Supplementary information to 'Attributing heat-related mortality to human-induced climate change in 854 cities in Europe during 2000-2025'

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Table S1: Median and 95% empirical confidence intervals for the factual and counterfactual expected numbers of heat-related deaths, and for the absolute and relative changes attributable to anthropogenic climate change, across 854 European cities during 2000–2025.

Year	Factual	Counterfactual	Difference	Proportion
2000	11,160 (9,459, 12,733)	6,179 (4,821, 7,482)	4,965 (4,121, 5,806)	0.45 (0.38, 0.51)
2001	13,641 (11,627, 15,476)	6,542 (5,011, 8,073)	7,024 (5,999, 8,074)	0.52 (0.45, 0.58)
2002	11,024 (9,239, 12,718)	5,514 (4,215, 6,840)	5,442 (4,553, 6,399)	0.50 (0.43, 0.56)
2003	30,027 (27,167, 32,672)	17,547 (14,835, 20,545)	12,406 (10,130, 14,390)	0.42 (0.34, 0.48)
2004	9,957 (8,207, 11,466)	4,152 (2,996, 5,412)	5,724 (4,735, 6,745)	0.58 (0.50, 0.65)
2005	11,692 (9,903, 13,189)	5,527 (4,313, 6,786)	6,098 (5,112, 7,067)	0.53 (0.46, 0.59)
2006	20,984 (18,727, 22,980)	11,773 (9,584, 14,028)	9,094 (7,369, 10,817)	0.44 (0.36, 0.52)
2007	13,869 (11,863, 15,667)	7,136 (5,615, 8,689)	6,688 (5,530, 7,799)	0.49 (0.41, 0.55)
2008	11,107 (9,157, 13,000)	4,493 (3,171, 5,918)	6,554 (5,501, 7,721)	0.59 (0.52, 0.67)
2009	12,764 (10,750, 14,670)	5,160 (3,704, 6,767)	7,502 (6,332, 8,736)	0.60 (0.52, 0.67)
2010	17,681 (15,420, 19,634)	8,778 (7,066, 10,668)	8,778 (7,375, 10,181)	0.50 (0.43, 0.57)
2011	10,578 (8,873, 12,240)	4,698 (3,458, 5,971)	5,852 (4,881, 6,828)	0.55 (0.48, 0.62)
2012	19,927 (17,390, 22,206)	10,021 (7,802, 12,241)	9,902 (8,136, 11,375)	0.50 (0.42, 0.57)
2013	16,396 (14,249, 18,326)	7,928 (6,285, 9,695)	8,392 (7,094, 9,707)	0.52 (0.44, 0.58)
2014	9,955 (8,315, 11,569)	3,961 (2,908, 5,107)	5,931 (4,918, 7,036)	0.60 (0.52, 0.67)
2015	24,721 (22,034, 27,049)	11,850 (9,318, 14,778)	12,858 (10,248, 15,094)	0.52 (0.42, 0.61)
2016	13,968 (11,802, 15,962)	5,326 (3,902, 6,959)	8,515 (7,129, 9,928)	0.62 (0.53, 0.69)
2017	19,145 (16,832, 21,306)	8,043 (6,087, 10,257)	11,100 (9,197, 12,833)	0.58 (0.49, 0.66)
2018	21,674 (19,135, 24,109)	9,307 (7,249, 11,853)	12,325 (10,111, 14,479)	0.57 (0.48, 0.65)
2019	24,034 (21,407, 26,564)	10,346 (8,176, 12,812)	13,652 (11,423, 15,699)	0.57 (0.48, 0.64)
2020	17,955 (15,781, 20,069)	7,917 (6,076, 10,073)	10,037 (8,177, 11,856)	0.56 (0.47, 0.64)
2021	17,426 (15,159, 19,604)	7,649 (5,832, 9,684)	9,729 (8,073, 11,250)	0.56 (0.47, 0.63)
2022	29,957 (27,046, 32,683)	13,206 (10,456, 16,534)	16,702 (13,648, 19,345)	0.56 (0.46, 0.64)
2023	22,488 (20,051, 24,816)	8,782 (6,578, 11,392)	13,655 (11,191, 15,718)	0.61 (0.51, 0.69)
2024	27,125 (24,019, 29,743)	9,622 (6,917, 13,016)	17,399 (14,187, 20,052)	0.64 (0.53, 0.73)
2025	24,429 (21,947, 26,650)	8,840 (6,640, 11,523)	15,503 (12,948, 17,771)	0.64 (0.54, 0.72)
Average	17,836 (15,636, 19,876)	8,099 (6,322, 9,983)	9,691 (8,099, 11,107)	0.55 (0.47, 0.61)

Table S2: Population and median and 95% empirical confidence intervals of number of annual average of expected heat-deaths in the factual scenario, the standardised heat-related deaths and the absolute and relative change due to human-made climate change during 2000-2025 in the 30 capitals.

Capital	Population	Heat-deaths	Standardised excess	Difference	Proportion
Amsterdam	616,727	46 (32, 72)	98 (71, 151)	17 (12, 22)	0.37 (0.21, 0.53)
Athens	2,269,492	555 (389, 711)	239 (167, 306)	405 (305, 505)	0.74 (0.64, 0.83)
Berlin	2,805,374	387 (308, 465)	146 (116, 175)	178 (123, 230)	0.46 (0.31, 0.59)
Bern	176,221	99 (73, 120)	520 (383, 630)	64 (47, 81)	0.65 (0.55, 0.75)
Bratislava	337,865	28 (15, 48)	110 (61, 186)	13 (5, 22)	0.47 (0.20, 0.70)
Brussels	808,139	85 (65, 107)	127 (98, 159)	24 (12, 39)	0.29 (0.14, 0.46)
Bucharest	1,665,377	284 (201, 421)	212 (150, 312)	139 (79, 207)	0.49 (0.27, 0.67)
Budapest	1,414,149	105 (54, 201)	78 (41, 150)	36 (12, 66)	0.36 (0.11, 0.57)
Copenhagen	415,428	14 (8, 22)	41 (24, 64)	6 (3, 11)	0.47 (0.28, 0.64)
Dublin	893,653	9 (3, 15)	15 (6, 26)	1 (-2, 5)	0.16 (-0.25, 0.49)
Helsinki	453,721	30 (18, 43)	83 (51, 117)	11 (2, 22)	0.37 (0.05, 0.62)
Lisbon	1,425,616	168 (142, 202)	111 (94, 134)	-32 (-53, -13)	-0.19 (-0.33, -0.08)
Ljubljana	217,685	65 (47, 83)	319 (231, 405)	24 (16, 34)	0.38 (0.26, 0.51)
London	5,894,656	403 (279, 515)	101 (69, 128)	130 (73, 197)	0.33 (0.20, 0.47)
Luxembourg	70,074	14 (11, 17)	253 (198, 300)	6 (5, 8)	0.45 (0.37, 0.54)
Madrid	2,871,466	398 (291, 541)	139 (101, 191)	248 (168, 331)	0.62 (0.47, 0.75)
Nicosia	171,474	18 (10, 26)	142 (76, 205)	10 (4, 17)	0.60 (0.22, 0.85)
Oslo	435,270	10 (2, 18)	33 (7, 60)	5 (1, 10)	0.56 (0.34, 0.78)
Paris	6,869,559	922 (735, 1,105)	152 (121, 182)	242 (154, 345)	0.26 (0.17, 0.37)
Prague	990,604	126 (78, 182)	146 (91, 210)	75 (46, 104)	0.60 (0.44, 0.71)
Riga	550,511	74 (14, 124)	132 (25, 222)	18 (1, 46)	0.25 (0.04, 0.54)
Rome	2,158,892	1,465 (1,291, 1,644)	609 (537, 684)	900 (703, 1,075)	0.62 (0.50, 0.72)
Sofia	950,740	124 (72, 202)	161 (95, 259)	84 (51, 124)	0.68 (0.49, 0.85)
Stockholm	1,142,160	52 (33, 72)	55 (34, 75)	25 (9, 45)	0.50 (0.20, 0.78)
Tallinn	316,478	23 (10, 38)	82 (35, 134)	5 (1, 13)	0.25 (0.05, 0.47)
Valletta	170,361	67 (51, 82)	487 (370, 594)	20 (-9, 41)	0.29 (-0.15, 0.59)
Vienna	1,315,748	182 (132, 248)	158 (115, 214)	95 (58, 133)	0.53 (0.33, 0.69)
Vilnius	429,750	35 (7, 74)	94 (18, 193)	11 (2, 26)	0.31 (0.13, 0.64)
Warsaw	1,381,256	83 (48, 132)	60 (35, 95)	46 (25, 69)	0.56 (0.35, 0.75)
Zagreb	630,723	315 (238, 387)	544 (413, 672)	134 (91, 180)	0.43 (0.31, 0.56)

Table S3: Population and median and 95% empirical confidence intervals of number of annual average of expected heat-deaths in the factual scenario, the standardised heat-related deaths and the absolute and relative change due to human-made climate change in 2003 in the 30 capitals.

