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Supplementary appendix

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Trends in Population Exposure to Compound Extreme-risk Temperature and Air Pollution across 35 European countries: a modeling study

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Supplementary materials

Supplemental methods description

Population data

The high-resolution gridded population data from the Gridded Population of the World, Version 4 (GPWv4) database were obtained at a spatial resolution of 30 arc-seconds (~1 km2) for the years 2000, 2005, 2010, 2015, and 2020. The gridded population data were upscaled to a 0.1-degree grid cell using the area-weighted sum method: the values of 1 km grid cells were aggregated based on their relative areas within the 0.1-degree grid cell. Then, Linear regression was used to interpolate population data for the remaining years between 2003 and 2019[1]. To further calibrated the population values, we aggregated 0.1-degree cells to NUTS3 level, matching with the Eurostat's annual population data (NUTS 3), and fitted the calibrated model with predictors year, GPWv4 population and random intercept for each NUTS3 region. The calibrated model is well cross-validated (R^2=0.96). We then applied calibrated model to calibrate each 0.1-degree cell.

Epidemiological models' parameters

In the first stage of location-specific analysis, the models incorporated the following components: (1) an intercept, (2) a natural cubic spline representing time with 8 degrees of freedom per year to account for seasonal and long-term trends, and (3) a cross-basis function designed to estimate the relationship between weekly temperatures (temp) and mortality counts (mort) with respect to exposure and lag.

$$\log\left(E(\text{mort})\right) = \text{intercept} + \text{ns}(\text{time}, 8\text{d. f. per year}) + \text{crossbasis}(\text{temp}; 0,1,2,3\text{ weeks}))$$

The lag–response function within the cross-basis was constructed using integer lag values of 0, 1, 2, and 3 weeks, while the exposure–response function was modeled using a natural cubic spline containing three internal knots placed at the 10th, 50th, and 90th percentiles of the location-specific weekly temperature distribution.

In the sensitive analysis, we found that the inclusion of relative humidity did not substantially alter the overall shape of the curve, suggesting that its confounding effect was minimal (Fig. s9). Fig s10 showed pooled the lag effects in extreme-temperature on mortality from all regions. The second-stage sensitivity analysis were shown table s12.

Cumulative time of exposure Indicators:

We calculated annual exposure time for extreme risk temperature (ERT) days, or its compound days with at least one pollutant exceeding daily limits.

The calculation of annual ERT or compound days has two steps: first is to obtain the annual person-days exposed to ERT or its compound episodes for each gird, second is to obtain the annual regional population-weighted (PW) average ERT or compound days.

For a given grid g and year Y, the annual ERT person-days were calculated as follows:

$$\text{annual ERT person-days}_{gY} = \sum_{d}^{Y} Pop_g \times I_{gd}$$

Where Pop_g represents the population of grid g in the corresponding year; I_{gd} is the Boolean value indicating whether the day d on grid g is ERT day. A similar approach was used to calculate the annual cumulative Air Quality Guideline (AQG) exceedance person-days or compound person-days.

The annual regional population-weighted average ERT or compound days was identified as:

$$\textit{ERT days or compound days} = \frac{\sum_{g}^{R} \text{annual ERT or compound person-days}_{gY}}{\sum_{g}^{R} Pop_g}$$

Where *ERT days or compound days* is population-weighted ERT or compound day on each NUTS-3 areas and year Y; $\sum_{g}^{R} \text{annual ERT or compound person-days}_{gY}$ is the sum of ERT or compound person-days for all grids g within area R for specified year Y; $\sum_{g}^{R} Pop_g$ is the total population of corresponding NUTS-3 areas.

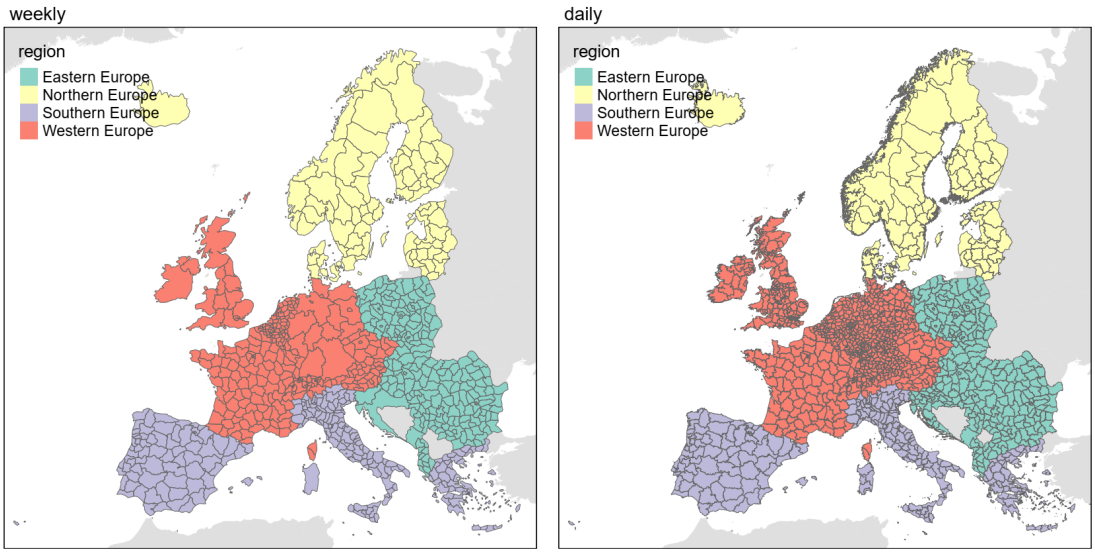

Figure s1. Comparison of weekly mortality data (823 NUTS regions) for the epidemiological model and exposure data (1426 NUTS-3 regions) for calculating extreme temperature days.

