

# **Supplementary Materials: Lower urban humidity moderates heat stress**

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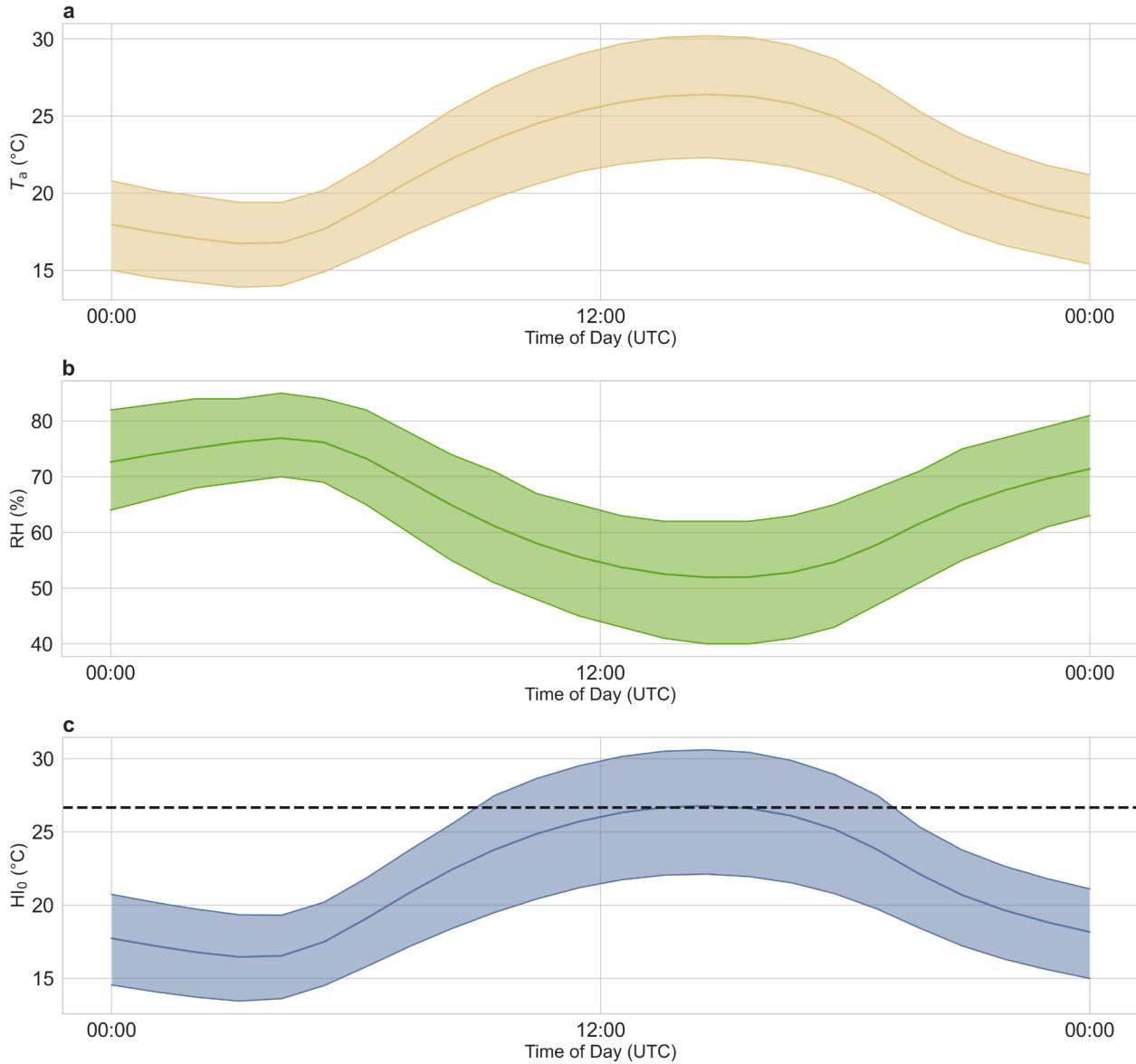
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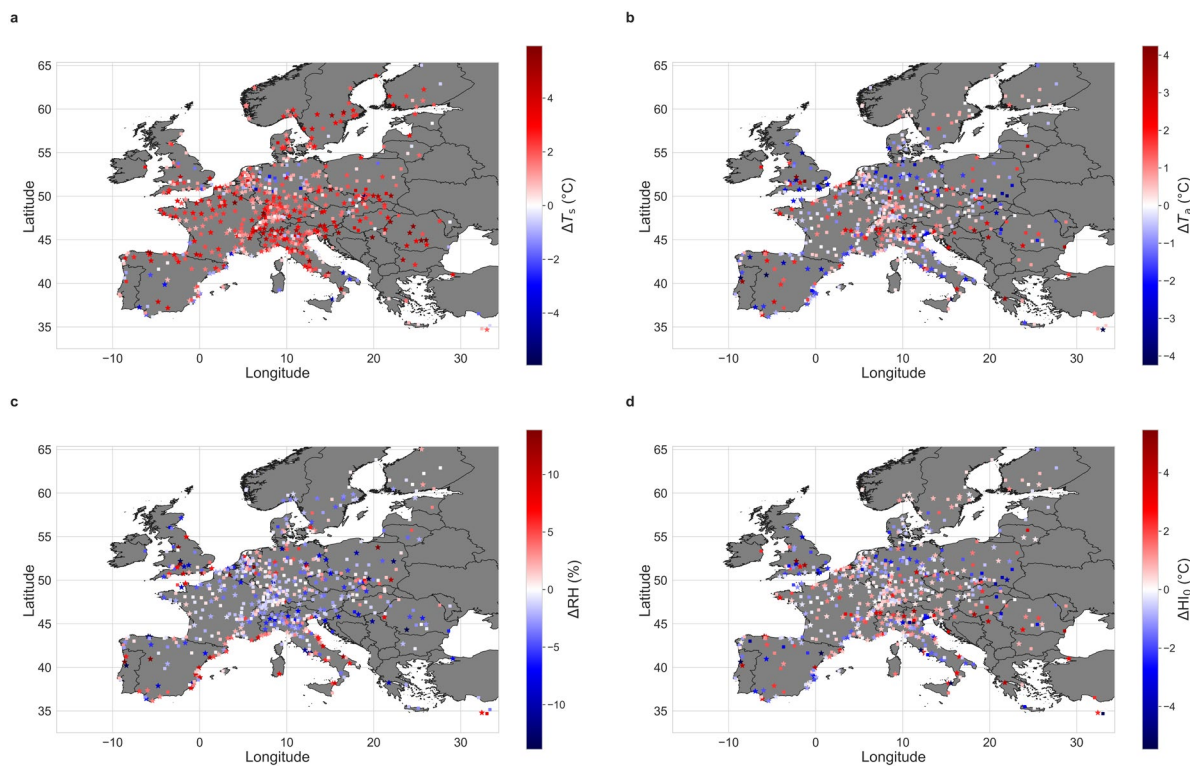
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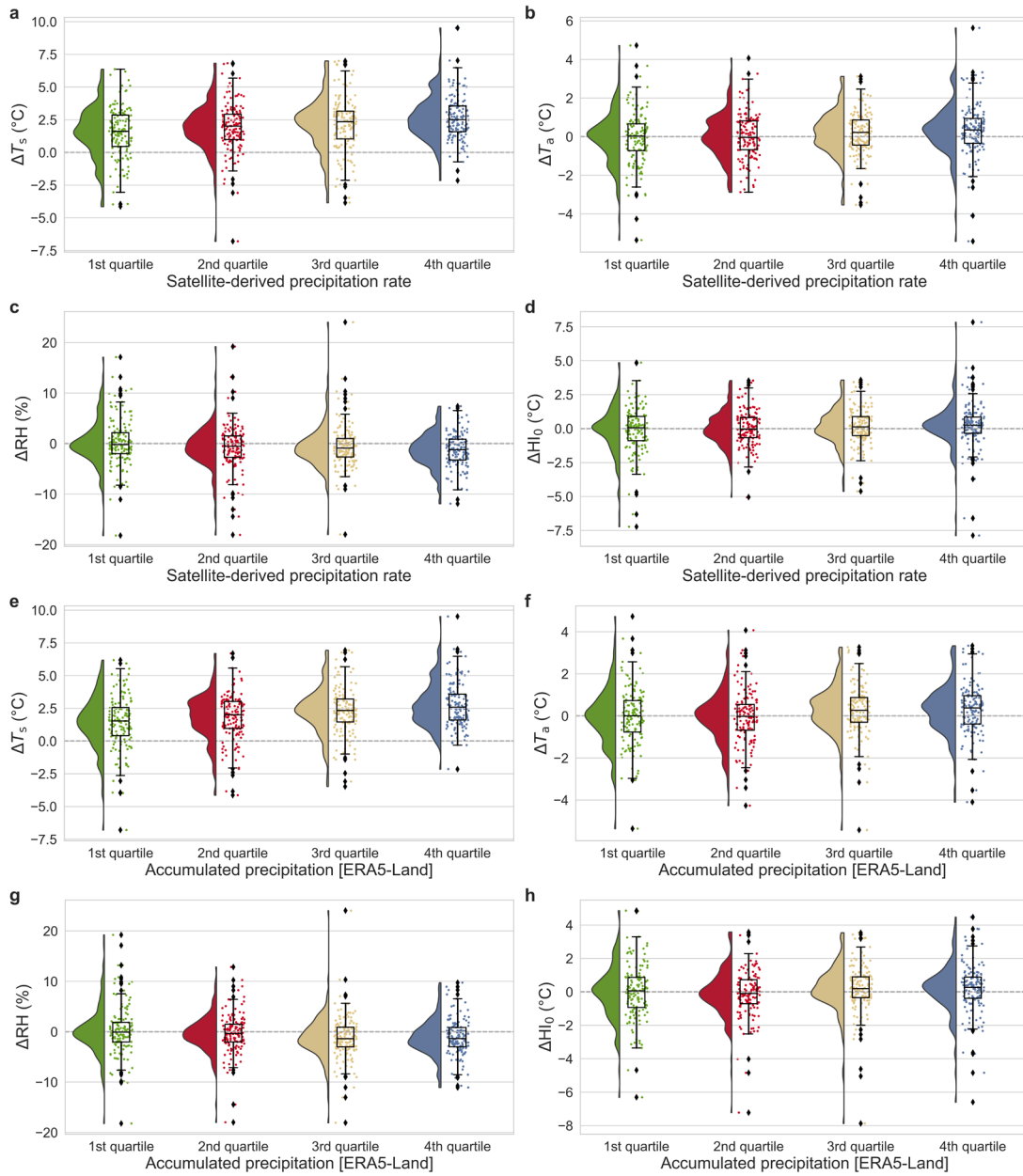
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**Fig. S1** Diurnal composites of citizen weather station data. Diurnal composites of Netatmo **a** air temperature ( $T_a$ ), **b** relative humidity (RH), and **c** heat index ( $HI_0$ ) from all stations in rural buffers considered in the present study. The upper and lower lines represent the 75% and 25% percentile of the measurements, and the middle line is for the mean from all the observations by hour of the day. The dashed horizontal line in sub-figure **c** shows the threshold below which the simplified equation is used for calculating  $HI_0$  (Eq. 1 in Methods).

