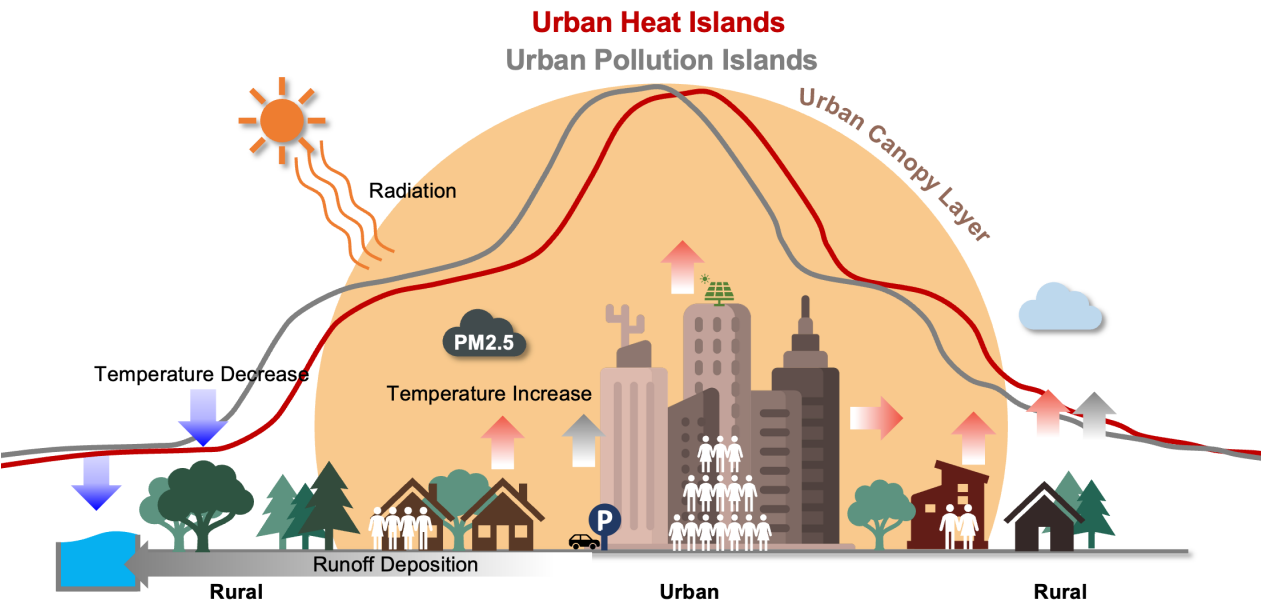
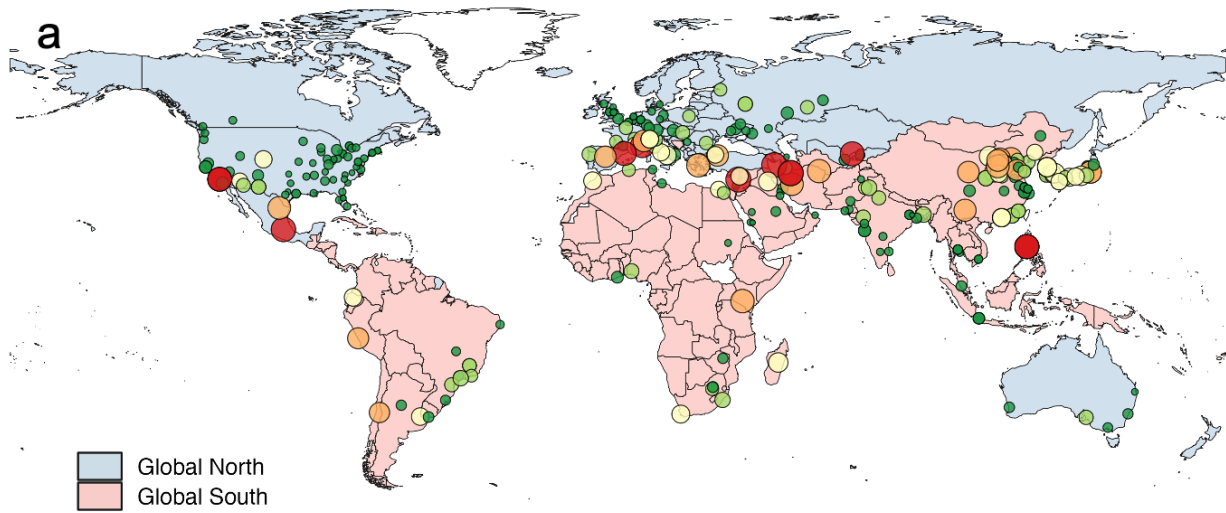


1 Underestimated Mortality Risks from Compound Urban Heat and Air
2 Pollution Islands in Global North Cities

5 Supplementary Information



6
7 Figure S1. Conceptual framework of urban heat island, urban air pollution island in urban canopy
8 layer and related urban exposure to heat and air pollution.



Compound frequency of UHI and UPI

• 0 ~ 50 • 100 ~ 200 • 300 ~ 360
• 50 ~ 100 • 200 ~ 300

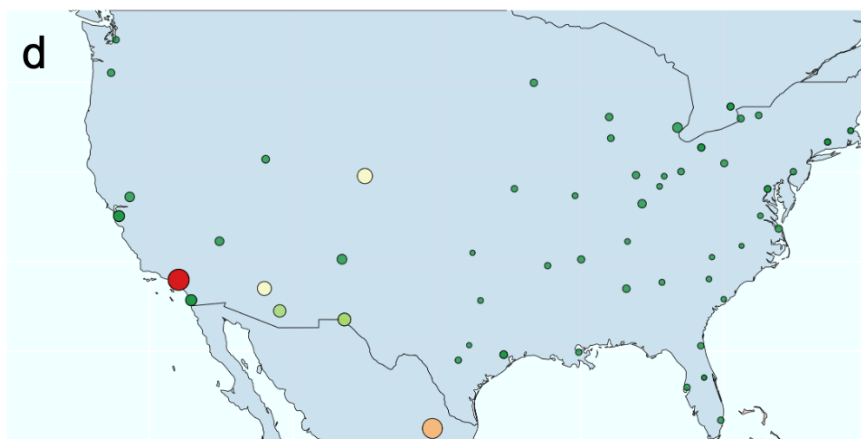
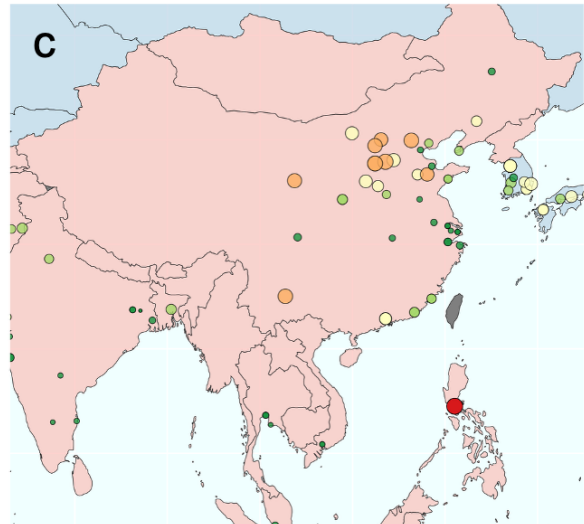
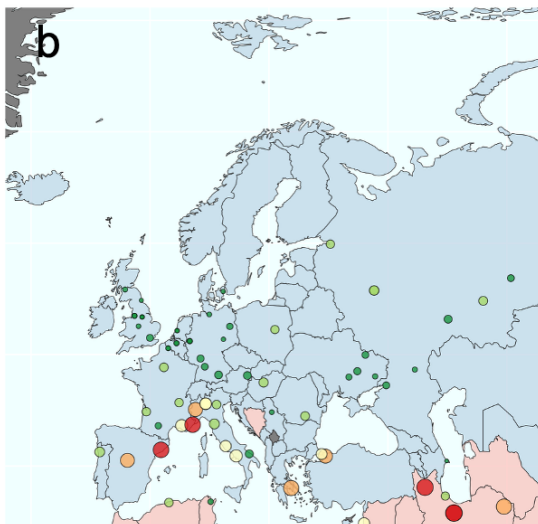


Fig. S2. Compound frequency of UHI UPI for global cities from 2003 to 2020 in (a) global, (b) Europe, (c) China and (d) United States.

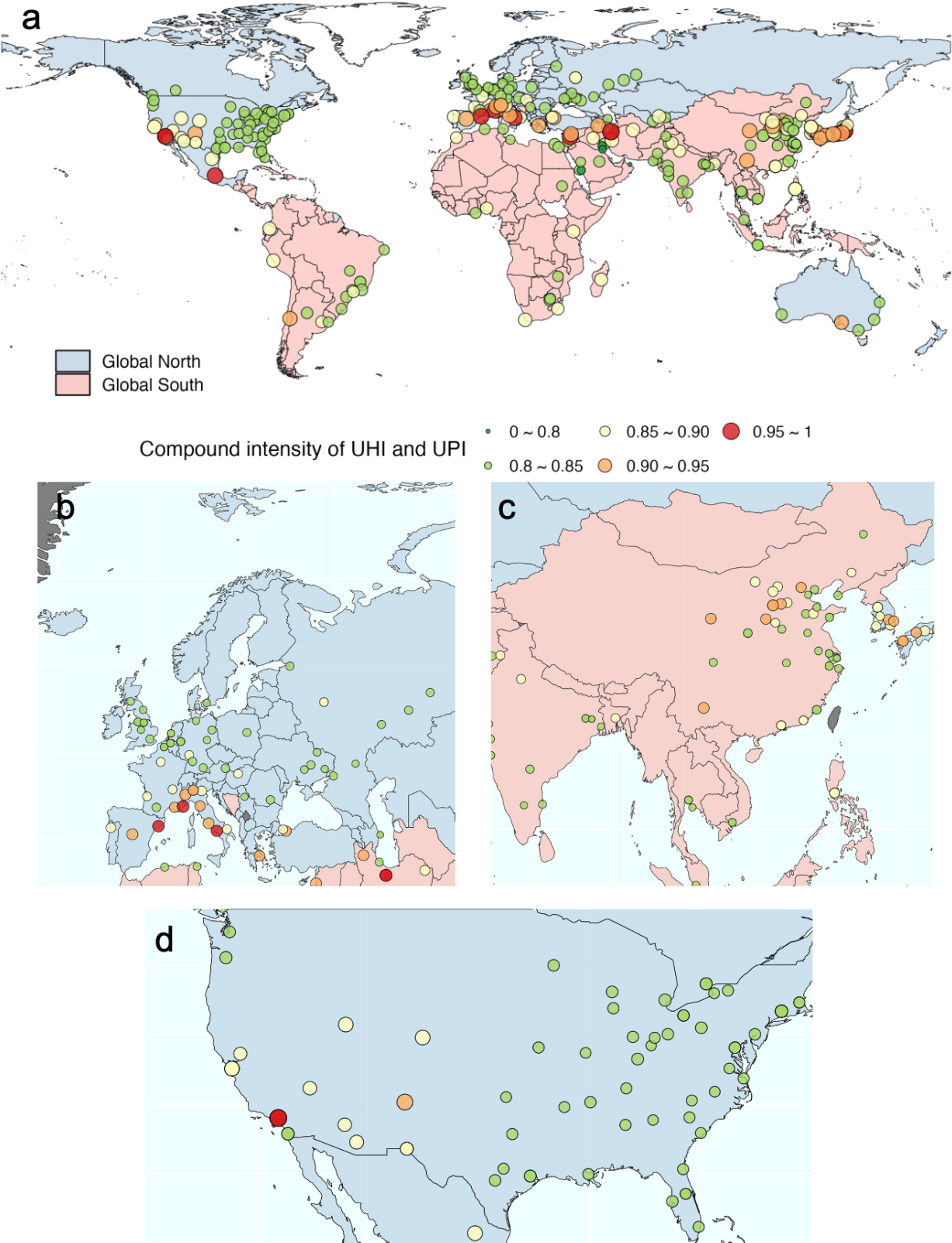


Fig. S3. Daily compound intensity of UHI and UPI for global cities from 2003 to 2020 in (a) global, (b) Europe, (c) China and (d) United States.

