



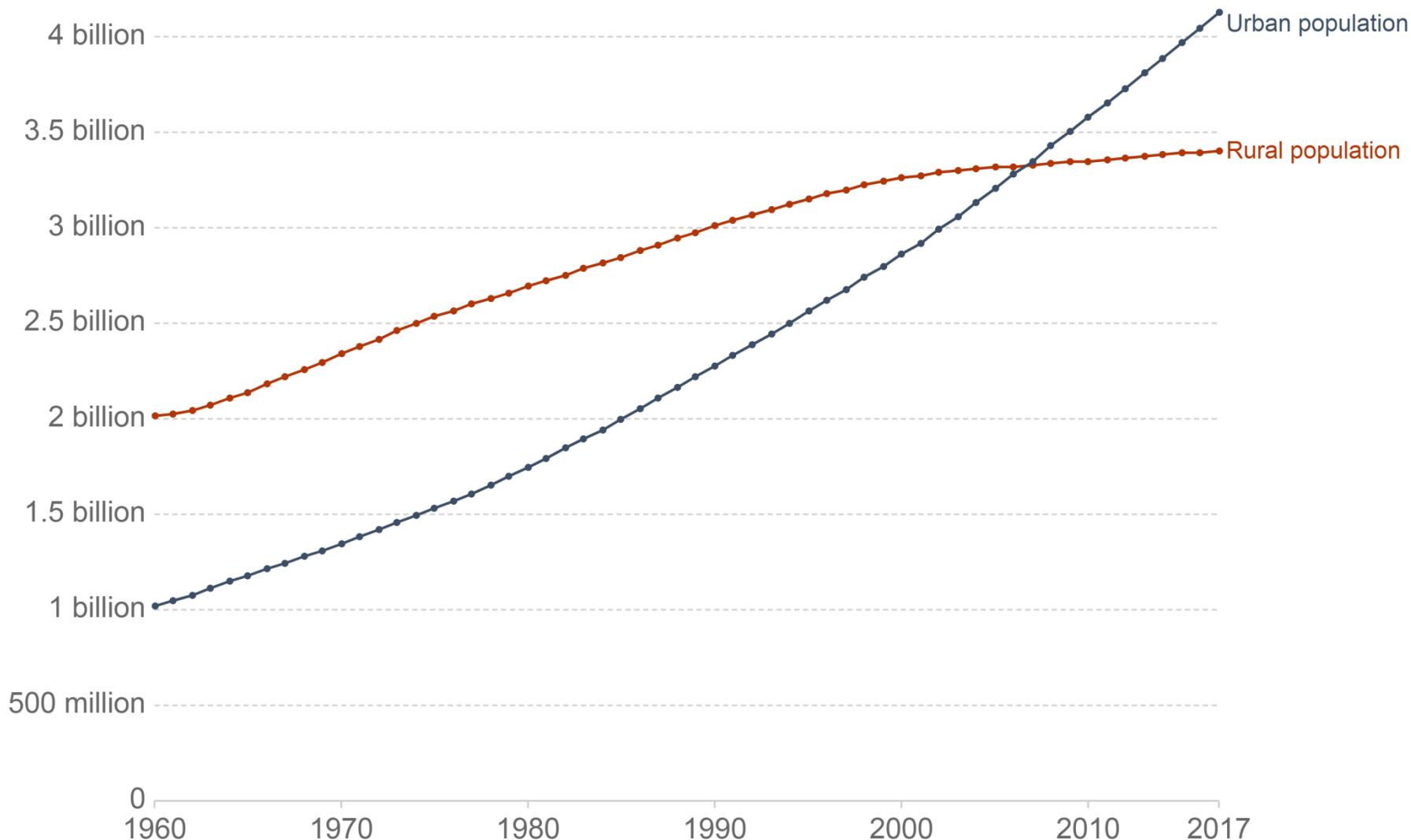
城市热岛效应的卫星遥感研究 进展与挑战

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南京信息工程大学
应用气象学院

2021-06-04

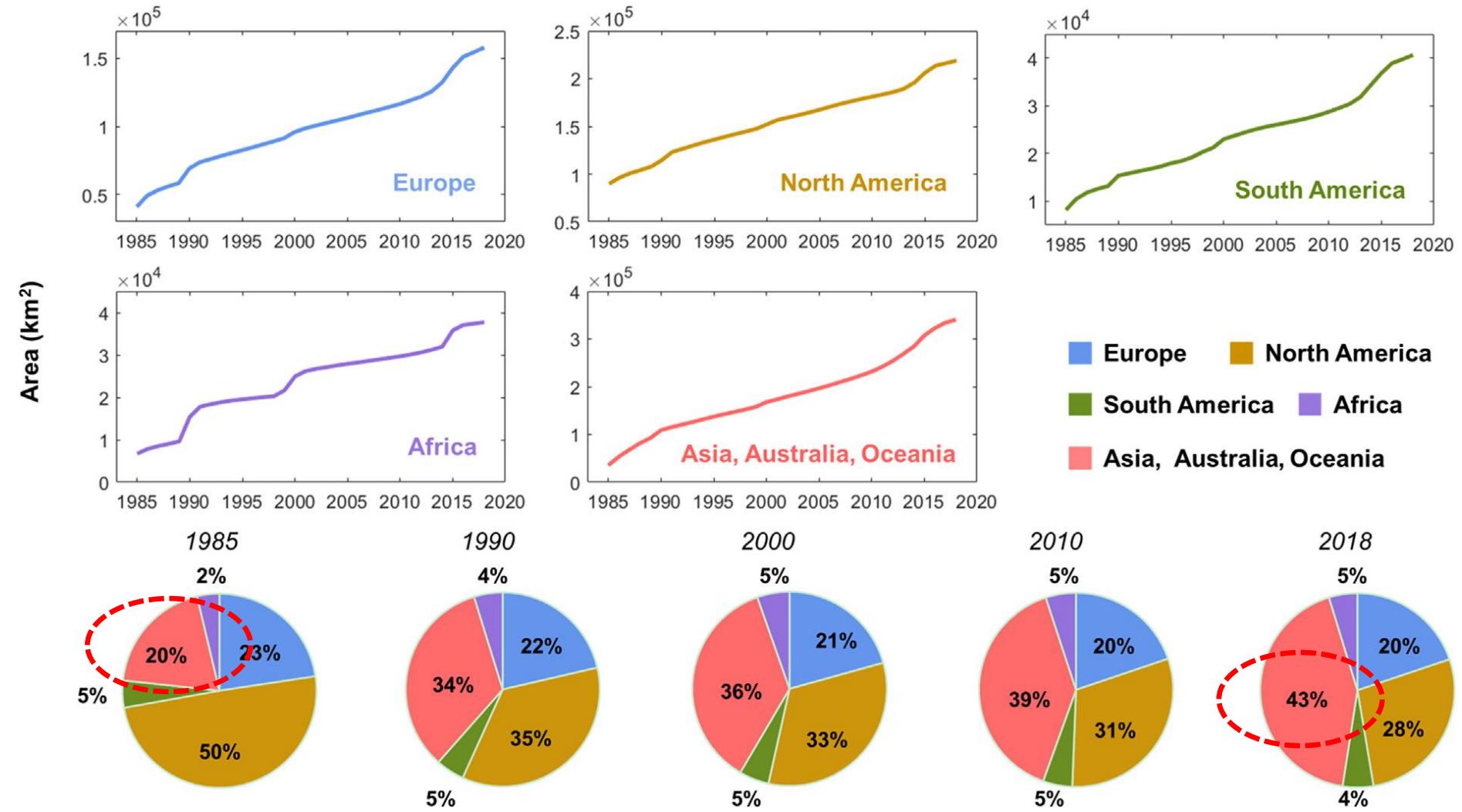
Number of people living in urban and rural areas, World, 1960 to 2017



Source: UN World Urbanization Prospects (2018)

Note: Urban populations are defined based on the definition of urban areas by national statistical offices.

OurWorldInData.org/urbanization • CC BY

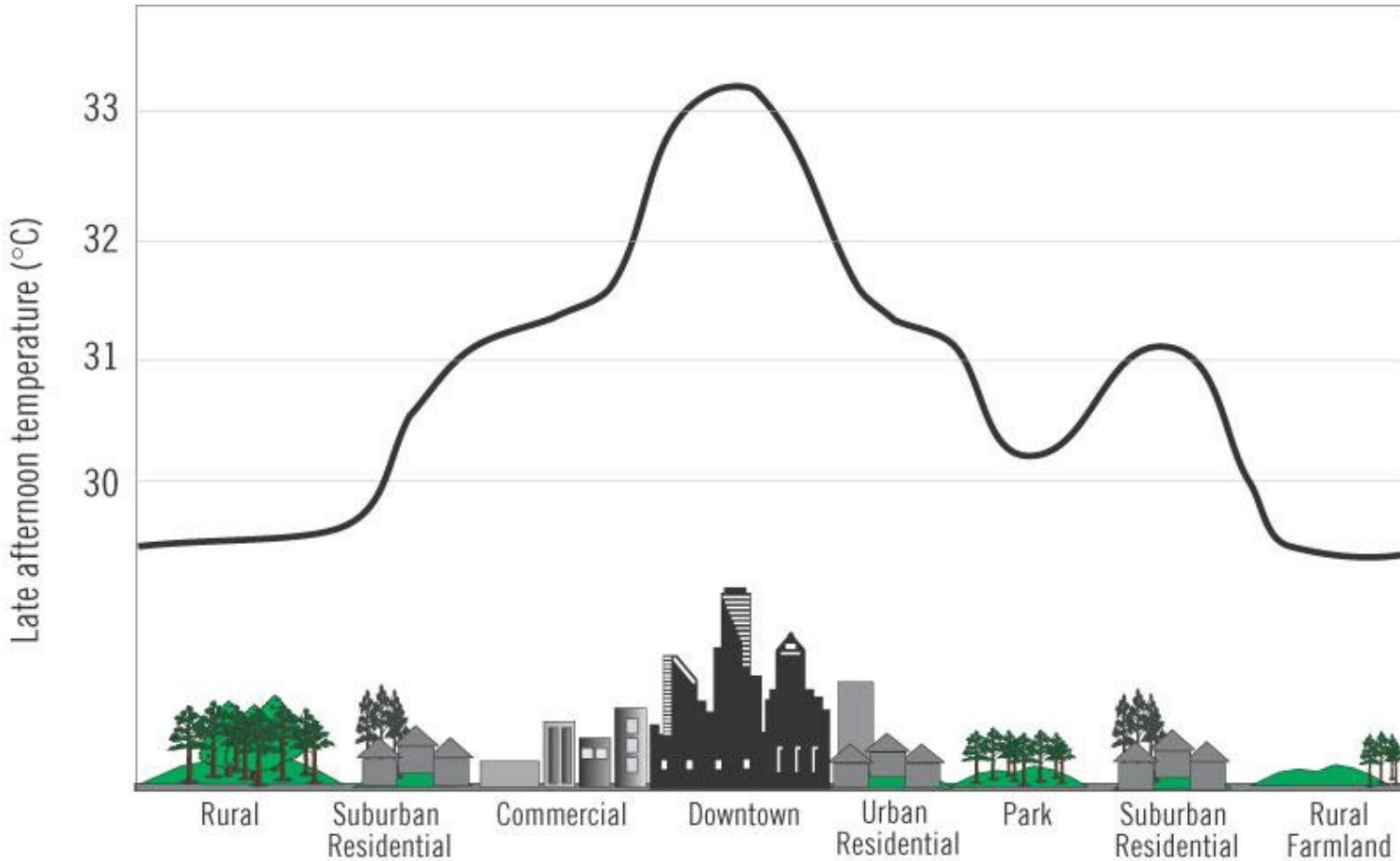


1990-2018年城市不透水面增加了1.5倍多

(Gong, 2020, RSE)

城市热岛 (UHI)

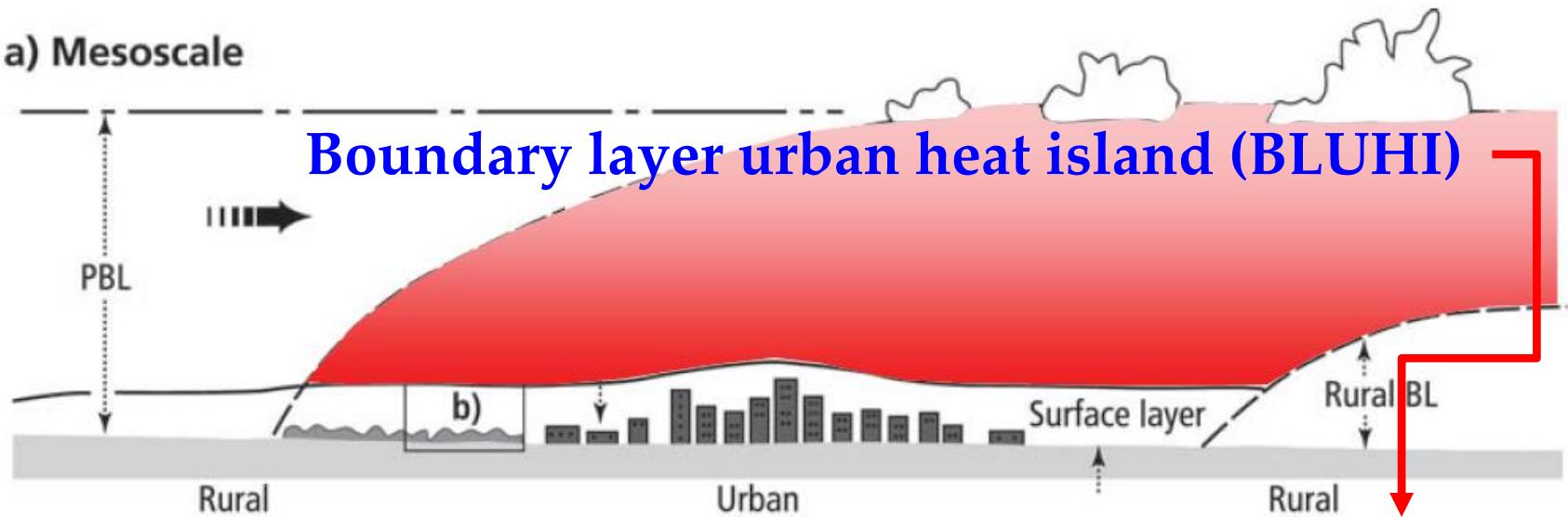
快速城市化最典型后果之一



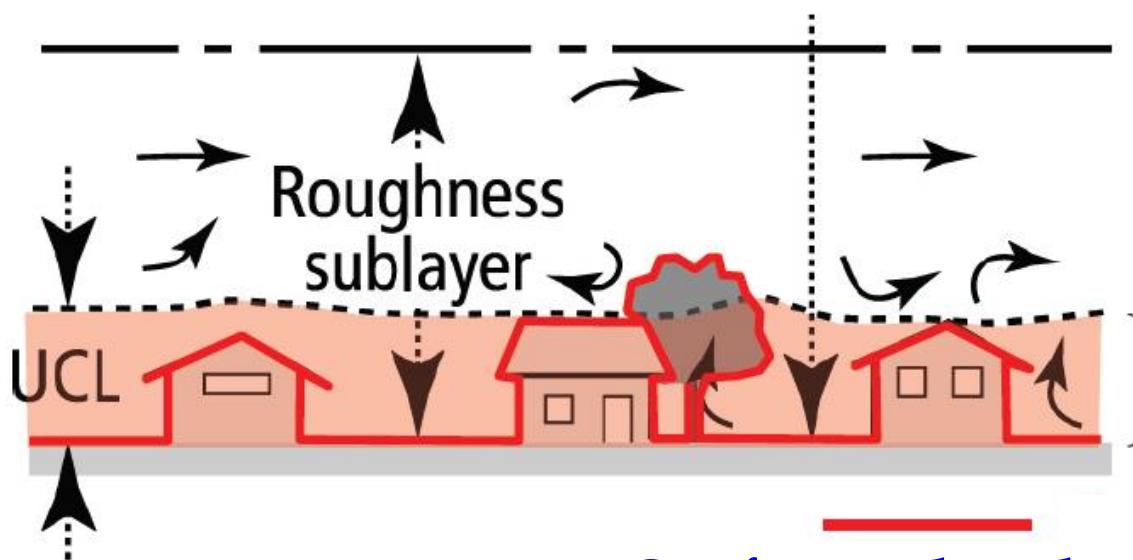
城市气象和城市生态研究热点

根据观测高度→3类UHI

a) Mesoscale



Air UHI
(AUHI)



