Enhancing Global-Scale Urban Land Cover Representation Using Local Climate Zones in the Community Earth System Model

Yuan Sun[1], Keith W. Oleson[2], Lei Zhao[3], Gerald Mills[4], Cenlin He[2], Matthias Demuzero[5], David O. Topping[1], Ning Zhang[6*], Zhonghua Zheng[1*]

[1] The University of Manchester, [2]NSF National Center for Atmospheric Research, [3]University of Illinois Urbana-Champaign, [4]University College Dublin, [5]B-Kode VOF, [6]Nanjing University

Urban land cover representation in CLMU

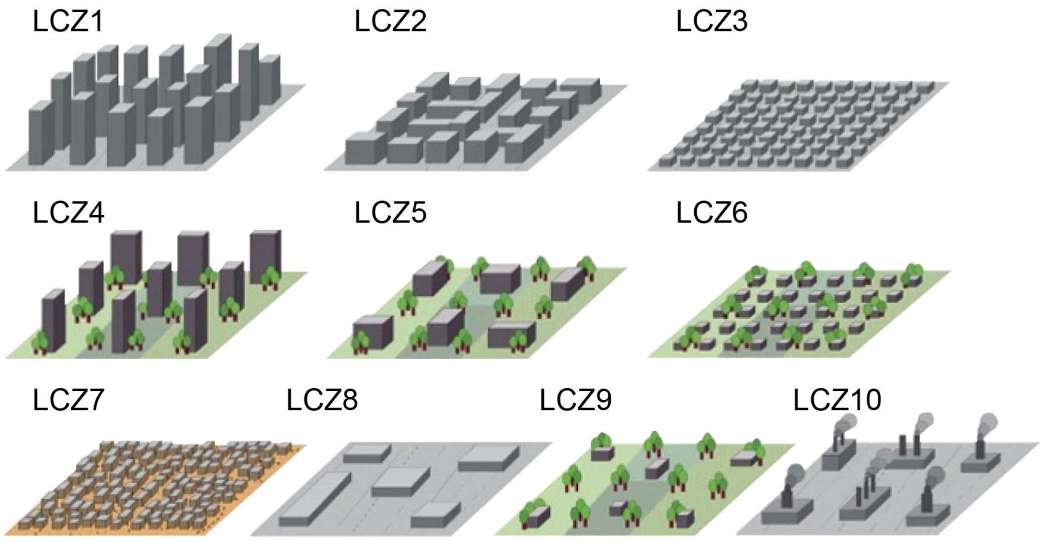
- Default 3-class scheme
  - Tall building district (TBD)
  - High density (HD)
  - Medium density (MD)

Based on LandScan urban population data

TBD only accounts for 0.08% global urban areas, HD and MD for 19.78% and 80.14%, respectively.

Parameters for HD and MD have relatively small differences.

Urban land cover representation based on Local Climate Zone (LCZ)

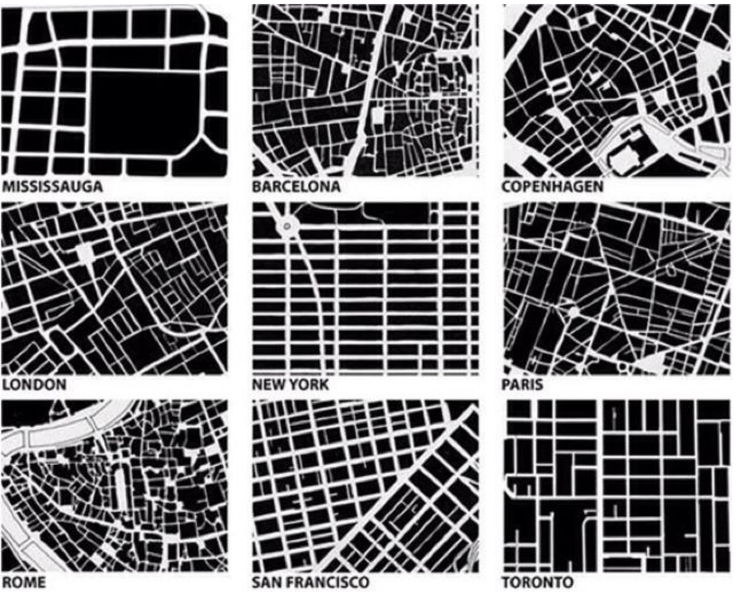


Based on urban forms

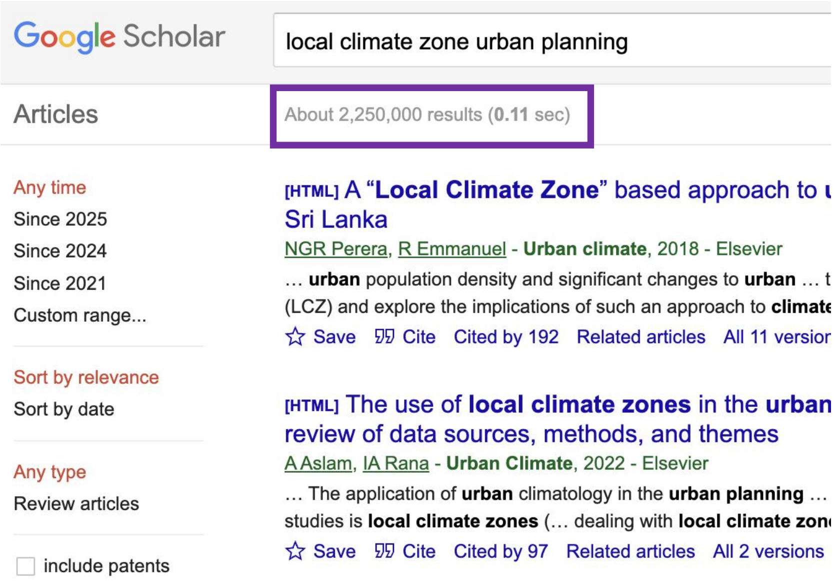
- Local climate zone (10-class)
  - Compact highrise (LCZ1)
  - Compact midrise (LCZ2)
  - Compact lowrise (LCZ3)
  - Open highrise (LCZ4)
  - Open midrise (LCZ5),
  - Open lowrise (LCZ6)
  - Lightweight lowrise (LCZ7)
  - Large lowrise (LCZ8)
  - Sparsely built (LCZ9)
  - Heavy industry (LCZ10)

Why Local Climate Zone (LCZ)?

