

# How do people update? The effects of local weather fluctuations on beliefs about global warming

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## *Abstract*

How people update their beliefs is an important question for economic theory and policy. Various systematic violations of Bayes' rule have been found by economists and psychologists. Climate change is a one-time uncertain event with no opportunities for learning; the belief updating process may not be fully rational. Using unique survey data on individuals' beliefs about global warming, I test how much weight individuals give to local weather fluctuations. I find some short-run (1-2 days) influences of weather that are inconsistent with Bayesian updating: for example, while the standard deviation of precipitation on the day of the survey affects beliefs, the average deviation over the week before the survey does not. Over a longer time period (up to 12 months), the pattern of belief formation is consistent with Bayesian updating when access to information is limited: longer periods of abnormal weather and more abnormal weather produce larger changes in beliefs.

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## 1. Introduction

Models with uncertainty often assume that agents update their beliefs using Bayes' rule. In some situations, this type of rationality is difficult to justify without empirical evidence. For example, climate change is a highly complex one-time event without opportunities for learning or well-defined objective probabilities. How individuals use information in this or similar contexts is an empirical question<sup>1</sup>.

In addition to informing theory and understanding human behavior in general, studying the updating process in settings such as climate change is relevant for policy. Climate change may be one of the most disruptive events of the 21st century. It is also a very visible issue, and thus some public consensus is necessary to implement policies that address it. For both of these reasons, it's important to consider how beliefs about climate change are formed and updated.

In this paper, I use a large representative sample of US adults who were surveyed about global warming (the underlying cause of climate change) to see what weight individuals give to recent local weather fluctuations when forming beliefs about the occurrence and seriousness of global warming. In addition to short-run maximum temperatures, the influence of which has been examined in previous studies<sup>2</sup>, my analysis includes precipitation and snowfall, which are also likely to be affected by global warming.

While it may be rational to update beliefs about global warming based on significant changes in global weather, a Bayesian who is perfectly informed about world weather and science should not give significant weight to recent weather in his county when updating his beliefs<sup>3</sup>. However, I find that some forms of temperature and precipitation abnormalities have an effect over short time scales of 1-2 days. Average weekly deviations and extreme events such as heat waves or droughts weeks or months before the survey have no effect on beliefs, suggesting that the short run effects are temporary and due to psychological heuristics.

Unlike previous studies, I also consider the effects of prolonged periods (1-12 months) of abnormal weather. I find that abnormally low precipitation and abnormally high temperatures are significant predictors of the degree to which people believe the effects of global warming have already begun to happen. The estimated patterns are consistent with how a Bayesian who only observes local information would update his beliefs, but I cannot rule out that informed individuals simply overweight their local weather.

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<sup>1</sup>The empirical evidence on updating is mixed. Evidence for various forms of irrational updating includes DeBontd and Thaler (1984) in finance, Terrell (1994) and Clotfelter and Cook (1993) in lottery play, and Egan and Mullin (2009), Risen and Critcher (2009), and Cameron (2005) in climate change beliefs. For a review of other behavioral findings and models in economics, see Ellison (2006), Bernheim and Rangel (2005), and DellaVigna (2007). For an overview of the relevant psychology research, see Kahneman et al. (1982).

<sup>2</sup>See Risen and Critcher (2009), Egan and Mullin (2010), Joireman et al. (2010), and Schuldt and Schwarz (2009).

<sup>3</sup>At best, local recent weather is a very weak signal of the effects of global warming. Thus, a Bayesian updater would use it only if he had no access to other information. I discuss this issue further in Section 2.1.

I also consider more extreme local events, such as heat waves, droughts, floods, and hurricanes, as well as the total damage they caused and find that beliefs about global warming remain largely unaffected, suggesting that one-time salient events are not weighted heavily in the updating process. In an additional test of how people update, I find that respondents also use local economic conditions to make an inference about the economic conditions in the US, and the pattern of how they use them is consistent with Bayesian updating with limited information.

Additionally, I find that beliefs about global warming vary strongly and significantly by characteristics such as gender, income, and political ideology. This raises interesting questions about how beliefs evolve to differ along dimensions that may not directly reflect different information sets. The estimated effects of weather are, for the most part, much smaller in absolute value than the coefficients on respondents' demographics, suggesting that local weather does not play a major role in belief formation and more attention should be devoted to political and educational influences.

Section 2 describes the rational and behavioral models of updating and links the theory to expected relationships in the data. Section 3 describes the data and the construction of the regression variables. The empirical framework and results are presented and discussed in Section 4, and Section 5 concludes.

## **2. Bayesian and behavioral theory**

### *2.1 Bayesian updating model*

A significant change in climate can be reliably detected only by using long-run data from numerous locations. If local climate can change if and only if global climate change is occurring or if beliefs can *only* be based on local weather, then it is rational to conclude that global climate change is occurring if one sees a significant change in local climate. However, for any reasonable priors, detecting a significant change in local climate requires a long period of abnormal weather. Furthermore, for the effect to be detectable empirically, people must observe local weather more precisely than weather elsewhere (otherwise the change in beliefs will be absorbed by year fixed effects). Unless an individual's ability to gather information is severely limited, it is irrational to give a non-trivial weight to local recent weather in updating beliefs about climate change. However, it is possible that, following an abnormal period of local weather, a rational Bayesian updater will change his beliefs about global warming significantly if he has limited access to other information. I elaborate on these points in the model below and outline the testable predictions that follow in the case of limited information Bayesian updating.

Let  $G$  and  $\neg G$  represent the states of the world with and without global warming, respectively. Let  $E$  be some evidence observed by a Bayesian updater. Beliefs about global warming will then

be determined by the following formula:

$$\Pr(G|E) = \frac{\Pr(E|G) \Pr(G)}{\Pr(E|G) \Pr(G) + \Pr(E|\neg G) (1 - \Pr(G))}$$

In general, evidence can include global or local weather, a news story on melting glaciers, an IPCC report, or long-run climate data. If all individuals observe the same information, then  $E$  will be identical for everyone in the population. The changes in beliefs will be driven by differences in priors. As long as priors are uncorrelated with recent local weather<sup>4</sup>, it will not be a significant predictor of beliefs in survey data.

If there is imperfect information,  $E$  will differ across individuals, and the posteriors will be different even with identical priors. However, as with the perfect information case, as long as  $E$  is uncorrelated with recent local weather, the latter will be an insignificant predictor of individuals' beliefs.

As an extreme, suppose that the Bayesian updater has no other source of information except local weather, represented by the vector  $\mathbf{w}$ . The initial posterior is:

$$\Pr(G|\mathbf{w}) = \frac{\Pr(\mathbf{w}|G) \Pr(G)}{\Pr(\mathbf{w}|G) \Pr(G) + \Pr(\mathbf{w}|\neg G) (1 - \Pr(G))}$$

If presented with additional weather variables,  $\mathbf{w}'$ , this posterior becomes the prior. The Bayesian updater's new beliefs will be:

$$\Pr(G|\mathbf{w}') = \frac{\Pr(\mathbf{w}'|G) \Pr(G|\mathbf{w})}{\Pr(\mathbf{w}'|G) \Pr(G|\mathbf{w}) + \Pr(\mathbf{w}'|\neg G) (1 - \Pr(G|\mathbf{w}))}$$

The change in beliefs,  $\Pr(G|\mathbf{w}') - \Pr(G|\mathbf{w})$ , depends on the prior,  $\Pr(G|\mathbf{w})$ , and the relative likelihood of the observed weather when there is global warming,  $\frac{\Pr(\mathbf{w}'|G)}{\Pr(\mathbf{w}'|\neg G)}$ . The larger the relative likelihood, the larger the change in posteriors. For a short length of time, such as a week or month, the ratio  $\frac{\Pr(\mathbf{w}'|G)}{\Pr(\mathbf{w}'|\neg G)}$  will be nearly 1.

The IPCC also makes it clear that short-run local or even global weather should not be used for inference about global warming, explicitly noting that a "common confusion [...] is thinking that a cold winter or a cooling spot on the globe is evidence against global warming" and that "determining whether a specific, single extreme event is due to a specific cause, such as increasing greenhouse gases, is difficult, if not impossible" (IPCC, 2007, pg 96 and 119).

If weather is a significant determinant of beliefs empirically, there are two valid interpretations. One is that people are irrationally using local weather in updating their beliefs about global warming. The other is that people are Bayesian but have access to very limited information and the

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<sup>4</sup>If priors are correlated with local climate, rather than local weather, this difference will be absorbed by regional fixed effects.

ratio  $\frac{\Pr(w'|G)}{\Pr(w'|-G)}$  is large. The second interpretation has several testable implications that follow from Bayes' formula:

1. Longer periods of abnormal weather will be a more significant influence than shorter periods.
2. More extreme weather will produce larger changes in beliefs.
3. Weather *levels* will not be significant predictors of beliefs, as Bayesian updaters should consider *deviations* from the norm rather than absolute levels<sup>5</sup>.

By looking at how coefficients change with the weather variable used, one can infer whether people act as Bayesians with full or nearly full information (in which case I expect to see no significant impacts of local weather), Bayesians with very limited information (in which case the pattern described above should emerge), or non-Bayesians (in which case weather will have a significant influence that's inconsistent with points 1-4 above).

## 2.2 Non-Bayesian updating: heuristics

Global warming fits into the category of rare and highly uncertain events, where learning through experimentation or repeated observation is impossible. Local weather is also more salient than statistical information about world weather. In addition, people are routinely unable to correctly form probability estimates, even when given all the relevant information (Kahneman and Tversky, 1972 and 1973; Kahneman et al., 1982). Thus, it is possible that people irrationally use local weather to form inferences about the effects of global warming.

There are at least three previously studied biases that may affect belief formation in this and other settings: associativeness, availability, and representativeness.

Under the associativeness heuristic, current events cause past instances of similar events to be recalled<sup>6</sup>. Abnormal weather could bias the recalled history toward similarly extreme events, leading the individual to conclude such events are more frequent than they are.

