

Supplementary Information: Comparison of weather station and climate reanalysis data for modelling temperature-related mortality

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- Fraction of excess mortality (%) – regional level.
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Table S3: Fraction of all-cause excess mortality due to cold and heat – MCC weather station, ERA5-Land and ERA5 – by countries.

Table S4: Summary of RFS by countries.

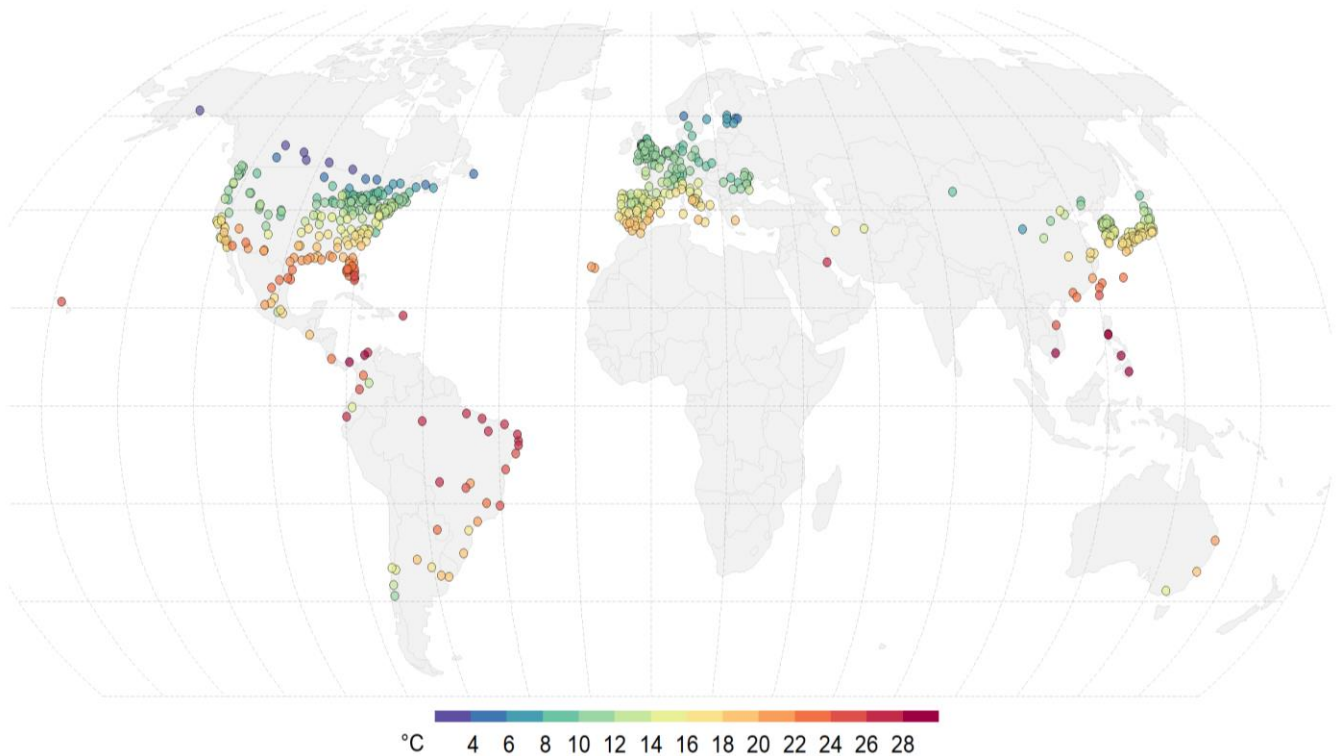


Figure S1: Average daily mean temperature (°C) at the 612 locations across 39 countries or territories used in this study. The average daily mean temperature is computed for the MCC data collection periods shown in Table S1.

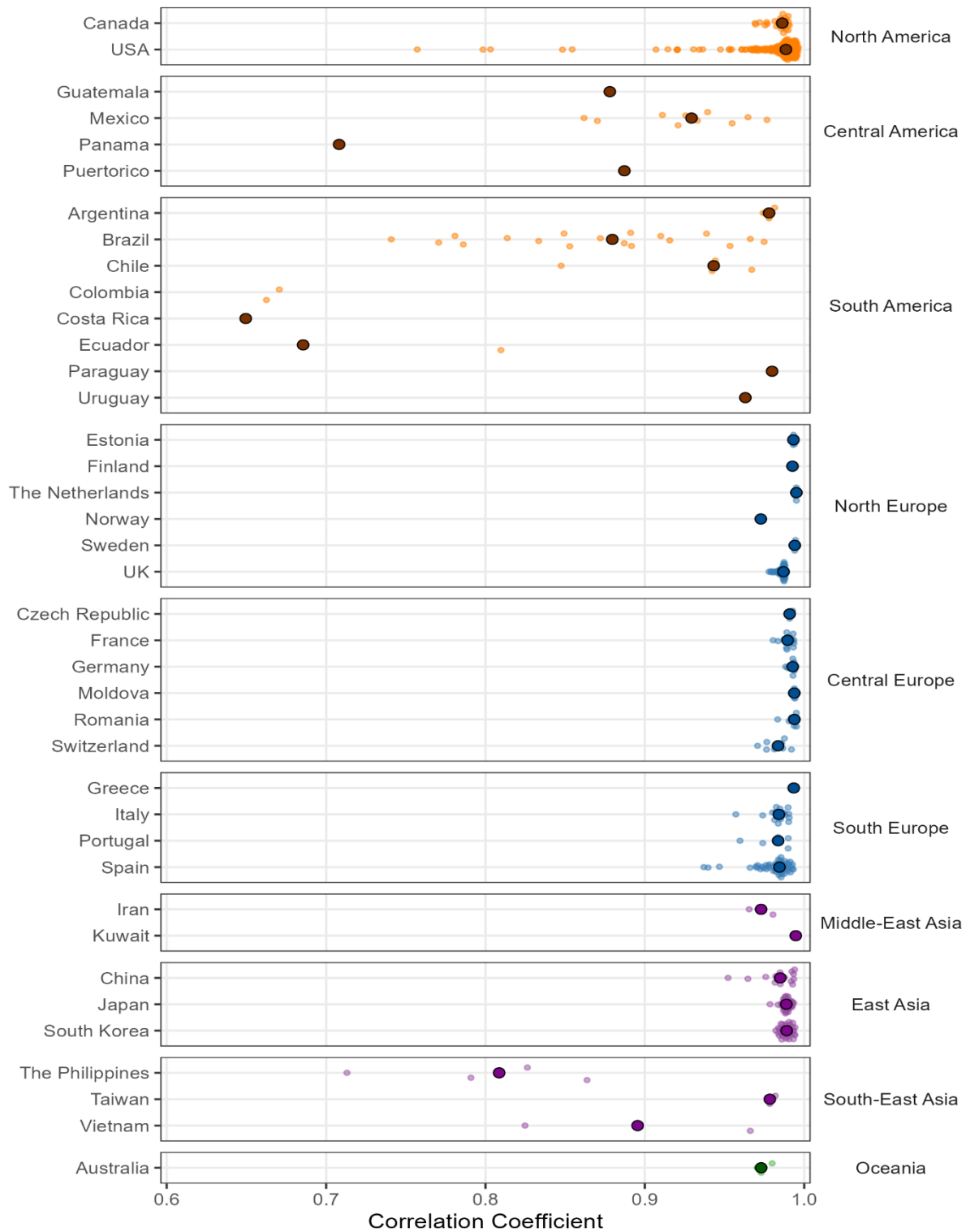


Figure S2: Correlation between MCC weather station and ERA5-Land daily mean temperature (°C) across the 612 locations used in the study grouped by 39 countries and 10 regions. The circle in each country panel depicts the median correlation.