Better resolving urban morphological diversity



Useful for supporting urban planning community



Consistent global urban database

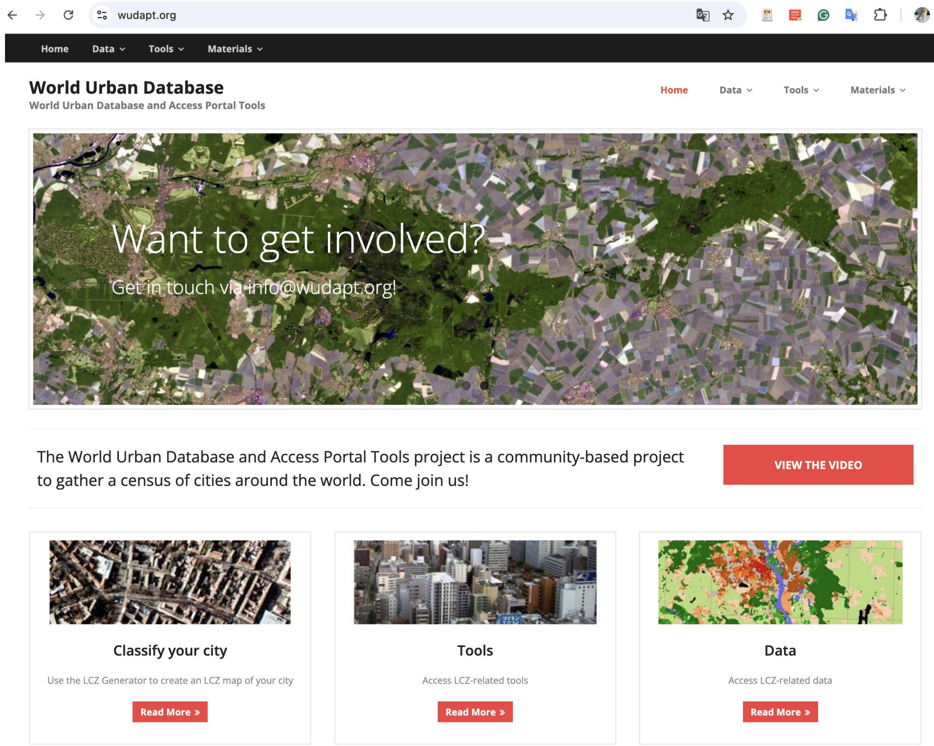
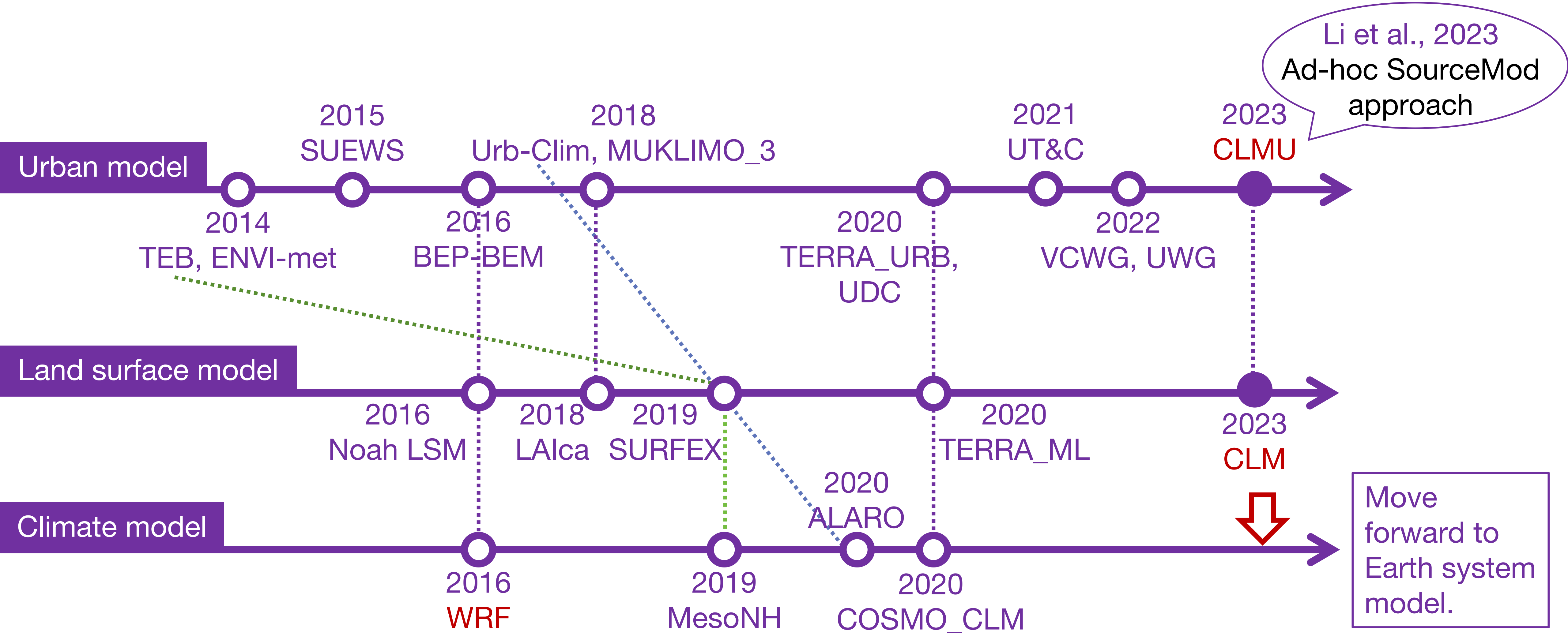


Figure source: (left) https://i.pinimg.com/736x/2b/08/40/2b084005a861fd04a08c9546db222115.jpg, (middle) https://scholar.google.com/, (right) https://www.wudapt.org/

Incorporating LCZs for numerical simulations



Li et al. (2023) Modeling urban heat islands and thermal comfort during a heat wave event in East China with CLM5 incorporating local climate zones. Journal of Geophysical Research: Atmospheres. 128(16):e2023JD038883.

