ARTICLES
PUBLISHED ONLINE: 6 APRIL 2015 | DOI: 10.1038/NCLIMATE2583

nature climate change

Geographic variation in opinions on climate change at state and local scales in the USA

Peter D. Howe[1]*, Matto Mildenberger[2], Jennifer R. Marlon[2] and Anthony Leiserowitz[2]

Addressing climate change in the United States requires enactment of national, state and local mitigation and adaptation policies. The success of these initiatives depends on public opinion, policy support and behaviours at appropriate scales. Public opinion, however, is typically measured with national surveys that obscure geographic variability across regions, states and localities. Here we present independently validated high-resolution opinion estimates using a multilevel regression and poststratification model. The model accurately predicts climate change beliefs, risk perceptions and policy preferences at the state, congressional district, metropolitan and county levels, using a concise set of demographic and geographic predictors. The analysis finds substantial variation in public opinion across the nation. Nationally, 63% of Americans believe global warming is happening, but county-level estimates range from 43 to 80%, leading to a diversity of political environments for climate policy. These estimates provide an important new source of information for policymakers, educators and scientists to more effectively address the challenges of climate change.

Decision makers need locally relevant information about the physical impacts of climate change to inform mitigation and adaptation efforts. In response, climate scientists have developed a variety of methods to downscale climate change projections from global models to finer regional and local scales. Mitigation and adaptation initiatives also depend heavily on social factors such as levels of public awareness, risk perceptions, policy support and knowledge of appropriate behavioural responses[1–6]. However, while these critical social data are often available at the national scale (for example, national surveys), they rarely exist at the sub-national levels required by scientists and policy makers. To comprehensively assess climate change risks and the prospects for mitigation and adaptation initiatives, it is necessary to have accurate local-scale data on public climate change beliefs, risk perceptions, policy preferences and behaviour. To address this need, this study uses national-scale data to 'downscale' estimates of public responses to climate change to sub-national scales, providing locally relevant information about public opinion for scientists and national, state and local decision makers.

Previous research has found that public climate change policy support and behaviour are greatly influenced by public beliefs, attitudes and risk perceptions[7–9]. In turn, these critical variables are influenced by other factors, including knowledge, emotion, ideology, demographics and personal experience[2,10–13]. Climate change mitigation and adaptation decisions are made at multiple spatial scales, including households, cities, counties and states[14–17], so understanding how beliefs, attitudes and risk perceptions shape public responses to climate change requires information on these factors at the appropriate level of decision-making. However, at present we know little about how public beliefs, attitudes and risk perceptions vary geographically or how they relate to policy outcomes at these critical sub-national scales.

Perceptions of climate change are likely to vary geographically as a function of demographics and of cultural and ideological factors, because people with similar demographic, cultural and ideological characteristics tend to cluster together[2,6,12,18]. In addition, climate change perceptions possibly exhibit geographic patterns due to differences in personal experience with extreme weather events and climate variability, since local weather is known to influence climate change perceptions[13,19–25]. Sociodemographic and ideological characteristics may also affect how personal experiences with climatic phenomena are translated into perceptions and beliefs[24,26,27].

National surveys in the US consistently find that a majority of Americans believe global warming is happening (63%), while fewer believe that it is human-caused (47%) or that most scientists think it is happening (42%; ref 28). However, national-level statistics obscure large variations in opinions between states. For example, Californians are more likely than Ohioans to believe that global warming is happening and that most scientists think global warming is happening[29]. While there have been several state and local surveys of public climate change opinion, there are at present no comprehensive assessments of the geographic variation in public climate change beliefs, attitudes and behaviours across the United States at the state, congressional district, county, and other sub-national scales. Conducting a comprehensive set of surveys in all 50 states and the District of Columbia, the 435 congressional districts, or the 3,143 counties across the United States would be prohibitively expensive, and pooling existing survey data from diverse sources is problematic due to often incompatible item wordings and different times of data collection.

Two primary methods have been used to address the problem of sparse public opinion data: national-level disaggregation[30,31] and Bayesian approaches such as multilevel regression and poststratification[32–34]. Disaggregation involves compiling a large set of nationally representative survey data, then pooling the responses of all respondents located in each unit of the geographic level of interest[30]—for instance, each state or congressional district. This approach, however, requires a large number of survey respondents to meet the minimal sample sizes necessary to obtain reliable estimates of public opinion. Disaggregating even very large data sets typically provides insufficient sample sizes to produce accurate estimates, especially in small population areas (for example, Wyoming). In addition, disaggregation often requires the

[1]Department of Environment and Society, Quinney College of Natural Resources, Utah State University, Logan, Utah 84322, USA. [2]School of Forestry and Environmental Studies, Yale University, New Haven, Connecticut 06511, USA. *e-mail: peter.howe@usu.edu

Table 1 | Top 10 and Bottom 10 US Metropolitan Areas, by proportion of the population who believe that global warming is happening.

Top 10 metro areas	Bottom 10 metro areas
Ann Arbor, MI	Casper, WY
Corvallis, OR	Dothan, AL
Ithaca, NY	Gadsden, AL
Kahului–Wailuku–Lahaina, HI	Jonesboro, AR
New York–Newark–Jersey City, NY–NJ–PA	Kingsport–Bristol–Bristol, TN–VA
San Francisco–Oakland–Hayward, CA	Lake Charles, LA
San Jose–Sunnyvale–Santa Clara, CA	Monroe, LA
Santa Cruz–Watsonville, CA	Owensboro, KY
Urban Honolulu, HI	Pine Bluff, AR
Washington–Arlington–Alexandria, DC–VA–MD–WV	Weirton–Steubenville, WV–OH

Metro areas listed alphabetically by category.

compilation of polling data over multiple years and therefore cannot account for changes in public opinion over time.

An alternative approach, multilevel regression and poststratification (MRP), also involves compiling data from multiple national surveys, but incorporates demographic, geographic and time variables to partially pool information about respondents across sub-groups. The first stage of MRP (multilevel regression) models individual outcome variables (for example, beliefs, attitudes, policy support, and so on) as a function of demographics, state- or region-specific geographic effects, and temporal effects to account for changes in public opinion over time. In the second stage (poststratification), modelled coefficients for each demographic–geographic respondent type are weighted by the proportion of each type within each geographic area. Unlike disaggregation, MRP methods can reliably project opinion in areas with sparse data coverage by partially pooling information from survey responses outside of that local geographic unit. Previous research has demonstrated that MRP methods can greatly improve the accuracy of public opinion estimates and reduce uncertainties compared to disaggregation methods at the state and congressional district level[35–38]. Questions remain, however, about its validity with small samples, higher-resolution geographies, and its applicability beyond the narrow range of political opinion variables to which it has previously been applied[39].

