Appendix A for

Temperature-related excess mortality in German cities at 2°C and higher degrees of global warming

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Supplementary methods

Handling of outliers and missing values in observational series

The mortality series were complete, with no missing values. Yet, we classified 7 data points (1 Jan during the 1990s) in the data for Frankfurt as outliers and removed them from the series. The temperature series included few missing values (Table S2), which we chose not to interpolate. In the case of Dortmund, no complete series was available for neither of the nearby weather stations. We joined data from Hagen-Fley (available up to 2007) with data from Bochum (available from 2008 onwards). We tested for zero difference in means between these two stations during the overlapping period (1 Jan 1993 to 30 Apr 1994) using a Welch two sample t-test ($p > 0.1$), giving us confidence that the bias from joining two distinct series was small.

Supplementary tables

Table A1. Districts codes (*Amtlicher Gemeindeschlüssel* (AGS)) used to extract city-specific mortality data from archive of the German Statistical Offices, and city-specific population data from 2015 (Source: GENESIS-Online Datenbank, Statistisches Bundesamt 2018). Total population of Germany in 2015 was 81.2 million.

City	AGS years	AGS code	Population (2015)
Berlin	1993-2015	11000	3,520,031
Bremen	1993-2015	04011	557,464
Dortmund	1993-2015	05913	586,181
Dresden	1993	14002	543,825
	1994-1995	14062	
	1996-2007	14262	
	2008-2015	14612	
Dusseldorf	1993-2015	05111	612,178
Frankfurt	1993-2015	06412	732,688
Hamburg	1993-2015	02000	1,787,408
Hannover	1993-2000	03201 + 03253	1,144,481
	2001-2015	03241*	
Cologne	1993-2015	05315	1,060,582
Leipzig	1993	14004	560,472
	1994-1995	14065	
	1996-2007	14365	
	2008-2015	14713	
Munich	1993-2015	09162	1,450,381
Stuttgart	1993-2015	08111	623,738

*01.01.2001: Merging of rural and urban districts

Table A2. Weather stations and number of missing values

City	Weather station(s)	DWD code	Missing values
Berlin	Berlin-Tempelhof	00433	None
Bremen	Bremen	00691	None
Dortmund	Hagen-Fley	01920	9 days in 1993-2007
	Bochum	00555	None in 2008-2016
Dresden	Dresden-Klotzsche	01048	None
Dusseldorf	Düsseldorf	01078	None
Frankfurt	Frankfurt-Main	01420	None
Hamburg	Hamburg-Fuhlsbüttel	01975	None
Hannover	Hannover	02014	None
Cologne	Köln-Bonn	02667	None
Leipzig	Leipzig-Holzhausen	02928	1 day
Munich	München-Stadt	03379	None
Stuttgart	Stuttgart-Schnarrenberg	04928	9 days

Table A3. Central year of 21-y windows where considered levels of GMT rise are reached, by GCM and RCP scenario.

GCM	Δ GMT above pre-industrial	RCP2.6	RCP4.5	RCP6.0	RCP8.5
GFDL-ESM2M	1°C	2015	2015	2017	2016
	2°C	-	-	2076	2053
	3°C	-	-	-	2084
HadGEM2-ES	1°C	2007	2007	2006	2006
	2°C	2039	2038	2041	2031
	3°C	-	2070	2069	2052
	4°C	-	-	-	2068
	5°C	-	-	-	2085
IPSL-CM5A-LR	1°C	2008	2011	2010	2009
	2°C	-	2045	2048	2037
	3°C	-	-	2086	2056
	4°C	-	-	-	2073
	5°C	-	-	-	2090
MIROC5	1°C	2012	2012	2017	2011
	2°C	-	2063	2069	2047
	3°C	-	-	-	2069

Table A4. Sensitivity analysis

Modelling choices	AF total (%)	AF cold (%)	AF warm (%)	MMT (percentile)
Default (all cities)	6.30	5.49	0.81	86th
Knots for exposure-response: 10th, 50th, and 90th	5.82	4.92	0.89	79th
Knots for exposure-response: 10th, 25th, 75th and 90th	6.00	5.21	0.79	88th
Cubic B-spline for exposure-response	4.36	3.81	0.54	89th
Quadratic B-spline for exposure-response	5.33	4.72	0.61	92nd
Df/year for seasonal control: 4	5.34	4.50	0.83	84th
Df/year for seasonal control: 6	5.36	4.60	0.75	86.5th
Df/year for seasonal control: 8	5.78	4.85	0.93	84th
Df/year for seasonal control: 10	5.38	4.46	0.92	84th

