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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The people of the US live predominantly in urban areas

According to the 2010 US Census, 81%* of us live in urban areas.

That is an increase of 13% over 2000 and it accompanies a 19% increase in urban land area.

Do urban areas affect severe storm behavior?

Yes, big urban areas affect storms:

Changnon 1981; Hjelmfelt 1982; Bornstein & Lin 2000; Shepard & Burian 2003; Niyogi *et al.* 2006; van den Heever & Cotton 2007; Lei *et al.* 2008; Shem & Shepard 2009; Zhang *et al.* 2009; Niyogi *et al.* 2011; Snow, Zeng *et al.* 2012

How about smaller urban areas?

Are there thresholds?

Does shape matter?

How about pollution state?

Focusing on the US Great Plains because:

1. **Relatively flat terrain**
2. **Distant from maritime influences**
3. **Cities embedded in agricultural land use**
4. **Lots of severe storms in warm season**
5. **Growing faster than US average**

What lessons can we pass on to urban planners?

Urbanized area effects on

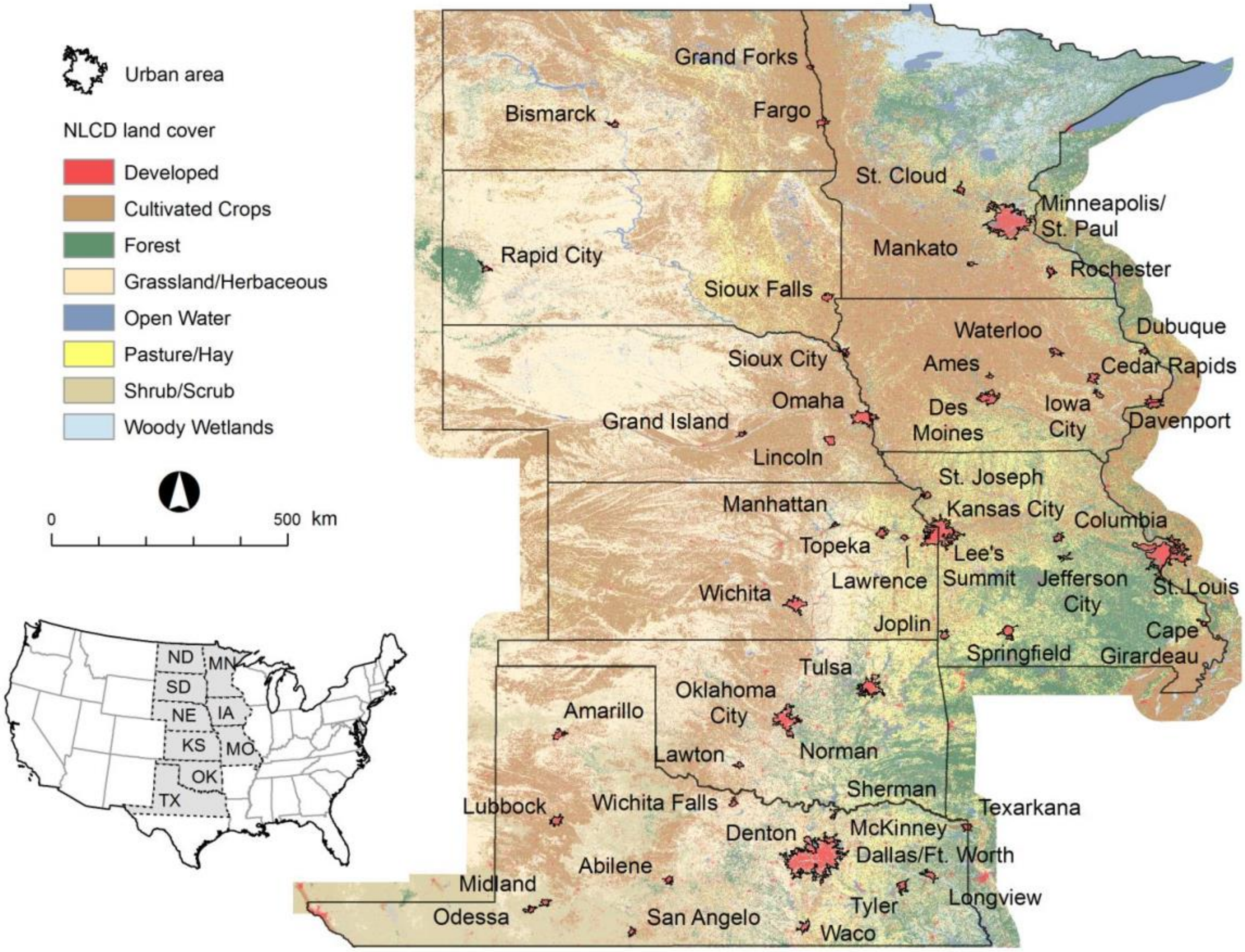
- Land surface phenology from MODIS **(Walker/de Beurs/Henebry)**
- Tornado tracks from NOAA/NWS/SPC/SVRGIS **(Al Mamun/Henebry)**
- Storm characteristics from NEXRAD time series **(Calhoun & REUs)**
- Dynamical aspects of severe storms from WRF modeling **(Reames/Stensrud)**
- Air pollution & storm effects from WRF-CHEM **(Kawecki/Steiner)**
- Land Cover Continuum: where does the city end? **(Small/Tomaszewska/Henebry)**