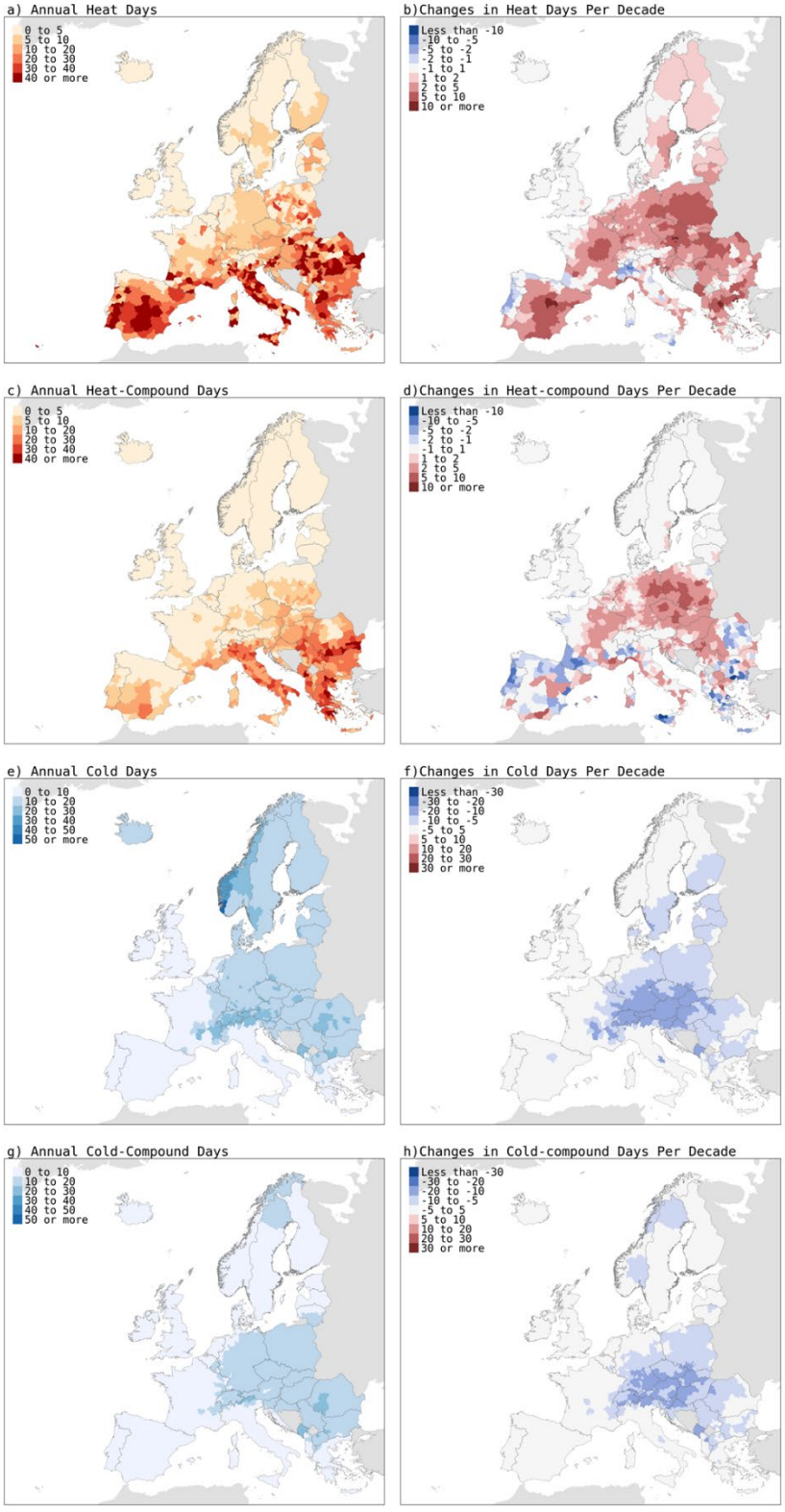

Figure s2. Europe maps of 18-year averages and trends in heat days (daily temperatures higher than 95th quantile in both Europe and within NUTS3 region) (a,b), heat-compound days (c,b), cold days (daily temperatures lower than 5th quantile in both Europe and within NUTS3 region) (e,f) and cold-compound days(g,h) between 2003-2020.

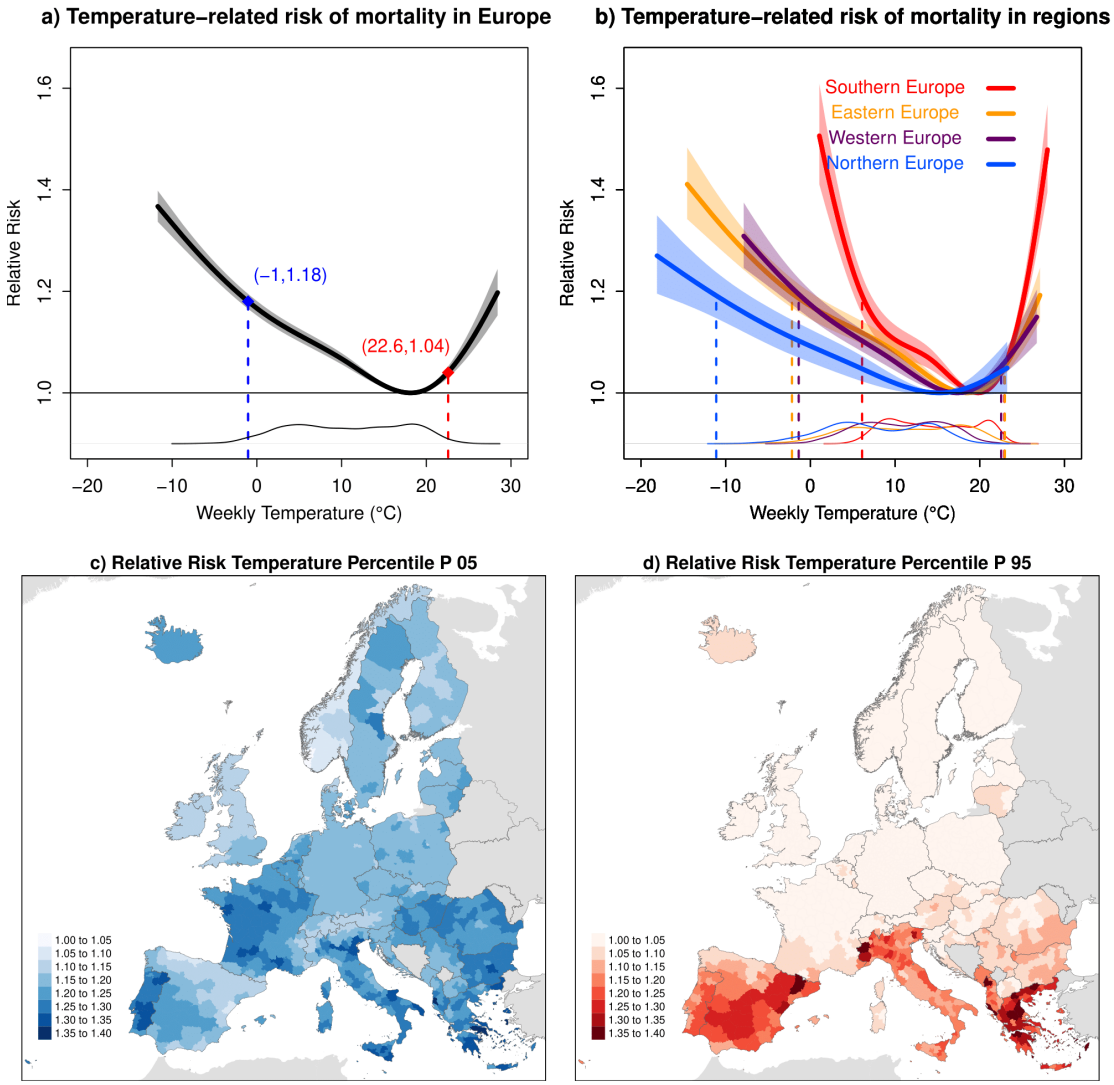

Figure s3. The meta predictions of cumulative relative risk of mortality (unitless) in Europe (a) and in regions (b), based on corresponding 7-days moving averages temperature data across 1426 NUTS-3 regions during 2003-2020. Europe regional relative risk of death (unitless) at the temperature 5th percentile (c), at the temperature 95th percentile (d).

