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When, not if: the inescapability of an uncertain climate future

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Climate change projections necessarily involve uncertainty. Analysis of the physics and mathematics of the climate system reveals that greater uncertainty about future temperature increases is nearly always associated with greater expected damages from climate change. In contrast to those normative constraints, uncertainty is frequently cited in public discourse as a reason to delay mitigative action. This failure to understand the actual implications of uncertainty may incur notable future costs. It is therefore important to communicate uncertainty in a way that improves people's understanding of climate change risks. We examined whether responses to projections were influenced by whether the projection emphasized uncertainty in the outcome or in its time of arrival. We presented participants with statements and graphs indicating projected increases in temperature, sea levels, ocean acidification and a decrease in arctic sea ice. In the uncertain-outcome condition, statements reported the upper and lower confidence bounds of the projected outcome at a fixed time point. In the uncertain time-of-arrival condition, statements reported the upper and lower confidence bounds of the projected time of arrival for a fixed outcome. Results suggested that people perceived the threat as more serious and were more likely to encourage mitigative action in the time-uncertain condition than in the outcome-uncertain condition. This finding has implications for effectively communicating the climate change risks to policy-makers and the general public.

1. Introduction

Uncertainty is an inherent feature of any scientific endeavour, and climate science is no exception. Considerable attention has therefore been devoted to understanding how to effectively communicate climate uncertainty [1–3]. The communication of uncertainty is challenging because the understanding of uncertainty among the general public often differs from that of the scientific community [1,4]. For example, a recent mathematical and computational analysis of the impact of climate uncertainty—operationalized as the variance of the presumed distribution of climate sensitivity [5]—demonstrates that greater uncertainty nearly always results in greater expected economic costs [6]; an article in this issue provides further confirmation and exploration of this finding [7]. This finding suggests that uncertainty should represent an impetus, rather than a barrier, for mitigative action. By contrast, the general public tends to view uncertainty as a barrier to such action [8–10]. This disconnect between the lay perception of uncertainty and the conceptualization held by the scientific community could result in substantial economic costs if uncertainty continues to be underscored in public and political discourse as a reason not to act on climate change. It is therefore important to communicate uncertainty in a manner that better calibrates people's risk perceptions with the actual anticipated consequences of climate change.

A growing body of the literature has revealed that the communication of uncertainty influences attitudes and behaviour relating to climate change (e.g. [9–12]). When uncertainty is high, people have stronger intentions to take action against climate change when projections highlight the likelihood of negative consequences *not* materializing as opposed to the likelihood of negative consequences materializing [11]. For example, people who were told that 'It is 10% to 30% likely that global warming will not cause abrupt and severe changes to regional weather patterns' showed stronger intentions to act than those told 'It is 70% to 90% likely that global warming of 2°C will cause abrupt and severe changes to regional weather patterns'. This effect can be explained by the fact that those focusing on the more desirable outcome (i.e. global warming not causing abrupt and severe changes to weather patterns) were more convinced of the effectiveness of environmental action than those focusing on the more undesirable outcome (i.e. global warming causing abrupt and severe changes to weather patterns). People also display a more positive attitude towards climate change mitigation when policies are justified by emphasizing the possibility of negative events *not* materializing as opposed to when justifications highlight the possibility of negative events occurring as a consequence of a failure to mitigate [12]. Messages about climate change that contain uncertainty also have a stronger influence on peoples' willingness to act when the message describes science as a debate rather than as a search of an absolute truth [13]. The source of the uncertainty also influences people's behaviour. Projections have a stronger influence on people's judgements of the likelihood of climate change events when the uncertainty is inherent in the climate model, as opposed to when it is due to conflict between experts [14].

