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Change in US state-level public opinion about climate
change: 2008–2020Jennifer R Marlon^{1,*} , Xinran Wang¹, Parrish Bergquist², Peter D Howe³ , Anthony Leiserowitz¹,
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E-mail: jennifer.marlon@yale.edu**Keywords:** US, state-level public opinion, climate change, risk perceptions, climate policy, multilevel regression and poststratification**Abstract**

Public attitudes toward climate change influence climate and energy policies and guide individual mitigation and adaptation behaviors. Over the last decade, as scientific certainty about the causes and impacts of, and solutions to the climate crisis has increased, cities, states, and regions in the United States have pursued diverse policy strategies. Yet, our understanding of how Americans' climate views are changing remains largely limited to national trends. Here we use a large US survey dataset ($N = 27\,075$) to estimate dynamic, state-level changes in 16 climate change beliefs, risk perceptions, and policy preferences over 13 years (2008–2020). We find increases in global warming issue importance and perceived harm in every state. Policy support, however, increased in more liberal states like California and New York, but remained stable elsewhere. Year-by-year estimates of state-level climate opinions can be used to support sub-national mitigation and adaptation efforts that depend on public support and engagement.

1. Main

Americans' views about global warming have been studied extensively over the past several decades [1–9]. During this time, Americans' climate opinions have changed dramatically, with the views of Democrats strengthening considerably, and the views of Republicans showing a less consistent trend [9–11]. Studies have found increasing issue salience, especially in recent years, along with growing partisanship and political polarization [9, 12–14]. Spatial and temporal analyses of public opinions in the US have also found that direct and vicarious experience with global warming impacts are now influencing Americans' climate views [8, 15–19]. Yet, most of the extant US public opinion research to date has either been focused at the national level, or else has focused on spatial variations for a single point in time, potentially obscuring important state-level differences through time. Here we use a large national dataset on Americans' views of

global warming and innovative statistical models to assess state-level trends for 16 different climate opinions in the US.

Prior research has demonstrated that the heterogeneity of Americans' climate views has important consequences for climate and energy policy [20, 21]. Howe *et al* [22] modeled spatial heterogeneity in public views about global warming for a single year at county, congressional district, and state levels using multilevel regression and poststratification (MRP) with a large nationally-representative survey dataset. Estimates from that model showed that belief that global warming is happening varied more than 20 percentage points across states, and support for policies varied more than 30 percentage points across counties in 2014. Consistent time-varying estimates of state-level climate concern generated by Bergquist and Warshaw from 1999 to 2017 [8] also showed that increasing temperatures have some effect on public concern. This model, estimated by compiling polling

data from a variety of sources, did not provide state-level differences in support for individual climate policies or specific dimensions of climate change attitudes. Understanding public beliefs about specific harms or opinions about specific policies, however, is important even if people's views about an issue are internally consistent.

Understanding how the absolute levels of public support or opposition to a given policy, or the details about which harms are of greatest concern in a given community, is vital for public health and safety. Efforts to reduce vulnerability and build adaptive capacity among the public in response to increasing extreme weather requires different strategies tailored for heterogeneous climate impacts, including wildfires in the northwest, water shortages in the southwest, severe storms in the Midwest, inland flooding in the northeast, and coastal flooding and hurricanes in the southeast [23, 24]. Yet, building community resilience depends not only on detailed information about changing physical conditions but also on the psychological, cultural, economic, and other influences on public climate change awareness, risk perceptions, policy support and knowledge [1, 25–29]. The design and development of economic policy- and decision-making also depends on climate risk awareness and the diffusion of information [30]. In coastal areas facing high risk of sea level rise, for example, buyers and sellers are already discounting home values by about 7% [31], while local banks and mortgage lenders are managing additional portfolio risk by increased securitization of mortgages [32].

Consistent sub-national and temporal data on Americans' climate views also reveal dynamic social norms that may help correct misconceptions causing many to underestimate policy support and overestimate the extent of political polarization on climate change today [33–38]. Increasing climate policy actions in Europe, for example, have been bolstered by growth in awareness and concern for environmental issues over the past two decades [39]. Exposure to wildfires and flooding have driven increased support for climate mitigation policies in places like the United Kingdom and California [17, 40]. Likewise, the recent election of officials with a strong climate policy agenda in Australia may have been driven, in part, by the public's recent experiences with the severe health and economic impacts of wildfires, floods and drought.

Understanding differences in state-based climate opinions is particularly important because US states are instrumental in driving both voluntary and mandatory climate and energy policies, whether by setting standards and targets, creating incentives to promote energy efficiency and adopt new technologies, or influencing social, consumer, and political behavior [41–44]. The recent passage of the Inflation

Reduction Act of 2022 will support significant new state and local efforts that will require changes in the behavior of millions of individuals as new policies are implemented [45].

Here we develop and report results from an innovative statistical model of 16 state-level climate opinions, over 13 years in the U.S. Among other findings, we identify state-level patterns of accelerating salience of global warming in the public mind (supplementary table A-1). The model and its validation is fully described in the supplementary material. Using recent advances in MRP models, we add a temporal component that enables dynamic predictions using a multilevel regression model with post-stratification over time (MRT) [46]. MRP approaches have proven significantly more accurate than conventional methods of imputing or predicting responses in data-sparse areas under certain conditions [47–49]. MRT provides a further advantage over MRP because MRP only provides estimates where data are spatially sparse, whereas MRT also provides estimates where data are temporally sparse. Thus, if a question was skipped during a survey wave, for example, MRT enables computation of an estimate for that year by leveraging information from other years.

Using MRT with a large dataset ($N = 27075$) of Americans surveyed in 23 waves from 2008 to 2020, we produce state-level climate opinion estimates for all 50 US states and the District of Columbia for each year from 2008 to 2020 (supplementary table A-3). We compute state-level variations in five beliefs, five risk perceptions, five policy preferences, and one behavior for a total of 16 different items. The survey data come from the Climate Change in the American Mind (CCAM) research project, a joint initiative of the Yale Program on Climate Change Communication (YPCCC) and the George Mason University Center for Climate Change Communication (4C). CCAM seeks to measure and understand Americans' climate change beliefs, attitudes, and behavior, and the psychological, cultural, and political factors that influence them [9].

An interactive tool that allows a full exploration of the data will be available online (URL forthcoming), with aggregated state-level time series available for public use.

2. Methods

2.1. Survey data

Survey data from 23 nationally representative climate change opinion surveys of adults 18 years and older, conducted between 2008 and 2020, were merged into a single combined dataset ($N = 27075$) (table A-2). The samples were drawn from the IPSOS KnowledgePanel®, which recruits respondents to an online panel using a probability-proportional-to-size

method that matches the overall sample to U.S. Census Bureau parameters on key demographic variables (e.g. gender, age, race, education, income, region). All survey respondents were geolocated using respondent's ZIP+9 codes or through geocoded addresses jittered within a radius of 150 m (to preserve respondent anonymity) provided by the survey contractors; state was then inferred for each respondent. Three global warming beliefs, six risk perceptions, eight policy preferences, and one behavior (table A-1) served as the 16 dependent variables. Demographic variables included gender (Male, Female), race (collapsed into White; African American; Hispanic or Latino; Other), and education (collapsed into Less than high school diploma; High school graduate, GED, or alternative; Some college or associates degree; Bachelors degree or higher) were used as individual level predictors. Aggregate-level predictors are described below. All dependent variables were recoded as binary (0/1), with values of one reflecting agreement with an attitude, support for a policy, or engagement in a particular behavior (see supplementary material A-1).

Using the 2012 to 2016 American Community Survey (ACS) 5-year estimates, custom race by education by sex population crosstabs were prepared for all US states and all US counties and county-equivalents. ACS does not directly provide race by education by sex cross-tabulations because of non-mutually exclusive relationships between race and ethnicity membership. We were able to use the ACS data to construct count crosstabs for 'Hispanic or Latino', 'White, non-Hispanic or Latino', 'African-American', 'Other, non-Hispanic or Latino' racial categories. This approach generates some error since Americans who identify as 'African-American, Hispanic or Latino' will be double-counted in both the 'African-American' and the 'Hispanic or Latino' categories; in practice, however, this error is minimal since this group is extremely small. ACS estimates of demographic and housing characteristics (Series DP05), economic data (Series DP03), and household and family data (Series S1101), were also compiled for each state. State-level data representing 2008, 2012, and 2016 Presidential Democratic vote share and data on per capita CO₂ emissions at the state level from the Vulcan Project [50] were also used.