Interdisciplinarity From Science to Practice **(Musacchio/Henebry)**

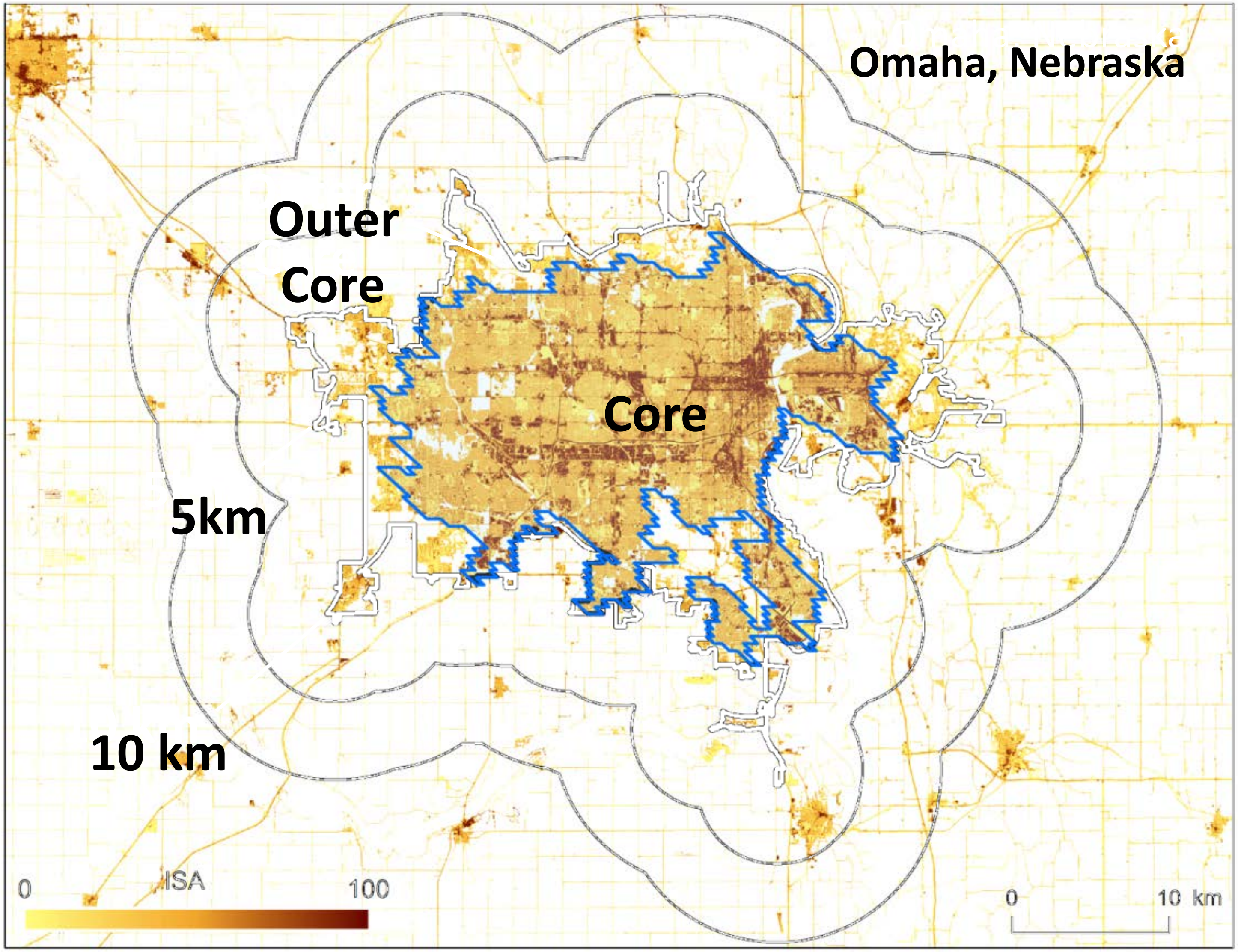
Earlier at Poster #13:

Effects of seasonality and land cover type on middle infrared (4 μm) radiance of urbanized areas **(Krehbiel/Henebry)**

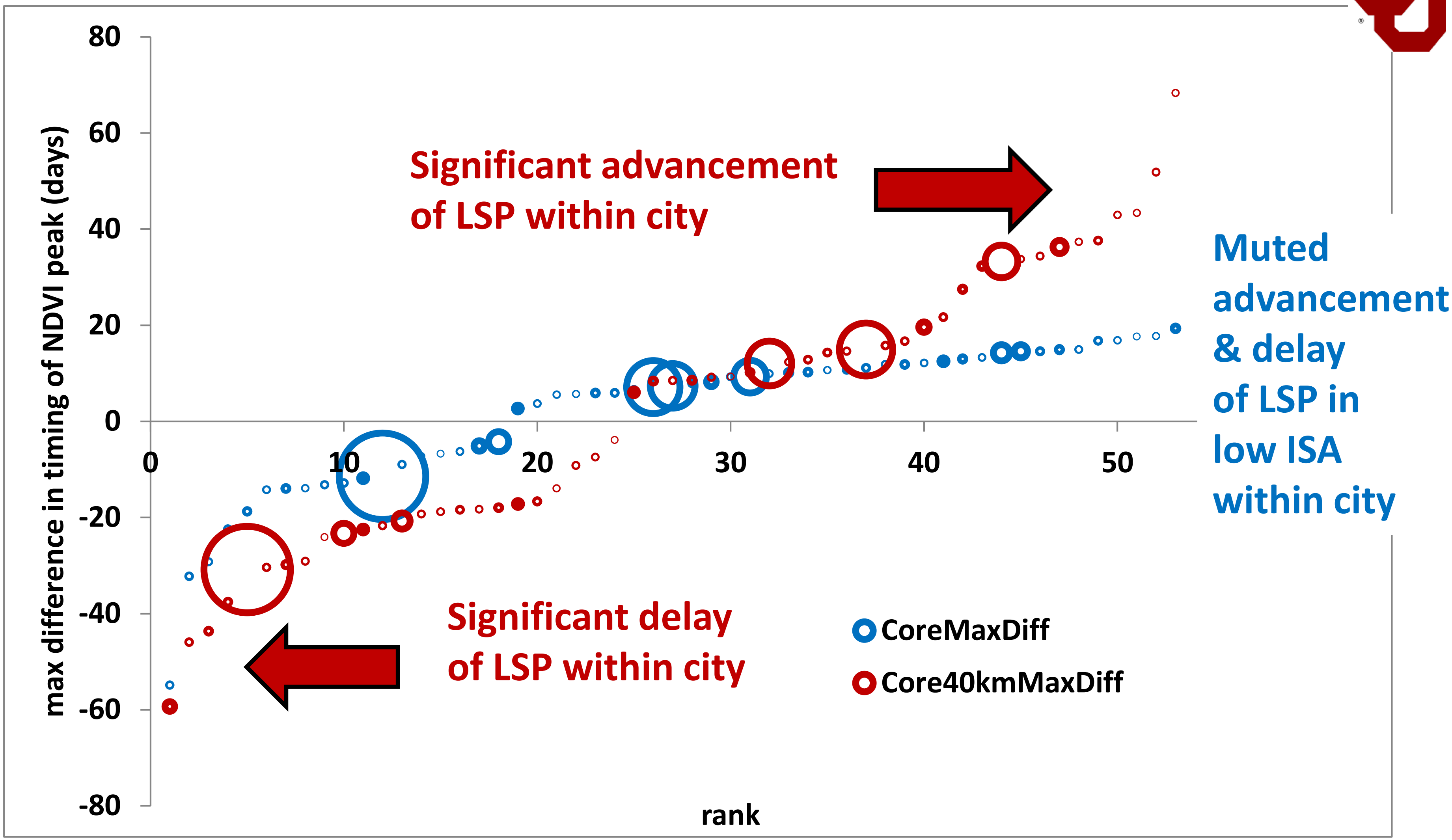
Data – Land Cover (NLCD 2006)
[53 urbanized areas with pop >50K]

