view hurricane frequencies as abnormal. I aimed to better understand whether, and to what extent, these perceptions are influenced by demographic factors and beliefs and how these factors influence support for immediate climate action.

Study 1 revealed that people believed climate change affects extreme weather events,[(53,58,61)] specifically with respect to increasing the frequency and severity of hurricanes. Lay respondents in Study 1 readily understood non-stationary processes when they were explained using simple spinner boards, and they were able to use these boards to correctly explain such processes to others.

The signal detection analysis (Study 2) found that, independent of their prior beliefs about whether the climate was changing, and whether those changes were affecting the frequency or intensity of hurricanes, all respondents across experimental groups performed comparably in identifying the occurrence of unusual hurricane events. When specifically asked to identify hurricane events that might be indicative of some influence from climate change, respondents were more conservative in making such an attribution, a reasonable position given that not all unusual events may be influenced by climate change. Not surprisingly, respondents who were more dubious about the existence of climate change required a higher threshold before they were willing to suggest that an unusual hurricane event might be influenced by climate change. Climate change beliefs, in addition to political ideology and weather salience beliefs, were significant predictors in the urgency of action analysis (Table 10).

Taken together I find these results encouraging: using a simple explanatory device, people can correctly understand the changing probabilities associated with non-stationary extreme events. They are fairly good at detecting unusual extreme (hurricane) events. They do not attribute all such events as evidence of an influence from climate change. Finally, if they have their doubts about climate change, they apply a higher threshold to making such an attribution; but as events become more extreme, they nevertheless begin to make such an attribution.

Increasingly, discussions of climate attribution of extreme events can be found in the media[52] newspapers,[49] or on commutes to work and school. While the science of climate attribution is progressing, the public is joining the conversation with their own sets of beliefs and heuristics. By establishing a number of baselines, the study results have practical implications for the development of risk communications on the impacts of climate change. In the past, many TV weather forecasters have been reluctant to mention climate change when talking about extreme events, although their views and acceptance are evolving.[75] Despite this, people's clear understanding of attribution when explained in terms of spinner boards, coupled with their fairly cautious interpretations in the signal detection study, may provide weather forecasters with a vehicle to provide compelling visual explanations, as well as a basis for arguing that employing such displays can be readily justified.

4. Public perceptions of individual and collective response-efficacy for emissions abatement

Abstract
When we burn coal, oil, and natural gas, that adds carbon dioxide (CO_2) to the atmosphere. As a greenhouse gas, CO_2 warms the planet, causing changes in the climate. Climate change requires people to make multiple decisions, sometimes involving conflicting objectives about whether to support climate change policies, and if so, which ones. Experts in the scientific community have identified many strategies that government, society, and individuals can adopt to reduce (and eventually stop, or perhaps, even reverse) CO_2 emissions. However, without some grasp of which private and public actions are both possible (self-efficacy) and effective (response-efficacy), laypeople may find it hard to make informed decisions about how to reduce their own carbon footprint and to cope with changes in the climate that impact their daily lives. I build upon this body of research by eliciting quantitative point estimates of laypeople's efficacy beliefs. I also examine beliefs about whether individuals and society at large have done enough to curb CO_2 emissions, if more could be done, and if more should be done. These findings could have important implications for the improvement of communications on what can be done to take action in response to climate risks.

4.1 Introduction

Burning coal, oil, and natural gas adds carbon dioxide (CO_2) to the atmosphere. As a greenhouse gas, CO_2 warms the planet, which causes the climate to change. The literature has long tracked laypeople's understanding and misunderstandings of the causes of climate change,(8-10) as well as how long CO_2 remains in the atmosphere and continues to change the climate.(65) While American's knowledge of climate change has improved somewhat over the years,(8) gaps still exist in that understanding with respect to causes, consequences, and the most effective solutions.(11,76) Many Americans do understand that burning fossil fuels causes the climate to change(8) and that a transition to renewable energy is one of the important solutions.(11) Misunderstandings of the causes of climate change, however, can lead to support for ineffective or counterproductive solutions, such as stopping rockets from punching new holes in the atmosphere or ending the use of nuclear power.

Emissions from human activity are driven by population growth, technological advancement, and economic growth, particularly in industrialized countries.(2) Responding to climate change requires people—particularly those living in industrialized countries—to take both collective and individual responsibility for addressing the problem.[2]

Individuals have two important roles in the effective management of anthropogenic emissions to mitigate climate change. The first is to support emissions abatement legislation and regulations. Without some grasp of which private and public actions are both possible (self-efficacy) and effective (response-efficacy), people may find it hard to make informed decisions about broader climate policy and how to cope with changes in the climate that impact their daily lives. The second role involves changes in lifestyles and consumer behavior to reduce one's own carbon footprint. Of course, knowledge regarding the causes of climate change alone does not necessarily lead to change in behavior,[12] although it is important.[13-15] Other social and economic factors, such as what it costs to take action and what the barriers are, influence how knowledge translates into action (or inaction).

Public opinion can drive decisions about addressing climate risks, divert action away from those risks, or have no influence at all. Although governments can implement some policies to address climate challenges without broad public involvement, public support strengthens these efforts and is essential for others.[77] Experts in the scientific community have identified several strategies that government, society, and individuals can adopt to reduce (and eventually stop, or perhaps, even reverse) CO_2 emissions.[77] While successfully mitigating or adapting to global climate change will require collective government and societal action, several individual changes can be made to create a "behavioral wedge"[78] to help reduce CO_2 emissions. However, individual behavior and choices alone can only contribute in a modest way to reducing the global changes in the climate that are resulting from the collective behaviors of billions of people; and the socio-economic systems in which we live are placing the Earth's climate system at ever greater risk of serious damage.[3,12]

Several studies have suggested the most effective ways to mitigate climate risks via private and public actions.[79-81] Bostrom and co-authors (2018) developed scales featuring laypeople's beliefs in their own ability and the effectiveness of their actions to mitigate the risks of climate change. However, even in a perfect world, where all recommended actions have been taken, it is unclear how the public perceives the overall response-efficacy of individual actions alone (e.g. traveling less, wasting less food). I build upon this body of research by eliciting quantitative point estimates of laypeople's efficacy beliefs. I also examine beliefs about whether individuals and society at large have done enough to curb CO_2 emissions, if more could be done, and if more should be done.

First, in a small face-to-face study, I explored peoples' understanding and perceptions of individual and collective actions to reduce CO_2 emissions, as well as their perceptions of scientists' views on the matter.

Then, in a larger study using Amazon Mechanical Turk (MTurk), I explore:

1. Whether laypeople's personal beliefs correspond to how they think *scientists* view individual and collective action to reduce CO_2 emissions;
2. What laypeople believe is the fraction of the total (possible) future reduction in CO_2 emissions that could come from individual actions alone without government or broader societal action;
3. The extent to which personal beliefs and individual difference measures are predictive of laypeople's responses to question (2); and,
4. Whether laypeople view the response-efficacy of individual or private action as the same as that of government action, where they believe most of the burden should fall in reducing CO_2 emissions, and how well these beliefs predict their support for immediate climate action.

4.2 Methods

4.2.1 Study 1: Face-to-face interviews

Participants: For the first study, a convenience sample of 28 face-to-face interviews was carried out through Carnegie Mellon's Center for Behavioral and Decision Research in Allegheny County (AC), Pennsylvania (PA). Note that this is a different set of interviewees than presented in Chapter 3 of this thesis. The ages of respondents in this sample ranged from 18-73 years old (mean = 30.0, median = 22.5). This convenience sample, on average, was younger than both the AC and U.S. populations (41 and 37, respectively). This sample was well educated compared to the U.S. population: 28 (100%) had finished high school [U.S. = 88%], 10 (36%) had completed college [$U.S._{some}$ = 59%; $U.S._{all}$ = 33%], and 6 (22%) had completed graduate training [U.S. = 12%]. Of the total sample, 17 (61%) identified as liberal [AC = 60%, U.S. 47%], and 13 (46%) were female [AC = 52%, U.S. = 51%]. The results are biased toward younger, educated liberals. The full demographic composition of the sample is displayed in Table 11.

TABLE 11: Demographic distribution of interview sample ($N = 28$)

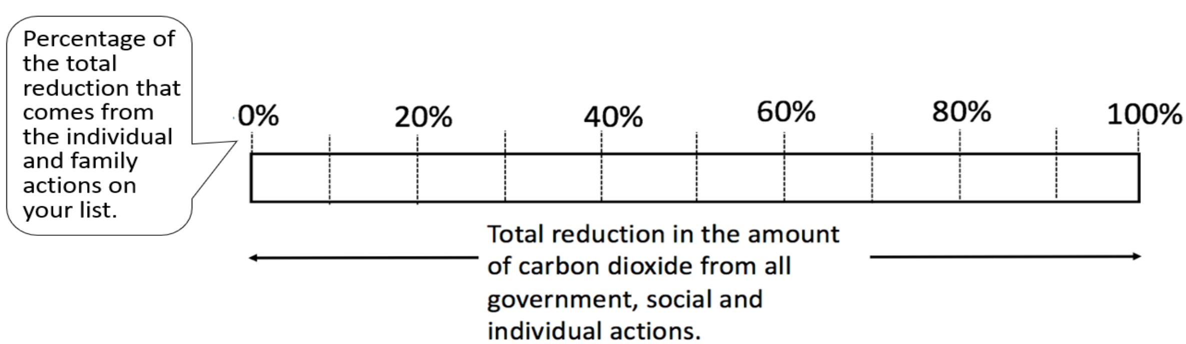
Demographics	Frequency	Fraction
Gender		
Female	13	0.46
Male	15	0.54
Political ideology		
Extremely Liberal	2	0.07
Liberal	11	0.39
Slightly Liberal	4	0.14
Moderate / Middle of the Road	6	0.21
Slightly Conservative	2	0.07
Conservative	3	0.11
Extremely Conservative	0	0.00
Education		
Some high school	0	0.00
High school graduate	1	0.04
Some four-year college, junior college or trade school	17	0.61
Junior or trade school graduate	0	0.00
Four-year college graduate	4	0.14
Graduate school in a non-technical field	3	0.11
Graduate school in a technical field	3	0.11

Procedure: On average, the semi-structured interviews lasted about 30 minutes, and participants were compensated $5.00 for their time. The interview protocol adopted wording from previous studies on public understanding of climate change.[(8-10)] Other questions were pre-tested in a set of pilot interviews. The interview protocol contained two major sections that explored: 1) what respondents thought had been and ought to be done by (a) individuals and families and (b) government and society to reduce how much CO_2 is being added to the atmosphere; and 2) respondents' assessments of what a group of experts thought were the most effective ways for (a) individuals and families and (b) government and society to reduce how much CO_2 was being added to the atmosphere. In the first section, participants devised their own list. In the second section, participants examined and assessed lists of actions developed by Carnegie Mellon Faculty members Granger Morgan, Inês Azevedo, Constantine Samaras, and Hadi Dowlatabadi (hereafter, "Expert Lists").

The first section began with the question: "What changes, if any, do you think government and society have already made to reduce how much CO_2 is being added to the air?" Following a series of neutral prompts, participants were then asked to describe everything they thought that government and society could do in the future to reduce CO_2 emissions. Parallel questions were then posed for individual efficacy actions and beliefs: "Have you or your family taken any actions to try to reduce how much CO_2 is being added to the air?" and "Tell me about all the other things you think you or your family could do in the future [to reduce CO_2 emissions]." Responses to all the questions in the first section comprised the "Participant's List" of suggested actions to reduce CO_2 emissions. In a second version of the interview, I reversed the order of questions about individual and government and societal actions.

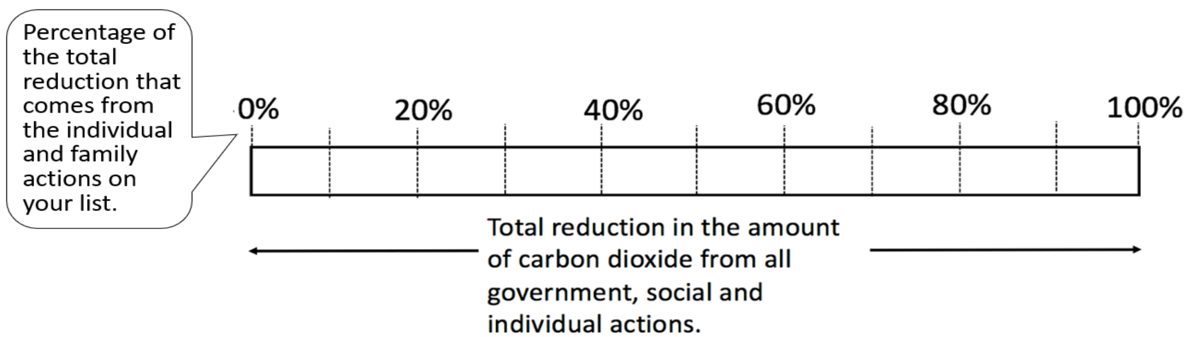
All respondents received the same version of a second section in which the elicitation began: "Suppose that in 2020, Americans and governments at all levels all got serious about doing the things on [the list the respondent had constructed]." Respondents received the following question:

> "Suppose that this bar represents the total reduction of CO_2 emissions in the year 2030 that would have occurred after all the changes on the two lists you just put together have been made by all members of society. Please put an X on the bar to show how much of that decrease you think would come from ONLY the actions of individuals and their families (not the additional things society could do). If you think that those individual actions would cause much or even most of the decrease, you should choose a high number. That is, you should put your X somewhere on the right-hand end of the bar. If you think that the individual actions will cause only a little of the decrease, you should choose a low number. That is, you should put your X somewhere on the left-hand side of the bar."



For a second set of similar questions, participants were given list of individual and collective actions that science and engineering experts had judged could result in the largest reductions in CO_2 (i.e. the "Expert Lists). Participants were told that there were many more things that could be added to these lists; but these were the things that experts said could do the most to reduce CO_2 emissions (Appendix C.1, "Expert Lists"). Participants were instructed to review the Expert Lists and then to answer a nearly identical question to the one previously posed:

> "Suppose that in 2020, Americans and governments at all levels all got serious about doing the things on these two lists. This time, suppose that this bar represents the total reduction of CO_2 emissions in the year 2030, due to all members of society making all of the changes on the two expert lists.
>
> Please put an X on the bar to show how much of that decrease you think would come from ONLY the actions of individuals and their families (not the additional things society could do). If you think that those individual and family actions would cause much or even most of the decrease, you should choose a high number. That is, you should put your X somewhere on the right-hand end of the bar. If you think individual and family actions would cause only a little of the decrease, you should choose a low number. That is, you should put your X somewhere on the left-hand side of the bar."



Those participants who changed their answers from the first scale bar question to the second were asked to explain their reasoning for the change.

The interview concluded with a short survey covering general belief questions (answered on a 5-point, degree of belief scale comprised of "true," "probably true," "don't know," "probably false," and "false"); public support questions (answered on a 5-point, degree of agreement scale comprised of "strongly disagree," "disagree," "neither disagree nor agree," "agree," and "strongly agree"); and demographic questions (i.e., gender, age, occupation, level of education, and political ideology). One question about "Who should be most responsible for taking actions to reduce carbon emissions?" was answered on a scale comprised of "individuals," "businesses," and "government:"

Results: Audio recordings of the interviews were transcribed and coded in ATLAS.ti based on thematic patterns. Because the issues raised were quite straight-forward, I did not have a second person code the responses, although I will do so before preparing the results for publication. Some broad themes I examined include self-efficacy beliefs, effectiveness of those beliefs, presence of general pro-environmental attitudes, and climate change beliefs. General findings and response statistics are described below.

While some participants suggested effective ways to reduce CO_2 emissions, such as greater use of renewable energy (54%) or converting to electric vehicles (71%), others cited general pro-environmental actions that do not significantly reduce CO_2 emissions, such as recycling (57%). No participant mentioned family planning or having fewer children as a means of reducing CO_2 emissions.

Most participants (71%) mentioned day-to-day behavioral actions, "the typical stuff like not leaving lights on when you leave a room and not running the water when you're brushing your teeth;" while one suggested more involved undertakings: "[My wife and I] have looked at going solar. It would take a long time to pay it back. It is something we are still considering" (male, 34 years old). The same participant continued that the large up-front investment in solar panels had, thus far, deterred his family from investing, although they hoped to be able to do so in the future. In line with the findings of Bostrom and co-authors (2018), people did not always know the most effective ways they could contribute to greenhouse gas reduction.

Based on the initial scale bar response, participants believed that anywhere between 10-80% of overall emissions reduction could come from individual and family actions alone (mean = 35%, median = 35%). After reviewing the Expert Lists, participants still believed anywhere from 10-80% of overall emissions reduction could come from individual and family actions alone. However, the mean response increased to 46% and the median to 45% (Fig. 10). All those who had changed responded that the Expert Lists were longer—and therefore—they believed those actions could lead to larger reductions. Dietz and co-authors (2009) find that "the national reasonably achievable emissions reduction (RAER) can be approximately 20% in the household sector within 10 years." Therefore, 20% is used as a "baseline" for comparison to participants' beliefs elicited in this thesis chapter.

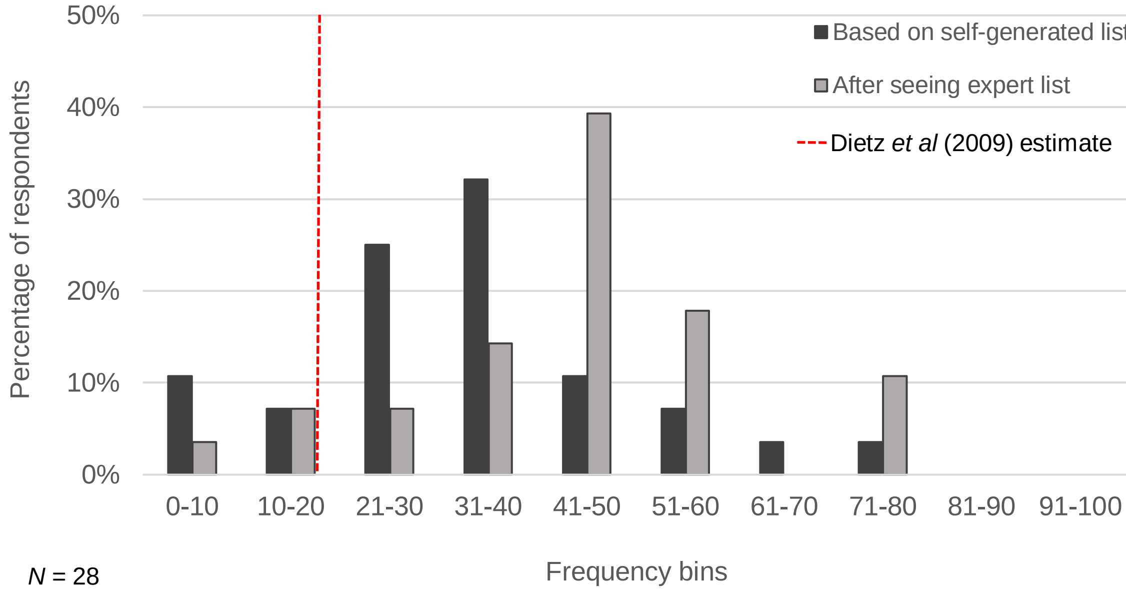


Figure 10: Response distribution to the percentage of total (possible) future reduction in CO_2 emissions that could come from individual actions alone for initial assessment based on respondents' self-generated lists (black bars) and subsequently on expert lists (gray bars). Respondents said that they increased their fraction in the latter case, because the expert list for individual action was longer, but apparently did not consider that *both* the individual and government action lists had gotten longer. The RAER estimate of 20% is shown in the red dotted line (Dietz *et al*, 2009).

4.2.2 Study 2: MTurk sample

Participants: The follow-on survey was informed by results from Study 1. For Study 2, a national, convenience sample was recruited via MTurk (N = 253). The ages of respondents in the MTurk sample ranged from 20-71 years old (mean = 35.9, median = 33). This convenience sample, on average, was slightly younger than the U.S. population (mean = 37). In this sample, 99% had finished high school [U.S. = 88%], 59% had completed college [$\text{U.S.}_{\text{some}}$ = 59%; U.S._{all} = 33%], and 8% had completed graduate training [U.S. = 12%]. Of the total sample, 56% identified as liberal (U.S. 47%), and 39% of respondents were female (U.S. = 51%). The results are biased toward younger, liberal males. The full demographic composition of the sample is displayed in Table 12.

TABLE 12: Demographic distribution of national MTurk sample (*N* = 253)

Demographics	Frequency	Fraction
Gender		
Female	98	0.39
Male	155	0.61
Political ideology		
Extremely Liberal	42	0.17
Liberal	64	0.25
Slightly Liberal	35	0.14
Moderate / Middle of the Road	47	0.19
Slightly Conservative	23	0.09
Conservative	36	0.14
Extremely Conservative	6	0.02
Education		
Some high school	2	0.01
High school graduate	38	0.15
Some four-year college, junior college or trade school	51	0.20
Junior or trade school graduate	14	0.06
Four-year college graduate	128	0.51
Graduate school in a non-technical field	12	0.05
Graduate school in a technical field	8	0.03

Procedure: Potential participants read a short description of the task posted to MTurk. If interested, they were routed to an online survey (implemented through Qualtrics). Upon completion of the task, participants received unique confirmation codes to redeem $1.25 as compensation for their time. The task took about 10 minutes to complete. To be eligible to participate in the study, participants had to be 18 or older, fluent in English, have access to a desktop computer, reside in the U.S., and have at least 95% approval rate and at least 500 previously approved tasks. I included three attention checks to assess whether participants were paying attention for the task duration.

As in Study 1, Study 2 consisted of four sections that asked about: 1) people's beliefs about actions already taken and if more could (or should) be taken by (a) individuals and families and (b) government and society to reduce how much CO_2 is being added to the atmosphere (9 items); 2) parallel questions to these in which respondents were asked how they think *scientists* view these issues (8 items); (3) a quantitative scale bar question that elicited people's beliefs on the fraction of total (possible) future reduction in CO_2 emissions that could come from individual actions alone (1 item); and (4) general belief questions about perceptions of climate change, CO_2, efficacy beliefs, and policy support (13 items). A number of questions adopted wording from previous studies on public understanding of climate change.[8-10] Others were pre-tested in the face-to-face interviews in Study 1. Eight "degree of agreement" questions and the quantitative scale bar question used in Study 1 were included in the MTurk survey. Common questions between the two studies are discussed in the main results section of this chapter where appropriate (Appendix C.2).

Questions in sections 1 and 2 of the MTurk study were randomly presented to each participant to mitigate (potential) order effects. Demographic questions (educational attainment, age, gender, political ideology, and state of residence) were placed at the end of the survey so as not to influence responses.

The survey began with a short introduction:

> Scientists and engineers have identified several things we can do to stop adding carbon dioxide (CO_2) to the atmosphere:
> - Some of these require government and society to make basic changes in the way energy is produced and used, and,
> - Some of these are things we and our families can do as individuals.

In the questions that followed, participants were asked to check the response that was closest to their best judgement about the statements on a 5-point degree-of-agreement scale. For their beliefs regarding individual and family action, participants were asked a series of questions that were randomly presented. These included whether: 1) many actions had already been taken by individuals and families to reduce how much CO_2 is being added to the atmosphere; 2) individuals and families could do more to reduce CO_2 emissions; 3) individuals and families should do more to reduce CO_2 emissions; 4) they believed they have already done their fair share to reduce CO_2 emissions; and 5) they believed it was possible for individuals and families alone to reduce nearly all CO_2 emissions without governmental or broader societal action.

The next section randomly presented parallel questions, swapping "individuals and families" with beliefs about the role of "governments and society." These first two sections were duplicated but instead of asking about their own personal beliefs, participants were asked to make judgements about how *scientists* viewed these topics.

Then, participants answered a scale bar question after reviewing the “Expert Lists” that included the different ways governments, society, individuals, and their families could make the largest reductions in CO_2 emissions (Appendix C.1, “Expert Lists”). The length of the Expert Lists was approximately the same and were presented at the same time.