Under the availability heuristic, people use salient instances of an event to judge its likelihood. For example, a person who has witnessed a serious auto accident will judge the probability of such an accident to be higher than someone who has not seen one (even if both have identical statistical information). This bias predicts that people may be more likely to believe that global warming is occurring if they have experienced local fluctuations in weather as opposed to hearing news stories about warmer weather in other regions. The bias should be more powerful if the local weather fluctuations are recent because recent events are more salient.

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<sup>5</sup>For example, observing 90 degree temperature in the summer should have a different effect on beliefs than 90 degree temperature in the spring.

<sup>6</sup>See Mullainathan (2002) for a formal model and empirical examples.

Representativeness is judging the probability of a sample by how much it resembles a salient feature of the population it came from. For example, people judge the sequence HTTHTH to be more probable than the sequences HHHHTH and HHHTTT (Kahneman et al., 1972), although all three sequences are equally likely. For other evidence of representativeness, see Kahneman et al. (1973) and Grether (1980). Importantly, the representativeness of a sample is not affected by the sample size; therefore, neither are the subsequent probability estimates made by individuals.

Even one of these biases is sufficient for recent local weather to play a role in belief formation, but all three may be present. First, the recency of extreme weather may make it more salient in the respondent's mind. Second, associativeness may cause similar past instances of extreme weather to come to mind. Third, beliefs may be formed based on how representative the recalled weather is of what the temperature patterns in a world where the effects of global warming are already occurring, without taking sample size or overall likelihood into account.

### **3 Data**

#### *3.1 Gallup survey*

For beliefs about global warming, I use Gallup's "Environmental Poll". Every March, about 1,000 US adults are surveyed within a 3-4 day window<sup>7</sup>. Although I have data for 2001-2010, county (fips) codes of respondents, necessary for getting measures of local weather, are available for 2003-2010 only. Over half of the US counties are represented.

Table 1 shows the breakdown of respondents' demographics for the full sample (10,125 people for 2001-2010) as well as for the sample for which county codes are available (8,059 people for 2003-2010). Overall, the two samples are very similar, which is not surprising, since each year's sample is meant to be nationally representative<sup>8</sup>.

[TABLE 1 about here]

The answers to two questions are used as the dependent variables in subsequent regression analysis: whether the effects of global warming have already started to happen ("Happening") and whether the respondent thinks global warming will be a serious threat to his or his way of life in his lifetime ("Threat"). The exact wording is shown in Table 2, along with the breakdown of answers.

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<sup>7</sup>Respondents are surveyed by phone. Global warming is not the sole focus of the survey; the topics include energy, the economy, environmental policies under the Bush administration, Arctic drilling, and environmental behaviors.

<sup>8</sup>The biggest difference in the two samples is the average income. This is an artifact of how the income questions were asked in different years, rather than a true difference in the samples. The highest income category in 2001-2003 was "More than \$75,000" while in 2004-2008 it was "More than \$500,000". Because I assign incomes of \$100,000 to those who are in the highest category in 2001-2003 and \$750,000 to those in the highest category in 2004-2008, this raises the average of the 2003-2008 sample artificially. This discrepancy in survey methods between years does not affect my main analysis because I include income category fixed effects, rather than income.

The numerical values assigned to each answer for regression analysis are in parentheses following the answer. “Refused” and “Don’t know” are treated as missing in the regression analysis<sup>9</sup>.

[TABLE 2 ABOUT HERE]

Overall, about 56.4% (out of 10,125) of respondents believe that the effects of global warming have already begun to happen, 9.7% think they will never happen, and the rest think they will happen sometime in the future. Only 33.5% of people think that global warming will pose a serious threat to them or their way of life.

One possible objection to using these questions for assessing effect on beliefs is that the answers are discrete rather than continuous. Although this does add some noise to the estimation, as long as there is some underlying probability that the individual uses to answer the question and as long those probabilities are not too lumpy across individuals, the effect of weather can still be seen using qualitative data.

Another concern is that survey data may be uninformative because respondents have no incentive to give thoughtful and truthful answers. For the purposes of this paper, it does not matter whether those beliefs are correct or not. The goal is to test whether the updating process is affected by weather fluctuations, which only requires that people have *some* beliefs prior to taking the survey. I nevertheless informally compare the answers of the public with answers to a survey of about 540 climate scientists by Bray and von Storch (2007), conducted in 1996 and 2003<sup>10</sup>. It asks whether scientists agree that "We can say for certain that global warming is a process already underway" and that "We can say for certain that, without change in human behavior, global warming will definitely occur some time in the future." Although the questions are not directly comparable to the ones I examine, they provide some idea of what beliefs "should" be. In 2003, 65% of scientists agreed or strongly agreed with the first statement (up from 52% in 1996) and only 8% disagreed or strongly disagreed; 67% agreed or strongly agreed with the second statement, up from 58% in 1996, and 10% disagreed or strongly disagreed. Based on this survey, the answers of Gallup respondents appear reasonable<sup>11</sup>.

To further check that beliefs are well-formed, I regress the answers to the questions in Table 2 on respondent demographics, using the entire 2001-2010 sample. Because "Happening" is categorical, the regression specification is an ordered probit (probit for "Threat")<sup>12</sup>. The included

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<sup>9</sup>These options never include more than 5% of the sample; for most of the questions, less than 3% of respondents chose these options.

<sup>10</sup>Although scientists may also have no incentive to give thoughtful and truthful answers, their opinions are more likely to be well-formed, making it easier to answer the questions. Furthermore, if bias is a concern, the two survey groups are likely to be biased in different ways, so that if answers are not thoughtful and truthful, we would expect to see differences in responses.

<sup>11</sup>For more on survey data reliability, see Bertrand and Mullainathan (2001).

<sup>12</sup>Modeling these relationship as linear does not change the qualitative results.

demographics are: a male dummy, age, age squared, a white dummy, log income<sup>13</sup>, log income squared, education level dummies, political ideology, and interactions between male and education and between male and political ideology.

The results are shown in Table 3. Beliefs are highly correlated with most of the included demographic variables and are thus less likely to be noise. There is a quadratic relationship between age and beliefs about the timing of global warming, increasing in age and decreasing in age squared. More educated people are more likely to believe that the effects of global warming have already begun to happen. By far, the largest determinant of belief differences is political ideology: conservatives are much less likely to believe that the effects of global warming have begun to happen or believe it will pose a threat.

[TABLE 3 ABOUT HERE]

Another way to address the concern that the survey answers may not reflect well-formed beliefs is to consider beliefs for which a Bayesian updater *would* use measurable local information. Respondents were also asked to rate the state of the economy: "excellent", "good", "only fair" or "poor". The exact wording and breakdown of answers are shown in Table 2. Overall, 31% of respondents say that economic conditions are good or excellent, 45.4% say they are fair, and 22.7% rate them as poor.

The US unemployment rate is clearly informative about the state of the economy. Between 1990 and 2008, the correlation between the county and US monthly unemployment rate was 0.36, while the correlation between the state and US unemployment rate was 0.68, according to Local Area Unemployment Statistics (LAUS). These correlations are significantly different from 0 with a p-value below 0.0001. Therefore, it is not unreasonable for a Bayesian updater to use local unemployment rates to make inferences about the economy as a whole.

[TABLE 4 ABOUT HERE]

I use an ordered probit regression to examine the relationship between the respondent's assessment of economic conditions in the US and the average local or state unemployment rates in the past month and in the 12 months before the survey. The results are shown in Table 4. An increase in the local or state unemployment rate over the past year has a large negative effect on the respondent's assessment of economic conditions<sup>14</sup>. All the estimates are significant, and the inclusion of state or county fixed effects does not change the results qualitatively.

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<sup>13</sup>I assume that income is the average of the reported income category. I do this for expositional ease; in the next section, income categories are treated as dummies.

<sup>14</sup>Note that because year fixed effects are included, the effect of county-level unemployment on beliefs is in addition to any inferences that people may make using the US unemployment rate.

There is a smaller negative effect of last month's state and local unemployment rates in the past month on the probability that the respondent states that economic conditions are excellent or good and they are insignificant or marginally significant once county or state fixed effects are included. The larger significance of the annual unemployment rate is consistent with a Bayesian updater giving more weight to a larger number of observations. This provides evidence that people use local information for updating beliefs in at least one case when it is reasonable to do so.

### 3.2 Weather data

This section outlines how I define abnormal weather fluctuations. I use National Climatic Data Center's weather station daily observations for maximum temperature, snowfall, and precipitation for 1949-2010<sup>15</sup>, matched to the county. These data were provided by Michael Greenstone and are used in Deschênes and Greenstone (2007a and 2007b).

The abnormality measure is the number of standard deviations away from the long run average:

$$num\_sd_{cd} = \frac{weather_{cd} - \overline{weather}_{cd}}{\overline{sd}_{cm}}$$

$d$  = day of year;  $c$  = county;  $m$  = month

$weather_{cd}$  is the observed maximum temperature, snowfall or precipitation in county  $c$  on day  $d$ .  $\overline{weather}_{cd}$  is the corresponding long run average<sup>16</sup>, constructed by computing a seven-day running average across all years that precede the year of the survey. In other words, for respondents in county  $c$  taking the survey in year  $Y$ :

$$\overline{weather}_{cd} = \frac{1}{7} \sum_{s=d-3}^{d+3} \sum_{y=1949}^{Y-1} weather_{cdy}$$

$\overline{sd}_{cm}$  is the measure of standard deviation, constructed by computing the standard deviation of observed weather in that month and county between 1949 and 2000<sup>17</sup>. I match each respondent's location and date of survey to the weather data to determine the respondent's weather deviations  $x$  days ago, where  $x$  ranges from 0 (day of the survey) to 364 (one year ago)<sup>18</sup>.

<sup>15</sup>If there are multiple weather stations in a county, I average their daily measurements.

<sup>16</sup>I assume that the long-run average has not changed due to global warming.

