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The impacts of temperature anomalies and political orientation on perceived winter warming

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Although perceptions of common weather phenomena moderately align with instrumental measurements of such phenomena[1], the evidence that weather or climatic conditions influence beliefs about anthropogenic climate change is mixed[2–13]. This study addresses both foci, which are important to scholars who investigate human–environment interactions and observers who expect greater exposure to weather or climate extremes to translate into stronger support for climate change adaptive measures and mitigative policies. We analyse the extent to which state-level winter temperature anomalies influence the likelihood of perceiving local winter temperatures to be warmer than usual and attributing these warmer temperatures mainly to global warming. We show that actual temperature anomalies influence perceived warming but not attribution of such warmer-than-usual winter temperatures to global warming. Rather, the latter is influenced more by perceived scientific agreement; beliefs about the current onset, human cause, threat and seriousness of global warming; and political orientation. This is not surprising given the politicization of climate science[14,15] and political polarization on climate change beliefs[16,17] in recent years. These results suggest that personal experience with weather or climate variability may help cultivate support for adaptive measures, but it may not increase support for mitigation policies.

Many notable extreme weather events—such as the 2010 Russian heat wave, 2012 Superstorm Sandy along the US East Coast, and 2013 Pacific Typhoon Haiyan—have occurred in recent years, consistent with expectations for a warming world[18,19]. The extent to which such weather patterns—and, more importantly, longer-term climatic conditions—are perceived by the public as 'unusual' and influence perceptions of anthropogenic climate change are important, policy-relevant questions. Accurate perceptions of variability in local or regional climates may be essential for strengthening adaptive capacity[20,21], and personal experience with climate change impacts may increase support for effective mitigation policies[2,22]. Some studies employing instrumentally measured weather or climate phenomena (as opposed to perceptions of them) find that weather or climate patterns influence climate change perceptions[2–8], whereas others do not[9–13]. These disparate results in this emerging literature are probably due to differences in approaches and methods used, indicators of weather/climate phenomena observed, geographical units observed, outcome variables measured, and analytical techniques employed.

This study focuses specifically on winter 2012 in the contiguous United States, which was the fourth warmest winter in that country's temperature record going back to 1895[23]. Yet, this record warmth was not uniform across the 48 contiguous states. Most of the abnormal warmth occurred east of the Great Plains, while most of the Western US experienced near-normal temperatures. Given the results of previous studies[1–8], it seems reasonable to predict that variation in 2012 winter temperature anomalies across US states is correlated with the likelihood that people throughout the US perceive local winter temperatures to be warmer than usual and attribute these warmer temperatures mainly to global warming. However, given the political polarization on climate change beliefs in the US (refs 16,17), it seems equally reasonable to predict that political orientation has a greater influence than do temperature anomalies, particularly on the attribution of warmer-than-usual temperatures to global warming—a more complex belief than perception of temperature.

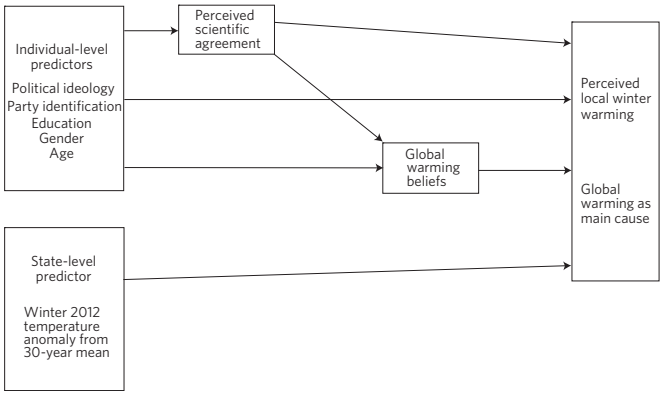

Figure 1 | Analytical model. Effects of individual-level predictors and state-level temperature anomaly on perceived local winter warming and global warming as main cause of warmer local winter temperatures through mediators.

To examine these predictions, we employ a multi-level random intercept model (Fig. 1) that extends an analytical model found efficacious in previous individual-level studies of Americans' climate change perceptions[24–26]. This model expects that individuals who believe that scientists agree on climate change and believe in the current onset, human cause, threat and seriousness of global warming will be more likely to perceive that local winter temperatures were warmer than usual and attribute these warmer temperatures mainly to global warming. Further, though some scholars conceptualize the role of perceived scientific agreement differently[24], the model also expects that its influence is mediated by general global warming beliefs, consistent with recent studies[25–27]. To examine the predictions from the literature

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Table 1 | Definitions of endogenous (mediator and outcome) variables.

