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How warm days increase belief in global warming

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Climate change judgements can depend on whether today seems warmer or colder than usual, termed the local warming effect. Although previous research has demonstrated that this effect occurs, studies have yet to explain why or how temperature abnormalities influence global warming attitudes. A better understanding of the underlying psychology of this effect can help explain the public's reaction to climate change and inform approaches used to communicate the phenomenon. Across five studies, we find evidence of attribute substitution, whereby individuals use less relevant but available information (for example, today's temperature) in place of more diagnostic but less accessible information (for example, global climate change patterns) when making judgements. Moreover, we rule out alternative hypotheses involving climate change labelling and lay mental models. Ultimately, we show that present temperature abnormalities are given undue weight and lead to an overestimation of the frequency of similar past events, thereby increasing belief in and concern for global warming.

During a particularly hot summer in 1988, James Hansen testified before a congressional hearing on the dangers of global warming. The night before his testimony, committee members had opened the room's windows and turned off the air conditioning, hoping the sweltering heat would underscore Hansen's warnings and make the greenhouse effect concrete to anyone present[1]. This intuition, that today's temperature would affect climate change beliefs, anticipates a more recent finding that subjective temperature does, in reality, affect reported beliefs in climate change.

Given that the challenge of reducing carbon emissions depends, in part, on changes in individual behaviour, it is important to understand the basis of global climate change perception and concern. Notably, individuals' beliefs about the phenomenon seem to be constructed at the moment of elicitation, rather than simply retrieved from memory[2]. This is demonstrated by the fact that individuals are sensitive to normatively irrelevant features of the judgement context, including transient temperature[3–8]. Mounting evidence shows personal experience with the daily weather tends to dominate more diagnostic but paler statistical information provided by experts[9–11], because the former is more vivid and accessible. Notably, perceived abnormalities in present temperature have been linked causally with changes in belief in global warming, an effect termed local warming[12]. Specifically, respondents who perceived today's temperature as being warmer than usual exhibited greater belief in and heightened concern for global warming and also donated more money to a climate change charity.

Despite accumulating evidence that global warming judgements are influenced by short-lived temperature variation and local weather, the underlying psychological processes regarding how or why this relationship occurs have not been fully explored in the literature (see Supplementary Table 1 for a review of existing literature). There are at least three mechanisms by which transient, local temperatures may influence individuals' judgements about global climate change. One mechanism suggests that choice option labels influence belief construction. For many issues, subtle changes in question terminology can result in pronounced differences in obtained answers[13,14], a phenomenon supported by the literature on attribute framing effects in decision research[15,16]. Specifically, the term global warming, which has been used in previous studies, may prime heat-related cognitions, leading to biased judgements. Second, the local warming effect could be due to a knowledge deficit on the part of respondents, causing them to mistakenly believe that long-term climate and short-term temperature deviations are highly related. A third explanation, rooted in the cognitive heuristics literature[17], proposes that individuals use less relevant but salient and available information (for example, today's temperature) in place of more diagnostic but less accessible information (for example, global climate change patterns) in belief generation. Although this process, known as attribute substitution[18], may seem highly irrational if done consciously and explicitly, other psychological process implementations give it greater plausibility. In particular, we suggest that unusually warm or cold weather conditions may increase the availability of other unusual warm or cold temperature events in memory, changing estimates of the frequency of such events, and thereby affecting respondents' global warming attitudes. To preview our results, we find evidence for only the last of these three mechanisms.

Main results

Study 1 explored whether the local warming effect is caused by the use of the term global warming in question wording. Global warming may prime associations of heat-related impacts and rising temperatures[19], whereas the term climate change is more readily associated with a wider range of weather events[20]. To examine if the influence of perceived temperature depends on the phrasing of the survey question, we asked respondents ($N = 686$) about their belief in and concern for global warming or climate change using a web-based study (see Supplementary Table 2 for demographic details for all studies). Participants also reported whether the local temperature on the day they completed the survey was colder or warmer than usual for that time of year.