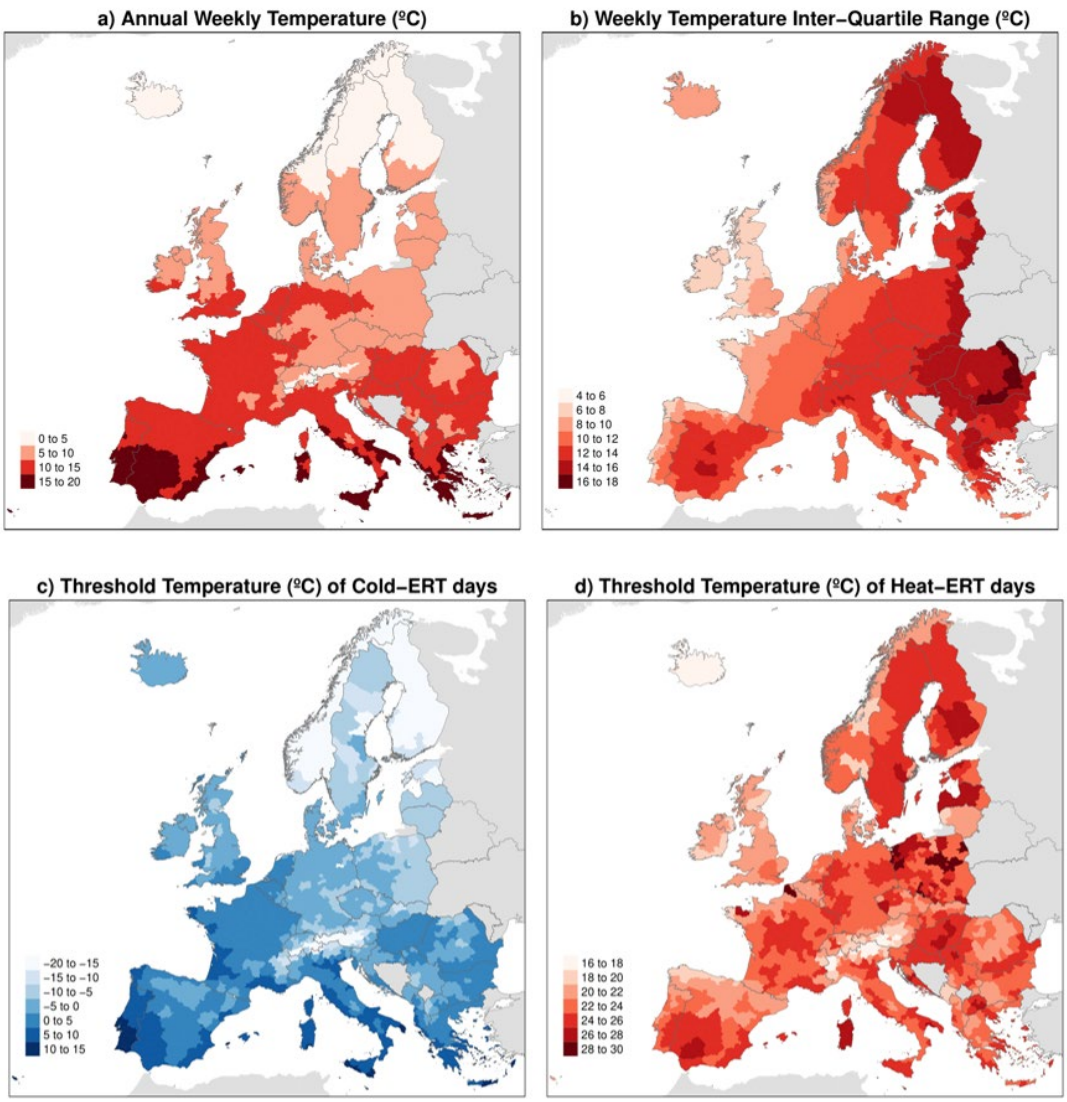

Figure s4. Meta-predictors included in the meta-regression: the regional annual mean weekly temperature (a, °C), temperature inter-quartile range (b, °C); The extreme-risk temperature (ERT) for cold (RR >=1.19) and heat (RR >=1.05) extracted from location-specific temperature–mortality relationship in Europe

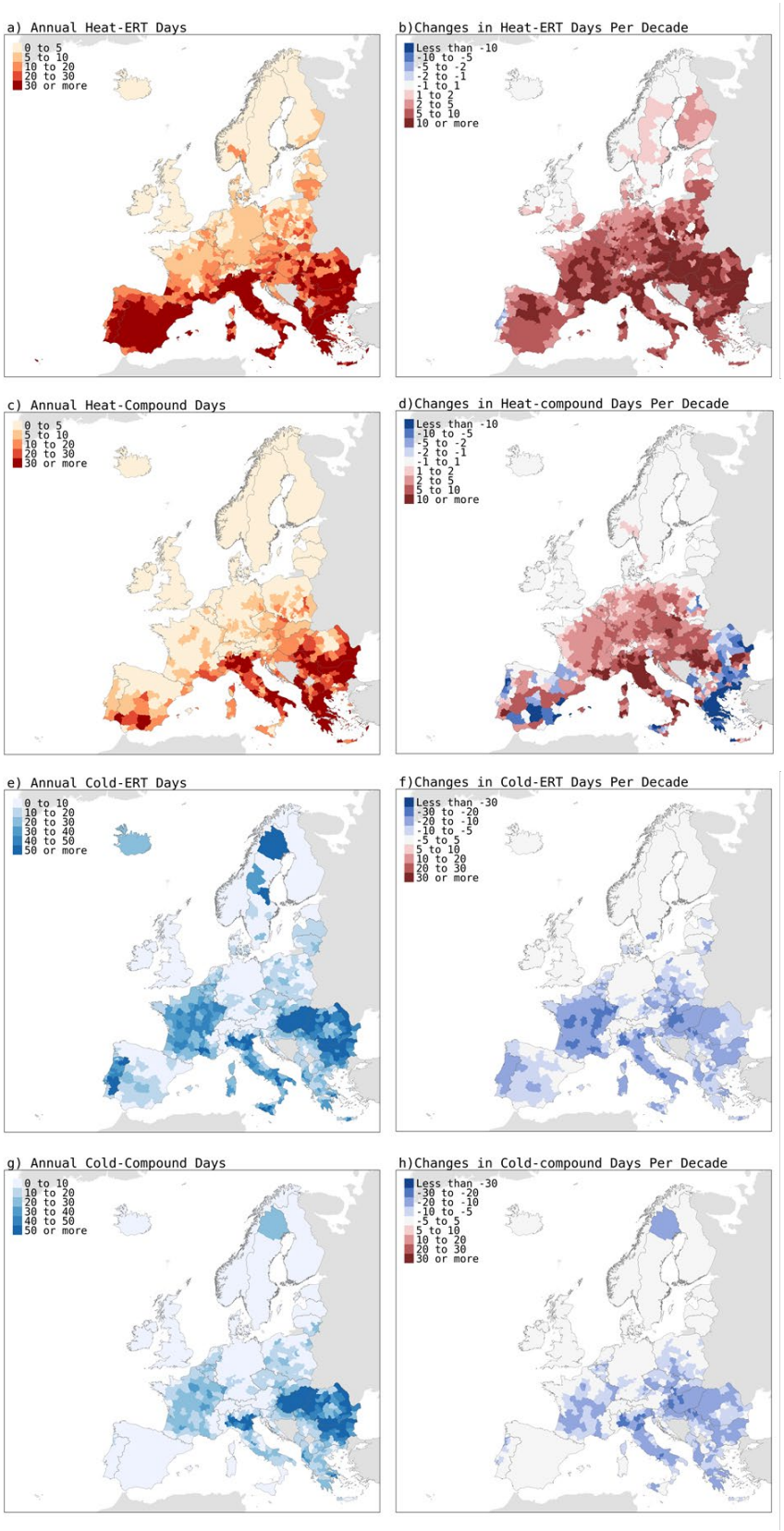

Figure s5. Regional ERT days and associate compound days in Europe during 2003-2020 without considering the adaptation. Europe maps of 18-Year Annual Averages and Decadal Trends in Heat-ERT(extreme-risk temperature) days (a,b), Heat-compound days (c,d), Cold-ERT(extreme-risk temperature) days (e,f) and Cold-compound days (g,h).