	Survey items	Coded response categories
Outcome variables		
Perceived local winter warming	'Next, I'd like you to think about the weather in your local area this winter season compared to past winters. Have temperatures in your local area been:'	(0) 'colder than usual this winter', (0) 'about the same', or (1) 'warmer than usual this winter'
Global warming as main cause	'Do you think temperatures are warmer mainly due to:'	(1) 'global warming', (0) 'normal year-to-year variation in temperatures'
Mediator variables		
Perceived scientific agreement	'Just your impression, which one of the following statements do you think is most accurate:'	3-point scale: (3) 'most scientists believe that global warming is occurring', (1) 'most scientists believe that global warming is not occurring', or (2) 'most scientists are unsure about whether global warming is occurring or not'
Global warming beliefs	(5 items; factor loadings in parentheses)	
	'Which of the following statements reflects your view of when the effects of global warming will begin to happen': (0.84)	(4) 'they have already begun to happen', (3) 'they will start happening within a few years', (2) 'they will start happening within your lifetime', (1) 'they will not happen within your lifetime, but they will affect future generations', (0) or 'they will never happen'
	'And from what you have heard or read, do you believe increases in the Earth's temperature over the last century are due more to:' (0.78)	(1) 'the effects of pollution from human activities' or (0) 'natural changes in the environment that are not due to human activities'
	'I'm going to read you a list of environmental problems. How much do you personally worry about...global warming?' (0.82)	(3) 'a great deal', (2) 'a fair amount', (1) 'only a little', or (0) 'not at all'
	'Do you think that global warming will pose a serious threat to you or your way of life in your lifetime?' (0.74)	0 = no 1 = yes
	'Thinking about what is said in the news, in your view is the seriousness of global warming:' (0.81)	(0) 'generally exaggerated', (1) 'generally correct', or is it (2) 'generally underestimated'

noted above, our expanded multi-level model (MLM) incorporates a relationship between state-level winter temperature anomalies and (1) individuals' perceptions about the winter, as well as (2) the attribution of warmer temperature to global warming—among those who perceived this winter as unusually warm. Finally, the model also includes political orientation[16,17] and key social and demographic predictors[28,29] that previous studies find to correlate with climate change perceptions.

We merge nationally representative individual-level survey data from a March 2012 US Gallup Poll with state-level temperature data from the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). Analyses using this integrated social and climatological data set allow for examination of the relative importance of relevant political, social and demographic indicators at the individual level and a winter temperature anomaly measure at the state level on perceptions of local winter warming.

The March 2012 Gallup Poll, which was administered a few weeks after the end of the exceptionally warm winter 2012, included two items we use to measure the outcome variables in our model. Table 1 shows the survey items and response categories for the two outcome variables and the two mediator variables in our model. Table 2 describes the study sample. Approximately 80% of respondents in the contiguous 48 states (818 of 1,020) report that winter temperatures in their local area were warmer than usual. Of these, approximately 35% (286 of 818) believe that global warming was the main cause of these warmer winter temperatures. Although climate scientists caution against attributing specific extreme weather events and unusual seasonal temperatures to anthropogenic climate change, many use a 'loaded dice' metaphor to emphasize that anthropogenic climate change shifts the probability distribution of such phenomena—making them more likely in a warming world[30,31].

To model the individual-level predictors and mediating factors discussed above, and to accommodate the multi-level nature of our data set (that is, individuals nested in states), we used an approach that integrates structural equation modelling and multi-level modelling. An alternative model specification—a multi-level structural equation model (SEM) adding random intercepts to both mediators—finds no statistically significant state-level variation in, or fixed effect of temperature anomaly on, perceived scientific agreement or global warming beliefs and produces very similar results to those presented here. Supplementary Table 1 presents the direct effects of individual-level predictors on the two mediator variables, which are incorporated into the full SEM. Table 3 reports the results of our full multi-level SEM predicting the likelihood that respondents perceive their local winter 2012 temperatures to be warmer than usual, our first outcome variable.

As this variable is dichotomous, our SEM is essentially a logistic regression model with one latent mediator (global warming beliefs) and one observed mediator (perceived scientific agreement). At the state level, we applied linear regression analysis, because the outcome is the random intercept component of the individual-level SEMs (see the state-level fixed effect in Table 3). The intraclass

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Table 2 | Descriptive statistics of the study sample.

