climate change initiative

→ LAND SURFACE TEMPERATURE

Are Urban Surface Temperatures Warming Faster Than Rural?

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land surface temperature cci

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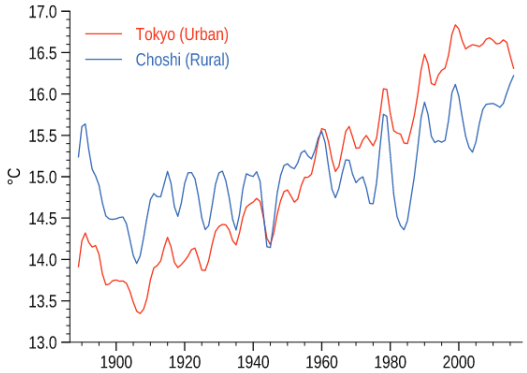
Benjamin Bechtel, Marzie Naserikia, Negin Nazarian, Melissa Hart,and Darren Ghent

Urban Warming

(b) Temperature evolution Japan examples



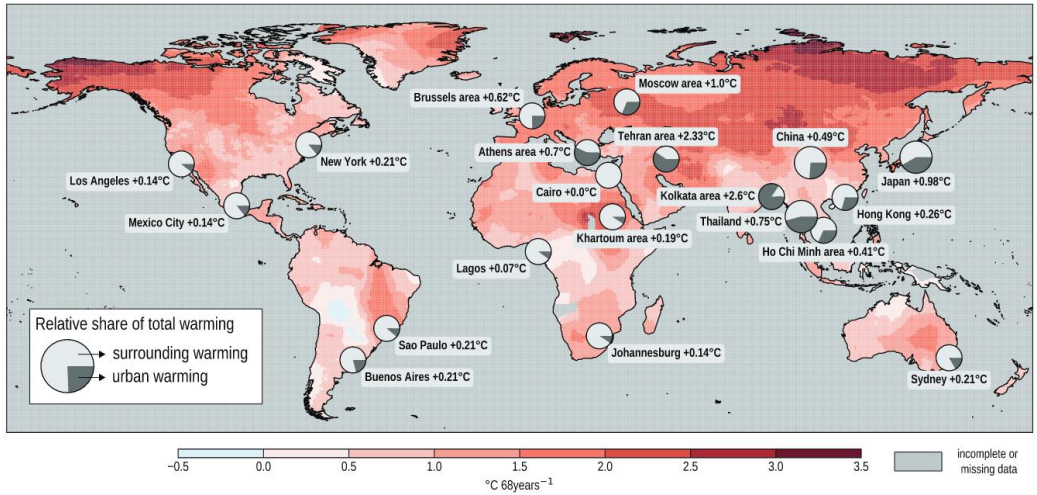
Source: IPCC: Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

Box 10.3 (continued)

Observed trends

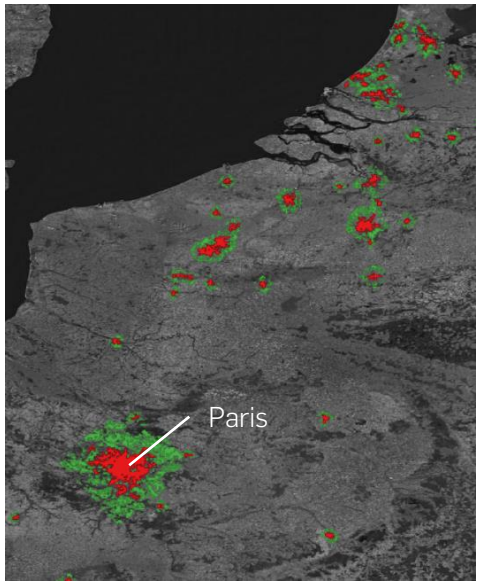
There is *medium evidence* but *high agreement* (Parker, 2010; Zhang et al., 2013; H. Chen et al., 2016) that the global annual mean surface air temperature response to urbanization is negligible. There is very high confidence that the different observed warming trend in cities as compared to their surroundings can partly be attributed to urbanization (Box 10.3, Figure 1; Park et al., 2017).

