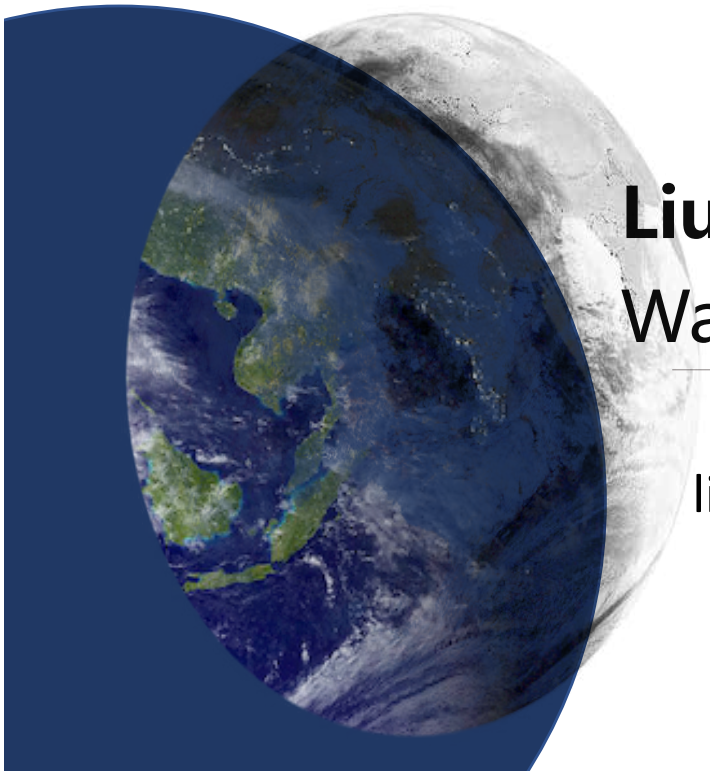
State Key Laboratory of Numerical Modeling for Atmosphere Sciences and Geophysical Fluid Dynamics Institute of Atmospheric Physics,
Institute of Atmospheric Physics, Chinese Academy of Sciences

ICRC-CORDEX 2019 （Beijing, China）

Increases in anthropogenic heat release from energy consumption lead to more frequent extreme heat events



Liu Bin，**Xie Z.**，Qin P.，Jia B.，Li R.，
Wang L.，Wang Y.，Chen S.，Xie J.，Shi C.

liubin@mail.iap.ac.cn

Beijing

2019. 10. 15

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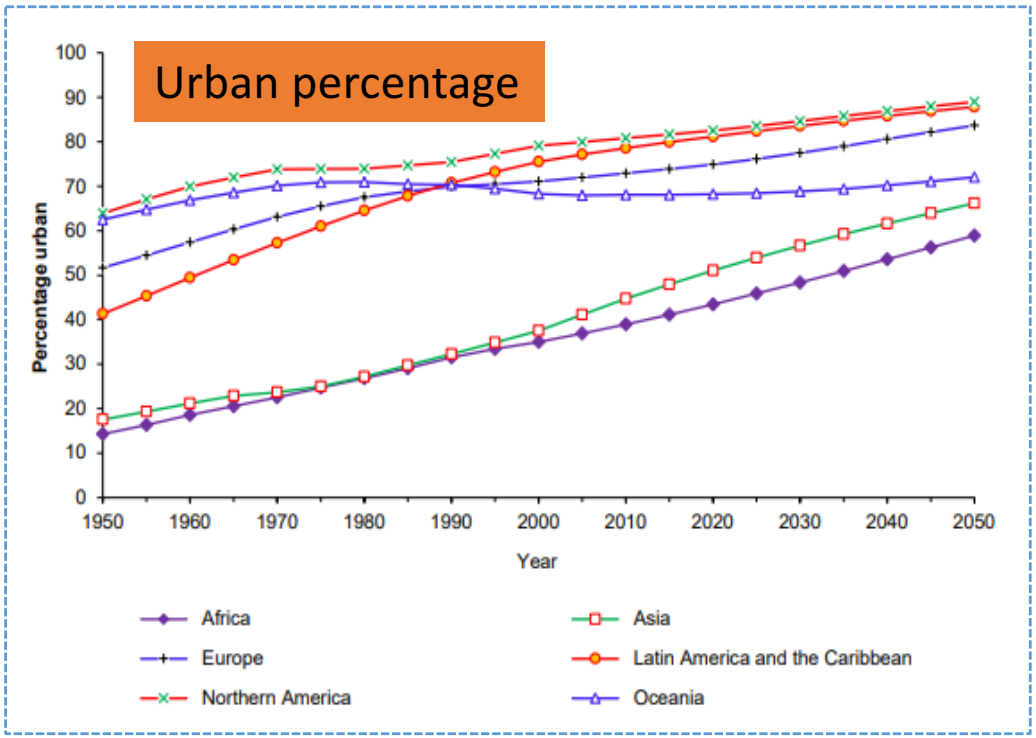
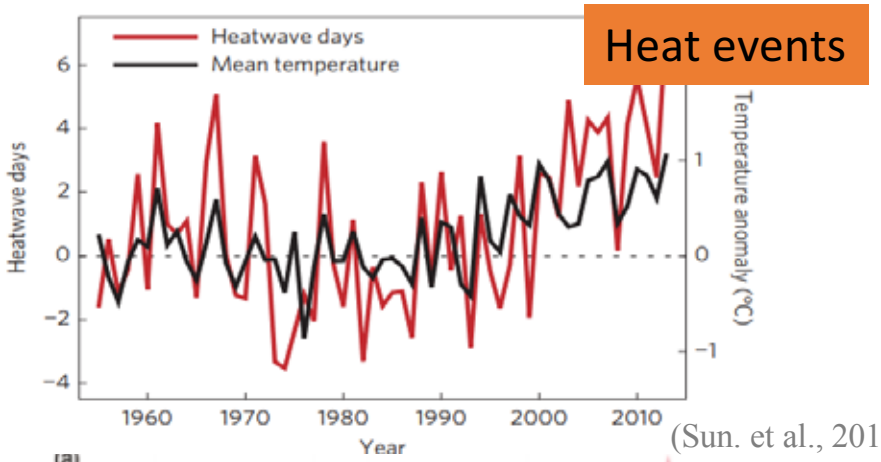
BACKGROUND

