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Supplementary appendix

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VARIATION IN REPORTING OF HEATSTROKE MORTALITY: EVIDENCE FROM A MULTI-COUNTRY STUDY

Supplementary Material

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Appendix A. Summary information on heatstroke data collection.

Region	Country	Study period	Mortality data source	ICD10	
				X30	T67
North America	Canada	2000-2015	The Canadian Vital Statistics Death Database provided annual national-level death counts (as ICD-10 code X30).	818	0
North America	United States	2000-2022	The National Center for Health Statistics (NCHS) provided annual death counts for the continental United States (as ICD-10 codes X30 and T67), covering 99% of the population.	10,477	17,644
Central America	Mexico	2000-2022	The National Institute of Informatics, Statistics, and Geography (INEGI) provided daily death counts by municipality (as ICD-10 code X30). Data were aggregated to obtain annual national-level counts.	416	0
Central America	Costa Rica	2014-2022	The Instituto Nacional de Estadística y Censos de Costa Rica provided annual national-level death counts (as ICD-10 code X30).	2	0
South America	Colombia	2005-2022	The Integral Information System for Social Protection (SISPRO) of Colombia's Ministry of Health provided annual national-level death counts (as ICD-10 codes X30 and T67).	18	18
South America	Ecuador	2013-2022	The Instituto Nacional de Estadística y Censos de Costa Rica provided annual national-level death counts (as ICD-10 code X30).	3	0
South America	Peru	2003-2020	The Sistema Nacional de Defunciones of the Peruvian Ministry of Health (MINSA) provided daily death counts by department (as ICD-10 codes X30 and T67). Data were aggregated to obtain annual national-level counts.	17	107
South America	Brazil	2000-2021	The Brazilian Mortality Information System provided daily death counts by municipality (as ICD-10 code X30). Data were aggregated to obtain annual national-level counts.	80	NR
South America	Uruguay	2012-2022	The Departamento de Estadísticas Vitales (DIGESA) of the Ministerio de Salud Pública provided annual national-level death counts (as ICD-10 code X30).	4	NR
South America	Chile	2000-2021	The Departamento de Estadísticas e Información de Salud (DEIS) provided annual national-level death counts (as ICD-10 codes X30 and T67).	15	13
South America	Argentina	2005-2015	The Sistema de Estadísticas Vitales of the Dirección de Estadísticas del Ministerio de Salud de la Nación provided annual national-level death counts (as ICD-10 code X30).	64	NR
North Europe	Iceland	2000-2018	Personal communication with the Icelandic Directorate of Health, which provided annual national-level death counts (as ICD-10 codes X30 and T67); however, no heat-stroke deaths were reported for the study period.	0	3
North Europe	Sweden	2000-2022	The Swedish Cause of Death Register at the Swedish National Board of Health and Welfare provided annual national-level death counts (as ICD-10 code X30).	25	0
North Europe	United Kingdom	2001-2020	The Office for National Statistics (ONS) for England and Wales provided annual death counts for the 112 major towns and cities, corresponding to settlements with populations >75,000 inhabitants (as ICD-10 codes X30), covering 85% of the population. Data were aggregated into annual death counts.	25	NR
East Europe	Czech Republic	2000-2022	The Czech Statistical Institute and the Institute of Health Information and Statistics of the Czech Republic provided annual death counts for the 76 districts (as ICD-10 code X30), which were aggregated to obtain annual national-level counts.	30	0
East Europe	Moldova	2005-2015	The Directorate of Health Data Management of the National Agency for Public Health provided daily death counts at the city level (as ICD-10 code X30). Data were aggregated to obtain annual national-level counts.	25	0
East Europe	Romania	2000-2019	The National Statistics Institute of Romania (Institutul Național de Statistică – INS) provided daily death counts (as ICD-10 codes X30 and T67). Data were aggregated to obtain annual national-level counts.	9	12
West Europe	Germany	2000-2022	Annual death counts in hospitals of all 16 German Federal States with a diagnosis of ICD-10 code T67 were extracted from publicly available cause-specific hospital statistics (Genesis table 23131-0001). The data exclude heatstroke deaths occurring outside German hospitals.	NA	195
West Europe	France	2006-2022	The Système National des Données de Santé (SNDS) provided annual national-level death counts (as ICD-10 code X30).	1,414	0
West Europe	Switzerland	2000-2022	The Cause of Death Statistics from the Swiss Federal Office of Statistics provided daily death counts for eight cantons (as ICD-10 code X30), covering 66% of the population. Data were aggregated into annual death counts.	34	0
South Europe	Portugal	2010-2021	Statistics Portugal (INE) provided annual national-level death counts (as ICD-10 codes X30 and T67).	121	122
South Europe	Spain	2000-2016	The Spanish National Institute of Statistics (INE) provided daily death counts for the 52 provincial capital cities (as ICD-10 code X30), covering 70% of the population. Data were aggregated into annual death counts.	206	NR
South Europe	Italy	2006-2015	Total death counts for the study period were available only at the regional level for the Lazio Region, as provided by the Regional Register of Causes of Death (ICD-10 codes X30 and T67).	12	29
Africa	South Africa	2000-2013	Statistics South Africa, which had no role in the study, provided daily district-level death counts (as ICD-10 codes X30 and T67). Data were aggregated to obtain annual national-level counts.	148	2

