Cities & Storms: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather

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In today's brief talk, I'll touch on results from two modeling studies that are part of the constellation of research within this interdisciplinary NASA project:

Effects of urban plume aerosols on a mesoscale convective system

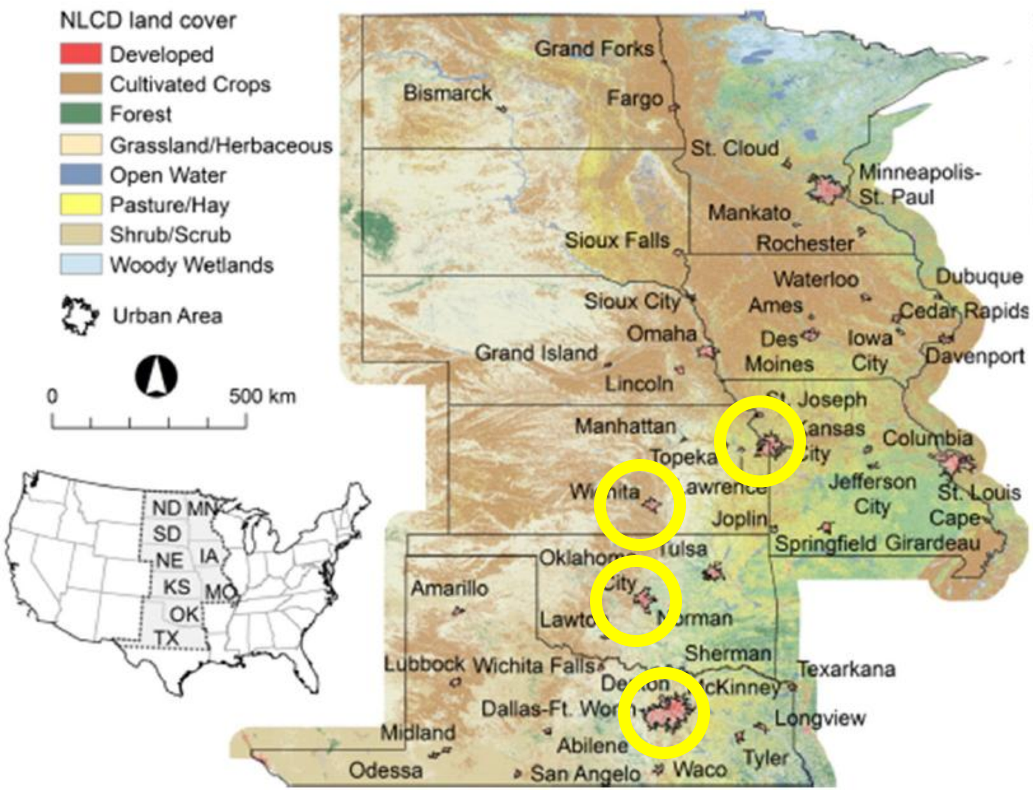
Stacey Kawecki & Allison Steiner [University of Michigan]

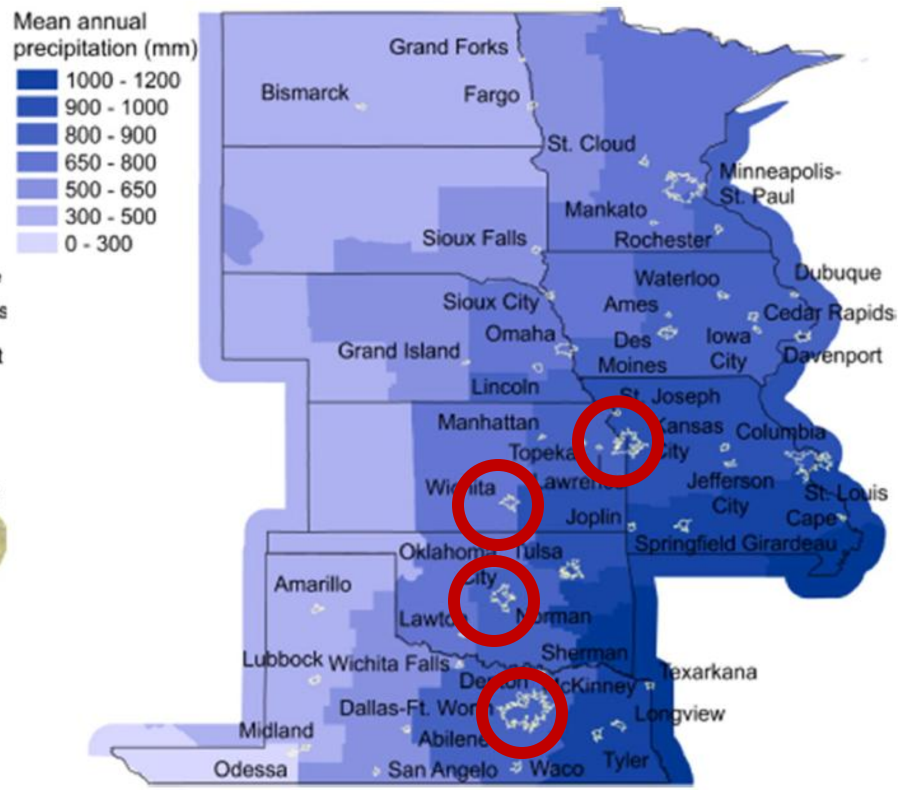
Does city size influence storm severity?

Larissa Reames [University of Oklahoma] & Dave Stensrud [Penn State]

Study Area in 2006 National Land Cover Data (NLCD)

51 Metropolitan Statistical Areas (MSAs) with population >50K





Why the Great Plains?

- Relatively flat terrain
- Distant from maritime influences
- Cities embedded in agricultural land use matrix
- Growing faster than US average
- Lots of severe storms in warm season

How do cities affect severe storms?

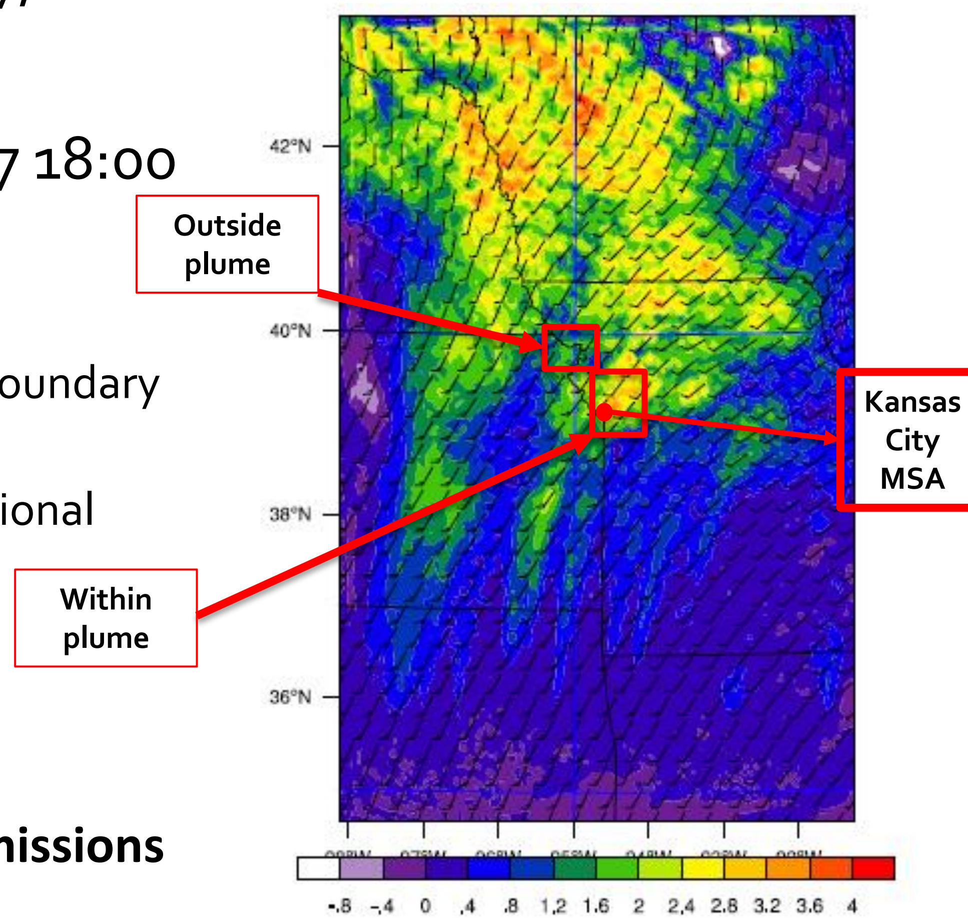
#1 effects of urban plume aerosols on a mesoscale convective system