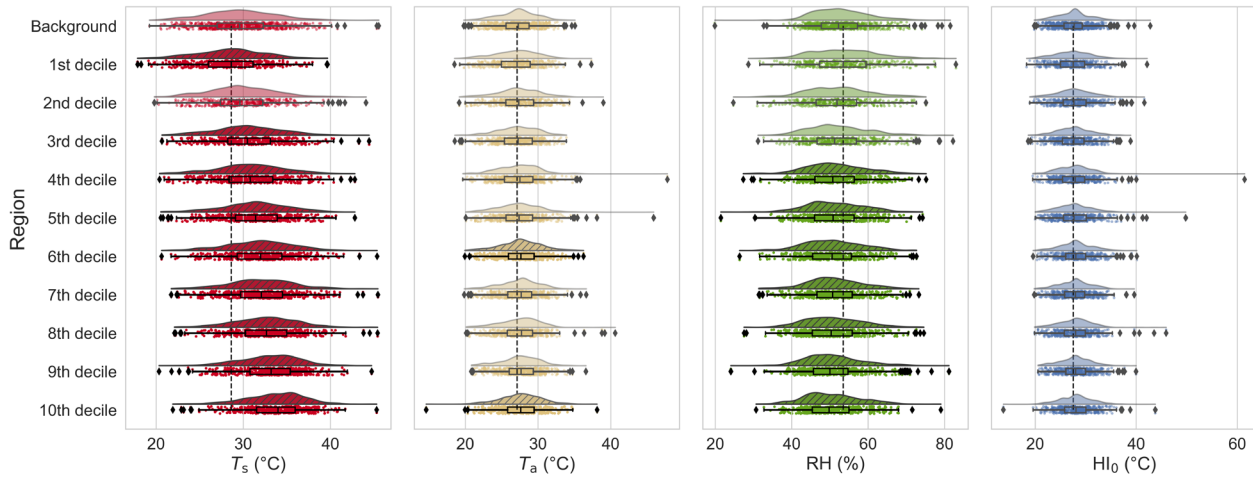
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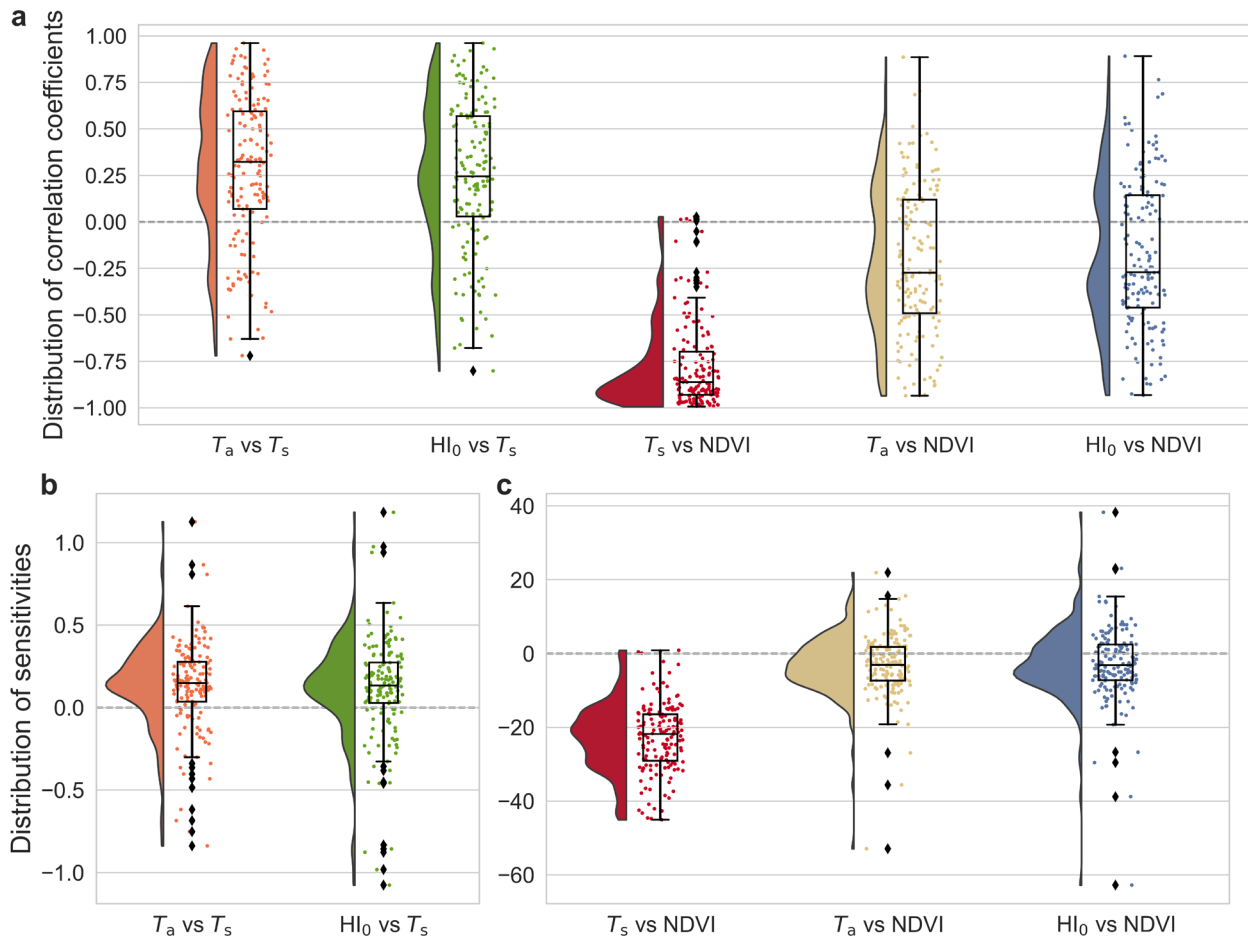
**Fig. S2** Urban-rural differences for Terra day across urban clusters in Europe. Spatial distribution of urban-rural differences in **a** surface temperature ( $\Delta T_s$ ), **b** air temperature ( $\Delta T_a$ ), **c** relative humidity ( $\Delta RH$ ), and **d** heat index ( $\Delta HI_0$ ) for urban clusters in Europe with sufficient data corresponding to the Terra satellite daytime overpass ( $\approx 10:30$  am local time) for July 2019. The stars represent clusters with statistically significant ( $p < 0.01$ ) differences between the urban and rural values.