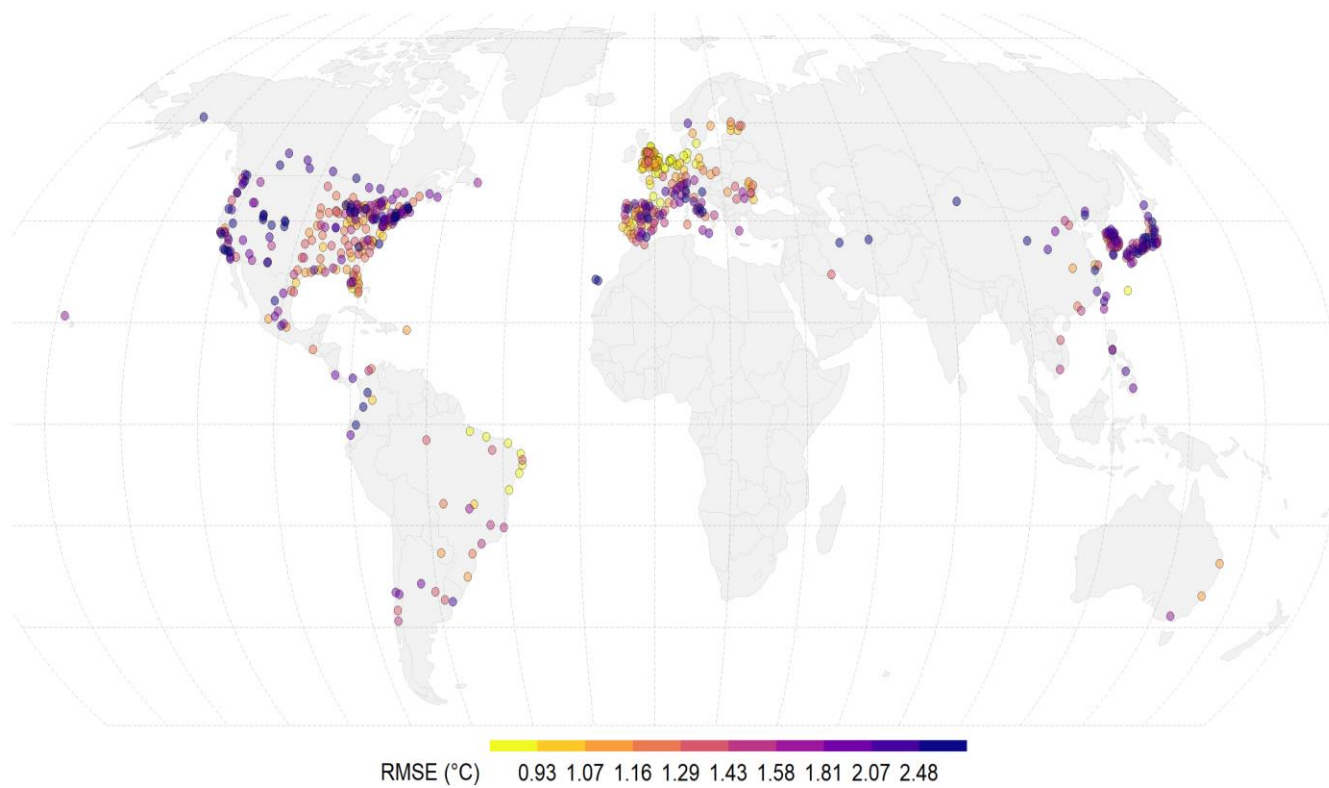


Figure S3: Root Mean Square Error (RMSE) computed as the squared difference between MCC weather station and ERA5-Land daily mean temperature (°C) across the 612 locations used in the study.

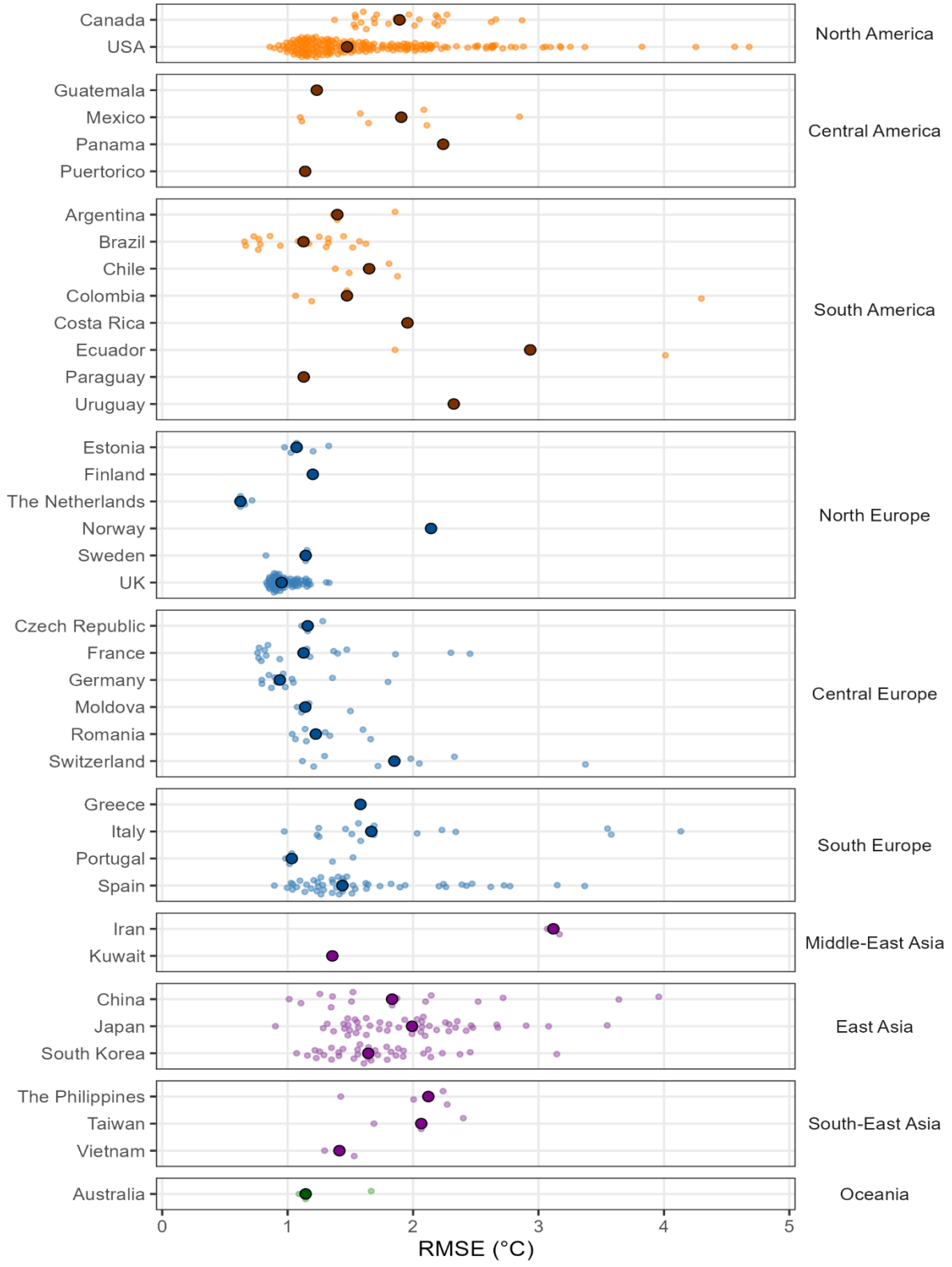


Figure S4: Root Mean Square Error (RMSE) computed as the squared difference between MCC weather station and ERA5-Land daily mean temperature (°C) across the 612 locations used in the study grouped by 39 countries and 10 regions. The circle in each country panel depicts the median RMSE.

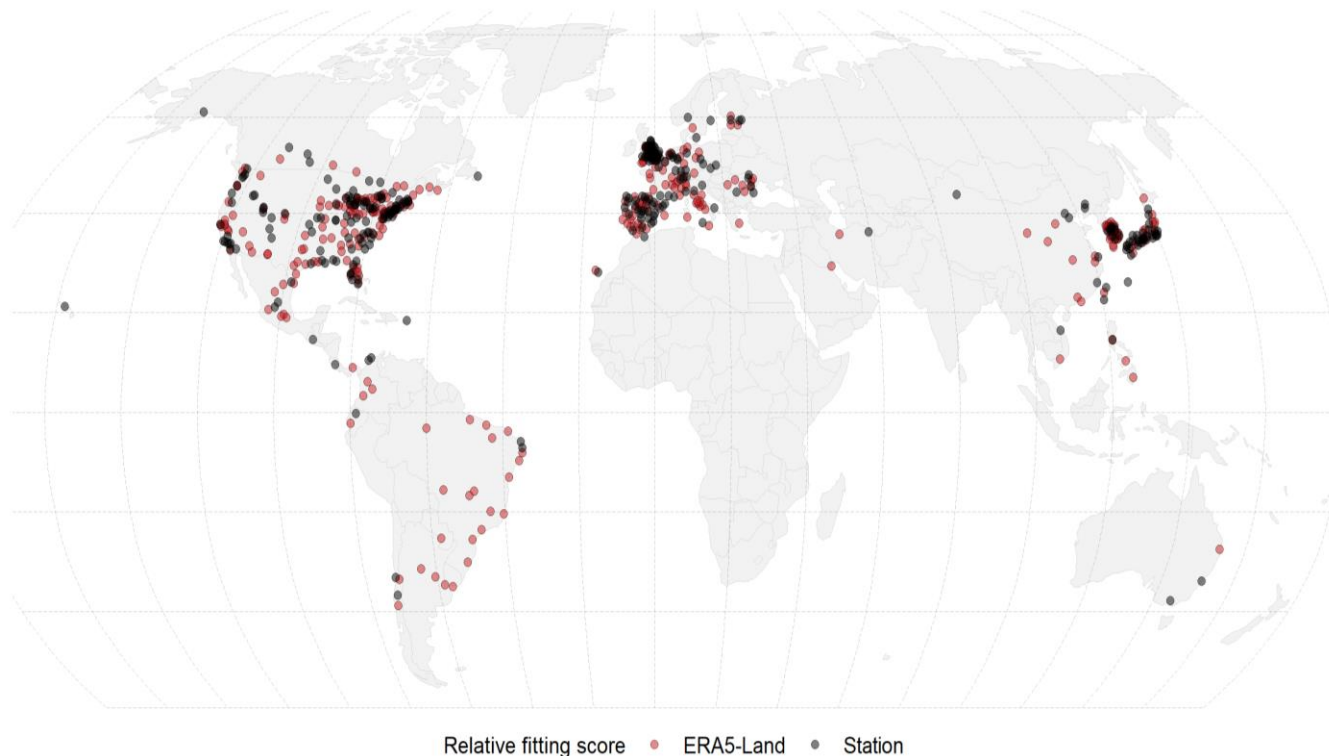


Figure S5: Relative Fitting Score (RFS) for station observations and ERA5-Land. A negative RFS represented by red dots implies a superior predictive ability of ERA5-Land at the location. Conversely a positive RFS represented by black dots indicates a better performance of ground station observations at the location.