Stacey Kawecki & Allison Steiner [University of Michigan]

Chemistry-Meteorology Simulations

- WRF-Chem (v. 3.6)
- Domain centered on Kansas City, MO
- ~2.M population in MSA
- 2013 May 25 06:00 UTC – May 27 18:00 UTC
  - Horizontal Grid spacing: 4 km
  - Meteorological Boundary Initial and Boundary Conditions: NAM-Reanalysis, 12 km
  - Anthropogenic Emissions: USEPA National Emissions Inventory (USNEI 2005)

850 mb wind (vectors) and
2X – BASE PM 2.5 (color contours)



Sensitivity Simulations:

- **0.5X, 1X, 2X of Normal NEI 2005 emissions**

Inside the plume, doubled emissions initially suppressed precipitation due to the second aerosol indirect effect. During later squall line development, additional aerosol enhanced precipitation.

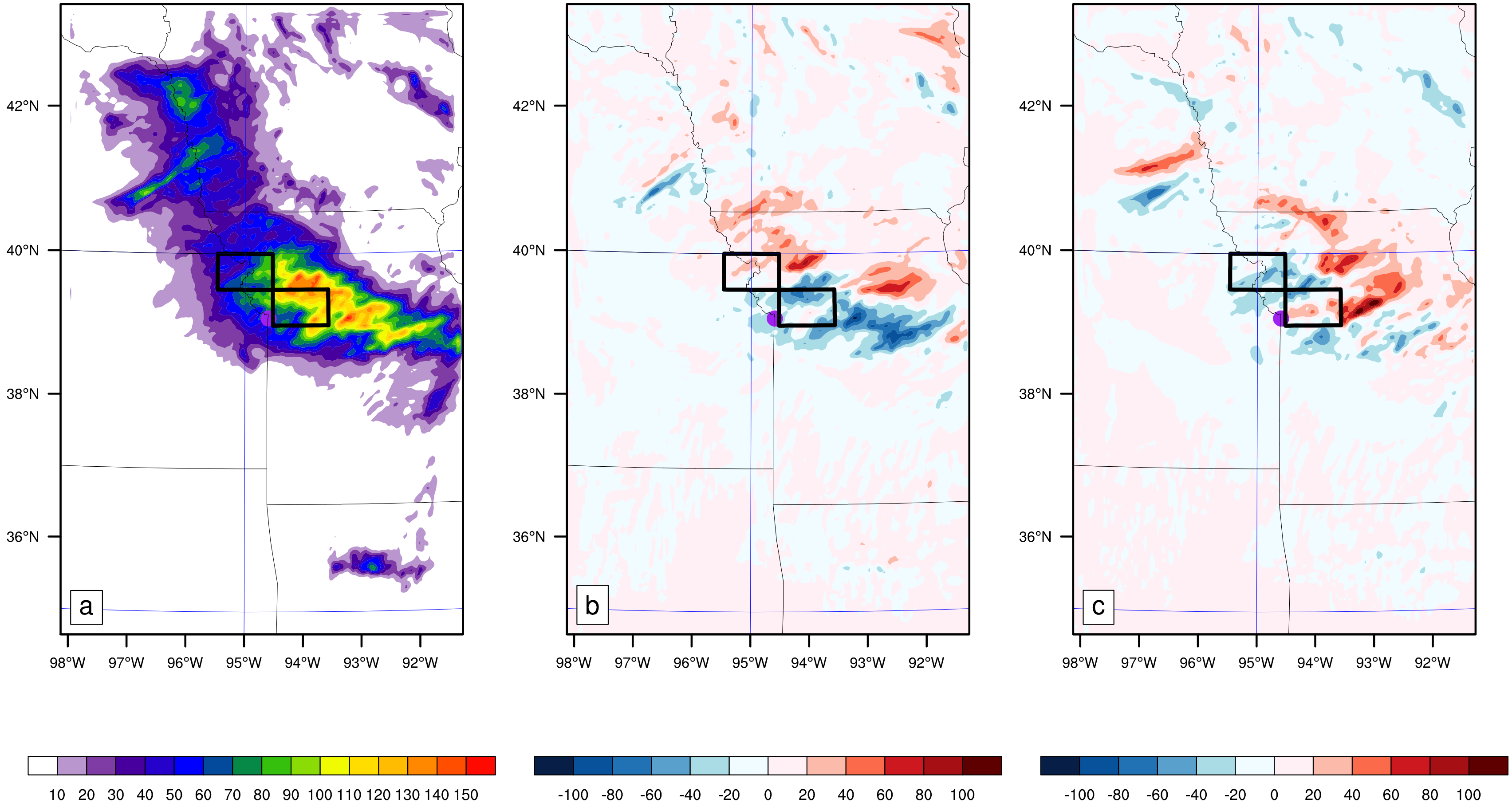
With reduced aerosol emissions and fewer CCN, cloud drops grew faster and precipitated out of the cloud earlier, which initially strengthened the MCS, but reduced available water and weakened the squall line as the storm progressed.

These changes in MCS propagation and strength were a function of cold pool strength, which is determined by microphysical processes and directly influenced by aerosol load.

Outside the plume there was a similar signal, with reduced effects due to lower aerosol load.

Overall, small-scale changes in the microphysics triggered large-scale changes in storm morphology and accumulated precipitation patterns. These results show that aerosols within an urban plume can enhance or suppress precipitation depending on the time within the storm development and the relative magnitude of aerosol load.

Kawecki et al., Effects of urban plume aerosols on a mesoscale convective system, ***J Atmos Sci***, in review