Figure 11: Response method for question that asked participants to drag the slider to the percentage that reflected how much individual and family actions alone could reduce total future CO_2 emissions.

Participants then answered a number of questions about climate change, CO_2, efficacy beliefs/policy support questions, and demographics (Appendix C.3). All responses were anonymous.

4.3 Results

4.3.1 Do laypeople’s personal beliefs correspond to how they think scientists view individual and collective action to reduce CO_2 emissions?

Descriptive statistics: The pattern and magnitude of how people viewed these issues versus how they believed *scientists* viewed these issues are displayed in Table 13. The more positive the values, the more people agreed with the question. Of the 8 question pairs, all were positively correlated ($p < 0.001$ for all; Table 14), and 4 showed a statistically significant difference between how people viewed these issues compared to how they believed *scientists* viewed them (Table 13). Only these 4 cases are discussed further.

Both sets of views (i.e. personal and beliefs on scientists’ views), on average, indicated disagreement about whether individuals have already taken many actions to reduce how much CO_2 is being added to our atmosphere (Table 13). However, personal disagreement was not as strong as the disagreement people thought scientists had with this statement (paired *t*-test, $t = 3.29$, $df = 252$, $p = 0.001$, 95% *CI* [0.08, 0.32]).

Both sets of views, on average, indicated agreement that individuals should do more to reduce how much CO_2 is being added to our atmosphere (Table 13). However, personal agreement was not as strong as how much people thought scientists would agree with this statement (paired *t*-test, $t = -2.42$, $df = 252$, $p = 0.02$, 95% *CI* [-0.21, -0.02]).

Both sets of views, on average, indicated disagreement that government and society have already taken many actions to reduce how much CO_2 is being added to our atmosphere (Table 13). However, personal disagreement was not as strong as the disagreement people thought scientists had with this statement (paired *t*-test, $t = -3.76$, $df = 252$, $p < 0.001$, 95% *CI* [-0.32, -1.00]).

Finally, both sets of views, on average, indicated disagreement that government and society have already done their fair share of CO_2 reduction (Table 13). However, personal disagreement was not as strong as the disagreement people thought scientist had with this statement (paired *t*-test, $t = -2.65$, $df = 252$, $p = 0.01$, 95% *CI* [-0.24, -0.04]).

TABLE 13: Comparison of personal views versus views on what *scientists* believe regarding individual and broader societal/governmental actions to reduce CO_2 emissions. Responses are coded as Strongly Agree (2), Agree (1), Neither Disagree nor Agree (0), Disagree (-1), and Strongly Disagree (-2). Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Question Pairs	Personal Views	Beliefs in Scientists' Views
	Mean	Mean
Govt/Society *could* do more	1.45	1.40
Govt/Society *should* do more	1.37	1.45
Individuals *could* do more	1.24	1.28
Individuals *should* do more	1.23*	1.34*
Govt/Society has done fair share	0.84**	0.98**
Individuals *alone* can reduce most CO_2	0.57	0.51
Govt/Society have *already* taken many actions	0.31***	0.52***
Individuals have *already* taken many actions	-0.12***	-0.32***

TABLE 14: Correlations between personal views and views on what *scientists* believe regarding individual and broader societal/governmental actions to reduce CO_2 emissions. Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Question Pairs	Spearman's rho (ρ)
Govt/Society *could* do more	0.65***
Govt/Society *should* do more	0.58***
Individuals *could* do more	0.48***
Individuals *should* do more	0.56***
Govt/Society has done fair share	0.75***
Individuals *alone* can reduce most CO_2	0.68***
Govt/Society *already* taken many actions	0.74***
Individuals *already* taken many actions	0.64***

4.3.2 What do laypeople believe is the fraction of the total (possible) future reduction in CO_2 emissions that could come from individual actions alone without government or broader societal action? To what extent are personal beliefs and individual difference measures predictive of their response?

Descriptive statistics: Figure 12 shows responses to the scale bar question, displayed as the percentage of respondents indicating their beliefs in the fraction of total future reduction in CO_2 emissions that could come from individual actions alone (mean = 34%, median = 30%; *N* = 251). This corresponds to the mean response of 35% in Study 1 (*N* = 28) and is higher than the finding of 20% by Dietz and co-authors (2009). These proportions show that participants believe individual actions, on their own, have higher response-efficacy than may be attainable. This sentiment is also reflected in responses to the question: "It is possible for individual and families *alone* to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action" (Fig. 13). Note that the sample size change in some of the results is due to item non-response.

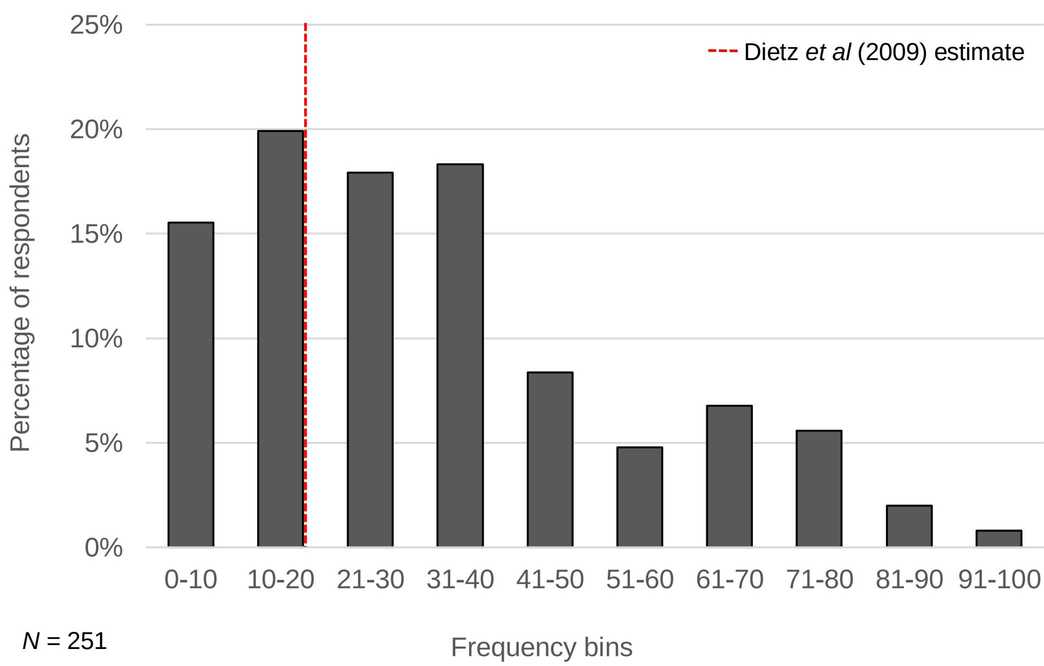


Figure 12: Response distribution to the fraction of total (possible) future reduction in CO_2 emissions that could come from individual actions alone. The RAER estimate of 20% is shown in the red dotted line (Dietz *et al*, 2009).

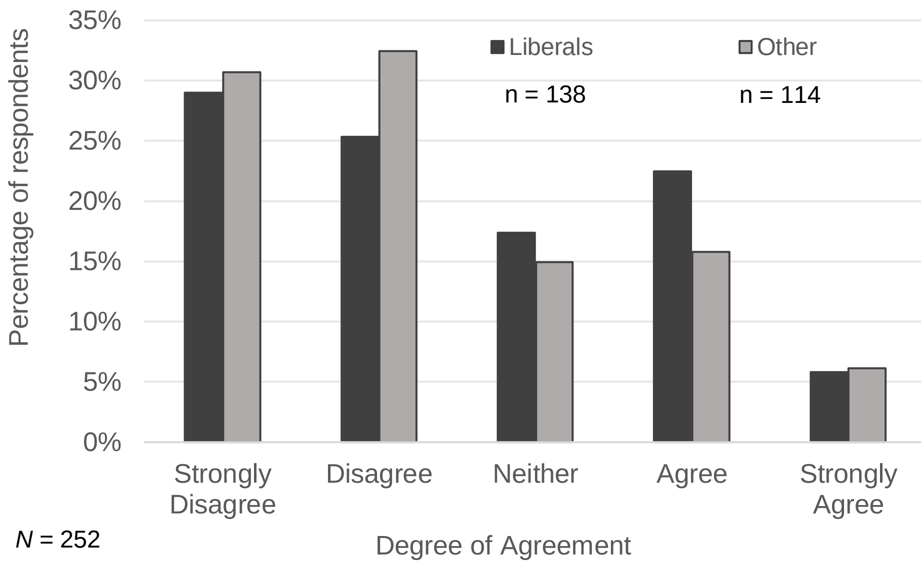


Figure 13: Response distributions to whether it is possible for individuals and families *alone* to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action by liberals (n = 138) and others (n = 114).

Factor analysis and scale construction: First, I conducted a variance inflation factor (VIF) multicollinearity test for all independent variables. There was some indication of multicollinearity (VIFs ranged from 1.17 to 3.75), and high correlations were present in a pairwise correlation matrix (Fig. C.3.1). Next, I conducted a factor analysis (KMO = 0.87) to reduce the data and build scales measuring people's beliefs to regress onto two dependent variables (Table 15 and Table 16).

A total of six reliable factors were found (see scree plot in Appendix C.3): (1) Climate Change (Causal) beliefs (3 items; Cronbach's α = 0.82), (2) Government Action beliefs (4 items; Cronbach's α = 0.86), (3) Individual Action beliefs (3 items; Cronbach's α = 0.75), (4) beliefs that More Action (is) Needed (8 items; Cronbach's α = 0.89), (5) Individual self-efficacy beliefs (2 items; Cronbach's α = 0.81), and (6) Individual and Governmental (combined) response-efficacy (2 items; Cronbach's α = 0.78). For each multi-item factor, I therefore computed a new variable (Appendix C.3).

Inferential statistics: Table 15 shows results of regression analysis predicting responses to the scale bar question. I regressed scale bar responses onto two main sets of predictors: (a) demographic variables and (b) six scales measuring beliefs about the causes of climate change, government and individual actions, the need for further action, and self- and -response-efficacy.

TABLE 15: Coefficient estimates (and standard errors) for predicting scale bar response, i.e. how much individual actions alone can reduce CO_2 emissions. Gender is coded as Male (0), Female (1). Politics is coded as Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), and Extremely Conservative (-3). Values in bold with an asterisk (*) denote $p <$ 0.05. Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Predictor	Prediction for Scale Bar Response	
	Estimate	Standard Error
Intercept	40.34***	5.91
Demographics		
Age	-0.19	0.12
Female	-1.59	2.50
Education	-0.09	0.91
Politics	0.34	0.71
Beliefs		
Climate Change (Cause)	-0.18	1.65
Government Actions	-5.89**	1.86
Individual Actions	-0.65	1.66
More Action Needed	3.00	1.68
Self-efficacy Individual	-8.33***	1.38
Response-efficacy Individual and Govt	-0.33	1.24
R^2		0.27

Table 15 displays the coefficients estimated for responses to how much individual actions alone could reduce CO_2 emissions. The predictors accounted for 52% of the variance. There were significant effects for governmental actions ($p < 0.01$) and individual self-efficacy beliefs ($p < 0.0001$).

There is a negative correlation between each of these independent variables and the scale bar response (i.e. beliefs in how much reduction in CO_2 is possible from individual actions alone). As the Government Actions predictor decreases (i.e. people tend to agree that governments and society have already taken many actions and done their fair share to reduce

CO_2 emissions), the mean scale bar response tends to increase. As the Individual Self-Efficacy predictor decreases (i.e. people tend to agree that it is possible for individuals alone to reduce nearly all CO_2 that is being added to our atmosphere), the mean scale bar response tends to increase.

4.3.3 Do laypeople view the response-efficacy of individual or private action the same as government action? Where do people believe most of the burden should fall in reducing CO_2 emissions, and how well do efficacy beliefs predict their intention to act in response to climate change?

Descriptive statistics: Participants answered two parallel questions about their beliefs on government (individual) response-efficacy: “I feel that actions the government (individuals) has (have) or could take to reduce CO2 emissions are effective in slowing global warming.” Participants, on average, agreed with these statements and showed no statistically significant difference between governmental (mean = 0.51) and individual (mean = 0.41) response-efficacy beliefs (paired *t*-test, $t = -1.72$, $df = 248$, $p = 0.09$, 95% *CI* [-0.22, 0.02]). In other words, these results suggest that laypeople (with similar characteristics to this sample) view individual and governmental response-efficacy the same; however, I would expect different results if participants were asked about specific actions taken by individuals versus the government (see Bostrom, Hayes, & Crosman, 2018).

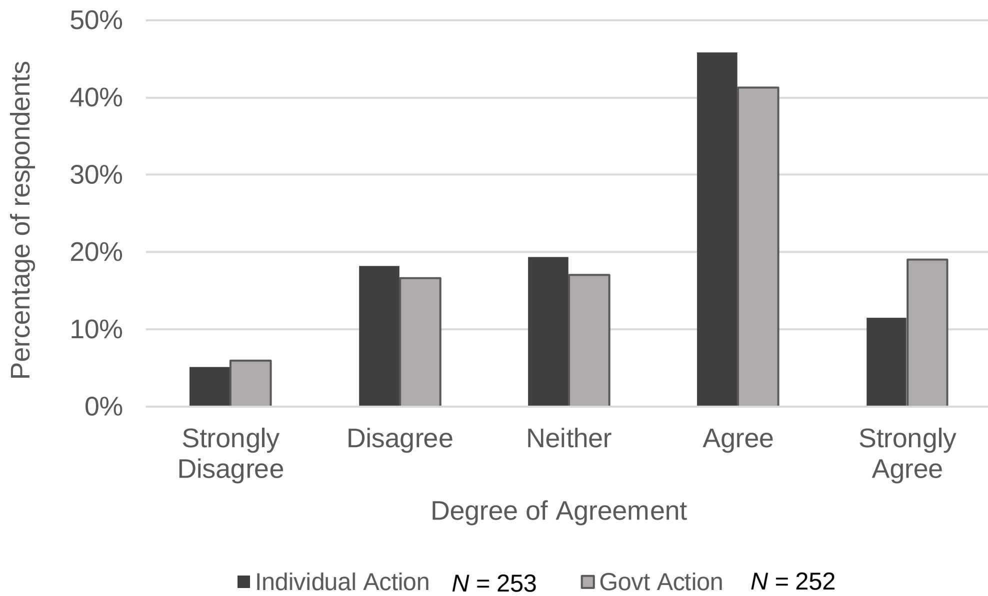


Figure 14: Response distribution to response-efficacy beliefs for individual and governmental actions. Note that the difference in sample size is due to item non-response for governmental actions.

Participants in Study 1 (*N* = 28) and Study 2 (*N* = 253, MTurk) answered an identical closed-form question: “Who is most responsible for taking actions to combat climate change?” Response options included “Individuals,” “Businesses,” and “Government.” While participants in both studies (Study 1, Study 2) judged the role of businesses similarly (21% vs 22%), they differed on their perceptions on the role of individuals (32% vs 20%) and the government (46% vs 58%).

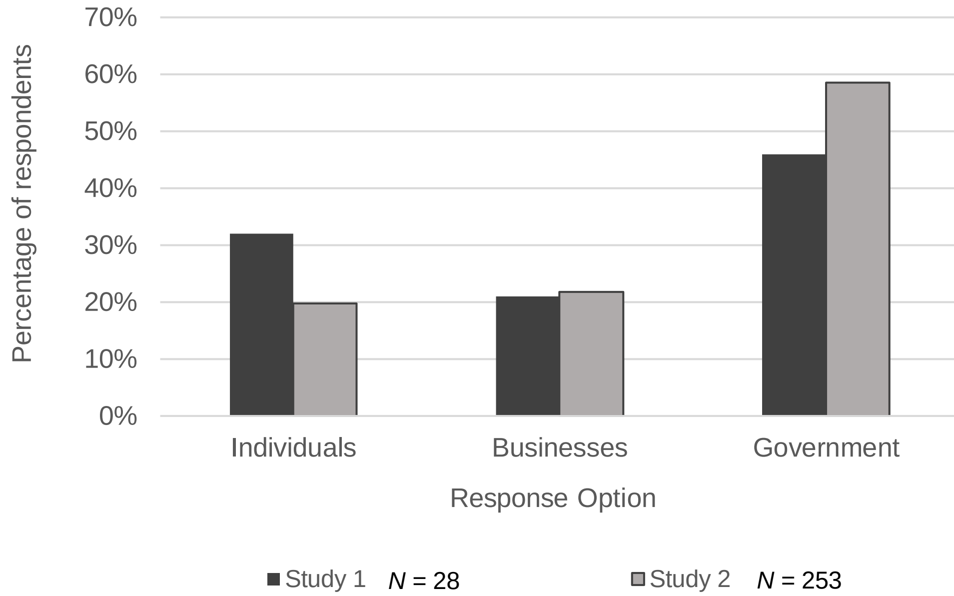


Figure 15: Response distribution as to where the burden to take actions against climate change should fall for Study 1 (*N* = 28, interview sample) and Study 2 (*N* = 253, MTurk sample) participants.

Inferential statistics: Table 16 shows results of regression analysis predicting support for immediate climate action. I regressed support onto two main sets of predictors: (a) demographic variables and (b) six scales measuring beliefs about the causes of climate change, government and individual actions, the need for further action, and self- and -response-efficacy.

TABLE 16: Coefficient estimates (and standard errors) for predicting support for immediate climate action: "The only way to avoid possible future serious changes in the climate is to take action to stop them now." Response options are coded as Strongly disagree (-2), Disagree (-1), Neither Agree nor Disagree (0), Agree (1), and Strongly Agree (2). Gender is coded as Male (0), Female (1). Politics is coded as Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), and Extremely Conservative (-3). Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Predictor	Support for immediate climate action	
	Estimate	Standard Error
Intercept	1.31***	0.29
Demographics		
Age	-0.01	0.01
Female	-0.14	0.12
Education	-0.02	0.04
Politics	0.17***	0.04
Beliefs		
Climate Change (Cause)	0.03	0.08
Government Actions	0.02	0.09
Individual Actions	-0.05	0.08
More Action Needed	-0.00	0.08
Self-efficacy Individual	-0.01	0.07
Response-efficacy Individual and Govt	0.33***	0.06
R^2		0.22

Table 16 displays the coefficients estimated for support for immediate climate action. The predictors accounted for 47% of the variance. There were significant effects for political ideology ($p < 0.0001$) and response-efficacy beliefs ($p < 0.0001$).

There is a positive correlation between each of these independent variables and support for immediate climate action. As people identify as more liberal, the mean support for climate action also tends to increase. As the Response-Efficacy predictor increases (i.e. people tend to agree that both individual and government actions are effective in slowing global warming), the mean support for immediate climate action also tends to increase.

4.4 Conclusion

While individual behavior and choices alone can contribute somewhat to global changes in the climate, the collective behaviors of billions of people, and the socio-economic system in which they live, are driving unprecedented change in the Earth's climate. Public opinion is a critical component in either driving decisions about climate risks or diverting attention away from those risks. Scientists have identified several strategies that government, society, and individuals can adopt to reduce (and eventually stop, or perhaps, even reverse) CO_2 emissions. Previous studies have tracked self- and response-efficacy beliefs, as well as the most effective ways to mitigate climate risks through private and public action.[(77)] However, even in a perfect world where all recommended actions to mitigate the climate have been taken, it has been unclear how the public perceives the overall response-efficacy of individual actions alone (e.g. traveling less, wasting less food).

For individual actions, participants have higher response-efficacy (35%) than what is likely to be attainable (i.e. compared to 20% estimate);[(78)] but they do understand that individual actions cannot lead to the majority of needed reduction, of which will require broader governmental and societal action. As people tend to agree that governments and society have already done their fair share to reduce CO_2 emissions (i.e. Government Action beliefs), the mean response for the relative reduction that *can* be achieved by individual actions alone tends to increase. As people tend to agree that it is *possible* for individuals alone to reduce nearly all CO_2 that is being added to our atmosphere (i.e. Individual Self-Efficacy beliefs), the mean response for the relative reduction that *can* be achieved by individual actions alone also tends to increase.

As in prior studies, response-efficacy beliefs were predictive of laypeople's support for immediate action on climate change. These samples judged that the responsibility to take action against the climate falls on the government, individuals, and businesses, in that order. This sample judged individual and governmental response-efficacy to be the same in terms of *effectiveness*, but this does not reflect peoples' beliefs in the relative magnitude of their effectiveness.

In addition to the main conclusions, personal views and public views on what scientists think differed. These views were significantly different for beliefs about individual and governmental actions that have *already* been taken to reduce CO_2 emissions and to what extent individuals *should* do more to minimize their own carbon footprint. On average, laypeople indicated agreement with how scientists viewed these issues, but they systematically felt that scientists had stronger beliefs on each of these matters. This finding could have important implications for the improvement of risk perceptions and communications, suggesting it is probably important to focus less on getting the public to agree with scientific consensus and more on communicating the things we do agree on, such as the need for greater action on the part of individuals and society at large.

5. Discussion

Public opinion can drive decisions that will address climate risks, divert action away from those risks, or have no influence at all. Although governments can implement some policies to address climate challenges without broad public involvement, public support strengthens these efforts and is essential for others. The literature has long tracked public perceptions of various environmental and climate issues and how these views influence policy support. The aim of this thesis is to provide an update on the climate change perceptions literature and to model beliefs that predict the need for immediate climate action found in these samples. While I identify a number of knowledge gaps found in prior studies that still exist, I also provide a first demonstration of laypeople's misunderstanding of how long CO_2 remains in the atmosphere and continues to change the climate. In fact, I identify a number of gaps in knowledge, beliefs, and decision strategies when it comes to the causes and consequences of climate change. This thesis also contributes to the emerging field of climate attribution, adds to an emerging understanding of what individuals think they can do with regard to climate change, and yields practical implications for the development of risk communications on the impacts of climate change.

Understanding climate change knowledge gaps and their implications

Chapter 2 employs a two-pronged survey to provide the first demonstration of laypeople's fundamental misunderstanding of how long CO_2 remains in the atmosphere and continues to change the climate. Most participants in the studies reported in Chapter 2 systematically underestimate how long CO_2 remains in the atmosphere by several orders of magnitude and assess its atmospheric residency time to be the same as common air pollution. Such a belief in a short residence time could lead people to the false conclusion that if and when the effects of climate change ever get serious, those effects could be reversed in just a few decades or less by reducing emissions of CO_2, i.e. effectively delaying necessary climate action. While knowledge deficits are rarely the primary drivers of policy support, specific knowledge sometimes does explain meaningful differences in policy support or intention to act. It is arguable that the gap between scientific and laypeople's knowledge must be narrowed to move forward with successful climate policy that will require consistent attention to reducing CO_2 emissions over the course of many decades, due to the long-lived nature of CO_2 and its persistent impact on climate.

Whether or not people correctly understand the scientific details of climate change, if they become concerned about climate risks, their obvious question is: "So what can we do?" Previous studies have tracked self- and response-efficacy beliefs, as well as the most effective ways to mitigate climate risks through private and public action, but how the public perceives the response-efficacy of their own individual actions has not yet been heavily discussed in the literature. For individual actions, participants have higher response-efficacy (35%) than what is likely to be attainable (i.e. compared to 20% estimate);[(78)] but they do understand that individual actions cannot lead to the majority of reduction, of which will require broader governmental and societal action. Despite this, climate change beliefs consistently predicted support for immediate action in response to climate change across my studies and samples described in this thesis. Specifically, this thesis describes studies where climate change beliefs were the largest drivers shaping how people make decisions about when to attribute abnormal hurricanes to climate change (Chapter 3) and were strong predictors of support for immediate action (Chapters 2 and 3).

Contribution to emerging climate attribution field

Apart from the causes of climate change, I evaluated how people viewed potential consequences of climate change. Building upon Study 1 in Chapter 3 of this thesis—where laypeople cited hurricanes as one of the most prominent impacts of climate change—I present the first psychophysical investigation of climate attribution for hurricanes, a topic of growing interest and attention in public and scientific discourse. My goal was to assess the extent to which people perceive certain extreme weather events as attributable to climate change and when they view hurricane frequencies as abnormal. I aimed to better understand whether, and to what extent, these perceptions are influenced by demographic factors and beliefs and how these factors influence support for immediate climate action.