Although research to date has increased our understanding of the psychological implications of uncertainty communication, there are other important factors that warrant attention. One such factor relates to whether uncertainty is expressed in the outcome itself or in the time at which the outcome is expected to arrive. Communication of the risks associated with climate change typically focuses on the outcome of climate change. For example, projections reported by the IPCC generally imply statements along the lines of 'by year X, average global surface temperature will rise by between Y and Z degrees'.[1] Conventional statements of this type place all uncertainty

[1]Although the IPCC does not refer to specific years when presenting verbal conclusions, interpretations of climate change projections generally emphasize uncertainty in the outcome as opposed to the timeframe.

about the future into the outcome itself—that is, it highlights uncertainty about the impact of climate change (e.g. the extent of the rise in global surface temperature).

However, uncertainty also exists along the temporal dimension. Just as there is uncertainty in the projected outcome for a given point in time, there is also uncertainty in the projected time at which a given outcome will occur. This psychologically different perspective on uncertainty reverses the role of the variables and takes a (nearly) certain outcome for granted but presents its temporal arrival in uncertain terms. To illustrate, given knowledge of the data, one could replace the above projection with the statement: 'Average global surface temperature will rise by X degrees, and this will occur between Year Y and Year Z'. In other words, this framing of an uncertain event refers to *when, not if* it will occur. There is evidence to suggest that expressing uncertainty in the time of arrival of a certain outcome provides more meaningful information than focusing on single point in time [15,16].

Although no research has directly examined the influence of expressing uncertainty in terms of outcome or timeframe on an individual's risk perception, there has been some related work examining the effects of different aspects of uncertainty on group decision-making [17]. Using a 'common good' laboratory simulation of an international community, Barrett & Dannenberg [17] examined how uncertainty influenced the people's ability to cooperate and avoid the adverse consequences associated with crossing a threshold (e.g. a 2°C increase in global temperatures). In one condition, the threshold was known but there was uncertainty about the consequences of crossing it. Thus, there was no uncertainty in whether or not one's actions would lead to the threshold being breached. This condition is analogous to knowing an outcome will occur but being uncertain about when it will arrive. In the other condition, the location of the threshold was uncertain, which is analogous to being uncertain about what outcome will occur. Barrett and Dannenberg found that people were able to cooperate and avoid the threshold when the threshold was known, but the consequences of crossing it were unknown. However, when the threshold was unknown (but the consequences of crossing it were known), people failed to cooperate and a 'tragedy of the commons' ensued with adverse consequences for the entire simulated community. This work provides evidence that drawing people's attention to particular dimensions of uncertainty may influence their perception of the risks associated with climate change.

Importantly however, the study by Barrett & Dannenberg [17] presented participants with environments that differed as a function of which aspect of uncertainty was operationalized. In one condition, the environment contained an uncertain threshold; in the other condition, the consequences of crossing the threshold were uncertain. Thus, the uncertainty manipulation did not simply impact the way information was expressed. The manipulation actually changed the nature of the environment. The question of interest in the current research, by contrast, is whether expressing the same uncertainty about identical physical circumstances in different ways influences people's responses to climate change projections. There is evidence in support of such an effect. Research has shown that people engage in 'wishful thinking' when faced with uncertain future outcomes [18]. For example, people tend to overestimate the likelihood of positive life events and underestimate the likelihood of negative life events [19]. This effect has also been demonstrated with climate change events [1]. When asked to interpret statements from the 2007 IPCC report that used verbal indicators of likelihood (e.g. 'very likely' is used to represent a likelihood of greater than 90%), people systematically underestimated the likelihood of negative climate change events even when provided with a guide to interpreting the verbal indicators.

Construal level theory [20] also suggests that expressing uncertainty in different ways might influence people's perception of the projection. Construal level theory proposes that the psychological distance between an object and the self-influences the level at which an object is construed. Objects that are more psychologically distant (e.g. events that are removed in space or time, or are hypothetical as opposed to real) are construed at a higher, more abstract level. Objects that are less psychologically distant are construed at a lower, more concrete level. From a construal level theory perspective, expressing an outcome as certain (albeit with an uncertain time of arrival) may reduce the psychological distance between the projected event and the individual, compared to when the outcome itself is expressed as uncertain. As a result, the projection may be processed at a lower level of abstraction, be perceived as more immediate, and therefore elicit a stronger response.