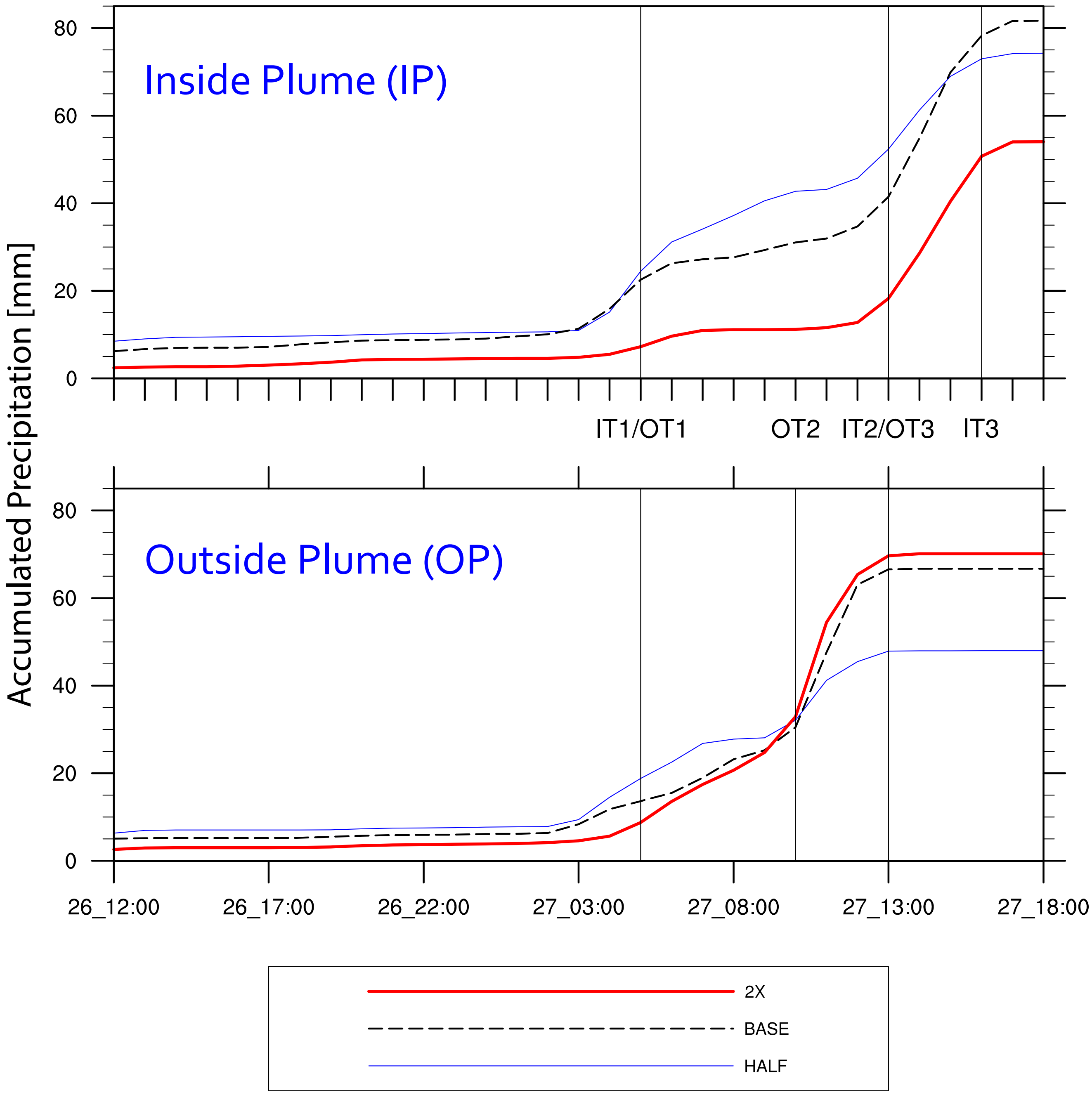


BASE case accumulated precipitation (mm) over the duration of the simulation (May 26 06:00 UTC – May 27 18:00 UTC)

2X – BASE difference in accumulated precipitation (mm)

HALF – BASE difference in accumulated precipitation (mm)

Kawecki et al., Effects of urban plume aerosols on a mesoscale convective system, ***J Atmos Sci***, in review

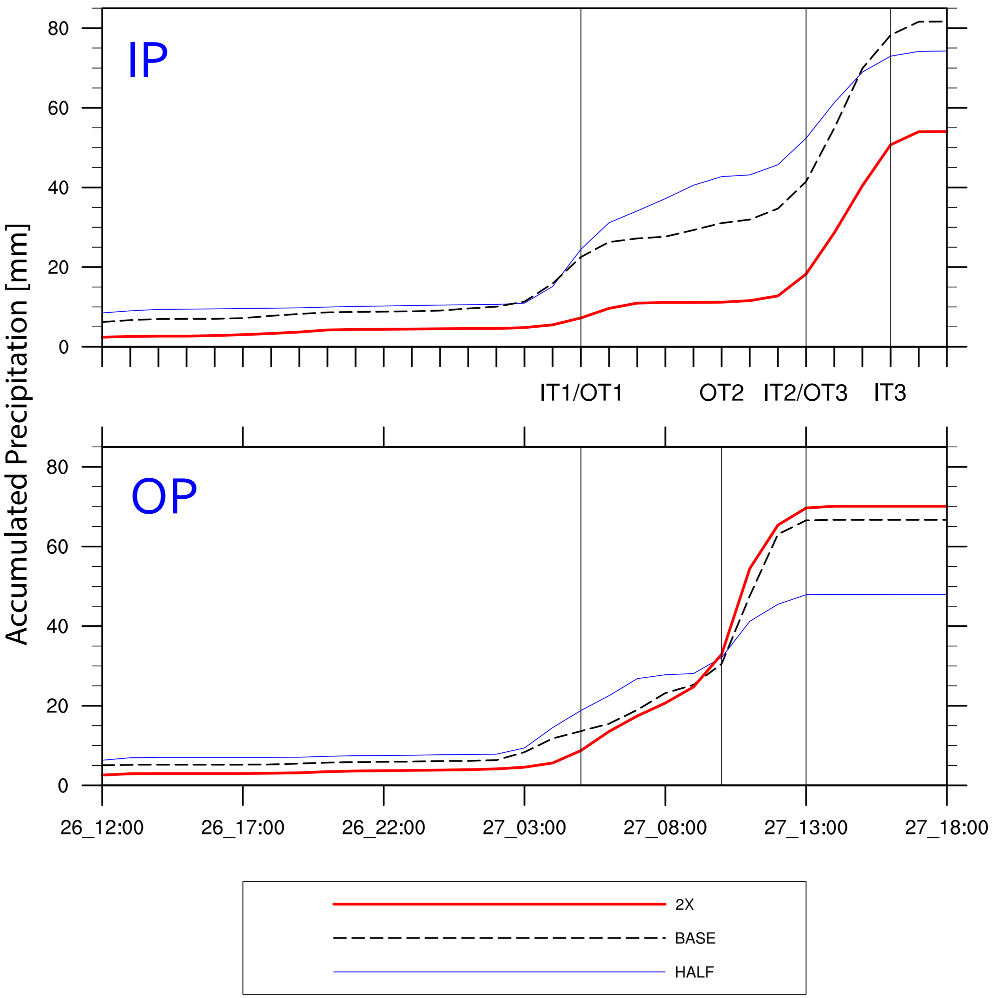


T1: passage of outflow boundary
➔ 0500 for OP
➔0500 for IP

T2: passage of the squall line
➔ 1000 for OP
➔ 1200 for IP

T3: after passing of squall line
➔ 1300 for OP
➔ 1600 for IP

Kawecki et al., Effects of urban plume aerosols on a mesoscale convective system, ***J Atmos Sci***, in review



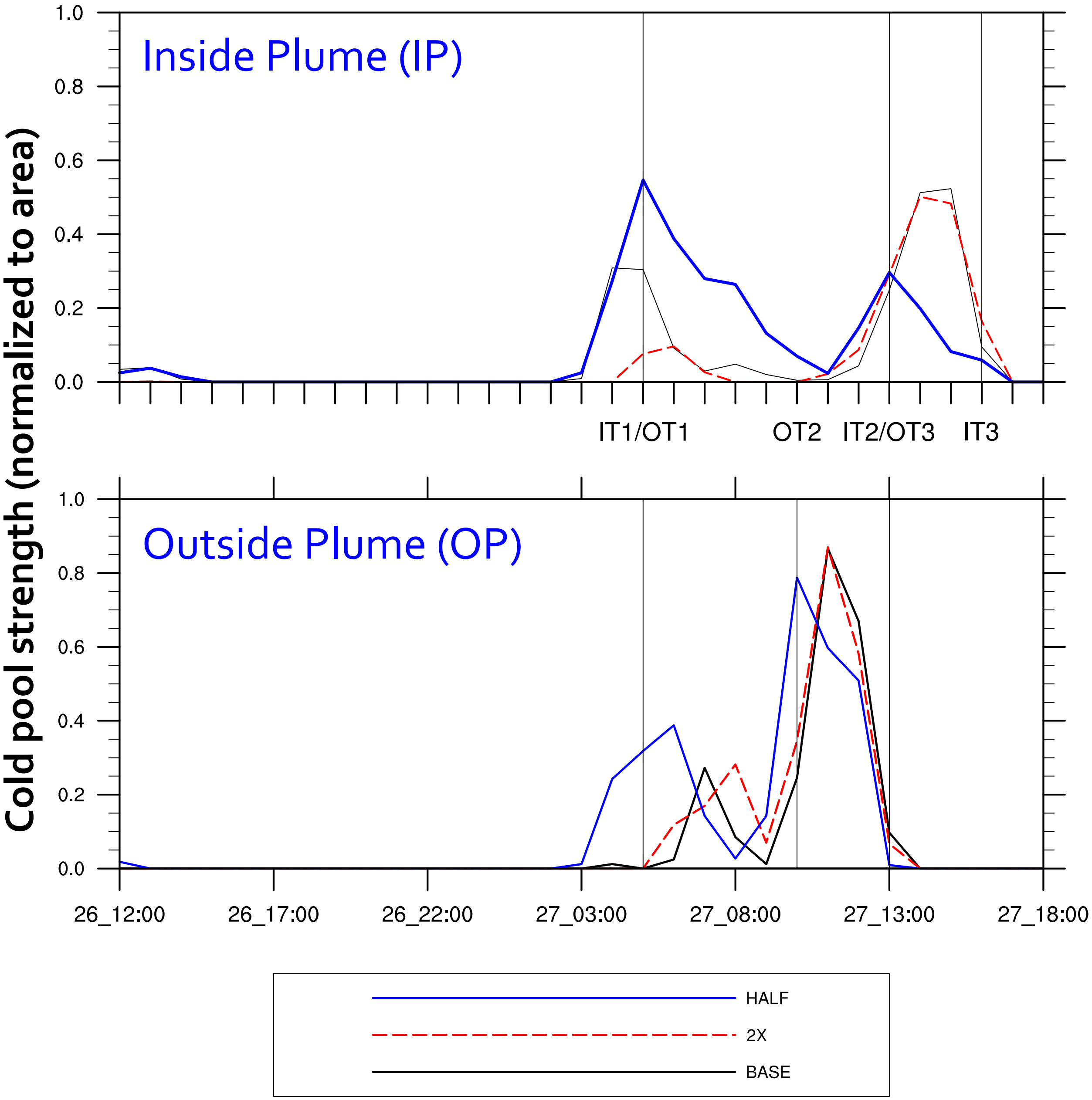
In the early storm stages, increasing aerosols reduces cloud drop growth inside the plume, leading to suppression of warm precipitation.

