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Experience exceeds awareness of anthropogenic climate change in Greenland

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Although Greenland is a hub for climate science, the climate perceptions of Greenland's predominantly Indigenous population have remained largely unstudied. Here we present two nationally representative surveys and show that Greenlanders are more likely than residents of top oil-producing Arctic countries to perceive that climate change is happening and about twice as likely to have personally experienced its effects. However, half are unaware that climate change is human-caused and those who are most affected appear to be least aware. Personal experience and awareness of human-induced climate change diverge along an Inuit cultural dimension. Indigenous identity positively predicts climate change experience, whereas subsistence occupation and no post-primary education negatively predict attribution beliefs. Despite Greenland's centrality to climate research, we uncover a gap between the scientific consensus and Kalaallit views of climate change, particularly among youth. This science–society gulf has implications for local climate adaptation, science communication and knowledge exchange between generations, institutions and communities.

Kalaallit Nunaat (Greenland) is home to the world's largest Indigenous population by percentage (~90%), living along the coastal margins of Earth's second largest ice sheet by volume[1,2]. Kalaallit Nunaat's physical environment is a critical tipping element in the Earth climate system contributing to global sea level rise and coastal inundation[3–5], and its human population is part of an intricate social-ecological system adapting to compound environmental changes[6–10]. The circumpolar region is warming several times faster than the global average[11], exposing ecosystems and populations—including Indigenous communities—to changes in sea ice[6,12], snow cover[13], permafrost[14,15], precipitation[16], rain-on-snow[17,18], ice sheet hydrology[19] and coastal sedimentary flux[20]. Coupled climate and social-ecological changes[21,22] pose adaptive challenges and opportunities for mobility and natural resource accessibility[23–26], traditional hunting and fishing[8,27], northern migration route and rangeland access[17,18,28], recreation and tourism[29–31], psychosocial outcomes and health[32–34], shipping and regional security[35,36], personal property and cultural heritage[37].

The Inuit are a highly adapted Arctic and subarctic Indigenous population spanning Kalaallit Nunaat, Inuit Nunangat in Canada and Alaska, as well as the Chukchi Peninsula in Siberia[38]. Kalaallit Nunaat, meaning 'The Land of Kalaallit', is a modern multi-ethnic society of around 56,000 people, most of whom have Inuit forebearers. Naalakkersuisut, the Government of Greenland, has initiated efforts to promote beneficial climate adaptation, and climate change has emerged as a topic of public interest and concern[39,40]. Today, the population is highly connected via phone, radio, internet and both televised and print-based news in Kalaallisut (Greenlandic) and Danish[2]. Knowledge coproduction linking Indigenous knowledge—knowledge orally transmitted from one generation to the next generation by Indigenous communities[41]—and scientific approaches to knowledge production, seeks to promote

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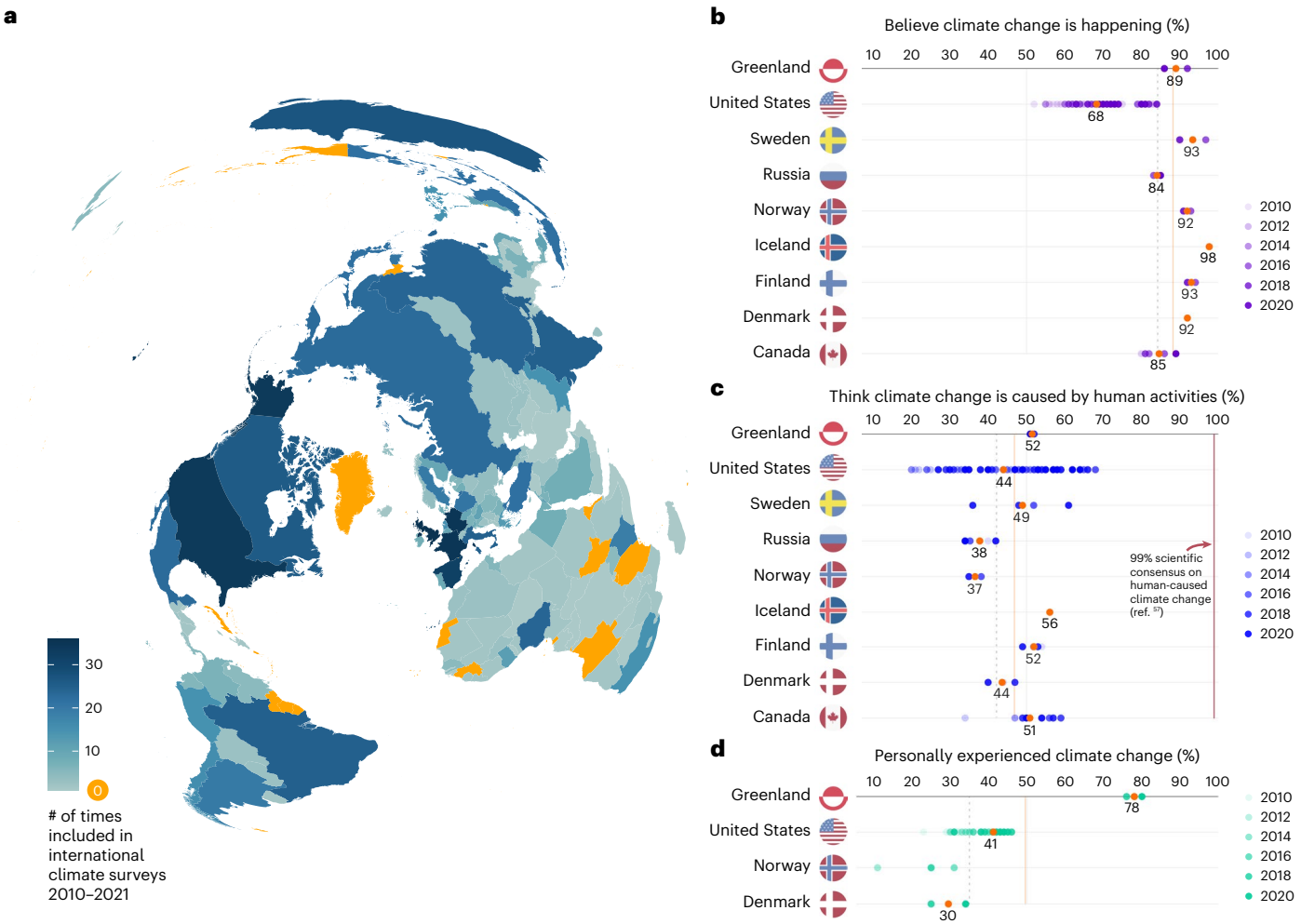

Fig. 1 | Previous international climate change social surveys have overlooked Greenland, where personal experiences of climate change are more pervasive. a, The perspectives of Kalaallit Nunaat's Inuit population have not been covered by multinational climate change opinion surveys conducted between 2010 and 2020 (Methods and Source Data). Darker blue regions indicate countries that were included more often, while those in orange have yet to be included. **b**, Drawing on population estimates from recent national surveys (Methods and Source Data), awareness that climate change is happening is higher on average in Kalaallit Nunaat than the average level of awareness across the top four oil-producing Arctic countries (dotted grey line), but similar to the average climate belief prevalence across all Arctic countries (orange line). Each coloured dot depicts the country-specific result for a given survey wave, while orange dots show the 2018–2020 averages. **c**, Knowledge of human-caused climate change is markedly lower among Greenlanders compared with publishing climate scientists (dark red line). **d**, More than twice as many Greenlanders say they have personally experienced the effects of climate change compared with other Arctic countries with equivalent data.

mutual understanding about the human dimensions of climate change in the circumpolar region[42]. Previous investigations have characterized how lived experiences of climate change in Kalaallit Nunaat are deeply situated in the variegated environments and coastal communities where Greenlanders live, work, recreate, hunt and fish[6,10,26,43–48].

