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More talk, no action? The link between exposure to extreme weather events, climate change belief and pro-environmental behaviour

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ABSTRACT
Previous research has shown a link between extreme weather events and people's beliefs about climate change and their pro-environmental behaviour. This indicates that people may become more environmentally friendly amid increasing extreme weather events. Still, the influence of experiencing extreme weather events on actual behaviour has rarely been tested with large-scale individual-level data and longitudinal methods. This study links panel data from 35,678 individuals to floods across England and heatwaves across the UK and applies within-person estimators to account for pre-existing differences between affected and unaffected individuals. Results reveal that individuals are more likely to believe in climate change after being affected by a geographically proximate flood or a temporally proximate heatwave. This association is stronger among initially right-leaning partisans and those initially more sceptic about the existence of climate change, thereby indicating attitudinal updating due to experiential learning. However, those exposed to extreme weather events do not change their environmental behaviour such as energy saving, sustainable shopping or mode of transportation. Even among those who are more likely to believe in climate change, people's behaviour does not react to extreme weather events.

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KEYWORDS Climate change; climate change belief; climate change mitigation; pro-environmental behaviour; extreme weather events; floods; heatwaves; individual panel data

1. Introduction

Continued severe droughts and record temperatures throughout 2023 have once again underscored the tremendous impact of the climate

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crisis on societies across the globe. Most nations have not dramatically changed their polluting behaviours and therefore, greenhouse gas emissions continued to increase over the past decade (IPCC 2022). Climate projections predict that the frequency of natural disasters will substantially increase above current levels in the foreseeable future (Roudier *et al.* 2016), and affect a substantial amount of people (Mora *et al.* 2017). Northern Europe is expected to be particularly impacted by floods and heat extremes (IPCC 2022).

Mitigation of climate change and its impacts are thus listed among the most pressing challenges of our time (Dietz *et al.* 2020; IPCC 2022). Yet, many societal and political actions critically hinge on the support of individual actors (Brügger *et al.* 2015b; van Valkengoed and Steg 2019). It is, therefore, important to understand the drivers of people's attitudes towards climate change and relevant behavioural patterns. Several studies have shown that individual experiences of climate-related events – like floods, extreme precipitation, or heatwaves – are linked to stronger beliefs in climate change (Howe *et al.* 2019; Hornsey *et al.* 2016; Larcom *et al.* 2019; Myers *et al.* 2013; Osberghaus and Fugger 2022; Spence *et al.* 2011) and green voting (Baccini and Leemann 2020; Hazlett and Mildenberger 2020; Hoffmann *et al.* 2022), thereby indicating that climate change itself may change people's attitudes and behaviour. Still, many empirical findings are based on cross-sectional comparisons (Demski *et al.* 2017; Howe 2018; Howe *et al.* 2019) or use spatially aggregated data only (Howe *et al.* 2019).

This study investigates how exposure to extreme weather events – floods and heatwaves – influences people's belief in climate change and their pro-environmental behaviour based on large-scale individual-level data in the UK. The study also investigates several theoretical mechanisms. First, it uses the natural variation in spatial and temporal distance of extreme weather events to investigate the role of experiential learning. Second, we compare the association across several subgroups, such as political partisans and initial sceptics to contrast experiential learning against motivates reasoning patterns.

The study contributes to the existing literature in several ways. First, we use individual-level panel data of nearly 36,000 individuals and link those to recorded flood outlines in England and weather data across the UK based on participants' place of residence. Second, we apply panel-data methods and within-person estimators to rule out person-specific confounding. Third, the study investigates two types of extreme weather events – floods and heatwaves – increasing the robustness and generalisability of results. Fourth, it tests the impact of extreme weather on climate change belief and various forms of behaviour, which allows us to test if attitudinal changes translate into more sustainable behaviour. Fifth, it differentiates the impact of extreme weather events by spatial and temporal distance to the respective events. Finally, we explore heterogeneous effects according to partisanship and initial climate scepticism, which provides additional insights into the psychological pathways of the relation.

Results reveal that floods and heatwaves indeed increase the belief in climate change. The magnitude of this association increases with spatial and temporal proximity, which is in line with experiential learning. Moreover, right-leaning partisans and those initially more sceptic about climate change show the strongest impact on climate change belief after being affected by an extreme weather event. This indicates that extreme weather events can actually update people's attitudes. However, updating attitudes does not change peoples' pro-environmental behaviour. Extreme weather events have a negligible impact on peoples' behaviour, and this finding is consistent across floods and heatwaves, across different behavioural measures, as well as across several subgroups.

2. Theory

There are several pathways in which extreme weather events can influence people's beliefs and attitudes, which are all related to the concept of experiential learning. This section will briefly outline the theoretical idea of experiential learning and subsequently argue that it is hard to predict how changes in attitudes will translate into individual behaviour.

2.1. Attitudinal updating

It is often argued that the link between extreme weather events and attitudes is based on experiential learning. Processing scientific information and making an informed risk assessment of an abstract construct like climate change requires motivation and cognitive effort (Myers *et al.* 2013). However, people often avoid spending cognitive resources, but instead rely on subconscious cognitive processes when forming opinions or making decisions (Dietz 2020; Kahneman 2011; Myers *et al.* 2013). Providing (more) statistical evidence is, therefore, unlikely to convince people who do not believe in the existence of climate change or to increase their concern. Experiential learning – personally experiencing climate change – can be more influential for several reasons. First, personal experience increases the mental accessibility of concrete events related to the abstract concept of climate change (Demski *et al.* 2017; Howe 2018; Taylor *et al.* 2014; Pryce *et al.* 2011; Adger *et al.* 2013; Grothmann and Patt 2005; Spence *et al.* 2011). Second, experiencing extreme weather events can induce strong emotional feelings attached to environmental issues (Whitmarsh 2008; Zaalberg *et al.* 2009; Leiserowitz 2006; McAdam 2017). Third, directly experiencing extreme weather events reduces the perceived spatial and temporal distance of climate change (Brügger *et al.* 2015b; Brügger *et al.* 2015a; Evans *et al.* 2014; Mildenberger *et al.* 2019; Spence *et al.* 2012). Affected people adjust their prior belief that climate change only happens at far geographical and temporal distances (Druckman and McGrath 2019; Howe 2018).

