Attribution of Urban Heat Island for Cities in China

YNCenter Video Conference

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Outline

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- Motivation
- Method
- Results
- Conclusion
- On-going work

Background

- More than half of the world's population reside in urban area which consists of 2% of global land area.
- Urbanization gives rise to Urban Heat Island (UHI) which has impact on local climate and human health.
- Community Earth System Model (CESM) climate model has incorporated urban canopy model to study urban climatic response under atmospheric condition in the future.
- Study on UHI for cities in North American showed that convection efficiency is the main driver of UHI variation across climatic zones.

Motivation

- What is the UHI spatial pattern across different climatic zones in China?
- What is the driver of UHI variation for cities in China?
- What is the contribution of each biophysical process to UHI?

Method

- 39 cities in China
- Exclude elevation and latitude difference between urban and rural area more than 100 meters and 1°
- Exclude water pixels
- Avoid ‘oasis effect’ for semi-arid cities (Hotan)

Other data

- Precipitation data: National Climate Center
- Air temperature data: National Climate Center
- Normalized Difference Vegetation Index data: MODIS MYD13Q1 250m 16-day
- White Sky Albedo data: MODIS MCD43A3 500m 16-day
- Population data: China Population and Employment Statistics Yearbook, 2013

Observational land surface temperature

- 2003-2013
- MODIS Land Surface Temperature (LST)

    MYD11A2 1km 8-day

    daytime 13:30

    nighttime 1:30

Model simulation

- Community Land Model 4.0 - CLMU
- 1972-2004, 0.23° longitude × 0.31° latitude
- Offline, Qian et al forcing data
- Extract data at 1:00 and 13:00 (local time) and for clear-sky condition

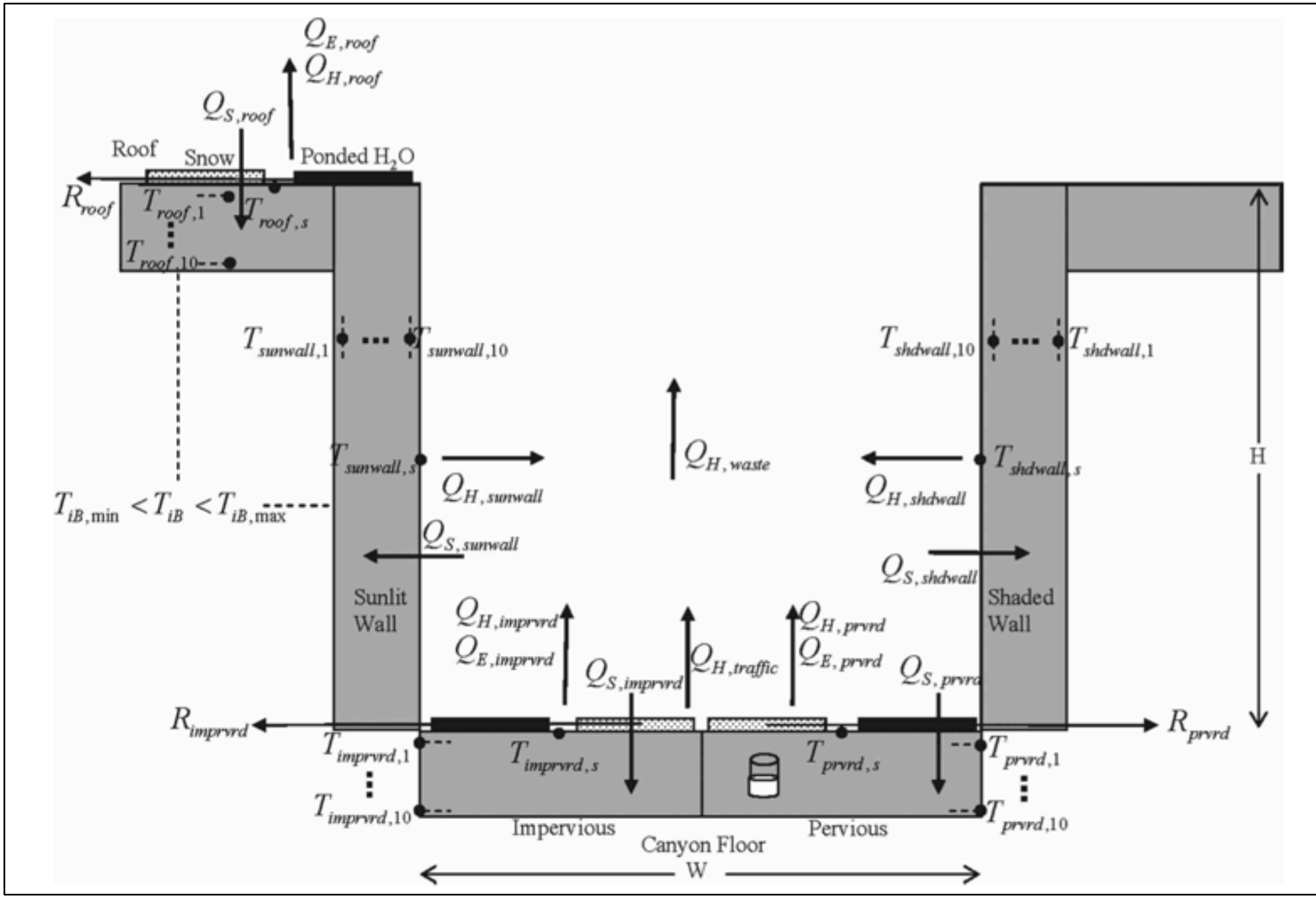


Figure 1 | Schematic overview of urban land unit in CLM

Source: Oleson, Bonan, Feddema et al. (2008) *J Appl Meteor Climatol* 47: 1038-1060