West Asia	Cyprus	2005-2018	The Health Monitoring Unit of the Ministry of Health of Cyprus provided daily death counts at the city level (as ICD-10 code X30). Data were aggregated to obtain annual national-level counts. The ideas and opinions expressed herein are those of the author, and no endorsement by the Ministry of Health of Cyprus is intended or should be inferred.	40	0
West Asia	Kuwait	2000-2016	The National Center for Health Information of the Ministry of Health provided annual national-level death counts (as ICD-10 code T67. ICD-10 codes X30 and W92 were considered external causes and were not included under the data use agreement); however, no heat-stroke deaths were reported for the study period.	NA	0
East Asia	China	2013-2019	Daily death counts were provided at the subregional level by the local Centers for Disease Control and Prevention for Shanghai and Suzhou (ICD-10 code X30) and were aggregated into annual death counts.	507	NR
East Asia	South Korea	2015-2022	The Korean National Cause of Death Statistics (MDIS) provided national daily death counts for the 16 metropolitan cities and provinces in South Korea (as ICD-10 codes X30 and T67). Data were aggregated to obtain annual national-level counts.	454	515
East Asia	Japan	2000-2020	The Ministry of Health, Labor and Welfare provided daily death counts for Japan's 47 prefectures (as ICD-10 codes X30 and T67). Data were aggregated to obtain national-level counts.	15,555	16,275
East Asia	Taiwan	2000-2022	The Health and Welfare Data Science Center (HWDC) of the Ministry of Health and Welfare of Taiwan provided daily death counts at the city level (as ICD-10 code X30). Data were aggregated to obtain national-level counts.	26	0
South-East Asia	Philippines	2007-2019	The Philippine Statistics Authority provided daily death counts at the city level (as ICD-10 code X30). Data were aggregated to obtain annual national-level counts.	86	0
South-East Asia	Thailand	2015-2022	The Ministry of Public Health provided daily death counts at the country level using Thai-ICD-10 codes (as ICD-10 codes X30 and T67). Data were aggregated to obtain annual national-level counts.	40	1,020
South-East Asia	Malaysia	2000-2022	The Department of Statistics Malaysia (DOSM) of the Ministry of Economy provided daily death counts for all 13 states and 3 federal territories in Malaysia (as ICD-10 codes X30). Data were aggregated to obtain annual national-level counts.	74	0
Australia	Australia	2009-2020	The Death Unit Record File (COD URF) dataset provided annual national-level death counts (as ICD-10 codes X30 and T67).	223	2

NA: ICD-10 code X30 not accessible; NR: ICD-10 code T67 not recorded as the underlying cause of death.

Appendix B. Details on the computation of the heat attributable all-cause mortality using the MCC dataset.

The temperature–mortality association was estimated by extending the analytical two-stage framework used in a previous MCC study by Gasparrini et al.¹

In the first stage, we applied a city-specific time-series quasi-Poisson regression model, adjusted for seasonality and long-term trends using a natural cubic spline of time with 8 degrees of freedom per year, and included an indicator variable for day of the week. Temperature was modeled using Distributed Lag Non-Linear Models (DLNMs), specifying a quadratic B-spline with three internal knots placed at the 10th, 75th, and 90th percentiles of the local temperature distribution to capture the exposure–response relationship. The lag–response association was modeled using a natural cubic spline with three internal knots equally spaced on the logarithmic scale, extending the lag period up to 21 days.