Here we present validated MRP model estimates of public climate change beliefs, risk perceptions, policy preferences and behaviour based on 12 nationally representative surveys conducted by the Yale Project on Climate Change Communication and George Mason Center for Climate Change Communication between 2008 and 2013 ($n=12,061$). The models use individual-level demographic predictors, state-, district- and county-level random effects, random effects based on the year of the survey and the survey mode, and geographic-level covariates. By incorporating random effects for the year of each survey we can account for changes in public opinion over time. Estimates presented here are averages for the year 2013. This paper provides estimates of public climate change beliefs, risk perceptions, policy preferences and behaviours at four geographic levels within the US: each of the 50 states and the District of Columbia, 381 Metropolitan Statistical Areas, 435 congressional districts, and 3,143 counties or county-equivalents.

The data set comprises surveys with dozens of identical questions measuring public responses to climate change, providing an unusually comprehensive source of detailed information on climate change beliefs, risk perceptions, policy preferences and behaviours. This data set contrasts with previous research using MRP, which has focused on only a narrow set of public opinion variables and relied on data sets that collapse differently worded questions from multiple independent surveys into a single latent construct.

The results are validated using two methods: internal cross-validation, and external validation against independently conducted surveys at the state and metropolitan levels. The external validations, using multiple independent surveys across diverse state and metropolitan areas with identical questions, improve on and extend previous MRP research. Both validation methods indicate that the MRP model provides accurate estimates of public responses to climate change at each sub-national scale investigated (typically within 0–5% points). Bootstrap margins of error based on 95% confidence intervals average ±5% points for the state-level models, ±7% points for congressional district-level models, and ±8% points for the county-level models.

We illustrate the approach by describing the distribution of public belief that global warming is happening, the belief that global warming is human-caused, beliefs about scientific agreement regarding global warming, public support for climate policy, and global warming risk perceptions. Model estimates of additional public climate change opinion variables for a range of geographies in 2014 are available at http://environment.yale.edu/poe/v2014

Sub-national opinion estimates

The results demonstrate that public responses to climate change vary substantially within the United States. Figure 1 illustrates model estimates at the state level for the four following beliefs and policies: global warming is happening; if global warming is happening it is caused mostly by human activities; most scientists think global warming is happening; and support for regulating carbon dioxide as a pollutant. The left-hand column of Fig. 1 provides the estimated absolute levels of belief in each state; maps in the right-hand column depict the differences between the estimated opinion in each state and the national average. The model estimates that a majority of adults in all states believe that global warming is happening, ranging from lows of 54% and 55% in West Virginia and Wyoming to highs of 75% and 81% in Hawaii and the District of Columbia respectively. Geographic patterns depend on the particular belief, risk perception, policy, or behaviour in question. For example, although majorities of the public in all states believe that global warming is happening (Fig. 1a) and that carbon dioxide should be regulated as a pollutant (Fig. 1d), many states do not have majorities who believe that global warming, if it is happening, is caused mostly by human activities (Fig. 1b) or that most scientists think that global warming is happening (Fig. 1c). The Supplementary Information includes the full estimates at each geographic level.

Public opinion about climate change also exhibits substantial variation within states at the level of congressional districts, metropolitan areas and counties. Figure 2 illustrates estimates at the congressional district level for the belief that global warming is happening, and support for renewable energy standards. Figure 3 provides estimates at the county level for belief that global warming is happening and perceptions of harm to the United States caused by global warming. County-level estimates of belief that global warming is happening range from a low of 43% in Trimble County, Kentucky to a high of 80% in New York County, New York (which is coterminous with the Borough of Manhattan). Of 3,143 counties or county-equivalents, 75 have rates of belief that global warming is happening of less than 50%. County-level results illustrate broadly similar geographic patterns to those at the state level, but also reveal sub-state hotspots with substantially different rates of belief from the state average. For example, an estimated 70% of California residents believe that global warming is happening, but rates of belief at the county level range from 61% in Plumas County to 79% in San Francisco County.