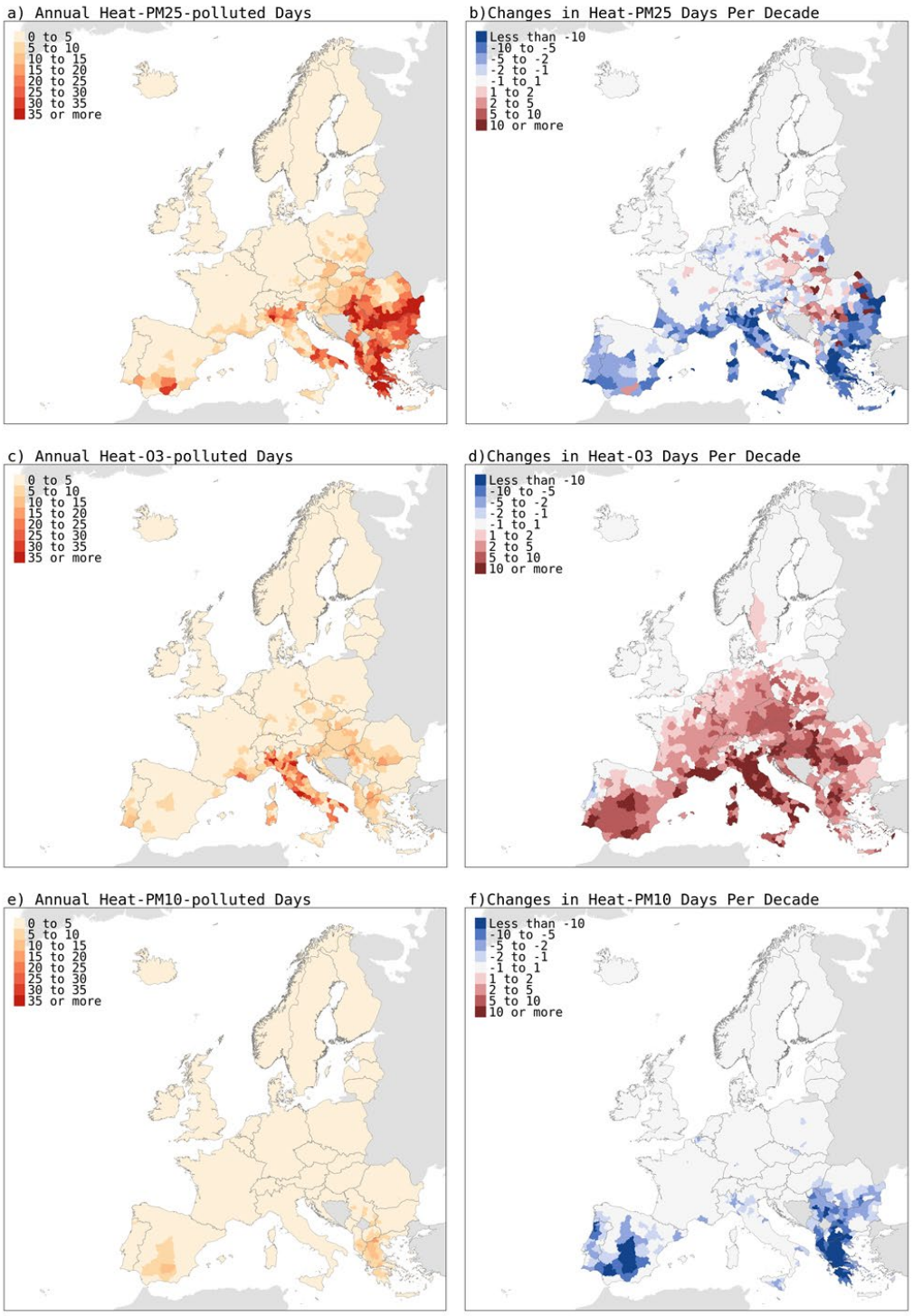

Figure s6. Maps of 18-year averages and trends in Heat-PM_{25} compound days (a,b), Heat-O_3 compound days (c,d), Heat-PM_{10} compound days(e,f) between 2003-2020. Notes: Heat-NO_2 compound days is too rare to plot.

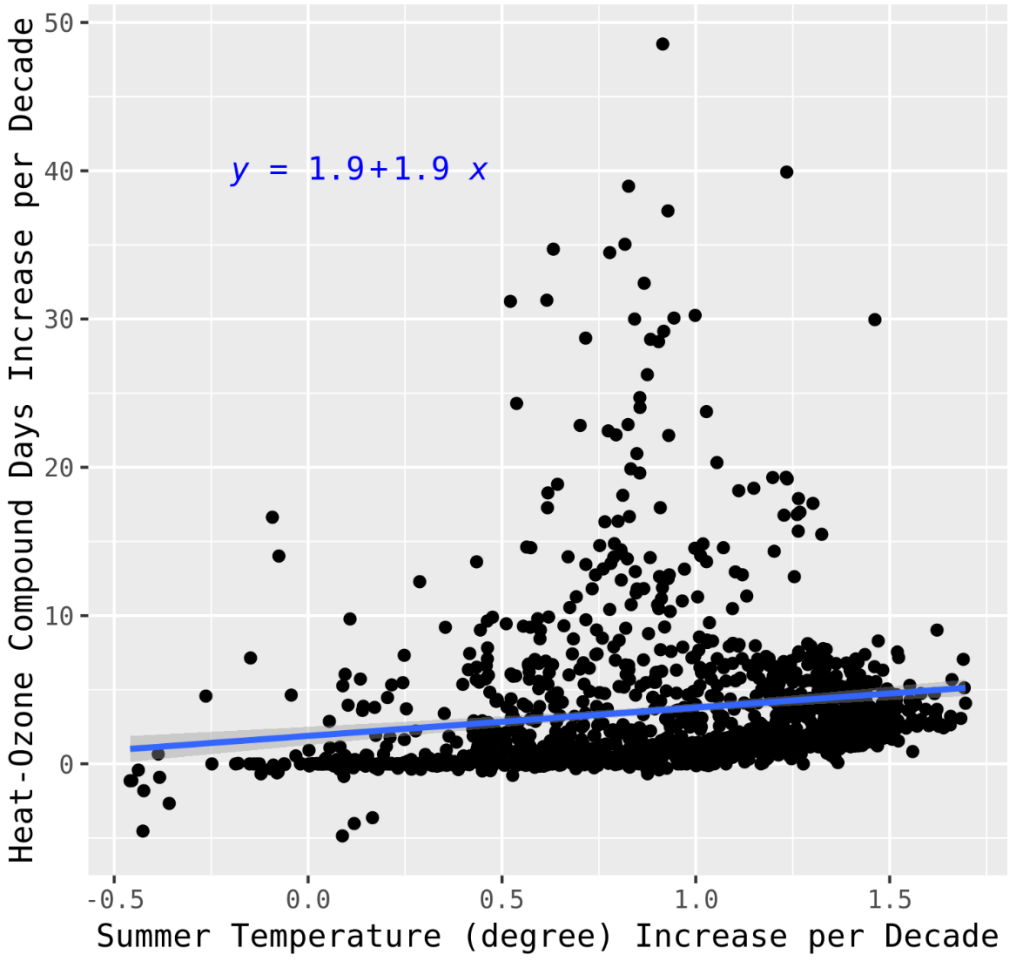

Figure s7. Scatter plot of the summer temperature increase per decade and Heat-ozone compound days increase per decade.