Capital	Population	Heat-deaths	Standardised excess	Difference	Proportion
Amsterdam	616,727	46 (32, 72)	98 (71, 151)	15 (11, 21)	0.33 (0.20, 0.49)
Athens	2,269,492	555 (389, 711)	239 (167, 306)	409 (309, 508)	0.75 (0.65, 0.84)
Berlin	2,805,374	387 (308, 465)	146 (116, 175)	160 (113, 206)	0.41 (0.29, 0.52)
Bern	176,221	99 (73, 120)	520 (383, 630)	62 (46, 77)	0.63 (0.55, 0.69)
Bratislava	337,865	28 (15, 48)	110 (61, 186)	10 (4, 17)	0.37 (0.16, 0.56)
Brussels	808,139	85 (65, 107)	127 (98, 159)	23 (14, 34)	0.27 (0.17, 0.39)
Bucharest	1,665,377	284 (201, 421)	212 (150, 312)	132 (86, 188)	0.47 (0.31, 0.61)
Budapest	1,414,149	105 (54, 201)	78 (41, 150)	33 (12, 60)	0.32 (0.10, 0.52)
Copenhagen	415,428	14 (8, 22)	41 (24, 64)	6 (3, 10)	0.44 (0.28, 0.60)
Dublin	893,653	9 (3, 15)	15 (6, 26)	1 (-2, 4)	0.16 (-0.18, 0.46)
Helsinki	453,721	30 (18, 43)	83 (51, 117)	9 (4, 16)	0.30 (0.16, 0.45)
Lisbon	1,425,616	168 (142, 202)	111 (94, 134)	-34 (-53, -16)	-0.20 (-0.32, -0.09)
Ljubljana	217,685	65 (47, 83)	319 (231, 405)	21 (14, 30)	0.33 (0.23, 0.44)
London	5,894,656	403 (279, 515)	101 (69, 128)	121 (69, 183)	0.30 (0.19, 0.44)
Luxembourg	70,074	14 (11, 17)	253 (198, 300)	6 (5, 8)	0.43 (0.35, 0.51)
Madrid	2,871,466	398 (291, 541)	139 (101, 191)	244 (164, 327)	0.61 (0.46, 0.75)
Nicosia	171,474	18 (10, 26)	142 (76, 205)	8 (5, 12)	0.48 (0.33, 0.63)
Oslo	435,270	10 (2, 18)	33 (7, 60)	5 (1, 9)	0.53 (0.38, 0.71)
Paris	6,869,559	922 (735, 1,105)	152 (121, 182)	221 (139, 316)	0.24 (0.16, 0.34)
Prague	990,604	126 (78, 182)	146 (91, 210)	69 (42, 96)	0.55 (0.40, 0.66)
Riga	550,511	74 (14, 124)	132 (25, 222)	16 (1, 33)	0.21 (0.06, 0.39)
Rome	2,158,892	1,465 (1,291, 1,644)	609 (537, 684)	867 (676, 1,032)	0.59 (0.48, 0.69)
Sofia	950,740	124 (72, 202)	161 (95, 259)	82 (53, 118)	0.66 (0.50, 0.81)
Stockholm	1,142,160	52 (33, 72)	55 (34, 75)	22 (12, 36)	0.43 (0.25, 0.62)
Tallinn	316,478	23 (10, 38)	82 (35, 134)	5 (1, 10)	0.21 (0.09, 0.36)
Valletta	170,361	67 (51, 82)	487 (370, 594)	25 (14, 36)	0.38 (0.23, 0.51)
Vienna	1,315,748	182 (132, 248)	158 (115, 214)	79 (51, 110)	0.44 (0.29, 0.58)
Vilnius	429,750	35 (7, 74)	94 (18, 193)	11 (2, 23)	0.29 (0.13, 0.59)
Warsaw	1,381,256	83 (48, 132)	60 (35, 95)	43 (24, 64)	0.51 (0.32, 0.70)
Zagreb	630,723	315 (238, 387)	544 (413, 672)	121 (83, 163)	0.39 (0.28, 0.51)

Table S4: Population and median and 95% empirical confidence intervals of number of annual average of expected heat-deaths in the factual scenario, the standardised heat-related deaths and the absolute and relative change due to human-made climate change in 2025 in the 30 capitals.

Capital	Population	Heat-deaths	Standardised excess	Difference	Proportion
Amsterdam	616,727	42 (29, 68)	88 (63, 141)	21 (15, 28)	0.52 (0.28, 0.74)
Athens	2,269,492	1,098 (922, 1,286)	472 (396, 553)	885 (740, 1,055)	0.81 (0.70, 0.89)
Berlin	2,805,374	220 (173, 296)	82 (65, 111)	139 (104, 173)	0.63 (0.45, 0.77)
Bern	176,221	53 (39, 65)	280 (202, 343)	40 (28, 52)	0.76 (0.59, 0.89)
Bratislava	337,865	17 (9, 32)	67 (36, 123)	13 (6, 23)	0.78 (0.43, 0.94)
Brussels	808,139	85 (64, 107)	126 (96, 159)	45 (29, 61)	0.54 (0.37, 0.70)
Bucharest	1,665,377	477 (359, 616)	356 (269, 457)	291 (144, 416)	0.62 (0.29, 0.82)
Budapest	1,414,149	142 (84, 236)	106 (63, 176)	88 (44, 140)	0.64 (0.34, 0.83)
Copenhagen	415,428	8 (5, 13)	25 (15, 40)	6 (3, 10)	0.76 (0.50, 0.92)
Dublin	893,653	10 (4, 18)	18 (8, 30)	5 (0, 11)	0.54 (-0.02, 0.85)
Helsinki	453,721	27 (16, 39)	73 (44, 105)	20 (5, 33)	0.78 (0.15, 0.99)
Lisbon	1,425,616	84 (62, 122)	56 (41, 81)	-9 (-41, 17)	-0.11 (-0.52, 0.18)
Ljubljana	217,685	35 (24, 46)	171 (116, 228)	19 (11, 28)	0.56 (0.35, 0.72)
London	5,894,656	460 (309, 603)	115 (77, 150)	323 (204, 461)	0.71 (0.51, 0.86)
Luxembourg	70,074	7 (5, 9)	119 (89, 149)	4 (3, 5)	0.63 (0.48, 0.78)
Madrid	2,871,466	417 (305, 564)	147 (106, 199)	348 (237, 462)	0.84 (0.65, 0.96)
Nicosia	171,474	16 (10, 21)	128 (81, 165)	6 (-6, 14)	0.42 (-0.36, 0.81)
Oslo	435,270	25 (7, 40)	84 (23, 137)	16 (4, 30)	0.69 (0.33, 0.94)
Paris	6,869,559	581 (437, 751)	95 (72, 123)	426 (307, 556)	0.74 (0.58, 0.85)
Prague	990,604	45 (26, 73)	52 (31, 84)	35 (21, 55)	0.78 (0.61, 0.89)
Riga	550,511	47 (9, 96)	85 (17, 174)	28 (4, 70)	0.71 (0.16, 0.98)
Rome	2,158,892	1,280 (1,133, 1,432)	533 (471, 597)	1,033 (848, 1,189)	0.81 (0.70, 0.89)
Sofia	950,740	165 (104, 242)	214 (135, 313)	99 (48, 155)	0.62 (0.32, 0.81)
Stockholm	1,142,160	31 (19, 44)	33 (20, 46)	26 (11, 42)	0.91 (0.39, 1.00)
Tallinn	316,478	15 (6, 24)	52 (20, 85)	9 (3, 18)	0.67 (0.25, 0.95)
Valletta	170,361	36 (25, 46)	257 (184, 331)	20 (-25, 36)	0.56 (-0.72, 0.94)
Vienna	1,315,748	113 (80, 158)	97 (69, 136)	85 (54, 120)	0.77 (0.52, 0.92)
Vilnius	429,750	29 (4, 69)	76 (11, 180)	20 (3, 49)	0.76 (0.42, 0.97)
Warsaw	1,381,256	83 (51, 128)	60 (36, 92)	65 (39, 94)	0.79 (0.61, 0.91)
Zagreb	630,723	201 (139, 258)	350 (240, 450)	131 (90, 178)	0.66 (0.49, 0.81)

Table S5: Population, and median and 95% empirical confidence intervals for the annual average expected number of heat-related deaths in the factual scenario, standardized heat-related deaths, and the absolute and relative changes attributable to anthropogenic climate change during 2000–2025 across 854 European cities, by country using a variable mortality rate.

Country	Population	Heat-deaths	Standardised excess	Difference	Proportion
Austria	2,056,195	205 (154, 268)	115 (86, 150)	128 (86, 175)	0.64 (0.45, 0.78)
Belgium	2,592,559	198 (153, 253)	82 (63, 105)	93 (61, 127)	0.49 (0.33, 0.64)
Bulgaria	2,812,386	580 (390, 807)	246 (167, 340)	355 (229, 503)	0.65 (0.47, 0.78)
Croatia	1,038,972	442 (331, 544)	487 (364, 602)	240 (173, 314)	0.57 (0.44, 0.68)
Cyprus	401,527	34 (22, 43)	130 (86, 167)	18 (5, 29)	0.57 (0.16, 0.80)
Czechia	2,538,347	189 (116, 280)	92 (57, 135)	117 (68, 171)	0.64 (0.47, 0.77)
Denmark	1,451,136	44 (27, 65)	39 (24, 57)	23 (12, 38)	0.58 (0.36, 0.75)
Estonia	433,058	24 (8, 45)	65 (24, 121)	8 (2, 19)	0.42 (0.16, 0.66)
Finland	1,566,944	60 (27, 99)	46 (21, 76)	26 (7, 53)	0.50 (0.21, 0.74)
France	18,235,411	1,125 (906, 1,414)	64 (51, 80)	624 (452, 805)	0.57 (0.41, 0.71)
Germany	23,461,496	2,214 (1,788, 2,665)	109 (88, 130)	1,094 (785, 1,407)	0.52 (0.38, 0.64)
Greece	4,022,494	982 (754, 1,187)	258 (198, 312)	629 (483, 789)	0.65 (0.53, 0.75)
Hungary	2,794,665	333 (204, 505)	162 (101, 243)	162 (84, 249)	0.51 (0.31, 0.68)
Ireland	1,245,105	6 (2, 11)	8 (3, 13)	2 (-1, 5)	0.50 (-0.47, 1.01)
Italy	16,651,294	4,908 (4,128, 5,670)	270 (227, 312)	3,267 (2,498, 3,958)	0.67 (0.53, 0.77)
Latvia	763,497	147 (29, 280)	226 (49, 430)	42 (2, 109)	0.34 (0.08, 0.59)
Lithuania	892,253	96 (18, 187)	128 (26, 246)	32 (1, 74)	0.37 (0.09, 0.61)
Luxembourg	78,631	7 (5, 9)	109 (80, 143)	4 (3, 5)	0.64 (0.47, 0.82)
Malta	156,189	28 (20, 36)	229 (164, 292)	12 (-8, 23)	0.43 (-0.35, 0.77)
Netherlands	6,804,367	418 (270, 682)	73 (48, 119)	154 (99, 223)	0.37 (0.21, 0.56)
Norway	882,432	23 (9, 37)	36 (14, 57)	12 (4, 21)	0.61 (0.35, 0.79)
Poland	9,786,347	983 (635, 1,396)	125 (81, 176)	539 (334, 759)	0.56 (0.40, 0.70)
Portugal	3,491,884	231 (181, 306)	71 (56, 93)	30 (-13, 70)	0.14 (-0.06, 0.33)
Romania	5,127,898	941 (621, 1,301)	240 (161, 328)	523 (319, 754)	0.59 (0.40, 0.73)
Slovakia	879,013	89 (54, 134)	139 (85, 207)	50 (27, 74)	0.57 (0.37, 0.73)
Slovenia	314,357	57 (39, 73)	209 (144, 270)	32 (21, 44)	0.59 (0.43, 0.71)
Spain	18,398,828	2,211 (1,756, 2,838)	126 (100, 161)	1,332 (943, 1,732)	0.59 (0.44, 0.72)
Sweden	3,042,720	82 (53, 114)	30 (19, 42)	39 (15, 67)	0.52 (0.22, 0.75)
Switzerland	1,898,020	197 (141, 259)	109 (78, 145)	120 (82, 159)	0.62 (0.42, 0.80)
United Kingdom	27,004,332	749 (581, 918)	32 (25, 40)	453 (298, 618)	0.68 (0.50, 0.80)