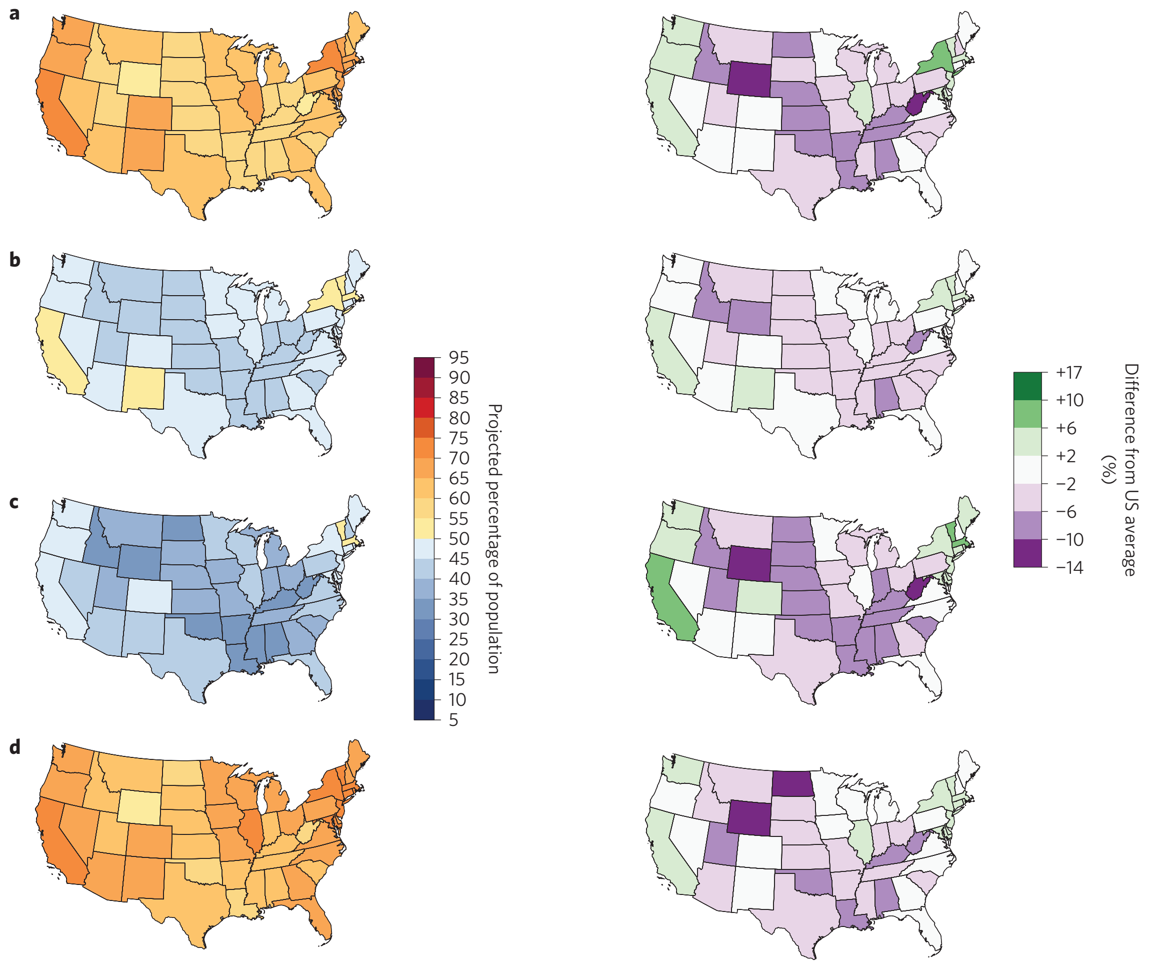

Figure 1 | Estimates of four different opinions about global warming at the state in 2013. a–d, The maps depict the percentage of American adults in each state who believe that global warming is happening (**a**); believe global warming is mostly human-caused (**b**); believe that most scientists think global warming is happening (**c**); somewhat or strongly support the regulation of CO_2 as a pollutant (**d**). Left-hand panels depict the projected population percentages, whereas right-hand panels depict the relative differences from the national average to facilitate comparisons between states.

The Supplementary Information provides additional estimates of belief that global warming is happening for census core-based statistical areas, including metropolitan statistical areas (MSA) and micropolitan statistical areas, which are aggregations of counties. Table 1 presents, alphabetically, the ten metropolitan areas with the highest and lowest percentage of their population who believe that global warming is happening.

Validation

The model estimates were verified using two different types of validation analysis: direct external validation using independent representative public opinion surveys and internal cross-validation.

For direct external validation, representative telephone-based surveys were conducted in four states (California, Texas, Ohio and Colorado, $n = 800$ per state) and two MSAs (Columbus and San Francisco, $n = 700$ per MSA). The validation surveys were conducted in 2013 using mobile and landline telephones, whereas the majority of survey data used in the model were collected via a nationally representative online panel.

The external validation indicates that the model estimates are highly accurate. Figure 4 depicts the independent validation survey results (x-axis) against the model estimates (y-axis) for four states and two metropolitan areas across 11 variables measuring diverse constructs (for example, climate change beliefs, risk perceptions, policy preferences and behaviour). The model estimates and survey results were strongly correlated within each geographic area. Across the 11 variables and accounting for mode differences, the mean absolute difference between model estimates and validation survey results was 2.9 (s.d. = 1.5) percentage points among the four states and 3.6 (s.d. = 2.9) percentage points among the two metropolitan areas, within the margins of error at 95% confidence for the survey results alone. The Supplementary Information also reports results from a comparison of the MRP model results with disaggregated results from a second independent survey data set, the Cooperative Congressional Election Survey (CCES; ref. 40), using a differently worded measure of public belief that global warming is happening. Disaggregated CCES climate opinion and the most similar question in our data set were correlated above the 0.8 level for all geographies.

Cross-validation was also used to compare the accuracy of the MRP model estimates to raw disaggregation based on subsets of the data set. Following previous work[36], a subsample of responses was randomly selected from a large-population state and used to replicate smaller state sample sizes within a simulated data set. For example, the number of respondents in Florida was randomly sampled and reduced to the equivalent number of respondents from variously sized states, such as a Wyoming-sized state ($n = 19$), an Alabama-sized state ($n = 166$), or an Ohio-sized state ($n = 507$). Model estimates from each simulated sample were then compared to a baseline of disaggregated values for the state from the full data set. As found in previous research, the MRP model consistently outperformed the disaggregation method, especially

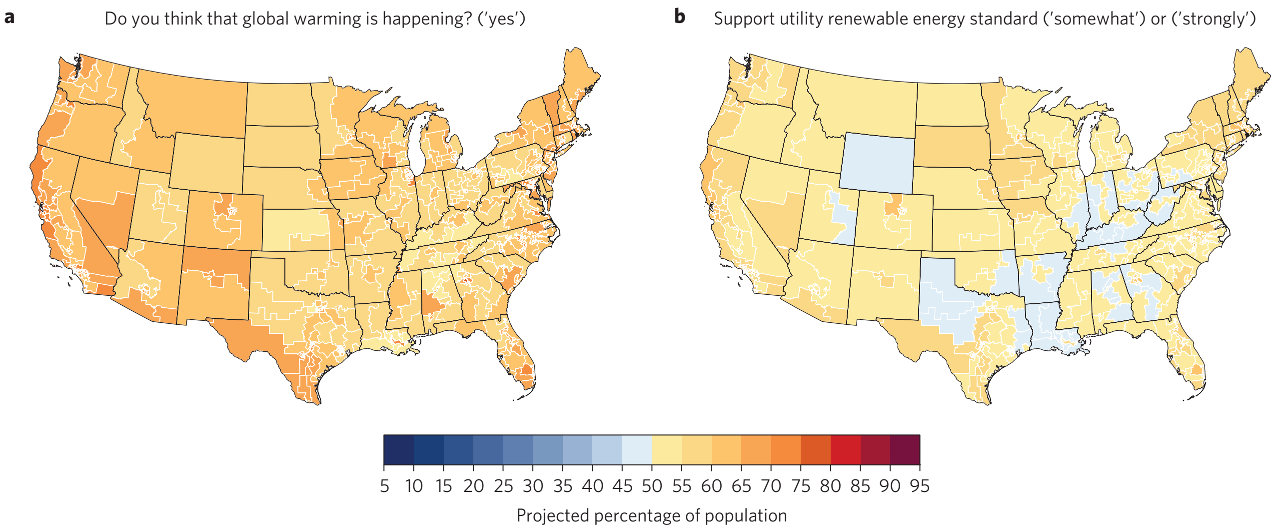

Figure 2 | Estimates of two different opinions about global warming at the 113th congressional district level in 2013. a, Belief that global warming is happening. **b**, Support for a policy to require electric utilities to produce at least 20% of their electricity from wind, solar, or other renewable energy sources, even if it costs the average household an extra $100 a year.