Sensitivity results using ERA5

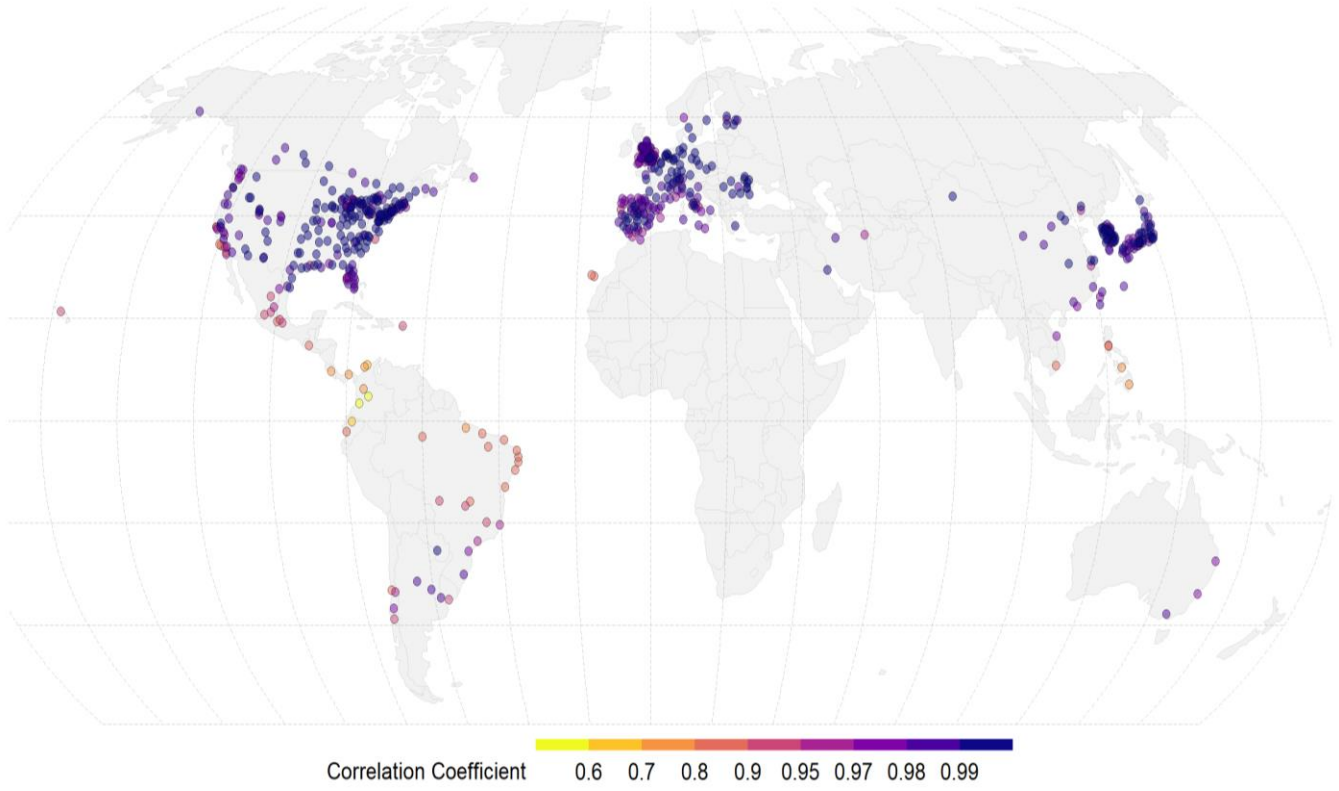


Figure S6: Correlation between MCC weather station and ERA5 daily mean temperature ($^{\circ}\text{C}$) across the 612 locations used in the study.

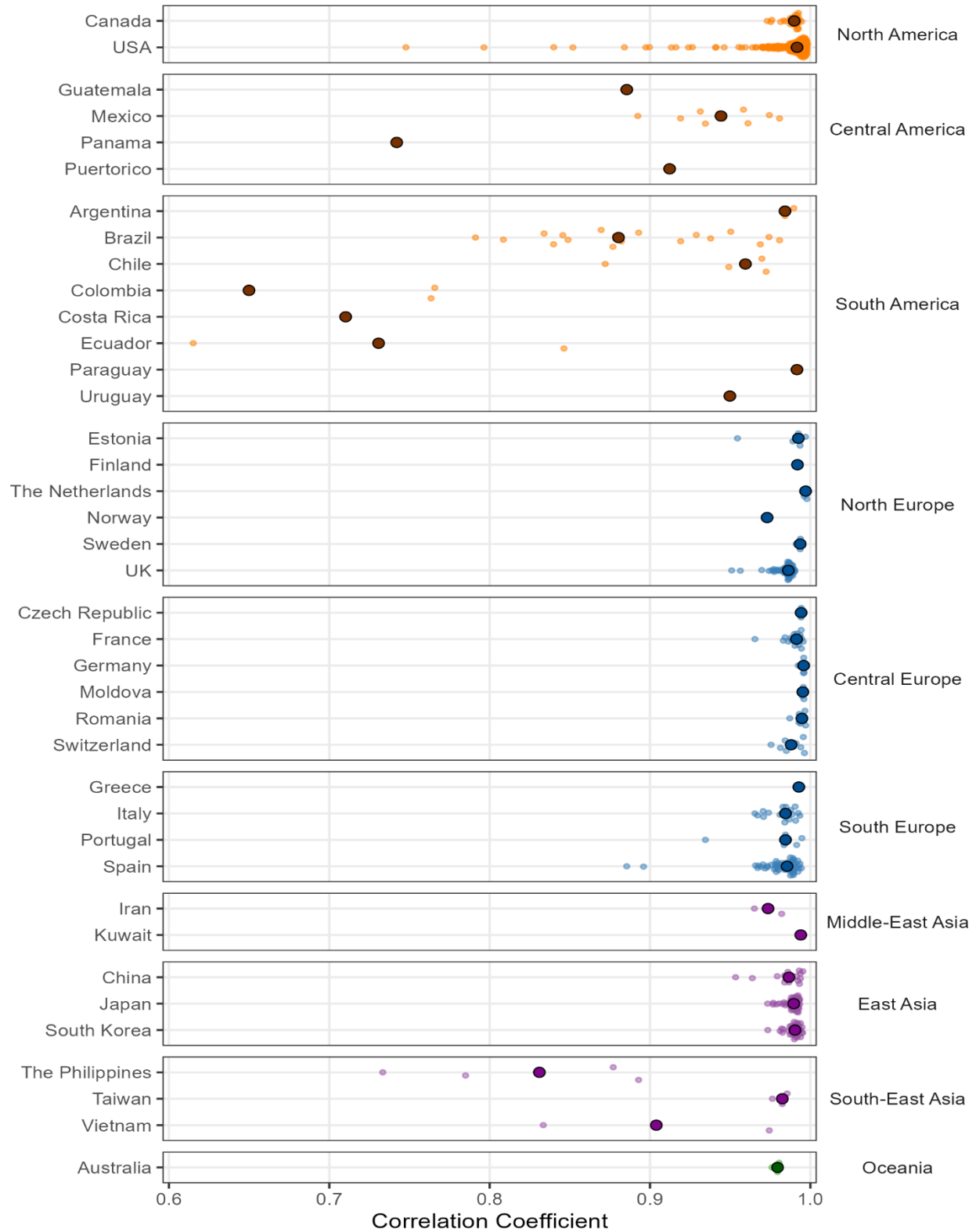


Figure S7: Correlation between MCC weather station and ERA5 daily mean temperature ($^{\circ}\text{C}$) across the 612 locations used in the study grouped by 39 countries and 10 regions. The circle in each country panel depicts the median correlation.

