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Multi-scale Study of Chicago Heat Island and the Impacts of Climate Change

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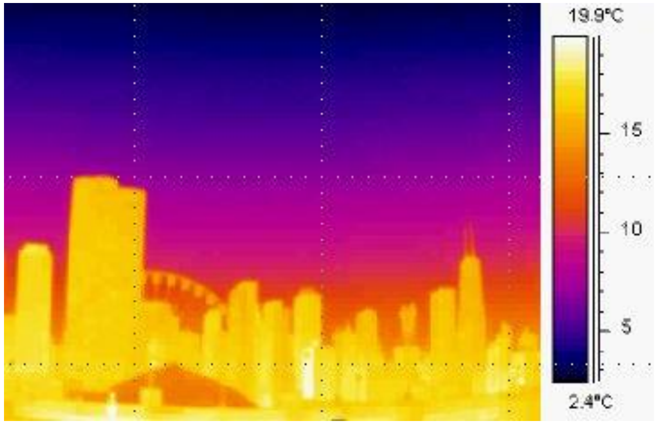
Chicago heat island

- July 1995 heat wave
  - Record 106 °F at Chicago Midway
  - 465 deaths
- Chicago Climate Action Plan
- Want to better understand Chicago's vulnerabilities
  - Plan and implement UHI adaptation initiatives in face of climate change



Infrared image showing UHI taken near Chicago lakeshore

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Multi-scale approach

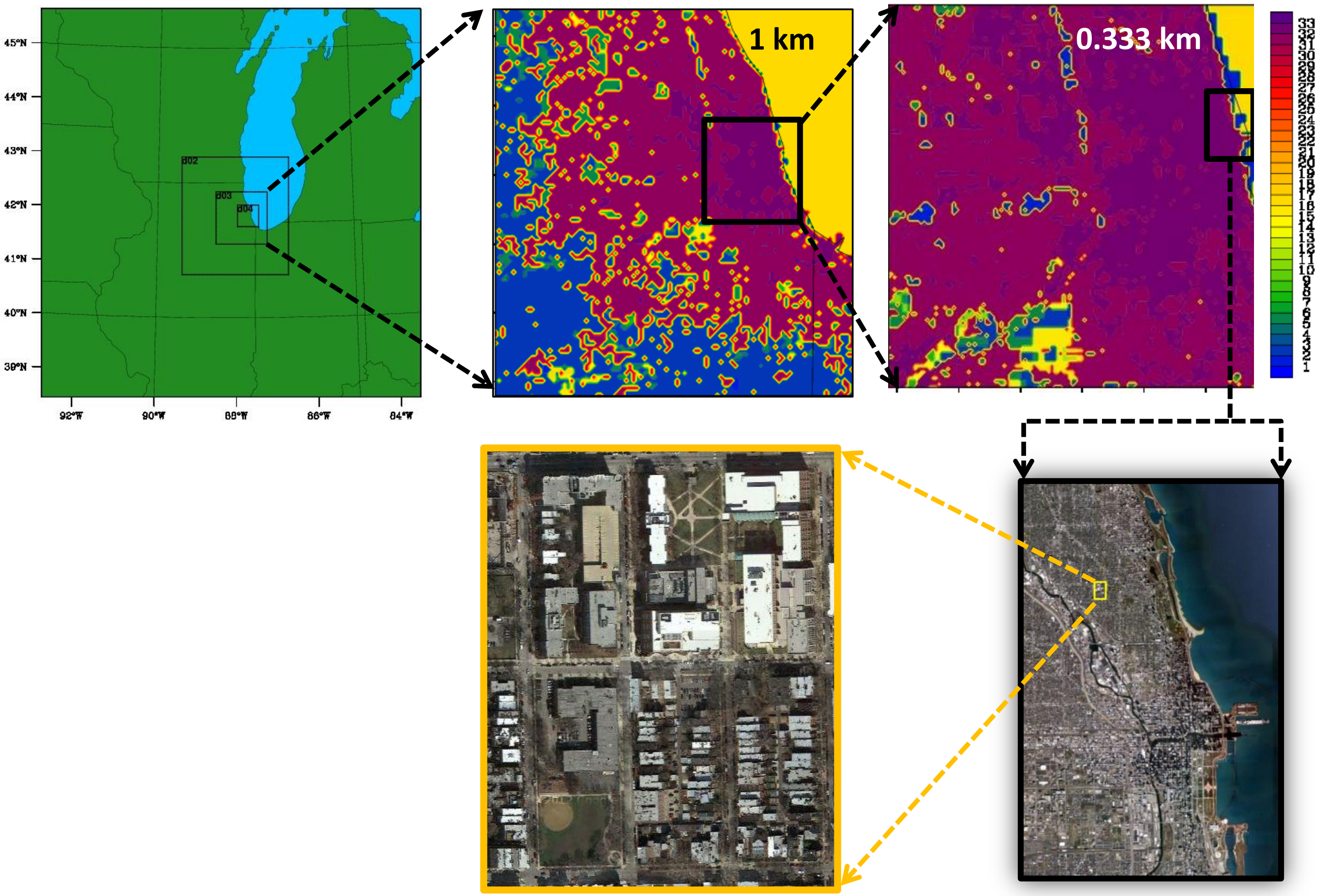
- UHI is phenomenon with effects ranging the physical scales
  - Need modeling tool to do same
- Multi-model approach via dynamical downscaling
  - Global to regional to city to neighborhood scales
  - 2.5 degrees ➡ 9 km ➡ 3 km ➡ 1 km ➡ 333 m ➡ 2 m