<sup>17</sup>It is possible to construct the standard deviation measure in the same way that the long-run averages were computed, by taking a running average. However, using the same standard deviation for the entire month gives more observations from which to compute it.

<sup>18</sup>The respondents are called between 5pm and 9pm local time, making the inclusion of that day's weather reasonable.

To allow for a cumulative effect of longer stretches of abnormal weather, I construct variables that measure the fraction of days over a given time period on which the number of standard deviations was above a positive threshold and the fraction of days on which it was below a negative threshold. The exact threshold depends on the weather variable. The formulas for these variables are:

$$\begin{aligned} \text{frac\_above}_{ct} &= \frac{\sum_{t=0}^T 1(\text{num\_temp\_sd}_{ct} \geq k)}{T} \\ \text{frac\_below}_{ct} &= \frac{\sum_{t=0}^T 1(\text{num\_temp\_sd}_{ct} \leq -m)}{T} \end{aligned} \quad (1)$$

where 1 is an indicator function,  $t$  is now relative to the day the respondent took the survey and  $k$  and  $m$  are chosen to have about the same mass of observations fall outside the threshold for the dataset as a whole<sup>19</sup>.  $T$  ranges from 7 to 360 days.

While I cannot measure very short-run effects of extremely hot days because all the surveys are conducted in March, I can look at the medium-run effects by looking at heat waves in the year before the respondent took the survey. I use the common definition of 3 or more consecutive days on which the temperature exceeds 90 degrees. I also create a "number of heat wave days" variable, which is equal the total number of days over the past year that were part of a heat wave.

Finally, related studies have found that beliefs about global warming are influenced by recent temperature changes (Schuldt and Schwarz, 2009) as well as temperature abnormalities the week before (Egan and Mullin, 2009). Thus, I also construct these measures, defined as the change in weather between the day prior to the survey and two days ago and the average standard deviation from the mean over the week before the survey.

[TABLE 5 ABOUT HERE]

Table 5 shows the means, standard deviations, minimums and maximums of weather deviations on the day before the respondent took the survey, the change in weather between two days and one day before the respondent took the survey, the average number of standard deviations over the week before the survey, as well as of the number of heat waves and heat wave days. The mean deviations are indistinguishable from 0, suggesting that the estimated long-run averages are close to the actual values. Standard deviations of maximum temperature are close to symmetrically

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<sup>19</sup>The reason  $k$  and  $m$  are not always the same is because precipitation and snowfall distributions are skewed. I use -2 and 2 standard deviations (more extreme) and -1.5 and 1.5 (less extreme) standard deviations as the maximum temperature thresholds. For snow and precipitation I use less than -0.8 and greater than 1 standard deviations for snow (-0.5 and 0 as another specification) and less than -0.8 and greater than 2 for rainfall (-0.55 and 1 as another specification).

distributed. Because snowfall and precipitation levels are bounded below by 0, the distribution of their deviations is skewed.

The average number of heat waves is 2.7, with a standard deviation of 3.3. The average number of heat wave days in a county is 16.6, with a standard deviation of 29.9. Because of the high maximum values for these variables (18 for the number of heat waves and 178 for the number of heat wave days), I later exclude Arizona, Nevada, Florida and New Mexico from the heat wave regressions, as these states have especially hot weather and temperatures above 90 degrees may not feel extraordinarily hot to residents.

[TABLE 6 ABOUT HERE]

Table 6 shows summary statistics for the fraction of days on which maximum temperature deviations exceeded a given threshold over various time periods, as described by equation 1. The distributions for the fraction of days on which maximum temperature deviations were negative and below a given threshold are similar. The average fraction of days on which temperatures exceeded the 1.5 sd threshold ranges from 0.05-0.08, depending on the length of the time period. The fraction of days on which they exceeded the 2 sd threshold ranges from 0.03 to 0.02, indicating that these are rare events. The variances of both measures decrease with the time period, but there is still substantial variation. Similar measures for precipitation and snowfall allow me to estimate the effect of longer periods of extremes.

#### **4. Effects of weather**

##### *4.1 Conceptual and empirical framework*

In this section, I outline the procedure for testing whether local weather fluctuations significantly affect people's beliefs about global warming and if so, whether this is due to limited information or irrational updating. Before describing the empirical framework, I discuss the theoretical link between beliefs about the timing of global warming and the threat it poses.

Conceptually, whether someone believes global warming will pose a significant threat to his way of life is related to (a) when the respondent believes the effects of global warming will begin to happen and (b) the probability that, conditional on occurring, global warming will have significantly negative consequences to the respondent (which are a function of global warming's intensity as well as respondent characteristics, such as wealth). This can be written as:

$$\Pr(\textit{Threat} = 1)_i = V_i(\Pr(T|G), \Pr(G))$$

where  $\Pr(G)$  is the probability that global warming is occurring and  $T$  represents an event that directly impacts the respondent's well-being. A change in beliefs about each of these can lead to a

change in the probability that the respondent believes global warming will pose a threat to him in his lifetime. Note that  $V_i$  may reflect an individual's wealth (wealthy individuals are more easily able to avoid the negative consequences of climate change), age (younger people are more likely to experience negative effects of global warming in their lifetime), and other characteristics<sup>20</sup>.

"Threat" is related to the timing of the occurrence of global warming, but it also encompasses the extensive margin of global warming severity. Because willingness to pay to mitigate global warming is not just a function of whether one believes it's happening or will happen soon, it is useful to consider the effects of local weather on this dimension as well. For example, finding that extreme temperatures affect whether one believes the effects of global warming have already started to happen but not whether one believes that global warming will pose a threat indicates that respondents do not give much weight to the timing of global warming's occurrence when forming beliefs about the threat it causes. Alternatively, finding that beliefs about whether global warming is a threat are affected, but beliefs about the occurrence of global warming are not signals that extreme weather leads to updating on the intensive margin.

To test whether these beliefs are affected by weather fluctuations, I regress beliefs on weather abnormalities in the respondent's county:

$$\begin{aligned} \text{Happening}_{ict} &= \text{Weather}_{ct}\beta_1 + X_{ict}\gamma_1 + \varepsilon_{ict} \\ \text{Threat}_{ict} &= \text{Weather}_{ct}\beta_3 + X_{ict}\gamma_3 + \eta_{ict} \\ i &= \text{individual}; c = \text{county}; t = \text{survey date} \end{aligned}$$

The regression specification is an ordered probit.  $\text{Weather}_{ct}$  is some measure of county-level weather fluctuations, as described in Section 3.2.  $\text{Happening}_{ict}$  is the belief about the timing of the occurrence of global warming (equal to 5 if the respondent said it has already begun to happen, equal to 1 if the respondent said it will never happen, and taking on intermediate values for the other answer options)<sup>21</sup>.  $\text{Threat}_{ict}$  is equal to 2 if the respondent said "yes" and 1 if he said "no".  $X_{ict}$  is a set of flexible controls, including sex, race, age, education, income, political ideology dummies, and region-year fixed effects. Because precipitation, temperature and snowfall are related physically (i.e. it cannot snow if it's raining and it's more likely to be snowing if the temperature is low), I never use more than one weather measure in the same regression to avoid multicollinearity. The null hypothesis of Bayesian updating with full information is  $\beta_j = 0$  for  $j = 1, 2, 3$ .

<sup>20</sup>As long as these and other factors are unrelated to weather fluctuations, they will not affect the estimation.

<sup>21</sup>The full numerical coding of the questions is shown in Table 2.

The choice of spatial and temporal fixed effects affects both the expected results and interpretation of findings. Including year fixed effects will absorb the effect of national variation in weather and other events observed by all the participants. For a Bayesian updater, fluctuations on a larger spatial scale should matter more than very local fluctuations. If region-by-year fixed effects are included, the effect of weather on beliefs will be estimated off of sub-regional weather fluctuations. For state-by-year fixed effects, the coefficient will be estimated off of sub-state fluctuations. Because state and county weather is heavily correlated, especially for smaller states, the inclusion of state-year fixed effects would drastically reduce the amount of variation in weather. In addition, non-linear models such as ordered probit are not well-behaved when there is a large number of fixed effects (see Green, 2002). I thus choose region-by-year fixed effects as my primary specification.

The ordered probit specification assumes that there is an unobserved continuous variable corresponding to each belief,  $Belief_{ict}^*$ , which is a function of characteristics, weather, and a random error component:

$$Belief_{ict}^* = Weather_{ct}\beta_1 + X_{ict}\gamma_1 + \varepsilon_{ict}$$

Observed beliefs,  $Belief_{ict}$ , take on discrete values  $\{1, 2, \dots, n\}$  that are determined as follows:

$$\begin{aligned} Belief_{ict} &= 1 \text{ if } Belief_{ict}^* \leq \mu_1 \\ &= 2 \text{ if } \mu_1 < Belief_{ict}^* \leq \mu_2 \\ &\dots \\ &= n \text{ if } \mu_{n-1} < Belief_{ict}^* \end{aligned}$$

The errors are normally distributed across observations, so the probability of observing each value is given by:

$$\begin{aligned} \Pr(Belief_{ict} = 1) &= \Phi(\mu_1 - Weather_{ct}\beta_1 - X_{ict}\gamma_1) \\ \Pr(Belief_{ict} = 2) &= \Phi(\mu_2 - Weather_{ct}\beta_1 - X_{ict}\gamma_1) - \Phi(\mu_1 - Weather_{ct}\beta_1 - X_{ict}\gamma_1) \\ &\dots \\ \Pr(Belief_{ict} = n) &= 1 - \Phi(\mu_{n-1} - Weather_{ct}\beta_1 - X_{ict}\gamma_1) \end{aligned}$$

where  $\Phi(\cdot)$  is the normal cdf.

