A Novel Downscaling Approach for Urban Climate: Land-Surface-Physics-Based Downscaling

Lingbo XUE

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8:30 am – 5:00 pm MDT

NCAR FOOTHILLS LAB (EOL-ATRIUM), BOULDER, USA AND HYBRID

1 Motivation, Purpose and Method

Motivation

What are cities?

- Population Centers
- Economic Hubs
- Innovation and Culture

Climate-related risks faced by cities

- Thermal stress
- Sea-level rise
- Tropical cyclones
- Storm surges
- Heavy rainfall

Sky Tree, Tokyo
Lingbo XUE 2022

Building City-Level Climate Change Information

- **Targeted Responses:**

  Cities have unique climate risks and exposures
- **Support Decision Making:**

  Aids urban planning, public policy, and capacity to respond to climate change.
- **Enhance Adaptation Capacity:**

  Understanding specific climate risks, reducing losses and damages from climate change.

(IPCC 6th Report)

Numerical Modeling Downscaling Approach

Dynamical Downscaling (D-DS)

(Hamdi et al. 2014)

- Adequate city-atmosphere interactions
- Computationally too expensive
- Introducing more model biases

Statistical downscaling (S-DS)

(Hoffmann et al. 2012)

- Computationally very inexpensive
- Not considering physical processes
- Only for a few cities and fail to capture complex interactions

Gap

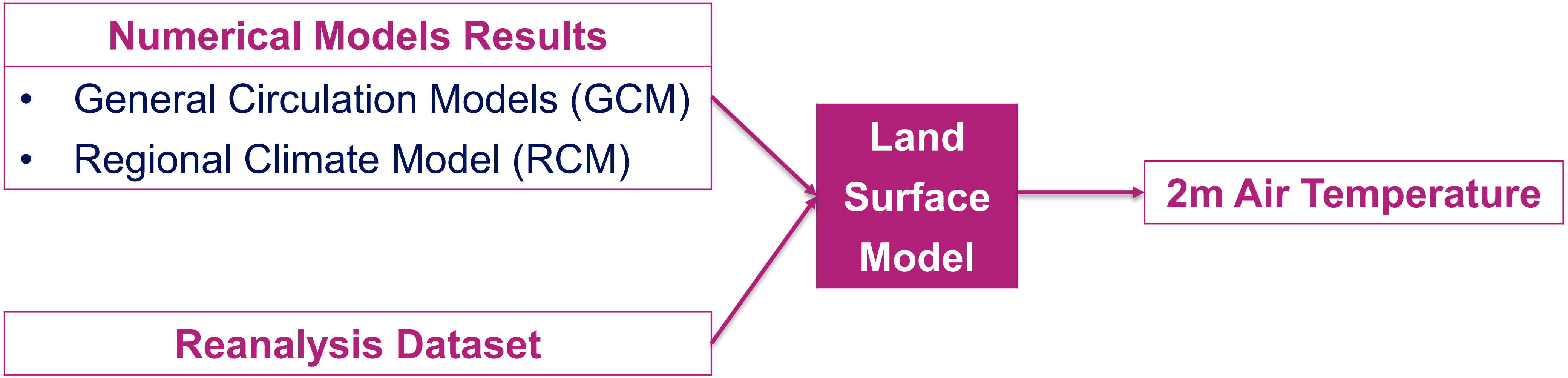
A more effective and requires fewer computational resources downscaling method

(DuchÊne et al. 2020)

Purpose

Land-Surface-Physics-Based Downscaling (LSP-DS)

- Easy to gain insight
- Easy to do experiments
- Require fewer computational resources (~1 Hour for 1 month by PC)
- Can be widely used by policymakers



HRLDAS: Offline Driver of Noah-MP

One of the most widely used land surface models in the world !