Personal experience of climate change elsewhere is linked to climate change beliefs[49–53] and adaptive behaviours[54] that may in turn reduce vulnerability to climate impacts. Perception of the existence of climate change and knowledge about its primary human causes are touchstones of climate literacy and are predictive of mitigation and adaptation behaviours and intentions[54–56]. However, public perceptions lag behind the scientific consensus of human-caused climate change (Fig. 1c)[13,55,57,58], and cognitive, economic, sociopolitical and environmental factors can sway public knowledge about climate change in ways that are proadaptive or maladaptive[50,54,59–62]. Although Kalaallit Nunaat's ice sheet, landscapes and waters are populated with visiting physical scientists, automated environmental sensing devices and remote research platforms that inform the international scientific knowledge base on past climate variability and now-human-caused climate change[63], the climate beliefs and experiences of Greenland's own primarily Indigenous population have only recently been surveyed systematically, similar to other countries[49,50,59,61,64–68]. Recent research indicates that knowledge of human-caused climate change is positively associated with opportunistic climate adaptation policy preferences in Kalaallit Nunaat[23]. However, the overall prevalence, distribution and predictors of climate change personal experience and attribution beliefs remain unknown for Kalaallit Nunaat's communities (Fig. 1a).

In this paper, we examine four exploratory research questions. First, given Kalaallit Nunaat's elevated exposure and vulnerability to climate change[2,6,26,46], to what extent is Kalaallit Nunaat's population represented in previous multinational climate change social surveys compared to other countries globally? Second, since climate change beliefs can inform adaptive behaviours[54] yet may be swayed by carbon-intensive economic interests[69], how does awareness about the existence and primary cause of climate change among Kalaallit Nunaat's population compare to other Arctic regions and the largest oil producers among them? Third, how do climate change experiences and beliefs vary across Kalaallit Nunaat spatially and demographically?

Table 1 | Pooled survey sample composition before and after weighting by Statistics Greenland adult population demographic characteristics

Surveyed demographic group	# of respondents (unweighted)		% of sample (unweighted)		% of sample adjusted to Statistics Greenland population data (weighted)		% of combined sample (weighted)
	IPS '20–'21	GPS '18–'19	IPS '20–'21	GPS '18–'19	IPS '20–'21	GPS '18–'19	IPS+GPS
Total	939	646	100	100	100	100	100
Age: 18–29	232	108	25	17	25	24	24
Age: 30–39	178	132	19	20	19	18	19
Age: 40–49	111	110	12	17	14	15	14
Age: 50–64	295	193	31	30	30	29	30
Age: 65+	123	71	13	11	12	10	11
Age: Unreported	0	32	0	5	0	4	2
Self-identified gender: F	447	340	48	53	49	47	48
Self-identified gender: M	492	306	52	47	51	53	52
Region: Kujalleq (South)	122	73	13	12	12	12	12
Region: West Sermersooq (Southwest)	294	189	31	29	33	36	34
Region: East Sermersooq (East)	30	51	3	8	6	5	6
Region: Qeqqata (Midwest)	164	104	18	16	17	16	17
Region: Qeqertalik (Northwest)	132	92	14	14	12	12	12
Region: Avannaata (North)	197	137	21	21	20	19	19
Location: Town	827	507	88	78	87	87	87
Location: Village	112	139	12	22	13	13	13

Percent estimates rounded to the nearest whole number.

Fourth, what are the predictors of climate change experience and knowledge among Greenlanders, which are important for informed responses[54–56]? Because sociocultural factors frame climate perceptions in other Arctic regions[50,61], we further enquire whether an underlying social-ecological dimension predicts personal experience of climate change's effects or awareness of its anthropogenic cause.

To address these questions, we systematically reviewed previous international and Arctic national climate opinion surveys and conducted two original national surveys that adopted systematically inclusive approaches to invite the climate perspectives of representative samples of Kalaallit Nunaat's adult population. A combined total of 4% of Kalaallit Nunaat's adult population took either the 2018–2019 Greenlandic Perspectives (GPS) field survey ($N_1 = 646$) or the 2020–2021 Indigenous Perspectives (IPS) phone survey ($N_2 = 939$), which included identical climate change belief, personal experience items and additional demographic questions (Methods). All reported percentages and statistical estimates were weighted for representativeness to account for Kalaallit Nunaat's population distribution over this period using probability weights reflecting Statistics Greenland demographic population data (Table 1). Weighted logit regression models were employed to assess predictors of climate change experiences and beliefs (Methods, and Supplementary Tables 1 and 2). Our results reveal three paradoxes: (1) Greenland's residents are among the least-represented in previous multinational climate social surveys despite being among the most affected by climate change, (2) those 'personally experiencing' the effects the most are the least 'aware of human-caused' climate change and (3) Greenland's youth are relatively less aware of anthropogenic climate change, contrasting the global trend of youth-led climate engagement.

Results

International climate surveys are important global fora for mapping climate change knowledge to inform mitigative and adaptive decisions. Tabulating the total count of appearances in international climate change surveys between January 2010 and December 2020 reveals that Kalaallit Nunaat was not covered by any identified social surveys and polls assessed during this period (Fig. 1a and Methods). Among Arctic countries, Kalaallit Nunaat's residents constituted the only unsurveyed population.

Arctic populations' climate change perceptions

Averaging the results of two nationally representative surveys taken between 2018 and 2020, approximately 9 in 10 (89%) residents of Kalaallit Nunaat are aware climate change is happening, in line with the average awareness found in other Arctic countries (Fig. 1b and Source Data Fig. 1), and Iceland's residents are most aware (98%). The top five oil-producing Arctic countries in 2020 (United States, Russia, Canada, Norway and Denmark[70]), including top contributors to anthropogenic climate change historically, have relatively lower population awareness that climate change is happening on average (84%), with the lowest awareness found in the United States (68%), followed by Russia (84%) and Canada (85%).

Despite Greenland's centrality to climate science, only half of Kalaallit Nunaat's population (52%) know that climate change is primarily human-caused (Fig. 1c), marginally higher than Arctic countries generally (47%) and considerably higher than the top five oil-producing Arctic countries (43%). Knowledge that climate change is mainly human-caused lags behind the scientific consensus across all Arctic countries and was lowest on average from 2018–2020 in Norway (37%), Russia (38%), Denmark and the United States (44%) (Fig. 1c and Source Data Fig. 1). By contrast, about 8 in 10 Greenlanders (78%) report that they have personally experienced the effects of climate change, over twice the average in top oil-producing Arctic countries (36%) (Fig. 1d and Methods).