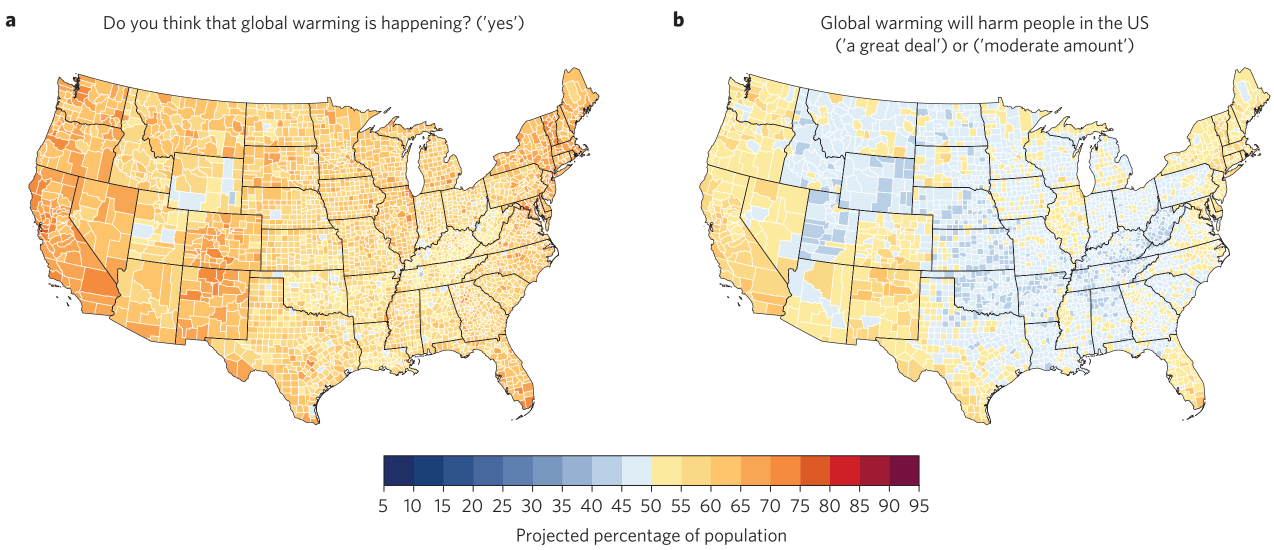

Figure 3 | Estimates of two different opinions about global warming at the county level in 2013. a, Belief that global warming is happening. **b**, Belief that global warming will harm people in the United States 'a great deal' or 'a moderate amount.'

for low-population areas[35–38]. Figure 5 illustrates the mean absolute error between simulated sample estimates based on the full sample across six simulated sample sizes at the state level, MSA level and county level for both the MRP results and a raw disaggregation. Additional cross validation analyses indicate that the MRP model significantly outperforms disaggregation across each geographic level, even in low-population counties (Supplementary Figs 6 and 7).

Geographic patterns of climate opinion

Modelling public climate change beliefs, risk perceptions, policy preferences and behaviours using MRP methods on a large survey data set (for example, more than 10,000 respondents) produces highly accurate results, as verified by both independent validation data (Fig. 4) and cross-validation techniques (Fig. 5). Such high levels of accuracy may seem unexpected given the inherent difficulty in predicting individual-level beliefs, but they are analogous to model projections of long-term climate versus short-term weather. Although climate models cannot accurately project weather conditions in a specific place on a single day, they are able to accurately project long-term average weather conditions. Similarly, it is possible to accurately estimate average opinion among sub-groups of the population even while estimates for a particular individual would be less accurate. The MRP models presented here are not designed to be individual-level predictive models, because the independent variables are limited to those that can be obtained for the entire US at each geographic level of analysis. However, these models take advantage of the hierarchical geographic structure of national survey data sets, combined with geographic covariates, to produce valid estimates for aggregated populations at sub-national scales.

The results demonstrate that, as with previous MRP studies of controversial policy issues, public opinion about global warming exhibits substantial variation between and within regions, states and cities. Geographic patterns in beliefs are often consistent with what one might expect from political patterns, with traditionally 'blue states' such as California and New York, for example, showing relatively high concern about climate change, and 'red states' such as Wyoming and Oklahoma showing lower concern. However,