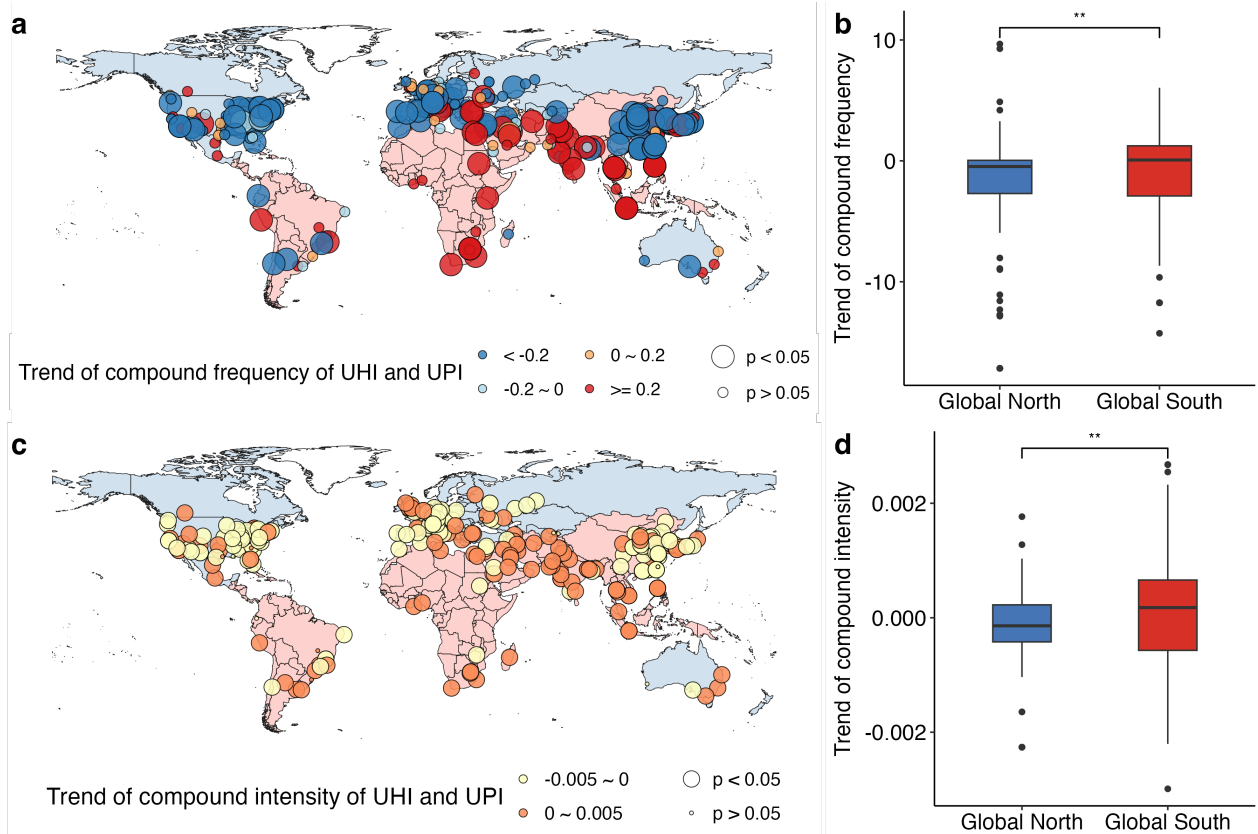


Fig. S4. Compound UHI and UPI frequency and intensity trend in 327 cities between 2003 and 2020. (a). Trend of compound UHI-UPI frequency (number of days/year) for global cities between 2003 and 2020. (b). Summary of compound UHI-UPI frequency trend of Global North and Global South cities. (c). Trend of compound UHI and UPI intensity for global cities between 2003 and 2020. (d). Summary of compound UHI and UPI intensity for Global South and Global North cities between 2003 and 2020. The linear regression is used to estimate the long-term trend of compound frequency of UHI and UPI. The Seasonal Kendall Test is used to estimate the long-term trend of compound intensity UHI and UPI.

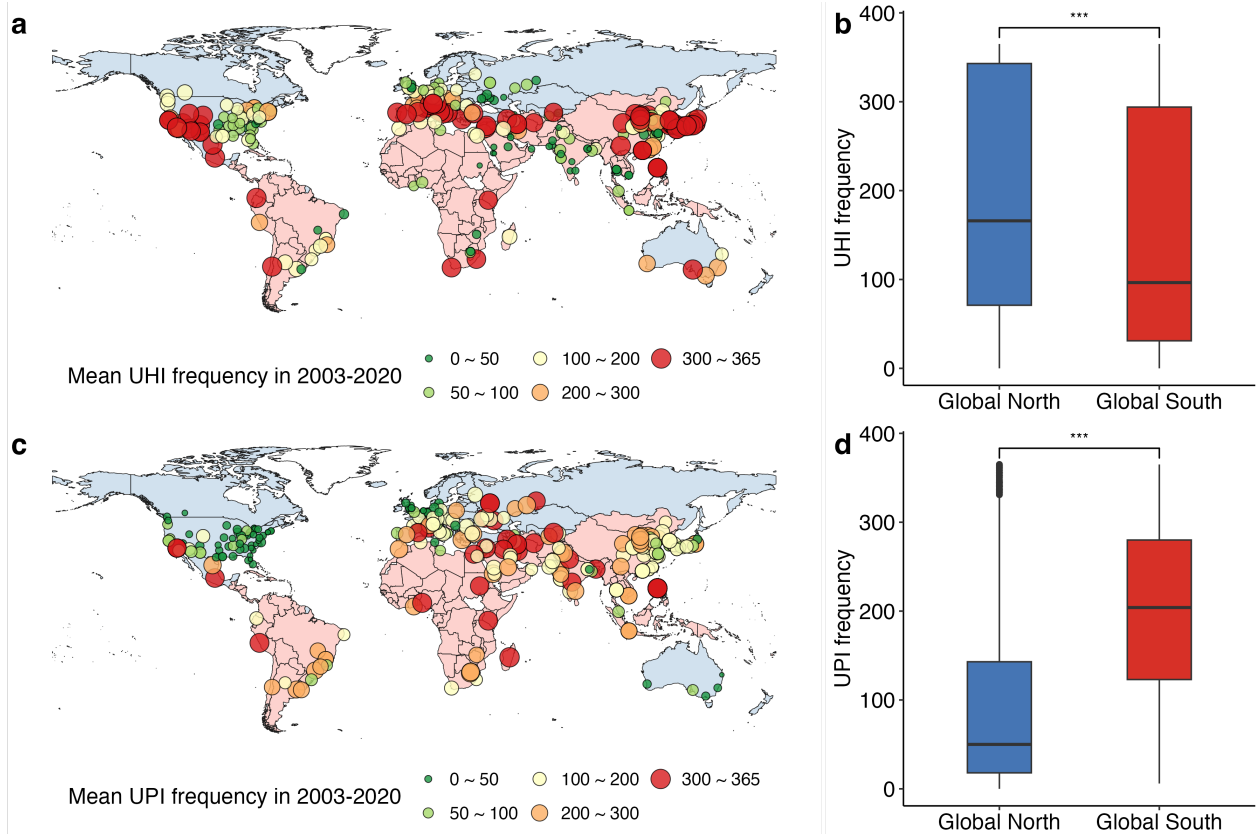


Fig. S5. Frequency of UHI and UPI for global 327 cities from 2003 to 2020. (a) Mean UHI frequency for global 327 cities from 2003 to 2020. (b) Summary of UHI frequency for Global North and Global South cities from 2003 to 2020. (c) Mean UPI frequency for global cities from 2003 to 2020. (d) Summary of UPI frequency for Global North and Global South cities from 2003 to 2020. ‘***’ indicates significant differences at the 0.001 levels.