Predictors and variables	Total sample (N=1,020)
Individual-level predictors	
Political ideology (1–5 scale: very conservative–very liberal)	2.81 (1.01)
Party identification (1–5 scale: Republican–Democrat)	3.11 (1.62)
Education (bachelor's degree percentage)	30.80
Gender (female percentage)	51.50
Age (years)	47.62 (17.49)
Mediator variables	
Perceived scientific agreement (1–3 scale)	2.49 (0.64)
Global warming beliefs	
Timing of global warming effects (0–4 scale)	2.58 (1.63)
Primary cause of global warming (0–1 scale)	0.51 (0.50)
Personal worry about global warming (0–3 scale)	1.55 (1.14)
Perceived threat of global warming (0–1 scale)	0.29 (0.46)
Seriousness of global warming (0–2 scale)	0.83 (0.84)
Outcome variables	
Perceived local winter warming (0–1 scale)	0.80 (0.40)
Global warming as main cause (0–1 scale; N=818)	0.37 (0.47)

Standard deviation is given in parentheses.

Table 3 | Standardized direct, indirect and total effects from multi-level SEM predicting perceived local winter warming.

Predictors	Perceived local winter warming		
	Direct	Indirect	Total
Individual-level predictors			
Political ideology	−0.02	0.14*	0.12
Party identification	−0.02	0.16*	0.14*
Education	0.03	−0.02	0.01
Female	−0.13	0.08*	−0.05
Age	0.16*	−0.07	0.09
Mediator variables			
Perceived scientific agreement	−0.15	0.36*	0.21*
Global warming beliefs	0.59*	-	0.59*
State-level fixed effect			
Winter 2012 temperature anomaly from 30-year mean	0.92*	-	0.92*
Random intercept			
Variance			0.48*
Residual variance			0.07
Intraclass correlation			0.27
χ^2/degrees of freedom			93.39/33
Root mean square error of approximation			0.04
Comparative fit index			0.98
Tucker–Lewis index			0.97

*p<0.05. Individual N=1,020; state N=48.

correlation coefficient, which measures the homogeneity of second-level units on the outcome variable[32], is large (0.27)—indicating sufficient state-level variation to necessitate multi-level modelling. The variance of the random intercept (0.48) indicates the same. The model fit statistics reported at the bottom of Table 3 indicate that this model has a good fit.

When it comes to perceiving whether local winter temperatures were warmer than usual (rather than colder or about the same), the winter 2012 temperature anomaly from a 30-year mean has a strong positive effect. That is, the greater the deviation of winter 2012 temperatures from the 30-year winter temperature average in respondents' states, the more likely that respondents report local winter temperatures to be warmer than usual. The unstandardized effect of the winter 2012 temperature anomaly from a 30-year mean is 0.32 (Supplementary Table 2), which applies to the intercept of the individual-level logistic regression predicting the log of the odds of answering that local winter temperatures were warmer than usual rather than answering that they were colder or about the same as usual. Holding all other variables constant, a shift from the 25th percentile to the 75th percentile in the winter 2012 temperature anomaly from a 30-year mean (from 0.71 °F to 4.58 °F) increases the odds of respondents perceiving local winter temperatures to be warmer than usual by 2.45 times ($e^{3.87*0.32}=3.45$).

As it is not clear what time span people use when forming their perceptions of 'normal' temperatures for a locale[33], we created six additional anomaly measures across a range of time spans. For each of the 48 contiguous US states, we calculated the deviation of winter 2012 temperatures from the mean winter temperatures over 1 (2011), 5 (2007–2011), 10 (2002–2011), 20 (1992–2011), 50 (1962–2011) and 100 (1912–2011) years. We then ran additional multi-level SEMs with identical specifications to the one reported in Table 3, save only for using a different mean winter temperature anomaly measure. As the individual-level results are identical across each of these models, Supplementary Table 2 simply presents the coefficients for these state-level indicators. These results are clear. Regardless of the baseline of comparison (from 1 to 100 years), all of the mean winter temperature anomaly measures have a positive effect on the likelihood that respondents report local winter temperatures to be warmer than usual. This pattern of consistent effects confirms the clarity and strength of the warm temperature signal in winter 2012.