Based on these arguments and related precedents, we expect that people will be more concerned about climate change and more supportive of mitigative action when an outcome is expressed as fixed, but with an uncertain time of arrival, compared to when the outcome is expressed as uncertain with a fixed time of arrival. In the latter case, the uncertainty in the outcome may provide the opportunity for wishful thinking, thereby reducing concern and support for action. In the former case, the outcome is presented as inevitable, thereby limiting the scope of wishful thinking. In the following sections, we report an experiment that tests this prediction.

Participants in the experiment were presented with verbal and graphical information about a series of climate change indicators, which varied in how the uncertainty was expressed. Participants then reported their level of concern about each indicator and their support of mitigative action.

2. Material and methods

(a) Participants

A sample of 196 US residents was recruited online in late May 2014 via electronic invitations from Qualtrics.com, a panel service that administers internet surveys to representative samples. Respondents were drawn from panel of nearly 500 000 US residents. Invitations were propensity weighted so that prospective respondents were representative in terms of age, gender and geography. For example, if males were over-represented in the sample at a given point in time, then females would be invited more preferentially to restore gender balance. While this propensity weighting system increases the representativeness of the sample, it does not guarantee full representativeness, especially given that some respondents were filtered out from the final sample (see below). Qualtrics compensated respondents with cash-equivalent points. The average cash value of the points received by respondents was $1.90 (USD).

A total of 324 individuals entered the survey page. Of these, 19 did not consent to participate in the study and therefore did not proceed past the initial screen. Of those that provided consent, 64 respondents did not proceed beyond the training section of the survey. A further 45 failed one of five attention filter items. The final sample thus consisted of the 196 participants who proceeded beyond the training items and who passed all of the attention filter items. Of these respondents, 189 completed all test items. These respondents included 76 males and 113 females with ages ranging from 21 to 86 ($M = 48.99$, s.d. $= 12.93$). Thus, despite the propensity weighting system, the sample consisted of a higher proportion of males and had a higher mean age than is representative of the general population. The remaining seven respondents did not provide age or gender data.

Following the recommendations of Myers [21], we used hot deck imputation to deal with the missing data from the seven respondents who completed some but not all of the test items. We imputed 445 observations using the 'hot.deck' package in R [22]. After imputation, the total number of observations in the dataset was 17 444.

(b) Design

We used a between-groups design with two levels of the single experimental variable: outcome-uncertain versus time-uncertain presentation of uncertainty. We presented participants in each condition with information about the same four indicators of climate change: global mean surface temperature (GMST) rise, sea-level rise, ocean acidification and reduction in Arctic sea ice extent. For each indicator, we asked participants to provide information about their perceived levels of certainty and concern, perceived seriousness and endorsement of mitigative action.

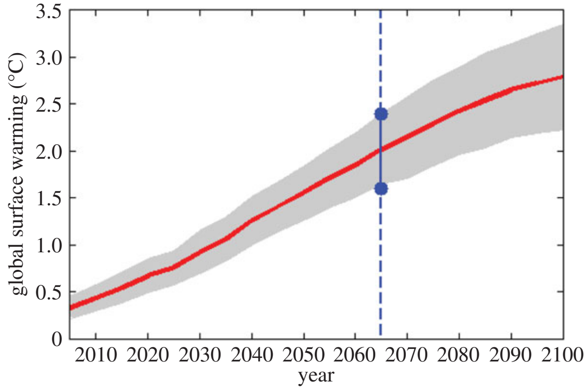

Figure 1. Example graph shown to participants in outcome-uncertain condition. (Online version in colour.)