Global
Community Climate System Model (CCSM5)

Mesoscale
Weather Research and Forecasting (WRF) model coupled with sophisticated urban model

Micro-scale
ENVI-met

Multi-scale approach

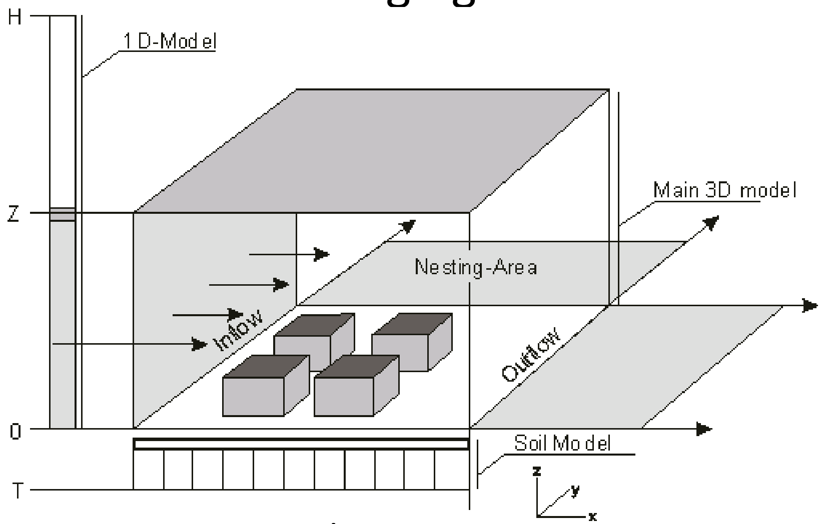


Mesoscale model

- Used sensitivity studies of metropolitan Chicago to test WRF urban schemes
- WRF model uses BEP+BEM scheme with modified parameters to model urban climate
- Initial and boundary conditions from either North American Regional Reanalysis (NARR) dataset (present) or CCSM5 (future)

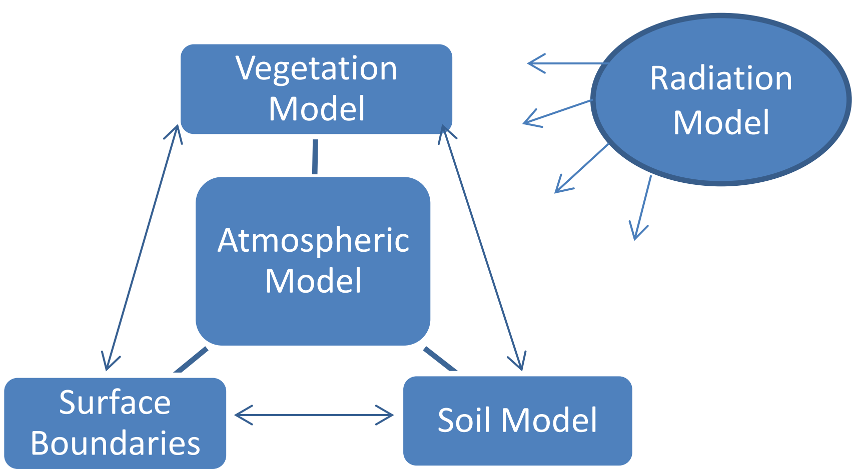
Micro-scale model

- ENVI-met v3.1 developed by Michael Bruse (Bruse and Fleer 1998)
- 3D Reynolds Averaged Navier-Stokes model
  - Boussinesq approximation
  - k-ε 1.5 order turbulence closure scheme
- 1D model supplies lateral/upper boundary conditions for 3D model
  - Only initial conditions fed by user; thereafter marches forward in time without further nudging