In the second stage, the overall cumulative exposure–response associations from each location were reduced by integrating over the lag period, and then pooled using a multivariate meta-regression model. This meta-regression incorporated country indicators, as well as location-specific mean temperature and temperature range as meta-predictors to account for between-location heterogeneity. The resulting pooled coefficients were used to compute Best Linear Unbiased Predictions (BLUPs) of the temperature–mortality relationship for each location. The optimum temperature, defined as the point of minimum mortality risk (MMT), was derived from the BLUP curve for each site and served as the reference for calculating attributable risk.

Overall heat-attributable mortality was calculated by integrating the excess risk above the MMT up to the maximum daily temperature, while extreme heat-attributable mortality was defined as mortality associated with temperatures above the 97.5th percentile of the local temperature distribution, consistent with prior definitions of extreme weather.^{2,3}

References

1. Gasparrini A, Guo Y, Hashizume M, et al. Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *Lancet* 2015; 386(9991): 369-75.
2. Hajat S, Armstrong B, Baccini M, et al. Impact of high temperatures on mortality: is there an added heat wave effect? *Epidemiology* 2006; 17(6): 632-8.
3. Peng RD, Bobb JF, Tebaldi C, McDaniel L, Bell ML, Dominici F. Toward a quantitative estimate of future heat wave mortality under global climate change. *Environ Health Perspect* 2011; 119(5): 701-6.

Table S1. Heatstroke mortality rates by country (per 1 million population).

Region	Country	Study period	Heatstroke deaths	Mortality rate	(95% CI)
North America	Canada	2000-2022	818	1.03	(0.47 , 2.25)
North America	United States	2000-2022	10,477	1.46	(1.24 , 1.73)
Central America	Mexico	2000-2022	416	0.16	(0.12 , 0.21)
Central America	Costa Rica	2014-2022	2	0.04	(0.01 , 0.16)
South America	Colombia	2005-2022	18	0.02	(0.01 , 0.04)
South America	Ecuador	2013-2022	3	0.02	(0.01 , 0.05)
South America	Peru	2003-2020	17	0.03	(0.02 , 0.06)
South America	Brazil	2000-2021	80	0.02	(0.01 , 0.02)
South America	Uruguay	2012-2022	4	0.11	(0.04 , 0.31)
South America	Chile	2000-2021	15	0.04	(0.02 , 0.07)
South America	Argentina	2005-2015	64	0.14	(0.10 , 0.20)
North Europe	Iceland	2000-2018	0		
North Europe	Sweden	2000-2022	25	0.11	(0.06 , 0.22)
North Europe	United Kingdom	2001-2020	25	0.02	(0.01 , 0.04)
East Europe	Czech Republic	2000-2022	30	0.12	(0.07 , 0.21)
East Europe	Moldova	2005-2015	25	0.79	(0.31 , 2.01)
East Europe	Romania	2000-2019	9	0.02	(0.01 , 0.05)
West Europe	Germany	2000-2022	195	0.10	(0.07 , 0.15)
West Europe	France	2006-2022	1,414	1.26	(0.87 , 1.82)
West Europe	Switzerland	2000-2022	34	0.28	(0.16 , 0.50)
South Europe	Portugal	2010-2021	121	0.97	(0.35 , 2.69)
South Europe	Spain	2000-2016	206	0.39	(0.20 , 0.75)
South Europe	Italy	2006-2015	12	0.02	(0.01 , 0.14)
Africa	South Africa	2000-2013	148	0.21	(0.17 , 0.26)
West Asia	Cyprus	2005-2018	40	2.51	(1.36 , 4.61)
West Asia	Kuwait	2000-2016	0		
East Asia	China	2013-2019	507	2.42	(1.21 , 4.85)
East Asia	South Korea	2015-2022	454	1.10	(0.64 , 1.90)
East Asia	Japan	2000-2020	15,555	5.81	(4.43 , 7.62)
East Asia	Taiwan	2000-2022	26	0.05	(0.03 , 0.09)
South-East Asia	Philippines	2007-2019	86	0.07	(0.04 , 0.10)
South-East Asia	Thailand	2015-2022	40	0.09	(0.06 , 0.13)
South-East Asia	Malaysia	2000-2022	74	0.11	(0.09 , 0.14)
Australia	Australia	2009-2020	223	0.79	(0.50 , 1.25)