Following this last strand of argumentation, more proximate events – in space and time – should have stronger impacts on prior climate change beliefs. As personal exposure also elevates the perceived risk of experiencing more adverse impacts and provides more specific goals of mitigating action (Howe and Leiserowitz 2013; Myers *et al.* 2013; Spence *et al.* 2011), it should increase the propensity of engaging in mitigating behaviour (Brügger *et al.* 2015b; Demski *et al.* 2017). We thus expect extreme weather events to have a stronger impact on climate change belief and pro-environmental behaviour, the closer these events are in time and space.

Nevertheless, if and especially how extreme weather events influence attitudes towards climate change has been a subject of debate (Brügger *et al.* 2021), and many theories hinge on critical assumptions. First, people need to be aware of the respective events. Second, people need to accurately attribute local events to long-term climate change (Howe 2018; Ogunbode *et al.* 2019). Moreover, from a motivated reasoning perspective, a person could consider past experiences as invalid evidence if these experiences are not congruent with their prior beliefs (Druckman and McGrath 2019; Howe and Leiserowitz 2013; Howe 2018; Myers *et al.* 2013). People, who initially do not believe in climate change, may not use personal experiences to update their existing opinions. For instance, previous research (Hazlett and Mildenberger 2020) has found that wildfire exposure affects voting behaviour for green policies among Democrats but not among Republicans. Still, it is debated if this results from partisanship itself or whether it is a result of general scepticism about climate change (Ogunbode *et al.* 2019). Recent research in Germany (Osberghaus and Fugger 2022) has found that proximate floods increased climate change belief, especially among those who were initially more likely to believe in climate change. People might thus interpret personal experiences in a way that reinforces their existing beliefs instead of updating their prior beliefs and concerns.

2.2. Behavioural changes

Overall, the previous literature on attitudinal changes provides some hope for climate change mitigation in the sense that more frequent extreme weather events will nudge peoples' behaviour in a more sustainable direction. Still, there is a substantial gap between attitudes and behaviour: regarding individual pro-environmental behaviour, additional barriers need to be taken into account (Ajzen 1991; Best and Kneip 2011; Diekmann and Preisendorfer 2003).[1]

For instance, affected people need to project the experience of extreme weather events on their motivation to prevent potential future impacts (Brügger *et al.* 2015a; Pryce *et al.* 2011; Mildenberger *et al.* 2019). However, the personal experience could also induce the opposite behaviour because people doubt the effectiveness of mitigation strategies, thus lacking a feeling of efficacy (Brügger *et al.* 2015a; Mildenberger *et al.* 2019; Zhou 2016). If people feel incapable of dealing with climate change, they may cope with the uncomfortable situation by denying their individual responsiveness or contribution (Brügger *et al.* 2015a). Moreover, construal level theory would predict that immediate needs and short-term cost–benefit calculations can become more important for behavioural intentions in the face of proximate threats, in turn, lowering the likelihood of engaging in costly pro-environmental behaviour (Brügger *et al.* 2015a; Spence *et al.* 2012).[2]

While the above-mentioned barriers affect individual and collective responses, the dilemma of collective action (Olson 1971; Ostrom 1998) constitutes another well-known barrier to changes in long-term collective behaviour or mitigation of climate change. Although small changes among all individuals in a society would greatly benefit

[1]For a more comprehensive understanding of the relationship between values, beliefs and actual behavioural changes, we encourage readers to consult additional literature that delves into this complex relationship (e.g. Ajzen 2011; Mayerl and Best 2019).

[2]Recent literature has criticized the validity of measures of abstraction in construal level theory (Mac Giolla *et al.* 2022).

global climate change mitigation, the contribution of a single person to global climate change is objectively close to zero (Lubell *et al.* 2006; Olson 1971). Even if the perceived risk is high, every single person has the incentive to free-ride – avoiding the behavioural costs of pro-environmental actions – and to rely on others providing the collective good (Lubell *et al.* 2006; Ostrom 1998). In other words, everyone profits from successful global mitigation and no one can be excluded from using the common good (Ostrom 1998). Also in the face of direct extreme weather experiences, it might thus still be the 'rational' (in the sense of maximizing self-interests) response to not change behavioural patterns.

Although several studies have documented a positive link between extreme weather events and pro-environmental behaviour (Adger *et al.* 2013; Grothmann and Patt 2005; Spence *et al.* 2011; van Valkengoed and Steg 2019; Zaalberg *et al.* 2009), it has previously been criticized (Demski *et al.* 2017; Howe 2018; Howe *et al.* 2019) that many studies rely on cross-sectional data. This makes it difficult to establish causal relations. The risk of experiencing an extreme weather event often may correlate with spatial patterns in attitudes and behaviour (Betz *et al.* 2020; Howe *et al.* 2019), thereby affecting estimates in cross-sectional studies. Recent longitudinal studies have confirmed previous findings by identifying the impacts of extreme weather events on voting behaviour (Baccini and Leemann 2020; Hazlett and Mildenberger 2020; Hoffmann *et al.* 2022) and environmental attitudes (Osberghaus and Fugger 2022). Still, it is not clear if those impacts also translate into changes in individual behaviour which would help in mitigating long-term climate change. Given the problem of collective action, we assume that the effect of extreme weather events on behaviour is weaker than the effect on attitudes.