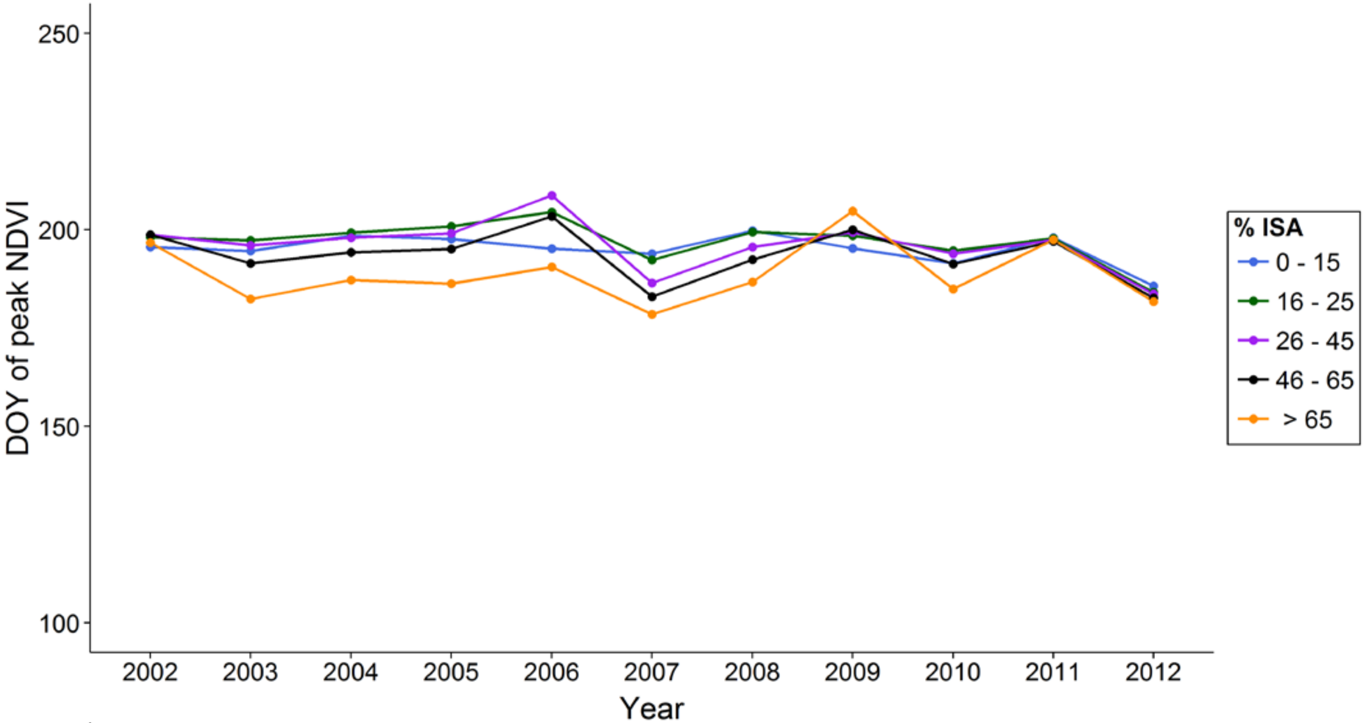


Data - Impervious Surface Area (NLCD 2006)



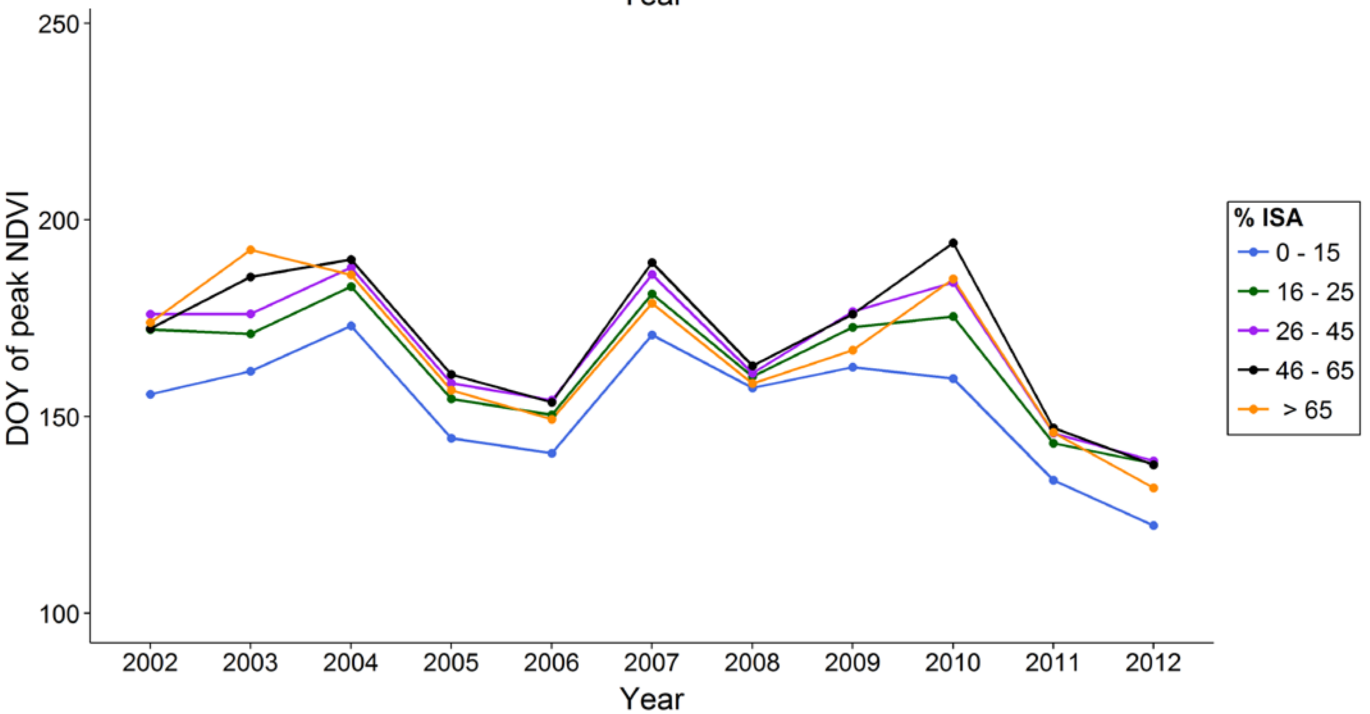
Rank plot of **maximum difference** (in days) in the timing of peak NDVI (2002-2012) for in core low ISA minus high ISA pixels & for in core low ISA pixels minus in 40km ring low ISA pixels