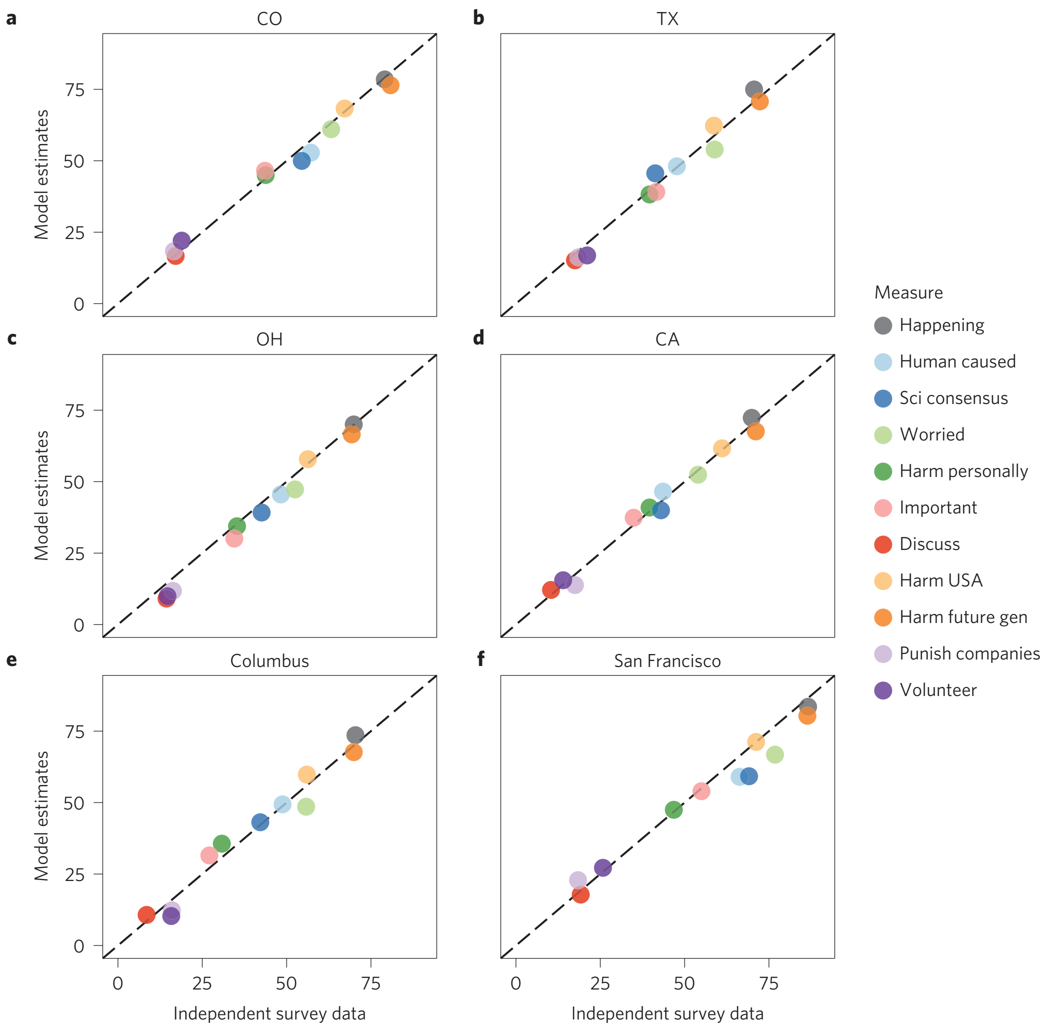

Figure 4 | Comparison of MRP estimates with public opinion results from independent, representative surveys across 11 survey questions. a, Colorado. **b**, Texas. **c**, Ohio. **d**, California. **e**, Columbus, Ohio. **f**, San Francisco, California.

summarizing perceptions at the state level obscures variability at finer scales. In Teton County, Wyoming, for example, we estimate that 64% of adults believe that global warming is happening, similar to the national average, despite an estimate for the state as a whole of 55%. Likewise, projected belief in global warming is relatively low (55%) in Lewis County, Washington, a blue state, whereas the level of belief in the state as a whole is higher (67%).

Additional patterns showing geographic variation in public opinion are visible in the congressional district- and county-level maps. Southwestern Texas, for example, shows belief in global warming in the 60–70% range, about 10% points higher than other areas of the state, possibly due to the greater proportion of Hispanic/Latino adults there who tend a greater tendency to believe that global warming is happening than whites, on average[41]. Similar geographic variations in racial and ethnic composition at the county level also translate to elevated levels of belief that global warming is happening in the majority-Black counties of central Alabama that stand in contrast to the rest of the state. The interplay of demographic and geographic influences on climate change opinions are also reflected in variations between urban and rural areas of the country. Most counties that include the nation's largest cities, such as New York, Chicago and Los Angeles, show relatively high levels of belief that global warming is happening, whereas proportions in most rural counties are significantly lower. In rural areas, we also find lower levels of belief that global warming is happening in some Midwestern and Western counties with large greenhouse-gas-producing industries, such as coal-fired power plants. The presence of colleges and universities also appears to be a factor associated with high levels of belief that there is a scientific consensus that global warming is happening.

Cross-validation results indicate that the model estimates in low-population areas are likely to be somewhat less accurate than the estimates for areas that have a larger number of respondents in nationally representative survey data sets, although they still far exceed the accuracy of estimates from disaggregation. This uncertainty is more pronounced in county-level models. Although 1,281 of 3,143 counties (40.7%) lack respondents in the national survey data because of their low populations, these counties represent only 6.5% of the total US population. In these cases, estimates are driven by demographic and geographic covariates rather than any endogenous random effects that might be detected if respondents from the area were included in the baseline survey data set, and are thus likely to exhibit less variance than their true values. Additional survey data from low-density areas would probably improve estimates in these areas, and future research should be directed towards validating and refining MRP estimates in low-population areas. Future research should also investigate how time interacts with different geographic subunits, which may improve the model estimates. However, our validation results indicate that the estimates are highly accurate measures of contemporary public

