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Model study of Heatwave and Urban Heat Island: A case study for Chicago on summertime, 2012

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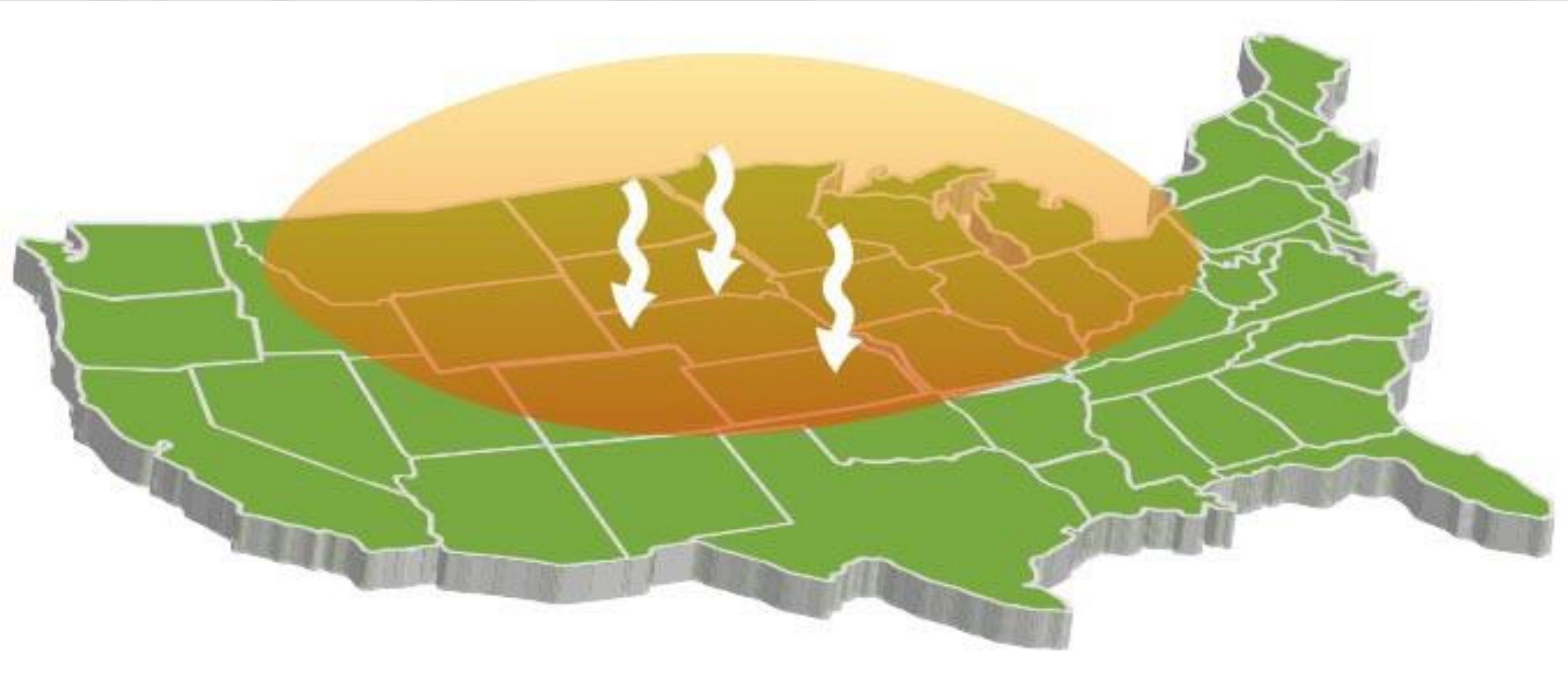
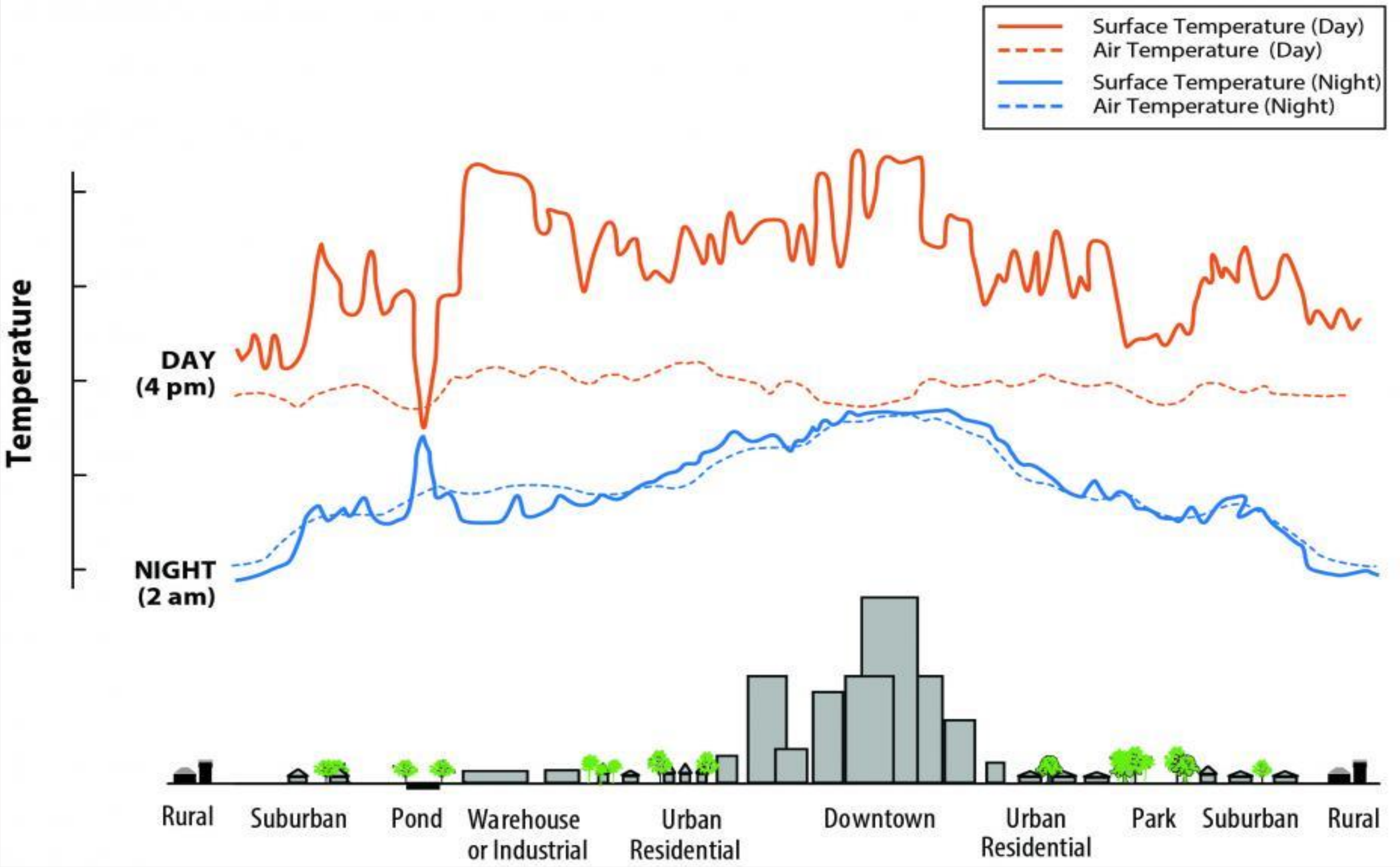
Heatwave (HW)

