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1 **Title: Mortality Burden of Diurnal Temperature Range and Its Temporal Changes: A**
2 **Multi-Country Study**

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42 **ABSTRACT**

43 Although diurnal temperature range (DTR) is a key index of climate change, far few studies
44 have reported the health burden of DTR and its temporal changes at a multi-country scale.
45 Therefore, we assessed the attributable risk fraction of DTR on mortality and its temporal
46 variations in a multi-country data set. We collected time-series data covering mortality and
47 weather variables from 308 cities in 10 countries from 1972 to 2013. The temporal change in
48 DTR-related mortality was estimated for each city with a time-varying distributed lag model.
49 Estimates of each city were pooled using a multivariate meta-analysis. The results showed that
50 the attributable fraction of total mortality to DTR was 2.5% (95% eCI: 2.3-2.7%) over the entire
51 study period. In overall countries, the attributable fraction has increased from 2.4% (2.1-2.7%)
52 to 2.7% (2.4-2.9%) between the first and last study years. This study found that DTR has
53 significantly attributed to mortality in overall countries, and this attributable fraction has
54 significantly increased overtime in the USA, UK, Spain, and South Korea. Therefore, because
55 the health burden of DTR is likely to increase in future, countermeasures are needed against
56 the increase.

57 **Keywords:** Diurnal temperature range, Attributable mortality risk fraction, Time-varying
58 Effect, Climate Change.

59 **Abbreviations:** Attributable risk fraction (ARF), Distributed Lag Non-linear Model (DLNM).

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62 1. Introduction

63 Diurnal temperature range (DTR, i.e., the intra-day temperature change) is a well-known risk
64 factor of weather-related human health. Numerous studies have described a positive association
65 between DTR and mortality (Cao et al. 2009; Lim et al. 2015; Tam et al. 2009; Vutcovici et al.
66 2014; Yang et al. 2013a), and have reported that people who are elderly, less educated, female
67 or have cardiovascular or respiratory disease are more susceptible to DTR than others (Kan et
68 al. 2007b; Lim et al. 2012a; Yang et al. 2013b). In addition, because the DTR has been reported
69 as an important meteorological indicator closely related with global climate change (Braganza
70 et al. 2004; Kan et al. 2007b; Yang et al. 2013b), an in-depth investigation of the DTR-mortality
71 relationship becomes important as it helps to assess the future health impact of climate change
72 more comprehensively.

73

74 Biological mechanisms through which a sudden change in absolute temperature might affect
75 mortality have been described in previous medical and epidemiological studies (Garrett et al.
76 2009; Garrett et al. 2011; Greenberg et al. 1983; Keatinge et al. 1984a; Martinez-Nicolas et al.
77 2015; Qiu et al. 2013). Sudden changes in within-day temperature may cause physiological
78 health problems (Garrett et al. 2009; Garrett et al. 2011); unstable weather or temperature
79 changes can lead to the onset of cardiovascular events brought on by increased workload. This
80 can affect the respiratory system by triggering inflammatory nasal responses (Ballester et al.
81 1997; Carder et al. 2005; Graudenz et al. 2006; Hashimoto et al. 2004; Imai et al. 1999; Luurila
82 1980). These mechanisms have been suggested as potential causes of increasing human
83 mortality (Buguet 2007; Guo et al. 2016).

84

85 Based on this biological evidence, previous studies have tried to estimate the risk of DTR on
86 mortality (Lim et al. 2015; Tam et al. 2009; Vutcovici et al. 2014). However, most previous
87 studies assessed the risk of DTR using only terms of relative risk (RR), not attributable risk
88 fraction which can quantify the mortality burden. Furthermore, because a majority of the
89 previous studies were conducted in single cities or single countries and used statistically
90 different methods (Kan et al. 2007b; Lim et al. 2012a; Yang et al. 2013b), results of these
91 studies might have limited applicability to a multi-country scale.

92

93 Most previous studies estimated the risk of DTR on mortality using historical data (Kan et al.
94 2007b; Lim et al. 2012a) and the estimated impact of DTR was assumed to be consistent
95 overtime. However, this assumption might not be suitable in predicting the health impacts of
96 climate change because several factors, including intrinsic biological (e.g., disease/nutrition
97 status) and extrinsic factors (e.g., forecast and infrastructure improvements, local environment,
98 or social system conditions), can modify the population's vulnerability to absolute temperature
99 and rapid temperature change within a day (Gasparrini et al. 2015a; Linares et al. 2014; Wu et
100 al. 2014). Therefore, it is important to assess temporal change in the DTR-related mortality
101 relationship to examine whether people are adapted or mal-adapted to DTR.

