Beyond politics: Climate concern responds to changing temperatures in the American states

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Abstract

In the United States, many of the most important policies to address climate change have come from the states. As a result, there is a strong need to understand the drivers of public concern about climate change and support for policies to address it at the state level. But there is no existing measure of how public concern about climate change is changing at the state level; nor is there a consensus about the link between changes in the climate and public concern about global warming. Here, we develop a new, comprehensive index of the mass public's latent concern about climate change in each state from 1999-2016. We show that climate concern peaked in 2000 and again in 2016. Next, we show that state-level climate concern is responsive to changes in average temperatures. But we find no evidence that annual changes in drought, wildfires, and precipitation have an effect on public opinion at the state level. Overall, these results suggest that continued increases in temperature are likely to cause public concern about climate change to grow in the future. Thus, a warming climate is likely to make it more feasible to pass new policies that address climate change.

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While there is robust evidence that anthropogenic greenhouse gas emissions are causing changes in the earth's climate (Solomon, 2007), the extent of warming around the United States varies considerably (Kaufmann et al., 2016). Likewise, there is wide variation in levels of belief in climate change around the country (Howe et al., 2015). But we do not know the extent to which variation in locally experienced climate change causes differences in belief in and concern about the phenomenon. Since higher levels of belief in climate change are associated with a greater likelihood that states enact policies to address global warming (Egan and Mullin, 2017), there is a strong need to understand the drivers of public concern about climate change and support for policies to address it.

In this paper, we develop a new, comprehensive index of the mass public's concern about climate change in each state from 1999-2016. This dataset is the first to show trends in state-level concern about climate change at the level at which it arguably matters most for policy. The index also enables us to causally identify the effect of exposure to climate change with a new level of robustness. We show that state-level climate concern is responsive to changes in average temperatures. Our results suggest that continued increases in temperature are likely to cause public concern about climate change to grow in the future. Thus, a warming climate is likely to make it more feasible to pass new policies that address climate change.

Background

Scholarship has not definitively identified the degree to which changes in the climate influence public opinion. Some studies find non-existent or conditional effects (Marquart-Pyatt et al., 2014; Deryugina, 2013; Mildenberger and Leiserowitz, 2017). Others find short-lived or substantively small ones (Konisky, Hughes, and Kaylor, 2016; Egan and Mullin, 2012; Palm, Lewis, and Feng, 2017), while still others find at least suggestive evidence that Americans do respond to climate signals (Donner and McDaniels, 2013; Shao et al., 2014; Brooks et al., 2014; Kaufmann et al., 2016).

One of the main challenges for assessing the drivers of public concern about climate change is measuring subnational public opinion over an extended time period. Thus, most studies examine the association between subnational temperature and opinion over a short time frame (Kaufmann et al., 2016; Konisky, Hughes, and Kaylor, 2016; Egan and Mullin, 2012; Brooks et al., 2014; Mildenberger and Leiserowitz, 2017; Palm, Lewis, and Feng, 2017). These studies arrive at mixed conclusions, highlighting the need for studies whose results are generalizable beyond a short time frame. Only a few studies have examined the effect of state or local level variation in climate change on public opinion over a longer time scale (Deryugina, 2013; Shao et al., 2014). Tantalizingly, these studies generally find a modest link between annual changes in temperature and public opinion. But they use small survey samples and sometimes find inconsistent effects across polls. Their analyses also only go through 2010 so it is not clear whether there is still a link between climate and public opinion as partisan polarization on climate change continues to grow (McCright and Dunlap, 2011).

Many previous studies focus on a long-running series of questions about climate change on Gallup Poll's Social Series (McCright and Dunlap, 2011; Marquart-Pyatt et al., 2014; Deryugina, 2013; Donner and McDaniels, 2013). These questions indicate that public concern about climate change reached its maximum in about 2000 (e.g., Figure 1, panel a), dipped over the next few years, and then rebounded between 2005 and 2008. Concern then slumped again around 2011, remained low between 2012 and 2015, and ticked up in 2016 when nearly 70% of the public indicated they were worried about climate change.

Despite its ubiquity in the literature, there are downsides of focusing exclusively on the Gallup series: the sample sizes are too small to produce state-level estimates, and the questions offer incomplete time coverage across the previous two decades. Focusing on the Gallup surveys also leaves out dozens of other questions that have been asked on surveys about climate change.

Research Design

To address these limitations, we assembled a dataset of all publicly available survey data on climate change from 1999-2016. The dataset includes approximately 348,500 survey respondents from 155 individual polls. It includes questions about belief in climate change, concern about global warming, support for prioritizing policies to address climate change, and whether climate change is caused by human activities. Figure 1 shows a sample of these questions, and a full list is provided in Supplementary Appendix A. Figure 1 indicates that trends in public opinion are highly correlated across survey questions.

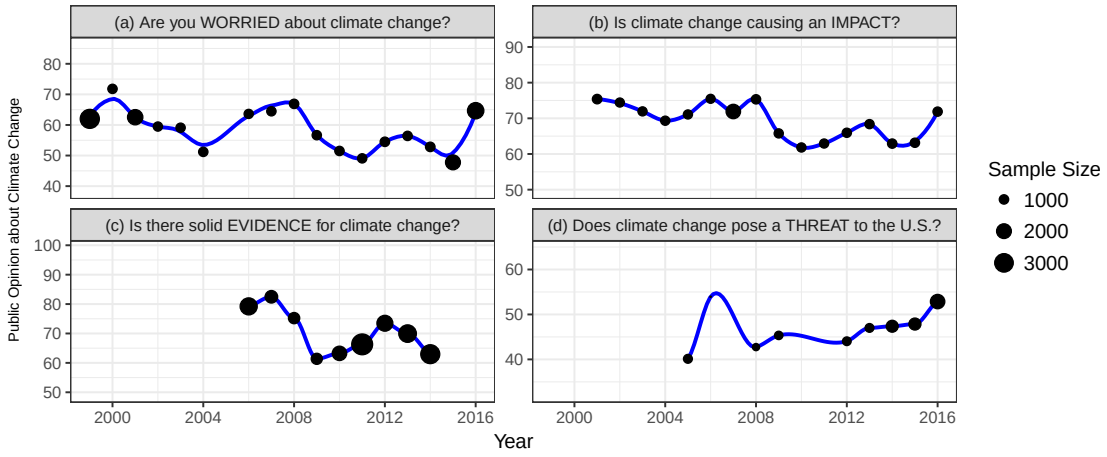

Figure 1: Trends in Public Opinion on Individual Climate Poll Questions: This graphs shows trends in four question series about respondents' views on climate change.