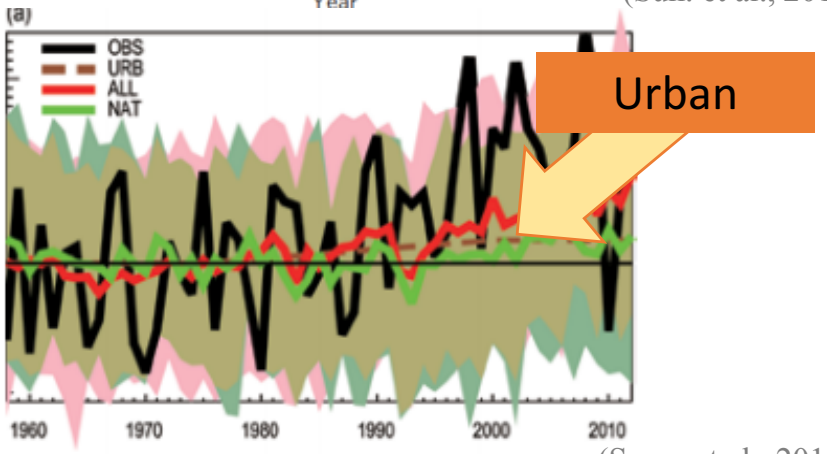
The population and energy consumption are increasing, meanwhile extreme heat events occurred are easier, urban function a important role in extreme temperature events.



(Source: United Nations, department of economic and social affairs, World Urbanization prospects, 2018 Revision)



(Sun. et al., 2014)



(Song. et al., 2015)

BACKGROUND

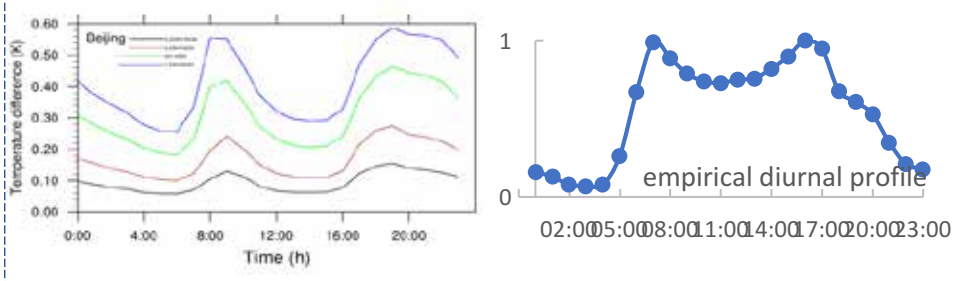
- **Anthropogenic heat** is referred to the waste heat flux released from land surface to atmosphere, mainly by energy consumption and will change the urban thermal environment.

- previous studies is mainly focus on the weather and short-term climate effects of AHR .
- This work aims to reveal the long-term frequency and trend of extreme temperature events caused by anthropogenic heat release(AHR)

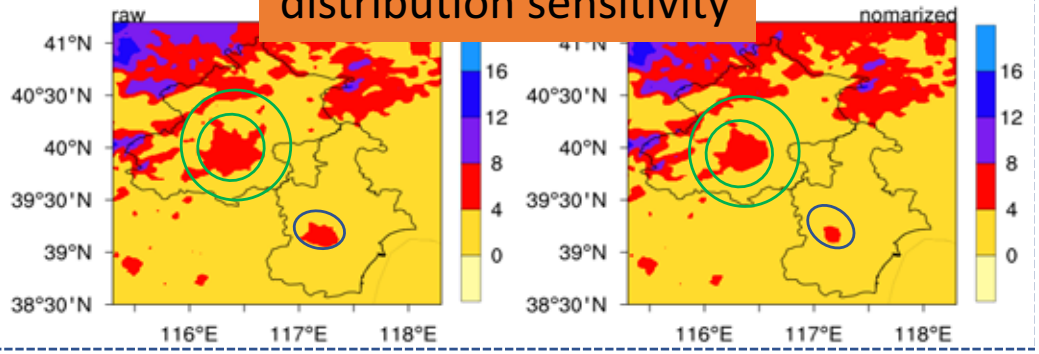
Methods

Default scheme: Anthropogenic heat is based on fixed AHR values according to urban types

Strength sensitivity



distribution sensitivity



Temporal-spatial variation anthropogenic heat release (AHR) scheme was developed based on energy consumption.

$$\mathrm{AHR} = \sum_{i=1}^{9} a_i \times E_i$$

$$\overline{AHR_{i,j}} = \sum_{i \in I} \frac{\propto \times POP_{i,j}}{\sum POP_{i,j}} AHR$$

$$AHR_{new} = \overline{AHR_{i,j}} \times \mathrm{g(y, m, h, T)} = \overline{AHR_{i,j}} \times g_1(y) \times g_2(m) \times g_3(h)$$

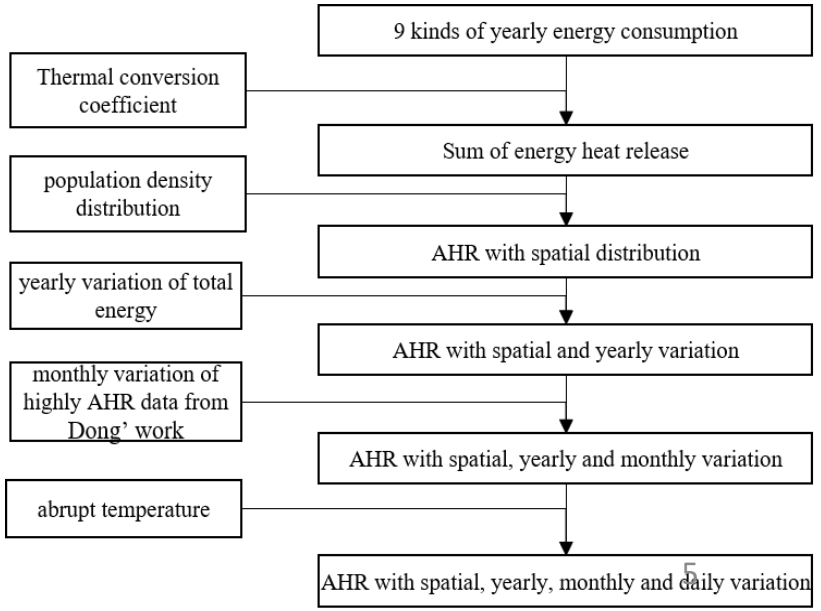
$$g_3(h) = \mathrm{f}(h) \times g_4(T, \bar{T})$$

$$g_4(T, \bar{T}) = \begin{cases} 1, & |T - \bar{T}| < b; \\ 1 + a \times |T - \bar{T}|, & |T - \bar{T}| \geq b; \end{cases}$$