102

103 In this study, we assess the percent increases in risks and the attributable risk fraction of DTR
104 for 308 cities of 10 countries. We examine whether the excessive risks and attributable risk
105 fractions have changed during the study period. We used a Multi-Country Multi-City (MCC)
106 Collaborative Network to assess the impacts of weather on mortality using a multi-country data
107 set as referenced in previous papers (Gasparrini et al. 2015a; Gasparrini et al. 2016; Guo et al.
108 2014; Guo et al. 2016).

109

110 **2. Material and methods**

111 **2.1. Data**

112 Time-series data covering mortality and weather variables were collected from 385 locations
113 in 10 countries: Canada (26 cities, 1986-2011), United States (USA) (135 cities, 1985-2006),
114 Brazil (18 cities, 1997-2011), Colombia (5 cities, 1998-2013), United Kingdom (UK) (10
115 regions, 1990-2012), Ireland (6 regions, 1984-2007), Spain (51 cities, 1990-2010), Japan (47
116 prefectures, 1972-2012), South Korea (7 cities, 1992-2010), and Australia (3 cities, 1988-2009).
117 For convenience of interpretation, the location is described as “city” in this study. The daily
118 mortality count is the daily count of death for all causes. **If a daily count of all causes of death
119 was not available for a city, then death for non-external causes (ICD-9: 0-799, ICD-10: A00-
120 R99) was used instead.** DTR was chosen as the exposure index, computed from monitoring
121 stations as the difference between the daily maximum and daily minimum temperatures.
122 Detailed information regarding data collection is provided in the Supplementary Material (Data
123 details).

124

125 **2.2. First-stage time series model**

126 The first-stage time series model was divided into a two-step procedure. First, a time-series
127 regression was applied, based on a generalized linear model using a quasi-Poisson distribution
128 with parameters for: DTR, the day of week, seasonal long-term trend, inter-day temperature
129 change (the change in mean temperature between two neighboring days), and absolute
130 temperature. We modeled the DTR-response curve with a linear function and the lag-response
131 curve with two internal knots placed at equally spaced values on a log scale using natural cubic

132 B-spline with 14 days of lag. Inter-day temperature change was adjusted in the same way as
133 DTR. We also modeled the temperature-response relationship using a quadratic B-spline with
134 three internal knots (placed at the 10th, 75th, and 90th percentiles of location-specific
135 temperature distributions) and a lag-response (up to 21 days) curve with natural cubic B-spline
136 with three internal knots placed at equally spaced values on the log scale. This model approach
137 was used in a previous multi-country temperature-mortality study using a distributed lag non-
138 linear model (DLNM) (Gasparrini et al. 2010; Gasparrini et al. 2015b). Seasonal trends were
139 adjusted using a natural cubic B-spline of time with 8 degrees of freedom (df) per year, and
140 day of week was included as an indicator variable. Results of the first stage estimate the
141 association between DTR and mortality for each city.

142

143 **2.3. Time varying distributed lag non-linear model**

144 The DLNMs, described in the first-stage analysis, assumed that the exposure-lag-response
145 associations between DTR and mortality in each location were constant across the whole study
146 period. We also applied a time-varying DLNM with a linear interaction (Gasparrini et al. 2015a;
147 Gasparrini et al. 2016) between DTR and year. Using the time-varying DLNM, we derived
148 coefficients representing the exposure-lag-response association for the first and last year of the
149 study periods for each city. The set of four coefficients (the entire period, the first and the last
150 year for each location) were reduced to one coefficient that modeled the overall cumulative
151 associations between DTR and mortality. The sets of four coefficients were used to determine
152 the lag-response relationships at the 99th percentile of DTR reference at 0°C DTR.

153

154 **2.4. Second stage meta-analysis**

155 We pooled one parameter of the overall cumulative exposure-response relationship and the four
156 parameters of the lag-response relation. Multivariate random-effect meta-regression was used
157 to pool the parameters by country. We used indicators of country as predictors in the meta-
158 regression to country-pooled estimates and city-specific predicted parameters (Best Linear
159 Unbiased Prediction, BLUP). Overall pooled coefficient (only for calculating excessive
160 relative risk of overall countries) was estimated by meta-analysis without predictors. All
161 analyses were performed using R software (version 3.3.1) packages `dlnm` and `mvmeta`
162 (Gasparrini 2011; Gasparrini et al. 2012; Gasparrini et al. 2010).

163

164 **2.5. Attributable mortality risk fraction**

165 Overall cumulative relative risk estimated from BLUP for each city was used to compute the
166 attributed number of deaths, and the fraction of deaths over the following 14 days at each
167 location. **The total number of deaths attributed to DTR was calculated as the sum of all days in**
168 **the series when DTR contributed to death and its ratio with the total number of deaths; this**
169 **provides the ‘total attributable fraction’ (Gasparrini and Leone 2014).** We also computed the
170 time-varying attributable risk of DTR based on BLUP for each city from the time-varying
171 DLNM. Although time-dependent distributions of DTR and death could be used to estimate
172 time-varying attributable risk, we used DTR and mortality distribution for the entire period
173 because we did not find a clear difference between DTR distributions for the first and last three
174 years of the series for each city (Table 1).