Table A5. Second-stage random-effects meta-regression model

Model	Predictor	Test for predictor	Q test	I^2
Intercept-only	-	-	<0.001	59.4%
Single predictor	Average temperature	<0.01	<0.01	42.3%
	Temperature range	<0.1	<0.001	48.1%
Full model	Average temperature	<0.001		
	Temperature range	<0.001	>0.1	22.3%

Table A6. Heat-related, cold-related and net change in excess mortality (%, 95%CI) by city and global warming level.

		GMT rise above pre-industrial				
		1°C	2°C	3°C	4°C	5°C
Berlin	heat	1.09 (0.81 to 1.44)	1.97 (1.51 to 2.50)	2.98 (2.23 to 3.96)	4.64 (3.89 to 5.44)	6.50 (5.13 to 7.98)
	cold	5.75 (4.04 to 7.47)	5.03 (3.40 to 6.69)	4.53 (2.96 to 6.13)	4.01 (2.46 to 5.56)	3.66 (2.16 to 5.16)
	net	-	0.11 (-0.38 to 0.53)	0.6 (-0.14 to 1.23)	1.87 (1.23 to 2.47)	3.39 (2.09 to 4.70)
Bremen	heat	0.43 (0.17 to 0.70)	0.77 (0.31 to 1.22)	1.18 (0.47 to 1.96)	1.77 (0.70 to 2.82)	2.5 (0.92 to 4.26)
	cold	3.05 (-0.28 to 6.27)	2.39 (-0.8 to 5.47)	2 (-1.11 to 4.87)	1.65 (-1.34 to 4.4)	1.47 (-1.38 to 4.09)
	net	-	-0.37 (-0.85 to 0.13)	-0.36 (-0.9 to 0.15)	-0.06 (-0.9 to 0.76)	0.49 (-0.83 to 1.94)
Cologne	heat	1.24 (0.81 to 1.68)	2.21 (1.57 to 2.72)	3.49 (2.58 to 4.60)	5.49 (4.60 to 6.44)	7.61 (5.88 to 9.50)
	cold	5.52 (3.47 to 7.57)	4.79 (2.84 to 6.78)	4.26 (2.39 to 6.16)	3.72 (1.93 to 5.52)	3.30 (1.61 to 4.99)
	net	-	0.19 (-0.13 to 0.55)	0.94 (0.27 to 1.85)	2.58 (1.84 to 3.30)	4.28 (2.66 to 5.95)