- A period of at least two or more days of excessively hot weather.
- High pressure
- Warm air sink and trapped



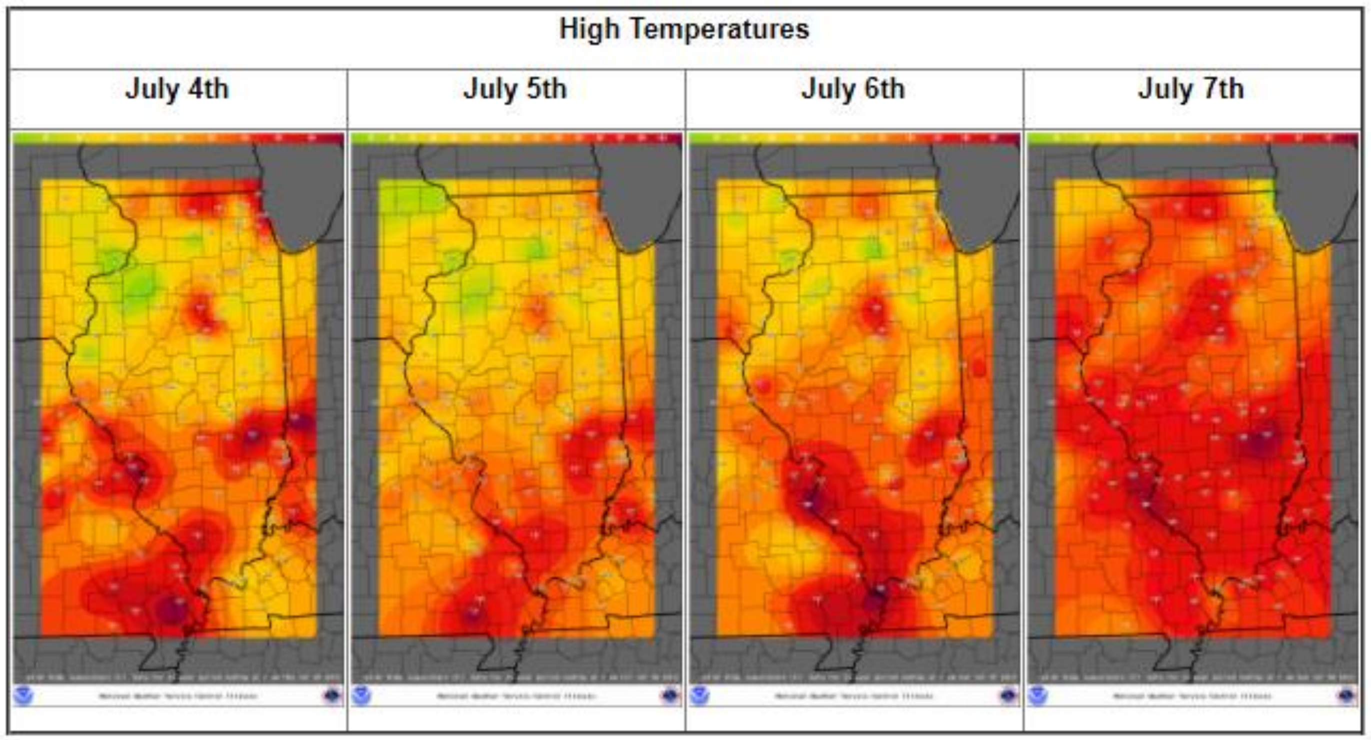
How heat waves formed (https://www.directenergy.com/learning-center/heatwave)

- **Urban Heat Island (UHI)**: Temperature differences between urban (warm) and the surrounding rural area (cool)