175

176 **2.6. Sensitivity analysis**

177 In order to test the sensitivity of our results to the modeling parameters and assumptions

178 described above, we changed lag days for DTR (21 days), inter-day temperature changes (10
179 and 21 days), and the degrees of freedom (df) of lag knots for DTR (df=5), and analyzed the
180 first results. We also assessed sensitivity to controlling for humidity (only for 6 countries which
181 include relative humidity data), air pollution (Korea, O₃ and PM₁₀), flexibility of long-term
182 trend (df=7 and 9) and absolute temperature using various knot percentiles and changing lag
183 days (14 and 28 days).

184

185 **3. Results**

186 Descriptive statistics of mortality, absolute temperature, and the distribution of DTR are in
187 Table 1. Fig. 1 displays the geographical distributions of the 308 cities within the 10 countries
188 included in the analyses and the corresponding annual averaged DTR ($^{\circ}\text{C}$). The data set
189 included 85,912,372 deaths. A variability in DTR was observed among countries over the entire
190 study period, with mean values ranging from 6.7 $^{\circ}\text{C}$ (Ireland, 6 cities) to 10.9 $^{\circ}\text{C}$ (USA, 135
191 cities). Table 1 also shows the DTRs and absolute temperature distributions during the first and
192 second halves of the time periods for each country. As expected, the mean temperature
193 increased slightly over time, although we did not detect a clear temporal pattern in the DTR
194 values. City-specific descriptive statistics are reported in Supplementary Table S1.

195

196 The percent increases in risks and attributable mortality risk fraction of DTR estimated from
197 the model with no interaction (i.e. the average throughout the study period) are reported in
198 Table 2. Percent increases in risks of DTR (per 10 $^{\circ}\text{C}$) are highest in South Korea (6%, 95%
199 CI: 3-9.1%), Spain (4.4%, 3-5.8%), and Brazil (4.2%, 1.7-6.7%). Colombia (-1.2%, -6.3-4.1%)
200 and Ireland (0.3%, -3-3.8%) showed the lowest percent increases in risk of DTR, although

201 both were not significant. Table 2 also displays the total percentage of deaths attributable to
202 DTR (reference at minimum DTR of each city, 2.5% with 95% empirical confidence interval
203 (95% eCI): 2.3–2.7%). Similar with percent increases in risk, most of the country-specific
204 estimated attributable risks were statistically significant. The risk fraction was highest in Korea
205 (4.5%, 3-5.9%) and Spain (4.2%, 3.5-4.9%). The fractions were lowest in Colombia (-1.5%, -
206 5.1–2.1%) and in Ireland (0.2%, -1.2–1.4%).

207

208 Fig. 2 displays the country-pooled lag-response associations at the 99th percentile of DTR
209 referenced at 0°C. The coldest (Canada, Ireland, and UK) and warmest (Brazil, Colombia)
210 countries showed the highest RR at lag 0 and lasted to a lag from 4–7 days. Other countries,
211 which had moderate temperatures, have the highest RR in approximately 1–3 lag days and were
212 limited to a lag of 7–14 days. The corresponding city-specific lag-response is displayed in
213 Supplementary Fig. S1.

214

215 Results from an analysis of the temporal variation in the percent increases in risk of DTR are
216 illustrated in Fig. 3. Table 3 displays temporal variation of estimates per year and test results
217 for linear interaction (null hypothesis is the pooled interaction term is 0; the null hypothesis is
218 that no temporal change occurred). The percent increases in risk of DTR increased from 2.5%
219 (95% CI: 1.8–3.3%) to 3.8% (95% CI: 3.1–4.5%) between the first and last periods. Except for
220 Ireland and Japan, all countries showed patterns of increasing percent increases in DTR risk,
221 with -2.9–5% in the first year and 1.5–13.8% in the last year of the series. The temporal increase
222 of percent increases in DTR risk were significant (P-value<0.05) in USA, UK, Spain, and South
223 Korea (Table 3). Country-pooled temporal changes in the lag-response relationship are
224 displayed in Supplementary Fig. S2. A comparison between the curves suggests that a longer

225 lag-association and smaller harvesting effect were observed in most countries.

226

227 Fig. 4 and Table 3 display the temporal variation in the attributable mortality risk fraction of
228 DTR. In overall, the attributable risk fraction of deaths increased from 2.4% (95% eCI: 2.1-
229 2.7%) to 2.7% (2.4-2.9%) between the first and last periods. The increase in the attributable
230 risk fraction of death overtime was observed in all countries except Japan (0.07% decrease per
231 a year) and Ireland (0.23% decrease per a year). Korea (0.56% per year) and Colombia (0.31%
232 per year) showed the fastest increase of risk fraction, whereas Canada (0.03% per year), USA
233 (0.09% per year) and UK (0.11% per year) showed the slowest increasing patterns.
234 Corresponding city-specific estimates are reported in the Supplementary Material
235 (Supplementary Table S2). And main conclusions were robust to sensitivity analysis
236 (Supplementary Table S3).