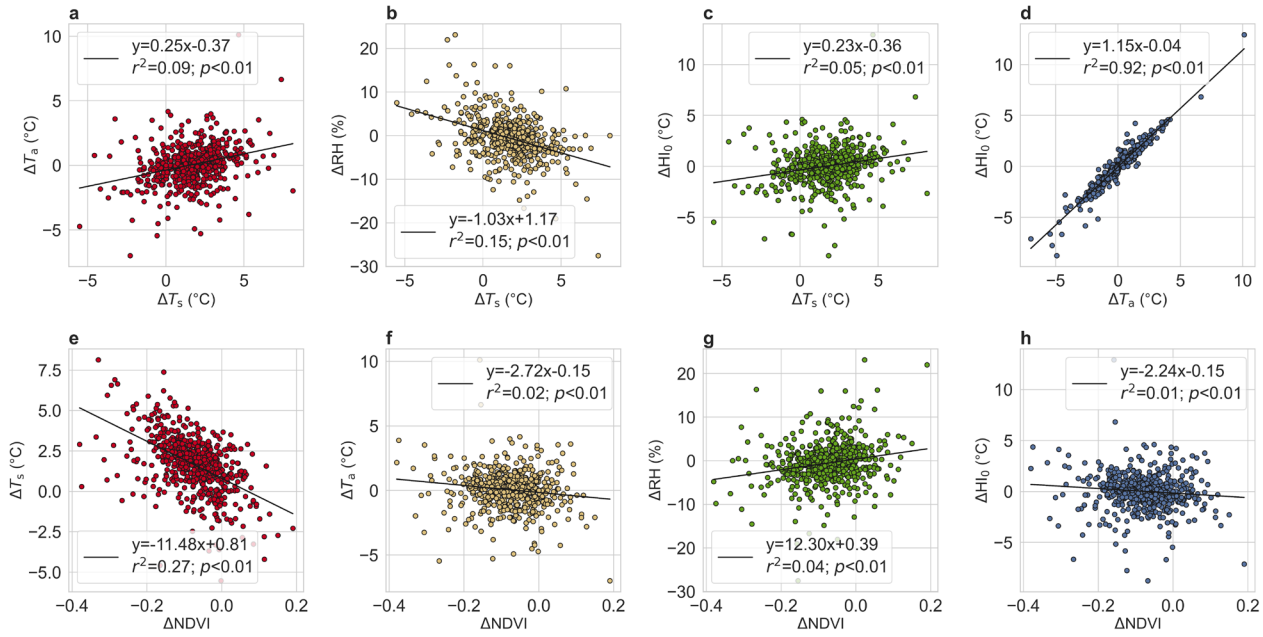
**Fig. S3** Urban-rural differences in variables for precipitation quartiles. Distributions of urban-rural differences in **a** surface temperature ( $\Delta T_s$ ), **b** air temperature ( $\Delta T_a$ ), **c** relative humidity ( $\Delta RH$ ), and **d** heat index ( $\Delta HI_0$ ) corresponding to the Aqua daytime overpass ( $\approx 1:30$  pm local time) for quartiles of satellite-derived precipitation rate in July 2019. Sub-figures **e**, **f**, **g**, and **h** are similar, but use quartiles of accumulation precipitation in July 2019 from the ERA5-Land reanalysis dataset.



