Supplementary Online Content

Ambient Heat and Risks of Emergency Department Visits among Adults in the United States

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Table of Contents

Figure S3. Sensitivity analysis by testing different modelling choices for overall lag structure in effects of extreme heat on emergency department visits for any cause, heat-related illness, renal, cardiovascular, respiratory disease, and mental disorders.

Supplemental references

eAppendix. Ambient Temperature Assessment

We estimated daily maximum ambient temperature using the Parameter-elevation Relationships on Independent Slopes (PRISM) model, a validated spatiotemporal model with approximately four-kilometer horizontal grid spacing.[1] To represent population exposure to temperature, we calculated a population-weighted average of daily maximum temperature for each day in each county.[2] Briefly, we first obtained the population centroids for each census tract in each of the 2,939 US counties of interest from the 2000 Census. Next, we extracted daily PRISM-predicted temperatures at the grid cell overlaying each of these census tract population centroids. Finally, we used these extracted grid cells to calculate a daily time series of population-weighted maximum temperature for each day in each county. Specifically, for each extracted grid cell, we multiplied its daily temperature value by the proportion of the county population falling within that census tract. We then summed the resulting values across all grid cells located within each county to obtain the county population-weighted mean value.

Appendix. Calculation of absolute excess risk

To calculate the absolute excess risk in ED visits associated with heat, we used $\alpha_c(1 - \exp(-\widehat{\beta_c}))$ with a standard error calculated as $\alpha_c \exp(-\widehat{\beta_c})\, \widehat{se_c}$, where α_c is the baseline rate for cause-specific ED visits *c*, calculated using the total number of cause-specific ED visits during 2010 to 2019 among beneficiaries covered by a health plan divided by the total person-days for beneficiaries covered by a health plan, and $\widehat{\beta_c}$ and $\widehat{se_c}$, are the coefficient and standard error for heat extracted from the conditional logistic regression for cause-specific ED visits *c*.[3,4]

Table S1. Codes to identify emergency department visits.

Current Procedural Terminology (CPT) codes	99281, 99282, 99283, 99284, 99285, 99288
Revenue code	0450, 0451, 0452, 0453, 0454, 0455, 0456, 0457, 0458, 0459, 0981
Place of service code	23

Table S2. The characteristics of the study beneficiaries and US resident population on 1 July 2015.

Characteristics	No. of enrollees on 1 July 2015	No. of resident population on 1 July 2015[a]	% of enrollees	*p*-value[b]
Total No.	20,437,195 (100.0)	319,248,785 (100.0)	6.4	--
Age, years				<0.001
<20	4,461,357 (21.8)	81,578,778 (25.6)	5.5	
20-64	12,893,647 (63.1)	190,218,906 (59.6)	6.8	
≥65	3,082,191 (15.1)	47,451,101 (14.9)	6.5	
Gender				<0.001
Male	10,434,342 (51.1)	157,114,900 (49.2)	6.6	
Female	10,002,853 (48.9)	162,133,885 (50.8)	6.2	
NCA4 Region				<0.001
Northeast	3,449,765 (16.9)	65,752,582 (20.6)	5.2	
Southeast	5,263,111 (25.8)	80,333,704 (25.2)	6.6	
Midwest	5,015,397 (24.5)	61,484,176 (19.3)	6.2	
Northern Great Plains	322,126 (1.6)	5,130,642 (1.6)	6.3	
Northwest	485,123 (2.4)	12,854,258 (4.0)	3.8	
Southern Great Plains	3,082,258 (15.1)	34,292,093 (10.7)	9.0	
Southwest	2,819,415 (13.8)	59,401,330 (18.6)	4.7	

Abbreviations: NCA4, US Global Change Research Program's Fourth National Climate Assessment

--Not applicable.

[a]Number of US resident population were obtained from the US Census Bureau, Population Division.[5]

[b]p-values were calculated using Chi-squared test.

Table S3. Excess relative risk and excess absolute risk of cause-specific emergency department visits associated with moderate and extreme temperature defined by daily mean temperature over lag days 0-5 in 2,939 US counties, 2010-2019. Moderate and extreme heat were defined based on the 85th and 95th percentiles of the local county-specific warm-season temperature distribution and excess risks are expressed versus the local 1st percentile. On average across the country, moderate heat was at 26.0 ºC and extreme heat was at 27.5 ºC. Data presented as mean and 95% confidence intervals. Ambient temperature (°F) = (°C×9/5) + 32.