Dortmund	heat	0.95	1.73	2.79	4.37	6.09
		(0.64 to 1.30)	(1.19 to 2.12)	(2.06 to 3.70)	(3.59 to 5.22)	(4.51 to 7.84)
	cold	5.27	4.55	4.04	3.53	3.15
		(3.22 to 7.33)	(2.58 to 6.55)	(2.16 to 5.93)	(1.72 to 5.34)	(1.44 to 4.85)
	net	-	0.01	0.55	1.75	3.09
			(-0.28 to 0.32)	(0.04 to 1.26)	(1.10 to 2.39)	(1.64 to 4.61)
Dresden	heat	0.76	1.48	2.37	3.68	5.36
		(0.50 to 1.13)	(0.98 to 2.10)	(1.49 to 3.54)	(2.58 to 4.92)	(3.48 to 7.52)
	cold	4.57	3.92	3.51	3.09	2.82
		(1.56 to 7.54)	(1.04 to 6.78)	(0.78 to 6.29)	(0.44 to 5.77)	(0.28 to 5.37)
	net	-	0.02	0.49	1.49	2.9
			(-0.41 to 0.47)	(-0.22 to 1.37)	(0.49 to 2.49)	(1.10 to 4.82)
Dusseldorf	heat	1.23	2.16	3.36	5.14	7.02
		(0.85 to 1.64)	(1.52 to 2.68)	(2.49 to 4.43)	(4.22 to 6.14)	(5.27 to 8.94)
	cold	5.55	4.73	4.15	3.56	3.13
		(3.21 to 7.86)	(2.53 to 6.96)	(2.05 to 6.28)	(1.54 to 5.57)	(1.23 to 5.04)
	net	-	0.05	0.66	2.02	3.47
			(-0.29 to 0.46)	(0.01 to 1.55)	(1.15 to 2.88)	(1.74 to 5.26)
Frankfurt	heat	1.11	2.09	3.57	5.69	8.06
		(0.73 to 1.68)	(1.40 to 2.80)	(2.35 to 5.15)	(4.28 to 7.25)	(5.42 to 11.02)
	cold	8.4	7.61	7.03	6.4	5.86
		(4.89 to 11.6)	(4.20 to 10.64)	(3.76 to 9.92)	(3.34 to 9.14)	(2.97 to 8.44)
	net		0.14	1.03	2.64	4.47
		-	(-0.22 to 0.54)	(0.15 to 2.24)	(1.47 to 3.81)	(2.02 to 7.02)
Hamburg	heat	0.43	0.80	1.24	1.92	2.77
		(0.19 to 0.68)	(0.38 to 1.22)	(0.58 to 1.96)	(0.93 to 2.85)	(1.32 to 4.31)
	cold	4.30	3.62	3.22	2.85	2.61
		(1.13 to 7.43)	(0.60 to 6.60)	(0.30 to 6.05)	(0.08 to 5.56)	(0.01 to 5.13)
	net	-	-0.35	-0.34	0.02	0.64
			(-0.77 to 0.09)	(-0.86 to 0.13)	(-0.74 to 0.76)	(-0.58 to 1.88)
Hannover	heat	0.93	1.65	2.56	3.90	5.4
		(0.63 to 1.25)	(1.19 to 2.15)	(1.85 to 3.41)	(3.16 to 4.73)	(4.08 to 6.86)
	cold	3.67	3.05	2.64	2.23	1.97
		(1.75 to 5.59)	(1.22 to 4.89)	(0.89 to 4.42)	(0.54 to 3.93)	(0.37 to 3.57)
	net	-	0.05	0.54	1.6	2.83
			(-0.37 to 0.50)	(0.08 to 1.14)	(0.94 to 2.23)	(1.60 to 4.10)
Leipzig	heat	1.21	2.21	3.41	5.16	7.17
		(0.87 to 1.66)	(1.60 to 2.93)	(2.45 to 4.70)	(4.07 to 6.35)	(5.20 to 9.38)
	cold	3.86	3.19	2.76	2.31	2.03
		(1.76 to 5.95)	(1.17 to 5.23)	(0.80 to 4.73)	(0.43 to 4.21)	(0.23 to 3.85)
	net	-	0.28	1.03	2.48	4.21
			(-0.25 to 0.82)	(0.33 to 2.00)	(1.53 to 3.44)	(2.36 to 6.20)
Munich	heat	0.57	1.16	2.10	3.44	5.35
		(0.39 to 0.81)	(0.77 to 1.56)	(1.37 to 2.96)	(2.49 to 4.44)	(3.30 to 7.66)
	cold	6.44	5.71	5.22	4.69	4.27
		(4.05 to 8.75)	(3.39 to 8.01)	(3.00 to 7.43)	(2.60 to 6.78)	(2.27 to 6.28)
	net	-	-0.18	0.29	1.14	2.62
			(-0.48 to 0.15)	(-0.31 to 0.98)	(0.30 to 1.94)	(0.68 to 4.7)
Stuttgart	heat	0.89	1.71	2.98	4.83	7.15
		(0.63 to 1.24)	(1.22 to 2.27)	(2.06 to 4.17)	(3.72 to 6.05)	(4.81 to 9.75)
	cold	6.9	6.10	5.55	4.94	4.43
		(4.46 to 9.31)	(3.76 to 8.45)	(3.31 to 7.80)	(2.80 to 7.09)	(2.39 to 6.46)
	net	-	-0.03	0.68	2.02	3.82
			(-0.31 to 0.31)	(-0.03 to 1.69)	(1.01 to 3.05)	(1.57 to 6.24)

Supplementary figures

Figure A1. Map of Germany showing the locations of the 12 cities included in the study.