The signal detection analysis (Chapter 3, Study 2) found that, independent of their prior beliefs about whether the climate was changing, and whether those changes were affecting the frequency or intensity of hurricanes, all respondents across experimental groups performed comparably in identifying the occurrence of unusual hurricane events. In addition, laypeople used local extreme weather as evidence or cues of a potential larger-scale driver, like climate change. However, when specifically asked to identify hurricane events that might be indicative of some influence from climate change, respondents were more conservative in making such an attribution. Not surprisingly, respondents who were more dubious about the existence of climate change, required a higher threshold before they were willing to suggest that an unusual hurricane event might be influenced by climate change. This demonstrates that while people may be sensitive to perceived changes in the frequency or severity of hurricanes, the degree to which they attribute those changes to a changing climate is driven in part by their prior and political beliefs—with those most dubious imposing a higher threshold.

Limitations

Several limitations should be considered when interpreting the results presented in this thesis: (1) convenience sample biases; (2) adherence to social science guidelines; and (3) inclusion of participants who failed one or more attention checks.

First, the convenience samples in this thesis were primarily biased toward more educated and more liberal respondents. Samples of this composition could be expected to have higher climate change beliefs, on average, which could explain why all participants mention global warming as a change in the weather that could occur from adding CO_2 to the atmosphere. This educated group may also have more readily understood the changing probabilities associated with non-stationary, rare events using spinner boards (Chapter 3, Study 1) than a less educated sample.

Second, the design of the research protocol does not always *strictly* adhere to best-practices in the social science literature. For example, in Chapter 3, Study 1 participants were asked to list examples of "extreme weather events." All participants listed non-weather events, such as earthquakes, likely because they misunderstood or misheard the term as "extreme events," overlooking the word "weather." The term "extreme weather event" may not be part of most peoples' everyday language. If the survey protocol asked participants about "extreme weather"—i.e. more everyday wording—then perhaps fewer bogus events might have been mentioned. In addition, while the use of "global warming" terminology was appropriate for the Broomell et al (2017) signal detection study, Study 2 (Chapter 3) uses "global warming" and "climate change" interchangeably. Specifically, participants in the climate condition where asked to identify whether a hurricane is evidence of "global warming" or not. This may make people think of increasing temperatures rather than hurricanes—and therefore, the term "climate change" would have been more appropriate in this case.(32,82)

The inclusion of participants who failed attention checks in Chapters 3 (Study 2) and 4 (Study 2) is another limitation. In Chapter 3, 14% of participants (N = 250) failed at least one attention check; the failure rate in Chapter 4 was much higher (41%, N = 253) due to a more difficult attention check question. Following the review of the Expert Lists (Chapter 4, Study 2), participants were asked which action was NOT on the Expert Lists. Sixty percent of all respondents failed this question. If this question was omitted, then only 2% of respondents failed an attention check in Chapter 4 (Study 2; N = 253). Whether the removal of participants who failed attention checks would have affected the main findings is unknown.

Policy implications and future study

As the science of climate attribution progresses, the public is joining the conversation with their own sets of beliefs and heuristics. Due to the relative infancy of attribution science, it is important to understand how it may be interpreted and used by different members of the public. A necessary first step is to establish baselines of when, and to what extent, people cite extreme events as evidence of climate change (Chapter 3). Future work could employ similar signal detection methods presented in this thesis for different stimuli (i.e. different types of extreme weather events) for comparison. Further testing should also be done using alternative methods for presenting the stimuli (i.e. not using hypothetical news headlines). These approaches could also be expanded to other groups of interest (e.g. decision makers), and gaps could be identified between their sensitivities and decision thresholds and those of diverse publics.

Understanding what "signals" people to attribute an event to climate change could aid in the development of risk communications, as well as improving our understanding of how perceptions of climate change may influence how people classify extreme events. Identifying all the perceptual biases that cause systematic and predictable attribution of extreme weather to climate change will enable researchers to explore alternative decision-making for protective actions, as well as other educational strategies or interventions. It is also important to continue to explore ways to communicate the probabilistic nature of attribution science, in order to not get laypeople bogged down with the details, but rather, to provide enough information to narrow the gap between science and its application. I demonstrate one successful way to communicate non-stationary processes such as these by using simple spinner boards (Chapter 3).

Although this thesis addressed individual and collective actions in a broad sense (Chapter 4), future studies would continue to delve into specific actions and the ease with which they could be accomplished.[77] Since people are more likely to take actions that can be done with ease,[83] future work should continue to explore the relationship between perceived level of difficulty of individual and collective actions versus the perceived *effectiveness* of these actions. These findings should also explicitly test how sets of efficacy beliefs relate to willingness to act and, perhaps, actions that have already been taken. In addition to efficacy research in the context of long-term hazards (i.e. climate change, in this case), studies of this nature are also important for short-term hazards (e.g. extreme weather); and perhaps future work could combine some of the methods in Chapters 3 and 4 to approach such issues.

This thesis demonstrates that, on average, laypeople agree with how scientists view private and public action to combat the risks posed by climate change (Chapter 4), can readily understand non-stationary processes when explained using simple clear methods, and are readily able to detect extreme events (Chapter 3). These finding carry important implications for improving risk perceptions and communications, suggesting it is probably important to focus less on getting the public to perfectly align with scientific consensus and more on communicating and acting upon platforms where we do agree. While identifying knowledge gaps is important, it is necessary to move beyond trying to quickly correct key gaps and capitalize on the strong support for immediate action to reduce climate risks regardless of individual beliefs or political ideologies.

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Appendix A: Supplemental Information for Chapter 2

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Appendix A.1: Mail survey protocol

(begins on next page)

PLEASE DO NOT WRITE YOUR NAME ON THIS SURVEY

PART 1: A few questions about air pollution.

Please answer the following questions about air pollution:

1. Listed below in alphabetical order are four things that cause **common air pollution** (that is pollutants like smog, oxides of sulfur and nitrogen, organic gases, and fine particles). Please number these sources in terms of your best guess of how much each contributes to air pollution in the region where you live. Write a 1 in front of the thing that causes the most, 2 for the next most, 3 for the next most, and 4 for the least.

__________all kinds of **industries** and factories

__________**power plants** making electricity

__________**residential and commercial** sources (for example furnaces and water heaters in homes, stores and office buildings)

__________all kinds of **transportation** (airplanes, cars, trains, trucks, ships, etc.).

Listed below are two statements about **common air pollution** like smog, oxides of sulfur and nitrogen, organic gases, and fine particles. Please check the response that is closest to your best judgment about the statement.

2. Less than a few percent of the **common air pollution** that is in the atmosphere here in the United States has come from places that are thousands of miles away.

True	Probably true	Don't know	Probably false	False

3. Imagine that the world's modern factories, transportation and power plants all stopped emitting **common air pollution** now. How long would it take for the amount of pollution in the air to fall back to what it was before those modern factories, transportation and power plants existed?

Hours to days	Weeks to months	Years	Decades	Centuries	Never

PLEASE DO NOT WRITE YOUR NAME ON THIS SURVEY

PART 2: A few questions about carbon dioxide (CO_2).

We are interested in your best guess of where the carbon dioxide (CO_2) the United States puts into the atmosphere comes from.

1. Please give us your best guess by filling in the lines below. The sum should come to 100%, since all of the **carbon dioxide** (CO_2) that the United States puts in the atmosphere comes from somewhere.

__________% comes from **power plants** making electricity

__________% comes from all kinds of **transportation** (airplanes, cars, trains, trucks, ships, etc.)

__________% comes from all kinds of **industries** and factories

__________% comes from **residential and commercial** sources (for example furnaces and water heaters in homes, stores and office buildings)

__________% **other** (sources that do not involve burning coal, oil or gas)

___100____% Total of all sources

2. Listed below in alphabetical order are four parts of the world. Please number them in terms of how much **carbon dioxide** (CO_2) you think each one released into the atmosphere last year (2015). Write a 1 in front of the region that you think released the most, 2 for the next most, 3 for the next most, and 4 for the least.

__________ China

__________ European Union

__________ India

__________ United States

Listed below are two statements about carbon dioxide (CO_2). Please check the response that is closest to your best judgment about the statement.

3. Less than a few percent of the **carbon dioxide** (CO_2) that is in the atmosphere here in the United States has come from other countries.

True	Probably true	Don't know	Probably false	False

4. Imagine that the world's modern factories, transportation and power plants all stopped emitting **carbon dioxide** (CO_2) today. How long would it take for the amount of **carbon dioxide** (CO_2) in the air to fall back to what it was before those modern factories, transportation and power plants existed?

Hours to days	Weeks to months	Years	Decades	Centuries	Never

PART 3: A few questions about electricity.

Listed below are several statements about electricity. Please check the response that is closest to your best judgment of the statement.

1. Most of the electricity used in the United States comes from large power plants.

True	Probably true	Don't know	Probably false	False

2. The average price of electricity in the United States is much higher than in Europe.

True	Probably true	Don't know	Probably false	False

3. The way we make much of our electricity in the United States today produces **air pollution**.

True	Probably true	Don't know	Probably false	False

4. The way we make much of our electricity in the United States today produces **carbon dioxide** (CO_2).

True	Probably true	Don't know	Probably false	False

5. If the United States built a very large number of wind and solar plants, just those plants alone could reliably supply all the electric power we use in the United States.

True	Probably true	Don't know	Probably false	False

We are interested in your best guess of where, on average across the United States, electricity comes from.

Please give us your best guess by filling in the lines below. The sum should come to 100%, since all of our electricity comes from somewhere. You might find it easier to first fill in the ones you think are the largest. Feel free to use a calculator if that helps.

__________ % comes from **biomass** (burning wood, trash etc.)

__________ % comes from **coal**

__________ % comes from **hydro** (electric generators at dams)

__________ % comes from **natural gas**

__________ % comes from **nuclear** power plants

__________ % comes from **solar** (all kinds - PV and thermal)

__________ % comes from **wind**

__________ % comes from **other** sources

___100___ % Total of all sources

PART 4: A few questions about climate change.

Listed below are a number of statements about climate change. Please check the response that is closest to your best judgment about the statement.

1. If the climate is changing today, it is mainly being caused by natural causes.

True	Probably true	Don't know	Probably false	False

2. If the climate is changing today, it is not mainly caused by anything people are doing.

True	Probably true	Don't know	Probably false	False

3. The climate is changing today, and the change is mainly caused by people burning coal, oil and natural gas.

True	Probably true	Don't know	Probably false	False

4. The climate is changing today, and that change is mainly caused by adding more carbon dioxide (CO_2) to the atmosphere.

True	Probably true	Don't know	Probably false	False

5. Nuclear power is a significant cause of climate change.

True	Probably true	Don't know	Probably false	False

6. Using aerosol spray cans today is a significant cause of climate change.

True	Probably true	Don't know	Probably false	False

Please indicate your level of agreement or disagreement with each of the statements below.

A. If the climate is changing, there is not much people *can* do about it.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree

B. If the climate is changing, there is not much people *should* do about it.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree

C. If the climate is changing, and those changes ever get serious, we'll be able to stop them in the future when they happen (just like we stopped the worst air pollution).

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree

D. If the climate is changing, and those changes ever get serious, we will *not* be able to stop them in the future when they happen.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree

E. The only way to avoid possible future serious changes in the climate is to take action to stop them now.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly agree

PART 5: A few anonymous questions about you.

1. Female Male

2. Your Age: ____________years

3. Your highest level of education:

Some high school	Junior college or trade school graduate
High school graduate	Four-year college graduate
Some four-year college, junior college or trade school	Graduate school in a non-technical field
	Graduate school in a technical field

4. Household Income: less than $50,000 Between $50,000 and $100,000

more than $100,000

5. Roughly how many years have you lived in the Pittsburgh area? ___________

6. Your party affiliation:

Democrat Republican Libertarian
Independent Other:_________________________

7. Your religion:

Protestant	Catholic	Jewish	Muslim
Hindu	Buddhist	None	Other:____________

8. On the questions about **common air pollution,** I rate my knowledge as:

Almost none Expert

9. On the questions about **carbon dioxide** (CO_2), I rate my knowledge as:

Almost none Expert

10. On the questions about **electric power,** I rate my knowledge as:

Almost none Expert

11. On the questions about **climate change,** I rate my knowledge as:

Almost none Expert

Thanks again for your help with this study.

Appendix A.2: MTurk survey questions
(excerpted from larger survey)

1. Is the global climate changing?

Yes	No	Unsure

2. Have humans caused any of this change?

Yes	No	Unsure

3. Aerosol spray cans are a major cause of global warming.

True	Probably true	Don't know	Probably false	False

4. Use of nuclear power is a major cause of global warming.

True	Probably true	Don't know	Probably false	False

5. If the world's modern factories, transportation and power plants stopped emitting the sort of pollutants that cause acid rain and smog, how fast would the amount of those pollutants in the atmosphere fall to what it was before those things were invented?

Hours to days	Weeks to months	Years	Decades	Centuries	Never

6. If the world's modern factories, transportation and power plants stopped emitting carbon dioxide (CO2), how fast would the amount of CO2 in the atmosphere fall to what it was before those things were invented?

Hours to days	Weeks to months	Years	Decades	Centuries	Never

Appendix A.3: Multicollinearity and factor analysis

First, a variance inflation factor (VIF) multicollinearity test was conducted. There was some indicated of multicollinearity (VIFs ranged from 1.27 to 2.71), and high correlations were present in a pairwise correlation matrix (Fig. A.3.1).

Correlation Matrix

		Less than a few percent of the common air pollution that is in the atmosph ere here in the United States has come from places that are thousand s of miles away.	Imagine that the world's modern factories, transport ation and power plants all stopped emitting common air pollution now. How long would it take for the amount of	Less than a few percent of the carbon dioxide (CO_2) that is in the atmosph ere here in the United States has come from other countries .	Imagine that the world's modern factories, transport ation and power plants all stopped emitting carbon dioxide (CO_2) today. How long would it take for the amount of carbon dioxide (CO_2) in the air to fall back to what it was before those modern factories	Most of the electricity used in the United States comes from large power plants.	The average price of electricity in the United States is much higher than in Europe.	The way we make much of our electricity in the United States today produces air pollution.	The way we make much of our electricity in the United States today produces carbon dioxide (CO_2).	If the United States built a very large number of wind and solar plants, just those plants alone could reliably supply all the electric power we use in the United States	If the climate is changing today, it is mainly being caused by natural causes.	If the climate is changing today, it is not mainly caused by anything people are doing.	The climate is changing today and the change is mainly caused by people burning coal, oil and natural gas.	The climate is changing today and that change is mainly caused by adding more carbon dioxide (CO_2) to the atmosph ere.	Nuclear power is a significan t cause of climate change.	Using aerosol spray cans today is a significan t cause of climate change.	If the climate is changing , there is not much people can do about it.	If the climate is changing , there is not much people should do about it.	If the climate is changing , and those changes ever get serious, we'll be able to stop them in the future when they happen (just like we stopped the worst air pollution) .	If the climate is changing , and those changes ever get serious, we will not be able to stop them in the future when they happen.	The only way to avoid possible future serious changes in the climate is to take action to stop them now.
Correlation	Less than a few percent of the common air pollution that is in the atmosphere here in the United States has come from places that are thousands of miles away.	1.000	.097	.522	.098	-.118	.047	.096	.077	.072	.069	.148	.004	.102	.102	-.004	.115	.222	.114	.207	.021
	Imagine that the world's modern factories, transportation and power plants all stopped emitting common air pollution now. How long would it take for the amount of	.097	1.000	.194	.781	-.077	.026	.051	-.105	.060	.123	.089	-.063	-.181	-.112	-.081	-.034	-.044	-.005	.229	.112
	Less than a few percent of the carbon dioxide (CO_2) that is in the atmosphere here in the United States has come from other countries.	.522	.194	1.000	.177	-.105	.005	.025	-.013	.127	.086	.066	-.079	.032	.075	.032	.146	.076	.129	.165	-.017
	Imagine that the world's modern factories, transportation and power plants all stopped emitting carbon dioxide (CO_2) today. How long would it take for the amount of carbon dioxide (CO_2) in the air to fall back to what it was before those modern factories	.098	.781	.177	1.000	-.181	.008	.029	-.024	.085	.198	.142	-.041	-.136	-.040	-.017	.000	-.024	.017	.267	.120
	Most of the electricity used in the United States comes from large power plants.	-.118	-.077	-.105	-.181	1.000	.001	.110	.094	.032	-.122	.057	.069	-.030	-.074	-.098	-.085	-.085	.130	-.189	.018
	The average price of electricity in the United States is much higher than in Europe.	.047	.026	.005	.008	.001	1.000	.084	.098	.210	.135	.114	-.066	.233	.244	.131	.044	-.064	.155	.077	.004
	The way we make much of our electricity in the United States today produces air pollution.	.096	.051	.025	.029	.110	.084	1.000	.644	.057	-.040	-.009	-.035	.023	.104	.172	.151	.011	.203	-.084	-.038
	The way we make much of our electricity in the United States today produces carbon dioxide (CO_2).	.077	-.105	-.013	-.024	.094	.098	.644	1.000	-.036	.038	.070	-.093	.036	.181	.084	.057	.093	.116	-.019	.010
	If the United States built a very large number of wind and solar plants, just those plants alone could reliably supply all the electric power we use in the United States	.072	.060	.127	.085	.032	.210	.057	-.036	1.000	-.050	-.105	.174	.137	.302	.208	.164	.123	-.033	.052	-.233
	If the climate is changing today, it is mainly being caused by natural causes.	.069	.123	.086	.198	-.122	.135	-.040	.038	-.050	1.000	.623	-.230	-.117	-.027	-.174	-.173	-.048	.156	.242	.308
	If the climate is changing today, it is not mainly caused by anything people are doing.	.148	.089	.066	.142	.057	.114	-.009	.070	-.105	.623	1.000	-.217	-.122	-.126	-.083	-.167	-.105	.190	.285	.425
	The climate is changing today and the change is mainly caused by people burning coal, oil and natural gas.	.004	-.063	-.079	-.041	.069	-.066	-.035	-.093	.174	-.230	-.217	1.000	.363	.043	.156	.368	.244	.000	.039	-.219
	The climate is changing today and that change is mainly caused by adding more carbon dioxide (CO_2) to the atmosphere.	.102	-.181	.032	-.136	-.030	.233	.023	.036	.137	-.117	-.122	.363	1.000	.231	.299	.189	.208	.089	.001	-.185
	Nuclear power is a significant cause of climate change.	.102	-.112	.075	-.040	-.074	.244	.104	.181	.302	-.027	-.126	.043	.231	1.000	.417	.049	.177	.021	-.107	-.124
	Using aerosol spray cans today is a significant cause of climate change.	-.004	-.081	.032	-.017	-.098	.131	.172	.084	.208	-.174	-.083	.156	.299	.417	1.000	.305	.062	-.017	-.156	-.068
	If the climate is changing, there is not much people can do about it.	.115	-.034	.146	.000	-.085	.044	.151	.057	.164	-.173	-.167	.368	.189	.049	.305	1.000	.357	.115	.024	-.112
	If the climate is changing, there is not much people should do about it.	.222	-.044	.076	-.024	-.085	-.064	.011	.093	.123	-.048	-.105	.244	.208	.177	.062	.357	1.000	.148	.131	-.161
	If the climate is changing, and those changes ever get serious, we'll be able to stop them in the future when they happen (just like we stopped the worst air pollution).	.114	-.005	.129	.017	.130	.155	.203	.116	-.033	.156	.190	.000	.089	.021	-.017	.115	.148	1.000	.168	.184
	If the climate is changing, and those changes ever get serious, we will not be able to stop them in the future when they happen.	.207	.229	.165	.267	-.189	.077	-.084	-.019	.052	.242	.285	.039	.001	-.107	-.156	.024	.131	.168	1.000	.274
	The only way to avoid possible future serious changes in the climate is to take action to stop them now.	.021	.112	-.017	.120	.018	.004	-.038	.010	-.233	.308	.425	-.219	-.185	-.124	-.068	-.112	-.161	.184	.274	1.000

Figure A.3.1: Pairwise correlation matrix of all individual, independent variables.

Principal axis factoring with an orthogonal rotation method was used to eliminate multicollinearity amongst independent factors and minimize the number of variables that have high loadings on each factor. The results of the factor analysis yielded seven latent constructs (Fig. A.3.2), one of which included only one survey item and two that included survey questions with different response scales (e.g., one question measured degree-of-agreement while another had a true-false scale). These three factors were deemed not the most appropriate for the statistical analyses. This left four independent variables: (1) Indiscriminate Green Beliefs (3 items; Cronbach's $\alpha = .59$); (2) Residence Time (2 items; Cronbach's $\alpha = .88$); (3) Distant Source (2 items; Cronbach's $\alpha = .69$); and (4) Electricity Source (2 items; Cronbach's $\alpha = .78$).

The Indiscriminate Green Beliefs scale was combined from three related survey questions. If people have Indiscriminate Green Beliefs, they meet at least one of the following requirements: (1) answered true or probably true that nuclear power is a significant cause of climate change; (2) answered true or probably true that aerosol spray cans are a significant cause of climate change; or (3) answered true or probably true that renewable forms of energy (like solar and wind) could reliably supply United States electricity demands. If any of these requirements were met, the respondent received a coding of '1,' signifying that they had Indiscriminate Green Beliefs. All other respondents were coded as '0.'

The Residence Time factor represents the difference between air pollution and carbon dioxide responses to questions regarding atmospheric residence time.

The Distant Source factor represents the computed average of air pollution and carbon dioxide responses (each weighted by coefficients from factor analysis) to the questions regarding the geographic source of each.

Similar to the "Distant Source" factor, the Electricity Source factor represents the computed average of air pollution and carbon dioxide responses (each weighted by coefficients from factor analysis) to questions regarding electricity by-products.

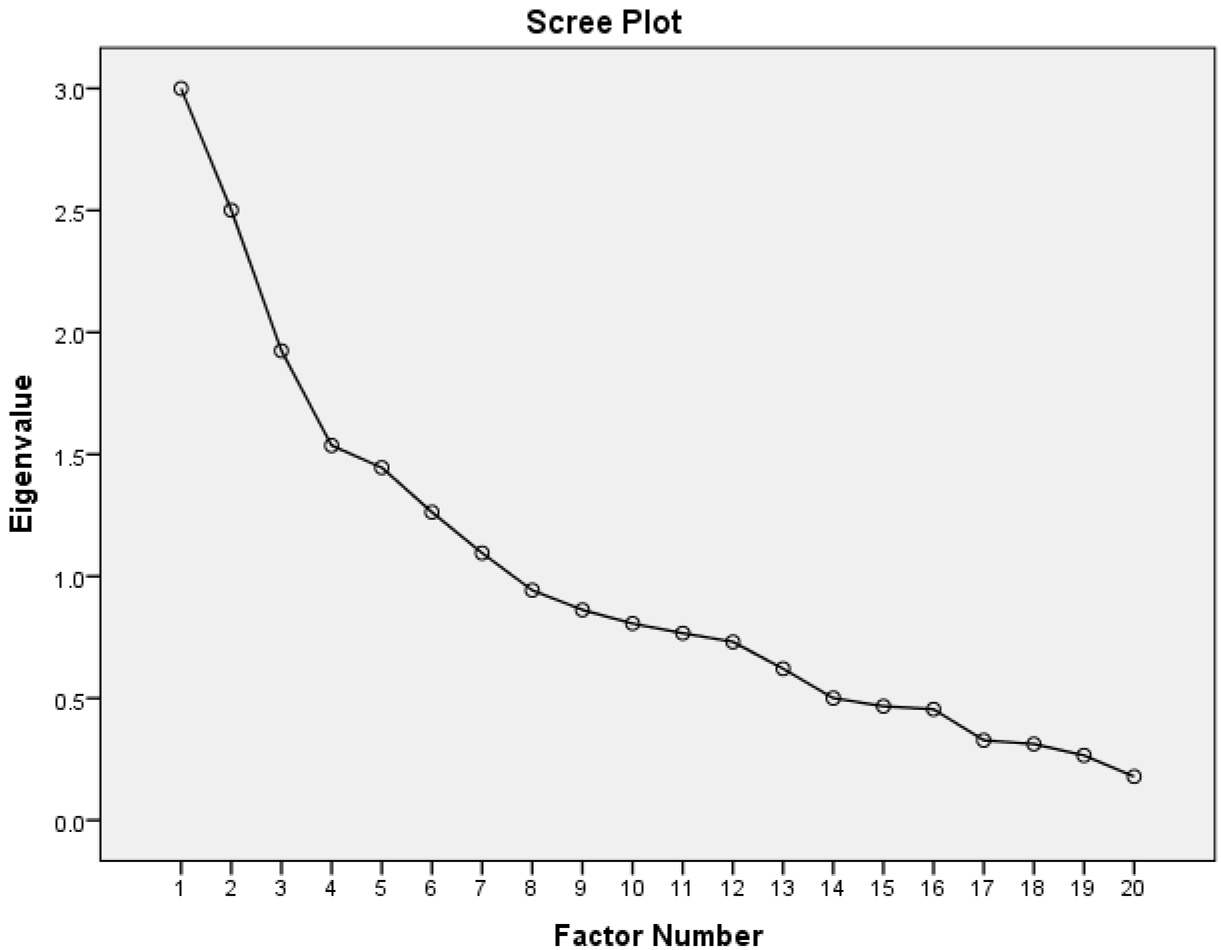

Figure A.3.2: Scree plot for factor analysis.