Regional and demographic differences in climate perceptions

We find vast majorities in each regional subpopulation reporting that they have personally experienced the effects of climate change (Fig. 2b),

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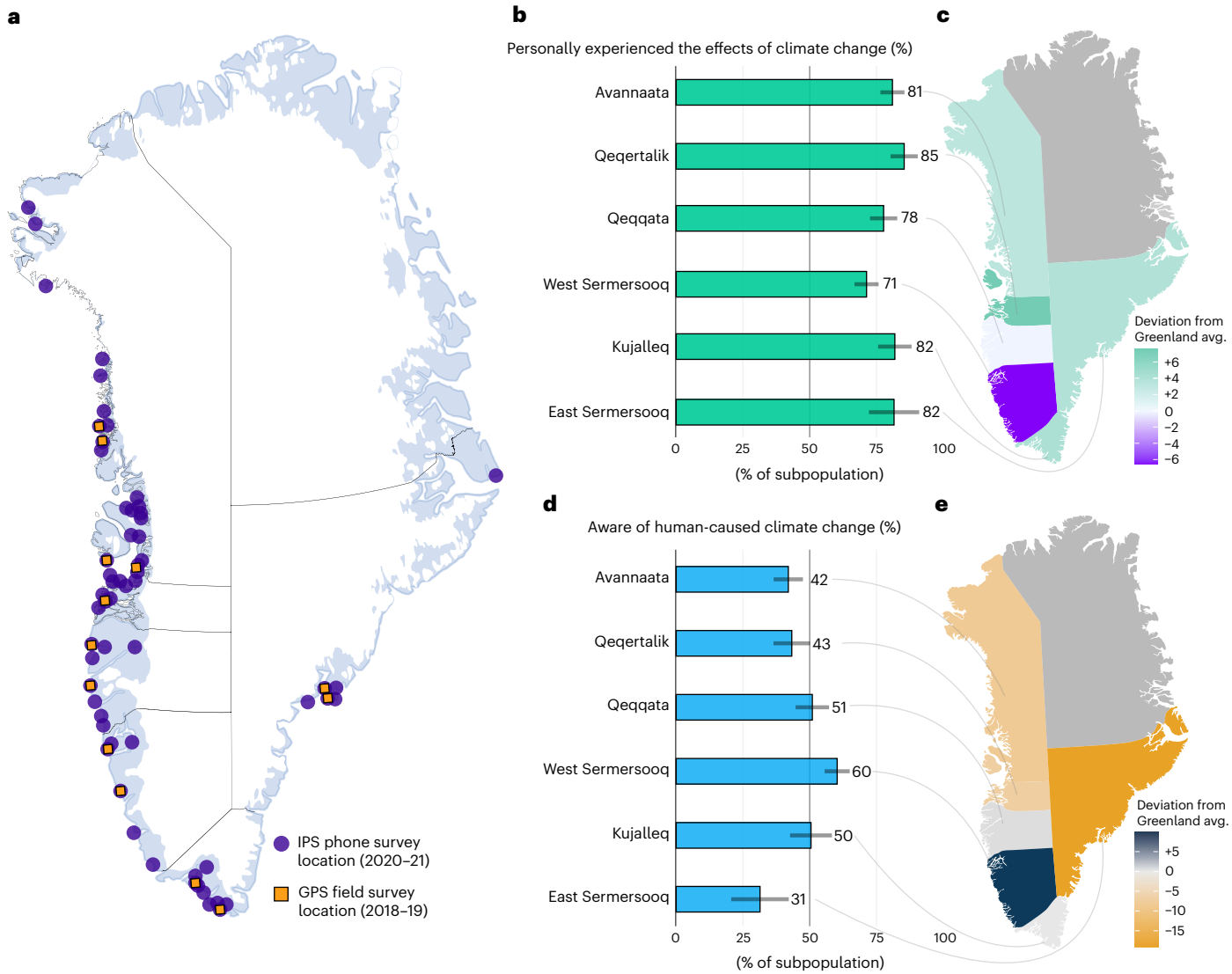

Fig. 2 | Personal experience of climate change's effects greatly exceeds awareness of its primary human cause in Kalaallit Nunaat. a, Between 2018 and 2021, ~4% of Kalaallit Nunaat's adult population took the GPS or IPS climate surveys. Purple dots indicate locations sampled by the IPS phone survey and orange shapes depict towns (squares) and villages (circles) sampled by the GPS field survey. **b**, Large majorities of residents across all of Kalaallit Nunaat's geographic regions report that they have personally experienced the effects of climate change. Error bars depict 95% confidence intervals (CIs). Avannaata $n = 334$, Qeqertalik $n = 224$, Qeqqata $n = 268$, West Sermersooq $n = 483$, Kujalleq $n = 195$, East Sermersooq $n = 81$. **c**, Personal experiences of climate change are more pervasive (darker green) among residents in northwest Kalaallit Nunaat and marginally less pervasive (darker purple) among residents in the southwest capital region. **d**, Approximately half or fewer residents in all but Kalaallit Nunaat's capital region are aware of human-caused climate change. Error bars depict 95% CIs. Avannaata $n = 334$, Qeqertalik $n = 224$, Qeqqata $n = 268$, West Sermersooq $n = 483$, Kujalleq $n = 195$, East Sermersooq $n = 81$. **e**, Awareness of human-caused climate change is highest in the southwest capital region containing the city of Nuuk, but is lower than the national average in north, northwest and east Kalaallit Nunaat. Basemaps in **a**, **c** and **e** were adapted from Statistics Greenland (http://www.stat.gl/GFE2021/p1).

with higher prevalence in Qeqertalik (85 ± 5%), Kujalleq (82 ± 6%), East Sermersooq (82 ± 9%), Avannaata (81 ± 5%) and Qeqqata (78 ± 5%), compared with the capital region of West Sermersooq (~71 ± 4%). Conversely, a majority of residents in West Sermersooq (60 ± 4%) attribute climate change to human causes, whereas fewer than half do in Qeqertalik (43% ± 7%), Avannaata (42 ± 5%) and East Sermersooq (31 ± 10%). These results indicate that regions where relatively more people have personally experienced climate change's effects also tend to have relatively less awareness of human-induced climate change (Fig. 2c,e).

We also uncover age and education-specific differences in climate change perceptions (Fig. 3). Young adults have lower awareness of human-caused climate change (43 ± 6%). Similarly, the prevalence of personal experience of climate change is lowest among young adults (67 ± 5%) increasing consistently across the lifespan before plateauing around the age of 50 (85 ± 3%). Among adult residents with no post-elementary education, only about 4 in 10 (39 ± 4%) attribute climate change to human causes, compared with nearly 6 in 10 (58 ± 3%) residents with post-primary education. Despite these differences in attribution beliefs, the prevalence of climate change experience is similar across education levels.

Interestingly, a diverging pattern of climate change personal experience and awareness of anthropogenic climate change extends across social-ecological dimensions of community scale, Indigenous identity and subsistence occupation (Fig. 3). The prevalence of people who have personally experienced climate change's effects is highest among hunters or fishers (84 ± 6%), village residents (83 ± 5%) and those identifying as Kalaallit (80 ± 3%), whereas relatively greater awareness

