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Projected impacts on heat-related mortality from changes in the mean and variability of temperature with climate change

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Introduction: The aim of this paper is to demonstrate the importance of changing temperature variability with climate change in assessments of future heat-related mortality. Previous studies have only considered changes in the mean temperature. Here we present estimates of heat-related mortality resulting from climate change for six cities: Boston, Budapest, Dallas, Lisbon, London and Sydney. They are based on climate change scenarios for the 2080s (2070-2099) and the temperature-mortality (t-m) models constructed and validated in Gosling et al. (2007). We propose a novel methodology for assessing the impacts of climate change on heat-related mortality that considers both changes in the mean and variability of the temperature distribution.

Methods

1. Climate Data: HadCM3 is a dynamical coupled atmosphere–ocean general circulation model (AOGCM) developed at the Met Office Hadley Centre in the UK. For each city, the grid box that included the location of the weather station used to calibrate the t-m models in Gosling et al. (2007) was identified. Modelled daily temperatures for the periods 1961-1990 and 2070-2099 were obtained from HadCM3 for the SRES A2 and B2 scenarios.

2. Considering the impacts of changes in the mean and variability of temperature with climate change on heat-related mortality: Using a scenario based approach the burden of heat-related mortality attributable to climate change can be calculated by Eq (1):

Eq (1) *AD = D[CLIMATE CHANGE SCENARIO] – D[BASELINE CLIMATE e.g. 1961-1990]*

Where *AD* = burden of heat-related mortality attributable to climate change

D = heat-related mortality calculated by the t-m model for the daily temperature time series in the parenthesis [ ]

This assumes nothing changes in the future world except the climate. We assumed that the demographic structure of the population remained unchanged in the future so all impacts are presented as death rates (per 100,000). The baseline climate period that heat-related mortality was calculated for is hereafter referred to as 'present' and was taken as 1961-1990. Heat-related mortality burdens were also calculated under climate change scenarios, hereafter referred to as 'future': 2070-2099. To consider the impacts of changes in the mean and variability of temperature we investigated the impacts in 3 cases. The cases were based on various combinations of mean and variability changes in temperature with climate change and are summarised in Table 1.

3. A novel method for considering changes in the mean and variability of temperature with climate change in assessments of future heat-related mortality: We assessed the impacts associated with an artificial future temperature time series that included changes in the mean and variability of temperature with climate change. The time series was created as follows. Firstly we fitted logistic distributions to the modelled (SRES A2) present temperature distribution, the present point observations distribution, and the future SRES A2 distribution respectively. We fitted logistic distributions to all distributions for consistency and because it has larger tails than a normal distribution, which made it more appropriate to the temperature data. The changes in the location (ξ) and scale (α) parameters between the logistic distributions for the modelled (SRES A2) present and future SRES A2 were calculated. The changes in each parameter were then added to the respective location and scale parameters estimated from the present point observations distribution. The new parameters allowed for the creation of a new artificial temperature distribution. A 30-year daily time series was sampled from the artificial distribution and represents the artificial future time series. Heat-related mortality attributable to climate change was then calculated by Eq (5).

Eq (5) AD = D[Artificial Future] – D[O Present]

Results: Unlike previous climate change-heat-related mortality assessments, we considered the role of changing temperature variability. The importance of temperature variability can be highlighted by comparing the impacts estimated in Case 2 (change in temperature mean only applied to modelled present) to Case 1. More deaths were attributed to changes in the mean *and* variability of temperature with climate change (Case 1), than due to the change in mean alone (Case 2) except for Dallas, i.e. with the exception of Dallas, the other cites presented increases in future temperature variability that were associated with increases in future mortality. The results from Case 3 (change in temperature variability only) support this by showing that increases in variability were associated with increases in mortality. Interestingly, the change in variability reduced the number of future annual heat-related deaths relative to present for Dallas. This is likely due to Dallas being the only city where the future HadCM3 A2 variability was lower than the present HadCM3 A2 variability. The results demonstrate that if changes in temperature variability are ignored, it is likely that the full impacts of changing temperatures with climate change on heat-related mortality are not represented.

The novel method we applied to create a temperature projection time series removed the influence of climate model bias in the modelled present on the mortality estimates, whilst at the same time allowing for projected changes in mean and variability of temperature. By comparing the mortality estimates from this method with those of Case 1, the influence of climate model bias in the modelled present when considering changes in the mean and variability of temperature on the impacts is clear. For example, Dallas and Lisbon were the two cities with the greatest model positive bias. Future mortality estimates were 125.8 and 7309.5 (per 100,000) respectively in Case 1 but when the influence of model present bias was removed by using the novel methodology we present, the estimates reduced to 32.3 and 556.6 respectively.

Conclusion: Our results demonstrate that higher mortality is attributed to increases in the mean *and* variability of temperature with climate change than with the change in mean temperature alone. This has implications for interpreting existing impacts estimates that have used the delta method to create temperature projection time series. The impacts may be underestimated because they do not consider the role of changing temperature variability with climate change. Therefore we recommend that future assessments consider changes in the mean and variability of temperature. The novel method we have presented allows temperature projection time series that include changes in the mean and variability of temperature to be created. The method is robust because it avoids climate model bias in the modelled present influencing the final temperature projection time series.

Table 1. The 3 cases investigated.

Case	Rationale for analysis	Eq	Equation form	Comments
Case 1: Change in temperature mean and variability	To investigate how a change in the mean *and* variability of the temperature distribution with climate change impacts future heat-related mortality. Illustrate the role of uncertainty in future greenhouse gas emissions.	(2)	$A_D = D[M_{future}] - D[M_{present}]$	Attributable mortality is estimated separately for modelled temperatures from the SRES A2 and B2 emissions scenarios respectively. The present temperature time series' were modelled by HadCM3 for A2 and B2. Climate model bias has an influence on the impacts.
Case 2: Change in temperature mean only	To investigate how a change in the mean temperature *only*, for SRES A2, impacts future heat-related mortality.	(3a) (3b)	$A_D = D[(\overline{M_{future}} - \overline{M_{present}}) + M_{present}] - D[M_{present}]$ $A_D = D[(\overline{M_{future}} - \overline{M_{present}}) + O_{present}] - D[O_{present}]$	To consider the effect of climate model bias in the modelled present, heat-related mortality was calculated by Eq (3a) and Eq (3b) respectively. Eq (3a) means that modelled present HadCM3 bias influences the temperature projection time series, and consequently the heat-related mortality impacts. Eq (3b) removes the influence of climate model bias by using observed present temperatures.
Case 3: Change in temperature variability dniy	To investigate how a change in the variability of temperature *only*, for SRES A2, impacts future heat-related mortality.	(4)	$A_D = D[M_{future} - (\overline{M_{future}} - \overline{M_{present}})] - D[M_{present}]$	Assumes that any change in the temperature distribution that was not represented by a change in the mean associated with climate change, was due to a change in variability. Climate model bias impacts on future heat-related mortality.

Where: A_D = burden of heat-related mortality attributable to climate change
D = heat-related mortality calculated by the t-m model for the daily temperature time series in the parenthesis [ ]
present = temperature time series is for the period 1961-1990 O = observed daily temperature from point observations
future = temperature time series is for the period 2070-2099 M = modelled daily temperature from HadCM3

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