Appendix A.4: Extended discussion of logistic regression

To test my hypothesis, I fit a simple logistic model. I use the four previously discussed factors along with Democrat (coded 1 = Democrat; 0 = not Democrat) for a total of five independent variables in my model. The "Female" factor was significantly correlated with both Democrat and the Indiscriminate Green Beliefs and was omitted from the regression. The dependent variable is how respondents answered the question: "The only way to stop future serious changes in the climate is to take action to stop them now." Those who agreed or strongly agreed with this statement were coded as '1,' or those who believe we should act now to combat climate change. Those who disagreed or strongly disagreed with this statement were coded as '0,' or those who do not believe action is needed now.

Here, I show the results of a simple and more complex logistic model for predicting the 'Act Now' dependent variable.

$$\text{Simple:}\quad 1.3 + 2.0[Democrat] + .2[Res\ Time]$$

$$\text{Complex:}\quad -1.6 + 4.6[Democrat] - 1.0[Res\ Time] + 5.4[IGB] - 1.3[Dist\ Source] + 1.5[Elect\ Source]$$

For the complex model, the Democrat variable is 4.6 on the log odds scale (p = 0.01, 95% CI [2.9, 3715.3]). The Indiscriminate Green Beliefs variable is 5.4 on the log odds scale (p = 0.002, 95% CI [7.1, 6330.4]). No other independent variables were statistically significant. Probabilities are discussed in the main text of Chapter 2.

Appendix B: Supplemental Information for Chapter 3

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Appendix B.1: Extended description of methods

Participants: I recruited participants (N = 250) for the main signal detection task via Amazon Mechanical Turk (MTurk). Potential participants read a short description of the task posted to MTurk. If interested, they were routed to an online survey (implemented through Qualtrics). Upon completion of the task, participants received unique confirmation codes to redeem $2.50 as compensation for their time. The task took less than 20 minutes to complete. To be eligible to participate in the study, participants had to be 18 or older, fluent in English, using a desktop computer, reside in the U.S., and have at least 95% approval rate and at least 500 previously approved tasks.

I included four attention checks with obvious answers to assess whether participants were paying attention for the task duration.

For the national MTurk sample, ages ranged from 20 to 79 years old (mean = 35.4, median = 32). Of the total sample, 32% lived on a coast, and 38% of respondents were female. The full demographic composition of the sample is displayed in Table B.1.1.

TABLE B.1.1: Demographic distribution of survey sample (N = 250).

Demographics	Frequency	Fraction
Location		
Non-U.S. Coast	169	0.68
U.S. Coast	81	0.32
Gender		
Female	94	0.38
Male	156	0.62
Political ideology		
Extremely Liberal	26	0.10
Liberal	76	0.30
Slightly Liberal	30	0.12
Moderate / Middle of the Road	45	0.18
Slightly Conservative	25	0.10
Conservative	34	0.14
Extremely Conservative	14	0.06
Education		
Some high school	1	< 0.01
High school graduate	51	0.20
Some four-year college, junior college or trade school	43	0.17
Junior or trade school graduate	13	0.05
Four-year college graduate	124	0.50
Graduate school in a non-technical field	12	0.05
Graduate school in a technical field	6	0.02

Design: I ran a between-subjects design where I manipulated the frame of the instructions for classifying hurricanes in the signal detection task. The control condition asked participants to classify each hurricane observation as either **normal** or **abnormal**. The climate condition asked participants to classify each hurricane observation as either **evidence** of global warming or **not evidence** of global warming.

Procedure: All participants completed two tasks: (1) *extreme event attribution,* where they classified 21 extreme events from a list containing both real (based on the IPCC AR5 report) and bogus examples of events attributable to man-made climate change, and (2) *perception of hurricanes,* where they classified 45 hurricane observations projected over the next decade. I estimated each participant's sensitivity and decision threshold for the hurricane perception task using signal detection theory. Participants then completed a collection of survey questions.

Extreme event attribution task: First, the participants completed a short extreme event attribution task to measure their perceptions of extreme events that could be attributable to climate change. Table B.1.2 displays a list of events in the IPCC AR5, events that *could* be indirectly linked to climate change, and bogus events attributable to climate change and the fraction of trials that were categorized as attributable and not attributable to man-made climate change. The top list was derived from the IPCC AR5 report of events that could be (to some degree) attributable to anthropogenic climate change. The "Bogus" list included events used in prior studies (e.g. Broomell, Winkles & Kane, 2017).

TABLE B.1.2: List of examples of events that could and could not be attributable to man-made climate change in the extreme event attribution task. Values for "fraction of trials" should be above 0.5 for events linked to climate change and below 0.5 for bogus events. The situation for indirect effects is less clear. Fraction of trials significantly different than random chance (i.e. 0.50) are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$. Fraction of trials for events **in bold** are not significantly different from random chance.

Changes in events that could be linked to climate change in IPCC AR5:	Fraction of Trials Categorized as "Could be evidence of man-made climate change"
Heat waves	0.75***
Wildfires	0.75***
Droughts	0.71***
Floods	0.68***
Hurricanes	0.64***
Cold waves	0.58**
Heavy rainfall	0.57*
Heavy snow	**0.56**
Tornadoes	**0.53**
Hail	0.42*
Ice	0.42**
Winds	0.36***
Ocean waves	0.34***
Changes in events that could be indirectly linked to climate change (i.e. *via* precipitation and / or warming temperature):	
Landslides	**0.55**
Avalanches	**0.45**
Sinkholes	0.44*
Bogus:	
Holes in the ozone layer	0.81***
Gas eruptions from deep water lake (i.e. limnic eruptions)	0.39***
Earthquakes	0.32***
Solar flares	0.24***
Volcanic eruptions	0.20***

The participants were shown these lists (in random order) and were asked to categorize each into one of two bins labeled, "Could be evidence of man-made climate change" and "Could NOT be evidence of man-made climate change" (Fig. B.1.1).

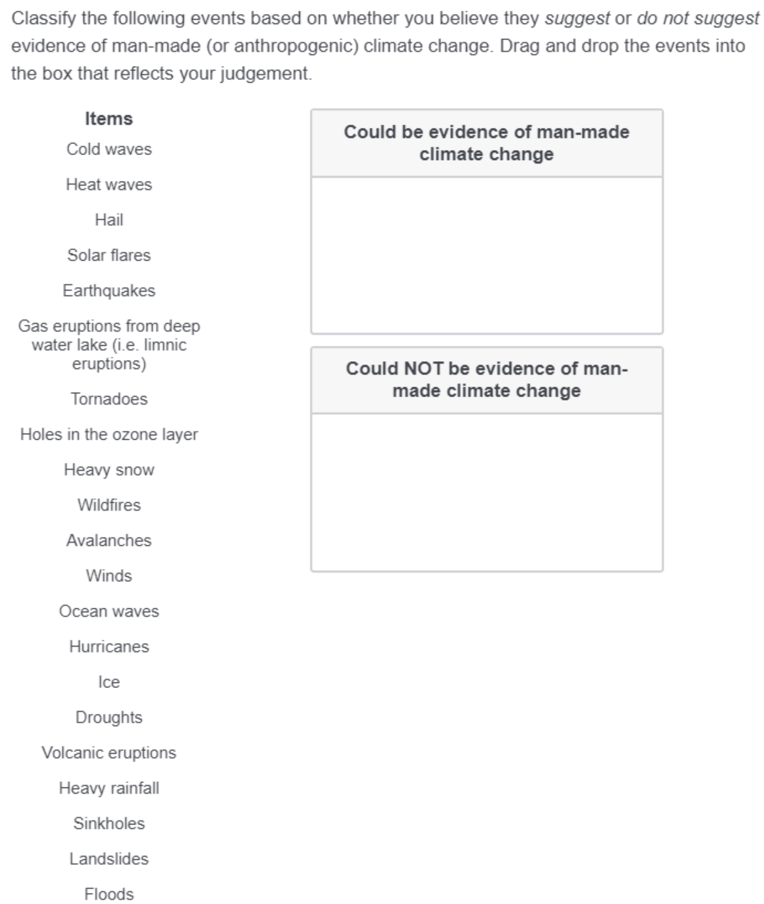

Figure B.1.1: Multi-event sorting task window in Qualtrics. Events listed on the left were randomly presented for each participant. Participants were instructed to sort the events based on their judgement of whether it could be evidence of man-made climate change.

Hurricanes perception task: Next, the participants completed the main signal detection task. Participants were randomly assigned to either the control or climate condition. Individuals assigned to the control condition read the following instructions:

> "Every year, some parts of the U.S. are hit by hurricanes. Whether that happens at a particular location depends on many uncertain factors.
>
> Hurricanes grow out of tropical storms that circle around a low-pressure system and are fueled by warm ocean waters. The National Hurricane Center categorizes hurricanes based on how fast their sustained winds are blowing. To do that, they use something called the Saffir-Simpson Scale. This scale assigns a 1 to 5 rating to storms based on their potential to cause property damage.

This table from the National Hurricane Center shows the range of windspeeds for each hurricane category. Category 1 hurricanes have the lowest windspeeds, and Category 5 hurricanes have the highest windspeeds:

Category	Sustained Winds	Danger Level
1	74-95 mph	Very dangerous
2	96-110 mph	Extremely Dangerous
3 (Major)	111-129 mph	Devastating
4 (Major)	130-156 mph	Catastrophic
5 (Major)	157 mph or higher	Catastrophic

We are interested in understanding how frequently the public expects to see hurricanes of different intensities during "normal" hurricane seasons in the U.S. in the future. In this study, we will show you hypothetical news headlines that describe experts' forecasts of the number of hurricanes expected to make landfall in the U.S. over the next decade.

We would like you to tell us whether you think the headline describes a **normal** or an **abnormal** number of hurricanes over the next decade. An abnormal hurricane season would mean that there are either **many fewer** or **many more** hurricanes than you would expect. For each number of hurricanes, we will ask you to also rate how confident you are about your decision."

It should be noted that although I did not make mention of global warming in the task instructions for the control group, it is possible that participants may have been influenced by the initial sorting task (i.e. assigning events as possible evidence of anthropogenic climate change).

Individuals assigned to the climate condition read identical instructions, except the wording of the final two paragraphs differed to reflect their unique response options. The final paragraphs for the climate condition read:

"We are interested in understanding what the public thinks could suggest evidence in the future of global warming during hurricane seasons in the U.S. In this study,

> we will show you hypothetical news headlines that describe experts' forecasts of the number of hurricanes expected to make landfall in the U.S. over the next decade.
>
> We would like for you to tell us whether you think the headline suggests evidence of global warming or does not suggest evidence of global warming during the next decade. For each number of hurricanes, we will ask you to also rate how confident you are about your decision."

Participants then proceeded to classify 45 hurricane observations. The 45 observations were composed of hypothetical news headlines projecting the potential number of hurricane landfalls and their intensity over the next decade. The headlines followed this form:

> "Roughly [*frequency*] Category [*intensity*] Hurricanes could Strike the U.S. over the Next Decade, Study says"

The hurricane stimuli were generated for the U.S. from decadal means and standard deviations of hurricane landfall data from NOAA Hurricane Research Division from 1851 to 2017. Since the hypothetical news headlines asked participants to judge observations "over the next decade," evaluating historical hurricane incidence by decade was appropriate. The mean number of landfalls, their highest intensity, and standard deviations were computed for each decade in the U.S. over the 166-year period-of-record (POR). Note that this POR cannot strictly be interpreted in this manner, since hurricane observation methods have changed over this time period and would lead to potential differences in frequency, intensity, or landfall records. An alternative formulation would be to extract stimuli from the POR when satellite observations were in operation (i.e. 1970s to present day). Summary statistics for each POR follow.

Based on the 166-year POR, the mean number of hurricane landfalls in the U.S. (per decade) was: 7 category 1 hurricanes (std. dev. = 2); 5 category 2 hurricanes (std. dev. = 2); 4 category 3 hurricanes (std. dev. = 2); 1 category 4 hurricanes (std. dev. = 1); and 0 category 5 hurricanes (std. dev. = 0). Based on a POR from 1971 to 2017, the mean number of hurricane landfalls in the U.S. (per decade) was: 6 category 1 hurricanes (std. dev. = 2); 3 category 2 hurricanes (std. dev. = 2); 3 category 3 hurricanes (std. dev. = 2); 1 category 4 hurricanes (std. dev. = 1); and 0 category 5 hurricanes (std. dev. = 0). The calculations and results to follow are based on the full, 166-year POR.

Given the greater incidence of category 1-3 hurricanes, frequencies ranged from 0 to 10 to adequately capture the mean number of hurricanes per decade, as well as frequencies above and below the mean. Category 4 and 5 hurricanes included a range from 0 to 5, due to the historically lower incidence of strong hurricanes in the database in both the full, 166-year POR and the POR from 1971 to 2017. The presentation of category 1-5 hurricanes was randomized, as well as random presentation of frequencies within each hurricane category. For each trial, participants were asked to rate their confidence in their decision (i.e. low, medium, or high).

Defining Abnormal Hurricane Frequencies

For the control condition, I classified landfall frequencies that were 1 (or more) standard deviations above or below the decadal mean as abnormal. All other trials were classified as normal.

More than one standard deviation above or below the decadal mean represented adequate variability compared to probability estimates of various frequencies using a Poisson arrival process. For example, a Poisson arrival process took the decadal mean (e.g. 7 category 1 landfalls) and calculated the probability of arrivals over the following decade via the equation:

$$F(x) = \boldsymbol{P}\{X \leq x\} = \sum_{k=0}^{x} \frac{e^{-\lambda}\lambda^{k}}{k!}$$

I evaluated an approximate 0.5 cut-off for what would be classified as abnormal. In the case of category 1 hurricanes with an arrival rate of 7 per decade (i.e. the mean), the probability of the following decade seeing 8 or more category 1 hurricanes was 0.40. The probability of seeing 9 or more dropped to 0.27; therefore, 9 and 10 were deemed abnormal based on their low probability of occurrence. The possibility of 8 category 1 hurricanes was considered normal, since the probability was 0.4 (closer to the 0.5 cut-off). Calculating all the probabilities across all hurricane categories came up with similar or stricter guidelines than the criterion of $\pm$ 1 standard deviation. Therefore, I adopted this latter criterion to allow for more variance in human judgment than a stricter, Poisson approach (as well as a more even set of stimuli).

The control group classification scheme based on standard deviations is presented in Table B.1.3 for the full, 166-year POR and Table B.1.4 for the POR from 1971 to 2017. The alternative classification scheme for the control group based on a Poisson arrival process is presented in Table B.1.5.

TABLE B.1.3: Classification of abnormal (green, signal, n = 26) and normal (red, noise, n = 19) hurricane frequencies per category based on one standard deviation above and below the decadal mean for each category (box with dotted outline) from 1851 – 2017.

	Saffir-Simpson Hurricane Category				
Frequency	1	2	3	4	5
0	Abnormal	Abnormal	Abnormal	Normal	Normal
1	Abnormal	Abnormal	Abnormal	Normal	Abnormal
2	Abnormal	Abnormal	Normal	Normal	Abnormal
3	Abnormal	Normal	Normal	Abnormal	Abnormal
4	Abnormal	Normal	Normal	Abnormal	Abnormal
5	Normal	Normal	Normal	Abnormal	Abnormal
6	Normal	Normal	Normal		
7	Normal	Normal	Abnormal		
8	Normal	Abnormal	Abnormal		
9	Normal	Abnormal	Abnormal		
10	Abnormal	Abnormal	Abnormal		

TABLE B.1.4: Classification of abnormal (green, signal, n = 26) and normal (red, noise, n = 19) hurricane frequencies per category based on one standard deviation above and below the decadal mean for each category (box with dotted outline) from 1971 – 2017.

	Saffir-Simpson Hurricane Category				
Frequency	1	2	3	4	5
0	Abnormal	Abnormal	Abnormal	Normal	Normal
1	Abnormal	Normal	Normal	Normal	Abnormal
2	Abnormal	Normal	Normal	Normal	Abnormal
3	Abnormal	Normal	Normal	Abnormal	Abnormal
4	Normal	Normal	Normal	Abnormal	Abnormal
5	Normal	Normal	Normal	Abnormal	Abnormal
6	Normal	Abnormal	Abnormal		
7	Normal	Abnormal	Abnormal		
8	Normal	Abnormal	Abnormal		
9	Abnormal	Abnormal	Abnormal		
10	Abnormal	Abnormal	Abnormal		

TABLE B.1.5: Classification of abnormal (green, signal, *n* = 33) and normal (red, noise, *n* = 12) hurricane frequencies per category based on a Poisson arrival process with an approximate 0.5 cut off. This classification scheme was stricter than the $\pm$ 1 standard deviation approach.

	Saffir-Simpson Hurricane Category				
Frequency	1	2	3	4	5
0	Abnormal	Abnormal	Abnormal	Normal	Normal
1	Abnormal	Abnormal	Abnormal	Normal	Abnormal
2	Abnormal	Abnormal	Abnormal	Abnormal	Abnormal
3	Abnormal	Abnormal	Normal	Abnormal	Abnormal
4	Abnormal	Normal	Normal	Abnormal	Abnormal
5	Abnormal	Normal	Normal	Abnormal	Abnormal
6	Normal	Normal	Abnormal		
7	Normal	Abnormal	Abnormal		
8	Normal	Abnormal	Abnormal		
9	Abnormal	Abnormal	Abnormal		
10	Abnormal	Abnormal	Abnormal		

Defining Evidence of Climate Change

For the climate group, I estimated the SDT parameters based on the results from the face-to-face interviews, where all participants said that climate change caused hurricanes to be more frequent and more intense (see Chapter 3 main text). I classified frequencies that were higher than the decadal mean number of landfalls as representing evidence of global warming. This definition was not meant to represent the scientific community's understanding of how climate change may influence (rather than *cause*) hurricanes—but rather—I adopted laypeople's mental models in evaluating how they may understand "evidence" of global warming. Because participants stated that climate change would *increase* the severity and frequency of hurricanes, I concluded that anything below the mean (and the mean itself) would not be identified as evidence of global warming.

The classification scheme for the climate group is presented in Table B.1.6.

TABLE B.1.6: Classification of evidence (green, signal, *n* = 23) and not evidence (red, noise, *n* = 22) of climate change per category based on laypeople's mental models of global warming *increasing* the frequency and severity of hurricanes. I adopted laypeople's definitions rather than scientific definition of what could be evidence of climate change (defined here as any frequency above, and including, the decadal mean).

	Saffir-Simpson Hurricane Category				
Frequency	1	2	3	4	5
0	Not Evidence	Not Evidence	Not Evidence	Not Evidence	Not Evidence
1	Not Evidence	Not Evidence	Not Evidence	Not Evidence	Evidence
2	Not Evidence	Not Evidence	Not Evidence	Evidence	Evidence
3	Not Evidence	Not Evidence	Not Evidence	Evidence	Evidence
4	Not Evidence	Not Evidence	Not Evidence	Evidence	Evidence
5	Not Evidence	Not Evidence	Evidence	Evidence	Evidence
6	Not Evidence	Evidence	Evidence		
7	Not Evidence	Evidence	Evidence		
8	Evidence	Evidence	Evidence		
9	Evidence	Evidence	Evidence		
10	Evidence	Evidence	Evidence		

Figure B.1.2 displays a screen shot of the hurricane perception task for each condition.

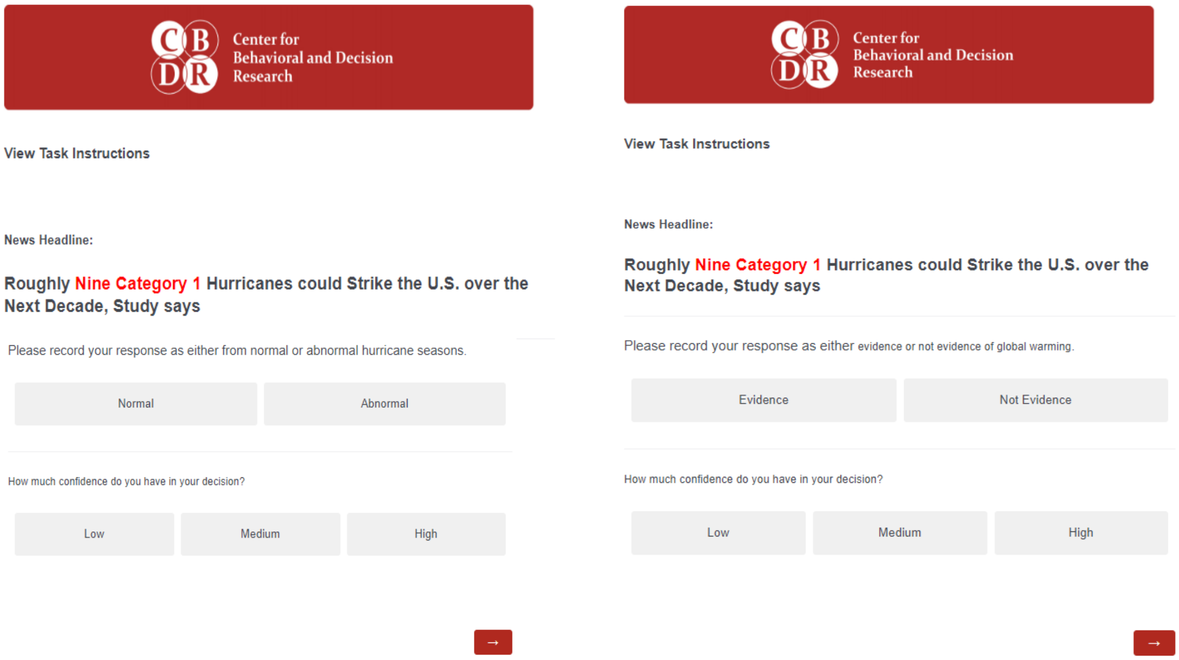

Figure B.1.2: Example task window for control group (left) and climate-framing group (right) for the news headline describing roughly nine category 1 hurricanes to make landfall over the next decade in the U.S. Response options for the control group were "Normal" or "Abnormal" to describe the headline; response options for the climate-framing group were "Evidence" or "Not Evidence" of global warming to describe the headline. Response options for confidence ratings remained the same for both groups.