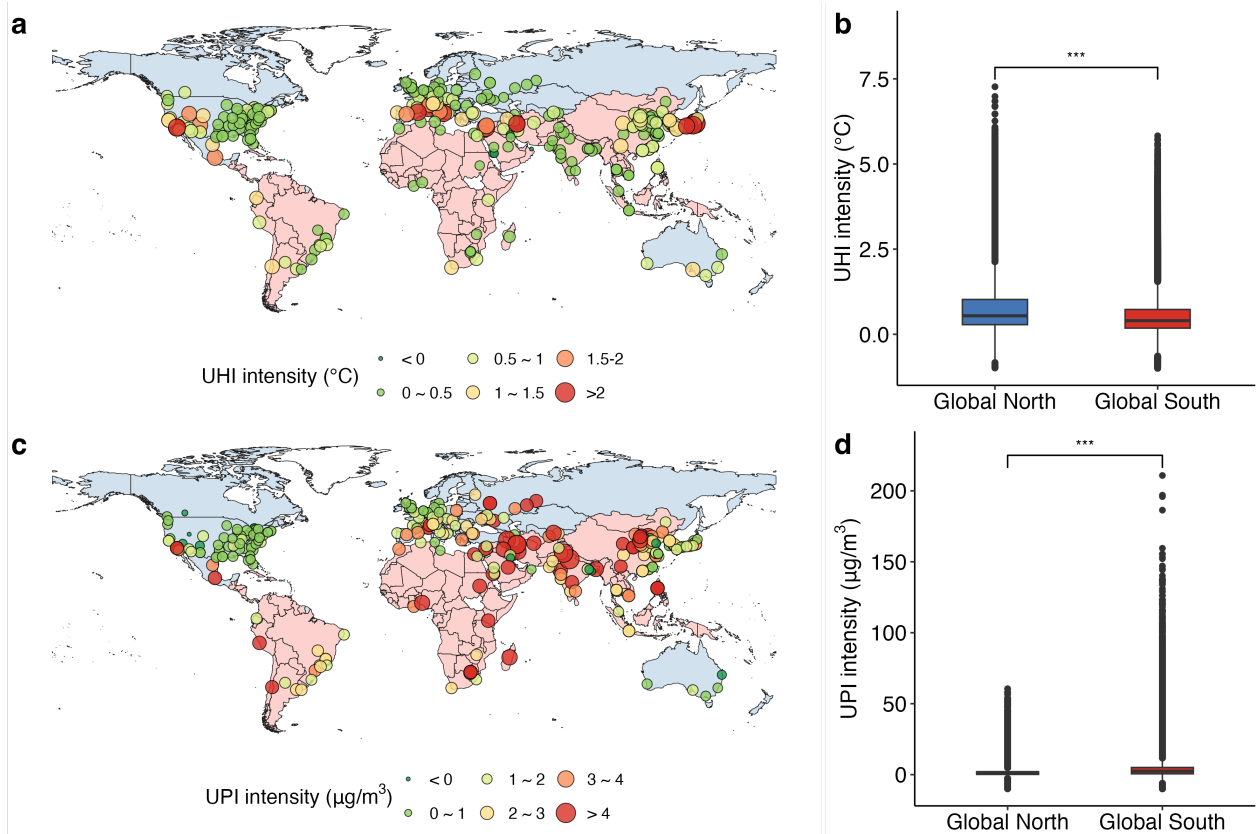


Fig. S6. Intensity of UHI and UPI for global 327 cities from 2003 to 2020. (a) Mean UHI intensity for global 327 cities from 2003 to 2020. (b) Summary of UHI intensity for Global North and Global South cities from 2003 to 2020. (c) Mean UPI intensity for global cities from 2003 to 2020. (d) Summary of UPI intensity for Global North and Global South cities from 2003 to 2020. ‘***’ indicates significant differences at the 0.001 levels.

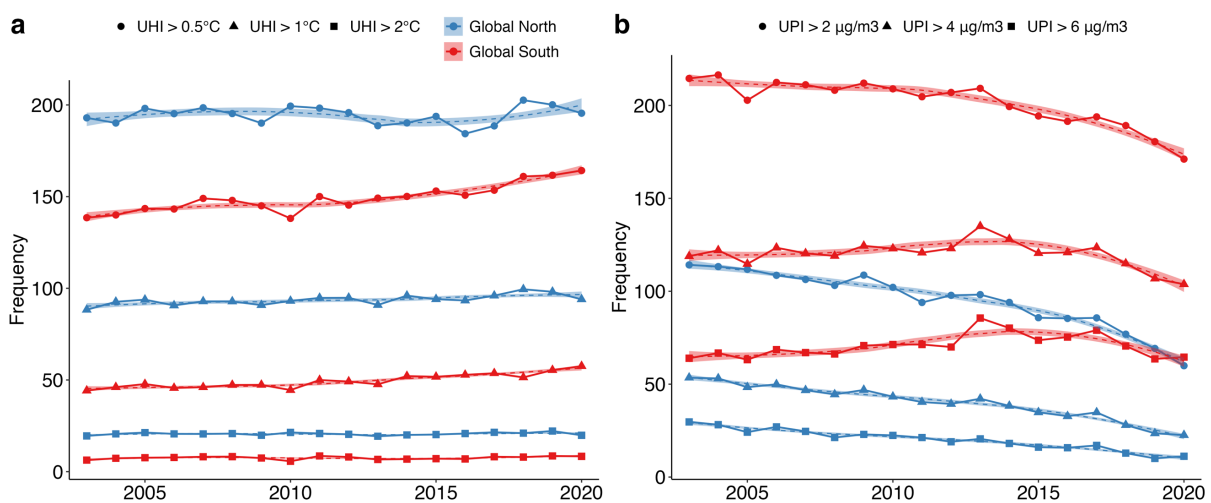


Fig. S7. Frequency (number of days per year) change of UHI (a) and UPI (b) in Global South and Global North cities from 2003 to 2020.

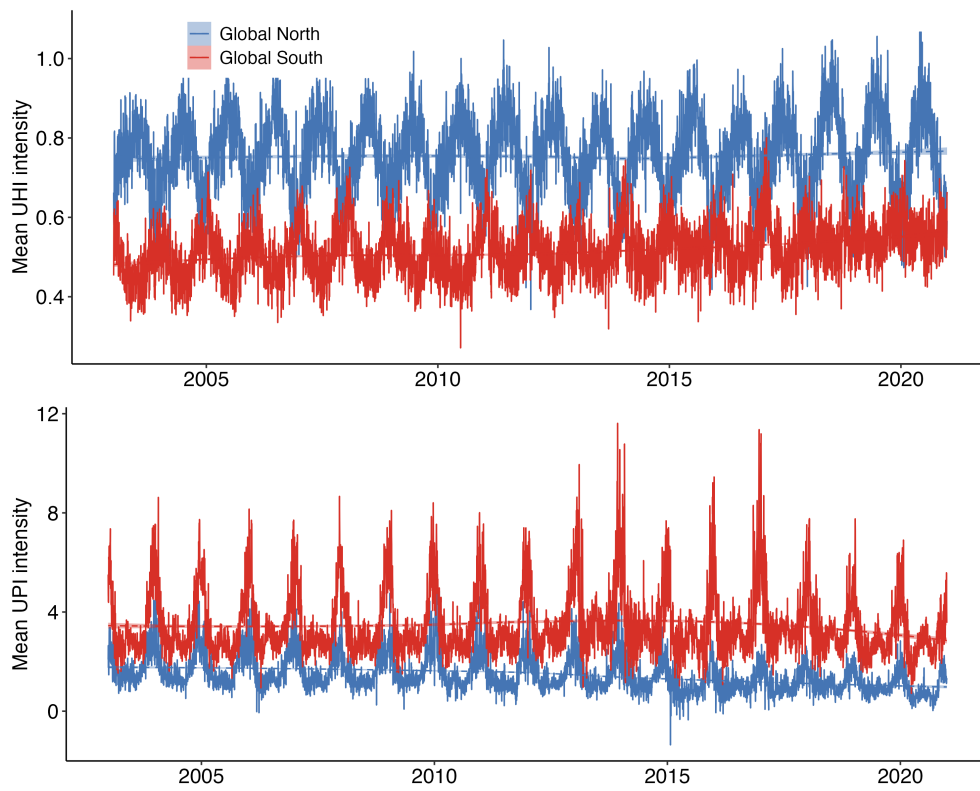


Fig. S8. Intensity change of UHI (top) and UPI (bottom) in Global South and Global North cities from 2003 to 2020.

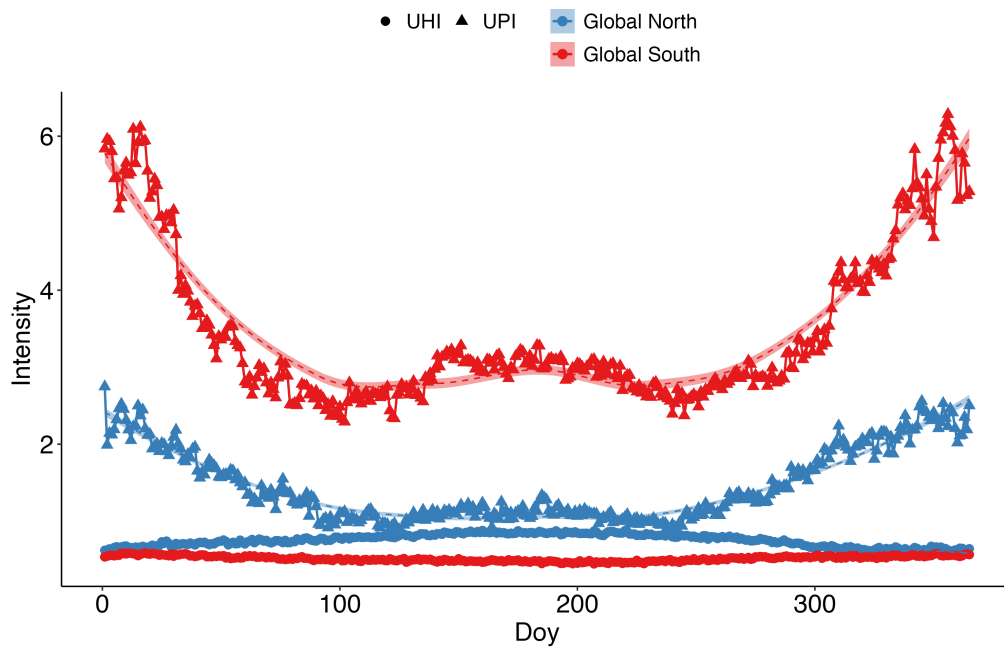


Fig. S9. Seasonal variations of daily UHI and UPI intensity in Global South and Global North cities.

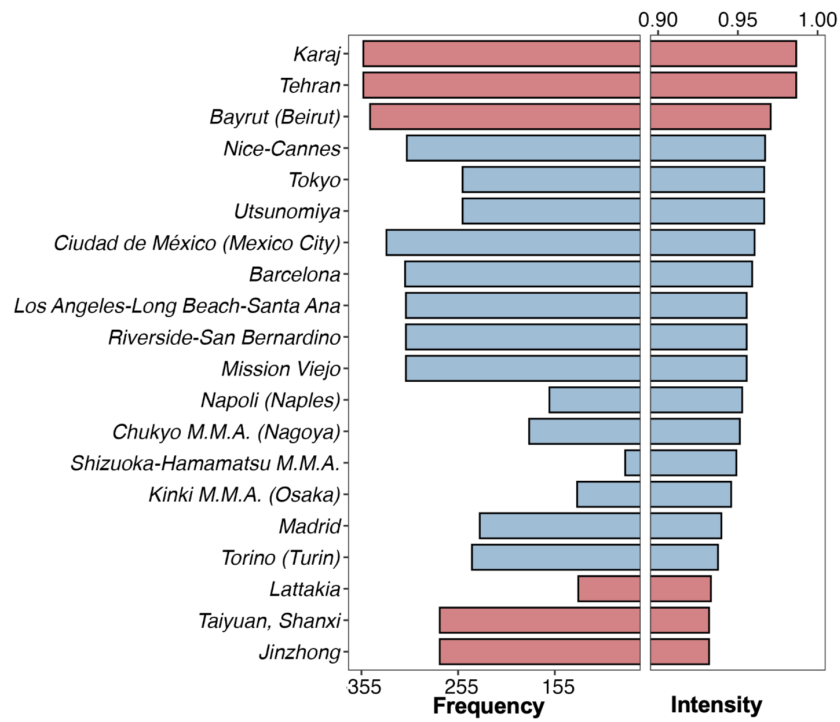


Fig. S10. The top 20 cities with the highest compound intensity of UHI and UPI and their associated compound frequency of UHI and UPI.