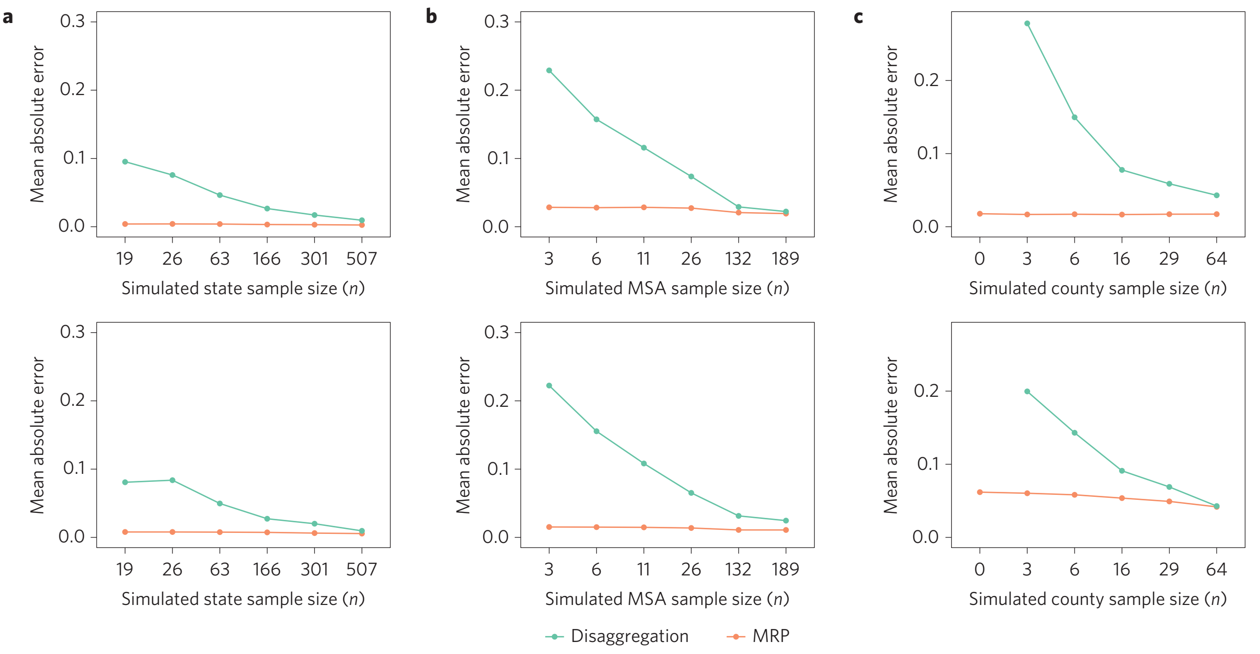

Figure 5 | Cross-validation comparison across six simulated sample sizes ($n = 99$ simulations) of mean absolute error between MRP results and disaggregation against the full sample. a, State level. **b**, MSA level. **c**, County level. The analysis is for two variables: support for regulating CO_2 as a pollutant (top) and belief that global warming is happening (bottom). Comparisons based on Florida ($n = 750$) (**a**), New York–New Jersey–Jersey City, NY–NJ–PA MSA ($n = 654$) (**b**) and Los Angeles County, CA ($n = 266$) (**c**).

opinion in the moderate-to-high-density areas in which most of the US population resides.

Given the lack of comprehensive, spatially consistent data on public climate change beliefs, risk perceptions, policy preferences and behaviour, MRP modelling, when properly optimized and validated, can provide a valuable method for generating estimates or projections at multiple, sub-national geographic scales. This method allows researchers to investigate how public beliefs, attitudes and risk perceptions influence behaviour and policy outcomes related to climate change across the range of decision-making scales. The results can also inform policy and decision-making about mitigation and adaptation at state and local levels, as well as support broader public awareness, outreach and education campaigns. For example, estimates could be used to evaluate support for renewable energy initiatives, to understand transportation behaviours, to gauge levels of policy support and to identify discrepancies between public opinion and political decision-making at various geographic scales. In addition, our results make comparisons of perceived risk versus physical vulnerability feasible at relatively fine scales.

This study is the first to provide high-resolution estimates of public climate change beliefs, risk perceptions, policy preferences and behaviours in the US. The MRP model accurately and reliably predicts these variables at state and municipal scales, finding substantial geographic variation both nationally and within individual states. Public opinion data at these sub-national and sub-state scales has previously been sparse compared to nationally representative data. States, municipalities and counties across the United States are at present making critical decisions about climate change mitigation and adaptation. State- and local-level estimates of public responses to climate change can provide important information for policymakers, planners, educators and scientists working at these sub-national scales.

Methods

Data. Data from 12 nationally representative climate change opinion surveys conducted between 2008 and 2013 for the Yale Project on Climate Change Communication and George Mason Center for Climate Change Communication were merged into a single combined data set ($n = 12{,}061$). Eleven of the surveys were probability-based online surveys (conducted by GfK Knowledge Networks). We also included a nationally representative telephone survey (conducted by Abt SRBI) that was administered concurrently with the state- and metropolitan-level validation surveys using the same item wording as the online panel surveys. The national-level phone data set was included in the multilevel regression model to control for mode differences when comparing the model estimates against the validation surveys. We at present use 2013 as our projected year to match our validation surveys, but future survey data can be added to the model to provide updated estimates that account for changes in opinion over time.

Survey questions are provided in the Supplementary Information. 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, county, congressional district and MSA of residence were then inferred for each respondent. Using the 2012 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 at state, congressional district and county levels. State-, congressional district- and county-level data representing 2008 Presidential Democratic vote share and data on per capita CO_2 emissions at the state and county level from the Vulcan Project[42] were also merged into the data set.

Model specification. Multilevel regression and poststratification (MRP) was used to project local-level climate opinions across the United States (for more detailed treatments, see refs 33,35,37,39). MRPs comprise two steps. In an initial multilevel regression step, individual survey responses are modelled as a function of both individual-level demographics (equation (1)) and geography-level covariates (equation (2)). In a subsequent poststratification step, a weighted sum of the beliefs of demographic–geographic types are generated for each geographic subunit. In the multilevel regression step, a hierarchical model was used to estimate the relationship of individual- and geography-level covariates with the probability Pr that a given individual i had a positive response to the specific question being modelled, h, represented by $y_{h[i]}$. For clarity, we present the model for just a single variable, dropping the indexing over h. Thus, at the individual level:

$$Pr(y_i=1)=\text{logit}^{-1}(\gamma_0+\alpha^{\text{race}}_{j[i]}+\alpha^{\text{education}}_{k[i]}+\alpha^{\text{gender}}_{l[i]}+\alpha^{\text{mode}}_{m[i]}+\alpha^{\text{time}}_{n[i]}+\alpha^{\text{geography}}_{g[i]}) \quad (1)$$

where

$$\alpha^{\text{race}}_j \sim N(0,\sigma^2_{\text{race}}),\ \text{for } j=1,\ldots,4$$

$$\alpha^{\text{education}}_k \sim N(0,\sigma^2_{\text{education}}),\ \text{for } j=1,\ldots,4$$

$$\alpha^{\text{gender}}_l \sim N(0,\sigma^2_{\text{gender}}),\ \text{for } l=1,2$$

$$\alpha^{\text{mode}}_m \sim N(0,\sigma^2_{\text{mode}}),\ \text{for } m=1,2$$

$$\alpha^{\text{time}}_n \sim N(0,\sigma^2_{\text{time}}),\ \text{for } n=1,\ldots,5$$