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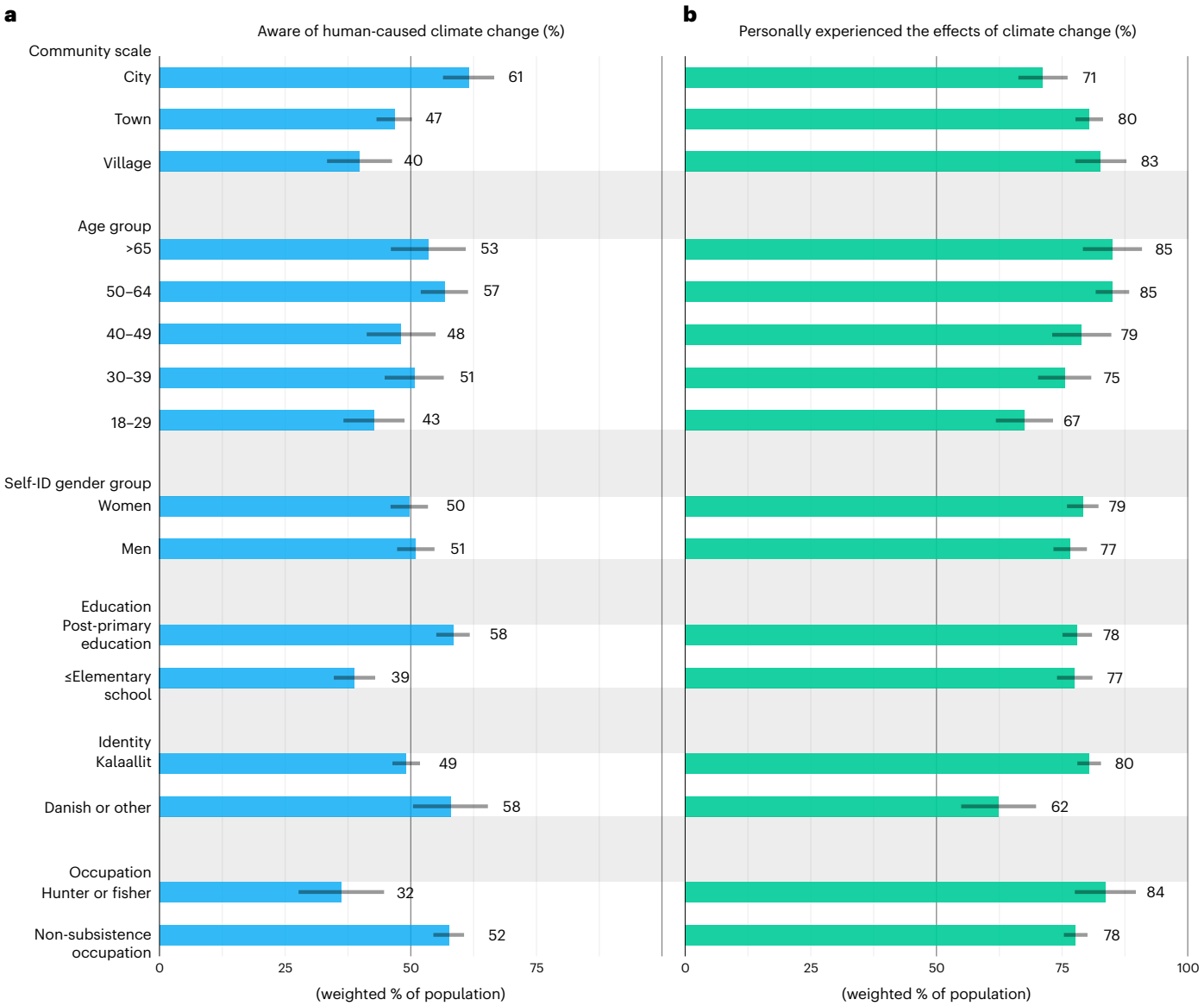

Fig. 3 | Climate change knowledge and experience vary considerably across socioenvironmental and demographic contexts. a, Awareness of anthropogenic climate change is higher among more populated communities, older age groups, post-elementary educated demographics, mixed or Danish identity groups and non-subsistence occupations. Separate colour shades indicate different subpopulation comparisons. Error bars depict 95% CIs around subpopulation-weighted mean estimates. City $n = 416$, town $n = 918$, village $n = 251$; 18–29 yr $n = 340$, 30–39 yr $n = 310$, 40–49 yr $n = 221$, 50–64 yr $n = 488$, ≥65 yr $n = 194$; post-primary education $n = 935$, primary school or less $n = 650$; mixed or Danish identity $n = 197$, Kalaallit identity $n = 1{,}388$; non-subsistence occupation $n = 1{,}374$, hunting or fishing occupation $n = 172$. **b**, The prevalence of those who say they have personally experienced the effects of climate change is higher in less populated community contexts, older age groups, those who identify as Kalaallit and among hunters and fishers. Error bars depict 95% CIs. City $n = 416$, town $n = 918$, village $n = 251$; 18–29 yr $n = 340$, 30–39 yr $n = 310$, 40–49 yr $n = 221$, 50–64 yr $n = 488$, ≥65 yr $n = 194$; post-primary education $n = 935$, primary school or less $n = 650$; mixed or Danish identity $n = 197$, Kalaallit identity $n = 1{,}388$; non-subsistence occupation $n = 1{,}374$, hunting or fishing occupation $n = 172$.

of anthropogenic climate change was found among more populated communities, those who identify as Danish or mixed identity (58 ± 7%) and those employed in non-subsistence occupations (52 ± 3%).

Thus, while about 6 in 10 (61 ± 5%) residents attribute climate change to human causes in the capital city of Nuuk, only about 4 in 10 (40 ± 6%) do in villages where more than 8 in 10 (83 ± 5%) report personally experiencing the effects of climate change.

Predictors of climate change experience and awareness

Inuit culture is theorized to consist of deeply intertwined cultural and social-ecological dimensions[6,44]. Inspecting demographic characteristics across community scales confirms that a greater proportion of residents in village communities respectively identify as Kalaallit (village: 96 ± 3% vs city: 73 ± 4%), have no post-elementary education (village: 62 ± 6% vs city: 20 ± 4%) and are employed as hunters or fishers (village: 26 ± 6% vs city: 7 ± 3%) (Fig. 4a). These separate variables are geographically and socially interrelated. Factor analysis suggests that for analytical purposes, they might be parsimoniously combined to form an indicator for an underlying Inuit cultural dimension (Supplementary Fig. 1 and Methods).

Inuit culture correlates, of course, with other individual and place characteristics, such as people's age and whether they live in towns or smaller settlements (Fig. 4a). The stratified population-weighted estimates graphed in Fig. 3 might plausibly reflect some of these other factors and be partly spurious. To test this possibility and assess the relative strength of various individual and place characteristics,

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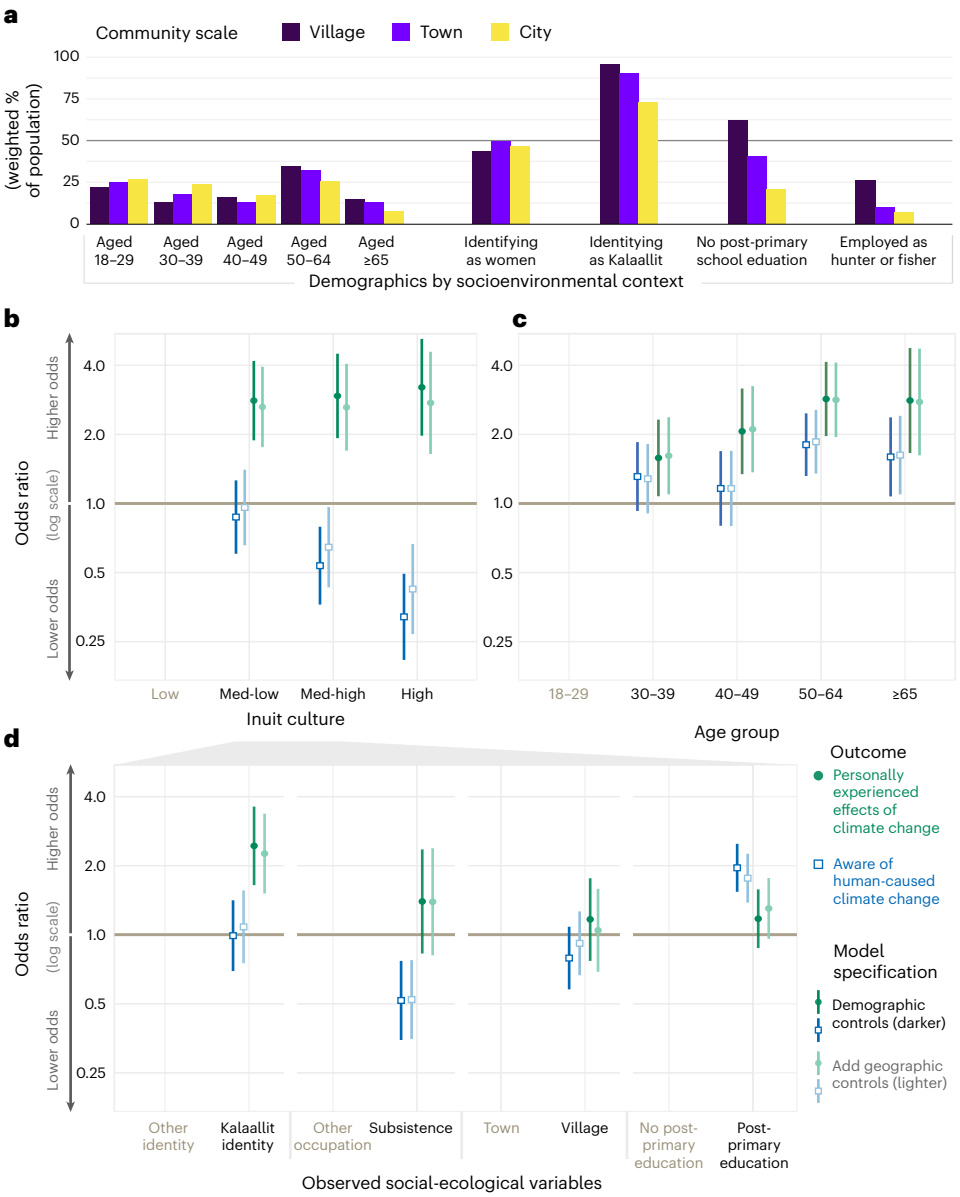