Table S6: Median and 95% empirical confidence intervals for the factual and counterfactual expected numbers of heat-related deaths, and for the absolute and relative changes attributable to anthropogenic climate change, across 854 European cities during 2000–2025 using a variable mortality rate.

Year	Factual	Counterfactual	Difference	Proportion
2000	9,847 (8,260, 11,199)	5,312 (4,068, 6,616)	4,471 (3,600, 5,295)	0.46 (0.38, 0.53)
2001	12,177 (10,284, 13,837)	5,698 (4,242, 7,205)	6,431 (5,393, 7,489)	0.53 (0.45, 0.60)
2002	10,074 (8,343, 11,623)	4,821 (3,588, 6,102)	5,167 (4,245, 6,130)	0.52 (0.44, 0.59)
2003	26,891 (24,296, 29,269)	15,098 (12,472, 18,116)	11,723 (9,273, 13,798)	0.44 (0.35, 0.52)
2004	9,155 (7,504, 10,574)	3,717 (2,623, 5,011)	5,359 (4,375, 6,429)	0.59 (0.50, 0.68)
2005	10,810 (9,181, 12,224)	4,853 (3,640, 6,144)	5,902 (4,823, 6,905)	0.55 (0.46, 0.63)
2006	19,735 (17,592, 21,657)	10,584 (8,222, 12,950)	9,018 (7,018, 10,988)	0.46 (0.36, 0.56)
2007	13,124 (11,170, 14,804)	6,522 (5,029, 8,215)	6,523 (5,239, 7,755)	0.50 (0.41, 0.58)
2008	10,653 (8,736, 12,486)	4,133 (2,842, 5,514)	6,474 (5,352, 7,732)	0.61 (0.52, 0.69)
2009	12,190 (10,219, 13,983)	4,743 (3,258, 6,342)	7,340 (6,031, 8,628)	0.61 (0.52, 0.69)
2010	17,158 (14,893, 19,066)	8,190 (6,384, 10,186)	8,805 (7,242, 10,380)	0.52 (0.44, 0.60)
2011	10,442 (8,665, 12,096)	4,423 (3,149, 5,795)	5,968 (4,837, 7,036)	0.58 (0.49, 0.65)
2012	19,612 (17,123, 21,866)	9,419 (7,106, 11,934)	10,165 (8,093, 11,903)	0.52 (0.42, 0.60)
2013	16,479 (14,316, 18,399)	7,586 (5,838, 9,569)	8,802 (7,226, 10,265)	0.54 (0.45, 0.62)
2014	10,200 (8,455, 11,811)	3,775 (2,669, 5,074)	6,321 (5,190, 7,587)	0.63 (0.54, 0.70)
2015	24,927 (22,234, 27,287)	11,145 (8,427, 14,491)	13,753 (10,587, 16,283)	0.55 (0.43, 0.65)
2016	14,324 (12,110, 16,354)	5,083 (3,568, 6,927)	9,119 (7,438, 10,769)	0.64 (0.54, 0.73)
2017	19,904 (17,541, 22,074)	7,525 (5,513, 10,031)	12,312 (9,836, 14,372)	0.62 (0.51, 0.71)
2018	22,308 (19,719, 24,757)	8,784 (6,500, 11,704)	13,420 (10,782, 15,902)	0.61 (0.49, 0.70)
2019	24,865 (22,203, 27,441)	9,640 (7,314, 12,723)	15,176 (12,387, 17,573)	0.61 (0.51, 0.69)
2020	18,762 (16,550, 20,885)	7,686 (5,689, 10,153)	11,079 (8,754, 13,136)	0.59 (0.48, 0.68)
2021	18,090 (15,736, 20,278)	7,320 (5,358, 9,707)	10,742 (8,658, 12,564)	0.60 (0.49, 0.68)
2022	31,406 (28,451, 34,133)	12,616 (9,526, 16,559)	18,696 (14,803, 21,842)	0.60 (0.47, 0.69)
2023	23,631 (21,096, 26,040)	8,350 (5,990, 11,448)	15,204 (12,041, 17,670)	0.65 (0.52, 0.73)
2024	28,508 (25,377, 31,263)	9,074 (6,152, 13,167)	19,381 (15,382, 22,416)	0.68 (0.55, 0.77)
2025	26,079 (23,509, 28,370)	8,141 (5,636, 11,511)	17,878 (14,509, 20,495)	0.69 (0.56, 0.77)

Table S7: Population and median and 95% empirical confidence intervals of number of annual average of expected heat-deaths in the factual scenario, the standardised heat-related deaths and the absolute and relative change due to human-made climate change in 2022 in 854 European cities by country.

Country	Population	Heat-deaths	Standardised excess	Difference	Proportion
Austria	1,949,160	255 (194, 320)	145 (110, 182)	172 (120, 229)	0.69 (0.50, 0.82)
Belgium	2,455,390	318 (256, 381)	131 (105, 158)	147 (92, 208)	0.47 (0.30, 0.64)
Bulgaria	2,596,877	542 (360, 772)	231 (155, 327)	380 (251, 547)	0.72 (0.51, 0.85)
Croatia	1,101,531	499 (379, 606)	483 (368, 587)	304 (225, 391)	0.62 (0.48, 0.73)
Cyprus	457,113	30 (18, 41)	87 (52, 121)	21 (6, 34)	0.74 (0.20, 0.96)
Czechia	2,522,881	237 (148, 337)	109 (69, 153)	165 (102, 232)	0.69 (0.53, 0.82)
Denmark	917,663	43 (26, 63)	53 (31, 76)	28 (15, 42)	0.64 (0.46, 0.80)
Estonia	440,155	46 (18, 73)	110 (42, 175)	15 (4, 30)	0.33 (0.14, 0.52)
Finland	1,460,602	102 (49, 159)	75 (36, 116)	49 (18, 87)	0.47 (0.26, 0.66)
France	17,962,199	2,467 (2,030, 2,835)	131 (108, 151)	1,395 (1,009, 1,795)	0.57 (0.42, 0.70)
Germany	23,406,685	3,691 (3,048, 4,278)	152 (126, 176)	2,003 (1,459, 2,527)	0.54 (0.40, 0.66)
Greece	3,401,064	765 (558, 953)	213 (154, 265)	579 (441, 733)	0.77 (0.64, 0.88)
Hungary	2,806,295	549 (352, 782)	212 (136, 300)	270 (134, 404)	0.49 (0.27, 0.66)
Ireland	1,090,316	18 (8, 28)	24 (11, 38)	4 (-4, 12)	0.27 (-0.22, 0.61)
Italy	17,186,805	8,836 (7,743, 9,899)	441 (386, 494)	6,036 (4,608, 7,233)	0.69 (0.54, 0.79)
Latvia	874,434	157 (32, 264)	177 (37, 300)	51 (5, 111)	0.33 (0.11, 0.56)
Lithuania	1,033,748	174 (36, 317)	173 (36, 313)	60 (-3, 138)	0.35 (-0.02, 0.62)
Luxembourg	70,074	9 (6, 11)	155 (113, 194)	6 (4, 8)	0.69 (0.55, 0.83)
Malta	170,361	60 (46, 73)	437 (331, 533)	25 (-16, 48)	0.42 (-0.26, 0.77)
Netherlands	5,644,325	564 (395, 817)	109 (77, 157)	231 (150, 329)	0.41 (0.26, 0.58)
Norway	829,551	14 (6, 24)	23 (9, 38)	9 (3, 16)	0.66 (0.41, 0.83)
Poland	10,396,899	1,541 (1,043, 2,045)	166 (113, 221)	885 (579, 1,181)	0.58 (0.42, 0.70)
Portugal	3,457,781	322 (264, 402)	90 (74, 112)	51 (-21, 112)	0.16 (-0.07, 0.36)
Romania	6,010,799	1,370 (880, 1,893)	262 (170, 357)	889 (560, 1,247)	0.66 (0.44, 0.81)
Slovakia	877,322	126 (81, 178)	194 (124, 273)	68 (37, 100)	0.55 (0.34, 0.70)
Slovenia	308,320	83 (58, 106)	284 (200, 365)	49 (33, 67)	0.61 (0.44, 0.73)
Spain	17,714,878	4,427 (3,738, 5,281)	235 (198, 281)	2,500 (1,670, 3,280)	0.56 (0.38, 0.70)
Sweden	2,807,484	142 (91, 195)	53 (34, 72)	81 (43, 126)	0.58 (0.33, 0.75)
Switzerland	1,977,029	312 (230, 385)	161 (119, 200)	206 (141, 269)	0.66 (0.48, 0.80)
United Kingdom	26,545,907	2,202 (1,762, 2,621)	94 (75, 112)	1,015 (635, 1,413)	0.47 (0.30, 0.61)

Table S8: List of CMIP6 climate models and realisations used in the attribution analysis