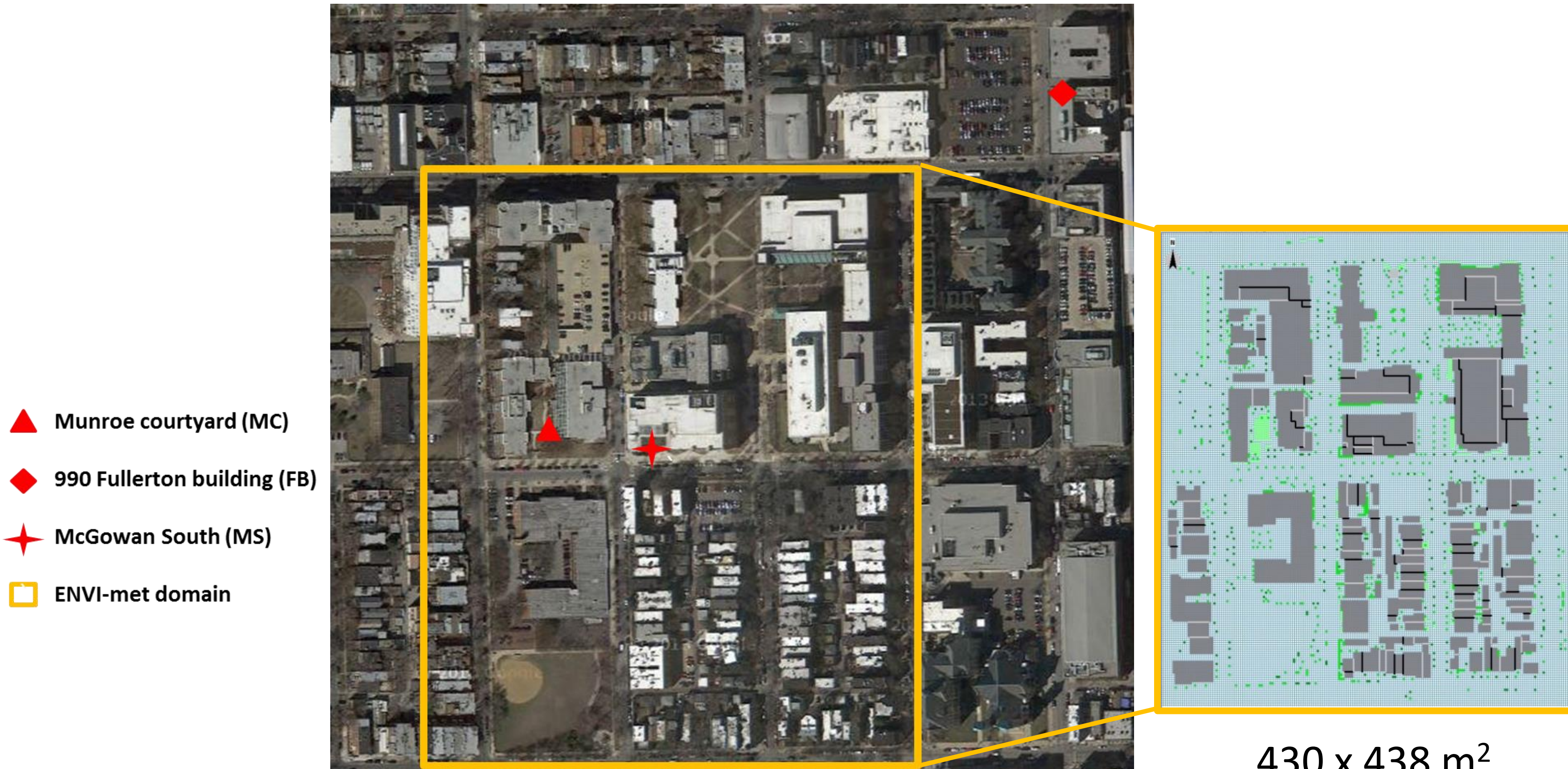
www.envi-met.com

- Includes additional models:



Micro-scale model

ENVI-met model domain and experimental locations



430 x 438 m^2

Experimental campaign

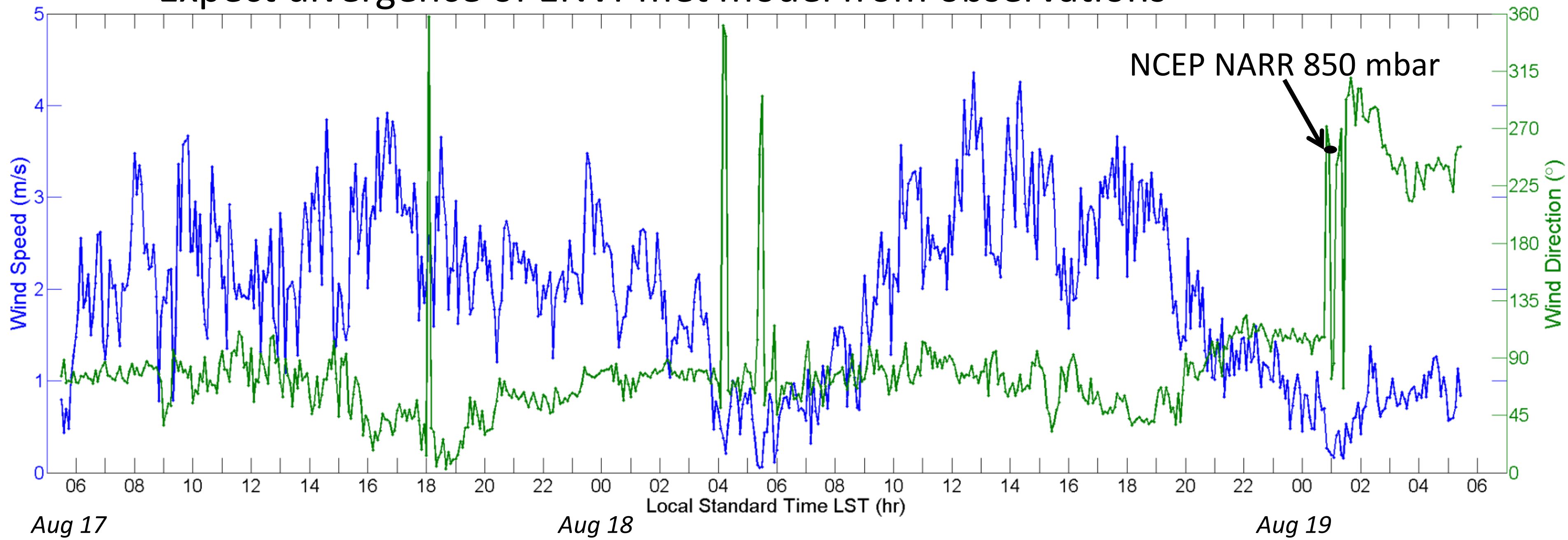
July 24 to August 20, 2013

Location	Tower	Instruments
McGowan South building rooftop (MS)	MS1[a,b]	1 RM Young 81000 sonic anemometer, 1 Campbell Scientific HMP45C Temp/RH Probe, 3 thermocouples
	MS2[b]	2 thermocouples
Munroe Courtyard (MC)	MC1[b]	2 thermocouples
	MC2[a]	1 thermocouple
990 Fullerton building rooftop (FB)	FB[a]	1 RM Young 81000 sonic anemometer, 3 thermocouples

[a] used for model initialization *[b] used for model validation*

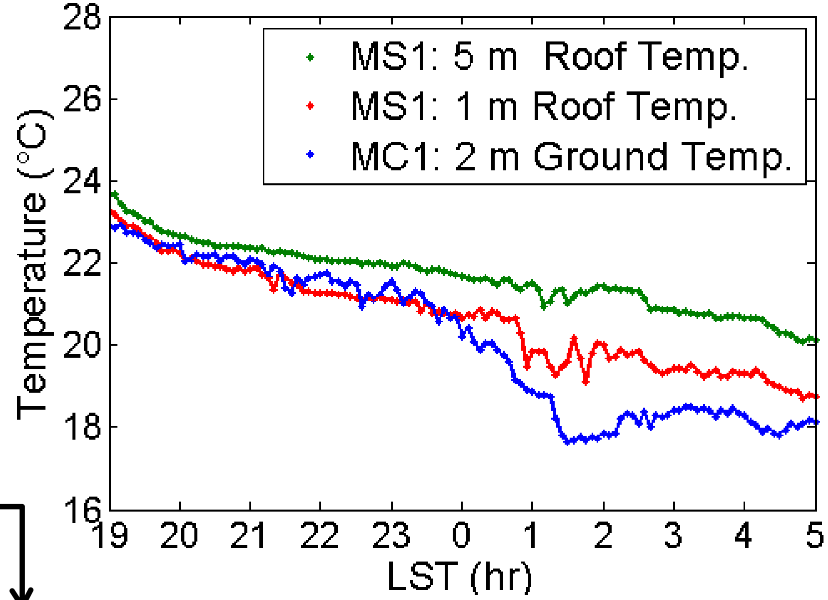
Model validation

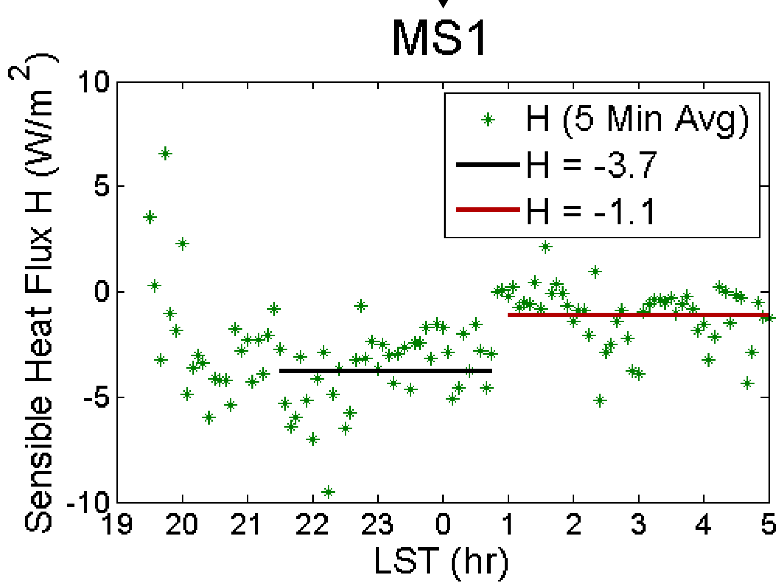
- August 17 and 18 – period of relatively steady regional conditions
  - Low synoptic gradient winds; local eastern lake breeze dominates
  - Expect ENVI-met model to perform well
- 1 AM August 19 – front passage
  - Sudden transition to synoptic southwest wind (matches NARR wind direction)
  - Expect divergence of ENVI-met model from observations