2.2. Model specification

In our multi-level regression model, we use individual-level demographics, state-level geographic characteristics and a time smoothing variable. Race, gender, educational attainment, and an interaction term of race by gender by education are treated as random effects. Individuals are also grouped geographically according to their state evaluate the random intercepts. State-level geographic characteristics

are used as fixed effects predictors to improve model fit.

State-level covariates include the percentage of individuals who drive alone in a given state, the percentage of same-sex households in a given state, the level of point source carbon dioxide emissions in a given state, and the Democratic Presidential vote share (2008, 2012 or 2016) in a given state. These covariates have shown to be predictive of climate beliefs and behaviors in other studies [22, 51]. We further allow the coefficients of these covariates to vary by year. We also include a time smoothing variable: *year* and *yearsquared* with coefficients varying by state to model intercept shifts in each state at a given year. For post-stratification, we use 5-year American Community Survey data cross-tabulated by education attainment, gender, and race/ethnicity across all states for the relevant year (table A-2). Our fitted model is then used to estimate the average opinion of each demographic-geographic individual type, for each year. For instance, the model estimates the average response of a White male with a Bachelor's degree or higher living in the Arizona in 2012.

2.3. Model validation

Public opinion scholars have elaborated and validated MRP generally [47, 52–55]. We conduct cross-validation and additional validation with three independent datasets, including (a) four-state phone-based surveys conducted by the YPCCC and SRBI in 2013 that used identical question wording [22]; (b) modeled estimates of an aggregated climate concern index for all 50 states for each year from 2008 to 2017 produced by Bergquist and Warshaw (2019); and (c) nine state-based surveys conducted by Climate Nexus using four questions with identical wording. Details about the validation datasets are provided in supplementary Information.

Cross-validation of our estimates with bootstrap confidence intervals (1000 iterations) produce a mean error range of ± 6.87 percentage points (supplementary figure 8). We also compare our results with previous estimates of a wide range of climate opinions among American adults produced by the YPCCC using the methods of [22] for 50 states, 435 congressional districts, and 3142 counties. The MRP estimates for five years (2014, 2016, 2018–2020) and 14 identical questions show positive correlations above 0.79 and a mean absolute difference (MAE) of 2.01 pp (supplementary figure 9). In general, the belief and risk perception items are more highly correlated than the policy items, but results overall are highly similar, typically within two or three percentage points for any given state-year-question combination.

The first independent validation was based on six representative telephone surveys (conducted by SRBI) for CA, CO, OH, and TX and two cities (San Francisco, Columbus). These surveys used

identical item wording and were administered concurrently with the 2013 nationally representative YPCCC/GMU CCAM survey. We compared both the MRT and MRP methods and both produced estimates for 2013 within three percentage points of the SRBI results for each state. However, the MRT results are 0.8 percentage points (pp) more accurate than the MRP results (figure 10). The MAE across eight identically-worded questions and four states is 2.59 pp for MRP and 1.79 pp for MRT.

Time-series validation was also performed against results from a climate concern index based on approximately 400 000 survey respondents from 170 different polls conducted between 1999 and 2017 by Bergquist and Warshaw (2019). The authors used a hierarchical group-level model based on item-response theory to estimate latent public opinion for a single integrated measure of public climate concern at the state level. All but three of our questions produce a correlation above 0.74 with the climate change concern index (figure 11). In general, beliefs and risk perceptions are more highly correlated than the policy preferences, but support for the statement that Congress should do more to reduce global warming produced the highest correlation coefficient (0.87) of the complete question set.

A final validation exercise was conducted using data from Climate Nexus based on a series of four large, nationally representative surveys of registered voters in 2018 and early 2019 ($N = 24\,000$ registered voters in total, supplementary table 3). Four questions employed identical wording in nine different states during 2019 and 2020. Again, the MRT model slightly outperformed the MRP model, producing a mean absolute error of 6.4 pp versus 7.3 pp averaged across all nine states and four questions (figure 12). The primary reason behind the larger discrepancy between our model and the Climate Nexus survey results is likely that Climate Nexus conducts its polls of registered voters, whereas our estimates are based on all American adults.

3. Dynamic state-level analysis

Americans' views on climate change have shifted substantially over the past decade. Using three-year averages to capture the roughly decade-long trend reveals that state-level beliefs about the reality, human causes, and importance of global warming have increased about five to ten percentage points over the 13-year period (table 1). State-level beliefs in the scientific consensus that global warming is happening increased nearly 16 pp from 2008 to 2020. More people in every state also say that global warming is important to them (+9 pp) and will harm future generations (+9 pp), people in the U.S. (+14 pp), and themselves personally (+11 pp). Support for policies

to address climate change, however, moved less than 5 pp from 2008 to 2020 (table 1). More people think Congress and local officials should do more about global warming (+4 pp and +5 pp, respectively), but there was little change in state-level views about funding research into renewable energy or regulating carbon dioxide as a pollutant. There was also virtually no change in state-level views of how often people talk about global warming with family and friends from 2008 to 2020.

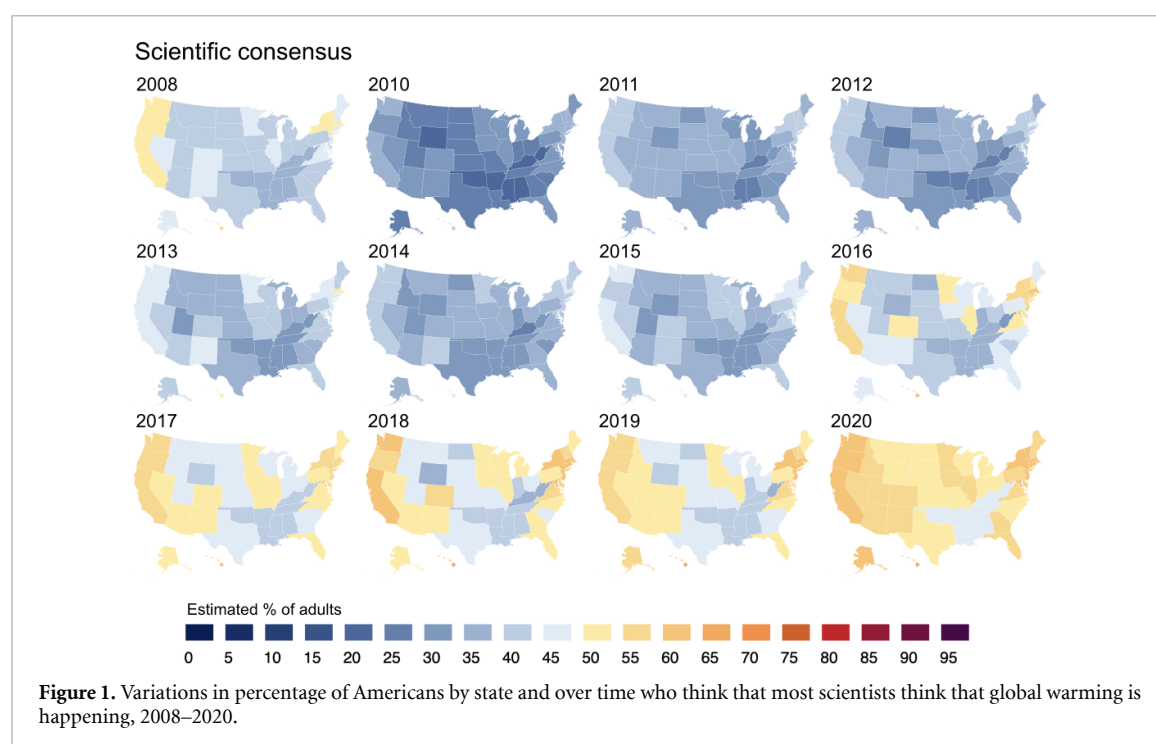
For many climate opinions, state-level views changed as much from 2015 to 2020 as they did from 2008 to 2020 (table 1). Personal experience with global warming, for example, increased by more than 10 pp from 2015 to 2020—about the same magnitude of change that occurred from 2008 to 2020 overall. Annual maps of opinion changes show how state-level shifts vary from year to year. In 2008, for example, majorities in liberal “blue states” like California and New York (figure A-1) thought most scientists agreed that global warming was happening, but fewer than half of these state's residents believed that between 2010 and 2015 (figure 1). Similar patterns are evident in personal experience with global warming (figure 2) and the opinion that global warming is already causing harm now (figure 3). Strong majorities in every state have supported funding more research into renewables from 2008 to 2020, but like many other opinions, 2013 and 2014 were low points for climate attitudes (figure 4).