ACCESS-CM2 r1i1p1f1	ACCESS-ESM1-5 r1i1p1f1	AWI-CM-1-1-MR r1i1p1f1
BCC-CSM2-MR r1i1p1f1	CAMS-CSM1-0 r1i1p1f1	CanESM5 r1i1p1f1
CanESM5-CanOE r1i1p2f1	CAS-ESM2-0 r1i1p1f1	CESM2-WACCM r1i1p1f1
CIESM r1i1p1f1	CMCC-CM2-SR5 r1i1p1f1	CMCC-ESM2 r1i1p1f1
CNRM-CM6-1-HR r1i1p1f2	CNRM-ESM2-1 r1i1p1f2	E3SM-1-1 r1i1p1f1
EC-Earth3 r1i1p1f1	EC-Earth3-CC r1i1p1f1	EC-Earth3-Veg r1i1p1f1
FGOALS-f3-L r1i1p1f1	FIO-ESM-2-0 r1i1p1f1	GFDL-CM4 r1i1p1f1
GFDL-ESM4 r1i1p1f1	GISS-E2-1-G r1i1p1f2	HadGEM3-GC31-MM r1i1p1f3
IITM-ESM r1i1p1f1	INM-CM4-8 r1i1p1f1	INM-CM5-0 r1i1p1f1
IPSL-CM6A-LR r1i1p1f1	KACE-1-0-G r1i1p1f1	MCM-UA-1-0 r1i1p1f2
MIROC-ES2L r1i1p1f2	MIROC6 r1i1p1f1	MPI-ESM1-2-HR r1i1p1f1
MRI-ESM2-0 r1i1p1f1	NESM3 r1i1p1f1	NorESM2-MM r1i1p1f1
TaiESM1 r1i1p1f1	UKESM1-0-LL r1i1p1f2	

Supplementary figures

Fig. S1: Median heat-related deaths in the factual (red lines) and counterfactual (black lines) scenarios, and the number of deaths attributable to human-induced climate change (shaded areas), by year and capital city. Values below 0 represent the same shaded region (number of deaths attributable to human-induced climate change), reflected about the origin.

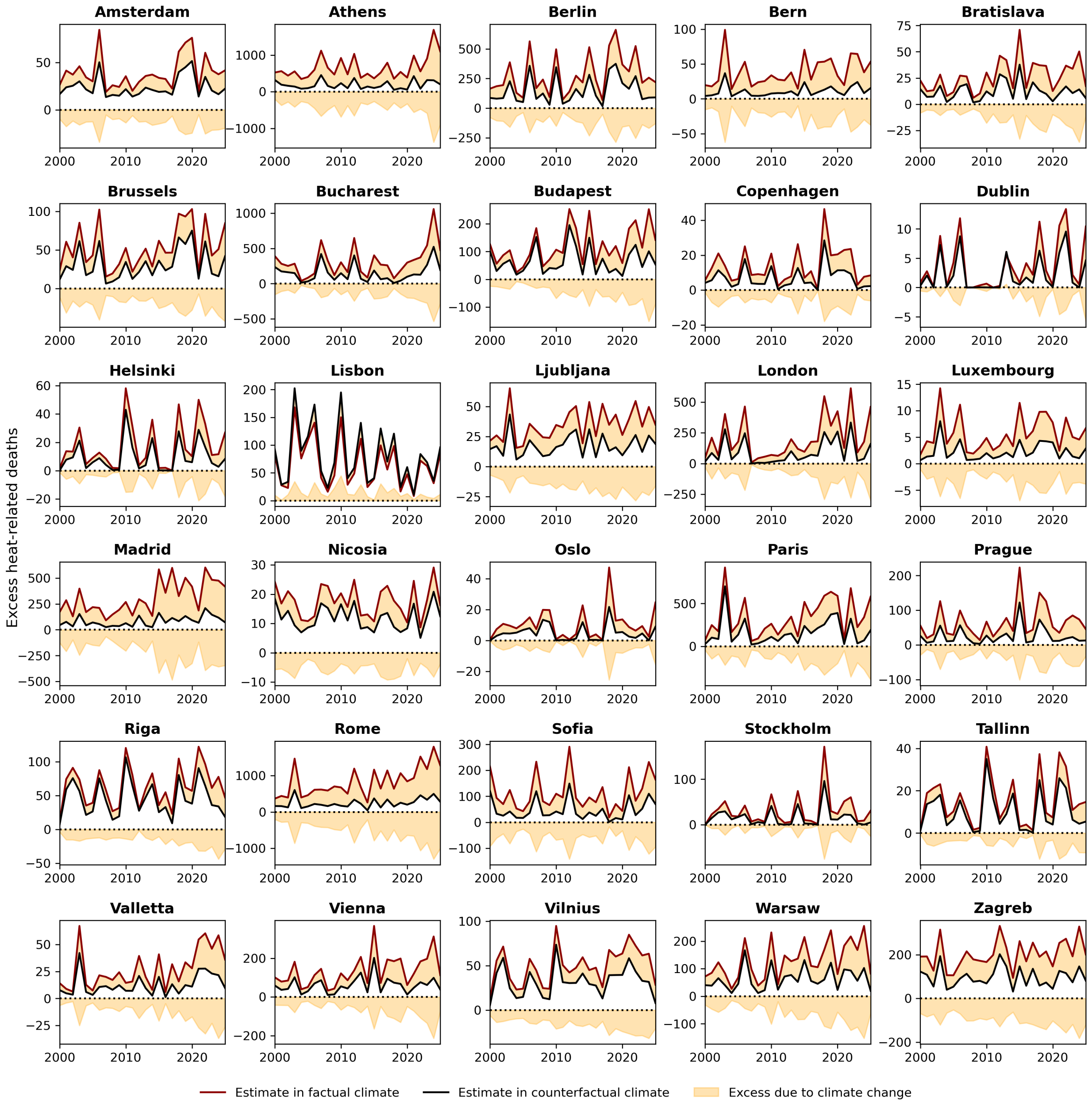
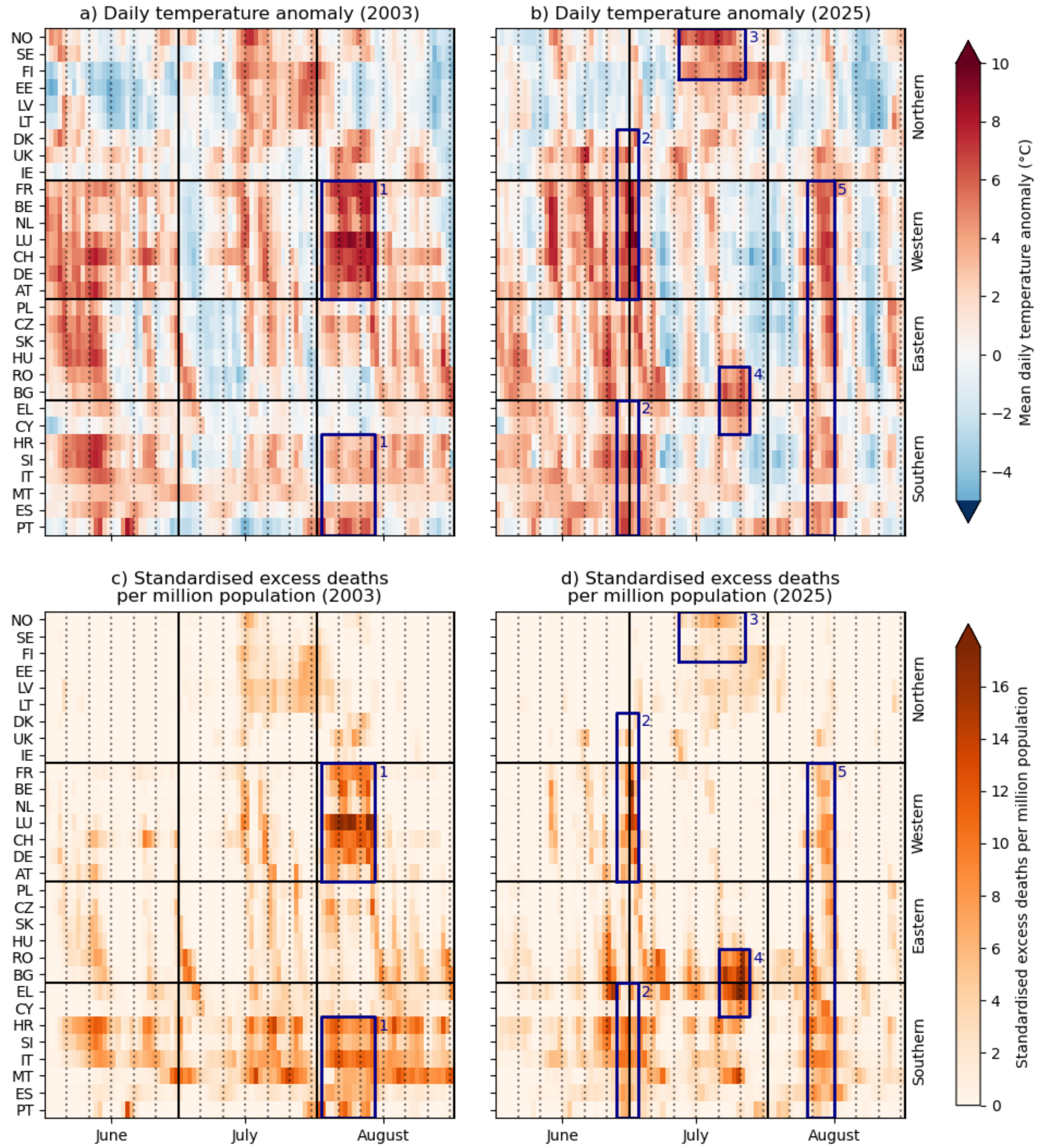


Fig. S2: Daily mean temperature anomaly (°C, relative to the 1990-2020 daily mean over a two-week moving window centred on each date (top panels), and standardized excess deaths per million population for the summers of 2003 and 2025 across 30 European countries (bottom panels) in 2003 (left) and 2025 (right). Numbered boxes indicate periods of particularly dangerous heat that have previously been the subject of attribution studies. (1) The 2003 heatwave; (2) early spring heatwave triggering heat health warnings across Europe; (3) 2025 Fennoscandia heatwave; (4) record-breaking heatwaves linked to wildfires in the Balkans; (5) record-breaking heatwaves linked to wildfires in the Iberian peninsula.



