Implementing LCZs to Community Land Model Urban (CLMU)

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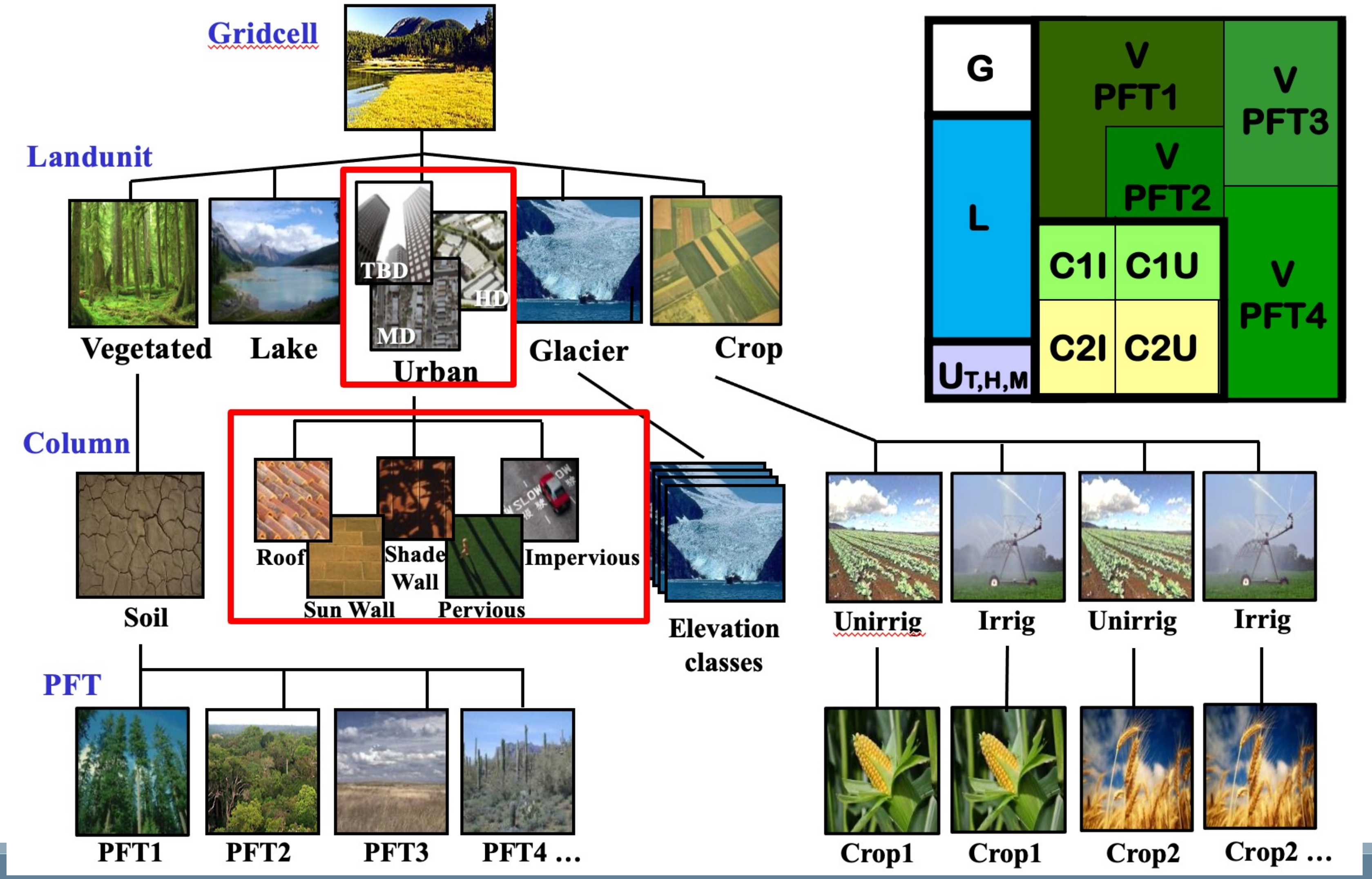
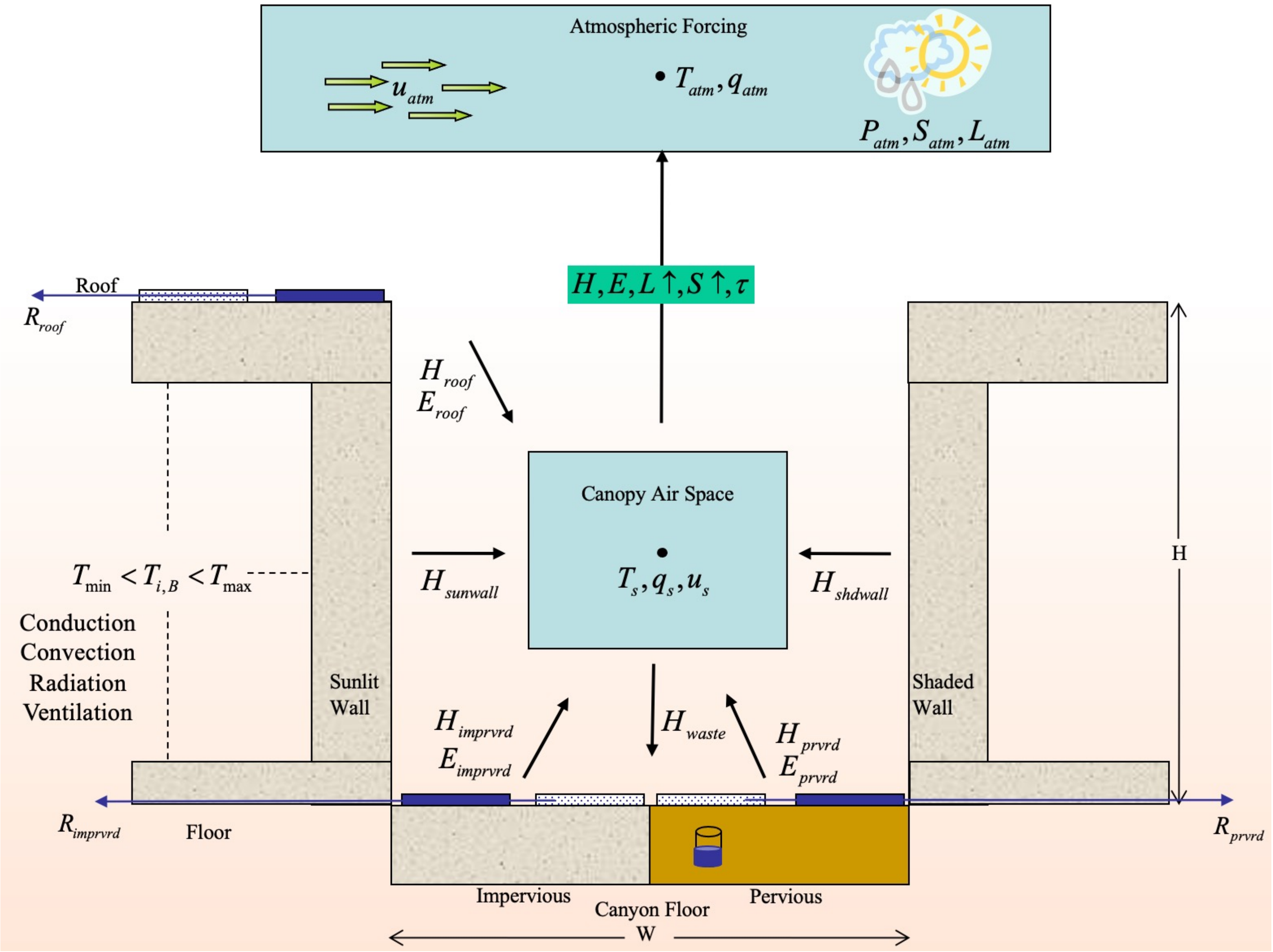
CLMU: representing urban areas in CESM