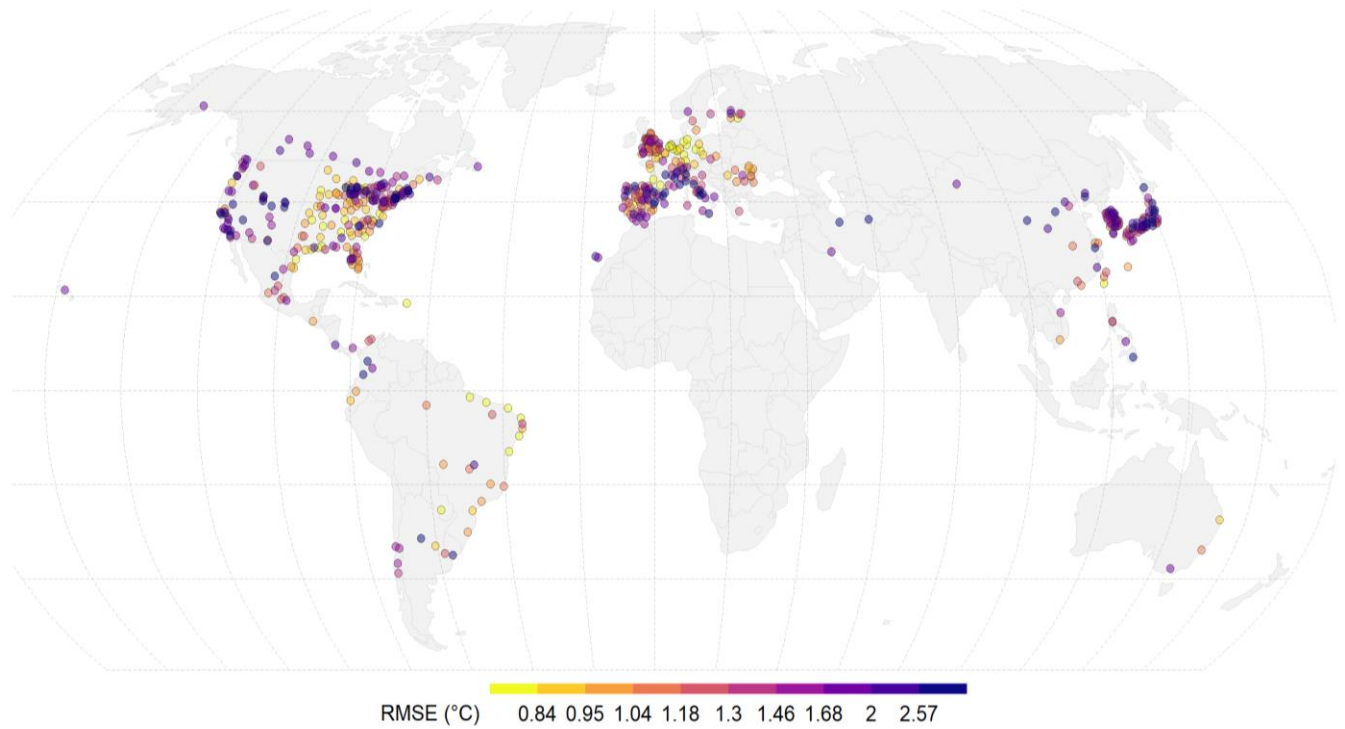


Figure S8: Root Mean Square Error (RMSE) computed as the squared difference between MCC weather station and ERA5 daily mean temperature ($^{\circ}\text{C}$) across the 612 locations used in the study.

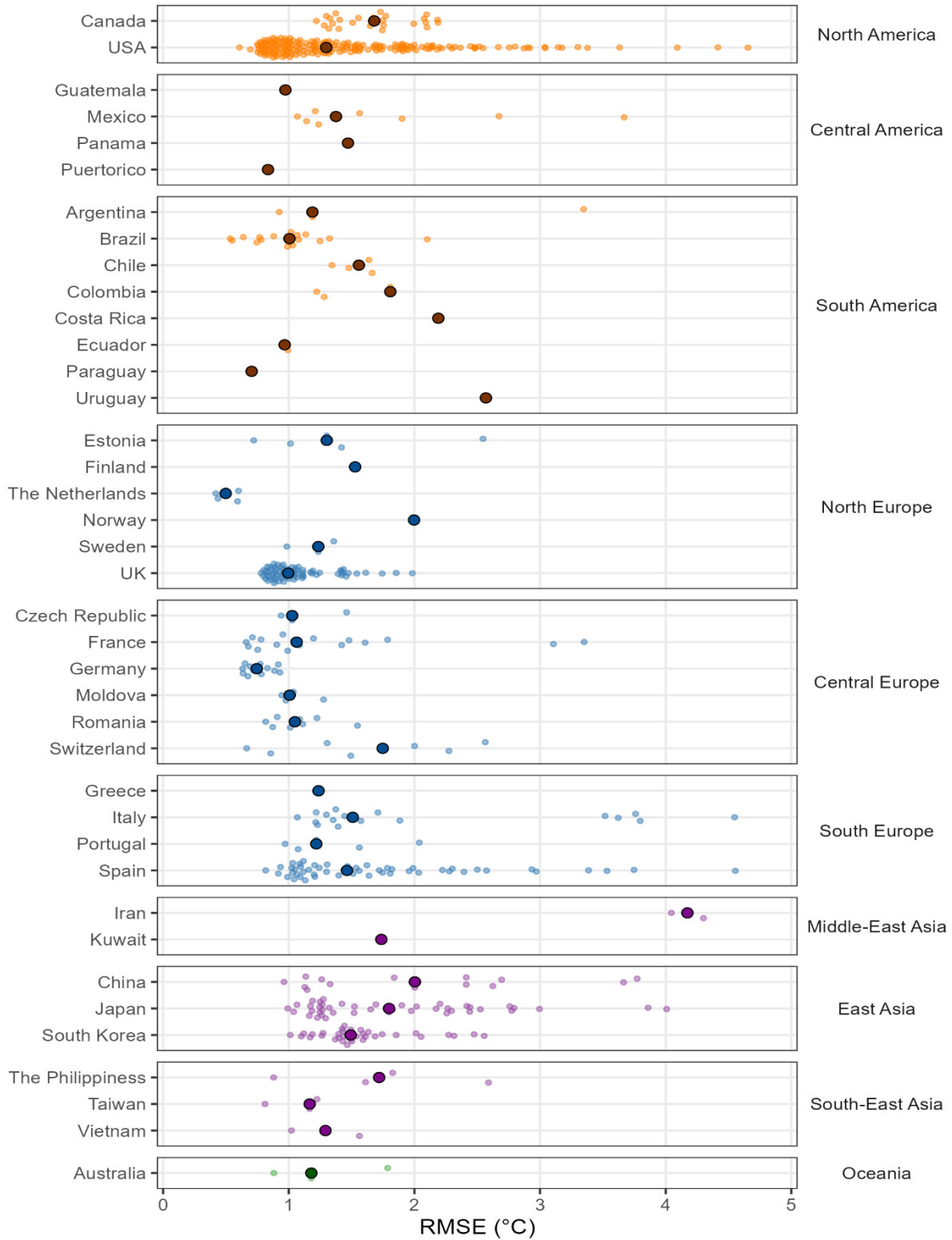


Figure S9: Root Mean Square Error (RMSE) computed as the squared difference between MCC weather station and ERA5 daily mean temperature (°C) across the 612 locations used in the study grouped by 39 countries and 10 regions. The circle in each country panel depicts the median RMSE.

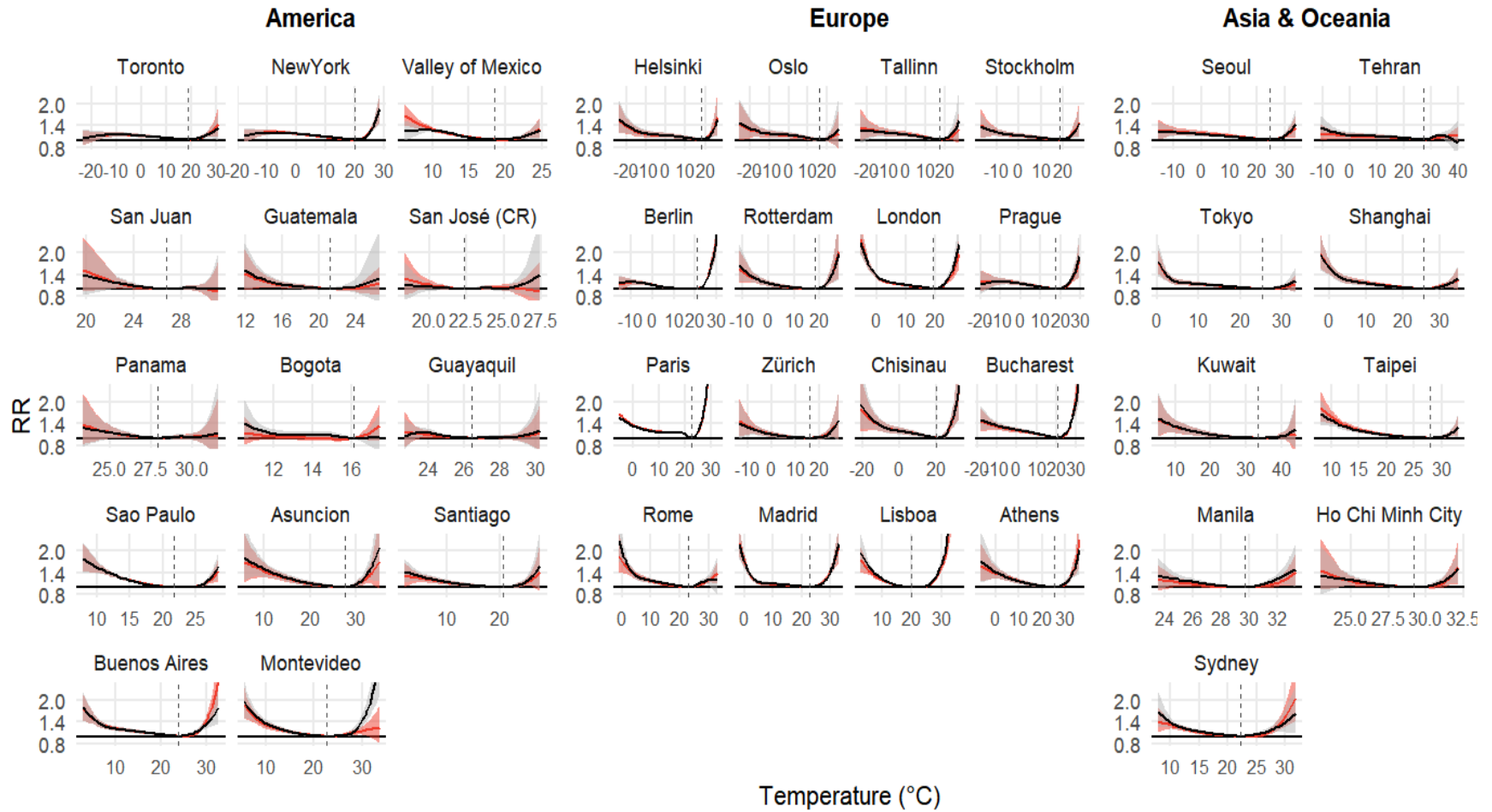


Figure S10: Overall cumulative exposure-response associations in selective cities representative of the 39 countries (station observations -**black** and ERA5 -**red**, with 95% confidence intervals (CI) -shaded, see Methods). Exposure-response associations as best linear unbiased prediction (BLUP) using the distribution drawn from station temperature. Dashed vertical grey lines are the minimum mortality temperatures (MMTs). RR=relative risk.