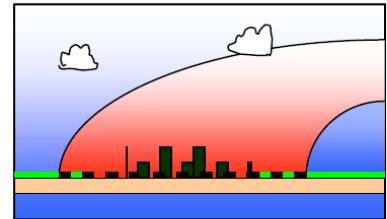
Canopy layer
urban heat
island (CLUHI)

Surface urban heat island (SUHI)

(Oke, 1997)

不同类型UHI 的观测方法

BLUHI

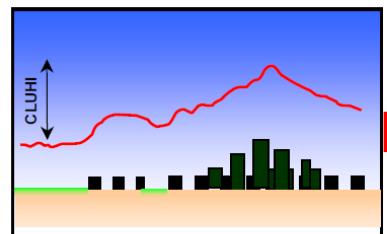


Fixed
tower

Traverse
aircraft

Remote
sodar

不同观测高度

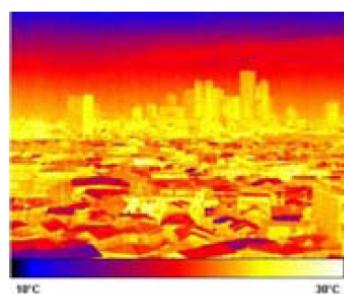


Fixed
station

Traverse
automobile

代表性差
成本较高
站点进城

CLUHI



SUHI

(Voogt, 2007)

不同地表定义

True 3-D
(Complete)

Bird's-eye 2-D
aircraft, **satellite**

Ground
(road)

连续 | 一致 | 重复观测
范围大 | 成本低 | 标准化

1. 文献综述
2. SUHI 研究卫星传感器
3. SUHI量化方法
4. 主要研究发现
5. 面临的挑战
6. 未来可能研究方向

1、文献综述 (1972- 2018)

文献收集： ISI Web of Science + Google Scholar

Journal publications + English

初步检索 → >3000



摘要阅读 → 778



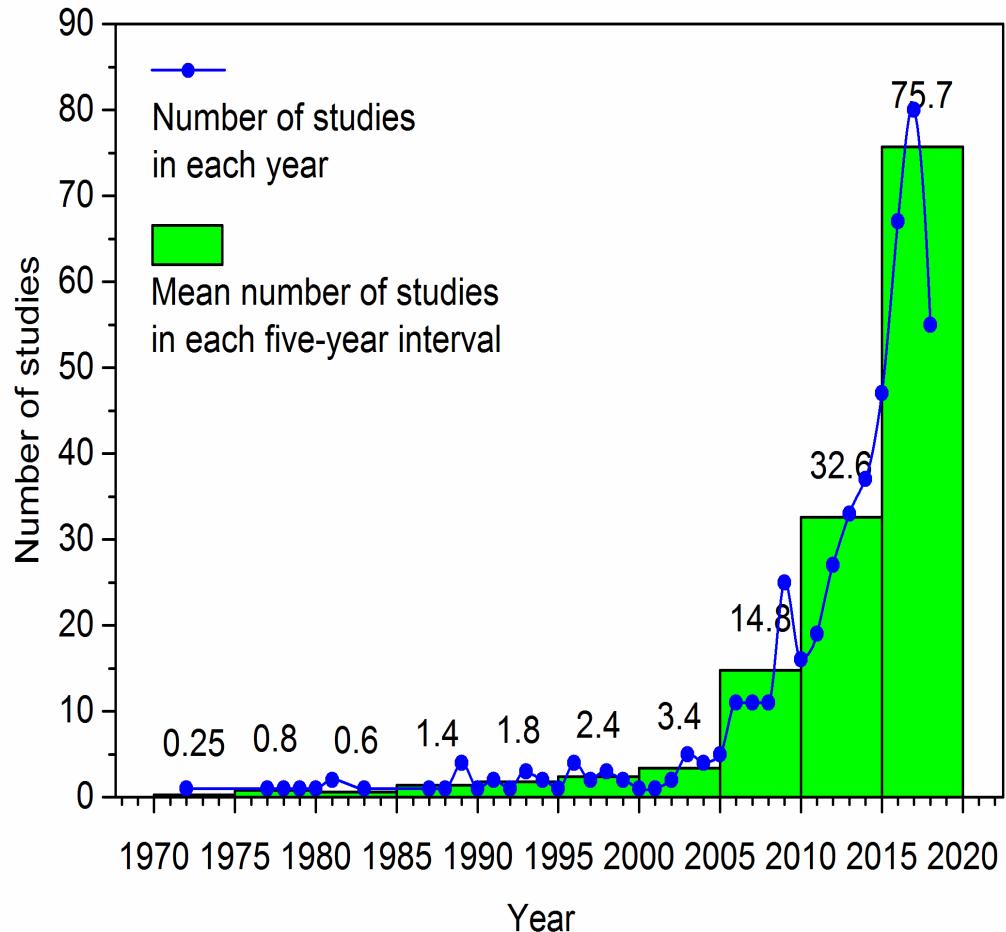
全文阅读 → 492



Title | Author | Source journal | Publication year
Sensor types | Study cities | Study time | Research foci

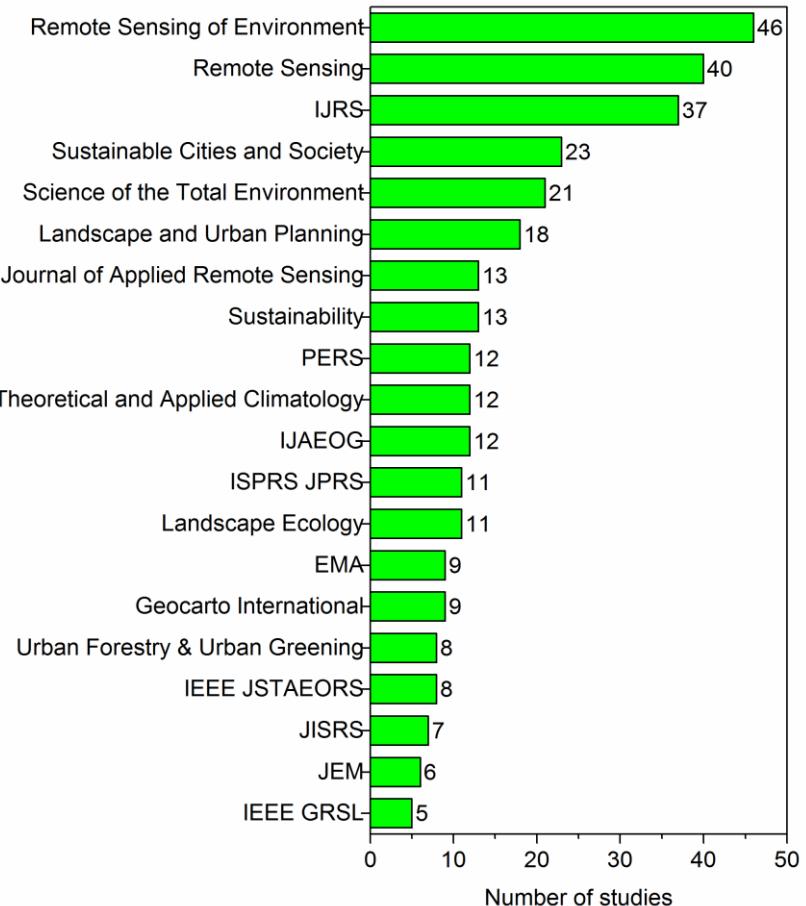
(Zhou, 2019, RS)