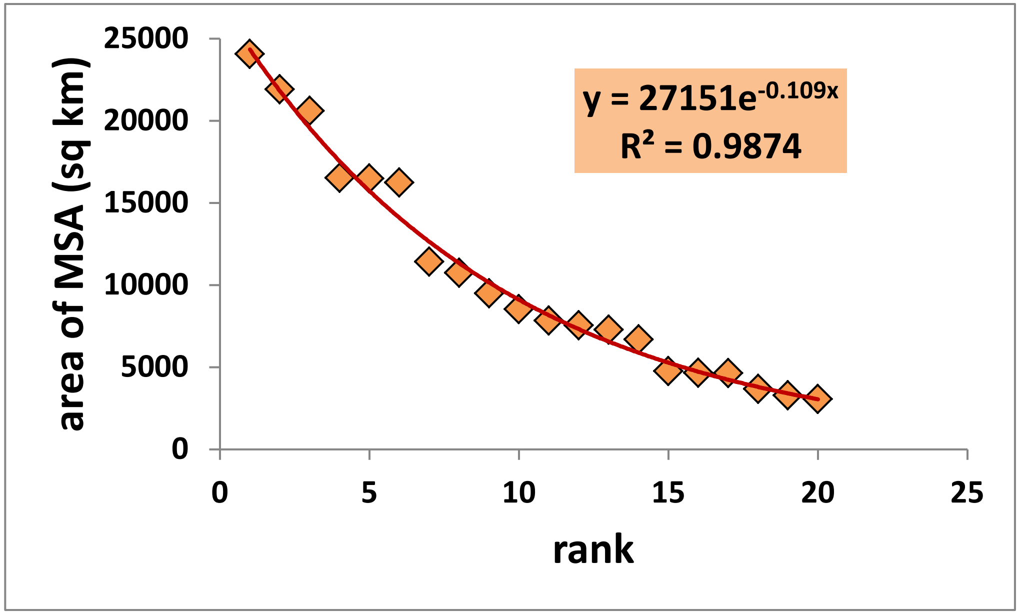
MSP: 2002-2012

LSP earlier in higher ISA



DFW: 2002-2012

LSP earlier in lower ISA



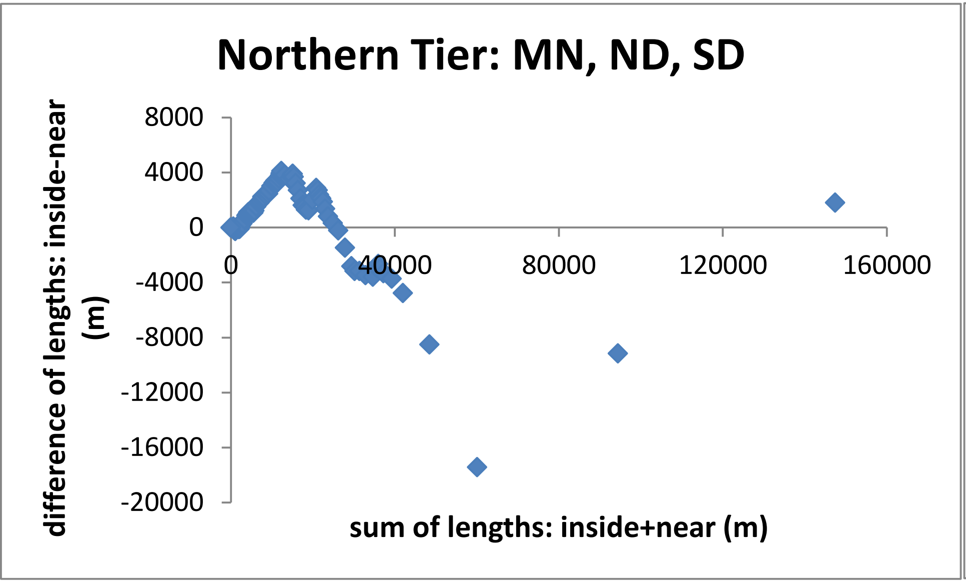
	City	MSA Area (km^2)
1	Dallas-Ft. Worth, TX	24,059
2	Saint Louis, MO	21,910
3	Kansas City, MO	20,596
4	Oklahoma City, OK	16,512
5	Minneapolis-St. Paul, MN	16,483
6	Tulsa, OK	16,237
7	Omaha, NE	11,414
8	Wichita, KS	10,743
9	Amarillo, TX	9,482
10	Topeka, KS	8,521
11	Springfield, MO	7,824
12	Des Moines, IA	7,542
13	Fargo, ND	7,278
14	Sioux Falls, SD	6,680
15	Manhattan, KS	4,760
16	Lubbock, TX	4,659
17	Longview, TX	4,623
18	Lincoln, NE	3,662
19	Joplin, MO	3,279
20	Iowa City, IA	3,064

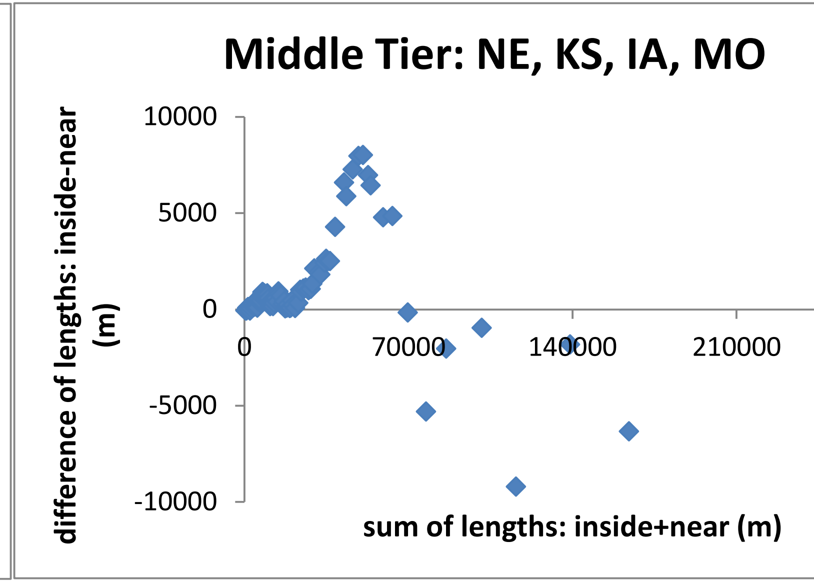
Metropolitan Statistical Area (MSA) size of the 20 urbanized areas follow an exponential rather than power-law distribution.

Tornado tracks near OKC, 1983-2011 [SVRGIS]

Tornado tracks are not directly reported, but starting and ending locations are available.

Thus, we can infer the length of a tornado track by taking the Euclidean distance, realizing that the actual path(s) of the tornado may well deviate from a straight-line.





SDSU

Northern Tier Counts	Inside:	42 (11.3%)
	Near:	47 (9.4%)

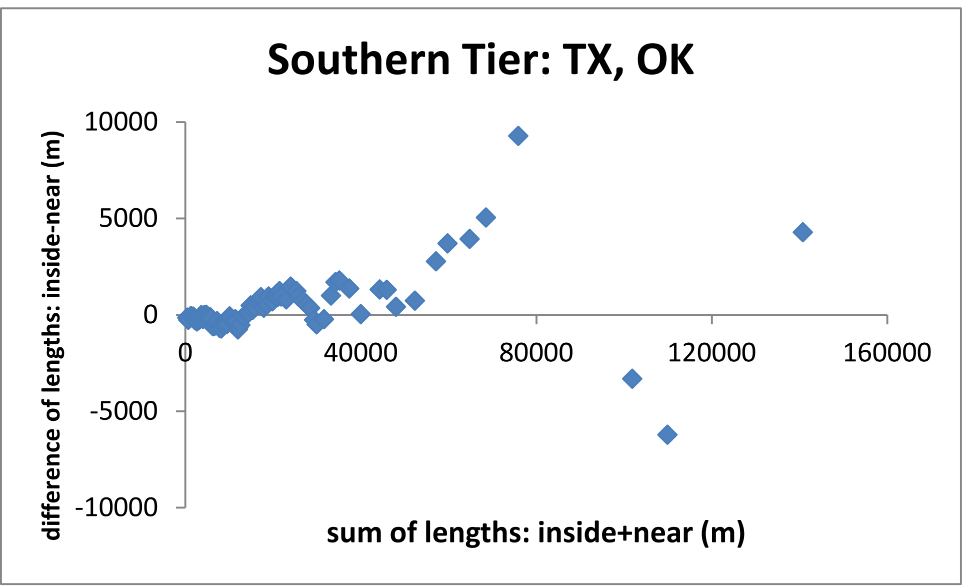
For shorter tracks, ***inside*** longer

For longer tracks, ***near*** longer

Middle Tier Counts	Inside:	175 (46.9%)
	Near:	261 (52.3%)