After 2015, attitudes toward global warming changed rapidly in many cases (supplementary figure A-2). Issue importance, for example, increased in every state (figure 5), rising by 10 percentage points or more in six red states, nine purple states and all blue states except New Mexico. Even deeply conservative states like Mississippi, Montana, and Nebraska saw the importance of global warming increase by 9 pp.

Overall, beliefs and risk perceptions about global warming increased in every state except Wyoming and West Virginia (for the human-caused question) from 2008 to 2020, while policy preferences and reported discussions about climate change varied much less and less consistently (figure 6). For example, support for state governors doing more about climate change showed the smallest change over the full interval (+2 pp on average), with support for regulating CO₂ as a pollutant and for Congress and local officials doing more increasing slightly more (3 pp, 4 pp, and 5 pp on average, respectively). Support for funding research into renewable energy remained high and stable from 2008 to 2020. Considering the estimate uncertainties, maps showing color changes in the outermost two ranges (i.e. above 6 pp and below 7 pp) reflect changes in climate views over the 13-year period that are outside the range of uncertainty in the estimates from the validation tests

Table 1. Some climate opinions have changed much more than others. Average percentage point changes are shown for the full interval (2008–2020) based on three year averages from the beginning and ending periods to limit the effects of natural year-to-year variation, and for the five year period from 2015 to 2020. Changes in average opinion from 2015 to 2020 are also shown separately for Red States and Blue States (as defined by the 2020 election results, see supplementary figure A-1).

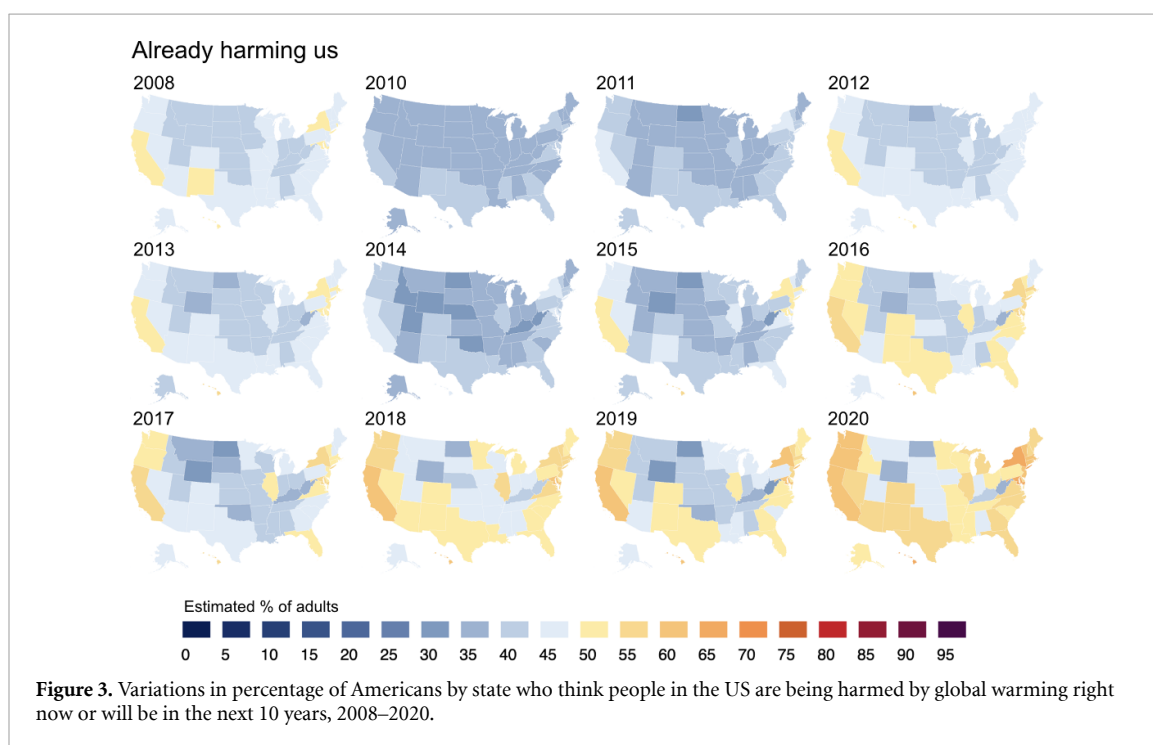
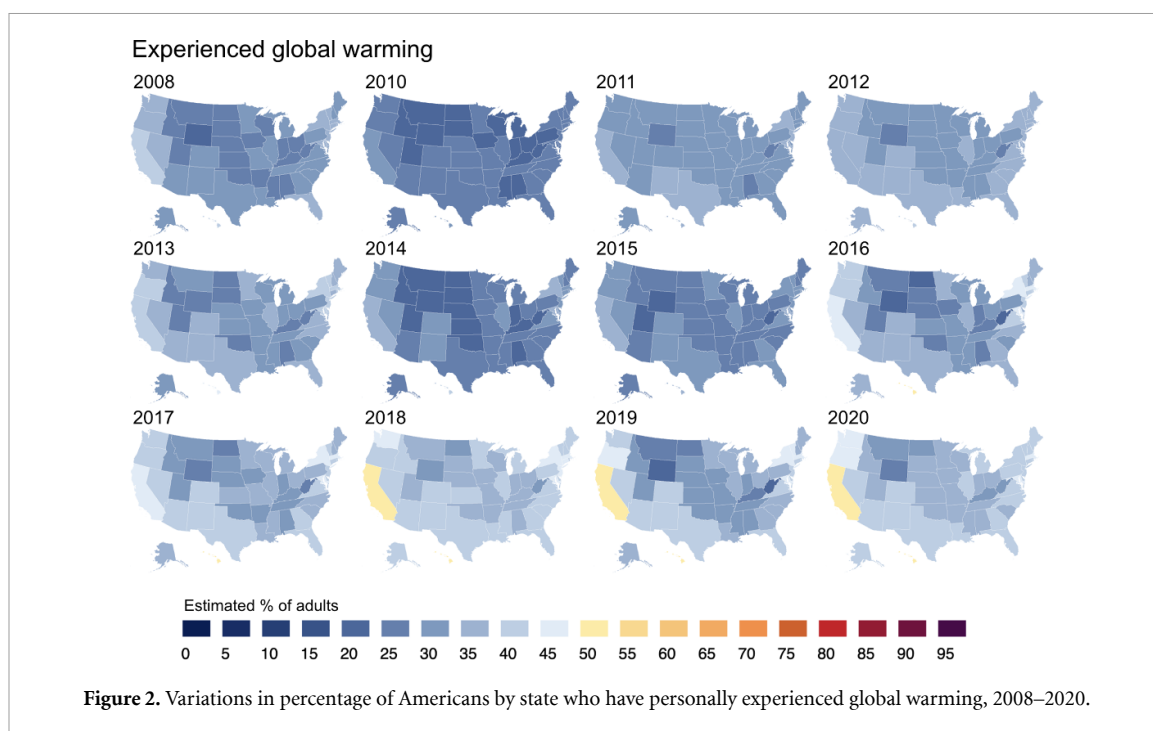
Question	Avg. % Pt. Change 2008–2020	Avg. % Pt. Change 2015–2020	Blue States 2015–2020	Red States 2015–2020
Beliefs				
Happening	6.25	6.16	6.15	6.17
Human-caused	5.38	3.87	5.30	2.37
Scientific consensus	15.67	15.83	15.67	15.99
Experience	9.50	10.66	11.52	9.76
Important	9.25	10.30	11.81	8.71
Risk perceptions				
Worried	7.92	8.02	9.07	6.92
Harm future gen.	9.30	3.82	4.19	3.44
Harm USA	14.27	7.91	8.33	7.47
Harm already	9.91	11.08	12.13	9.98
Harm personal	10.59	3.57	3.14	4.01
Policy Pref. & behavior				
Fund renewables	0.34	1.20	3.31	−1.0
Regulate CO ₂	2.73	−0.03	−0.57	−0.02
Congress	4.40	−1.73	−0.19	1.86
Governor	2.18	−3.01	−3.02	−2.99
Local officials	4.87	0.81	−0.92	−2.56
Discuss	0.59	2.16	3.94	0.30



discussed below. More muted color variations in the maps (e.g. for most of the policy preferences) reflect changes that are within the error ranges and thus may be suggestive of slight changes in a particular direction but are less robust.