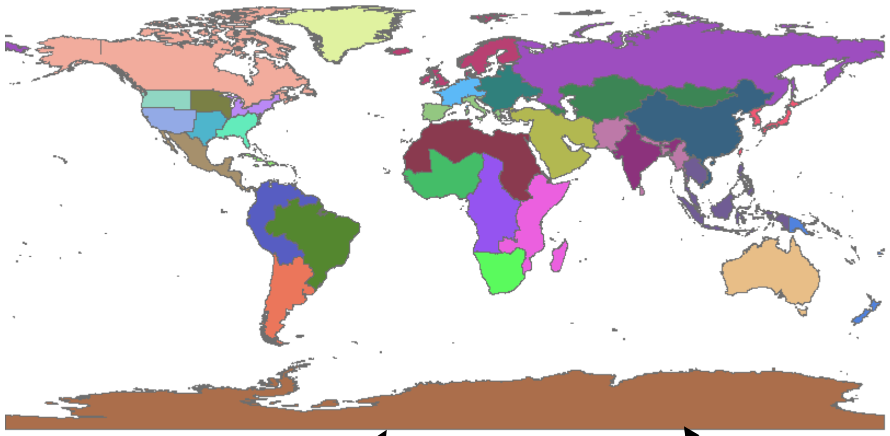


Community Land Model Urban



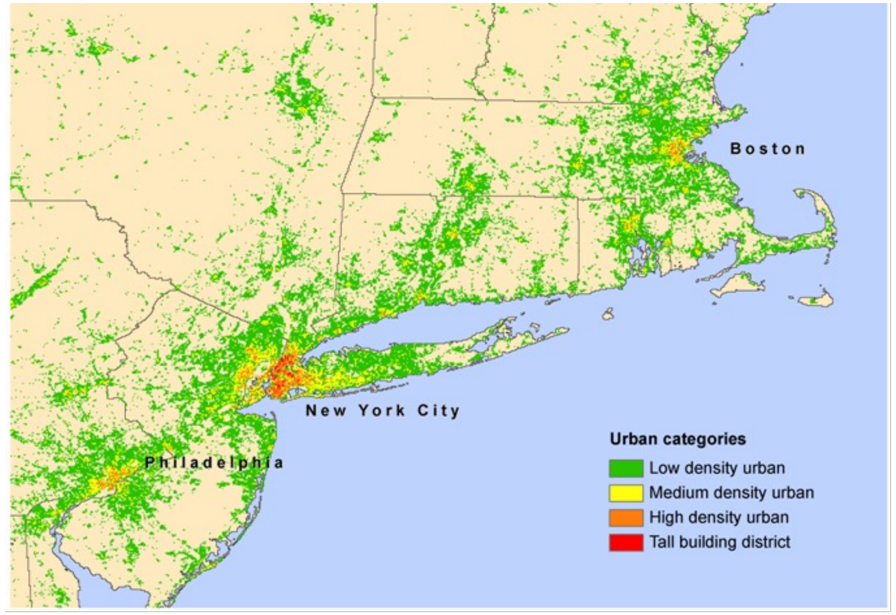
Global Urban Characteristics Dataset

33 Global Regions



→ **To CLMU**

Urban Extent - Landscan 2004



Urban Properties – Compilation of building databases for three density types

Morphological
- ***Building Height***
- ***H/W ratio***
- ***Pervious fraction***
- ***Roof fraction***

Radiative – Roof/Wall/Road
- ***Albedo***
- ***Emissivity***

Thermal – Roof/Wall/Road
- ***Conductivity***
- ***Heat Capacity***

Interior temperature settings (HAC)

Jackson et al. 2010; Oleson and Feddema 2019

CLMU-CESM is a powerful tool to study urban climates, especially on large scales

Urban heat islands

LETTER

doi:10.1038/nature13462

Strong contributions of local background climate to urban heat islands

Lei Zhao[1,2], Xuhui Lee[1,2], Ronald B. Smith[3] & Keith Oleson[4]