GEO_EM File from WPS

- Domain
- Land Use
- Terrain
- Soil Texture

Interpolate to Daily

- Leaf Area Index
- Green Fraction

ERA5 Dataset

- Air Temperature
- Humidity
- Wind Speed

De-accumulate to hourly

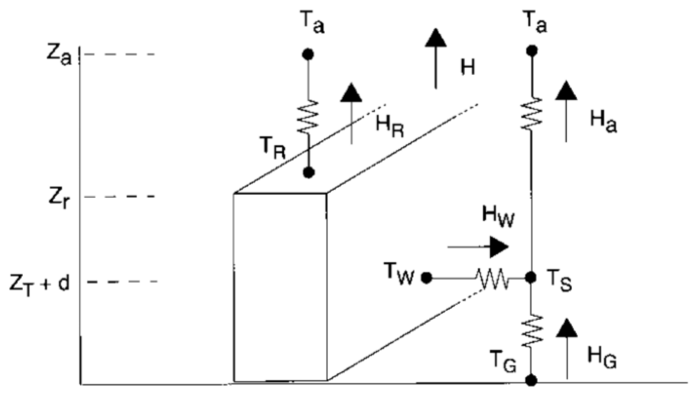
- Radiation
- Precipitation

High-Resolution Land Data Assimilation System (HRLDAS)

Land Surface States

- Temperature
- Energy budgets
- ...

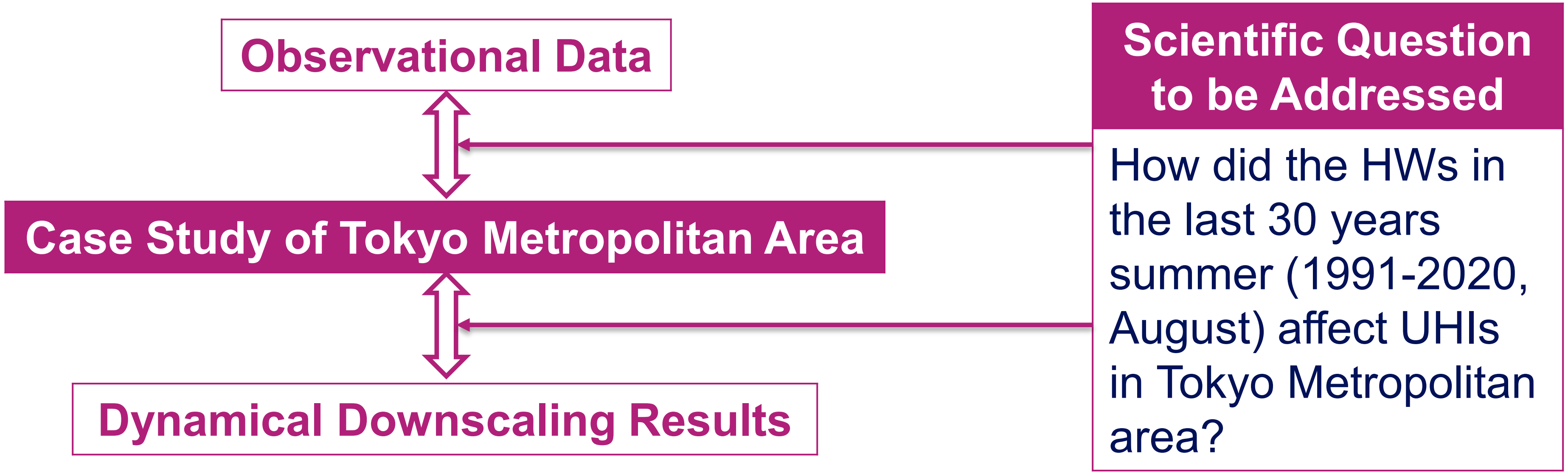
Single-Layer Urban Canopy Model (SLUCM)



(Kusaka et al. 2001)