Disease	Moderate heat (26.0 ºC on average)		Extreme heat (27.5 ºC on average)	
	Excess relative risk (%)	Excess absolute risk (No. per 100,000 persons at risk per day)	Excess relative risk (%)	Excess absolute risk (No. per 100,000 persons at risk per day)
All-cause	7.3 (7.0 to 7.7)	7.9 (7.6 to 8.3)	7.6 (7.2 to 8.1)	8.2 (7.8 to 8.7)
Heat-related	48.7 (44.2 to 53.3)	19.9 (18.7 to 21.2)	68.7 (62.7 to 75.0)	24.8 (23.5 to 26.1)
Renal disease	24.1 (18.7 to 29.7)	12.2 (10.0 to 14.5)	31.6 (24.7 to 38.9)	15.2 (12.6 to 17.7)
Cardiovascular	-1.2 (-2.4 to 0.10)	-0.83 (-1.73 to 0.06)	-2.3 (-3.8 to -0.71)	-1.6 (-2.7 to -0.49)
Respiratory	-5.9 (-7.0 to -4.7)	-4.6 (-5.6 to -3.6)	-6.9 (-8.3 to -5.4)	-5.4 (-6.7 to -4.2)
Mental disorders	7.7 (5.5 to 9.9)	5.8 (4.3 to 7.3)	8.9 (6.3 to 11.7)	6.7 (4.8 to 8.5)
Negative control: Epilepsy	0.10 (-6.4 to 7.1)	0.07 (-5.2 to 5.4)	-1.2 (-9.1 to 7.3)	-0.10 (-7.6 to 5.6)

Table S4. Excess relative risk and excess absolute risk of cause-specific emergency department visits associated with moderate and extreme temperature defined by daily minimum temperature over lag days 0-5 in 2,939 US counties, 2010-2019. Moderate and extreme heat were defined based on the 85th and 95th percentiles of the local county-specific warm-season temperature distribution and excess risks are expressed versus the local 1st percentile. On average across the country, moderate heat was at 19.9 ºC and extreme heat was at 21.3 ºC. Data presented as mean and 95% confidence intervals. Ambient temperature (°F) = (°C×9/5) + 32.

Disease	Moderate heat (19.9 ºC on average)		Extreme heat (21.3 ºC on average)	
	Excess relative risk (%)	Excess absolute risk (No. per 100,000 persons at risk per day)	Excess relative risk (%)	Excess absolute risk (No. per 100,000 persons at risk per day)
All-cause	7.1 (6.8 to 7.5)	7.7 (7.4 to 8.1)	7.4 (7.0 to 7.8)	8.0 (7.6 to 8.5)
Heat-related	49.0 (44.5 to 53.6)	20.0 (18.8 to 21.3)	65.0 (59.1 to 71.1)	24.0 (22.6 to 25.3)
Renal disease	23.3 (18.0 to 28.9)	11.9 (9.7 to 14.2)	29.9 (23.1 to 37.1)	14.5 (11.9 to 17.2)
Cardiovascular	-0.82 (-2.1 to 0.44)	-0.58 (-1.5 to 0.31)	-1.5 (-3.0, 0.10)	-1.0 (-2.1 to 0.08)
Respiratory	-6.7 (-7.8 to -5.5)	-5.3 (-6.3 to -4.3)	-8.0 (-9.4 to -6.5)	-6.4 (-7.6 to -5.1)
Mental disorders	7.7 (5.6 to 9.9)	5.8 (4.3 to 7.3)	9.1 (6.5 to 11.9)	6.8 (5.0 to 8.6)
Negative control: Epilepsy	0.53 (-6.0 to 7.5)	0.41 (-4.9 to 5.7)	-0.43 (-8.3 to 8.2)	-0.34 (-6.9 to 6.2)

Table S5. Excess relative risk of cause-specific emergency department visits associated with extreme temperature defined by daily maximum temperature over the study period over lag days 0-5 in 2,939 US counties, 2010-2019, results from main analysis compared with a model additionally adjusted for daily difference between maximum and minimum temperature on the same day (lag 0) modeled as a linear continuous variable. Extreme heat was defined based on the 95th percentiles of the local county-specific warm-season temperature distribution and excess risks are expressed versus the local 1st percentile. Abbreviation: ED visit=emergency department visit.