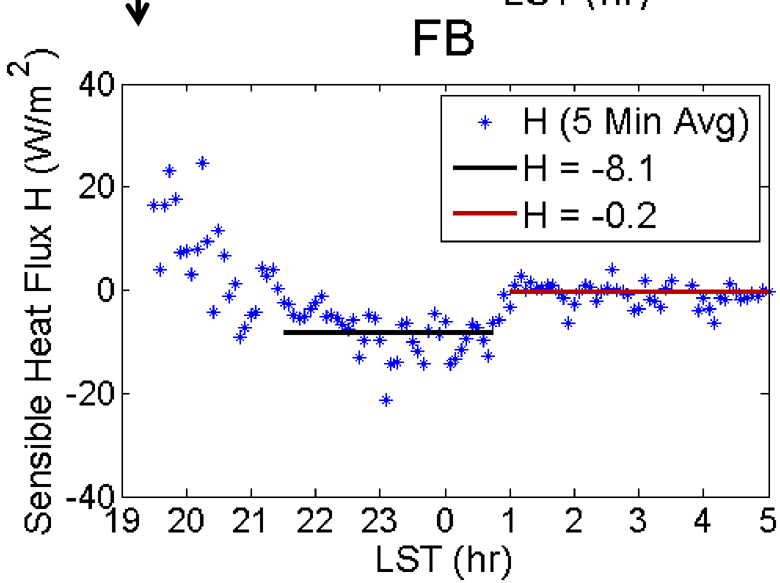


Model validation

- August 18-19 nighttime front transition affects local conditions
  - Vertical air temperature gradient
  - Sensible heat flux (H)