(a) Trend in global surface air temperature (CRU TS, 1950-2018)



Research Objectives

Urban Areas and Rural Buffers



Research Questions

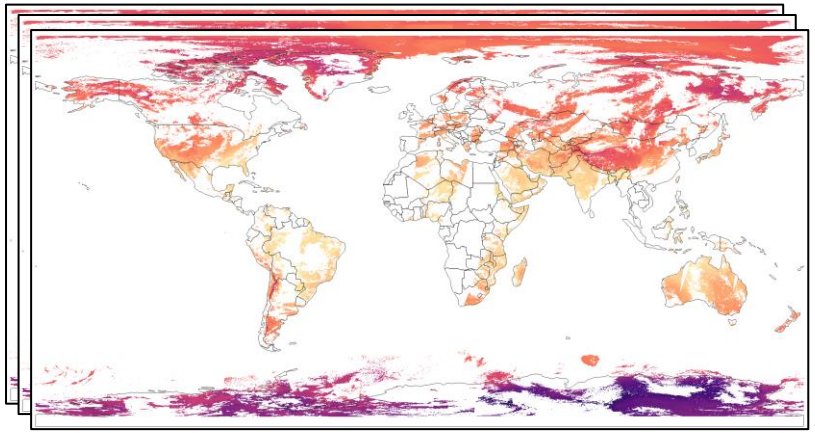
1) How fast has the LST of urban areas been increasing in the last 20 years?
2) Do the urban and surrounding rural warmings rate differ?

Why they are relevant / important for understanding Climate Change?

- LST and Air Temperatures trends agree very well (see Good et al., 2022).
- Satellite data offer complete spatial coverage; compared to weather station networks.

Data Extraction

Nighttime LST

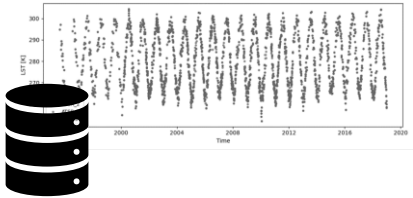


LST_cci Dataset: **0.01 deg MODISAN v4.00**

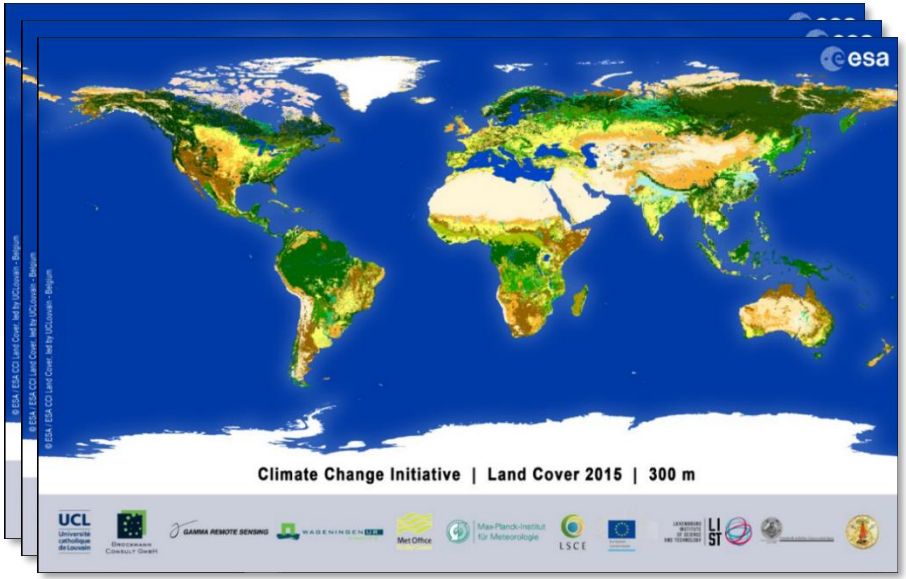
One file for each day (2002-2021) – 01:30 am