Over the longer-term (2008–2020), more liberal (blue) states increased their belief that global

warming is happening, human-caused, and a serious risk more than conservative (red) states (figure 7). Blue states with large populations consistently show the highest levels of belief and concern (CA, NY, IL), but state-specific changes have also occurred. For example, support for more action from your governor was reduced in California in 2020 (figure 7).



Maryland shows the largest increases of any state in a variety of climate opinions, including belief that global warming is human-caused and will harm future generations (+12 pp in both cases) (table 2). From 2015 to 2020, the views of residents in conservative states like Utah and Idaho changed more than those in the largest blue states. For example, Utahans increased their belief in the scientific consensus about global warming by 22 pp from 2015 to 2020, and worry among Idahoans increased by 11 pp.

4. Shifting climate change concerns and discourse

The modeled estimates of year-by-year state level climate opinion changes do not in themselves provide information about the causes of Americans' changing climate-related beliefs, risk perceptions, policy support and behaviors. However, model results are consistent with many well-known changes in the political, economic, social and physical environment

Fund renewables research

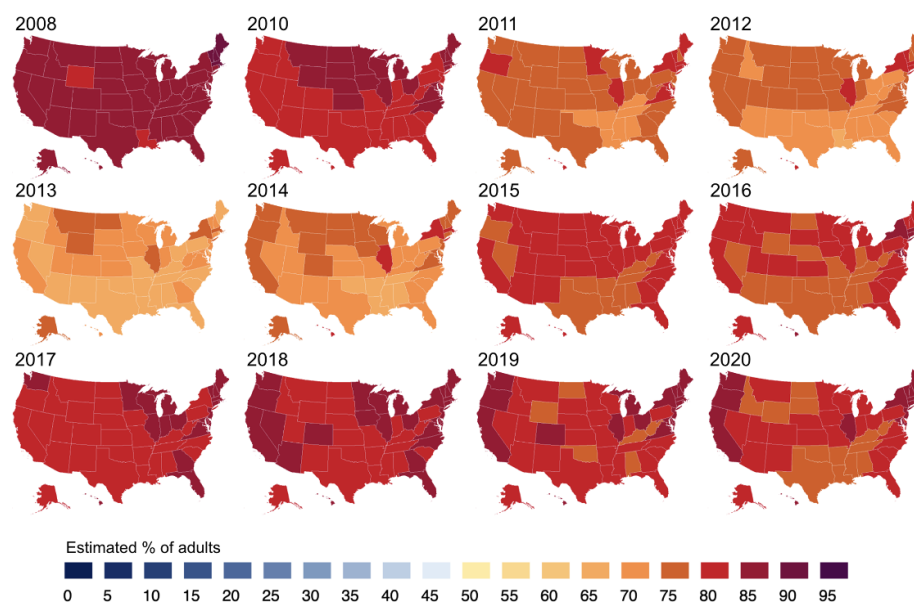


Figure 4. Variations in percentage of Americans by state who somewhat or strongly support funding more research into renewable energy, 2008–2020.

% of Americans who say that global warming is very or extremely important to them personally

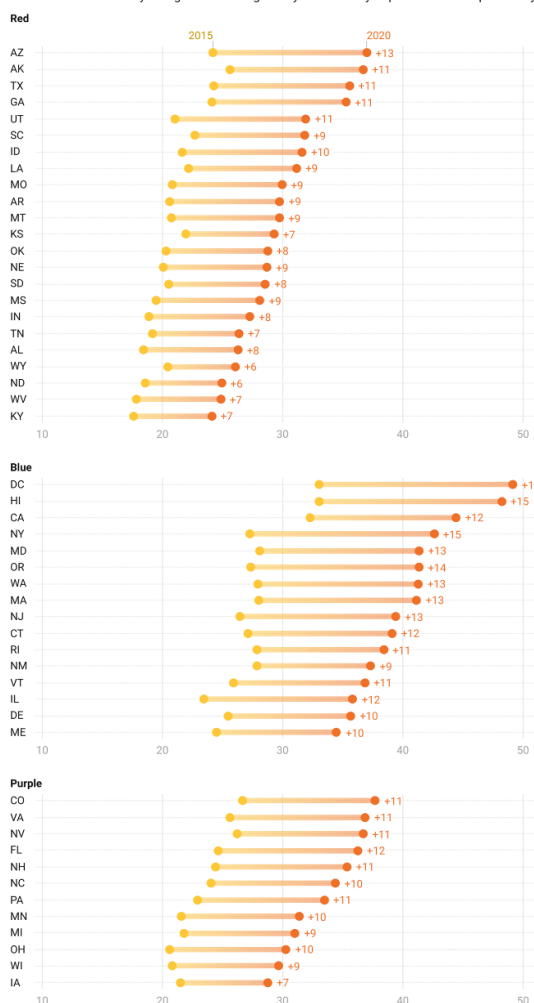


Figure 5. State-level changes in global warming issue importance from 2015 to 2020.

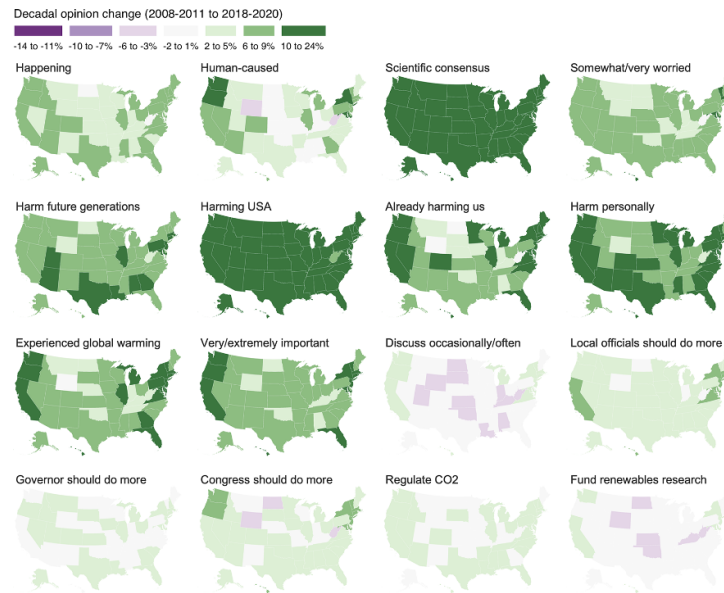


Figure 6. Changes in 16 climate opinions by state 2008–2011 to 2018–2020.