Results from study 1 show that the overall effect of perceived temperature deviation on belief in and concern for global climate

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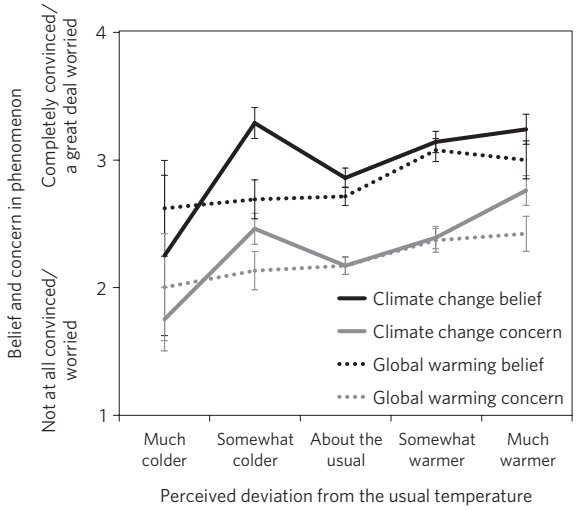

Figure 1 | Climate change labelling and local warming. Level of belief in and concern about climate change and global warming as a function of perceived temperature deviation in study 1. Bars denote ±1 s.e.m.

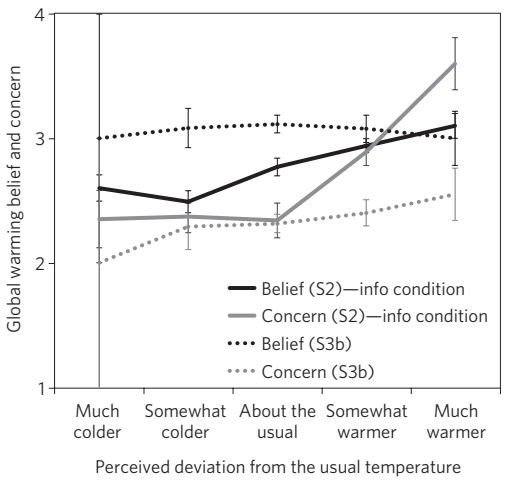

Figure 2 | Information, recency and local warming. Level of belief in and concern about global warming as a function of perceived temperature deviation, given the information condition in study 2 (S2). Level of belief in and concern about global warming as a function of yesterday's perceived temperature deviation in study 3b (S3b). Bars denote ±1 s.e.m.

change persisted whether the phenomenon was described as climate change or global warming. A multiple regression testing the effect of perceived temperature, framing condition (warming versus change) and their interaction on belief and concern revealed a main effect of perceived temperature on concern, $\beta = 0.16$, $t(683) = 3.03$, $p < 0.01$ and a marginally significant effect on belief, $\beta = 0.10$, $t(683) = 1.73$, $p = 0.08$. However, the interactions were not significant (concern, $p = 0.64$ and belief, $p = 0.47$), suggesting that there was no effect of phrasing (Fig. 1). We conducted a number of additional regressions that directly control for actual temperature, actual deviation from the historical average, gender, education, age, income, political affiliation, environmental attitude and subjective knowledge of the phenomenon (see Supplementary Tables 3-A and 3-B). The effect of perceived temperature remained significant in the presence of these controls for both frames. Furthermore, to control for reverse causality and omitted variable biases, we employed instrumental variable regression, an econometric tool used to help establish causality in observational data. Using actual temperature deviation as an instrument for perceived deviation, we causally link perceived temperature abnormalities with changes in global warming attitude (see Supplementary Information). Although attribute labels can produce pronounced differences in judgements and choices[13,21], termed attribute framing effects in decision research[15,16], the idea that the local warming effect is simply caused by being primed with the term global warming was not supported by our results.