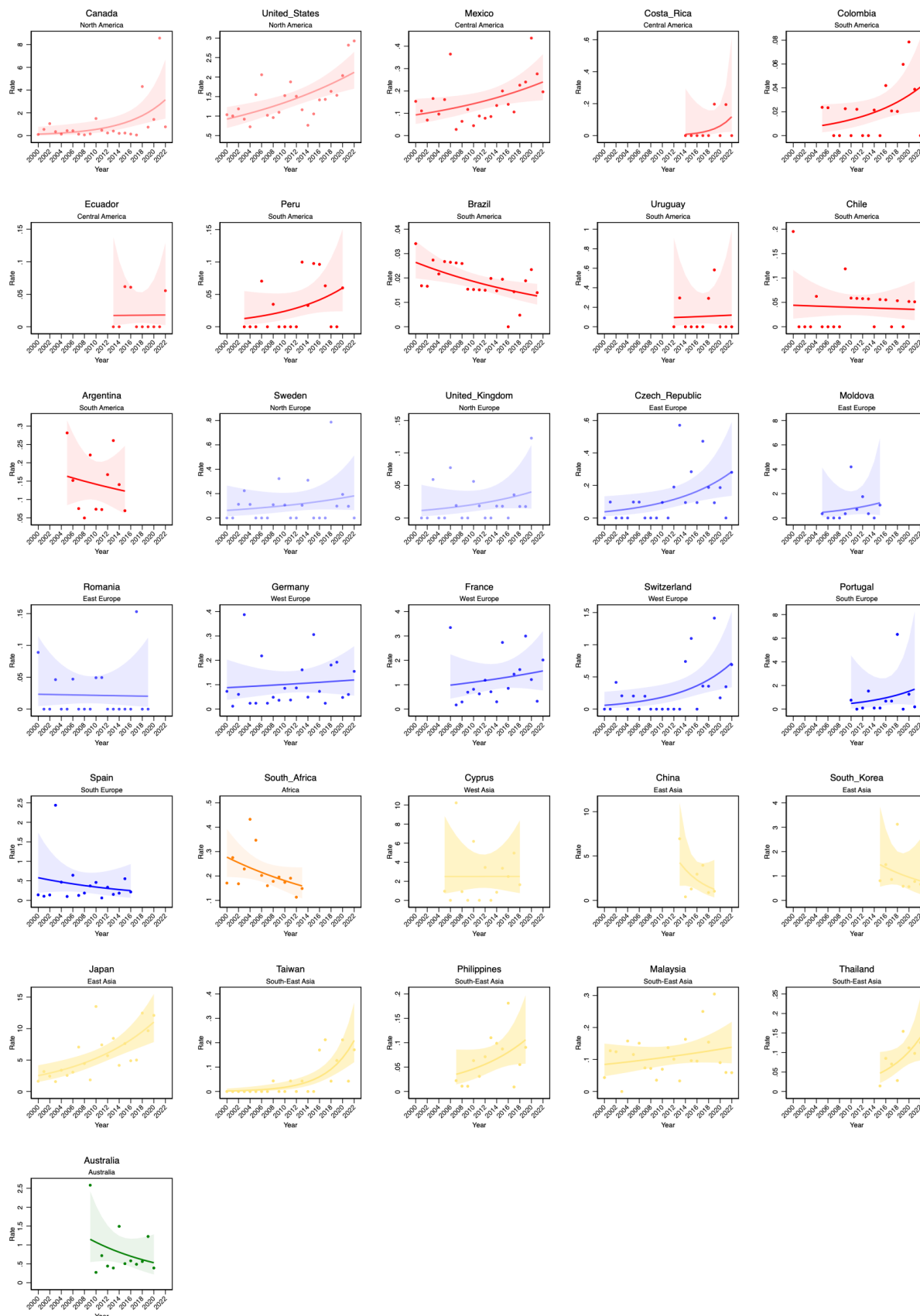
Note: Heatstroke mortality ICD-10 code X30 for all countries, except Germany (hospital-based mortality coded as ICD-10 T67). Data for Italy are regional (Lazio), and data for China are subregional (Shanghai and Suzhou).