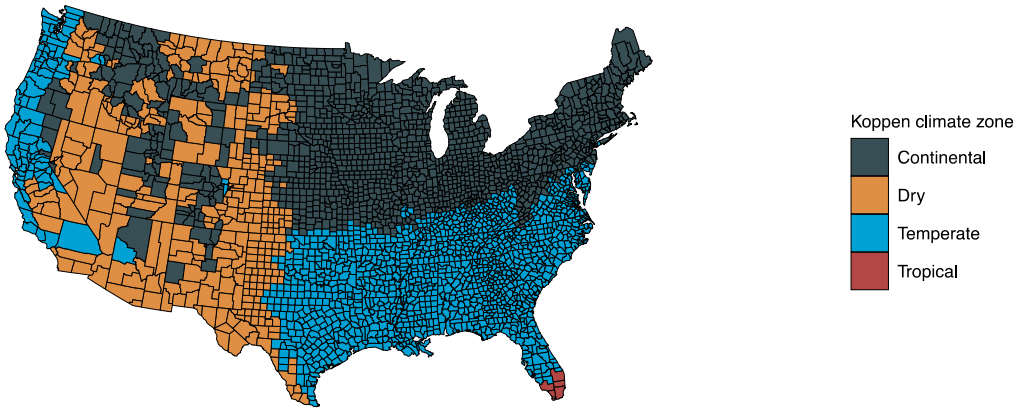
	Main Model	Sensitivity analysis	
Cause of ED Visit	**Excess Relative Risk (%) associated with maximum daily temperature at 95th percentile**	**Excess Relative Risk (%) associated with maximum daily temperature at 95th percentile**	**Excess Relative Risk (%) associated with a 10°C increase in the difference between daily maximum and minimum temperature**
All-cause	7.8 (7.3 to 8.2)	8.0 (7.5 to 8.4)	-0.8 (-1.1 to -0.5)
Heat-related	66.3 (60.2 to 72.7)	67.3 (61.0 to 73.8)	-2.3 (-4.8 to 0.2)
Renal disease	30.4 (23.4 to 37.8)	30.9 (23.8 to 38.5)	-1.5 (-5.1 to 2.1)
Cardiovascular	-2.2 (-3.7 to -0.6)	-2.2 (-3.8, -0.6)	0.3 (-0.8 to 1.3)
Respiratory	-5.0 (-6.5 to -3.4)	-5.4 (-6.9 to -3.8)	0.7 (-0.6 to 2.0)
Mental disorders	7.9 (5.2 to 10.7)	8.1 (5.3 to 10.9)	-0.6 (-2.2 to 1.0)
Negative control: Epilepsy	-3.3 (-11.2 to 5.3)	-3.5 (-11.6 to 5.2)	0.8 (-4.9 to 6.4)

Table S6. Relative risk and excess absolute risk of heat-related emergency department visits associated with moderate and extreme temperature defined by daily maximum temperature over lag days 0-5 in 2,939 US counties, 2010-2019. Moderate and extreme heat were defined based on the 85th and 95th percentiles of the local county-specific warm-season temperature distribution and excess risks are expressed versus the local 1st percentile. On average across the country, moderate heat was at 32.6 ºC and extreme heat was at 34.4 ºC. Data presented as mean and 95% confidence intervals. Ambient temperature (°F) = (°C×9/5) + 32.

ICD codes	Moderate heat (32.6 ºC on average)		Extreme heat (34.4 ºC on average)	
	Odds ratio	Excess absolute risk (No. per 100,000 persons at risk per day)	Odds ratio	Excess absolute risk (No. per 100,000 persons at risk per day)
Original definition: ICD-9: 276, 992, E900.0, and E900.9 or ICD-10: T67, E86, E87, X30	1.49 (1.45 to 1.53)	20.0 (18.8 to 21.3)	1.65 (1.59 to 1.71)	24.0 (22.6 to 25.3)
Restrictive definition: ICD-9: 992, E900.0 or ICD-10: T67, X30	28.3 (23.3 to 34.5)	56.1 (55.7 to 56.5)	52.4 (42.4 to 64.8)	57.1 (56.8 to 57.3)

Figure S1. Köppen-Geiger climate zone (A) and Global Change Research Program's Fourth National Climate Assessment geographic region (B) and in the United States.