Energy consumption

popultaion

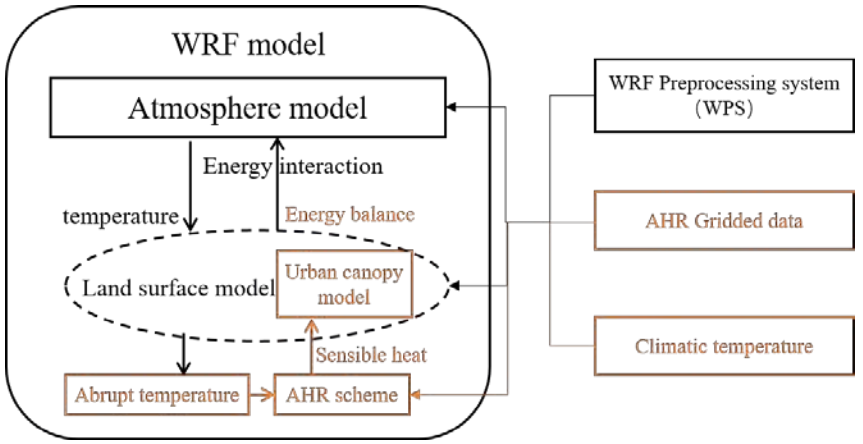
Temporal-spatial variation



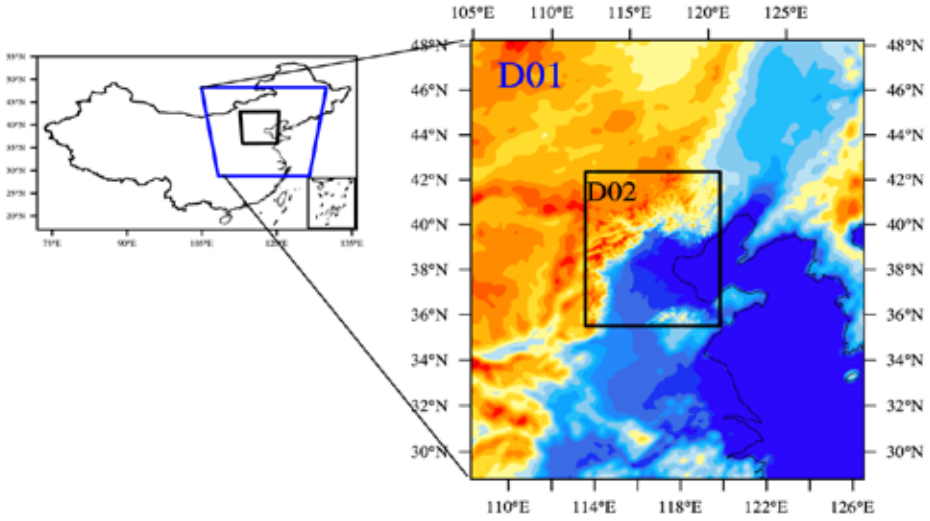
Methods

- **Model：** WRF3.9.1
- **ICBC：**
  - NCEP FNL (0.5° x0.5°)
  - SST (OISST)
  - Simulation period: 1999-2017
- **Experiment design：**
  - **SPINUP：** year 1999-2000
  - 2 experiments: no anthropogenic heat release (no-AHR)
    anthropogenic heat release (AHR)
  - resolution：3m (2-nested)
- **Physical Schemes**

Physical Scheme	Selected scheme option
Microphysics	Kessler scheme
Longwave	RRTM scheme
Shortwave	MM5 shortwave scheme
Cumulus	Grell-Devenyi
Planetary boundary physics	ACM2 PBL scheme
Land surface model	NOAH-MP
Urban model	SLUCM



New AHR scheme couple with WRF



Simulation area (Beijing)