For shorter tracks, ***inside*** longer

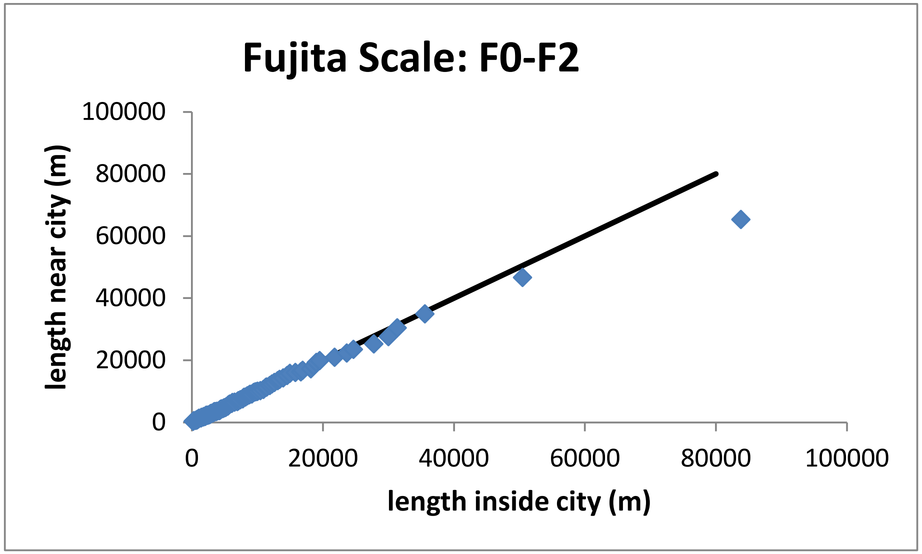
For longer tracks, ***near*** longer

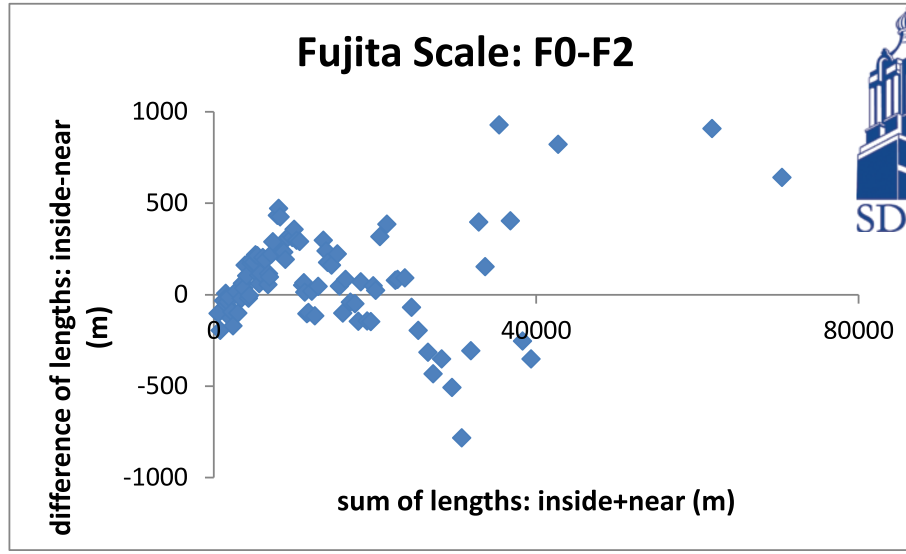


Southern Tier Counts	Inside:	156 (41.8%)
	Near:	191 (38.3%)