**Fig. S4** Intra-urban gradients of variables for Terra day. Distributions of composite mean surface temperature ( $T_s$ ), air temperature ( $T_a$ ), relative humidity (RH), and heat index ( $HI_0$ ) in each of the  $T_s$  decile neighborhoods across the urban clusters considered. The vertical dashed lines mark the median of the distribution of the corresponding variable in the 1st  $T_s$  decile neighborhood. Decile neighborhoods that show statistically significant ( $p < 0.01$ ) differences from the background reference values are shown using hatched density plots and darker shades. All calculations are for the Terra daytime overpass ( $\approx 10:30$  am local time) for July 2019.

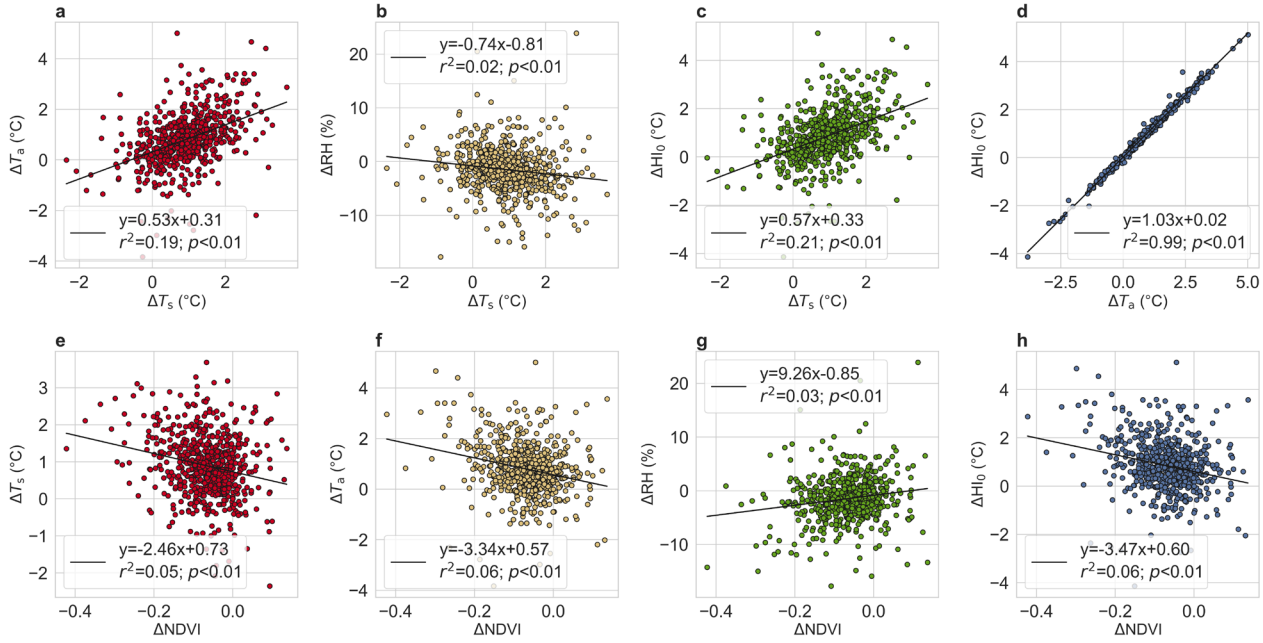


**Fig. S5** Associations between variables within urban clusters for Terra day. Sub-fig **a** shows the distributions of the correlation coefficient ( $r$ ) of linear regressions between surface temperature ( $T_s$ ) and air temperature ( $T_a$ ),  $T_s$  and heat index ( $HI_0$ ), Normalized Difference Vegetation Index (NDVI) and  $T_s$ , NDVI and  $T_a$ , and NDVI and  $HI_0$ , respectively, for urban clusters in Europe. Each data point is from a linear regression between pairs of variables for a cluster. The linear regressions have a sample size of ten (one for each  $T_s$  decile neighborhood). Sub-fig **b** and **c** show the distributions of the slope of those linear regressions, or the sensitivity of one variable to unit changes in the other. The unit of sensitivity in Sub-fig **c** is  $^{\circ}\text{C}$  per unit NDVI. All calculations are for the Terra daytime overpass ( $\approx 10:30$  am local time) for July 2019.