历史趋势



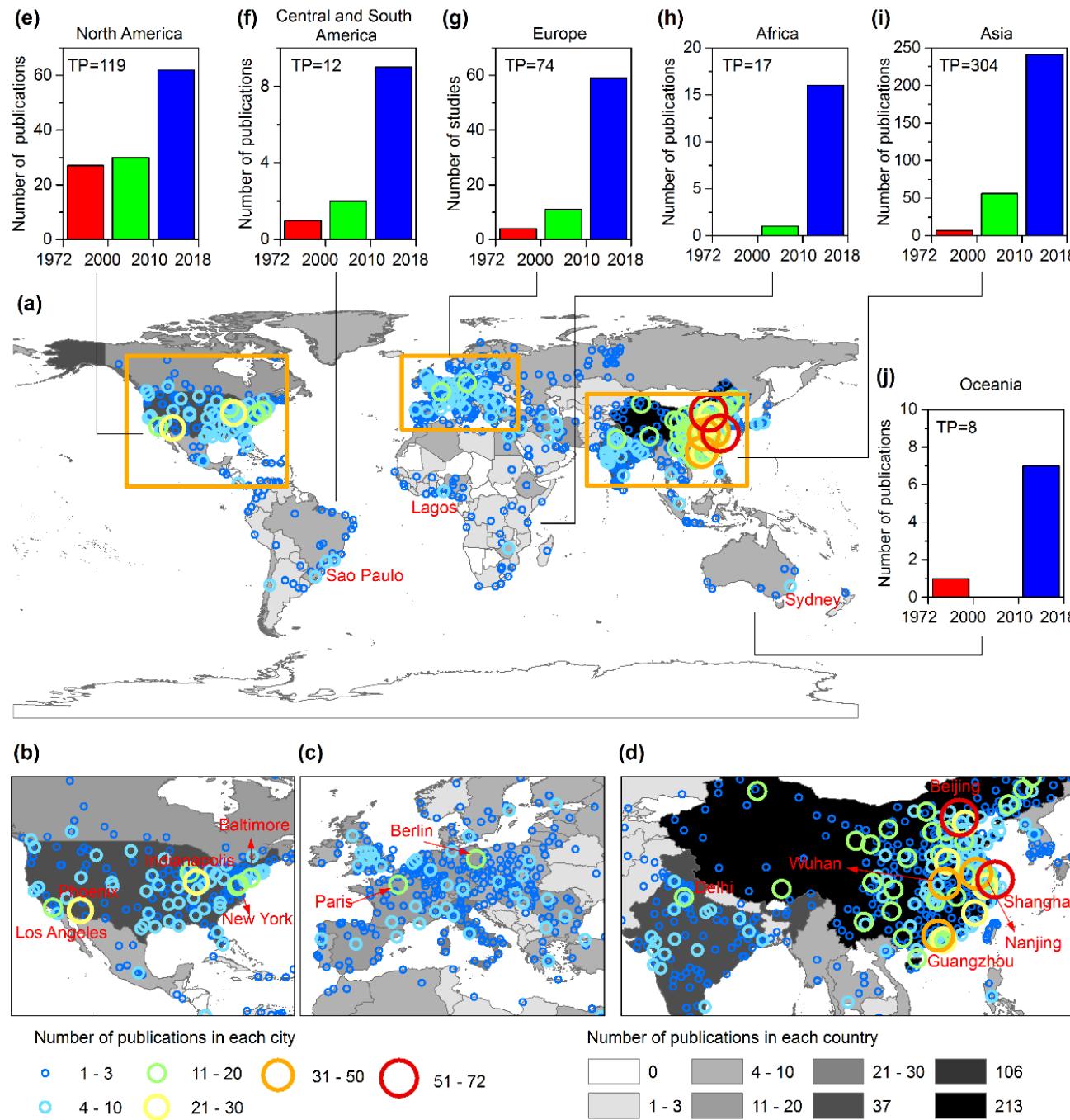
2005年后呈指数增加趋势

期刊



107种期刊，遥感类为主

地理分布

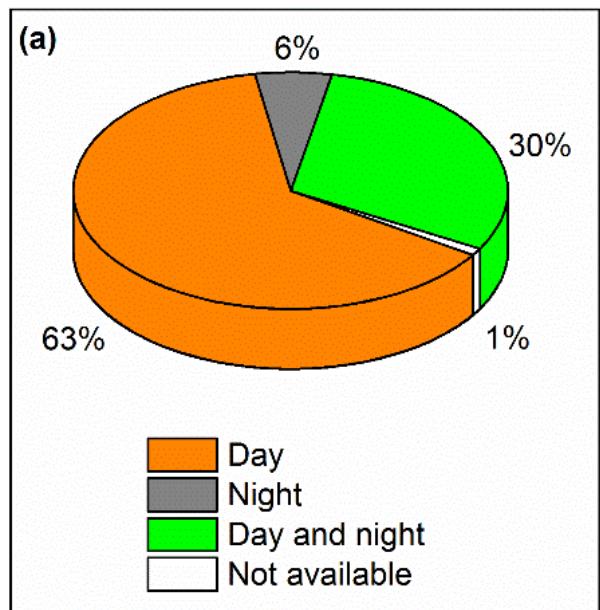


中国 213

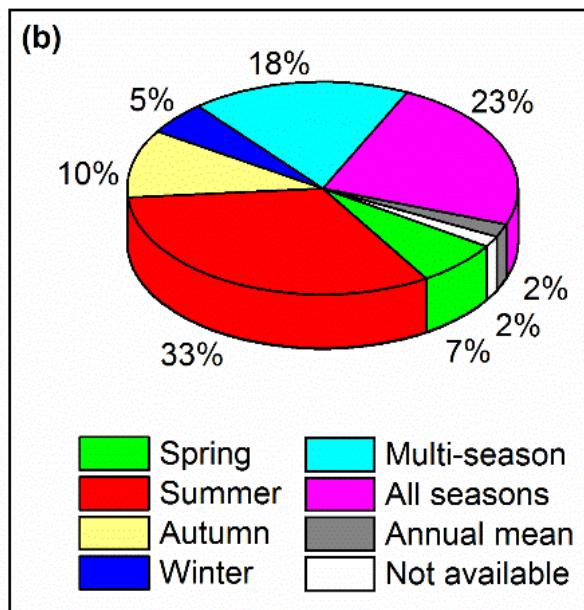
北京 72

上海 51

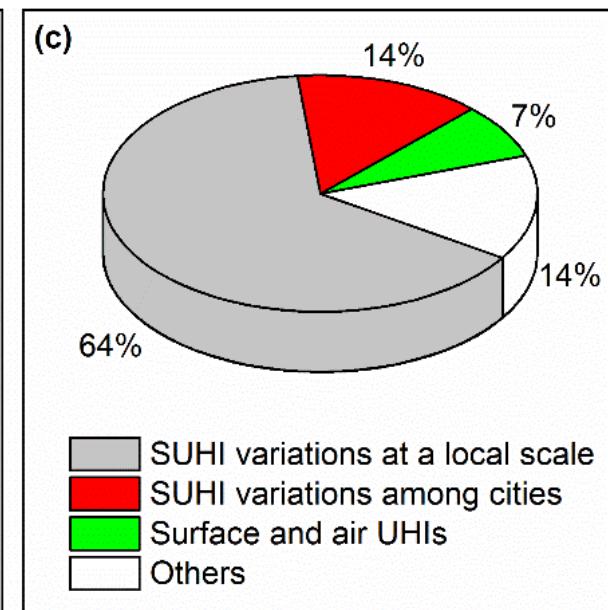
时间



季节



关注问题



白天

夏季

局地尺度（像元或
街区）SUHI的变化

SUHI卫星遥感研究一些里程碑事件

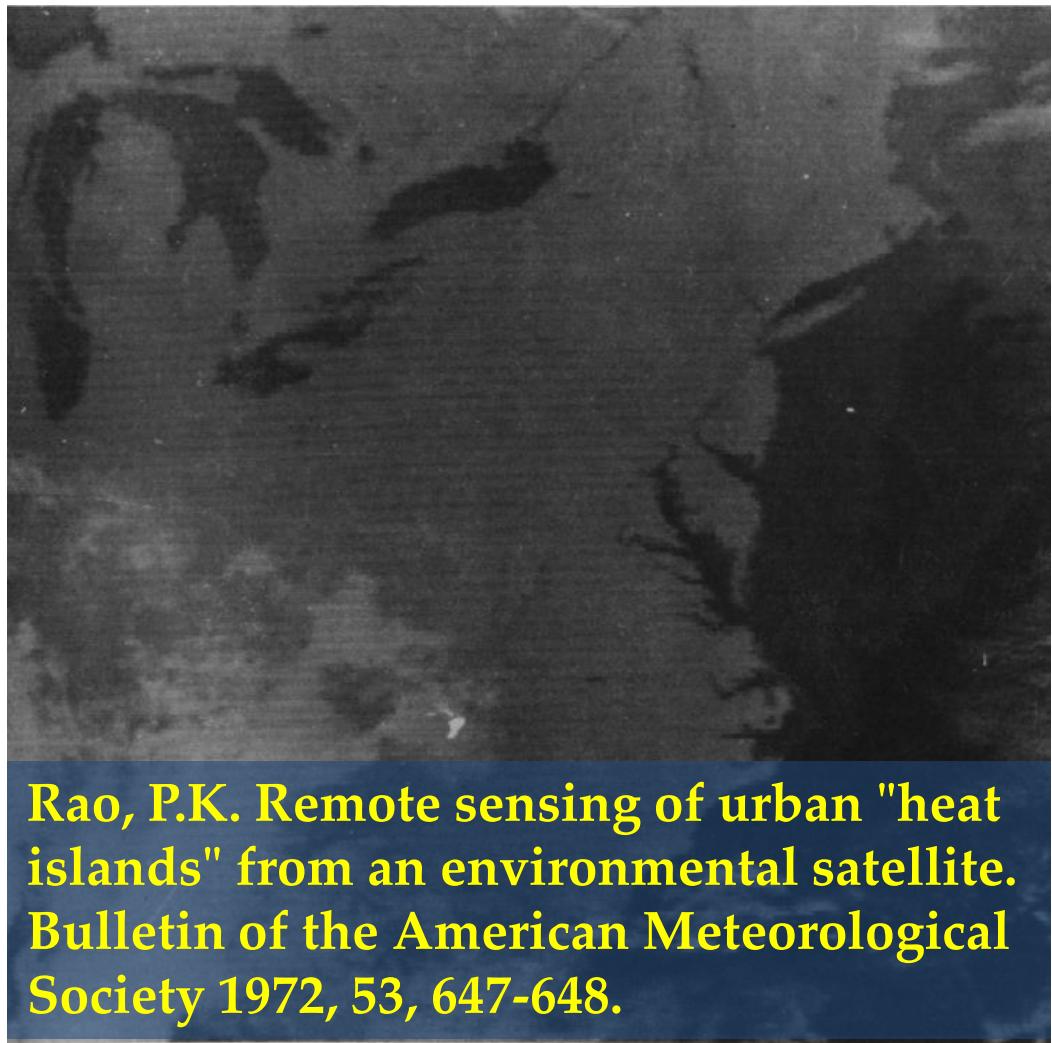
始于1972

P. KRISHNA RAO

Research Physical Scientist,
National Environmental
Satellite Service (NESS) of the
National Oceanic and
Atmospheric Administration
(NOAA).



?



Rao, P.K. Remote sensing of urban "heat islands" from an environmental satellite.
Bulletin of the American Meteorological Society 1972, 53, 647-648.

ITOS-1, 19 Oct. 1970, East Coast, USA

1990: Landsat首次用于热岛效应研究 (Carnahan, W.H.; Larson, R.C. An analysis of an urban heat sink. *Remote Sens. Environ.* 1990, 33, 65–71.)

2004: MODIS被用于热岛效应研究 (Zhang, X.; Friedl, M.A.; Schaaf, C.B.; Strahler, A.H.; Schneider, A. The footprint of urban climates on vegetation phenology. *Geophys. Res. Lett.* 2004, 31)

2005: ASTER被用于热岛效应研究 (Nichol, J. Remote sensing of urban heat islands by day and night. *Photogramm. Eng. Remote Sens.* 2005, 71, 613–621.)

综述了卫星遥感在城市热岛研究中的应用与局限性

Roth, M.; Oke, T.R.; Emery, W.J. Satellite-derived urban heat islands from three coastal cities and the utilization of such data in urban climatology. *Int. J. Remote Sens.* **1989**, 10, 1699–1720. 引用873次

Voogt, J.A.; Oke, T.R. Thermal remote sensing of urban climates. *Remote Sens. Environ.* **2003**, 86, 370–384. 引用2413次

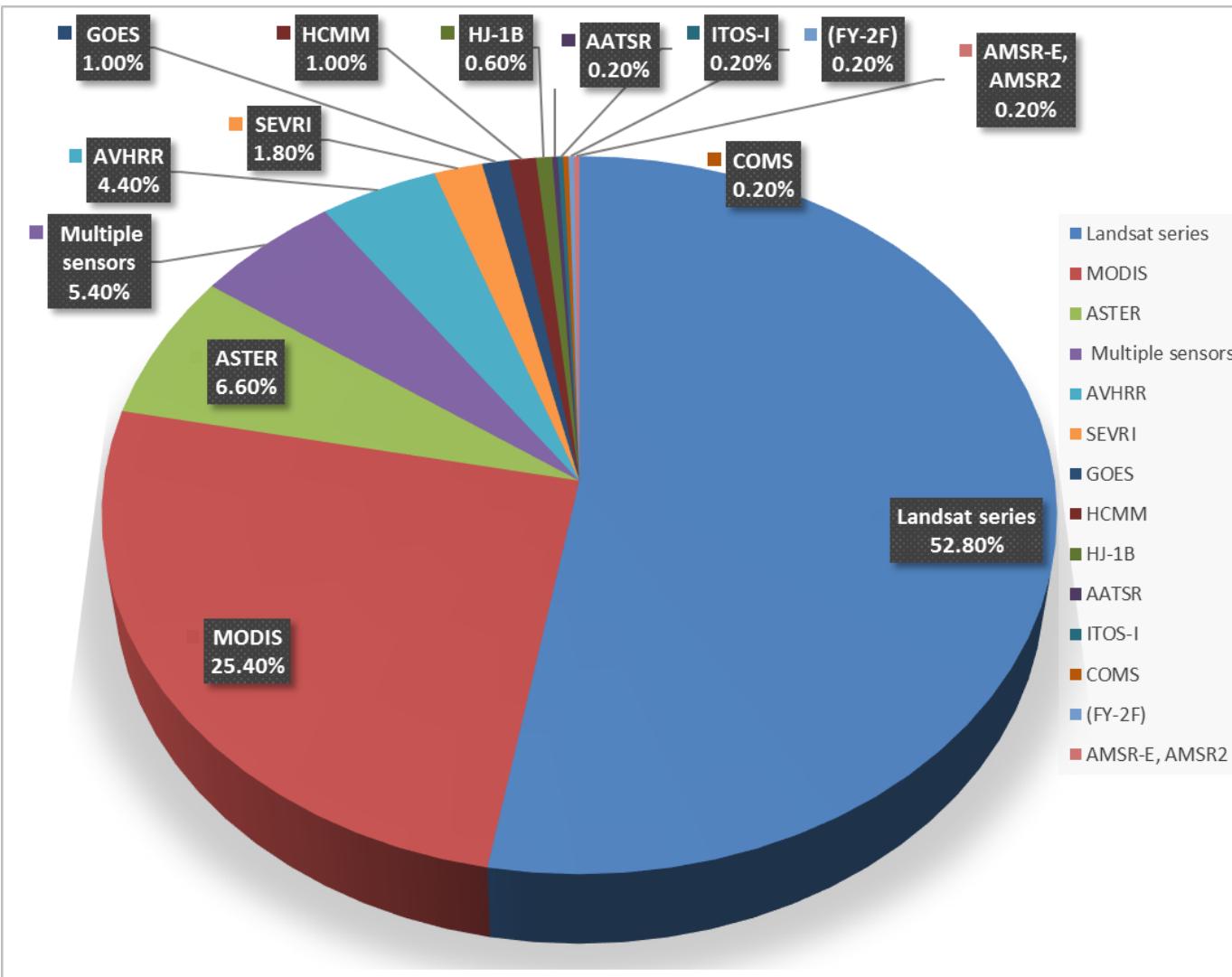
将混合像元分解技术用于热岛效应研究

Weng, Q.; Lu, D.; Schubring, J. Estimation of land surface temperature–**vegetation abundance** relationship for urban heat island studies. *Remote Sens. Environ.* **2004**, 89, 467–483. 引用2193次

首个全球尺度的研究

Jin, M.L.; Dickinson, R.E.; Zhang, D.L. The footprint of urban areas on global climate as characterized by MODIS. *J. Clim.* **2005**, 18, 1551–1565

2、SUHI 研究卫星传感器



Landsat 系列

1982-

白天

60-120m

16天

MODIS

2000-

白天夜晚

1000m

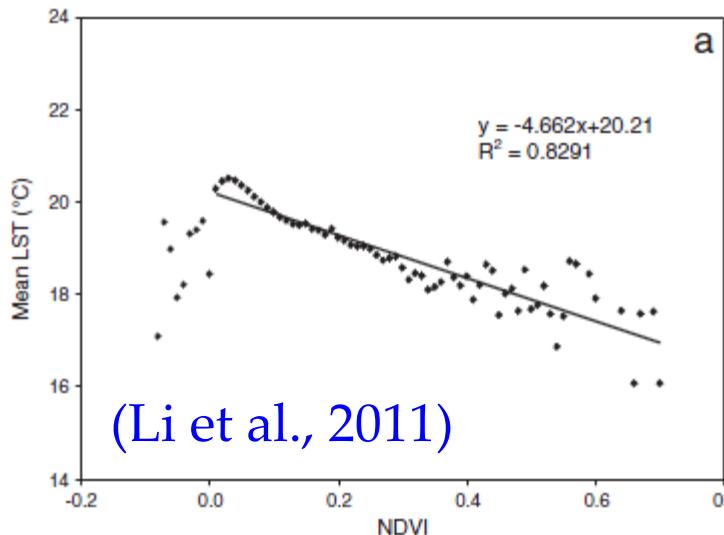
逐日

不同产品

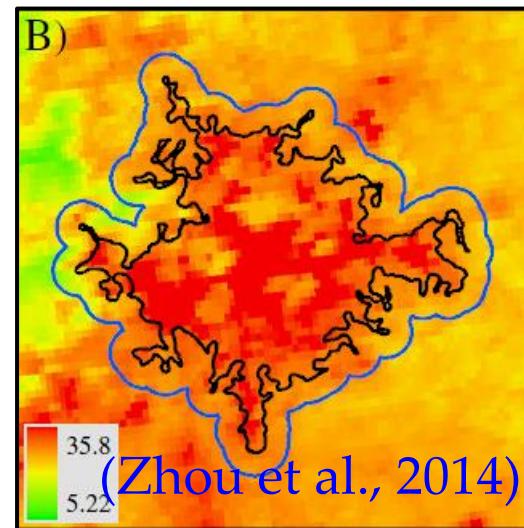
ASTER: 2000- ● 白天夜晚 ● 90m ● 16天 ● 不同产品

3、SUHI量化方法

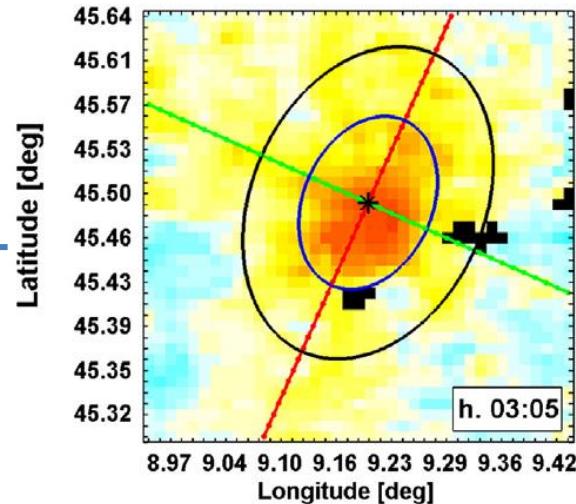
温度近似法



城郊（乡）温差法



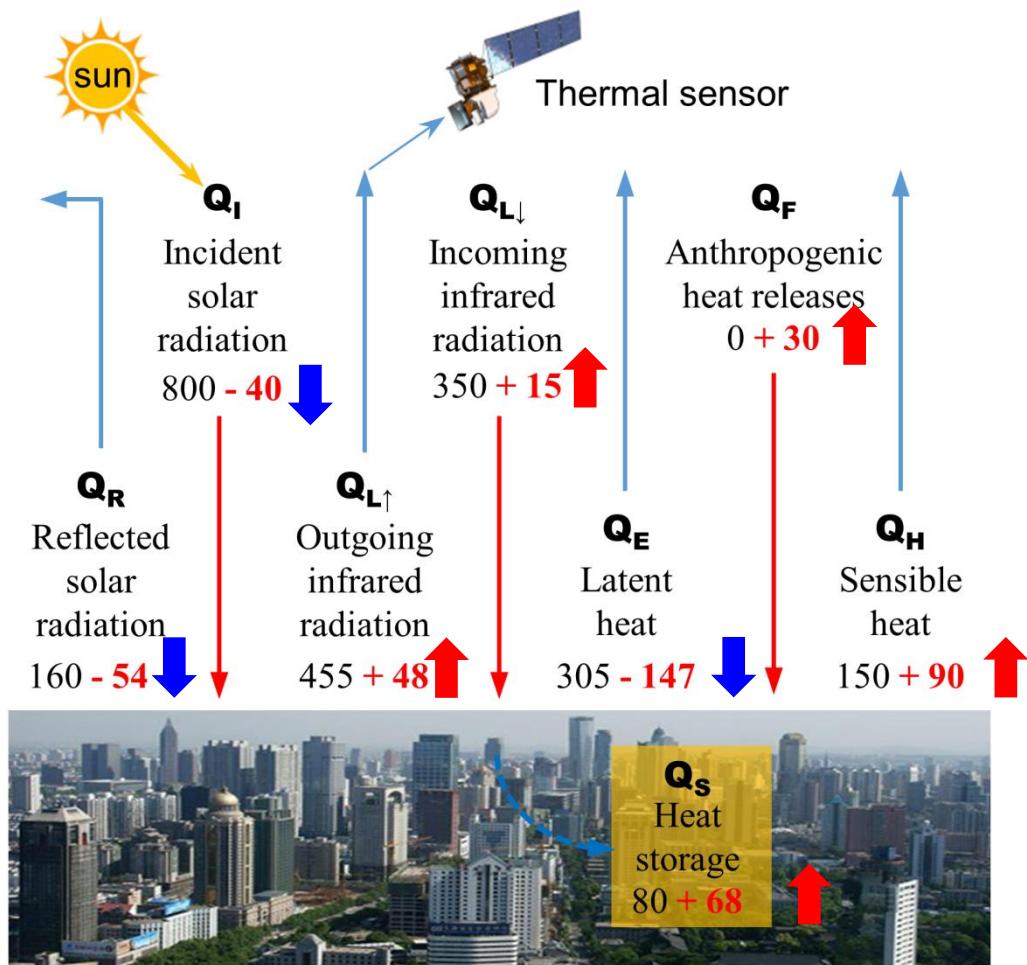
局地尺度
(像元尺度)