Incorperating LCZs in CTSM

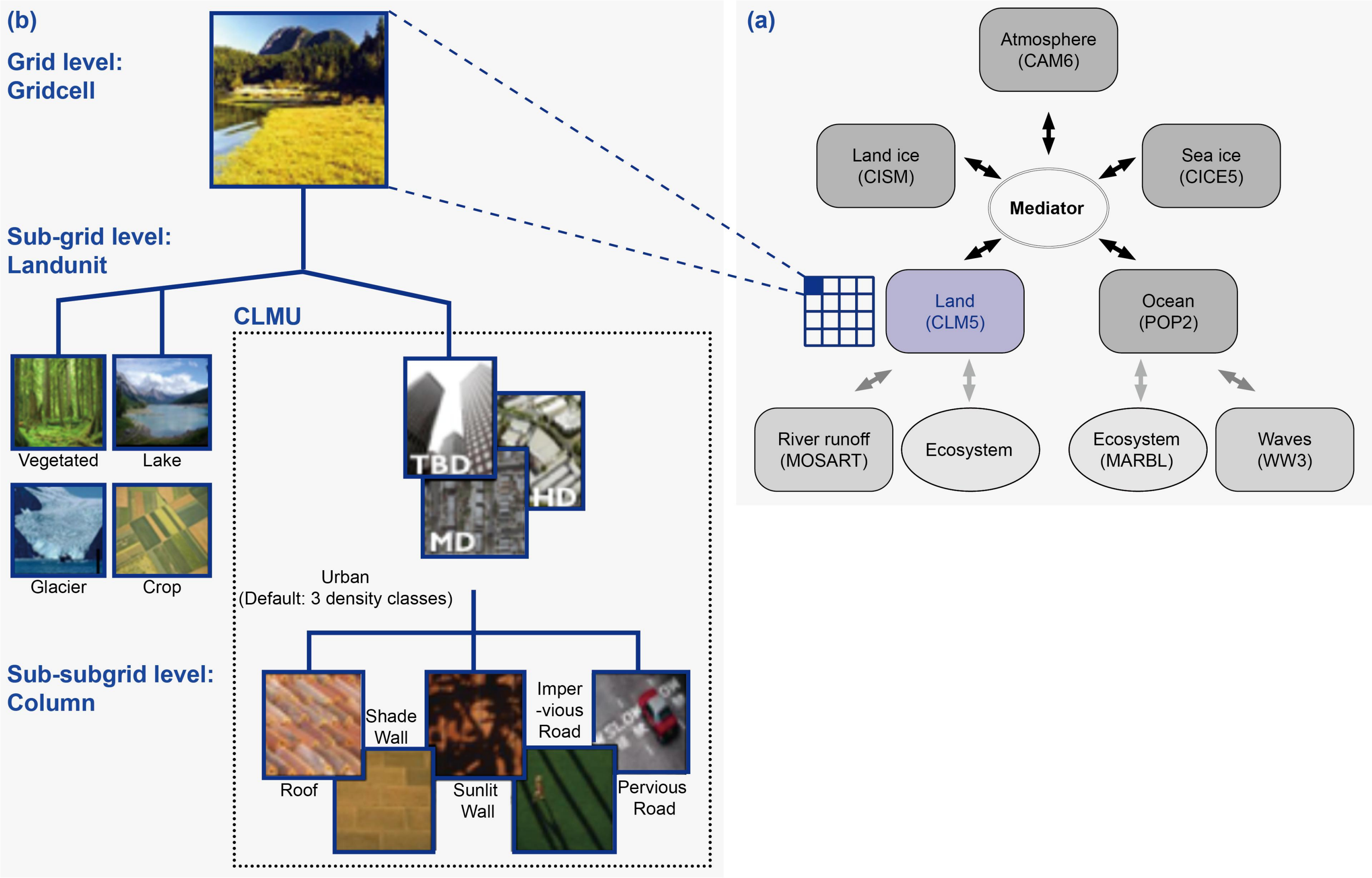
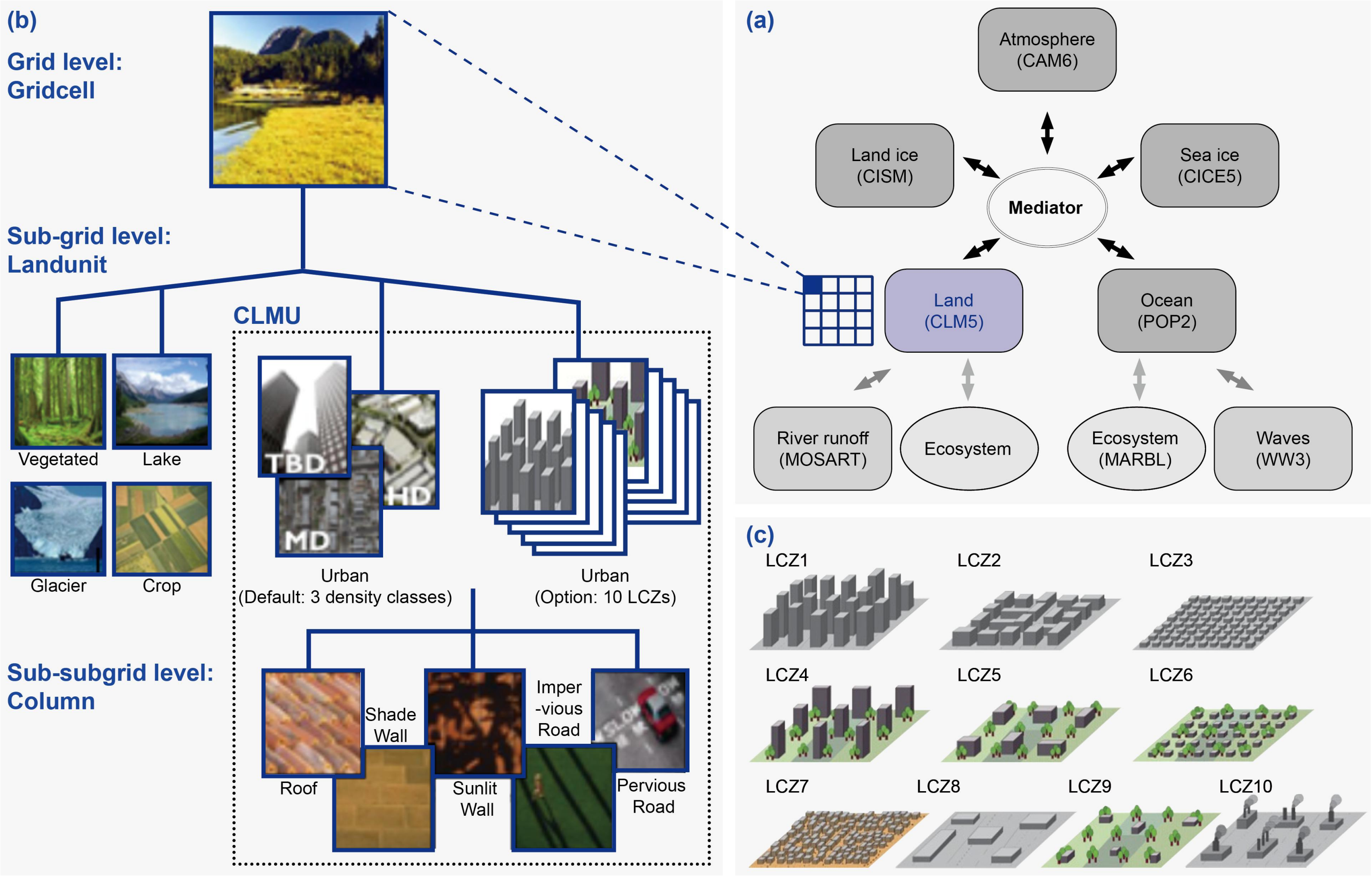


