Temperature Related Mortality in Germany and England and Wales in the 21st Century

Background:

Extreme temperatures were accountable for the highest proportion of deaths from natural disasters in Europe in the period of 1970-2012 (WMO 2014:30). Various studies have discussed the effects of climate change and heat waves on mortality (Baccini et al., 2008; Ballerster et al., 2008; D'Ippoliti et al., 2010; Gasparrini et al., 2015; Huynen et al., 2001; Kovats, 2004; Vicedo-Cabrera et al., 2019, 2021). The research question we address is whether temperature-related mortality is increasing in the face of climate change during the first two decades of the 21st century in England & Wales and Germany. Furthermore, we will discuss potential demographic dimensions of vulnerability to outdoor temperature and long-term trends in those regions.

Data:

Daily death counts were obtained from the Office for National Statistics of the United Kingdom and from the Federal Statistical Office of Germany. They were matched with daily mean temperature data from the MET Office Hadley Centre observation datasets for the English and Welsh data and the daily mean across all weather stations from the German Weather Service. The original data from both countries covered different periods and were trimmed to identical periods from Jan 1st , 2000 to Dec 31st, 2019.

Methods:

We estimated temperature-related mortality in two steps: First, we estimated an exposure-response relationship between temperature and mortality. We did this by applying a distributed lag model (DLM) as developed by Armstrong (2006) and Gasparrini et al. (2010). These models allow lagged effects which can vary by temperature. Thus, we did not estimate the conventional exposure-response *curve* but an exposure-response *surface*. More specifically, we used the penalised distributed lag non-linear model by Gasparrini et al. (2017). It is estimated within a Generalized Additive Model (GAM) framework (Hastie & Tibshirani, 1990; Wood, 2006). As it does not require any a priori functional (parametric) form for the relationship, it is highly flexible. Smoothness of the effects is ensured by penalization in the splines-based model (Eilers and Marx, 1996). In addition to the original model specification (Gasparrini et al., 2017) we used the log of the population data as an offset to exclude spurious trends in death counts due to changing population size.[1] In the second step we estimate the absolute number as well as the fraction of deaths attributable to temperature (Gasparrini & Leone, 2014). Based on the model estimated for each country for the whole period we show annual estimates for heat- and cold-related mortality. Trend lines have been estimated and added based on the LOESS local regression model (Cleveland et al., 1993:314).

Results*:*

The estimated exposure-response surfaces for England & Wales and Germany are presented in Figure 1. The effect of the lag varies by temperature exposure. Extreme warm temperatures at a lag of zero display the highest mortality risk in both models. In England and Wales, the relative mortality risk declines below 1 within the first two days of heat exposure. This reduced risk persists for 20 days, suggesting a mortality displacement effect ("harvesting"). This negative effect is not observed in the German data where the increased risk of mortality at heat exposure returns to a relative risk of one after five days. Cold temperatures display an initial protective effect on the mortality risk at the time of exposure and shortly thereafter but are associated with an increased relative mortality risk for more than three weeks in both regions.