The urban heat island (UHI), a common phenomenon in which surface temperatures are higher in urban areas than in surrounding rural areas, represents one of the most significant human-induced changes to Earth's surface climate[1,2]. Even though they are localized hotspots in the landscape, UHIs have a profound impact on the lives of urban residents, who comprise more than half of the world's population[3]. A barrier to UHI mitigation is the lack of quantitative attribution of the various contributions to UHI intensity[4] (expressed as the temperature difference between urban and rural areas, ΔT). A common perception is that reduction in evaporative cooling in urban land is the dominant driver of ΔT (ref. 5). Here we use a climate model to show that, for cities across North America, geographic variations in daytime ΔT are largely explained by variations in the efficiency with which urban and rural areas convect heat to the lower atmosphere. If urban areas are aerodynamically smoother than surrounding rural areas, urban heat dissipation is relatively less efficient and urban warming occurs (and vice versa). This convection effect depends on the local background climate, increasing daytime ΔT by 3.0 ± 0.3 kelvin (mean and standard error) i decreasing ΔT by 1.5 ± 0.2 kelvin in dry clima ern United States, there is evidence of higher Δ relationships imply that UHIs will exacerbate hea health in wet climates where high temperatu compounded by high air humidity[6,7] and in itive temperature anomalies may be reinforc temperature feedback[8]. Our results support a a viable means of reducing ΔT on large scale

The conversion of natural land to urban land perturbations to the Earth's surface energy balan orative cooling is generally thought to be the do uting to UHI. Anthropogenic heat release is an the energy balance and should increase the surfa input by solar radiation will also increase if al process of land conversion. Buildings and other store more radiation energy in the daytime than and soil; release of the stored energy at night co

Environmental Research Letters

CrossMark

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LETTER

Interactions between urban heat islands and heat waves

Lei Zhao[1,9], Michael Oppenheimer[2], Qing Zhu[3], Jane W Baldwin[4], Kristie L Ebi[5], Elie Bou-Zeid[6], Kaiyu Guan[7] and Xu Liu[8]

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Zhao et al., *Nature* 2014

Zhao et al., *ERL* 2018

Climate impacts

Climate adaptation & mitigation

Climatic Change (2018) 146:455–470
DOI 10.1007/s10584-016-1779-x

CrossMark

Projected trends in high-mortality heatwaves under different scenarios of climate, population,

Research

Heat Waves in the United States: Mortality Risk during Heat Waves and Effect Modification by Heat Wave Characteristics in 43 U.S. Communities

G. Brooke Anderson[1] *and Michelle L. Bell*[2]

[1]Environmental Engineering Program, and [2]School of Forestry and Environmental Studies, Yale University, New Haven, Connect

BACKGROUND: Devastating health effects from recent heat waves, and projected increases in frequency, duration, and severity of heat waves from climate change, highlight the importance of understanding health consequences of heat waves.

OBJECTIVES: We analyzed mortality risk for heat waves in 43 U.S. cities (1987–2005) and investigated how effects relate to heat waves' intensity, duration, or timing in season.

METHODS: Heat waves were defined as ≥ 2 days with temperature ≥ 95th percentile for the community for 1 May through 30 September. Heat waves were characterized by their intensity, duration, and timing in season. Within each community, we estimated mortality risk during each heat wave compared with non-heat wave days, controlling for potential confounders. We combined individual heat wave effect estimates using Bayesian hierarchical modeling to generate overall effects at the community, regional, and national levels. We estimated how heat wave mortality effects were modified by heat wave characteristics (intensity, duration, timing in season).

effects of heat waves decreased as su gressed. Studies estimating other e the temperature–mortality relationship a found differences in effects with timing in s son. Effects of single days of high temperatu were larger earlier in the summer in seve U.S. and European cities (e.g., Baccini et 2008; Hajat et al. 2002; Kalkstein and Smo 1993). A study in Philadelphia, Pennsylvan using a synoptic approach found that oppr sive air masses had greater effects when th occurred earlier in the summer (Kalkstein et

A wedge strategy for mitigation of urban warming in future climate scenarios

Lei Zhao[1,2,3]**, Xuhui Lee**[2,3]**, and Natalie M. Schultz**[3]

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[2]Yale-
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ENVIRONMENTAL RESEARCH
LETTERS

TOPICAL REVIEW

Cooling hot cities: a systematic and critical review of the numerical modelling literature

E Scott Krayenhoff[1,2,3], Ashley M Broadbent[2,3], Lei Zhao[4], Matei Georgescu[2,3], Ariane Middel[2,5,6], James A Voogt[7], Alberto Martilli[8], David J Sailor[2,3] and Evyatar Erell[9,10]

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Keywords: Urban heat mitigation, green infrastructure, reflectivity, albedo, temperature reduction, simulation

Supplementary material for this article is available online

Urban climate projections and uncertainty

ARTICLES
https://doi.org/10.1038/s41558-020-00958-8

Global multi-model projections of lo climates

Lei Zhao[1,2] ✉, Keith Oleson[3], Elie Bou-Zeid[4], E. Scott Krayenhoff
Qing Zhu[7], Zhonghua Zheng[1], Chen Chen[8] and Michael Oppenhei

Effective urban planning for climate-driven risks relies on robust climate projections s jections are absent because of a near-universal lack of urban representation in global- combine climate modelling and data-driven approaches to provide global multi-model p twenty-first century. The results demonstrate the inter-model robustness of specific l regions under climate change. Under a high-emissions scenario, cities in the United State northeastern China and inland South America and Africa are estimated to experience su larger than regional warming—by the end of the century, with high inter-model confider need for multi-model global projections of local urban climates for climate-sensitive devel ture intervention as an effective means of reducing urban heat stress on large scales.

nature COMMUNICATIONS

ARTICLE

Check for updates

https://doi.org/10.1038/s41467-021-24113-9 OPEN

Large model structural uncertainty in global projections of urban heat waves

Zhonghua Zheng[1], Lei Zhao[1,2] ✉ & Keith W. Oleson[3]

Urban heat waves (UHWs) are strongly associated with socioeconomic impacts. Here, we use an urban climate emulator combined with large ensemble global climate simulations to show that, at the urban scale a large proportion of the variability results from the model structural uncertainty in projecting UHWs in the coming decades under climate change. Omission of this uncertainty would considerably underestimate the risk of UHW. Results show that, for cities in four high-stake regions – the Great Lakes of North America, Southern Europe, Central India, and North China – a virtually unlikely (0.01% probability) UHW projected by single-model ensembles is estimated by our model with probabilities of 23.73%, 4.24%, 1.56%, and 14.76% respectively in 2061–2070 under a high-emission scenario. Our findings suggest that for urban-scale extremes, policymakers and stakeholders will have to plan for larger uncertainties than what a single model predicts if decisions are informed based on urban climate simulations.

