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Global perceptions of local temperature change

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It is difficult to detect global warming directly because most people experience changes only in local weather patterns, which are highly variable and may not reflect long-term global climate trends. However, local climate-change experience may play an important role in adaptation and mitigation behaviour and policy support[1–3]. Previous research indicates that people can perceive and adapt to aspects of climate variability and change based on personal observations[4–6]. Experience with local weather may also influence global warming beliefs[7,8]. Here we examine the extent to which respondents in 89 countries detect recent changes in average local temperatures. We demonstrate that public perceptions correspond with patterns of observed temperature change from climate records: individuals who live in places with rising average temperatures are more likely than others to perceive local warming. As global climate change intensifies, changes in local temperatures and weather patterns may be increasingly detected by the global public. These findings also suggest that public opinion of climate change may shift, at least in part, in response to the personal experience of climate change.

As average global temperatures rise, humans around the world will experience local weather events that fall outside the range of recent experience[9]. For example, abnormally hot weather will generally become more likely and abnormally cold weather will generally become less likely as average global temperatures rise[9]. Although average temperatures have risen significantly across much of the world in recent decades[10], it may be difficult for people to directly perceive these long-term changes owing to the variability of the climate system[11]. As a result, climate change has been considered a phenomenon that is particularly challenging for humans to perceive directly, resulting in climate-change risk communication messages that emphasize descriptive evidence of global warming rather than direct experience[2]. However, local climates in many places are now changing in ways that may be directly perceptible through everyday experiences of weather[12], and recent polling suggests that many individuals are indeed perceiving these changes[13]. This finding is important because for climate-related risks considered abstract by the public, descriptive information alone may not motivate concern or behaviour change to the same extent as recent personal experience[1]. Thus, there is a need to understand how people interpret climate change based on their personal experience.

This study examines perceptions of recent local temperature change among residents of 89 countries in Africa, the Americas, Asia and Europe in 2007–2008 ($n = 91{,}073$), a sample that is representative of 80% of the global population. We investigate the extent to which perceptions of local climate change correspond with high-resolution historical climate data. We predict that perceptions of local temperature change correspond with departures from normal temperature at the national and local scale. Furthermore, we predict that the season in which respondents are asked about local temperature change positively biases perceptions of local temperature change, with individuals more likely to perceive recent warming during the local warm season.

Previous research has found that experience with local weather can influence beliefs about climate change. For example, direct visceral experience of warmth has been found to affect belief in global warming among US college students[7,14]. Among residents of the US and Australia, perceptions of increasing local temperatures have been found to influence belief and concern about global warming[8,15]. Experiencing extreme weather events such as floods has also been shown to influence global warming risk perceptions and mitigation behaviour[3]. Although discrete local weather events may influence beliefs about global warming, it is also possible that individuals may not notice gradual local climate changes as they spend increasing amounts of time in climate-controlled spaces[16]. More generally, as climates change in local places around the world it remains unknown whether most people can accurately detect change in long-term average conditions through personal experience. Detecting change requires comparison of present conditions with memories of past or 'normal' conditions (that is, a reference point), and it is possible that gradual changes may remain beneath the threshold of perception[17]. It is increasingly important to understand how perceptions of local climate variability and change among vulnerable individuals and communities may influence adaptive capacity to climate change[18].

Exposure to external climatic stimuli through the everyday experience of local weather may serve as a non-trivial source of information from which individuals form judgements about changes in local climate. The experience of an unusually hot or cold day is probabilistic evidence—however slight—for a shift in average local temperatures. Over the long term, climate change may be perceived by accessing memories of accumulated weather experience to judge the difference between present and past conditions. Indeed, case-study research indicates that individuals can perceive and adapt to local climate variability and change without the use of modern meteorological data collection and analysis[19]. Such first-hand knowledge can be obtained through personal weather experience, observations of plant and animal phenology, and landscape changes[20–24]. Climate knowledge is then transmitted in context-dependent ways through, for example, cultural narratives and agricultural practices[25,26]. Evidence also suggests that individuals can accurately perceive climate variation at fine spatial scales[27].