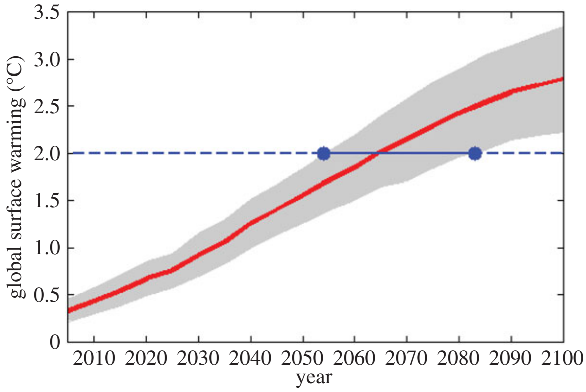

Figure 2. Example graph shown to participants in time-uncertain condition. (Online version in colour.)

(c) Materials

The survey was divided into four sections that each addressed a different indicator of climate change: GMST rise, sea-level rise, ocean acidification and reduction in Arctic sea ice extent. Each section included a statement and graph that communicated a projection pertaining to the relevant indicator. In the outcome-uncertain condition, the timeframe was expressed as fixed, but the outcome projection included an upper and lower bounds (the 95% CI around the mean projected outcome for that particular year). For example, the global surface temperature rise projection for the outcome-uncertain condition was expressed with the following statement (see figure 1 for associated graph):

> It is extremely likely that by 2065, average global surface temperature will rise by between 1.6 and 2.4 degrees C (which is between 2.9 and 4.3°F), with 2 degrees C (3.6°F) being the average projection.

In the time-uncertain condition, the outcome projection was expressed as fixed, but the timeframe projection included an upper and lower bounds (the 95% CI around the mean projected year of arrival for that particular outcome, derived from the relevant graph by reading off the horizontal intersection of the mean projection with the published uncertainty bounds). For example, the global surface temperature rise projection for the outcome-uncertain time condition was expressed with the following statement (see figure 2 for associated graph):

> It is extremely likely that average global surface temperature will rise by at least 2 degrees C (3.6°F), and this will occur between 2054 and 2083.

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Table 1. List of test items. The blank space in item 3 was filled with one of the following phrases depending on the relevant indicator: *global surface temperature rise, sea-level rise, the oceans becoming more acidic, Arctic sea ice reduction*. The blank spaces in items 4–6 were filled with one of the following phrases: *rising global surface temperature, rising sea level, the oceans becoming more acidic, decreasing Arctic sea ice*.

item	label	response scale
(1) How certain are you that [repeat projection]? Please rate your level of certainty on a scale from 1 (not at all certain) to 9 (extremely certain)	certainty	1 = not at all certain, 9 = extremely certain
(2) How concerned are you about the above projection? Please rate your level of concern on a scale from 1 (not at all concerned) to 9 (extremely concerned)	concern	1 = not at all concerned, 9 = extremely concerned
(3) How serious of a problem do you think ______ caused by global warming will be for the United States during the next 100 years —— extremely serious, very serious, moderately serious, slightly serious, or not serious at all?	seriousness	1 = not at all serious, 5 = extremely serious
(4) How much do you think the federal government should do to reduce the effects of ______ in the future — a great deal, quite a bit, some, a little, or nothing?	federal	1 = nothing, 5 = a great deal
(5) How much do you think the state government should do to reduce the effects of ______ in the future—a great deal, quite a bit, some, a little, or nothing?	state	1 = nothing, 5 = a great deal
(6) How much do you think the local government should do to reduce the effects of ______ in the future—a great deal, quite a bit, some, a little, or nothing?	local	1 = nothing, 5 = a great deal
(7) How much do you think that businesses should do to reduce the effects of ______ in the future — a great deal, quite a bit, some, a little, or nothing?	businesses	1 = nothing, 5 = a great deal