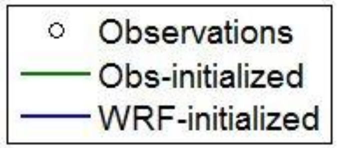




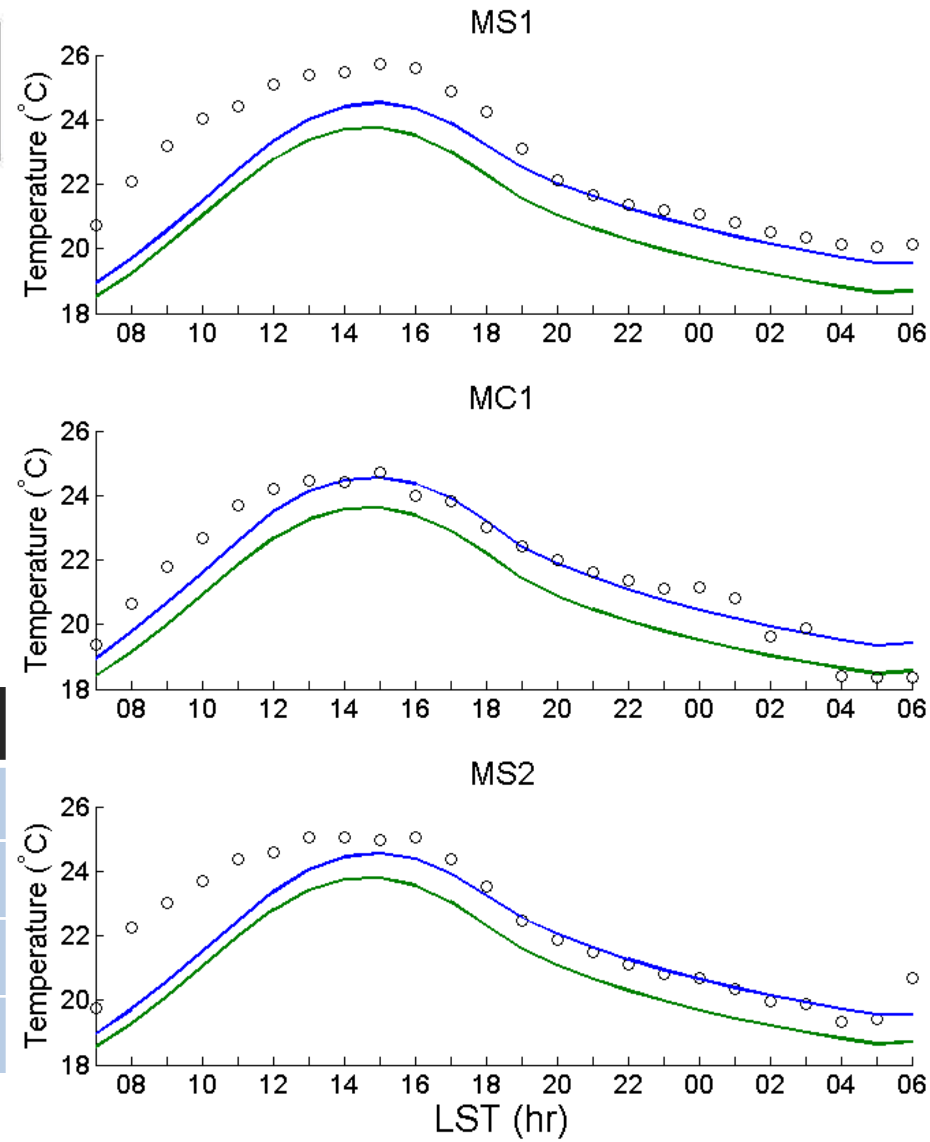


Model validation

- August 17, 2013
- Difference measures (Wilmott 1982)
  - Root mean square error (RMSE)
  - Mean average error (MAE)
  - Index of agreement (*d*)
    - Values approaching 1.0 – good model performance

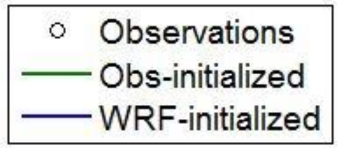


Station	RMSE (°C)		MAE (°C)		*d*	
	Obs.	*WRF*	*Obs.*	*WRF*	*Obs.*	*WRF*
MS1	1.90	1.29	1.80	1.01	.802	.891
MC1	1.20	0.65	1.09	0.52	.907	.971
MS2	1.54	1.06	1.37	0.72	.855	.921



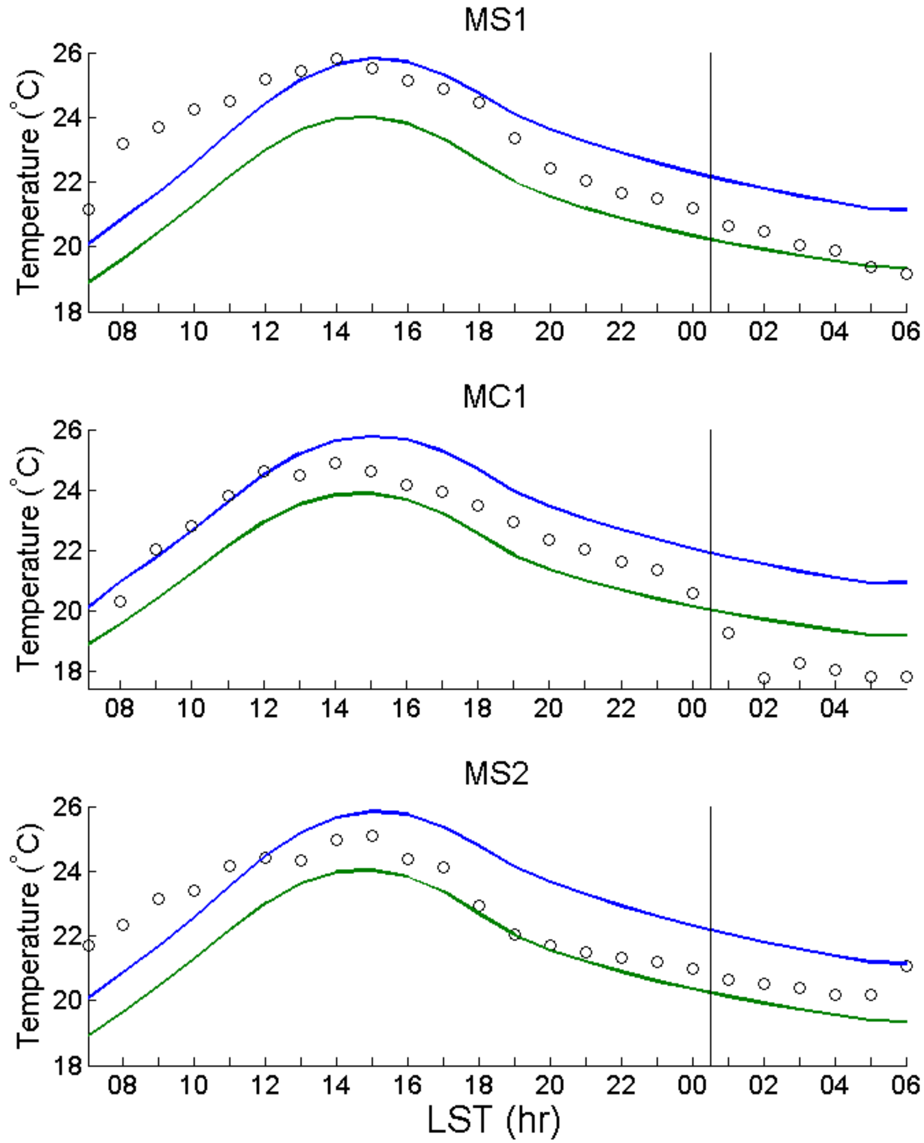
Model validation

- August 18, 2013
- Difference measures pre-1 AM:



Station	RMSE (°C)		MAE (°C)		*d*	
	Obs.	*WRF*	*Obs.*	*WRF*	*Obs.*	*WRF*
MS1	1.96	1.13	1.77	0.97	.709	.863
MC1	1.08	0.99	0.98	0.89	.897	.915
MS2	1.44	1.38	1.12	1.28	.777	.782

- After 1 AM begins to diverge at MS1 and MC1
  - For instance for MS1 WRF-initialized:
    - RMSE = 1.60 °C, MAE = 1.59 °C
    - *d* = 0.412



Climate change impacts

- Future conditions
  - CCSM5 output averaged over years 2076 to 2081 fed into WRF-urban
  - Average over the entire month of August to get an average future August day – provides initial conditions to ENVI-met model
- Present conditions
  - Take August 18 as “typical” day
  - Ensemble to obtain current climatology not yet completed (future work)
- For impacts on pedestrian thermal comfort 2 m results are relevant

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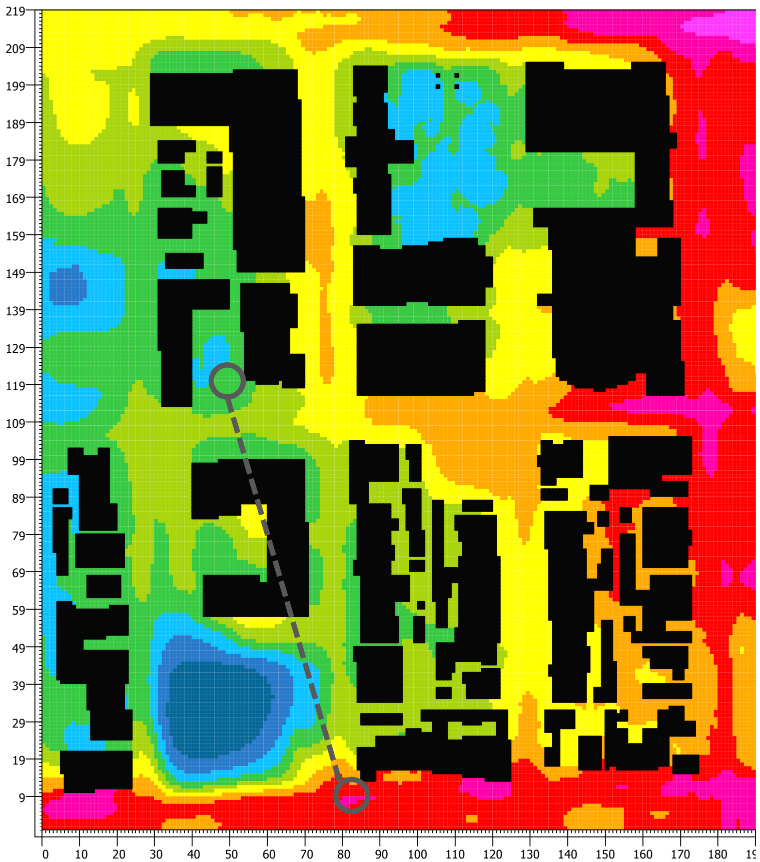
Climate change impacts