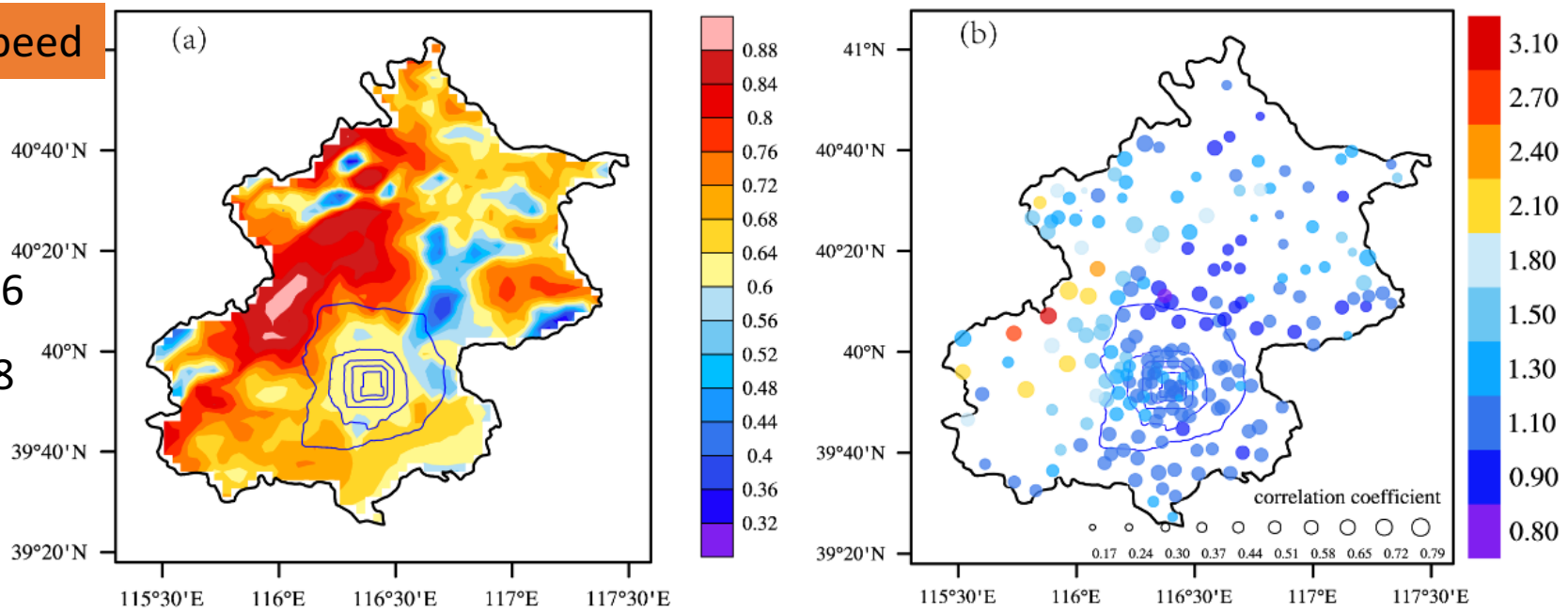
VALIDATIONS

Site/Regional	variables	Resource	Other descriptions
Site	temperature	National meteorological stations	20 observation sites; hourly; 2001–2017
	wind speed	Automatic weather stations	205 observation sites; hourly; Dec,2008-Dec,2010
Regional	Temperature and wind speed	CLDAS(China Meteorological Administration Land Data Assimilation System)	0.0625°×0.0625°; hourly; 2008–2014

Wind speed

CC>0.6

RMSE<1.8



Wind speed comparisons between observed and simulated values: (a) correlation coefficients between CLDAS reanalysis data and AH simulations (b) correlation coefficients and RMSEs between stations' observation and AH simulations, the sizes of circles mean the values of correlation coefficient and the colors represent RMSE.

VALIDATION

Regional:

correlation coefficients (CC) > 0.95

RMSE = 0.8℃

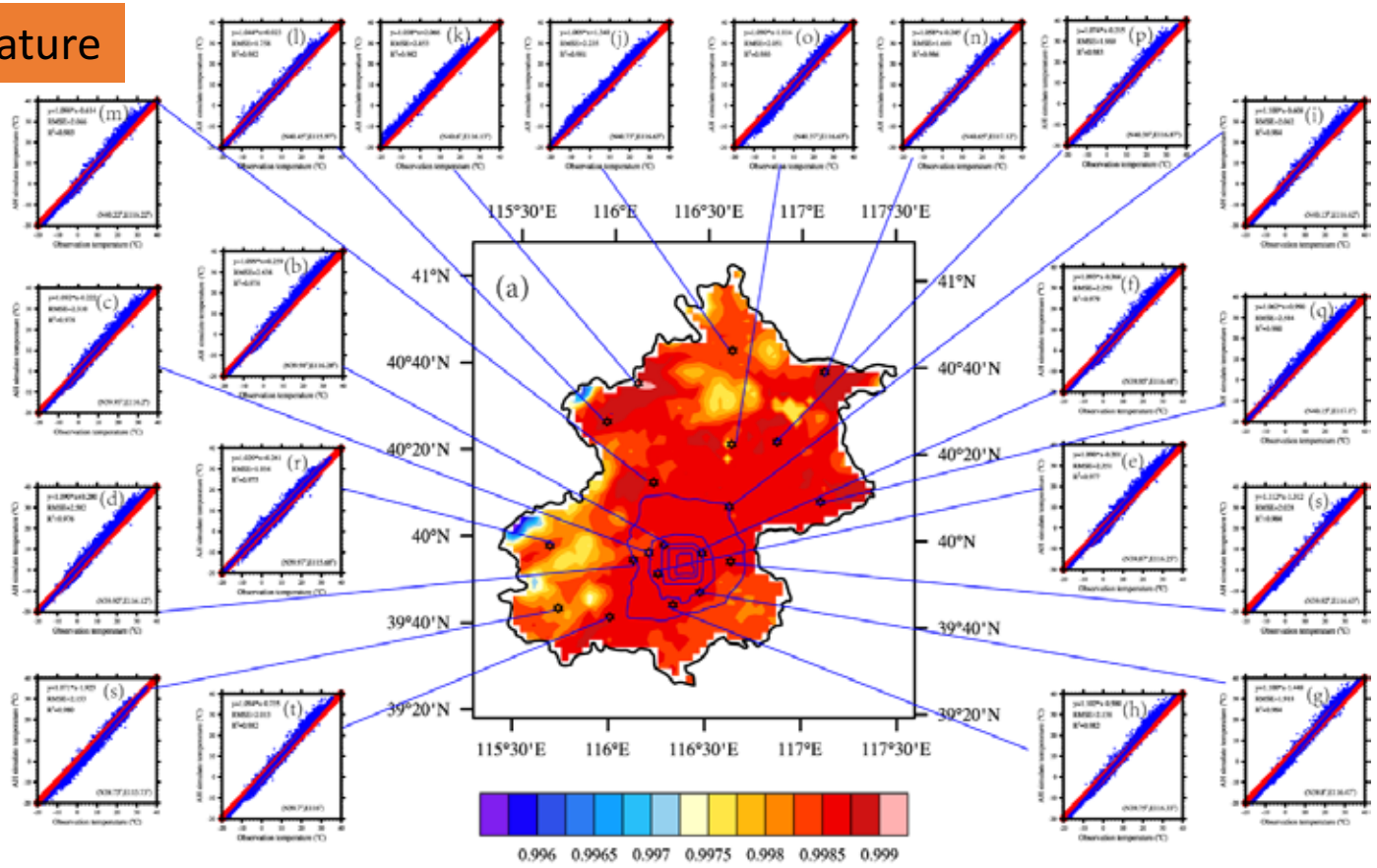
Site:

regression coefficients (RC) : 1~1.1

RMSE almost < 2.5℃

R^2 > 0.95

Temperature

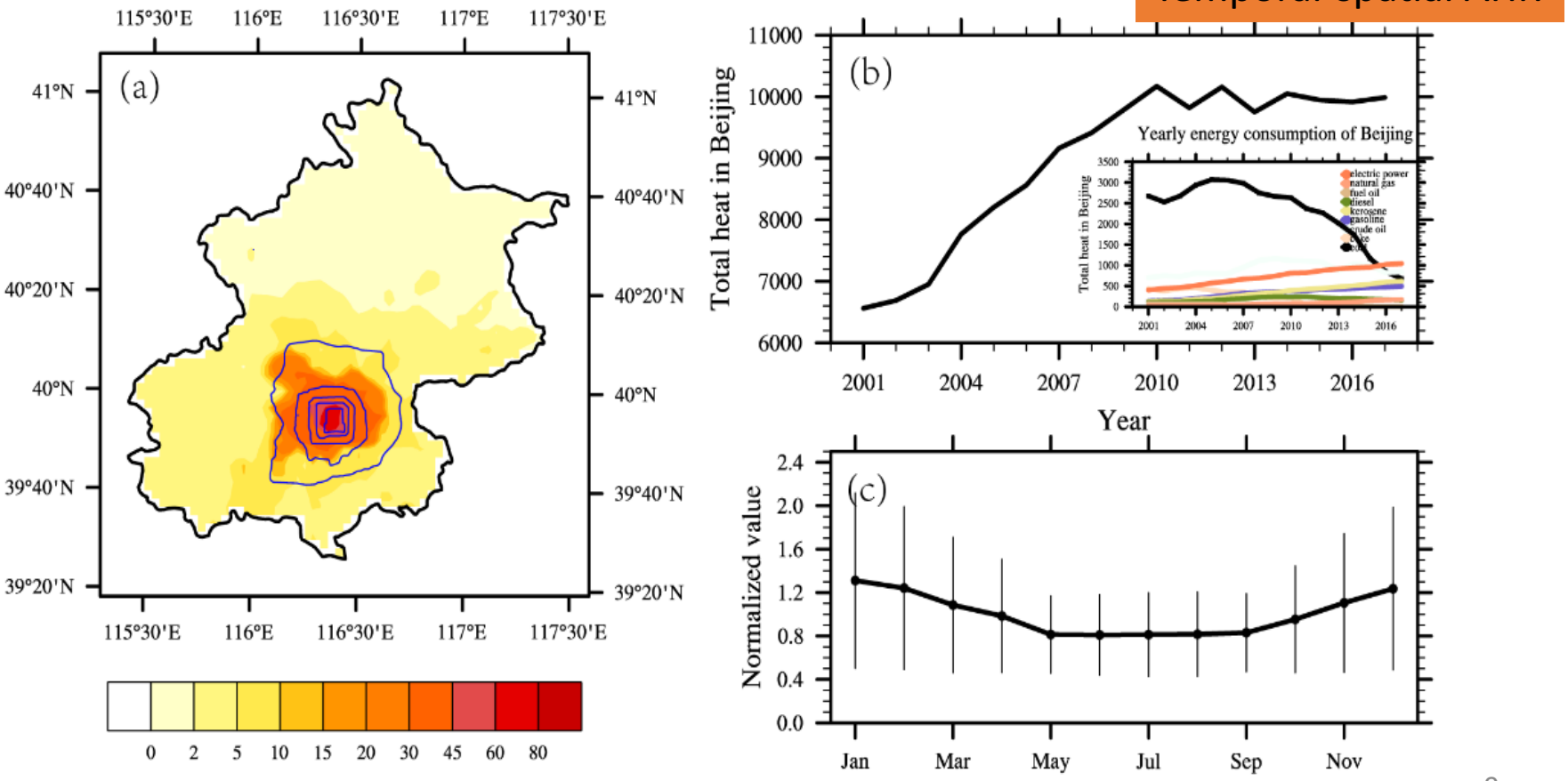


Comparisons between observed and simulated values: (a) correlation coefficients between CLDAS temperatures and AHR simulated temperatures; (b)–(u) 1:1 lines between observed temperatures and AHR simulated temperatures.