237

238 **4. Discussion**

239 Our findings show that DTR is responsible for a higher mortality risk increase (3.1%, 95% CI:
240 2.7–3.5%) and fraction of deaths (2.5%, 95% eCI: 2.3–2.7%) in all the countries studied. South
241 Korea and Spain showed the highest percent increase in risk (6% and 4.4%, respectively) and
242 attributable risk fractions (4.5% and 4.2%, respectively). This study also provides evidence of
243 the incremental health impact of DTR during the last few decades. With the exception of Japan
244 and Ireland, an increasing pattern of percentile increases in risks (3.8% in the last year of the
245 study periods, compared with 2.5% in the first year) was observed, and the attributable risk
246 fraction showed the same temporal increasing pattern (2.7% in the last year of the study periods,
247 compared with 2.4% in the first year).

248

249 This study is comparable to a recent temperature variability-mortality association study in the
250 MCC Collaborative Network (Guo et al. 2016). Both studies were based on a similar multi-
251 country data set and addressed the significant association between temperature variability and
252 mortality, even after controlling for the main effect of absolute temperature. Guo et al.
253 developed a new composite index of intra- and inter-day temperature variability using a
254 standard deviation of minimum and maximum temperatures during the exposure days, and
255 found the temperature variability-mortality relationship varied with exposure days (0–7 days),
256 countries (twelve countries/regions with 372 communities), and season (cold, hot, and
257 moderate). Meanwhile, our study only focused on the association between intra-day
258 temperature variability and mortality, using a classical meteorology index (DTR) and flexible
259 statistical method, which considers a flexible lag-response structure of DTR. In addition, our
260 study included data from 308 cities in the 10 countries with more than 15 years of study data
261 to estimate the temporal changes in the DTR-mortality association. It also described an overall
262 increase in the health burden of DTR on mortality during recent decades.

263

264 Interestingly, our finding suggested that the DTR effects on mortality were higher in warm
265 countries (Brazil, Australia, and Spain) compared to cold countries (Canada, Ireland, and UK),
266 although Korea and Colombia were exceptions. These finding are consistent with previous
267 studies, such as multi-country studies that reported that the effect of temperature variability
268 with short exposure durations (0–1, and 0–2 days) on mortality is highest in hot area ($>22.9^{\circ}\text{C}$)
269 than other areas (cold, moderate cold, and moderate hot areas) (Guo et al. 2016). U.S. studies
270 also showed that higher DTR effect in southern areas (percent change of non-accidental
271 mortality per one unit of DTR 0.24-0.31%) than other regions (0.22-0.27%) (Lim et al. 2014).

272 Studies in China also showed a similar trend of a relatively higher and more significant effect
273 of DTR in warm cities (Guangzhou, and Shanghai) than cold cities (Anshan and Xi'an,
274 although Tangshan is an exception). To specifically assess the association between the DTR
275 effects and annual mean of absolute temperature, we fitted a weighted regression model
276 (Supplementary Fig. S3); a city-specific BLUP of DTR coefficient (i.e. log of relative risk,
277 estimated from the second stage analysis) was used as a response variable, annual mean
278 temperature was used as an explanatory variable, and inversed city-specific variances of the
279 DTR coefficient were used as weights. We observed a significantly positive linear association
280 between the DTR effect and the annual mean temperature from the weighted regression model
281 (P-value=0.01). This result can be interpreted as evidence to support the hypothesis that there
282 may be an impact on mortality from the positive interactions between long-term temperature
283 and DTR.

284

285 The synergism effect of the DTR and long-term temperature on mortality may be due to a
286 number of factors. One mechanism may be aggravation. Hot temperature can disturb normal
287 physiological thermoregulation, including changes in blood viscosity, plasma cholesterol level,
288 and red blood cell count (Keatinge et al. 1986). Increasing DTR may also impact mortality
289 through lowering the thermoregulatory system and negatively affecting the heart rate, heart rate
290 variability, blood platelets, red blood cells, and blood viscosity (Keatinge et al. 1984b; Lim et
291 al. 2012b). Because warm countries can be exposed to hot weather more often, the DTR effect
292 of warm areas can be amplified by the increase in biological burden. Another hypothesis is that
293 the effect of the DTR is higher in warm areas because people in warm and moderate areas are
294 more likely to keep their windows open and spend more time outdoors, which may increase
295 exposure to DTR, thus increasing the effect of DTR. However, our results only suggest the

296 possible associations of the aggravation hypothesis; further research should be conducted to
297 find the causal relationship between DTR and long-term temperature on mortality.