12:00 LST

Air Temperature T_a

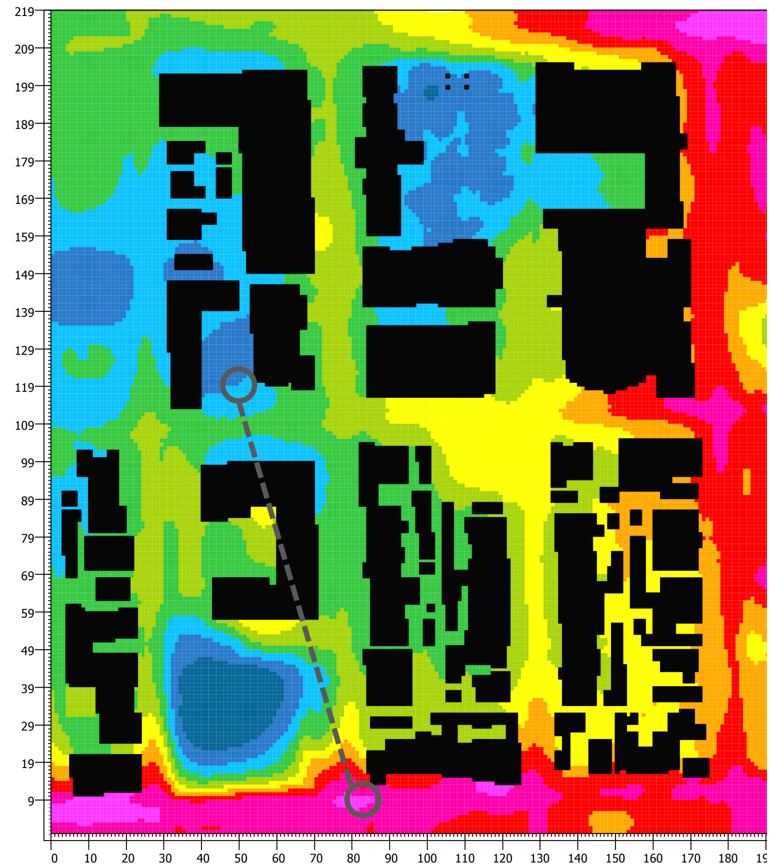
Present



$\Delta T_a = 0.38$ °C

- < 23.8 °C
- 23.8 °C
- 23.9 °C
- 24.0 °C
- 24.1 °C
- 24.2 °C
- 24.3 °C
- 24.4 °C
- 24.5 °C
- > 24.5 °C

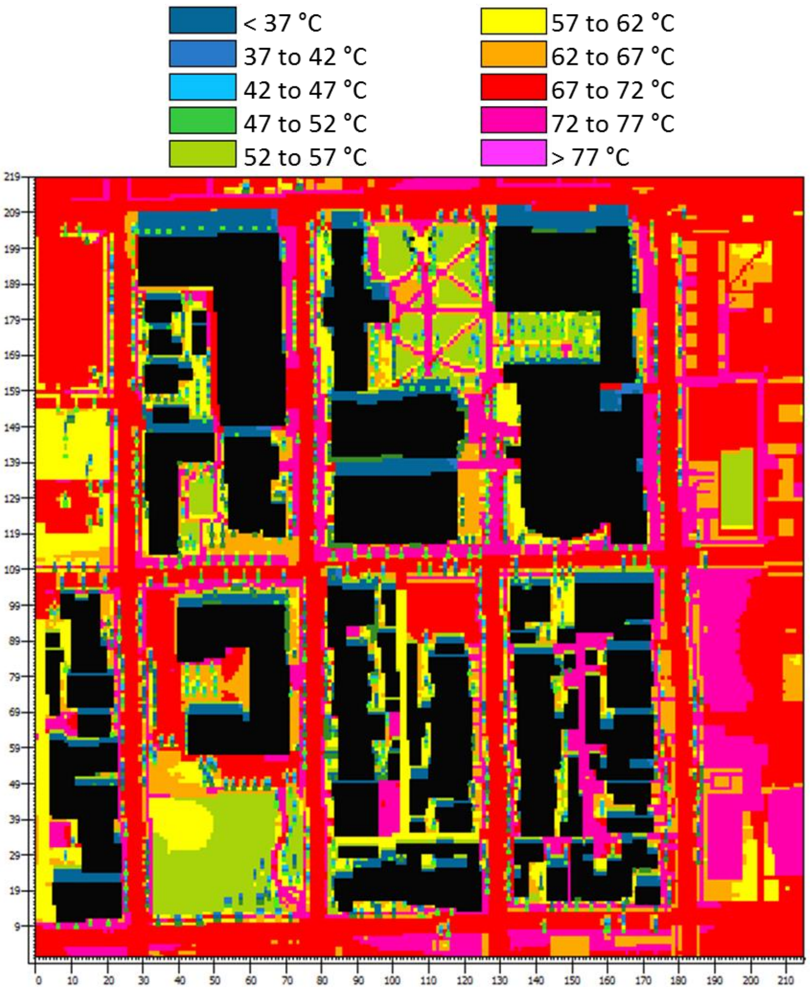
Future



$\Delta T_a = 0.60$ °C

- < 26.5 °C
- 26.5 °C
- 26.6 °C
- 26.7 °C
- 26.8 °C
- 26.9 °C
- 27.0 °C
- 27.1 °C
- 27.2 °C
- > 27.2 °C

Climate change impacts



Mean radiant temperature (T_{mrt}) contour at 12:00 LST on an August 2081 day

LST (hr)	T_{mrt} (°C)	T_a (°C)
08:00	23-72	23.1-23.6
10:00	30-76	24.7-25.3
12:00	33-81	26.4-27.1
14:00	33-83	27.5-28.2
16:00	31-81	27.6-28.2
18:00	21-42	26.6-27.2
20:00	16-21	25.3-26.0
22:00	15-19	24.6-25.3
00:00	14-18	24.1-24.7
02:00	13-18	23.6-24.3
04:00	13-18	23.3-23.9
06:00	17-45	23.1-23.7

Conclusions

- Multi-model chain coupled via dynamical downscaling – comprehensive instrument for studying UHI
- ENVI-met model can predict urban microclimate accurately during periods of steady synoptic conditions
  - Allows application to future climate scenarios where change in average conditions is concern
- Source of initial conditions matters
  - Area-representative WRF-urban output outperforms observations
- Micro-scale climate change output being applied to building energy in addition to pedestrian thermal comfort

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Thank you