To summarize this comprehensive dataset of public opinion on climate change, we use a group-level item response theory (IRT) model to generate an aggregate index of latent concern about climate change in each state/year between 1999 and 2016 (Caughey and Warshaw, 2015).[1] No previous study has described trends in public opinion about climate at the state level, where they arguably matter most for policy. The long time frame from 1999 to 2016 provides sufficient statistical power to detect small effects of climate change on public opinion. It also ensures that any findings are generalizable beyond a particular

[1]See Supplementary Appendices A and B for more details about the model. In Supplementary Appendix C, we provide evidence that concern about climate change can be reduced to a single dimension. We also validate our estimates by comparing them to the best-available published measures of state-level climate concern (Howe et al., 2015).

snapshot in time. Our extended time period also enables us to examine whether the effect of temperature on public opinion is decreasing as the public grows more polarized.

We conduct a battery of analyses to examine whether changes in the climate of each state influence public opinion. First, we examine the effect of temperature on public opinion based on variation in the annual average of monthly high temperatures in each state. Next, we examine five indicators of extreme events in each state that are linked to trends in precipitation: storms, short- and long-term drought severity, precipitation, and wildfires. We standardize each extreme-events measure for comparability across indicators, and we lag all measures by one year to ensure that public opinion is measured post-treatment.

To isolate the causal effects of local changes in temperature and extreme events from other time-varying confounders and to test the persistence of the effect of temperature, we estimate a series of increasingly nuanced time series, cross-sectional (TSCS) models (see Supplementary Appendix D). We first use a model with both state and year fixed effects. The year fixed effects account for national-level shocks, such as recessions or the debut of *An Inconvenient Truth*, while the state fixed effects control for variation in average climate conditions as well as the political culture of each state (McCright and Dunlap, 2011; Marquart-Pyatt et al., 2014; Shao et al., 2014; Deryugina, 2013). Next, we add linear time trends within each state (Angrist and Pischke, 2014). This allows us to account for smooth changes in state characteristics over time (such as ideological or economic changes) that might influence public attitudes about climate change. Finally, we use a model with a lagged dependent variable to capture other, time-varying omitted variables in each state and to determine whether the effect of temperature is persistent over time (Beck and Katz, 2011).

Results

Figure 2 shows trends in temperature (upper panel) and public opinion (lower panel) at the national level from 1999-2016. One way to interpret the climate concern index is that when

our index is at 0, approximately 59% of the public worries a 'great deal or fair amount' about climate change in Gallup's annual polls (see Supplementary Figure C2). In addition, a one standard-deviation change in our latent scale is roughly equivalent to a 7% change in the percentage of people that worry about climate change. Overall, the lower panel of Figure 2 confirms the trends observed on individual survey questions (see Figure 1). Public concern about climate change peaked in 2000. It then declined until 2004, rebounded until 2008, declined and hovered through 2015, and peaked again in 2016.

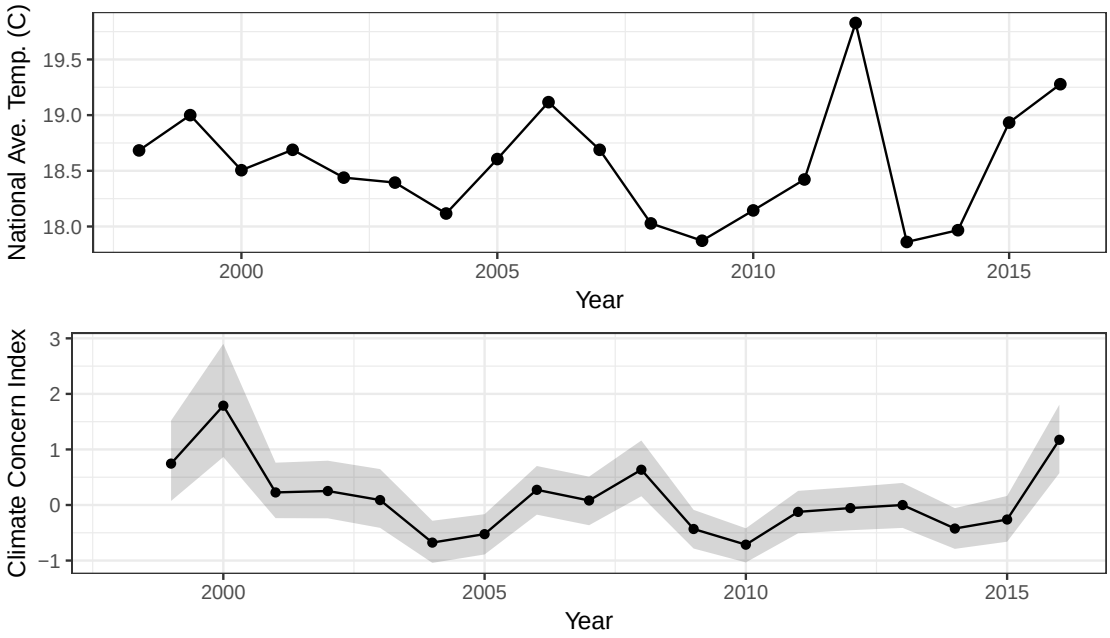

Figure 2: Trends in Temperature and Climate Concern at the National Level: This graph shows trends in annual averages of monthly high temperatures and our index of climate concern at the national level. The figure shows 90% credible intervals around the estimates.

The figure suggests that there is a strong correlation between national-average temperature and public concern about climate change in the following year. Regression analysis indicates that a one-degree Celsius change in temperature is associated with a 0.73 standard-deviation change in opinion (Supplementary Appendix E). While this association is large, it could be confounded by any number of omitted variables. Moreover, there is high variation in locally experienced warming trends (Kaufmann et al., 2016).

To address these limitations, we next examine the public's climate concern at the state

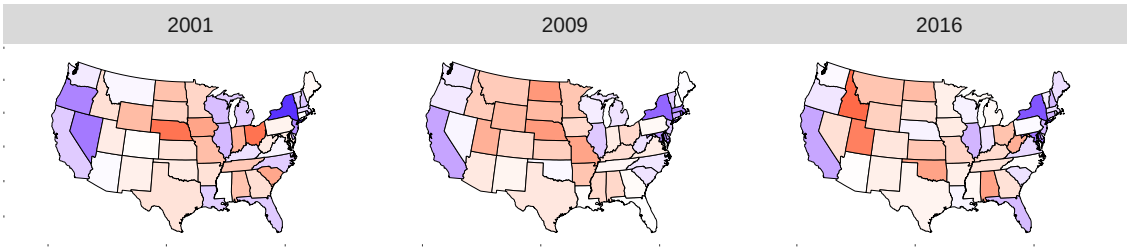

Figure 3: Average state climate concern, 2001–2016. Redder colors represent states with less concern about climate change, while bluer colors represent states with more concern about climate change.

level. Figure 3 shows how state-level concern about climate change has changed over the past 15 years. The figure conforms with prior research showing that politics matters a great deal in shaping public opinion about climate change (Egan and Mullin, 2012; Marquart-Pyatt et al., 2014; Deryugina, 2013; Shao et al., 2014; Brooks et al., 2014; Mildenberger and Leiserowitz, 2017). Overall, states that tend to elect Republicans such as those in the Southeast have generally become more skeptical about the existence of climate change, whereas Democratic states like California have become more likely to believe in anthropogenic climate change.