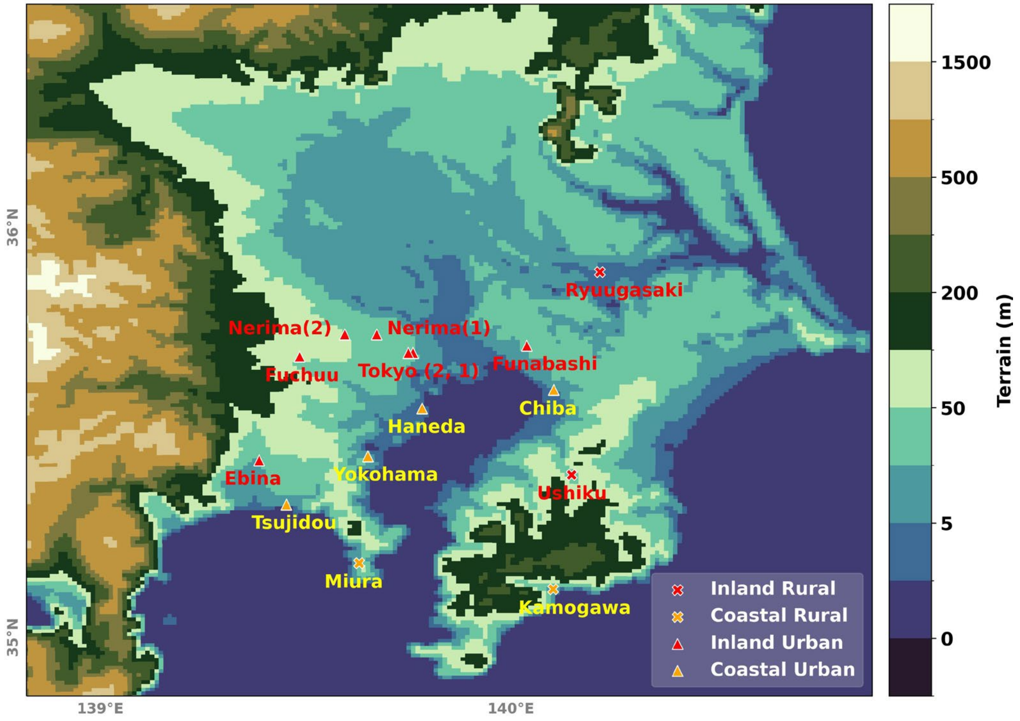
2 Research Plan

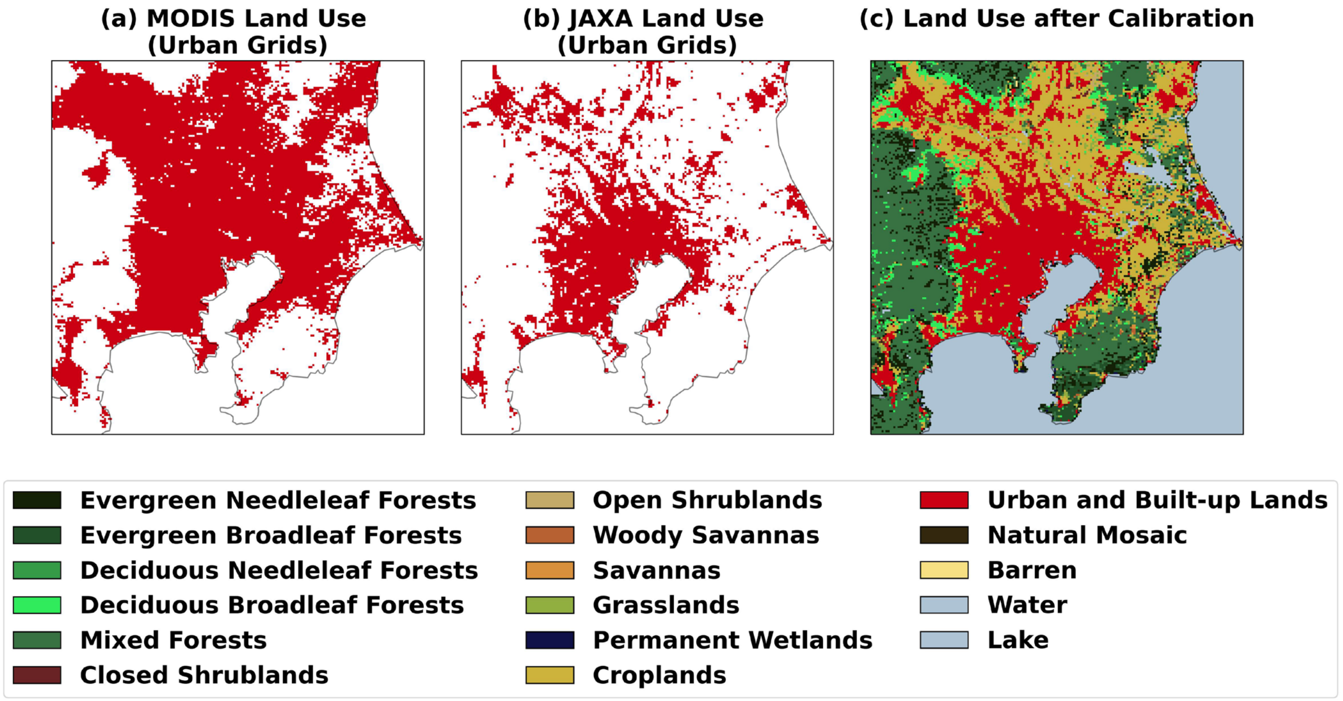
Research Plan



Terrain and Land Use

MODIS shows a higher urban area !