We now turn to the individual-level component of our model reported in Table 3. As expected, both mediator variables—perceived scientific agreement and global warming beliefs—influence respondents' perceptions of local winter warming. The more respondents perceive scientific agreement on climate change and the more they believe in the current onset, human cause, threat and seriousness of global warming, the more likely they report local winter temperatures to be warmer than usual. Only one other individual-level predictor—party identification—influences perceptions of local winter warming, with Democrats more likely than Republicans to perceive local winter temperatures as warmer than usual.

Table 4 reports the results of a single-level SEM predicting the likelihood that respondents attribute the warmer-than-usual winter temperatures in their local area to global warming (versus yearly variation), our second outcome variable. Here we only use data from those 818 of the initial 1,020 respondents who answered that local winter temperatures were warmer than usual, with no data change at the state level (state $N=48$). Before the single-level SEM, we ran MLMs and found that the intraclass correlation coefficient for this outcome variable is quite low (0.01), indicating such minimal state-level variation that an MLM is unwarranted. A state-level mean winter temperature anomaly has no effect on whether or not respondents attribute warmer-than-usual local winter temperatures to global warming.

As with the previous model, the two mediating variables have a strong influence on respondents' attribution of local winter warming to global warming. The more respondents perceive scientific agreement on climate change and the more they believe

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Table 4 | Standardized direct, indirect and total effects from single-level SEM predicting global warming as main cause of warmer local winter temperatures.

	Global warming as main cause		
Predictors	**Direct**	**Indirect**	**Total**
Individual-level predictors			
Political ideology	−0.14*	0.25*	0.11*
Party identification	−0.01	0.31*	0.30*
Education	−0.03	0.04	0.01
Female	0.03	0.15*	0.18*
Age	0.09*	−0.17*	−0.08
Mediator variables			
Perceived scientific agreement	−0.01	0.52*	0.52*
Global warming beliefs	0.93*	-	0.93*
Intraclass correlation			0.01
χ^2/degrees of freedom			138.97/37
Root mean square error of approximation			0.06
Comparative fit index			0.96
Tucker–Lewis index			0.94

*$p < 0.05$. As the intraclass correlation is low (indicating that a multi-level model is not needed), we report the results from a single-level SEM. Individual $N = 818$; state $N = 48$.

in the current onset, human cause, threat and seriousness of global warming, the more likely they report warmer local winter temperatures to be due mainly to global warming rather than normal yearly variation. Democrats, liberals and females are more likely than are their Republican, conservative and male counterparts to attribute the warmer-than-normal local winter temperatures to global warming than to normal yearly variation.

Overall, these results are consistent with the basic structure of our analytical model at the individual level[25–27], as the influence of perceived scientific agreement on both outcome variables is fully mediated by global warming beliefs. Further, they illustrate the crucial importance of perceived scientific agreement and global warming beliefs for explaining how people perceive local weather phenomena, as these two variables have the strongest effects in both models.

Returning to the predictions suggested by the literature, this study finds that perceptions of local winter warming do align with objective measurements of such warming—regardless of the time span used for baseline comparisons. This confirms a similar finding from a study that examined winter 2011 (ref. 1), which saw slightly colder-than-average temperatures in the Midwest and Eastern United States. Thus, this pattern—a positive correlation between perceived and measured temperature anomalies—seems to hold even as the strength of the climatological signal varies. Such results, which illustrate accurate perceptions of local or regional climate variability, suggest that some degree of optimism regarding building public support for adaptive measures might be warranted[20,21].

This finding indicates that citizens may attend to weather/climatic signals from wider geographical areas (for example, their state) than might be expected. As there is substantial variation in the choice of geographical units employed in this literature—zip code[4,5,12], nearby large city[11], county[3,8], NOAA climatic division[2,9], and nation[6,13]—and because the geographic reach of influence may depend on the type of weather/climatic signal in question (for example, temperature, precipitation, drought, hurricanes and so on), the effect of employing differing geographic units should itself be examined carefully in future research.

This study further finds that state-level mean temperature anomalies do not influence whether or not people attribute warmer-than-normal local winter temperatures to global warming. Given the politicization of climate science[14,15] and political polarization on climate change beliefs in the US (refs 16,17), it is not surprising that attribution of warmer-than-usual winter temperatures to global warming is filtered through partisan and ideological lenses. Thus, although personal experience with weather or climate variability may help cultivate support for enhancing adaptive capacity, it seems unlikely at present to increase support for climate change mitigation policies.