Fig. 4 | Inuit culture is the predominant positive predictor of climate change personal experience and negative predictor of awareness of anthropogenic climate change. a, Villages have a higher percent of residents who respectively identify as Kalaallit, have no post-elementary education and are employed as hunters or fishers. **b**, Controlling for demographic factors, Inuit culture is positively associated with personal experience of the effects of climate change (green) but negatively associated with awareness of human-caused climate change (blue). The estimated relationships remain significant when additionally controlling for geographic factors (lighter colours). Estimates are multiplicative effects compared to the baseline reference category (gold line). Error bars depict 95% CIs. High Inuit culture $n = 261$, Medium high Inuit culture $n = 430$, Medium low Inuit culture $n = 691$, Low Inuit culture $n = 171$. **c**, Personal experience of the effects of climate change monotonically increases across age cohorts while awareness of anthropogenic climate change only significantly increases in later adulthood. Error bars depict 95% CIs. 18–29 yr $n = 340$, 30–39 yr $n = 310$, 40–49 yr $n = 221$, 50–64 yr $n = 488$, ≥65 yr $n = 194$. **d**, Substituting observed variables for the Inuit cultural factor, Kalaallit identity positively predicts climate change personal experience, whereas post-primary education and subsistence occupation emerge sequentially as positive and negative predictors of awareness of human-caused climate change. Error bars depict 95% CIs. Village $n = 243$, Town $n = 1273$; no post-primary education $n = 587$, post-primary school $n = 929$; mixed or Danish identity $n = 165$, Kalaallit identity $n = 1,351$; non-subsistence occupation $n = 1,347$, hunting or fishing occupation $n = 169$.

we entered them together as predictors in weighted logit regression models (Supplementary Tables 1 and 2). Controlling for demographic factors, we find that the odds individuals with high levels of Inuit culture have personally experienced the effects of climate change are 3.2 (95% CI: 2.0–5.2) times those of individuals with low levels (Fig. 4b, dark green estimates). Conversely, the odds adults with high levels of Inuit culture attribute climate change to human causes are only about a third (0.3, (0.2–0.5)) of those with low levels of the Inuit cultural component (Fig. 4b, dark blue estimates).

Examining the effect of age after controlling for gender and Inuit culture, we find that personal experience of climate change increases significantly across sequentially older age groups compared with the young adult baseline (Fig. 4c), consistent with our subpopulation estimates (Fig. 3b). The odds that residents 65 and older have personally experienced climate change are 2.8 (1.7–4.8) times those of young adults. Awareness of anthropogenic climate change increases significantly in later adulthood. The odds that adults aged 50–64 attribute climate change to human causes are 1.8 (1.3–2.5) times those of young

adults aged 18–29. Comparing effect sizes (Fig. 3a,b), we find that Inuit culture is the dominant negative predictor of awareness of anthropogenic climate change and the main positive predictor of personal experience of its effects, surpassing other sociodemographic factors (Supplementary Tables 1 and 2).

Substituting the Inuit culture component with the underlying observed factors in our full weighted logit specification (Methods), education level and older age emerge successively as the strongest positive predictors of 'awareness of anthropogenic' climate change, whereas subsistence occupation is the strongest negative predictor. Kalaallit identity is neither a significant nor sizable predictor of attributing climate change to human causes (Supplementary Table 2). By contrast, Indigenous identity and older age are the strongest predictors of 'personally experiencing' climate change effects, while educational attainment is not a significant predictor (Supplementary Table 1). Adjusting for age, education and subsistence occupation appear associated with divergent beliefs about the extent to which climate behaviour can be altered by human behaviour, while Indigenous identity and associated beliefs or practices may predict experiences of the effects of climate change to a greater degree. All of our primary results persist when adjusting for regional differences (Fig. 4b–d, lighter-coloured estimates) as well as survey wave (Supplementary Tables 1 and 2).

Discussion

Our study uncovers two climate information gaps. First, multinational climate change social surveys conducted over the past decade have routinely overlooked the perceptions of the world's largest Indigenous country by percent of total population. Presenting comprehensive evidence from the first two nationally representative surveys on climate change experience and attribution beliefs in Greenland, we find that most residents are personally experiencing the effects of climate change—approximately twice the percentage seen in top oil-producing Arctic countries. Second, despite being one of the most visited destinations by climate scientists, our results imply that Kalaallit Nunaat's population may not have broad access to the science these visitors produce, including fundamental information on anthropogenic climate change needed for informed adaptation. In Kalaallit Nunaat, we find evidence of a mismatch. 'Awareness of anthropogenic' climate change is lowest among the Kalaallit communities who are 'personally experiencing' the effects of climate change most acutely. In Kalaallit Nunaat's villages, the power relation between human behaviour and climate patterns may be primarily experienced in reverse. There, the number of people who have experienced climate change outnumber those who attribute climate change to human activities by two to one. The gap between the scientific consensus on human-caused climate change and public beliefs is greatest in the east and northwest regions of Kalaallit Nunaat (Supplementary Table 2).

Pronounced warming and high internal climate variability in Greenland may expose communities to climatic changes but increase the psychological distance[71] to the anthropogenic signal in the climate system in the short term, whereas this signal may become more discernible with age (Fig. 4c and Supplementary Information: Theoretical implications). Previous Indigenous knowledge from Greenland suggests that Sila—meaning the Spirit of the air, weather, intelligence/consciousness and the natural condition of the world[72]—is a pervasive life-giving and taking force that integrates Inuit selfhood with the rhythms of the natural world and universe[73]. As such, climatic changes may be experienced acutely and personally by those who identify as Kalaallit[74]. Among Kalaallit navigating often unpredictable weather and sea conditions to subsist, primarily outside of more urbanized areas, humans may not be viewed as powerful in relation to Sila. These results contribute to earlier ethnographic and social evidence of elevated perceived climate impacts in Arctic Indigenous communities[6,43,74–76] and are consistent with climate change information deficits found among non-Arctic communities disproportionately exposed to climate impacts[51,52,55]. Large-scale climate opinion surveys have historically not reached many Indigenous and tribal communities, and we show that global regional coverage remains uneven (Fig. 1a). Since awareness of anthropogenic climate change has been shown to be predictive of societal adaptation policy support in Kalaallit Nunaat[23], the science–society gap highlighted here may pose a psychosocial barrier to transformative adaptive actions[2,7,8,29–31,35,36,39,54].

