Projecting extreme heat-related mortality in Europe under climate change

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Abstract

The assessment of health impacts of extreme hot weather under climate change is important for adaptation and mitigation actions. This thesis has developed techniques for estimating changes in heat-related mortality in Europe, with a focus on extreme daily mortality counts. The use of these techniques is illustrated through the projections of extreme elderly mortalities for London, UK and Budapest, Hungary from 2010 to 2099, using temperature projections from the perturbed physics ensemble of the regional climate model HadRM3.

The present-day relationship between daily number of deaths and temperatures at each location is modelled by Poisson generalized additive models. In order to account for possible discrepancies in climate model simulations, temperature projections from HadRM3 are calibrated by two approaches, bias correction and change factor. These are based on assumptions on the relationships in location, scale and shape between observed and modelled temperature distributions. In particular, a novel method using the Box-Cox transformation is developed to correct the bias in the upper tails of present-day simulated temperature distributions. Finally, future mortalities are projected by driving the mortality models with calibrated temperature projections.

Results of temperature calibration show that the two calibration approaches give substantially different estimates of future extreme temperatures. The estimates of 10-summer temperature return level by the two approaches differ by more than 4 °C over many parts of Europe in the period 2070 to 2099. For London and Budapest, the effect of this calibration uncertainty on extreme temperature projections is comparable to the effect of the uncertainty in climate model parameters which is estimated by the range of perturbed physics ensemble estimates. These two sources of uncertainties, together with the uncertainty in how the mortality-temperature relationship is modelled, contribute to large uncertainties in extreme mortality projections. Assuming constant elderly population in the future, the projected change in the 2-summer return level of number of daily elderly deaths in the period 2070 to 2099 relative to the the present-day ranges from -12% to $+75\%$ for London and from -16% to $+22\%$ for Budapest.

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List of symbols

$\vert$	conditional on
$\sim$	distributed as
$\lfloor . \rfloor$	integer part
$\overset{d}{=}$	equality in distribution
$A(.)$	Box-Cox transformation function
$B(.)$	transfer function for bias correction calibration approach
$C(.)$	transfer function for change factor calibration approach
C_n	rate of convective heat loss from the human body
$[c_1, c_2]$	upper and lower bounds of confidence intervals
d	component of deviance
D	deviance
$\mathbb{E}$	expectation (population mean)
E_{re}	rate of heat loss from the human body through respiration
E_{sw}	rate of heat loss from the human body through evaporation of sweat
e^s	vapour pressure observed at meteorological stations (hPa)
e^s_i	daily mean value of e^s (hPa)
F_O	cumulative distribution function of O
F_G	cumulative distribution function of G
$F^{-1}(.)$	inverse of a cumulative distribution function
G	climate model simulated variable
G_p	p quantile of G
$(.)_i$	order of individual (daily) values in regression models
K	rate of heat loss through conduction from the human body

l	log-likelihood
l_p	penalized log-likelihood
M	metabolic heat production rate
m	basis dimension of smoothing functions in GAM
n_o	number of observations in a statistical model
n_p	degrees of freedom in a statistical model
n_r	residual degrees of freedom in a statistical model
n_u	number of observations above a threshold
N	normal distribution
O	observed climate variable
O'_b	calibrated future climate variable (O') by the bias correction approach
O'_c	calibrated future climate variable (O') by the change factor approach
$O_{(k)}$	k^{th} order statistic in the sample of O
O_p	p quantile of O
P_i	interpolated daily elderly population
$Pr(.)$	probability of an event
Q	quantile of a Poisson distribution
$[q_1, q_2]$	lower and upper bounds of prediction intervals
R_n	rate of radiative heat loss from the skin
r_i	time (in years), e.g. $[0, 10]$ (Budapest) $[0, 11]$ (London)
r_m	return period
s	standard deviation
T^{ap}	apparent temperature
T_i^{ap}	daily mean value of T^{ap}
T_i^a	simulated daily mean air temperature by HadRM3 forced by ERA-40 (°C)
T_m	return level of a temperature variable (e.g. O and G) (°C)
T_i^o	gridded observed daily mean air temperature from E-OBS data set (°C)
T_i^g	simulated daily mean air temperature by HadRM3 forced by HadCM3 (°C)
T^s	air temperature observed at meteorological observation stations (°C)
T_i^s	daily mean value of T^s (°C)

u	threshold used in a GP distribution
v^s	wind speed observed at meteorological observation stations (m s^{-1})
W	rate of work done by the body
X	covariates (explanatory variables) in a GLM or GAM
$\mathbf{X}$	set of covariates
Y	daily number of elderly deaths (random variable)
y	observations of daily number of elderly deaths
y_+	new mortality observation
α_O	location parameter of distribution of O
α_G	location parameter of distribution of G
β	parameters in regression models
$\boldsymbol{\beta}$	set of parameters in regression models
β_O	scale parameter of distribution of O
β_G	scale parameter of distribution of G
ϵ	residuals of a normal linear model
ϵ^d	deviance residuals of a GLM or GAM
λ_O	power parameter of Box-Cox transformation on O
λ_G	power parameter of Box-Cox transformation on G
μ	mean elderly death rate
η	linear predictor of a GLM or GAM
ρ	Pearson product-moment correlation coefficient
θ	canonical parameter of a distribution from the exponential family
Φ	cumulative distribution function of standard normal distribution
ϕ	dispersion parameter of a distribution from the exponential family

Notes:

- In Chapter 5, $(.)'$ is used to indicate future values (2010-99), while $\tilde{(.)}$ is used to indicate Box-Cox transformed variables. The symbols O, G, O' and G' refer to daily mean air temperatures in Sections 5.3 to 5.6.
- $\hat{(.)}$ represents an estimate.

List of acronyms

AR4	fourth assessment report of the Intergovernmental Panel on Climate Change
AT	apparent temperature
BC-L	bias correction in location
BC-LS	bias correction in location and scale
BC-LSB	bias correction in location and scale for Box-Cox transformed variables
c.d.f.	cumulative distribution function
CET	Central England Temperature
CF-L	change factor in location
CF-LS	change factor in location and scale
d.f.	degree(s) of freedom
ECMWF	European Centre of Medium Range Forecasts
e.d.f.	effective degree(s) of freedom
ERA-40	ECMWF re-analysis (from September 1957 to August 2002)
GAM	Generalized Additive Model
GCM	Global Climate Model
GEV	generalized extreme value
GLM	Generalized Linear Model
GP	generalized Pareto
HadCM3	Hadley Centre coupled ocean-atmosphere model version 3
HadSM3	slab ocean configuration of HadCM3
HadRM3	Hadley Centre regional climate model version 3
IPCC	Intergovernmental Panel on Climate Change

IQR	interquartile range
MME	multi-model ensemble
p.d.f.	probability density function
PHEWE	Assessment and prevention of acute health effects of weather conditions in Europe
PPE	perturbed physics ensemble
PRUDENCE	Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects
RCM	Regional Climate Model
s.d.	standard deviation
SRES	Special Report on Emission Scenarios
UBRE	un-biased risk estimator
UKCP09	UK Climate Projections (published in 2009)
w.r.t.	with respect to