Appendix B.2: Extended description of results

Descriptive Statistics: I used responses to the hurricane perception task to individually estimate the signal detection parameters. I estimated participants' *sensitivities* and *decision thresholds* (using the methods described here and in the main text). The mean sensitivity and decision threshold are provided in Table B.2.1 for each condition. I estimated the sensitivity and decision threshold parameters by creating a receiver operating characteristic (ROC) curve for each participant. ROC curves were calculated using the Hit Rate (HR, or accurate signal detection based on my grading criteria; Appendix B.1), False Alarm Rate (FAR, or inaccurate signal detection), and self-reported confidence. The sensitivity measure was estimated by the area under the ROC curve (AUC) and ranged from 0 (perfect *reverse* discriminability between signal and noise) to 1 (perfect discriminability between signal and noise) with a score of 0.5 in the middle, representing random chance. The decision threshold was calculated by the equation: *Criterion C* $=-0.5[\Phi^{-1}(1 - HR) + \Phi^{-1}(1 - FAR)]$ where Φ^{-1} is the inverse Gaussian cumulative density function (Gescheider, 2013). The decision threshold measure was designed such that negative numbers indicated a bias towards a response that a hurricane observation was abnormal / evidence of global warming (i.e. a *change* was detected); while positive numbers indicated a bias towards responses of normal / not evidence of global warming (i.e. no *change* was detected).

The distribution of the two parameters is displayed in Figure B.2.1. The scatter plot showed that the estimates had no association with each other, as assumed by the theory of signal detection. The correlation (R^2) between sensitivity (AUC) and decision threshold (criterion *C*) was virtually zero in the hurricane perception task ($R^2 < 0.01$, $p = 0.97$).

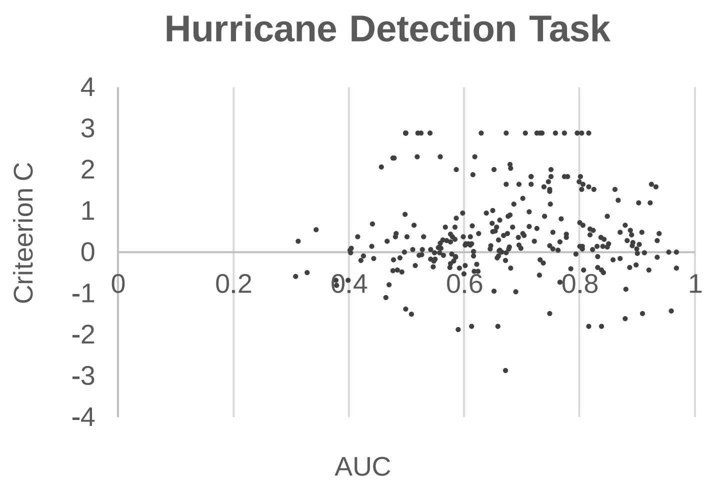

Figure B.2.1: Scatter plot displaying the estimates of sensitivity (AUC) and decision threshold (Criterion C) for the hurricane detection task (combined across both conditions).

The descriptive statistics for the estimates of the SDT parameters are displayed in Table B.2.1 for each condition separately. Sensitivity estimates from the sample ranged from 0.31 (minimum) to 0.97 (maximum). Decision threshold estimates ranged from -2.88 (lax thresholds resulting in more abnormal / evidence responses) to 2.88 (strict thresholds resulting in more normal / not evidence responses). The results in Table B.2.1 display several patterns in the data. The climate condition has a better sensitivity, on average, than the control condition. The average sensitivity for the control condition [mean (*M*) = 0.62, standard deviation (SD) = 0.12] was lower than the climate condition (*M* = 0.73, SD = 0.16), and participants in both conditions performed significantly better than chance in discriminating hurricane frequencies (one-sample *t*-test, $p < 0.0001$). The average decision threshold for the control condition (*M* = 0.23, SD = 0.61) was less strict than the climate condition (*M* = 0.78, SD = 1.41), reflecting parallel findings of Broomell and co-authors (2017).

TABLE B.2.1: Descriptive statistics of the individually estimated signal detection variables, accuracy, and bias.

Variable	Mean	Std Dev	Minimum	Maximum
Control Condition (n = 125)				
Hurricane Sensitivity (AUC)	0.62	0.12	0.33	0.90
Hurricane Threshold (Criterion C)	0.23	0.61	-1.11	2.31
Climate Condition (n = 125)				
Hurricane Sensitivity (AUC)	0.73	0.16	0.31	0.97
Hurricane Threshold (Criterion C)	0.78	1.41	-2.88	2.88

Extended Regression Analysis: I performed regression analysis separately for the measures of sensitivity and decision threshold in the perceptions of hurricane frequencies. The dependent variables were the signal detection parameters estimated from individual's perceptions of the 45 hurricane observations. I organized the predictor variables into five sets: (a) design variables (experimental condition and location), (b) demographic variables, (c) the four scales measuring beliefs and experience, (d) extreme event preparation measures, and (e) numeracy, plus one knowledge question on whether people know a hurricane watch is less severe than a hurricane warning. I was interested in the impact of each set of predictors. Table B.2.2 (Chapter 3, Table 9) displays the model fit for decision threshold (criterion C) and sensitivity (Area under the ROC).

TABLE B.2.2: Coefficient estimates (and standard errors) for predicting decision threshold (criterion *C*) and sensitivity (area under the ROC curve) in classifying hurricane frequencies. Group is coded as Control = 0, Climate = 1; Location is coded as Non-coast = 0, Coastal = 1; Gender is coded as Male = 0, Female = 1. Politics is coded as Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), and Extremely Conservative (-3). The decision threshold for interpreting hurricanes is neutral at 0, with negative values indicating bias toward abnormal / evidence of global warning responses and positive values indicate bias toward normal / not evidence of global warming responses. Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Predictor	Decision threshold for hurricane frequencies (criterion *C*)				Sensitivity for hurricane frequencies (area under the ROC curve)			
	Estimate		Std. err.		Estimate		Std. err.	
Intercept	0.22		0.18		0.65***		0.02	
Design variables								
Climate group	0.44*		0.21		0.08**		0.03	
Coastal	0.08		0.15		-0.04*		0.02	
	Main effect (control group baseline slope)		Interaction effect (change in slope for climate group relative to control group)		Main effect (control group baseline slope)		Interaction effect (change in slope for climate group relative to control group)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Demographics								
Age	-0.05	0.10	0.09	0.14	0.01	0.01	-0.01	0.02
Female	-0.01	0.10	0.01	0.14	-0.01	0.01	0.02	0.02
Education	0.05	0.09	-0.07	0.13	0.01	0.01	-0.02	0.02
Politics	-0.01	0.11	0.04	0.15	0.01	0.01	0.00	0.02
Beliefs								
Climate Change	0.02	0.11	-0.67***	0.14	0.01	0.01	0.06***	0.02
Weather Salience	-0.04	0.10	-0.15	0.14	0.00	0.01	-0.02	0.02
Experience	0.06	0.15	0.10	0.21	0.02	0.02	-0.01	0.03
Impacts	-0.03	0.13	-0.22	0.21	-0.03	0.02	0.01	0.02
Preparation								
Shelter	-0.11	0.25	0.14	0.34	-0.01	0.03	0.03	0.04
Supplies	0.02	0.25	0.03	0.34	0.01	0.03	0.02	0.04
Knowledge								
Numeracy	-0.05	0.10	0.33*	0.14	0.02	0.01	0.03*	0.02
Knows Watch < Warning	0.00	0.10	0.11	0.14	0.01	0.01	0.02	0.02
R^2			0.31				0.46	

Potential influence of outliers in climate condition: In addition to the regression results reported in Chapter 3 and reproduced in Table B.2.2, I identified and removed outliers and re-ran the main regression analysis to check if any of my statistical inferences changed. Figure B.2.1

showed a cluster of points at the top of the graph that I identified as possible outliers. Decision threshold estimates in the sample ranged from -2.88 (lax thresholds resulting in more abnormal / evidence responses) to 2.88 (strict thresholds resulting in more normal / not evidence responses). I removed any decision thresholds that were greater than 2.88 or less than -2.88. There were 23 cases that fit this criteria. The regression results following the removal of these 23 cases are presented in Table B.2.3.

I identified some differences in estimates for predicting decision threshold (criterion C) for hurricane frequencies. The variance explained by the modeled decreased with the removal of outliers (initial $R^2 = 0.31$; $R^2 = 0.15$ after removal). The main effect for experimental group lost its significance after the removal of outliers (initial estimate 0.44, $p = 0.04$; new estimate = 0.13, $p = 0.52$). Other main effects for predicting decision threshold were similar between the initial model and model with outliers removed. However, because the main effect of experimental group dropped out of the model after removing outliers, some interaction terms were also affected. The interaction estimate between group and climate change beliefs changed from -0.67 ($p < 0.0001$) to -0.40 ($p = 0.01$). This interaction term remained very strong. However, the interaction estimate between group and numeracy changed from 0.33 ($p = 0.02$) to 0.19 ($p = 0.16$), losing its significance in the new model. Estimates of main and interaction effects in predicting sensitivity (area under the ROC curve) stayed essentially the same after the removal of outliers. This makes sense since sensitivity and decision threshold are theoretically independent (Fig. B.2.1), and I removed cases based on decision threshold criteria. Explained variance remained the same as the initial model, as well as estimates for experimental group and all other main effects. Estimates for some interaction terms changed slightly, but no terms that were significant in the initial model lost their significance in the new model.

TABLE B.2.3: Coefficient estimates (and standard errors) for predicting decision threshold (criterion *C*) and sensitivity (area under the ROC curve) in classifying hurricane frequencies after removal of outliers. Group is coded as Control = 0, Climate = 1; Location is coded as Non-coast = 0, Coastal = 1; Gender is coded as Male = 0, Female = 1. Politics is coded as Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), and Extremely Conservative (-3). The decision threshold for interpreting hurricanes is neutral at 0, with negative values indicating bias toward abnormal / evidence of global warning responses and positive values indicate bias toward normal / not evidence of global warming responses. Significance levels are denoted as follows: (*) denotes $p \leq 0.05$; (**) denotes $p \leq 0.01$; and (***) denotes $p \leq 0.001$.

Predictor	Decision threshold for hurricane frequencies (criterion *C*)				Sensitivity for hurricane frequencies (area under the ROC curve)			
	Estimate		Std. err.		Estimate		Std. err.	
Intercept	0.24		0.16		0.65***		0.02	
Design variables								
Climate group[†]	0.13		0.20		0.08***		0.03	
Coastal	0.06		0.13		-0.05**		0.02	
	Main effect (control group baseline slope)		Interaction effect (change in slope for climate group relative to control group)		Main effect (control group baseline slope)		Interaction effect (change in slope for climate group relative to control group)	
	Est.	S.E.	Est.	S.E.	Est.	S.E.	Est.	S.E.
Demographics								
Age	-0.06	0.08	0.21	0.13	0.01	0.01	-0.02	0.02
Female	-0.01	0.09	-0.14	0.13	-0.01	0.01	0.02	0.02
Education	0.05	0.08	-0.09	0.12	0.01	0.01	-0.02	0.02
Politics	-0.01	0.09	0.08	0.13	0.01	0.01	0.00	0.02
Beliefs								
Climate Change	0.02	0.09	-0.40**	0.15	0.01	0.01	0.04*	0.02
Weather Salience	-0.04	0.09	-0.14	0.13	0.00	0.01	-0.02	0.02
Experience	0.07	0.12	0.05	0.19	0.02	0.02	0.00	0.03
Impacts	-0.03	0.11	-0.13	0.19	-0.03	0.02	0.00	0.03
Preparation								
Shelter	-0.12	0.21	0.01	0.31	-0.01	0.03	0.05	0.04
Supplies	0.03	0.21	0.24	0.31	0.01	0.03	0.01	0.04
Knowledge								
Numeracy	-0.06	0.09	0.19	0.14	0.02	0.01	0.05**	0.02
Knows Watch < Warning	0.00	0.08	0.11	0.12	0.01	0.01	0.02	0.02
R^2			0.15				0.46	

[†] A closer examination revealed that the 23 outliers were all in the climate condition. As a result, I decided to keep these cases in the dataset for the main regression.

Regression Diagnostics: This section contains regression diagnostics for modeling decision threshold (Fig. B.2.2) and sensitivity (Fig. B.2.3) as dependent variables.

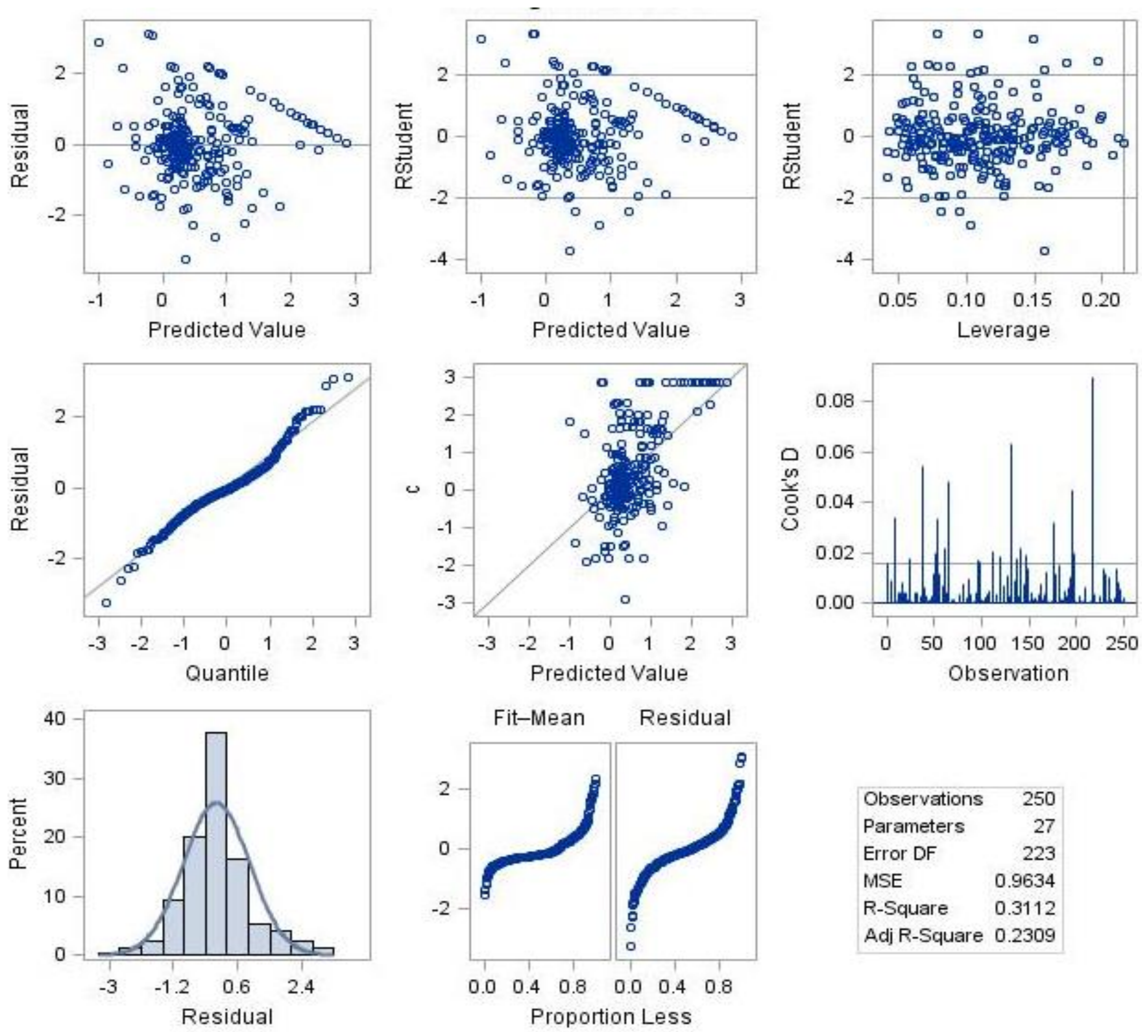

Figure B.2.2: Fit diagnostics for predicting decision threshold in the main regression. Note that diagnostics were similar after removing outliers.

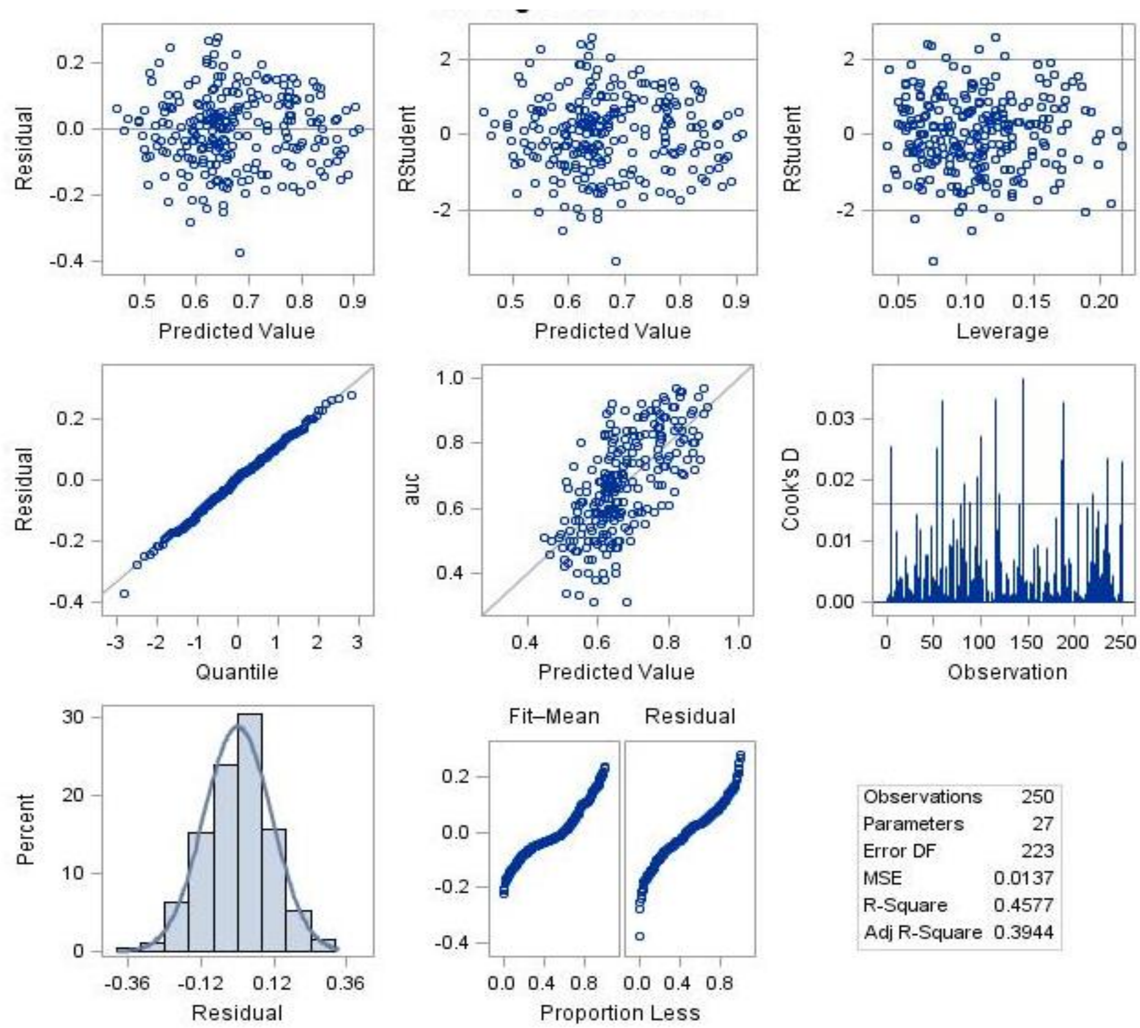

Figure B.2.3: Fit diagnostics for predicting sensitivity in the main regression. Note that diagnostics were similar after removing outliers.

Appendix B.3: Personal questions and individual difference measures

After completing the two main tasks, participants were asked a series of personal questions as the last task of the experiment. Participants were asked for their age, gender, education political ideology, and state of residence. They also answered questions about their hurricane experience, interest and knowledge regarding weather and climate, level of emergency preparedness, primary news source, beliefs in climate change, and belief in the need for immediate climate action. Finally, they completed two standard instruments: (a) a seven-item weather salience questionnaire (short form) to gauge psychological significance of weather (Stewart *et al*, 2012; Stewart, 2009); and (c) a five-item objective numeracy test (Weller *et al*, 2013) based on the proportion of questions answered correctly.

I analyzed the dependent variables of sensitivity and threshold in hurricane perception as a function of (a) experimental condition (control or climate group) and location (non-coastal or coastal resident), (b) demographic variables, (c) the four scales measuring beliefs and experience, (d) extreme event preparation measures, and (e) numeracy, plus one knowledge question on whether people know a hurricane watch is less severe than a hurricane warning. I also analyzed the dependent variable of intention to act as a function of: (a) demographic variables, (b) the four scales measuring beliefs and experience, (c) extreme event preparation measures, and (d) numeracy.

Personal Questions: Table B.3.1 contains the questions that make up the Objective Numeracy Test. Table B.3.2 makes up the Weather Salience Questionnaire (Short Form; Stewart *et al*, 2012); Table B.3.3 contains questions about climate change beliefs; Table B.3.4 contains questions about hurricane experience, weather knowledge and interest, emergency preparedness, and need for climate action; and finally, Table B.3.5 contains the demographic questions. Questions were displayed in the order shown within and between the tables. Table B.3.6 contains summary descriptive statistics.

Individual Difference Measures: Here, I summarize the individual difference measures, created from the demographic and other personal questions (Tables B.3.1, B.3.2, B.3.3, B.3.4, and B.3.5), and used in modelling of *d'*, *c*, and support for immediate climate action (see Chapter 3 Results). Table B.3.6 contains descriptive statistics for these individual difference measures.

The seven questions of the Weather Salience Questionnaire (Short Form) were summed (with item 10 in Table B.3.2 reverse scored) to form the weather salience score for each participant (Stewart *et al*, 2012; Stewart *et al*, 2009). The questions had a Cronbach's α of 0.66. Each participant's responses on the numeracy questions were scored as correct (1) or incorrect (0). This produced participants' Numeracy Score as the proportion of questions answered correctly.

The six questions of the Climate Change Beliefs Questionnaire were summed (with items 13 and 14 in Table B.3.3 reverse scored). The questions had a Cronbach's α of 0.81.

I created a variable, *coast*, to indicate whether the participant was located on the U.S. coast (coast = 1, non-coast = 0). Coastal states (reported within the sample) consisted of Alabama, California, Connecticut, Delaware, Florida, Georgia, Hawaii, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, Texas, Virginia, and Washington state. All other states reported in the sample were classified as non-coastal. See Table B.3.7 for full breakdown of the sample by state.

The questions meant to gauge participants' hurricane experience (items [19-27 in Table B.3.4) were summed to create an *experience score*, and standardized. The Cronbach's α for these items was 0.85.

Items 31 (having planned a place to shelter), 32 (having emergency supplies), and 34 (selecting which of "hurricane watch" or "hurricane warning" meant a greater threat) in Table B.3.4 were kept separate and untransformed. The subjective hurricane impact score (item 28 in Table B.3.4) was standardized. Finally, I created a binary variable *fail*, equal to 1 if the participant failed any of the attention checks, and 0 otherwise.

TABLE B.3.1: Questions that comprise the Objective Numeracy Test (Short Form; Weller *et al*, 2013). Scored based on proportion of questions answered correctly.

	Question	Response Options
[1]	Imagine that we roll a fair, six-sided die 1,000 times. Out of 1,000 rolls, how many times do you think the die would come up as an even number?	Participant inputs response. Correct answer: 500
[2]	If the chance of getting a disease is 20 out of 100, this would be the same as having a __% chance of getting the disease.	Participant inputs response. Correct answer: 20
[3]	If the chance of getting a disease is 10%, how many people would be expected to get the disease out of 1,000?	Participant inputs response. Correct answer: 100
[4]	A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?	Participant inputs response. Correct answer: $0.05
[5]	In a lake, there is a patch of lilypads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?	Participant inputs response. Correct answer: 47 days

TABLE B.3.2: Questions that comprise the Weather Salience Questionnaire (Short Form; Stewart *et al*, 2012).