大尺度
(城市尺度)

统计模型
Gaussian surface

4、主要研究发现



$$\text{净辐射 } Q_I + Q_{L\downarrow} - Q_R - Q_{L\uparrow} + Q_F = Q_E + Q_H + Q_s$$

红色数字表示城市相对于乡村能量变化量

(1) 能量控制机制

不同时间季节不同

白天

反射+潜热+人为热

夜晚

储热+人为热

(Oke, 1988; Shepherd 2005)

(2) 局地（像元|街区）尺度SUHI 变化及驱动因子

Land cover/land use and their changes

(Built-up areas, vegetation, water | industrial, residential, commercial)

Urban site
characteristics
(2D/3D)

Landscape
composition and
configuration



Built-up areas: ISA, IBI, NDBI, UI, height, volume, FAI, FAR, SVF. **Vegetation:** NDVI, VF, shape, orientation, distance, abundance, height, volume, and specie. **Water:** NDWI, distance

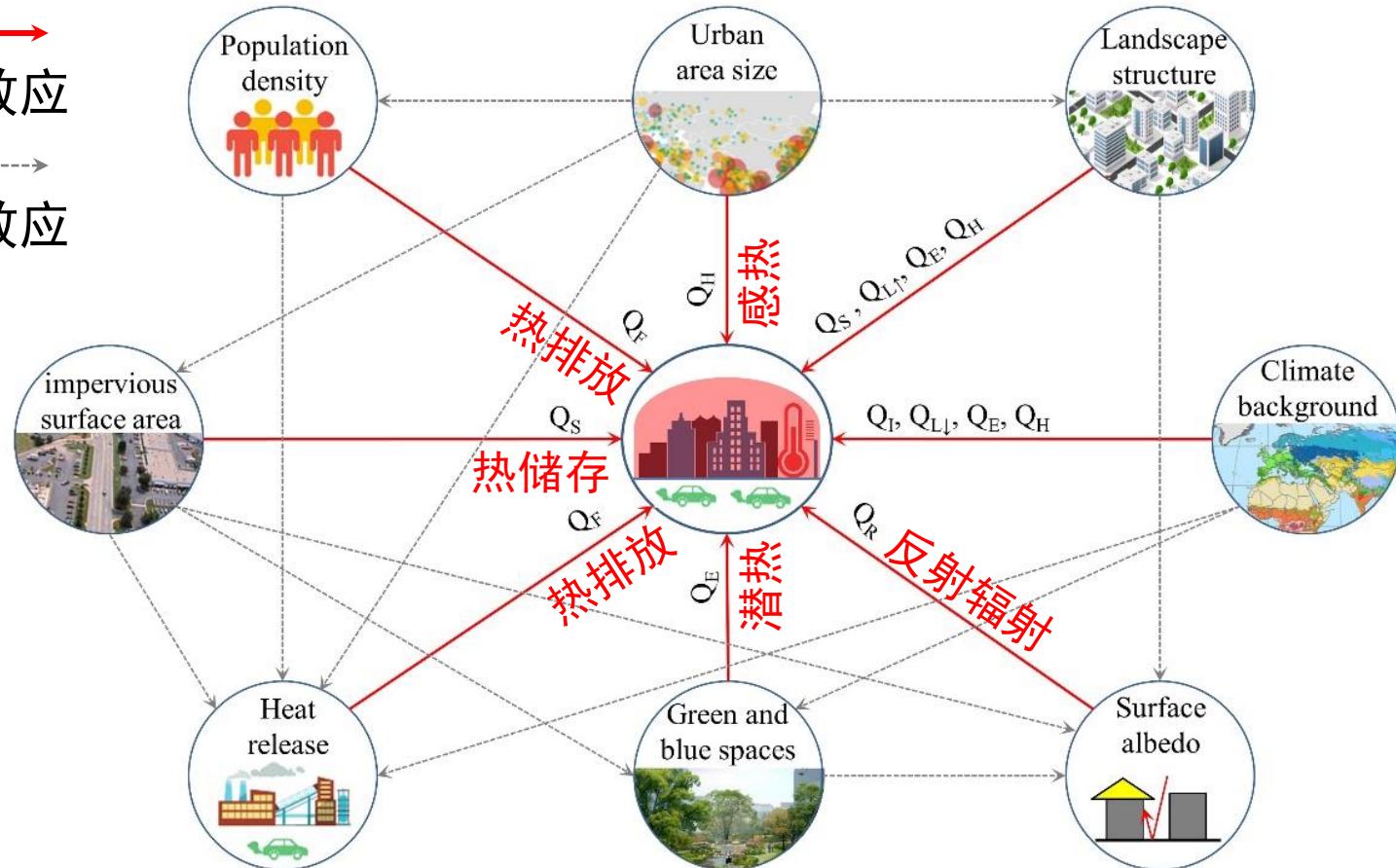
PD, ED, MSI, SHDI, LPI, Tree cover, Grass cover, etc.
Whether landscape composition or configuration is more important?

More indicators ≠ Better

(3) 不同城市（城市尺度）热岛差异及驱动因子

区域→国家→全球

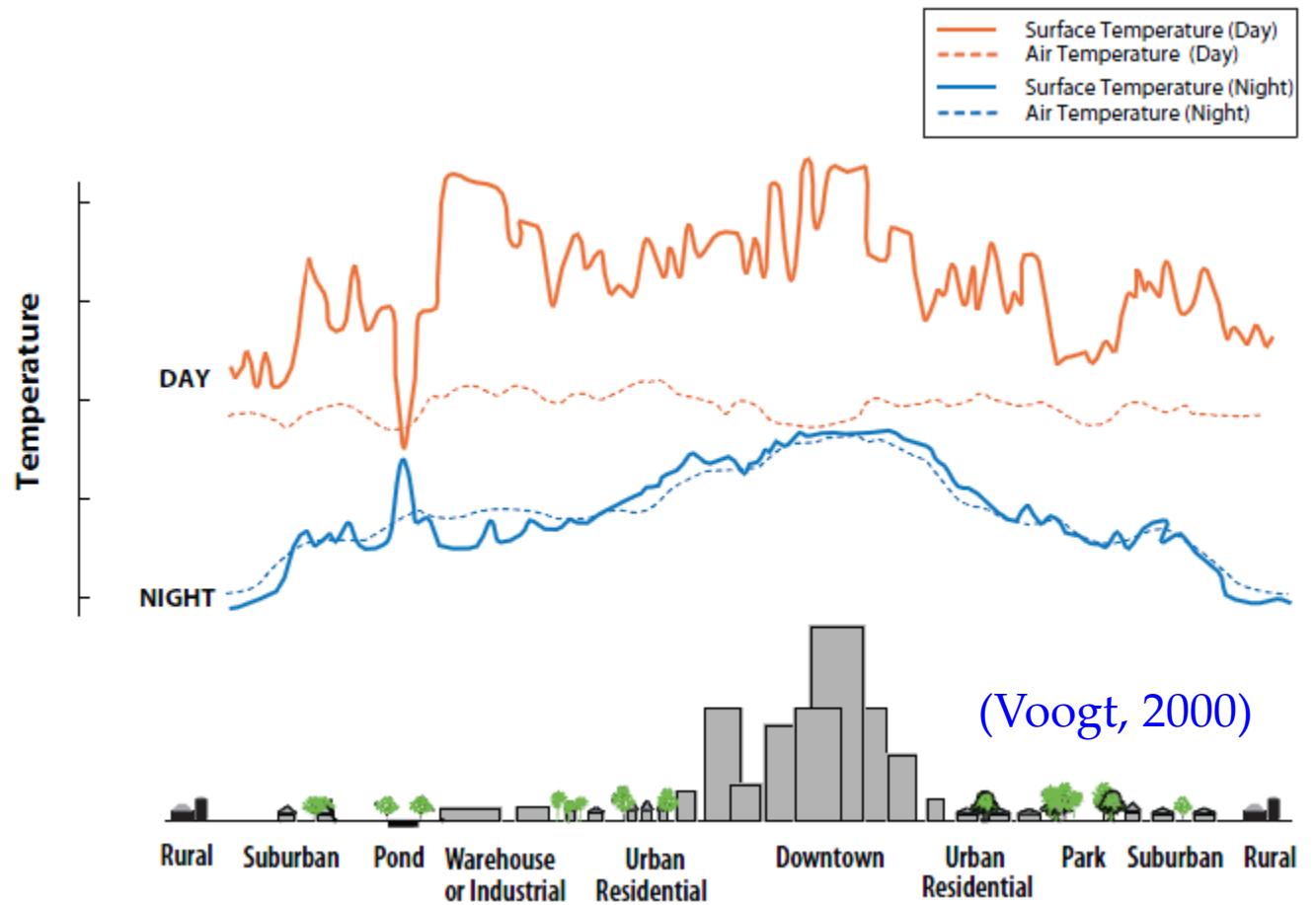
直接效应
间接效应



SUHI时空异质性极大
More cities ≠ better

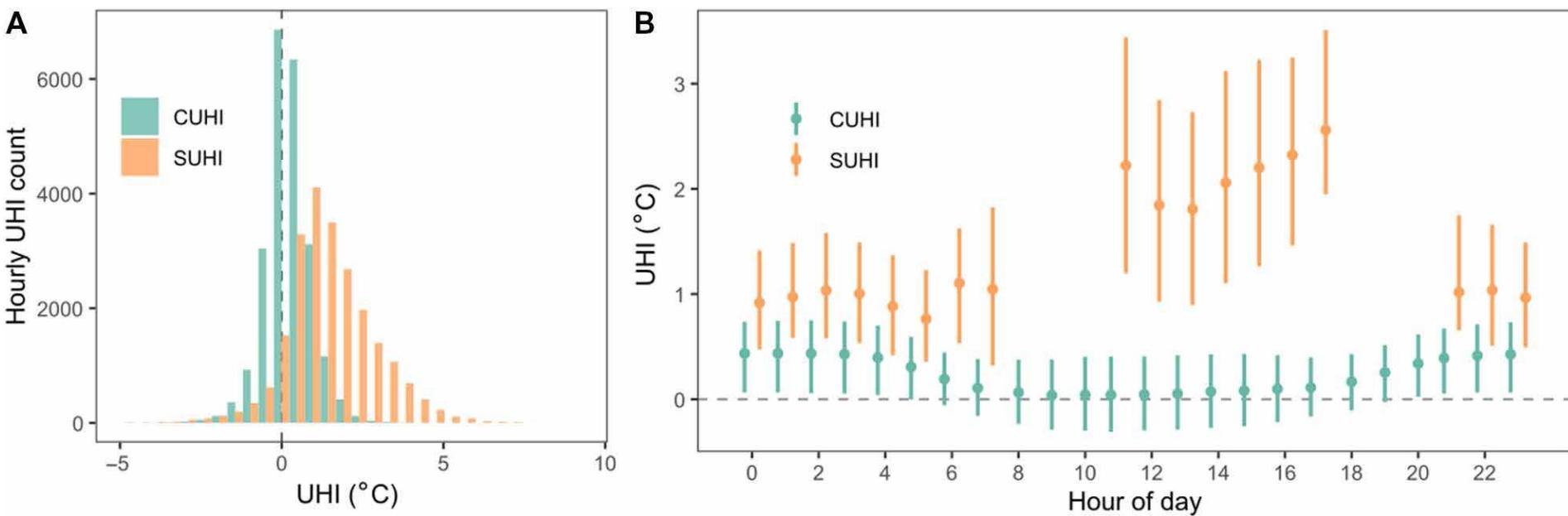
驱动因子复杂
研究结果争议大

(4) 地表与大气热岛效应的关系



大气UHI夜晚强
SUHI白天强

地表与大气UHI相关性
夜晚高 • 白天低 (季节变化大)



SCIENCE ADVANCES | RESEARCH ARTICLE

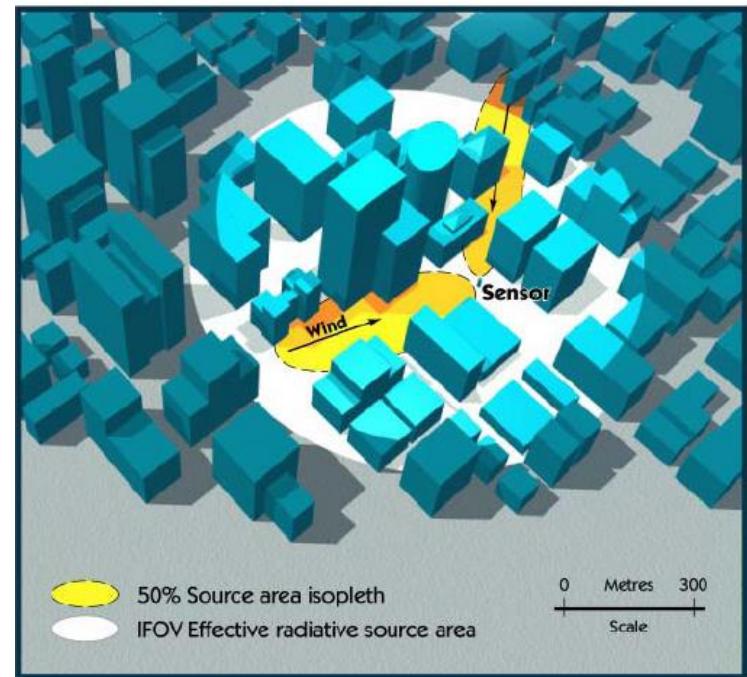
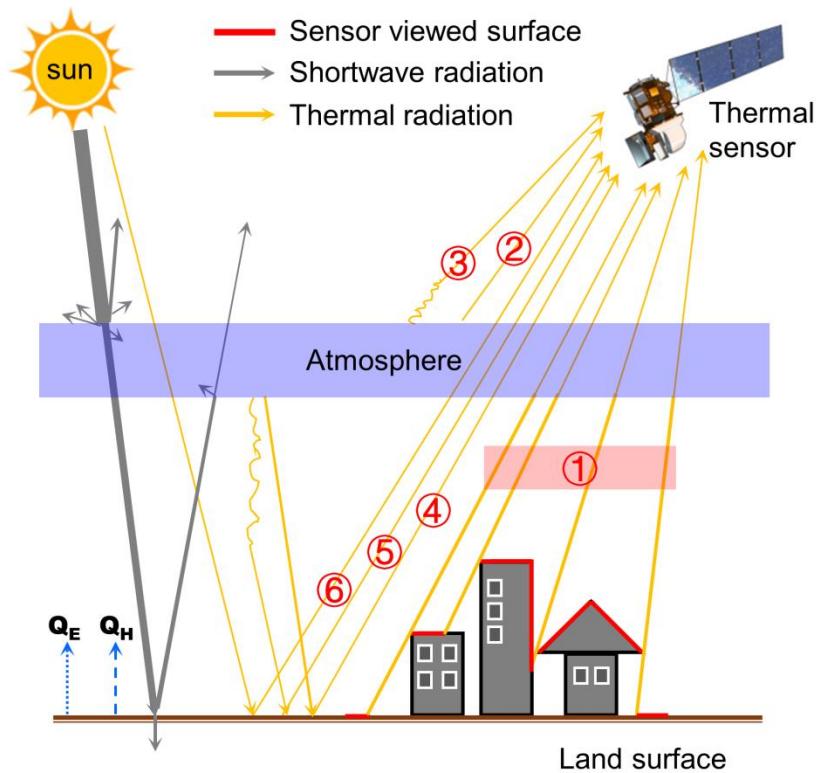
CLIMATOLOGY