Zhao et al., *Nat. Clim. Change* 2021

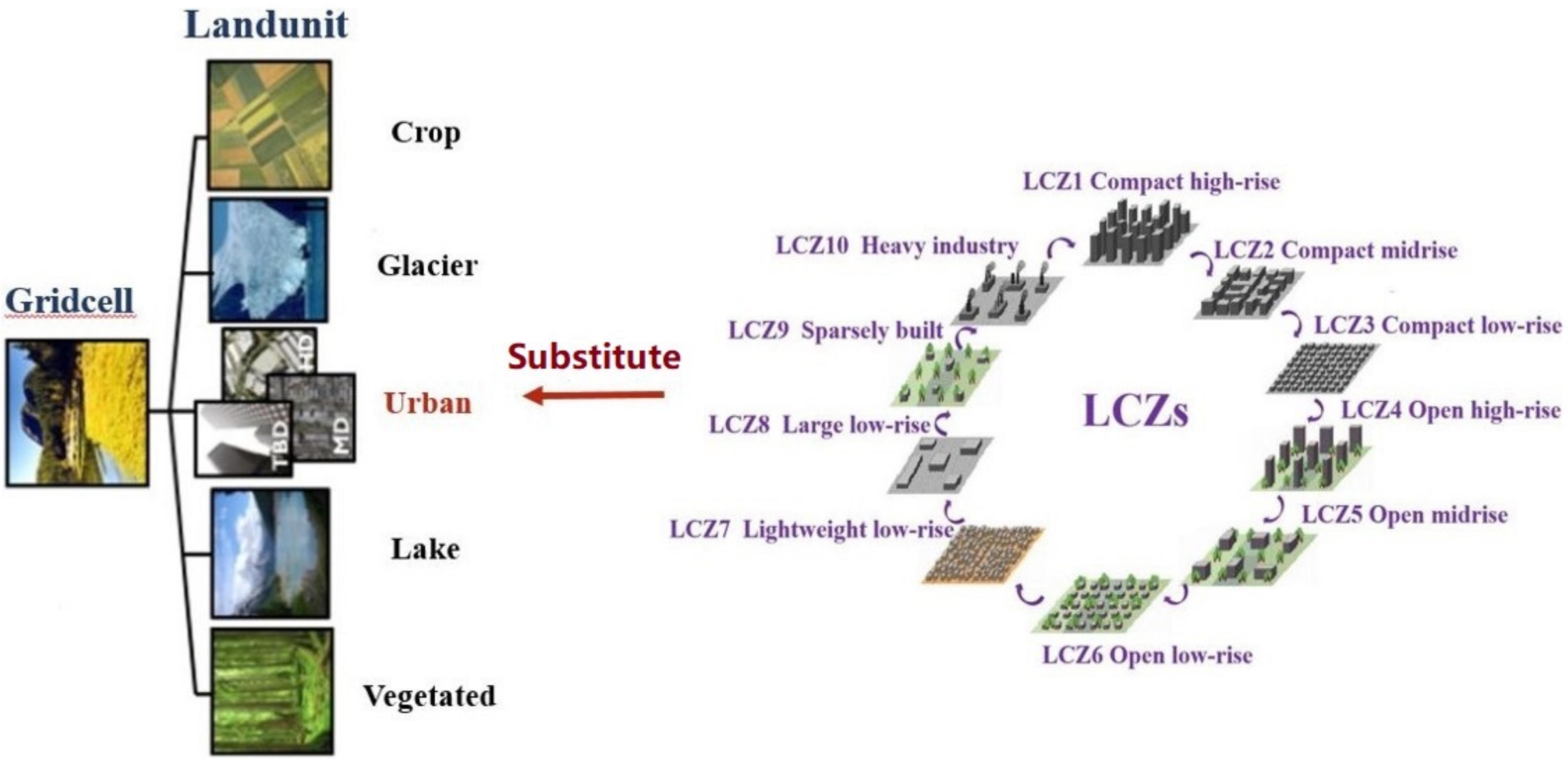
Zheng et al., *Nat. Comm.* 2021

Implementing LCZs to CLMU: a case study

Implement of Local Climate Zones in CLM5: A Case Study (CLM5-LCZs)