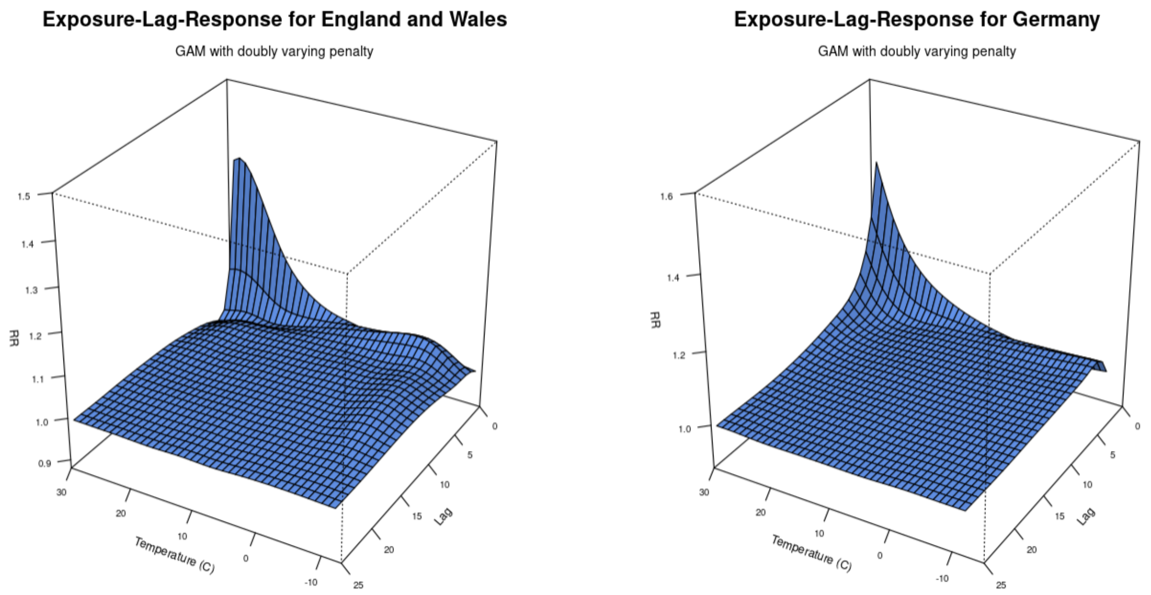

Figure 1: Exposure-ResponseSurfaces for England & Wales (left) and Germany (right).

[1]The log of the population size was used since deaths counts were modeled in this „GAM" as poisson-distributed with the canonical log link.

Figure 2 shows the marginal effects by temperature (including confidence intervals). With 17.5°C in England and Wales and 18°C in Germany, the temperatures of minimum mortality are similar to each other. Both countries also exhibit a similar shape of relative mortality risk by temperature exposure: Mortality increases steeper with hotter temperatures than with colder temperatures.

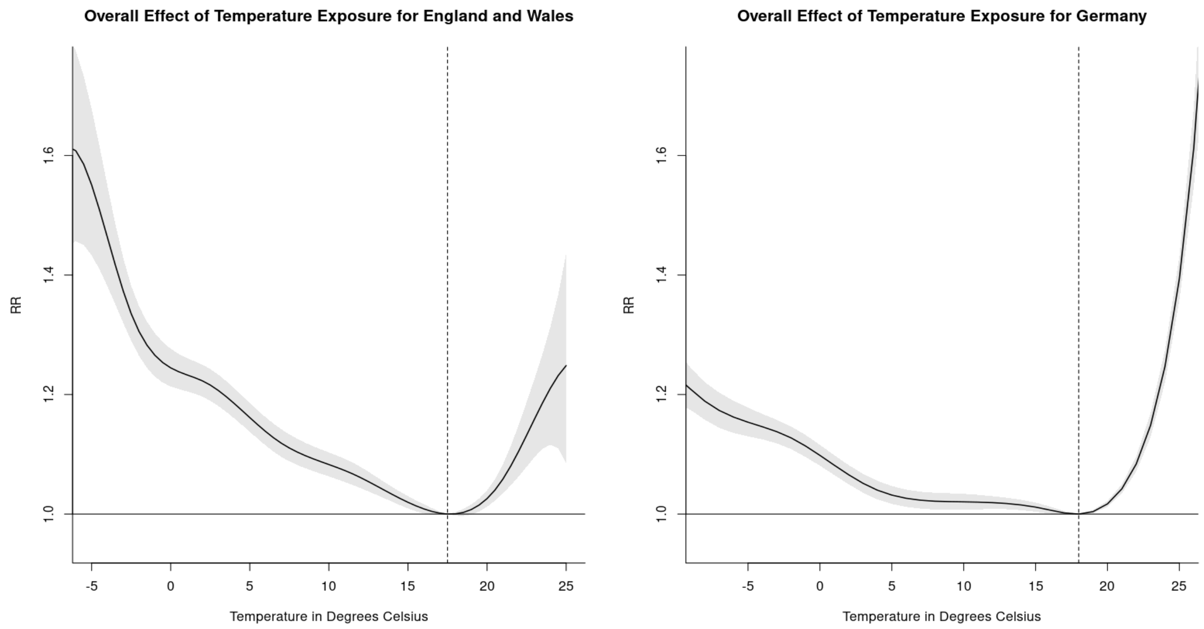

Figure 2: Marginal effects by temperature for England & Wales (left) and Germany (right).