Result

Spatial variation

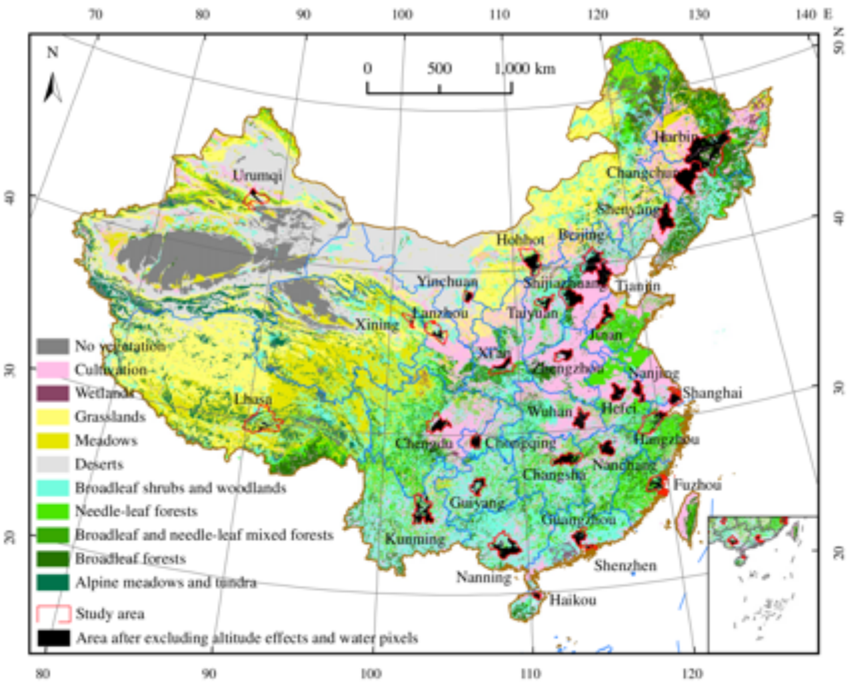


Figure 2 | Vegetation of China
Source: Zhou, Zhao, Liu et al. (2014) *Sci of Tol Env* 488: 136-145

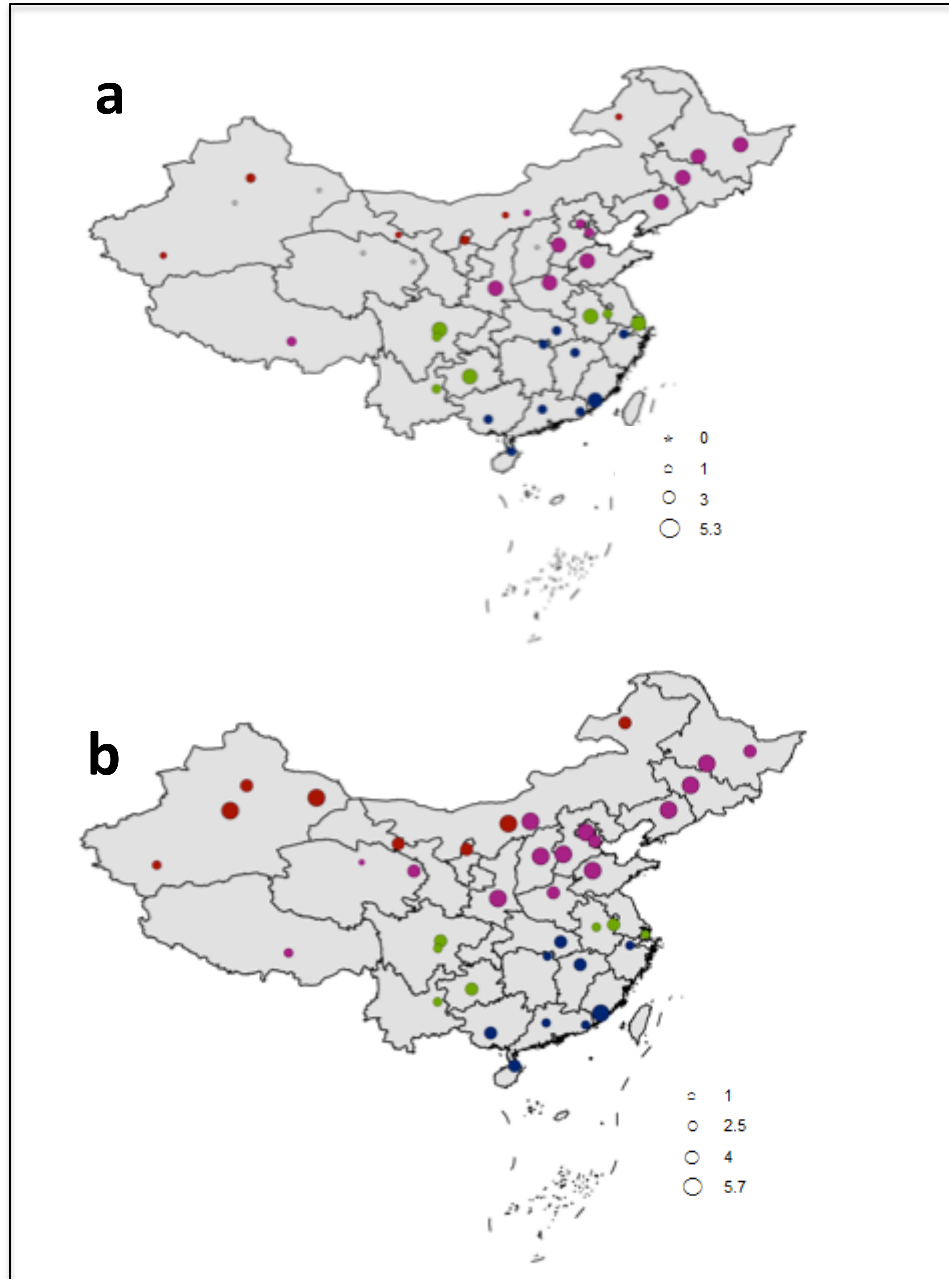


Figure 3 | Spatial variation of MODIS-derived annual-mean daytime (a) and night-time (b) UHI.

Cropland pixel fraction of rural area

(MODIS land cover)

	Humid	**Semi-humid**	**Semi-arid**	**Averaged**
China	0.53	0.80	0.29	0.51
North American	0.20	0.44	0.23	0.30