Congyuan Li & Ning Zhang

School of Atmospheric Sciences, Nanjing University

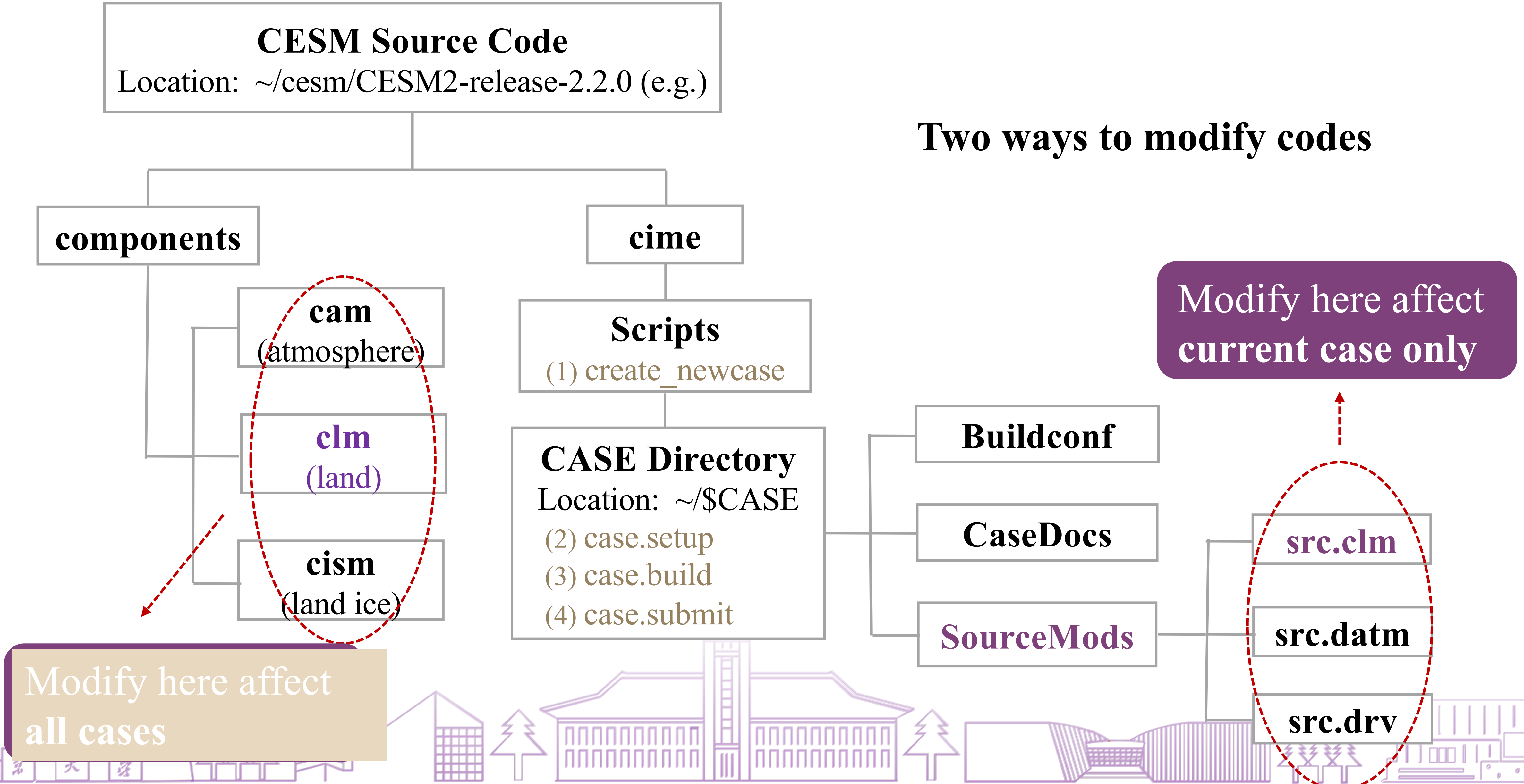


Replace current urban density classes with LCZs classification

- ✓ Modify corresponding modules within CLM5
- ✓ Update initial conditions within CLM5
- ✓ Resample LCZs map for surface dataset
- ✓ Create input parameter table for each urban LCZ

Modify corresponding modules within CLM5

Two ways to modify codes



Modify corresponding modules within CLM5

```
! ! Modifying urban landunits with 10 LCZs, and altering relative functions   (licy)

! call subgrid_get_info_urban_tbd(gi, npatches_temp, ncols_temp, nlunits_temp)
! call accumulate_counters()
! call subgrid_get_info_urban_hd(gi, npatches_temp, ncols_temp, nlunits_temp)
! call accumulate_counters()
! call subgrid_get_info_urban_md(gi, npatches_temp, ncols_temp, nlunits_temp)
! call accumulate_counters()

call subgrid_get_info_urban_lcz1(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz2(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz3(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz4(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz5(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz6(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz7(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz8(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz9(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
call subgrid_get_info_urban_lcz10(gi, npatches_temp, ncols_temp, nlunits_temp)
call accumulate_counters()
```

(e.g., The modification for subgridMod.F90)

1) Copy the corresponding module from the CESM Source Code into a new directory and modify it.

2) Copy this directory in current case, then submit the case.

Update initial conditions within CLM5

✓ Making a new initial file for CLM5-LCZs

clmi.I2000Clm50BgcCrop.2011-01-01.1.9x2.5_gx1v7_gl4_simyr2000_LCZs.nc

(Location: ~/cesm/inputdata/lnd/clm2/initdata_map)

(1) Changing the numbering of landunits, columns and PFTs

- Expand landunits with 10 urban LCZs within current global initial conditions
- Adding 10*5 columns with 10 urban LCZs, each LCZ consists of 5 urban subsurface (roof, sunlit\shaded wall, impervious/pervious road)
- Adding 10*5 PFTs

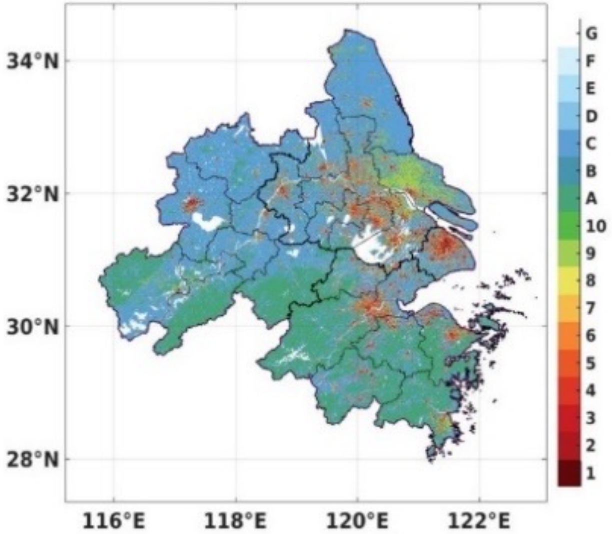
(2) Adding some initial parameter values for urban LCZs