3. Materials and methods

3.1. Data and variables

This study uses individual-level panel data from the harmonized British Household Panel Study (BHPS, 1991–2008) and UK Household Longitudinal Study (UKHLS, 2009–2020), a nationally representative panel study with annual information from 1991 to 2020 (University of Essex, Institute for Social and Economic Research n.d.). The special access version includes information on the current place of residence down to the level of Lower Layer Super Output Areas (LSOA). On average, an LSOA includes 1400 individuals (600 households) and thus provides a very fine-grained spatial resolution, especially in densely populated areas. This geographical information was matched to (1) the Environment Agency's Recorded Flood Outlines data in England,[3] which contains the date and geographic information on floods from rivers, the sea, groundwater and surface water; and to (2) the HadUK-Grid climate observations (Hollis *et al.* 2019), which provide UK-wide information on daily temperature. The residential history of respondents and population-weighted centroids of LSOAs were used to match flood events and maximum daily temperature.

To measure the experience of flood events in England, we first created a series of buffers around the population-weighted centroid of each LSOA. Buffer widths of 1, 2 and 5 km radius were used to measure floods in varying spatial proximity. As exemplarily shown in Figure 1, we then calculated the spatial overlap between the buffers and all flood outlines for each single day. An LSOA was classified as experiencing a flood, if – on a given day – one hectare (10,000 m^2) of the respective buffer area was covered by floodings. The area of one hectare is close to approximately 1.5 soccer fields in size. This cutoff point was chosen to exclude very small (potentially unrecognisable) floods. Following previous literature (Hazlett and Mildenberger 2020), only floods within the previous two years before the interview date were included to construct the flood-exposure indicator (see Figures S5 for alternative specifications). Based on the available data, we can however not identify if an individual has directly experienced harm to health or property due to the flood.

As noted earlier (Howe *et al.* 2019), extreme weather events like heatwaves do not happen on a local scale but usually affect a very large area (see Figure 2). High temperatures or heatwaves are thus not suited to explore the role of spatial proximity. However, given the higher number of respondents affected, heatwaves provide a setting to investigate the role of temporal proximity. To measure the exposure to extreme temperatures or heatwaves, LSOA outlines were intersected with the 5 × 5km grid of the HadUK-Grid climate observations, including information on the daily maximum temperature. Subsequently, an LSOA was coded as experiencing a heatwave if the daily maximum temperature

[3]The dataset is publicly available at https://data.gov.uk/dataset/16e32c53-35a6-4d54a111-ca09031eaaaf/recorded-flood-outlines#licence-info (last access: October 28, 2020).

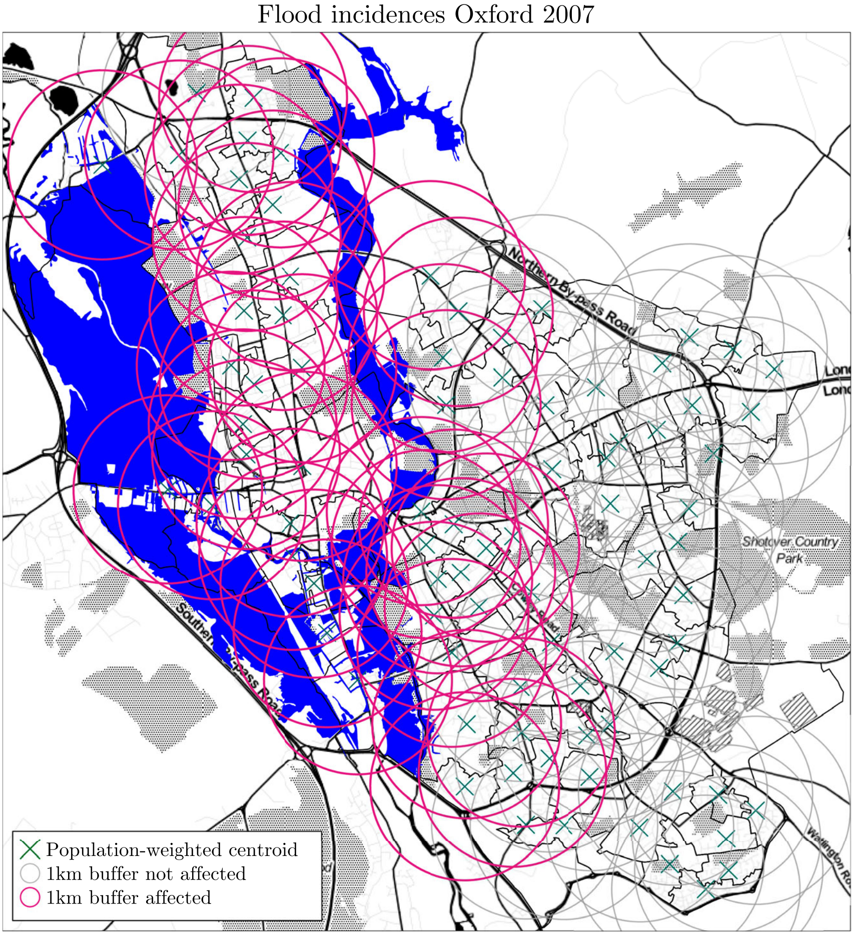

Figure 1. Merging strategy between 1 km buffer around the population-weighted centroid of each LSOA and flood outlines using the example of Oxford 2007. Flooded areas are indicated in blue.

equals or exceeds 29°C for at least three consecutive days. The threshold of 29°C has been used in previous research on the effect of heatwaves (Larcom *et al.* 2019). To avoid classifying single hot days as 'heatwave', we coded only instances as an event in which the high temperature remained at 29°C for at least three consecutive days up to the respective date. This information is available for the entire UK, including Northern Ireland, Scotland and Wales. To examine the role of temporal proximity, we constructed the heatwave indicator for being affected within the past 14 days, within the past month and within the past 4 months before the interview date.