From the above formula, it is clear that  $\beta_1$ , the marginal effect of weather on  $Belief_{ict}^*$ , does not correspond to the marginal effect of weather on  $Belief_{ict}$ ,  $\frac{\partial \Pr(Belief_{ict}=1)}{\partial Weather_{ct}}$ . In general, for  $j \neq 1$  or

$n$ , the marginal effect of  $Weather_{ct}$  on  $\Pr(Belief_{ict} = j)$  equals  $(\phi(\mu_{j-1} - Weather_{ct}\beta_1 - X_{ict}\gamma_1) - \phi(\mu_j - Weather_{ct}\beta_1 - X_{ict}\gamma_1))$  where  $\phi$  is the normal pdf.

It is difficult to know which function of the weather variables a non-Bayesian could use to update beliefs about global warming. This prompts me to consider various transformations of weather variables. I use those that best measure how extreme the weather is over various time periods and those that a limited information Bayesian may reasonably use. Specifically, I use the following variables, as outlined in the Section 3:

1. The number of standard deviations from the long-run average on a given day and the average standard deviation over a week.
2. The change in weather from two days before the survey to one day before.
3. The fraction of days on which the standard deviation was above a positive threshold or below a negative threshold over various time periods, ranging from 7 days to 1 year.
4. The number of heat waves, defined as the number of occurrences over the past year on which the daily maximum temperature was over 90 degrees for at least three consecutive days, and the number of heat wave days, defined as the total number of days over the past year which were part of a heat wave.

None of these variables should influence beliefs under the null hypothesis of a fully informed Bayesian. Under the alternative of Bayesian updating with limited information, the estimated coefficients should follow the patterns outlined in Section 2.1. If there are psychological heuristics present, then abnormally warm temperatures should increase the probability that the respondent believes the effects of global warming have already started to happen. The sign of the effect of precipitation and snowfall under the alternative hypothesis is unclear because there are no aggregate scientific predictions for how snowfall and precipitation will be affected by global warming, as there are for temperatures, so how they affect beliefs is an empirical question. However, in the case of fully informed Bayesian updating, there should be no effect; in the case of partially informed Bayesian updaters, the patterns outlined in Section 2.1 should emerge; and in the case of irrational updating, there should be some other pattern.

The effect of warmer temperatures on the respondent's level of concern about global warming (as opposed to its timing) under the alternative of irrational updating may depend on his location. Someone living in Michigan might perceive an increase in average local temperatures as beneficial while someone living in Arizona might view it as detrimental. However, more heat waves and more heat wave days are not desirable outcomes anywhere. Therefore, under the alternative hypothesis of behavioral updating, heat waves should have a positive effect on "Happening" and "Threat".

Depending on which bias is more powerful, accounting for weather over longer time periods may exacerbate or dampen the estimated effect under the alternative hypothesis of behavioral updating. If representativeness is a strong influence on beliefs, the effect should be stronger. If associativeness is a major driver, including weather over longer time periods should also increase the significance of the coefficient. If the availability heuristic is important, longer time periods may result in a weaker effect, since less recent weather is more difficult to recall. Nonetheless, under the null of Bayesian updating with full information, there should be no relationship between local recent weather and any of the beliefs.

#### 4.2 Results

I first regress survey answers on standard deviations of maximum temperature, snowfall, and precipitation on the day of the survey and the day prior to the survey, using an ordered probit specification. The marginal effects for each answer category (estimated at the mean) are shown in Table 7. "Answer = 1" corresponds to "The effects of global warming will never happen" for "Happening" and "Global warming will not be a serious threat to me in my lifetime" for "Threat".

The estimated effects of maximum temperatures and snowfall are small and insignificant for the day before and day of the survey, with the exception of abnormally high snowfall on the day of the survey marginally increasing the probability that the respondent believes global warming will pose a threat to him by 0.002 (0.2 percentage points). Rainfall anomalies on the day before the survey have no effect on beliefs. Precipitation abnormalities on the day of the survey are estimated to have significant effects on both "Happening" and "Threat". In particular, a one standard deviation increase in precipitation increases the probability that the respondent believes the effects of global warming have already begun to happen by 0.020 (while lowering the probabilities of all the other answer categories) and increases the probability that the respondent believes global warming will pose a threat by 0.028. These estimates are very significant and provide some evidence that there are very short-run effects of precipitation.

[TABLE 7 ABOUT HERE]

Table 8 shows the estimated effect of the *change* in weather between (a) the day of the survey and the day before and (b) one and two days before the survey. An increase of one degree between one and two days ago is estimated to *decrease* the probability that the respondent believes global warming has already begun to happen by 0.001 (or 0.1 percentage points) and decreases the probability that the respondent believes global warming will pose a threat by 0.003 (both estimates are significant at the 5% level). There is no significant effect of snowfall changes on either days. A one inch increase in precipitation between zero and one days ago is estimated to increase the

probability that the respondent believes the effect of global warming have already begun to happen by 0.049 (4.9 percentage points), significant at the 1% level, but has no effect on whether the respondent believes global warming will pose a threat to him in his lifetime.

The maximum temperature result seems counterintuitive and inconsistent with either the behavioral or limited information Bayesian alternative. However, it may also be an indication that absolute changes in variables are not the appropriate metric. If temperatures were previously below normal, an increase in temperatures may be interpreted as evidence that the effects of global warming are not happening. In March, respondents may expect temperatures to increase; thus a positive change in temperature levels may be taken as a sign that global warming is not occurring.

[TABLE 8 ABOUT HERE]

Table 9 shows the estimated effect of the average number of standard deviations over the week before the respondent took the survey<sup>22</sup>. Unlike previous researchers, I find no significant effect of the average weekly deviation from the mean in any of these variables. Using the mean deviation in *levels* over the week before the survey yields similar results.

[TABLE 8 ABOUT HERE]

To extend this analysis to a longer time period, I regress beliefs about the timing of global warming on daily maximum temperature deviations from 0 days ago (the day of the survey) to 364 days ago. If there are persistent effects, then coefficients should be statistically significant throughout. The point estimates and fitted confidence intervals are shown in Figure 1. The pattern of estimated coefficients appears to be random and few are statistically significant. Other combinations of weather variables and beliefs yield similar patterns.

[FIGURE 1 ABOUT HERE]

Overall, this set of results provides some evidence that people's beliefs respond to short-run local weather fluctuations. However, it appears that the effects are not permanent. The fact that daily weather fluctuations have a negligible effect on any objective estimate of the probability of global warming and the fact that they do not produce permanent effects suggests that the observed pattern is not due to Bayesian updating with limited information. Specifying "Happening" as binary (1 if the respondent said the effects of global warming have already begun to happen and 0 if he said anything else) and using a probit or linear specification does not change the results qualitatively<sup>23</sup>.

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<sup>22</sup>This is equivalent to the total number of standard deviations over the past week divided by 7.

<sup>23</sup>The full set of results is available from the author by request.

I now consider prolonged periods of abnormal weather. I regress beliefs on two other variables: the fraction of days for which the number of standard deviations exceeded an upper threshold and the fraction of days for which it was below a lower threshold<sup>24</sup>, as described in equation 1. The omitted category is the fraction of days on which the weather was between the two thresholds. This specification allows for different impacts of left-tail and right-tail extremes. I do this for various time periods, ranging from 0-7 days ago to 0-360 days ago, in increments of 60 days for days 60-360. Table 10 shows the p-values of the F-test of the fraction of days with positive and negative weather extremes for each of the time periods and both high and low thresholds.

Maximum temperature extremes have a persistent effect on beliefs about the timing of the occurrence of global warming, but no effect on the degree to which the respondent perceives it as a threat. The results for precipitation and snowfall are mixed. A similar, but weaker pattern, is true for snowfall and temperatures. It appears that the effects of more extreme thresholds are more significant for both snowfall and precipitation, but a similar pattern does not hold for temperatures.

[TABLE 10 ABOUT HERE]

Table 10 is not informative about the size or direction of the effect. Figure 2 shows the average estimated effect of maximum temperature extremes (positive and negative) on beliefs about the timing of global warming. Standard errors are clustered on county-year. More days on which temperature deviations exceeded 1.5 and 2 appear to increase the degree to which the respondent believes the effects of global warming have already begun to happen. Days on which maximum temperatures were below -1.5 or -2 standard deviations do not appear to have an offsetting negative effect. The estimated coefficient on days with positive deviations is larger for longer time periods and for the more extreme threshold. If there is Bayesian updating with limited information, results using more extreme thresholds should be more significant, since they give greater weight to more abnormal weather.

[FIGURE 2 ABOUT HERE]

Figures 3 and 4 show the average estimated effect of snowfall and precipitation extremes (respectively) on beliefs about the timing of global warming.

[FIGURE 3 and 4 ABOUT HERE]

The estimated effects of positive snowfall extremes on beliefs about the timing of global warming are negative, but the estimates are at best marginally significant. Prolonged periods of very low

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<sup>24</sup>The more extreme set of thresholds is -2 and 2 for maximum temperatures, -0.8 and 1 for snowfall and -0.8 and 2 for precipitation. The less extreme thresholds are -1.5 and 1.5, -0.5 and 0, and -0.55 and 1, respectively.

snowfall (more extreme threshold) increase the likelihood that people believe the effects of global warming have already begun to happen. Prolonged periods of low snowfall (less extreme threshold) do not have an effect on beliefs. The estimated effects of prolonged periods of abnormally high precipitation on beliefs about the timing of global warming are positive and increasing with the time period, but are only marginally significant. The estimated effect when using the more extreme threshold is larger. The effects of extremely *low* precipitation are likewise positive and many of the point estimates are statistically significant. Here too, the effect is estimated to be larger when the more extreme threshold is used. Interpreted from the point of view of a limited information Bayesian, these estimates would imply that both abnormally high and abnormally low precipitation are a signal of global warming, i.e. that people are uncertain about what their local precipitation patterns will be like, but expect them to change. The qualitative nature of the results does not change if I include state-by-year, state and year or year fixed effects instead of region fixed effects.

Although the magnitudes of some coefficients in Figures 2-4 are large, it should be kept in mind that they represent the change in beliefs if the weather standard deviations exceeded the positive threshold (or were below a negative threshold) over the entire time span. The largest fraction of days on which maximum temperatures exceeded two standard deviations over a year is 0.8 and the 95th percentile is only 0.07. Because it does not snow in the summer, the estimated effect of 360 days of abnormally high or low snowfall is hypothetical. In practice, the magnitude of the effect for any reasonable realization of long-term fluctuations is likely to be small.