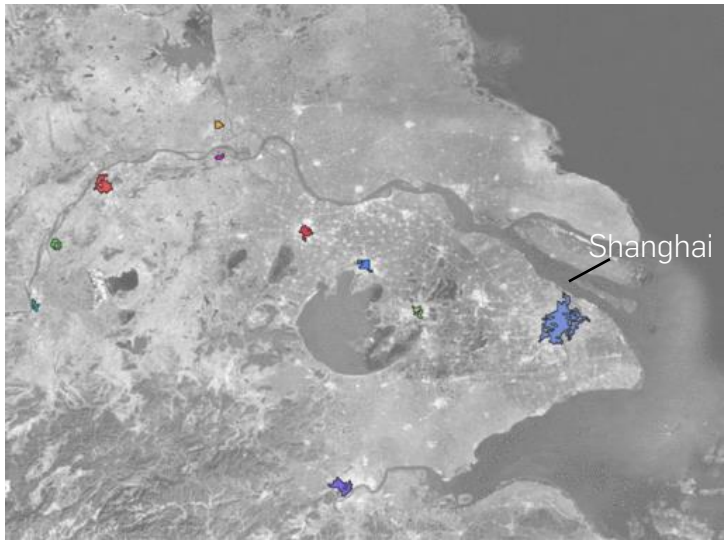
Aggregate the satellite data per city

Store each **time series** into a DB



Tracking how the Cities Change over Time



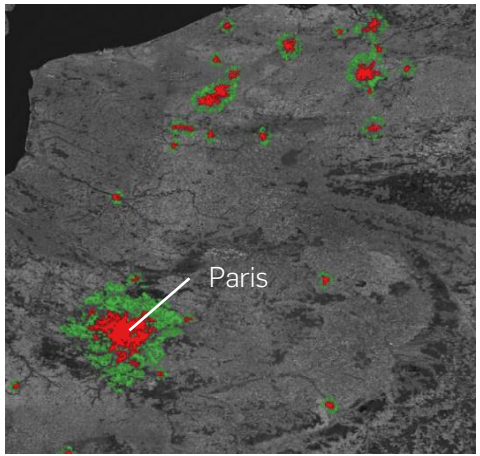


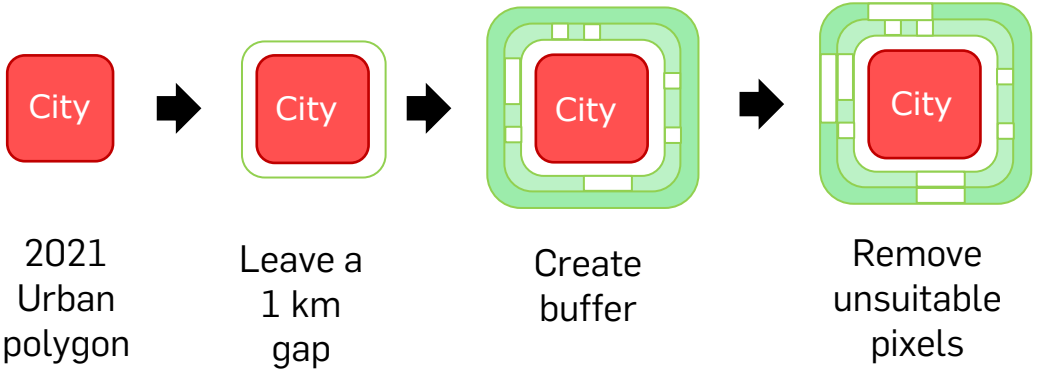
300 m, annual data from 2002 to 2021

>1500 cities detected.

Rural Buffers

We **iteratively expand** a buffer around each city until they have approximately the same size as the city:



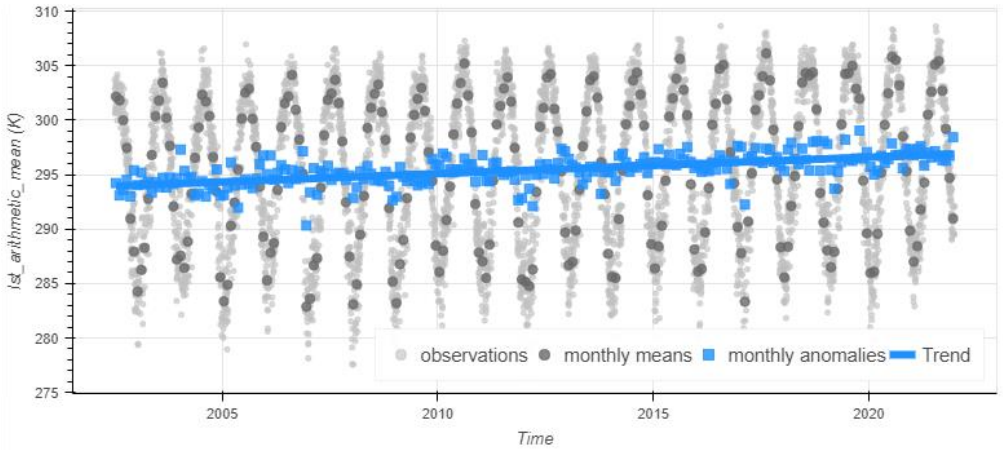


Trend Estimation

For each city:

Calculate the weighted monthly means → De-season → Calculate the monthly anomalies → Calculate the **Theil-Sen** slope

LST data

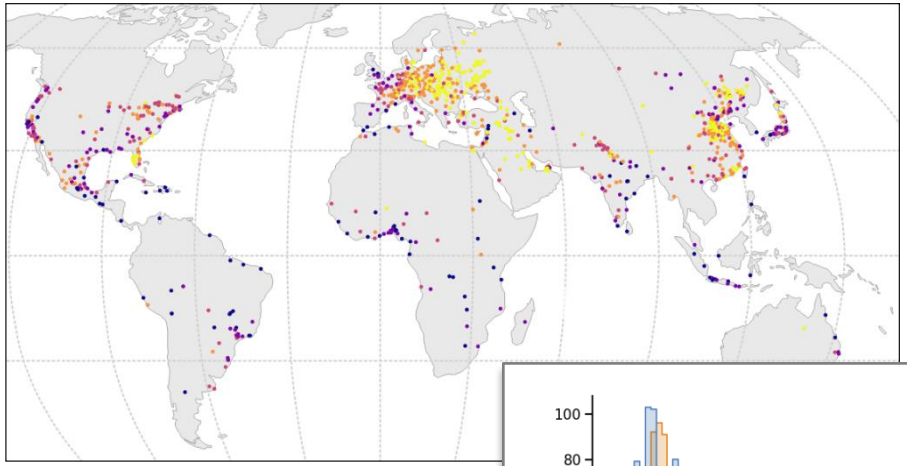


QC

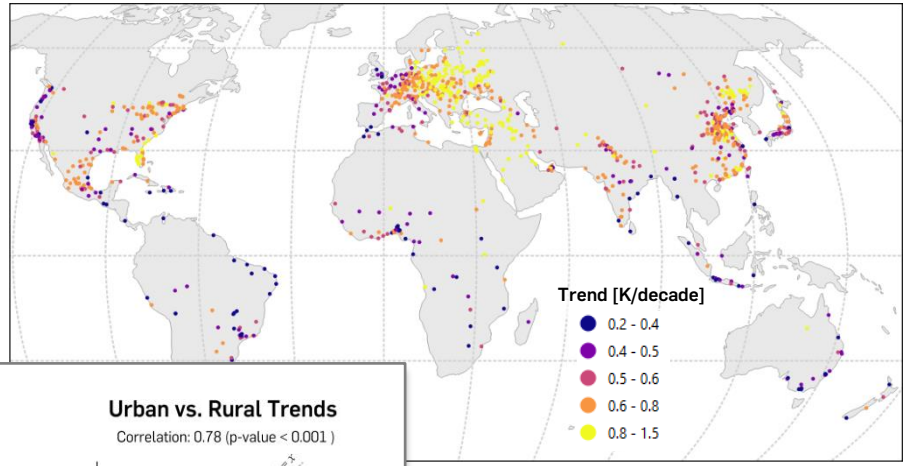
LST trend + CI95

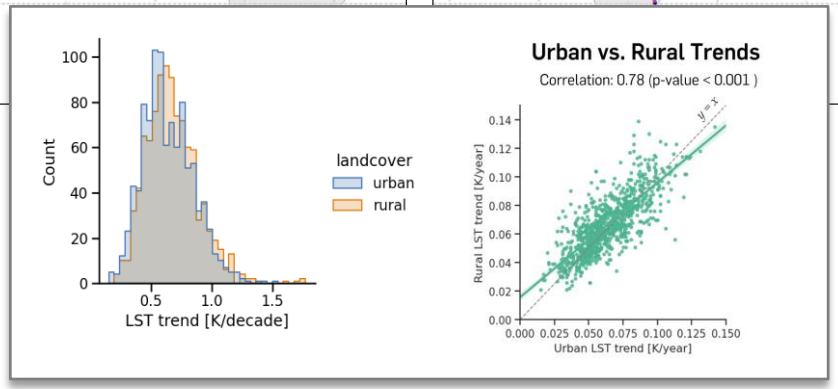
Urban vs. Rural Trends ["observed"]