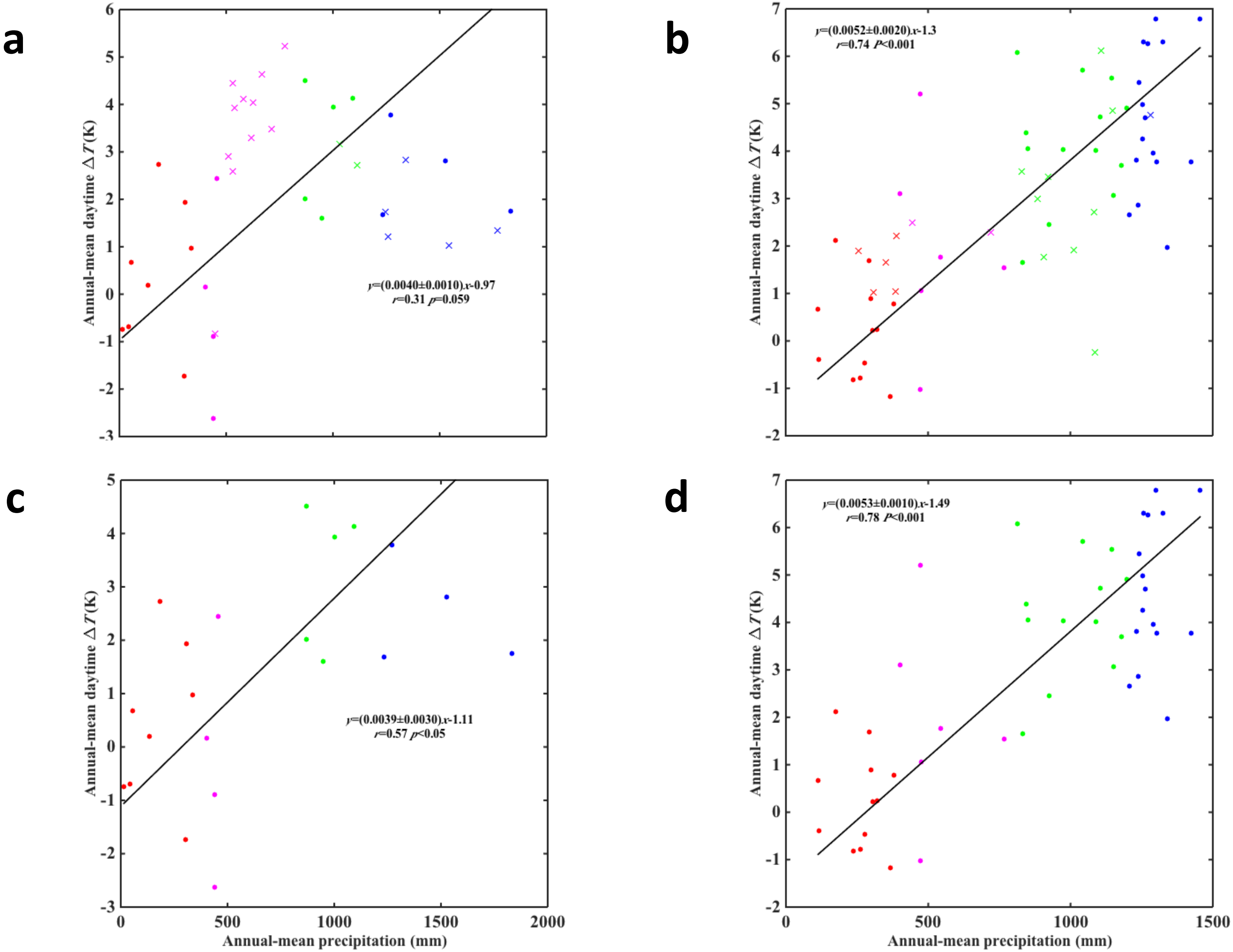


Figure 4 | Precipitation influence on annual daytime UHI. a, All 39 cites in. b, Without cities whose rural area has cropland pixel fraction bigger than 0.5. c and d are the same as a and b but for North American cities

Relationship between UHI and variables

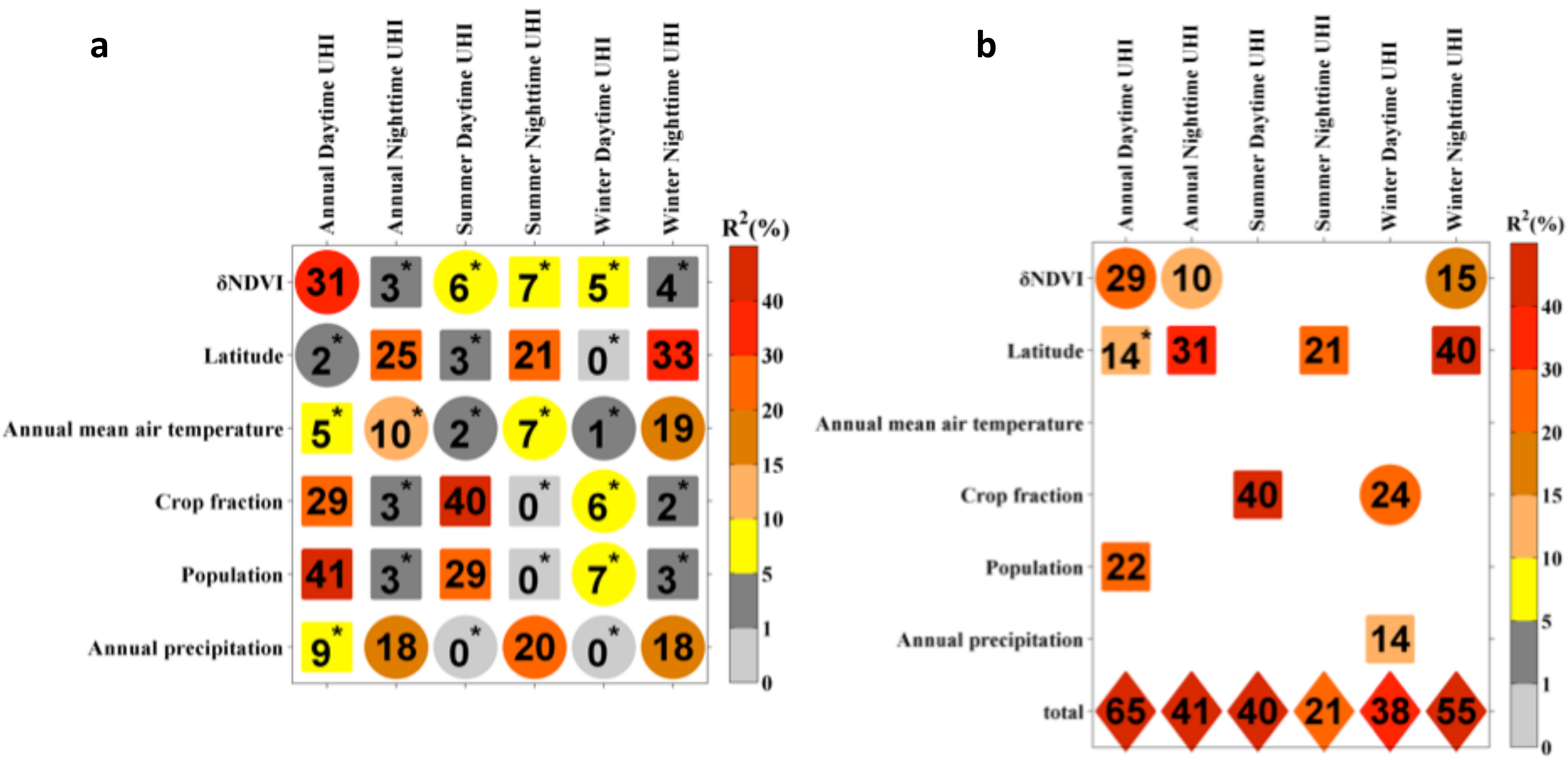


Figure 5 | The square of linear correlation coefficients (R^2) (a) and stepwise multiple linear regression derived explanation (b) of each variable for cities in China.