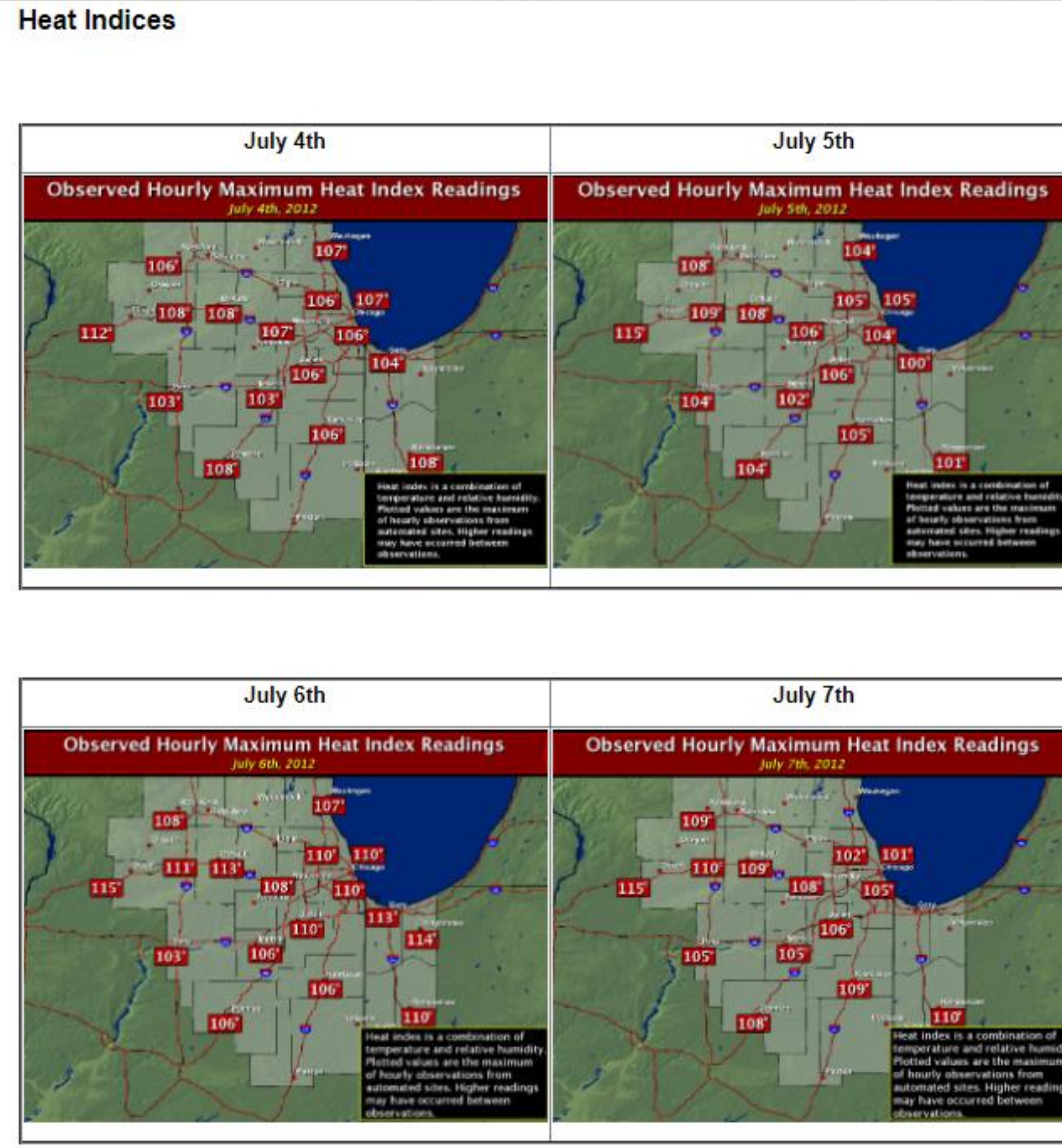


The urban heat island effect is greatest in the Central Business District. (metlink.org/fieldwork-resource/urban-heat-island-introduction/)

• Chicago heat wave event 2012



National Weather Service (https://www.weather.gov/lot/2012July_heat)



National Weather Service (https://www.weather.gov/lot/2012July_heat)

Objectives

- Evaluate the model performances
- Quantify the HW impacts and the UHI intensity (UHII)
- Estimate the heat-related health risk

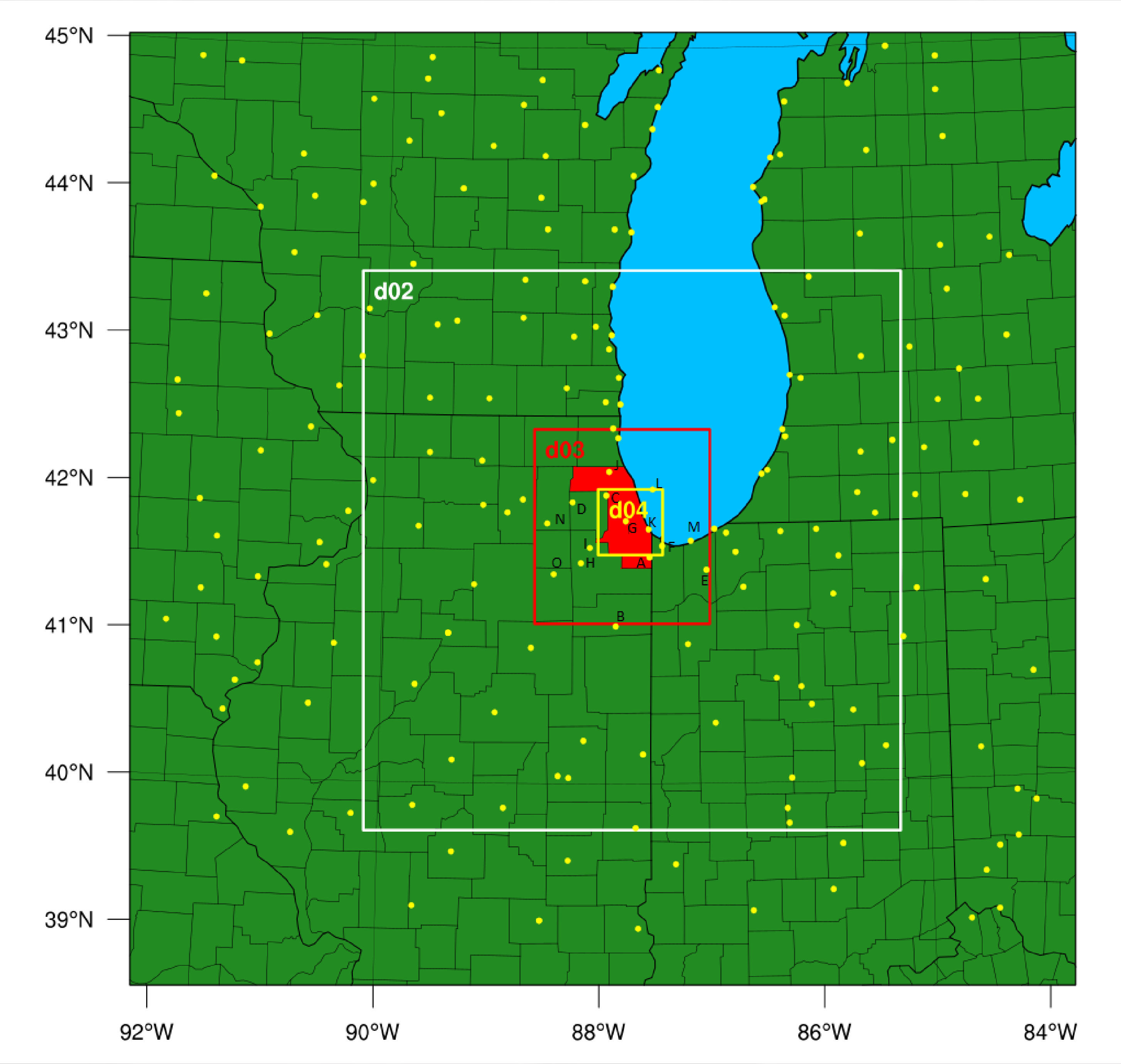
High Resolution Land Data Assimilation System (HRLDAS) vs. Weather Research and Forecasting (WRF) model

Common

- Land cover data
- Land surface model
- Urban canopy model

Differences

- Resolution (nested vs. 1km)
- Atmospheric dynamic (WRF)
- Soil moisture & surface temperature (HRLDAS)



Domain settings and locations of observation stations

WRF configurations

Scenario ID	D	M	N
Scenario Name	Default	MLUCM	Nudging
Urban surface physics	N/A	MLUCM_BEP	MLUCM_BEP
Nudging option	N/A	N/A	Nudging on the coarse domain (d01)
Number of urban atmosphere layers	N/A	15	15
PBL scheme	MYJ		
Land surface option	Noah Land-Surface Model		
Surface layer option	Monin-Obukhov (Janjic Eta) Similarity scheme		
Longwave/shortwave Radiation option	RRTMG scheme		