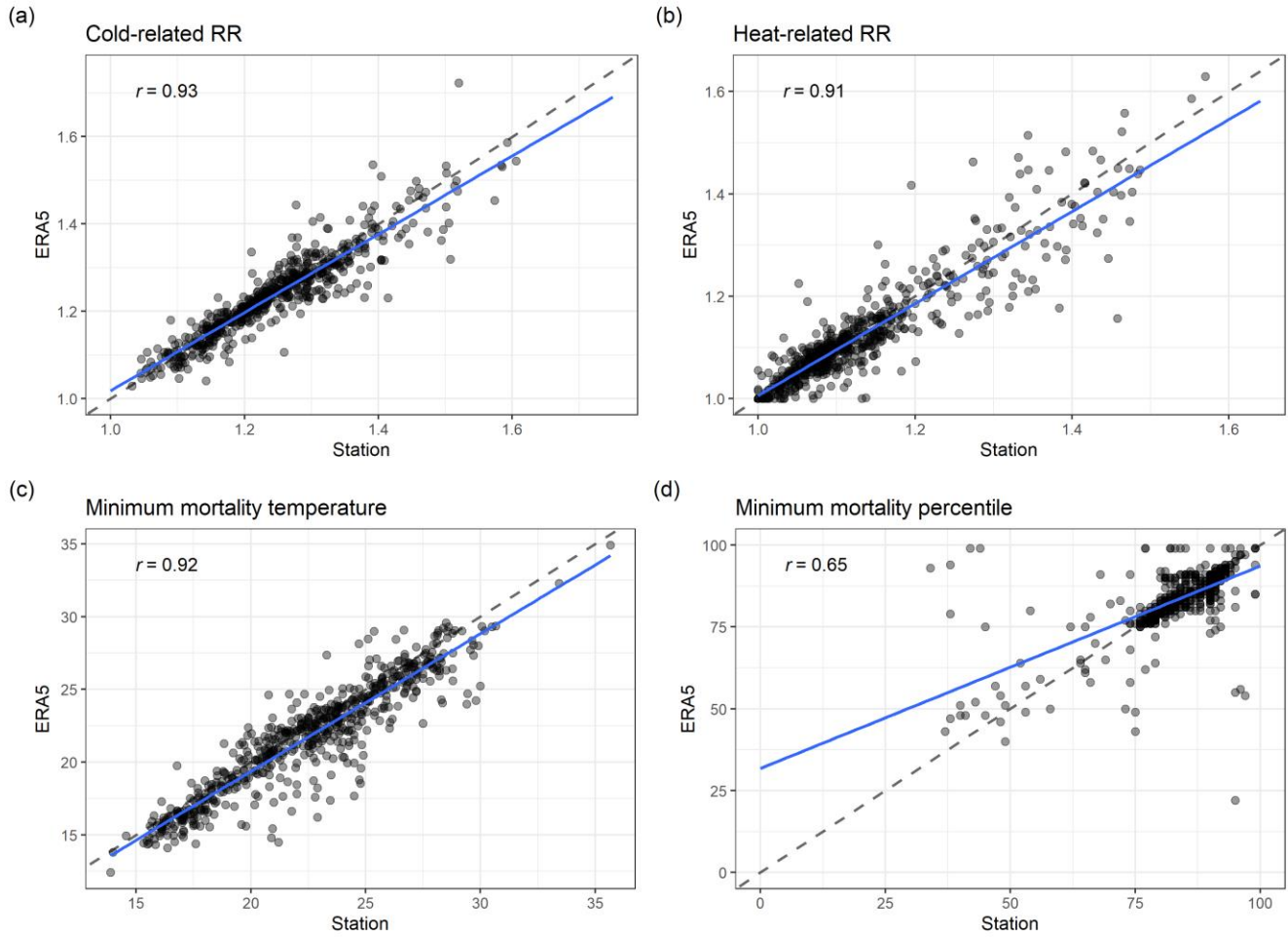


Figure S11: Scatterplots of: (a) and (b) cumulative relative risks (RRs) at the 1st and the 99th percentile respectively; (c) Minimum mortality temperature (MMT) and (d) Minimum mortality percentile (MMP). The RRs, MMP and MMT are based on the station and ERA5 temperatures of the best linear unbiased predictions (BLUPs) for individual cities. Blue lines and the r values represent the linear regression trend and the correlation coefficient of compared variables respectively. The dashed black line represents the 1:1 line.

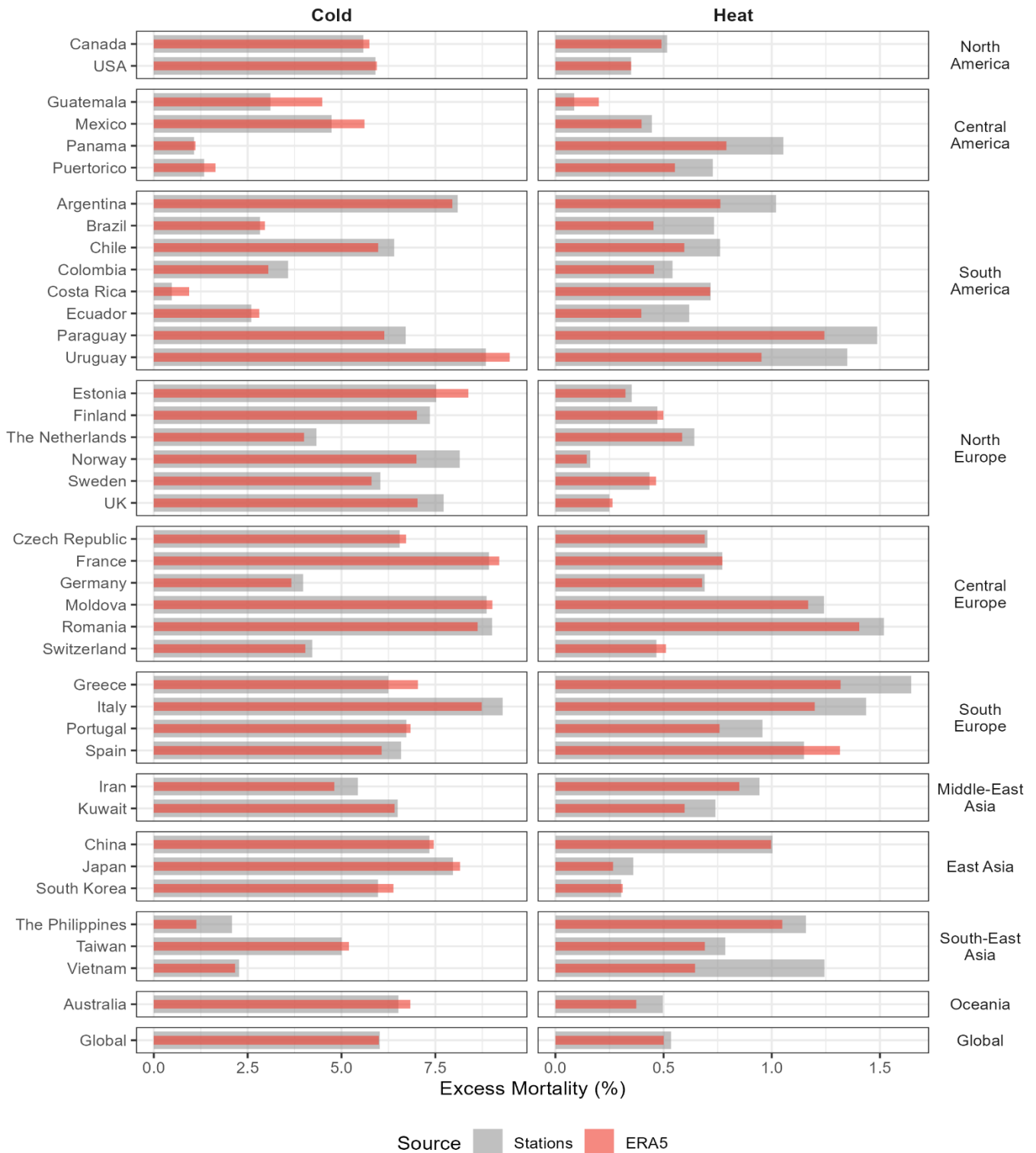


Figure S12: Fraction of all-cause excess mortality (%) due to cold and hot temperatures by countries and all 612 locations (Global) estimated using station observations (gray) and ERA5 (red). The bar plots represent the excess deaths. The 95% empirical confidence intervals (eCI) computed using Monte Carlo simulations (see Methods) are reported in Table S3. Note: the range of y-axes are different in the two panels