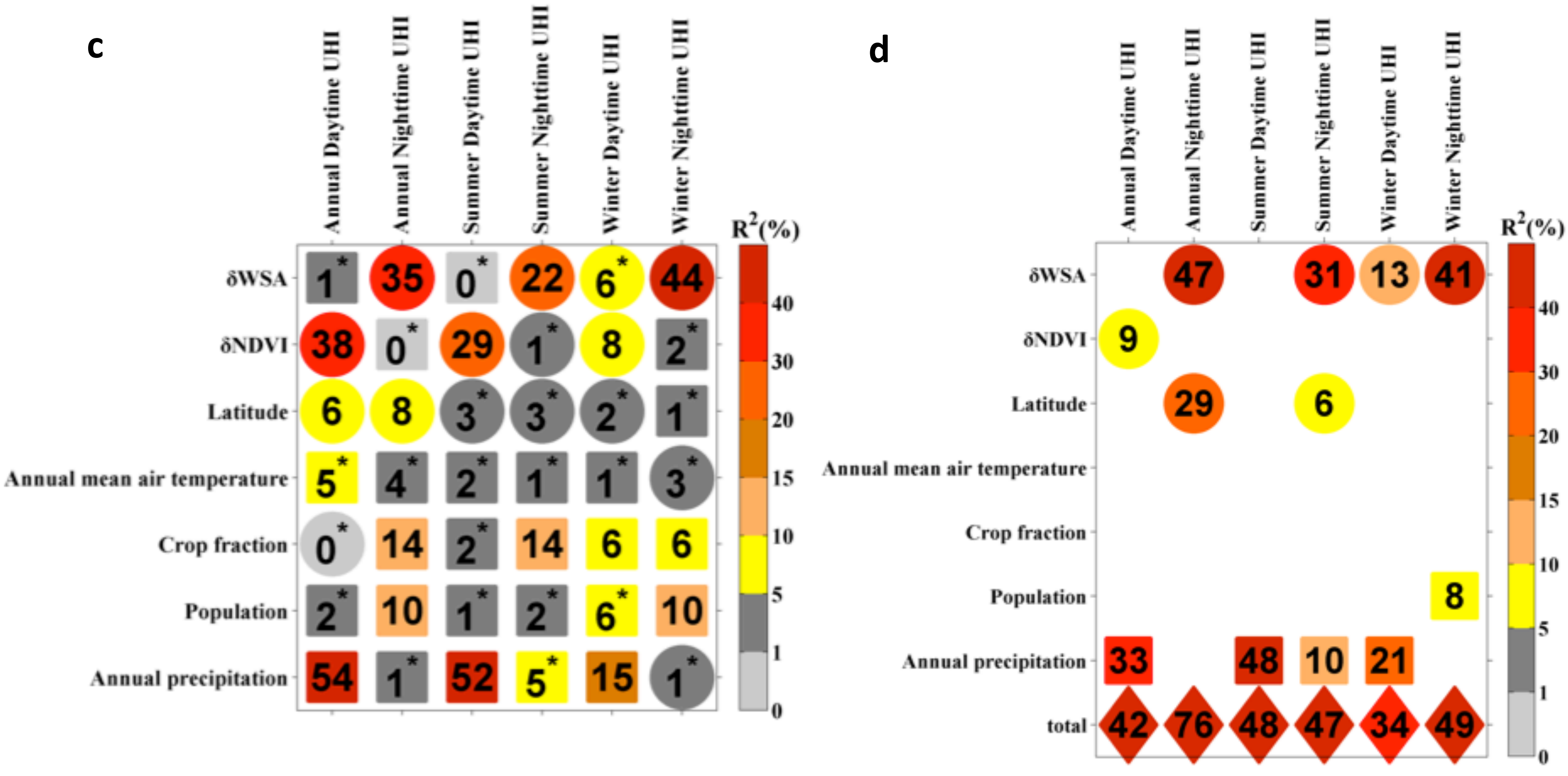


Figure 5 | The square of linear correlation coefficients (R^2) (c) and stepwise multiple linear regression derived explanation (d) of each variable for cities in North American.