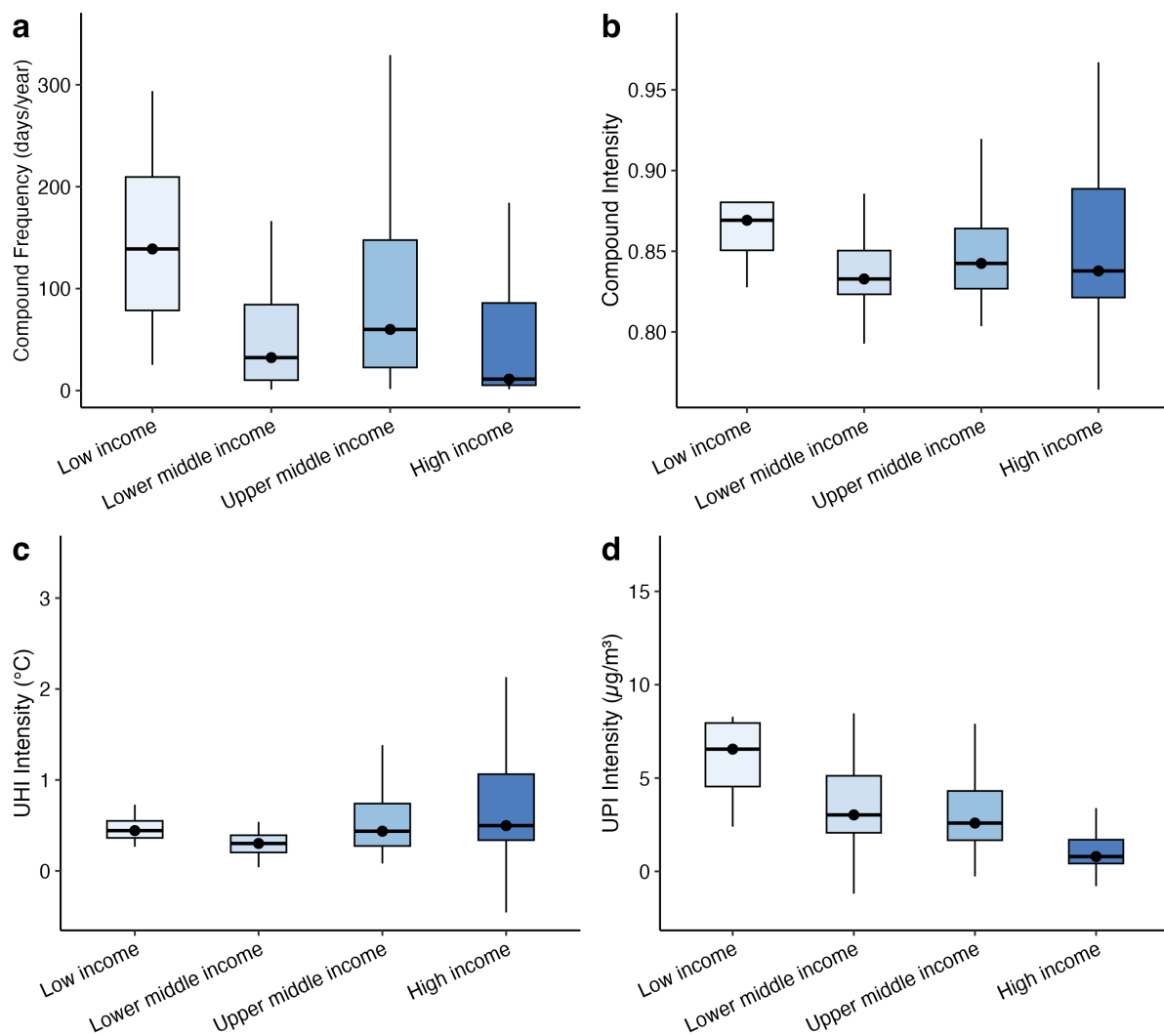


Fig. S11. Comparison of (a) compound frequency, (b) compound intensity, (c) UHI intensity and (d) UPI intensity in countries of different income.

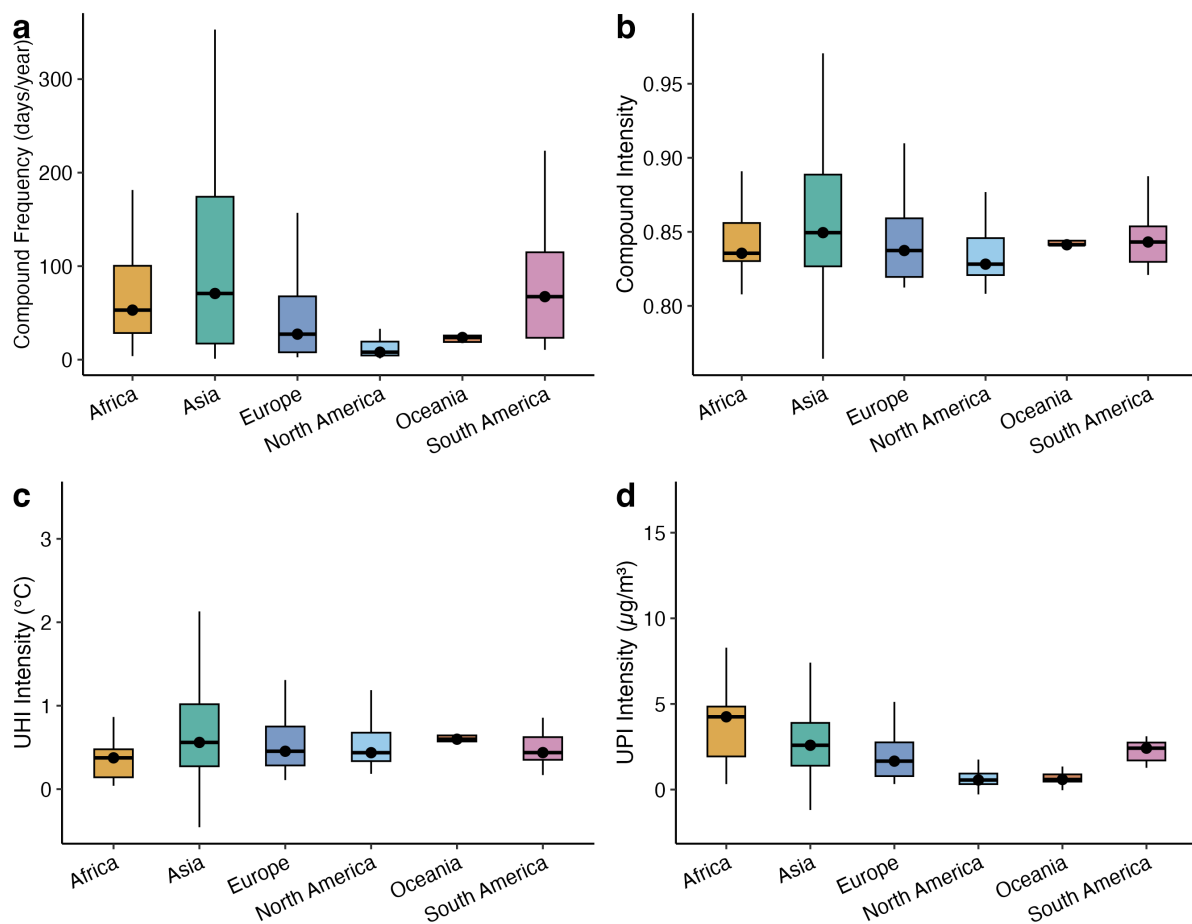


Fig. S12. Comparison of (a) compound frequency, (b) compound intensity, (c) UHI intensity and (d) UPI intensity in different continents.

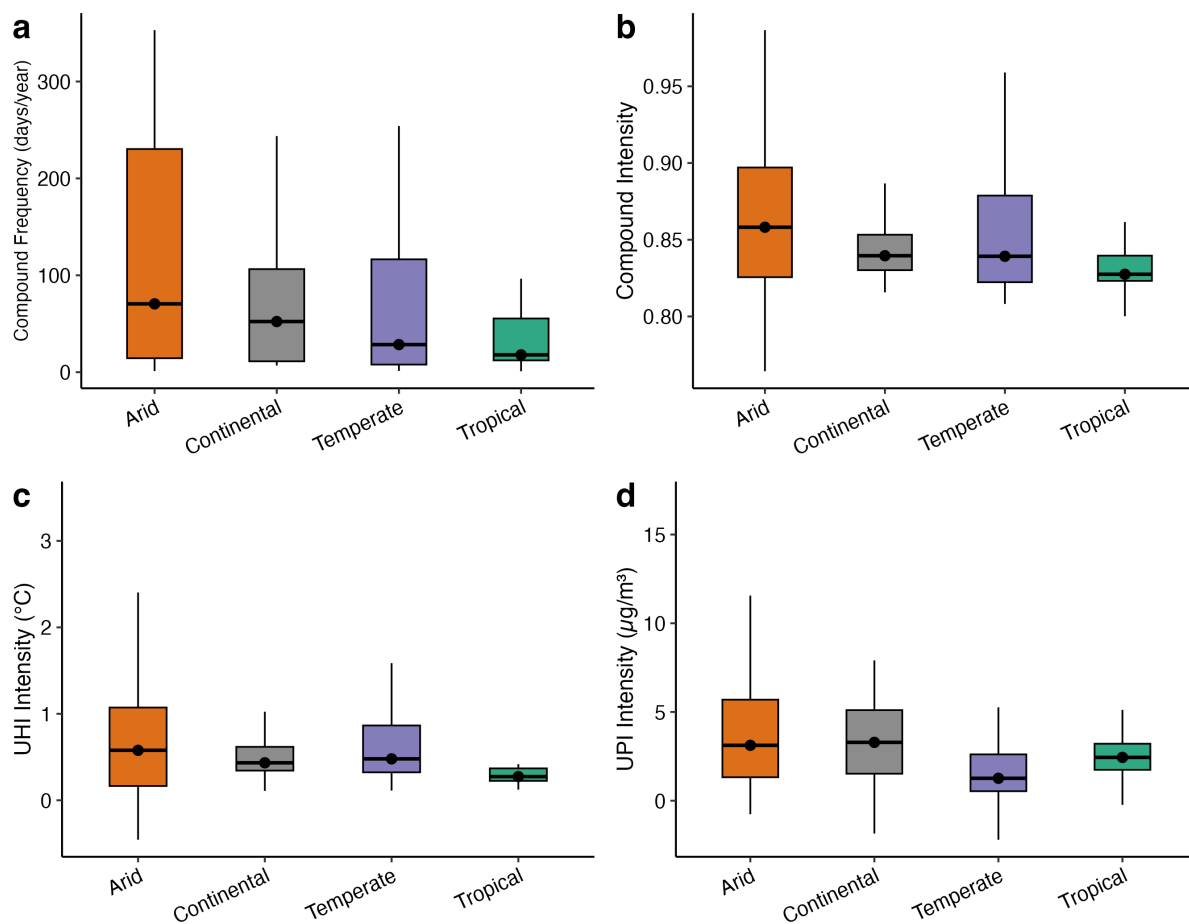


Fig. S13. Comparison of (a) compound frequency, (b) compound intensity, (c) UHI intensity and (d) UPI intensity in different climate regions.