Supplementary Text

S1. Sensitivity Analysis: Updated Population and Mortality Rates

In a sensitivity analysis, we derived city-specific annual mortality estimates for 2000–2025. Briefly, we combined all-cause mortality data at the third level of the Nomenclature of Territorial Units for Statistics (NUTS3) with gridded population data to estimate age-specific mortality rates in each NUTS3 region. We then assumed that each city (URAU specification) shared the mortality rate of its corresponding NUTS3 region and applied this rate to city-level population counts to estimate the annual number of deaths by age group and city.

We retrieved weekly all-cause mortality data from Eurostat, aggregated by NUTS3 region and five-year age groups (0–4, 5–9, . . . , 85–89, 90+). For Germany, Croatia, Ireland, Malta and Slovenia, mortality data were only available at annual resolution, Table S10. Data availability varied across countries: some had long and complete time series, whereas others had more limited temporal coverage, Table S10. We aggregated the available data into age groups consistent with the main analysis, namely 20–44, 45–64, 65–74, 75–84 and 85+ years, and then summed deaths to the annual level for all available years.

The NUTS3 classification provided in the dataset corresponds to the year to which the data refer. To ensure consistent spatial boundaries over time, we harmonised all data to the most recent available NUTS3 classification, which was 2024 for most countries and 2021 for the UK. We retained the NUTS3 regions containing the 854 study cities and achieved an almost exact match between the 2024 and historical NUTS3 regions in all countries except Portugal. In Portugal, the Área Metropolitana de Lisboa was split in the 2024 NUTS classification into two regions, Grande Lisboa and Península de Setúbal. To preserve consistent boundaries over time, we aggregated these two regions into a single unit.

In a small number of NUTS3 regions, the total number of deaths recorded in one year was fewer than 5% of the next-smallest year. For these specific NUTS3 regions, the outlying year of data was removed as errors. Additionally, for NUTS3 regions where the total number of deaths recorded in a year was at least twice that of the next largest year, we also removed these data as errors.

We obtained population estimates for the study period from WorldPop (https://www.worldpop.org/). Our study period spans two WorldPop products: the WorldPop 'Global 1' estimates [2] for 2000–2014 and the 'Global 2' estimates [3] for 2015–2025, both at a spatial resolution of 30 arc-seconds (approximately 1 km at the equator). Population counts in both products are provided in five-year age groups, although the definition of the oldest age group differs between products. In 'Global 1', the oldest age group is 80+, whereas in 'Global 2' the oldest is 90+. To obtain population estimates consistent with the age groups used in our study, we aggregated the original five-year age groups into the analysis groups. For older ages, we estimated the proportion of individuals aged 80+ who were aged 85+ using the 2015 WorldPop estimates, and applied this proportion to split the pre-2015 80+ population into 80–84 and 85+ groups. We then aggregated the gridded population estimates to both NUTS3 regions and URAU city units (hereafter referred to as cities).

For each NUTS3 region in which the centroid of a city was located, we estimated the annual age-specific mortality rate by dividing the all-cause mortality counts retrieved from Eurostat by the corresponding NUTS3 population totals, Fig. S5. To infer mortality rates for years without Eurostat data, we fitted a mixed-effects regression model to the NUTS3 regions included in the analysis. For each country, annual mortality trends were modelled using a linear term, with random slopes for the NUTS3 regions containing our 854 cities to allow for region-specific deviations. This partial pooling improved the stability of slope estimates, particularly in regions with limited temporal coverage and small numbers. For countries with only one NUTS3 region of interest, we used a fixed slope. The resulting annual mortality-rate estimates for each NUTS3 region were then used as proxies for the mortality rates of cities within that region and applied to city population counts to estimate the annual number of deaths at the city level.

The results of this approach are shown in Figs. S6–S7. Fig. S6 compares the annual mortality rates observed in the 30 capitals (black points) with the constant rate used by Masselot et al. [1] (blue line) and the rate predicted by our mixed model (red line). The two approaches were generally consistent, with larger differences mainly in areas with sparse data or outlying observations. Fig. S7 compares the estimated number of deaths in a random sample of 30 cities across the five age groups with the constant mortality counts used by Masselot et al. [1]. These estimates were also broadly consistent, with differences usually below 15%. Some spatial heterogeneity was apparent, especially in cities with smaller death counts, and discrepancies were greatest at the beginning and end of the study period.

Table S9: Description of data availability for mortality data estimates (All the data not mentioned here are available for weakly data across all age groups, NUTS3 regions, and years from 2000 to 2025).

Country	NUTS3 ID	Age group	Years available	Temporal resolution	Source
Croatia (HR)	HR024, HR025, HR050	All groups	2020-2024	annual	[4]
Croatia (HR)	HR031, HR033, HR035, HR036	All groups	2013-2024	annual	[4]
Cyprus (CY)	All regions	All groups	2014-2025	weekly	[5]
Czechia (CZ)	All regions	All groups	2005-2025	weekly	[5]
Denmark (DK)	All regions	All groups	2007-2025	weekly	[5]
Estonia (EE)	EE00A	All groups	2019-2024	weekly	[5]
Estonia (EE)	EE001, EE008	All groups	2000-2024	weekly	[5]
Finland (FI)	All regions	All groups	2000-2022, 2024-2025	weekly	[5]
France (FR)	All regions	All groups	2012-2025	weekly	[5]
Germany (DE)	DEB31	20-44	2013-2017	annual	[4]
Germany (DE)	See Note 1	20-44	2013-2017, 2023	annual	[4]
Germany (DE)	See Note 2	20-44	2013-2017, 2023-2024	annual	[4]
Germany (DE)	DE222	45-64	2013-2017, 2020-2023	annual	[4]
Germany (DE)	See Note 3	45-64, 65-74, 75-84, 85+	2013-2017, 2020-2024	annual	[4]
Greece (EL)	All regions	All groups	2014-2025	weekly	[5]
Ireland (IE)	All regions	All groups	2013-2024	annual	[4]

Table S9: Description of data availability for mortality data estimates (All the data not mentioned here are available for weakly data across all age groups, NUTS3 regions, and years from 2000 to 2025). *(continued)*

Country	NUTS3 ID	Age group	Years available	Temporal resolution	Source
Italy (IT)	All regions	All groups	2011-2025	weekly	[5]
Lithuania (LT)	All regions	All groups	2010-2025	weekly	[5]
Malta (MT)	All regions	All groups	2013-2024	annual	[4]
Netherlands (NL)	All regions	All groups	2014-2025	weekly	[5]
Romania (RO)	All regions	All groups	2014-2025	weekly	[5]
Slovenia (SI)	All regions	All groups	2013-2024	annual	[4]
United Kingdom (UK)	All regions	All groups	2014-2020	weekly	[5]

Note:

1: DE112, DE117, DE122, DE125, DE129, DE131, DE141, DE211, DE221, DE222, DE232, DE242, DE252, DE253, DE261, DE262, DE263, DE273, DE279, DE401, DE402, DE403, DE404, DE501, DE502, DE711, DE712, DE713, DE722, DE731, DE803, DE804, DE80J, DE911, DE912, DE913, DE925, DE931, DE935, DE944, DE945, DEA11, DEA13, DEA17, DEA18, DEA19, DEA24, DEA2B, DEA31, DEA32, DEA51, DEA54, DEA56, DEB21, DEB32, DEB38, DED2D, DED44, DED45, DEE01, DEF01, DEF02, DEF04, DEG01, DEG02, DEG05

2: DE111, DE113, DE115, DE126, DE134, DE136, DE138, DE142, DE144, DE147, DE212, DE213, DE241, DE254, DE271, DE300, DE600, DE714, DE719, DE721, DE724, DE732, DE80L, DE80N, DE91C, DE929, DE943, DEA12, DEA14, DEA15, DEA16, DEA1A, DEA1D, DEA1F, DEA22, DEA23, DEA26, DEA2C, DEA2D, DEA33, DEA34, DEA36, DEA41, DEA47, DEA52, DEA53, DEA55, DEA58, DEA5A, DEB11, DEB34, DEB35, DED21, DED41, DED51, DEE02, DEE03, DEF03, DEG03

3: DE111, DE112, DE113, DE115, DE117, DE122, DE125, DE126, DE129, DE131, DE134, DE136, DE138, DE141, DE142, DE144, DE147, DE211, DE212, DE213, DE221, DE222, DE232, DE241, DE242, DE252, DE253, DE254, DE261, DE262, DE263, DE271, DE273, DE279, DE300, DE401, DE402, DE403, DE404, DE501, DE502, DE600, DE711, DE712, DE713, DE714, DE719, DE721, DE722, DE724, DE731, DE732, DE803, DE804, DE80J, DE80L, DE80N, DE911, DE912, DE913, DE91C, DE925, DE929, DE931, DE935, DE943, DE944, DE945, DEA11, DEA12, DEA13, DEA14, DEA15, DEA16, DEA17, DEA18, DEA19, DEA1A, DEA1D, DEA1F, DEA22, DEA23, DEA24, DEA26, DEA2B, DEA2C, DEA2D, DEA31, DEA32, DEA33, DEA34, DEA36, DEA41, DEA47, DEA51, DEA52, DEA53, DEA54, DEA55, DEA56, DEA58, DEA5A, DEB11, DEB21, DEB31, DEB32, DEB34, DEB35, DEB38, DED21, DED2D, DED41, DED44, DED45, DED51, DEE01, DEE02, DEE03, DEF01, DEF02, DEF03, DEF04, DEG01, DEG02, DEG03, DEG05

Fig. S3: Map of URAU city boundaries (red) and corresponding NUTS3 regions (blue) for the 30 European capitals, linked based on city centroid locations (black stars).

Fig. S4: Time trends in annual mortality rates (2000-2025) by age group and shown for the 30 capital cities. Displayed are the mortality rates used in [1] (blue) and those estimated for our sensitivity analysis (red). The data used to estimate the mortality rates in our sensitivity analysis are also displayed (black).