Table S2. Proportion of heatstroke deaths within overall and extreme heat-attributable all-cause mortality.

Region	Country	Study period overlapping heatstroke and MCC datasets	Geographical coverage		Heatstroke deaths	Proportion of heatstroke deaths within	
			Heatstroke dataset	MCC dataset (% overlap)*		overall heat (%)	extreme heat (%)
North America	Canada	2000-2015	Nationwide	26 cities (~80%)	211	2.0	3.7
North America	United States	2000-2006	Continental US	136 cities (~80%)	2,478	10.8	23.0
Central America	Mexico	2000-2022	Nationwide	11 districts (~38%)	416	2.4	5.7
Central America	Costa Rica	2014-2017	Nationwide	1 city (~50%)	0		
South America	Colombia	2005-2013	Nationwide	5 cities (~45%)	4	0.0	0.0
South America	Ecuador	2014-2018	Nationwide	2 cities (~38%)	2	0.1	7.4
South America	Peru	2008-2014	Nationwide	18 regions (~82%)	5	0.7	0.9
South America	Brazil	2000-2018	Nationwide	18 cities (~26%)	68	0.3	0.9
South America	Uruguay	2012-2016	Nationwide	1 city (~40%)	1	0.0	0.1
South America	Chile	2004-2021	Nationwide	5 cities (~60%)	15	0.2	0.5
South America	Argentina	2005-2015	Nationwide	3 cities (~40%)	64	1.5	4.0
North Europe	Iceland	2000-2018	Nationwide	1 city (~65%)	0	0.0	0.0
North Europe	Sweden	2000-2016	Nationwide	3 cities (~40%)	13	0.7	1.3
North Europe	United Kingdom	2001-2020	112 towns	112 towns (100%)	25	0.2	0.2
East Europe	Czech Republic	2000-2020	Nationwide	3 cities/1 region (~32%)	27	0.6	0.8
East Europe	Moldova	2005-2015	Nationwide	4 cities (~43%)	25	3.2	3.9
East Europe	Romania	2000-2019	Nationwide	8 cities (~23%)	9	0.1	0.2
West Europe	Germany	2000-2020	Nationwide	Nationwide (100%)	177	0.2	0.2
West Europe	France	2006-2017	Nationwide	20 cities (~41%)	862	12.4	20.8
West Europe	Switzerland	2000-2018	8 cantons	8 cantons (100%)	19	1.2	1.5
South Europe	Portugal	2010-2018	Nationwide	6 districts (~50%)	106	1.6	2.9
South Europe	Spain	2000-2014	52 cities	52 cities (100%)	181	0.9	1.8
South Europe	Italy	2006-2015	Lazio region	Lazio region (100%)	12	0.3	1.1
Africa	South Africa	2000-2013	Nationwide	Nationwide (100%)	148	1.7	4.5
West Asia	Cyprus	2005-2018	Nationwide	5 districts (~75%)	40	2.4	10.1
West Asia	Kuwait	2000-2016	Kuwait City	Kuwait City (100%)	0	0.0	0.0
East Asia	China	2013-2015	Shanghai	Shanghai (100%)	64	1.1	9.1
East Asia	South Korea	2015-2018	16 cities/provs.	16 cities/provs. (100%)	321	0.3	8.5
East Asia	Japan	2000-2020	47 prefectures	47 prefectures (100%)	15,555	23.9	54.1
East Asia	Taiwan	2000-2014	Nationwide	3 cities (~52%)	3	0.1	0.2
South-East Asia	Philippines	2007-2019	Nationwide	13 cities (~15%)	86	0.6	2.4
South-East Asia	Malaysia	2000-2019	13 states	13 states (100%)	67	0.3	1.8
Australia	Australia	2009-2019	Nationwide	5 cities (~65%)	215	18.6	20.5