For shorter tracks, ***inside*** longer

For longer tracks, n is too low





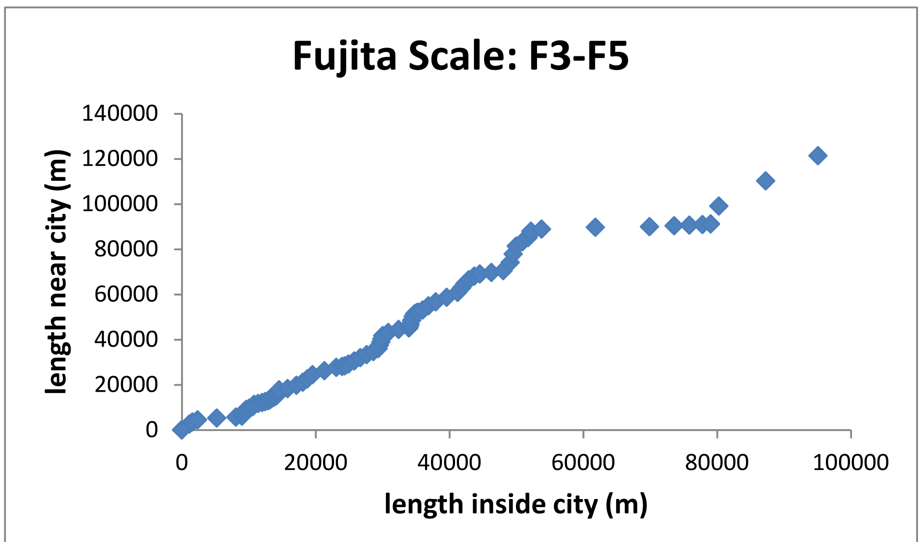
Intensity Grouping

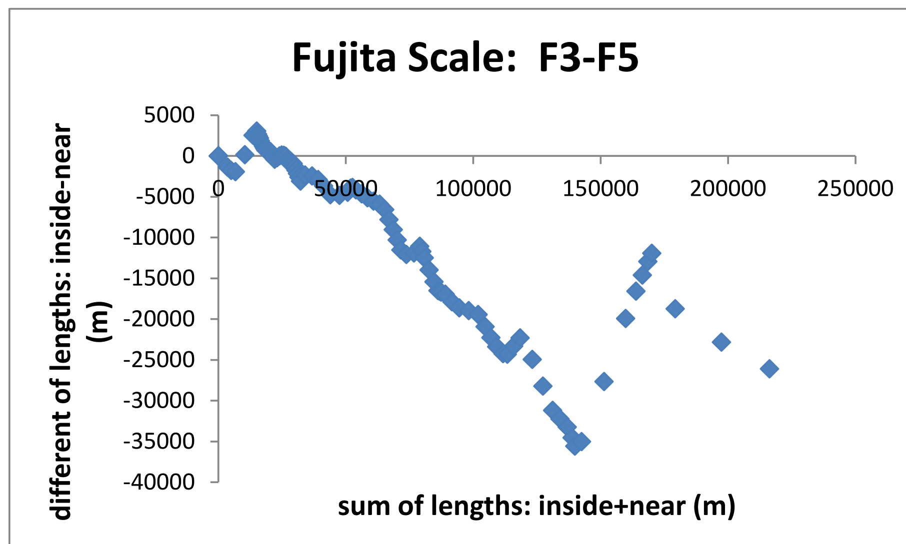
Weaker: F0, F1, F2

With weaker tornadoes

For longer tracks, n is too low

For shorter tracks, ***inside*** longer





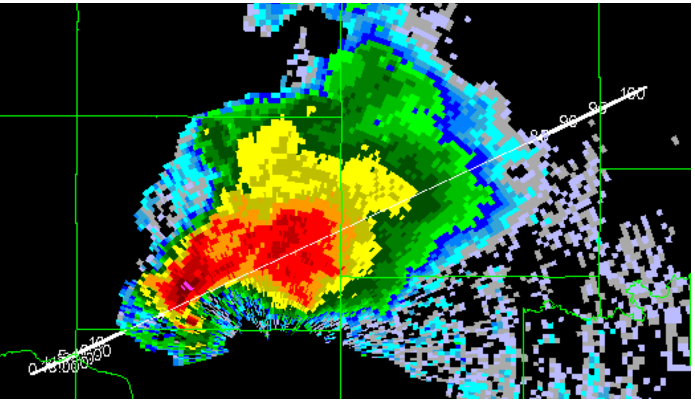
Intensity Grouping

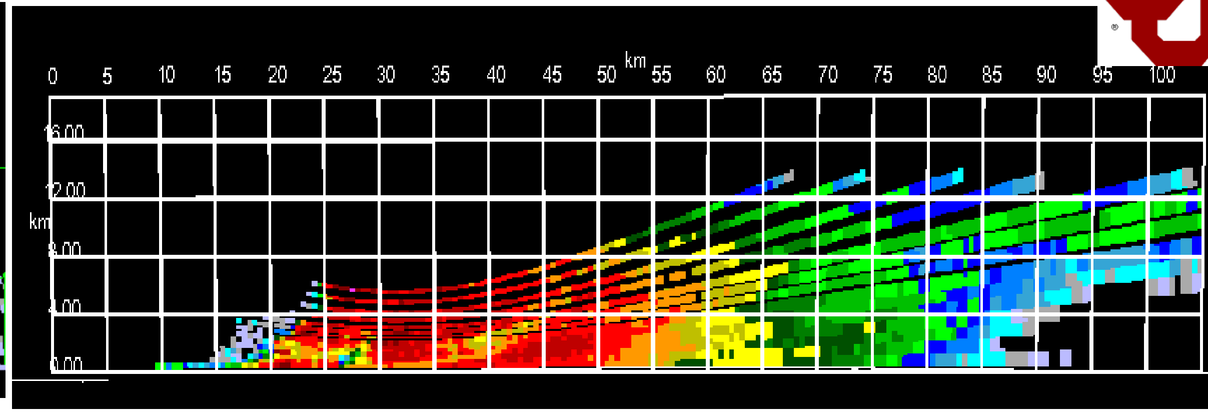
Stronger: F3, F4, F5

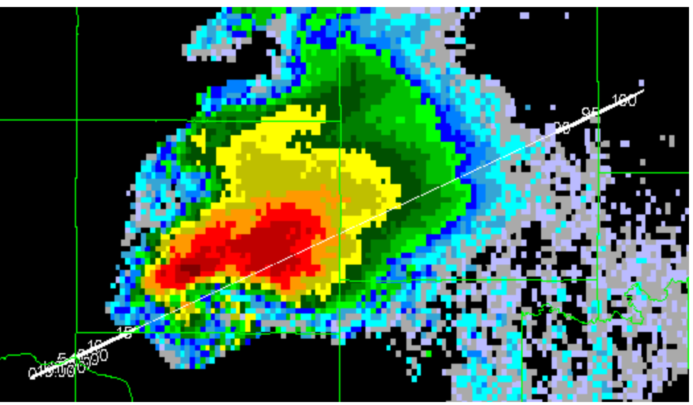
With stronger tornadoes

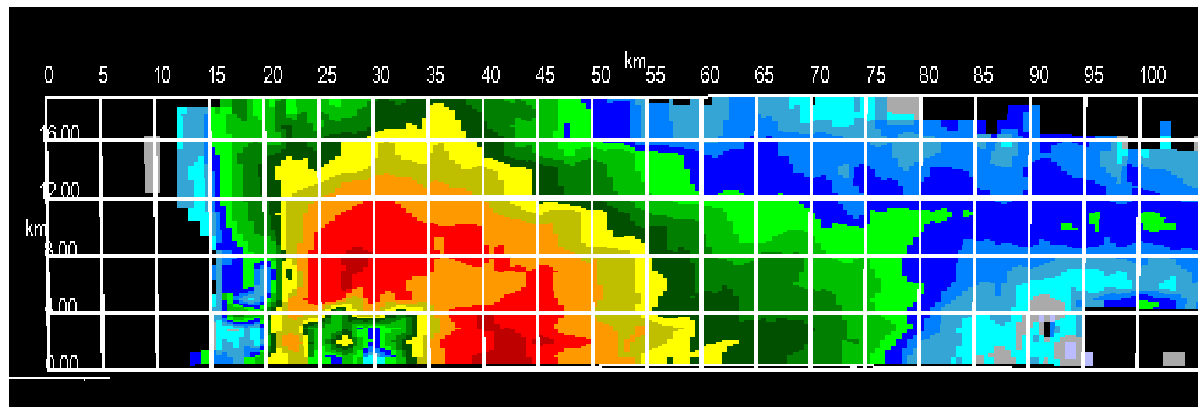
For almost all lengths, ***near*** longer

Merging weather radars to fill the cones of silence







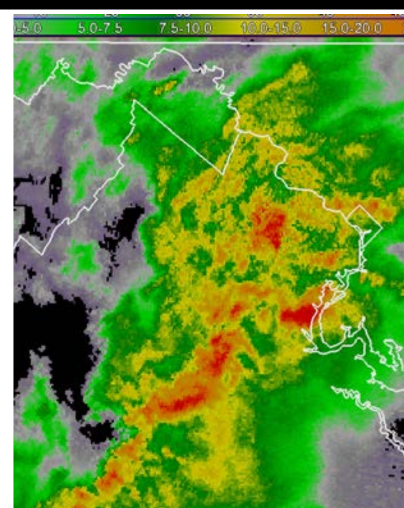


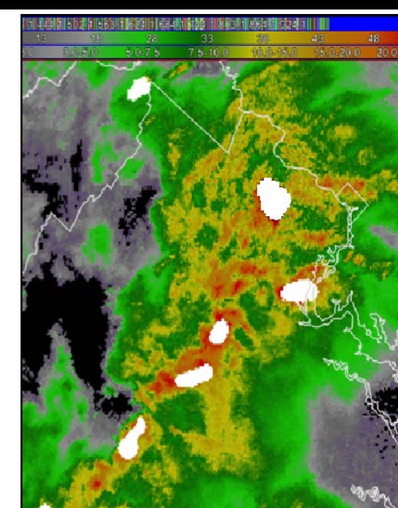
Storm tracking accomplished through WDSS-II: w2segmotionll