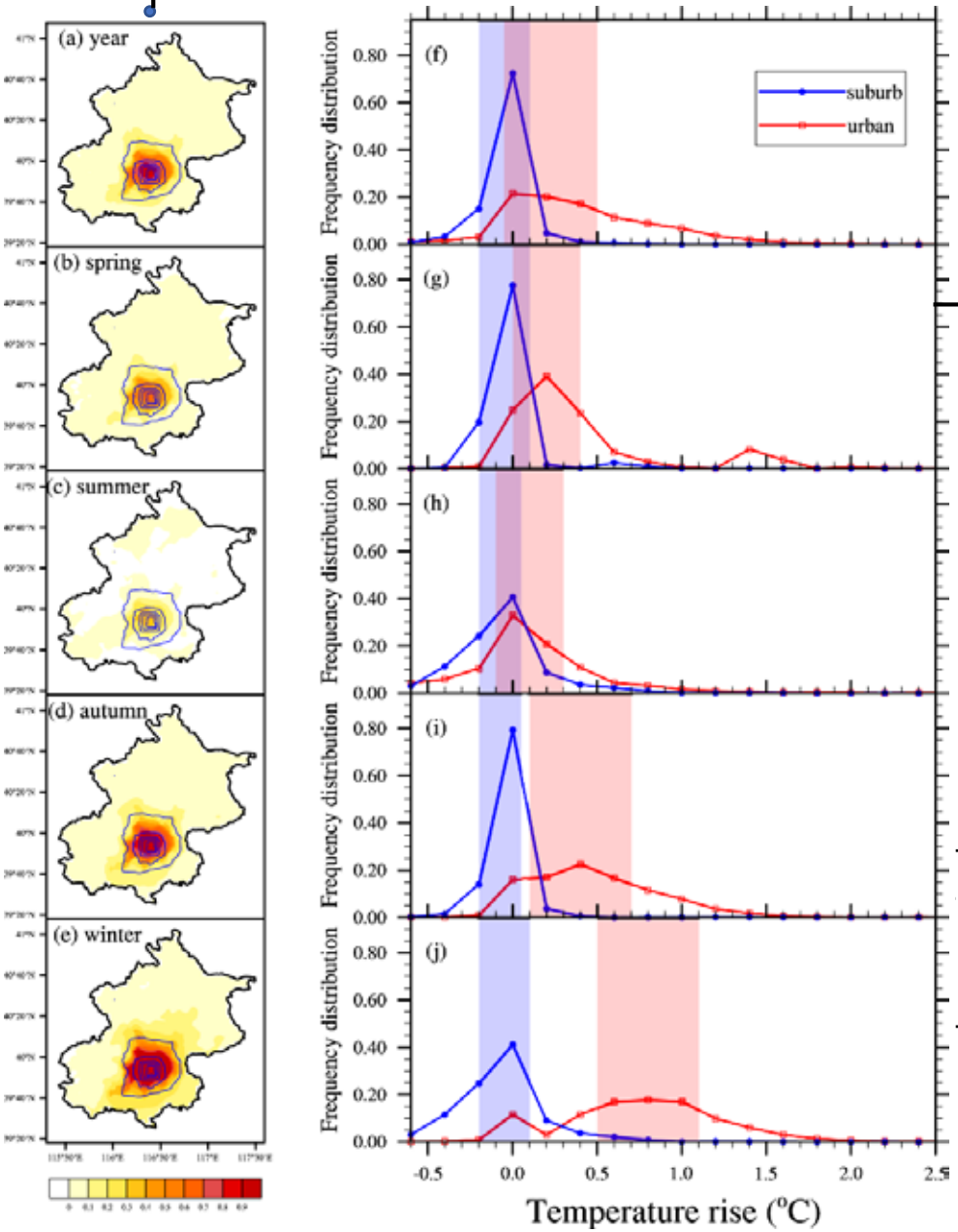
RESULTS

- **Spatial distribution:** most AHR is concentrated within the six ring roads of Beijing
- **Yearly:** AHR of Beijing increased from 2001 to 2010, then became stable and reached a maximum
- **Monthly:** AHR is higher in winter than in other seasons

Temporal-spatial AHR



RESULTS



Yearly and seasonal temperature rises due to AHR

Yearly and seasonal frequency distribution of temperature rise due to AHR

Both frequency distributions of temperature increase show that **the city center experiences a stronger effect** than the suburbs

	Year	Spring	Summer	Autumn	Winter
ΔT	0.525	0.362	0.191	0.621	0.936
AHR	5.289	5.084	4.300	5.095	6.679
ΔT/AHR	0.099	0.071	0.044	0.122	0.140

heating efficiency (**ΔT/AHR**) of AHR in summer is **less significant** than in other seasons

RESULTS

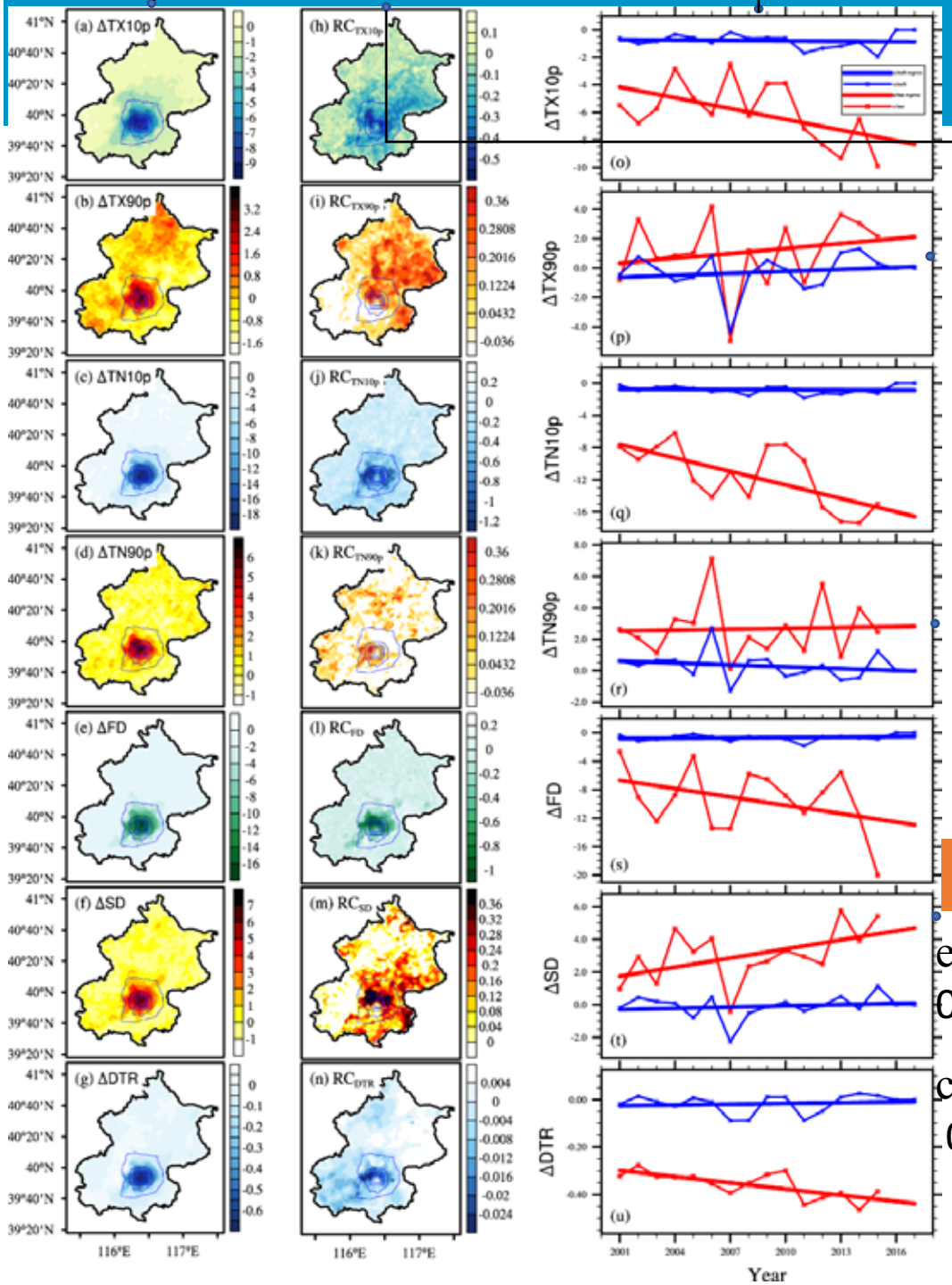
Seven extreme temperature indices (ETIs) were to represent both the extreme heat events and extreme cold events