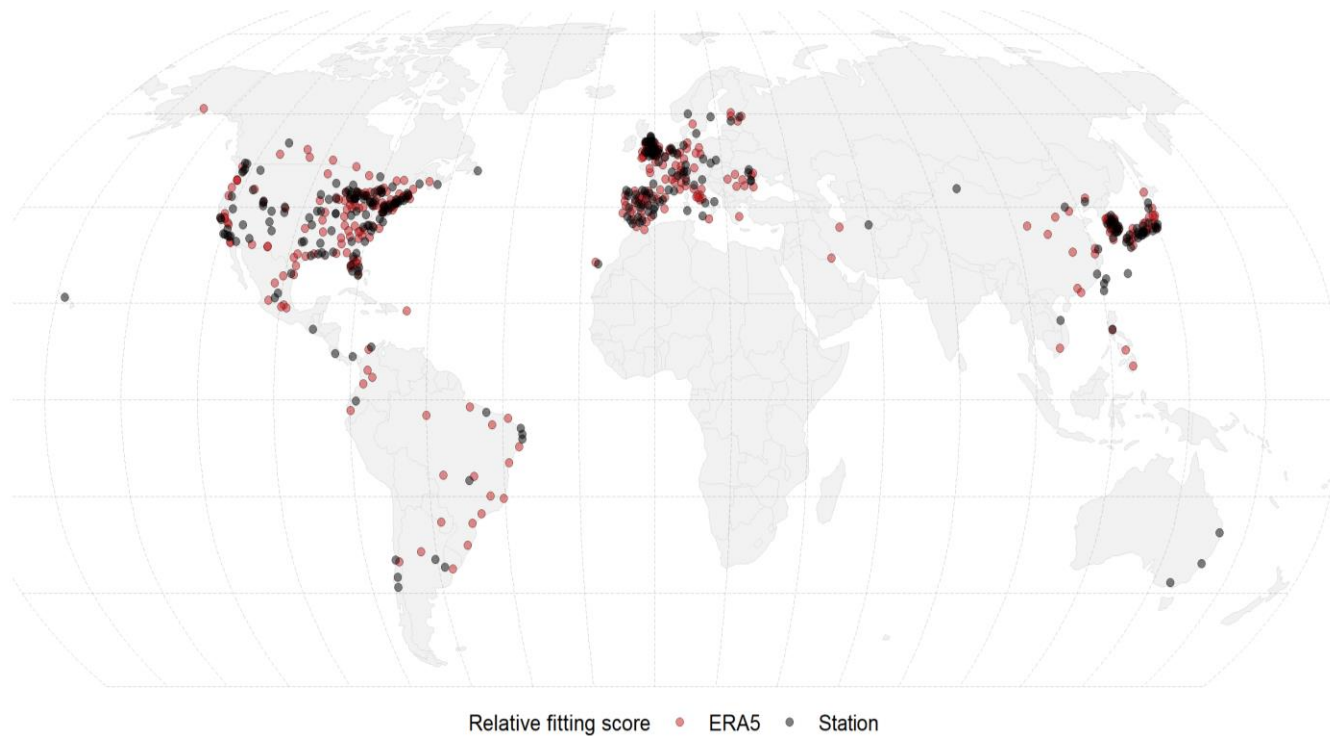


Figure S13: Relative fitting score (RFS) for station observations and ERA5. A negative RFS represented by red dots implies a superior predictive ability of ERA5 at the location. Conversely a positive RFS represented by black dots indicates a better performance of ground station observations at the location.

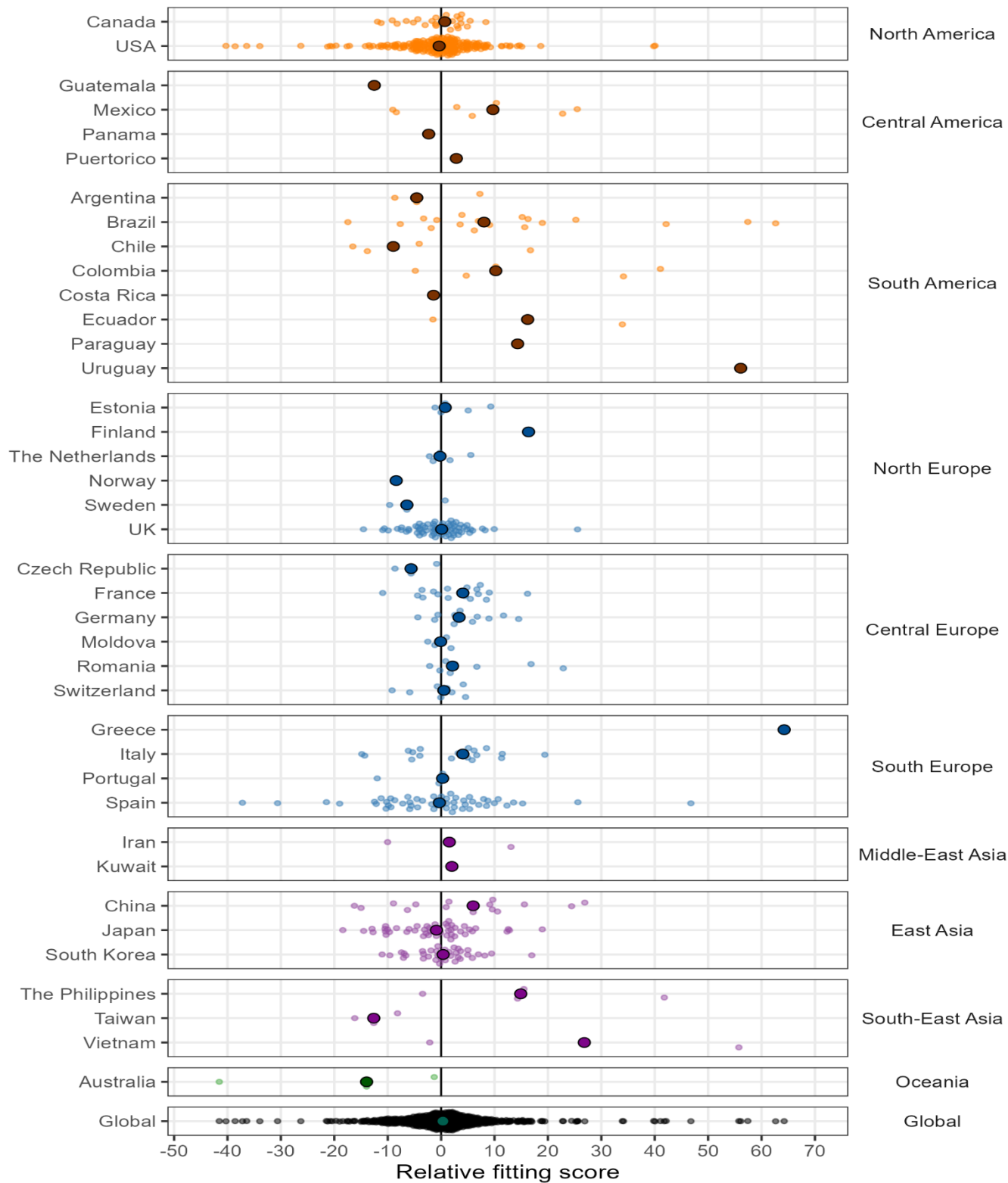


Figure S14: Relative fitting score (RFS) for station observations and ERA5 by country. A negative score indicates a better performance of the model based on ERA5 temperature relative to the model fitted using station temperature at a location. The shaded circle in each country panel depicts the median RFS. ‘Global’ implies all 612 locations used in the study.

Table S1 Description of the observed temperature (°C) and mortality data for the MCC locations used in the study. Where not indicated otherwise, the mean daily temperature is computed as the 24-hour average based on hourly measurements from weather station.

Country	No. and Type of Locations	Time Period	Mortality Data (Type – Source)	Meteorological Data (Source and Remarks)
Argentina	3 cities	2005-2015	Non-external causes only (ICD-9: 0-799; ICD-10: A00-R99) - National Ministry of Health (Ministerio de Salud de la Nación)	Weather station located within each city - Servicio Meteorológico Nacional (National Weather Service)
Australia	3 cities	1988-2009	Non-external causes only (ICD-9: 0-799; ICD-10: A00-R99) - Australian Bureau of Statistics	Weather stations located within ≤30 km of each city – Australian Bureau of Meteorology
Brazil	18 cities	1997-2011	Non-external causes only (ICD-9: 0-799; ICD-10: A00-R99) - Ministry of Health	Weather stations located within the urban area - National Institute of Meteorology of Brazil
Canada	26 (25 census metropolitan areas -CMA- and 1 city)	1986-2015	All causes - Canadian Mortality Database	Nearest weather station - Environment Canada
Chile	4 cities	2004-2014	All causes - Department of Statistics and Information, Ministry of Health (Departamento de Estadísticas e Información de Salud, Ministerio de Salud)	Nearest weather station - Ministerio del Medio Ambiente, Sistema de Información Nacional de Calidad del Aire (SINCA)
China	15 cities	1996-2015	Non-external causes only (ICD-9: 0-799; ICD-10: A00-R99) - Municipal Center for Disease Control and Prevention in each city	Weather station located within each city - China Meteorological Data Sharing Service System (http://data.cma.cn/)
Colombia	5 cities	1998-2013	All causes - National Administrative Department of Statistics (DANE)	Nearest weather station - Instituto de Hidrología, Meteorología y Estudios Ambientales de Colombia (IDEAM)
Costa Rica	1 city	2000-2017	All causes - Instituto Nacional de Estadística y Censo. Open Access.	Meteorological data - World Meteorological Organization – National Oceanic and Atmospheric Administration (WMO-NOAA) Surface Data Hourly Global (DS3505)
Czech Republic	3 cities	1994-2015	All causes - Czech Statistical Office and the Institute of Health Information and Statistics	Weather station located within each city - Czech Hydrometeorological Institute (measurements in standard climatic terms 7:00, 14:00 and 21:00 local time, and daily means)
Ecuador	2 cities	2014-2018	All causes - <i>Estonian Causes of Death Registry</i>	Meteorological data - WMO-NOAA Surface Data Hourly Global (DS3505)
Estonia	5 cities	1997-2018	All causes - Estonian Causes of Death Registry	Nearest weather station - Estonian Environment Agency
Finland	1 city	1994-2014	All causes - Statistics Finland	Mean daily temperature - Finnish Meteorological Institute. The weather stations around the