"Observed" Urban LST Trends



"Observed" Rural LST Trends





Mean ± SD = **0.64 ± 0.21 K/decade**

Min. = 0.15 K / decade

Max. = 1.54 K / decade

Mean ± SD = **0.67 ± 0.21 K/decade**

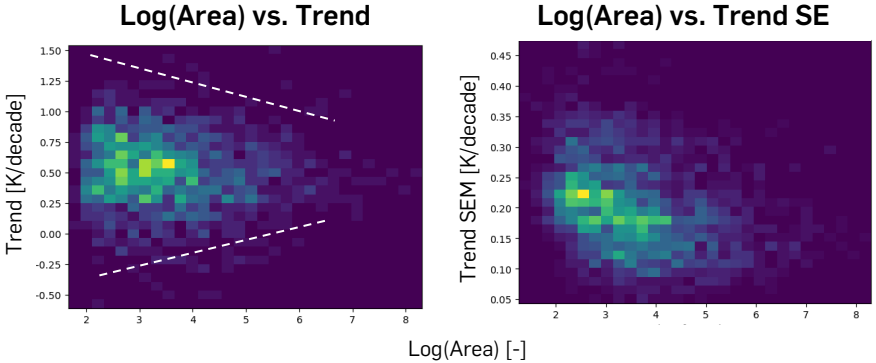
Min. = 0.21 K / decade

Max. = 1.77 K / decade

Dataset Particularities

Artificial variations within the LST dataset can also influence the observed LST trends.

Rural polygons **same** for all years. ≠ **Urban polygons** **increase** every year.



Trend estimates exhibit **greater variability** in smaller cities compared to larger ones.

Larger cities yield **more reliable** trend estimates.

Multilevel Bayesian Modeling

To analyze the trends, we use a multi-level Bayesian model with **partial-pooling** and **varying non-centered intercepts**:

Rural

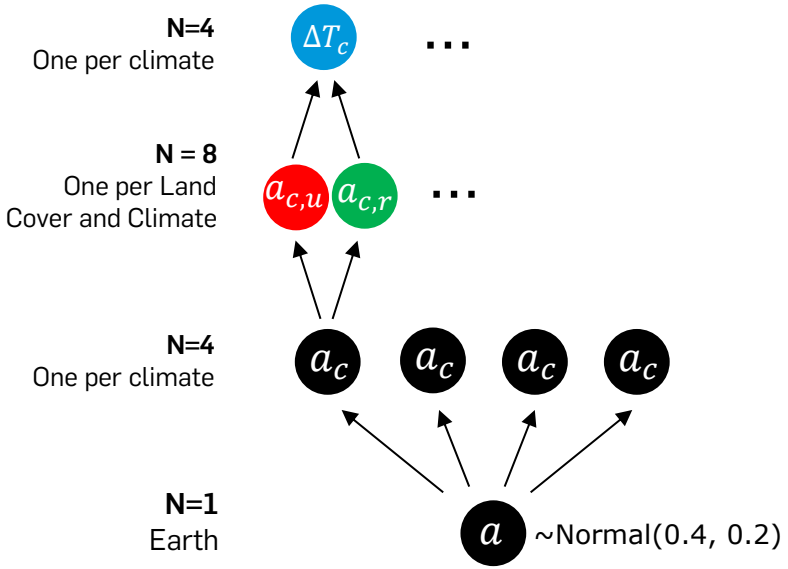
$$T_i \sim \text{Normal}(\mu_i, \sigma)$$
$$\mu_i = \alpha_{c,r}$$
$$\alpha_{c,r} = a_c + \delta_{c,r}\sigma_{\alpha_c}$$

Urban

$$T_i \sim \text{Normal}(\mu_i, \sigma)$$
$$\mu_i = \alpha_{c,u} + \beta_{\Delta A}\Delta A_i$$
$$\alpha_{c,r} = a_c + \delta_{c,r}\sigma_{\alpha_c}$$
$$\beta_{\Delta A} \sim \text{Normal}(0, 0.1)$$