We also observed suppression of the formation of ice phase hydrometeors.

As the storm progresses, the presence of additional aerosols intensifies the squall line.

Aerosol-cloud microphysics drive this intensification based on changes to the thermodynamic state of the storm system, which influences the dynamics of the storm.

Kawecki et al., Effects of urban plume aerosols on a mesoscale convective system, ***J Atmos Sci***, in review



Cold pool is a function of area, maximum simulated radar reflectivity, and magnitude of perturbation potential temperature.

We consider a "strong" cold pool to be one with a perturbation temperature in the lowest model level (Kalina *et al.* 2014) less than -7 K and a maximum simulated radar reflectivity of at least 40 dBz.

We divide by the respective area (of the IP region or the OP region) to attain a normalized-to-area cold pool strength.

Kalina *et al.* 2014. Aerosol effects on idealized supercell thunderstorms in different environments. *J Atmos Sci* 71:4558-4580.

How do cities affect severe storms?

#2 Does city size influence storm severity?

Larissa Reames [University of Oklahoma] & Dave Stensrud [Pennsylvania State University]

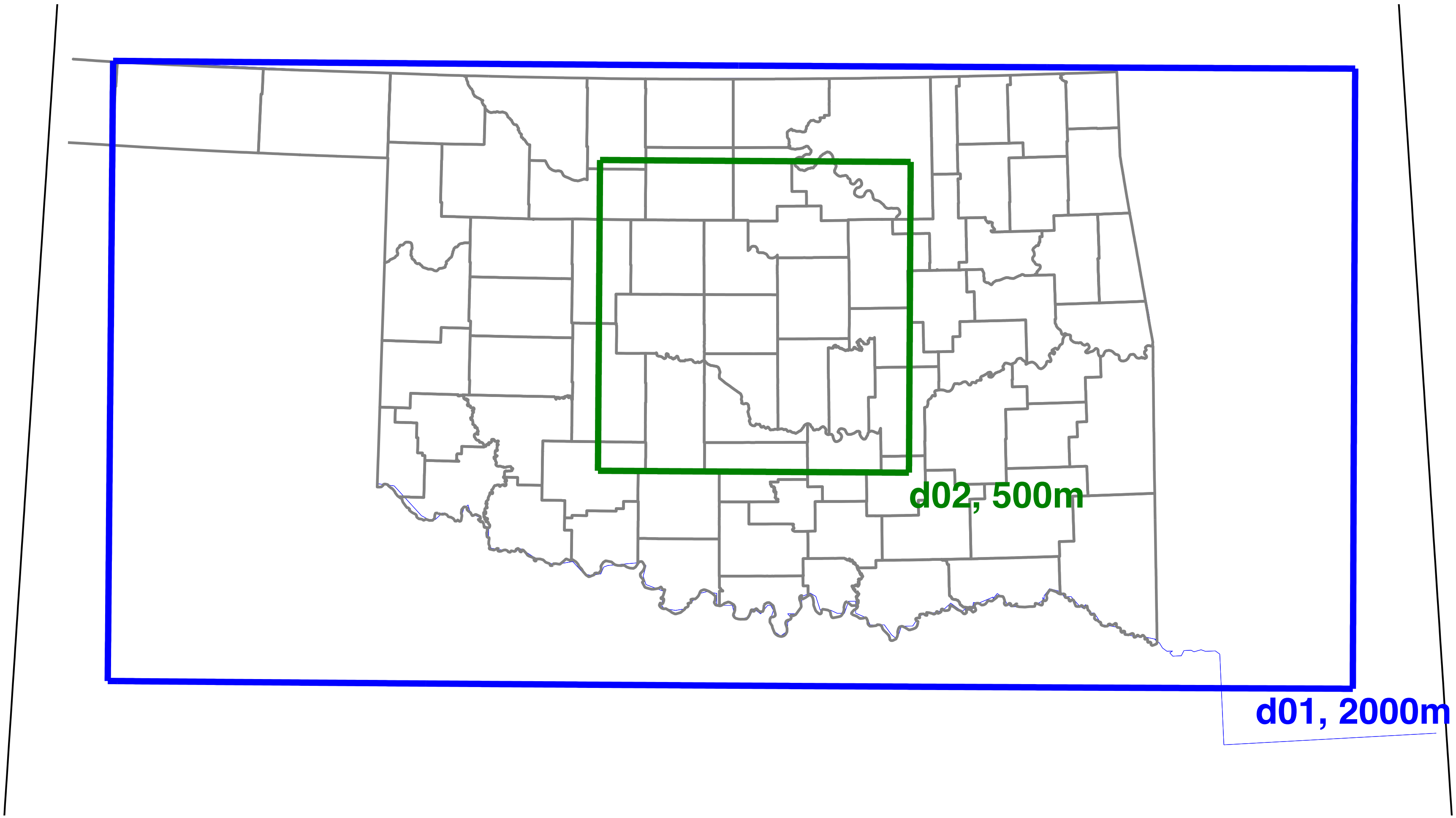
Model Information

- Weather Research and Forecasting (WRF) model Advanced Research version 3.6.1
- Use forecasts from the RUC model for initialization of atmospheric variables, and NLDAS-Noah offline for soil initialization
- *Parameterization Schemes*: Mellor-Yamada-Janjic for boundary layer, **Noah LSM**, NSSL two-moment microphysics, **BEP urban scheme**
- *Simulation Period*: 06 UTC 10 May - 06 UTC 11 May

4 comparative cases run in WRF:

a. **CTRL (no urban areas in d02)**
b. **Wichita, KS (ICT in d02)** **[~640K in MSA, 84th in US]**
c. **Oklahoma City, OK (OKC in d02)** **[~1.3M in MSA, 42nd in US]**
d. **Dallas-Fort Worth, TX (DFW in d02)** **[~7.0M in MSA, 4th in US]**