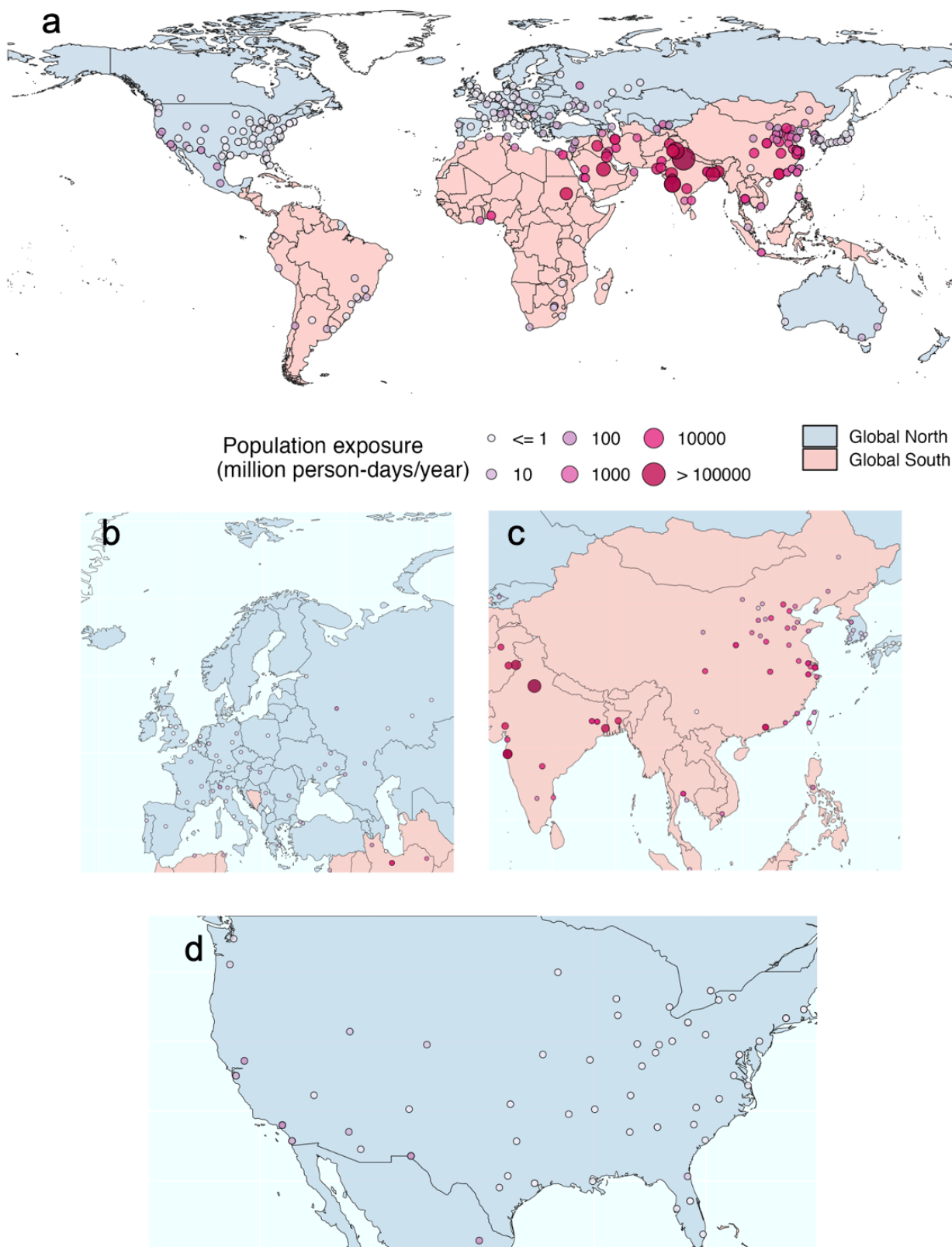


Fig. S14. Mean compound exposure to heat and air pollution (PM2.5) during 2003 to 2020 in (a) global, (b) Europe, (c) China and India, and (d) United States.

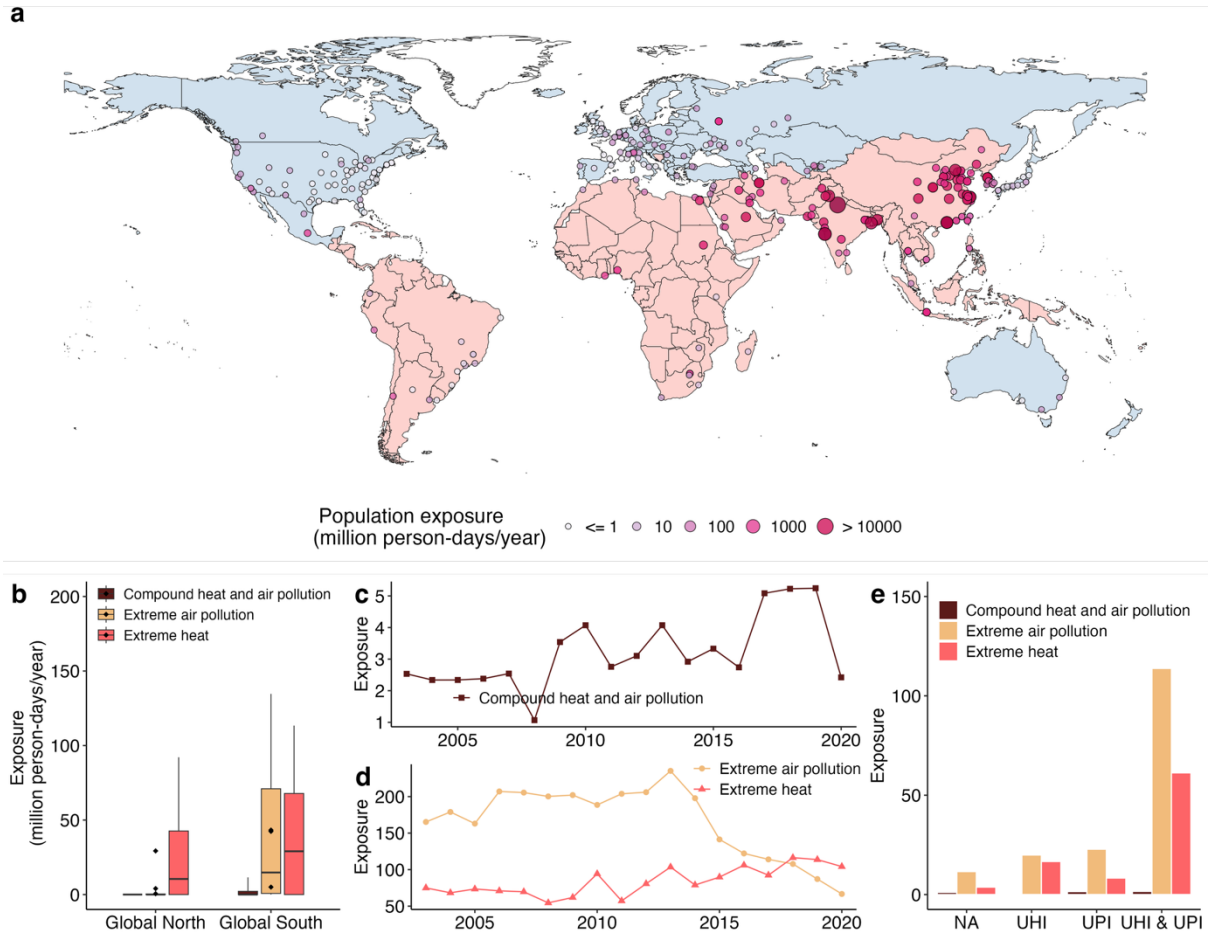


Fig. S15. Compound exposure to extreme heat and air pollution in global cities. a, Averaged compound exposure to heat and air pollution ($PM_{2.5}$) from 2003 to 2020, the threshold of daily extreme heat was 95% percentile and the threshold of daily extreme air pollution was $75 \mu g/m^3$. b, Averaged exposure (million person-days/year) to heat, $PM_{2.5}$ and compound risk of cities in Global North and Global South from 2003 to 2020. c, Time series annual compound exposure (million person-days/year) to extreme heat and air pollution of cities from 2003 to 2020. d, Time series annual exposure (million person-days/year) to extreme heat and air pollution of cities from 2003 to 2020. e, Averaged exposure (million person-days/year) to heat, $PM_{2.5}$, and compound risk of cities with UHI, UPI, both UHI & UPI and non UHI & UPI (NA) from 2003 to 2020.

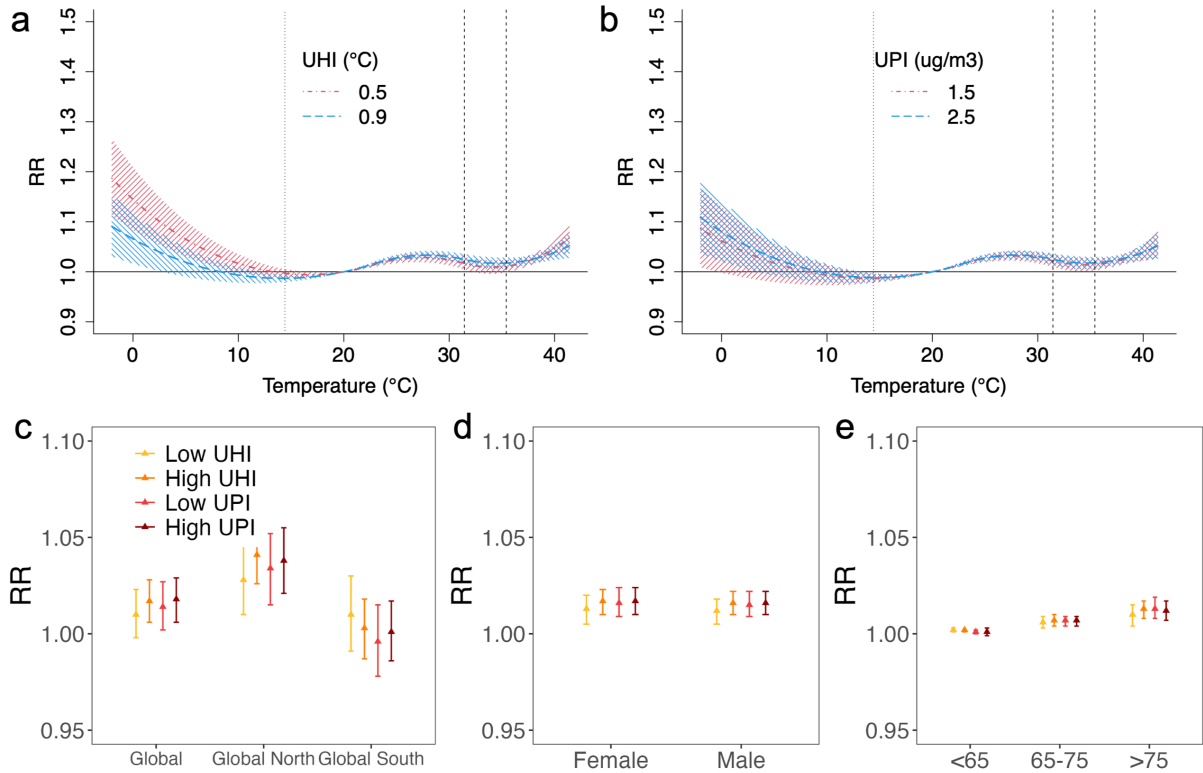


Fig. S16. Cumulative relative risk (RR) of cities in high and low UHI and UPI levels and different groups. (a) RR of in high UHI and low UHI levels. (b) RR of in high UPI and low UPI levels. (c) RR of cities globally, in Global North and in Global South with different UHI and UPI levels. (d) RR of different sex groups in global cities with different UHI and UPI levels. e, RR of different age groups in global cities with different UHI and UPI levels.