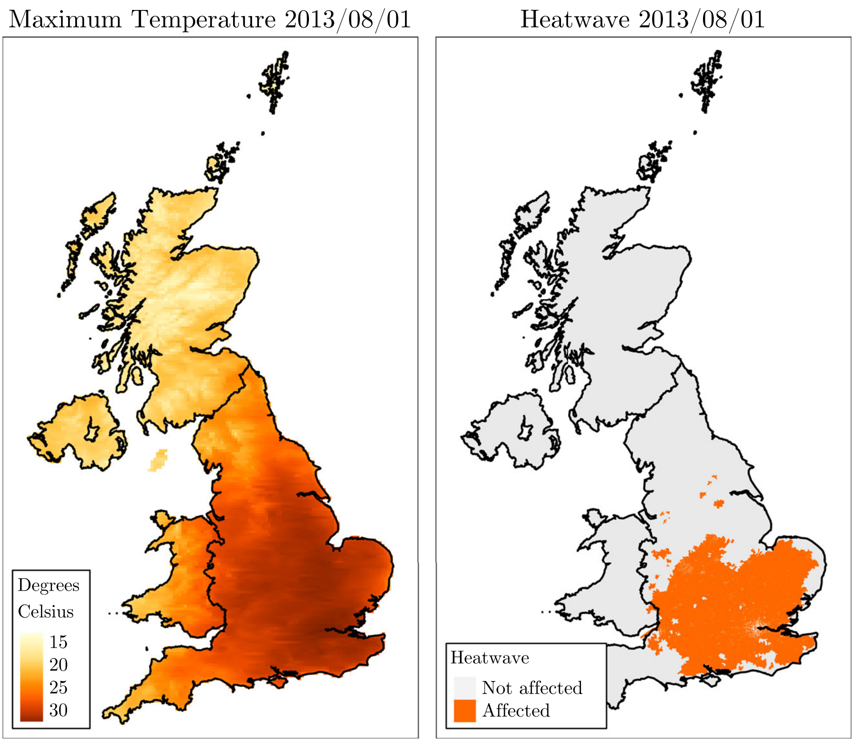

Figure 2. Heatwave classification based on the example of 1 August 2013. The left panel shows the daily maximum temperature on that specific day. The right panel shows the LSOAs which were classified as experiencing a heatwave on the respective day. The marked areas have experienced a daily maximum temperature of ≥ 29°C for at least three consecutive days (2 days before date + respective date).

This study tests the effect of extreme weather experience on two outcome measures: belief in climate change and pro-environmental behaviour. Belief in climate change was measured by the question 'Please select whether, on the whole, you personally believe or do not believe each of the following statements. – People in the UK will be affected by climate change in the next 30 years' with response options 'Yes, I do believe this' or 'No, I do not believe this'. Although previous studies have used different measures for environmental beliefs (e.g. Lübke 2022; Osberghaus and Fugger 2022), it is close to what previous studies have used with an emphasis on perceived impact (Poortinga *et al.* 2019). Pro-environmental behaviour was measured by an average index of seven (recoded) questions on how often respondents do the following: 'Leave your TV on standby for the night'; 'Switch off lights in rooms that aren't being used'; 'Keep the tap running while you brush your teeth'; 'Put more clothes on when you feel cold rather than putting the heating on or turning it up'; 'Decide not to buy something because you feel it has too much packaging'; 'Buy recycled paper products such as toilet paper or tissues'; 'Take your own shopping bag when shopping'.[4] All questions were answered on a 5-point scale from 'always' to 'never', and were recoded in the way that larger numbers refer to more environmentally friendly behaviour. These two measures – climate change belief and pro-environmental behaviour – are available for three BHPS/UKHLS waves (survey years 2008–2011, 2012–2014 and 2018–2020). Sample descriptives can be found in Section A of the Supplementary Material.

To test heterogeneous treatment effects, we used the following questions. For partisanship, we used party support and preference. Right-leaning parties are 'Conservatives', 'Ulster Unionist', 'Democratic unionist', 'UK Independence Party' and 'The Brexit Party'. Left-leaning parties are 'Labour', 'Liberal Democrat', 'Scottish National Party', 'Plaid Cymru', 'Green Party', 'Alliance Party', 'SDLP' and 'Sinn Fein'. Those not stating a party preference or indicating that their party support is 'not very strong' are coded as having no partisanship. To measure scepticism, we used the following three questions: (a) 'The so-called 'environmental crisis' facing humanity has been greatly exaggerated', (b) 'The effects of climate change are too far in the future to really worry me', and (c) 'If things continue on their current course, we will soon experience a major environmental disaster' (reversed). Any person agreeing ('Yes, I believe this') on one of those statements was coded as sceptic and everyone not agreeing as not sceptic.

3.2. Analytical strategy

Cross-sectional methods rely on the main identification assumption that the indicator of interest is strictly exogenous conditional on the observed controls: $\mathrm{E}(\varepsilon_{it}|\tau_{it}, x_{it}) = 0$, where τ_{it} is the extreme weather indicator, x_{it} a row-vector of time-constant and time-varying control variables and ε_{it} the error term. This assumption, for instance, would be violated if a person-specific trait – say affinity to nature – influences the likelihood of being affected by a weather event and the belief in climate change or

[4]The selected items include all items on environmental behaviour which are consistently available in BHPS and UKHLS across waves. Including the remaining items only available in UKHLS would reduce the sample by approx. 60% because of excess of missing values. Supplementary analyses E use transportation behaviour as an alternative index of environmental behaviour and come to the same conclusions.

pro-environmental behaviour, respectively. It would also be violated by regional differences in the likelihood of extreme weather events and environmental attitudes (see for instance placebo tests, Figures S6 and S7 in the Supplement).