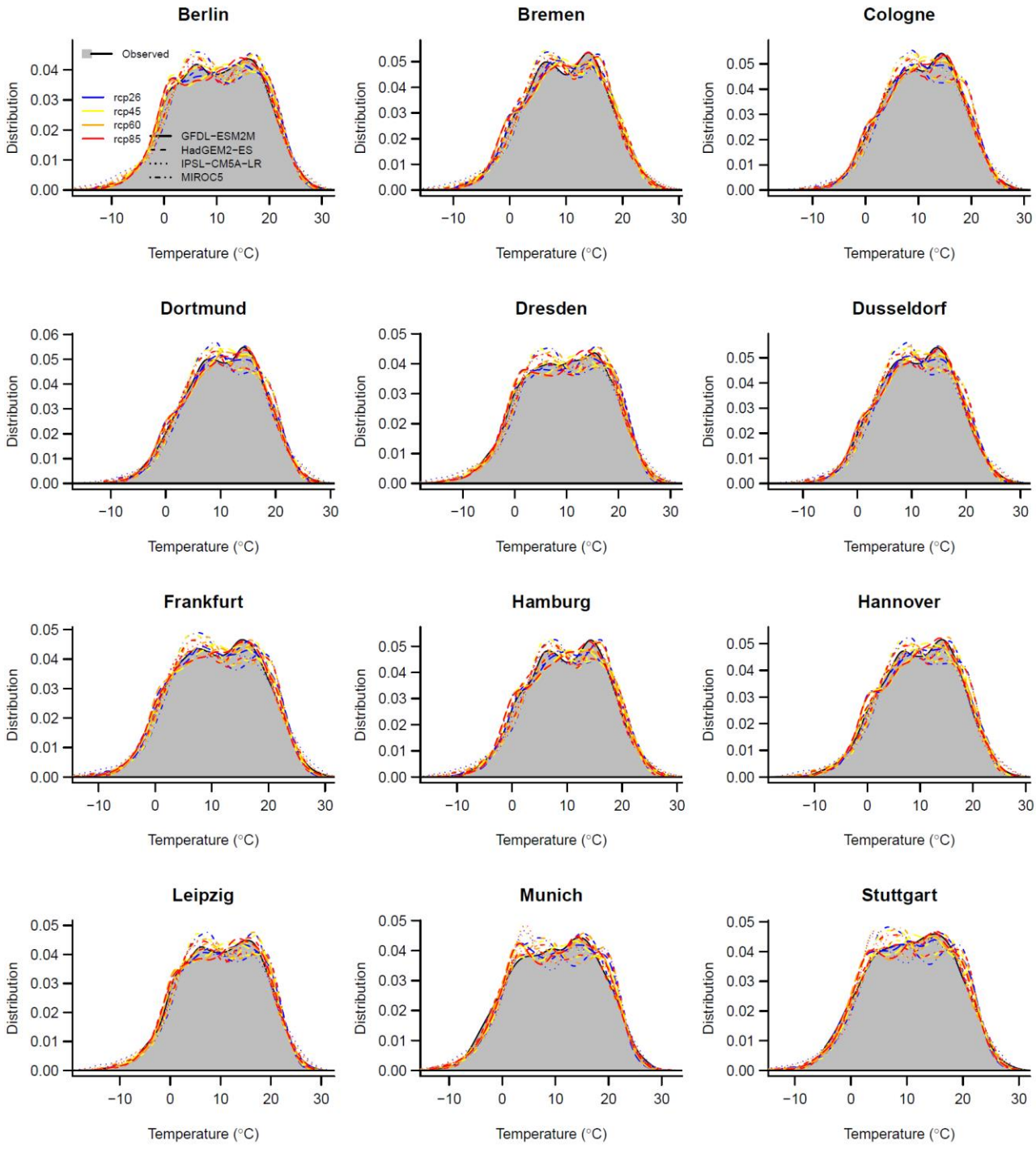

Figure A2. Distribution of mean daily temperatures comparing weather station data with GCM data. We joined historical runs with RCP runs to derive complete series in the study period 1993-2015.