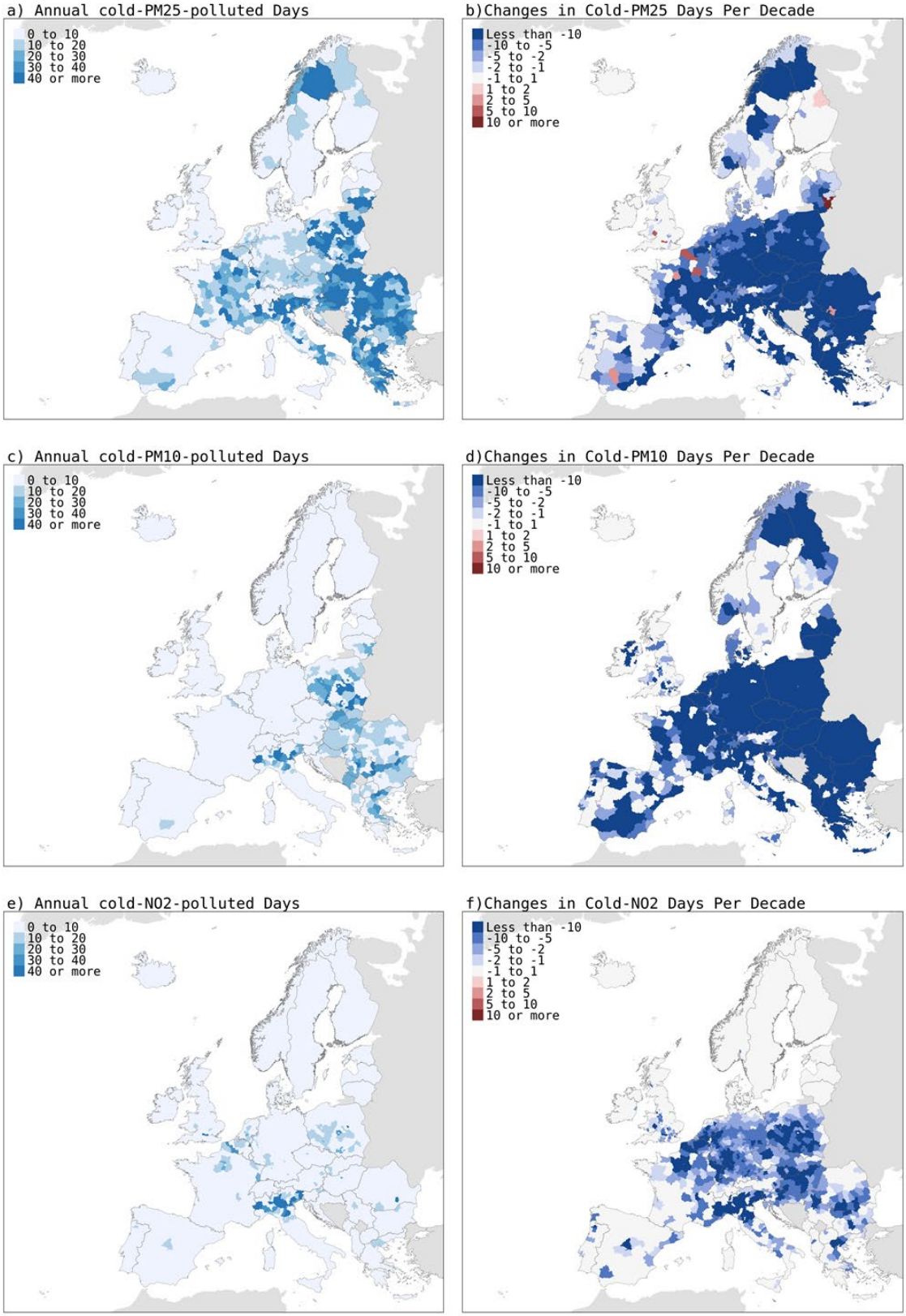

Figure s8. Europe maps of 18-year averages and trends in Cold-PM_{25}-compound days (a,b), Cold-PM_{10}- compound days (c,d), Cold-NO_2-compound days(e,f) between 2003-2020. Notes: Cold-O_3-compound days is too rare to plot.

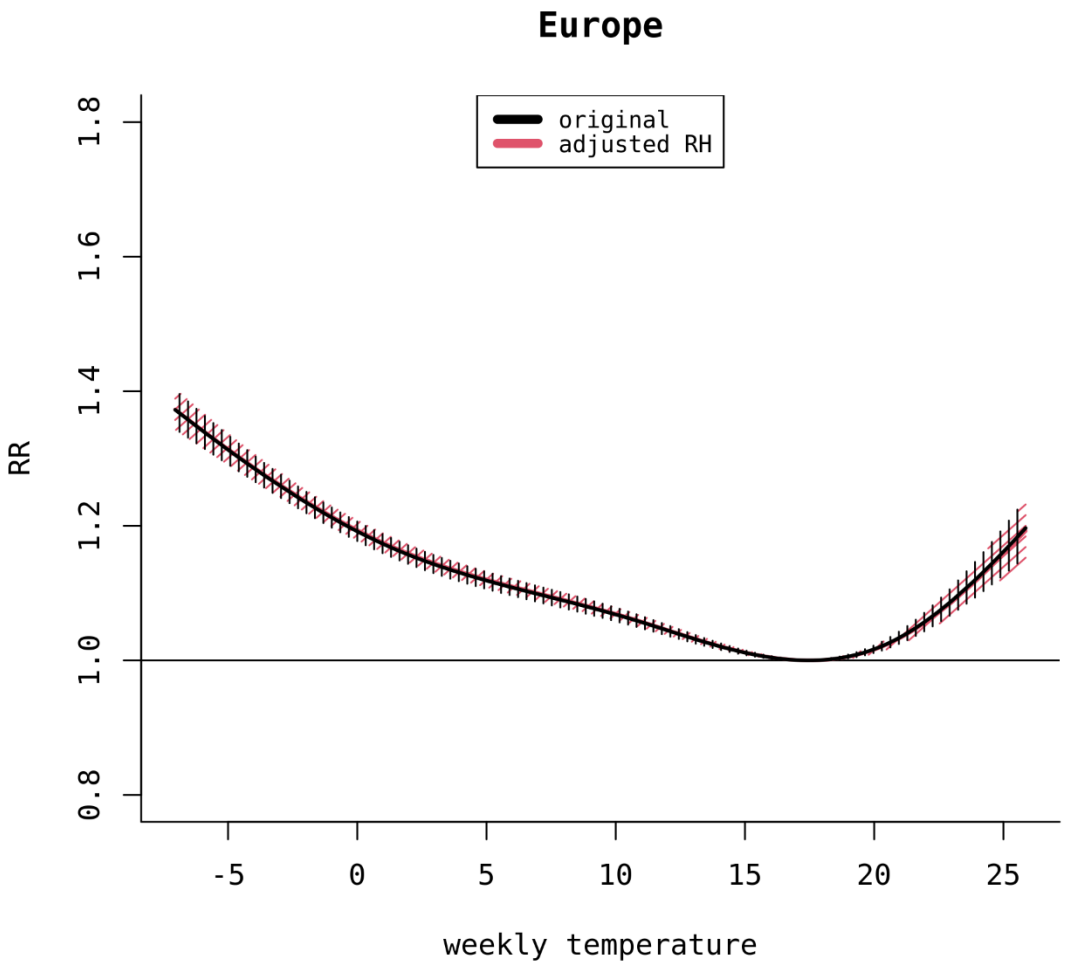

Figure s9. The comparison between original Exposure-response curve and the curves adjusted by relative humidity, using nature splines with 3df

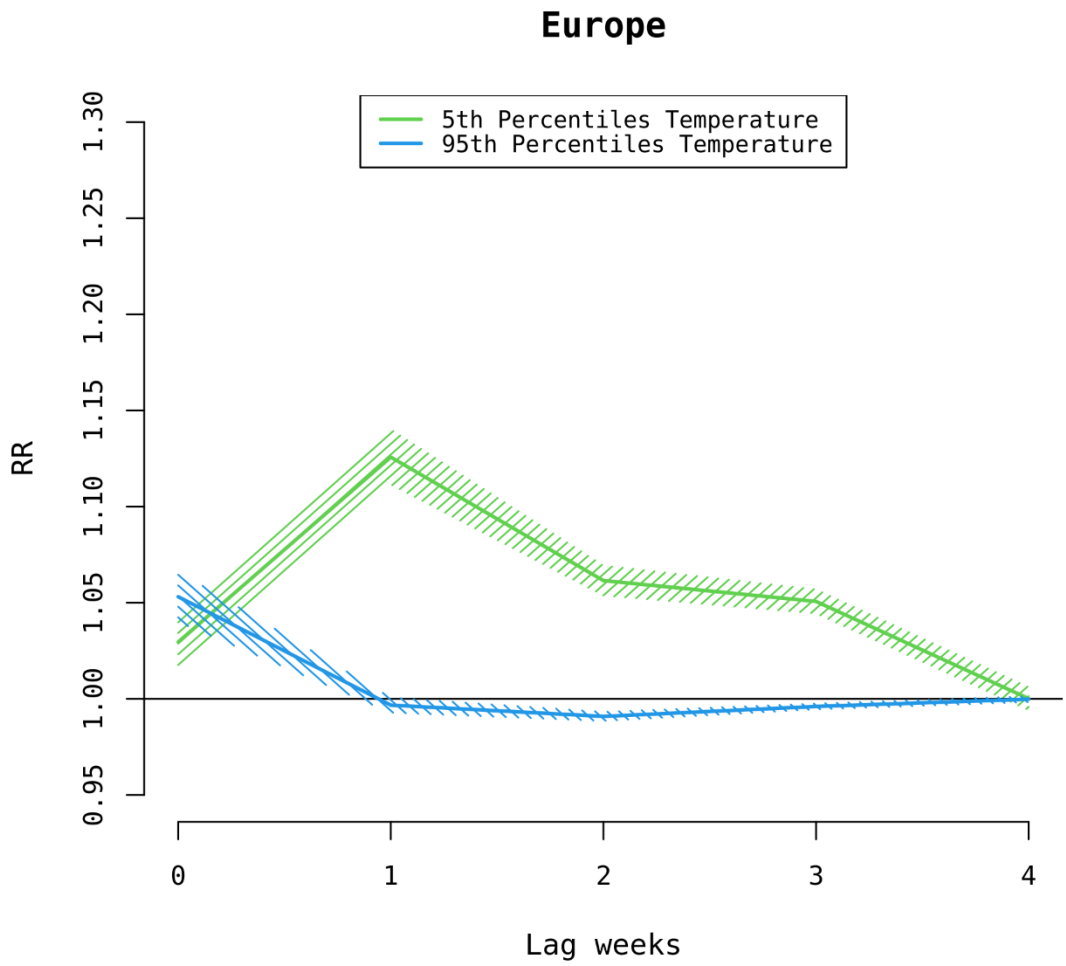

Figure S10. The lag effects of 5th or 95th percentiles weekly temperature on mortality