To tackle these issues, we use two-ways person-fixed effects (FE) estimators with group-specific time trends in the main analysis. The FE estimator calculates if becoming affected by a flood is correlated to within-person changes in attitudes and behaviour. This rules out any bias due to time-constant person-specific confounders (Wooldridge 2010). Formally, we estimated the following FE model:

$$y_{it} = \tau_{it}\beta + z_{it}\vartheta + \alpha_i + \eta_s * \delta_i + \epsilon_{it} \quad (1)$$

where α_i are individual-specific fixed effects, and z_{it} is a subset of time-varying control variables in x_{it}. This relaxes the main identification assumption to $\mathrm{E}(\varepsilon_{it}|\tau_{it}, z_{it}, \alpha_i, \eta_s, \delta_i) = 0$. While the indicator for extreme weather events still needs to be unrelated to idiosyncratic variation in ε_{it}, we account for all time-constant between-person differences. Yet, in the conventional two-ways FE specification, we still need the assumption of parallel trends between 'treatment' and 'control' group $\mathrm{E}(\eta_{si}|\tau_{it}, z_{it}) = 0$, i.e. those affected by an event would have had the same temporal trend in the outcome than the unaffected if they would not have been affected (Goodman-Bacon 2021; Rüttenauer and Ludwig 2023). This assumption is further relaxed here by interacting the seasonal fixed effects η_s with δ_i, an indicator of whether an individual ever received or will receive 'treatment' (ever affected by flood or heatwave, respectively), thereby accounting for group-specific temporal trends. This δ_i indicator is constructed using the full observed residential history of each individual, which in the most informative cases ranges from 1991 to 2020 (UKHLS respondents are only observed from 2009 onwards).

All models were estimated as linear probability (climate change belief) or linear (environmental behaviour) models via least squares methods for the sake of simplicity. However, as also shown in previous studies (Lübke 2022; Poortinga *et al.* 2019), climate change belief is heavily skewed with most people already believing in climate change. To account for the skewness, supplementary robustness checks use probit models for the binary indicator of climate change belief. These supplementary results fully support the main results (see Figure S4). Nevertheless, we will stick to the linear probability model given the difficulties of interpreting coefficients in non-linear models with fixed effects (Rüttenauer and Best 2022). All models control for the year-season, and additional estimates include individual-level controls which have been shown to influence environmental attitudes and behaviour (Hornsey *et al.* 2016; van Valkengoed and Steg 2019): age (5-year intervals), highest education, child(ren) in the household, marital status and household income (decile intervals). Supplementary pooled OLS models (Figure S2) also include the time-constant controls of sex, ethnicity and migration background. Standard errors are clustered at the individual and the LSOA level. The *R* package *sf* (Pebesma 2018) was used for spatial operations, *lfe* (Gaure 2013) and *plm* (Croissant and Millo 2008) for the estimation of FE models, and *ggplot2* (Wickham 2016) and *texreg* (Leifeld 2013) for the presentation of results.

To test the interaction between experience and partisanship or scepticism respectively, the entire right-hand side of Equation (1) was interacted with the respective time-constant group indicator, thereby accounting for potential interactions with other controls and the time trends. Note that we used first-wave information only to measure initial partisanship and initial scepticism. This is important as partisanship and scepticism could be the subject of attitudinal updating due to experiencing extreme weather events themselves.

4. Results

Figure 3 descriptively shows the average level of pro-environmental behaviour for observations ever affected by a heatwave and observations never affected along the temporal proximity to the actual event. The distance to the event for the control group is calculated by matching never-affected observations to affected observations based on the interview date – we are thus comparing affected individuals to unaffected individuals who answered on similar dates. Although observations exposed to a heatwave more often engage in pro-environmental behaviour (see also Figure S2), a large share of the behavioural difference between affected and unaffected individuals already existed prior to the actual event. This indicates that the spatial patterns of pro-environmental behaviour correlate with the likelihood of experiencing an extreme weather event. The treated and control groups likely differ on various dimensions.

Similarly, cross-sectional models based on placebo outcomes – which should be independent of extreme weather events – indicate a significant relation between extreme weather events and theoretically unrelated outcomes like religiosity or satisfaction with income (Figures S6 and S6). Obviously, this is not because floods and heatwaves affect religiosity or

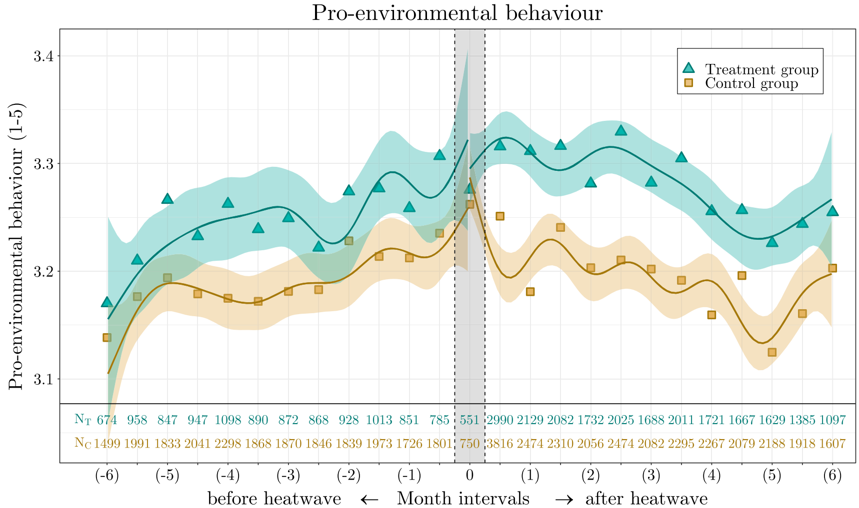

Figure 3. Average pro-environmental behaviour before and after experiencing a heatwave. Triangles and squares are the averages within 15-day interval bins. Trend lines and respective 95% confidence intervals are based on thin-plate spline smoothness estimates of the original continuous data (not shown). The treatment group contains respondents who were affected in the past (after the heatwave) or will be affected in the future (before the heatwave). Distance to the event for the control group is constructed by using nearest neighbours matching – solely based on the interview date – with a maximum of 5 days distance and 1–3 matches per treated unit.

satisfaction with income, but because the spatial patterns of extreme weather events are not random (Betz *et al.* 2020; Howe *et al.* 2019) and correlate with the spatial patterns of other covariates. These spurious associations vanish once we rely on person-fixed effects (FE) estimators with group-specific time trends (Figures S6 and S6). This strategy eliminates all time-constant person-specific differences, and additionally accounts for potentially non-parallel trends between treatment and control groups. The within-person estimates are hence to be preferred when aiming to identify a causal relation between extreme weather events and attitudes or behaviour. These estimates are identified by the temporal variation of being exposed to extreme weather events. This is very likely as good as random although we cannot completely rule out time-varying unobserved confounding.