Study 2 tested the possibility that participants have limited understanding of climate science and incorrectly believe that today's local temperature is relevant information to use in global warming judgements. Local short-term and broad long-term temperature trends are related, but it is only when temperatures are averaged over space and time that climate change patterns emerge[22]. If the local warming effect is due to a lay understanding that local temperature is a useful metric for predicting long-term temperature trends, then information about the scientific distinction between local temperature and global climate change should reduce or eliminate the local warming effect. We randomly assigned participants ($N = 330$) to either an information or no-information (control) condition. Those in the information condition read a passage highlighting the differences between minor weather fluctuations and global climate change whereas those in the no-information condition read a passage on the science of sleep (see Supplementary Methods for study 2 passages). This was followed by a series of questions to assess text comprehension. All participants then completed an unrelated filler task and answered the same temperature, belief and concern questions used in study 1.

Results from study 2 show that increased knowledge does not eliminate the local warming effect. A moderation analysis using hierarchical multiple regression revealed a main effect of perceived temperature deviation on belief ($\beta = 0.16$, $p = 0.02$), but there was no main effect of information ($\beta = 0.08$, $p = 0.76$). Notably, the information × perceived temperature interaction term was also non-significant ($\beta = 0.04$, $p = 0.67$). Similarly, for concern, we find a main effect of perceived temperature deviation ($\beta = 0.14$, $p = 0.04$), but neither a main nor an interaction effect for the information condition. Participants in the information condition were more likely to believe in and be concerned about global warming if they perceived today to be warmer than usual (belief, $\beta = 0.14$, $t(132) = 3.27$, $p < 0.01$ and concern, $\beta = 0.15$, $t(132) = 0.16$, $p = 0.03$), suggesting that the effect of perceived temperature on climate change perceptions cannot be attributed to a knowledge deficit or incorrect lay theory (Fig. 2).

Having eliminated the first two possible mechanisms, we turn to examining the details of attribute substitution. Specifically, we hypothesized that the availability of today's temperature deviation may make today's temperature observation disproportionately salient, changing estimates of the frequency of similar events[9,23], and affecting respondents' global climate change judgements. This interpretation has several testable implications, which we examine in the following studies. Ultimately, we provide a process-level explanation for how attribute substitution leads to biased judgements about global warming.

Studies 3a and 3b examined the role of accessibility of temperature abnormalities. In study 3a, we manipulated accessibility using a priming methodology. A body of research in psychology suggests that behaviours and social inferences can be subtly influenced through the use of temperature primes[6,24,25]. We hypothesized that when the concept of heat or cold is activated in one's mind (primed), that concept is more likely to be used for subsequent evaluation of global warming. Participants ($N = 300$) first answered the standard temperature perception question and completed one version (heat-prime, cold-prime or control) of a scrambled-sentences priming task[26] (see Supplementary Methods for study 3a scrambled-sentences text). After completing the

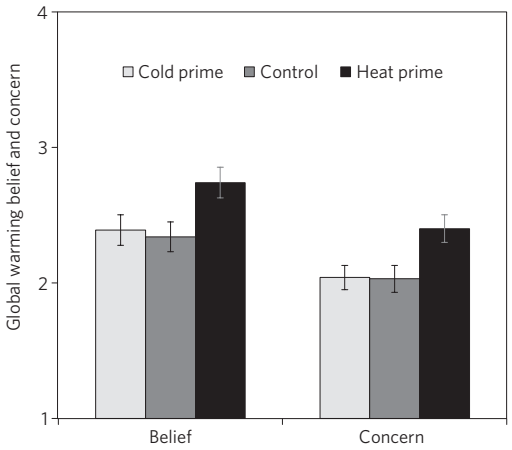

Figure 3 | Temperature priming and local warming. Effect of cold and heat temperature primes on global warming belief and concern (study 3a). Bars denote ±1 s.e.m.