Outer (2km) & Inner (500m) domains used in WRF simulations



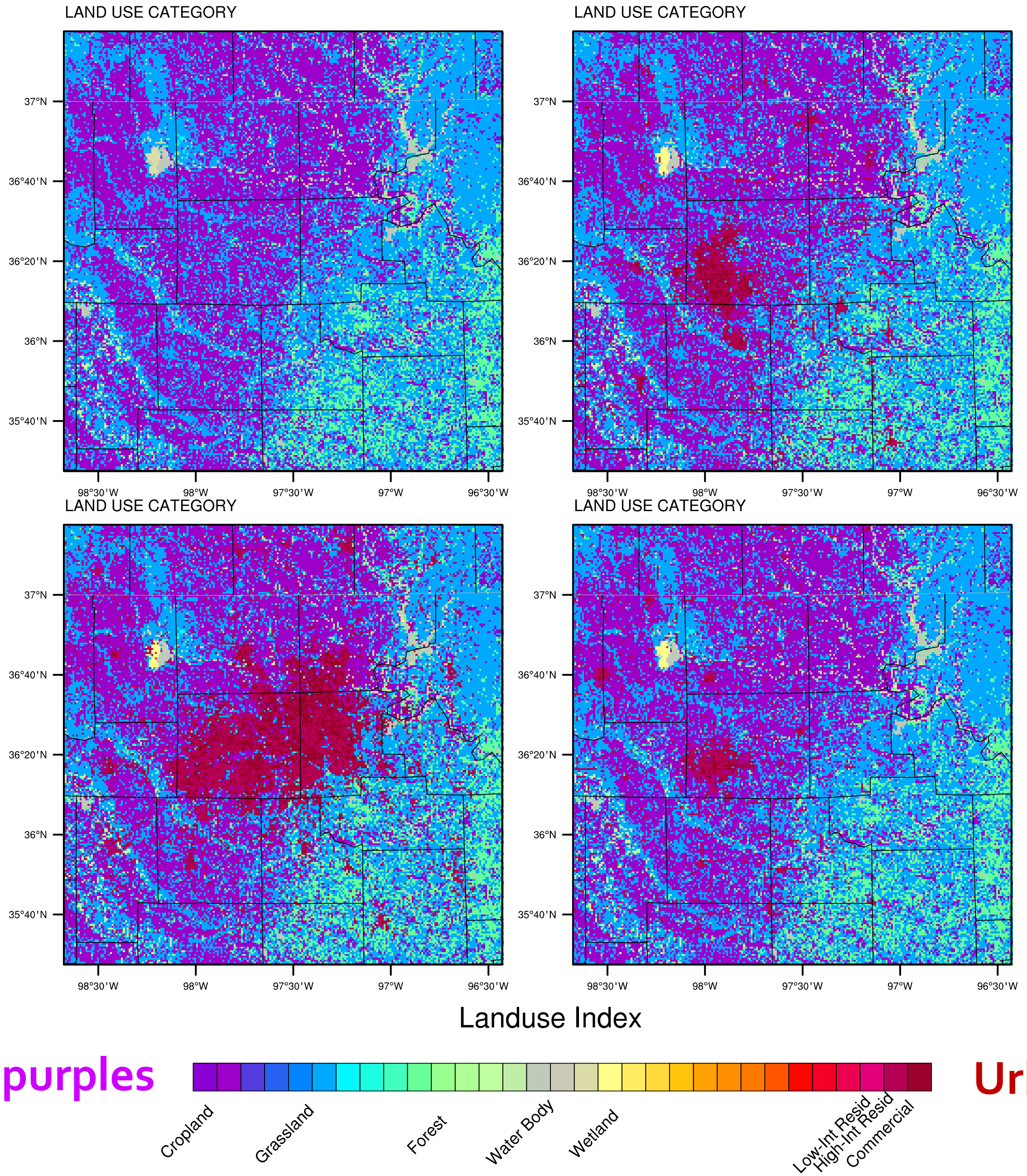
Land Use in WRF [LU_INDEX]