Figure 4 depicts how climate change belief and pro-environmental behaviour change when individuals are exposed to floods (upper panel) and heatwaves (lower panel) compared to periods in which they are not exposed. If individuals are exposed to floods within 2 or 1 km of their homes, they are more likely to believe in climate change than

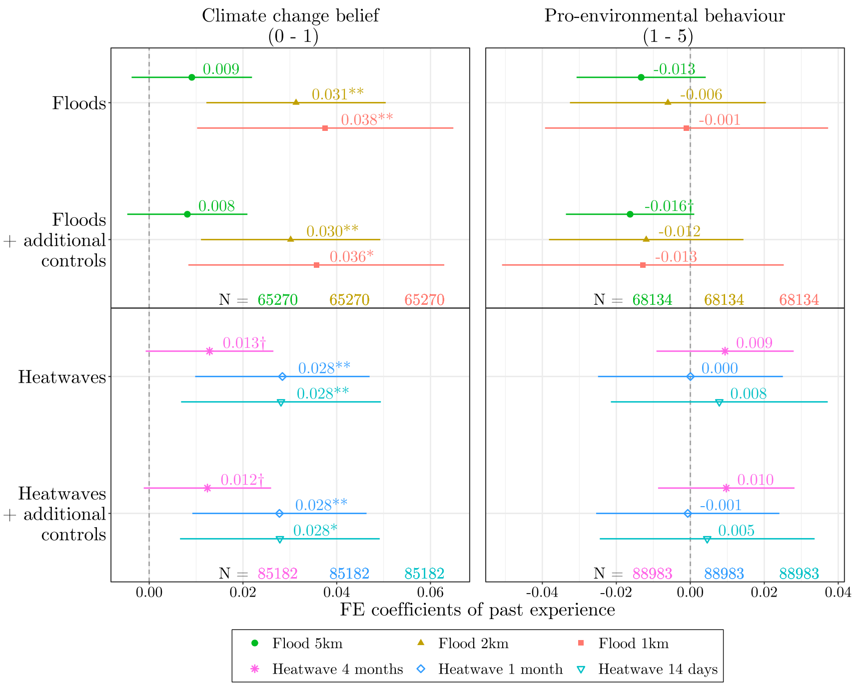

Figure 4. Coefficient of past flood/heatwave experience for different spatial distances to floods and temporal distances to the heatwave incidences, respectively. Linear individual fixed effects (FE) estimator. Error bars represent a 95% confidence interval ($***p < 0.001$, $**p < 0.01$, $*p < 0.05$, $\dagger p < 0.1$). Two-sided test with cluster robust standard errors (clustered by person and LSOA). Basic controls: year-season of interview. Additional controls: age (5-year intervals), highest education, child(ren), marital status and household income (decile intervals). N describes the number of observations in each estimation sample (constant across spatial and temporal distances).

they are in unaffected periods. This holds no matter of additional socio-demographic controls. Net of controls, being exposed within 2 km changes the likelihood of believing in climate change by 3.0%-points ($p < 0.01$) and being exposed within 1km by 3.6%-points ($p < 0.05$). In relative terms, exposing a randomly drawn individual to a flood within 1km would increase the expected likelihood of this individual to believe in climate change by 4.5% (from the overall sample probability of 79.5%). For floods occurring within 5km, the effect size essentially drops to zero ($\beta = 0.008$, $p > 0.1$), thereby implying a strong distance decay. This finding is in line with the assumption that proximate events have a stronger effect on risk perception and attitudinal updating (Brügger *et al.* 2015b; Brügger *et al.* 2015a; Evans *et al.* 2014; Mildenberger *et al.* 2019; Spence *et al.* 2012). However, the strong distance decay also implies that the societal significance of the floods is limited: only 3.6% of the observations experienced a flood within 2 km of their residence (Table S1). Even if flood incidences were to double during the next decade, this would only marginally affect the overall share of people believing in climate change (an increase of 0.26% points in total).

More importantly, this change in belief does not translate into changes in behaviour. For all geographical distances, being affected by a flood exhibits only minor and non-significant coefficients on changes in pro-environmental behaviour (β from −0.016 to −0.001, all $p > 0.05$). By trend, the estimates even point in an unexpected direction, indicating a slight decrease in pro-environmental behaviour. This might be explained by adverse reactions to proximate threats (Brügger *et al.* 2015a; Spence *et al.* 2012). The pattern looks strikingly similar when using transportation behaviour as outcome: being affected by an extreme weather event exerts a null effect on the frequency of travelling by car and the frequency of using a bicycle (see Figure S3).

For heatwaves (bottom panel of Figure 4), again we find that temporally proximate events significantly change an individual's belief about climate change. Experiencing a heatwave within the past month prior to the interview increases the probability of climate change belief by 2.8%-points ($p < 0.01$). Similarly, being exposed within 14 days increases the probability by 2.8%-points ($p < 0.01$). The effect is however undetectable for a temporal distance of four months ($\beta = 0.012$, $p > 0.05$). This pattern according to temporal proximity is very similar to the geographical pattern of floods. Both extreme weather events exhibit a positive association with climate change belief, and this association increases in magnitude with temporal and spatial proximity. Again, the distance decay is relatively strong with coefficients being non-significant for 4-month temporal distance. Yet, the positive association between heatwaves and climate change belief does not translate into changes in pro-environmental behaviour. None of the temporal bandwidths indicates a significant relation between past heatwave exposure and pro-environmental behaviour (β from 0.001 to 0.010, all $p > 0.1$). Moreover, the point estimates are negligible in magnitude: based on a coefficient of 0.01 points (on a 5-point scale), we would expect a randomly drawn individual to increase their pro-environmental behaviour by only 0.31% when being exposed to a heatwave. Again, supplementary analyses corroborate these results regarding mobility behaviour: individuals do not adjust their frequency of travelling by car or bicycle after experiencing an extreme weather event (see Figure S3).