**Fig. S6** Associations between variables across urban clusters for Terra day. Associations between urban-rural differences in **a** surface temperature ( $\Delta T_s$ ) and air temperature ( $\Delta T_a$ ), **b**  $\Delta T_s$  and relative humidity ( $\Delta RH$ ), **c**  $\Delta T_s$  and heat index ( $\Delta HI_0$ ), **d**  $\Delta T_a$  and  $\Delta HI_0$ , **e** Normalized Difference Vegetation Index ( $\Delta NDVI$ ) and  $\Delta T_s$ , **f**  $\Delta NDVI$  and  $\Delta T_a$ , **g**  $\Delta NDVI$  and  $\Delta RH$ , and **h**  $\Delta NDVI$  and  $\Delta HI_0$  across urban clusters in Europe. Each dot represents one cluster and the lines and equations of best fit are shown. All calculations are for the Terra daytime overpass ( $\approx 10:30$  pm local time) for July 2019.

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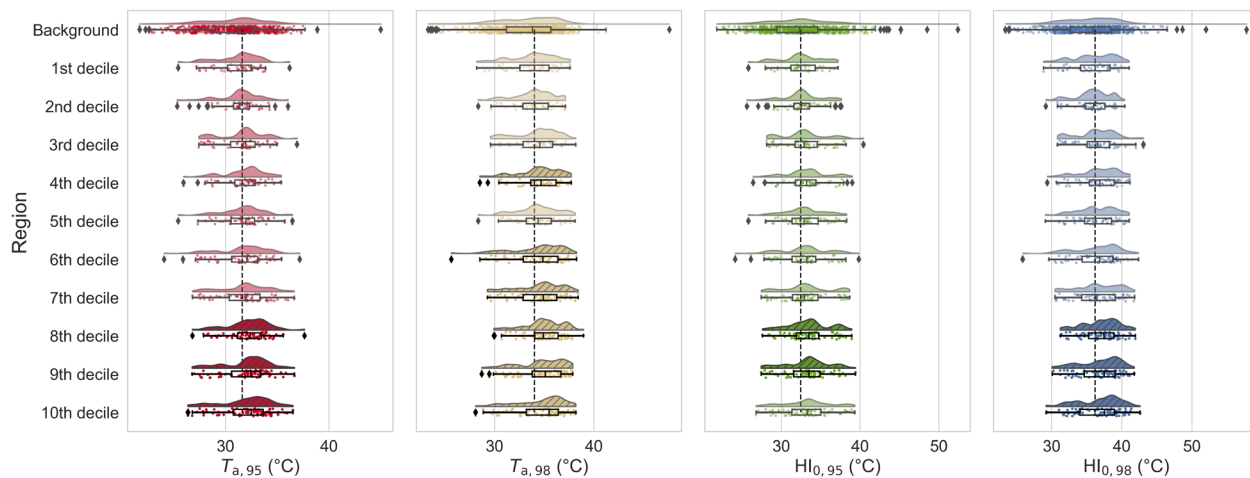
76 **Fig. S7** Associations between variables across urban clusters for Aqua night. Associations  
 77 between urban-rural differences in **a** surface temperature ( $\Delta T_s$ ) and air temperature ( $\Delta T_a$ ), **b**  $\Delta T_s$   
 78 and relative humidity ( $\Delta RH$ ), **c**  $\Delta T_s$  and heat index ( $\Delta HI_0$ ), **d**  $\Delta T_a$  and  $\Delta HI_0$ , **e** Normalized  
 79 Difference Vegetation Index ( $\Delta NDVI$ ) and  $\Delta T_s$ , **f**  $\Delta NDVI$  and  $\Delta T_a$ , **g**  $\Delta NDVI$  and  $\Delta RH$ , and **h**  
 80  $\Delta NDVI$  and  $\Delta HI_0$  across urban clusters in Europe. Each dot represents one cluster and the lines  
 81 and equations of best fit are shown. All calculations are for the Aqua nighttime overpass ( $\approx 1:30$   
 82 am local time) for July 2019.