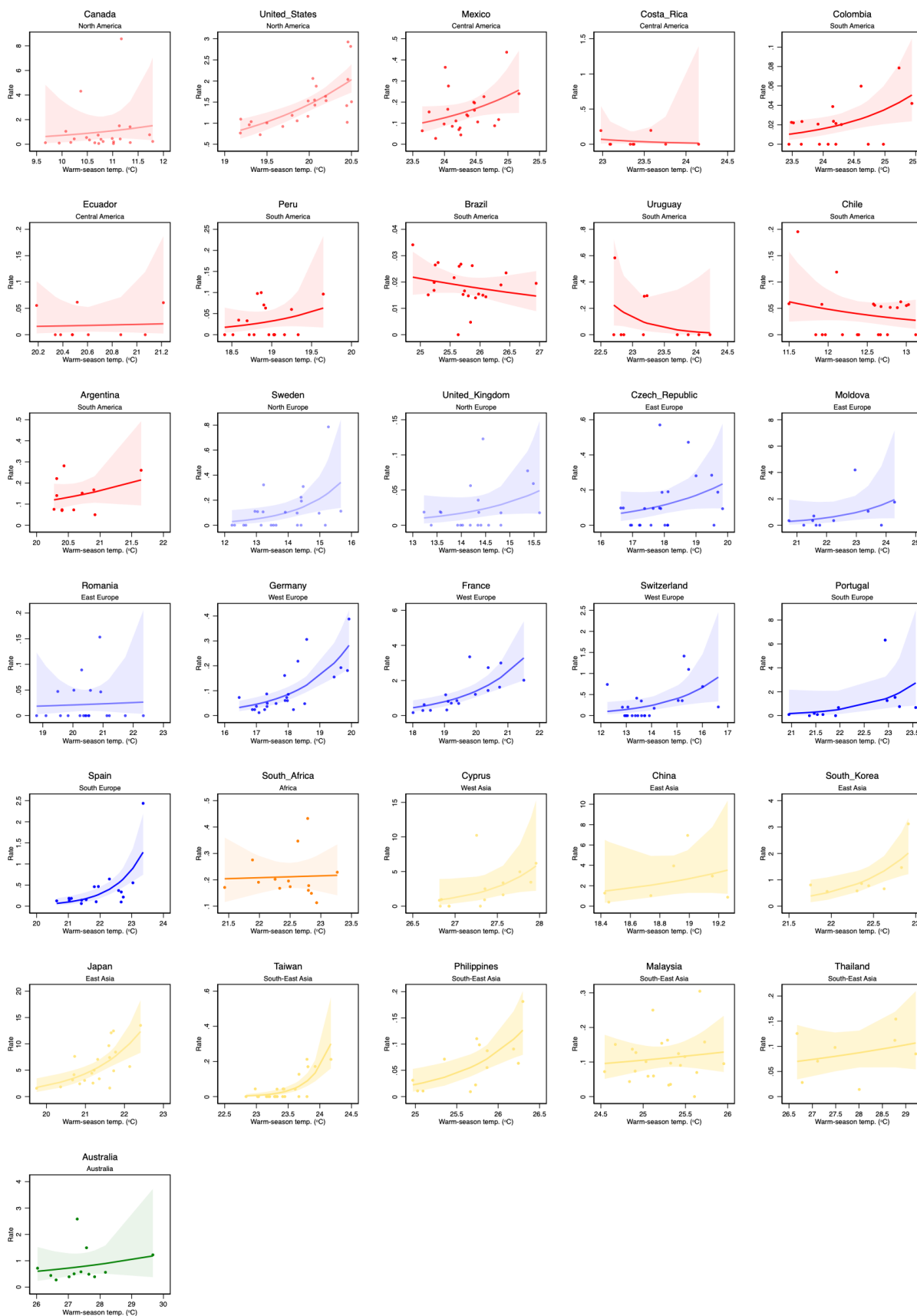
*Proportion of the population within the geographical overlap between collected heatstroke data and the main MCC dataset.

Figure S1. Annual trends in the heatstroke mortality rates by country.



Note: Heatstroke mortality ICD-10 code X30 for all countries, except Germany (hospital-based mortality coded as ICD-10 T67). Data for Italy are regional (Lazio), and data for China are subregional (Shanghai and Suzhou). No deaths were reported for Iceland and Kuwait.

Figure S2. Relationship between heatstroke mortality rates and warm-season temperatures by country.



Note: Heatstroke mortality ICD-10 code X30 for all countries, except Germany (hospital-based mortality coded as ICD-10 T67). Data for Italy are regional (Lazio), and data for China are subregional (Shanghai and Suzhou). No deaths were reported for Iceland and Kuwait.

Figure S3. Relationship between heatstroke mortality rates and the proportion of heatstroke deaths within total heat-attributable all-cause mortality.