4.1. Updating vs. motivated reasoning

A matter of debate in the previous literature is *how* extreme weather events affect attitudes (Brügger *et al.* 2015a; Brügger *et al.* 2021; Ogunbode *et al.* 2019). In the following, we thus test if extreme weather events indeed work through the updating of prior beliefs or rather the reinforcement of existing views. We differentiate between groups with different initial characteristics: (a) people who initially state a strong political partisanship (left-leaning or right-leaning) and (b) those who initially express higher scepticism about the existence of climate change. Note that the groups are formed based on information from the first wave only as these dimensions in later waves may be subject to updating themselves.

We find that right-leaning partisans are more responsive to extreme weather events (Figure 5, upper panel). Being exposed to a flood within 1 km increases the likelihood of believing in climate change by 8.4%-points among people with strong support for right-leaning parties. Similarly, being exposed to a recent heatwave elevates climate change belief among right-leaning partisans by 10%-points or 13.9% from the group-specific mean ($p < 0.01$). This is a substantially higher association than what we observe among left-leaning partisans and those without any partisanship, and the differences in the heatwave response are statistically significant at the 5% level ($p = 0.030$, see Supplement C). Although those who initially support a right-leaning party have a lower likelihood of believing in climate change at the beginning, we predict that being exposed to a temporally close heatwave elevates their likelihood onto a level similar to those who initially support a left-leaning party. A strikingly similar picture emerges when we compare those who initially expressed a higher scepticism about climate change (Figure 5, lower panel). Those who were initially more sceptic experience stronger changes due to being exposed to extreme weather events. Being exposed to a spatially close flood increases the likelihood by 7.9%-points and being exposed to a temporally close heatwave by 3.8%-points. Those who are initially less sceptic about climate change, however, do not significantly change their belief after experiencing an extreme weather event. Again, those differences are statistically significant ($p < 0.01$ and $p = 0.042$, see Supplement C).

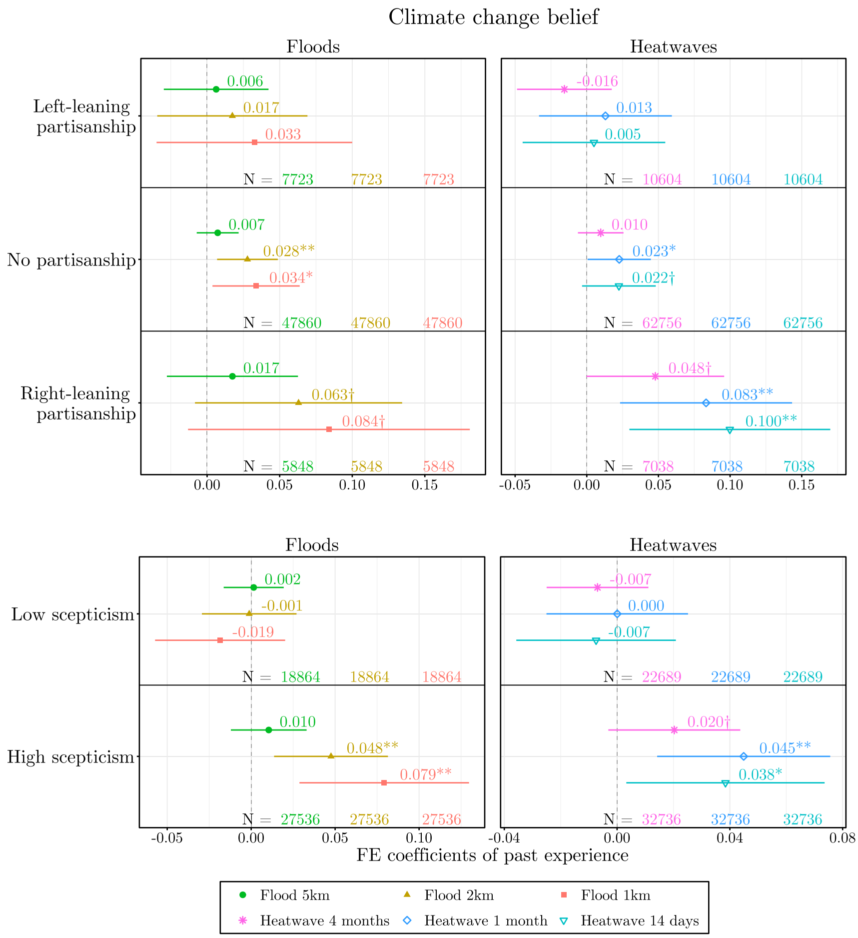

Figure 5. Coefficient of past flood/heatwave experience on climate change belief for different spatial distances to floods and temporal distances to the heatwave incidences, respectively. Separated by respondents initially indicating strong partisanship and high scepticism about climate change, respectively. Linear individual fixed effects (FE) estimator. Error bars represent a 95% confidence interval ($***p < 0.001$, $**p < 0.01$, $*p < 0.05$, $\dagger p < 0.1$). Two-sided test with cluster robust standard errors (clustered by person and LSOA). Controls: year season of the interview, age (5-year intervals), highest education, child(ren), marital status and household income (decile intervals). All controls interacted with partisanship and scepticism, respectively. N describes the number of observations in each estimation sample (constant across spatial and temporal distances).

These additional results indicate that people indeed update their prior views due to personal experiences; they rather contradict the idea of motivated reasoning. If motivated reasoning were the dominant reaction to extreme weather events, we would expect lower responsiveness among right-leaning partisans and those who are initially more sceptic about climate change. The observed patterns are strikingly similar across the two measures of extreme weather events – floods and heatwaves. Moreover, the distance decay is only visible among right-leaning partisans and initial sceptics. This is in line with the idea that experiential learning and updating works by reducing the perceived temporal and spatial distance of extreme weather events.