298

299 Additional questions should be raised as to why the effect of DTR on mortality changed across
300 time. We speculate several plausible explanations. The first hypothesis is deterioration by
301 climate change, suggested in the previous paragraph. We found the higher risk and sharper risk
302 increase in hot cities. This finding suggests that climate change may increase the risk of DTR.
303 Secondly, an aging population may also be an important factor, as numerous studies have
304 revealed that elderly people are more susceptible to DTR (Kan et al. 2007a; Lim et al. 2012a;
305 Yang et al. 2013a), and the populations of developed and developing countries included in our
306 research are aging (Börsch-Supan 2008; Faunce 2008). However, we could not identify the
307 exact reason of the temporal increase, hence additional research regarding this topic is needed
308 in further studies.

309

310 Although not found in our study, prior studies have reported that climate change factors
311 (greenhouse gases, urbanization, and aerosols) have led to global decline in the DTR during
312 twenty century, because the nocturnal minimum temperatures have increased faster than
313 maximum temperature (Braganza et al. 2004; Makowski et al. 2008). However, it is still unclear
314 how this decline in the DTR will affect human health. Also, since the increasing nocturnal
315 temperatures can affect mortality and distribution of DTR simultaneously, a confounding effect
316 of the nocturnal temperatures needs to be considered to estimate the effect of DTR on death.
317 Even if the effect of increasing nocturnal minimum temperature is partly considered in our
318 study by controlling the daily averaged temperature, there is a limitation to control the effect
319 of nocturnal temperature due to lack of data. Therefore, we expect more comprehensive studies

320 to be carried out under various climate conditions with longer study periods and more detailed
321 weather data.

322

323 As described earlier, although DTR and absolute temperature may affect human health in
324 different ways, because both have a mechanism that negatively affects human health, the effects
325 of absolute temperature and temperature variability on mortality have been an interesting topic
326 of prior environmental research. In addition, comparing the health effects of two variables has
327 important implications for understanding human health in a climate change context (which can
328 increase both the average values and the variability of temperature)(Guo et al. 2016; Stocker
329 2014; Vicedo-Cabrera et al. 2016). Recent studies asserted that DTR has a lesser effect than
330 absolute temperature on mortality (Lee et al. 2017; Vicedo-Cabrera et al. 2016). Our results
331 also suggest a lesser effect of DTR on mortality when compared with the total attributable
332 mortality fraction of absolute temperature from a previous study (Gasparrini et al. 2015b). The
333 total fraction of DTR attributed to mortality (2.5%) was much smaller than the fraction for total
334 absolute temperature (7.71%)(Gasparrini et al. 2015b). However, our results may differ from
335 the conclusions of previous studies (Chen et al. 2007; Kan et al. 2007a; Lim et al. 2015; Tam
336 et al. 2009; Yang et al. 2013a) that used modeling strategies that did not fully control the flexible
337 lag structures of absolute temperature. Because the effect of absolute temperature delayed up
338 to several weeks of exposure, the estimates of DTR on mortality could be overestimated unless
339 the main effects of temperature are fully adjusted. Hence, we contend that our modelling
340 approach provides more appropriate results in estimating the health effects of DTR, in
341 comparison with prior studies.

342

343 In this study, more acute DTR–mortality relationships (highest RR at 0 lag days) were observed

344 in warm and cold countries (Brazil, Colombia, Canada, Ireland, and UK). In contrast, more
345 delayed DTR–mortality relationships (highest RR at 2–4 lag days) were observed in other
346 moderate temperature countries. Although this study does not explain the difference, we
347 speculate that the exact factors are related to the physiological, technological, and behavioral
348 adaptations to the climate.

349

350 A key strength of our study is the use of a large multi-country, multi-city data set with different
351 demographic distributions, climate conditions, and socio-economic characteristics. To the best
352 of our knowledge, our study is the largest of its kind including 308 locations and more than 85
353 million deaths from 10 countries. Our study also is the first and the largest study of time-
354 varying DTR-related mortality, and the use of a uniform statistical framework across all cities
355 makes the results directly comparable. In addition, unlike previous studies that have quantified
356 the association on terms of RR (Kan et al. 2007b; Vicedo-Cabrera et al. 2016; Yang et al. 2013b),
357 our study provides the attributable mortality burden of DTR. Because the attributable fraction
358 considers the distribution and risks of each variable, we contend that the attributable fraction
359 is a suitable measure to estimate mortality burden of the exposure variable and to establish
360 corresponding public health strategies.