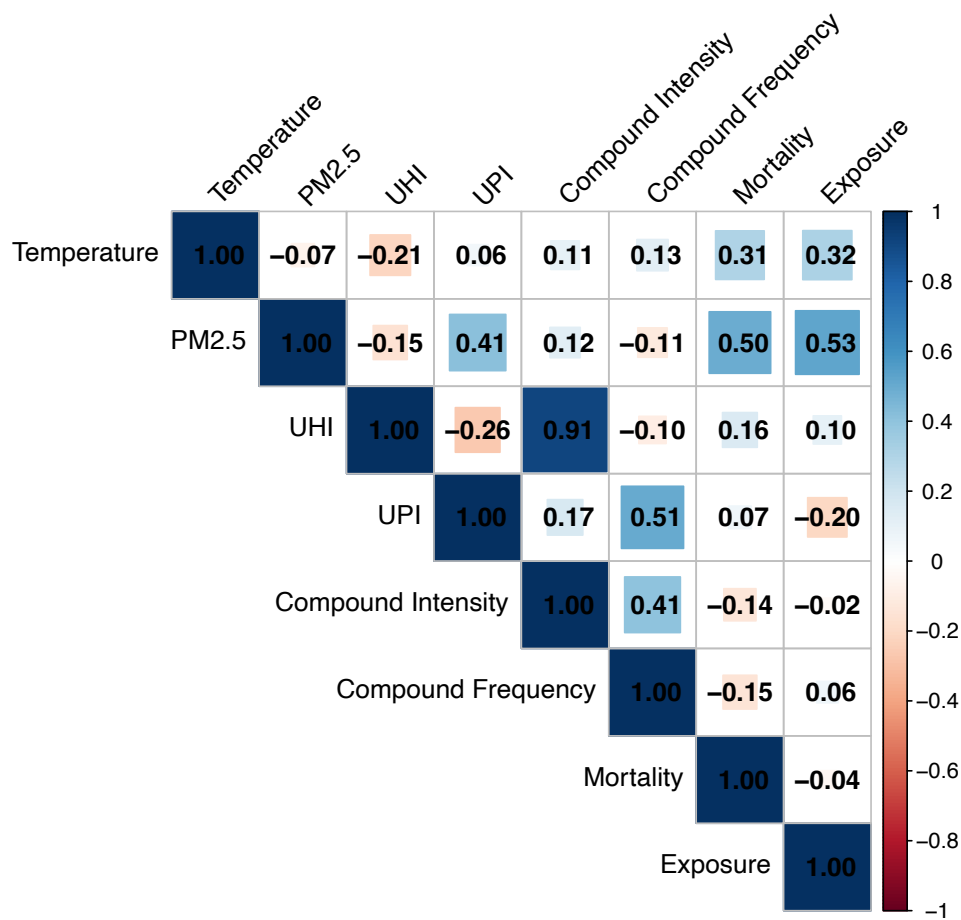


Fig. S17. Partial correlation among temperature, PM_{2.5}, UHI, UPI, compound frequency of UHI and UPI, compound intensity of UHI and UPI, and mortality rate.

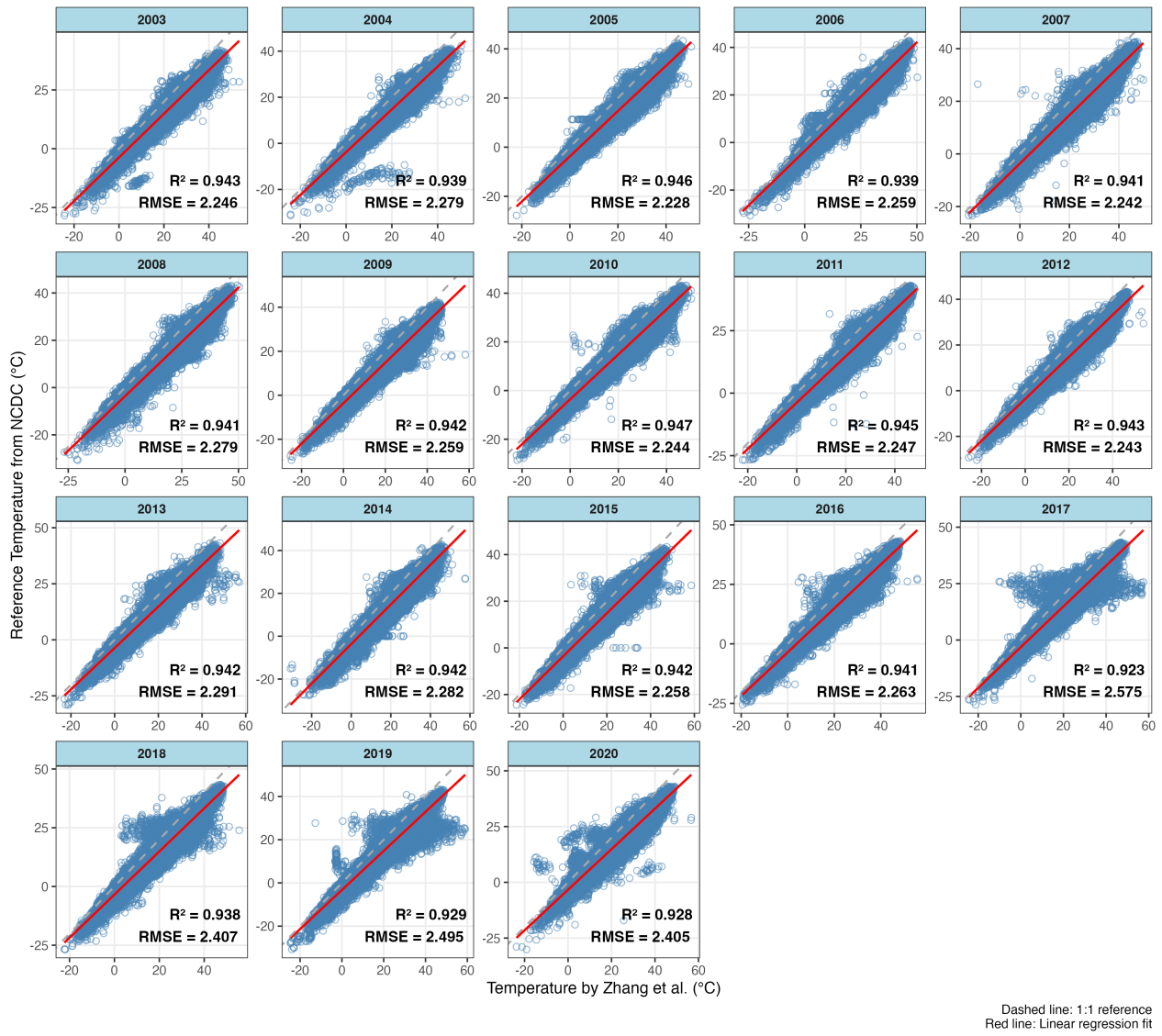


Fig. S18. Scatter plots between the daily maximum air temperature by Zhang et al. and the observed T_a from NCDC from 2003 to 2020. The dashed line indicates the 1:1 reference line and the red line indicates the linear regression fit.

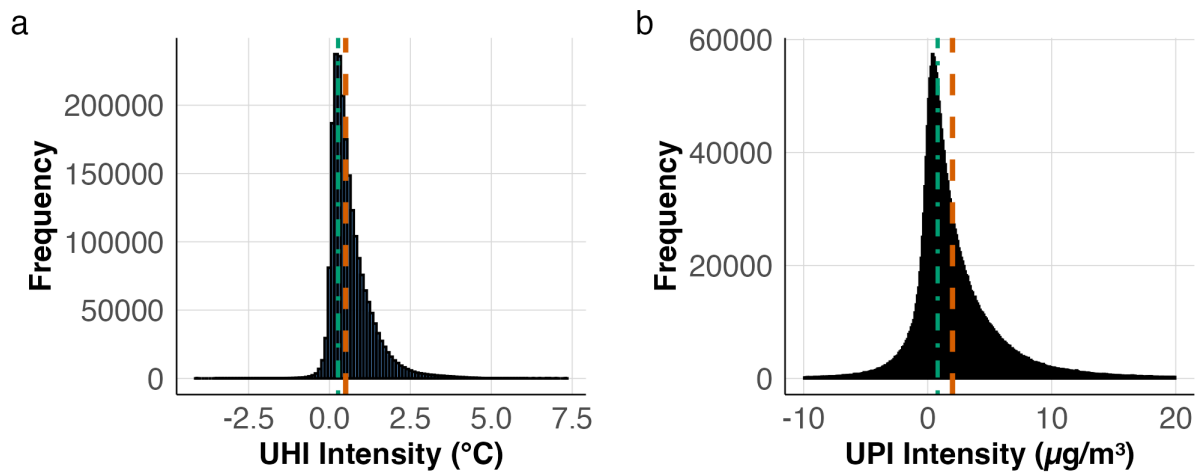


Fig. S19. The histogram of (a) UHI intensity and (b) UPI intensity. The orange dashed line indicates the proposed threshold while the green dotdash line indicates the 25th percentile of the value greater than 0. The proposed threshold for UHI intensity is 0.5 °C, with a corresponding 25th percentile of 0.27 °C. For UPI intensity, the proposed threshold is 2 $\mu\text{g}/\text{m}^3$, and the 25th percentile is 0.8 $\mu\text{g}/\text{m}^3$.