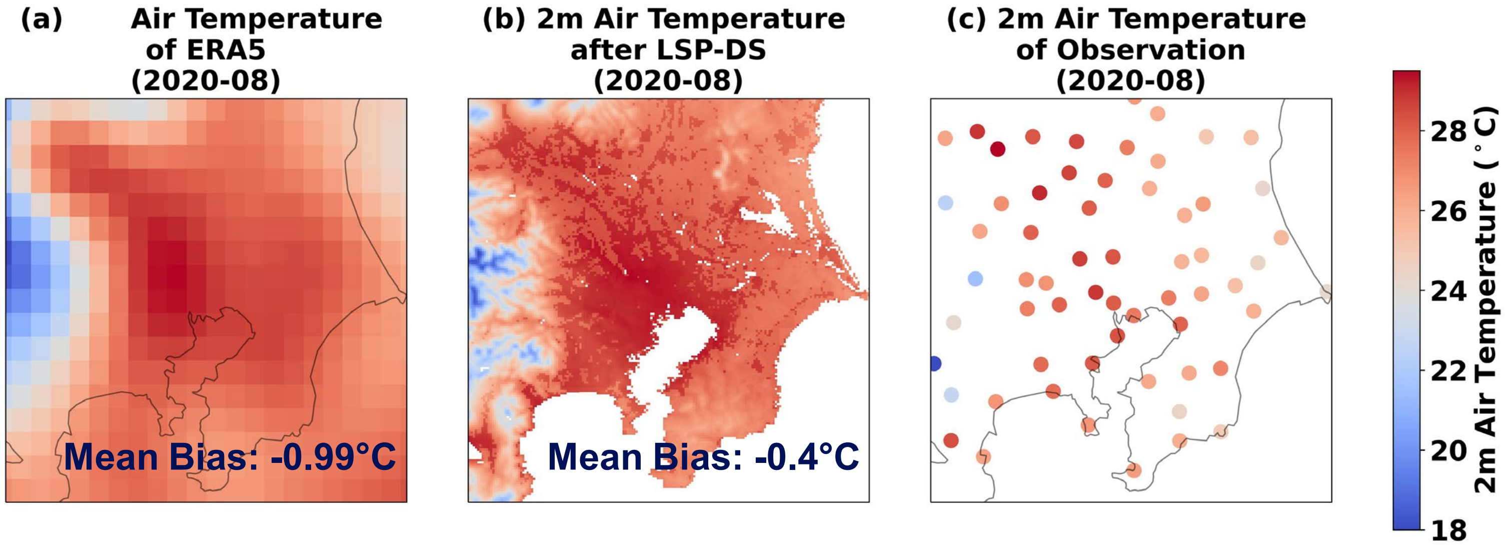
Domain Setting	
Grids	190*190
Resolution	1 km

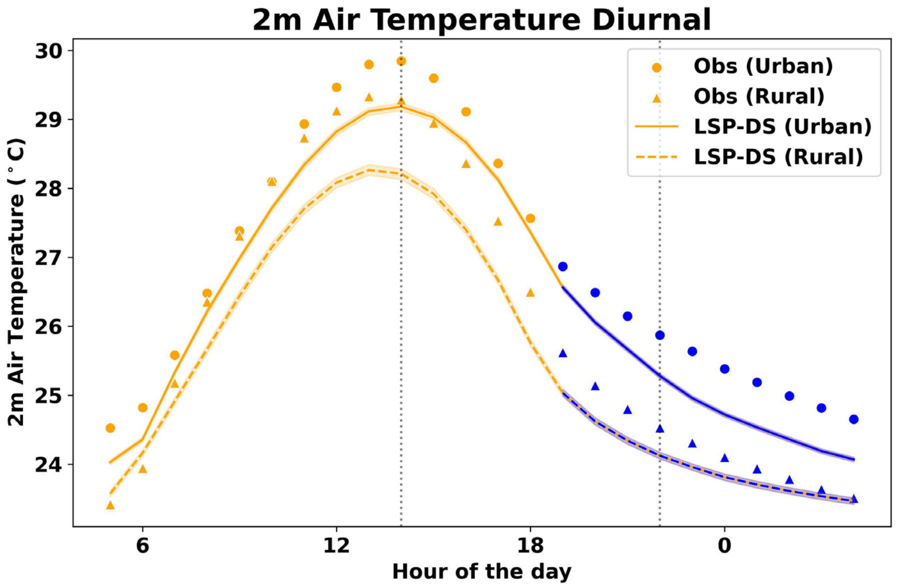
13 observational stations are selected:

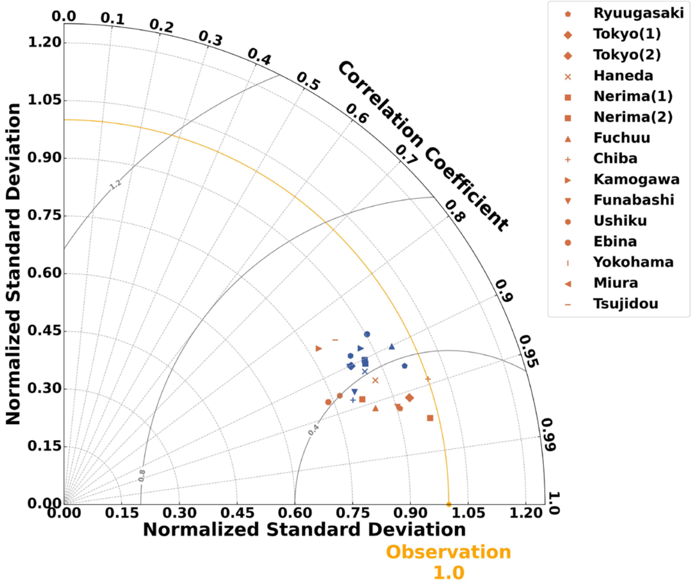
	Urban	Rural
Inland	5	2
Coastal	4	2

2.1 Compare with Observational Data

Downscaled 2m Air Temperature







After LSP-DS:

Temperature of Urban:
28°C to 29°C ↑

Temperature of Mountain:
22°C to 18°C ↓

Mean Bias:
-0.99°C to -0.4°C ↓

Correlation Coefficient:

Tmax: ~0.95

Tmin: ~0.90

How Does Urban Heat Island Intensity Change Under Heat Waves?

Added Heat Load (AHL,

how much UHII changes under heat waves):

Daytime AHL (1400 local time)

Nighttime AHL (2200 local time)

Heat Waves:

Daytime HWs(1400 local time)

Nighttime HWs (2200 local time)

Compound HWs (both 1400 and 2200 local time)

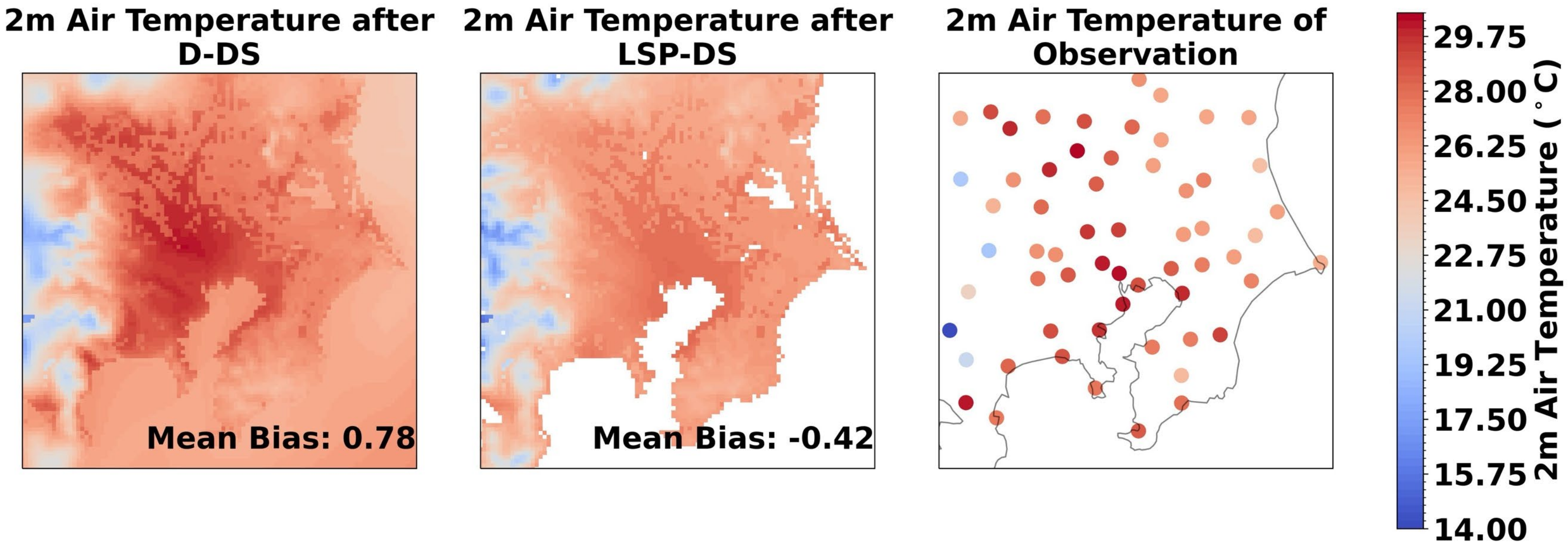
- The definition of heat wave **doesn't affect AHL**
- LSP-DS **can catch** the AHL