The x-axis of each graph represented the year, which ranged from 2005 to 2100. The y-axis represented either GMST expressed as anomalies relative to the relevant climatological baseline (ranging from 0 to 3.5°C; data adapted from [23], fig. 10.4, scenario A1B), sea level expressed as anomalies relative to the relevant climatological baseline (ranging from −20 to 140 cm; data adapted from [24], fig. 4, scenario A1B), ocean acidity (ranging from 7.7 to 8.1 pH, data adapted from [23], fig. 10.24, scenario A1B) or Arctic sea ice extent anomalies relative to the relevant climatological baseline (ranging from −8 to 1 million kilometres; data adapted from [23], fig. 10.13b, scenario A1B). Each graph showed the mean projection (indicated by a red line) and the 95% confidence interval associated with that projection (indicated by a grey uncertainty envelope around the mean). In the uncertain-outcome condition, the graph included a blue line that ran vertically denoting the range of possible outcomes for the relevant year. In the uncertain-time condition, the graph included a blue line that ran horizontally denoting the range of possible years of arrival for the relevant outcome.

Each section also included seven test items (table 1). Respondents were asked how certain they were that the projected event would occur, how concerned they were by the projected indicator, how serious of a problem they thought the projected indicator would be for the USA during the next 100 years, and, each separately, how much they thought the federal government, state governments, local governments and businesses should do to reduce the effects of the projected indicator in the future.

Table 2. Reliability, means and standard deviations (in parentheses) for test items.

	reliability	means and s.d.	
item label	α	outcome uncertain	time uncertain
(1) certainty	0.92	5.98 (2.09)	6.24 (1.99)
(2) concern	0.94	5.85 (2.19)	6.24 (2.17)
(3) seriousness	0.93	3.49 (1.17)	3.82 (1.06)
(4) federal	0.96	3.54 (1.32)	3.89 (1.11)
(5) state	0.96	3.36 (1.32)	3.73 (1.16)
(6) local	0.96	3.23 (1.32)	3.54 (1.22)
(7) businesses	0.95	3.38 (1.28)	3.89 (1.11)

(d) Procedure

Respondents were randomly allocated to one of the two conditions upon entering the survey. After reading an information screen and providing consent to participate, respondents completed a training section in which they were presented with a statement and graph that expressed a projection (in line with the relevant uncertainty condition) about the decline in Emperor Penguin population. Participants were presented with two training items that tested their understanding of the projection. Participants only proceeded to the experimental sections once they had correctly answered both training items.

For the experimental sections, respondents then completed the four sections described above in randomized order. Within each segment, participants first read a paragraph of general information pertaining to the relevant indicator variable. They were then presented with the statement and graph before being asked to respond to the test items. After completing the four sections, respondents were asked to report their gender and age. In addition to the test items and demographic questions, respondents were also presented with other items at various points in the survey. These items were included for exploratory reasons and to inform subsequent research. We do not present the analyses of these additional items here although they are available in the electronic supplementary material. The entire survey took about 30 min to complete.

3. Results

For each participant, we averaged scores for each test item across the four indicator variables (i.e. across sections). Averaging across indicators was appropriate because there was high internal consistency among indicators for each test item (table 2), and there were no interactions between indicator and uncertainty condition for any of the test items (see the electronic supplementary material). Neither gender nor age was significantly associated with any of the test items (see the electronic supplementary material). We therefore did not include gender or age in the remaining analyses. Table 2 shows the reliability of the seven test items, and their means and standard deviations for each uncertainty condition averaged across indicator variables.

In line with our predictions, the mean for each item was higher in the time-uncertain condition than in the outcome-uncertain condition. We used a one-way MANOVA to examine whether responses to the seven test items differed significantly between conditions. This analysis revealed that overall, responses differed between the time-uncertain condition and the outcome-uncertain condition, $\Lambda = 0.93$, $F_{7,188} = 2.16$, $p = 0.039$. We therefore conducted follow-up t-tests to identify the particular items on which scores differed between conditions. The follow-up tests revealed that in the time-uncertain compared to the outcome-uncertain condition, respondents thought the projections presented a significantly more serious problem, $t_{194} = 2.09$, $p = 0.038$, and that the federal government, state governments and businesses should do significantly more to reduce the effects of the projected change indicator (federal government: $t_{194} = 2.03$, $p = 0.044$, state governments: $t_{194} = 2.08$, $p = 0.039$ and businesses: $t_{194} = 2.98$, $p = 0.003$).