				country were interpolated onto a 10×10 km grid covering the whole of Finland, using a Kriging model
France	18 cities	2000-2014	All causes - French National Institute of Health and Medical Research (CepiDC)	Nearest weather station, usually the airport - Meteo France
Germany	12 cities	1993-2015	All causes - Research Data Centres of the Federation and the Federal States of Germany (Forschungsdatenzentrum der Statistischen Ämter des Bundes und der Länder)	Nearest weather station - Climate Data Centre of the German National Meteorological Service (Deutscher Wetterdienst)
Greece	1 city	2001-2010	All causes - Hellenic Statistical Authority	National observatory of Athens (http://www.noa.gr/) from site "Thisio" located in the city of Athens.
Guatemala	1 city	2009-2016	All causes - Instituto Nacional de Estadística, Unidad de Estadística de Salud.	Nearest weather station - Instituto Nacional de Sismología, Vulcanología, Meteorología y Hidrología.
Iran	2 cities	2002-2015	All causes - Ferdows organization of Mashhad Municipality	Nearest weather station - IRAN Meteorological Organization (IRIMO) (http://www.irimo.ir)
Italy	18 cities	2006-2015	All causes - local mortality registries and the rapid mortality surveillance system	Airport monitoring station located closest to the city centre - Meteorological Service of the Italian Air Force. 24-h average based on 6-h measurements
Japan	47 cities	2011-2015	All causes - Ministry of Health, Labour and Welfare	Weather station located within the urban area of the capital city - Japan Meteorology Agency (JMA)
Kuwait	1 city	2000-2016	Non-external causes only (ICD-9: 0-799; ICD-10: A00-R99) - National Center for Health Information, Ministry of Health	Nearest weather station – the Directorate General of Civil Aviation (Kuwait Airport) and Kuwait's Environmental Public Authority.
Mexico	10 cities	1998-2014	All causes - National Institute of Statistics, Geography and Informatics	Weather station located within the urban area or at a near airport - Primarily Servicio Meteorológico Nacional (SMN) Estaciones Sinópticas Meteorológicas (ESIMES), Estaciones Meteorológicas Automáticas (EMAS)* and Observatories. Otherwise (i) Instituto Nacional de Ecología y Cambio Climático (INECC). (ii) Red de Meteorología y Radiación Solar (REDMET) from the Sistema de Monitoreo Atmosférico de la Ciudad de México (SIMAT). (iii) WMO stations from the Weather Underground.)
Moldova	4 cities	2001-2010	All causes - National Centre for Health Management	Nearest weather station - State Hydrometeorological Service, Moldova. Mean

				daily temperature computed as the average between daily minimum and maximum
The Netherlands	5 cities	1995-2016	All causes - Statistics Netherlands	Nearest weather station – Royal Dutch Meteorological Institute (KNMI)
Norway	1 city	1985-2018	All causes - Norwegian Cause of Death registry	Mean daily temperature based on the observational modelled dataset from the Norwegian Meteorological Institute.
Panama	1 city	2013-2016	All causes Instituto Nacional de Estadística y Censo, Centro de Información Estadística.	Open access temperature data - Empresa de Transmisión Eléctrica, S.A. (ETESA)
Paraguay	1 city	2004-2019	All causes - Ministerio de Salud Pública y Bienestar Social, Dirección General de Información Estratégica en Salud, Subsistema de Información de Estadísticas Vitales	Meteorological data - WMO-NOAA Surface Data Hourly Global (DS3505)
The Philippines	4 cities	2006-2010	All causes - Philippine Statistics Agency	Station in or near location - Philippine Atmospheric Geophysical and Astronomical Services Administration
Portugal	5 cities	1985-2018	All causes - Statistics Portugal	Meteorological data - WMO-NOAA Surface Data Hourly Global (DS3505)
Puerto Rico	1 city	2009-2016	All causes - Instituto de Estadísticas Vitales de Puerto Rico, Área de Estadísticas Vitales del Departamento de Salud	Meteorological data - WMO-NOAA Surface Data Hourly Global (DS3505)
Romania	8 cities	1994-2016	All causes - Romanian National Institute of Statistics	Mean daily temperature - National Meteorological Administration of Romania (NMARO, accessed from https://www.ecad.eu/)
South Korea	36 cities	1997-2018	All causes – South Korea Bureau of Statistics	Weather station located within the location - Korea Meteorological Administration
Spain	52 cities	1990-2014	Non-external causes (ICD-9: 0-799; ICD-10: A00-R99) - Spain National Institute of Statistics.	Weather station in the location or at a near airport - Spain National Meteorology Agency
Sweden	3 cities	1990-2016	All causes - Swedish Cause of Death Register at the Swedish National Board of Health and Welfare	Weather station in the location or at a near airport (Environment and Health Administration)
Switzerland	8 (7 cities and 1 metropolitan area -Lugano)	1995-2013	Non-external causes only other than accidents (ICD-10codes A00-R99, V01-V99, W00-X59) - Federal Office of Statistics	Weather station located within or near the urban area for each city - IDAWEB database (a service provided by MeteoSwiss, the Swiss Federal Office of Meteorology and Climatology).
Taiwan	3 cities	1994-2014	All causes - Department of Health	1-15 stations per location - Taiwan Environmental Protection Administration
UK	70 cities	1990-2016	All causes - Office of National Statistics.	29 stations on average per location - British Atmospheric Data Centre (BADC)
Uruguay	1 city	2012-2016	Non-external causes - Ministerio de Salud Publica (MSP)	Nearest weather station - Instituto Uruguayo de Meteorología (INUMET)

USA	211 cities	1985-2006	All causes - National Center for Health Statistics	Weather station closest to the city centre - National Climatic Data Center (NCDC) of NOAA
Vietnam	2 cities	2009-2013	All causes - Provincial Department of Health	Weather station at city airport

Table S2: Detailed summary statistics

File **Supplementary_Table_S2.xlsx** goes here.

Table S3: Fraction of all-cause excess mortality (%) due to cold and heat by countries and all 612 locations (Global) estimated using station observations, ERA5-Land and ERA5. The 95% empirical confidence intervals (eCI) computed using Monte Carlo simulations (see Methods) are reported in box brackets.