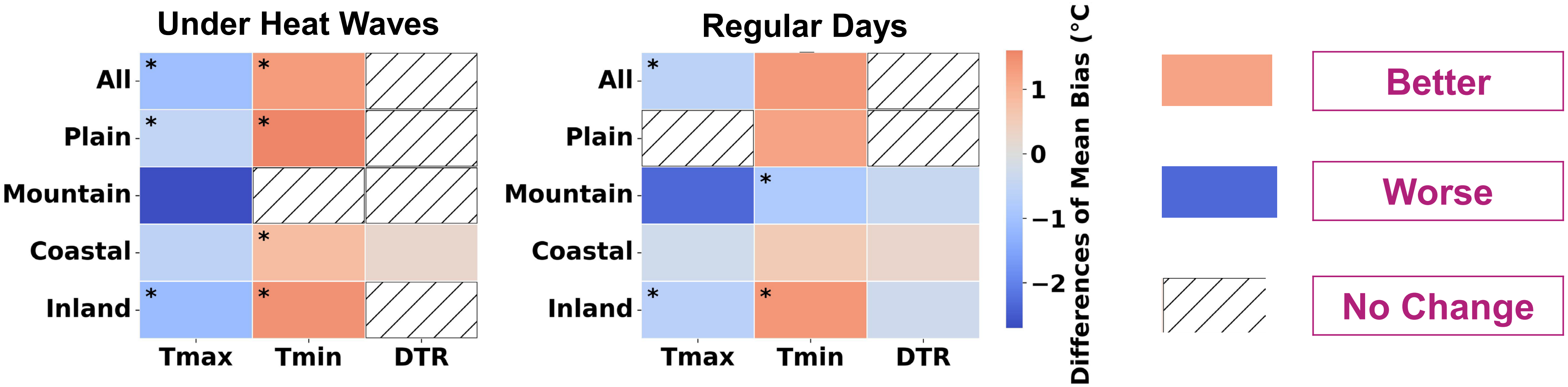
Observation Stations	Added Heat Load (Daytime)						Added Heat Load (Nighttime)					
	Observation			LSP-DS			Observation			LSP-DS		
	compound	daytime	nighttime	compound	daytime	nighttime	compound	daytime	nighttime	compound	daytime	nighttime
Tokyo(1)-Ryuugasaki	-0.6	-0.4	-0.6	-0.3	-0.3	-0.5	0.5	0.4	0.4	-0.1	-0.1	-0.2
Tokyo(1)-Ushiku	-0.3	-0.1	-0.4	0.5	0.6	0.4	0.5	0.4	0.4	0.6	0.7	0.3
Tokyo(2)-Ryuugasaki	0.0	-0.4	-0.1	-0.2	-0.1	-0.0	0.3	0.4	0.4	0.2	0.2	0.2
Tokyo(2)-Ushiku	0.3	0.1	0.2	0.4	0.5	0.5	0.8	0.8	0.6	0.9	0.8	0.7
Nerima(1)-Ryuugasaki	0.3	0.4	0.2	-0.3	-0.2	-0.3	0.9	0.5	0.7	-0.0	0.1	-0.1
Nerima(1)-Ushiku	0.5	0.4	0.3	0.5	0.8	0.4	0.9	0.4	0.6	0.7	0.7	0.4
Nerima(2)-Ryuugasaki	0.0	-0.4	-0.3	-0.0	0.1	-0.0	0.5	0.4	0.4	0.4	0.4	0.3
Nerima(2)-Ushiku	0.2	0.1	-0.0	1.0	1.0	0.8	0.9	0.8	0.6	1.2	1.1	0.9
Fuchuu-Ryuugasaki	0.3	0.2	0.1	-0.3	-0.1	-0.3	0.6	0.4	0.4	0.2	0.2	0.1
Fuchuu-Ushiku	0.4	0.3	0.2	0.6	0.9	0.4	0.7	0.4	0.4	1.0	0.9	0.6
Funabashi-Ryuugasaki	-0.6	-0.3	-0.6	-0.3	-0.2	-0.4	0.2	0.3	0.1	0.1	0.1	-0.0
Funabashi-Ushiku	-0.3	0.1	-0.5	0.6	0.5	0.5	0.4	0.7	0.3	0.7	0.7	0.4
Ebina-Ryuugasaki	0.1	-0.0	-0.0	-1.0	-1.0	-0.9	0.1	0.2	0.1	-0.3	-0.3	-0.3
Ebina-Ushiku	0.3	0.1	0.0	-0.5	-0.1	-0.6	0.0	0.2	-0.0	0.4	0.3	0.3
Chiba-Kamogawa	0.9	1.0	0.6	1.6	1.7	1.2	1.1	1.0	0.9	0.7	0.7	0.5
Chiba-Miura	0.9	0.9	0.8	2.0	2.2	1.4	1.0	0.9	1.0	0.7	0.6	0.6
Yokohama-Kamogawa	1.1	1.3	0.5	0.7	0.7	0.4	0.6	0.6	0.5	0.5	0.4	0.3
Yokohama-Miura	1.1	1.1	0.9	0.9	0.8	0.6	0.6	0.5	0.6	0.4	0.4	0.3
Tsujidou-Kamogawa	0.1	0.5	-0.4	0.2	0.4	-0.0	0.4	0.7	0.2	0.4	0.3	0.2
Tsujidou-Miura	0.2	0.1	-0.2	0.2	0.4	0.2	0.4	0.3	0.3	0.2	0.2	0.2
Haneda-Kamogawa	1.1	1.4	0.7	1.3	1.3	0.9	0.9	0.8	0.5	0.6	0.6	0.4
Haneda-Miura	1.2	1.3	0.9	1.7	1.6	1.1	0.8	0.7	0.6	0.6	0.6	0.4