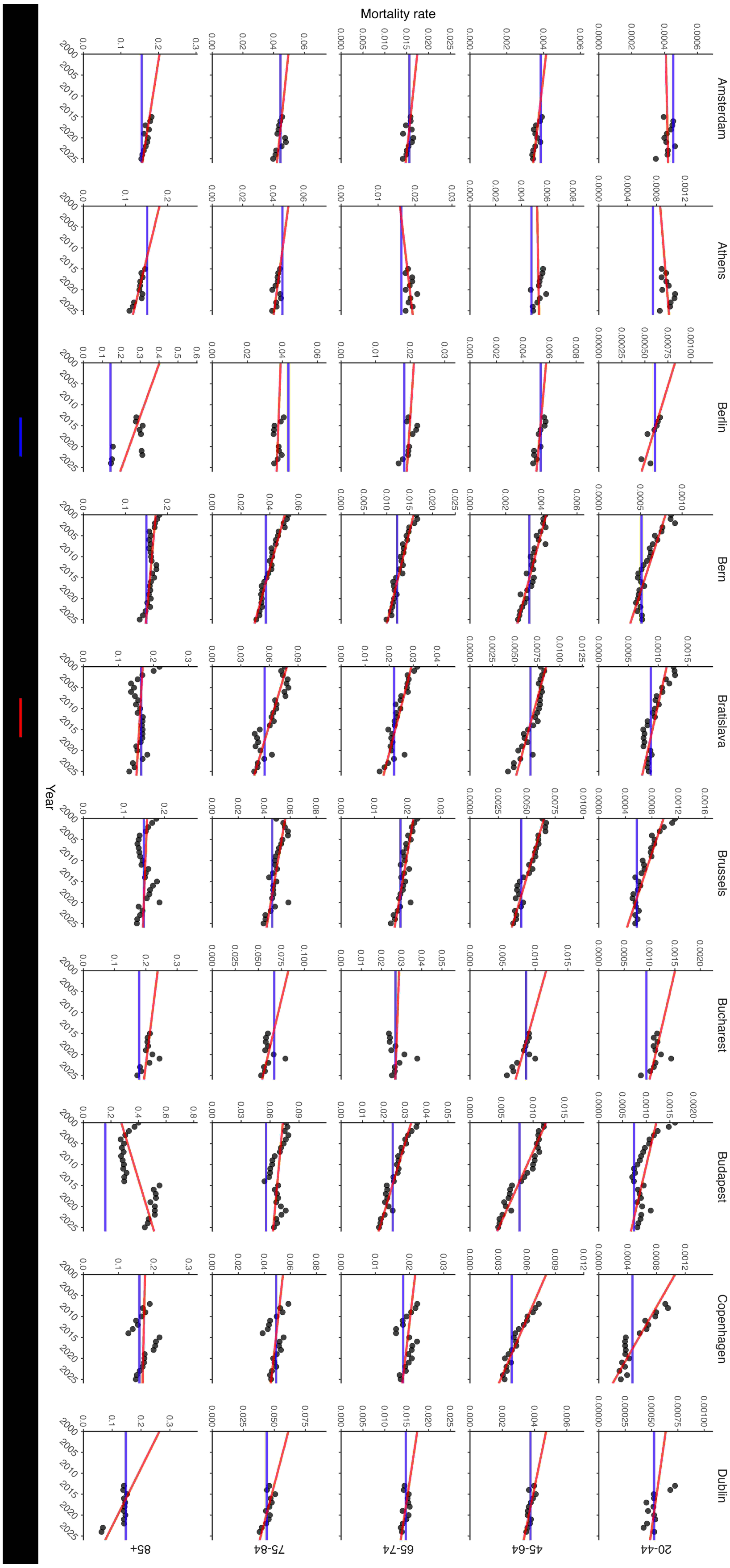
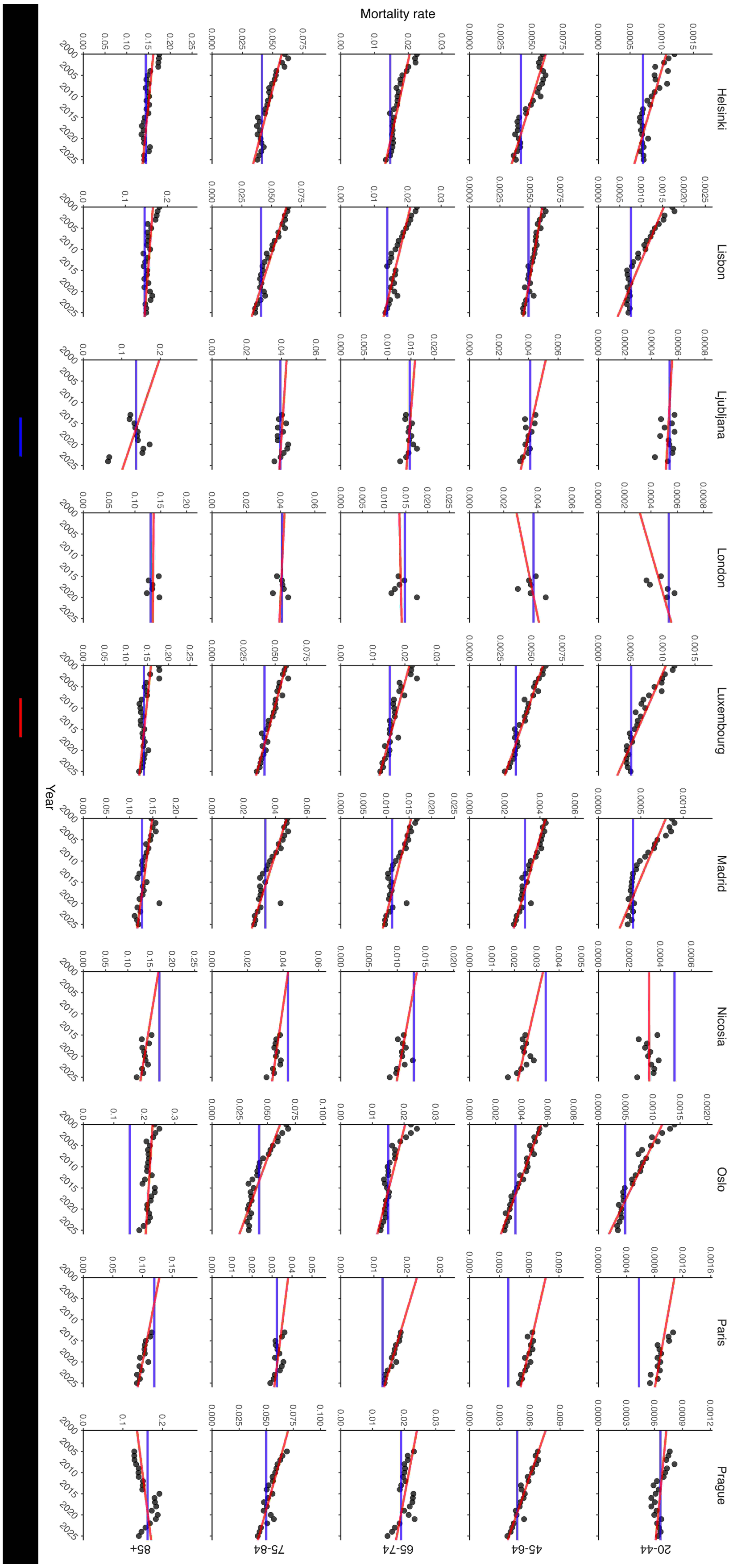


Fig. S4



Mortality rate
Year
Helsinki
Lisbon
Ljubljana
London
Luxembourg
Madrid
Nicosia
Oslo
Paris
Prague
20-44
45-64
65-74
75-84
85+