Fig. CLM representation hierarchy.

Incorperating LCZs in CTSM



LCZ urban landunits

Fig. CLM representation hierarchy.

Incorperating LCZs in CTSM

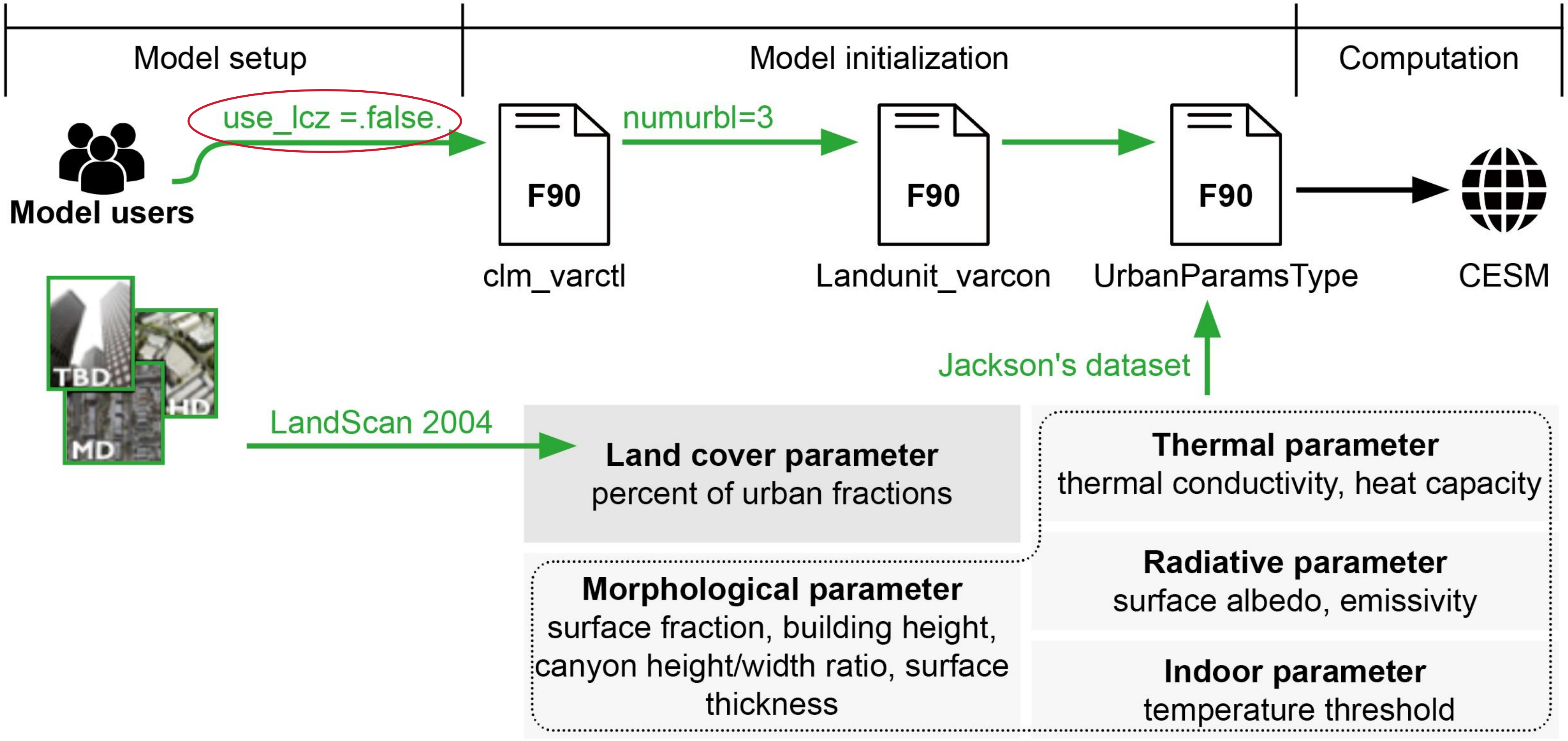


Fig. Workflow of ‘use_lcz’.