There are several considerations that should be weighed when interpreting this study. First, since national survey designs, sampling approaches, question items, administration approaches and survey dates varied across most Arctic countries, our inter-regional comparisons should be interpreted as indicative estimates of underlying population differences in climate beliefs. Nevertheless, comparing our results to equivalently worded survey items[77] administered in the top oil-producing Arctic country (United States) yields consistent comparative results (Source Data Fig. 1). Second, since our national survey results for Kalaallit Nunaat rely on a pooled analysis of two survey waves, it is possible that systematic differences in survey administration and sampling approaches between the IPS and GPS may slightly bias inference. To test and statistically adjust for any systematic differences in responses across the two survey waves, we repeated our analyses including a dummy variable denoting the waves. Differences between waves were not significant (Supplementary Tables 1 and 2).

Third, it is likely that other unmeasured psychosocial, sociodemographic or environmental factors[53] may be important predictors of personal experience and awareness of anthropogenic climate change. For instance, other factors that sculpt worldviews, including sociopolitical identity, may be consequential for climate change beliefs in Kalaallit Nunaat, similar to patterns seen in other countries[50,61,62]. We confirm that our results persist when adding sociopolitical controls to our full model (Supplementary Tables 1 and 2), suggesting that an information deficit may be in part linked to Greenland's apparent science–society gulf in climate beliefs. Fourth, although the present study statistically adjusted for regional factors, controlling for general differences in internet speed and access, future investigations should examine the putative influence of media usage and online exposure to climate change information in the Arctic[40,78]. Lastly, future mixed methods research should seek to elucidate the processes elevating climate change experiences and diminishing awareness of anthropogenic climate change among Inuit in Kalaallit Nunaat, and to establish whether this diverging pattern extends across Inuit Nunangat, Sápmi and the Chukchi Peninsula.

Despite the influx of climate scientists to Kalaallit Nunaat, our results reveal a rift between the scientific consensus and coastal Indigenous views of climate change. To bridge this science–society gulf, we recommend that Kalaallit Nunaat's policymakers, civic institutions, foundations and researchers support the convergence of highly adaptive Inuit knowledge of Sila and local climate variability with climate scientists' knowledge of Kalaallit Nunaat's climate in the deep past and future trajectory within Earth's changing climate system. We recommend that the most salient insights of climate science, including both the scientific consensus on human-caused climate change, downscaled climate projections for Kalaallit Nunaat and historical insights derived from the Greenland Ice Sheet, be widely disseminated and integrated into Greenland's primary school educational curricula in concert with Inuit knowledge. Prioritizing parity of Kalaallit climate experience and international climate science may help to ensure that the future generations of Greenlanders can be equipped with the diverse knowledge distilled from one of the largest Indigenous-managed areas in the world[79]—knowledge that may be increasingly needed to make informed decisions about climate adaptation and mitigation in a warming Arctic.

As it currently stands, Kalaallit Nunaat's young adults are the least aware of anthropogenic climate change across age groups, opposite the pattern of youth-led climate change awareness and concern

found in several other countries[50,67,80,81]. While future research should seek to uncover the possible online and offline social drivers of this intergenerational knowledge gap, a recent survey found limited certainty of human-caused climate change among Greenland's pre-service teachers[82]. Improving access to climate science via the engagement of Greenland's civic institutions, Kalaallit-led teacher training, curricular development, additional education[83], intergenerational dialogue, community outreach, media involvement and weathercaster communication[84] may be formative for linking experienced climatic changes to carbon-intensive human activities globally and locally. Such awareness may be an important antecedent for assessing loss and damage from human-caused climate change in Greenland, navigating complex sustainability challenges in the new Arctic and adapting to transformative opportunities afforded by amplified warming.

Online content

Any methods, additional references, Nature Portfolio reporting summaries, source data, extended data, supplementary information, acknowledgements, peer review information; details of author contributions and competing interests; and statements of data and code availability are available at https://doi.org/10.1038/s41558-023-01701-9.

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Methods

We conducted two national surveys of residents' views about environmental changes, which have been previously described[23,40].

The IPS phone survey

The IPS, a national telephone survey, was administered by trained native-speaking staff from the independent polling organization HS Analyse, based in Nuuk. Personnel contacted randomly selected phone numbers from adult residents residing in all of Kalaallit Nunaat's municipal regions. The numbers were drawn from a comprehensive list of all registered landline, mobile phone and pre-paid sim card numbers in Kalaallit Nunaat. Adult respondents (939) completed the survey between December 2020 and January 2021, equivalent to nearly ~2.5% of Greenland's adult population, yielding country-level margins of error of ±3 percentage points at the 95% confidence level.

The GPS field survey

The GPS, a national field survey, was conducted across all geographic regions of Kalaallit Nunaat from July 2018 to January 2019 by trained research personnel affiliated with Ilisimatusarfik (University of Greenland) and the University of Copenhagen[40]. In partnership with Statistics Greenland, surveys were randomly allocated to residents living in randomly selected towns and settlements from each of Greenland's municipalities and geographic regions, along with Nuuk and Upernavik. Nearly 2% of the adult population ($n = 646$) took the survey, yielding country-level margins of error between ±3 and ±4 percentage points at the 95% confidence level. The GPS sampling design consisted of a stratified multistage cluster sampling procedure. In the first stage, Kalaallit Nunaat was separated into each of its five municipal regions[85], with Sermersooq separated into both West and East coasts, resulting in six primary geographic regions (Fig. 2). Locations within each were classified using Statistics Greenland operationalized definitions, where locations with more than approximately 500 residents were labelled as towns. This resulted in 12 stratified geographic layers, with one layer for each region's collection of settlements and one for each region's towns. Locations were randomly sampled from these geographic layers using R statistical software, while Nuuk was sampled as a self-representing city within the West Sermersooq town layer (Nuuk contains ~30% of Kalaallit Nunaat's total adult population), and the additional self-representing town of Upernavik was sampled in the northern half of the Avannaata region to extend coverage along Kalaallit Nunaat's geographically extensive north coastal margin. Statistics Greenland then randomly allocated surveys within each of these 13 locations proportionally to the population total for the corresponding geographic layer, using the universe of population registry data for each location. Since the GPS field survey was administered in person by trained research assistants, randomly selected participants were able to participate even if they did not have internet access or a connected phone, and they were provided the option to dictate their answers verbally if they lacked the ability to read or write.

Applying AAPOR standard definition 4 (ref. 86), we recovered similar response rates of 47% for the IPS phone survey and 46% for the GPS field survey. To correct for potential sampling biases, probability weights were applied to ensure results were representative for the adult population. Consistent across survey waves, analyses were weighted for representativeness by self-identified gender, age group and municipal division, using demographic registry data for Kalaallit Nunaat's adult population in 2018 (GPS) and 2020 (IPS) (Table 1), as serviced by Statistics Greenland (www.stat.gl). The surveys were administered in three languages: Kalaallisut (Greenlandic), Danish and English and each question was tri-lingually translated and reverse-translated to ensure continuity.

The three climate survey items employed in this study were consistent across the IPS and GPS survey waves and adopted the item structure of standard multiple-choice climate change awareness, knowledge and perception questions widely used in the literature, including in other Arctic countries. All climate perception items were piloted in advance of the full survey administration in both Danish and Kalaallisut among students at Ilisimatusarfik (University of Greenland), as well as among adult residents in the village of Kapisillit. Additional demographic background items were also fielded to control for age group, self-identified gender and other common sociodemographic factors.

Inclusion and ethics

The research included local researchers and research assistants throughout the research process, including the study design, data collection, interpretation and authorship. To avoid potential information delay and dislocation, rapid national survey results from the GPS survey were shared with the public first via local presentations and a visual report published by Ilisimatusarfik. We took into account local and regional research relevant to our study. Survey research administration and analysis followed the American Association for Public Opinion Research code of ethics and informed consent was obtained from all respondents. The GPS field survey additionally received ethical approval for in-person surveying from the Scientific Ethical Committee for Health Sciences Research in Greenland. All respondent information from both surveys was anonymized in a pre-processing stage.