Each variable is indexed over individual i and over response categories j,k,l,m,n and g for race, education, gender, mode, time and geography variables respectively, while γ_0 refers to the overall intercept of the regression. Each variable is modelled as drawn from a normal distribution with mean zero and estimated variance σ^2. The geography variable index, g, is flexible, indexing either states (s), counties (co), congressional districts (cd) or metropolitan areas (m), depending on the level of geographic subunit being modelled. Mode captures whether respondents were contacted through a telephone or online survey. Time captures the year in which respondents were surveyed, which accounts for changes in aggregate public opinion across each year of the survey. For state models ($g=s$), the geography-level term is modelled as:

$$\alpha^{\text{state}}_s \sim N(\alpha^{\text{region}}_{r[s]}+\gamma^{\text{drive}}\cdot\text{drive}_s+\gamma^{\text{samesex}}\cdot\text{samesex}_s+\gamma^{\text{carbon}}\cdot\text{carbon}_s+\gamma^{\text{pres}}\cdot\text{pres}_s,\sigma^2_s),\ \text{for } s=1,\ldots,51 \quad (2)$$

where drive describes the percentage of individuals who drive alone in a given state, samesex describes the percentage of same-sex households in a given state, carbon describes the level of point source per capita carbon emissions in a given state, and pres describes the 2008 Democratic Presidential vote share in a given state. The region variable describes the census region in which a respondent resides, the effect of which is modelled in turn by:

$$\alpha^{\text{region}}_r \sim N(0,\sigma^2_{\text{region}}),\ \text{for } j=1,\ldots,9$$

County, core-based statistical area and congressional district models have similar specifications, with some modifications to account for the different nested nature of geographic subunits (for example, county and congressional district models also include a state random effect); full specifications are presented in the Supplementary Information. All models were fit in R using the GLMER function in the lme4 package[43]. MRP models will be most accurate when they include geographic-level covariates that are strongly linked to the specific opinion domain being projected and when the ratio of inter-unit to intra-unit variation in opinion is high[39]. This model combines geographic covariates that have broad predictive power in other studies (for example, refs 35,37 use percentage same-sex households as an effective proxy for liberalism) with customized variables that are linked to climate and energy beliefs and behaviours (for example, driving behaviour and carbon emissions). The current model includes presidential Democratic vote share as a geographic covariate to marginally improve the model's descriptive accuracy. For studies where the estimates may be used in analyses of political behaviour, it is possible to drop this term while finding substantively similar results.

During the second, poststratification stage, the multilevel regression model results are used to project the average opinion of each demographic–geographic-year individual type. For instance, the model projects the average belief of a Hispanic/Latina woman with a bachelors degree or higher living in Orange County, California in 2013. The model allows for 32 unique sex–race–education categories, which then interact with either 51 states (including the District of Columbia), 435 congressional districts, or 3,143 counties (and county-equivalents), generating 1,632 unique population types for the state-level model, 13,952 unique population types for the congressional district-level model, and 100,576 unique population types for county-level models. The census-derived population counts tables provide the count of each population type in each subunit. Final MRP estimates weight the model-projected belief of each population type by the true population count of that type in a given geographic subunit. Let ϑ_c describe the projected opinion of each unique demographic–geography type, indexed over cell c, and N_c give the population count for that cell, then the MRP estimate of beliefs in any given geographic subunit is the weighted sum of these estimates and population counts, over geographic subunit variable g:

$$y^{mrp}_g=\frac{\Sigma_{c\epsilon g}N_c\vartheta_c}{\Sigma_{c\epsilon g}N_c}$$

Received 30 October 2014; accepted 19 February 2015; published online 6 April 2015

References

1. O'Connor, R. E., Bord, R. J. & Fisher, A. Risk perceptions, general environmental beliefs, and willingness to address climate change. *Risk Anal.* **19,** 461–471 (1999).
2. Leiserowitz, A. Climate change risk perception and policy preferences: The role of affect, imagery, and values. *Climatic Change* **77,** 45–72 (2006).
3. Marx, S. M. *et al.* Communication and mental processes: Experiential and analytic processing of uncertain climate information. *Glob. Environ. Change* **17,** 47–58 (2007).
4. Dietz, T., Gardner, G. T., Gilligan, J., Stern, P. C. & Vandenbergh, M. P. Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proc. Natl Acad. Sci. USA* **106,** 18452–18456 (2009).
5. Spence, A., Poortinga, W., Butler, C. & Pidgeon, N. F. Perceptions of climate change and willingness to save energy related to flood experience. *Nature Clim. Change* **1,** 46–49 (2011).
6. Gromet, D. M., Kunreuther, H. & Larrick, R. P. Political ideology affects energy-efficiency attitudes and choices. *Proc. Natl Acad. Sci. USA* **110,** 9314–9319 (2013).
7. Lorenzoni, I. & Pidgeon, N. Public views on climate change: European and USA perspectives. *Climatic Change* **77,** 73–95 (2006).
8. Leiserowitz, A. American risk perceptions: Is climate change dangerous? *Risk Anal.* **25,** 1433–1442 (2005).
9. Weber, E. U. & Stern, P. C. Public understanding of climate change in the United States. *Am. Psychologist* **66,** 315–328 (2011).
10. Slovic, P. Trust, emotion, sex, politics, and science: Surveying the risk-assessment battlefield. *Risk Anal.* **19,** 689–701 (1999).
11. McCright, A. M. & Dunlap, R. E. The politicization of climate change and polarization in the American public's views of global warming, 2001–2010. *Sociological Q.* **52,** 155–194 (2011).
12. Kahan, D. M., Jenkins-Smith, H. & Braman, D. Cultural cognition of scientific consensus. *J. Risk Res.* **14,** 147–174 (2011).
13. Zaval, L., Keenan, E. A., Johnson, E. J. & Weber, E. U. How warm days increase belief in global warming. *Nature Clim. Change* **4,** 143–147 (2014).
14. Wilbanks, T. J. & Kates, R. W. Global change in local places: How scale matters. *Climatic Change* **43,** 601–628 (1999).
15. Adger, W. N., Arnell, N. W. & Tompkins, E. L. Successful adaptation to climate change across scales. *Glob. Environ. Change A* **15,** 77–86 (2005).
16. Van der Horst, D. NIMBY or not? exploring the relevance of location and the politics of voiced opinions in renewable energy siting controversies. *Energy Policy* **35,** 2705–2714 (2007).
17. Bulkeley, H. & Betsill, M. M. Revisiting the urban politics of climate change. *Environ. Politics* **22,** 136–154 (2013).
18. McCright, A. M. & Dunlap, R. E. Cool dudes: The denial of climate change among conservative white males in the United States. *Glob. Environ. Change* **21,** 1163–1172 (2011).
19. Akerlof, K., Maibach, E. W., Fitzgerald, D., Cedeno, A. Y. & Neuman, A. Do people "personally experience" global warming, and if so how, and does it matter? *Glob. Environ. Change* **21,** 81–91 (2013).
20. Egan, P. J. & Mullin, M. Turning personal experience into political attitudes: The effect of local weather on Americans' perceptions about global warming. *J. Politics* **74,** 796–809 (2012).
21. Goebbert, K., Jenkins-Smith, H. C., Klockow, K., Nowlin, M. C. & Silva, C. L. Weather, climate and worldviews: The sources and consequences of public perceptions of changes in local weather patterns. *Weather Clim. Soc.* **4,** 132–144 (2012).
22. Hamilton, L. C. & Keim, B. D. Regional variation in perceptions about climate change. *Int. J. Climatol.* **29,** 2348–2352 (2009).
23. Howe, P. D., Markowitz, E. M., Lee, T. M., Ko, C-Y. & Leiserowitz, A. Global perceptions of local temperature change. *Nature Clim. Change* **3,** 352–356 (2013).
24. Howe, P. D. & Leiserowitz, A. Who remembers a hot summer or a cold winter? the asymmetric effect of beliefs about global warming on perceptions of local climate conditions in the US. *Glob. Environ. Change* **23,** 1488–1500 (2013).
25. Capstick, S. B. & Pidgeon, N. F. Public perception of cold weather events as evidence for and against climate change. *Climatic Change* **122,** 695–708 (2014).