Country	Estimated excess mortality due to cold [eCI]			Estimated excess mortality due to heat [eCI]		
	Station Observations	ERA5-Land	ERA5	Station Observations	ERA5-Land	ERA5
Argentina	8.10 [6.33 - 9.90]	8.07 [6.18 - 9.87]	7.95 [6.25 - 9.59]	1.02 [0.65 - 1.35]	0.62 [0.43 - 0.81]	0.76 [0.49 - 1.02]
Australia	6.52 [4.53 - 8.43]	7.42 [5.23 - 9.36]	6.83 [4.79 - 8.87]	0.50 [0.25 - 0.71]	0.39 [0.27 - 0.48]	0.37 [0.26 - 0.47]
Brazil	2.83 [2.29 - 3.38]	2.90 [2.07 - 3.69]	2.96 [2.11 - 3.80]	0.73 [0.47 - 0.99]	0.70 [-0.14 - 1.50]	0.45 [0.23 - 0.62]
Canada	5.58 [4.71 - 6.42]	6.53 [5.65 - 7.39]	5.74 [4.79 - 6.63]	0.52 [0.38 - 0.64]	0.43 [0.31 - 0.55]	0.49 [0.37 - 0.60]
Chile	6.40 [3.61 - 9.12]	5.51 [3.02 - 7.97]	5.98 [3.36 - 8.48]	0.76 [0.24 - 1.27]	0.48 [-0.09 - 0.99]	0.60 [0.08 - 1.06]
China	7.34 [6.06 - 8.57]	7.35 [6.29 - 8.49]	7.46 [6.22 - 8.59]	1.00 [0.73 - 1.23]	0.88 [0.63 - 1.10]	1.00 [0.74 - 1.25]
Colombia	3.58 [-0.51 - 7.30]	3.24 [1.27 - 5.12]	3.05 [0.96 - 5.13]	0.54 [0.06 - 1.00]	0.50 [0.19 - 0.78]	0.46 [0.20 - 0.74]
Costa Rica	0.48 [-0.80 - 1.67]	1.26 [-0.81 - 3.11]	0.94 [-0.53 - 2.42]	0.72 [-1.38 - 2.68]	0.81 [-0.74 - 2.24]	0.72 [-0.76 - 2.31]
Czech Republic	6.55 [4.59 - 8.50]	6.85 [4.97 - 8.69]	6.72 [4.75 - 8.53]	0.70 [0.38 - 0.98]	0.62 [0.35 - 0.86]	0.69 [0.42 - 0.93]
Ecuador	2.60 [0.53 - 4.62]	4.47 [-2.40 - 11.18]	2.81 [0.50 - 5.05]	0.62 [-0.26 - 1.43]	0.03 [-0.15 - 0.17]	0.40 [-0.38 - 1.17]
Estonia	7.52 [5.05 - 9.85]	8.36 [6.34 - 10.41]	8.38 [5.37 - 11.07]	0.35 [0.14 - 0.54]	0.36 [0.07 - 0.61]	0.32 [0.09 - 0.53]
Finland	7.35 [3.09 - 11.39]	7.56 [3.76 - 10.93]	7.01 [2.41 - 10.78]	0.47 [0.13 - 0.76]	0.42 [0.08 - 0.73]	0.50 [0.21 - 0.78]
France	8.93 [7.78 - 9.94]	9.28 [8.06 - 10.44]	9.20 [7.98 - 10.40]	0.77 [0.70 - 0.83]	0.70 [0.63 - 0.77]	0.77 [0.72 - 0.82]
Germany	3.98 [3.01 - 4.80]	3.90 [2.95 - 4.71]	3.66 [2.75 - 4.55]	0.69 [0.60 - 0.76]	0.61 [0.54 - 0.67]	0.68 [0.59 - 0.74]
Greece	6.25 [3.22 - 9.49]	7.20 [4.20 - 10.20]	7.03 [4.14 - 9.81]	1.64 [0.99 - 2.34]	1.14 [0.44 - 1.81]	1.32 [0.67 - 2.00]
Guatemala	3.11 [-0.50 - 6.63]	3.77 [-1.21 - 8.38]	4.49 [-0.94 - 9.60]	0.09 [-0.29 - 0.43]	0.29 [-0.13 - 0.65]	0.20 [-0.31 - 0.64]
Iran	5.44 [2.52 - 8.21]	5.00 [2.05 - 7.76]	4.81 [1.96 - 7.34]	0.94 [0.50 - 1.43]	0.88 [0.31 - 1.37]	0.85 [0.31 - 1.32]
Italy	9.29 [8.06 - 10.42]	9.22 [7.71 - 10.63]	8.73 [7.32 - 10.07]	1.44 [1.19 - 1.64]	1.24 [1.02 - 1.45]	1.20 [0.96 - 1.41]
Japan	7.97 [6.93 - 8.96]	8.49 [7.50 - 9.46]	8.16 [7.12 - 9.08]	0.36 [0.23 - 0.47]	0.25 [0.13 - 0.36]	0.27 [0.15 - 0.36]
Kuwait	6.50 [2.60 - 9.91]	6.02 [2.01 - 9.47]	6.41 [2.59 - 10.19]	0.74 [-0.35 - 1.70]	0.69 [-0.37 - 1.71]	0.60 [-0.47 - 1.61]
Mexico	4.73 [3.57 - 5.84]	5.38 [4.30 - 6.30]	5.61 [4.49 - 6.58]	0.45 [0.22 - 0.68]	0.44 [0.26 - 0.61]	0.40 [0.24 - 0.53]
Moldova	8.86 [5.08 - 12.44]	9.11 [5.45 - 12.46]	9.02 [5.41 - 12.00]	1.24 [0.41 - 1.95]	1.07 [0.45 - 1.64]	1.17 [0.46 - 1.80]
The Netherlands	4.33 [2.73 - 5.86]	4.07 [2.49 - 5.55]	4.00 [2.20 - 5.50]	0.64 [0.44 - 0.82]	0.52 [0.35 - 0.68]	0.59 [0.41 - 0.75]
Norway	8.15 [3.70 - 12.49]	8.17 [2.85 - 13.02]	7.00 [1.39 - 11.84]	0.16 [-0.15 - 0.44]	0.17 [-0.15 - 0.47]	0.14 [-0.19 - 0.47]
Panama	1.07 [-0.33 - 2.46]	1.30 [-0.56 - 3.10]	1.11 [-0.71 - 3.00]	1.05 [-1.31 - 3.29]	0.94 [-0.92 - 2.75]	0.79 [-1.22 - 2.56]

Paraguay	6.71 [3.31 - 9.92]	5.19 [2.27 - 7.80]	6.14 [3.21 - 9.13]	1.49 [0.66 - 2.31]	0.95 [0.10 - 1.71]	1.24 [0.47 - 1.99]
The Philippines	2.08 [0.88 - 3.26]	1.14 [0.43 - 1.86]	1.13 [-1.13 - 3.24]	1.16 [0.65 - 1.64]	1.00 [0.46 - 1.49]	1.05 [0.42 - 1.65]
Portugal	6.73 [5.65 - 7.84]	7.18 [5.59 - 8.80]	6.84 [5.33 - 8.17]	0.96 [0.74 - 1.15]	0.81 [0.71 - 0.91]	0.76 [0.62 - 0.89]
Puerto Rico	1.34 [-0.32 - 2.88]	2.14 [-0.42 - 4.32]	1.64 [-0.68 - 3.74]	0.73 [-1.40 - 2.91]	0.71 [-0.87 - 2.27]	0.55 [-1.17 - 2.16]
Romania	9.01 [7.43 - 10.48]	8.97 [7.41 - 10.43]	8.62 [7.12 - 9.98]	1.52 [1.24 - 1.76]	1.21 [0.96 - 1.45]	1.40 [1.13 - 1.64]
South Korea	5.97 [4.86 - 7.15]	6.69 [5.34 - 7.86]	6.38 [5.28 - 7.60]	0.30 [0.17 - 0.44]	0.31 [0.18 - 0.43]	0.31 [0.16 - 0.43]
Spain	6.59 [5.86 - 7.28]	6.37 [5.69 - 7.00]	6.07 [5.41 - 6.69]	1.15 [1.03 - 1.28]	1.20 [1.06 - 1.33]	1.32 [1.18 - 1.43]
Sweden	6.03 [3.64 - 8.37]	6.58 [4.41 - 8.82]	5.80 [3.62 - 7.83]	0.43 [0.22 - 0.64]	0.44 [0.23 - 0.65]	0.46 [0.26 - 0.67]
Switzerland	4.22 [2.36 - 5.93]	4.22 [2.59 - 5.85]	4.03 [2.38 - 5.35]	0.47 [0.17 - 0.72]	0.44 [0.20 - 0.71]	0.51 [0.23 - 0.76]
Taiwan	5.00 [3.60 - 6.36]	5.38 [4.10 - 6.61]	5.20 [3.85 - 6.61]	0.79 [0.31 - 1.24]	0.64 [0.22 - 1.07]	0.69 [0.30 - 1.08]
UK	7.72 [7.06 - 8.33]	7.17 [6.58 - 7.73]	7.02 [6.35 - 7.70]	0.25 [0.20 - 0.29]	0.26 [0.22 - 0.30]	0.26 [0.22 - 0.30]
Uruguay	8.85 [5.66 - 11.56]	9.22 [6.01 - 12.21]	9.48 [6.46 - 12.80]	1.35 [0.57 - 2.02]	1.01 [0.33 - 1.74]	0.95 [0.22 - 1.65]
USA	5.90 [5.60 - 6.18]	6.25 [5.98 - 6.51]	5.94 [5.59 - 6.21]	0.35 [0.30 - 0.39]	0.33 [0.28 - 0.38]	0.35 [0.29 - 0.40]
Vietnam	2.27 [0.00 - 4.55]	1.83 [0.25 - 3.23]	2.16 [-0.88 - 5.18]	1.24 [0.33 - 2.02]	1.04 [-0.07 - 1.94]	0.65 [-0.15 - 1.35]
Global	6.02 [5.80 - 6.18]	6.25 [6.05 - 6.41]	5.99 [5.79 - 6.16]	0.53 [0.50 - 0.56]	0.49 [0.43 - 0.53]	0.50 [0.47 - 0.52]

Table S4: Summary of the Relative Fitting Score (RFS) by countries.

Country	Total number of locations in the study	Number of locations where ERA5-Land (Station Observations) perform better
Argentina	3	0 (3)
Australia	3	2 (1)
Brazil	18	2 (16)
Canada	26	12 (14)
Chile	4	2 (2)
China	15	7 (8)
Colombia	5	2 (3)
Costa Rica	1	1 (0)
Czech Republic	3	3 (0)
Ecuador	2	1 (1)
Estonia	5	3 (2)
Finland	1	0 (1)
France	18	7 (11)
Germany	12	5 (7)
Greece	1	0 (1)
Guatemala	1	1 (0)
Iran	2	1 (1)
Italy	18	5 (13)
Japan	47	31 (16)
Kuwait	1	0 (1)
Mexico	10	2 (8)
Moldova	4	2 (2)
The Netherlands	5	3 (2)
Norway	1	1 (0)
Panama	1	0 (1)
Paraguay	1	0 (1)
The Philippines	4	1 (3)
Portugal	5	2 (3)
Puerto Rico	1	1 (0)
Romania	8	3 (5)
South Korea	36	10 (26)
Spain	52	29 (23)
Sweden	3	2 (1)
Switzerland	8	3 (5)
Taiwan	3	2 (1)
UK	70	39 (31)
Uruguay	1	0 (1)
USA	211	106 (105)
Vietnam	2	1 (1)
Global	612	292 (320)

MCC Collaborative Research Network.

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