Table 1: Effect of State-Level Temperature on Public Opinion

	Climate Concern		
	(1)	(2)	(3)
Average Monthly High Temperature$_{t-1}$ (°C)	0.118***	0.097***	0.095**
	(0.038)	(0.036)	(0.038)
Lagged Climate Concern			0.345***
			(0.055)
State Fixed Effects	X	X	X
Year Fixed Effects	X	X	X
State-specific time trend		X	
Lagged outcome Variable			X
Observations	882	882	833
R^2	0.833	0.893	0.855
Note:	*p<0.1; **p<0.05; ***p<0.01		

What is the effect of changes in climate at the state level on public concern about climate

change? We find that changes in annual-average temperatures have a robust effect on climate concern. Across specifications, a one-degree Celsius increase in temperature in a state leads to an increase of 0.1 - 0.12 standard deviations in the state-level climate-concern index (Table 1). This effect implies that a one-degree Celsius increase in temperature causes an increase of about .8% in the proportion of people in a state that worry a 'great deal or fair amount' about climate change (Supplementary Figure C2). Moreover, this effect persists even in the face of growing polarization on climate change (Supplementary Appendix F).

While the effects we uncover are relatively small in size, it is important to note that the year fixed effects in our regression models net out changes in temperature that are shared across states. This specification ensures that our results are not confounded by omitted variables at the national level, such as changes in the national economy. But it also means that our results may underestimate the effect of changes in temperature on public opinion since changes in temperature tend to be correlated across states.

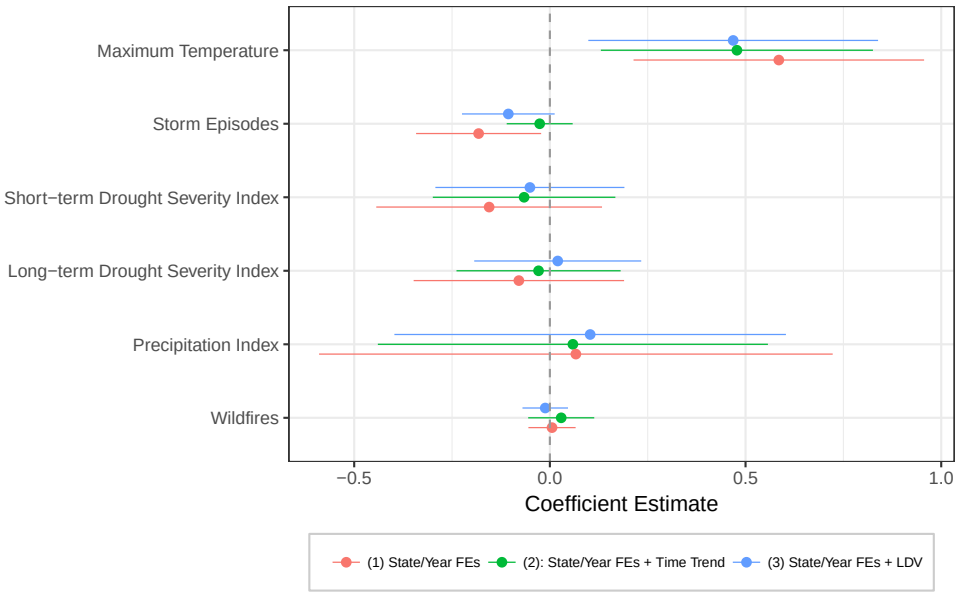

Figure 4: The effect of a one standard-deviation change in various climatic indicators on public opinion. The indicators are measured at the state level and refer, from top to bottom, to the annual average of monthly maximum temperature in degrees Celsius, the duration of storm events, annual average of monthly short-term drought, annual average of monthly long-term drought, reduction from median annual precipitation, and the (logged) acres that experienced wildfires.

Finally, we examine the effect on public opinion of an array of standardized indicators of extreme events in each state that are linked to trends in precipitation. None of the climate-extremes indicators have a robust, significant effect on public opinion (Figure 4). Since we assess responses to extreme events and wildfires that occurred in the previous year, our results leave open the possibility that these indicators can affect public opinion on a scale of weeks or months (Konisky, Hughes, and Kaylor, 2016). They do not appear to have a persistent effect on public opinion at the state level though.

Conclusion

We present the first estimates of trends in state-level climate concern across nearly two decades. These estimates enable us to assess the causal relationship between indicators of a changing climate and public concern about the phenomenon with a new level of rigor. They also open new opportunities for robust research into the causes and consequences of climate concern at the state level.

Overall, the findings in this paper show a robust causal link between temperature trends as people actually experience them and climate concern at the level at which it matters most for policy. This result complements cross-sectional studies finding a significant effect of changing temperatures (e.g., Egan and Mullin, 2012; Kaufmann et al., 2016), but we extend this work in two crucial ways. Our 20-year time frame ensures that our findings are robust across time, and our dynamic model allows us to measure the persistence of the effect. This is substantively crucial since our results show that continued increases in temperature due to global warming are likely to gradually increase the public's concern about climate change. This suggests that rising temperatures are likely to improve the political feasibility of passing state-level policies to reduce greenhouse gas emissions, and that passing climate policy is more feasible in states that have experienced greater levels of warming.

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Supplementary Appendix A: Public Opinion Questions on Climate Change

Table A1: Illustrative Question Categories

Category	Question
Belief	Do you believe that climate change is happening or will happen?
Worry	Do you worry about climate change?
Scientific Consensus	Do scientists agree that climate change is happening and humans are contributing to it?
Evidence	Is there solid evidence that climate change is happening?
Causes	Is climate change caused by human activities?
Policy	Should the government take policy action to address climate change?
Impacts	Is climate change causing a serious impact, or will it in the future?