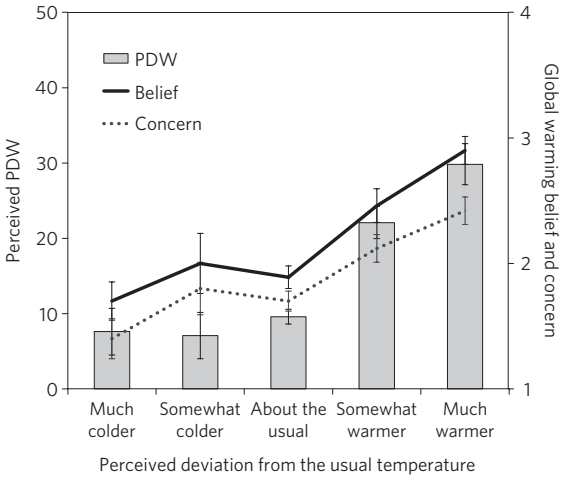

Figure 4 | Perceived PDW and local warming. Perceived PDW and belief in and concern about global warming as a function of perceived deviation from the usual temperature (study 4). Bars denote ±1 s.e.m.

scrambled-sentences task, all participants reported their belief in and concern about global warming.

Supporting the role of immediate temperature perception in generating the local warming effect, we find that priming individuals with heat-related cognitions increases levels of belief and concern in global warming. The priming manipulation had a direct effect on average ratings of reported belief in and concern about global warming, as shown in Fig. 3. There was a significant main effect of condition on global warming belief, $F(2, 288) = 3.88$, $p = 0.02$ and concern, $F(2, 288) = 4.74$, $p = 0.01$. *Post hoc* comparisons showed that those in the heat condition exhibited greater concern for global warming than those in the control condition ($p = 0.02$) and cold condition ($p = 0.03$). Similarly, those in the heat condition showed greater belief in global warming than those in the control condition ($p = 0.03$) and cold condition ($p = 0.07$).

Study 3b examined the need for recency of temperature abnormalities by exploring whether prompting people to think about yesterday's perceived temperature deviation also affects their belief in or concern about global warming. We predicted that people rely on the most immediately available temperature (today's deviation) and that past temperature events, such as the previous day's temperature, will have less influence on global warming belief and concern. Participants ($N = 251$) were asked, "was yesterday's temperature in your local city or town colder or warmer than usual for this time of year?" Respondents then reported their belief in and concern about global warming. We used participants' ZIP code information to calculate actual objective temperature deviations for the day that subjects participated in the study (today), as well as the day before subjects participated (yesterday).

Asking respondents about yesterday's temperature eliminated the relationship between perceived temperature deviation and global warming judgements. This suggests that the immediacy of experience with temperature affects judgements of global climate change. Linear regressions revealed that perceived deviation of yesterday's temperature had no effect on belief, $\beta = -0.02$, $t(250) = -0.38$, $p = 0.70$ or concern, $\beta = 0.08$, $t(250) = 1.30$, $p = 0.20$ (Fig. 2). When controlling for political affiliation and other demographic variables, the results remain non-significant for belief, $\beta = -0.06$, $t(208) = -0.79$, $p = 0.43$ and concern, $\beta = 0.03$, $t(208) = 0.43$, $p = 0.67$ (see Supplementary Tables 4-A and 4-B). To confirm that subjects were attending to yesterday's temperature deviation and not today's temperature, we compared yesterday's perceived temperature ratings with actual objective temperature deviations from the historical average for both yesterday and today. Results show that yesterday's perceived temperature deviation correlated positively with yesterday's actual deviation from the historical average ($r_s = 0.26$, $p < 0.01$). However, yesterday's perceived temperature deviation did not correlate with today's actual temperature deviation ($r_s = 0.08$, $p = 0.23$); suggesting that participants were indeed attending to yesterday's temperature and not today's. Additional regressions controlled for actual temperature and demographic factors, including political affiliation (see Supplementary Tables 4-A and 4-B), and found that the effect of perceived deviation on belief and concern remained non-significant. These findings suggest that it is the immediacy of experience with temperature that affects judgements of global climate change. Although one difference between yesterday and today relates to recency of experience, another important distinction is that the former is a memory and the latter is currently experienced as sensory input. Thus, our results are also consistent with the hypothesis that beliefs are influenced by the use of the most salient sensory information available (for example, perceived deviation of today's temperature).