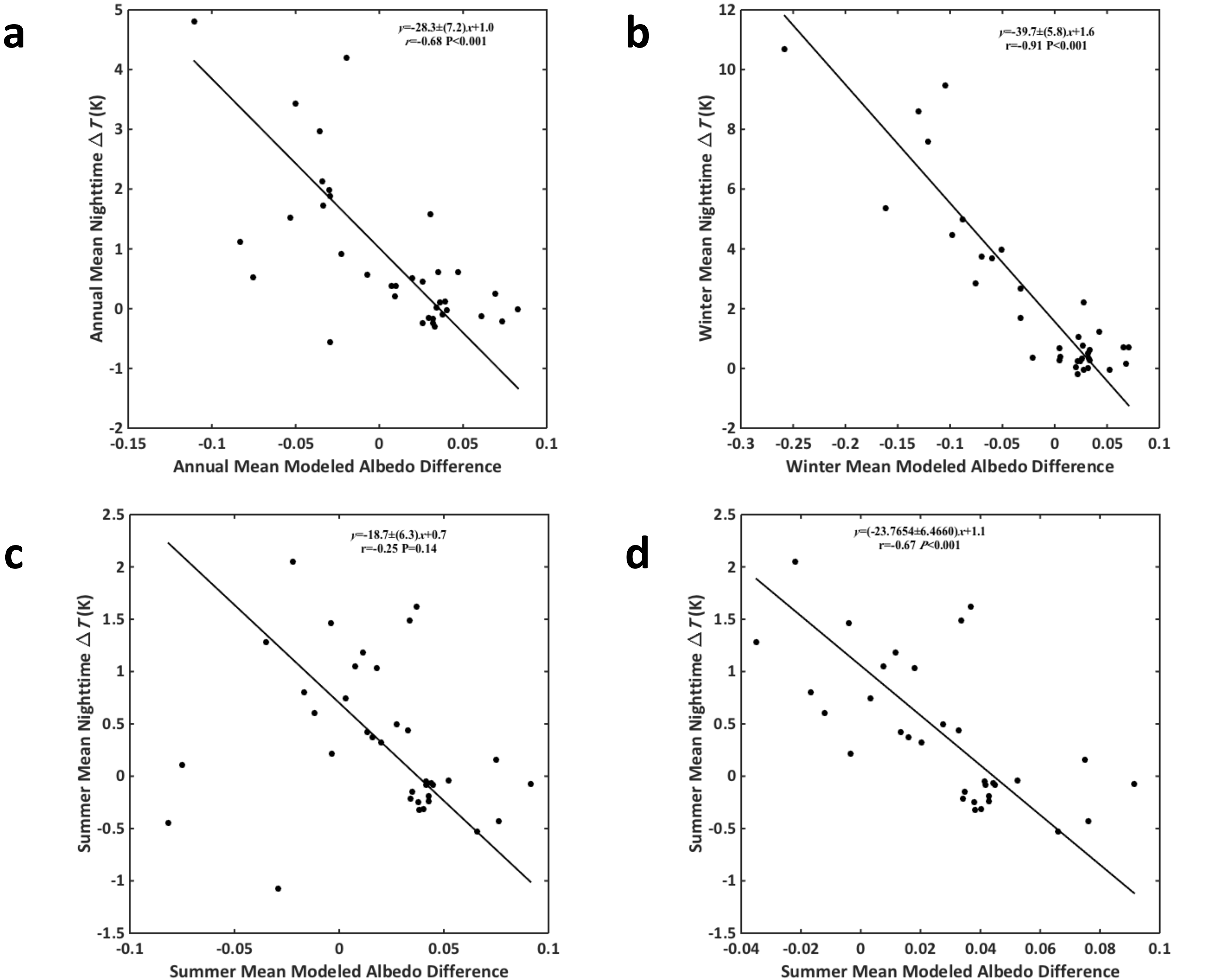


Figure 6 | Modelled albedo influence on modelled annual mean (a), winter (b) and summer (c) night-time UHI intensity

Attribution to model-predicted UHI

$$(1-\alpha)K_{\downarrow}+L_{\downarrow}-\sigma T_s^4=H+LE+Q_s-Q_{AH} \qquad (1)$$

$$\sigma T_s^4=\sigma T_a^4+4\sigma T_a^3(T_s-T_a)$$

$$H=\rho Cp\frac{T_s-T_a}{r_a}$$

$$LE=\frac{H}{\beta}$$

$$\lambda_0=1/4\varepsilon\sigma T^3$$

$$f=\frac{\lambda_0\rho C_p}{r_a}(1+\frac{1}{\beta})$$

$$\Delta T=\frac{\lambda_0}{1+f}(R_n^*-Q_s+Q_{AH}) \qquad (2)$$

$$\Delta T\approx\frac{\lambda_0}{1+f}\Delta R_n^*+\frac{-\lambda_0}{(1+f)^2}(R_n^*-Q_s+Q_{AH})\Delta f_1 + \frac{-\lambda_0}{(1+f)^2}(R_n^*-Q_s+Q_{AH})\Delta f_2+\frac{-\lambda_0}{1+f}\Delta Q_s + \frac{\lambda_0}{1+f}\Delta Q_{AH} \qquad (3)$$

$$R_n^*=(1-\alpha)K_{\downarrow}+L_{\downarrow}-(1-\varepsilon)L_{\downarrow}-\varepsilon\sigma T_a^4$$

$$\Delta f_1=\frac{-\lambda_0\rho C_p}{r_a}(1+\frac{1}{\beta})\frac{\Delta r_a}{r_a}$$

$$\Delta f_2=\frac{-\lambda_0\rho C_p}{r_a}\frac{\Delta\beta}{\beta^2}$$

Model UHI

$$L_{\downarrow}-(1-\varepsilon)L_{\downarrow}-\varepsilon\sigma T_s^4=L_{net} \qquad (4)$$

$$T_s=\sqrt[4]{\frac{L_{\downarrow}+(L\_net)/\boxed{\varepsilon})}{\sigma}} \qquad (5)$$