Crowdsourced air temperatures contrast satellite measures of the urban heat island and its mechanisms

Zander S. Venter^{1*}, Tirthankar Chakraborty², Xuhui Lee²

5、面临的挑战

(1) 卫星获取地表温度的本质—明显不同于大气温度



(Voogt & Oke, 2003)

上行热辐射

大气效应、地表发
射率、视场角

温度反演固有的问题

反演方程病态问题：测量值永远小于反演参数

$$B_i(T_i) = \varepsilon_i B_i(T_s) \tau_i + (1 - \varepsilon_i)(R_{atm_i} \downarrow + R_{atm_i}^s \downarrow) \tau_i + R_{atm_i} \uparrow + R_{atm_i}^s \uparrow + \rho_{bi} R_i^s \tau_i$$

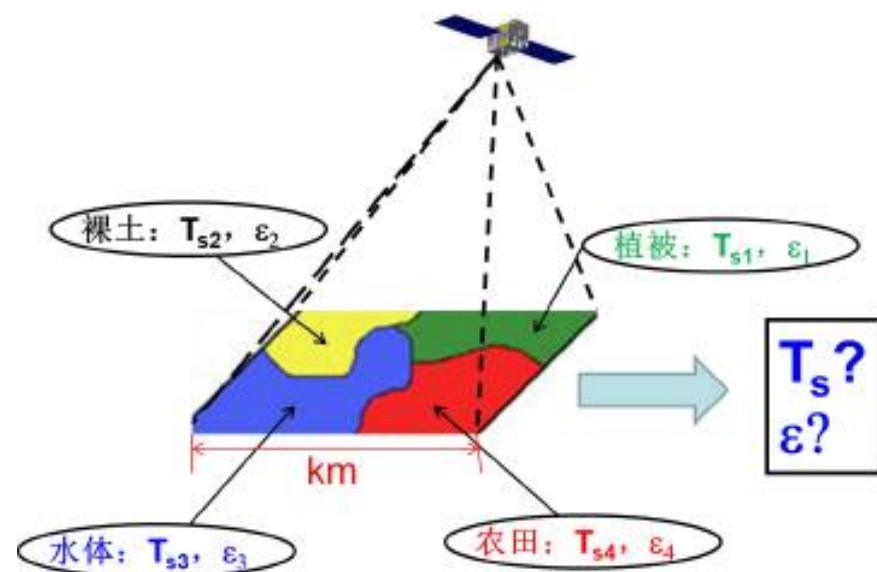
大气效应校正

比辐射率校正

地表温度物理理解不清

真实性检验困难

邻近像元效应



High resolution \neq High accuracy

(李召良，2019热红外遥感会议)

(2) 云和其它因子对LST的影响

去云算法→数据缺失

时态聚集→时态信息和精度的降低

无缝式逐日产品（多源、多时相、辅助数据、时空插值）

→效率、精度、晴空数据

(3) 时空分辨率

空间降尺度
时间升尺度

(6) 归因分析

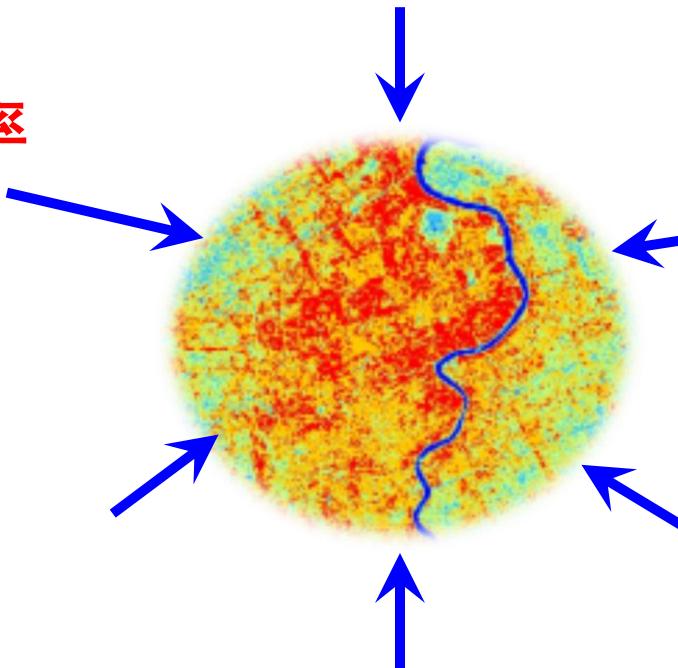
统计方法的固有缺陷
(共线性问题, 机制
解释不清)

(4) 估算方法 不同方法差异大

(5) 同步土地利用 与覆盖数据的获取

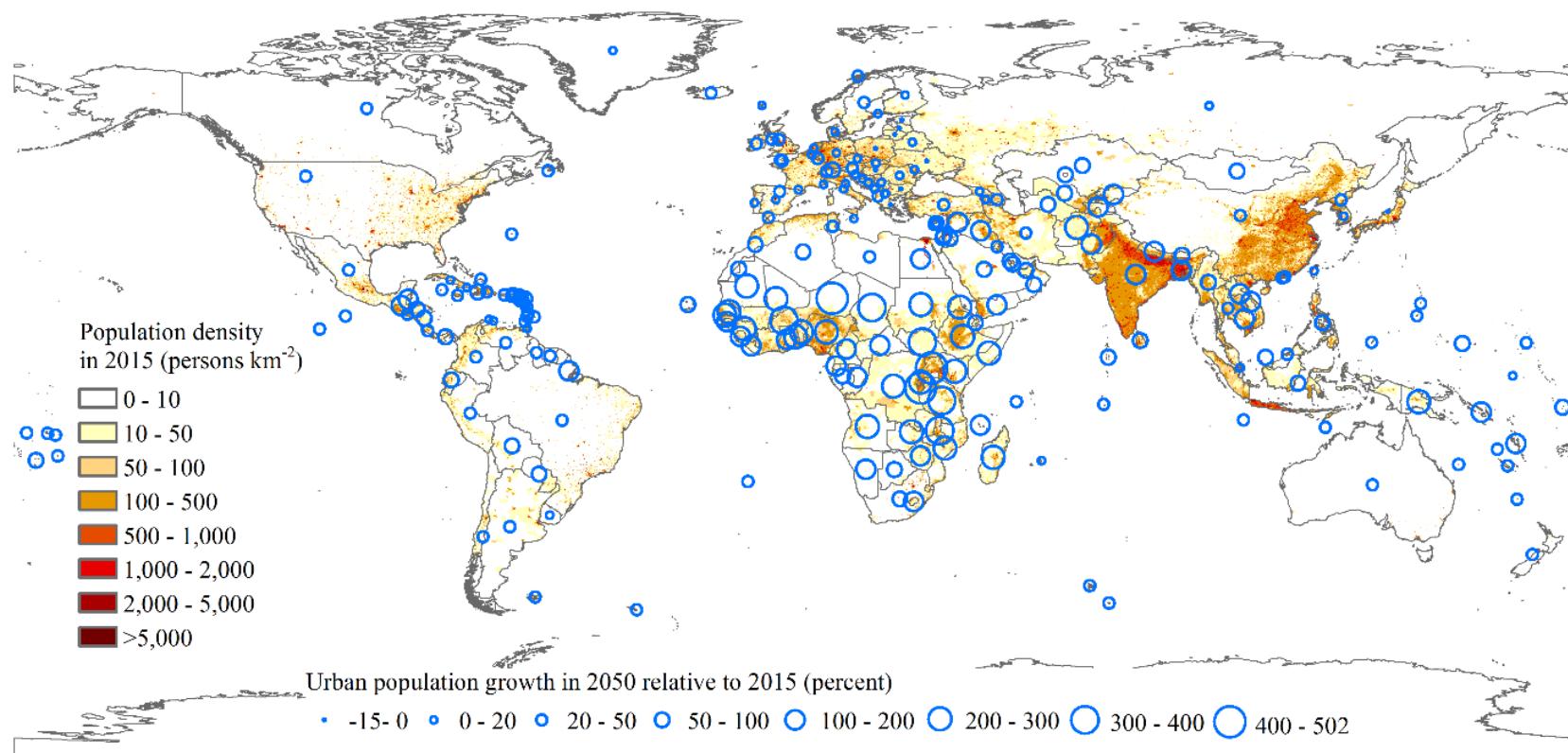
(7) 精度评价难度大

T-based | R-based | inter-comparison



6、未来可能的研究方向

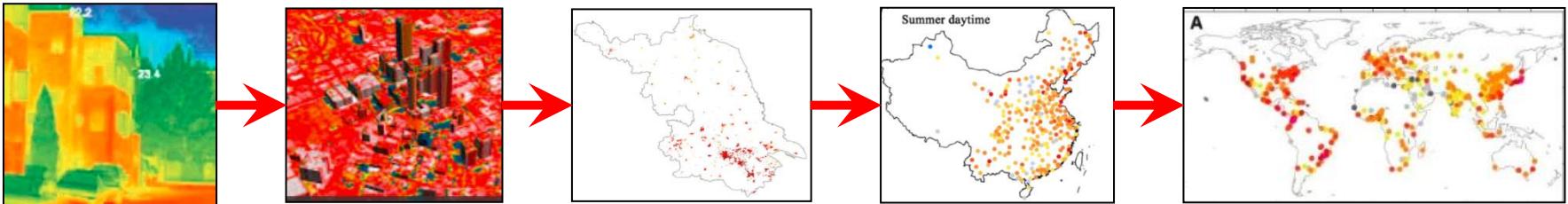
(1) 更多关注研究薄弱区域和城市



非洲 • 南美洲 • 印度 • 中小城市

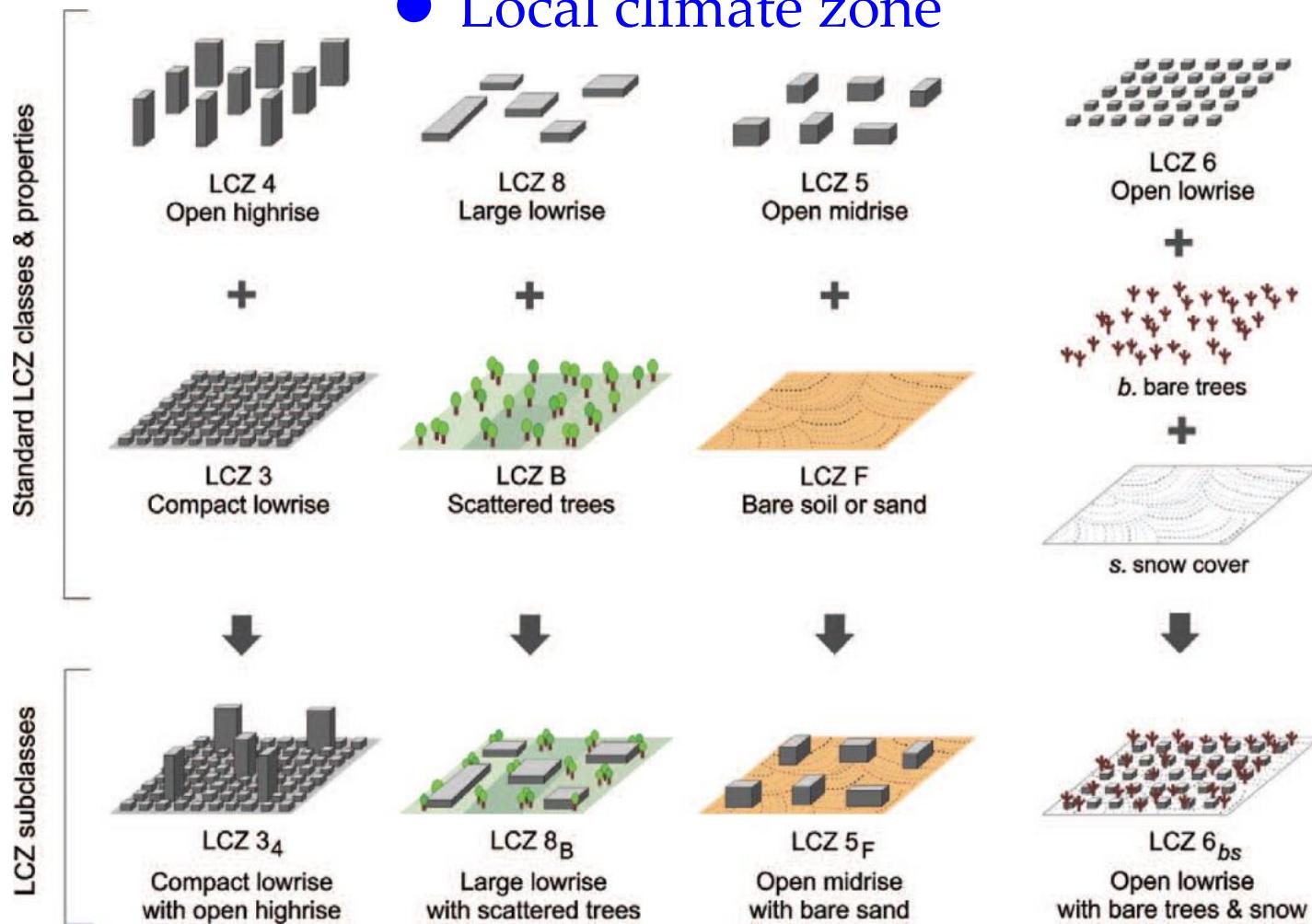
(2) SUHI中的尺度问题

- What are the differences in the factors contributing to the SUHI at local, regional, and global scales?
- Are there predictable differences in the magnitudes and patterns of SUHI derived from the LST observation at different spatial and temporal resolutions?
- What is the extent of a metro city SUHI impact on the climate or SUHI of associated satellite cities?
- What is the optimal scale for conducting measures to mitigate SUHI?