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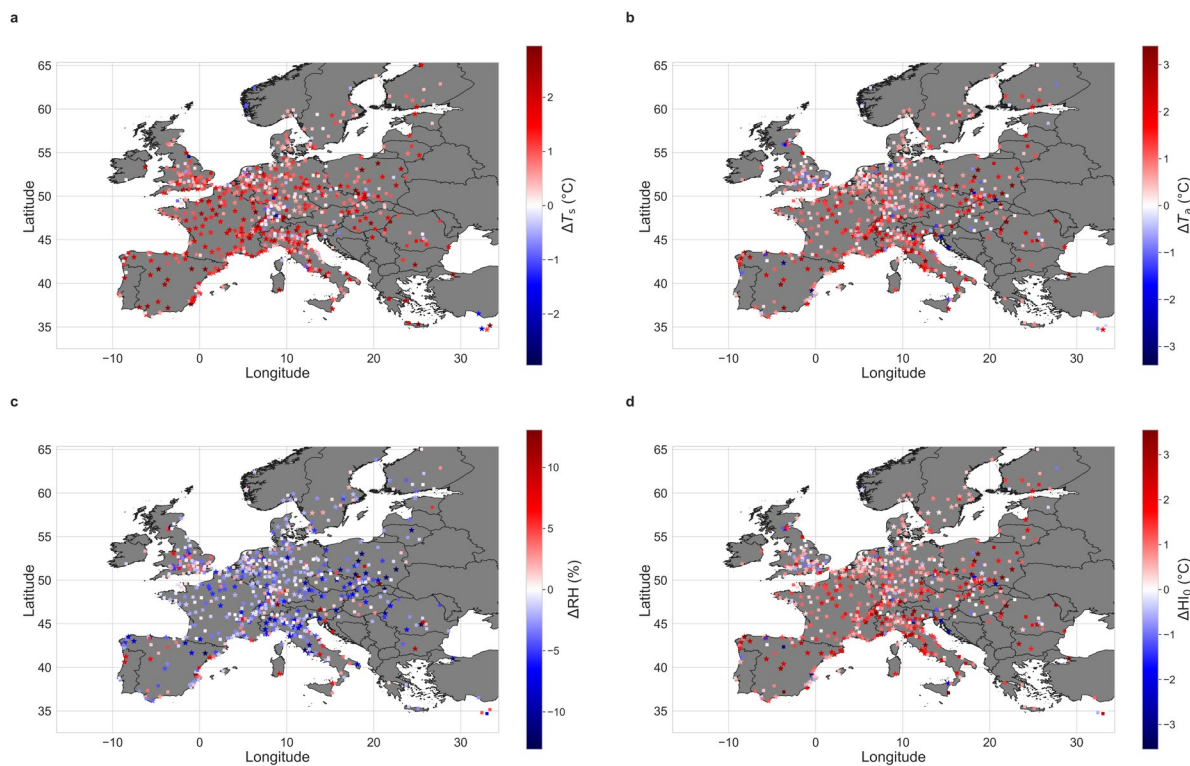
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**Fig. S8** Intra-urban gradients of extremes. Distributions of the 95<sup>th</sup> and 98<sup>th</sup> percentile of hourly observations in July 2019 of air temperature ( $T_a$ ) and heat index ( $HI_0$ ) in each of the  $T_s$  decile neighborhoods across the urban clusters considered. The vertical dashed lines mark the median of the distribution of the corresponding variable in the 1st  $T_s$  decile neighborhood. Decile neighborhoods that show statistically significant ( $p < 0.01$ ) differences from the background reference values are shown using hatched density plots and darker shades.



**Fig. S9** Urban-rural differences for Aqua night across urban clusters in Europe. Spatial distribution of urban-rural differences in **a** surface temperature ( $\Delta T_s$ ), **b** air temperature ( $\Delta T_a$ ), **c** relative humidity ( $\Delta RH$ ), and **d** heat index ( $\Delta HI_0$ ) for urban clusters in Europe with sufficient data corresponding to the Aqua satellite nighttime overpass ( $\approx 1:30$  am local time) for July 2019. The stars represent clusters with statistically significant ( $p < 0.01$ ) differences between the urban and rural values.

**Table S1.** P-values of the Mann –Whitney two-sample statistic between the observations corresponding to the Aqua daytime overpass ( $\approx 1:30$  pm local time) in the background reference region and the observations in the decile neighborhoods for surface temperature ( $T_s$ ), air temperature ( $T_a$ ), relative humidity (RH), US National Weather Service heat index ( $HI_0$ ), four additional estimates of heat index ( $HI_1$  to  $HI_4$ ), and the humidex for July 2019.

Group	$T_s$	$T_a$	RH	$HI_0$	$HI_1$	$HI_2$	$HI_3$	$HI_4$	Humidex
1 <sup>st</sup> decile	<0.01	0.16	0.25	0.26	0.21	0.24	0.21	0.18	0.23
2 <sup>nd</sup> decile	0.25	0.23	0.06	0.25	0.27	0.25	0.32	0.23	0.39
3 <sup>rd</sup> decile	0.01	0.43	0.38	0.39	0.40	0.38	0.42	0.41	0.46
4 <sup>th</sup> decile	<0.0001	0.38	<0.01	0.74	0.72	0.74	0.94	0.43	0.91
5 <sup>th</sup> decile	<0.0001	0.09	<0.01	0.25	0.23	0.24	0.34	0.1	0.43
6 <sup>th</sup> decile	<0.0001	0.01	<0.01	0.05	0.05	0.05	0.09	0.02	0.14
7 <sup>th</sup> decile	<0.0001	0.02	<0.0001	0.13	0.11	0.13	0.24	0.03	0.37
8 <sup>th</sup> decile	<0.0001	<0.01	<0.0001	0.05	0.04	0.05	0.11	<0.01	0.20
9 <sup>th</sup> decile	<0.0001	<0.0001	<0.0001	<0.001	<0.001	<0.001	<0.01	<0.0001	<0.01
10 <sup>th</sup> decile	<0.0001	<0.0001	<0.0001	<0.01	<0.01	<0.01	<0.01	<0.0001	0.03

111 **Table S2.** P-values of the Mann –Whitney two-sample statistic between the observations  
 112 corresponding to the Terra daytime overpass ( $\approx 10:30$  am local time) in the background reference  
 113 region and the observations in the decile neighborhoods for surface temperature ( $T_s$ ), air  
 114 temperature ( $T_a$ ), relative humidity (RH), US National Weather Service heat index ( $HI_0$ ), four  
 115 estimates of heat index ( $HI_1$  to  $HI_4$ ), and the humidex for July 2019.