Validation

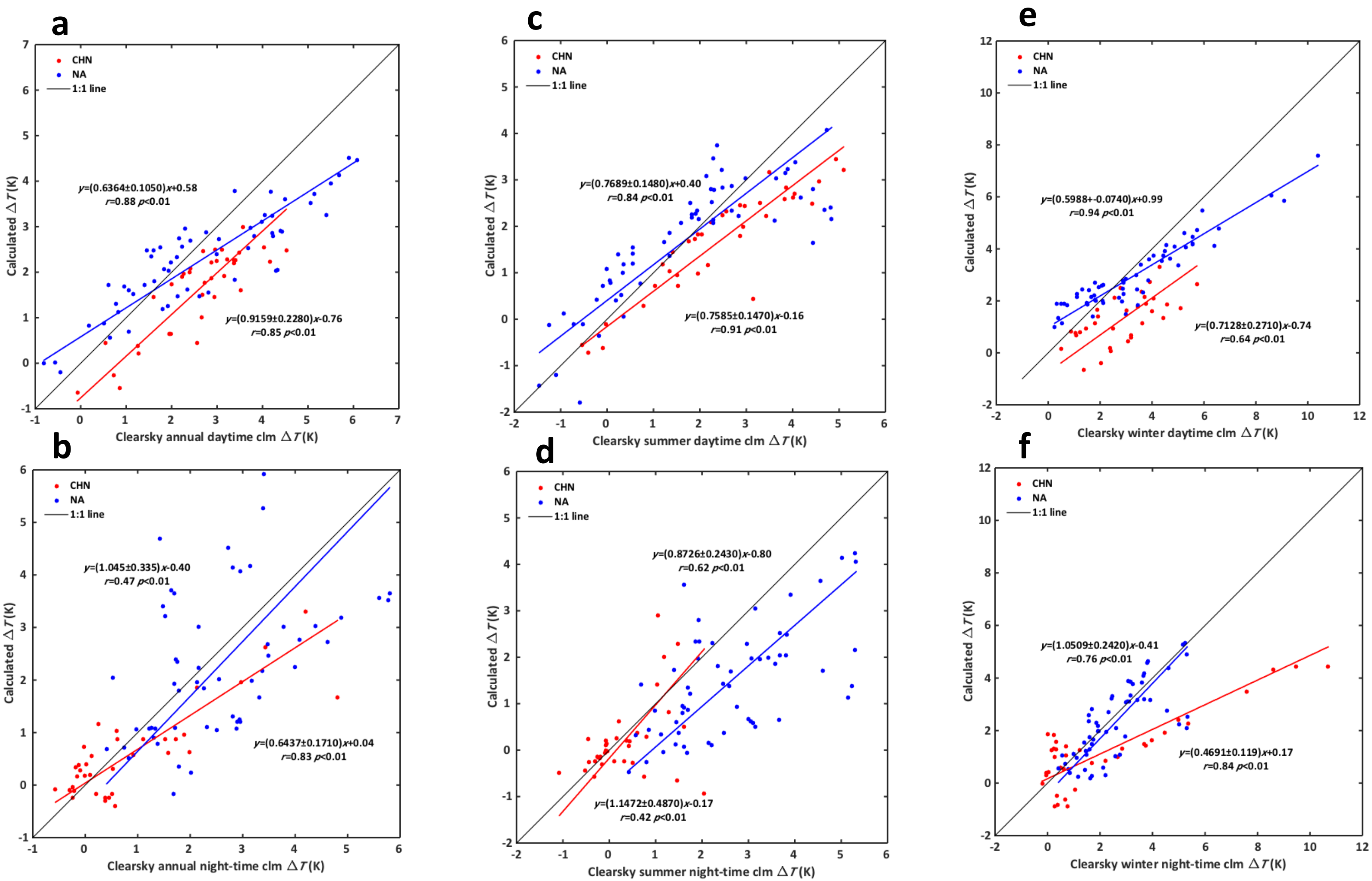


Figure 7 | Model-predicted ΔT vs calculated ΔT. a, Annual-mean daytime. b, Annual-mean night-time. c, Summer mean daytime. d, Summer mean night-time. e, Winter mean daytime. f, Winter mean night-time.

Tuning emissivity

- North American: 0.88 (urban area)
  0.96 (rural area)

$$T_s = \sqrt[4]{\frac{L_{\downarrow} + (L\_net)/\varepsilon)}{\sigma}}$$

- Chinese cities (combined with CLM and MODIS emissivity, H/W ratio)

	Humid	**Semi-humid**	**Semi-arid**
Urban	0.914	0.960	0.969
Rural	0.927	0.980	0.973

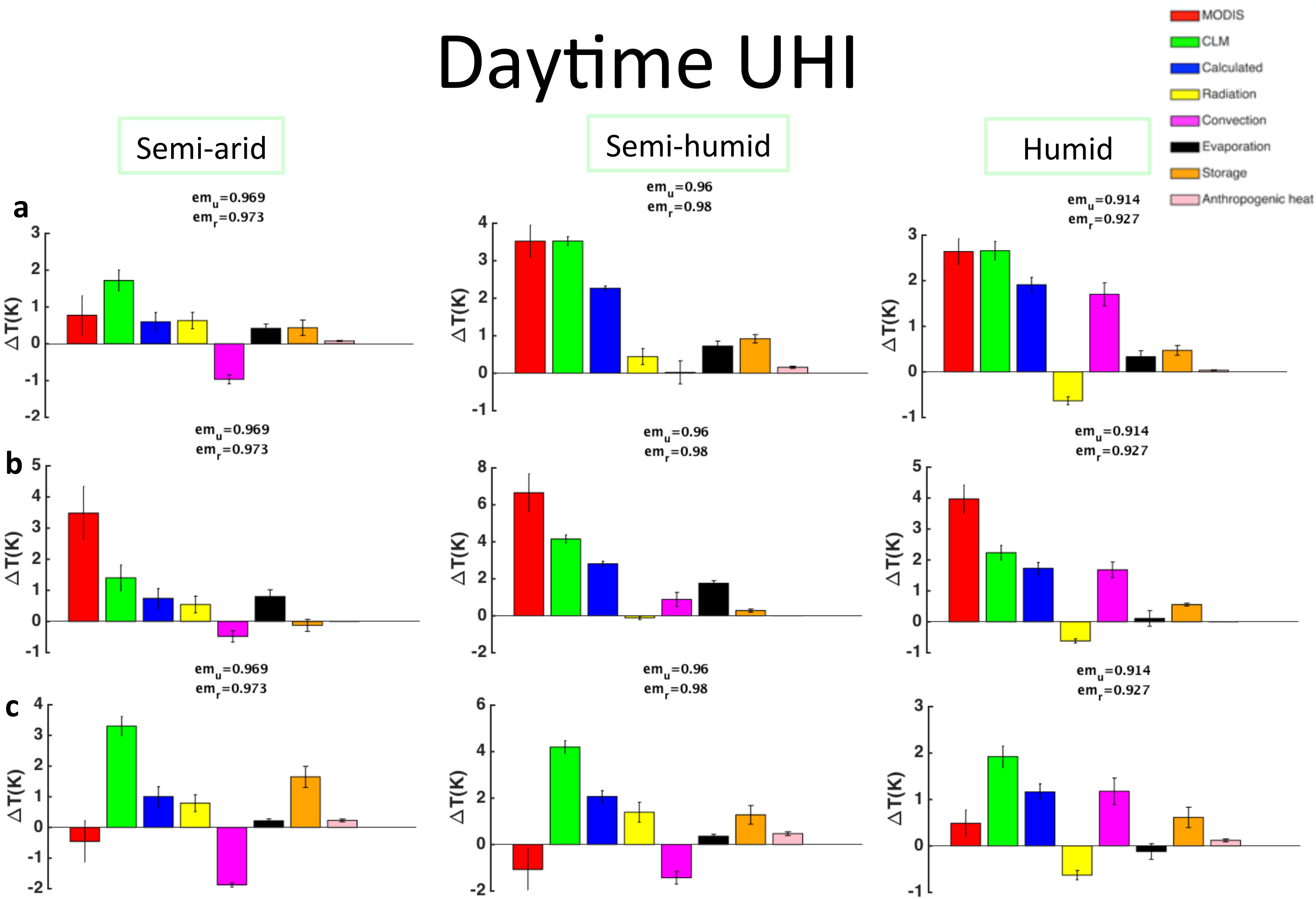


Figure 8 | Attribution of UHI intensity in three climate zones in annual-mean (a), summer (b) and winter (c) daytime.