Factor analysis

To assess whether the intertwined factors of community scale, Indigenous identity, education and subsistence occupation reduced to an underlying cultural dimension, we entered these variables together in a principal components factor analysis. All variables loaded onto a single latent dimension, explaining 61% of the combined variance. Additionally, we conducted a parallel analysis comparing scree plots of the data to random parallel matrices, finding clear visual evidence of a break after the first component (Supplementary Fig. 1). The first principal component yielded an eigenvalue over 2; other components had eigenvalues below 1, meaning each accounted for less than a single indicator's variance.

Survey analysis

We followed a common quantitative empirical approach for survey analysis described previously[23]. Population-weighted national and subnational response estimates were computed using R (v4.1.3) and the R 'Survey' package[87]. We estimated primary and secondary weighted quasi-binomial logit regressions to sequentially assess and test predictors of climate change knowledge and experience, while also assessing robustness to adjusting for additional sociospatial covariates (Supplementary Tables 1 and 2).

Assuming that $p(y_i = 1)$ denotes the conditional probability of a specific climate change experience response (for example, Personal experience of climate change) or knowledge response (for example, Awareness of anthropogenic climate change) for the individual respondent, the odds of this response is given as $O(y_i = 1) = p(y_i = 1)/p(y_i \neq 1)$. This logistic regression specification models the conditional log odds as a function of k predictor variables $x_{1i}, x_{2i}, \ldots, x_{ki}$.

$$\ln[O(y_i = 1)] = \ln\left[\frac{p(y_i = 1)}{p(y_i \neq 1)}\right] = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \ldots + \beta_k x_{ki} + \epsilon_i \quad (1)$$

We estimated equation (1) via a weighted quasi-binomial method described in ref. 87 and exponentiated the estimated β coefficients to obtain odds ratios, interpreted as the multiplicative effects on $O(y_i = 1)$. Odds ratios greater than 1.0 imply that higher values of an independent variable are associated with higher odds that $y = 1$ and thus signify 'positive effects', while odds ratios below 1.0 mean that higher x values are associated with lower odds that $y = 1$ and thus describe 'negative effects'.

We specified predictors for each outcome of interest, starting with our preferred multivariate model that estimates the conditional probability of possessing a particular climate belief as a function of the factor analysis-derived variable of Inuit Culture binned into four component loading levels (base: culture level low) and the sociodemographic covariates of self-identified gender (base: men) and age group (base: adults aged 18–29). Then we proceeded sequentially to models that add a geographic categorical control variable with levels for each primary municipal region, with Sermersooq divided into West and East coastal regions following the natural Greenland Ice Sheet boundary (base: West Sermersooq (Capital Region) (Fig. 2b)). Awareness of anthropogenic climate change, which is a standard measure in studies on climate-related opinions and behaviours[88], was coded using the responses from two standard survey items previously piloted and adapted for use in nationwide surveys in Kalaallit Nunaat, following a previously described approach[23]. Question items for climate change beliefs, knowledge and personal experience were adopted from a Yale-George Mason CCAM survey[89] and adapted to the Kalaallit context and Kalaallisut via pilot studies with the input of students at Ilisimatusarfik and community members from Nuuk and Kapisillit. The first item assesses climate change awareness ('1. Do you think that climate change is happening?'), while the second records knowledge about the perceived primary cause of climate change ('2. If climate change is happening, do you think it is caused mostly by…?'). Accordingly, respondents who responded 'Yes' to climate change happening and 'Human activities' as the main cause of climate change were coded as being aware of anthropogenic climate change (AACC = 1) while those who responded otherwise were coded as unaware of human-caused climate change (AACC = 0), creating a binary indicator comparable to those used in many non-Arctic studies[67,68,88]. Similarly, affirmative responses to the climate change experience item ('3. Have you personally experienced the effects of climate change?') were coded as a binary outcome where EXP = 1 signified that a respondent had experienced the effects of climate change.

International climate survey inclusion analysis

2010 was the first complete calendar year following the passage of 'The Self-Government Act' in Kalaallit Nunaat which also granted Greenlanders' legal recognition as a separate people from Danes under international law. To assess the relative frequency in which countries' populations have been invited to share their climate perceptions and opinions as part of international climate opinion surveys conducted over the period from January 2010 to December 2020, we conducted Google Scholar searches (scoped to English language surveys) using the search strings: (1) 'global climate change survey' OR 'global climate change poll' OR 'international climate change survey' OR 'international climate change poll' OR 'world climate change survey' OR 'world climate change poll' OR 'multinational climate change survey' OR 'multinational climate change poll' and (2) ('climate' OR 'climate change' OR 'global warming') AND ('world' OR 'global' OR 'worldwide' OR 'international' OR 'multinational') AND ('survey' OR 'poll'). Additionally, we conducted a Google search of grey literature featuring international climate opinion polls, using the same search criteria. When relevant surveys were identified, additional manual searches were conducted to locate other international climate surveys or polls conducted by a given polling organization (for example, Gallup, Pew, Globescan and so on). We identified 1,144 total country-level survey appearances during the scoping period, with invited countries spanning all inhabited continents except for Antarctica (Source Data: Fig. 1 2010_2020_Global_Climate_Survey_Coverage.csv).

For the subset of Arctic countries, national survey estimates derived from questions that asked participants about their awareness that climate change is happening, knowledge that climate change is primarily human-caused and experience of climate change were extracted from both the international surveys identified by our initial literature search (outlined above) as well as an additional literature search where we modified our previous search criteria to identify Arctic country-specific survey results. Specifically, we used the search strings (1) (Arctic country name) AND ('climate change survey' OR 'climate change poll' OR 'global warming survey' OR 'global warming poll') AND ('aware*' OR 'knowledge' OR 'literacy' OR 'literate' OR 'opinion*' OR 'belief*' OR 'perception*' OR 'experience*') and (2) (Arctic country name) AND ('climate' OR 'climate change' OR 'global warming') AND ('*survey' OR '*poll'). For each country-specific search, we scanned the first ten pages of Google Scholar results for articles containing relevant national survey estimates for climate change awareness, knowledge or experience outcomes (Source Data: Fig. 1 2010_2020_Arctic_Nation_Climate_Survey_Responses.csv).

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The anonymized replication data that support the findings of this study are available at https://doi.org/10.7910/DVN/FQNJYO. Source data are provided with this paper.

Code availability

The code employed in this article's analysis is available at https://doi.org/10.7910/DVN/FQNJYO (ref. 90).

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Author contributions

K.M., M.T.R., D.D.L., L.H. and M.L.J. conceptualized the project; K.M. and L.H. structured the data; K.M. and L.H. conducted formal analysis; K.M., M.L.J., L.H., D.D.L., M.T.R. and M.B. conducted investigations; K.M., L.H., M.T.R. and D.D.L. developed the methodology; K.M. and L.H. developed software; K.M. and L.H. performed visualization; K.M. wrote the original draft; K.M., M.L.J., M.T.R., L.H., D.D.L. and M.B. reviewed and edited the manuscript; M.T.R., D.D.L. and L.H. supervised the project; D.D.L., M.T.R., K.M. and M.B acquired funding.

Competing interests

The authors declare no competing interests.

Additional information

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Software and code

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Policy information about availability of data

All manuscripts must include a data availability statement. This statement should provide the following information, where applicable:

- Accession codes, unique identifiers, or web links for publicly available datasets
- A description of any restrictions on data availability
- For clinical datasets or third party data, please ensure that the statement adheres to our policy

All respondent information was anonymized in a pre-processing stage, and only aggregate statistics are reported. Summarized multi-national and Arctic country survey data are available as supplementary files. The data and code that support the findings of this study will be deposited via Harvard's Dataverse prior to publication.