Resample LCZs map to create surface dataset

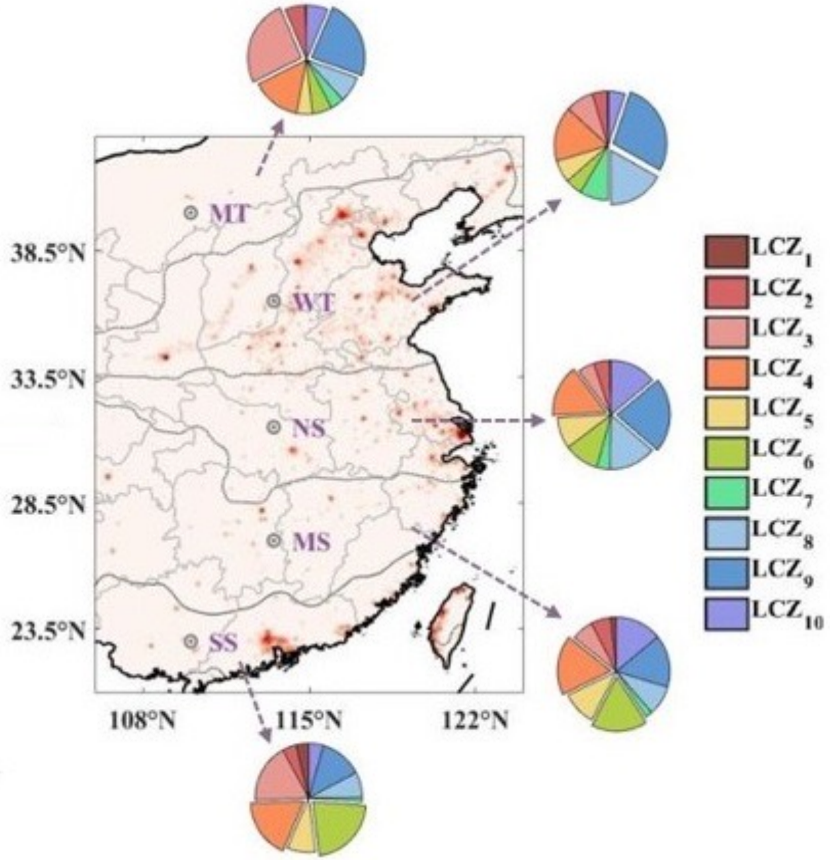
✓ **LCZs map based on the WUDAPT method**

(Ching et al., 2018@*BAMS*,
Bechtel et al., 2019@ *Urban Climate*)

✓ **Input surface dataset created by LCZs map** (~100m) **and MODIS land-use data** (~500m)



(LCZs map)



(Surface data (0.1°) utilized in CLM5-LCZs)

Create input parameter values for each urban LCZs

- ✓ **Appropriate input parameters needed to represent urban LCZs forms**

  (Stewart and Oke, 2012@*BAMS*
  Stewart et al., 2014@*I.JC*,)

- ✓ **Creating surface dataset comprising these parameters**

  Location:
  ~/cesm/inputdata/lnd/clm2/surfdata_map/surfdata_${GRIDNAME}_hist_78pfts_CMIP6_simyr2000_LCZs.nc

  ~/cesm/inputdata/lnd/clm2/urbandata/CLM50_tbuildmax_Oleson_2016_0.9x1.25_simyr1849-2106_LCZs.nc

	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

（urban LCZs parameters）

Evaluation of CLM5-LCZs with Nanjing Observations

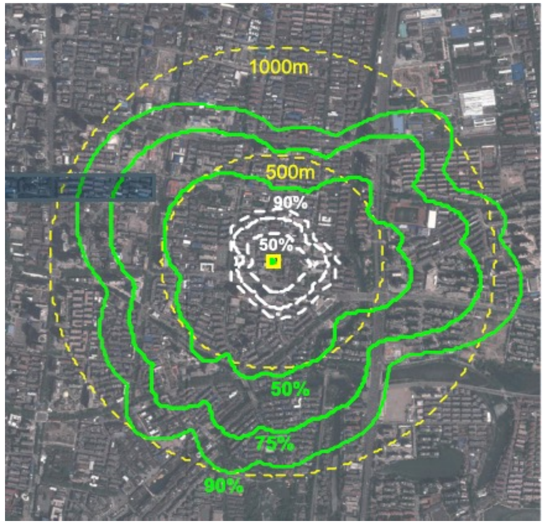
Model: CESM – CLM5.0

Urban parameterization： modified CLMU5
Simulation period： 2013
Simulation domain： Nanjing

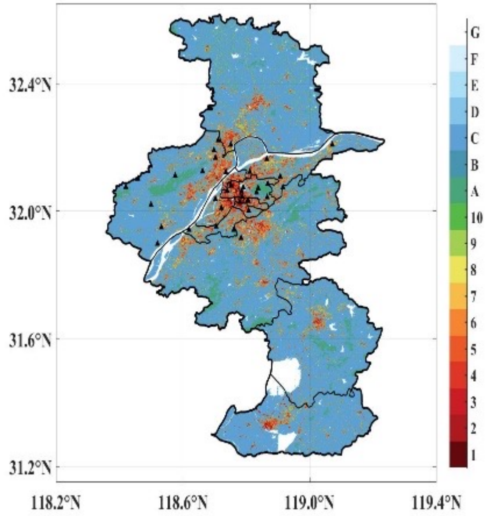
Data

Forcing data： observation obtained from tower measurement
Observed 2-m temperature： Automatic weather stations
Land-use data: LCZs map+MODIS

		CLM5 – 10 扌				LCZs					閿嬫
		1	2	3	4	5	6	7	8	9	10
Area Fraction	郤巈	0.095	0.388	0.051	0.122	0.122	0.02	0	0.003	0	0.031	0.167