For the whole observation period combined, the models estimate a temperature-related excess mortality of 7.94% for England and Wales, and 3.82% for Germany. Deaths occurring at temperatures above the respective minimum mortality temperatures make up only 0.12% of all deaths in England and Wales compared to 0.54% for Germany. Thus, it is not surprising that deaths associated with cold temperatures make up a distinctively larger proportion of all deaths (England and Wales: 7.82%; Germany: 3.27%).

Figure 3 exhibits annual estimates for England & Wales (left) and Germany (right) for the years 2000 through 2019 for heat-related mortality (top row), cold-related mortality (middle row) and combined (bottom) row. The LOESS regression illustrates the trends over those two decades. Heat-related mortality has a positive trend as proportion of overall deaths since 2010, while cold-related mortality declines since 2013. Accumulated effects show a stable trend in recent years for England and Wales, but an upward trend for Germany. Apart from the actual proportions, those trends are robust, even if cold-related mortality only applies to temperatures at 5°C and below (results not shown here).

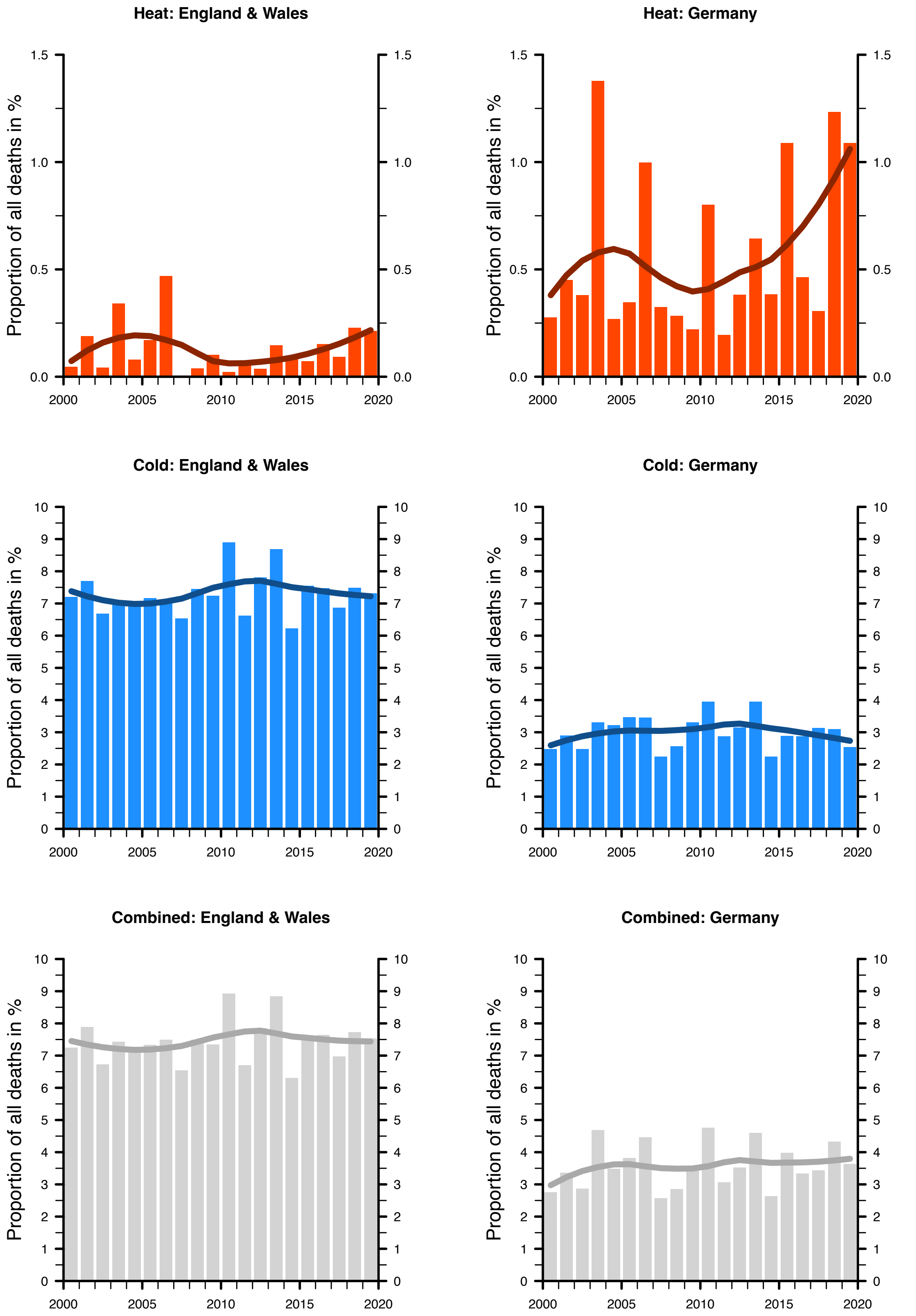

Figure 3: Attributable fractions of overall deaths to temperature-related mortality. For temperatures above the minimum-mortality temperature (1st row), temperatures below (2nd row) and the overall temperature-related mortality (3rd row) for England & Wales (left) and Germany (right).

Further Research:

Since temperatures can vary considerably within a country we will proceed with an analysis on the regional level. England and Wales will be divided into 10 regions, Germany into its 16 Federal States. This regional breakdown will allow for more precise estimates of temperature-related mortality, the minimum mortality temperature as well as a more detailed interpretation of results. In addition, we aim to identify some rural-urban differences in responsiveness to outdoor temperatures and look further into changes in temperature-related mortality over the years. Ideally, we will extend our observation period to include data from the last century, providing a better understanding of long-term trends.