Model evaluation

- Observation data from 194 monitoring stations (d01, coarse domain)
- 15 stations for Chicago and surrounding regions (d03)
- Statistical metrics: root square mean errors (RSME), mean gross errors (GE), mean bias (MB)

Quantify UHII

Traditional:

$UHII=\Delta T= T_{urban}-T_{rural}$

New (Li H, et al, 2019):

$T= URB\_FRC \times UHII+T_{vegetation}$

Excess Heat Factor (EHF)

EQ 1: EHI_sig = T3-T95

EQ 2: EHI_accl = T3-T30

EQ 3: EHF = EHI_sig × MAX (1, EHI_accl)

- T3: mean temperature in the previous consecutive 3 days
- T30: mean temperature in the previous consecutive 30 days
- T95 refers to the 95th percentile of mean temperature across the previous ten years (2003-2012)
- Functions briefly introduced in Nairn and Fawcett (2015)

Model evaluations

ID	Station name	RSME				GE			
		D	M	N	H	D	M	N	H
A	LANSING MUNICIPAL	4.68	3.78	3.85	5.24	2.94	2.55	2.20	4.11
B	GREATER KANKAKEE AIRPORT	3.77	3.67	3.46	5.31	2.99	2.96	2.68	4.86
C	CHICAGO O'HARE INTERNATIONAL	3.93	2.30	2.59	3.01	3.24	1.67	1.85	2.71
D	DUPAGE AIRPORT	2.59	2.61	2.24	3.92	2.07	2.06	1.67	2.93
E	PORTER COUNTY MUNICIPAL AIRPO	3.34	3.19	3.00	5.1	2.59	2.49	2.08	4.26
F	GARY/CHICAGO AIRPORT	4.66	2.89	2.74	5.19	3.77	1.97	1.99	4.12
G	CHICAGO MIDWAY INTL ARPT	3.63	2.38	2.59	3.24	2.98	1.68	1.87	3.13
H	JOLIET REGIONAL AIRPORT	3.28	3.09	3.24	4.22	2.49	2.34	2.32	4.6
I	LEWIS UNIVERSITY AIRPORT	3.48	3.18	3.33	4.43	2.71	2.37	2.52	3.76
J	PALWAUKEE MUNICIPAL ARPT	3.48	2.25	2.82	4.86	2.70	1.71	2.26	4.24
K	CALUMET IL	2.95	2.64	2.59	5.53	2.42	2.16	1.94	3.78
L	CHICAGO	3.14	2.92	4.98	5.94	2.41	2.05	4.09	4.01
M	BURNS HARBOR	2.85	2.62	3.15	6.76	2.47	2.26	2.58	4.39
N	AURORA MUNICIPAL AIRPORT	3.31	3.10	3.05	4.47	2.52	2.31	2.28	3.62
O	MORS MUNI-J.R. WSBRN FD AP	4.44	4.07	4.07	5.57	3.59	3.29	3.21	4.94
	Average	3.57	2.98	3.18	4.85	2.79	2.26	2.37	3.96

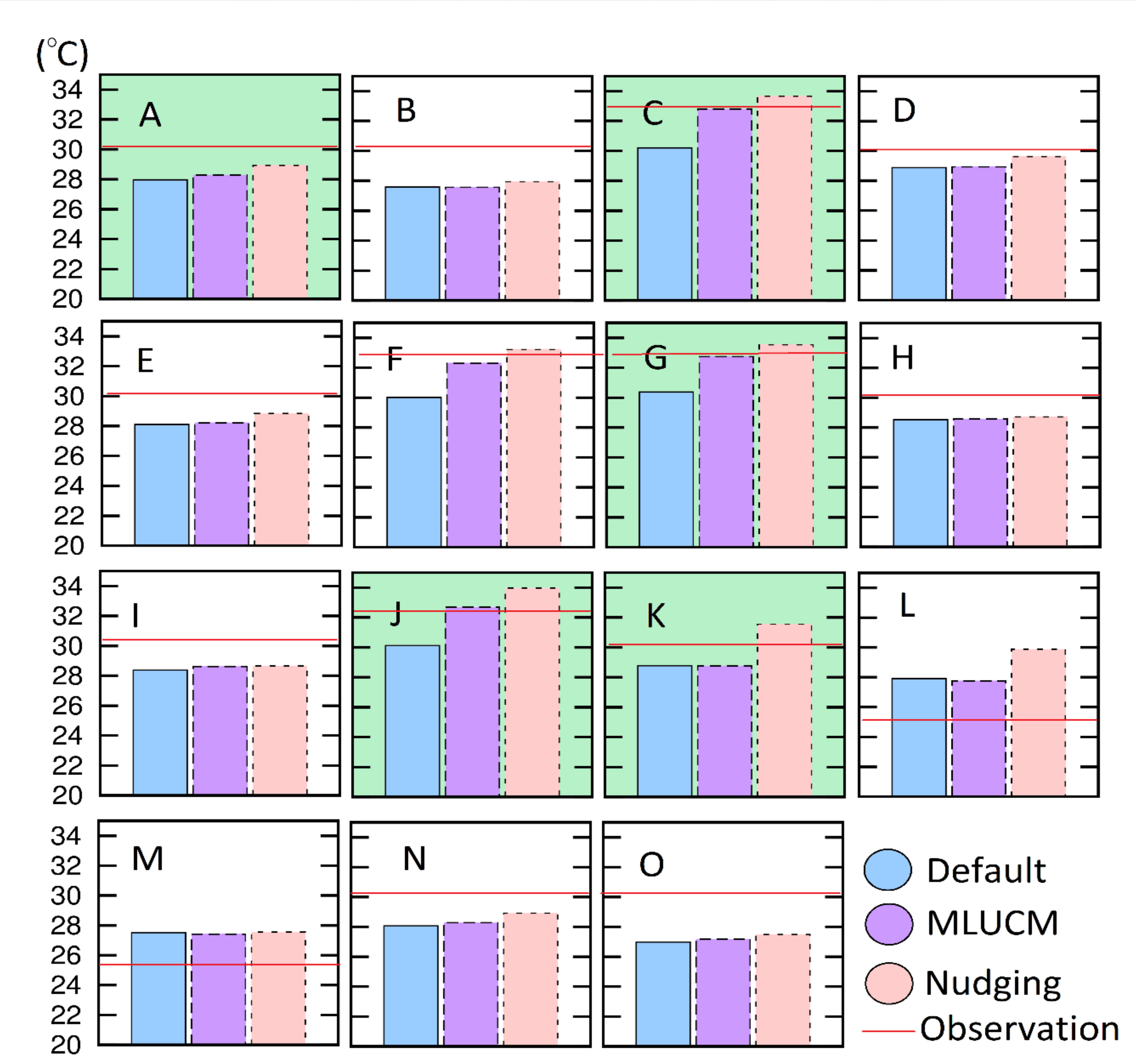
Statistical metrics of temperatures at 15 stations