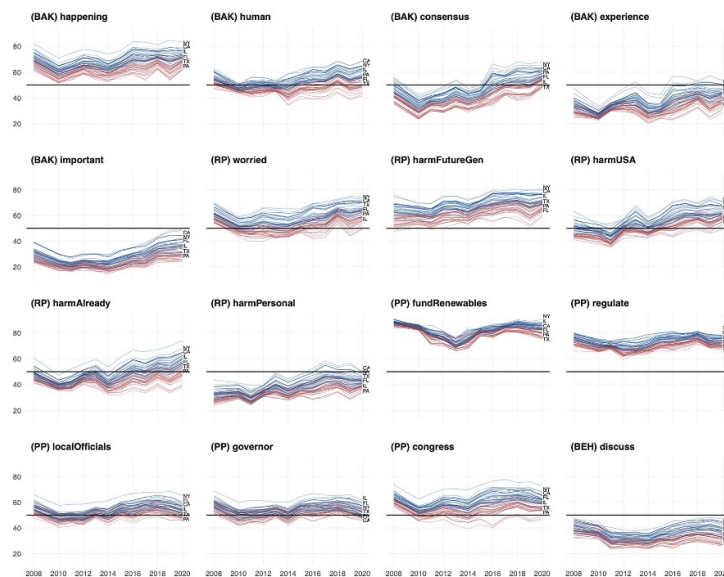


Figure 7. Trends in 16 climate opinions including five beliefs and knowledge items (BAK), five risk perceptions (RP), five policy preferences (PP), and one behavior (BEH) for all 50 states from 2008 to 2020. Colors indicate whether state voted for Trump (red) or Biden (blue) in 2020.

during the 13-year period, such as increasing political polarization in climate views [56]. The largest change in climate opinions nationally occurred between 2008 and 2010 during the Great Recession, when beliefs and policy support dropped dramatically, due largely to ‘political elite cues’ associated with the rise of the Tea Party and conservative reaction to the Waxman-Markey cap and trade climate bill [10]. In general, more liberal states show larger increases than

more conservative states, which reinforces evidence for the importance of ideology and partisanship in determining climate opinions [57]. The much more limited increases (or even declines) in climate views in states with economies closely tied to fossil fuels, such as Wyoming, the Dakotas, and West Virginia, point toward concerns about job security and economic activity that can influence individuals’ climate views [36].

Table 2. More liberal states show the greatest percentage point changes from 2008–2011 to 2018–2020 in beliefs and knowledge, risk perceptions, policy preferences, and behavior, with Maryland showing the greatest gains across all 16 questions.

Question	State	Largest PP Δ (2008–2020)	State	Largest PP Δ (2015–2020)
Beliefs				
Happening	MA	8.58	ID	8.88
Human-caused	MD	12.21	DC	9.19
Scientific consensus	NJ	20.15	UT	21.86
Experience	CA	15.86	CA	15.01
Important	DC	15.04	DC	16.13
Risk perceptions				
Worried	MD	12.31	ID	10.87
Harm future generations	MD	12.35	UT	7.94
Harm USA	MD	17.99	MD	10.43
Harm personal	HI	14.18	KS	6.52
Harm already	DC	17.17	OR	15.57
Policy Pref. & behavior				
Fund renewables	CA	3.46	DC	7.09
Regulate CO ₂	MI	4.65	OH	1.52
Congress	MD	9.12	UT	5.28
Governor	GA	5.65	MD	−0.85
Local officials	NY	8.28	MA	0.71
Discuss	DC	6.20	DC	8.77

The results also suggest the importance of sociocultural influences on changes in public discourse and Americans' ideas about global warming, particularly in relation to key beliefs about whether the problem is happening and human-caused, and whether scientists agree about these facts. Concerted efforts have been made to deepen and broaden climate communication by scientific experts, advocates, activists, politicians, and others. Efforts to convey the near-absolute scientific consensus about the reality and causes of global warming received widespread attention in the scientific community and beyond. In part these efforts were designed to counter the concerted mis- and dis-information campaigns supported by the fossil fuel industry to sow doubt and uncertainty in the public mind, to block or delay the transition from fossil fuels to clean, renewable energy [58]. Research demonstrating the message's effectiveness, however, was also likely helpful in securing investments for larger communication campaigns [36, 59, 60]. Efforts to spread the message were also catalyzed by many non-scientists [61, 62].

The influence of increased communication efforts is less evident on public support for climate policies and on the one behavior item that measures self-reported discussion frequency with family and friends, which increased only 3 pp on average across all states during the past five years. This finding is unsurprising given the complexity of climate change policy and the relative absence of major legislative

initiatives that have garnered much attention in the past decade (prior to Biden's Build Back Better agenda and the Inflation Reduction Act of 2022). States with recent and substantial climate and energy policy efforts, such as in California and in many northeastern states, however, have seen public support grow. Determining whether public opinion shifts preceded or followed these efforts, however, will require further research.

Changing climate and weather events themselves have also influenced people's climate opinions over time [19]. Many state-level climate opinion shifts are consistent with observed heterogeneous climate impacts relating to heat, drought, and flooding [16, 18, 63]. State-level changes in personal experience with global warming, for example, show distinct patterns that may reflect the multidimensional nature of individual's experiences, perceptions, and understanding about climate change [64]. California and Connecticut, for instance, showed the largest changes over the 13-year interval for the question about personal harm, with 22% more residents in both states saying they had been personally harmed by global warming. Risk perceptions have also accelerated in the years prior to 2020, with Florida, Virginia, and North Carolina in the south showing large increases in perceived personal harm from global warming (+13 pp for each), along with Arizona, Washington, Oregon, and California in the west (also 13 pp or larger increases), and Kansas and Michigan (+12 pp) in the Midwest during the past five years.

Many of these states experienced increases in coastal flooding and other exceptionally destructive weather events since 2008, such as extreme heat, drought, wildfires and hurricanes [65]. Such examples are consistent with the growing literature demonstrating that worsening climate impacts are contributing to the growing issue salience of climate change in the US.

The MRP and MRT approaches have several limitations. First, such models pool information from similar geographic-demographic subgroups to provide opinion estimates for geographic areas that may not have been sampled directly or that have limited sample sizes. Pooling information over time and across space reduces the variance of the estimates by pulling in estimates in places with sparse data towards the national mean. The reduced variance in the dependent variable increases the standard errors of ordinary least squares estimates, making it harder to detect an effect of things like extreme weather events. Changes in opinion estimates for a given state and year may still be useful, however, for generating hypotheses about the effects of particular events or the relationships between opinions and the factors that influence them. Another limitation of the data is that the estimates are predicted by demographics, state-level vote share data, and census data that are correlated with political attitudes in each state (e.g. the percentage of same-sex households in a state, which is an indicator of liberalism versus conservatism). Thus, scholars should not use these MRT estimates as a dependent variable if the predictors of interest are endogenous to covariates used to estimate the MRT model, such as state-level vote shares.

The results here prompt a series of important questions for future research. While cross-sectional survey data can provide some insight into *why* people are changing their attitudes toward global warming, such questions are ultimately better addressed with panel data or carefully-designed experiments [19, 66]. Likewise, understanding why people's views are changing more in some states than others will require further analysis of the many factors that may influence such geographic variation, such as partisan segregation [67]. Shifts in political leadership (e.g. which party has gubernatorial control), climate and energy policy, economic trends, media coverage, and changing environmental conditions may also influence state-level climate opinions, and these factors may interact with trends in partisanship, ideology, and demographics, among others. The opinion estimates provided here may facilitate investigation into some of these questions, but caution is required given that demographic and political data are key inputs into the model and mapped estimates.

5. Conclusion

The nature of Americans' changing climate views will continue to be a major determinant of the strength of US climate and energy response as both mitigation and adaptation plans are developed and implemented and at national and subnational levels. While the more severe heat waves, wildfires, and flooding in recent years has elevated public understanding of the harms that climate change can cause, understanding of the connections between fossil fuel burning and climate change impacts still remains poorly understood by many within the American public. Nonetheless, the increasing salience of climate change, especially in the past five years, is consistent with the new momentum that the issue is finally gaining that can support more aggressive climate and energy policy in many states, especially if that momentum is broadly known. The impacts of global warming are unevenly distributed and its solutions demand deep cooperation among diverse actors. State-level trends in Americans' climate opinions will support new and ongoing efforts to achieve coordinated and just multi-scale action at the national, state, and local levels and can provide a basis for additional finer-scale analyses [4, 68, 69].

6. Supplementary material

6.1. MRT model specification

MRP and MRT modeling involves two stages. First, the probabilities of holding a particular climate opinion (converted to a dichotomized measure) for distinct demographic-geographic-period groups are estimated from survey data and from local (aggregate) geographic, economic, political, and other relevant predictors. Geographic predictors are matched to the survey respondents by location and year (A-2). Second, fitted probability estimates for each demographic-geographic-period respondent type are weighted by their actual (census-based) population percentages for a given area. The modeling approach leverages information from similar demographic-geographic groups and time periods that have more data to produce estimates for places and time periods with less data.