Finally, Table 11 shows the average estimated effect of heat waves over the past year, defined as the number of times the maximum temperature exceeded 90 degrees for three or more days in a row. The alternate measure is the number of heat wave days, defined as the number of days that were part of a heat wave. New Mexico, Arizona, Nevada, and Florida are excluded from these regressions, since residents of those states experience extremely hot weather quite frequently. The coefficients in both regressions are at best marginally significant and all are very close to 0. The results are robust to defining a heat wave as 3 or more consecutive days of maximum temperature 15 or more degrees above average and to including the four states listed above or excluding Texas and California in addition to the other hot states.

[TABLE 11 ABOUT HERE]

I now consider the magnitudes of the effects. The marginal effect of ideology on the probability that the respondent says "the effects of global warming have already begun to happen", relative to moderates, is -0.305 (-30.5 percentage points) for "very conservative", -0.150 for "conservative", 0.138 for "liberal" and 0.113 for "very liberal"<sup>25</sup>. The marginal effects of education, relative to

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<sup>25</sup>All are significant at the 1% level.

high school, is 0.045 for "some college", 0.101 for "college", and 0.166 for "graduate school"<sup>26</sup>. A day on which precipitation is 2.5 standard deviations above normal would produce a change in beliefs about the timing of global warming comparable to the estimated correlation between beliefs and "some college". Precipitation would have to be 8 standard deviations above normal to produce a change in beliefs comparable to the coefficient of "graduate school". A change in temperatures of 30 degrees is required to produce a change in beliefs comparable to the coefficient of "very conservative". While the latter two quantities are not outside the observed variation, they are above the 95th percentile, suggesting that the average change in beliefs is unlikely to be large. In addition, the effects are short-lived because the average standard deviation over the past week does not change beliefs<sup>27</sup>.

Overall, there is some evidence that weather fluctuations affect people's beliefs about the timing of global warming and whether it poses a threat. In the short run, the estimates are inconsistent with Bayesian updating, as people give much more weight to precipitation abnormalities on the day they are surveyed than the entire week prior to the survey, for example. In addition, recent *changes* in precipitation and temperatures affect beliefs, sometimes in unexpected ways. In the medium run (1-12 months), however, the patterns are consistent with limited information Bayesian updating, as longer and more extreme periods of abnormal weather have a larger effect on beliefs<sup>28</sup>.

Of course, this does not conclusively show that people are Bayesians who have limited information. It could be that individuals have access to a lot of information but overweight recent local weather when forming their beliefs. I do not know how much weight individuals should give to longer-run weather abnormalities because I do not observe their entire information set. Thus, determining which of these two models is the correct one is not possible in my setting; laboratory experiments or surveys that elicit the amount of other information people have would be helpful.

In a related paper, Egan and Mullin (2009) do find that recent temperature abnormalities have a significant effect on how convincing people find the evidence for the occurrence of global warming. Their data come from a different survey and the question they consider is not about the occurrence of climate change or its seriousness, but about the quality of scientific evidence. In addition, some of their surveys were done in the summer around the time of a heat wave. Since all the Gallup surveys are done in March, it's possible that there's a short-run effect of abnormally hot summer temperatures that I cannot estimate with my data.

Joireman et al. (2010) finds that the degree to which undergraduate psychology students be-

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<sup>26</sup>All are significant on at least the 5% level.

<sup>27</sup>I also estimate the impacts of extreme weather events and disaster declarations on beliefs and find that they are insignificant. These results are shown and discussed in the Appendix.

<sup>28</sup>It's important to note that weather fluctuations are unlikely to significantly change beliefs of a country as a whole. Although weather is spatially correlated, there is substantial regional variation, and periods of abnormally hot weather are likely to be offset by periods of abnormally cold weather.

lieve that (a) they had noticed signs of global warming and (b) temperatures are warmer now than in years before or when participants were children were positively correlated with outdoor temperatures, even when participants were inside and could not observe the outdoor weather. Risen and Critcher (2009) find that individuals are more convinced of the existence of global warming when the surrounding temperature is higher, whether they are indoors or outdoors. In contrast to Joireman et al., they find that the individual's perception of outdoor temperature has no effect on the strength of beliefs when the individual is indoors. Shuldt and Schwarz (2008) likewise find that outdoor temperature levels do not influence beliefs, but that recent temperature changes do. The different findings of different researchers suggest that which factors beliefs are swayed may depend on how questions are asked, priming<sup>29</sup>, or the identity of the participants. To understand the formation and evolution of beliefs, this discrepancy should be investigated further.

## 5. Conclusion

How individuals form and update beliefs is an important question for policy, theory, and general understanding of human behavior. Various violations of Bayesian updating have been found empirically. Biases such as representativeness, associativeness, and availability can cause individuals to deviate from rational models. Limited access to information or overweighting of certain information can likewise cause observed behavior to differ from that of a perfectly informed Bayesian.

In this paper, I study the updating of beliefs about global warming. Using a multi-year survey, I test whether individuals use local weather abnormalities to form inferences about global warming's occurrence and the threat it poses. Global warming is a highly uncertain event whose occurrence is very difficult to determine objectively, even for climate scientists. In addition, most people do not have all the information that a climate scientist does. Thus, it is plausible that individuals may give significant weight to local weather when updating their beliefs.

I find that some weather abnormalities 1-2 days before they survey are significant predictors of beliefs about the occurrence of global warming and the threat it presents to the respondent, but weather abnormalities the week before the survey are not, suggesting that short-run updating is influenced by psychological heuristics such as representativeness. Over time periods of 1-12 months, however, weather abnormalities also affect beliefs significantly. Longer periods of abnormal weather and more extreme weather produce larger changes in beliefs about the occurrence of global warming, which is consistent with Bayesian updating in a limited information environment.

However, the exact pathway through which these effects work is difficult to determine. Because I do not observe individuals' information set, I cannot rule out that individuals observe weather everywhere but irrationally give larger weight to local weather. It's also possible that the effects of

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<sup>29</sup>In Shuldt and Schwarz (2009), for example, respondents were asked to judge whether world temperature had changed in the past few years before being asked about the occurrence of global warming.

weather are indirect. For example, more extreme weather could lead to more discussion of global warming in the local media and more exposure to other evidence about global warming, such as IPCC reports<sup>30</sup>.

Another question remains unanswered: how do people come to form their beliefs about global warming in the first place? My analysis shows that there are substantial differences in beliefs which cannot easily be explained by differences in information, such as the influence of ideology, the male-female difference of the effect of education and political party and the significance of race. It is possible that these observable characteristics are correlated to true differences in information possessed by the individual; however, further investigation of this question would be of interest to the study of belief formation.

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<sup>30</sup>For example, Shanahan and Good (2000) find that climate issues were more likely to be covered in the New York Times during periods of unusually high temperatures.

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### **Appendix. Effects of major disasters and extreme weather**

In this appendix, I investigate whether individuals respond to extreme events that are not easily measured with standard weather data. In particular, I consider the effect of local natural disasters, such as droughts and floods<sup>31</sup>. The data on these weather extremes come from the SHELDUS database (Hazards & Vulnerability Research Institute, 2009).

The basic specification is as follows:

$$\begin{aligned} Answer_{ict} &= \alpha + \beta Disaster_{ict} + X_i' \gamma + \alpha_{rt} + \varepsilon_{ict} \\ i &= \text{individual}; c = \text{county}; t = \text{year}; r = \text{region} \end{aligned}$$

As before, *Answer* is the respondent's reply to questions about the timing of global warming's effects ("Happening") and whether he believes it will be a threat to his way of life ("Threat").

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<sup>31</sup>Because of their local nature, even these extreme events should still have a negligible effect on a fully informed Bayesian updater.

*Disaster* is a dummy for a heat wave, hurricane, or drought in the respondent's county. In another specification, I also use the reported damages (in logs) as the independent variable.

[TABLE A1 ABOUT HERE]

Results are shown in Table A1. There is no consistent evidence that extreme weather in one's own county or the damage it causes influences beliefs about global warming, with the exception that larger damages caused by extreme heat are associated with an increase in the probability that the respondent believes global warming will be a threat to him in his lifetime.

I also test whether weather events that are big enough to warrant a federal "major disaster" declaration influence beliefs about global warming. I regress beliefs about global warming on whether the individual's county was part of a major disaster declaration in the past year<sup>32</sup>.

$$Answer_{ict} = \alpha + \beta Declaration_{ct} + \alpha_t + \alpha_c + \varepsilon_{ict}$$

*Declaration<sub>ct</sub>* is a dummy for whether an individual's county was included in a major disaster declaration in the 12 months prior to the respondent taking the survey.