Furthermore, we plan to incorporate demographic variables, such as age and sex, into the analysis. This will allow us to identify which age groups are most vulnerable to heat and cold exposure, and whether significant differences exist in temperature-related mortality between genders.

References:

Armstrong, Ben. 2006. ‘Models for the Relationship Between Ambient Temperature and Daily Mortality’. *Epidemiology* 17(6):624–31. doi: 10.1097/01.ede.0000239732.50999.8f.

Baccini, Michela, Annibale Biggeri, Gabriele Accetta, Tom Kosatsky, Klea Katsouyanni, Antonis Analitis, H. Ross Anderson, Luigi Bisanti, Daniela D’Ippoliti, Jana Danova, Bertil Forsberg, Sylvia Medina, Anna Paldy, Daniel Rabczenko, Christian Schindler, and Paola Michelozzi. 2008. ‘Heat Effects on Mortality in 15 European Cities’. *Epidemiology* 19(5):711. doi: 10.1097/EDE.0b013e318176bfcd.

Ballester, Joan, Jean-Marie Robine, François Richard Herrmann, and Xavier Rodó. 2011. ‘Long-Term Projections and Acclimatization Scenarios of Temperature-Related Mortality in Europe’. *Nature Communications* 2(1):358. doi: 10.1038/ncomms1360.

Cleveland, William S., Eric Grosse, William M. Shyu. 1993. ‘Local Regression Models’. in *Statistical Models in S*. London: Chapman & Hall.

D’Ippoliti, Daniela, Paola Michelozzi, Claudia Marino, Francesca de’Donato, Bettina Menne, Klea Katsouyanni, Ursula Kirchmayer, Antonis Analitis, Mercedes Medina-Ramón, Anna Paldy, Richard Atkinson, Sari Kovats, Luigi Bisanti, Alexandra Schneider, Agnès Lefranc, Carmen Iñiguez, and Carlo A. Perucci. 2010. ‘The Impact of Heat Waves on Mortality in 9 European Cities: Results from the EuroHEAT Project’. *Environmental Health* 9(1):37. doi: 10.1186/1476-069X-9-37.

Eilers, Paul HC, and Brian D. Marx. 1996. "Flexible smoothing with B-splines and penalties." Statistical Science 11(2)): 89-121.