Table s1. Spatial cross-validation of air pollutant estimations

Variable	Region	Nobs	Spatial Cross-validation		
			Cor	NMB(%)	NRMSE(%)
PM25	Europe	3,633,755	0.8	-0.6	1.84
	Western Europe	1,459,054	0.83	-0.58	2.02
	Southern Europe	1,525,558	0.81	0.64	1.58
	Eastern Europe	203,386	0.75	0.02	2.69
	Northern Europe	445,756	0.72	1.86	1.47
PM10	Europe	3,411,511	0.79	-3.81	2.07
	Western Europe	1,551,077	0.8	-1.93	2.06
	Southern Europe	1,371,250	0.78	-2.77	1.97
	Eastern Europe	246,642	0.74	-6.33	3.77
	Northern Europe	242,542	0.67	-9.38	2.77
NO2	Europe	5,040,695	0.79	-1.99	8.99
	Western Europe	2,660,963	0.81	1.84	8.18
	Southern Europe	1,950,906	0.78	-4.75	10.29
	Eastern Europe	264,151	0.78	-3.85	11.51
	Northern Europe	164,674	0.8	7.99	11.57
O3 8h	Europe	6,244,634	0.9	0.02	3.35
	Western Europe	3,354,027	0.93	-0.12	3.46
	Southern Europe	2,420,175	0.88	0.33	4.06
	Eastern Europe	355,369	0.77	0.23	4.83
	Northern Europe	115,063	0.83	-0.73	6.04

Table s2. Temporal cross-validation of air pollutant estimations

YEAR	PM25			PM10			NO2			O3 8H		
	Nobs	Cor	NRMSE (%)	Nobs	Cor	NRMSE (%)	Nobs	Cor	NRMSE (%)	Nobs	Cor	NRMSE (%)
2003	23,194	0.84	2.65	141,927	0.82	3.53	157,924	0.87	8.91	182,529	0.94	4.68
2004	45,304	0.79	2.85	124,557	0.82	2.52	173,094	0.88	7.52	202,711	0.93	5.37
2005	60,153	0.83	1.99	175,311	0.82	2.12	197,537	0.88	7.93	220,673	0.93	4.75
2006	68,158	0.85	2.14	180,594	0.82	2.58	202,591	0.88	7.98	231,113	0.94	4.66
2007	85,605	0.85	2.17	211,542	0.81	1.95	200,691	0.88	7.84	226,347	0.94	5.08
2008	120,205	0.83	3.61	223,958	0.82	2.12	216,634	0.89	7.5	240,322	0.94	5.31
2009	207,265	0.86	1.58	238,979	0.82	2.17	216,543	0.9	7.3	238,871	0.94	5
2010	266,339	0.86	1.79	212,193	0.82	2.53	219,231	0.89	7.47	241,350	0.93	4.9
2011	304,532	0.88	1.6	266,227	0.85	1.91	220,554	0.89	7.16	239,512	0.93	5.55
2012	270,896	0.77	4.48	213,145	0.69	2.83	146,337	0.88	7.51	162,799	0.92	6.43
2013	262,770	0.84	1.71	150,843	0.8	1.62	306,578	0.84	7.38	438,092	0.88	4.37
2014	289,009	0.86	1.91	151,163	0.82	2.36	365,789	0.86	6.68	486,890	0.88	3.42
2015	296,851	0.88	1.42	202,069	0.84	2.5	387,917	0.86	7.06	515,159	0.9	5.21
2016	258,390	0.88	2.48	167,603	0.83	1.89	400,716	0.85	7.19	533,326	0.89	4.31
2017	313,668	0.88	1.57	210,364	0.82	1.68	408,740	0.87	6.95	521,426	0.9	3.71
2018	312,782	0.87	1.86	164,852	0.81	1.65	418,451	0.86	6.28	533,397	0.91	3.79
2019	250,186	0.87	1.24	191,598	0.81	1.58	410,817	0.86	6.01	528,852	0.91	4.46
2020	198,448	0.86	1.67	184,586	0.81	1.78	390,551	0.84	6.88	501,265	0.9	5.36
TOTAL	3,633,755	0.86	2.15	3,411,511	0.81	2.18	5,040,695	0.87	7.25	6,244,634	0.91	4.80

Table s3. Threshold of Europe weekly temperature quantile and their corresponding relatively risk (RR) extracted from cumulative exposure–response curve

	Temperature Quantile	RR
heat	99th	1.12
	97.5th	1.09
	95th	1.05
	92.5th	1.03
cold	1th	1.27
	2.5th	1.23
	5th	1.19
	7.5th	1.17

Table s4. Definitions of compound days within a year

Compound	Definition
Heat/Cold-Compound Days	Days exceeding the risk threshold for extreme cold or heat, accompanied by at least one pollutant exceeding the WHO Daily Recommended Limit Value*.
Heat/Cold-Pollutant Specified Compound Days (e.g., Heat-PM2.5 Compound)	Days exceeding the risk threshold for extreme cold or heat, accompanied by at least the specified pollutant exceeding the WHO Daily Recommended Limit Value*.
Heat/Cold-Single Pollutant Compound Days (e.g., Heat-PM2.5 Only Compound)	Days exceeding the risk threshold for extreme cold or heat, accompanied by only the specified pollutant exceeding the WHO Daily Recommended Limit Value*.

*WHO standard recommended daily limit values: PM2.5: 15 μg/m³, PM10: 45 μg/m³, NO2: 25 μg/m³, O3 (8-hour maximum): 100 μg/m³.

Table s5. the percentile of temperatures corresponding to the relatively risk thresholds for each region.

	Cold Threshold RR=1.19		**Heat Threshold RR=1.05**	
	Percentiles	Weekly Average Temperature(°C)	Percentiles	Weekly Average Temperature(°C)
Europe	5th	-0.3	95th	21.8
Northern Europe	<1st	-11.2	>99th	20.4
Eastern Europe	6th	-4.6	95th	22.9
Southern Europe	10th	5.6	91th	23.2
Western Europe	4th	-5.1	97th	20.4

Table s6. Change of Heat ERT days and its compound days between 2003-2020

	Regions	Annual averages (days)	Average Change (days) per decades	P-value
Heat-ERT days	Europe	14.09	2.81	0.079
	Eastern Europe	23.47	8.81	0.046*
	Southern Europe	30.59	3.56	0.057
	Western Europe	5.99	1.60	0.286
	Northern Europe	3.88	1.08	0.390
Heat-Compound days	Europe	7.84	1.47	0.219
	Eastern Europe	16.36	4.12	0.108
	Southern Europe	14.66	1.71	0.214
	Western Europe	2.93	0.91	0.363
	Northern Europe	0.35	0.12	0.530
Heat-$PM_{2.5}$ days	Europe	5.74	-0.72	0.411
	Eastern Europe	15.19	2.92	0.124
	Southern Europe	9.08	-4.19	0.003*
	Western Europe	1.45	-0.23	0.429
	Northern Europe	0.09	-0.04	0.723
Heat-O_3 days	Europe	4.17	2.59	0.014*
	Eastern Europe	4.81	3.02	0.051
	Southern Europe	8.71	6.50	0.002*
	Western Europe	2.38	1.23	0.167
	Northern Europe	0.27	0.15	0.406
Portion (%) of Compound days in Heat-ERT days	Europe	59.61%	-0.69%	0.219
	Eastern Europe	78.25%	-15.16%	0.040
	Southern Europe	52.49%	-0.17%	0.414
	Western Europe	60.87%	0.91%	0.414
	Northern Europe	13.87%	0.12%	0.530