In study 4, we further investigated our proposed mechanism for attribute substitution, namely construct-consistent recall from memory. We hypothesized that thinking about today's unusually warm weather will increase the availability of other unusually warm temperature events from memory, leading respondents to overestimate the frequency of such events. To test this hypothesis, we examined whether days that are perceived as being warmer than usual lead one to overestimate the frequency of unusually warm days throughout the year and whether this overestimation mediates the local warming effect. Participants ($N = 270$) answered the temperature, belief and concern questions, as in the preceding studies. They then answered the question, "over the past year, what percentage of days seemed to be warmer than usual for that time of year, compared with the historical average?" We refer to this variable as percentage days warmer (PDW).

Results reveal that people who thought today was warmer than usual reported more days in the year as being warmer than usual compared with people who thought today was colder than usual (Fig. 4). PDW was positively correlated with perceived temperature deviation, $r = 0.41$, $p < 0.01$, today's actual temperature, $r = 0.15$, $p < 0.05$ and global warming belief and concern, $r = 0.35$, $p < 0.01$; $r = 0.33$, $p < 0.01$, respectively. A regression controlling for today's actual temperature and today's objective temperature deviation reveals perceived temperature deviation influenced PDW, $\beta = 0.39$, $t(269) = 7.4$, $p < 0.01$. This suggests that attention to and perception

of today's temperature, and not actual temperature deviation, affects recall of past temperature events. Path analysis conducted to test our mediation hypotheses indicates that perceived PDW partially mediates the effect of perceived temperature deviation on belief in and concern about global warming. A Sobel Z test showed a similar effect on belief in (perceived deviation, direct: $t(270) = 4.92$, perceived deviation, mediated: $t(268) = 2.74$, boot-strapped Sobel's $Z = 3.91$, $p < 0.01$) and concern about global warming (perceived deviation, direct: $t(270) = 3.84$, perceived deviation, mediated: $t(268) = 1.62$, boot-strapped Sobel's $Z = 4.02$, $p < 0.01$). Results from study 4 suggest that those who perceive today to be warmer than usual are more likely to overestimate the frequency of unusually warm days throughout the year, which then mediates global warming judgements.

Conclusions

A growing body of research shows that transient temperature variation influences the public's opinion of global climate change. We extend this research by examining several hypotheses regarding why this happens and exploring the mechanisms underlying the local warming effect. Our results suggest that an attempt to de-bias this robust effect will not be easy, as changes to survey terminology and enhanced scientific knowledge do not eliminate the effect of perceived temperature abnormalities. Further research is needed to determine how people's belief in global climate change can be encouraged to develop over time from constructed, experienced-based reactions to more stable conclusions. Furthermore, although we find that attribute substitution is an important cause of the effect, rule out two alternative explanations and show that temperature priming can influence global warming attitudes, there may well be other sources of biases and heuristics that lead to the very stable local warming effect.

The local warming effect is an important real-word demonstration of how opinion on important issues can be constructed in response to a direct enquiry, rather than retrieved from memory. For climate change, a complex issue with contradictory coverage, individuals can draw weak conclusions and seem to reconsider their opinion each time they are asked a question. This characterization of climate change opinion and the apparent difficulties individuals experience when dealing with uncertain climate-related decisions have strong implications for public policy. For instance, these findings raise important questions regarding the potential role of the local warming bias in polling results. Our results suggest that recency and salience of warming constructs are promising ways of promoting heightened concern about climate change, at least among those whose beliefs or disbeliefs are not well established[27]. However, the opposite can also occur: the so-called snowpocalypse of 2010 in Washington DC resulted in increased media coverage of climate sceptics denying the existence of climate change. As climate change continues to cause an increase in the intensity of extreme weather fluctuations[28], the local warming effect may lead to even greater confusion among the general public. Weather variability will need to become better associated with heightened belief in climate change, though this new association will need to be accomplished through education and analogies, and not personal experience. If the United States is to take a stronger stance against climate change, forecasters may be well advised to make increasing warming abnormalities more cognitively available to the general public.