Although previous studies have found that populations of agricultural communities can detect changes in locally relevant

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Table 1 | Descriptive statistics of survey sample.

	Total sample	Sample with local geographic data
Respondents (*n*)	91,073	46,819
Countries	89	46
Local geographic units		433
Demographic characteristics		
Age (years)	37.3 (16.9)	36.4 (16.0)
Gender (% female)	53.7	51.8
Local temperature change perception		
'Warmer' (%)	72.8	70.9
'Stayed about the same' (%)	16.9	18.7
'Colder' (%)	10.3	10.4
Climate characteristics		
Surveyed during warm season* (%)	63.5	64.3
Surveyed during wet season† (%)	43.8	44.3
12-month mean temperature anomaly‡ (°C)	0.80 (0.83)§	0.75 (0.65)‖

Standard deviations in parentheses. *Monthly mean temperature above annual mean temperature during month of survey completion. †Monthly total precipitation above annual mean monthly precipitation during month of survey completion. ‡Departure from 1961 to 1990 monthly mean temperature. §National-level population-weighted 12-month running mean temperature anomaly. ‖Local-level population-weighted 12-month running mean temperature anomaly.

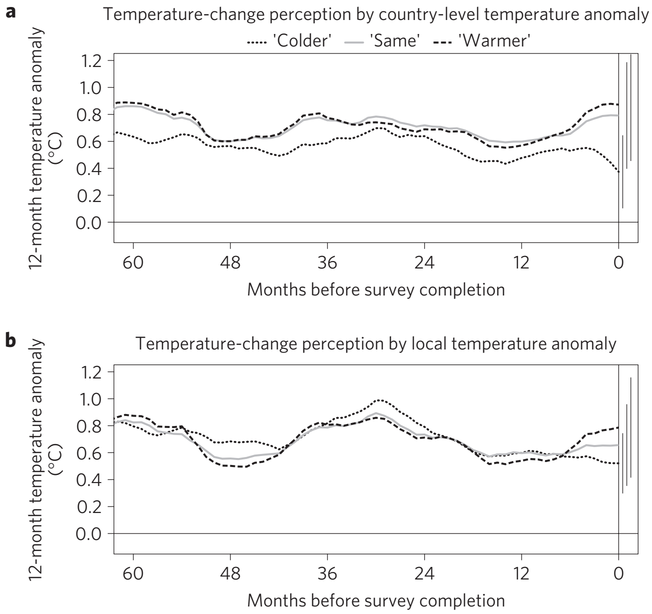

Figure 1 | Time series of mean temperature anomaly by response to 5-year temperature-change perception item. The vertical axis represents the population-weighted 12-month running mean temperature anomaly (departure from 1961 to 1990 mean). The horizontal axis represents months before the survey completion date. The vertical bars represent standard deviations. **a**, National population-weighted temperature anomalies (89 countries). **b**, Subnational population-weighted temperature anomalies (46 countries, 433 regions).

climatic indicators, there has been little broad-scale research on local climate-change perceptions seeking to make generalizable claims at cross-national scales. This study assesses whether recent changes in local temperatures have been perceived by a broad sample of the global population. We use nationally representative survey data collected in 2007–2008 by the Gallup World Poll. To gauge perceptions of recent local temperature change, respondents were asked, 'Over the past five years, would you say that the average annual temperatures in your local area have gotten warmer, colder, or stayed about the same'?

Survey responses were geo-referenced at the national level for the total sample of 89 countries, and at the local level by first-level administrative units within a subset of 46 countries for which higher-resolution geographic data were available. Climatic conditions can vary within countries, so this analysis uses a subset of data geo-referenced at the more precise subnational scale to confirm results obtained from coarser national-level data. To match survey responses to local climatic conditions, we calculated climate observations representing the average monthly temperature anomaly (difference from the 1961 to 1990 mean) experienced by a representative sample of residents of each country, and each subnational area where available, by combining high-resolution gridded monthly temperature data[28] with a high-resolution population distribution grid[29]. As the survey item of interest refers to perceptions of change in average annual temperatures, we use the 12-month moving average of the population-weighted monthly mean temperature anomaly leading up to the month each respondent was surveyed.