Incorperating LCZs in CTSM

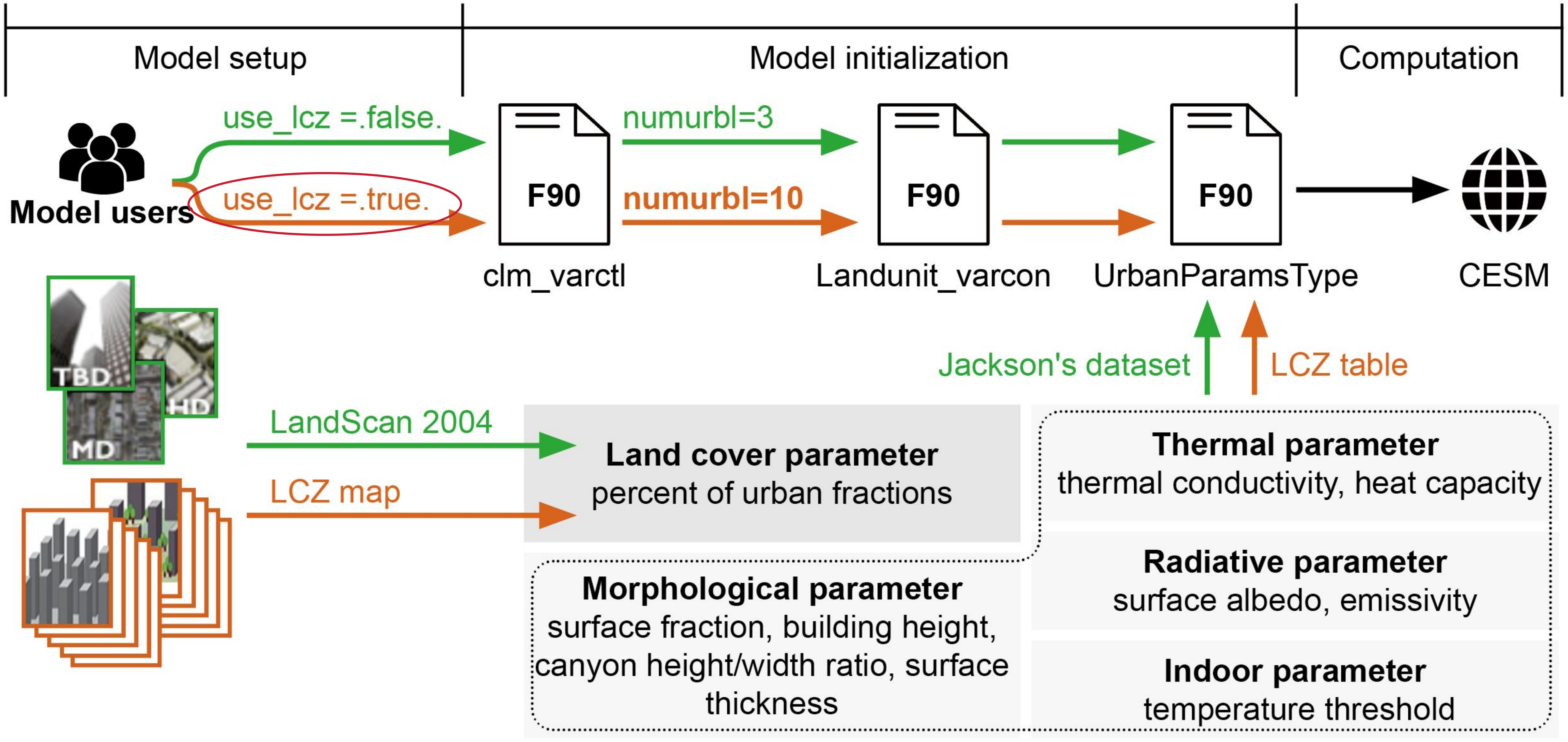


Fig. Workflow of ‘use_lcz’.

Two existing LCZ urban parameter tables

Table 1
Input Parameter Values of Each Urban LCZ for the CLM5-LCZs (Referring to Stewart et al. (2014) and Zonato et al. (2020))

	Local climate zones (LCZs)									
	1	2	3	4	5	6	7	8	9	10
Land cover										
f_b	0.50	0.50	0.55	0.30	0.30	0.30	0.75	0.40	0.15	0.25
f_i	0.45	0.40	0.30	0.35	0.40	0.40	0.10	0.45	0.15	0.30
f_p	0.05	0.10	0.15	0.35	0.30	0.30	0.15	0.15	0.70	0.45
Morphological										
H	37.5	17.5	6.5	30.0	17.5	6.5	3.0	6.5	6.5	10.0
HW	2.5	1.25	1. 25	1.0	0.5	0.5	1.5	0.2	0.15	0.35
Δz_r	0.3	0.3	0.2	0.3	0.25	0.15	0.1	0.12	0.15	0.05
Δz_w	0.3	0.25	0.25	0.2	0.2	0.2	0.1	0.2	0.2	0.05
Radiative										
α_r	0.23	0.28	0.25	0.23	0.23	0.23	0.55	0.28	0.23	0.20
α_w	0.35	0.30	0.30	0.35	0.35	0.35	0.55	0.35	0.35	0.30
α_i	0.14	0.14	0.14	0.14	0.14	0.14	0.18	0.14	0.14	0.14
α_p	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.22
ε_r	0.91	0.91	0.91	0.91	0.91	0.91	0.88	0.91	0.91	0.91
ε_w	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
ε_i	0.91	0.91	0.91	0.91	0.91	0.91	0.88	0.91	0.91	0.91
ε_p	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95	0.95
Thermal										
λ_r	1.70	1.70	1.09	1.25	1.70	1.09	0.50	1.07	1.09	2.00
λ_w	1.27	2.60	1.66	1.45	1.88	1.66	0.18	1.07	1.66	1.42
λ_i	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78	0.78
c_r	1.32	1.32	1.32	1.80	1.32	1.32	2.00	2.11	1.32	2.00
c_w	1.54	1.54	1.54	2.00	1.54	1.54	2.00	2.11	1.54	1.59
c_i	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
$T_{ib,max}$	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
$T_{ib,min}$	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

WRF / run / URBPARM_LCZ.TBL

cenlinhe Update urban LCZ parameter table with more reasonable values (#1969) 6156b78 · last year History