361

362 However, our study has some limitations that must be acknowledged. First, because regions of
363 Africa, and large countries in Europe and Asia (such as France, Russia, and India) were not
364 included in this study, our findings are not globally representative. Second, the data did not
365 include age- or gender-specific mortality rates, which could be explored in future research.
366 Third, we could only identify the suggestive association between DTR and all-causes mortality,
367 and not the causal effect of DTR on mortality. Future studies should strive to overcome these

368 limitations by expanding the study populations and improving the study design.

369

370 **5. Conclusions**

371 In summary, this study finds that the significant DTR effect on mortality across all countries,
372 and provides evidence that the effect of DTR was higher in warm regions. Although our
373 estimated attributable mortality fraction of DTR is smaller than fractions of absolute
374 temperature from a previous multi-country study (Gasparrini et al. 2015b), it is higher than
375 fractions of extreme heat and cold temperature. In addition, although the risks and contributions
376 of DTR on mortality varied for each country, it increased at the multi-country scale with
377 significant increases estimated in USA, UK, Spain, and South Korea; and non-significant
378 increments in Canada, Brazil, Colombia, and Australia. **The estimates of DTR-related mortality**
379 **increased throughout the study period in overall regions, which could be interpreted as**
380 **maladaptation to DTR. Consequently, there is a possibility that the health burden of DTR will**
381 **increase in the near future.** Hence, we suggest that public-health policies and climate change
382 research that have so far focused on the effects of extreme heat should be extended to account
383 for the health burden of DTR and its temporal variation.

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512 **Table 1. Descriptive statistics by country.** Including distribution of diurnal temperature range
 513 in first 3 years (First) and last 3 years (Last) of country-specific study periods. USA: United
 514 States of America, UK: United Kingdom.

Country (# of city)	Time Period	Total Deaths	Study Period (year)	Absolute temperature (°C)	Diurnal temperature range (°C)					
				Mean	Mean	10%	25%	50%	75%	90%
Canada (26)	Whole	2,989,901	1986- 2011	6.8	10	4.4	6.6	9.7	13	15.9
	First			7	10.1	4.5	6.7	9.8	13	16
	Last			6.9	9.9	4.4	6.4	9.4	12.9	16.1
USA (135)	Whole	22,896,409	1985- 2006	14.8	10.9	5.6	7.8	10.6	13.9	16.7
	First			14.7	11	5.6	7.8	10.6	13.9	17.2
	Last			15.1	10.7	5.6	7.8	10.6	13.3	16.1
Brazil (18)	Whole	3,435,502	1997- 2011	24.2	9	5.4	6.8	8.6	10.7	13.2
	First			24.1	8.8	5.1	6.6	8.4	10.6	13.1
	Last			24.3	9.1	5.5	7	8.6	10.7	13.4
Colombia (5)	Whole	956,539	1998- 2013	23.4	9	5.8	7	8.8	10.8	12.4
	First			23.1	8.9	5.6	6.8	8.7	10.8	12.5
	Last			23.5	8.9	6.1	7.2	8.7	10.4	12.1
UK (10)	Whole	1,2075,786	1990- 2012	10.3	7.3	3.8	5.2	6.9	9.1	11.3
	First			10.1	7.3	3.8	5.1	6.9	9.1	11.3
	Last			10.1	7.5	3.9	5.3	7	9.4	11.7
Ireland (6)	Whole	1,058,215	1984- 2007	9.7	6.7	3.4	4.8	6.4	8.3	10.3
	First			8.9	6.8	3.6	4.9	6.5	8.4	10.4
	Last			10.3	6.9	3.6	4.9	6.6	8.5	10.5
Spain (51)	Whole	3,480,531	1990- 2010	15.5	10.6	4.9	7	10	13.8	17
	First			15.1	10.7	5	7.2	10.2	13.8	17.2
	Last			15.5	10.4	4.8	6.8	9.8	13.6	17
Japan	Whole	3,6113,897	1972- 2012	15.1	8.4	4.2	6	8.2	10.6	12.8

(47)	First			14.4	8.8	4.4	6.3	8.6	11	13.3
	Last			15.5	8.2	4.1	5.9	8	10.2	12.4
South Korea	Whole	1,727,642	1992-2010	13.7	8.2	4.1	5.9	8	10.2	12.7
(7)	First			13.5	8	3.8	5.6	7.7	10.1	12.5
	Last			13.8	8.3	4.3	5.9	8	10.3	12.7
Australia	Whole	1,177,950	1988-2009	18.1	8.2	4.4	5.9	7.8	10	12.4
(3)	First			18.1	7.8	4.1	5.6	7.3	9.5	11.9
	Last			18.7	8.1	4.5	5.8	7.6	10	12.6

516 **Table 2.** Percent increases in risk (per 10°C) and attributable risk fraction (%) of diurnal
 517 temperature range on mortality by country. USA: United States of America, UK: United
 518 Kingdom.