Most respondents reported perceiving warmer annual average temperatures (Table 1). As would be expected if perceptions were responding to spatial variation in climate, countries with populations experiencing more-extreme positive mean temperature anomalies had a greater percentage of respondents perceiving higher annual average temperatures ($r = 0.32$, $p < 0.01$, $n = 89$). Above the 1 °C threshold all countries had greater than 60% of respondents reporting that temperatures had gotten warmer. Country-level results generally clustered in regional patterns (Supplementary Fig. S1). In Europe, for example, average temperatures were elevated owing to a summer heat wave preceding the survey in 2007, and high percentages of respondents reported perceiving recent warming.

At the individual level, respondents who perceived a recent warming trend were more likely to have been exposed to higher mean temperature anomalies at both the national and local level than those who perceived a cooling trend or no trend (Fig. 1). Respondents who perceived different temperature trends were experiencing significantly different 12-month average temperature anomalies when the survey was conducted, among both the national-level ($p < 0.001$) and local-level ($p < 0.001$) samples. At the national level, the annual mean temperature anomaly was 0.87 °C (s.d. = 0.84) for respondents who perceived recent warming, 0.79 °C (s.d. = 0.78) for respondents who perceived temperatures had stayed about the same, and 0.38 °C (s.d. = 0.54) for respondents who perceived recent cooling. Beginning about six months before the survey, respondents who would ultimately report that average temperatures had gotten warmer began to experience increasing average temperature anomalies relative to those who perceived that average temperatures had gotten colder. Between-group differences continued to increase until the date of the survey, suggesting that respondents were using their experiences over the most recent 6–12 months to judge whether temperatures were changing. Such experiences may include a combination of short-term extreme events such as heat waves or cold snaps, which can influence long-term averages, and more gradual changes. Despite the differences between groups, respondents who perceived recent cooling were experiencing average temperature anomalies above the 1961–1990 average, which may indicate that respondents were relying on a more recent reference period.

Table 2 | Multilevel model results predicting perceived local warming.

	National-level data		Local-level data	
	Null model	Full model	Null model	Full model
Intercept	1.09 (.09)***	0.58 (0.15)***	0.89 (0.06)***	0.28 (0.11)***
Demographics (level 1)				
Gender (1: female versus 0: male)		0.01 (0.02)		0.01 (0.02)
Age (×10 years)		−0.01 (0.01)		−0.01 (0.01)
Area-level variables (level 2)				
12-month mean temperature anomaly (°C)		0.29 (0.09)**		0.48 (0.09)***
Season: temperature (1: warm versus 0: cool)		0.42 (0.17)*		0.75 (0.14)***
Season: precipitation (1: wet versus 0: dry)		0.04 (0.16)		− 0.42 (0.14)**
Model characteristics				
n (level 1)	91,073	91,073	46,819	46,819
n (level-2 units)	89	89	433	433
Level-2 variance	0.70	0.57	1.48	1.19
Intraclass correlation*	0.18	0.15	0.31	0.27
Proportional change in variance†		−18.96%		−19.19%
Akaike information criterion	95,623	95,614	49,646	49,601

Unstandardized regression coefficients. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, Standard errors in parentheses. *Intraclass correlation calculated using latent variable method. †Percentage change in level-2 variance from null model.

Multilevel binary logistic regression models were used to investigate the influence of national and local areas (level 2) and individual (level 1) factors on temperature-change perceptions. Table 2 presents results of two models using the total sample geo-referenced at the national level—a null model and a fully fitted model—and a similar set of two models based on the subset of data that was geo-referenced at the local level. The outcome variable in each model is the probability that respondents will answer 'warmer' to the local average annual temperature change item (recoded to two levels: warmer or not). Perceptions of local warming had an intraclass correlation of 18% within national-level groups of respondents and 31% within local-level groups of respondents, as would be expected if perceptions were responding to local climate influences.