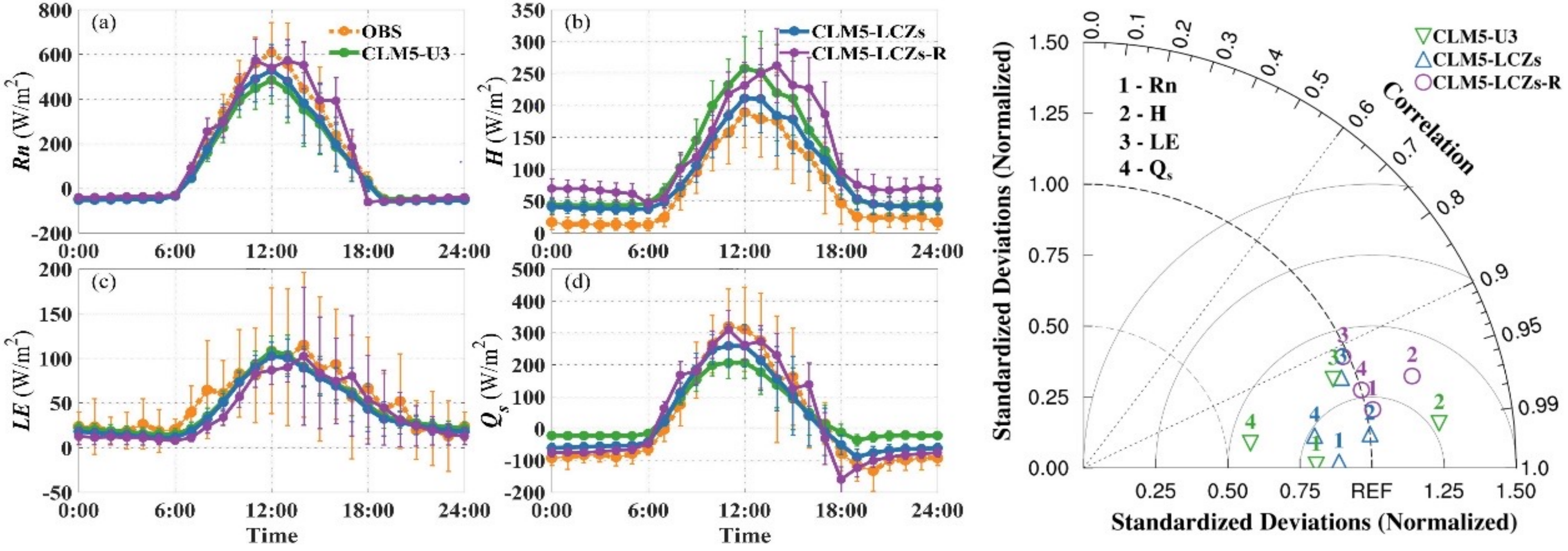


（Flux measurement site in Nanjing）
（32.0301° N，118.7916° E）



(Automatic stations in Nanjing）

Evaluation of CLM5-LCZs with Nanjing Observations

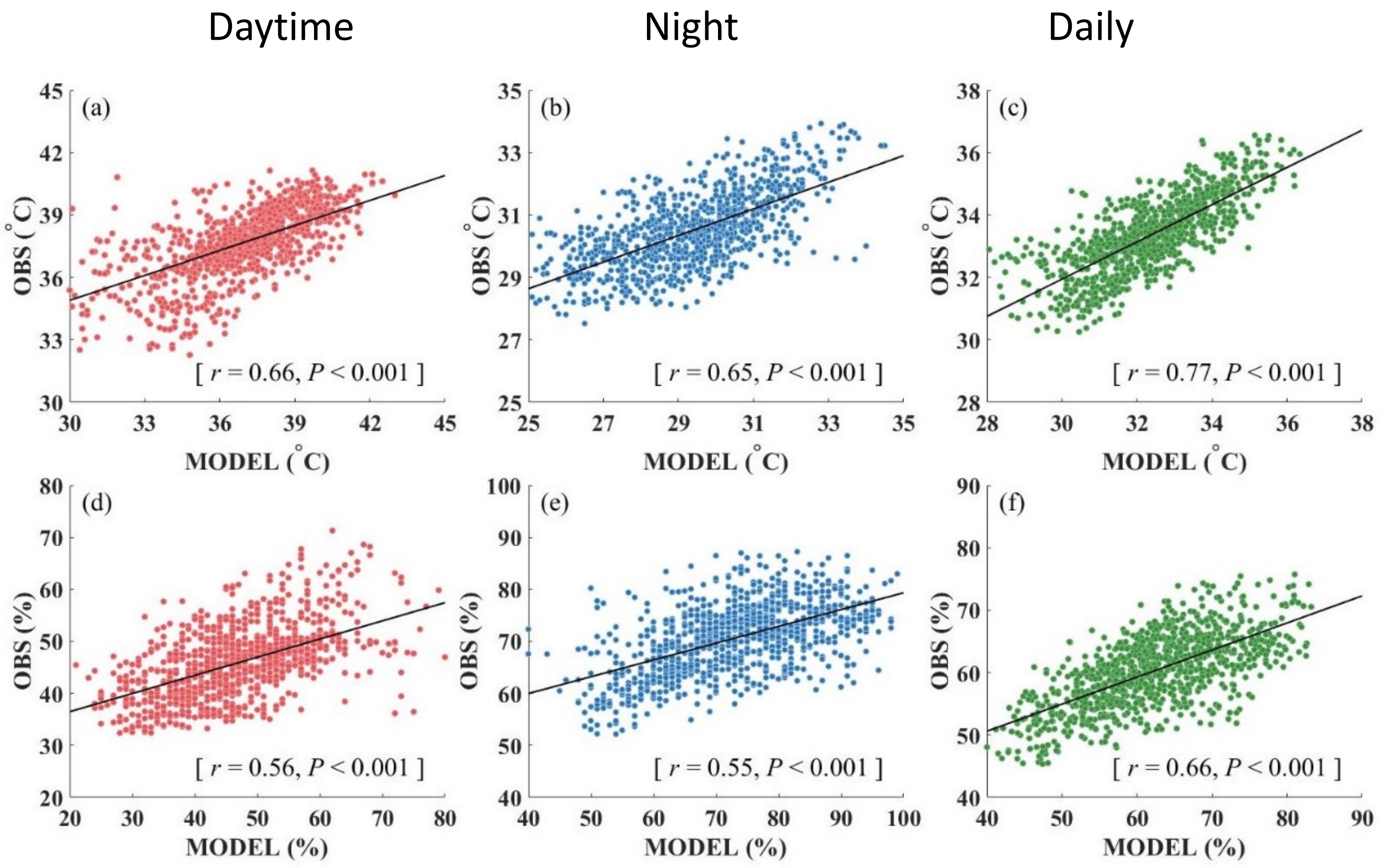


Case	Forcing data	Surface data	Domain
1	observation	MODIS (3 urban classes)	Nanjing-single
2	observation	LCZs (10 urban classes)	Nanjing-single
3	CMFD	MODIS (3 urban classes)	Nanjing-regional

CMFD (3-hr, 0.1 degree)

Yang, K., He, J. (2019). **China meteorological forcing dataset (1979-2018)**. National Tibetan Plateau Data Center

Evaluation of CLM5-LCZs with Nanjing Observations



Comparison with 36 automatic meteorological stations in Nanjing City (July and August, 2013)