Table A2: Survey Questions

Category	Years	Question Description	Sources
Belief	1999; 2010	Will climate change happen in the future?	Pew 1999a, 2010a
Belief	2006; 2007; 2008; 2012; 2016	Has climate change been happening over the past 100 years?	ABC News, Stanford University, and Time Magazine 2006; ABC News, Stanford University, and The Washington Post 2007; ABC News, Discovery Channel, Stanford University 2008; American National Election Studies 2012, 2016
Worry	2002; 2006; 2007	How important is global warming to you?	ABC News, Stanford University, and Time Magazine 2006; ABC News, Stanford University, and The Washington Post 2007; Pew 2006a; MIT Energy Study 2002
Worry	2007;2014; 2013; 2012; 2011; 2010; 2009	How concerned are you about global warming?	ABC, The Washington Post 2007; Social Science Research Solutions, CBS 2014; National Surveys on Energy and Environment 2013a, 2012a, 2011a, 2010a, 2009
Worry	1999; 2000; 2001; 2002; 2003; 2004; 2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014; 2015; 2016	How much do you worry about climate change?	Gallup 1999a,b; Pew 1999b; Gallup 2000, 2001; Pew 2001a; Gallup 2002, 2003, 2004, 2006, 2007a, 2008; Public Agenda Foundation 2009; Gallup 2009; Taylor Nelson Sofres 2009; Gallup 2010a, 2011, 2012, 2013, 2014, 2015; CBS 2015; Cooperative Congressional Election Study 2016
Worry	2015	Is climate change a critical issue to you?	Public Religion Research Institute 2015
Scientific Consensus	2006; 2007; 2008; 2009; 2015	Do scientists agree with each other about climate change?	ABC News, Stanford University, and Time Magazine 2006; ABC News, Stanford University, and The Washington Post 2007; ABC News, Discovery Channel, Stanford University 2008; ABC, The Washington Post 2009; ABC 2015
Scientific Consensus	2006; 2007; 2008	Do scientists agree climate is changing or is not changing? (asked of subset that believe scientists agree with each other about climate change)	ABC News, Stanford University, and Time Magazine 2006; ABC News, Stanford University, and The Washington Post 2007; ABC News, Discovery Channel, Stanford University 2008
Scientific Consensus	2007; 2009; 2010; 2011; 2012; 2013	Do scientists agree that humans are causing climate change?	Princeton Survey Research Associates International 2007; Pew 2009a, 2010b; Public Religion Research Institute 2011; Pew 2012a, 2013a
Scientific Consensus	2010	Is there consensus among scientists about the evidence for global warming?	Virginia Commonwealth University 2010
Scientific Consensus	2001; 2004; 2005; 2006; 2007; 2008; 2010; 2011; 2012; 2013; 2014; 2015	Do scientists agree that climate change is happening?	Knowledge Networks 2004, 2005; Princeton Survey Research Associates International 2007; Knowledge Networks 2010; Gallup 2001, 2006, 2008, 2010a, 2011, 2012, 2013, 2014, 2015
Scientific Consensus	2011; 2012	Do scientists agree climate change is an urgent problem and merits policy action?	Knowledge Networks 2011; Chicago Council on Global Affairs 2012
Scientific Consensus	2008	Do scientists agree with each other about how much of a threat climate change poses?	ABC News, Discovery Channel, Stanford University 2008
Evidence	2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014	Is there solid evidence the climate is changing?	Pew 2006b,a; Opinion Research Corporation, CNN 2007a; Pew 2007a, 2008a, 2009b, 2010b; Public Religion Research Institute 2011; Pew 2011a,b, 2012a; Public Religion Research Institute 2012; Pew 2013a,b, 2014a

Survey Questions A2 Continued from previous page

Category	Years	Question Description	Sources
Evidence	2003; 2006; 2007; 2008; 2009; 2016	Is there sufficient evidence to justify policy action?	Hart and McInturff Research Companies, NBC News, and the Wall Street Journal 2006; Hart and McInturff Research Companies, NBC News, and The Wall Street Journal 2007; Hart and McInturff Research Companies, NBC, and The Wall Street Journal 2009a,b; Cooperative Congressional Election Study 2016, 2006, 2007, 2009, 2010, 2011, 2012, 2013, 2014; MIT Energy Study 2007, 2008, 2003
Evidence	2012; 2011; 2010; 2009; 2013; 2008	Is there insufficient evidence for climate change?	National Surveys on Energy and Environment 2012a, 2011a, 2010a, 2009, 2013b, 2012b, 2011b, 2010b, 2008
Evidence	2012; 2011; 2010; 2009; 2013; 2008	Do scientists overstate the evidence for climate change?	National Surveys on Energy and Environment 2012a, 2011a, 2010a, 2009, 2013b, 2012b, 2011b, 2010b, 2008
Causes	2011; 2010; 2008	Is the earth's atmosphere too large for human activity to affect the climate?	National Surveys on Energy and Environment 2011b, 2010b, 2008
Causes	2012; 2016	Is climate change caused by human activities; or a combination of human and natural causes?	American National Election Studies 2012, 2016
Causes	2001; 2003; 2006; 2007; 2008; 2010; 2011; 2012; 2013; 2014; 2015	Is climate change due more to human activities or natural forces?	Gallup 2001, 2003, 2006, 2007a, 2008, 2010a, 2011, 2012, 2013, 2014, 2015
Causes	2000	Do you agree that every time we use coal or gas we contribute to the greenhouse effect?	General Social Survey 2000
Causes	2000; 2001; 2002; 2005; 2007	Is the burning of fossil fuels one of the causes of climate change?	Harris Interactive 2000, 2001, 2002; ABC News, The Washington Post 2005; CBS, The New York Times 2007
Causes	2013; 2012; 2011; 2010; 2009; 2015; 2014; 2016; 2008	Has the earth been getting warmer over the past 4 decades due to human causes?	National Surveys on Energy and Environment 2013a, 2012a, 2011a, 2010a, 2009, 2015a,b, 2014a,b, 2013b, 2012b, 2011b, 2010b, 2008, 2016
Causes	2005; 2006;2012	Is climate change caused by human activities? (asked of those who have heard about climate change)	Pew 2005a, 2006c; Public Religion Research Institute 2012
Causes	2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014	Is climate change happening and caused by human activities? (asked of those who believe climate is changing)	Pew 2006b,a; Opinion Research Corporation, CNN 2007a; Pew 2007a, 2008a, 2009b, 2010b, 2011a,b, 2012a, 2013a,b, 2014a
Causes	2007; 2008; 2009; 2010; 2011; 2013; 2014	Is climate change happening and caused by human activities? (option for climate change not happening; no subsetting question)	Opinion Research Corporation, CNN 2007b,c; Opinion Research Corporation and CNN 2008; Pew 2009a; Opinion Research Corporation and CNN 2009; Public Agenda Foundation 2009; Virginia Commonwealth University 2010; Opinion Research Corporation and CNN 2011, 2013, 2014
Causes	2011; 2012; 2013; 2014; 2015	Is climate change happening and caused by human activities? (option for climate change not happening; no subsetting question; option for both human and natural causes)	CBS and The New York Times 2011; CBS, 60 Minutes, and Vanity Fair 2012a,b; CBS 2013; CBS, 60 Minutes, and Vanity Fair 2013a,b; Social Science Research Solutions, CBS 2014; Social Science Research Solutions, CBS, and The New York Times 2014; CBS 2015
Causes	2012; 2011; 2010; 2009; 2008	Is global warming the result of natural causes?	National Surveys on Energy and Environment 2012a, 2011a, 2010a, 2009, 2011b, 2010b, 2008