Controlling for gender and age, local- and national-level climate characteristics were significant predictors of perceived local warming (other socio-demographic variables were not available for the full data set). Model comparisons indicate that the national- or local-level 12-month mean temperature anomaly accounts for between 8 and 13% of the level-2 variance in perceptions of local warming, and the addition of seasonal indicator variables for temperature and precipitation accounts for a further 6–11% of the area-level variance in perceptions of local warming. Including both sets of climate variables accounts for about 19% of the area-level variance in perceptions of local warming.

Whether the survey was conducted during the warm or cool season had a significant effect on perceptions of local warming. During the warm season—months with mean temperatures above the annual mean—respondents were 11–19% more likely than during the cool season to perceive that average temperatures had gotten warmer. Seasonal precipitation exhibited no effect on the total national-level sample, and a moderate effect on the local sample, which had a larger proportion of respondents residing in the tropics where seasons are mainly defined by variations in precipitation. During the dry season—months with total precipitation below the annual mean monthly total—respondents were about 10% more likely than during the wet season to report that average temperatures had gotten warmer.

When controlling for both demographic differences and seasonal effects, average annual national and local temperature anomalies remained a significant predictor of perceptions of local warming. An increase in the 12-month mean temperature anomaly of 1 °C was associated with a 7–12% increase in the probability that respondents would report that average temperatures had gotten warmer. This effect persists even when excluding respondents in Europe, who had recently experienced an extreme summer heat wave.

It is important to note that we cannot definitively show causal relationships between the climatic conditions experienced by respondents and their perceptions. However, the logical direction of the effect of changes in temperature on perceptions, and the lack of an alternative variable that would predict both actual and perceived temperature change, suggests that changes in temperature are a causal influence on perceptions. Further research using longitudinal data may allow for more robust inferences about the role of direct experience in individual climate-change perceptions.

Furthermore, perceptions probably respond to a complex set of climatic indicators. Future research should examine the interaction between the multiple climatological variables that make up local climate experience, how memory and perception differs among individuals and local contexts, and how effects may be nonlinear or threshold-dependent[7].

This study found that perceptions of local temperature change correspond to quantifiable observations of recent temperature change. In addition, there was a significant seasonal relationship with perceptions of local temperature change—during the warm season, respondents were more likely to report local warming over the long term. Thus, although perceptions were influenced by non-climate-change factors such as seasons, they also seem to respond to longer-term shifts in temperature.

These findings suggest that as global climate change continues to cause increases in local average temperatures, individuals may increasingly notice these changes through their own direct experience. In line with recent findings[30] regarding the effects of local weather on perceptions of climate change within the US, here we find evidence that across many countries people are detecting temperature changes in their local environments with some accuracy. This finding may have important implications for our collective ability and willingness to respond to climate change in the coming years (for example, mitigation and adaptation). Given past research linking perceptions of local change with concern over and willingness to respond to climate change, the present findings suggest that climate conditions over the past 6–12 months may affect public concern, motivating greater engagement with the issue as the climate warms.

Methods

Data collection. This study uses cross-national representative survey data collected by the Gallup World Poll in 2007–2008 in 89 countries. Owing to the size and complexity of the aggregated survey data set, geographic data at the local level were available only in a subset of 46 countries, representing 433 subnational administrative units. Surveyed countries included: Angola* Argentina, Armenia, Azerbaijan, Belarus*, Belgium, Belize, Benin*, Bolivia, Botswana*, Brazil, Burkina Faso*, Burundi*, Cambodia*, Cameroon*, Canada, Chad*, Chile, China, Colombia, Costa Rica, Czech Republic, Denmark, Djibouti*, Dominican Republic, Ecuador, Egypt, El Salvador, Georgia*, Ghana*, Greece, Guatemala, Guyana, Honduras, Hungary, India*, Indonesia, Iran, Israel*, Italy*, Japan*, Jordan, Kazakhstan*, Kenya*, Laos, Liberia, Madagascar*, Malaysia*, Mali*, Mauritania*, Mexico, Moldova*, Mongolia, Morocco, Mozambique*, Nepal*, Netherlands, Nicaragua, Niger*, Nigeria*, Palestinian Territories*, Panama, Paraguay, Peru, Philippines*, Poland*, Republic of Korea, Republic of the Congo*, Romania, Rwanda*, Saudi Arabia, Senegal*, Sierra Leone, Singapore, South Africa*, Spain, Sri Lanka*, Sweden, Thailand, Togo*, Turkey*, Uganda, Ukraine*, Tanzania*, United States of America*, Uruguay, Vietnam*, Zambia*, and Zimbabwe* (*: subnational geographic data are available). Burkina Faso and Singapore were surveyed in both 2007 and 2008 (Supplementary Table S1). Countries were sampled from all first- and second-order macro-geographical regions excluding Oceania. The largest countries not included in the sample, in descending order of population, were Pakistan, Bangladesh and Russia.