Methods

In studies 1, 3a and 3b, US participants were recruited from the website Amazon Mechanical Turk, where participants can take short surveys online in exchange for small payments[29]. In studies 2 and 4, US participants were recruited through Columbia University's Center for Decision Sciences national panel, which consists of more than 56,500 people who have agreed to participate in psychological and decision research for financial compensation. These panels represent a wide range of socioeconomic factors not seen in university lab settings (see Supplementary Table 2 for demographic details for all studies). Notably, the effect of temperature on global warming judgements has also been corroborated in nationally representative panels[5,7].

In study 1, participants were randomly assigned to the global warming versus climate change conditions and answered three standard questions, based on previous methodology[12]. Respondents reported how convinced they were "that global warming (climate change) is happening" and how much they "personally worried about global warming (climate change)". Response options ranged from 1 (not at all convinced/worried) to 4 (completely convinced/a great deal worried). These questions and response scales were adapted from previous public opinion studies about global warming[30]. Belief and concern correlated significantly in this and all subsequent studies ($r = 0.59$, $p < 0.01$). Participants also reported whether the local temperature on the day they completed the survey was colder or warmer than usual for that time of year, using a five-point scale that ranged from −2 (much colder) to 2 (much warmer). The belief question came before the concern question, in this and all subsequent studies; however, the presentation order of the belief/concern and temperature questions was counterbalanced. As well as these questions in this and all other studies, respondents provided information about political affiliation and extensive demographic information. We also collected actual temperature and historical temperature deviation data (degrees Fahrenheit) for the day that participants completed the studies, using their ZIP code information (see Supplementary Methods for actual temperature data collection methods).

In study 2, participants were first asked to read one of two passages (regarding the differences between minor weather fluctuations and global climate change or the science of sleep phases), which constituted our manipulation of knowledge. Participants were told that the purpose of the research was to determine the best way to present scientific information to the general public. Both passages were similar in length and educational in tone. To check our manipulation of knowledge, we examined whether participants in the information condition correctly answered an open-ended question about the difference between daily temperature and climate. Two coders independently categorized level of understanding (Cohen's Kappa measurement for agreement was 0.83, $p < 0.01$) and found that 82% of participants responded accurately. Only these participants were included in analyses. Participants were also asked to state what they thought the specific purpose of the study was. None of the participants correctly guessed the true purpose of the research.

In study 3a, participants were randomly assigned to one of the three experimental conditions. Mean perceived temperature ratings did not differ by condition ($F(2, 288) = 0.07$, $p = 0.93$), supporting random assignment of participants to conditions. After answering the standard temperature perception question, participants completed ten minutes of unrelated filler material. The scrambled-sentences priming task consisted of 13 sets of 5 scrambled words containing heat-related, cold-related, or neutral words[25,31]. For each set of available words, participants chose four words to make a grammatically correct sentence (see Supplementary Methods for scrambled-sentences text). Participants were told that the task was designed to clear their minds before other measures were taken. Twelve subjects did not complete the sentence task and were removed from further analysis.

In study 3b, unlike previous studies, all participants were first asked about yesterday's temperature rather that the present day's temperature. Participants responded using a five-point scale that ranged from 1 (much colder) to 5 (much warmer). As well as calculating the present day's objective temperature deviations, we used participants' ZIP code information to calculate objective temperature deviations for the day before subjects participated (yesterday). Study 3b did not include a control condition in which participants were asked about today's temperature and this prevents us from completely ruling out the possibility that we would not have found the local warming effect in this particular sample. This is unlikely, however, given the robust nature of the effect in previous studies drawn from the same subject pool.

In study 4, in addition to answering the temperature, belief and concern questions as in the preceding studies, participants were asked, "over the past year, what percentage of days seemed to be warmer than usual for that time of year, compared with the historical average?" Participants indicated their answer by clicking their mouse anywhere on a 100-point slide scale anchored by 0, 50 and 100%.

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Author contributions

L.Z. and E.A.K. designed studies 1 and 3b. L.Z., E.A.K. and E.U.W. designed studies 2, 3a and 4. L.Z. and E.A.K. analysed the data. All authors contributed to writing the manuscript. E.U.W. and E.J.J. supervised the project.

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 L.Z.

Competing financial interests

The authors declare no competing financial interests.