Survey Questions A2 Continued from previous page

Category	Years	Question Description	Sources
Policy	2001; 2004; 2005; 2008; 2009; 2011; 2012; 2013; 2014; 2016	Should climate change be an important foreign policy priority?	Pew 2001b; Greenberg Quinlan Rosner Research 2004; Pew 2004, 2005b; Knowledge Networks, The Chicago Council on Global Affairs 2008; Pew 2008b, 2009c, 2011c; Chicago Council on Global Affairs 2012; Pew 2013c; Knowledge Networks, The Chicago Council on Global Affairs 2014; Pew 2015a
Policy	2006; 2007; 2012; 2015	How much more should the government do to address climate change?	ABC News, Stanford University, and Time Magazine 2006; ABC News, Stanford University, and The Washington Post 2007; Public Religion Research Institute 2012; ABC 2015
Policy	2001; 2006; 2007	Should the government take action on climate change right away?	CBS 2001; CBS, The New York Times 2006a, 2007
Policy	2007; 2010	Should the government take action on climate change right away? (asked of subset)	Pew 2007a, 2010b
Policy	2015; 2016	Should the government take action on climate change right away despite high costs?	Chicago Council on Global Affairs 2016, 2015
Policy	2015	Should climate change be a priority for Congress?	Pew 2015a
Impacts	2012	Is climate change a threat to US national security?	Chicago Council on Global Affairs 2012
Impacts	2006	Is climate change a threat to you personally?	ABC News, Stanford University, and Time Magazine 2006
Impacts	2000; 2006; 2010	Does climate change threaten the environment?	General Social Survey 2000; ABC News, Stanford University, and Time Magazine 2006; General Social Survey 2010
Impacts	2002; 2005; 2006; 2008; 2009; 2012; 2013; 2014; 2015; 2016	Is climate change a threat to the U.S.?	Harris Interactive, Chicago Council on Foreign Affairs 2002; Princeton Survey Research Associates, Kaiser Family Foundation 2002; Taylor Nelson Sofres 2005; Knowledge Networks 2006; Program on International Policy Attitudes, Search for Common Ground 2006; Taylor Nelson Sofres 2006; Knowledge Networks, The Chicago Council on Global Affairs 2008; Pew 2009c; Chicago Council on Global Affairs 2012; Pew 2012b, 2013d, 2014b, 2015b, 2016
Impacts	2015; 2014; 2016	Has global warming influenced the weather on earth?	National Surveys on Energy and Environment 2015b, 2014a, 2016
Impacts	2006	How serious is the threat of climate change to quality of life?	ABC News, Stanford University, and Time Magazine 2006; CBS, The New York Times 2006a
Impacts: seriousness	2000; 2007; 2009	How serious is climate change; and should it be a high priority for government leaders?	Harris Interactive 2000; CBS, The New York Times 2007; CBS and The New York Times 2009
Impacts: seriousness	2015	Is climate change a serious problem facing this country?	ABC 2015
Impacts: seriousness	2007	How serious will climate change and its consequences be?	Gallup 2007b
Impacts: seriousness	2001; 2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014; 2016	Is climate change a very; fairly; or somewhat serious problem; or not a problem?	Harris Interactive, Time Magazine, and CNN 2001; Pew 2006a, 2007a,b, 2008a, 2009a,b,d, 2010b; Virginia Commonwealth University 2010; Pew 2011b, 2012a, 2013b; ABC 2014; Los Angeles Times 2001; ABC News, Discovery Channel, Stanford University 2008; ABC and The Washington Post 2009; Chicago Council on Global Affairs 2016
Impacts: time	2006; 2007	Will climate change become a more serious problem in the future?	ABC News, Stanford University, and Time Magazine 2006; ABC News, Stanford University, and The Washington Post 2007
Impacts: time	2003	Will climate change become a more serious problem in the future? (asked of subset)	CBS 2003
Impacts: time	2006; 2007	Is climate change causing serious impacts now?	CBS, The New York Times 2006a; CBS 2007a

Survey Questions A2 Continued from previous page

Category	Years	Question Description	Sources
Impacts: time	2003; 2006	Is climate change causing serious impacts now? (asked of subset)	CBS 2003; CBS, The New York Times 2006b
Impacts: time	2006	Is climate change causing serious impacts now? (follow-up question; but asked of full set)	ABC News, Stanford University, and Time Magazine 2006
Impacts: time	2001; 2007; 2009; 2010; 2011; 2012; 2013; 2014; 2015	Is climate change causing serious impacts now or will it in the future?	CBS 2001; CBS, The New York Times 2007; CBS and The New York Times 2007; CBS 2007b, 2009; CBS and The New York Times 2010; CBS, 60 Minutes, and Vanity Fair 2010; CBS 2010; CBS, 60 Minutes, and Vanity Fair 2011; CBS, The New York Times, 60 Minutes, and Vanity Fair 2012; CBS 2013; CBS, 60 Minutes, and Vanity Fair 2013b; Social Science Research Solutions, CBS 2014; CBS 2015
Impacts: time	2005; 2007; 2008	Is climate change a threat to future generations?	ABC News, The Washington Post 2005; Princeton Survey Research Associates International 2007; ABC News, Discovery Channel, Stanford University 2008
Impacts: time	2010	How serious is the threat of climate change to future generations?	Gallup 2010b,c
Impacts: time	2001; 2002; 2005; 2006; 2008; 2009; 2010; 2012; 2013; 2014; 2015	Does climate change pose a threat to you in your lifetime?	ABC News, The Washington Post 2005; ABC News, Discovery Channel, Stanford University 2008; Opinion Research Corporation and CNN 2014; Gallup 2001, 2002, 2006, 2008, 2009, 2010a, 2012, 2013, 2014, 2015
Impacts time	2001; 2002; 2003; 2004; 2005; 2006; 2007; 2008; 2009; 2010; 2011; 2012; 2013; 2014; 2015	Are climate change impacts happening now or will they happen soon?	Gallup 2001, 2002, 2003, 2004, 2005, 2006, 2007a,b, 2008, 2009, 2010a, 2011, 2012, 2013, 2014, 2015

Supplementary Appendix B: Model of State-Level Climate Concern

Public Opinion Data. In this study, we focus on the effect of changes in temperature and extreme events on public opinion about climate change at the state level. To build the most comprehensive sample to date of survey data about climate change, we collected all publicly available survey questions about climate change asked between 1999 and 2016. The dataset includes approximately 348,500 survey respondents from 155 individual polls on climate change. We obtained many of these surveys from the Roper Center for Public Opinion Research (e.g., polls from ABC News/Washington Post, CBS News/New York Times, Pew, etc). We also obtained surveys from the Cooperative Congressional Election Study, the General Social Survey, the American National Election Study, the National Surveys on Energy and the Environment, and the Gallup Poll Social Series (GPSS).