Country	Percent Increases in Risk (%, 95% CI)	Attributable Risk Fraction (%, 95% eCI)
Canada	2.6 % (0.9 , 4.2)	2.7 % (1.8 , 3.5)
USA	2.9 % (2.3 , 3.6)	3.2 % (2.9 , 3.5)
Brazil	4.2 % (1.7 , 6.7)	3.7 % (2.6 , 4.9)
Colombia	-1.2 % (-6.3 , 4.1)	-1.5 % (-5.1 , 2.1)
UK	2.9 % (1.5 , 4.4)	2.1 % (1.6 , 2.7)
Ireland	0.3 % (-3 , 3.8)	0.2 % (-1.2 , 1.4)
Spain	4.4 % (3 , 5.8)	4.2 % (3.5 , 4.9)
Japan	3.1 % (2.3 , 3.9)	2.7 % (2.4 , 3)
South Korea	6 % (3 , 9.1)	4.5 % (3 , 5.9)
Australia	4.2 % (0.7 , 7.9)	3.3 % (1.1 , 5.3)
Overall	3.1 % (2.7 , 3.5)	2.5 % (2.3 , 2.7)

519 eCI: empirical confidence interval.

520 **Table 3.** Variation of excessive relative risk (per 10°C) and attributable fraction (%) of diurnal
 521 temperature range on mortality per a year, and p-value of the test. USA: United States of
 522 America, UK: United Kingdom.

Variation (per year)				
Country	Study Period (Years)	Percent Increases in Risk	Attributable Risk Fraction	p-value*
Canada	26	0.06 %	0.03 %	0.4384
USA	22	0.09 %	0.09 %	0.0209
Brazil	15	0.25 %	0.23 %	0.2243
Colombia	16	0.29 %	0.31 %	0.6583
UK	23	0.17 %	0.11 %	0.0344
Ireland	24	-0.35 %	-0.23 %	0.0989
Spain	21	0.28 %	0.23 %	0.0025
Japan	41	-0.09 %	-0.07 %	<0.0001
South Korea	19	0.78 %	0.56 %	<0.0001
Australia	22	0.3 %	0.26 %	0.1543

523 * Significant test on temporal change by Wald type test of the pooled reduced coefficient of the
 524 year-interaction terms. The null hypothesis is that no change in year occurred.

525 **Figure legends**

526 **Fig. 1.** Geographical locations of study cities and their annual mean values of diurnal
527 temperature range (DTR, °C).

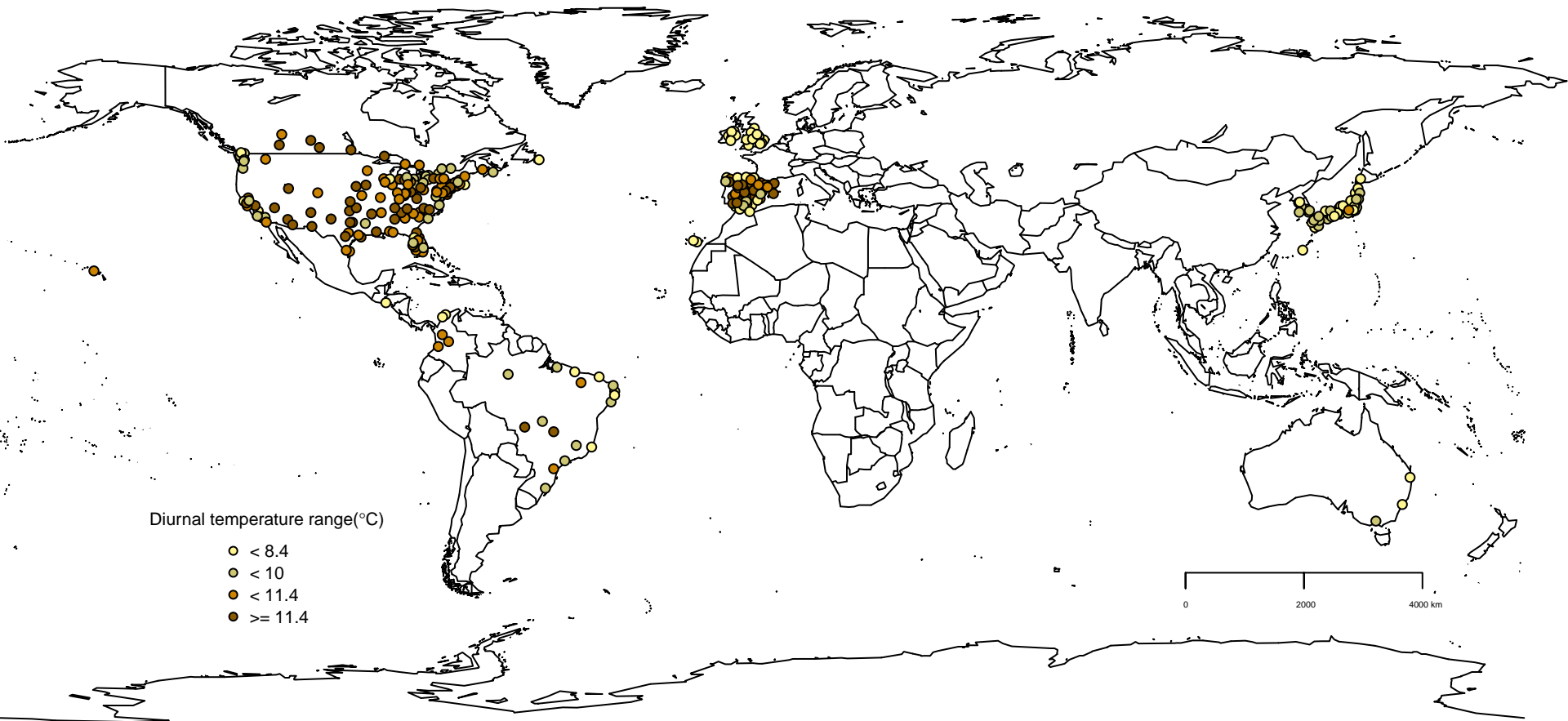
528 **Fig. 2.** Lag-response relationship between diurnal temperature range (DTR) and mortality
529 predicted for the overall study periods of 10 countries; RR: relative risk. USA: United States,
530 UK: United Kingdom.