[TABLE A2 ABOUT HERE]

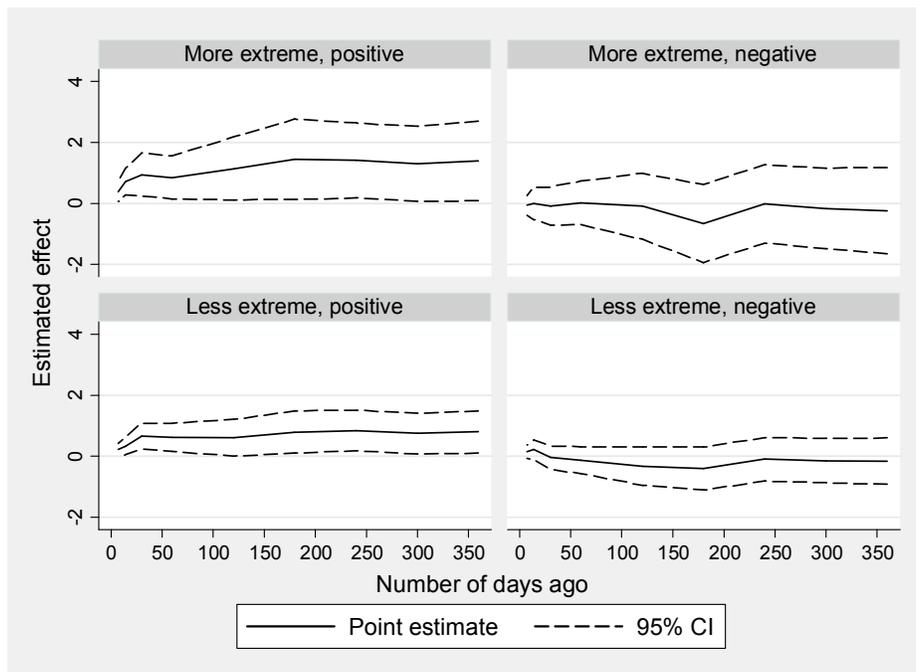
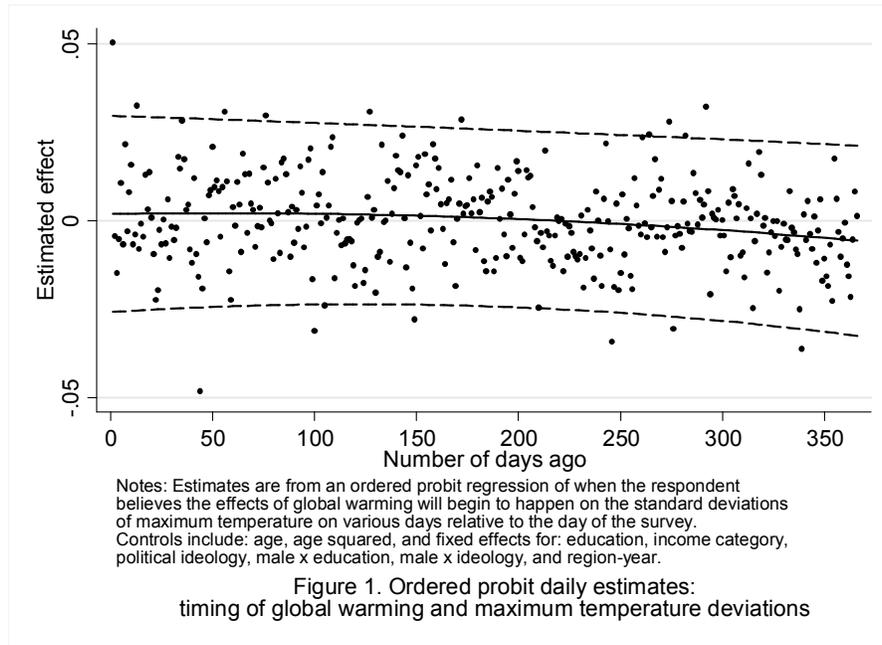
Results are shown in Table A2. There is no evidence that a major disaster declaration in one's county or state affects the probability that the respondent believes the effects of global warming have already begun to happen or perceives it as a threat.

Empirically, it appears that people give greater weight to prolonged periods of abnormal weather than to a particular event in their location. With the exception of extreme heat damages increasing the probability that respondents perceive global warming as a threat, individual extreme events do not appear to move beliefs significantly, at least in the medium run.

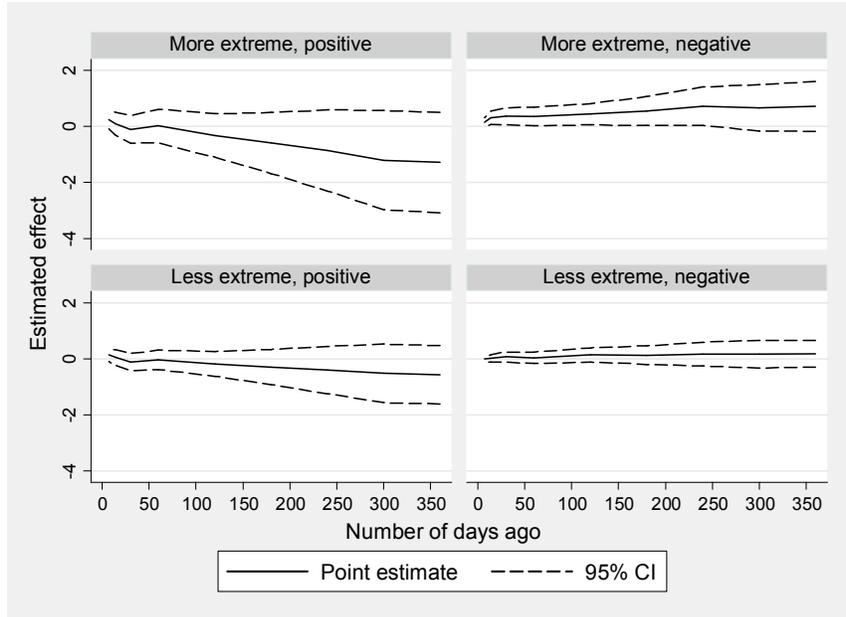
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<sup>32</sup>Although major disaster declarations can in theory be for non-weather related events, such as chemical spills, in practice most of the declarations are related to floods, hurricanes, winter storms, and other natural phenomena. The data are from the Public Entity Risk Institute (PERI).

## FIGURES

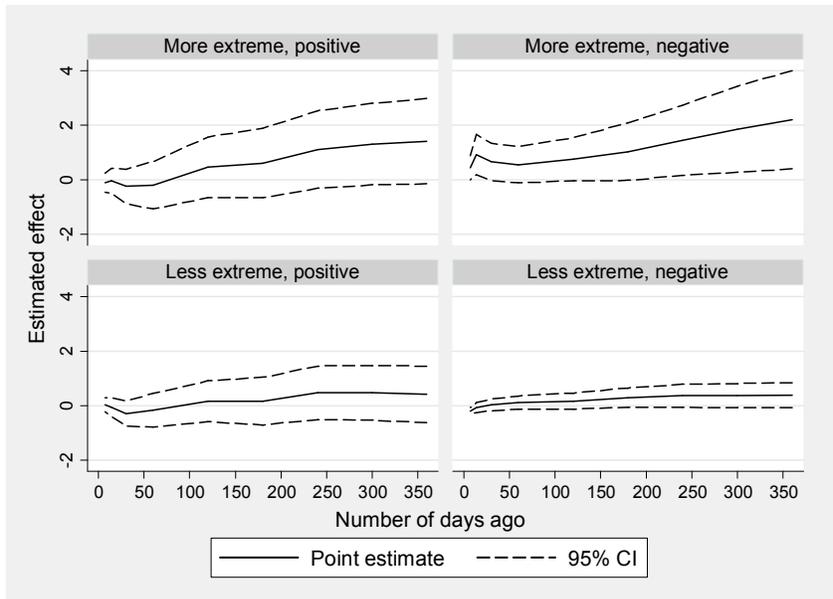


Notes: Estimates are from an ordered probit regression of when the respondent believes the effects of global will begin to happen on the fraction of days on which the number of standard deviations of maximum temperatures was below a negative threshold ("negative") or above a positive threshold ("positive"). "More extreme" threshold is  $\pm 2$  sds. "Less extreme" threshold is  $\pm 1.5$  sds. Controls include: age, age squared, and fixed effects for: education, income category, political ideology, male x education, male x ideology, and region x year.



Notes: Estimates are from an ordered probit regression of when the respondent believes the effects of global will begin to happen on the fraction of days on which the number of standard deviations of snowfall was below a negative threshold ("negative") or above a positive threshold ("positive"). "More extreme" threshold is  $+1/-0.8$  sds. "Less extreme" threshold is  $+0/-0.5$  sds. Controls include: age, age squared, and fixed effects for: education, income category, political ideology, male x education, male x ideology, and region-year.

Figure 3. Ordered probit cumulative estimates: timing of global warming and snowfall deviations



Notes: Estimates are from an ordered probit regression of when the respondent believes the effects of global will begin to happen on the fraction of days on which the number of standard deviations of precipitation was below a negative threshold ("negative") or above a positive threshold ("positive"). "More extreme" threshold is  $+2/-0.8$  sds. "Less extreme" threshold is  $+1/-0.55$  sds. Controls include: age, age squared, and fixed effects for: education, income category, political ideology, male x education, male x ideology, and region-year.

Figure 4. Ordered probit cumulative estimates: timing of global warming and precipitation deviations

TABLES

Table 1: Characteristics of survey respondents

	2001-2010		2003-2010	
	Number	Percent	Number	Percent
Education				
High school or less	3,073	30.35%	2,368	29.38%
Some college	2,865	28.30%	2,283	28.33%
College	1,960	19.36%	1,589	19.72%
Graduate school	2,183	21.56%	1,781	22.10%
Political ideology				
Very conservative	786	7.76%	652	8.09%
Conservative	3,193	31.54%	2,522	31.29%
Moderate	3,810	37.63%	3,006	37.30%
Liberal	1,607	15.87%	1,265	15.70%
Very liberal	429	4.24%	365	4.53%
Census region				
Northeast (1)	1,989	19.64%	1,500	18.61%
Midwest (2)	2,358	23.29%	1,867	23.17%
South (3)	3,519	34.76%	2,877	35.70%
West (4)	2,258	22.30%	1,814	22.51%
Male	5,006	49.44%	4,011	49.77%
White	8,794	86.85%	6,994	86.78%
Average income <sup>1</sup>		69,749		73,894
Average age		50.59		51.39
Number of respondents	10,125	10,125	8,059	8,059

<sup>1</sup>Reconstructed from income categories by taking the mean of income category as the household income. Anyone reporting income of over \$75,000 (2000-2003 surveys) was assigned an income of \$100,000. Anyone reporting income of over \$500,000 (2004-2010 surveys) was assigned an income of \$750,000  
*Notes:* percentages may not add up to 100% due to rounding, people responding "I don't know" or refusing to answer the question.