Gasparrini, A., B. Armstrong, and M. G. Kenward. 2010. ‘Distributed Lag Non-Linear Models’. *Statistics in Medicine* 29(21):2224–34. doi: 10.1002/sim.3940.

Gasparrini, Antonio, Yuming Guo, Masahiro Hashizume, Eric Lavigne, Antonella Zanobetti, Joel Schwartz, Aurelio Tobias, Shilu Tong, Joacim Rocklöv, Bertil Forsberg, Michela Leone, Manuela De Sario, Michelle L. Bell, Yue-Liang Leon Guo, Chang-fu Wu, Haidong Kan, Seung-Muk Yi, Micheline De Sousa Zanotti Stagliorio Coelho, Paulo

Hilario Nascimento Saldiva, Yasushi Honda, Ho Kim, and Ben Armstrong. 2015. ‘Mortality Risk Attributable to High and Low Ambient Temperature: A Multicountry Observational Study’. *The Lancet* 386(9991):369–75. doi: 10.1016/S0140-6736(14)62114-0.

Gasparrini, Antonio, and Michela Leone. 2014. ‘Attributable Risk from Distributed Lag Models’. *BMC Medical Research Methodology* 14(1):55. doi: 10.1186/1471-2288-14-55.

Hastie, Trevor J., and Robert J. Tibshirani, 1990. Generalized Additive Models. London, UK: Chapman & Hall

Huynen, M. M., P. Martens, D. Schram, M. P. Weijenberg, and A. E. Kunst. 2001. ‘The Impact of Heat Waves and Cold Spells on Mortality Rates in the Dutch Population.’ *Environmental Health Perspectives* 109(5):463–70.

Kovats, Sari. 2004. ‘Estimates of Temperature-Related Mortality Due To Climate Change In Europe’. *Epidemiology* 15(4):S95.

Vicedo-Cabrera, A., F. Sera, A. Tobias, C. Astrom, Y. Guo, Y. Honda, A. Deluca, D. Hondula, D. Ibarreta, V. Huber, and A. Gasparrini. 2019. ‘Heat-Related Mortality Impacts Attributed to Climate Change: A Global Study over Historical Period.’ *Environmental Epidemiology* 3:414. doi: 10.1097/01.EE9.0000610636.25240.e8.

Vicedo-Cabrera, A. M., N. Scovronick, F. Sera, D. Royé, R. Schneider, A. Tobias, C. Astrom, Y. Guo, Y. Honda, D. M. Hondula, R. Abrutzky, S. Tong, M. De Sousa Zanotti Stagliorio Coelho, P. H. Nascimento Saldiva, E. Lavigne, P. Matus Correa, N. Valdes Ortega, H. Kan, S. Osorio, J. Kyselý, A. Urban, H. Orru, E. Indermitte, J. J. K. Jaakkola, N. Ryti, M. Pascal, A. Schneider, K. Katsouyanni, E. Samoli, F. Mayvaneh, A. Entezari, P. Goodman, A. Zeka, P. Michelozzi, F. de’Donato, M. Hashizume, B. Alahmad, M. Hurtado Diaz, C. De La Cruz Valencia, A. Overcenco, D. Houthuijs, C. Ameling, S. Rao, F. Di Ruscio, G. Carrasco-Escobar, X. Seposo, S. Silva, J. Madureira, I. H. Holobaca, S. Fratianni, F. Acquaotta, H. Kim, W. Lee, C. Iniguez, B. Forsberg, M. S. Ragettli, Y. L. L. Guo, B. Y. Chen, S. Li, B. Armstrong, A. Aleman, A. Zanobetti, J. Schwartz, T. N. Dang, D. V. Dung, N. Gillett, A. Haines, M. Mengel,

V. Huber, and A. Gasparrini. 2021. ‘The Burden of Heat-Related Mortality Attributable to Recent Human-Induced Climate Change’. *Nature Climate Change* 11(6):492–500. doi: 10.1038/s41558-021-01058-x.

Wood, Simon, 2006. Generalized Additive Models: An Introduction with R. Chapman & Hall

World Meteorological Organization (WMO). 2014. *Atlas of Mortality and Economic Losses from Weather, Climate and Water Extremes (1970–2012)*. Geneva: WMO.