	Question	Response Options
[6]	"I notice changes that occur in the weather."	Never (1), Seldom (2), Sometimes (3), Usually (4), All of the time (5).
[7]	"I notice how the clouds look during various kinds of weather."	Same as item [7].
[8]	"I plan my daily routine around what the weather may bring."	Same as item [7].
[9]	"In the past I have wished for weather that would lead to a weather-related 'holiday' (i.e. cancellation of events due to severe weather."	Same as item [7].
[10]†	"The weather or changes in the weather really do not matter to me."	Strongly disagree (5), Disagree (4), Neither Agree nor Disagree (3), Agree (2), Strongly Agree (1).
[11]	"I am attached to the weather and climate of my hometown (or the place where my family of origin lives or lived)."	Strongly disagree (1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), Strongly Agree (5).
[12]	"It is important to me to live in a place that offers a variety of different weather conditions throughout the year."	Same as item [12].

† This item is reverse-scored.

TABLE B.3.3: Questions that comprise the Climate Change Belief Scale.

	Question	Response Options
[13]†	Scientists can't predict the climate of the future.	True (-2), Probably true (-1), Don't know (0), Probably false (1), False (2).
[14]†	If the climate is changing today, it is mainly being caused by natural causes.	Same as item [13].
[15]	People burning coal, oil, and natural gas is causing climate change.	True (2), Probably true (1), Don't know (0), Probably false (-1), False (-2).
[16]	Humans adding more CO_2 to the atmosphere is causing climate change.	Same as item [15].
[17]	Nuclear power is a significant cause of climate change.	Same as item [15].
[18]	Using aerosol spray cans today is a significant cause of climate change.	Same as item [15].

† This item is reverse-scored.

TABLE B.3.4: Questions about hurricanes and experience, weather knowledge, interest, and emergency preparedness (Dewitt *et al*, 2015), and need for climate action.

	Question	Response Options
[19]	Have you ever experienced a hurricane directly?	Yes (1), No (0).
[20]	Do you have friends or family who have experienced a hurricane directly?	Yes (1), No (0).
[21]	Have you ever seen hurricane reports, watches, or warnings on local TV, or heard them on the radio?	Yes (1), No (0).
[22]	Have you ever followed a hurricane watch or warning, to see if you should take action?	Yes (1), No (0).
	Have you or anyone in your household ever…	
[23]	…evacuated or left your residence to go someplace safer in responses to the threat of a hurricane?	Yes (1), No (0).
[24]	…been injured (including loss of life) due to a hurricane?	Yes (1), No (0).
[25]	…had damage to or loss of property because of a hurricane?	Yes (1), No (0).
[26]	…had any other financial losses such as business losses or loss of income because of a hurricane?	Yes (1), No (0).
[27]	…had emotional impacts or personal distress because of a hurricane?	Yes (1), No (0).
[28]	Overall, how severe have the impacts of your own hurricane experience(s) been?	Nine-point scale (0-8), from "Don't Know / No Experience" to "Extremely Severe."
[29]	How knowledgeable are you about the weather?	Four-point scale (1-4), from "Not at All" to "Extremely."
[30]	How interested are you in the weather?	Four-point scale (1-4), from "Not at All" to "Extremely."
[31]	Have you planned where you would take shelter during a severe weather event	Yes (1), No (0).
[32]	Have you prepared emergency supplies for a severe weather event or other emergency?	Yes (1), No (0).
[33]	In which of the following places would you most likely take shelter if you were threatened by a hurricane while you were at home? *Please select ONE option.*	Basement, storm cellar or safe room; Closet, hallway, bathroom, or other interior room above ground; Someone else's home, a public shelter, a business, etc.; I would get in my car and drive away; I would not take shelter or drive away; Other.

[34]	Which means a greater threat of a hurricane: a hurricane watch or a hurricane warning?	Warning (1), Watch (0).
[35]	How would you, personally, follow a hurricane watch or warning? *Please select any that apply*.	TV, Radio, Computer, Mobile phone, Rely on others (friends, family, coworkers).
[36]	Where do you get your news in general?	CBS/NBC/ABC, Fox, MSNBC/CNN, Newspapers, Radio, Rely on others (friends, family coworkers).
[37]	The only way to avoid possible future serious changes in the climate is to take action to stop them now.	Strongly disagree (1), Disagree (2), Neither Agree nor Disagree (3), Agree (4), Strongly Agree (5).

TABLE B.3.5: Demographic questions.

	Question	**Response Options**
[38]	Your Gender:	Female (1), Male (0).
[39]	Your Age (in Years):	Participant inputs age.
[40]	What is your occupation?	Participant inputs occupation.
[41]	Your Highest Level of Education:	Some high school (0), High school graduate (1), Some four-year college, junior college or trade school (2), Junior or trade school graduate (3), Four-year college graduate (4), Graduate school in a non-technical field (5), Graduate school in a technical field (6).
[42]	In which state do you currently reside?	Any state, Washington D.C., and any territories.
[43]	Do you consider yourself:	Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), Extremely Conservative (-3).

TABLE B.3.6: Descriptive statistics for items in Tables B.3.1- B.3.5. Note results for items [33], [35], and [36] from Table B.3.4 are reported in Figures B.3.1, B.3.2, and B.3.3, respectively.

Item		Mean	Std Dev	Min	Median	Max
[1]	Imagine that we roll a fair, six-sided die 1,000 times. Out of 1,000 rolls, how many times do you think the die would come up as an even number?	538	700	0	500	10060
[2]	If the chance of getting a disease is 20 out of 100, this would be the same as having a __% chance of getting the disease.	25	44	0	20	500
[3]	If the chance of getting a disease is 10%, how many people would be expected to get the disease out of 1,000?	88	51	0	100	500
[4]	A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost?	6	45	0	0	500
[5]	In a lake, there is a patch of lilypads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?	45	43	12	47	500
[6]	"I notice changes that occur in the weather."	3.7	0.9	1	4	5
[7]	"I notice how the clouds look during various kinds of weather."	3.5	1.0	1	3.5	5
[8]	"I plan my daily routine around what the weather may bring."	3.2	1.0	1	3	5
[9]	"In the past I have wished for weather that would lead to a weather-related 'holiday' (i.e. cancellation of events due to severe weather."	2.9	1.0	1	3	5
[10]	"The weather or changes in the weather really do not matter to me."	3.6	1.1	1	4	5
[11]	"I am attached to the weather and climate of my hometown (or the place where my family of origin lives or lived)."	2.9	1.2	1	3	5
[12]	"It is important to me to live in a place that offers a variety of different weather conditions throughout the year."	3.1	1.1	1	3	5
[13]	Scientists can't predict the climate of the future.	0.3	1.4	-2	1	2
[14]	If the climate is changing today, it is mainly being caused by natural causes.	0.6	1.4	-2	1	2
[15]	People burning coal, oil, and natural gas is causing climate change.	1.1	1.2	-2	1	2
[16]	Humans adding more CO_2 to the atmosphere is causing climate change.	1.2	1.2	-2	2	2
[17]	Nuclear power is a significant cause of climate change.	-0.5	1.5	-2	-1	2
[18]	Using aerosol spray cans today is a significant cause of climate change.	0.2	1.4	-2	1	2
[19]	Have you ever experienced a hurricane directly?*	0.4	0.5	0	0	1
[20]	Do you have friends or family who have experienced a hurricane directly?*	0.6	0.5	0	1	1

[21]	Have you ever seen hurricane reports, watches, or warnings on local TV, or heard them on the radio?*	0.8	0.4	0	1	1
[22]	Have you ever followed a hurricane watch or warning, to see if you should take action?*	0.6	0.5	0	1	1
	Have you or anyone in your household ever…					
[23]	…evacuated or left your residence to go someplace safer in responses to the threat of a hurricane?*	0.2	0.4	0	0	1
[24]	…been injured (including loss of life) due to a hurricane?*	0.1	0.2	0	0	1
[25]	…had damage to or loss of property because of a hurricane?*	0.2	0.4	0	0	1
[26]	…had any other financial losses such as business losses or loss of income because of a hurricane?*	0.1	0.3	0	0	1
[27]	…had emotional impacts or personal distress because of a hurricane?*	0.2	0.4	0	0	1
[28]	Overall, how severe have the impacts of your own hurricane experience(s) been?	1.5	1.6	0	1	6
[29]	How knowledgeable are you about the weather?	2.0	0.7	1	2	4
[30]	How interested are you in the weather?	2.4	0.8	1	2	4
[31]	Have you planned where you /would take shelter during a severe weather event?*	0.5	0.5	0	0	1
[32]	Have you prepared emergency supplies for a severe weather event or other emergency?*	0.5	0.5	0	0.5	1
[34]	Which means a greater threat of a hurricane: a hurricane watch or a hurricane warning?*	0.8	0.4	0	1	1
[37]	The only way to avoid possible future serious changes in the climate is to take action to stop them now.	4.0	1.1	1	4	5
[38]	Your Gender*	0.4	0.5	0	0	1
[39]	Your Age (in Years)	35	10	20	32	79

* Requires a binary response. See Tables C4 and C5 for coding scheme.

TABLE B.3.7: Responses for item [42], state of residence.

State	*N*
AL	4
AK	2
AZ	8
AR	4
CA	29
CO	4
CT	4
DE	2
FL	25
GA	6
HI	2
ID	1
IL	11
IN	3
IA	0
KS	1
KY	1
LA	0
ME	0
MD	2
MA	6
MI	6
MN	3
MS	2
MO	4
MT	0
NE	1
NV	2
NH	3
NJ	7
NM	0
NY	23
NC	11
ND	0
OH	2
OK	3
OR	6
PA	11
RI	2
SC	5

SD	0
TN	5
TX	15
UT	3
VT	0
VA	9
WA	6
WV	1
WI	4
WY	1

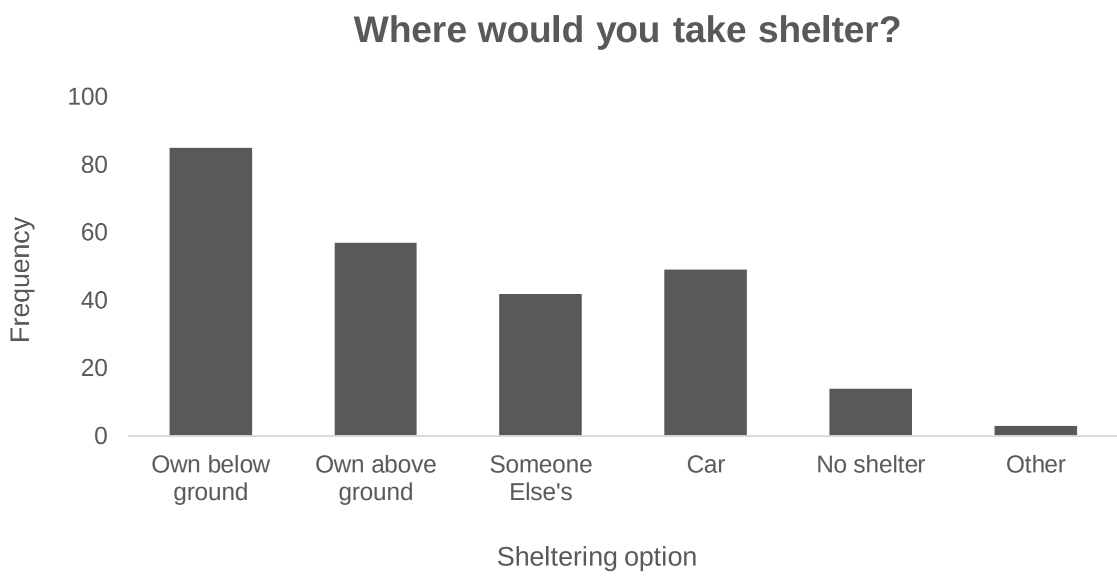

Figure B.3.1: Bar chart showing the distribution of responses to item [33], Table B.3.4: "In which of the following places would you most likely take shelter if you were threatened by a hurricane while you were at home? *Please select ONE option*." Response options included: Basement, storm cellar or safe room ("Own below ground" in figure); Closet, hallway, bathroom, or interior room above ground ("Own above ground" in figure); Someone else's home, a public shelter, a business, etc. ("Some Else's" in figure); 'I would get in my car and drive away' ("Car" in figure); 'I would not take shelter or drive away' ("No shelter" in figure); and Other.

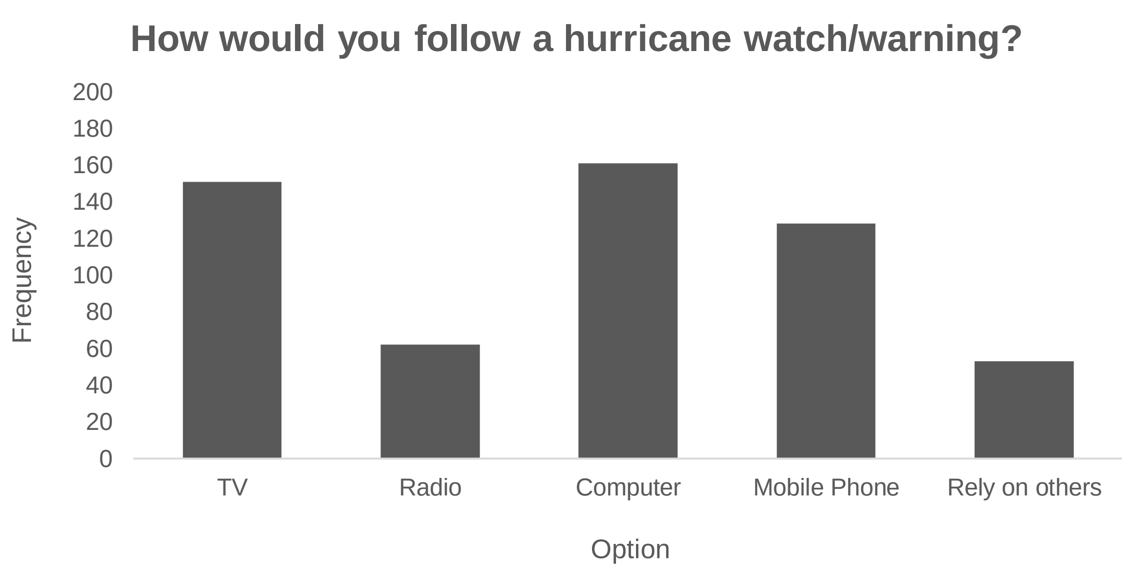

Figure B.3.2: Bar chart showing the distribution of responses to item [35], Table B.3.4: "How would you, personally, follow a hurricane watch or warning? *Please select any that apply*." Response options included: TV, Radio, Computer, Mobile Phone, and Rely on others (friends, family, coworkers).

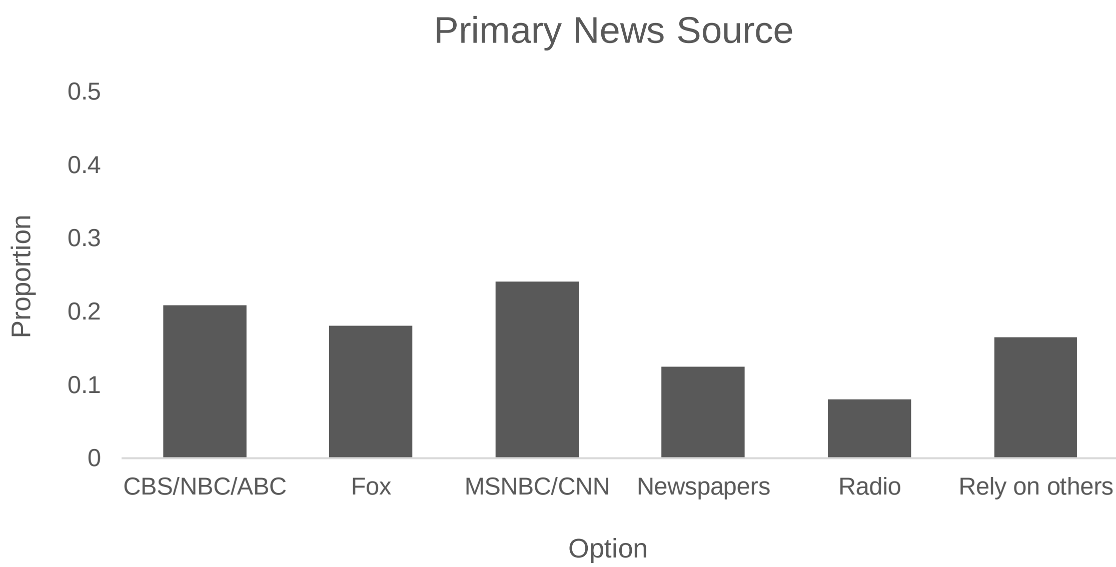

Figure B.3.3: Bar chart showing the distribution of responses to item [36], Table B.3.4: "Where do you get your news in general?" Response options included: CBS/NBC/ABC, Fox, MSNBC/CNN, Newspapers, Radio, Rely on others.

TABLE B.3.5: Summary of descriptive statistics for individual difference measures. Note that *climate change beliefs, experience,* and *impacts* below are standardized.

Covariate	Mean	Std Dev	Min	Median	Max
*coast** (1 = lives on U.S. coast)	0.7	0.5	-	-	-
*shelter** (1 = has planned shelter)	0.5	0.5	-	-	-
*supplies** (1 = has emergency supplies)	0.5	0.5	-	-	-
climate change beliefs (-12 - 12)	0.4	5.1	-12	3	12
weather salience (5-35)	22.9	4.2	8	23	35
experience (-1.25 - 2.3)	0.0	1.0	-1.3	-0.3	2.3
impacts (-0.9 - 2.8)	0.0	1.0	-0.9	-0.3	2.8
numeracy score (0-1)	0.7	0.3	0	0.8	1
*watch-warn** (1 = knew warning was more severe)			-	-	-

* Binary variables.

Appendix B.4: Appendix B references

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Appendix C: Supplemental Information for Chapter 4

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Appendix C.1: Survey protocol

Scientists and engineers have identified several things we can do to stop adding carbon dioxide (CO_2) to the atmosphere:

- Some of these require government and society to make basic changes in the way energy is produced and used, and,
- Some of these are things we and our families can do as individuals.

Listed below are a number of statements. Please check the response that is closest to your best judgment about the statement.

1. Individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

2. Individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

3. Individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

4. You and your family have ***already*** done more than your fair share of things to try and reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

5. It is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

6. Governments and society in general have ***already*** done more than their fair share of things to try to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

7. Governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

8. Governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

9. Governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

10. Scientists believe that individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

11. Scientists believe that individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

12. Scientists believe individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree | Disagree | Neither disagree nor agree | Agree | Strongly Agree

13. Scientists believe it is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

14. Scientists believe governments and society in general have done more than their fair share of things to try and reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

15. Scientists believe that governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

16. Scientists believe governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

17. Scientists believe governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

SCALE BAR

We asked a group of experts to make two lists of the things they thought could lead to the largest CO_2 emissions reduction by:

1) governments and society in general and
2) individuals and families in general.

While the experts were able to suggest a bunch of other things, we asked them to limit the length of each of their lists to a single page. Please take a few minutes to look over these lists.

EXPERT LISTS

What American Governments and society can do:

- Adopt ways to reduce CO_2 emissions from power plants, industry, and chemical plants.
  This could be done through emission fees, "cap and trade," and emission regulations. If this happens, it should be done in a way that helps companies plan ahead.

- Encourage more use of energy sources that do not emit CO_2 (wind, solar, hydro nuclear, etc.).

  - Do things that reduce CO_2 from cars and trucks.
    Promote electric vehicles.
    Make cars and trucks that use gas or diesel more fuel efficient.
    Make public transportation, including trains, much easier to use.
    Promote car services like Uber and Lyft, ride sharing, etc.
    Make it easier and safer to bike or walk.
    Improve road surfaces to improve vehicle mileage.
    Develop affordable liquid fuels or hydrogen system that do not result in any net CO_2 emissions (corn ethanol does not do this).

  - Adopt policies that move many more energy systems to use electricity (also called "electrification").
    This assumes that electric generation will continue to reduce CO_2 emissions.

  - Adopt policies that reduce other greenhouse gases besides CO_2.
    Stop leaks of methane from natural gas and other systems.
    Keep reducing emissions of coolants from refrigeration and cooling systems (that also destroy the ozone layer).

  - Adopt policies and technologies that do a better job of limiting emissions from farming and livestock.

  - Reduce deforestation and promote forest growth.

  - Adopt policies to reduce CO_2 from planes and ships.

- Pass laws that encourage institutional investments to be in "low carbon" mutual funds and other "green" investment programs.

- Engage with international policy with other major emitters, such as China and Europe.
  Share best practices and help developing countries reduce their emissions.

- Support family planning.

- Develop and deploy direct air capture technology that can "scrub" CO_2 out of the atmosphere.

- Expand research by government and industry to develop methods that can do all of the things listed above better and cheaper.

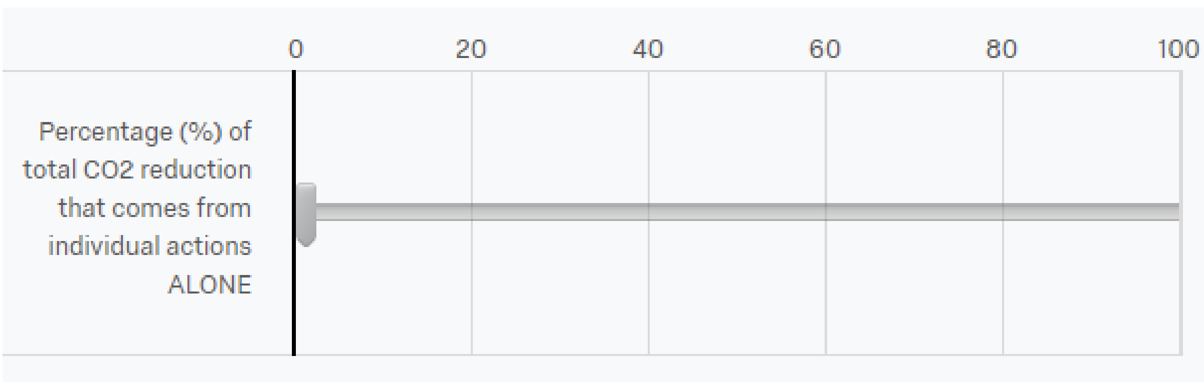
What individual Americans and their families can do:

- Improve insulation in homes and buildings.
  - Install better insulation, energy efficient windows, and storm doors and windows.
  - Use insulating drapes and blinds.
  - Make outside walls and roofs light-colored to reflect sunlight in the summer and don't give off as much heat in the winter.
  - Plant trees that lose their leaves in places that will shade your house in the summer but let sun in during the winter.
- Install more efficient heating and cooling.
  - Change to a high-efficiency furnace and air conditioning.
  - Change to a heat pump for heating and cooling.
  - Warp your water heater with insulation.
  - Change to a heat pump water heater.
- Switch to smaller houses.
- Lessen use of private cars and trucks that use gasoline.
  - Change to electric or hybrid vehicles.
  - Use more public transit and car pools.
  - Bike or walk.
  - Live closer to work.
- Switch to energy efficient lights.
  - Use compact fluorescent and LED lights.
  - Turn lights off when not in use.
- Energy efficient appliances
  - Check energy efficiency ratings when you buy a new appliance (especially ones that use a lot of electricity like refrigerators and flat screen TVs).
  - Turn off TV and other appliances when not in use (all the way off – not in "standby mode")
- Dress appropriately for the season.
  - In winter, wear sweaters, etc. In summer, wear short-sleeves and light cloths.
- Minimize disposable stuff you buy.
  - Don't buy bottled water.
- Recycle things to reduce trash in landfills.
- Minimize emissions from air travel.
  - Travel less.
  - Use trains when possible.
  - Buy "carbon offsets" when you fly.
- Change diet.
  - Eat more grain, fruit and vegetables.
  - Eat less meat - especially beef.
- Limit family size.
- Invest in "low carbon" mutual funds and other "green" investment programs.

There are many things that could be added to these lists. But these are the things experts told us could do the ***most*** to reduce CO_2 emissions.

Suppose that in 2020, Americans and governments at all levels all got serious about doing the things on these two lists. Suppose that this bar represents the total reduction of CO_2 emissions in the year 2030, after all the changes on these two lists the experts made were done by **all** members of society. Please slide the bar to indicate how much of that decrease you think would come from **ONLY the actions of individuals and their families**.