Fig. S4

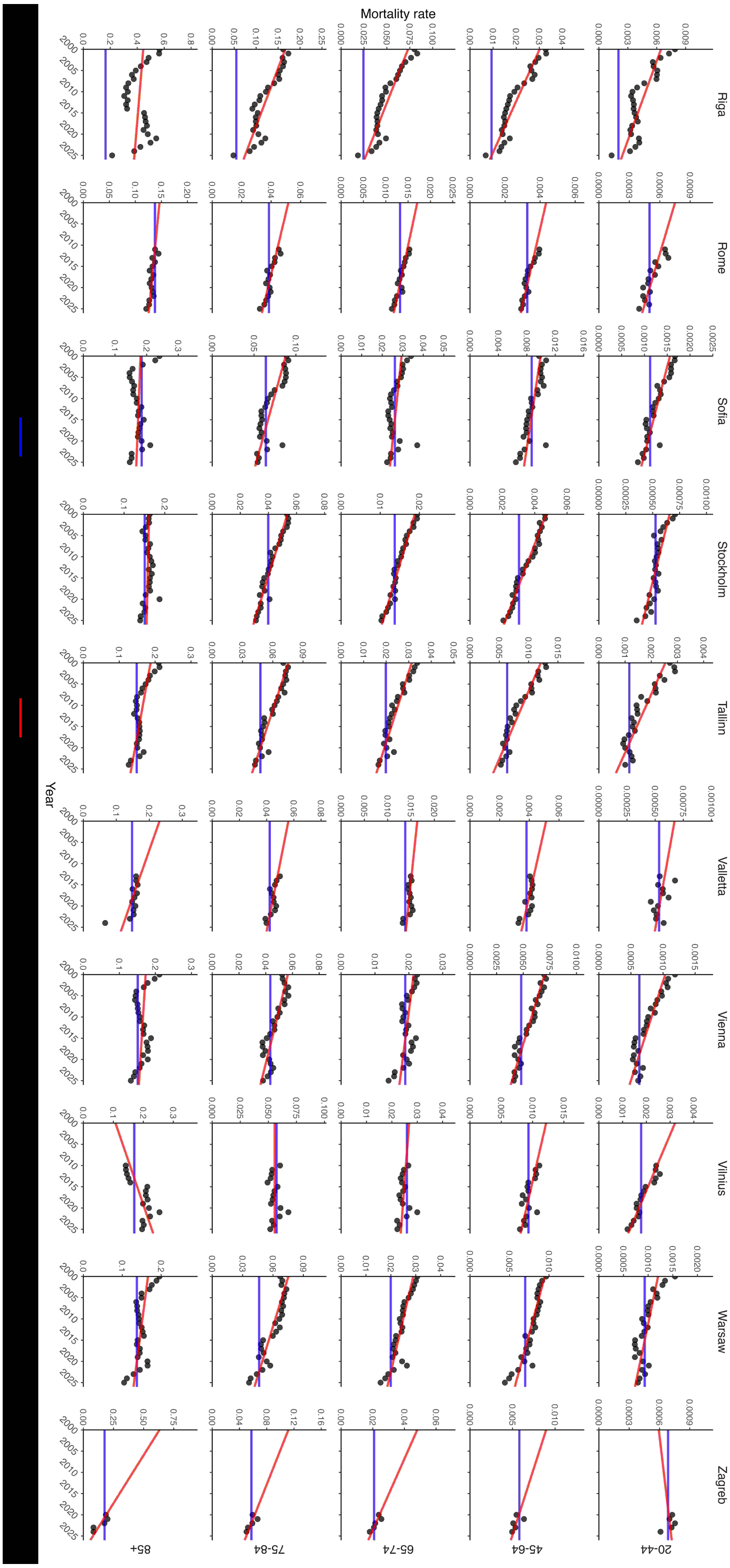

Mortality rate
Year
Riga
Rome
Sofia
Stockholm
Tallinn
Valletta
Vienna
Vilnius
Warsaw
Zagreb
20-44
45-64
65-74
75-84
85+

Fig. S5: Comparison between the number of annual city wide deaths (2000-2026) as used in [1] and as estimated for use in our sensitivity analysis, by age group and for a random subset of 30 cities. Here, data above the solid line indicate a higher mortality rate used in [1], and data below the solid line indicate a larger mortality rate used in our sensitivity analysis, where the dashed lines indicate a 5% and 10% magnitude of difference. The colour gradation indicates the year from 2000 (dark blue) to 2026 (light blue).

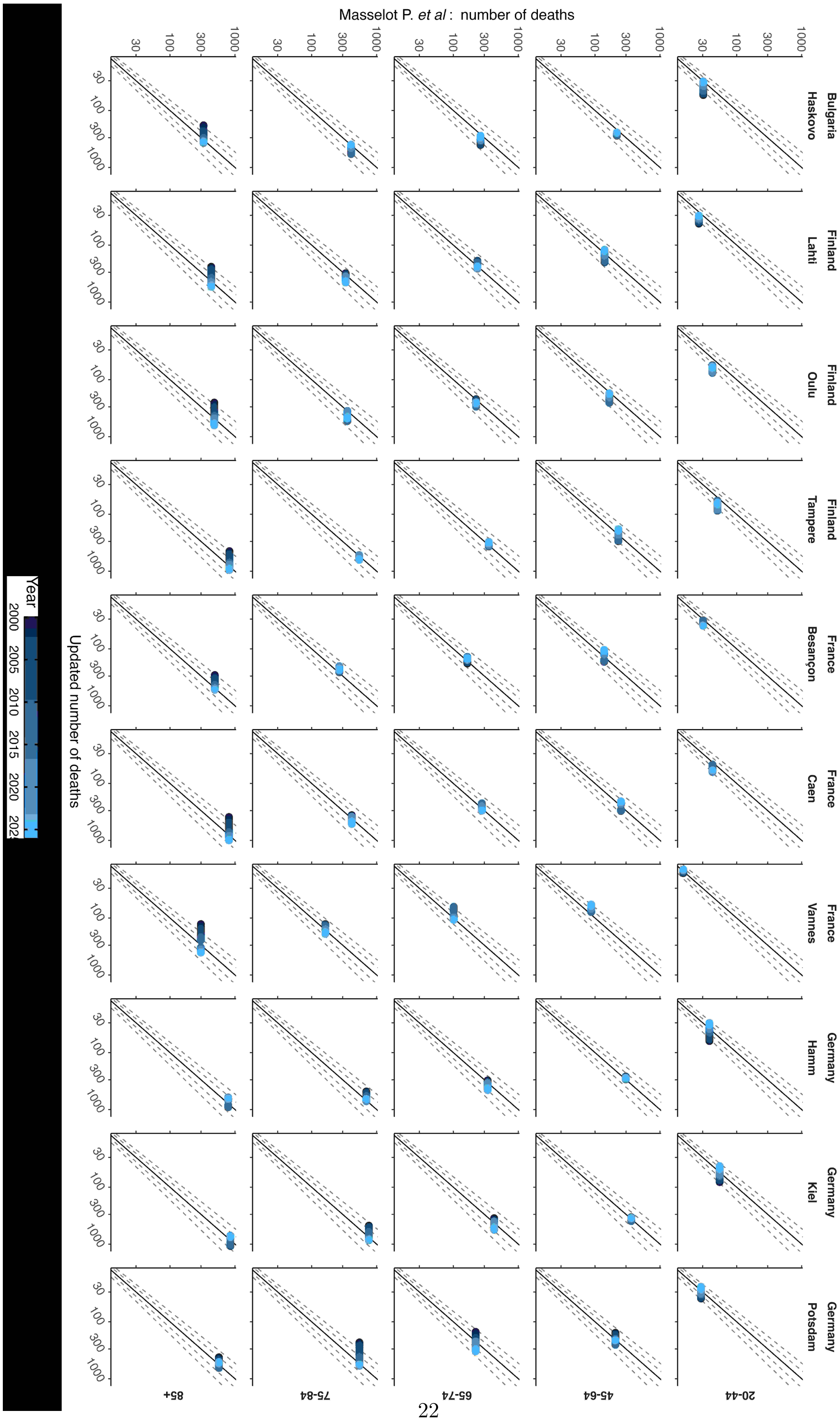


Fig. S5

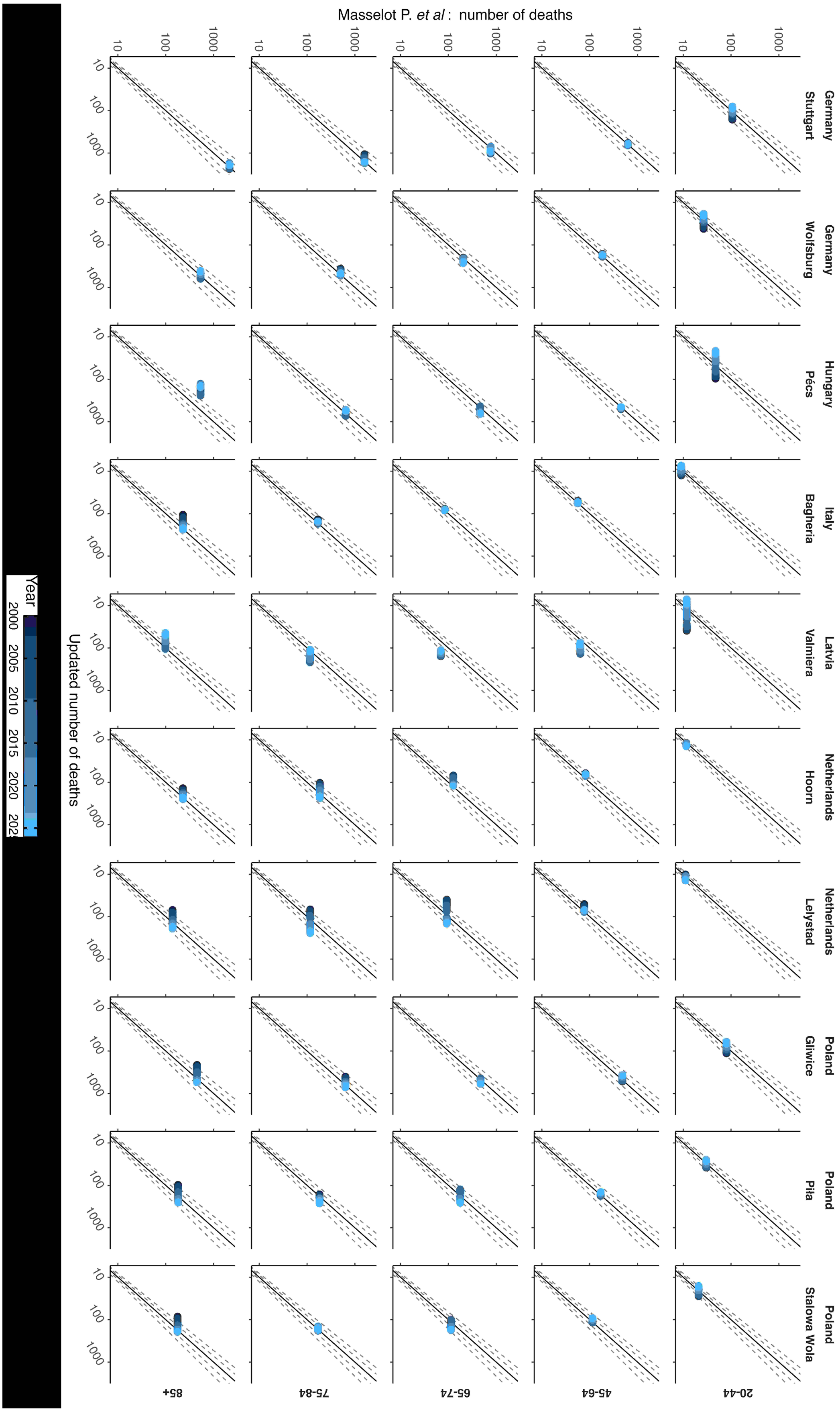
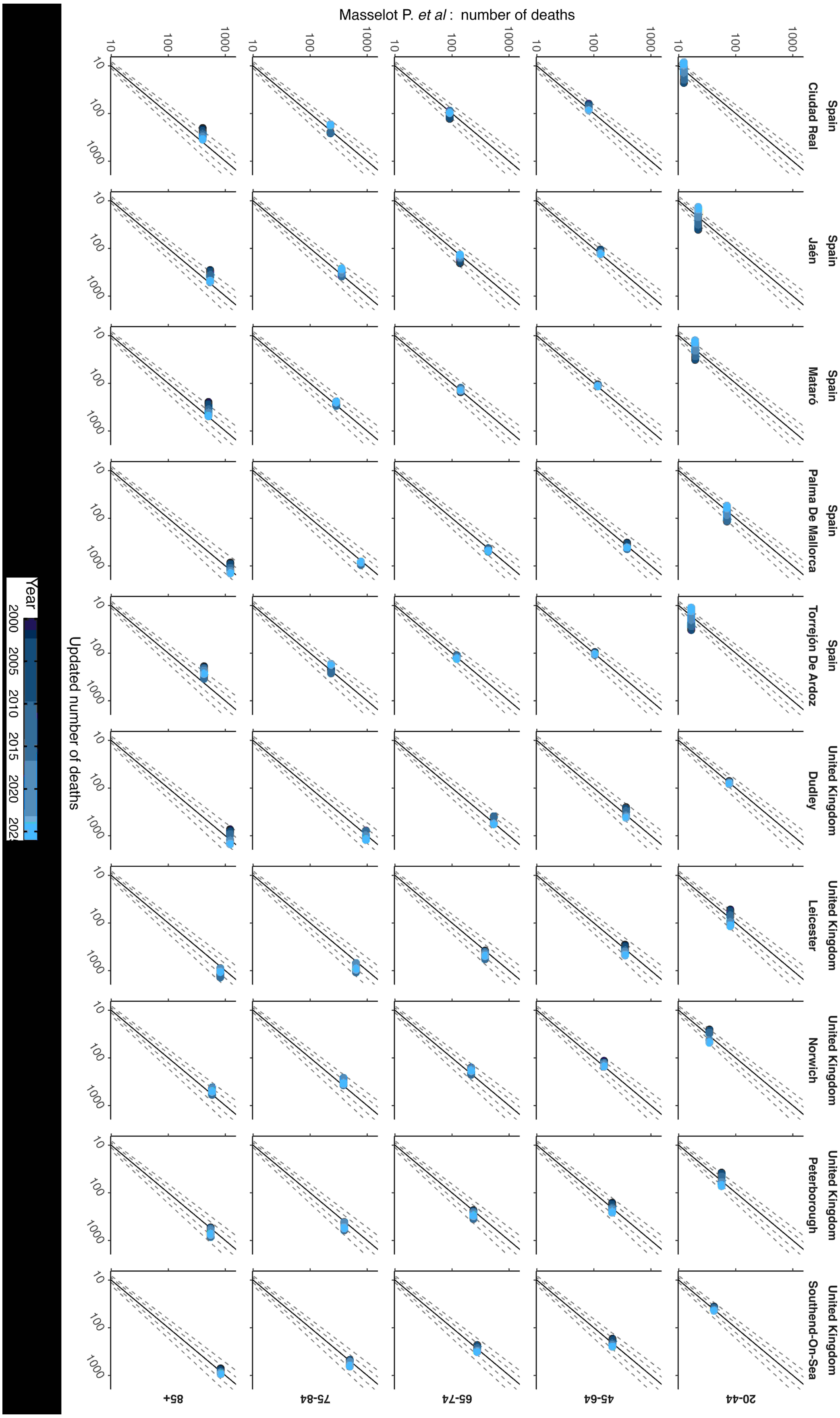