Surveys were conducted with randomly selected nationally representative samples using either telephone or face-to-face interviews (Supplementary Data). Survey questions were translated into the main languages of each country. Telephone interviews were conducted in countries where at least 80% of residents have telephone access or where it is the customary survey methodology. Survey sampling was representative of the national population aged 15 and older. The sampling frame includes all populated places within each country, both rural and urban, except inaccessible areas or where the safety of interviewers was threatened. In countries where face-to-face surveys were conducted, 100 to 135 ultimate clusters (Sampling Units) were selected, consisting of clusters of households. Sampling units were stratified by population size or geography and clustering was achieved through one or more stages of sampling. Where population information was available, sample selection was based on probabilities proportional to population size; otherwise simple random sampling was used. Samples were drawn independently of any samples drawn for surveys conducted in previous years. Within Sampling Units, random routes were used to sample households, with interviews attempted up to three times per household. Respondents were randomly selected within households using a Kish grid. In countries where telephone interviews were conducted, random-digit-dialling or a nationally representative list of phone numbers was used. In countries with high mobile phone use a dual mobile/land-line sampling frame was used.

Data analysis. This analysis used spatial climate data derived from the CRU TS 3.1 data set, a high-resolution ($0.5^\circ \times 0.5^\circ$) gridded global historical climate data set interpolated from station records[28]. Mean monthly temperature anomalies were calculated as the difference in the monthly mean of daily mean temperature in each grid cell from the 1961 to 1990 monthly mean. As population distribution is not spatially uniform within countries or administrative boundaries, this analysis used global gridded population distribution data to estimate the average temperature change experienced by a representative sample of the population within countries and subnational administrative regions. Temperature anomalies were extracted from climate grids using a spatial point model of population density created from the LandScan[29] 2008 global population grid using Monte Carlo simulation. Extracted climate values were averaged across population points within each country or subnational region to obtain population-weighted values that approximate a representative sample of the population within each area.

To test our hypotheses we calculated the 12-month running mean of the population-weighted monthly mean temperature anomalies at the national and subnational level for each respondent. We first compared group means by response to local temperature perceptions using Kruskal–Wallis one-way analysis of variance. To test climatic and individual influences on responses to the temperature perception item we constructed two sets of four multilevel binary logistic regression models, with the first set of models using the national-level climate data and the second set of models using the subnational level climate data.

This study relied on land surface temperature estimates averaged across the population distribution of countries or subnational units rather than local data geo-referenced at the household level. National or subnational data provide the best estimate of the average temperatures experienced by a representative sample of the population within regions of interest, but they do not capture variation within regions. The use of spatially aggregated data suggests that our results may underestimate the effect of local temperatures on perceptions, because higher-resolution pairing of respondent locations with climate data may allow more accurate measures of individual exposure, as we found when comparing results between data geo-referenced at the national level and the subnational level. These findings underscore the need for more precise geographic data in future survey research.

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Author contributions

P.D.H. conceptualized the research question and led the analysis. E.M.M. contributed to the research design and analysis. A.L. composed the survey item and contributed to the research design. T.M.L. and C-Y.K. assisted with research design. P.D.H. prepared the manuscript with input from all authors.

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.