- D: Default WRF
- M: Multi-Layer Urban Canopy Model + WRF
- N: M + Nudging technique
- H: HRLDAS
- Blue: Urban

- Accuracy:

Urban > rural/suburban

WRF > HRLDAS



Average temperature at 15 stations at urban Chicago and surrounding areas

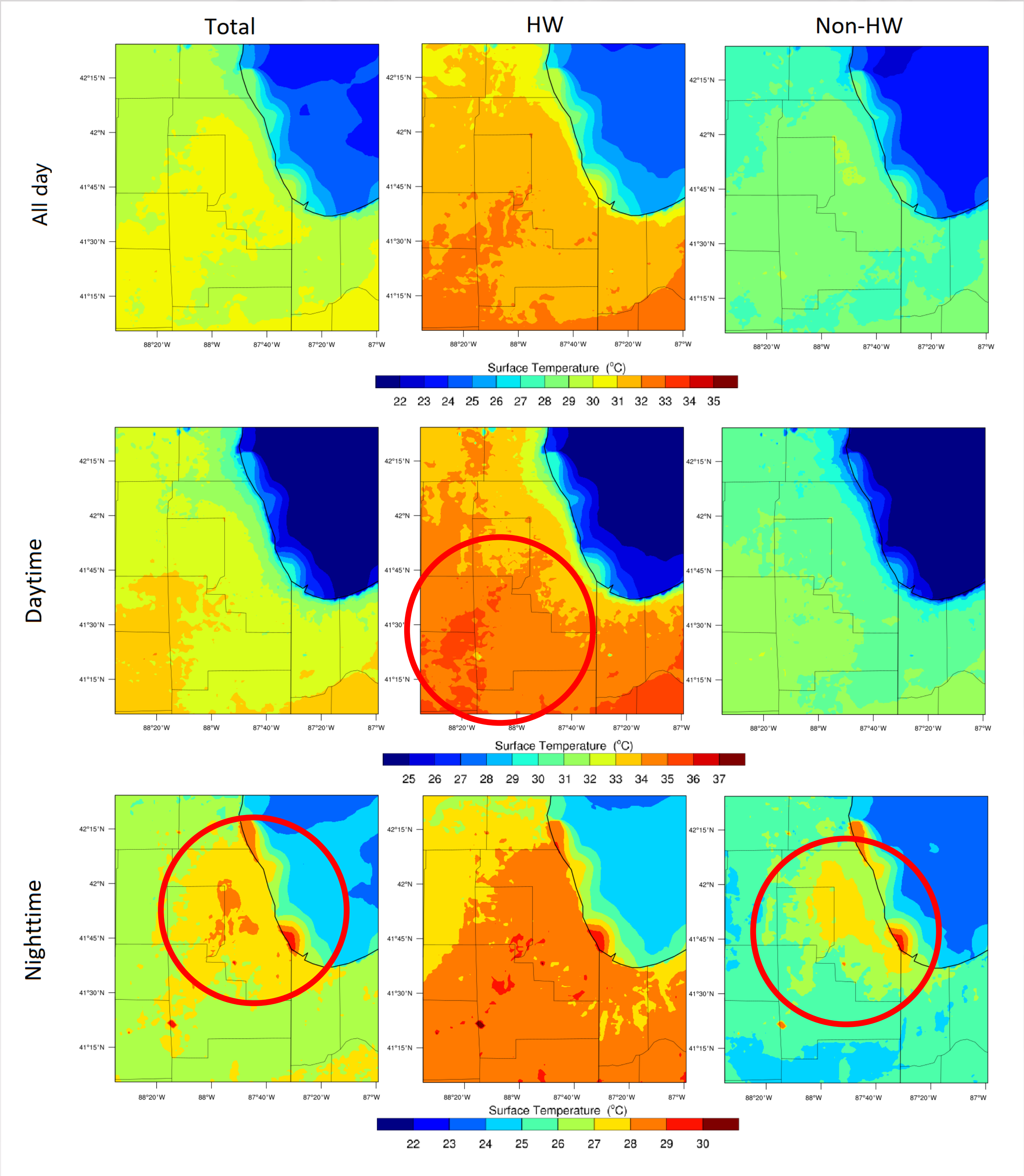
Model evaluations

Accuracy

- M > N > D
- Urban > Rural

- Green: Urban

Spatial results of temperatures

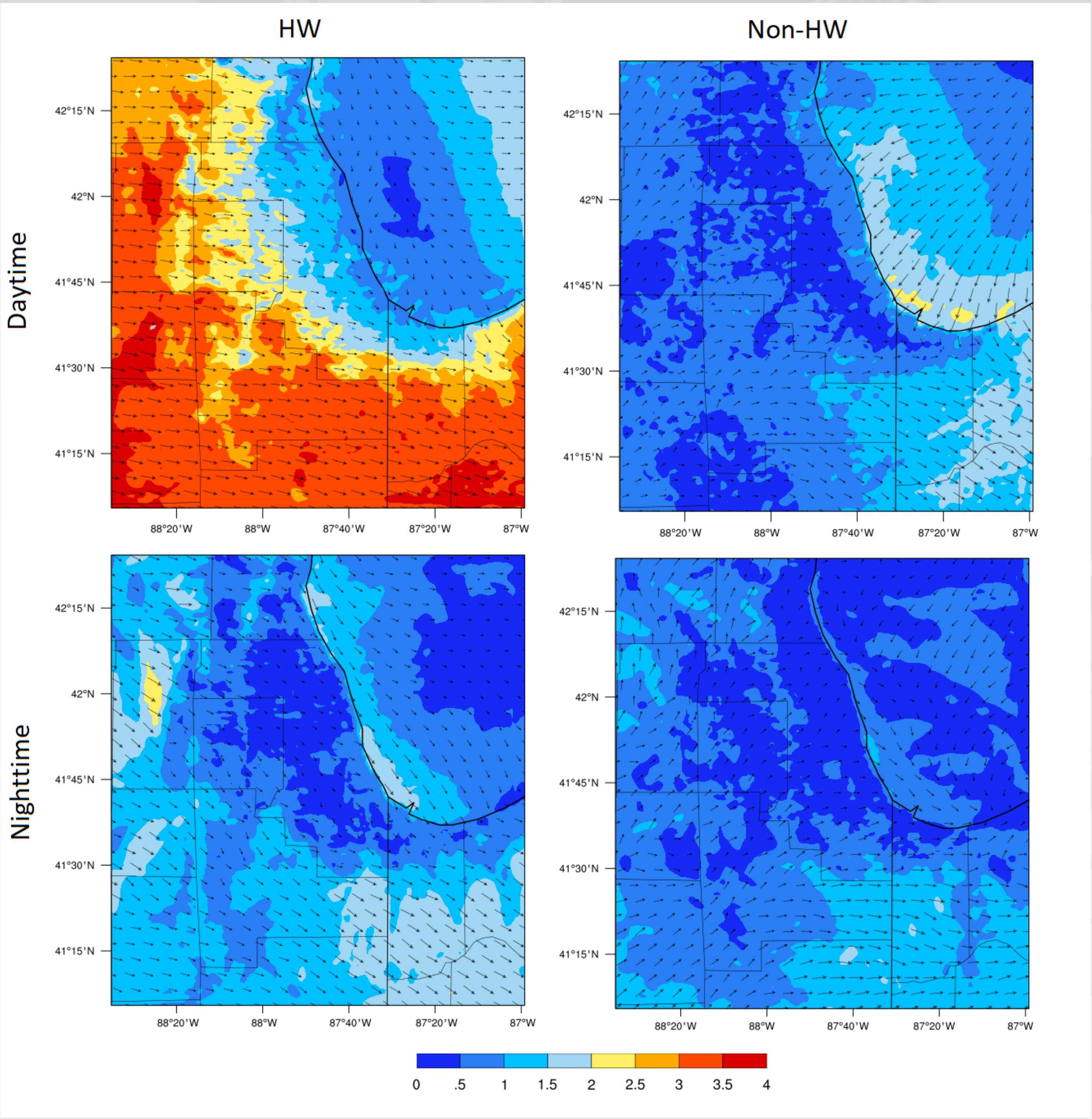


Simulated temperature at Chicago and surrounding areas

- HW: July. 4th-7th
- Daytime: 6:00am-18:00pm
- Nighttime: 18:00pm-6:00am(+1)