Methods

Data. Individual-level data are from the Gallup Organization's 2012 Environment Poll, conducted on 8–11 March. The survey is based on telephone interviews with a nationally representative sample of 1,024 adults (age 18 years or older) in the US. State-level temperature data for the 48 contiguous states are from NOAA's NCDC. Four individual cases without corresponding state-level data are dropped for a final individual-level N of 1,020.

Outcome variables. Table 1 provides the exact coding of these two items. Perceived local winter warming comes from the following Gallup question: 'Next, I'd like you to think about the weather in your local area this winter season compared to past winters. Have temperatures in your local area been colder than usual this winter, about the same, or warmer than usual this winter?' We recoded this variable dichotomously (warmer than usual = 1, all others = 0; ref. 1). The sub-sample of 818 respondents (80.0%) who answered that the winter temperatures in their local area were warmer than usual was asked a follow-up question (global warming as main cause): 'Do you think temperatures are warmer mainly due to global warming (coded as 1) or to normal year-to-year variation in temperatures (coded as 0)?'

Individual-level predictors and mediators. We employed five individual-level predictor variables, including political ideology (very conservative = 1 to very liberal = 5), party identification (Republican = 1 to Democrat = 5), education (high school or less = 1 to more than college graduate = 4), gender (0 = males and 1 = females), and age (in years, ranging from 18 to 99).

We used two variables as potential mediators in our model, perceived scientific agreement and global warming beliefs, which have been used in recent studies[26,27]. The former comes from a single Gallup question asking whether respondents think that most scientists believe global warming is occurring. The latter is modelled as a latent variable measured by five Gallup items asking respondents when the effects of global warming will happen, whether increases in global temperatures over the last century are due primarily to human activities, how much they personally worry about global warming, whether global warming will pose a serious threat to them or their way of life in their lifetime, and whether the seriousness of global warming is underestimated in the news (see Table 1 for exact wording).

State-level predictor. The NCDC provides each state's average winter temperature, which is the time-bias-corrected average temperature for December, January and February. Given that using a 30-year average as a temperature baseline is standard in existing literature[1,4–8,12], we use an anomaly measure of the difference between a state's winter 2012 temperature and its mean winter temperature over the previous 30 years of 1982–2011 (winter 2012 temperature anomaly from 30-year mean). Values range from a low of −0.16 °F (New Mexico) to a high of 8.06 °F (North Dakota), with an average of 3.38 °F and a standard deviation of 1.95 °F. To check for robustness across different baselines, for each of the 48 contiguous US states we also calculated the deviation of winter 2012 temperatures from the average winter temperatures over 1 (2011), 5 (2007–2011), 10 (2002–2011), 20 (1992–2011), 50 (1962–2011) and 100 (1912–2011) years. Supplementary Table 2 presents the relevant coefficients from full models with each of these state-level indicators.

Analytical techniques. To model the individual-level mediating factors discussed above and accommodate the multi-level nature of our data set (that is, individuals nested in states), we used an approach that integrates structural equation modelling and multi-level modelling by employing Mplus 7.11. The SEM component modelled the individual-level mediating factors. The MLM component modelled individual-level perceptions of winter warming as a function of state-level winter temperature anomalies, with a straightforward random intercept model. We analysed a multi-level SEM for each of the two dependent variables. Both structural models generally have a good fit as shown by comparative fit indices (0.96–0.98) and Tucker–Lewis indices (0.94–0.97) and reasonably small root mean squared errors of approximation (0.04–0.06).

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In additional analyses, we also controlled for three state-level variables: percentage voting for President Obama in 2012; percentage living in urban areas in 2010; and percentage employed in fossil fuels sector activities in 2012. None had a statistically significant influence on either outcome variable, and their inclusion did not change the effects of the other variables. The intraclass correlation coefficient, which measures the homogeneity of second-level units (states) on the outcome variable[32], was quite low (0.01) for our second dependent variable, indicating such minimal state-level variation that an MLM was unnecessary. As the model for our second dependent variable used a sub-sample of 818 of the original 1,020 respondents, we ran a Heckman selection model to check for possible bias due to non-random sample selection. Results indicate no statistically significant bias. Analyses examining education*party and education*ideology interaction terms[16,17] find no statistically significant effect.

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Author contributions

A.M.M. and R.E.D. conceptualized the research question. C.X. performed the data analyses. A.M.M. wrote the initial drafts of the manuscript. A.M.M., R.E.D. and C.X. revised the manuscript.

Additional information

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Competing financial interests

The authors declare no competing financial interests.

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