Group	$T_s$	$T_a$	RH	$HI_0$	$HI_1$	$HI_2$	$HI_3$	$HI_4$	Humidex
1 <sup>st</sup> decile	<0.0001	0.27	0.27	0.25	0.27	0.29	0.26	0.28	0.25
2 <sup>nd</sup> decile	0.49	0.41	0.08	0.55	0.58	0.49	0.70	0.44	0.80
3 <sup>rd</sup> decile	<0.001	0.85	0.06	0.86	0.82	0.89	0.60	0.91	0.49
4 <sup>th</sup> decile	<0.0001	0.28	<0.01	0.50	0.58	0.48	0.81	0.32	0.98
5 <sup>th</sup> decile	<0.0001	0.44	<0.001	0.81	0.86	0.74	0.85	0.52	0.70
6 <sup>th</sup> decile	<0.0001	<0.01	<0.0001	0.04	0.04	0.04	0.09	<0.01	0.16
7 <sup>th</sup> decile	<0.0001	0.05	<0.001	0.15	0.17	0.14	0.33	0.07	0.49
8 <sup>th</sup> decile	<0.0001	0.03	<0.0001	0.13	0.14	0.12	0.31	0.04	0.47
9 <sup>th</sup> decile	<0.0001	0.01	<0.0001	0.06	0.07	0.06	0.18	0.02	0.29
10 <sup>th</sup> decile	<0.0001	<0.01	<0.0001	0.03	0.04	0.02	0.09	<0.01	0.16

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119 **Table S3.** P-values of the Mann –Whitney two-sample statistic between the 95<sup>th</sup> and 98<sup>th</sup>  
120 percentile of hourly observations in July 2019 of air temperature ( $T_a$ ) and US National Weather  
121 Service heat index (HI<sub>0</sub>) for CWSs in the background reference region and the corresponding  
122 observations in the decile neighborhoods.

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Group	$T_{a,95}$	$T_{a,98}$	HI <sub>0,95</sub>	HI <sub>0,98</sub>
1 <sup>st</sup> decile	0.48	0.36	0.63	0.41
2 <sup>nd</sup> decile	0.40	0.34	0.54	0.69
3 <sup>rd</sup> decile	0.06	0.05	0.15	0.18
4 <sup>th</sup> decile	0.01	<0.01	0.04	0.02
5 <sup>th</sup> decile	0.05	0.03	0.13	0.11
6 <sup>th</sup> decile	0.03	<0.01	0.11	0.06
7 <sup>th</sup> decile	0.01	<0.01	0.06	0.03
8 <sup>th</sup> decile	<0.001	<0.0001	<0.01	<0.01
9 <sup>th</sup> decile	<0.001	<0.0001	<0.01	<0.01
10 <sup>th</sup> decile	<0.001	<0.0001	0.01	<0.01

125 **Table S4.** P-values of the Mann –Whitney two-sample statistic between the observations  
 126 corresponding to the Aqua nighttime overpass ( $\approx$ 1:30 am local time) in the background reference  
 127 region and the observations in the decile neighborhoods for surface temperature ( $T_s$ ), air  
 128 temperature ( $T_a$ ), relative humidity (RH), US National Weather Service heat index (HI<sub>0</sub>), four  
 129 additional estimates of heat index (HI<sub>1</sub> to HI<sub>4</sub>), and the humidex for July 2019.

Group	$T_s$	$T_a$	RH	HI <sub>0</sub>	HI <sub>1</sub>	HI <sub>2</sub>	HI <sub>3</sub>	HI <sub>4</sub>	Humidex
1 <sup>st</sup> decile	<0.0001	0.27	0.12	0.21	0.21	0.20	0.16	0.26	0.14
2 <sup>nd</sup> decile	0.14	0.42	0.01	0.46	0.48	0.30	0.57	0.43	0.61
3 <sup>rd</sup> decile	0.79	0.15	<0.01	0.18	0.18	0.21	0.25	0.16	0.28
4 <sup>th</sup> decile	0.01	0.02	<0.01	0.02	0.02	0.56	0.02	0.02	0.03
5 <sup>th</sup> decile	<0.001	0.01	<0.01	0.01	0.01	0.38	0.02	0.01	0.02
6 <sup>th</sup> decile	<0.0001	<0.0001	<0.0001	<0.000	<0.0001	0.45	<0.0001	<0.0001	<0.0001
7 <sup>th</sup> decile				1					
8 <sup>th</sup> decile	<0.0001	<0.0001	<0.0001	<0.000	<0.0001	0.63	<0.0001	<0.0001	<0.0001
				1					
9 <sup>th</sup> decile	<0.0001	<0.0001	<0.0001	<0.000	<0.0001	0.56	<0.0001	<0.0001	<0.0001
				1					
10 <sup>th</sup> decile	<0.0001	<0.0001	<0.0001	<0.000	<0.0001	0.47	<0.0001	<0.0001	<0.0001
				1					