- If you think that those **individual actions** would cause **much** or even **most** of the decrease, you should choose a high number. That is, you should drag the slider somewhere on the right-hand end of the bar.
- If you think that the individual actions will cause **only a little** of the decrease, you should choose a low number. That is, you should drag the slider somewhere on the left-hand side of the bar.



18. Which of the actions from the Experts List would you be most willing to take?

____

19. Which of the actions from the Experts List do you believe governments and society in general would be most willing to take?

____

Listed below are a couple of questions about CO_2. Please check the response that is closest to your best judgment about the statement.

20. Imagine that the world's modern factories, transportation and power plants all stopped emitting **carbon dioxide** (CO_2) today. How long would it take for the amount of **carbon dioxide** (CO_2) in the air to fall back to what it was before those modern factories, transportation and power plants existed?

Hours to days	Weeks to months	Years	Decades	Centuries	Never

21. What do you believe are the ***impacts*** of more CO_2 in the atmosphere?

____-

Listed below are a number of questions about climate change. Please check the response that is closest to your best judgment about the statement.

22. If the climate is changing today, it is ***mainly*** being caused by natural causes.

True	Probably true	Don't know	Probably false	False

23. The climate is changing today, and the change is ***mainly*** caused by people burning coal, oil, and natural gas.

True	Probably true	Don't know	Probably false	False

24. The climate is changing today, and that change is mainly caused by humans adding more CO_2 to the atmosphere.

True	Probably true	Don't know	Probably false	False

25. Nuclear power is a significant cause of climate change.

True	Probably true	Don't know	Probably false	False

26. Using aerosol spray cans today is a significant cause of climate change.

True	Probably true	Don't know	Probably false	False

27. I feel that actions the government has or could take to reduce CO_2 emissions are effective in slowing global warming.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

28. I feel that actions individuals have or could take to reduce CO_2 emissions are effective in slowing global warming.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

29. The only way to avoid possible future serious changes in the climate is to take action to stop them now.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

30. If we wait, and climate change gets serious, we can reverse it when that happens by cutting emissions of CO_2, just like we cleaned up air pollution in places like Pittsburgh and Los Angeles once it got really bad.

Strongly disagree	Disagree	Neither disagree nor agree	Agree	Strongly Agree

31. How much do you support or oppose reducing global warming by reducing carbon emissions?

Strongly oppose	Oppose	Neither support nor oppose	Support	Strongly Support	Don't Know

32. Who is most responsible for taking actions to combat climate change?

Individuals	Businesses	Government

ANONYMOUS QUESTIONS

1. Female ________ Male ________

2. Your Age: _____________years

3. Your highest level of education:

Some high school	Junior college or trade school graduate
High school graduate	Four-year college graduate
Some four-year college, junior college or trade school	Graduate school in a non-technical field
	Graduate school in a technical field

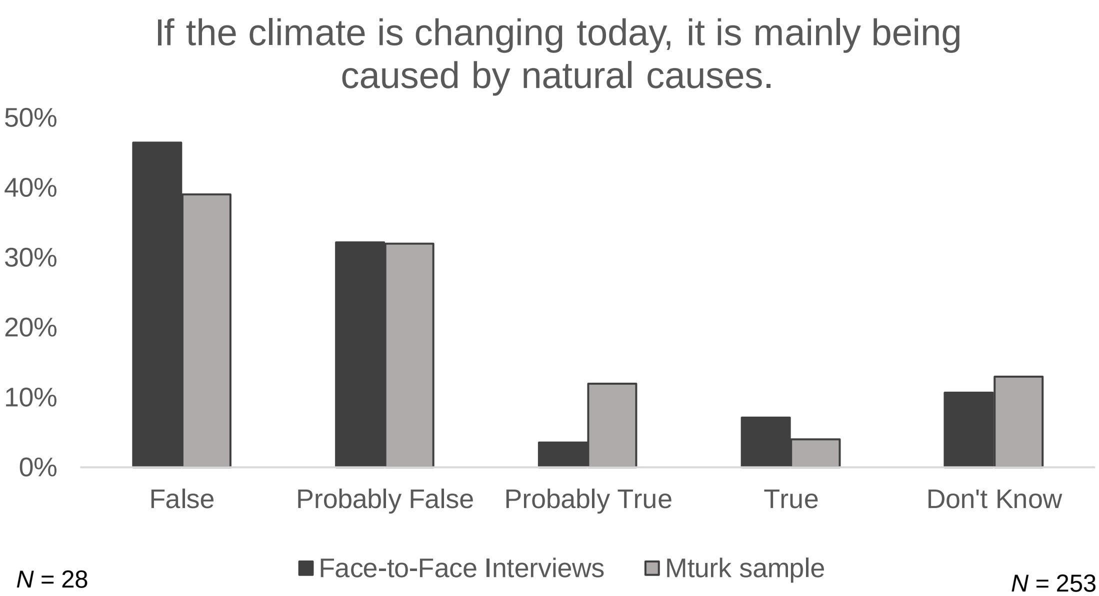
5. In which state do you currently reside? ________

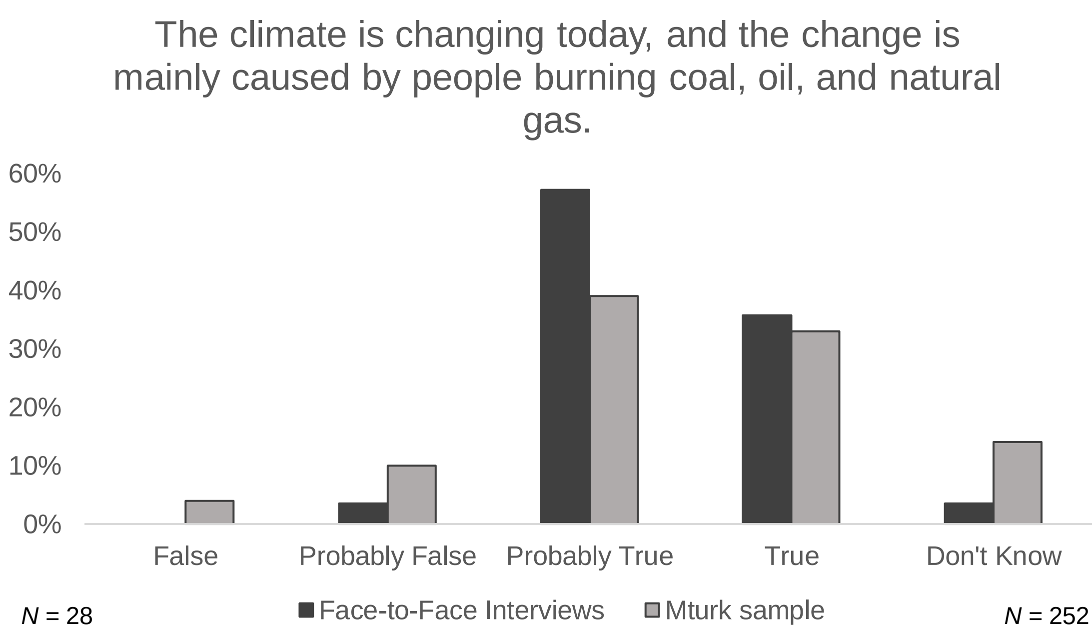
6. Your political ideology:

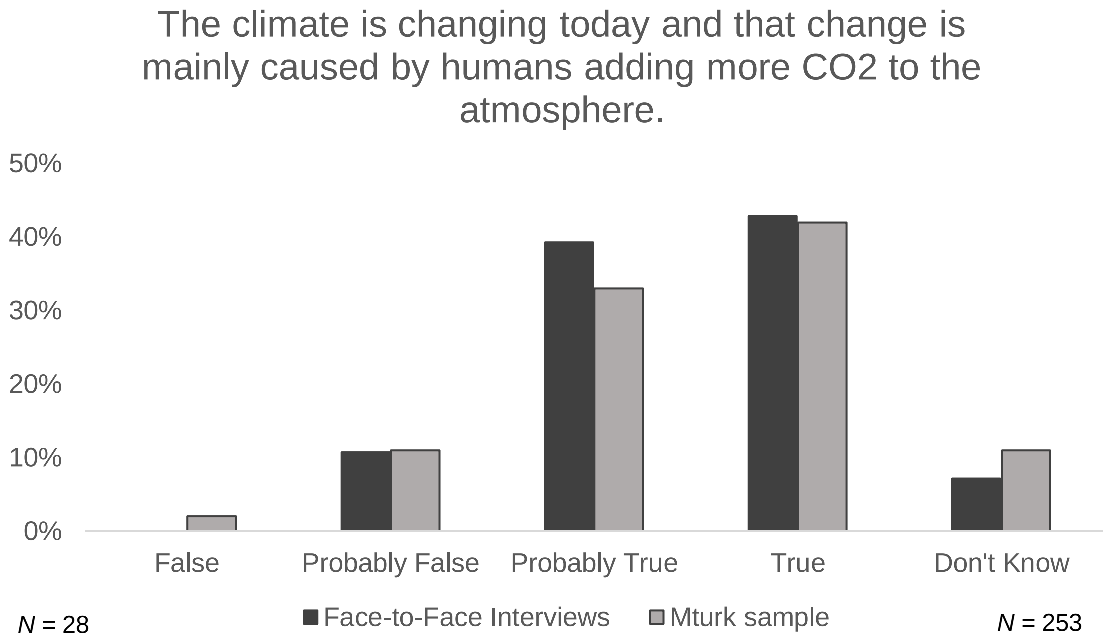
Extremely Liberal	Liberal	Slightly Liberal	Moderate/Middle of the Road	Slightly Conservative	Conservative	Extremely Conservative
1	2	3	4	5	6	7

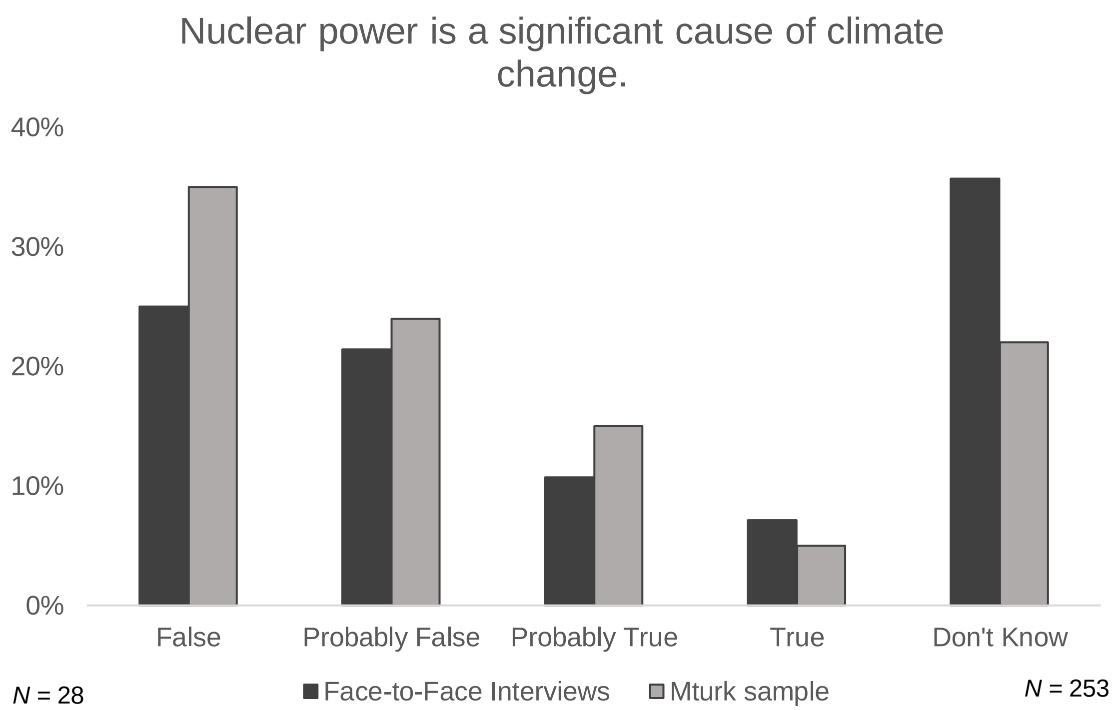
Appendix C.2: Extended comparison of interview and MTurk samples

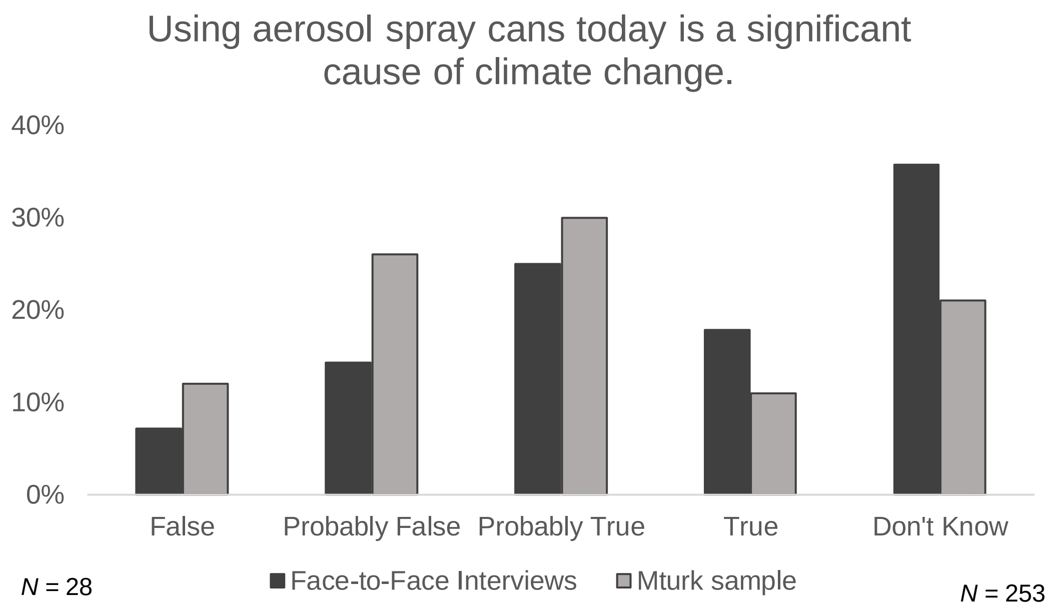
In addition to the quantitative scale bar question, there were 8 common questions between the interview (N = 28) and MTurk samples. MTurk samples vary from question to question due to item non-response.

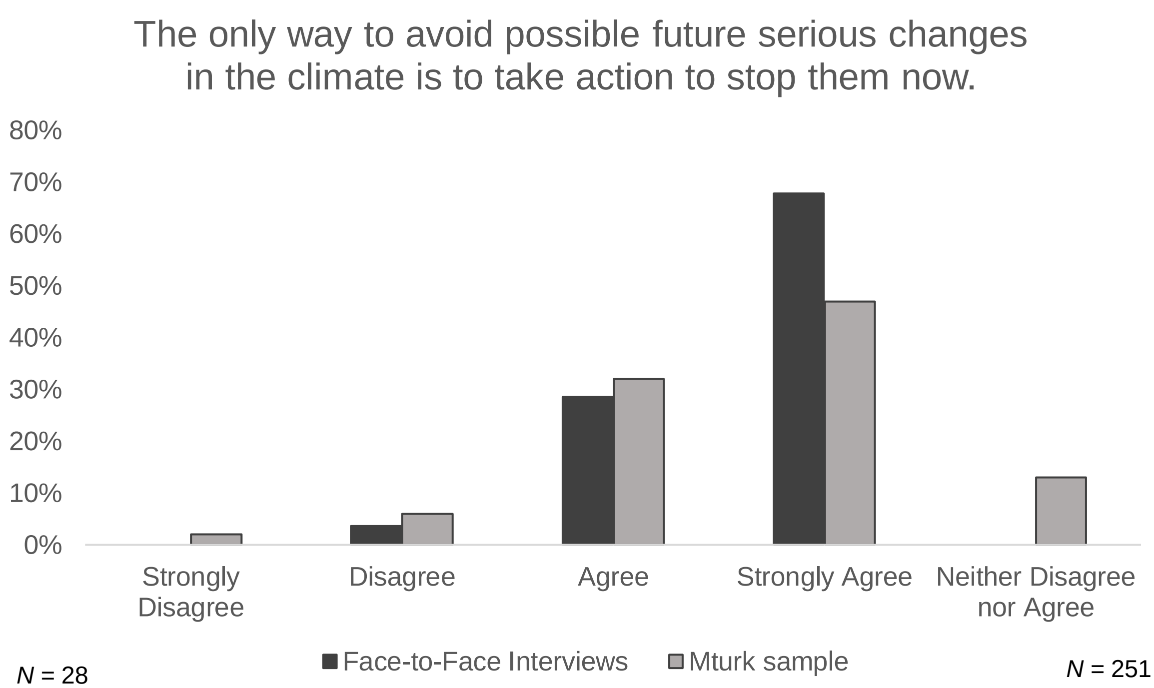


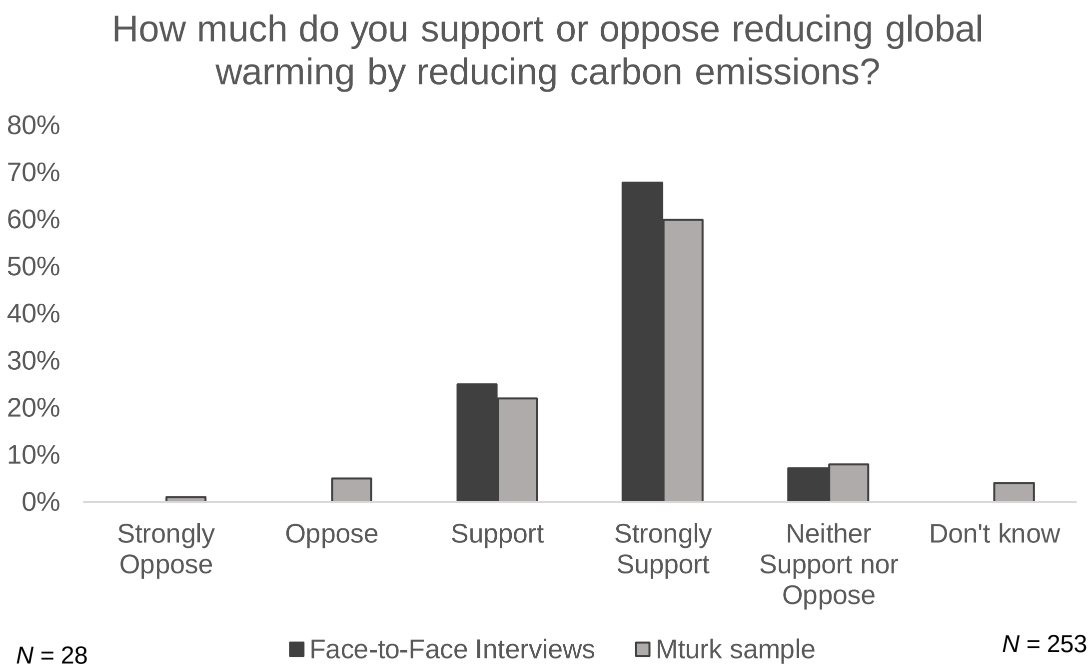


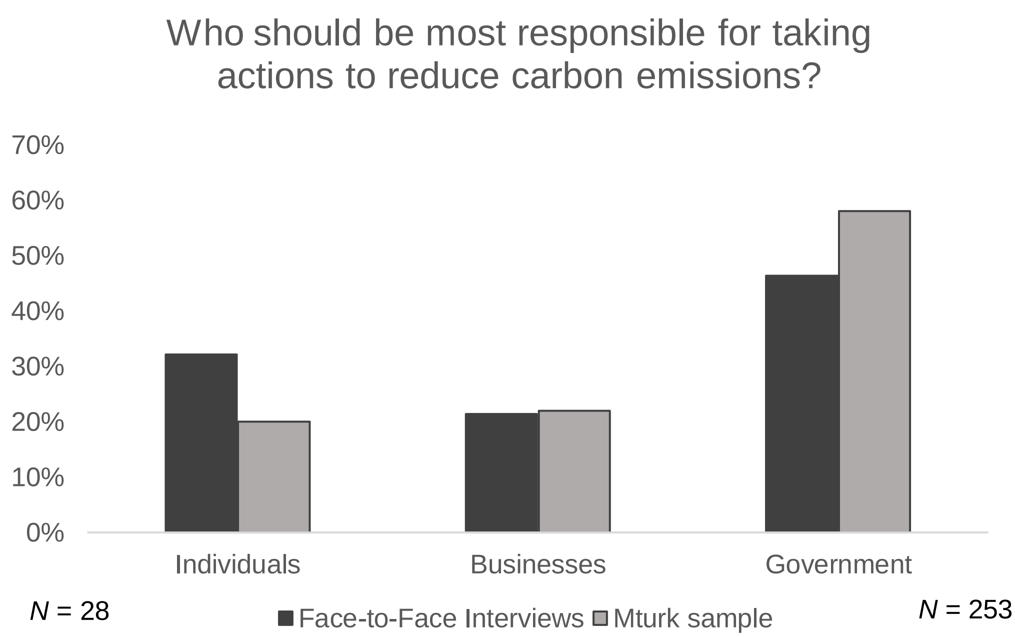

The climate is changing today and that change is mainly caused by humans adding more CO2 to the atmosphere.
50%
40%
30%
20%
10%
0%
False
Probably False
Probably True
True
Don't Know
N = 28
Face-to-Face Interviews
Mturk sample
N = 253


Nuclear power is a significant cause of climate change.
40%
30%
20%
10%
0%
False
Probably False
Probably True
True
Don't Know
N = 28
Face-to-Face Interviews
Mturk sample
N = 253


Using aerosol spray cans today is a significant cause of climate change.
40%
30%
20%
10%
0%
False
Probably False
Probably True
True
Don't Know
N = 28
Face-to-Face Interviews
Mturk sample
N = 253


The only way to avoid possible future serious changes in the climate is to take action to stop them now.
80%
70%
60%
50%
40%
30%
20%
10%
0%
Strongly Disagree
Disagree
Agree
Strongly Agree
Neither Disagree nor Agree
Face-to-Face Interviews
Mturk sample
N = 28
N = 251





Figures C.2.1: Comparison of the 8 common questions between the interview (N = 28) and MTurk samples. MTurk sample sizes vary from question to question due to item non-response.

Appendix C.3: Personal questions and individual difference measures

After completing the survey, participants were asked a series of personal questions. Participants were asked for their age, gender, education, political ideology, and state of residence. They also answered questions about their beliefs about the causes of climate change, self- and response-efficacy, intention to act in response to climate change, support for emissions reduction, and who is most responsible to act in response to climate change.

I analyzed the dependent variables for predicting (1) how much participants believed individual actions alone could reduce CO2 emissions, and (2) support for immediate climate action as a function of two main sets of predictors: (a) demographic variables, and (b) six scales measuring beliefs about the causes of climate change, government and individual actions, the need for further action, and self- and response-efficacy.

Personal Questions: Table C.3.1 contains questions that make up the Climate Change Cause belief scale. Table C.3.2 contains questions that make up the Government Action beliefs scale. Table C.3.3 contains questions that make up the Individual Action beliefs scale. Table C.3.4 contains questions that make up the beliefs that More Action (is) Needed scale. Table C.3.5 contains questions that comprise the Individual self-efficacy belief scale. Table C.3.6 contains questions that make up the Individual and Governmental (combined) response-efficacy scale. Table C.3.7 contains questions on participant's beliefs on CO_2 atmospheric residence time, climate change causes, delayed action, and responsible parties for acting in response to climate change. Table C.3.8 contains the demographic questions. Table C.3.9 contains summary descriptive statistics. Table C.3.10 contains responses to the state-of-residence question.

Individual Difference Measures: Here, I summarize the individual difference measures, created from the demographic and other personal questions (Tables C.3.1, C.3.2, C.3.3, C.3.4, C.3.5, C.3.6, C.3.7, and C.3.8), and used in modelling scale bar responses and support for immediate climate action (see Results in Chapter 4). Table C.3.11 contains descriptive statistics for these individual difference measures.