Human research participants

Policy information about studies involving human research participants and Sex and Gender in Research.

Reporting on sex and gender	Results are presented in the manuscript by self-identified gender.
Population characteristics	See behavioural and social sciences study section and description below for a description of how representative samples were drawn from the Greenland adult population.
Recruitment	The IPS phone survey The IPS, a national telephone survey, was administered by trained, native-speaking staff from the independent polling organization HS Analyse, based in Nuuk. Personnel contacted randomly selected phone numbers from adult residents residing in all of Kalaallit Nunaat's municipal regions. The numbers were drawn from a comprehensive list of all registered landline, mobile phone and pre-paid sim card numbers in Kalaallit Nunaat. 939 adult respondents completed the survey, equivalent to nearly ~2.5% of Greenland's adult population, yielding country-level margins of error of ±3 percentage points at the 95% confidence level. The GPS field survey The GPS, a national field survey was conducted across all geographic regions of Kalaallit Nunaat from July 2018 – January 2019 by trained research personnel affiliated with Ilisimatusarfik (University of Greenland) and University of Copenhagen(34). In partnership with Statistics Greenland, surveys were randomly allocated to residents living in randomly selected towns and settlements from each of Greenland's municipalities and geographic regions, along with Nuuk and Upernavik. Nearly 2% of the adult population (n = 646) took the survey, yielding country-level margins of error between ±3 to ±4 percentage points at the 95% confidence level. The GPS sampling design consisted of a stratified multi-stage cluster sampling procedure. In a first stage, Kalaallit Nunaat was separated into each of its five municipal regions with Sermersooq separated into both West and East coasts, resulting in six primary geographic regions. Locations within each were classified using Statistics Greenland operationalized definitions, where locations with more than approximately 500 residents were labelled as towns. This resulted in 12 stratified geographic layers, with one layer for each region's collection of settlements and one for each region's towns. Locations were randomly sampled from these geographic layers using R statistical software, while Nuuk was sampled as a self-representing city within the West Sermersooq Town layer (Nuuk contains >~30% of Kalaallit Nunaat's total adult population) and the additional self-representing town of Upernavik was sampled in the northern half of the Avannaata region to extend coverage along Kalaallit Nunaat's geographically extensive north coastal margin. Statistics Greenland then randomly allocated surveys within each of these 13 locations proportionally to the population total for the corresponding geographic layer, using the universe of population registry data for each location. Since the GPS field survey was administered in person by trained research assistants, randomly selected participants were able to participate even if they did not have internet access or a connected phone, and they were provided the option to dictate their answers verbally if they lacked the ability to read or write.
Ethics oversight	The research included local researchers and research assistants throughout the research process, including the study design, data collection, interpretation and authorship. To avoid potential information delay and dislocation, rapid national survey results from the GPS survey were shared with the public first via local presentations and a visual report published by Ilisimatusarfik. We have taken local and regional research relevant to our study into account. All respondent information was anonymized in a pre-processing stage, and only aggregate statistics are reported. Survey research administration and analysis followed the American Association for Public Opinion Research code of ethics and informed consent was obtained from all participants. The GPS field survey additionally received ethical approval for in-person surveying from the Scientific Ethical Committee for Health Sciences Research in Greenland.

Note that full information on the approval of the study protocol must also be provided in the manuscript.

Field-specific reporting

Please select the one below that is the best fit for your research. If you are not sure, read the appropriate sections before making your selection.

☐ Life sciences ☒ Behavioural & social sciences ☐ Ecological, evolutionary & environmental sciences

For a reference copy of the document with all sections, see nature.com/documents/nr-reporting-summary-flat.pdf

Behavioural & social sciences study design

All studies must disclose on these points even when the disclosure is negative.

Study description	Quantitative national social survey analysis
Research sample	Two nationally representative samples drawn from the Greenland adult population (see description below). All reported percentages and statistical estimates were weighted for representativeness to account for Kalaallit Nunaat's population distribution over this period using probability weights reflecting Statistics Greenland demographic population data.

Sampling strategy	The IPS phone survey The IPS, a national telephone survey, was administered by trained, native-speaking staff from the independent polling organization HS Analyse, based in Nuuk. Personnel contacted randomly selected phone numbers from adult residents residing in all of Kalaallit Nunaat's municipal regions. The numbers were drawn from a comprehensive list of all registered landline, mobile phone and pre-paid sim card numbers in Kalaallit Nunaat. 939 adult respondents completed the survey, equivalent to nearly ~2.5% of Greenland's adult population, yielding country-level margins of error of ±3 percentage points at the 95% confidence level. The GPS field survey The GPS, a national field survey was conducted across all geographic regions of Kalaallit Nunaat from July 2018 – January 2019 by trained research personnel affiliated with Ilisimatusarfik (University of Greenland) and University of Copenhagen(34). In partnership with Statistics Greenland, surveys were randomly allocated to residents living in randomly selected towns and settlements from each of Greenland's municipalities and geographic regions, along with Nuuk and Upernavik. Nearly 2% of the adult population (n = 646) took the survey, yielding country-level margins of error between ±3 to ±4 percentage points at the 95% confidence level. The GPS sampling design consisted of a stratified multi-stage cluster sampling procedure. In a first stage, Kalaallit Nunaat was separated into each of its five municipal regions with Sermersooq separated into both West and East coasts, resulting in six primary geographic regions. Locations within each were classified using Statistics Greenland operationalized definitions, where locations with more than approximately 500 residents were labelled as towns. This resulted in 12 stratified geographic layers, with one layer for each region's collection of settlements and one for each region's towns. Locations were randomly sampled from these geographic layers using R statistical software, while Nuuk was sampled as a self-representing city within the West Sermersooq Town layer (Nuuk contains >~30% of Kalaallit Nunaat's total adult population) and the additional self-representing town of Upernavik was sampled in the northern half of the Avannaata region to extend coverage along Kalaallit Nunaat's geographically extensive north coastal margin. Statistics Greenland then randomly allocated surveys within each of these 13 locations proportionally to the population total for the corresponding geographic layer, using the universe of population registry data for each location. Since the GPS field survey was administered in person by trained research assistants, randomly selected participants were able to participate even if they did not have internet access or a connected phone, and they were provided the option to dictate their answers verbally if they lacked the ability to read or write.
Data collection	See procedures for IPS and GPS data collection above.
Timing	IPS: December 2020 - January 2021 GPS: July 2018 - January 2019
Data exclusions	No data was excluded from the analyses.
Non-participation	Applying AAPOR standard definition 4, we recover similar response rates of 47% for the IPS phone survey and 46% for the GPS field survey. To correct for potential sampling biases, probability weights were applied to maintain results representative for the adult population. Consistent across survey waves, analyses were weighted for representativeness by self-identified gender, age group and municipal division, using demographic registry data for Kalaallit Nunaat's adult population in 2018 (GPS) and 2020 (IPS), as serviced by Statistics Greenland (www.stat.gl).
Randomization	Participants were not allocated into experimental groups for this study, but were randomly sampled.

Reporting for specific materials, systems and methods

We require information from authors about some types of materials, experimental systems and methods used in many studies. Here, indicate whether each material, system or method listed is relevant to your study. If you are not sure if a list item applies to your research, read the appropriate section before selecting a response.

Materials & experimental systems

n/a	Involved in the study
☒	☐ Antibodies
☒	☐ Eukaryotic cell lines
☒	☐ Palaeontology and archaeology
☒	☐ Animals and other organisms
☒	☐ Clinical data
☒	☐ Dual use research of concern

Methods

n/a	Involved in the study
☒	☐ ChIP-seq
☒	☐ Flow cytometry
☒	☐ MRI-based neuroimaging