In our multi-level regression model, we use individual-level demographics, state-level geographic characteristics and a time smoothing variable. Race, gender, educational attainment, and an interaction term of race by gender by education are treated as random effects. Individuals are also grouped geographically according to their state evaluate the random intercepts. State-level geographic characteristics are used as fixed effects predictors to improve model fit.

For each individual i , the model is specified as:

$$\begin{aligned} Pr(y_i = 1) = \text{logit}^{-1} & \left(\mu_0 + \alpha_{j[i]}^{\text{race}} + \alpha_{k[i]}^{\text{education}} \right. \\ & + \alpha_{l[i]}^{\text{gender}} + \alpha_{m[i]}^{\text{region}} + \alpha_{j[i],k[i],l[i]}^{\text{race.education.gender}} \\ & + \delta_{\text{year}[i]} \cdot \text{drive}_s + \delta_{\text{year}[i]} \cdot \text{samesex}_s \\ & + \delta_{\text{year}[i]} \cdot \text{carbon}_s + \delta_{\text{year}[i]} \cdot \text{pres}_s \\ & + \alpha_{s[i],y[i]}^{\text{state.year}} + \gamma_{1,\text{state}[i]} \cdot \text{year_std} \\ & \left. + \gamma_{2,\text{state}[i]} \cdot \text{year_sq_std} \right), \quad (1) \end{aligned}$$

where

$$\begin{aligned} \alpha_j^{\text{race}} & \sim N(0, \sigma_{\text{race}}^2), \text{ for } j = 1, \dots, 4 \\ \alpha_k^{\text{education}} & \sim N(0, \sigma_{\text{education}}^2), \text{ for } k = 1, \dots, 4 \\ \alpha_l^{\text{gender}} & \sim N(0, \sigma_{\text{gender}}^2), \text{ for } l = 1, 2 \\ \alpha_m^{\text{region}} & \sim N(0, \sigma_{\text{region}}^2), \text{ for } m = 1, \dots, 9 \\ \alpha_y^{\text{year}} & \sim N(0, \sigma_{\text{year}}^2), \text{ for } y = 1, \dots, 12 \\ \alpha_s^{\text{state}} & \sim N(0, \sigma_{\text{state}}^2), \text{ for } s = 1, \dots, 51, \\ \alpha_{j,k,l}^{\text{race.education.gender}} & \sim N(0, \sigma_{\text{race.education.gender}}^2), \\ & \text{ for } j = 1, \dots, 4; k = 1, \dots, 4; l = 1, 2, \end{aligned}$$

Each variable is indexed over individual i and over response categories j, k, l, m, y, s for race, education, gender, region, year, and state-level geography variable, respectively. ‘year_std’ is the year from 2008 to 2020 (standardized). ‘year_sq_std’ is the square of year running from 2008 to 2020 (standardized).

State-level covariates include the percentage of individuals who drive alone in a given state, the percentage of same-sex households in a given state, the level of point source carbon dioxide emissions in a given state, and the Democratic Presidential vote share (2008, 2012 or 2016) in a given state. These covariates have shown to be predictive of climate beliefs and behaviors in other studies [22, 51]. We further allow the coefficients of these covariates to vary by year. We also include a time smoothing variable: *year* and *yearsquared* with coefficients varying by state to model intercept shifts in each state at a given year.

For post-stratification, we use 5-year American Community Survey data cross-tabulated by education attainment, gender, and race/ethnicity across all states for the relevant year (table A-2). Our fitted model is then used to estimate the average opinion of each demographic-geographic individual type, for each year. For instance, the model estimates the average response of a White male with a Bachelor’s degree or higher living in the Arizona in 2012.

7. Model accuracy

Table 3. State, sample size and year of data collection from Climate Nexus.

State	Sample Size	Year
TX	715	2020
TX	1660	2019
AZ	1005	2019
IA	660	2020
IA	519	2019
NC	588	2020
WI	495	2020
WI	1112	2020
OR	543	2020
MI	820	2019
FL	1558	2019
MN	573	2020

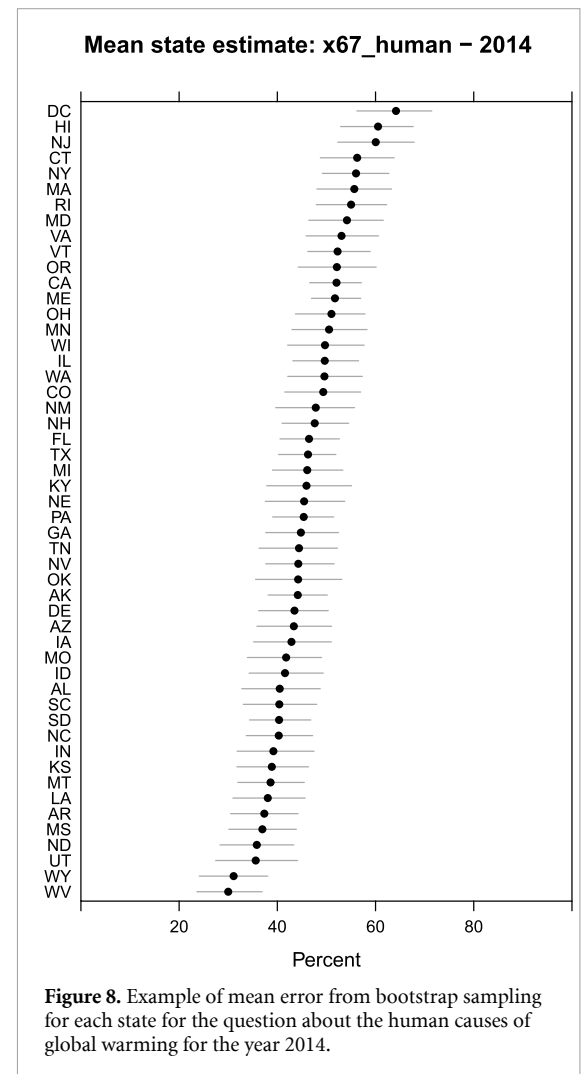


Figure 8. Example of mean error from bootstrap sampling for each state for the question about the human causes of global warming for the year 2014.

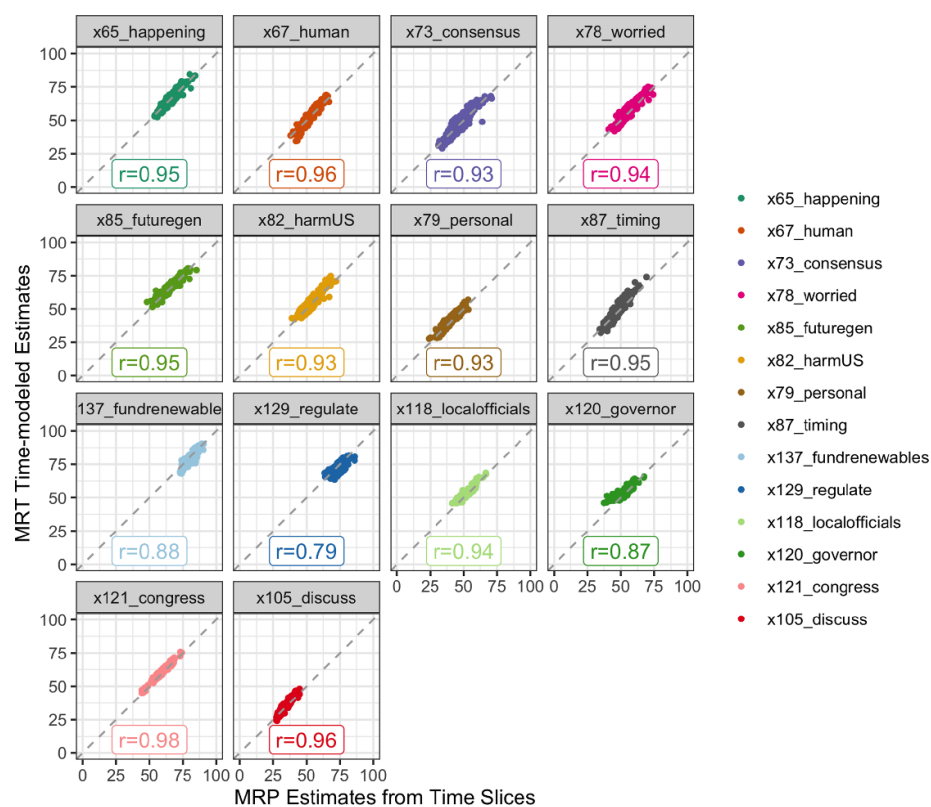


Figure 9. Comparisons between MRP and MRT estimates for the available five years and 14 questions showing that all correlations are over 0.79 and 11 of the 14 are over 0.92, thus yielding very similar results.