Table s7. Change of Cold ERT days and its compound days between 2003-2020

	Regions	Annual averages (days)	Average Change (days) per decades	P-value
Cold-ERT days	Europe	24.78	-20.69	<0.001*
	Eastern Europe	43.87	-35.33	<0.001*
	Southern Europe	31.62	-23.26	<0.001*
	Western Europe	15.12	-17.89	0.003*
	Northern Europe	31.85	-14.72	0.002*
Cold-Compound days	Europe	16.82	-15.21	<0.001*
	Eastern Europe	41.50	-30.83	<0.001*
	Southern Europe	17.66	-15.85	<0.001*
	Western Europe	9.97	-13.63	0.006*
	Northern Europe	7.79	-2.83	0.001*
Cold-$PM_{2.5}$ days	Europe	16.48	-14.32	<0.001*
	Eastern Europe	41.48	-30.45	<0.001*
	Southern Europe	17.28	-14.87	<0.001*
	Western Europe	9.54	-12.64	0.008*
	Northern Europe	7.35	-2.53	0.003*
Cold-PM_{10} days	Europe	5.04	-6.75	<0.001*
	Eastern Europe	14.25	-17.04	<0.001*
	Southern Europe	5.39	-8.06	<0.001*
	Western Europe	2.50	-5.16	0.002*
	Northern Europe	1.40	-0.40	0.006*
Cold-NO_2 days	Europe	4.14	-6.73	<0.001*
	Eastern Europe	4.25	-4.40	<0.001*
	Southern Europe	5.05	-8.53	<0.001*
	Western Europe	4.24	-7.27	0.002*
	Northern Europe	0.12	-0.13	0.001*
Portion (%) of Compound days in Cold-ERT days	Europe	64.70%	-11.74%	<0.001*
	Eastern Europe	82.88%	-7.47%	<0.001*
	Southern Europe	53.96%	-12.00%	<0.001*
	Western Europe	72.65%	-10.56%	0.002*
	Northern Europe	10.78%	-5.74%	0.001*

Table s8. Annual average heat-ERT days, heat- compound days and its proportion (%) across two periods under various quantile settings for extreme ERT temperature (main result based on 95th)

region	*period*	*Annual heat-ERT days*				*Annual heat- compound days*				*Proportion (%) of heat-compound days*			
		92.5th	**95th**	**97.5th**	**99th**	**92.5th**	**95th**	**97.5th**	**99th**	**92.5th**	**95th**	**97.5th**	**99th**
Europe	2003-2011	14.05	8.53	4.47	1.26	7.97	5.36	3.12	1.01	57.33	63.62	69.60	77.36
	2012-2020	18.23	10.68	4.63	0.74	9.27	5.89	2.77	0.46	50.89	57.98	64.43	69.25
Southern Europe	2003-2011	30.33	20.33	11.63	3.58	15.44	11.14	7.14	2.62	49.85	53.18	58.05	66.52
	2012-2020	35.80	24.46	12.49	2.22	16.10	11.83	6.36	1.14	44.99	48.22	51.86	55.16
Eastern Europe	2003-2011	18.81	11.01	5.59	1.56	14.49	9.38	5.06	1.48	78.07	85.38	90.48	95.15
	2012-2020	30.51	16.19	5.95	0.95	19.79	11.35	4.85	0.90	62.30	69.96	81.70	93.22
Western Europe	2003-2011	6.55	3.43	1.49	0.31	3.51	2.16	1.10	0.28	51.50	62.22	74.14	91.82
	2012-2020	8.08	3.80	1.22	0.09	3.81	2.13	0.80	0.07	48.28	58.07	68.79	79.81
Northern Europe	2003-2011	4.40	1.71	0.41	0.04	0.38	0.21	0.07	0.01	7.84	11.64	15.66	40.00
	2012-2020	3.80	1.60	0.29	0.00	0.47	0.21	0.06	0.00	9.40	10.70	16.87	0.00
region	**period**	**Annual heat-PM2.5 days**				**Annual heat-PM10 days**				**Annual heat-O3 days**			
		92.5th	**95th**	**97.5th**	**99th**	**92.5th**	**95th**	**97.5th**	**99th**	**92.5th**	**95th**	**97.5th**	**99th**
Europe	2003-2011	6.89	4.66	2.73	0.90	1.03	0.78	0.50	0.19	3.14	2.27	1.46	0.55
	2012-2020	5.41	3.32	1.58	0.31	0.05	0.04	0.03	0.01	5.95	4.08	2.02	0.32
Southern Europe	2003-2011	12.92	9.32	6.00	2.22	2.60	2.04	1.39	0.57	6.31	4.77	3.40	1.49
	2012-2020	6.32	4.64	2.61	0.58	0.19	0.17	0.12	0.03	13.24	9.89	5.36	0.92
Eastern Europe	2003-2011	14.19	9.22	5.00	1.47	1.55	1.14	0.70	0.26	2.69	1.99	1.26	0.46
	2012-2020	18.15	10.36	4.52	0.88	0.02	0.01	0.01	0.00	6.16	4.26	2.19	0.42
Western Europe	2003-2011	2.67	1.68	0.89	0.24	0.29	0.20	0.11	0.02	2.36	1.59	0.89	0.25
	2012-2020	1.33	0.74	0.31	0.03	0.00	0.00	0.00	0.00	3.43	1.96	0.74	0.06
Northern Europe	2003-2011	0.14	0.06	0.02	0.01	0.06	0.04	0.02	0.01	0.25	0.16	0.06	0.01
	2012-2020	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.45	0.20	0.06	0.00

Table s9. Annual average cold-ERT days, cold-compound days and its proportion(%) across two periods under various quantile settings for extreme ERT temperature (main result based on 5th)

region	*period*	*Annual cold-ERT days*				*Annual cold-compound days*				*Proportion (%) of cold-compound days*			
		7.5th	**5th**	**2.5th**	**1th**	**7.5th**	**5th**	**2.5th**	**1th**	**7.5th**	**5th**	**2.5th**	**1th**
Europe	2003-2011	41.54	36.84	21.24	13.55	27.83	24.78	14.27	9.02	69.41	69.73	69.34	67.62
	2012-2020	19.61	16.72	8.88	5.27	11.67	9.94	5.48	3.44	61.91	61.68	62.64	65.69
Southern Europe	2003-2011	48.09	43.10	25.65	16.12	27.47	24.76	14.97	9.60	58.44	58.67	58.78	59.37
	2012-2020	25.10	21.40	9.97	5.03	11.92	10.32	5.29	2.95	49.59	49.80	51.83	55.03
Eastern Europe	2003-2011	67.52	60.68	37.57	25.59	63.93	57.66	36.10	24.70	94.30	94.68	95.85	96.44
	2012-2020	32.01	27.22	15.51	10.03	30.26	25.82	14.86	9.67	93.82	94.18	95.44	96.25
Western Europe	2003-2011	28.60	24.57	11.93	6.47	18.24	15.75	7.37	3.64	67.25	67.91	66.57	58.94
	2012-2020	11.09	9.25	4.77	2.77	5.94	4.88	2.42	1.45	56.80	55.83	53.28	52.41
Northern Europe	2003-2011	44.65	41.32	29.25	22.44	8.77	8.28	6.66	5.70	18.14	18.50	20.87	23.12
	2012-2020	27.81	25.07	15.67	13.55	5.39	5.12	4.05	3.26	16.94	17.69	22.11	26.94
region	**period**	**Annual cold-PM25 days**				**Annual cold-PM10 days**				**Annual cold-NO2 days**			
		7.5th	**5th**	**2.5th**	**1th**	**7.5th**	**5th**	**2.5th**	**1th**	**7.5th**	**5th**	**2.5th**	**1th**
Europe	2003-2011	26.75	23.84	13.76	8.71	9.70	8.85	5.56	3.68	9.76	8.74	5.00	3.02
	2012-2020	11.50	9.80	5.42	3.41	2.14	1.88	1.11	0.73	2.44	2.07	1.10	0.67
Southern Europe	2003-2011	26.31	23.73	14.34	9.22	10.60	9.68	6.13	4.04	12.51	11.45	7.31	4.87
	2012-2020	11.61	10.05	5.19	2.93	2.80	2.44	1.35	0.86	4.34	3.81	2.14	1.30
Eastern Europe	2003-2011	63.89	57.63	36.08	24.69	25.47	23.45	16.03	11.51	10.55	9.80	6.72	4.84
	2012-2020	30.26	25.81	14.86	9.67	6.47	5.79	3.67	2.53	2.41	2.08	1.20	0.77
Western Europe	2003-2011	16.76	14.49	6.74	3.28	4.87	4.34	2.17	1.05	9.88	8.60	4.17	2.03
	2012-2020	5.76	4.74	2.36	1.41	0.60	0.49	0.23	0.13	1.98	1.62	0.77	0.45
Northern Europe	2003-2011	8.02	7.57	6.10	5.24	2.28	2.15	1.78	1.55	0.23	0.21	0.17	0.14
	2012-2020	5.35	5.08	4.02	3.24	0.25	0.23	0.20	0.18	0.03	0.03	0.03	0.03