(results from 1km-resolution regional run forced by CMFD

Looking forward:
global scale implementation of LCZs

– Approach and potential issues/concerns

Proposed Approach

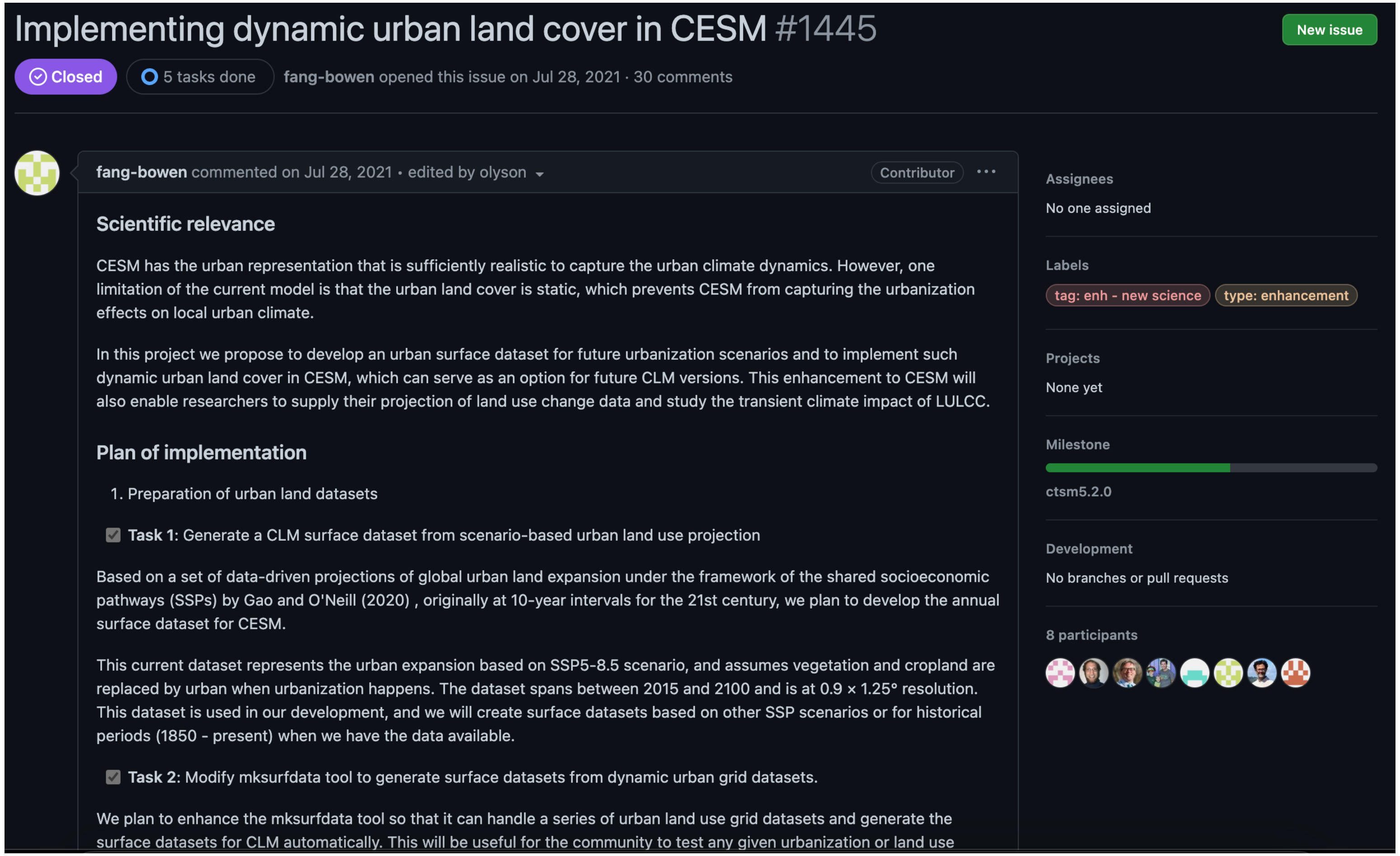
1. Data
   - global LCZ map (Demuzere et al., *ESSD* 2022)
   - urban extent data (land surface map, in relation to other land cover fractions in CESM)
   - urban property parameters (LCZ → parameters that CLMU reads)
2. Code dev
   - develop the CLMU-LCZ module (example: current CLMU-T/H/M module)
   - follow the CESM/CTSM-dev workflow on *github*: “issue” -> “branch” -> “code dev/change” -> “PR”
3. Test
   - NCAR test suite available that checks for proper operation under a large range of possible model setups and conditions, including evaluation of performance (speed), memory, and I/O.
4. Evaluation
   - CESM diagnostic tools available to do global/regional climatic assessments.
   - Urban measurements

Standard CESM/CTSM dev protocol

On CESM *Github* repo:

1. create an "issue" to describe planned projects involving CESM/CLMU
2. "branch" from latest CESM
3. develop code on our own "branch"
4. "Pull Request"

https://github.com/ESCOMP/CTSM/issues/1445



Potential issues/concerns

1. Computational cost

A quick test:

- 220 by 180 grids in east China
- two–year offline simulations
- 0.1 degree resolution

CLM-T/H/M (default)

```
Resource usage summary:

    CPU time :                          4467737.00 sec.
    Max Memory :                        31836 MB
    Average Memory :                    31499.45 MB
    Total Requested Memory :            -
    Delta Memory :                      -
    Max Swap :                          -
    Max Processes :                     258
    Max Threads :                       500
    Run time :                          18674 sec.
    Turnaround time :                   18675 sec.
```

CLM-LCZs

```
Resource usage summary:

    CPU time :                          6246277.00 sec.
    Max Memory :                        39402 MB
    Average Memory :                    39066.73 MB
    Total Requested Memory :            -
    Delta Memory :                      -
    Max Swap :                          -
    Max Processes :                     258
    Max Threads :                       500
    Run time :                          26108 sec.
    Turnaround time :                   26112 sec.
```

CLM-default:
Run time: 18674 sec
Memory:31499.45 MB

CLM-LCZ:
Run time: 26108 sec (40% more)
Memory:39066.73 MB (24% more)

Solution: provide user options (default T/H/M mode, LCZ mode, LCZ collapse, etc.)

Potential issues/concerns

1. Computational cost

2. NCAR CGD/TSS/LMWG resources (scientific & software engineer resources)

Thank you!

Comments & questions?