A combination of k-means and watershed segmentation used

Segmentation on merged composite reflectivity

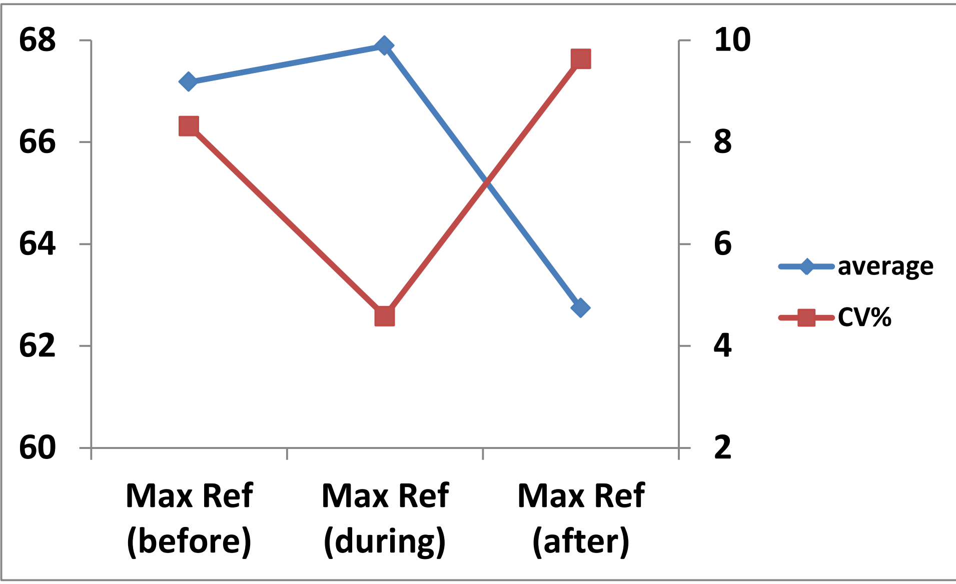
Storms identified at 200 km^2



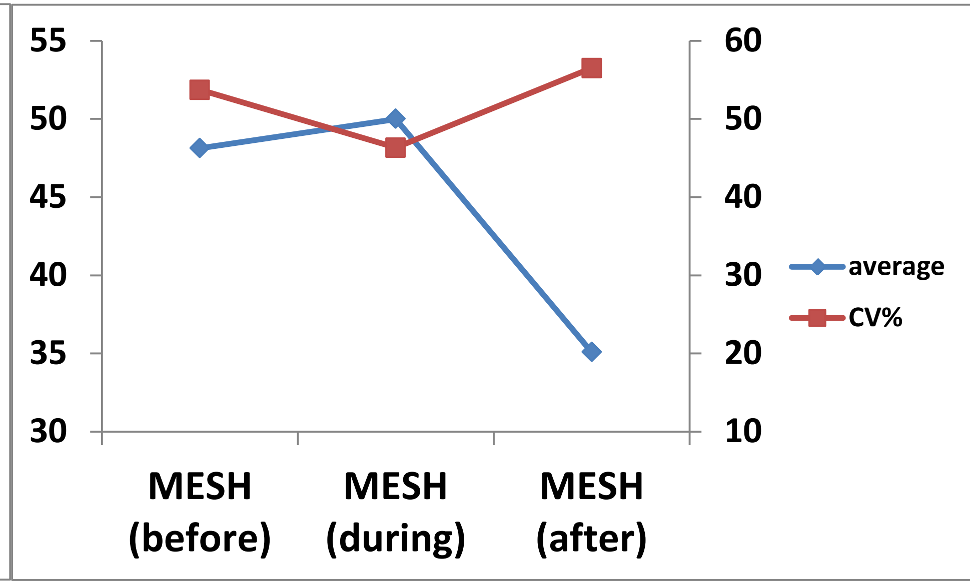


Analysis of selected "good storms" over OKC: 2010-2012

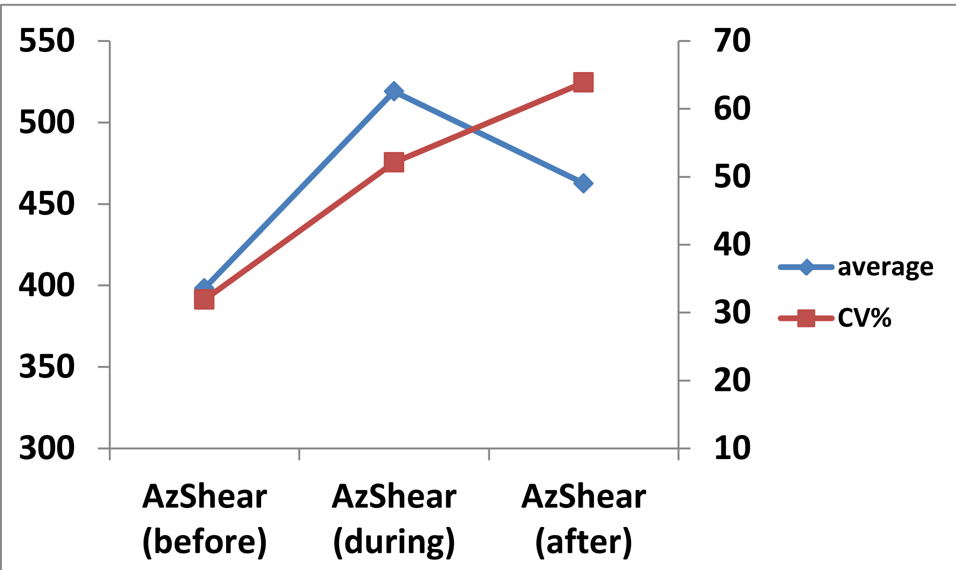
Maximum Reflectivity (dBZ)



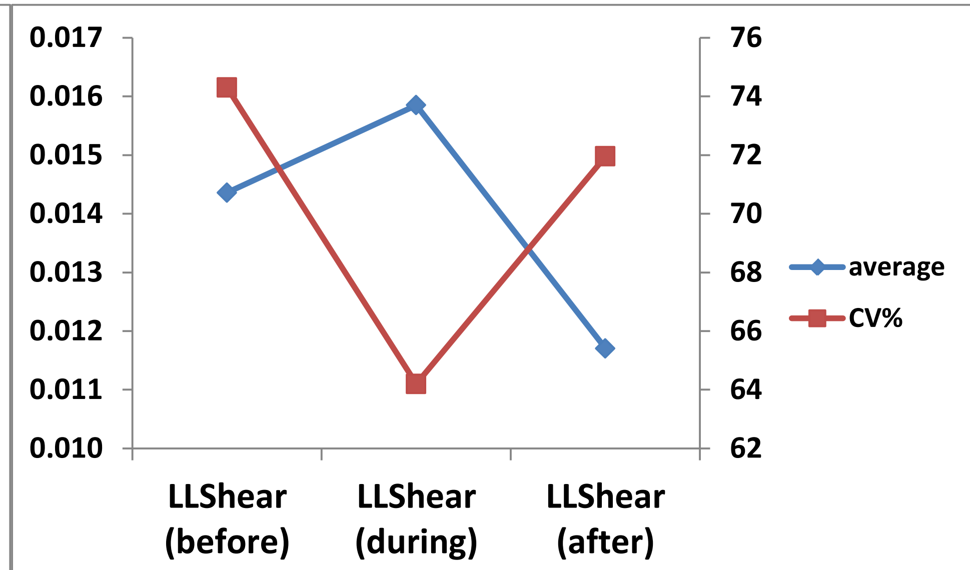
Maximum Estimated Size of Hail (mm)