Table s10: Countries heat extreme days and associate compound days during 2003-2020

Country	Heat-ERT days		Heat-compound days		Heat-O_3 compound days	
	Annual averages	Change per decade	Annual averages	Change per decade	Annual averages	Change per decade
Cyprus	33.01	18.79	18.45	-1.88	2.71	-0.66
North Macedonia	27.83	7.84	24.79	2.19	5.32	-8.02
Italy	26.97	4.62	14.95	3.36	11.53	-0.58
Portugal	24.18	-0.53	3.96	-0.37	2.97	-1.94
Serbia	23.66	1.35	21.32	-0.52	5.91	-3.55
Romania	22.92	7.88	16.73	-0.43	2.77	-0.95
Greece	18.91	7.15	13.77	-2.78	4.59	-5.27
Slovenia	17.15	17.16	8.67	8.17	6.92	-0.07
Albania	16.02	4.53	14.45	2.75	6.02	-5.73
Malta	15.73	4.06	4.31	0.25	2.95	-0.45
Spain	15.25	5.49	3.51	-0.41	1.45	-2.05
Bulgaria	13.90	2.33	11.55	-2.08	1.93	-1.90
Croatia	13.63	0.86	9.91	0.17	5.14	-0.14
Hungary	12.64	3.81	8.82	0.52	4.97	-0.34
Slovakia	10.90	13.47	5.39	4.90	3.72	-0.18
Montenegro	9.03	3.87	7.77	0.79	3.29	-1.14
Luxembourg	6.48	4.15	2.17	2.68	2.17	0.00
France	6.29	3.33	2.55	1.14	1.87	-0.04
Poland	4.96	2.76	2.98	0.95	1.19	-0.08
Austria	4.58	1.49	2.92	0.87	2.21	-0.03
Czechia	4.10	1.30	3.33	1.17	2.74	-0.09
Latvia	4.01	-1.02	0.39	-0.46	0.32	-0.36
Estonia	3.65	-0.94	0.43	-0.12	0.41	-0.04
Germany	3.29	2.28	2.10	1.55	1.89	-0.01

Country	Heat-ERT days		Heat-compound days		Heat-O_3 compound days	
	Annual averages	Change per decade	Annual averages	Change per decade	Annual averages	Change per decade
Switzerland	3.00	1.42	1.52	1.25	1.44	0.00
Liechtenstein	1.73	4.77	0.86	2.44	0.86	0.00
Finland	1.59	0.89	0.10	-0.08	0.08	-0.03
Denmark	1.54	0.80	0.35	0.13	0.28	-0.02
Netherlands	1.48	1.34	0.86	1.01	0.75	-0.05
Belgium	1.47	1.69	0.95	1.16	0.81	-0.21
Sweden	1.33	1.68	0.16	0.24	0.16	0.00
Lithuania	0.84	-0.32	0.13	-0.16	0.03	-0.04
United Kingdom	0.27	0.58	0.07	0.13	0.05	-0.01
Norway	0.23	-0.09	0.05	0.01	0.05	0.00
Ireland	0.07	0.17	0.02	0.05	0.02	0.00
Iceland	0.00	0.00	0.00	0.00	0.00	0.00

Table s11: Countries cold extreme days and associate compound days during 2003-2020

Country	Cold-ERT days		Cold-compound days		Cold-PM_{25} compound days	
	Annual averages	Change per decade	Annual averages	Change per decade	Annual averages	Change per decade
Montenegro	89.45	-38.96	87.18	-40.38	87.18	-40.39
Cyprus	78.68	-38.91	36.24	-31.54	35.96	-31.66
Lithuania	78.17	-34.56	35.43	-9.50	34.59	-7.84
Latvia	70.18	-21.59	7.06	-6.10	5.79	-3.98
Iceland	56.95	-8.58	0.04	0.02	0.02	0.06
Hungary	50.73	-41.04	49.53	-39.62	49.52	-39.60
Slovakia	50.63	-43.49	47.63	-39.87	47.60	-39.82
Poland	47.54	-24.26	44.47	-22.89	44.46	-22.88
Serbia	43.39	-25.82	43.36	-25.85	43.36	-25.85
Finland	41.17	-13.47	2.36	-1.46	2.00	-0.74
Albania	38.19	-24.66	36.15	-24.08	36.13	-24.06
Norway	36.66	-2.50	5.37	-4.14	5.11	-3.86
Sweden	36.57	-23.81	4.17	-3.31	4.14	-3.26
Romania	36.25	-27.68	34.55	-26.79	34.54	-26.76
Ireland	35.66	-10.21	1.02	-0.82	0.52	-0.18
Liechtenstein	34.20	-24.85	14.89	-13.01	14.89	-13.01
Greece	33.29	-26.54	27.77	-23.89	27.69	-23.78
Bulgaria	32.54	-35.22	31.05	-33.36	31.04	-33.33
Italy	30.33	-18.20	19.98	-14.91	19.80	-14.78
Spain	29.90	-22.56	4.66	-4.90	3.91	-3.67
France	29.45	-19.88	15.95	-10.28	15.51	-9.45
Slovenia	27.99	-19.80	21.66	-17.77	21.64	-17.73
Croatia	24.00	-27.38	22.22	-25.55	22.21	-25.53
North Macedonia	23.96	-24.46	22.81	-23.76	22.81	-23.76

Country	Cold-ERT days		Cold-compound days		Cold-PM_{25} compound days	
	Annual averages	Change per decade	Annual averages	Change per decade	Annual averages	Change per decade
Czechia	22.84	-17.66	11.48	-15.62	11.42	-15.50
Luxembourg	16.72	-12.02	9.04	-5.87	8.40	-4.88
Austria	14.86	-15.20	11.95	-15.80	11.94	-15.78
Estonia	14.79	-2.61	4.49	-0.47	4.39	-0.38
Netherlands	12.86	-10.76	8.97	-6.93	8.27	-5.82
Malta	12.83	-6.08	1.07	-1.39	0.05	-0.10
Germany	12.39	-13.46	9.95	-11.29	9.82	-11.08
Belgium	11.58	-11.04	9.78	-8.63	9.37	-7.84
United Kingdom	10.24	-4.82	2.45	-1.54	1.64	-0.60
Switzerland	10.16	-6.60	6.21	-7.50	6.16	-7.45
Portugal	9.66	-7.34	0.91	-1.20	0.35	-0.48
Denmark	5.90	-5.68	1.81	-1.64	1.77	-1.58

Table s12. Second-stage sensitivity analysis. Significance test for the meta-predictors (p-value), multivariate Cochran Q test for heterogeneity (p-value) and I^2 statistic (%)

		Wald test	Q test	I^2 (%)	AIC
Model 0	only Intercepts	---	<0.001	38.4	-1824.07
Model 1	TEMP_AVG	<0.001	<0.001	27.8	-1881.16
Model 2	TEMP_IQR	<0.001	<0.001	37.8	-1837.22
Full Model	TEMP_AVG	<0.001	<0.001	27.0	-1902.67
	TEMP_IQR	<0.001			

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