Night-time UHI

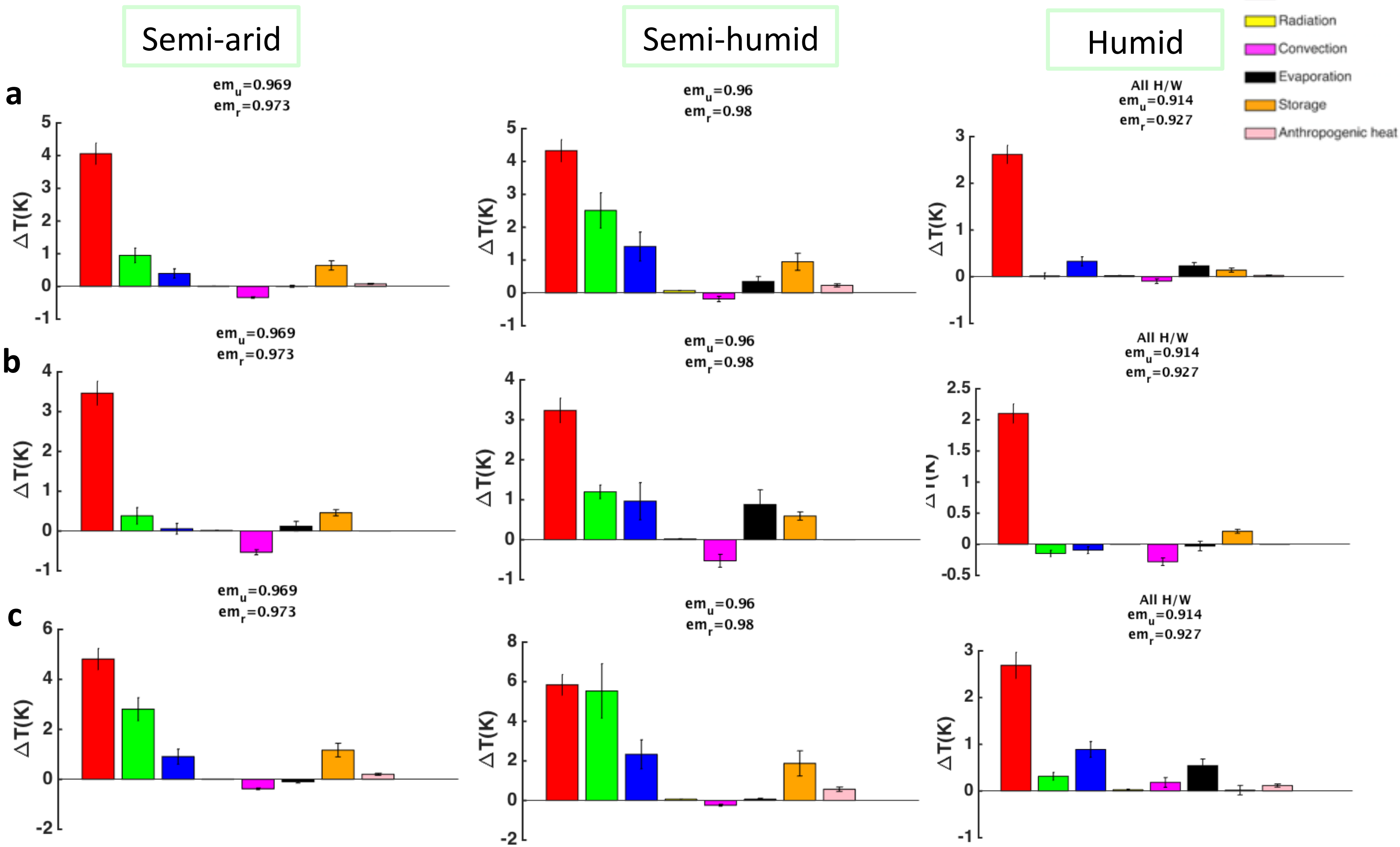


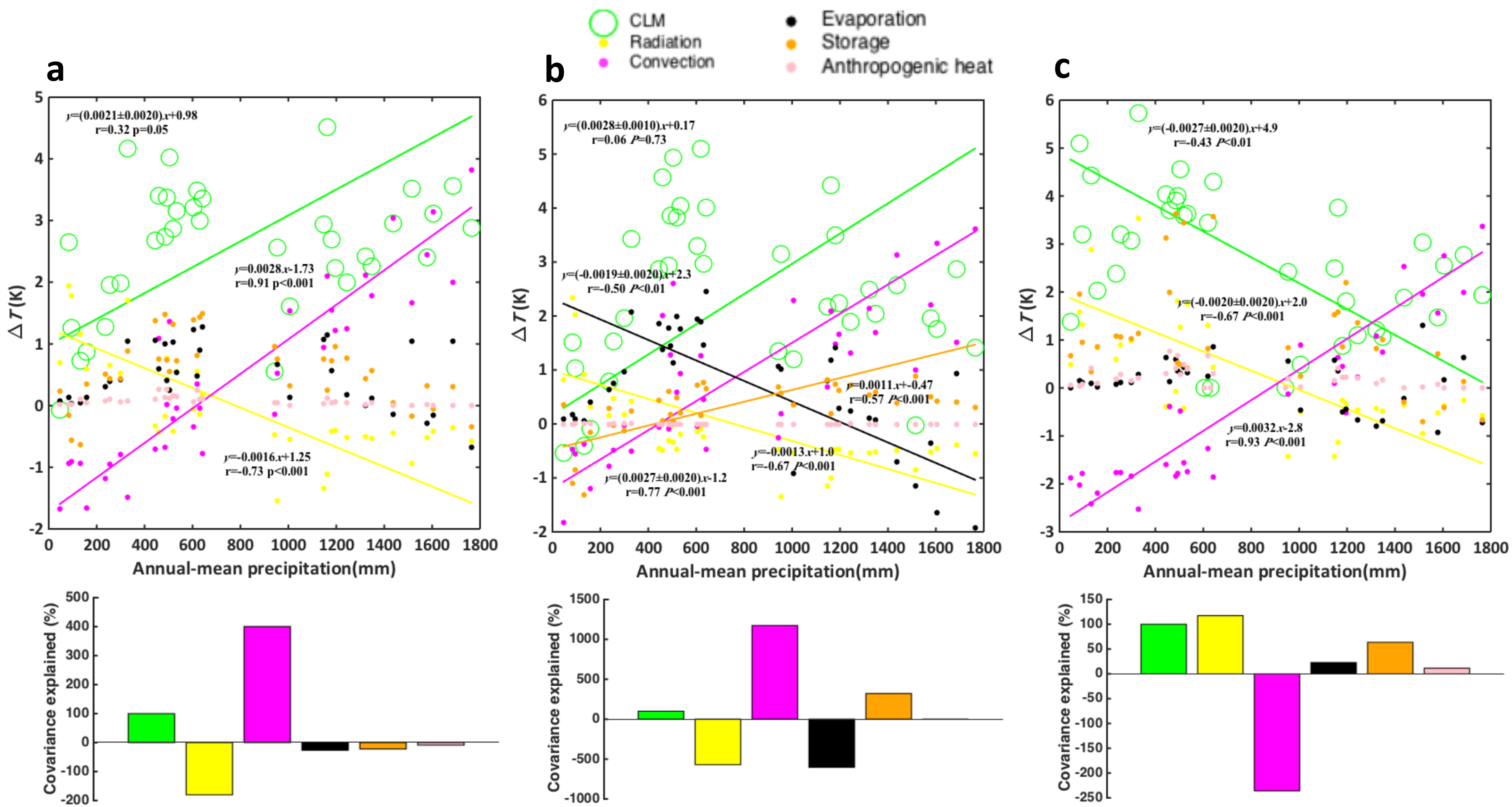
Figure 9 | Attribution of UHI intensity in three climate zones in annual-mean (a), summer (b) and winter (c) night-time.