Code Blame 647 lines (475 loc) · 15.8 KB · Raw

```
# The parameters in this table may vary greatly from city to city.
# The default values are probably not appropriate for any given city.
# Users should adapt these values based on the city they are working
# with.

# Urban Parameters depending on Urban type
# USGS

Number of urban categories: 11

#
#  Where there are multiple columns of values, the values refer, in
#  order, to: 1) Commercial, 2) High intensity residential, and 3) Low
#  intensity residential:  I.e.:
#
#  Index:        1                2              3             4           5           6               7                   8
#  Type:  Comp High-Rise, Comp Mid-Rise, Comp Low-Rise, Op H-Rise, Op M-Rise, Op L-Rise, Lightweight L-Rise, Large L-Rise

#
# ZR:  Roof level (building height)  [ m ]
#      (sf_urban_physics=1)

ZR: 37.5, 17.5, 6.5, 37.5, 17.5, 6.5, 3., 6.5, 6.5, 10., 10.

#
# SIGMA_ZED:  Standard Deviation of roof height  [ m ]
#      (sf_urban_physics=1)

SIGMA_ZED: 4.0,  3.0,  1.0, 1., 1., 1., 1., 1., 1., 1., 1.

#
# ROOF_WIDTH:  Roof (i.e., building) width  [ m ]
#      (sf_urban_physics=1)

ROOF_WIDTH: 22.2, 22., 9.6, 42.86, 26.25, 13., 25., 28.9, 43.33, 23.8, 5.
```