(3) SUHI 强度估算新方法

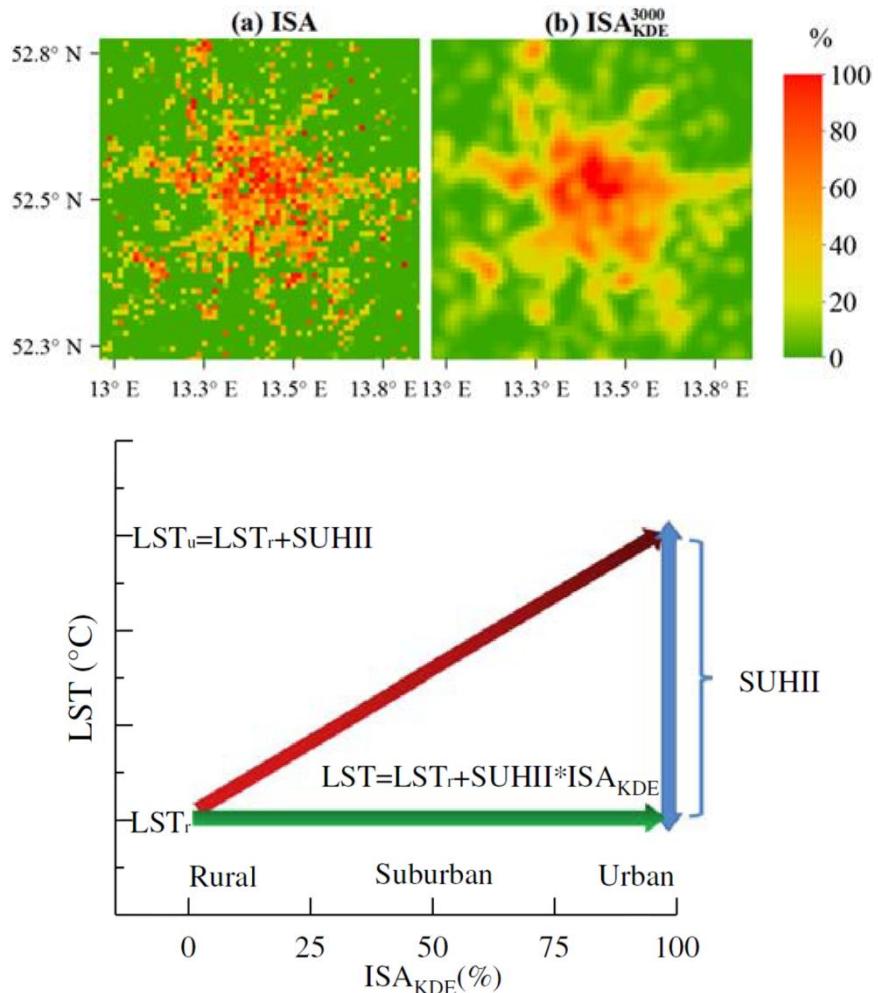
- Local climate zone



Stewart and Oke (2012)

- Relationship between LST and other indicators

LST与不透水面的关系



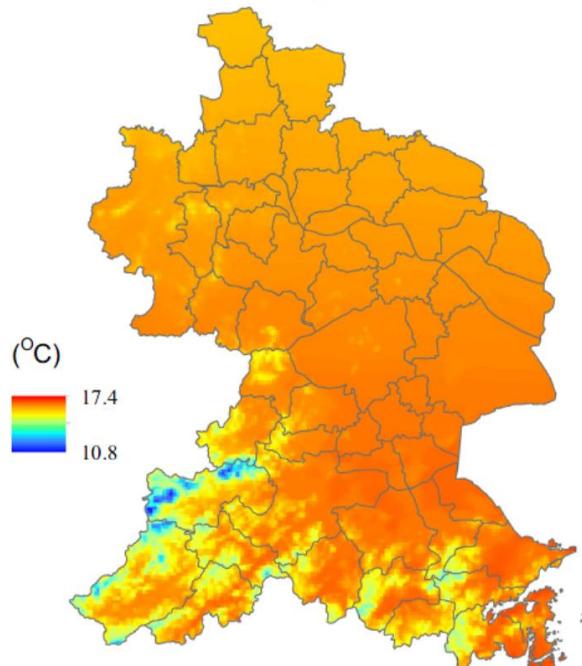
(Li et al., 2018, STE)

LST与地理位置的关系

$$\text{SUHII}(x,y,z) = \text{LST}(x,y,z) - T_{\text{forest}}(x,y,z)$$

$$T_{\text{forest}}(x,y,z) = T_0 + a_1 x + a_2 y + a_3 z$$

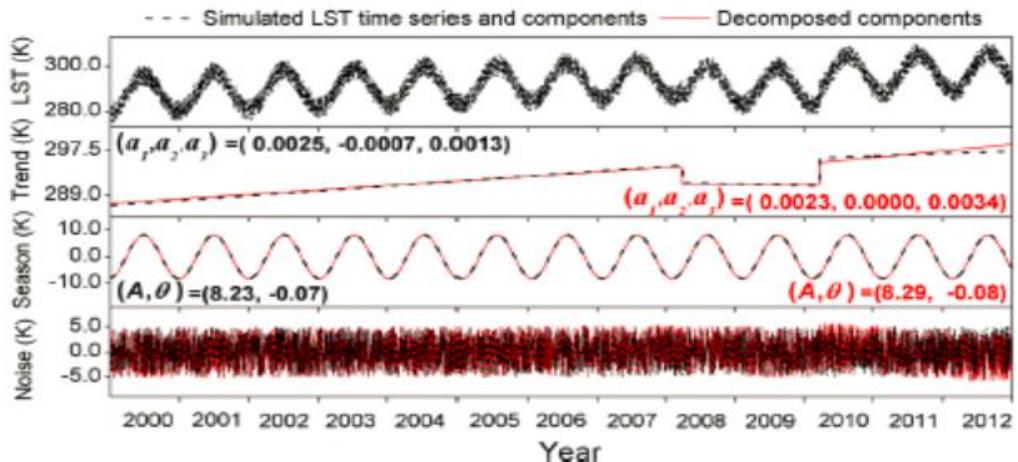
(a) Annual daytime reference LST estimated using method 1



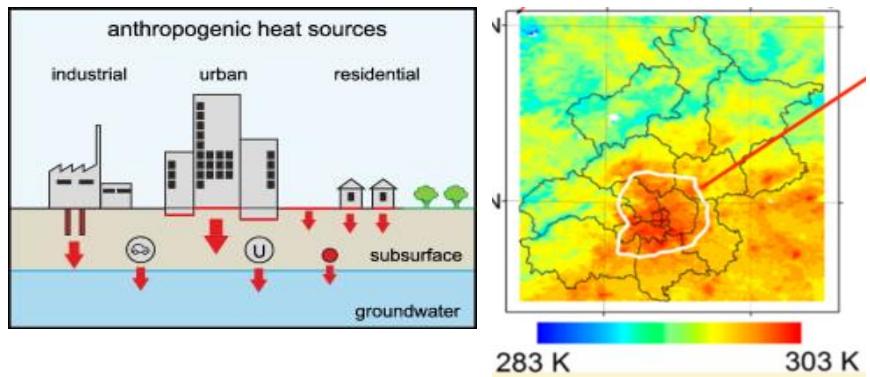
(Zhou et al., 2018, STE)

(4) 长期趋势与年际变率

(Quan et al., 2016)

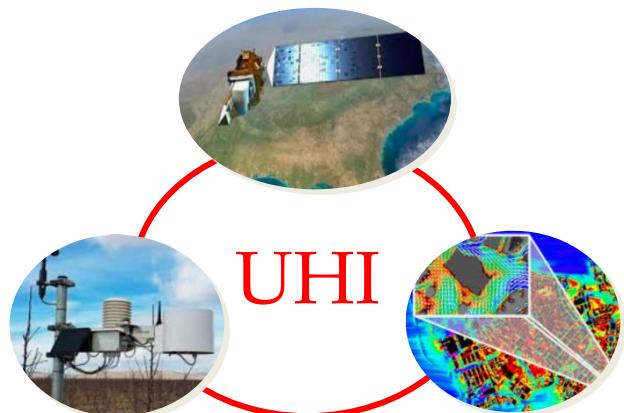


(5) 时空拓展



(Menberg et al., 2013; Zhan et al., 2014)

(6) 遥感+观测+模型





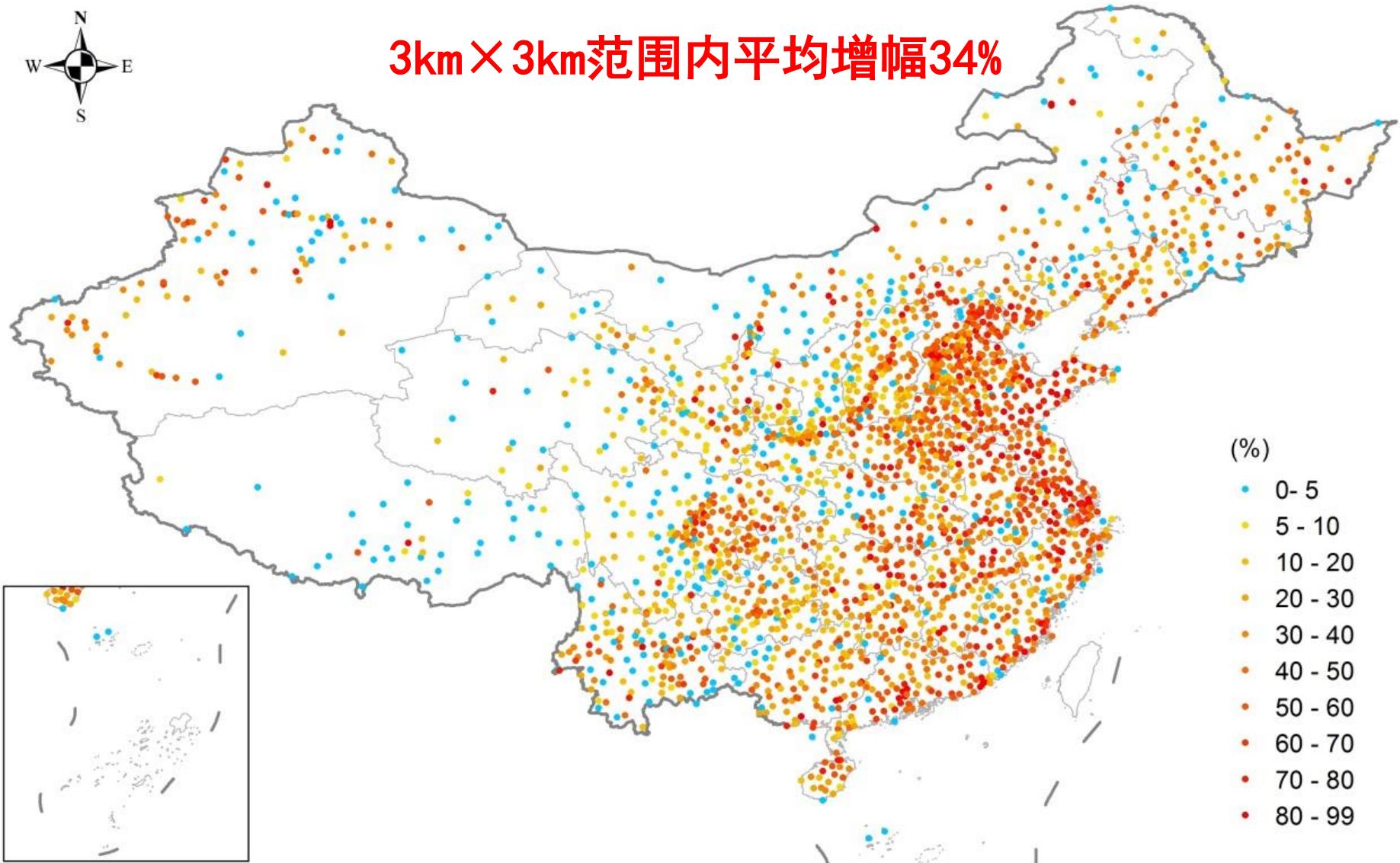
谢谢！敬请批评指正！

周德成 | zhoudc@nuist.edu.cn





3km×3km范围内平均增幅34%



1985–2015年国家气象站不透水面比例变化

热岛强度时空 异质性大

● 年均强度

白天：西北较低

夜间：南部较低

昼夜差

东南：白天>夜间

西北：白天<夜间

● 季节变化大

白天：夏季>冬季

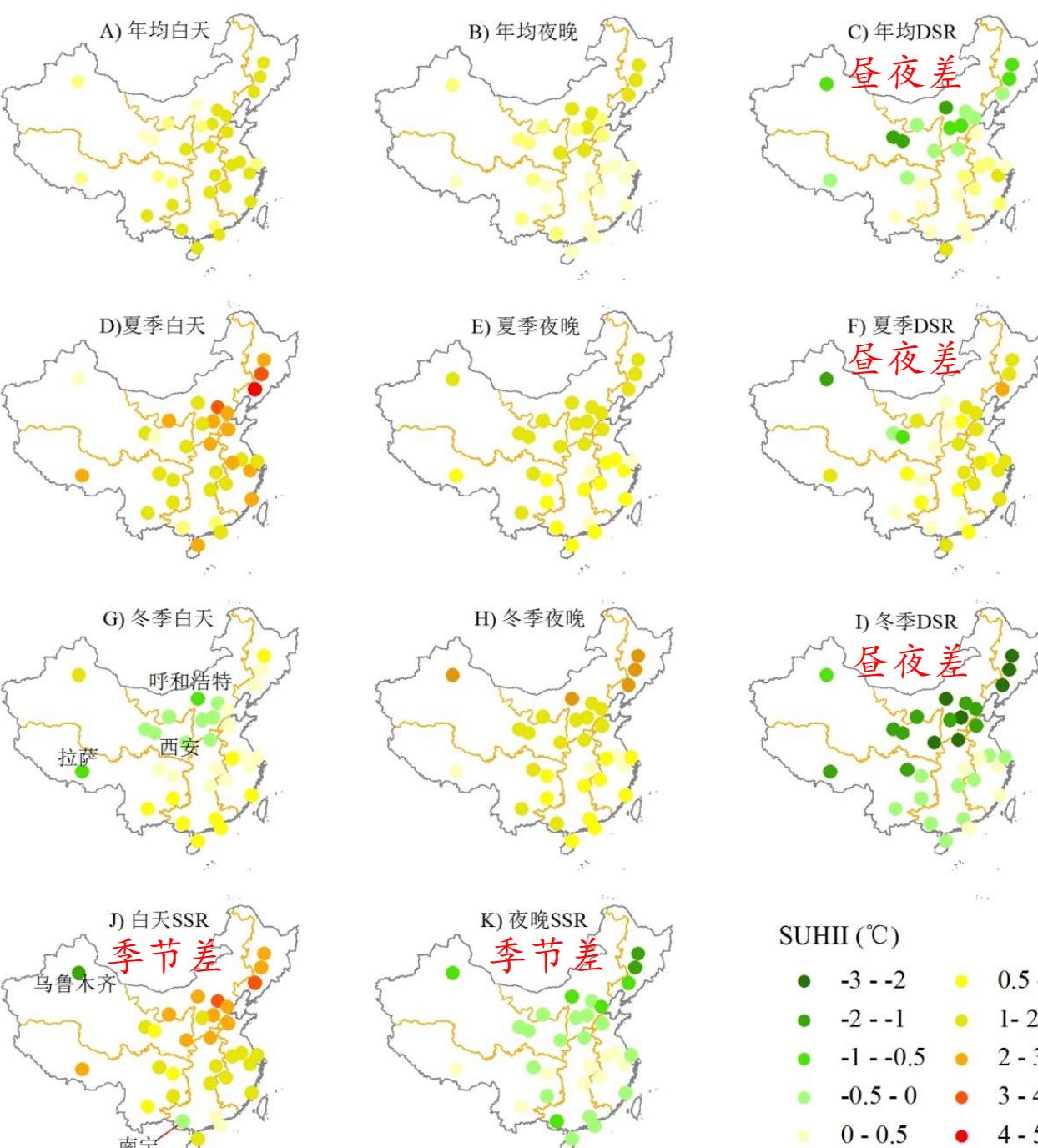
夜间：夏季<冬季

白天季节变化大

昼夜差

夏季：白天>夜间

冬季：白天<夜间

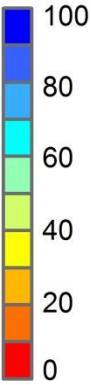
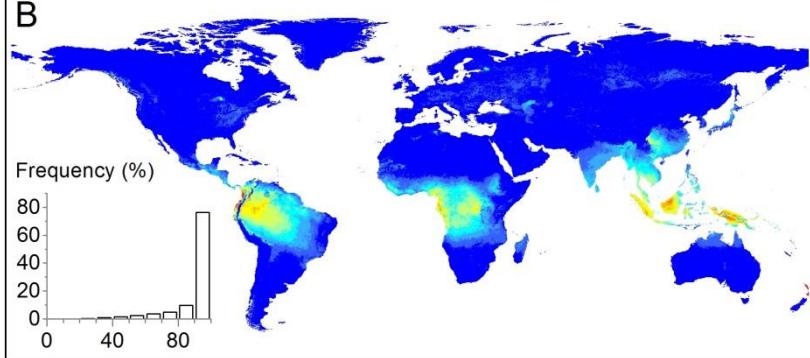