- Higher rural temperature
- Significant UHI at nighttime

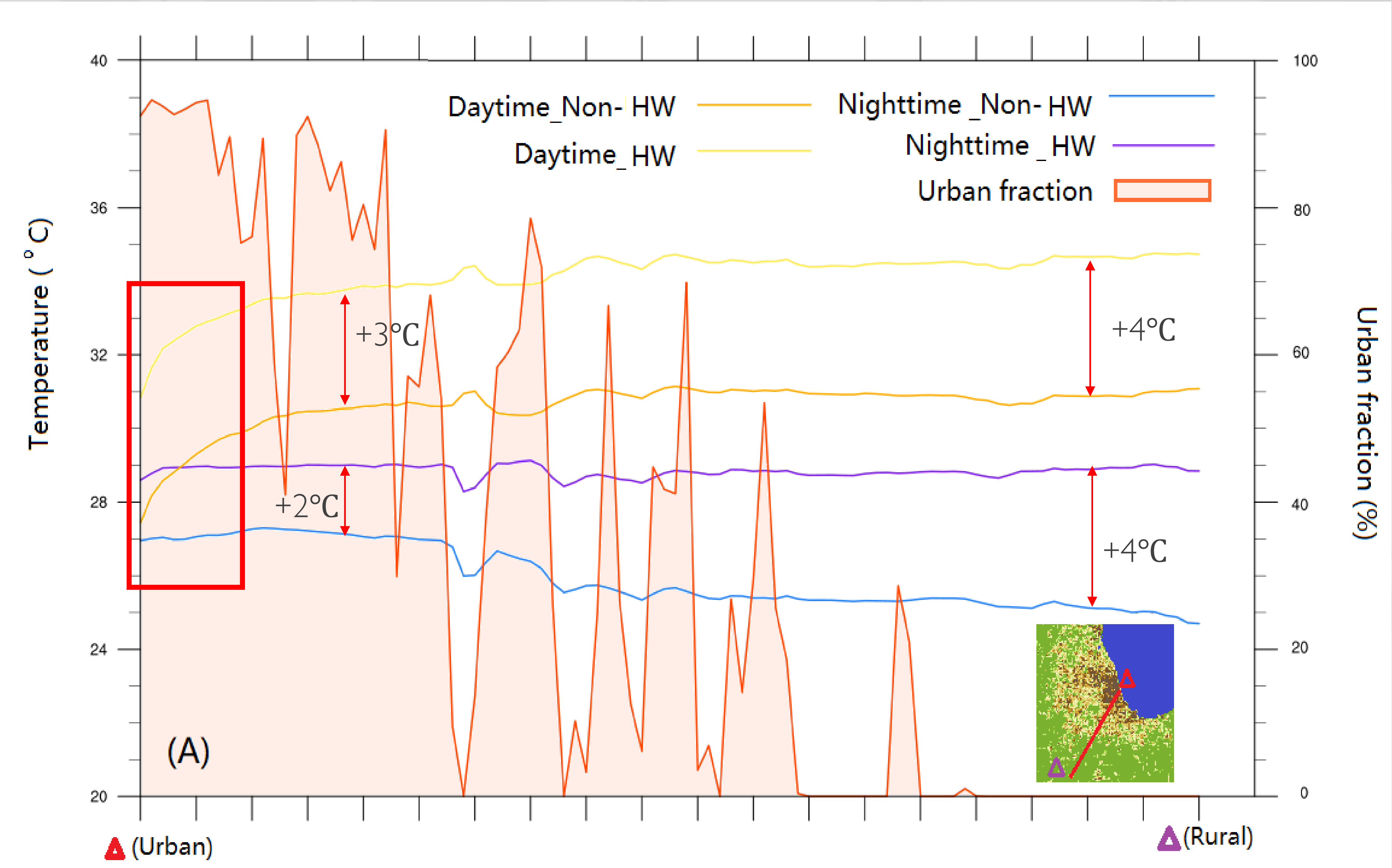
Spatial results of winds



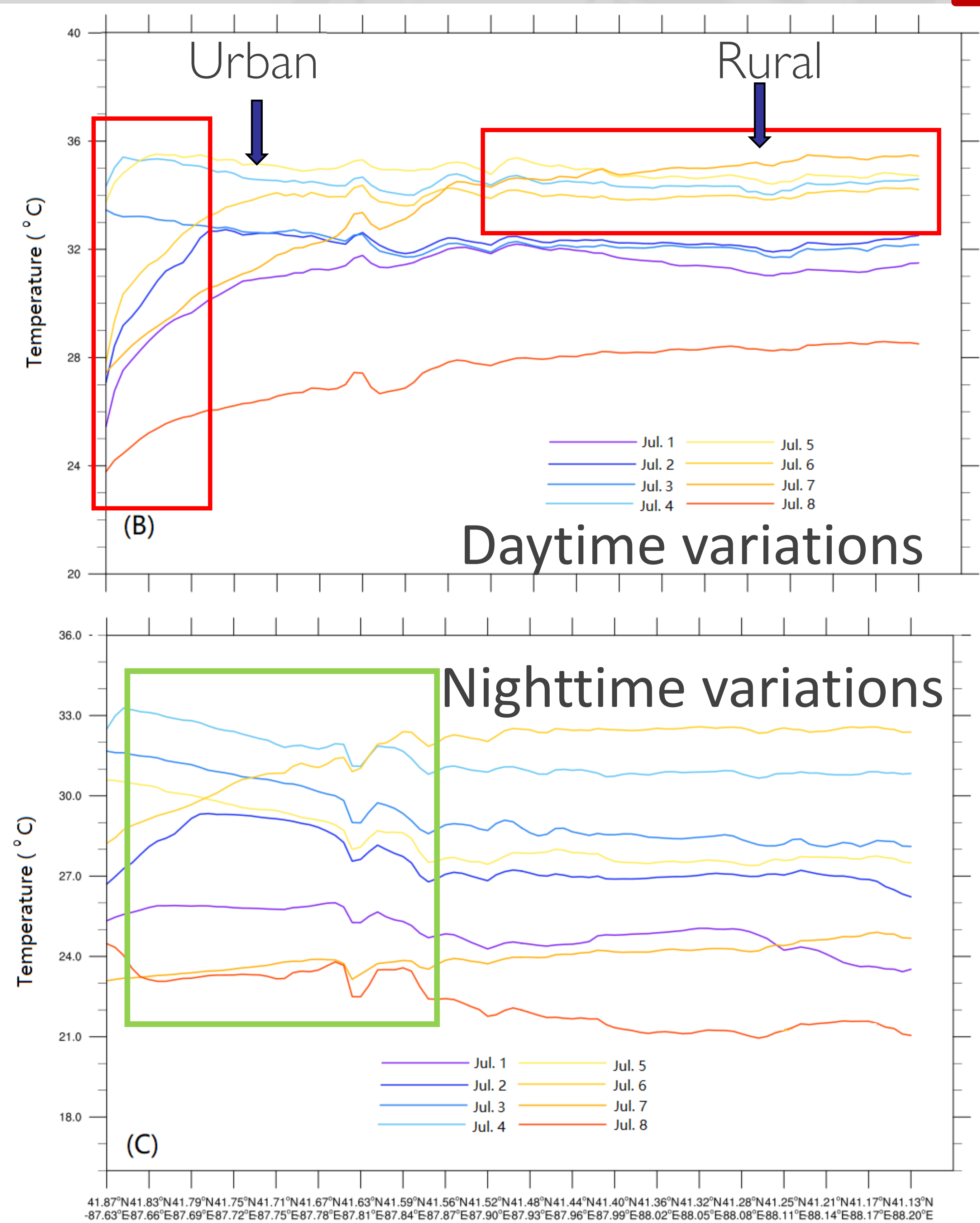
Simulated WS/WD at Chicago and surrounding areas

- Wind impacts on daytime are stronger than nighttime
- Breezes from the Lake Michigan significantly reduce coastal urban temperature

Cross section results of HW impacts



Temperature variations along urban to rural cross section during day/nighttime for HW/non-HW periods.