Added Heat Load (°C): 2.0, 1.5, 1.0, 0.5, 0.0, −0.5, −1.0

2.1 Compare with Dynamical Downscaling

How does LSP-DS perform compared to D-DS?





3 Future Plan

Conclusions

- LSP-DS is effective in simulating the detailed interplay between UHI and HWs
- LSP-DS shows less bias compared with D-DS and Reanalysis Dataset
- LSP-DS can be used as a possible downscaling method for urban climate

Future Plan

- **Deepening the understanding** behind the differences between D-DS and LSP-DS
- Compare LSP-DS with other **statistical downscaling approaches** e.g., using conventional statistical methods, or state-of-the-art deep learning techniques
- Evaluate the performance of LSP-DS for **other regions** in the world, such as desert cities, inland cities

Thank you for your attention!

References:
1. Xue, L., Doan, Q.-V., Kusaka, H., He, C., & Chen, F. (2024). Insights into urban heat island and heat waves synergies revealed by a Land-Surface-Physics-Based Downscaling method. *Journal of Geophysical Research: Atmospheres*, *129*, e2023JD040531. https://doi.org/10.1029/ 2023JD040531
2. Xue, L., Doan, Q.-V., Kusaka, H., He, C., & Chen, F. (2024). Comparison of Land-Surface-Physics-Based Downscaling method and dynamical downscaling method. Manuscript in preparation.