Index	Index name	Description
FD	Frost days	Days below 0ºC in one year
TN10p	Cold nights	Days when the daily minimum temperature is lower than the calendar day 10th percentile
TX10p	Cold days	Days when the daily maximum temperature is lower than the calendar day 10th percentile
TN90p	Warm nights	Days of the daily minimum temperature is higher than the calendar day 90th percentile
TX90p	Warm days	Days when the daily maximum temperature higher than the calendar day 90th percentile
SD	Summer days	Days above 25ºC in one year
DTR	Diurnal temperature range	Maximum temperature minus minimum temperature for each day in one year

extreme cold events

extreme heat events

RESULTS



spatial distribution of average ΔETIs from 2001 to 2017

regression coefficient between time series and extreme temperature index differences

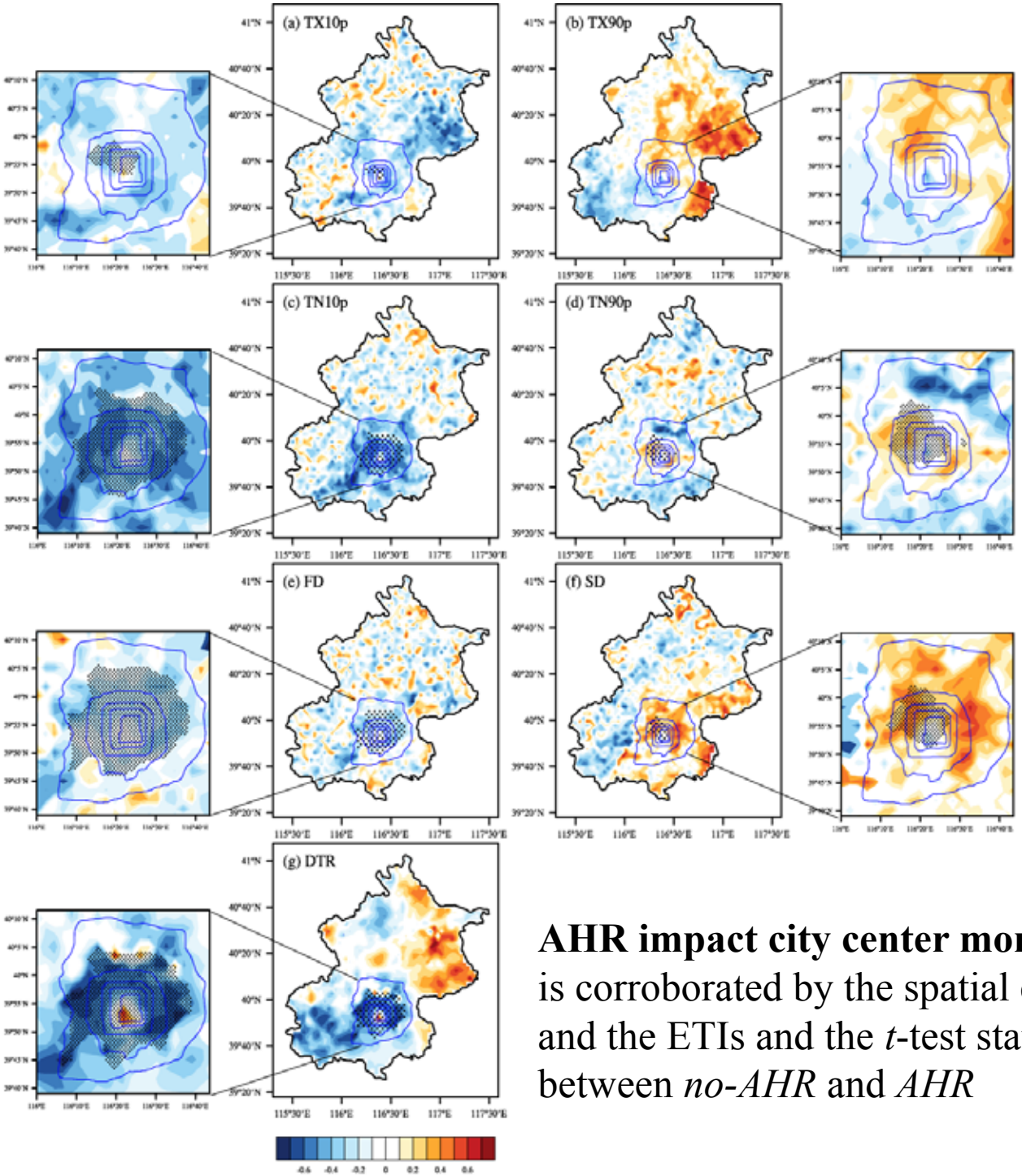
ΔETI time series and temporal trend lines from 2001 to 2017