A



B

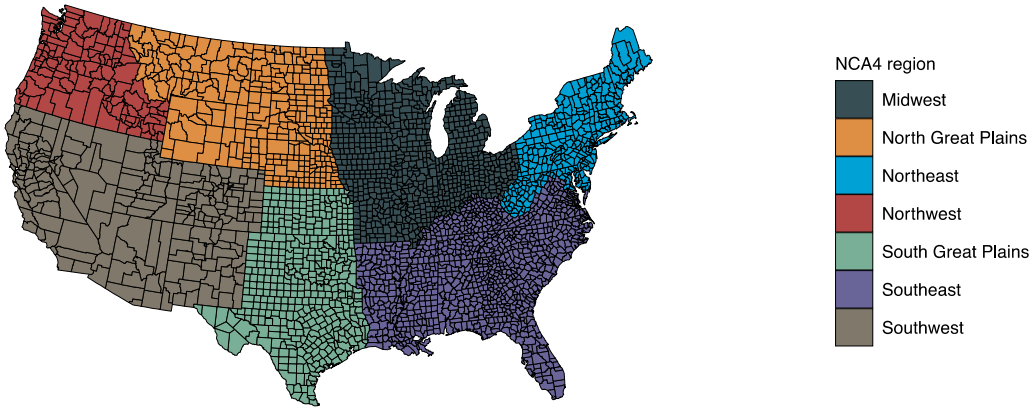


Figure S2. Sensitivity analysis by testing different modelling choices for cumulative exposure-response curves for the associations between daily maximum temperature and emergency department visits for any cause, heat-related illness, renal, cardiovascular, respiratory disease, and mental disorders. The blue bands represent 95% confidence intervals of the main model.