SUHII (°C)	
●	-3 --2
●	-2 --1
●	-1 --0.5
●	-0.5 - 0
●	0 - 0.5
●	0.5 - 1
●	1 - 2
●	2 - 3
●	3 - 4
●	4 - 5

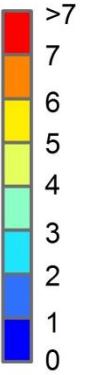
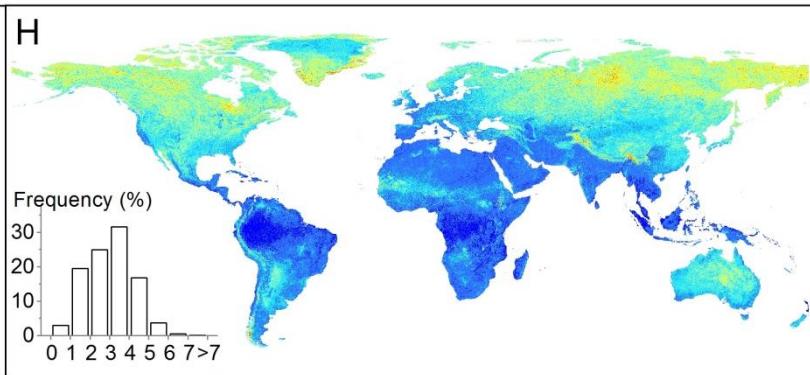
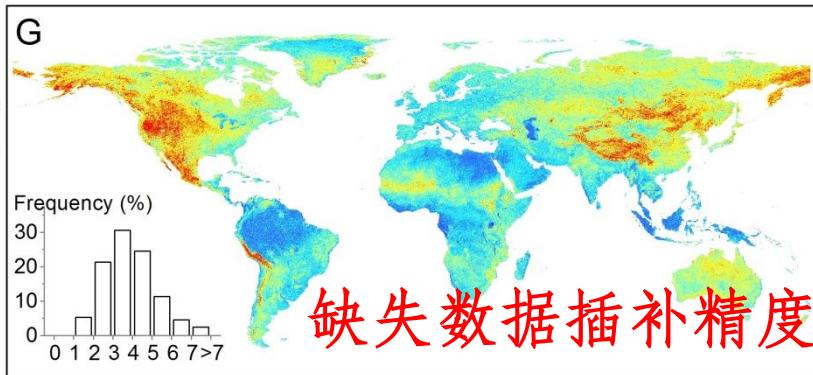
Daytime

Nighttime

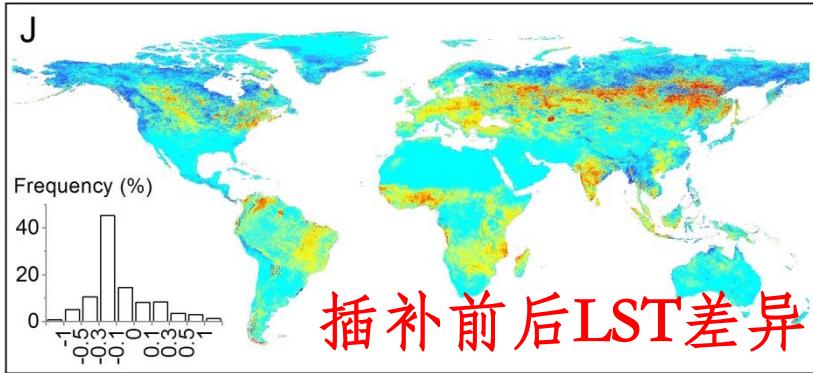
Available data (%)



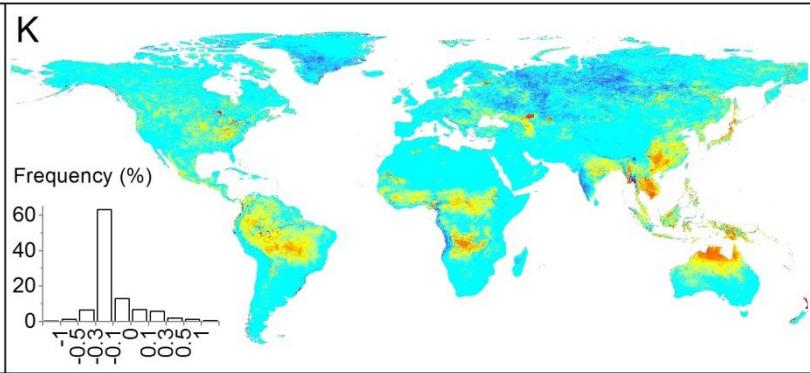
RMSE ($^{\circ}$ C)



LST difference ($^{\circ}$ C)



插补前后LST差异

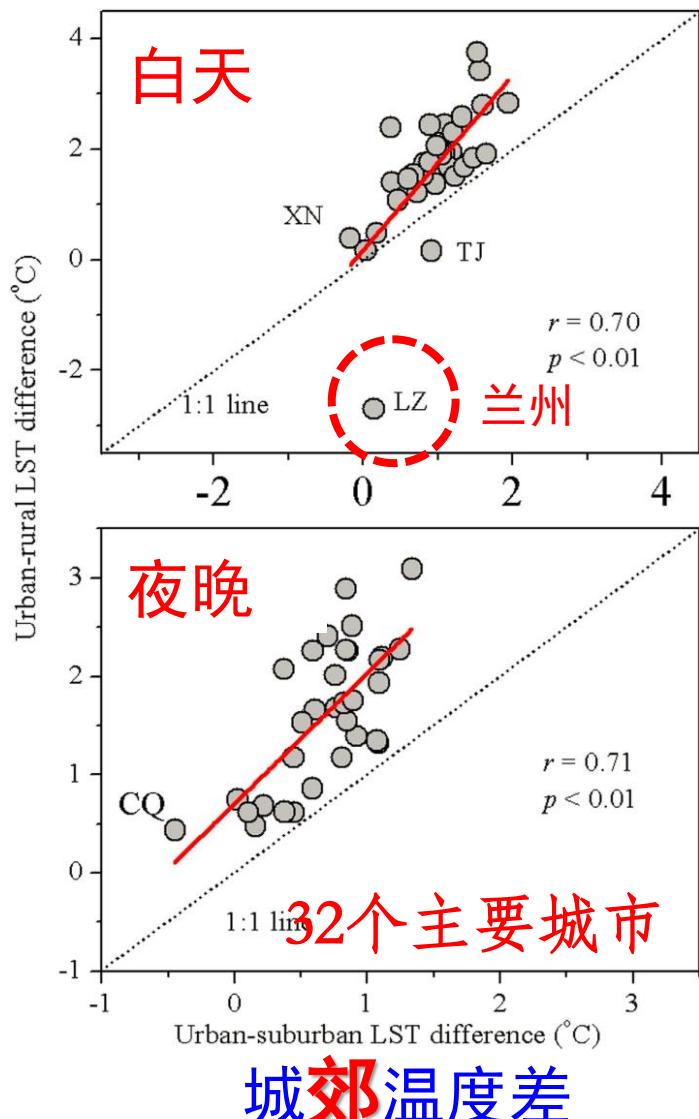


MODIS地表温度8天合成产品

(Zhou et al., 2021,in revision)

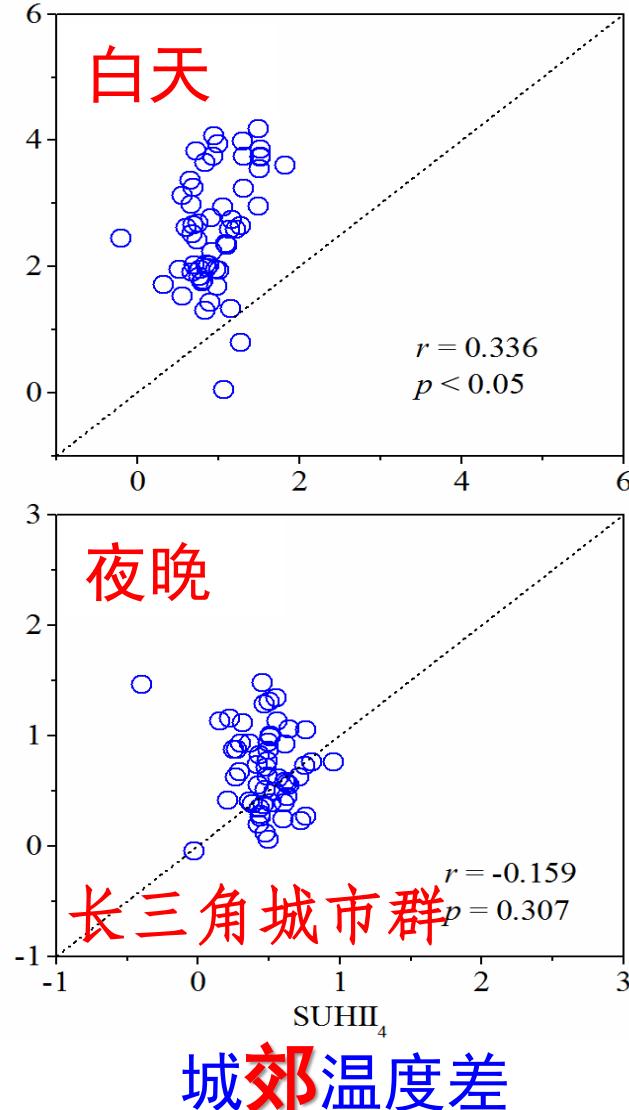
不同方法估算的热岛强度差异大

城乡温度差



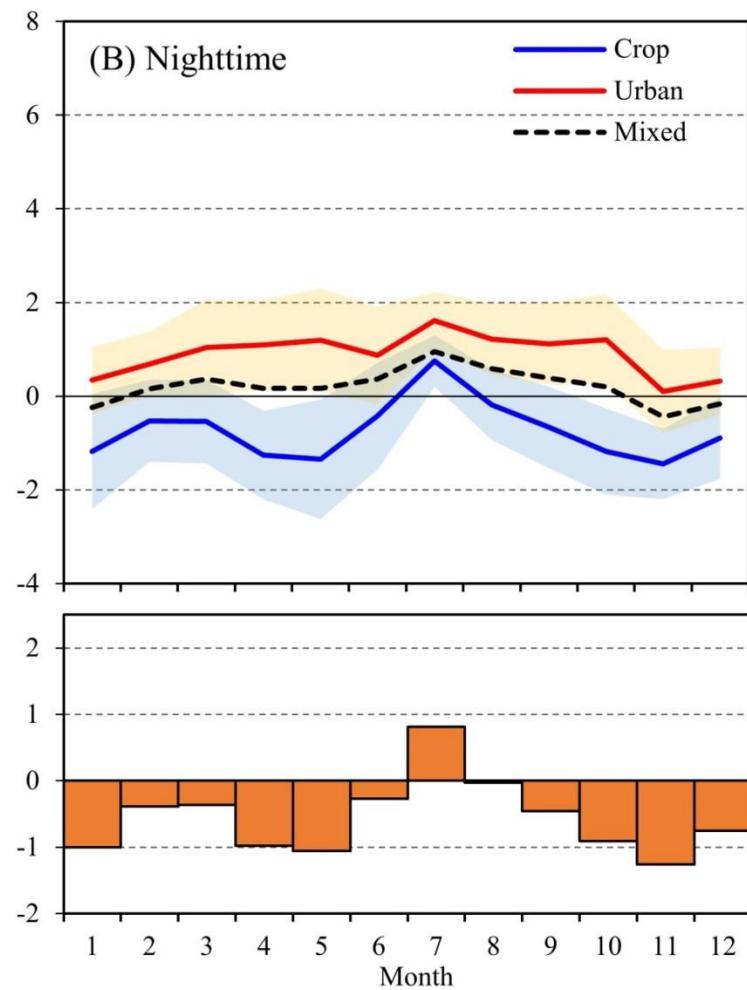
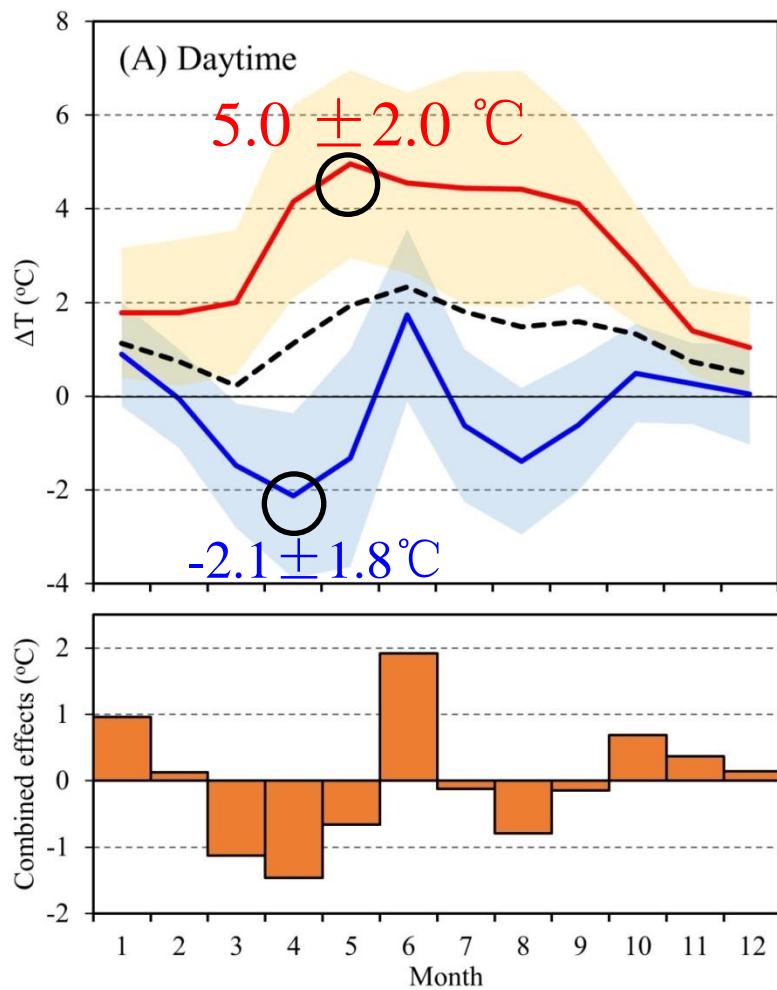
(Zhou et al., 2015, SR)