A challenge is that the survey questions on climate change differ in their content, wording, and response categories. For example, one question series asks in a single question whether climate change is occurring and whether human activities are causing it. Another series includes an initial question about the existence of climate change, coupled with a follow-up question about its causes. Only the subset of individuals who answered that climate change is occurring answered the follow-up question. Overall, our dataset includes 71 discrete question series in the seven categories shown in Supplementary Table 1. Supplementary Table 2 includes a paraphrase of each question series and the sources from which we include responses for each series.

Statistical Model for Index of Climate Opinion. To summarize all of this survey data on climate change, we use a hierarchical group-level IRT model, which estimates latent public opinion in population subgroups such as states (Caughey and Warshaw, 2015). Our model allows us to combine multiple survey questions into an aggregate index of the public's climate

concern. In reducing our data to a single dimension, we follow prior studies that have used factor analysis (Zahran et al., 2006) or the Stimson algorithm (Carmichael and Brulle, 2017) to aggregate various measures into a single measure of public opinion about climate change. Averaging multiple survey questions on global warming substantially reduces measurement error in our estimates of the public's concern about climate change.

The model adopts the general framework of item-response theory (IRT), which is commonly used to measure individuals' views about political issues by pooling their responses to several survey questions about the issue of interest. In an IRT model, individuals' question responses are jointly determined by their score on some unobserved trait–in our case, their level of belief in and worry about climate change as an anthropogenic phenomenon–and by the characteristics of the particular question. The relationship between responses to question q and the unobserved trait θ_i is governed by the question's threshold K_q, which captures the base level of support for the question, and its dispersion σ_q, which represents question-specific measurement error. The item parameters K_q and σ_q are held constant over time in order to bridge the model longitudinally. We recoded our survey variables as binary variables such that affirmative responses indicate belief in or worry about anthropogenic climate change and its impacts.

Under this model, respondent i's probability of selecting the affirmative response to question q is

$$\pi_{iq} = \Phi\left(\frac{\theta_i - K_q}{\sigma_q}\right), \tag{1}$$

where the normal CDF Φ maps $(\theta_i - K_q)/\sigma_q$ to the (0,1) interval. The model assumes that, the stronger someone's level of belief in climate change (higher values of θ_i), the higher their probability of answering q affirmatively. The strength of the relationship is inversely proportional to σ_q, and the threshold for an affirmative response is governed by K_q. By estimating the relationship of each question to the latent trait in this way, the model overcomes the lack of a single, valid time-varying measure of belief in climate change.

Since most surveys include only one or a few questions about climate change, each re-

spondent usually only answers one question. This prevents us from using an IRT model to estimate individuals' belief. We can infer the distribution of θ_i though. We model θ_i in group g as distributed normally around the group mean $\bar{\theta}_g$, and marginalize over the distribution of θ_i. Assuming that θ_i is normally distributed within subpopulation groups and given the normal ogive IRT model, the probability that a randomly sampled member of group g answers item q affirmatively is

$$\pi_{gq} = \Phi\left(\frac{\bar{\theta}_g - K_q}{\sqrt{\sigma_\theta^2 + \sigma_q^2}}\right), \tag{2}$$

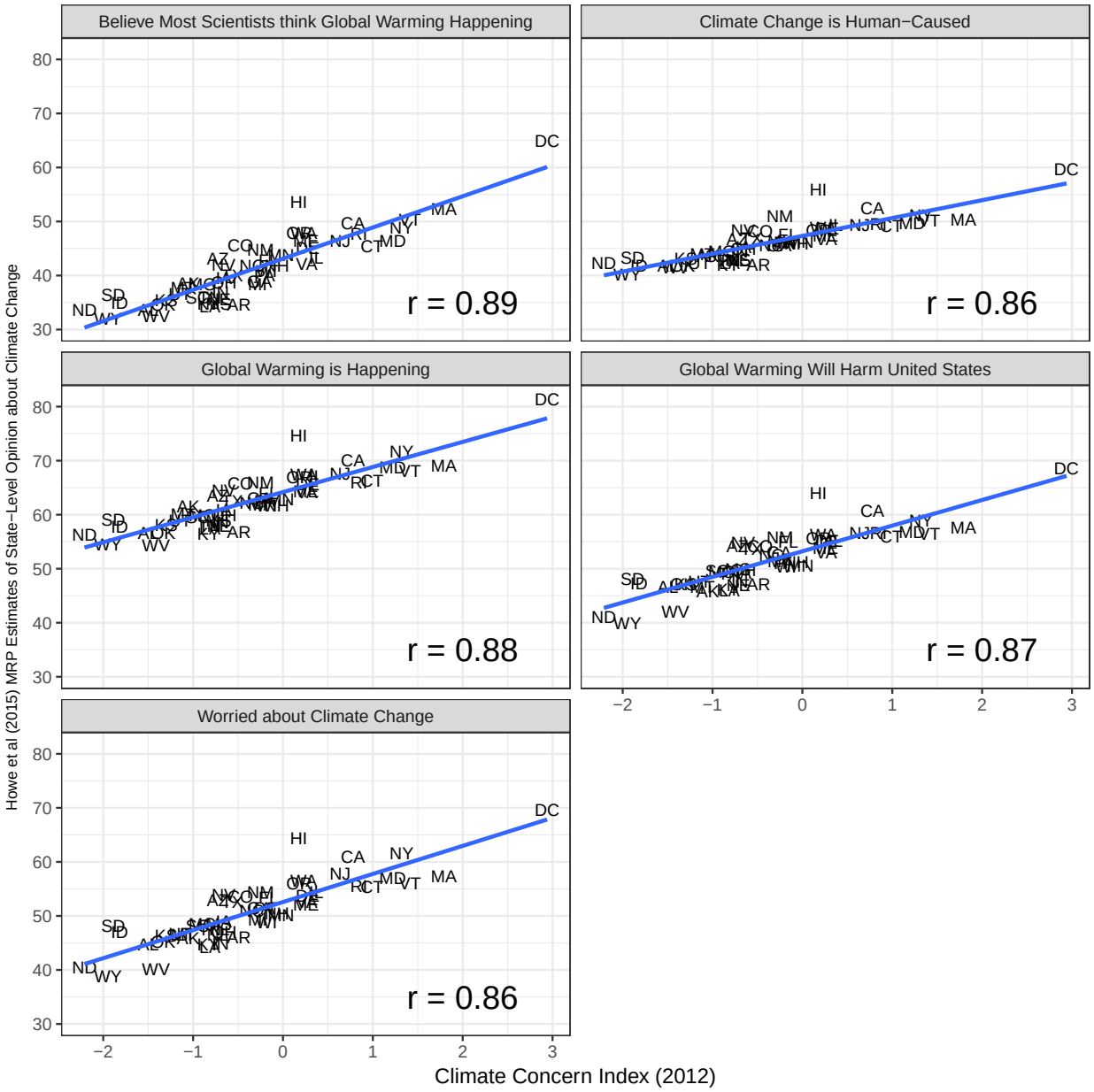
where $\bar{\theta}_g$ is the mean of θ_i in group g, and σ_θ is the within-group standard deviation of θ_i. In this way, rather than modeling the individual responses y_{iq}, we model $s_{gq} = \sum_i^{n_{gq}} y_{i[g]q}$, the total number of affirmative answers to item q out of the n_{gq} responses of subjects in group g. Also, we adjust the raw values of s_{gq} and n_{gq} to account for survey weights and for respondents who answer multiple questions (Caughey and Warshaw, 2015). To create state-level survey weights, we raked the survey data to match interpolated targets for gender and education level in each state public, based on microdata from the U.S. Census (Ruggles et al., 2010).