Table 2: Summary of responses to key questions, 2001-2010

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*Which of the following best reflects your view on when the effects of global warming will begin to happen?*

They have already begun to happen (5)	56.4%
They will start happening within a few years (4)	4.2%
They will start happening within your lifetime (3)	10.5%
They will not happen within your lifetime, but they will affect future generations (2)	16.4%
They will never happen (1)	9.7%
Observations	10,125

*Do you think that global warming will pose a serious threat to you or your way of life in your lifetime?<sup>1</sup>*

Yes (1)	33.5%
No (0)	66.5%
Observations	5,984

*How would you rate economic conditions in this country today -- as excellent, good, only fair, or poor?<sup>2</sup>*

Excellent (4)	3.58%
Good (3)	30.86%
Fair (2)	44.96%
Poor (1)	20.18%
Observations	8,099

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<sup>1</sup>Question was asked in 2001, 2002, 2006, and 2008-2010.

<sup>2</sup>Question was asked in 2001-2008.

*Notes:* The coding of responses into numerical values to create dummy variables is in parentheses following the answer choice. Percentages may not add up to 100% due to rounding, people responding "I don't know" or refusing to answer the question.

Table 3: Beliefs about global warming and respondent characteristics

	Happening	Threat	Happening	Threat
Male	-0.048 (0.056)	-0.257 (0.080)***	Male x grad. school	-0.249 (0.072)***
White dummy	-0.032 (0.042)	-0.537 (0.061)***	Very conservative	-0.738 (0.072)***
Age	0.021 (0.004)***	0.025 (0.007)***	Conservative	-0.360 (0.041)***
Age <sup>2</sup>	-2.58E-04 (4.14e-05)***	-4.24E-04 (6.55e-05)***	Liberal	0.292 (0.052)***
Log income	0.886 (0.208)***	0.353 (0.387)	Very liberal	0.305 (0.092)***
Log income <sup>2</sup>	-0.044 (0.010)***	-0.025 (0.018)	Male x very conservative	-0.448 (0.101)***
Some college	0.147 (0.039)***	-0.137 (0.071)*	Male x conservative	-0.185 (0.059)***
College	0.277 (0.055)***	-0.041 (0.080)	Male x liberal	-0.020 (0.074)
Graduate	0.460 (0.054)***	-0.024 (0.078)	Male x very liberal	0.184 (0.136)
Male x some college	-0.072 (0.065)	-0.022 (0.106)	$\mu_1$	3.531
Male x college	-0.234 (0.080)***	-0.166 (0.108)	$\mu_2$	4.231
Observations	8,861	5,352	$\mu_3$	4.556
			$\mu_4$	4.672

Notes: Robust standard errors (clustered by state-year) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Includes region-year fixed effects. Omitted categories are: moderate, high school education or less, male x moderate, male x high school or less.

Table 4: Beliefs about the state of the economy and local employment conditions

	Average unemployment rate over past year		Unemployment rate last month	
	<i>Panel A: local unemployment rates</i>			
Pr (excellent)	-0.003 (0.001)***	-0.002 (0.001)**	-0.001 (0.000)*	-0.003 (0.001)***
Pr (good)	-0.020 (0.004)***	-0.013 (0.006)**	-0.029 (0.014)**	-0.017 (0.004)***
Pr (fair)	0.004 (0.001)***	0.003 (0.001)**	-0.001 (0.001)	0.003 (0.001)***
Pr (poor)	0.019 (0.004)***	0.012 (0.004)**	0.031 (0.014)**	0.016 (0.004)***
Fixed effects	none	state	county	none
Observations	3,066	3,059	2,102	3,066
	<i>Panel B: state unemployment rates</i>			
Pr (excellent)	-0.004 (0.001)***	-0.005 (0.002)**	-0.002 (0.001)*	-0.004 (0.001)***
Pr (good)	-0.022 (0.004)***	-0.031 (0.012)**	-0.038 (0.017)**	-0.022 (0.004)***
Pr (fair)	0.005 (0.001)***	0.007 (0.003)**	0.003 (0.001)**	0.005 (0.001)***
Pr (poor)	0.021 (0.004)***	0.029 (0.010)**	0.037 (0.017)**	0.021 (0.004)***
Fixed effects	none	state	county	none
Observations	8,132	8,132	3,066	8,132

*Notes:* Robust standard errors (clustered by state) in parentheses. \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. All regressions control for age and age squared and include the following fixed effects: year, employment status, income category, race, male, political ideology and education.

Table 5: Weather variation

	Mean	Standard deviation	5 <sup>th</sup> percentile	95 <sup>th</sup> percentile	Min	Max
<i>Maximum temperatures</i>						
Value $t=-1$ - value $t=-2$	-0.68	(9.70)	-16.00	17.00	-45.14	43.00
Standard deviations (s.d.)	0.22	(1.22)	-1.80	2.07	-3.64	9.55
Average s.d. over previous week	0.18	(0.66)	-0.77	1.40	-2.10	9.24
<i>Heat waves</i>						
Days	16.60	(29.88)	0	86	0	178
Number	2.67	(3.32)	0	9	0	18
<i>Precipitation</i>						
Value $t=-1$ - value $t=-2$	0.01	(0.30)	-0.32	0.43	-3.34	3.05
Standard deviations (s.d.)	-0.11	(1.00)	-0.62	1.72	-1.07	11.98
Average s.d. over previous week	-0.06	(0.44)	-0.51	0.86	-0.95	3.70
<i>Snowfall</i>						
Value $t=-1$ - value $t=-2$	0.03	(0.65)	-0.16	0.45	-8.10	13.18
Standard deviations (s.d.)	-0.07	(2.80)	-0.77	0.89	-5.11	121.22
Average s.d. over previous week	-0.08	(1.29)	-0.58	0.23	-5.11	106.05

*Notes:* Snowfall and rainfall are measured in inches. Temperature is in degrees Fahrenheit. Unless otherwise indicated, summary is for the day prior to respondent taking the survey. Variable distributions in other times of the year are qualitatively similar for maximum temperatures and precipitation; they differ for snow because of seasonality.

Table 6: Distribution of exceedance measures for maximum temperature

Time period (days)	Mean	Standard deviation	5 <sup>th</sup> percentile	95 <sup>th</sup> percentile	Min	Max
	<i>Greater than 1.5 standard deviations above normal</i>					
7	0.08	(0.16)	0.00	0.38	0.00	1.00
30	0.06	(0.08)	0.00	0.19	0.00	0.71
120	0.06	(0.06)	0.00	0.19	0.00	0.64
180	0.05	(0.05)	0.00	0.15	0.00	0.73
360	0.05	(0.05)	0.00	0.15	0.00	0.83
<i>Greater than 2 standard deviations above normal</i>						
7	0.03	(0.10)	0.00	0.25	0.00	1.00
30	0.02	(0.04)	0.00	0.10	0.00	0.52
120	0.02	(0.03)	0.00	0.09	0.00	0.55
180	0.02	(0.03)	0.00	0.07	0.00	0.67
360	0.02	(0.03)	0.00	0.07	0.00	0.80

Table 7: Ordered probit marginal effects of recent weather abnormalities on beliefs about global warming

	Maximum temperature		Snowfall		Precipitation	
	Happening	Threat	Happening	Threat	Happening	Threat
<i>Panel A: Standard deviations on day of survey</i>						
Pr (Answer = 1)	2.92E-03 (0.003)	-0.009 (0.009)	2.52E-04 (0.000)	-0.002 (0.001)*	-0.009 (0.003)***	-0.028 (0.009)***
Pr (Answer = 2)	2.65E-03 (0.003)	0.009 (0.009)	2.27E-04 (0.000)	0.002 (0.001)*	-0.008 (0.003)***	0.028 (0.009)***
Pr (Answer = 3)	8.30E-04 (0.001)		7.12E-05 (0.000)		-0.002 (0.001)***	
Pr (Answer = 4)	1.88E-04 (0.000)		1.50E-05 (0.000)		-0.001 (0.000)***	
Pr (Answer = 5)	-6.59E-03 (0.007)		-5.65E-04 (0.001)		0.020 (0.006)***	
Observations	5,447	3,074	5,141	2,905	5,727	3,233
<i>Panel B: Standard deviations 1 day ago</i>						
Pr (Answer = 1)	2.83E-03 (0.003)	0.003 (0.009)	4.76E-04 (0.001)	-0.004 (0.002)	7.57E-04 (0.003)	-0.013 (0.009)
Pr (Answer = 2)	2.54E-03 (0.003)	-0.003 (0.009)	4.28E-04 (0.001)	0.004 (0.002)	6.81E-04 (0.003)	0.013 (0.009)
Pr (Answer = 3)	8.02E-04 (0.001)		1.34E-04 (0.000)		2.12E-04 (0.001)	
Pr (Answer = 4)	1.81E-04 (0.000)		2.83E-05 (0.000)		4.80E-05 (0.000)	
Pr (Answer = 5)	-6.36E-03 (0.007)		-1.07E-03 (0.002)		-1.70E-03 (0.007)	
Observations	5,442	3,068	5,142	2,906	5,722	3,230

Notes: Robust standard errors (clustered by county-year) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Marginal effects calculated at the mean of independent variables. Controls include male dummy, white dummy, age, age squared, education dummies, income category dummies, political ideology dummies, interaction of male and education, interaction of male and ideology, and region-year fixed effects.