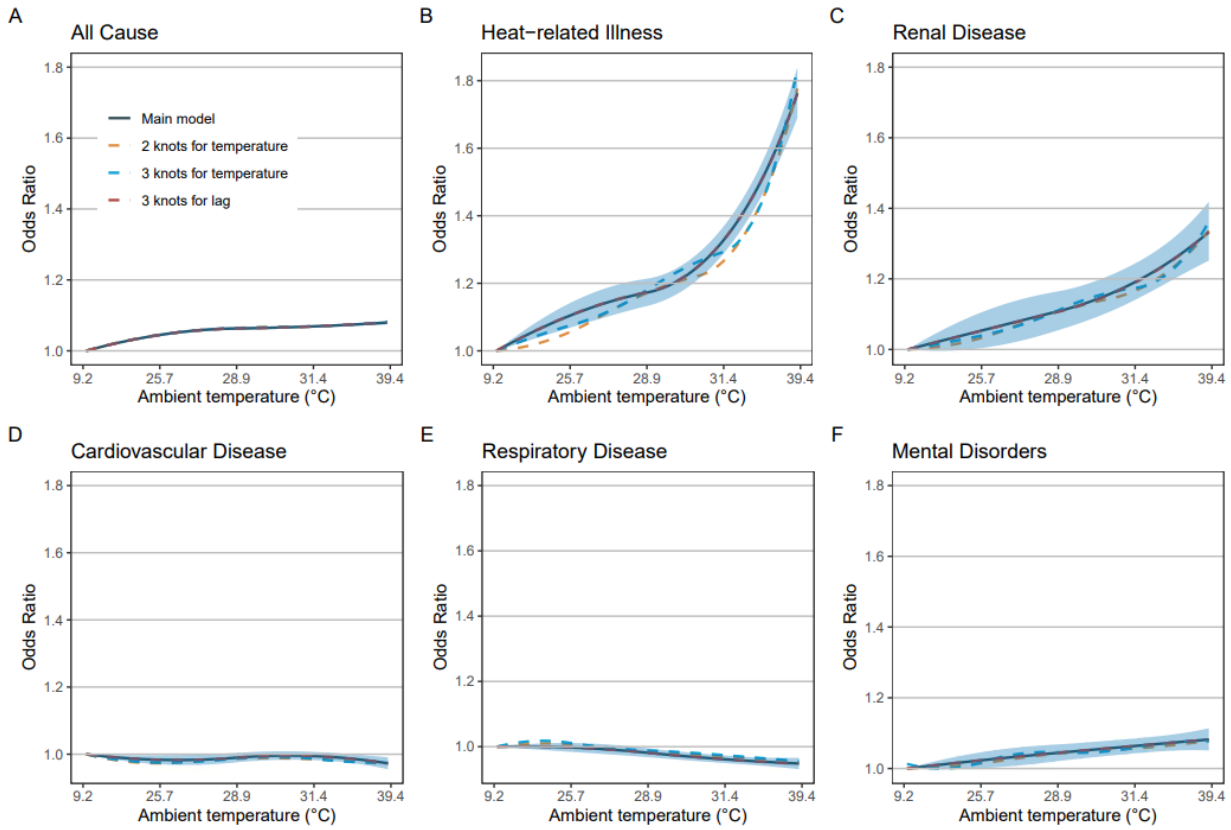
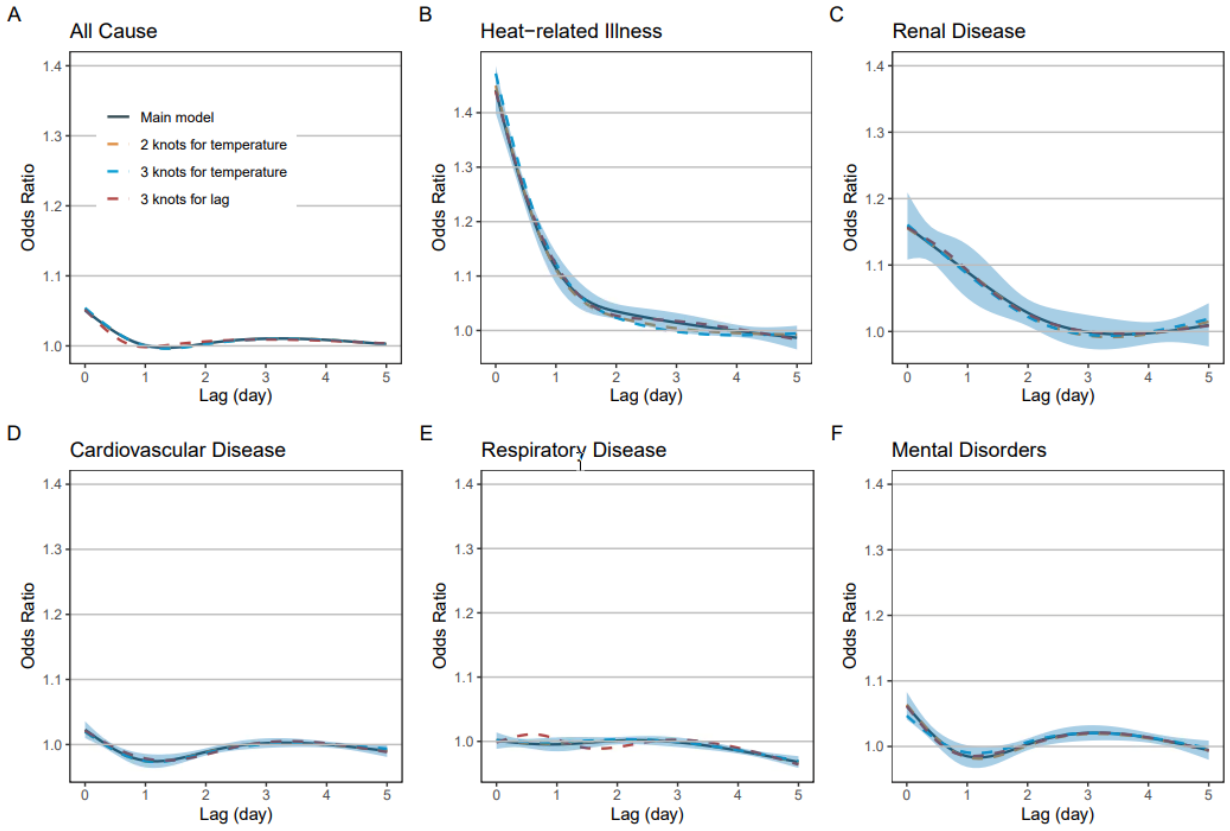


Figure S3. Sensitivity analysis by testing different modelling choices for overall lag structure in effects of extreme heat on emergency department visits for any cause, heat-related illness, renal, cardiovascular, respiratory disease, and mental disorders. The blue bands represent 95% confidence intervals of the main model.



Supplemental references

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