We use the dgo package in R to estimate group-level distributions and yearly group means of climate concern θ_{gq}, for whites and blacks in each state-year (Dunham, Caughey, and Warshaw., 2017). We use these estimates to build our weighted-average measure of state-level climate concern in each year (Park, Gelman, and Bajumi, 2004). For each state-year, we weight each group's mean climate concern by the proportion of the group in the state's population, based on data from the U.S. Census (Ruggles et al., 2010). Next we aggregate the weighted means to produce annual estimates of average latent climate concern in each state. These estimates are subject to uncertainty, which we are also able to estimate at the state level using the distribution of state estimates across simulation iterations. We standardize our index of climate concern to be mean 0 with standard deviation of 1 at the state level.

Supplementary Appendix C: Validation of State-Level Climate Concern

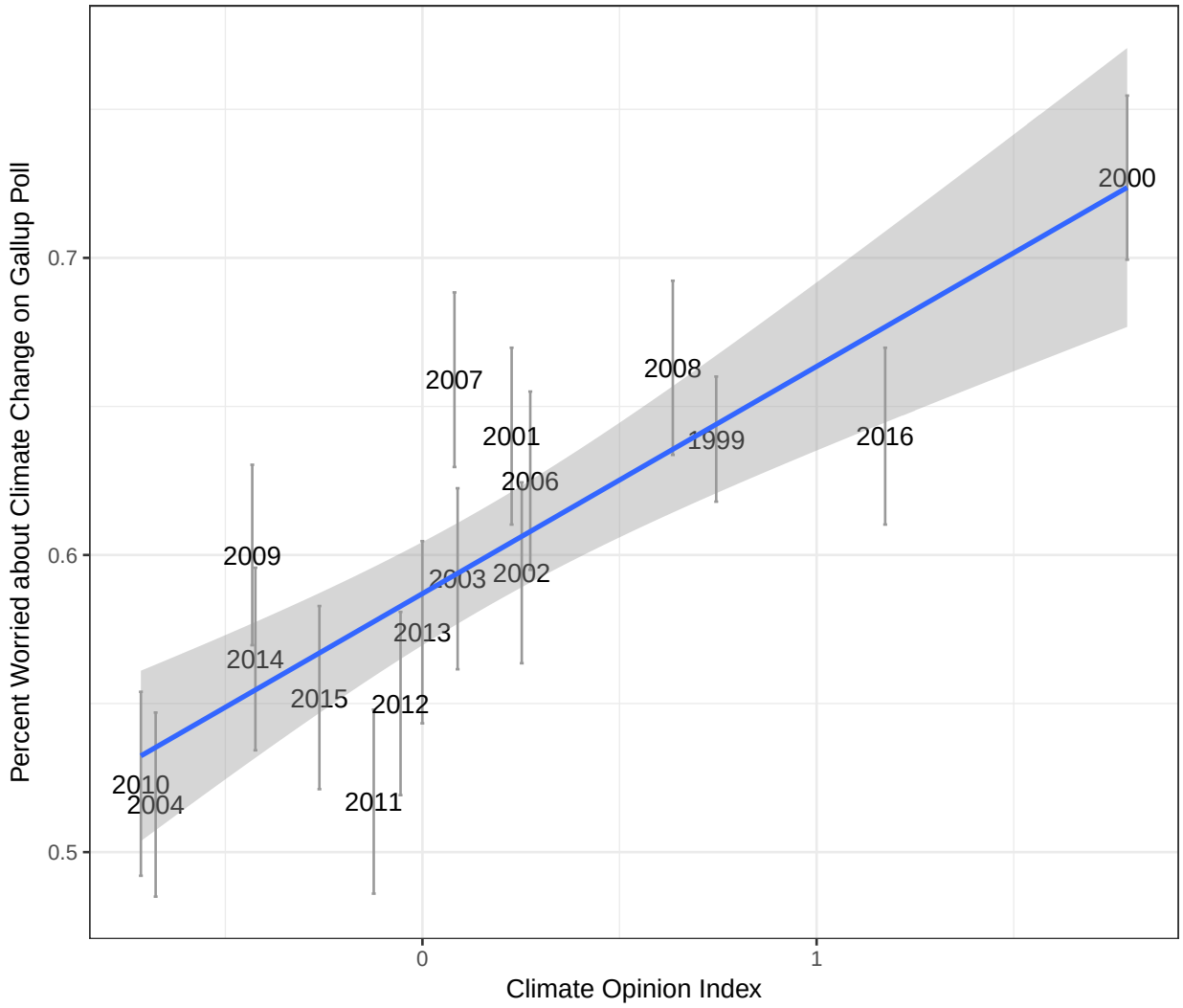
To formally validate the state-level index of climate opinion, we compare it to the best-available published measures of state-level public opinion about climate change (Howe et al., 2015). These estimates use a Bayesian multi-level regression and post-stratification (MRP) model, using proprietary survey data from the Yale Program on Climate Change Communication. Supplementary Figure 1 shows the relationship between our index and these cross-sectional estimates of public opinion on five individual survey questions about climate change. Overall, we find that our index in 2012 has a correlation of between 0.86 and 0.89 with the five different state-level measures of belief in and concern about climate change that they present. The high correlation with each of the individual climate questions modeled by Howe et al. (2015) suggests that latent climate concern is unidimensional. It is important to note that unlike the estimates from Howe et al. (2015), which are available for just one year, our index of state-level opinion about climate change is available in each year from 1999-2016.