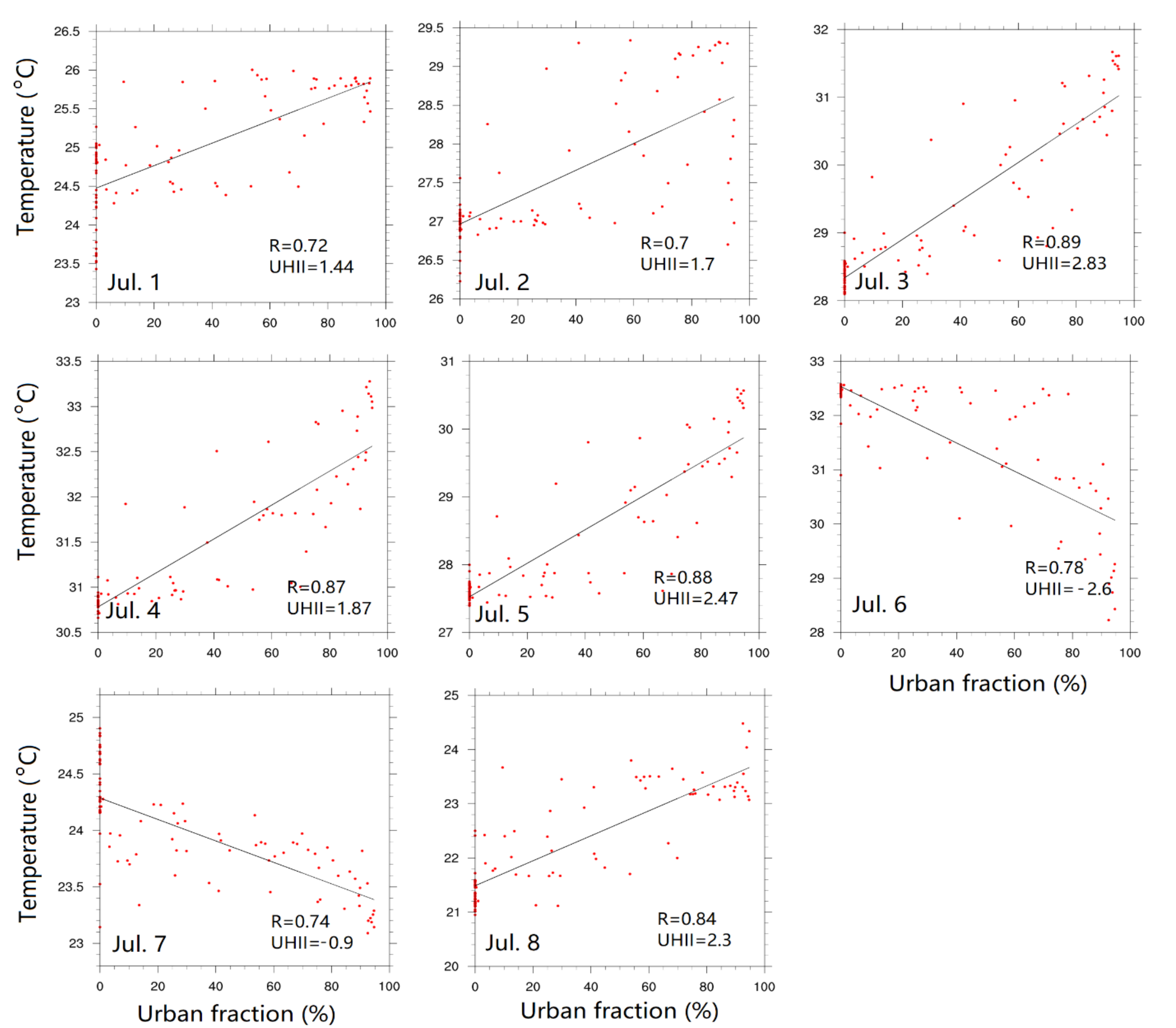


Daily variations of day/nighttime temperatures cross urban to rural areas

Daily temperature variations from urban to rural areas during day/nighttime

- HW impacts
- UHII

Quantify UHII

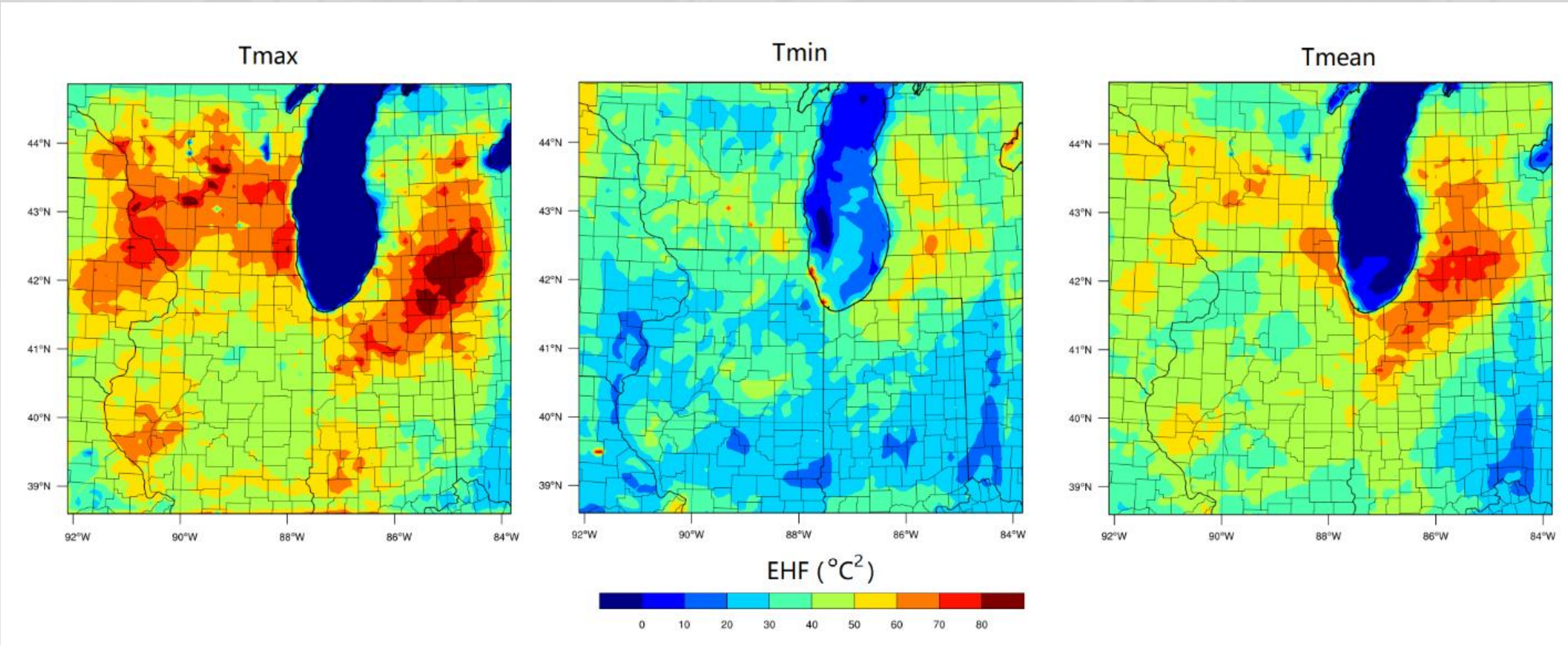


Relationship between nighttime temperature and the urban fraction

UHII (°C): 1.44~2.83

R: 0.7~0.89 (P<0.01)

Excess Heat Factor (EHF)



Excessive Heat Factor (EHF) during the 2012 Heatwave. Tmax, Tmin and Tmean represent the EHF calculated based on daily maximum, minimum and average temperatures.

- The EHF is more than 50°C² in the urban Chicago and reaches more than 60°C² in the coastal area
- Southern Wisconsin, southern Michigan and northern Indiana have a high EHF during the daytime, reaching more than 80°C².

Main findings and conclusions

- WRF has better performances than HRLDAS
- MLUCM provides more reliable simulations.
- HW has significant impacts on rural (~4 ℃) and urban (~3 ℃) during daytime. HW has more impacts (~4 ℃) on rural area during nighttime.
- UHI intensity is ~1.44-2.83 ℃.
- Potential heat stress is quantified using EHF. EHF is higher than 50 $℃^2$ at urban Chicago

Acknowledgments

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References