CTRL:
No city

OKC:
Oklahoma City, OK

DFW:
Dallas-
Ft. Worth, TX

ICT:
Wichita, KS

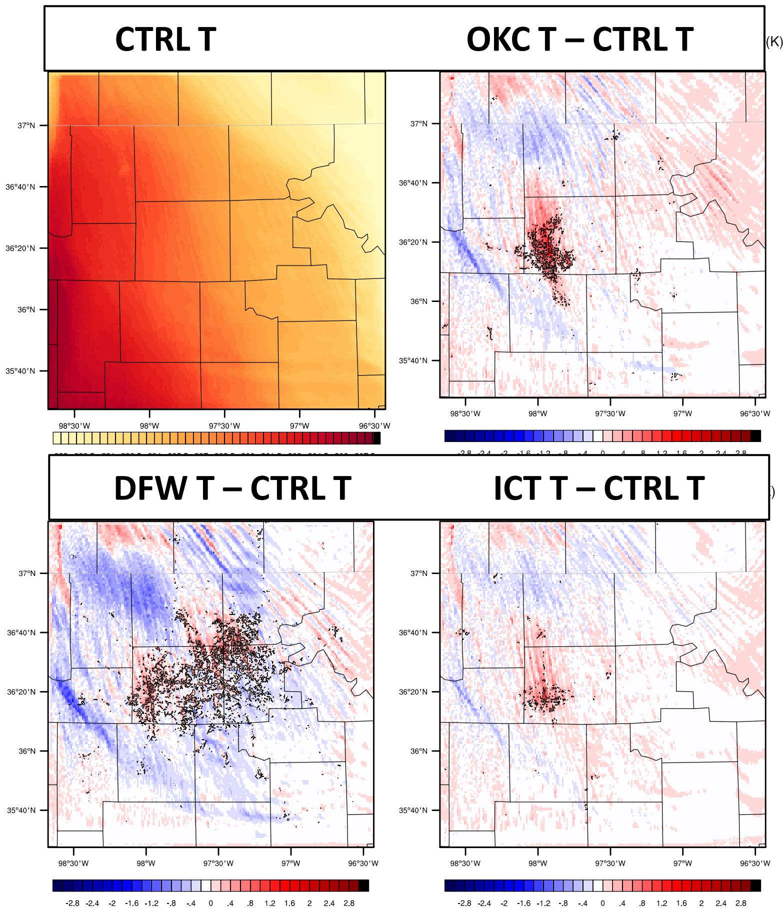


Croplands in purples

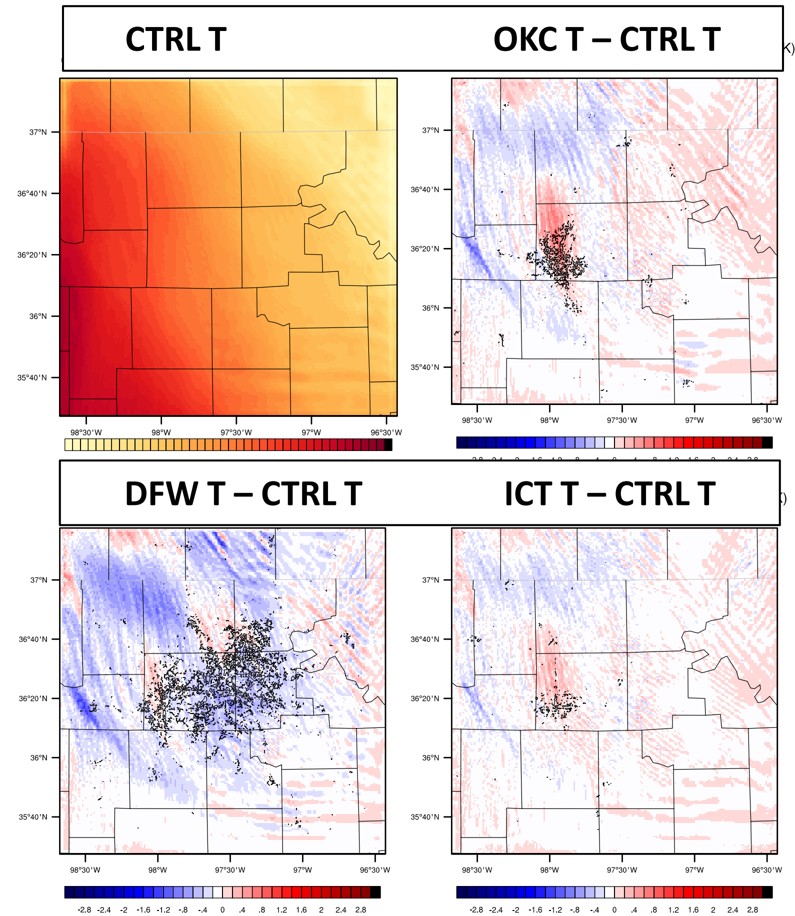
Urban areas in reds

Air temperature differences

30 m



300 m



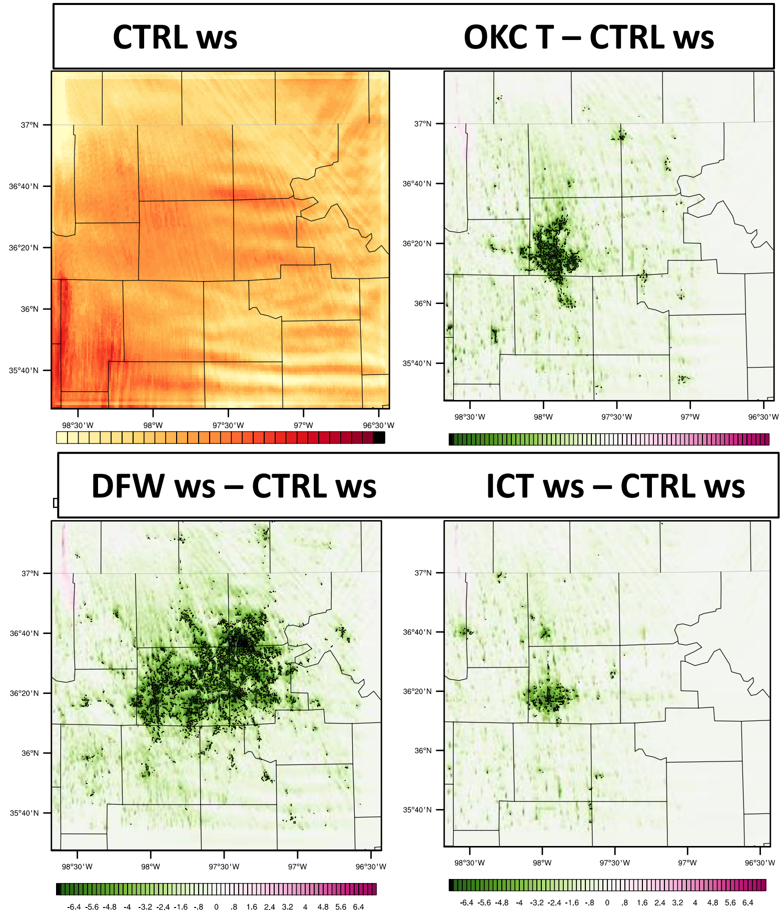
In difference plots, the color scale ranges **-3 to 3 K**