Masselot P. et al : number of deaths
Germany Stuttgart
Germany Wolfsburg
Hungary Pécs
Italy Bagheria
Latvia Valmiera
Netherlands Hoorn
Netherlands Lelystad
Poland Gliwice
Poland Piła
Poland Stalowa Wola
20-44
45-64
65-74
75-84
85+
10
100
1000
Updated number of deaths
Year
2000
2005
2010
2015
2020

Fig. S5

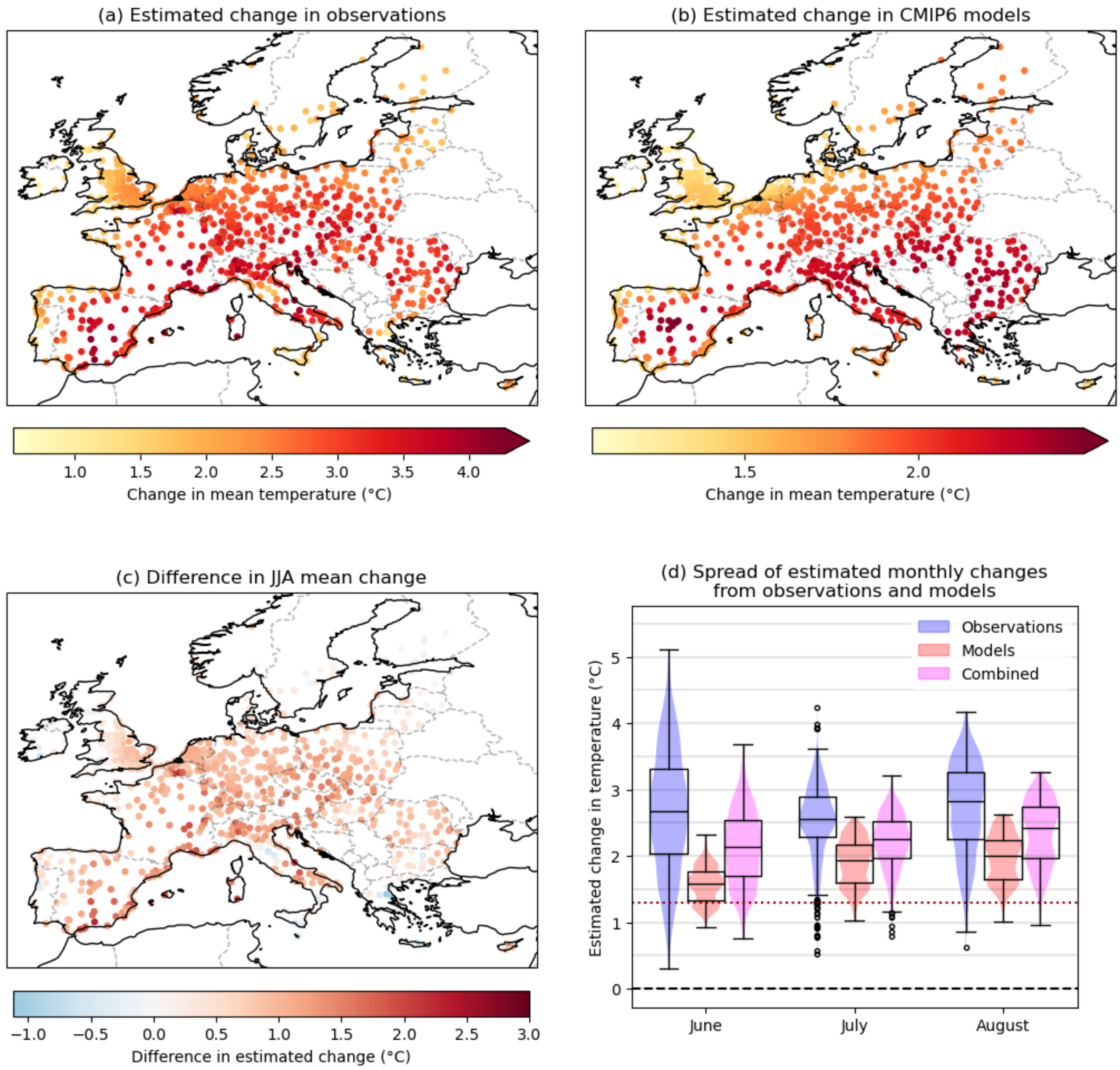

Masselot P. et al : number of deaths
Updated number of deaths
Year
2000
2005
2010
2015
2020
Spain
Ciudad Real
Spain
Jaén
Spain
Mataró
Spain
Palma De Mallorca
Spain
Torrejón De Ardoz
United Kingdom
Dudley
United Kingdom
Leicester
United Kingdom
Norwich
United Kingdom
Peterborough
United Kingdom
Southend-On-Sea
20-44
45-64
65-74
75-84
85+
10
100
1000

S2. Underestimation of European warming trends in climate models

Climate models are known to systematically underestimate the observed rate of warming across Europe, due to changes in atmospheric aerosols and circulation patterns that are not represented in the models [6–9]. It is therefore likely that the synthesised changes in temperature in Fig. 1 in the main text represent a conservative estimate of the true level of attributable warming across much of Europe. Fig. S6a shows a map of the historical change in temperatures in the 854 cities associated with 1.3°C of warming, obtained by averaging the change estimated from the two observational datasets. Panel b shows the average warming simulated by the 38 CMIP6 climate models, and panel c shows the difference between the two, highlighting where the underestimation is greatest.

While the spatial pattern of warming across the continent is fairly similar in models and observations, the climate models fail to simulate the full range of observed changes: in observations, the monthly changes range from 0.3 to 5.1°C, and in the climate models, from 0.9 to 2.6°C (Panel d, with the distribution of observed changes in blue and modelled changes in red). This is true in all calendar months but particularly in June, which has the widest spread of observed changes and the narrowest spread of modelled changes. The result of this is that for June temperatures, the synthesised changes (pink violins) are on average 0.6°C below the changes actually observed (95% central interval of differences: -1.2°C to +0.3°C); for July, 0.3°C below (-0.6°C to +0.2°C); and for August, 0.4°C below (-0.8°C to +0.2°C).The estimated temperature changes here should therefore be interpreted as a conservative estimate of the true level of human-caused warming across Europe. However, the inclusion of climate model data does produce much better-constrained estimates of the level of attributable warming, with substantially narrower confidence intervals than those estimated from observations alone.

Fig. S6: Maps of estimated change in summer temperatures in (a) observational data products and (b) CMIP6 climate models; (c) differences between the two data sources. (d) Boxplot and violinplots of the estimated changes each month across all cities, in observations (blue) and models (red), with synthesised change in pink. The box represents the central 50% of the distribution, the whiskers indicate points within 1.5 times the interquartile range of the box, and circles indicate points more extreme than this.



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