(left) Li et al., 2023
(right) WRF

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c_i	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
$T_{ib,max}$	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
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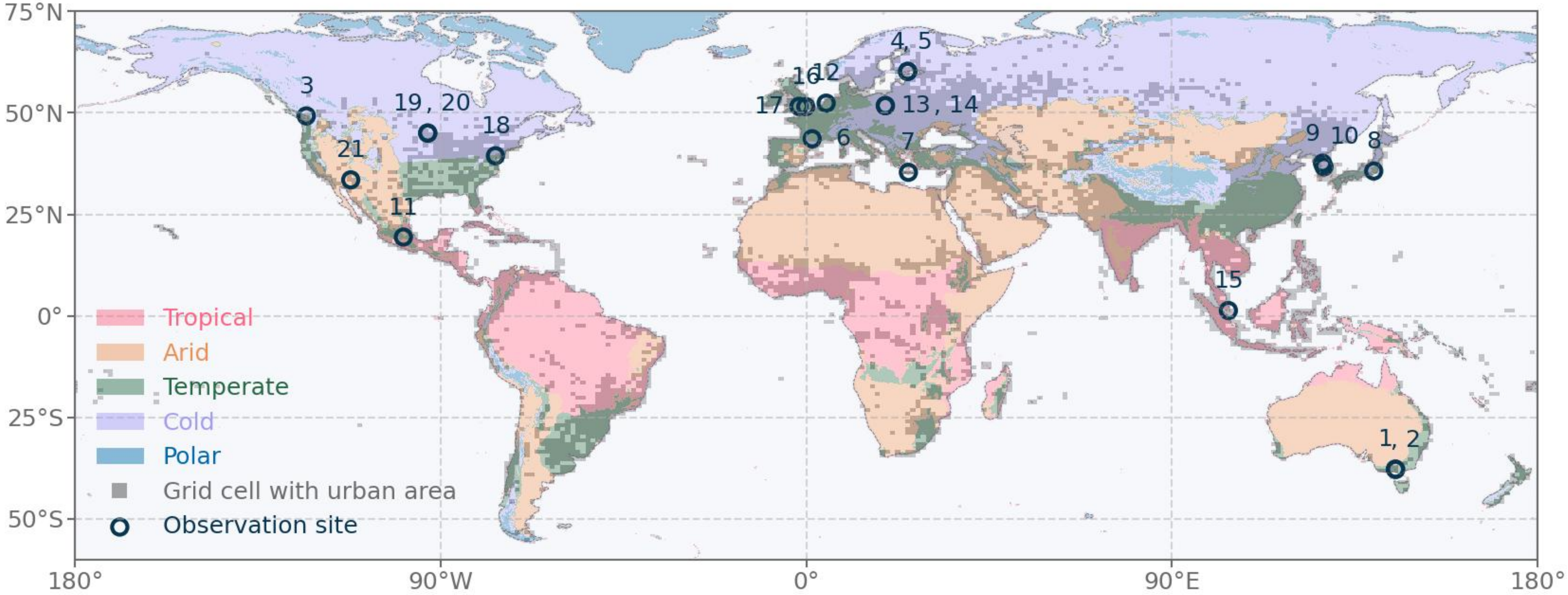
```

Urban parameters are simplified by using look-up tables.

(left) Li et al., 2023
(right) WRF

Model validation using Urban-PLUMBER atmosphere forcing and urban parameters

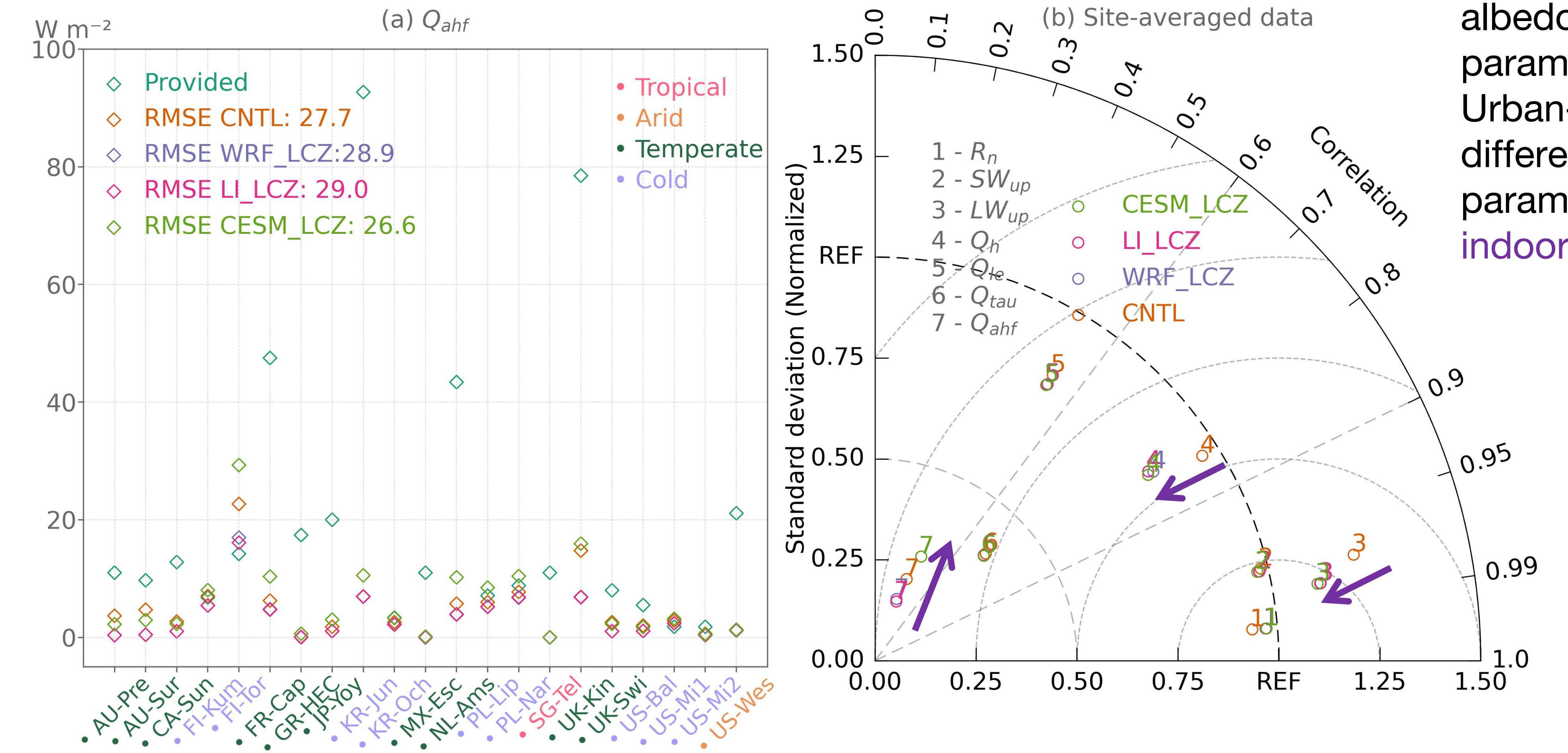


1- AU-Preston
2- AU-SurreyHills
3- CA-Sunset
4- FI-Kumpula
5- FI-Torni
6- FR-Capitole
7- GR-HECKOR
8- JP-Yoyogi
9- KR-Jungnang
10- KR-Ochang
11- MX-Escandon
12- NL-Amsterdam
13- PL-Lipowa
14- PL-Narutowicza
15- SG-TelokKurau06
16- UK-KingsCollege
17- UK-Swindon
18- US-Baltimore
19- US-Minneapolis1
19- US-Minneapolis2
20- US-WestPhoenix

20 urban flux tower sites with different background climates.

Lipson et al. (2024) Evaluation of 30 urban land surface models in the Urban-PLUMBER project: Phase 1 results. Quarterly Journal of the Royal Meteorological Society.150(758):126-69.

Urban flux variables



WRF_LCZ, LI_LCZ, and CESM_LCZ used the same albedo and morphological parameters provided by Urban-PLUMBER but different emissivity, thermal parameters and minimum indoor temperature.

Qahf is influenced by both T_BUILDING_MIN and background climate.

Fig. Urban flux variables at Urban-PLUMBER sites.

Discussion

Computation cost

More than twice costing but worthwhile for fine scale simulation

Urban extent changes

Interannal LCZ maps to represent urban extent changes

Urban parameter uncertainty

Develope more localized urban parameters rather than using a look up table

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After realizing the functionality and validating the modeling capacity with LCZs in single-point simulations, future works include input development and regional and global simulations.

LCZ thermal parameters reduce day-night difference in Qh compared to the default.

LCZ-based △Qh is closer to observations at some sites but not at others.

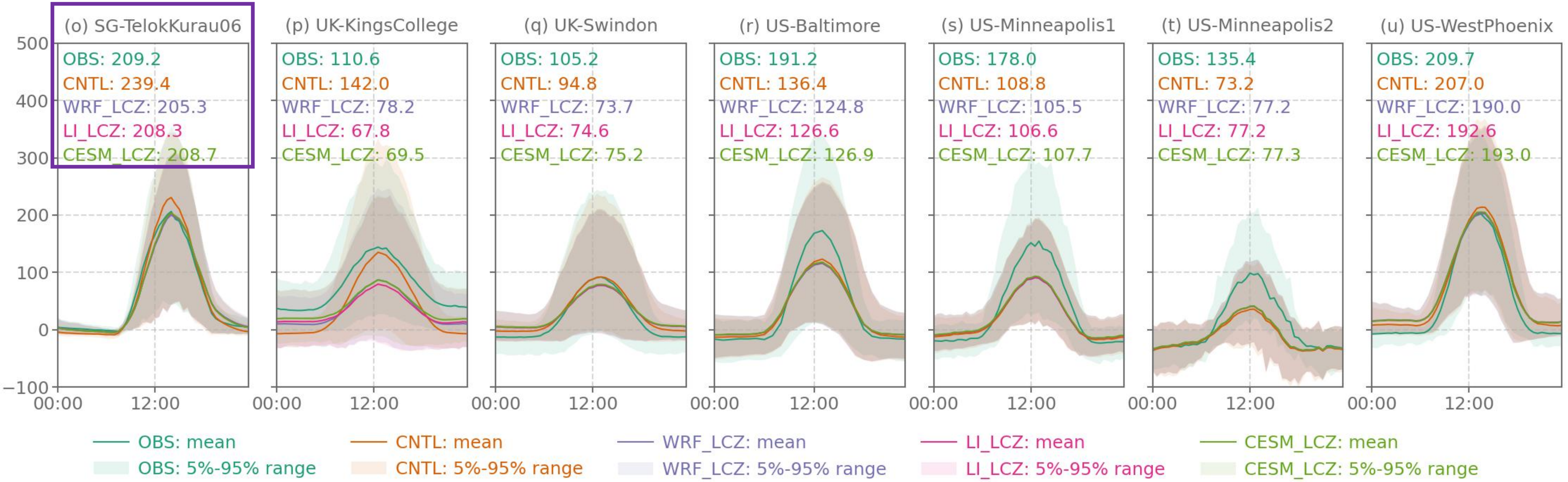
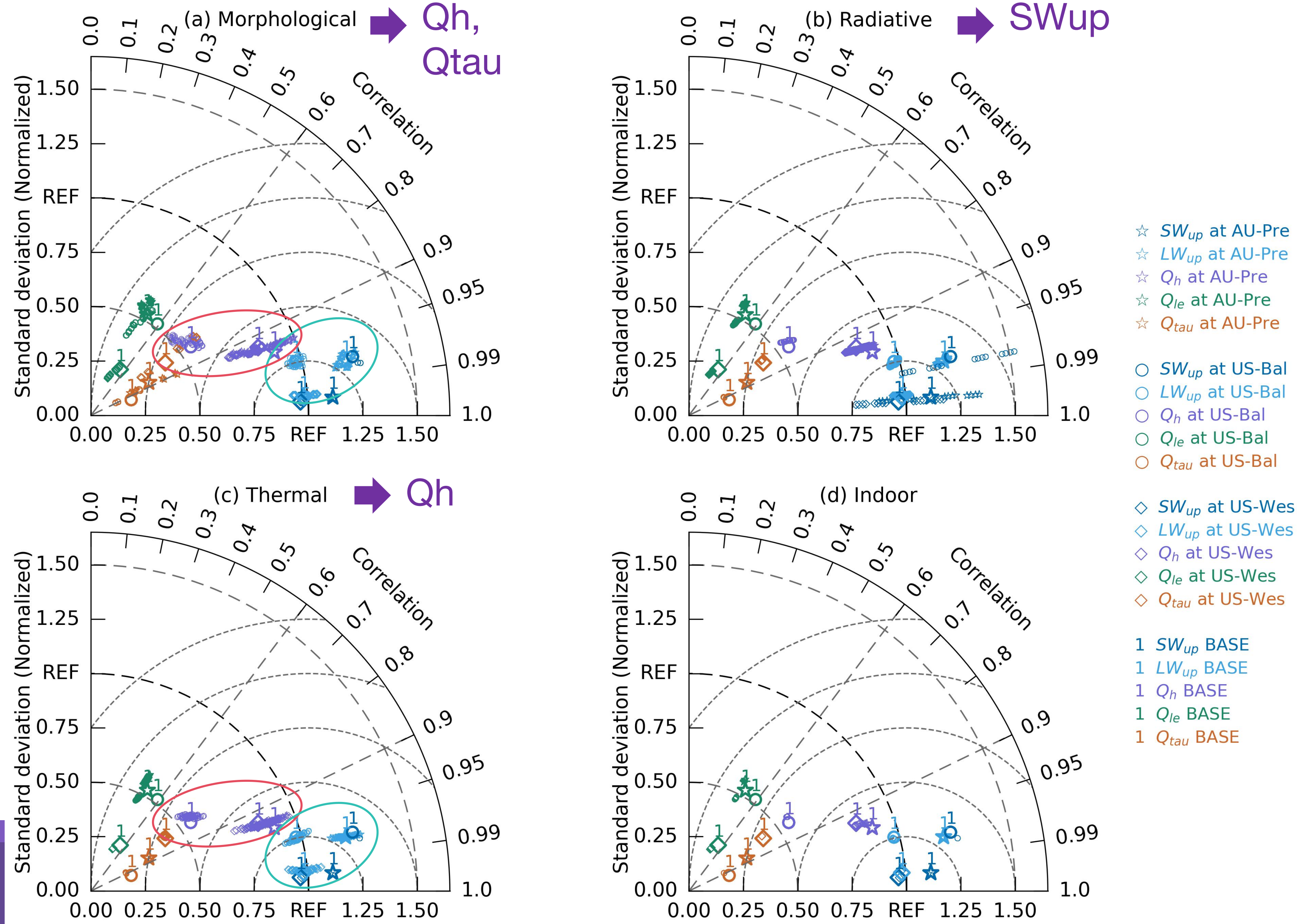


Fig. Diurnal mean sensible heat flux (Qh). Texts in plots denotes day-night difference in Qh (△Qh).

Model sensitivity to LCZ urban parameters



Divide urban parameters by four subsets and introduce perturbation factors 5%, 10%, 15%, 20%

Summary