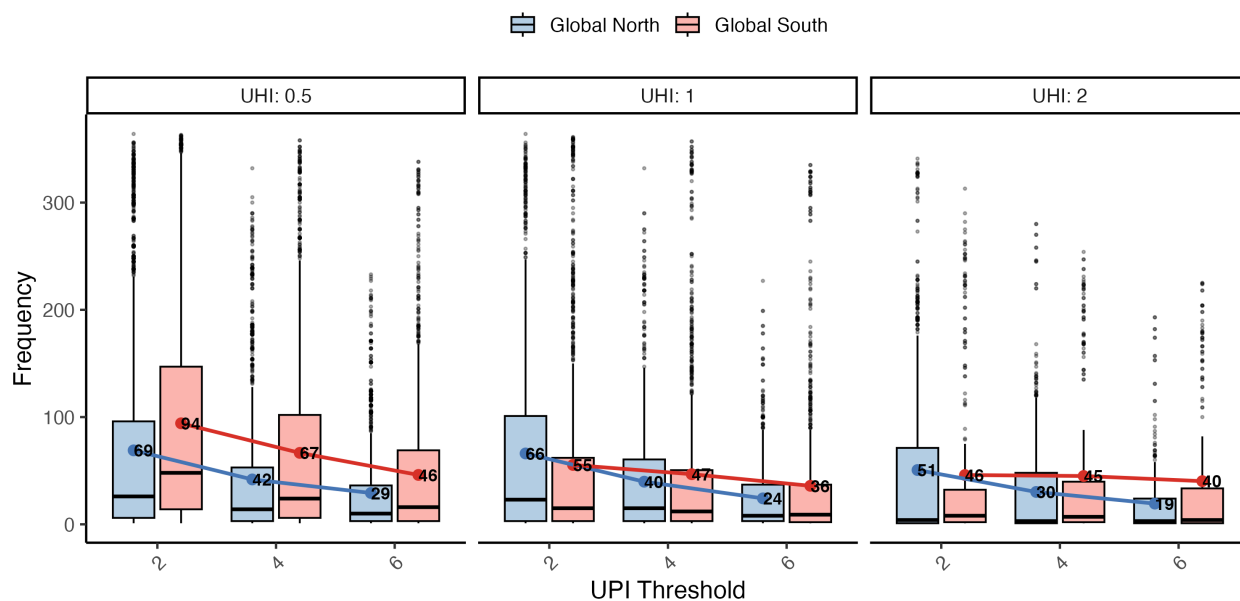


Fig. S20. The boxplot of the UHI with different threshold of 0.5°C, 1 °C and 2 °C and UPI with different threshold of 2 $\mu\text{g}/\text{m}^3$, 4 $\mu\text{g}/\text{m}^3$ and 6 $\mu\text{g}/\text{m}^3$.

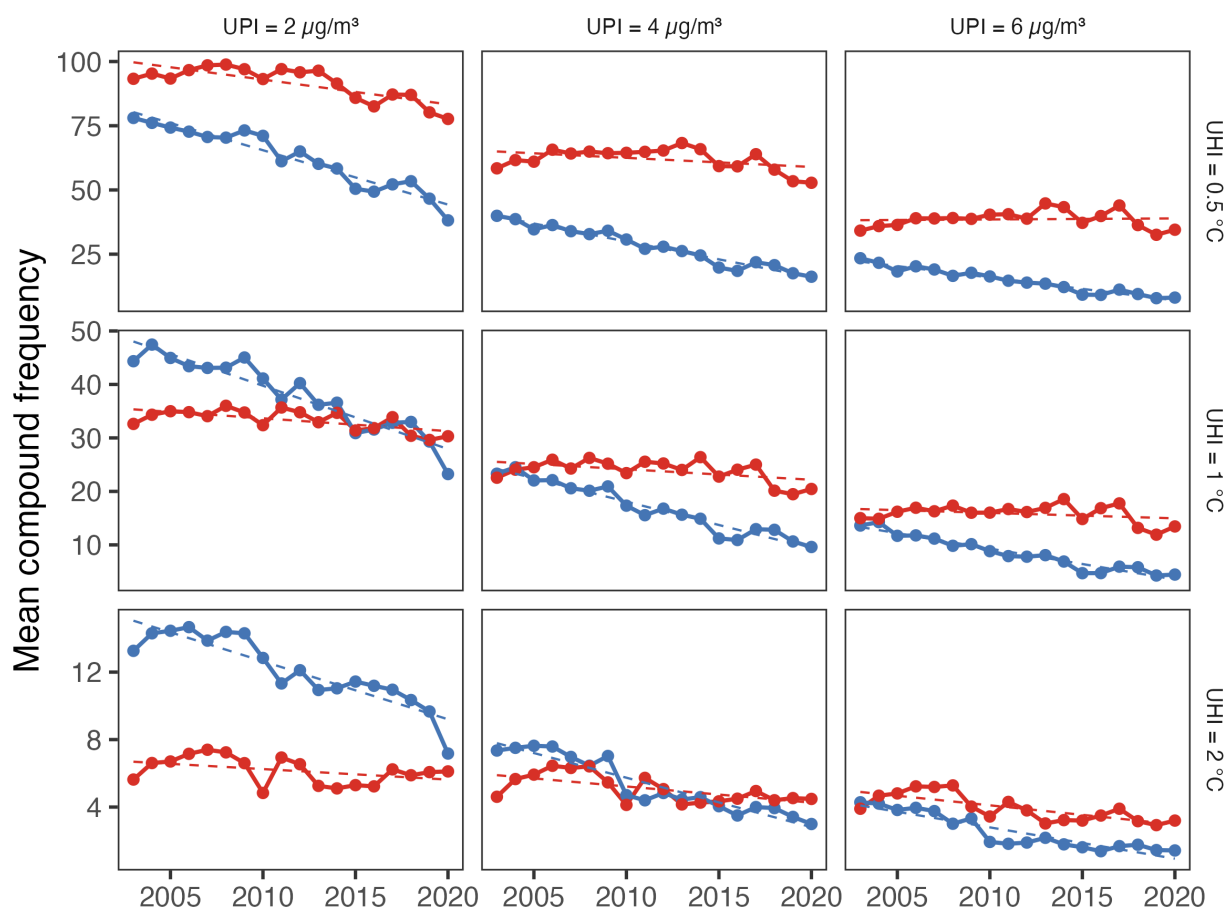


Fig. S21. Yearly changes for the compound frequency for the different threshold of UHI and UPI from 2003 to 2020. Row 1 from left to right, thresholds for UHI and UPI are 0.5 °C and 2 µg/m³, 0.5 °C and 4 µg/m³, and 0.5 °C and 6 µg/m³ respectively. Row 2 from left to right, thresholds for UHI and UPI are 1 °C and 2 µg/m³, 1 °C and 4 µg/m³, and 1 °C and 6 µg/m³ respectively. Row 3 from left to right, thresholds for UHI and UPI are 2 °C and 2 µg/m³, 2 °C and 4 µg/m³, and 2 °C and 6 µg/m³ respectively.

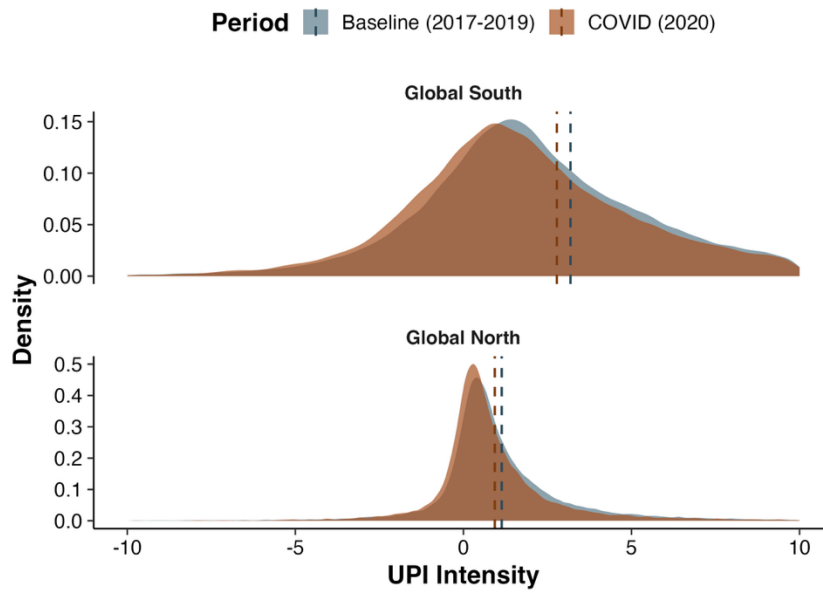


Figure S22. UPI intensity changes between baseline (2017-2019) and COVID (2020) period.

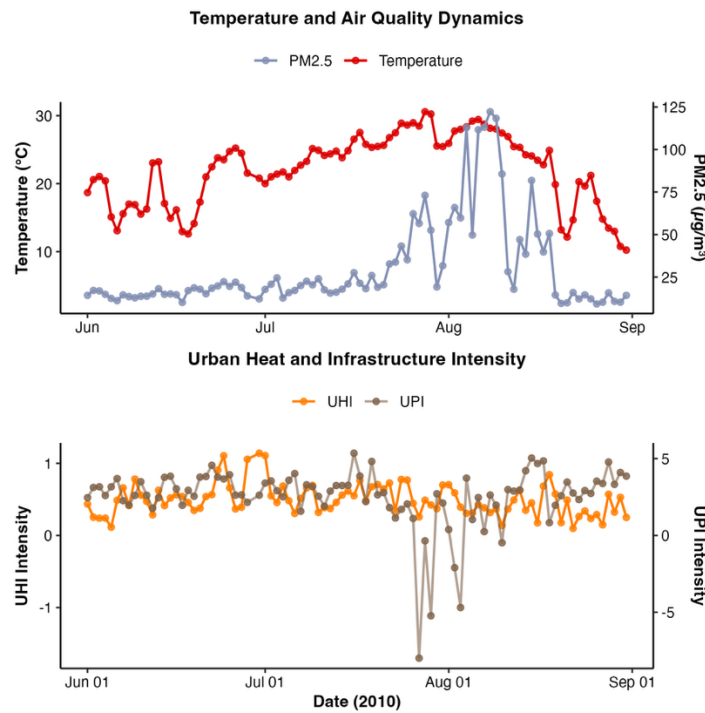


Fig. S23. Changes of temperature, PM2.5, UHI intensity and UPI intensity of the case Moscow wildfire during Jun 1 to Aug 31 in 2010.

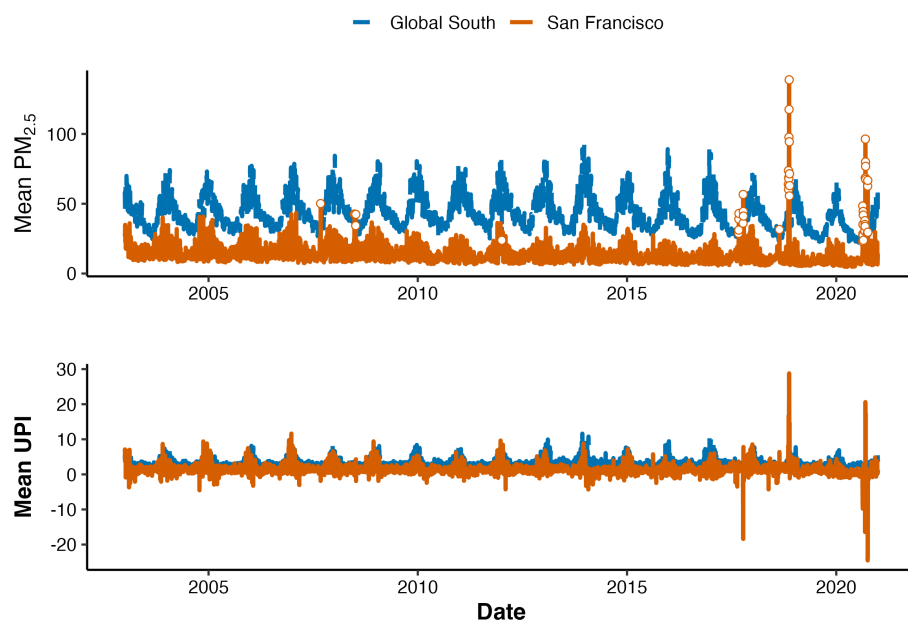


Fig. S24. Comparison between the mean $PM_{2.5}$ and mean UPI in San Francisco and Global South cities. The white dots indicate the date that the $PM_{2.5}$ of San Francisco exceeds the Global South cities.