531 **Fig. 3:** Temporal changes in percent increases in risk (%) between the first (First) and the last
532 (Last) year of country-specific study periods; USA: United States, UK: United Kingdom.

533 **Fig. 4.** Temporal changes in attributable risk fraction (%) between the first (First) and the last
534 (Last) year of country-specific study periods; USA: United States, UK: United Kingdom.

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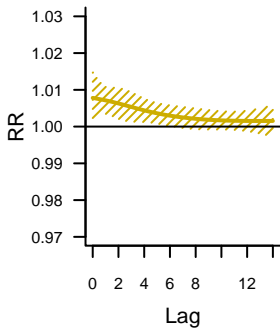
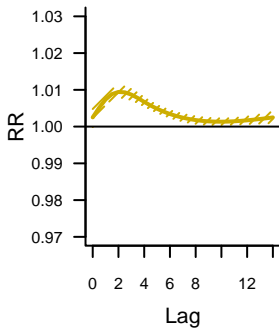
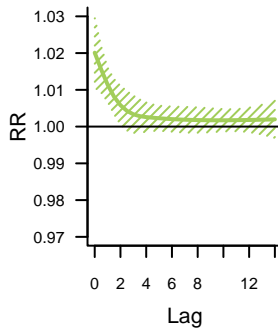
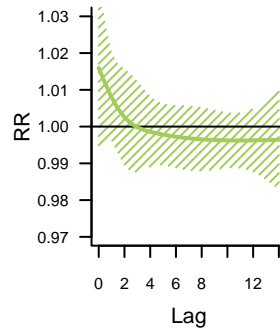
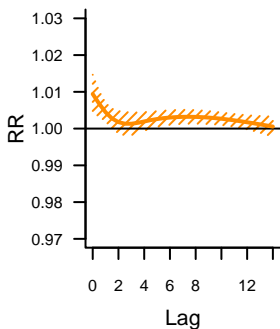
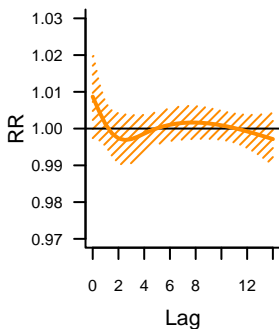
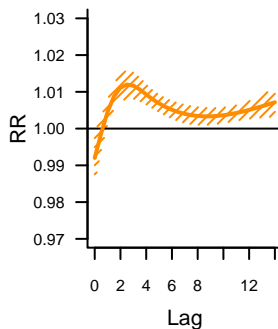
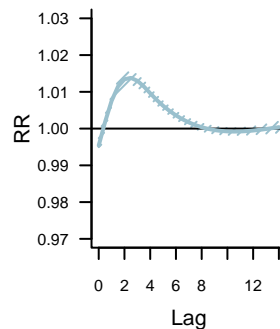
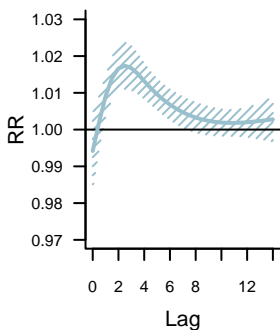
537 **Competing financial interest:** The authors declare they have no actual or potential competing
538 financial interests.



Diurnal temperature range(°C)

- < 8.4
- < 10
- < 11.4
- ≥ 11.4



Canada**USA****Brazil****Colombia****UK****Ireland****Spain****Japan****South Korea****Australia**