Multicollinearity and factor analysis: First, a variance inflation factor (VIF) multicollinearity test was conducted. There was some indication of multicollinearity (VIFs ranged from 1.17 to 3.75), and high correlations were present in a pairwise correlation matrix (Fig. C.3.1).

Correlation Matrix

		Zscore: wubi_already taken	Zscore: wubi_could do more	Zscore: wubi_should do more	Zscore: wubi_> than your share	Zscore: wubi_individuals alone possible	Zscore: wubc_already done fair	Zscore: wubc_already take action	Zscore: wubc_could do more	Zscore: wubc_should do more	Zscore: wsbi_already taken	Zscore: wsbi_could do more	Zscore: wsbi_should do more
Correlation	Zscore: wubi_already taken	1.000	-.116	-.194	-.414	-.124	-.457	-.543	-.203	-.168	.638	-.079	-.167
	Zscore: wubi_could do more	-.116	1.000	.619	.324	.090	.296	.040	.500	.467	-.165	.473	.370
	Zscore: wubi_should do more	-.194	.619	1.000	.382	.069	.303	.172	.633	.581	-.208	.348	.556
	Zscore: wubi_> than your share	-.414	.324	.382	1.000	.145	.492	.308	.307	.296	-.431	.277	.398
	Zscore: wubi_individuals alone possible	-.124	.090	.069	.145	1.000	.384	.199	.240	.182	-.129	.184	.093
	Zscore: wubc_already done fair	-.457	.296	.303	.492	.384	1.000	.614	.534	.573	-.485	.326	.328
	Zscore: wubc_already take action	-.543	.040	.172	.308	.199	.614	1.000	.377	.369	-.479	.048	.161
	Zscore: wubc_could do more	-.203	.500	.633	.307	.240	.534	.377	1.000	.716	-.210	.369	.442
	Zscore: wubc_should do more	-.168	.467	.581	.296	.182	.573	.369	.716	1.000	-.187	.347	.413
	Zscore: wsbi_already taken	.638	-.165	-.208	-.431	-.129	-.485	-.479	-.210	-.187	1.000	-.159	-.255
	Zscore: wsbi_could do more	-.079	.473	.348	.277	.184	.326	.048	.369	.347	-.159	1.000	.453
	Zscore: wsbi_should do more	-.167	.370	.556	.398	.093	.328	.161	.442	.413	-.255	.453	1.000
	Zscore: wsbi_individuals alone possible	-.109	.204	.189	.240	.680	.446	.190	.331	.272	-.130	.280	.130
	Zscore: wsbc > than their share	-.432	.266	.313	.488	.370	.750	.516	.487	.459	-.455	.422	.405
	Zscore: wsbc_already taken action	-.516	.062	.145	.283	.178	.494	.734	.289	.196	-.501	.048	.179
	Zscore: wsbc_could do more	-.176	.399	.505	.348	.315	.555	.358	.655	.556	-.210	.433	.484
	Zscore: wsbc_should do more	-.219	.411	.483	.309	.263	.514	.282	.551	.573	-.304	.430	.467
	Zscore: Govt action slow GW	-.033	.122	.069	.155	.009	.097	.135	.097	.142	-.004	.076	-.063
	Zscore: Indi action slow GW	-.028	.119	.026	.046	.021	.064	.097	.003	.092	-.001	.054	-.063
	Zscore: Cut when its bad	.101	.011	-.020	-.026	-.064	-.048	-.066	-.021	.034	.058	.041	-.110
	Zscore: Cause cc = natural	-.185	.357	.445	.312	.182	.476	.342	.559	.554	-.190	.214	.286
	Zscore: Cause = us burn stuf	-.155	.330	.451	.229	.170	.330	.212	.524	.528	-.146	.168	.243
	Zscore: Cause = + CO2	-.217	.376	.482	.290	.188	.489	.326	.599	.648	-.189	.326	.315
	Zscore(Nuclear)	.151	-.093	-.007	-.152	-.276	-.275	-.115	-.167	-.124	.104	-.117	-.127
	Zscore: Oppose reduce CO2	-.110	.081	.015	.053	-.068	.093	.122	.036	.042	-.017	-.038	-.058
	Zscore: Spray cans	.074	.102	.195	.057	-.241	-.054	-.068	.087	.079	.064	.054	.129

		Zscore: wsbi_individuals alone possible	Zscore: wsbc > than their share	Zscore: wsbc_already taken action	Zscore: wsbc_could do more	Zscore: wsbc_should do more	Zscore: Govt action slow GW	Zscore: Indi action slow GW	Zscore: Cut when its bad	Zscore: Cause cc = natural	Zscore: Cause = us burn stuf	Zscore: Cause = + CO2	Zscore (Nuclear)	Zscore: Oppose reduce CO2	Zscore: Spray cans
Correlation	Zscore: wubi_already taken	-.109	-.432	-.516	-.176	-.219	-.033	-.028	.101	-.185	-.155	-.217	.151	-.110	.074
	Zscore: wubi_could do more	.204	.266	.062	.399	.411	.122	.119	.011	.357	.330	.376	-.093	.081	.102
	Zscore: wubi_should do more	.189	.313	.145	.505	.483	.069	.026	-.020	.445	.451	.482	-.007	.015	.195
	Zscore: wubi_> than your share	.240	.488	.283	.348	.309	.155	.046	-.026	.312	.229	.290	-.152	.053	.057
	Zscore: wubi_individuals alone possible	.680	.370	.178	.315	.263	.009	.021	-.064	.182	.170	.188	-.276	-.068	-.241
	Zscore: wubc_already done fair	.446	.750	.494	.555	.514	.097	.064	-.048	.476	.330	.489	-.275	.093	-.054
	Zscore: wubc_already take action	.190	.516	.734	.358	.282	.135	.097	-.066	.342	.212	.326	-.115	.122	-.068
	Zscore: wubc_could do more	.331	.487	.289	.655	.551	.097	.003	-.021	.559	.524	.599	-.167	.036	.087
	Zscore: wubc_should do more	.272	.459	.196	.556	.573	.142	.092	.034	.554	.528	.648	-.124	.042	.079
	Zscore: wsbi_already taken	-.130	-.455	-.501	-.210	-.304	-.004	-.001	.058	-.190	-.146	-.189	.104	-.017	.064
	Zscore: wsbi_could do more	.280	.422	.048	.433	.430	.076	.054	.041	.214	.168	.326	-.117	-.038	.054
	Zscore: wsbi_should do more	.130	.405	.179	.484	.467	-.063	-.063	-.110	.286	.243	.315	-.127	-.058	.129
	Zscore: wsbi_individuals alone possible	1.000	.445	.210	.368	.331	.003	.010	-.042	.315	.237	.299	-.329	-.019	-.132
	Zscore: wsbc > than their share	.445	1.000	.547	.532	.554	.057	.062	-.060	.445	.266	.449	-.328	.059	-.068
	Zscore: wsbc_already taken action	.210	.547	1.000	.268	.277	.044	.021	-.128	.250	.109	.226	-.133	.059	-.088
	Zscore: wsbc_could do more	.368	.532	.268	1.000	.661	.146	.048	-.018	.477	.359	.433	-.216	.057	-.058
	Zscore: wsbc_should do more	.331	.554	.277	.661	1.000	.071	.026	-.017	.396	.328	.420	-.216	.001	-.043
	Zscore: Govt action slow GW	.003	.057	.044	.146	.071	1.000	.632	.003	.164	.100	.117	.011	.232	-.006
	Zscore: Indi action slow GW	.010	.062	.021	.048	.026	.632	1.000	.077	.049	-.051	.017	.014	.250	-.036
	Zscore: Cut when its bad	-.042	-.060	-.128	-.018	-.017	.003	.077	1.000	-.167	-.098	-.101	.119	-.180	.072
	Zscore: Cause cc = natural	.315	.445	.250	.477	.396	.164	.049	-.167	1.000	.470	.632	-.273	.138	.018
	Zscore: Cause = us burn stuf	.237	.266	.109	.359	.328	.100	-.051	-.098	.470	1.000	.697	.039	.066	.193
	Zscore: Cause = + CO2	.299	.449	.226	.433	.420	.117	.017	-.101	.632	.697	1.000	-.044	.041	.132
	Zscore(Nuclear)	-.329	-.328	-.133	-.216	-.216	.011	.014	.119	-.273	.039	-.044	1.000	-.089	.340
	Zscore: Oppose reduce CO2	-.019	.059	.059	.057	.001	.232	.250	-.180	.138	.066	.041	-.089	1.000	-.001
	Zscore: Spray cans	-.132	-.068	-.088	-.058	-.043	-.006	-.036	.072	.018	.193	.132	.340	-.001	1.000

Figure C.3.1: Pairwise correlation matrix of all individual, independent variables.

Principal component analysis (PCA) with a varimax rotation was used to explain the maximum amount of the observed variance with the minimum number of components (Fig. C.3.2). The PCA resulted in six reliable factors: (1) Climate Change Cause beliefs (3 items; Cronbach's $\alpha = 0.82$), (2) Government Action beliefs (4 items; Cronbach's $\alpha = 0.86$), (3) Individual Action beliefs (3 items; Cronbach's $\alpha = 0.75$), (4) beliefs that More Action (is) Needed (8 items; Cronbach's $\alpha = 0.89$), (5) Individual self-efficacy beliefs (2 items; Cronbach's $\alpha = 0.81$), and (6) Individual and Governmental (combined) response-efficacy (2 items; Cronbach's $\alpha = 0.78$). For each multi-item factor, I therefore computed a new variable.

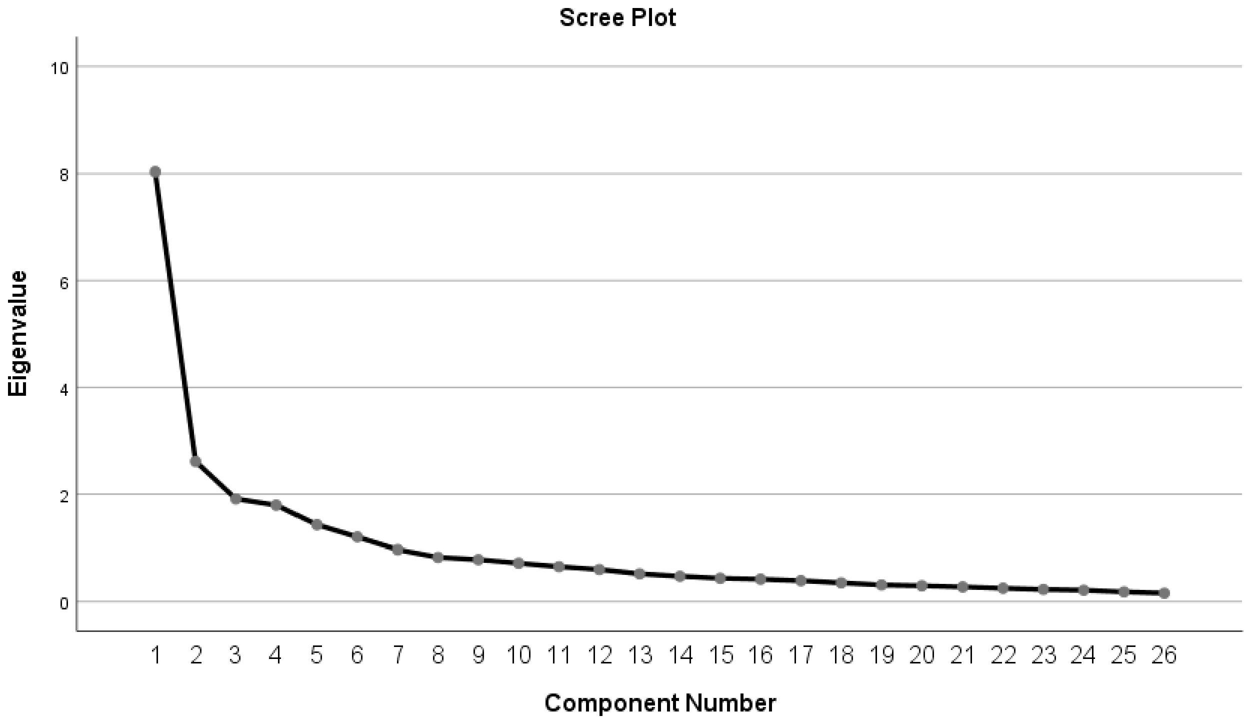


Figure C.3.2: Scree plot for factor analysis.

The Climate Change Cause beliefs scale was summed from three related survey questions: (1) The climate is changing today, and the change is ***mainly*** caused by people burning coal, oil, and natural gas; (2) The climate is changing today and that change is mainly caused by humans adding more CO_2 to the atmosphere; and (3) If the climate is changing today, it is ***mainly*** being caused by natural causes. Item 3 was reverse coded.

The Government Action beliefs scale was summed from four related survey questions: (1) Scientists believe that governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere; (2) Governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere; (3) Governments and society in general have ***already*** done more than their fair share of things to try to reduce how much CO_2 is being added to our atmosphere; and (4) Scientists believe governments and society in general have done more than their fair share of things to try and reduce how much CO_2 is being added to our atmosphere. All were reverse coded, as the coding scheme was designed such that positive values were biased toward agreement with statements and negative values were biased toward disagreement with statements.

The Individual Action beliefs scale was summed from three related survey questions: (1) Individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere; (2) Scientists believe that individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere; and (3) You and your family have ***already*** done more than your fair share of things to try and reduce how much CO_2 is being added to our atmosphere. None were reverse coded.

The More Action (is) Needed beliefs scale was summed from eight related survey questions: (1) Governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere; (2) Governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere; (3) Scientists believe individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere; (4) Scientists believe that individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere; (5) Individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere; (6) Individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere; (7) Scientists believe governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere; and (8) Scientists believe governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere. None were reverse coded.

The Individual self-efficacy beliefs scale was summed for two related items: It is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action; and (2) Scientists believe it is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action. Both were reversed coded.

The Individual and Governmental (combined) response-efficacy beliefs scale was summed for two related items: (1) I feel that actions the government has or could take to reduce CO_2 emissions are effective in slowing global warming; and (2) I feel that actions individuals have or could take to reduce CO_2 emissions are effective in slowing global warming. None were reverse coded.

TABLE C.3.1: Questions that comprise the Climate Change Cause belief scale (3 items; Cronbach's $\alpha = 0.82$).

	Question	**Response Options**
[1]	The climate is changing today, and the change is ***mainly*** caused by people burning coal, oil, and natural gas.	True (2), Probably true (1), Don't know (0), Probably false (-1), False (-2).
[2]	The climate is changing today, and that change is mainly caused by humans adding more CO_2 to the atmosphere.	Same as item [1].
[3]†	If the climate is changing today, it is ***mainly*** being caused by natural causes.	True (-2), Probably true (-1), Don't know (0), Probably false (1), False (2).

† This item is reverse-scored.

TABLE C.3.2: Questions that comprise the Government Action belief scale (4 items; Cronbach's α = 0.86).

	Question	Response Options
[4]†	Scientists believe that governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	Strongly disagree (2), Disagree (1), Neither Agree nor Disagree (0), Agree (-1), Strongly Agree (-2).
[5]†	Governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere	Same as item [4].
[6]†	Governments and society in general have ***already*** done more than their fair share of things to try to reduce how much CO_2 is being added to our atmosphere.	Same as item [4].
[7]†	Scientists believe governments and society in general have done more than their fair share of things to try and reduce how much CO_2 is being added to our atmosphere.	Same as item [4].

† This item is reverse-scored.

TABLE C.3.3: Questions that comprise the Individual Action belief scale (3 items; Cronbach's α = 0.75).

	Question	Response Options
[8]	Individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	Strongly disagree (-2), Disagree (-1), Neither Agree nor Disagree (0), Agree (1), Strongly Agree (2).
[9]	Scientists believe that individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	Same as item [8].
[10]	You and your family have ***already*** done more than your fair share of things to try and reduce how much CO_2 is being added to our atmosphere.	Same as item [8].

TABLE C.3.4: Questions that comprise beliefs that More Action (is) Needed scale (8 items; Cronbach's α = 0.89).

	Question	Response Options
[11]	Governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	Strongly disagree (-2), Disagree (-1), Neither Agree nor Disagree (0), Agree (1), Strongly Agree (2).
[12]	Governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].
[13]	Scientists believe individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].
[14]	Scientists believe that individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].
[15]	Individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].
[16]	Individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].
[17]	Scientists believe governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].
[18]	Scientists believe governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	Same as item [11].

TABLE C.3.5: Questions that comprise the Individual self-efficacy belief scale (2 items; Cronbach's α = 0.81).

	Question	Response Options
[19]†	It is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action.	Strongly disagree (2), Disagree (1), Neither Agree nor Disagree (0), Agree (-1), Strongly Agree (-2).
[20]†	Scientists believe it is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action.	Same as item [19].

† This item is reverse-scored.

TABLE C.3.6: Questions that comprise the Individual and Governmental (combined) response-efficacy belief scale (2 items; Cronbach's $\alpha = 0.78$).

	Question	Response Options
[21]	I feel that actions individuals have or could take to reduce CO_2 emissions are effective in slowing global warming.	Strongly disagree (-2), Disagree (-1), Neither Agree nor Disagree (0), Agree (1), Strongly Agree (2).
[22]	I feel that actions the government has or could take to reduce CO_2 emissions are effective in slowing global warming.	Same as item [21].

TABLE C.3.7: Questions about participant's beliefs on CO_2 atmospheric residence time, climate change causes, delayed action, and responsible parties for acting in response to climate change.

	Question	Response Options
[23]	How much of the decrease in CO_2 emissions do you think would come from only the actions of individuals and their families?	Participant denotes judgement on scale bar from 0% to 100%.
[24]	Imagine that the world's modern factories, transportation and power plants all stopped emitting **carbon dioxide** (CO_2) today. How long would it take for the amount of **carbon dioxide** (CO_2) in the air to fall back to what it was before those modern factories, transportation and power plants existed?	Hours to days (1), Weeks to months (2), Years (3), Decades (4), Centuries (5), Never (6).
[25]	Nuclear power is a significant cause of climate change.	True (2), Probably true (1), Don't know (0), Probably false (-1), False (-2).
[26]	Using aerosol spray cans is a significant cause of climate change.	Same as item [25].
[27]	If we wait, and climate change gets serious, we can reverse it when that happens by cutting emissions of CO_2, just like we cleaned up air pollution in places like Pittsburgh and Los Angeles once it got really bad.	Strongly disagree (-2), Disagree (-1), Neither Agree nor Disagree (0), Agree (1), Strongly Agree (2).
[28]	How much do you support or oppose reducing global warming by reducing carbon emissions?	Strongly oppose (-2), Oppose (-1), Neither Support nor Oppose/Don't know (0), Support (1), Strongly Support (2).
[29]	Who is most responsible for taking actions to combat climate change?	Individuals, Businesses, Government.

TABLE C.3.8: Demographic questions.

	Question	Response Options
[30]	Your Gender:	Female (1), Male (0).
[31]	Your Age (in Years):	Participant inputs age.
[32]	What is your occupation?	Participant inputs occupation.
[33]	Your Highest Level of Education:	Some high school (0), High school graduate (1), Some four-year college, junior college or trade school (2), Junior or trade school graduate (3), Four-year college graduate (4), Graduate school in a non-technical field (5), Graduate school in a technical field (6).
[34]	In which state do you currently reside?	Any state, Washington D.C., and any territories.
[35]	Do you consider yourself:	Extremely Liberal (3), Liberal (2), Slightly Liberal (1), Moderate / Middle of the Road (0), Slightly Conservative (-1), Conservative (-2), Extremely Conservative (-3).

TABLE C.3.9: Descriptive statistics for items in Tables C.3.1-C.3.8.

	N	Minimum	Maximum	Mean	Std Dev
Individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	-0.12	1.15
Individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	1.24	0.85
Individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	1.23	0.85
You and your family have ***already*** done more than your fair share of things to try and reduce how much CO_2 is being added to our atmosphere.	253	-2	2	-0.37	1.09
It is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action.	252	-2	2	0.57	1.26
Governments and society in general have ***already*** done more than their fair share of things to try to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	0.84	1.21
Governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	0.31	1.24
Governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-1	2	1.45	0.68
Governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	1.37	0.08
Scientists believe that individuals and families in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	-0.32	1.16
Scientists believe that individuals and families in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	1.28	0.80
Scientists believe individuals and families in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-1	2	1.34	0.74
Scientists believe it is possible for individuals and families ***alone*** to reduce nearly all CO_2 that is being added to the atmosphere without governmental or broader societal action.	253	-2	2	0.51	1.32
Scientists believe governments and society in general have done more than their fair share of things to try and reduce how much CO_2 is being added to our atmosphere.	253	-2	2	0.98	1.11
Scientists believe that governments and society in general have ***already*** taken many actions to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	0.52	1.21

Scientists believe governments and society in general ***could*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	1.40	0.78
Scientists believe governments and society in general ***should*** do more to reduce how much CO_2 is being added to our atmosphere.	253	-2	2	1.45	0.77
Scale bar	251	0	100	33.85	21.67
Imagine that the world's modern factories, transportation and power plants all stopped emitting **carbon dioxide** (CO_2) today. How long would it take for the amount of **carbon dioxide** (CO_2) in the air to fall back to what it was before those modern factories, transportation and power plants existed?	252	1	6	3.97	0.93
If the climate is changing today, it is ***mainly*** being caused by natural causes.	253	-2	2	0.89	1.17
The climate is changing today, and the change is ***mainly*** caused by people burning coal, oil, and natural gas.	252	-2	2	0.86	1.11
The climate is changing today, and that change is mainly caused by humans adding more CO_2 to the atmosphere.	253	-2	2	1.03	1.08
Nuclear power is a significant cause of climate change.	253	-2	2	-0.69	1.22
Using aerosol spray cans today is a significant cause of climate change.	253	-2	2	0.02	1.22
I feel that actions the government has or could take to reduce CO_2 emissions are effective in slowing global warming.	249	-2	2	0.51	1.15
I feel that actions individuals have or could take to reduce CO_2 emissions are effective in slowing global warming.	250	-2	2	0.41	1.07
The only way to avoid possible future serious changes in the climate is to take action to stop them now.	248	-2	2	1.15	1.02
If we wait, and climate change gets serious, we can reverse it when that happens by cutting emissions of CO_2, just like we cleaned up air pollution in places like Pittsburgh and Los Angeles once it got really bad.	250	-2	2	-0.38	1.22
How much do you support or oppose reducing global warming by reducing carbon emission?	250	-2	2	1.36	0.93
Who is most responsible for taking actions to combat climate change?	250	1	3	2.40	0.80
Gender	253	0	1	0.39	0.49
Age	250	20	71	35.95	10.14

TABLE C.3.10: Responses for item [34], state of residence.

State	*N*
AL	4
AK	1
AZ	7
AR	3
CA	22
CO	2
CT	2
DE	0
FL	23
GA	3
HI	0
ID	0
IL	7
IN	8
IA	1
KS	2
KY	11
LA	4
ME	0
MD	1
MA	3
MI	18
MN	7
MS	3
MO	5
MT	0
NE	2
NV	3
NH	0
NJ	10
NM	0
NY	23
NC	7
ND	0
OH	4
OK	3
OR	6
PA	8
RI	0
SC	8

SD	1
TN	4
TX	21
UT	1
VT	0
VA	4
WA	7
WV	0
WI	2
WY	1

TABLE C.3.11: Summary of descriptive statistics for individual differences measures. Note that all measures below are standardized.

	N	Minimum	Maximum	Mean	Std Dev
Climate Change Cause beliefs	252	-3.06	1.12	0	1
Government Action beliefs	253	-2.66	1.33	0	1
Individual Action beliefs	253	-1.87	2.46	0	1
Beliefs that More Action (is) Needed	253	-4.42	1.12	0	1
Individual Self-Efficacy beliefs	252	-2.14	1.24	0	1
Individual and Governmental (combined) Response-Efficacy beliefs	249	-2.45	1.53	0	1