Common Priors

$$\alpha_c = a + \delta_c\sigma_a$$
$$\delta_c \sim \text{Normal}(0, 0.5)$$
$$a \sim \text{Normal}(0.4, 0.2)$$
$$\sigma_a, \sigma_\beta \sim \text{Exp}(1.0)$$
$$\delta_{c,r}, \delta_{c,u} \sim \text{Normal}(0, 0.3)$$



Multilevel Bayesian Modeling

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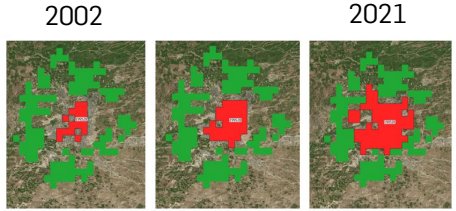
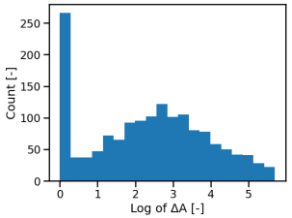


$$\Delta A_i = \log\left(A_{2021} - A_{2002}\right)$$



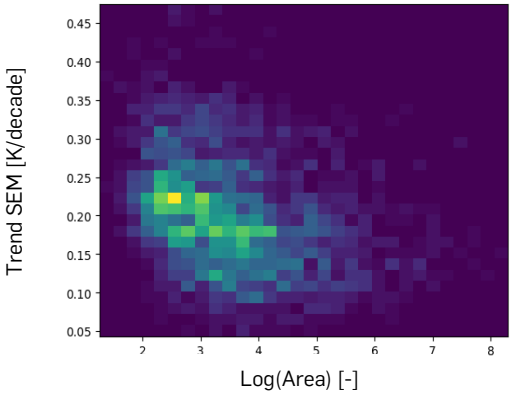
Multilevel Bayesian Modeling

To analyze the trends, we use a multi-level Bayesian model with **partial-pooling** and **varying non-centered intercepts**:

Rural	**Urban**	
$T_i^* \sim \text{Normal}(T_i, \text{SEM}_i)$	$T_i^* \sim \text{Normal}(T_i, \text{SEM}_i)$	Our estimates
$T_i \sim \text{Normal}(\mu_i, \sigma)$	$T_i \sim \text{Normal}(\mu_i, \sigma)$	True **(unobserved)**
$\mu_i = \alpha_{c,r}$	$\mu_i = \alpha_{c,u} + \beta_{\Delta A} \Delta A_i$	
$\alpha_{c,r} = a_c + \delta_{c,r}\sigma_{\alpha_c}$	$\alpha_{c,r} = a_c + \delta_{c,r}\sigma_{\alpha_c}$	
	$\beta_{\Delta A} \sim \text{Normal}(0, 0.1)$	

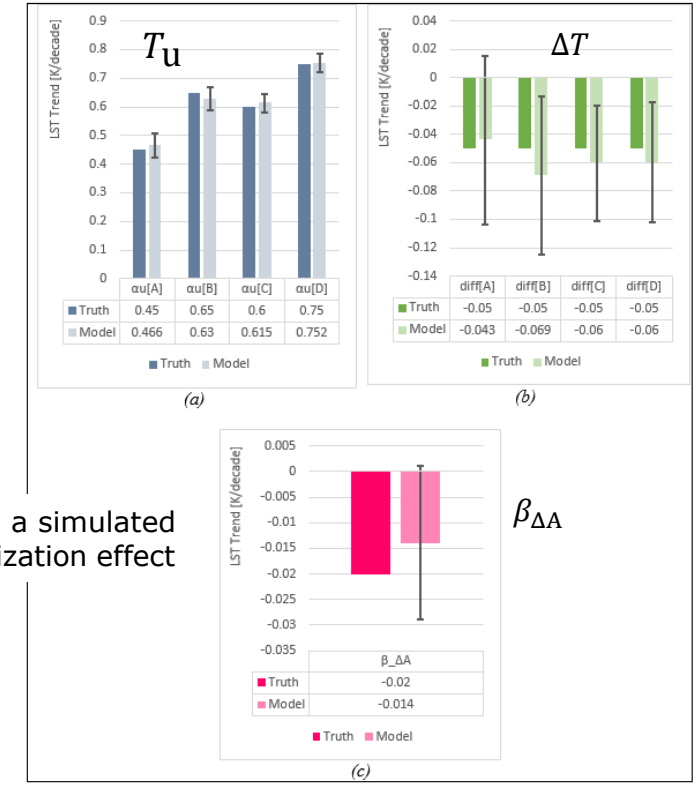
Common Priors

$\alpha_c = a + \delta_c \sigma_a$	$\sigma_a, \sigma_\beta \sim \text{Exp}(1.0)$
$\delta_c \sim \text{Normal}(0, 0.5)$	$\delta_{c,r}, \delta_{c,u} \sim \text{Normal}(0, 0.05)$
$a \sim \text{Normal}(0.4, 0.2)$	