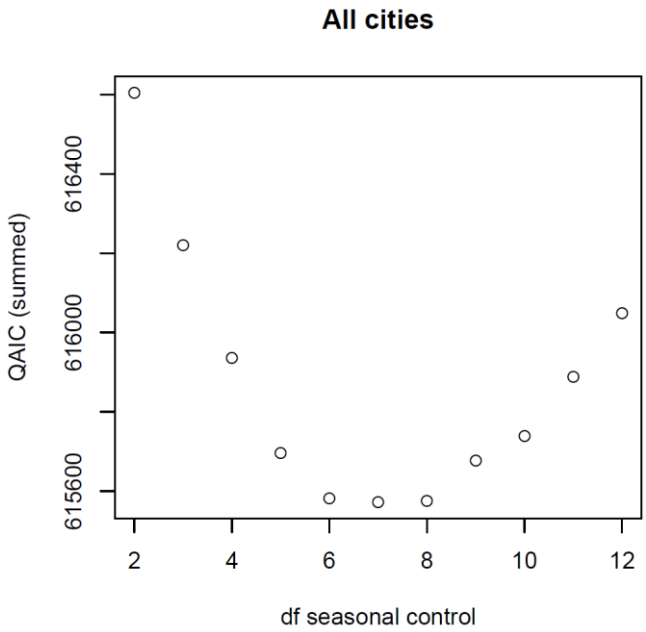

Figure A3. Sum of quasi-Akaike information criterion (QAIC) across all cities for models differing in the degrees of freedoms (df) used to control for seasonality and long-term trends.

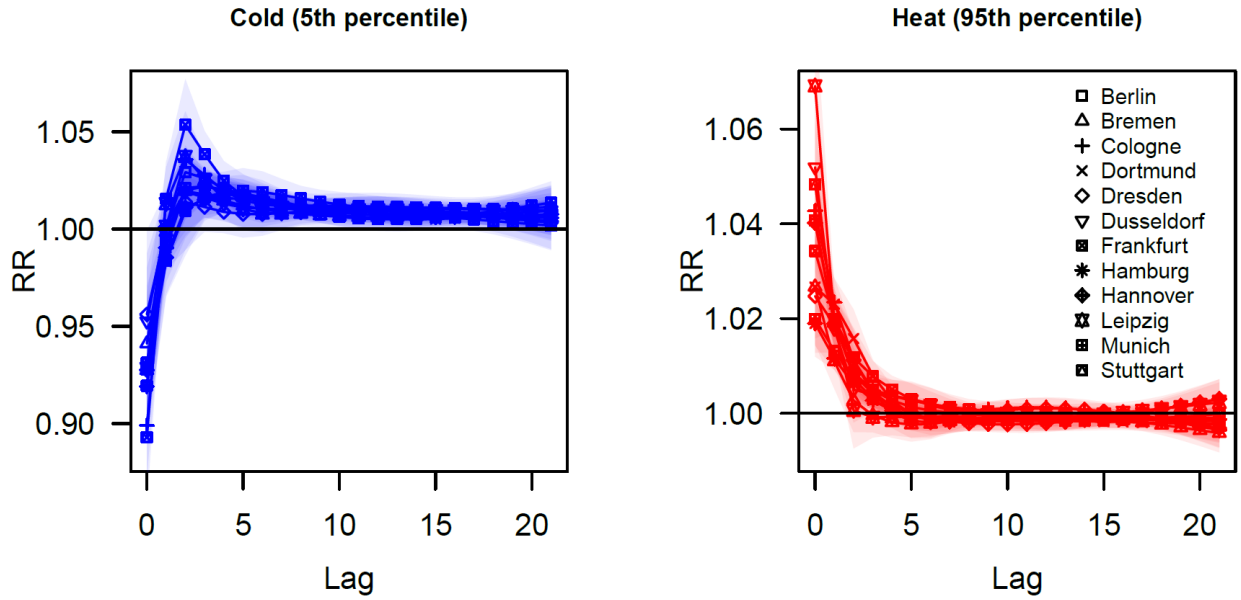

Figure A4. Temporal lag structure underlying the overall cumulative temperature-mortality associations shown in Fig. 1. Depicted is the relative risk (RR) at each lag considered (0 to 21 days) for an exposure to cold (2.5th percentile of daily mean temperatures) and heat (97.5th percentile of daily mean temperatures) in each city.