Tendency of extreme temperature events

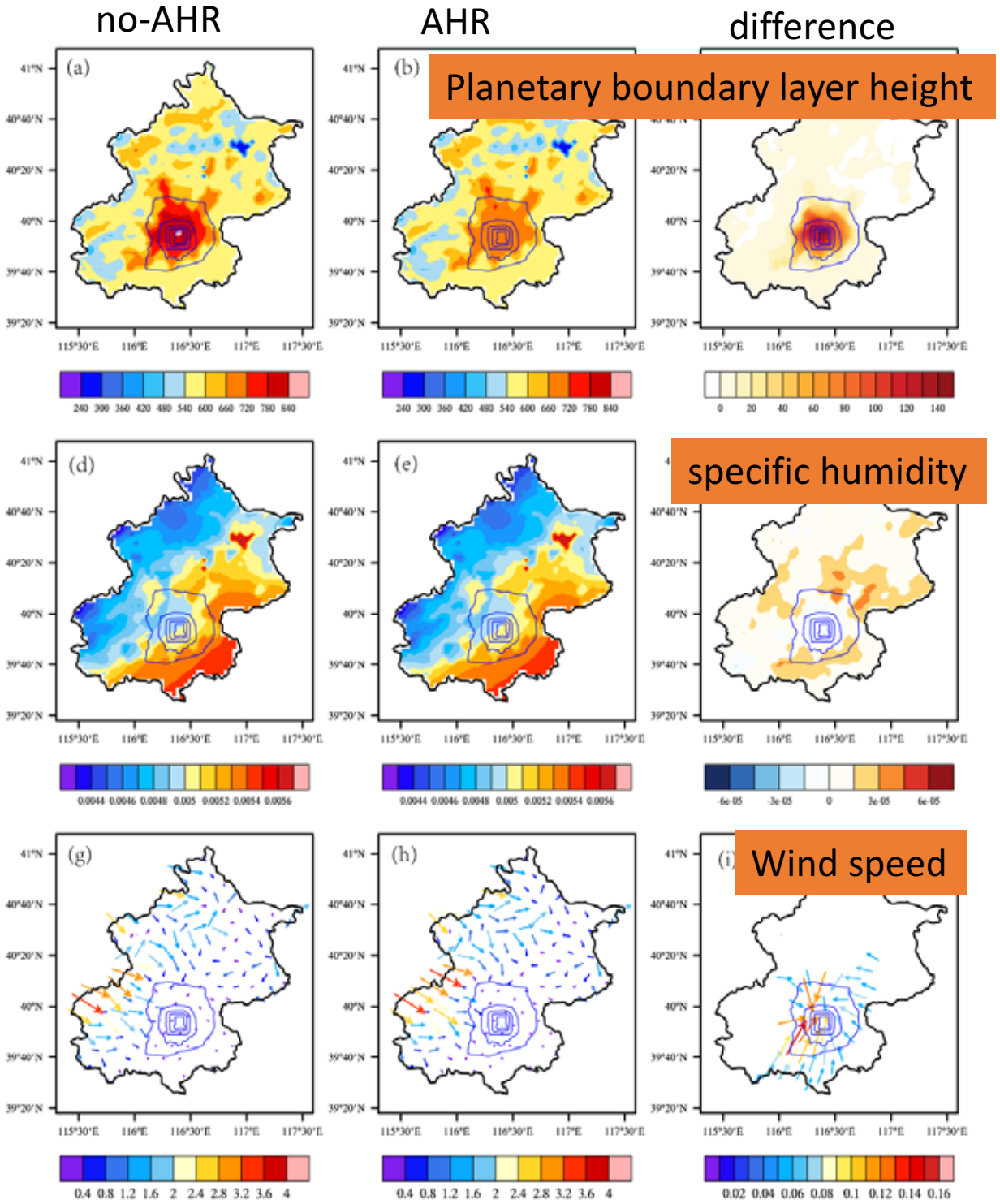
extreme heat events was increasing
0.11 (ΔTX90p), 0.02 (ΔTN90p), and 0.19 (ΔSD)

cold events were annually decreasing
0.26 (ΔTX10p), 0.56 (ΔTN10p), and 0.39 (ΔFD)

RESULTS



AHR impact city center more significant than suburb, which is corroborated by the spatial correlation coefficients of AHR and the ETIs and the *t*-test statistical significance of the ETIs between *no-AHR* and *AHR*



RESULTS

Increases in AHR had an impact on boundary **atmospheric dynamic processes**. The planetary boundary layer height (PBLH) increased with rising AHR

RESULTS

Extreme temperature events in this study were found to be controlled by the heating effect of AHR, but can be relieved slightly due to the cooling effect of the boundary dynamic process.

	TX10p	TX90p	TN10p	TN90p	FD	SD	DTR
a	-0.081	-0.126	-0.319	0.057	-0.124	0.140	-0.459
b	0.521	-0.528	0.572	-0.583	0.380	-0.553	0.445
c	-1.60E-07	6.38E-08	1.46E-08	4.91E-08	4.59E-08	1.15E-08	1.38E-07

a, b, and c are multiple regression coefficients in the formula $\Delta ETI = a \times AHR + b \times (-\Delta PBLH) + c$; ΔETI, AHR, and −ΔPBLH are normalized in the regression process.

	Year	Spring	Summer	Autumn	Winter
a	0.082	0.210	-0.258	0.128	0.381
b	-0.880	-0.811	-0.896	-0.879	-0.422
c	1.99E-07	5.37E-08	-7.75E-09	-2.85E-08	-1.27E-06

a, b, and c are multiple regression coefficients in the formula $\Delta T = a \times AHR + b \times (-\Delta PBLH) + c$. ΔT, AHR, and −ΔPBLH are normalized in the regression process.

CONCLUSIONS

Long term temporal and spatial variation data AHR were processed, A new AHR scheme was implemented in the Weather Research and Forecasting (WRF) model, and Two experiments with and without AHR were performed.

- Temperature rise due to the AHR heating effect was mainly concentrated in the urban center
- AHR reinforced the occurrence of extreme heat events, but restrained the development of extreme cold events
- AHR and the atmospheric dynamic process play opposite roles in urban temperature rise and the occurrence of extreme temperature events
- This simulation can applied to other cities, we guess other cities for those developing counties may have the similar results.


中国科学院大气物理研究所
大气科学和地球流体力学数值模拟国家重点实验室
State Key Laboratory of Numerical Modeling for Atmosphere Sciences and Geophysical Fluid Dynamics
Institute of Atmospheric Physics, Chinese Academy of Sciences
Thanks for your attention!