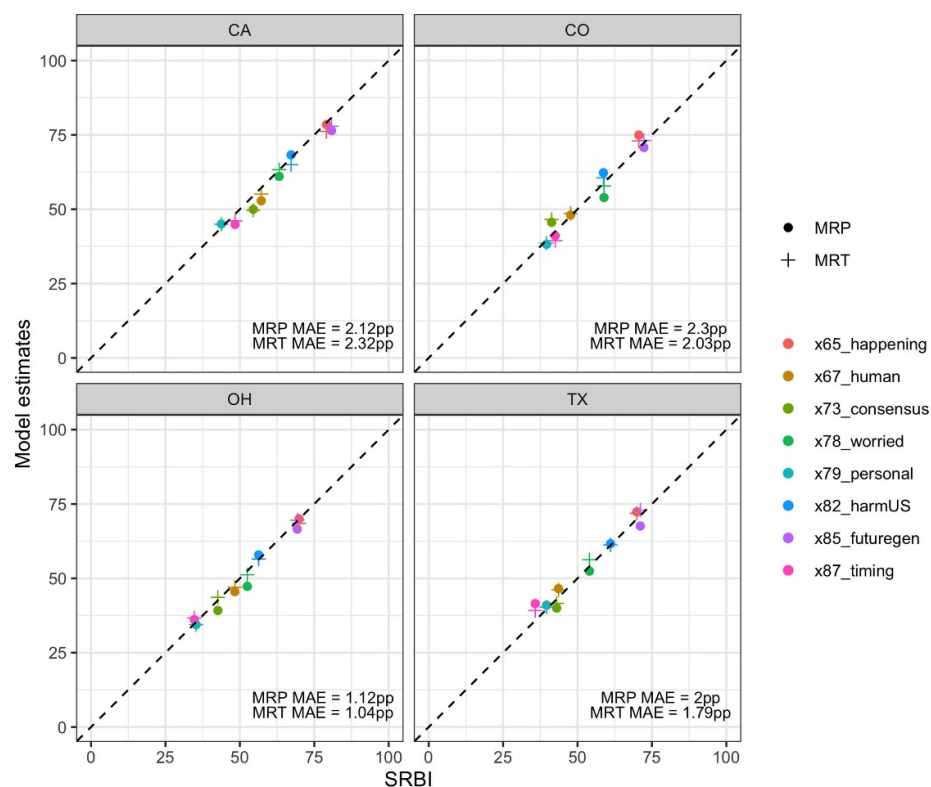


Figure 10. Validation comparison of MRP and MRT results with SRBI data from 2013.

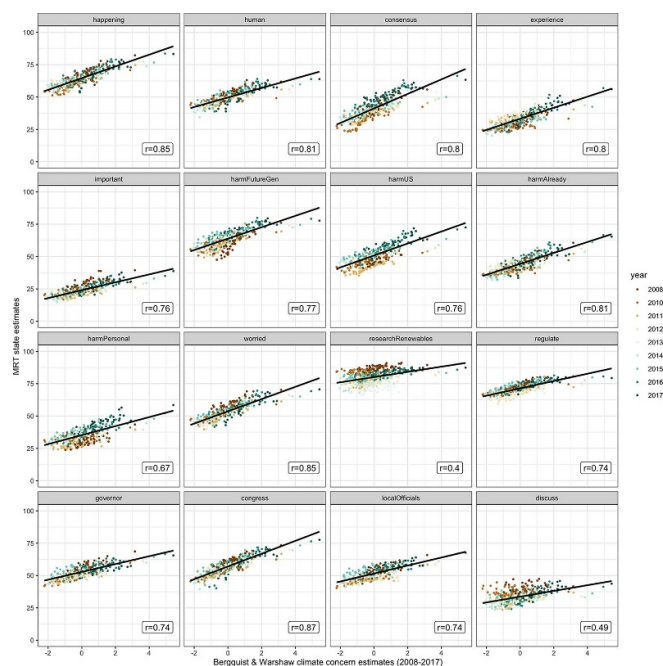


Figure 11. Comparison with estimates from Bergquist and Warsaw (2019) climate concern index showing strong positive correlations for climate beliefs and risk perceptions, and moderate correlations with climate policy support and behavior.

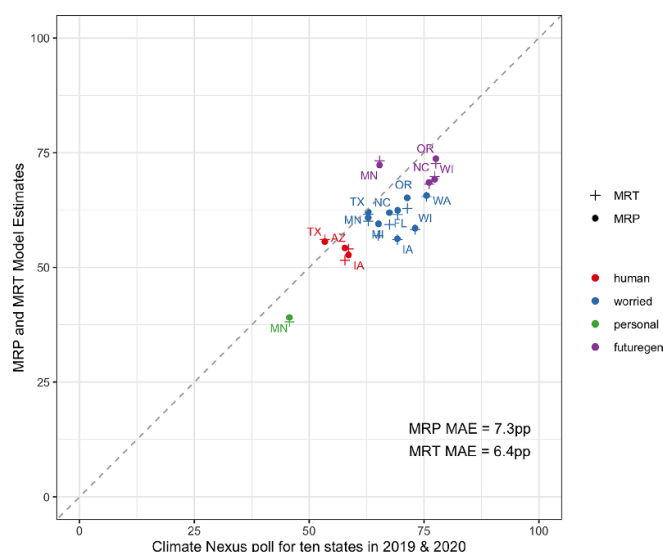


Figure 12. Validation comparison of MRP and MRT results with Climate Nexus data showing a mean absolute error of 6.4 pp for the MRT and 7.3 pp for MRP, indicating that the MRT results are slightly more accurate than the MRP results.

Data availability statement

The data that support the findings of this study will be openly available following an embargo at the following URL/DOI: <https://climatecommunication.yale.edu/visualizations-data/ycom-us/>. Data will be available from 01 February 2023.

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Author contributions: Jennifer Marlon, Parrish Bergquist, Matto Mildeberger, and Peter Howe developed the scope of work and design of the study.

Jennifer Marlon, Xinran Wang, and Parrish Bergquist performed data analyses. All authors wrote the manuscript.

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Electronic supplemental material: methods appendix

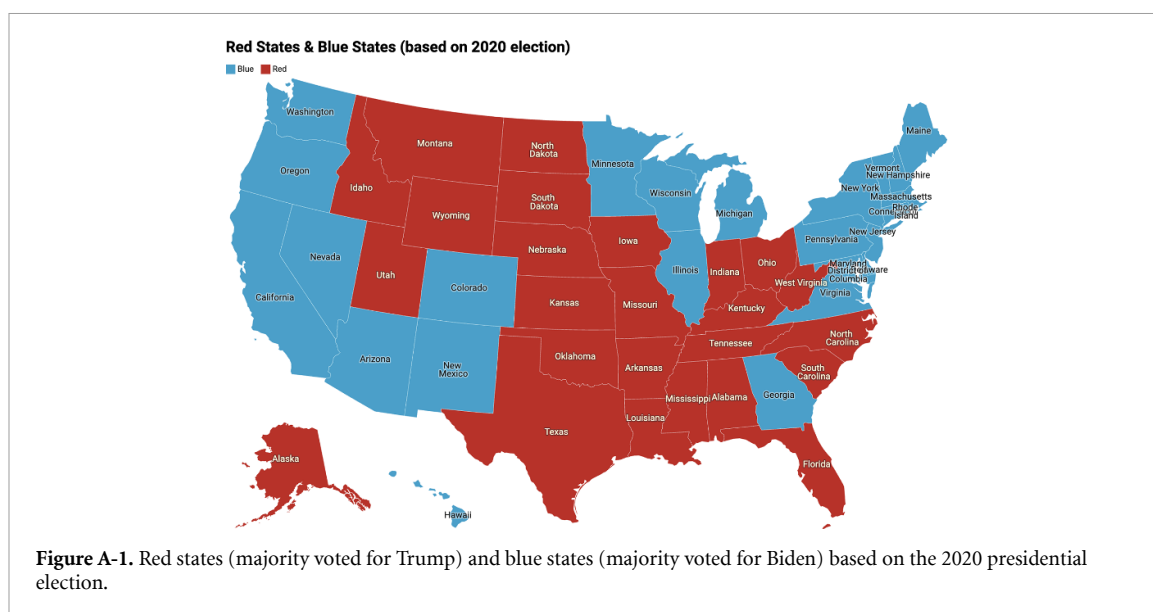
Modeled opinion estimates produced in this analysis are available at (URL forthcoming).