Blues are negative 🡐

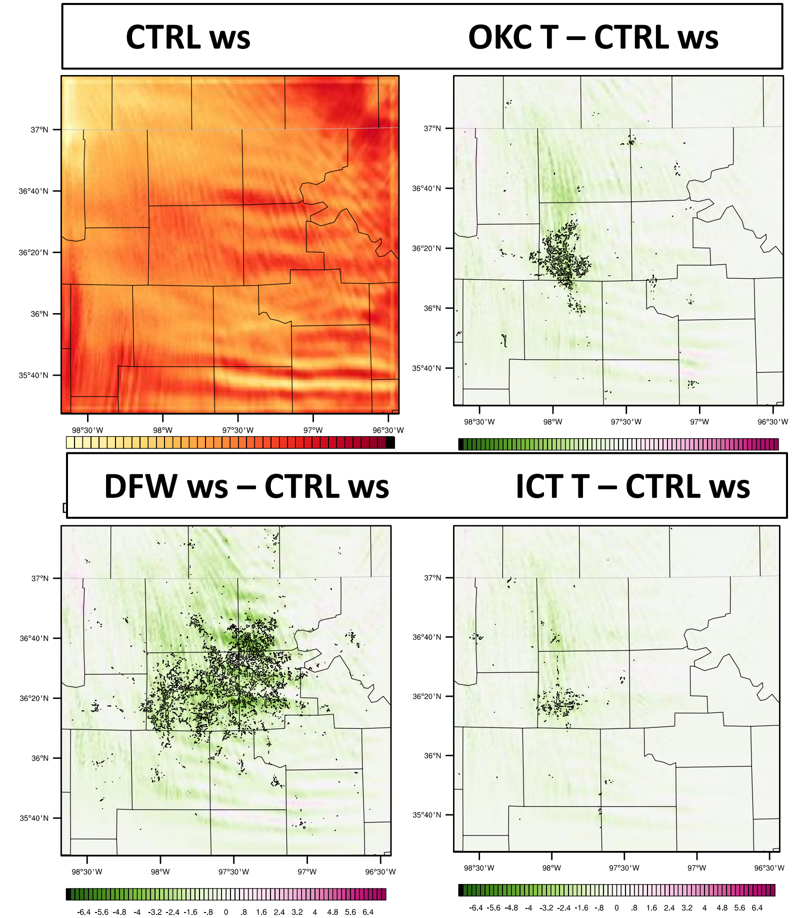
🡒 Reds are positive

Wind speed differences

30 m



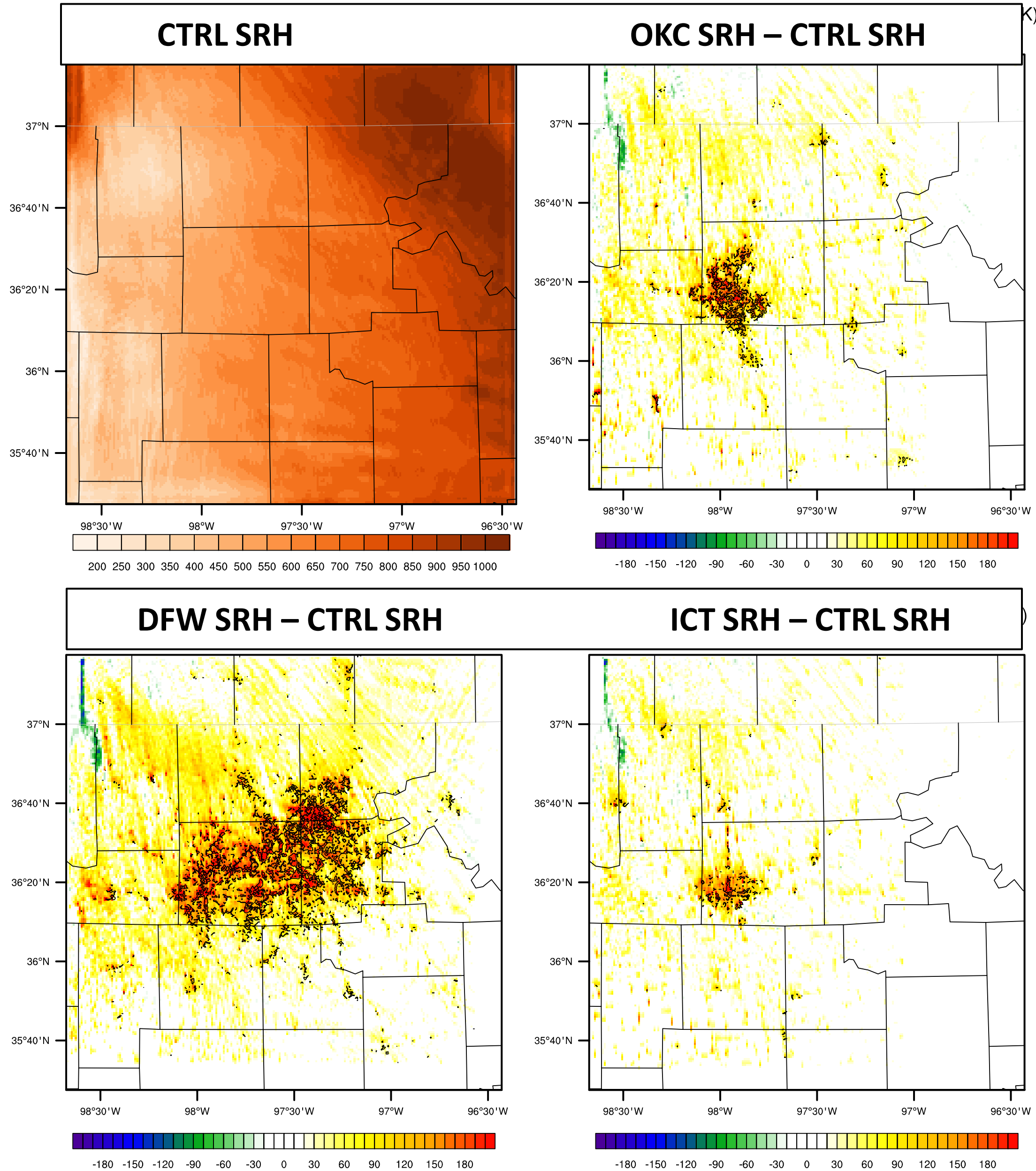
300 m



In difference plots, the color scale ranges **-6 to 6 ms^{-1}**

Greens are negative 🡐 **🡒 Magentas are positive**

0-1km Storm-Relative Helicity differences



$$SRH = \int_{0}^{z=1000\,m} (\vec{v} - \vec{c}) \cdot \xi$$

$$\xi = \left(-\frac{\partial v}{\partial z}, \frac{\partial u}{\partial z} \right)$$

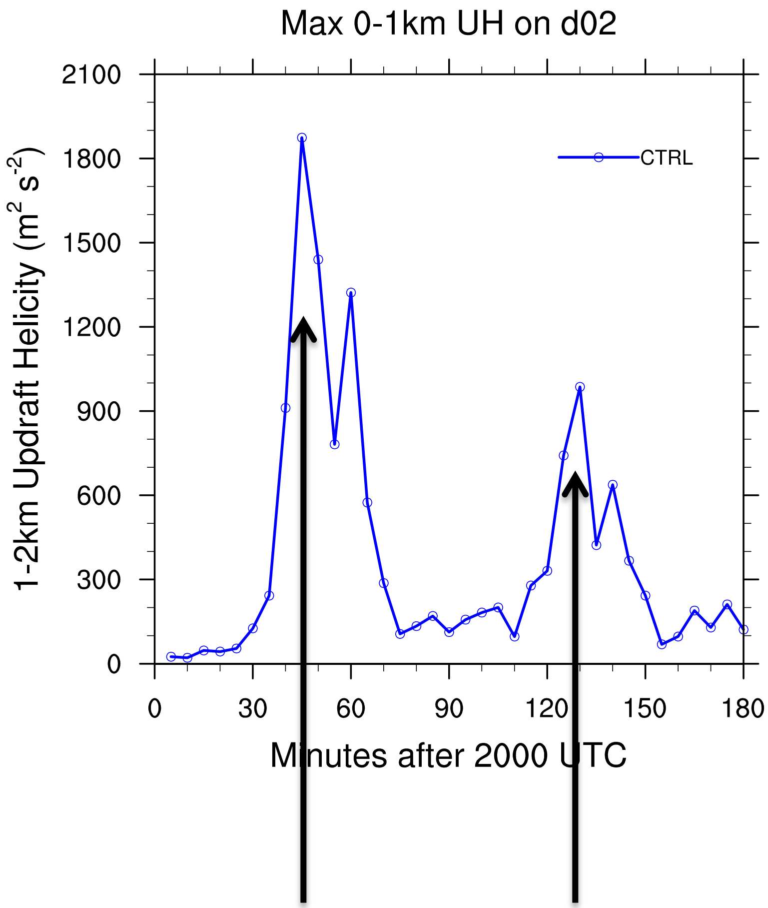
SRH is the integrated dot product of storm-relative horizontal wind with vertical vorticity of the horizontal wind.

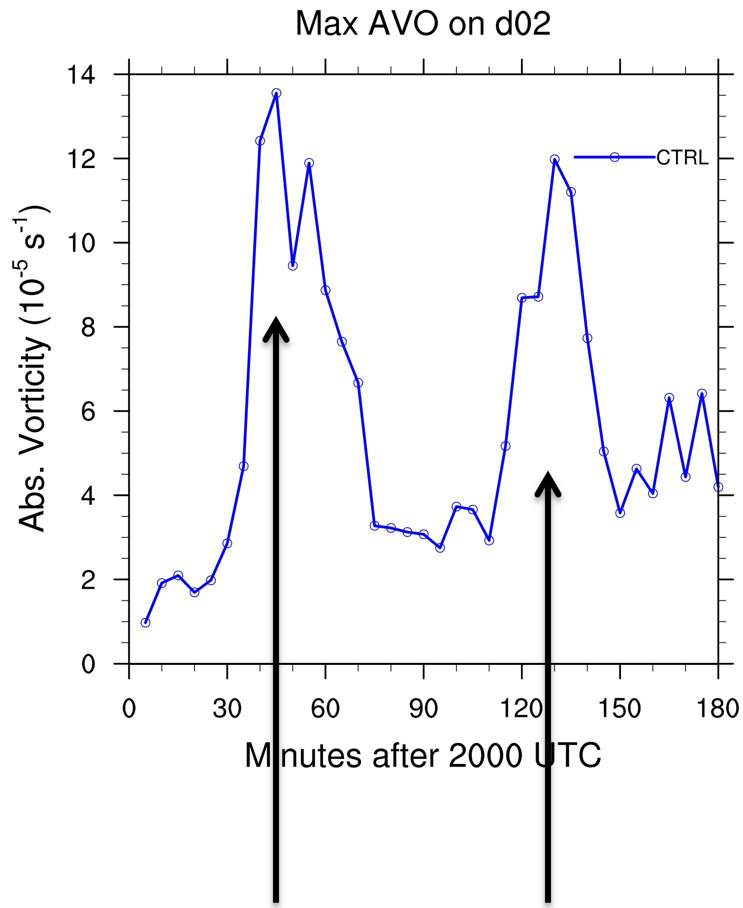
Higher values of SRH are associated with more intense low-level rotation in supercell thunderstorm.

Values of 0-1 km SRH are used to indicate the likelihood of tornadoes.

Results indicate that urbanized areas lead to locally higher values of SRH, suggesting that any storms that develop or move over the cities are more likely to be severe.