以林地为参照



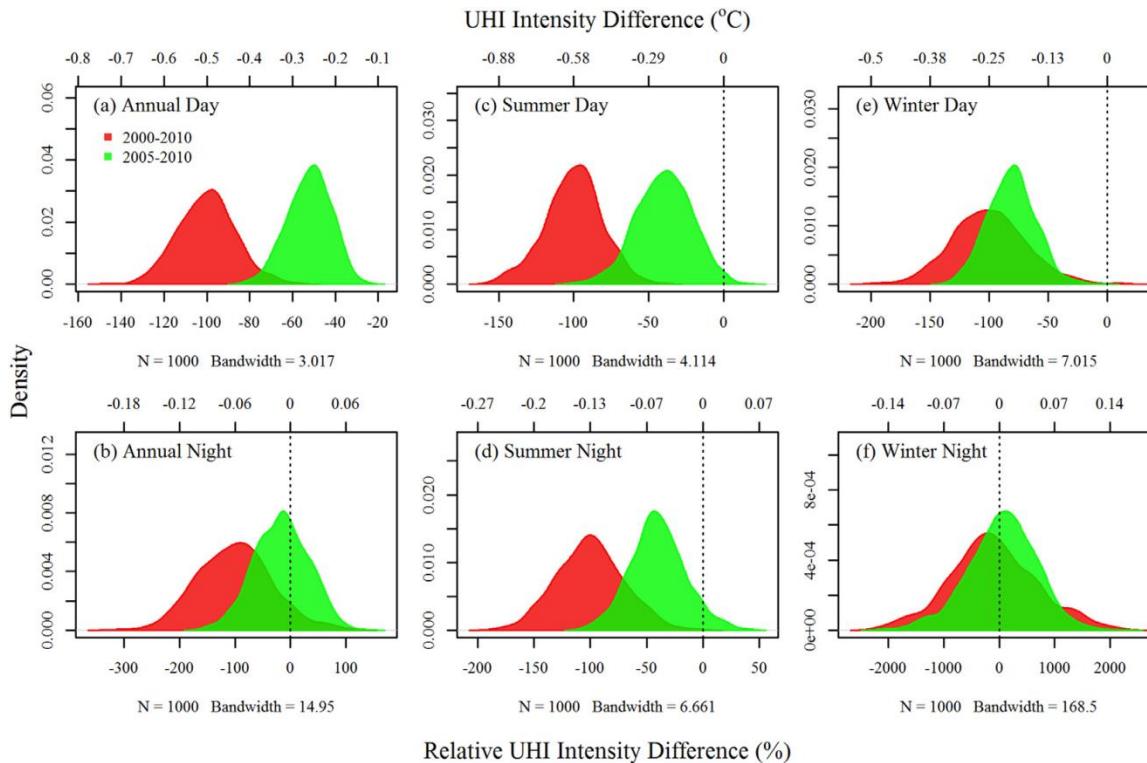
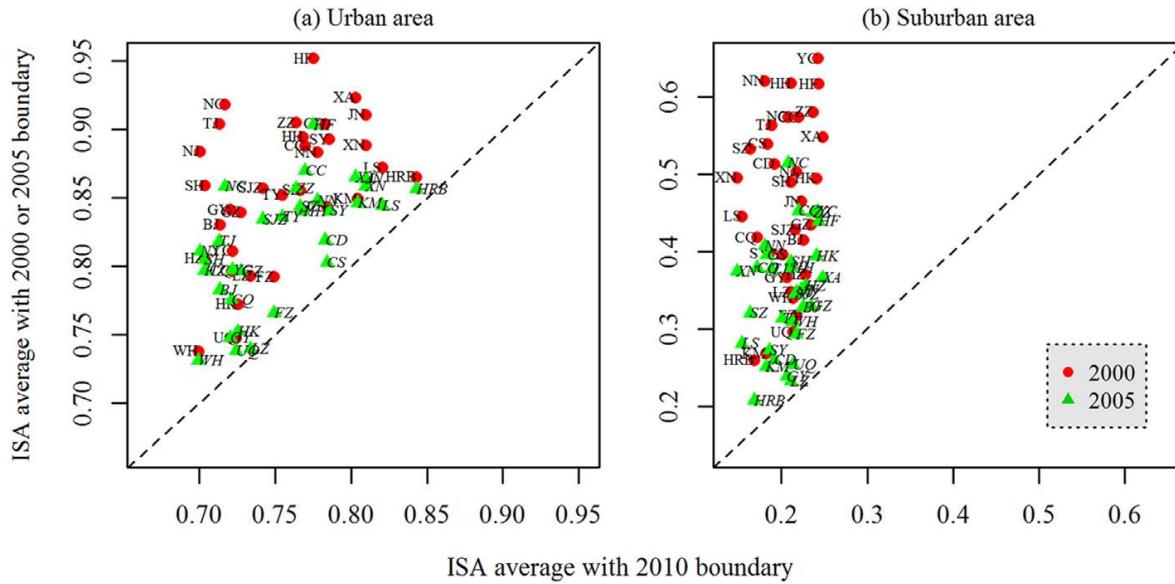
(Zhou et al., 2018, STE)

农业与城市用地热环境效应差异大



江苏为例

(Zhou et al., 2016, JGR. Atmos.)



采用过时土地利用数据对城市热岛的影响

(Zhao and Zhou, 2016, EP)

反照率常被用来解释夜晚热岛效应

Surface Urban Heat Island Across 419 Global Big Cities

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and night. The distribution of nighttime SUHII correlates positively with the difference in albedo and nighttime light between urban area and suburban area, while the distribution of daytime SUHII correlates n



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Surface urban heat island in China's 32 major cities: Spatial patterns and drivers

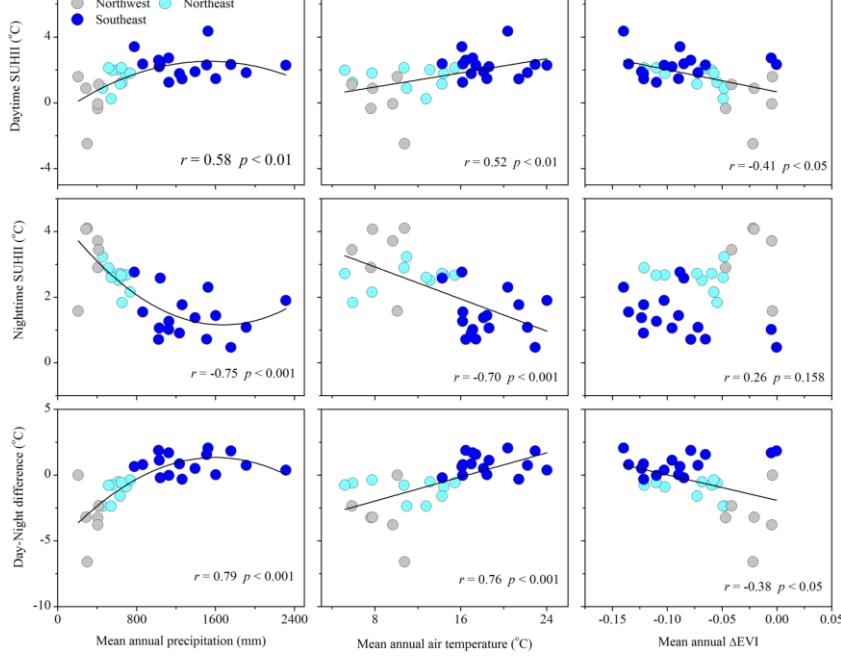


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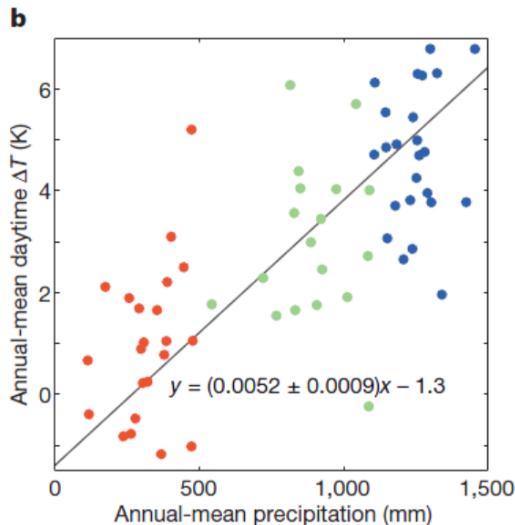
research period. The SUHII's distribution in the day related closely to vegetation activity and anthropogenic heat releases in summer, and to climate (temperature and precipitation) in winter, while that at night linked tightly to albedo, anthropogenic heat releases, built-up intensity, and climate in both seasons. Overall, we

Correlation ≠ Causation

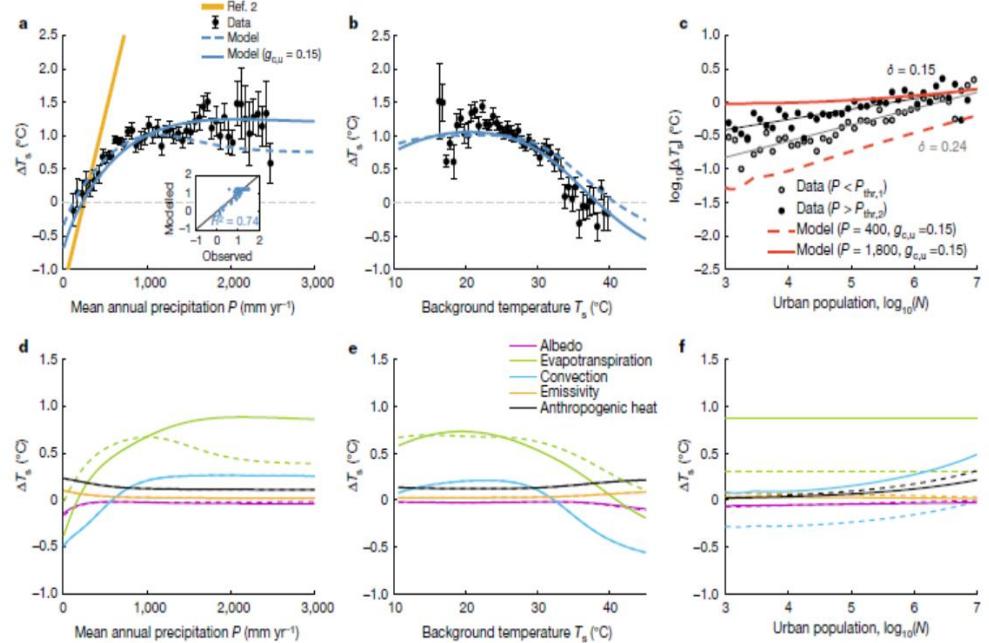
气候背景的影响是否存在阈值?



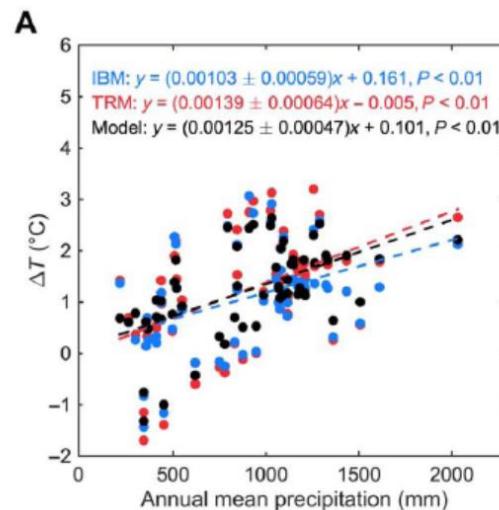
(Zhou et al., 2016, ERL)



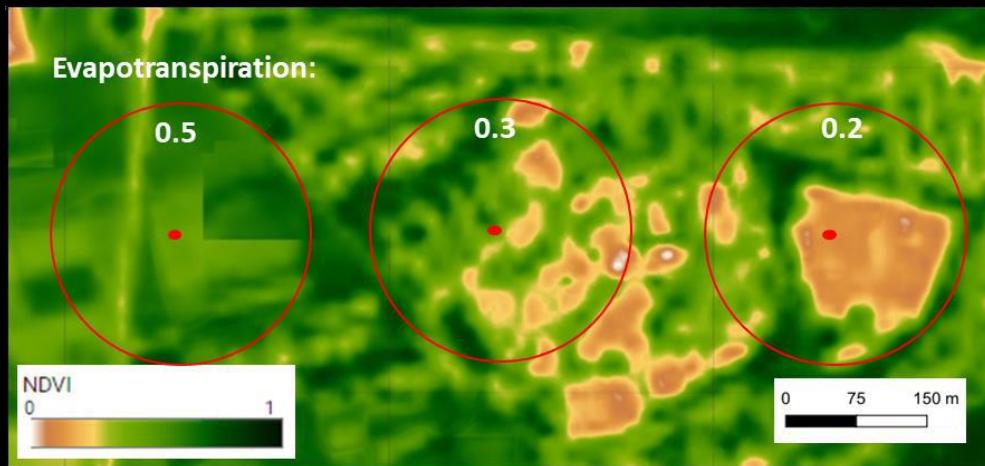
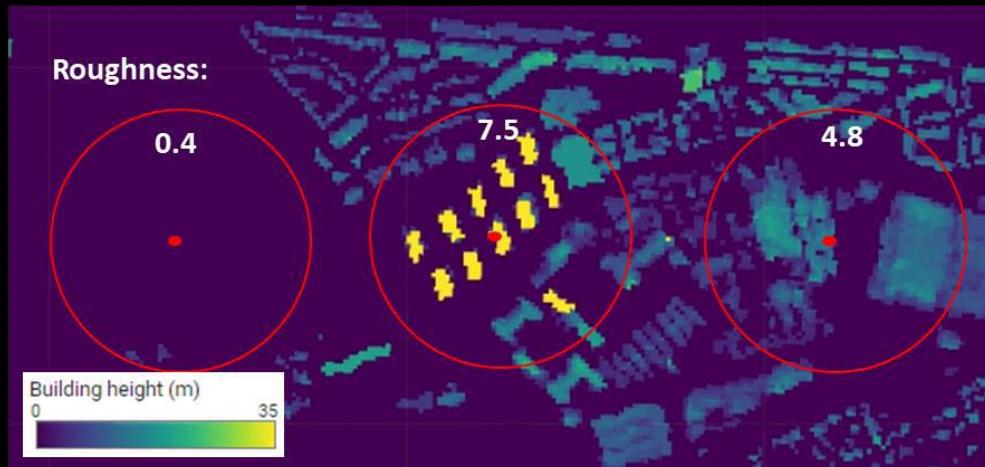
(Zhao et al.,
2014, Nature)



(Manoli et al., 2019, Nature)



(Li et al., 2019,
Science
Advances)



(Venter et al., 2021,
Science Advances)