Covariance analysis

$$\Delta T = C_R + C_H + C_{LE} + C_s + C_{AH} + e \quad (6)$$

$$\begin{aligned} Cov(\Delta T, P) = {} & Cov(C_R, P) + Cov(C_H, P) + Cov(C_{LE}, P) \\ & + Cov(C_s, P) + Cov(C_{AH}, P) + Cov(e, P) \end{aligned} \quad (7)$$

Daytime



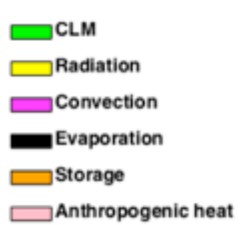


Figure 10 | Relationship between model-predicted daytime ΔT and precipitation among the cities in China. a (up), Correlation of ΔT and the biophysical components with annual-mean precipitation. a (bottom), ΔT-precipitation covariance explained by different biophysical factors. b and c are the same as a but for summer and winter.

Temporal sensitivity

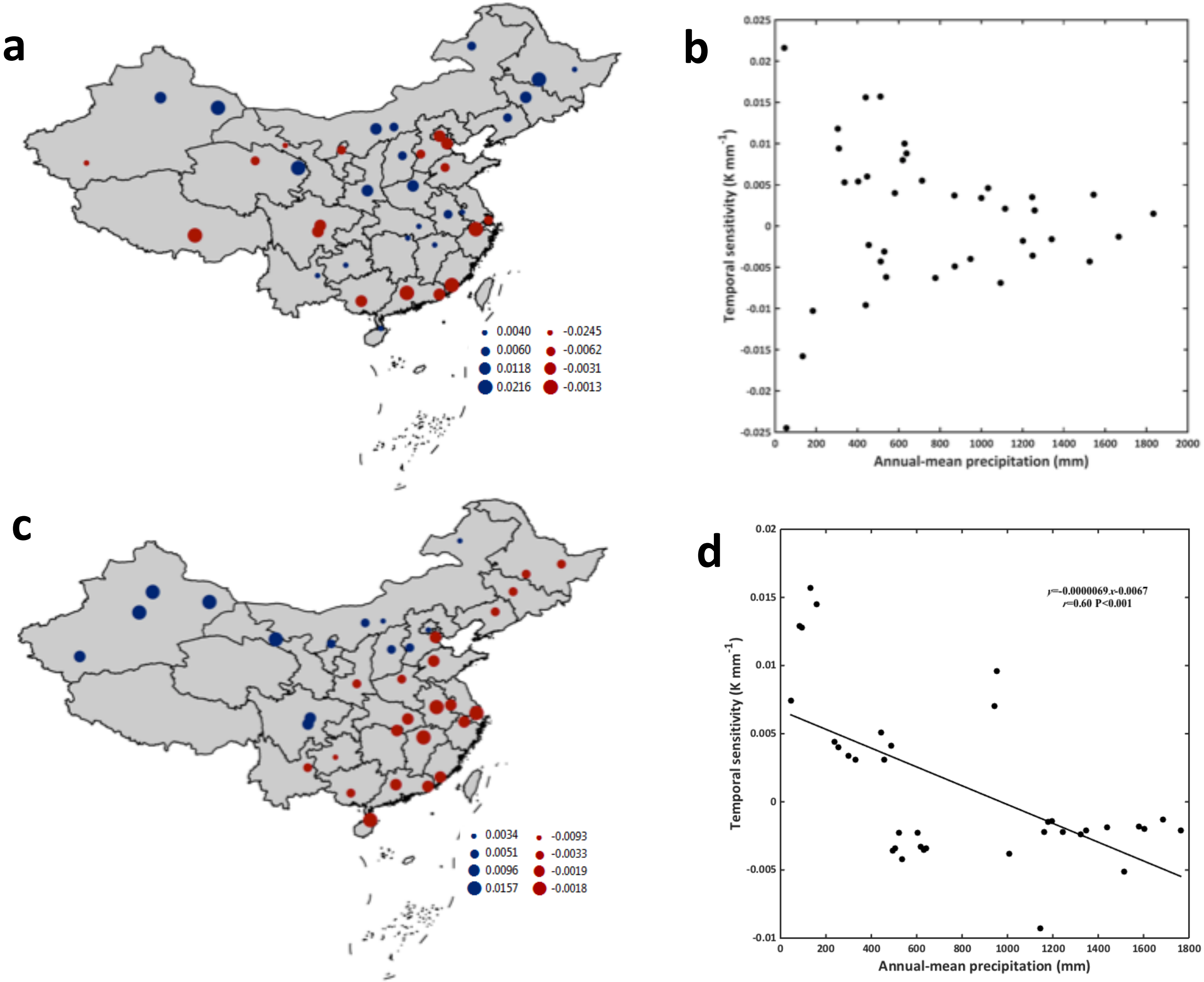


Figure 11 | Temporal sensitivity of UHI intensity to precipitation. a, c, Map of the temporal sensitivities according to MODIS (a) and climate model (c). b, d, Dependence of MODIS (b) and model-predicted (d) temporal sensitivity on annual mean precipitation.

Conclusion

- UHI pattern for cities in China are mainly depend on annual precipitation but high cropland fraction in rural area can weaken this relationship.
- Convection efficiency and storage heat is the dominant contributor to UHI at day time and night time respectively. Evaporation can be a significant factor for cities in drier region in summer daytime.

Future work

- Finding solutions to the underestimation of nighttime UHI
- Can soil moisture be an important factor?
- Investigating relationship between UHI and biochemical factors (aerosol..)

Thank you