Tracking storm strength

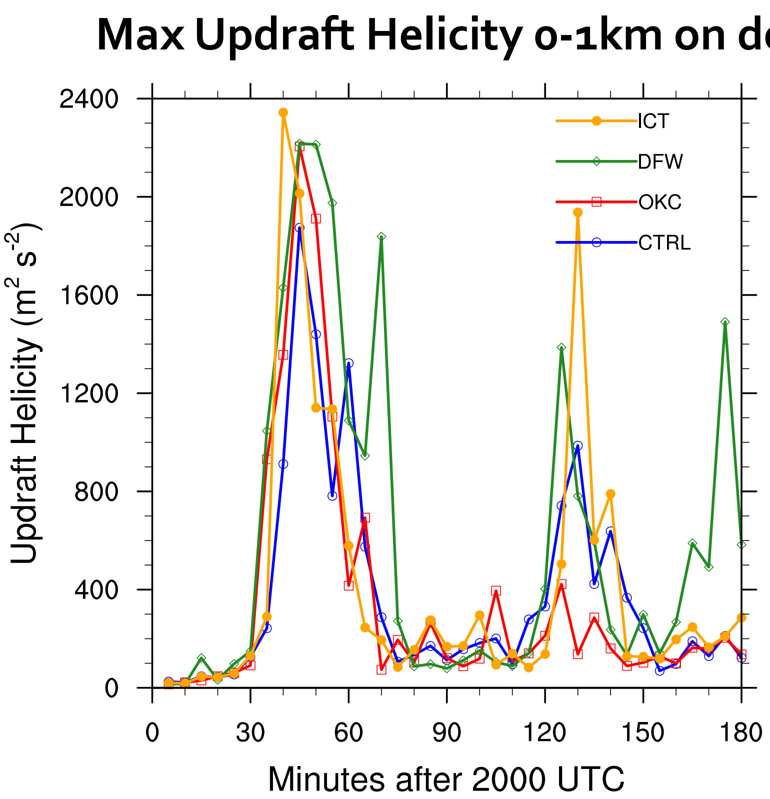


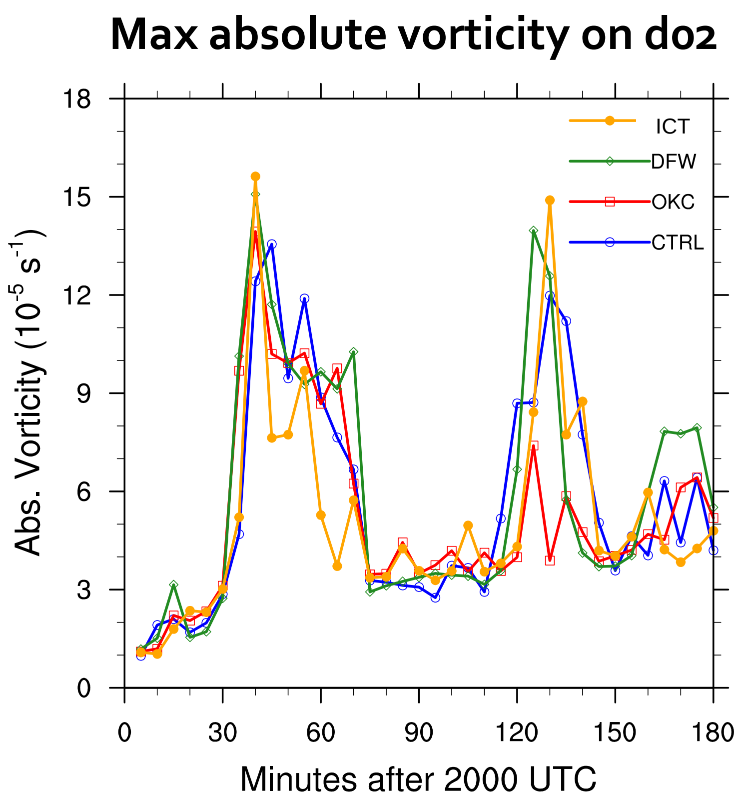


Storm “cycling” between strong and weaker states

**** 1-2km UH and Absolute Vorticity @ ~1500m above ground are both indicators of low-level storm rotational strength and the storm’s destructive potential**

Tracking storm strength





Results show that low-level storm cycling is not changed by the urban areas.

- All the storms have two periods of enhanced low-level rotation at roughly the same point in the storm lifecycle

Strength of the low-level rotation is changed when urban areas are present.

- Changes not dramatic for Wichita and Oklahoma City
- Longer period of low-level rotation suggested for DFW deserves further study and exploration

We have not be satisfied with the MYJ PBL scheme and have been exploring the YSU PBL parameterization because it includes entrainment.

But BEP does not support YSU.

- MYJ T, Skin Temp much lower than YSU
- Urban Cool Island (UCI) with SLUCM/BEP but not consistent with studies
- YSU has better boundary layer structure, better agreement with near-surface observations

Are urban models (SLUCM & BEP) appropriate for representing Great Plains cities?

Storms, Forms, and Complexity of the Urban Canopy: How Land Use, Settlement Patterns, and the Shapes of Cities Influence Severe Weather

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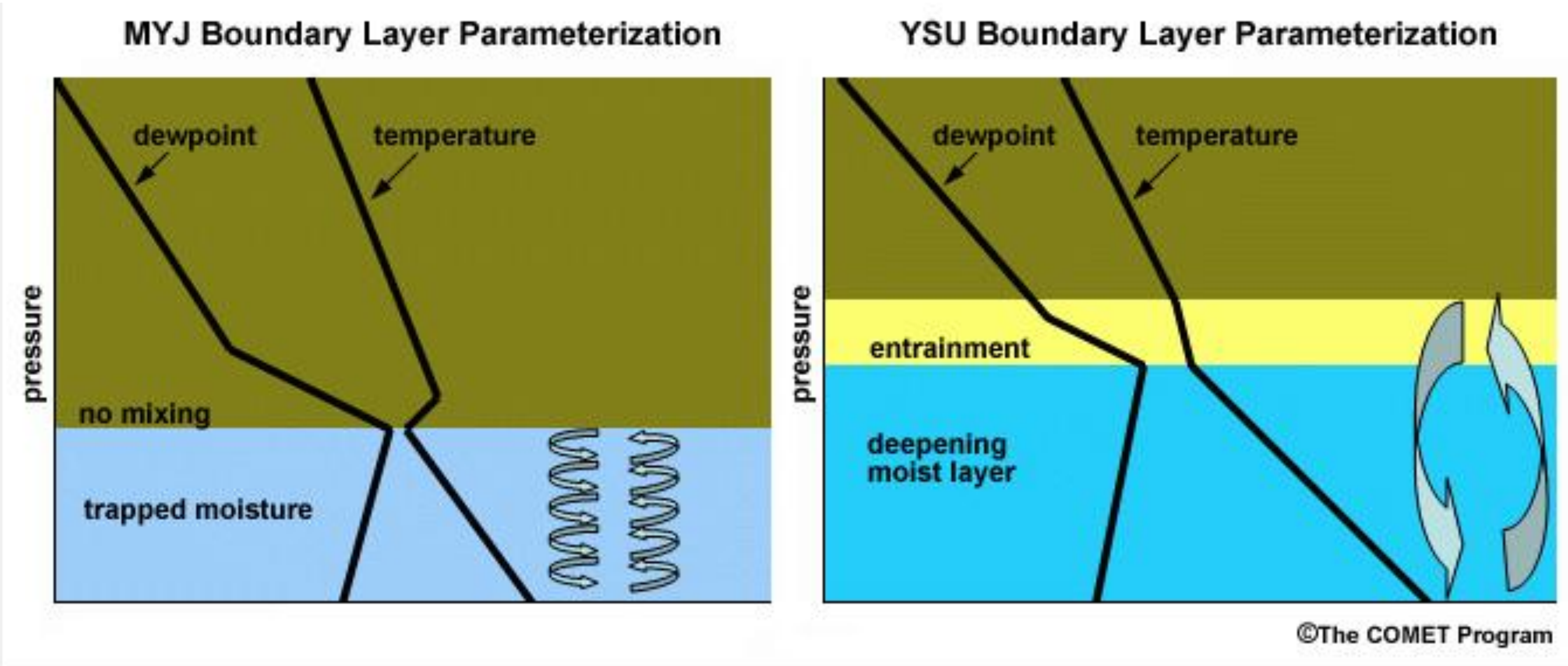
GSCE Website: http://globalmonitoring.sdstate.edu

Project Website: http://globalmonitoring.sdstate.edu/projects/cities_storms/

Land-Cover / Land-Use Change Program

Columbia University in the City of New York

MYJ vs. YSU



Typical characteristics:

- Too moist, too cool at surface from under-mixing, no entrainment
- Maintenance of appropriate CIN

Typical characteristics:

- Better moisture and temperature near surface, still too moist, too cool
- Too much erosion of CIN

Model Parameterizations

Parameterization Type	Parameterization Name	Details
Land Surface Scheme	Noah LSM	3 categories of urban; 17 parameters
Planetary Boundary Layer (PBL) Scheme	Mellor-Yamada-Janjic (MYJ)	Down-gradient diffusion based only on *local* gradients ; 1.5-order TKE closure
	YSU	1^{st} order non-local mixing; allows entrainment and fluxes not dependent on local gradients
Urban Scheme	Single layer urban canopy model (SLUCM)	
	Multi-layer, Building Environment Parameterization (BEP) scheme	**Works only with MYJ** or Boulac PBL (local, TKE-closure schemes)
Microphysics Scheme	NSSL 2-moment 4-ice	

Run summary

PBL Scheme	Urban	Landuse
MYJ	n/a	CTRL
MYJ	n/a	DFW
MYJ	SLUCM	DFW
MYJ	BEP	DFW
YSU	n/a	CTRL
YSU	n/a	DFW
YSU	SLUCM	DFW