- Nairn JR, Fawcett RJ. The excess heat factor: a metric for heatwave intensity and its use in classifying heatwave severity. International journal of environmental research and public health 2015; 12: 227-253.
- Li H, Zhou Y, Wang X, Zhou X, Zhang H, Sodoudi S. Quantifying urban heat island intensity and its physical mechanism using WRF/UCM. Science of the Total Environment 2019b; 650: 3110-3119.
- NCAR. NCEP North American Mesoscale (NAM) 12 km Analysis. Research Data Archive at the National Center for Atmospheric Research, Computational and Information Systems Laboratory, Boulder, CO, 2015.
- Emery C, Tai E, Yarwood G. Enhanced meteorological modeling and performance evaluation for two Texas ozone episodes. Prepared for the Texas natural resource conservation commission, by ENVIRON International Corporation 2001.
- Chen F, Manning KW, LeMone MA, Trier SB, Alfieri JG, Roberts R, et al. Description and evaluation of the characteristics of the NCAR high-resolution land data assimilation system. Journal of applied Meteorology and Climatology 2007; 46: 694-713.
- Chen F, Kusaka H, Bornstein R, Ching J, Grimmond C, Grossman-Clarke S, et al. The integrated WRF/urban modelling system: development, evaluation, and applications to urban environmental problems. International Journal of Climatology 2011; 31: 273-288.

Thanks for attentions!
Questions?