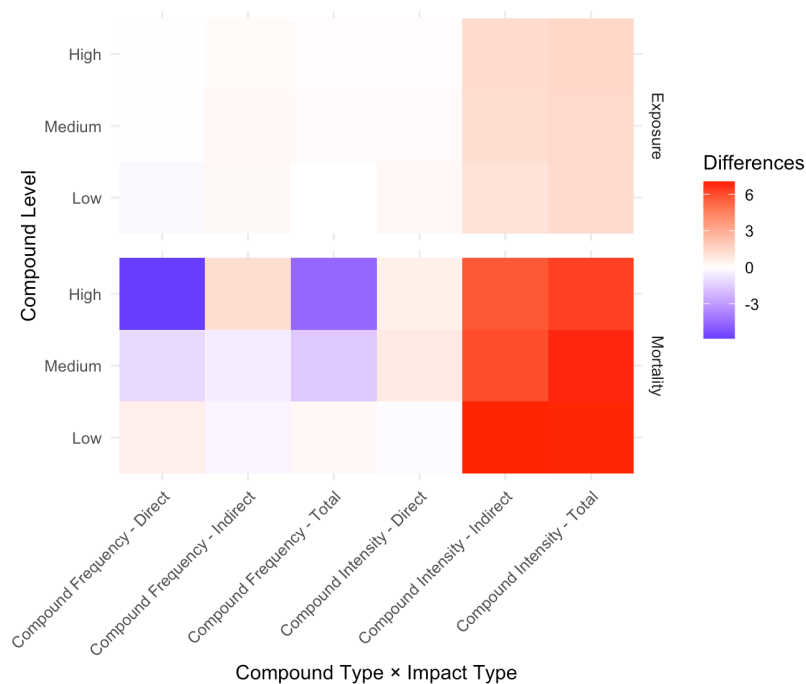


Fig. S25. Exposure and mortality risks at different compound frequency levels of structural equation modeling.

Table S1. Fitted measures for the SEM model of mortality among 70 selected cities.

Fitting Index	Evaluation criterion	Model
χ^2	$P > 0.05$	P=0.000
RMSEA	< 0.08	0.077
TLI	> 0.90	0.972
CFI	> 0.90	0.994
AIC	The smaller the better	11790.016
SRMR	< 0.08	0.019

Table S2. Fitted measures for the SEM model of exposure among 323 cities.

Fitting Index	Evaluation criterion	Model
χ^2	$P > 0.05$	P=0.000
RMSEA	< 0.08	0.078
TLI	> 0.90	0.969
CFI	> 0.90	0.996
AIC	The smaller the better	11843.814
SRMR	< 0.08	0.011

Table S3. Statistics of group SEM by Global South and Global North and group constraint SEM of mortality among selected 70 cities.

	Df	AIC	BIC	Chisq	Chisq diff	RMSEA	Df diff	Pr (>Chisq)
fit group	16	6721.3	7118.3	246.82				
fit group constraint	49	8807.4	9044.6	2398.9	2152.1	0.37042	33	$< 2.20E-16$ ***

Table S4. Statistics of group SEM by Global South and Global North and group constraint SEM of exposure among 323 cities.

	Df	AIC	BIC	Chisq	Chisq diff	RMSEA	Df diff	Pr (>Chisq)
fit group	10	45845	46403	263.15				
fit group constraint	46	51273	51603	5763.47	5500.3	0.26972	36	$< 2.20E-16$ ***

Table S5. Group SEM of mortality of selected 70 cities among urban population, compound frequency of UHI and UPI, compound intensity of UHI and UPI, urban greening, temperature, PM_{2.5}, and mortality in cities in Global South, and Global North.

Global South	Estimate	Std.Err	z-value	P(> z)
Mortality	~			
Temperature	1.003	0.231	4.334	0
PM25	0.588	0.074	7.99	0
Compound Intensity	0.04	0.28	0.143	0.886
Compound Frequency	-0.502	0.147	-3.419	0.001
Temperature	~			
UHI	1.453	0.16	9.082	0
UPI	0.249	0.027	9.206	0
Population	0.441	0.02	22.056	0
NDVI	-0.194	0.016	-12.411	0

Compound Intensity	-1.626	0.155	-10.495	0
Compound Frequency	0.017	0.031	0.537	0.591
PM25	~			
UHI	9	0.715	12.596	0
UPI	2.059	0.144	14.338	0
Population	-0.018	0.112	-0.16	0.873
Temperature	0.463	0.209	2.21	0.027
NDVI	-0.717	0.055	-13.011	0
Compound Intensity	-8.535	0.699	-12.208	0
Compound Frequency	0.671	0.089	7.535	0
Compound Intensity	~			
UHI	1.146	0.014	83.743	0
UPI	0.192	0.015	13.2	0
popu	-0.001	0.01	-0.081	0.936
Compound Frequency	~			
UHI	1.09	0.076	14.432	0
UPI	0.208	0.043	4.807	0
Population	0.176	0.027	6.524	0
UHI	~			
Population	0.074	0.038	1.937	0.053
UPI	~			
Population	0.124	0.091	1.354	0.176
UHI	-0.42	0.118	-3.543	0
Global North	Estimate	Std.Err	z-value	P(> z)
Mortality	~			
Temperature	0.26	0.012	21.023	0
PM25	-0.203	0.036	-5.629	0
Compound Intensity	-0.07	0.012	-5.702	0
Compound Frequency	0.074	0.015	4.815	0
Temperature	~			
UHI	-0.224	0.065	-3.458	0.001
UPI	-0.094	0.072	-1.316	0.188
Population	-0.06	0.064	-0.949	0.342
NDVI	-0.19	0.035	-5.383	0
Compound Intensity	0.038	0.087	0.432	0.666
Compound Frequency	0.415	0.093	4.455	0
PM25	~			
UHI	-0.228	0.03	-7.517	0
UPI	0.04	0.03	1.365	0.172
Population	0.119	0.023	5.179	0
Temperature	-0.011	0.01	-1.089	0.276
NDVI	0.001	0.01	0.069	0.945

Compound Intensity	0.227	0.034	6.617	0
Compound Frequency	0.137	0.038	3.584	0
Compound Intensity	~			
UHI	0.889	0.019	46.22	0
UPI	0.13	0.02	6.508	0
popu	0.173	0.022	8.006	0
Compound Frequency	~			
UHI	0.386	0.021	18.607	0
UPI	0.729	0.033	21.846	0
Population	0.369	0.038	9.678	0
UHI	~			
Population	0.703	0.061	11.608	0
UPI	~			
Population	0.522	0.05	10.424	0
UHI	0.265	0.043	6.184	0

Table S6. Group SEM of exposure of selected 323 cities among urban population, compound frequency of UHI and UPI, compound intensity of UHI and UPI, urban greening, temperature, PM_{2.5}, and mortality in cities in Global South, and Global North.

Global South	Estimate	Std.Err	z-value	P(> z)
Exposure	~			
Temperature	0.430	0.017	25.006	0.000
PM2.5	0.539	0.017	32.559	0.000
Compound Intensity	-0.021	0.030	-0.711	0.477
Compound Frequency	0.111	0.025	4.479	0.000
NDVI	-0.096	0.016	-6.060	0.000
Temperature	~			
UHI	-0.513	0.100	-5.120	0.000
UPI	-0.008	0.032	-0.264	0.792
popu	0.385	0.018	20.857	0.000
NDVI	0.113	0.022	5.069	0.000
Compound Intensity	-0.026	0.106	-0.244	0.807
Compound Frequency	0.059	0.031	1.891	0.059
PM2.5	~			
UHI	1.860	0.132	14.107	0.000
UPI	0.678	0.054	12.620	0.000
Population	0.263	0.021	12.639	0.000
Temperature	-0.346	0.026	-13.289	0.000
NDVI	-0.432	0.020	-21.394	0.000
Compound Intensity	-1.758	0.132	-13.301	0.000
Compound Frequency	-0.152	0.037	-4.090	0.000
Compound Intensity	~			

UHI	0.971	0.007	131.107	0.000
UPI	0.318	0.010	33.274	0.000
Population	0.010	0.004	2.255	0.024
Compound Frequency	~			
UHI	0.968	0.026	37.236	0.000
UPI	0.247	0.015	16.400	0.000
Population	0.030	0.017	1.757	0.079
UHI	~			
Population	-0.064	0.018	-3.613	0.000
NDVI	0.217	0.020	10.717	0.000
UPI	~			
Population	0.095	0.024	3.927	0.000
UHI	0.591	0.039	15.086	0.000
NDVI	-0.417	0.028	-15.025	0.000
Global North	Estimate	Std.Err	z-value	P(> z)
Exposure	~			
Temperature	0.140	0.018	7.622	0.000
PM2.5	0.520	0.048	10.906	0.000
Compound Intensity	0.254	0.027	9.235	0.000
Compound Frequency	-0.114	0.034	-3.363	0.001
NDVI	-0.205	0.019	-10.828	0.000
Temperature	~			
UHI	0.097	0.032	3.018	0.003
UPI	-0.441	0.039	-11.180	0.000
popu	-0.058	0.024	-2.370	0.018
NDVI	-0.058	0.027	-2.189	0.029
Compound Intensity	-0.190	0.048	-3.958	0.000
Compound Frequency	0.457	0.035	13.052	0.000
PM2.5	~			
UHI	-0.309	0.023	-13.188	0.000
UPI	-0.003	0.026	-0.118	0.906
Population	0.195	0.016	12.491	0.000
Temperature	-0.106	0.008	-13.957	0.000
NDVI	0.023	0.007	3.342	0.001
Compound Intensity	0.247	0.025	9.783	0.000
Compound Frequency	0.242	0.024	10.173	0.000
Compound Intensity	~			
UHI	0.796	0.012	67.875	0.000
UPI	0.442	0.007	64.426	0.000
Population	0.033	0.007	4.661	0.000
Compound Frequency	~			

UHI	0.480	0.013	35.797	0.000
UPI	0.757	0.019	39.189	0.000
Population	0.204	0.019	10.851	0.000
UHI	~			
Population	0.462	0.032	14.622	0.000
NDVI	0.297	0.032	9.299	0.000
UPI	~			
Population	0.321	0.027	12.083	0.000
UHI	0.184	0.014	12.773	0.000
NDVI	-0.107	0.024	-4.390	0.000