Figure C1: Relationship between our climate concern index and the estimates of climate opinion in Howe et al (2015)



This figure shows that there is a very high correlation between our index of climate concern in 2012 and Howe et al's (2015) cross-sectional estimates of public opinion on five individual survey questions about climate change.

Figure C2: Relationship between our climate concern index and Gallup's annual polls on climate concern



This figure shows the relationship between our climate concern index and the percentage of people worried about climate change on Gallup's annual polls. The correlation between the annual measures is 0.84. The figure shows 95% confidence intervals to account for sampling error.

Supplementary Appendix D: Modeling the Effect of Temperature on Public Opinion

In order to examine the link between changes in state-level climate indicators and our index of public opinion about climate change in each state, we use six different indicators of climate change:

- the annual average of monthly high temperatures in each state (Vose et al., 2014)
- an indicator of the duration of storm events in each state, which previous scholars have used as a proxy for changes in extreme events due to climate change (Konisky, Hughes, and Kaylor, 2016). This measure is based on a count of severe weather episodes, as recorded in the National Centers for Environmental Information's (NCEI, housed within NOAA) Storm Events Database (National Centers for Environmental Information, 2015). The NCEI records occurrences of 48 types of severe weather events that are sufficiently intense to cause fatalities, injuries, serious property damage, or business disruptions; are unusual enough to attract media attention; or are otherwise meteorologically significant. To capture the severity of the episodes, we weight each episode by its duration in days. To account for natural variation between states in the likelihood of experiencing severe weather, we standardize each state's annual weighted count by the standard deviation of the state's annual counts across the time period covered by our analysis. We use the natural logarithm of this variable in our analysis.
- an indicator of short-term drought severity in each state (Palmer Drought Severity Index)(Vose et al., 2014)
- an indicator of long-term drought severity (The Palmer Drought Severity and Hydrological Drought Index). This index range from -6 to +6, with zero indicating normal conditions. We have coded the variables such that values between 4 and 6 indicate extreme dry conditions (Vose et al., 2014).

- a standardized precipitation index for each state. The Standardized Precipitation Index measures the probability of experiencing a given amount of precipitation in inches, transformed into an index. The measure ranges from -3 to +3, where 0 is the median. We have coded the variable such that +3 reflects a very extreme dry spell (Vose et al., 2014).

- the natural log of the number of acres in each state that experienced wildfires (National Interagency Fire Center, 2017).

The temperature, precipitation, and drought data were all obtained from the National Oceanic and Atmospheric Administration's Global Historical Climatology Network. The wildfire data is from the National Interagency Fire Center. We lag each measure of climate change by one year to ensure that public opinion is measured post-treatment.

We use three basic time series, cross-sectional (TSCS) modeling strategies to identify the causal effect of changes in state-level temperature on public opinion. We first use a model with both state and year fixed effects (Equation 3). This allows us to control for both state and national-level confounders in order to isolate the causal effects of state variation in climate change. Crucially, the state fixed effects account for time-invariant omitted variables in each state, such as the general ideology or culture. This is important since political party and ideology have been found to be important predictors of public belief in anthropogenic climate change (McCright and Dunlap, 2011; Borick and Rabe, 2010; Marquart-Pyatt et al., 2014; Shao et al., 2014; Deryugina, 2013). The year fixed effects account for unobserved factors that may influence climate concern across the nation, such as the debut of *An Inconvenient Truth* in 2006. We use the equation:

$$y_{st} = \beta_1 T_{st-1} + \alpha_s + \xi_t + \epsilon_{st}, \tag{3}$$

where s and t index the states and years in our dataset, respectively. y_{st} is latent state-level concern about anthropogenic climate change, T_{st-1} is an indicator of climate change in the

previous year, β_1 is the effect of temperature, α is a vector of state fixed effects, ξ is a vector of year fixed effects, and ϵ is an error term.

Next, in Equation 4 we add linear time trends within each state (Angrist and Pischke, 2014). This allows us to account for smooth changes in state characteristics over time (such as ideological or economic changes) that might influence public attitudes about climate change.

$$y_{st} = \beta_1 T_{st-1} + \alpha_s + \alpha_s * time + \xi_t + \epsilon_{st}, \tag{4}$$

Finally, in Equation 5, we use a specification with a lagged dependent variable (LDV) to capture other, time-varying omitted variables in each state and to determine whether the effect of temperature is persistent over time (Beck and Katz, 2011). The lagged dependent variable can be interpreted as a measure of the persistence of the effect of temperature on climate concern. This persistence can be estimated by dividing β_1 by 1-β_2 in Equation 5. Our results indicate that $\beta_2 = 0.35$ (Supplemental Table 4). This means that climate concern quickly adjusts to a value that is more strongly explained by last year's temperature than by the years preceding it. In other words, even if climate concern rises in response to a particularly warm year, concern is unlikely to remain high if a cool year follows.

$$y_{st} = \beta_1 T_{st-1} + \beta_2 y_{st-1} + \alpha_s + \xi_t + \epsilon_{st}, \tag{5}$$

Supplementary Appendix E: Association between National-Average Temperature and Public Opinion

Table E1: Association between National-Average Temperature and Public Opinion

	Dependent variable (standardized):
	Climate Concern
National Average Temperature (°C)	0.729**
	(0.267)
Constant	−13.378**
	(4.954)
Observations	18
R^2	0.317
Adjusted R^2	0.274
Note:	*p<0.1; **p<0.05; ***p<0.01

Supplementary Appendix F: Results by Time Period

To test the persistence of the effect over time, we split the time frame into 5-year increments and examine results for models 1 and 2 in each period. The results, reported in Table F1, indicate that the effect has persisted into the present, even in the face of growing polarization on climate change.

Table F1: Effect of State-Level Temperature on Public Opinion for Split Time Series

	Dependent variable (standardized):		
	Climate Concern		
	1999-2004	2005-2010	2011-2016
Average Monthly High Temperature$_{t-1}$ (°C)	−0.004	0.171***	0.119**
	(0.020)	(0.064)	(0.056)
State Fixed Effects	X	X	X
Year Fixed Effects	X	X	X
Observations	294	294	294
R^2	0.959	0.853	0.848
Adjusted R^2	0.950	0.820	0.814
Note:			*p<0.1; **p<0.05; ***p<0.01

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