- We developed a modular approach for implementing an LCZ-based urban land cover representation in CESM.
- Simulations at 20 flux tower sites showed the effectiveness of urban climate modeling using the LCZ scheme.
- Future works will focus on devloping LCZ-based global inputs for coupled simulations.

Preprint available :)

Enhancing Global-scale Urban Land Cover Representation Using Local Climate Zones in the Community Earth System Model

This is a Preprint and has not been peer reviewed. This is version 1 of this Preprint.

Non-peer reviewed preprint submitted to *EarthArXiv*

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[3]Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign, Urbana, IL 61801, USA
[4]National Center for Supercomputing Applications, University of Illinois Urbana-Champaign, Urbana, IL 61801, USA
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[6]School of Geography, University College Dublin, Dublin, Ireland
[7]Research Applications Laboratory, NSF National Center for Atmospheric Research, Boulder, CO, USA
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[9]School of Atmospheric Sciences, Nanjing University, Nanjing, China
[10]Key Laboratory of Urban Meteorology, China Meteorological Administration, Beijing, China

Key Points:

- We developed a modular approach for implementing an LCZ-based urban land cover representation in CESM.
- Simulations at 20 flux tower sites showed the effectiveness of urban climate modeling using the LCZ scheme.
- Modeled sensible heat flux showed comparable sensitivity to LCZ morphological and thermal parameters.

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Abstract

Urban areas are increasingly vulnerable to the impacts of climate change, necessitating accurate simulations of urban climates in Earth system models (ESMs) in support of large-scale urban climate adaptation efforts. ESMs underrepresent urban areas due to their small spatial extent and the lack of detailed urban landscape data. To enhance the accuracy of urban representation, this study integrated the local climate zones (LCZs) scheme within the Community Earth System Model (CESM) to better represent urban heterogeneity. We adopted a modular approach to incorporate the ten built LCZ classes into CESM as a new option in addition to the default... more

DOI

https://doi.org/10.31223/X5GX4K

Subjects

Earth Sciences, Environmental Sciences

Scan it for the preprint!
Thank you!

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