Table A-1. Question wording: questions are available for all waves from 2008 to 2020 unless otherwise noted. An asterisk (*) next to a response category denotes response options that were combined to serve as the positive model outcome value for that survey question.

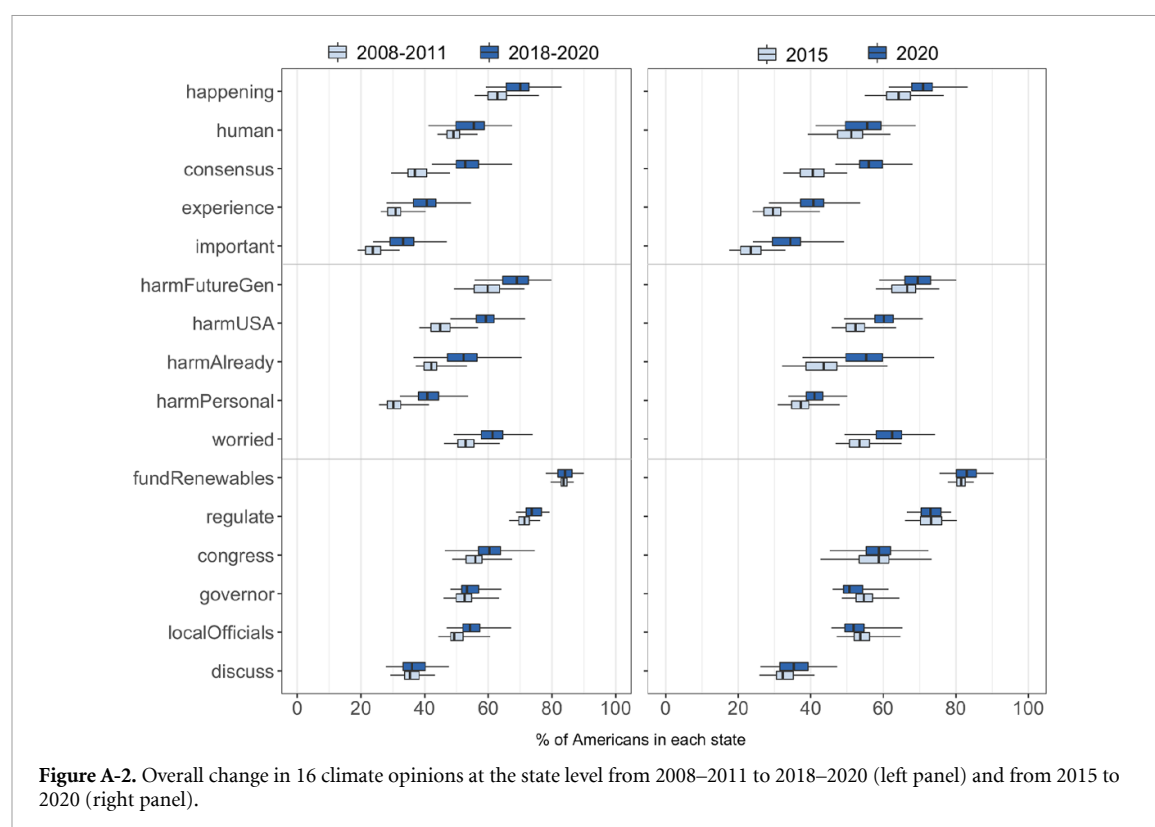
Label	Question wording
Happening	Recently, you may have noticed that global warming has been getting some attention in the news. Global warming refers to the idea that the world's average temperature has been increasing over the past 150 years, may be increasing more in the future, and that the world's climate may change as a result. What do you think: Do you think that global warming is happening? [Yes*; No; Don't know]
Human-caused	Assuming global warming is happening, do you think it is...? [Caused mostly by human activities*; Caused mostly by natural changes in the environment; None of the above because global warming is not happening; Other; Don't know]
Scientific consensus	(Missing Oct 2015) Which comes closest to your own view? [Most scientists think global warming is happening*; There is a lot of disagreement among scientists about whether or not global warming is happening; Most scientists think global warming is not happening; Don't know enough to say]
Experience	(Missing Oct 2015) I have personally experienced global warming. [Strongly disagree; Somewhat disagree; Somewhat agree*; Strongly agree*]
Important	How important is the issue of global warming to you personally? [Not at all; Not too important; Somewhat important; Very important*; Extremely important*]
Worried	How worried are you about global warming? [Not at all worried; Not very worried; Somewhat worried*; Very worried*]
Harm future generations	How much do you think global warming will harm future generations? [Not at all; Only a little; A moderate amount*; A great deal*; Don't know]
Harm USA	How much do you think global warming will harm people in the US? [Not at all; Only a little; A moderate amount*; A great deal*; Don't know]
Harm personally	How much do you think global warming will harm you personally? [Not at all; Only a little; A moderate amount*; A great deal*; Don't know]
Harm already	When do you think global warming will start to harm people in the United States? [Never; In 100 years; In 50 years; In 25 years; In 10 years*; They are being harmed right now*]
Fund renewables	How much do you support or oppose the following policies? Fund more research into renewable energy sources, such as solar and wind power [Strongly support*; Somewhat support*; Somewhat oppose; Strongly oppose]
Regulate CO ₂	(Missing May 2011) How much do you support or oppose the following policies? Regulate carbon dioxide (the primary greenhouse gas) as a pollutant [Strongly support*; Somewhat support*; Somewhat oppose; Strongly oppose]
Congress	Do you think the following should be doing more or less to address global warming? [Much more*; More*; Less; Much less; Currently doing the right amount]
Governor	Do you think the following should be doing more or less to address global warming? [Much more*; More*; Less; Much less; Currently doing the right amount]
Local officials	Do you think the following should be doing more or less to address global warming? [Much more*; More*; Less; Much less; Currently doing the right amount]
Discuss	How often do you discuss global warming with your family and friends? [Often*; Occasionally*; Rarely; Never]

Table A-2. Years of census data and election results that were used to match with survey respondents from each year in the study.

Survey	Census	Election
2008	2010	2008
2010	2010	2008
2011	2010	2008
2012	2010	2008
2013	2014	2012
2014	2014	2012
2015	2014	2012
2016	2014	2012
2017	2016	2016
2018	2016	2016
2019	2016	2016
2020	2016	2016

**Table A-3.** Survey date, mode, and sample size.

ID	Survey date (and mode)	Sample size
1	October 2008 (online)	2497
2	January 2010 (online)	1001
3	June 2010 (online)	1024
4	May 2011 (online)	1010
5	November 2011 (online)	1000
6	April 2012 (online)	1008
7	September 2012 (online)	1061
8	April 2013 (online)	1045
9	December 2013 (online)	830
10	May 2014 (online)	1384
11	October 2014 (online)	1275
12	March 2015 (online)	1263
13	October 2015 (online)	1330
14	March 2016 (online)	1204
15	November 2016 (online)	1226
16	June 2017 (phone)	1266
17	October 2017 (online)	1304
18	March 2018 (online)	1278
19	December 2018 (online)	1114
20	April 2019 (online)	1291
21	November 2019 (online)	1303
22	April 2020 (online)	1029
23	December 2020 (online)	1036



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