An alternative explanation for this finding could be potential ceiling effects on the (dichotomous) dependent variable: those initially more likely to believe in climate change just have a lower likelihood of being influenced by extreme weather events. Supplementary results, based on a subset of individuals who express no belief in the first wave, are less pronounced but point in the same direction (Figure S8). Moreover, the ceiling seems to be inherent in the theoretical discussion of experimental learning vs. motivated reasoning: it is plausible that environmental cues will not heavily influence those who are already very concerned about climate change. The believers and those already concerned may expect such events, and thus react less sensitive just because they are already convinced or highly concerned. In a food-related context, de Groot *et al.* (2021) derive similar conclusions: those with stronger pro-environmental norms are less affected by normative messages and behave more pro-environmentally-friendly regardless of external stimuli.

Nevertheless, these conclusions here only apply to climate change beliefs, and not to behavioural changes. Supplementary analyses (Figure S9) do not identify differences in behavioural responsiveness acroding to partisanship and initial scepticism. Apparently, attitudinal updating does not translate into behavioural changes. This might also explain why other studies measuring voting behaviour (Hazlett and Mildenberger 2020) or behavioural intentions (Ogunbode *et al.* 2017) derive different conclusions according to partisanship. However, the political landscape in the UK is also less divided along climate-related issues, potentially increasing the tendency for belief updating on this specific topic.

Given the absence of any behavioural responses to extreme weather events across the entire sample, we tested two additional explanations, namely (a) that people feel incapable of preventing climate change, thus lacking a subjective feeling of efficacy (Brügger *et al.* 2015a; Mildenberger *et al.* 2019; Zhou 2016), and (b) that they are aware of the social dilemma/the low contribution of their own individual behaviour (Lubell *et al.* 2006; Ostrom 1998). Although we observe slight positive reactions to heatwaves among those who do not think that climate change is beyond control and those less aware of the dilemma situation (Figure S10), the association between extreme weather events and behaviour remains small and statistically insignificant. Moreover, patterns are inconsistent across floods and heatwaves.

5. Discussion

Previous studies have documented a link between extreme weather events and beliefs about climate change. The present study confirms that experiencing floods or heatwaves in the immediate surroundings triggers changes in the likelihood of believing in climate change. In line with experiential learning, associations increase with spatial and temporal proximity to the event, with a strikingly consistent picture across floods and heatwaves. Based on individual-level data in the UK, the magnitude of the updating process is stronger among initially right-leaning partisans and those initially more sceptic about climate change. Overall, this supports the idea of attitudinal updating due to a reduction in the perceived spatial and temporal distance of climate change. This conclusion is somewhat at odds with previous studies reporting stronger relations among left-leaning (Hazlett and Mildenberger 2020; Ogunbode *et al.* 2017) and less sceptic respondents (Osberghaus and Fugger 2022). Further research is necessary to investigate if those differences in conclusions emerge due to country-specific differences, whether they are owed to different processes applying to voting decisions as compared to climate change attitudes, or if they are a product of different measures and methods.

Nonetheless, the positive association between extreme weather events and attitudes does not translate into more pro-environmental behaviour such as saving electricity, turning down the heating, buying sustainable products or switching to more sustainable modes of transportation. The reason for the hesitance to change behaviours contributing to long-term climate change mitigation remains unclear in this study. This lack in behavioural changes fits into the literature that documents the missing link between environmental awareness and environmental behaviour (Best and Kneip 2011; Lubell *et al.* 2006). We tested different possibilities such as motivated reasoning, perceived efficacy for mitigation, and awareness of the behavioural dilemma. However, along all the sub-groups tested here, behavioural reactions to extreme weather events remain negligible. Future research should aim to identify social dynamics which help to facilitate the link between attitudes or perceptions and pro-environmental behaviour (Keuschnigg and Kratz 2018; Wilson *et al.* 2020).

This study comes with several limitations. First, the outcome measures are not ideal. Using an existing panel study comes with the advantage of large-scale representative data, but environmental behaviour outcomes are relatively specific. The behavioural outcome measures actions which contribute to long-term collective mitigation of climate change but we lack information about private adaptation strategies. For instance, people might increasingly buy insurance against extreme weather events or protect themselves by better insulation. Second, the behavioural indicators are based on self-reported behaviour, and further research should aim for measures of the actual ecological footprint (Bruderer Enzler and Diekmann 2019). Still, supplementary results based on transportation behaviour support the main findings (Figure S3). Lastly, we cannot identify personal damages experienced by respondents based on the flood data. Personally experiencing flooded basements or homes is likely to exert stronger (and more long-lasting) impacts than purely observing floods in the residential area. However, this would require an even larger sample given the comparably low incidence rate of such events.

Overall, it seems unlikely that the problem of environmentally harmful behaviour will 'solve itself' due to increasing extreme weather events and a more local framing of these events. We find a positive association of extreme weather events with climate change belief but no impact on environmental behaviour. Although the increasing belief in climate change can help to boost the support for green policies (Baccini and Leemann 2020; Hazlett and Mildenberger 2020; Hoffmann *et al.* 2022), wisely designed political instruments (Beiser-McGrath and Bernauer 2019; Liebe *et al.* 2021) are needed to steer individual behaviour into a more sustainable direction.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

The Understanding Society and Harmonised BHPS Special Licence Access data (12th Edition) are not publicly available because of privacy restrictions, but access can be acquired via the UK Data Service (SN: 6931, http://doi.org/10.5255/UKDA-SN-6931-11) after application. The Recorded Flood Outlines data are publicly available via GOV.UK open data, https://data.gov.uk/dataset/16e32c53-35a6-4d54-a111-ca09031eaaaf/recorded-flood-outlines#licenceinfo. Data were downloaded as of 2020-06-23. The HadUK-Grid weather data are publicly available from the UK MET office after registration, http://dx.doi.org/10.5285/2fd7c824e7e549809c1b-c6a128ad74db. Data were downloaded as of 2020-12-04. R 4.2.2 was used for data analysis, see the Methods section for relevant packages. The R code for the replication of this study can be found at the author's GitHub repository: https://github.com/ruettenauer/ClimateChange_Replication

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