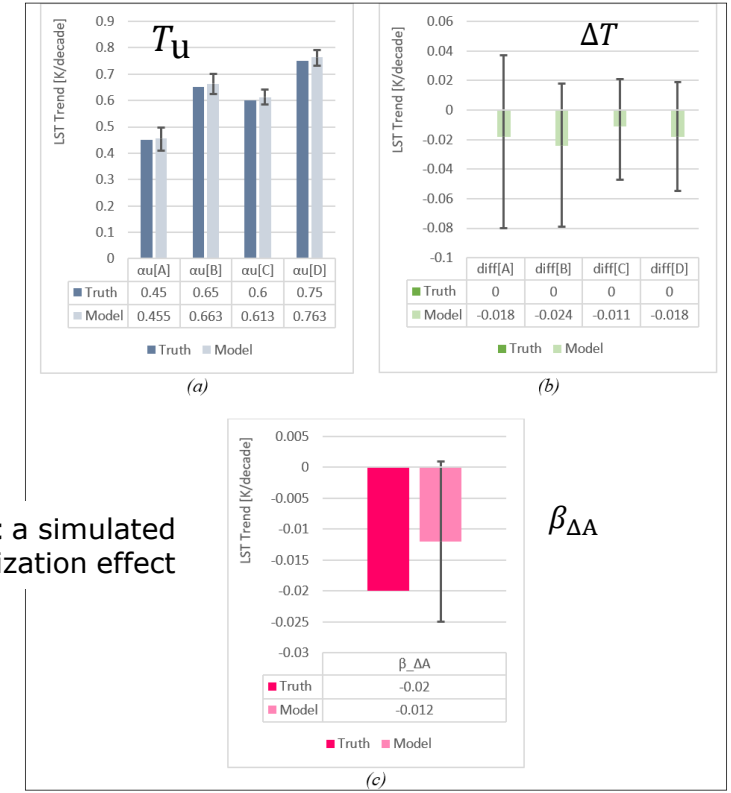


Testing on Synthetic Data

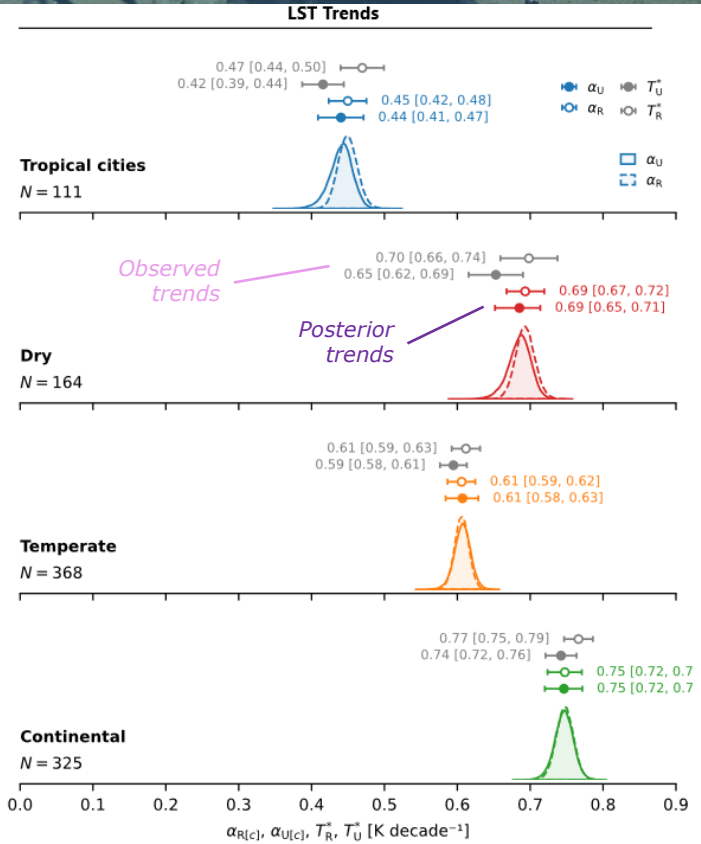
With a simulated urbanization effect



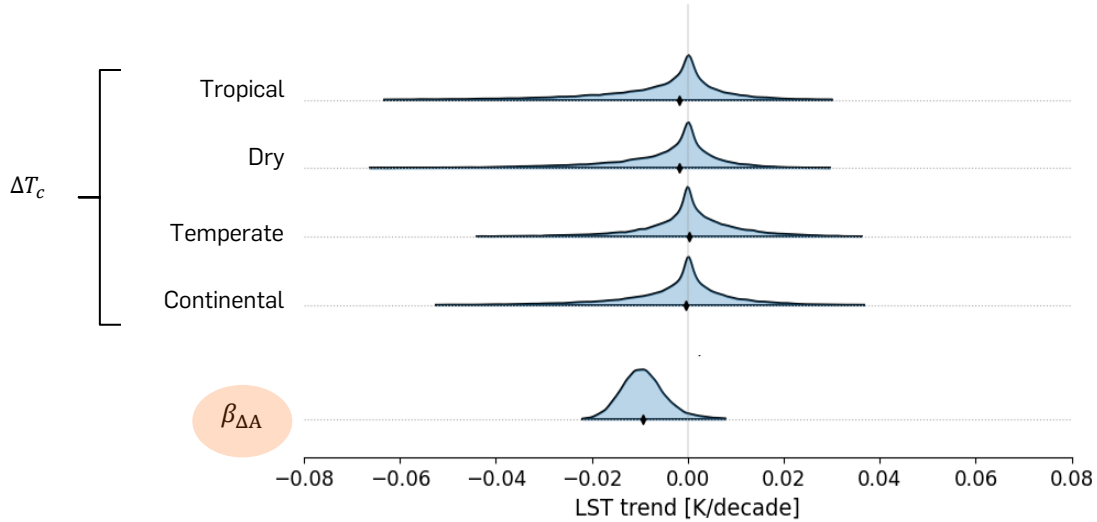
Without a simulated urbanization effect



Results


LST Trends
0.47 [0.44, 0.50]
0.42 [0.39, 0.44]
0.45 [0.42, 0.48]
0.44 [0.41, 0.47]
α_U T^*_U
α_R T^*_R
Tropical cities
$N = 111$
α_U
α_R
Observed trends
0.70 [0.66, 0.74]
0.65 [0.62, 0.69]
0.69 [0.67, 0.72]
0.69 [0.65, 0.71]
Posterior trends
Dry
$N = 164$
0.61 [0.59, 0.63]
0.59 [0.58, 0.61]
0.61 [0.59, 0.62]
0.61 [0.58, 0.63]
Temperate
$N = 368$
0.77 [0.75, 0.79]
0.74 [0.72, 0.76]
0.75 [0.72, 0.7
0.75 [0.72, 0.7
Continental
$N = 325$
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
$\alpha_{R[c]}$, $\alpha_{U[c]}$, T^*_R, T^*_U [K decade^{-1}]

The culprit



	Mean	HDI 95%	
Tropical	**-0.01**	[-0.05, 0.02]	K/decade
Dry	**-0.01**	[-0.04, 0.02]	
Temperate	**0.00**	[-0.02, 0.03]	
Continental	**0.00**	[-0.03, 0.03]	
$\beta_{\Delta A}$	**-0.01**	[-0.03, 0.00]	

Conclusions

Research Questions

1) How fast has the LST of urban areas been increasing in the last 20 years?

Answers

Cities	Nighttime LST Trend [K/decade]
Tropical	**0.45** [0.42, 0.48]
Dry	**0.69** [0.67, 0.72]
Temperate	**0.61** [0.59, 0.62]
Continental	**0.75** [0.74, 0.78]
Global	***0.62*** *[0.49, 0.74]*

Good et al. 2022 - Global	
LST	0.64-0.66
Tair	0.52-0.59

2) Do the urban and surrounding rural warmings rate differ?

No. The MODIS urban and rural posterior distributions are **statistically indistinguishable.**