By contrast, respondents' levels of certainty, concern and the amount that they thought *local* governments should do to reduce the effects of the projected change did not differ significantly between the two conditions (certainty: $t_{194} = 0.92$, $p = 0.360$; concern: $t_{194} = 1.27$, $p = 0.204$; local governments: $t_{194} = 1.72$, $p = 0.088$).

4. Discussion

We examined whether the manner in which the uncertainty accompanying climate projections is expressed influences people's perception of climate risk and their associated overall policy views. We compared attitudes between people exposed to projections expressed as a fixed outcome with an uncertain time of arrival and people exposed to projections expressed as an uncertain outcome with a fixed time of arrival. Our results showed that members of the former group perceived the problem as more serious and were more supportive of mitigative action from the federal government, state governments and businesses.

Our findings are consistent with the notion that uncertainty surrounding a future outcome invites 'wishful thinking' [18] and egocentric behaviour [8]. When faced with a projection that expresses a future climate change outcome as uncertain (with a specified time of arrival), wishful thinking may bias people towards anticipating outcomes that are less severe. As a consequence, people may perceive the problem as less serious and show less support for mitigative action. On the other hand, expressing the outcome as certain (albeit with an uncertain time of arrival) may prevent this optimistic bias because it forces people to focus on a particular outcome, removing the opportunity for wishful thinking.

This result is consistent with construal level theory [20], which states that the level at which an idea is construed influences people's evaluations and preferences. Specifically, projections expressing an outcome as certain may be processed at a lower level of abstraction, decreasing the psychological distance between the individual and the event, and leading individuals to respond more strongly (compared to projections expressing an outcome as uncertain).

A potential limitation that should be addressed is the fact that the projections in the two uncertainty conditions were imbalanced in a number of ways. First, the projections in the outcome uncertain condition included the mean projected outcome in addition to the upper and lower bounds of the confidence interval, whereas the projections in the time-uncertain condition did not include the mean projected year of arrival. Thus, more information was presented in the outcome-uncertain condition than in the time-uncertain condition. One might therefore argue that the effect of the experimental manipulation can be explained by differences in the amount of information that the projections contained. However, this explanation seems unlikely given that increasing the amount of information should strengthen rather than weaker people's responses to the projections.

Second, many of the projections in the outcome uncertain condition were presented in both metric and imperial terms (temperature rise in degrees Celsius and Fahrenheit, sea-level rise in centimetres and inches, and Arctic ice reduction in square kilometres and square miles). It is therefore possible that the outcome-uncertain projections were more difficult for respondents to comprehend. Lack of comprehension may therefore be an alternative explanation for respondents having weaker responses to outcome-uncertain projections. However, differences in comprehension between the two conditions should be limited by the fact that the graphs presented to respondents were identical across conditions (except for the blue line expressing the uncertainty). Furthermore, all respondents successfully completed comprehension items prior to starting the survey.

As this study is the first to have demonstrated a beneficial effect of time-uncertain presentation (to our knowledge), and in the light of the limitations addressed above, future work should seek to replicate the finding. Moreover, in this study, participants' responses were operationalized in the form of self-report measures. It would be useful to examine whether the findings translate into differences in observable behaviour. These findings have implications for practical efforts aimed at educating non-scientific audiences on the anticipated consequences of climate change. Such efforts will help to close the gap between the scientific community and the general public in understanding the implications of uncertainty regarding the expected impact of climate change, and hopefully, serve as an impetus for action aimed at reducing their effects.

Authors' contributions. Both authors made substantial contributions to designing the study. Data acquisition and analysis was carried out by T.B. The manuscript was drafted by T.B. and revised and approved by S.L.

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