26. Myers, T. A., Maibach, E. W., Roser-Renouf, C., Akerlof, K. & Leiserowitz, A. A. The relationship between personal experience and belief in the reality of global warming. *Nature Clim. Change* **3,** 343–347 (2013).
27. Van Der Linden, S. On the relationship between personal experience, affect and risk perception: The case of climate change. *Eur. J. Soc. Psychol.* **44,** 430–440 (2014).
28. Leiserowitz, A. *et al. Climate Change in the American Mind: Americans' Global Warming Beliefs and Attitudes in November, 2013* (Yale University and George Mason University, 2014); http://environment.yale.edu/climate-communication/article/Climate-Beliefs-November-2013
29. Leiserowitz, A., Feinberg, G., Howe, P. & Rosenthal, S. *Climate Change in the American Mind: A Focus on California, Colorado, Ohio, and Texas* (Yale University, 2013); http://environment.yale.edu/climate-communication/article/climate-change-in-the-american-mind-focus-on-california-colorado-ohio-and-t
30. Erikson, R. S., Wright, G. C. & McIver, J. P. *Statehouse Democracy: Public Opinion and Policy in the American States* (Cambridge Univ. Press, 1993).
31. Clinton, J. D. Representation in Congress: Constituents and roll calls in the 106th House. *J. Politics* **68,** 397–409 (2006).
32. Park, D. K., Gelman, A. & Bafumi, J. Bayesian multilevel estimation with poststratification: State-level estimates from national polls. *Political Anal.* **12,** 375–385 (2004).
33. Park, D. K., Gelman, A. & Bafumi, J. in *Public Opinion in State Politics* (ed. Cohen, J. E.) 209–228 (Stanford Univ. Press, 2006).
34. Gelman, A. & Little, T. Poststratification into many categories using hierarchical logistic regression. *Sur. Methodol.* **23,** 127–35 (1997).
35. Lax, J. R. & Phillips, J. H. How should we estimate public opinion in the states? *Am. J. Political Sci.* **53,** 107–121 (2009).
36. Pacheco, J. Using national surveys to measure dynamic us state public opinion a guideline for scholars and an application. *State Politics Policy Q.* **11,** 415–439 (2011).
37. Warshaw, C. & Rodden, J. How should we measure district-level public opinion on individual issues? *J. Politics* **74,** 203–219 (2012).
38. Tausanovitch, C. & Warshaw, C. Measuring constituent policy preferences in Congress, state legislatures, and cities. *J. Politics* **75,** 330–342 (2013).
39. Buttice, M. K. & Highton, B. How does multilevel regression and poststratification perform with conventional national surveys? *Political Anal.* **21,** 449–467 (2013).
40. *Cooperative Congressional Election Study* (Harvard University, 2013); http://projects.iq.harvard.edu/cces/home
41. Leiserowitz, A. & Akerlof, K. *Race, Ethnicity, and Public Responses to Climate Change* (Yale University and George Mason University, 2010); http://environment.yale.edu/climate-communication/files/Race_Ethnicity_and_Climate_Change_2.pdf
42. Gurney, K. R. *et al.* High resolution fossil fuel combustion CO_2 emission fluxes for the United States. *Environ. Sci. Technol.* **43,** 5535–5541 (2009).
43. Bates, D., Maechler, M., Bolker, B. & Walker, S. *lme4: Linear mixed-effects models using S4 classes* (R Foundation, 2014); http://cran.r-project.org/web/packages/lme4/index.html

Acknowledgements
This project was supported by the Skoll Global Threats Fund, the Energy Foundation, the 11th Hour Project, the Grantham Foundation for the Protection of the Environment, and the V. K. Rasmussen Foundation. The authors wish to thank E. Maibach, C. R-Renouf, G. Feinberg, L. Fernandez, S. Rosenthal and B. Schwarz.

Author contributions
P.D.H. and A.L. designed the study. P.H. and M.M. built the model. A.L. provided the modelling and validation data. P.H., M.M. and J.R.M. processed data and tested the model. All authors contributed to writing the manuscript.

Additional information
Supplementary information is available in the online version of the paper. Reprints and permissions information is available online at www.nature.com/reprints. Correspondence and requests for materials should be addressed to P.D.H.

Competing financial interests
The authors declare no competing financial interests.