Table 8: Ordered probit marginal effects of recent weather changes on beliefs about global warming

	Maximum temperature		Snowfall		Precipitation	
	Happening	Threat	Happening	Threat	Happening	Threat
<i>Panel A: Change between 0 and 1 days ago</i>						
Pr (Answer = 1)	1.63E-04 (0.000)	-0.002 (0.001)**	2.38E-03 (0.003)	0.015 (0.013)	-0.021 (0.008)***	-0.039 (0.026)
Pr (Answer = 2)	1.50E-04 (0.000)	0.002 (0.001)**	2.20E-03 (0.003)	-0.015 (0.013)	-0.020 (0.007)***	0.039 (0.026)
Pr (Answer = 3)	4.88E-05 (0.000)		6.98E-04 (0.001)		-0.006 (0.002)***	
Pr (Answer = 4)	1.05E-05 (0.000)		1.45E-04 (0.000)		-0.001 (0.001)***	
Pr (Answer = 5)	-3.73E-04 (0.001)		-5.42E-03 (0.007)		0.049 (0.018)***	
Observations	6,304	3,095	6,514	3,211	6,590	3,238
<i>Panel B: Change between 1 and 2 days ago</i>						
Pr (Answer = 1)	5.90E-04 (0.000)**	0.003 (0.001)***	-9.59E-04 (0.004)	-0.015 (0.014)	4.40E-04 (0.009)	-0.033 (0.029)
Pr (Answer = 2)	5.44E-04 (0.000)**	-0.003 (0.001)***	-8.85E-04 (0.003)	0.015 (0.014)	4.08E-04 (0.008)	0.033 (0.029)
Pr (Answer = 3)	1.76E-04 (0.000)**		-2.80E-04 (0.001)		1.30E-04 (0.003)	
Pr (Answer = 4)	3.80E-05 (0.000)**		-5.92E-05 (0.000)		2.78E-05 (0.001)	
Pr (Answer = 5)	-1.35E-03 (0.001)**		2.18E-03 (0.008)		-1.00E-03 (0.020)	
Observations	6,304	3,090	6,525	3,215	6,591	3,236

Notes: Robust standard errors (clustered by county-year) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Marginal effects calculated at the mean of independent variables. Controls include male dummy, white dummy, age, age squared, education dummies, income category dummies, political ideology dummies, interaction of male and education, interaction of male and ideology, and region-year fixed effects.

Table 9: Ordered probit marginal effects of average deviations over the past week on beliefs about global warming

	Maximum temperature		Snowfall		Precipitation	
	Happening	Threat	Happening	Threat	Happening	Threat
Pr (Answer = 1)	-1.24E-04 (0.001)	6.74E-04 (0.002)	-0.013 (0.011)	-0.034 (0.028)	-0.009 (0.027)	-0.011 (0.079)
Pr (Answer = 2)	-1.14E-04 (0.001)	-6.74E-04 (0.002)	-0.012 (0.010)	0.034 (0.028)	-0.008 (0.025)	0.011 (0.079)
Pr (Answer = 3)	-3.58E-05 (0.000)		-0.004 (0.003)		-0.003 (0.008)	
Pr (Answer = 4)	-7.66E-06 (0.000)		-0.001 (0.001)		-0.001 (0.002)	
Pr (Answer = 5)	2.81E-04 (0.001)		0.029 (0.025)		0.020 (0.062)	
Observations	7,021	3,492	7,021	3,492	7,021	3,492

*Notes:* Robust standard errors (clustered by county-year) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Marginal effects calculated at the mean of independent variables. Controls include male dummy, white dummy, age, age squared, education dummies, income category dummies, political ideology dummies, interaction of male and education, interaction of male and ideology, and region-year fixed effects.

Table 10: the effect of persistent extremes on beliefs about global warming

Outcome	Thresholds	7 days	14 days	30 days	60 days	120 days	180 days	240 days	300 days	360 days
<i>Panel A: maximum temperature extremes</i>										
Happen	+1/-1.5 sds	(0.074)*	(0.041)**	(0.008)***	(0.027)**	(0.096)*	(0.046)**	(0.045)**	(0.086)*	(0.074)*
	+2/-2 sds	(0.059)*	(0.006)***	(0.028)**	(0.059)*	(0.089)*	(0.043)**	(0.078)*	(0.104)	(0.094)*
Threat	+1.5/-1.5 sds	(0.386)	(0.518)	(0.518)	(0.575)	(0.939)	(0.995)	(0.999)	(0.898)	(0.693)
	+2/-2 sds	(0.137)	(0.312)	(0.961)	(0.992)	(0.611)	(0.596)	(0.763)	(0.699)	(0.721)
<i>Panel B: precipitation extremes</i>										
Happen	+1/-0.55 sds	(0.018)**	(0.665)	(0.455)	(0.609)	(0.449)	(0.202)	(0.081)*	(0.071)*	(0.074)*
	+2/-0.8 sds	(0.101)	(0.043)**	(0.093)*	(0.202)	(0.153)	(0.115)	(0.028)**	(0.014)**	(0.009)**
Threat	+1/-0.55 sds	(0.279)	(0.143)	(0.351)	(0.282)	(0.360)	(0.284)	(0.165)	(0.136)	(0.224)
	+2/-0.8 sds	(0.351)	(0.331)	(0.291)	(0.048)**	(0.112)	(0.150)	(0.057)*	(0.087)*	(0.177)
<i>Panel C: snowfall extremes</i>										
Happen	+0/-0.5 sds	(0.528)	(0.955)	(0.621)	(0.941)	(0.495)	(0.564)	(0.569)	(0.578)	(0.514)
	+1/-0.8 sds	(0.090)*	(0.041)**	(0.052)*	(0.115)	(0.045)**	(0.050)**	(0.050)*	(0.116)	(0.100)*
Threat	+0/-0.5 sds	(0.089)*	(0.187)	(0.167)	(0.316)	(0.153)	(0.129)	(0.128)	(0.116)	(0.131)
	+1/-0.8 sds	(0.123)	(0.597)	(0.437)	(0.344)	(0.186)	(0.196)	(0.190)	(0.195)	(0.186)

*Notes:* Robust standard errors (clustered by county-year) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Table shows the p-values from the joint significance test of positive and negative weather extremes. The estimates come from linear regressions of beliefs on the fraction of days on which standard deviations were above a positive threshold or below a negative threshold over the given time period. Controls include male dummy, white dummy, age, age squared, education dummies, income category dummies, political ideology dummies, interaction of male and education, interaction of male and ideology, and region-year fixed effects.

Table 11: The effect of heat waves on beliefs

	Heat wave days			Number of heat waves		
	Happening	Threat	Happening	Happening	Threat	Threat
Pr (Answer = 1)	7.31E-05 (0.000)	8.74E-05 (0.000)	3.87E-04 (0.001)	2.03E-03 (0.003)		
Pr (Answer = 2)	6.83E-05 (0.000)	-8.74E-05 (0.000)	3.61E-04 (0.001)	-2.03E-03 (0.003)		
Pr (Answer = 3)	2.18E-05 (0.000)		1.15E-04 (0.000)			
Pr (Answer = 4)	4.71E-06 (0.000)		2.49E-05 (0.000)			
Pr (Answer = 5)	-1.68E-04 (0.000)		-8.88E-04 (0.002)			
Observations	6,402	3,163	6,402	3,163	6,402	3,163

*Notes:* Robust standard errors (clustered by county-year) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Specification is an ordered probit. Excludes Arizona, Nevada, New Mexico and Florida. Controls include male dummy, white dummy, age, age squared, education dummies, income category dummies, political ideology dummies, interaction of male and education, interaction of male and ideology, and region-year fixed effects. A heat wave is defined as three or more consecutive days on which the maximum temperature exceeded 90 degrees F. A heat wave day is any day which is part of a heat wave under the previous definition.

Table A1: The effects of extreme weather events on beliefs about global warming

Disaster measure: Independent variable	Extreme heat		Drought		Hurricane	
	ln(damage+1)	Dummy	ln(damage+1)	Dummy	ln(damage+1)	Dummy
<i>Panel A: beliefs about timing of the effects of global warming</i>						
Pr (Answer = 1)	4.07E-04 (0.006)	0.011 (0.015)	5.72E-05 (0.001)	0.002 (0.008)	7.84E-04 (0.001)	0.004 (0.008)
Pr (Answer = 2)	4.06E-04 (0.006)	0.011 (0.015)	5.70E-05 (0.001)	0.002 (0.008)	7.81E-04 (0.001)	0.004 (0.008)
Pr (Answer = 3)	1.35E-04 (0.002)	0.004 (0.005)	1.90E-05 (0.000)	0.001 (0.003)	2.60E-04 (0.000)	0.001 (0.003)
Pr (Answer = 4)	2.83E-05 (0.000)	0.001 (0.001)	3.97E-06 (0.000)	1.57E-04 (0.001)	5.44E-05 (0.000)	3.08E-04 (0.001)
Pr (Answer = 5)	-9.77E-04 (0.015)	-0.026 (0.037)	-1.37E-04 (0.003)	-0.005 (0.018)	-1.88E-03 (0.002)	-0.011 (0.020)
Observations	8,723	8,723	8,723	8,723	8,723	8,723
<i>Panel C: beliefs global warming posing a serious personal threat</i>						
Pr (Threat = "yes")	0.036 (0.009)***	-0.117 (0.221)	0.001 (0.007)	0.018 (0.048)	0.000 (0.010)	-0.053 (0.061)*
Observations	5,212	5,212	5,212	5,212	5,212	5,212

Notes: Robust standard errors (clustered by state) in parentheses; \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Specification is an ordered probit. Includes region-by-year fixed effects, age, age squared, male dummy, race dummies, political ideology and education dummies.

Table A2: The effects of major disaster declarations on beliefs about global warming

	Happening		Threat	
Pr (Answer = 1)	-0.003 (0.006)	0.010 (0.006)	0.016 (0.023)	-0.012 (0.025)
Pr (Answer = 2)	-0.003 (0.006)	0.010 (0.006)	-0.016 (0.023)	0.012 (0.025)
Pr (Answer = 3)	-0.001 (0.002)	0.003 (0.002)		
Pr (Answer = 4)	0.000 (0.000)	0.001 (0.000)		
Pr (Answer = 5)	0.007 (0.014)	-0.025 (0.015)		
Observations	8,723	8,723	5,212	5,212
Level of declaration	State	County	State	County

*Notes:* Robust standard errors (clustered by county-year) in parentheses. \* significant at 10%; \*\* significant at 5%; \*\*\* significant at 1%. Estimates are from an ordered probit specification. Includes region-by-year fixed effects, age, age squared, male dummy, race dummies, political ideology and education dummies.