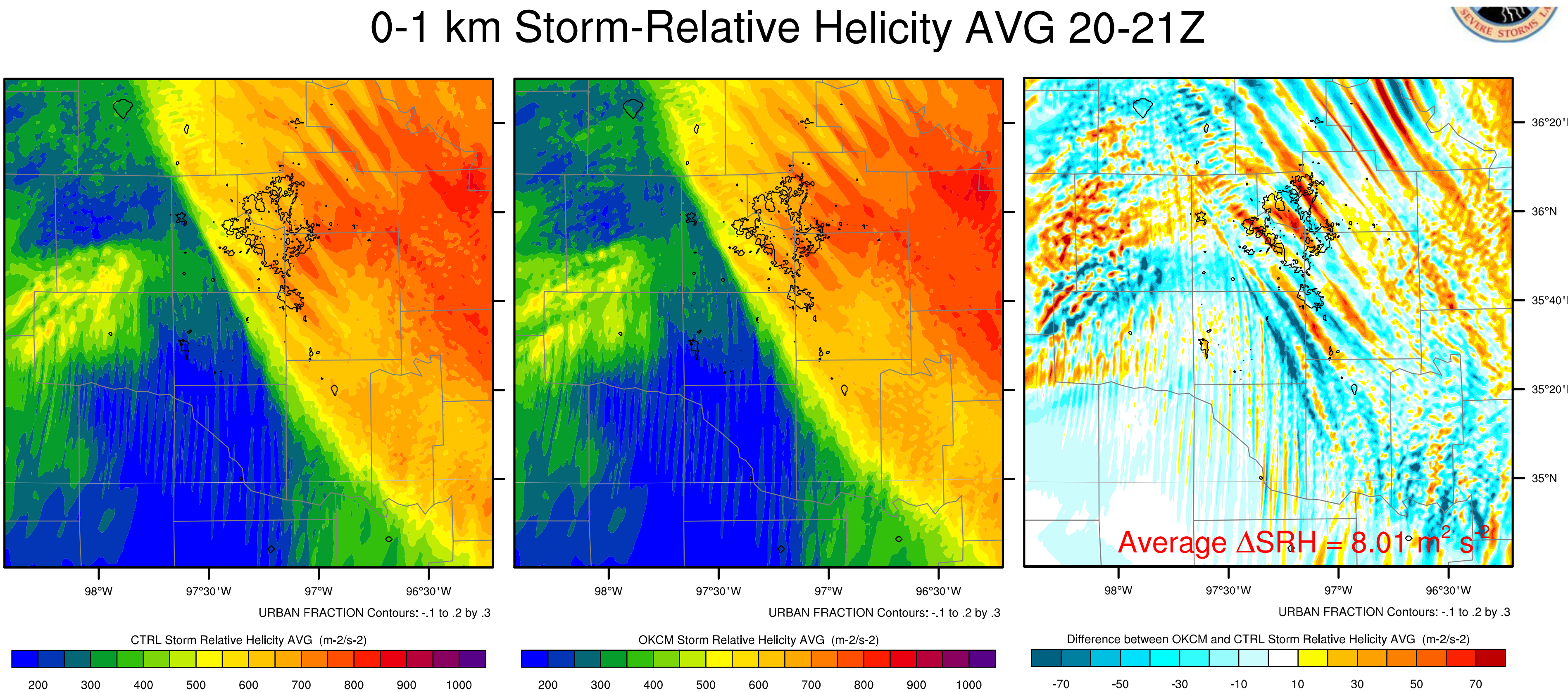
Azimuthal Shear (s^{-1})



Low Level (<3 km AGL) Shear (s^{-1})



0-1km Storm-Relative Helicity Changes



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

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

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

CTRL

OKCM

Updraft Helicity

$$UH = \int_{2000m}^{5000m} w\zeta \, dz$$

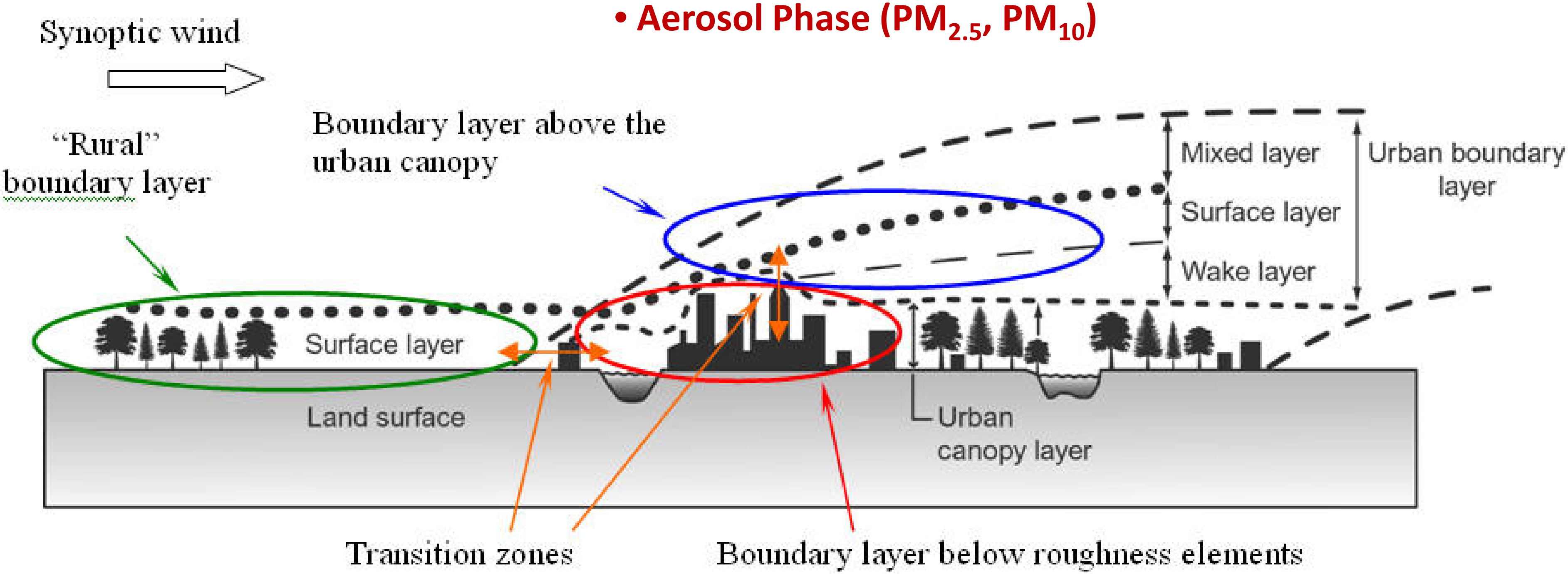
CRTL: max UH = 590 m^2/s^2

OKCM: max UH = 1539 m^2/s^2

The role of the urban pollution state

EPA Criteria Pollutants

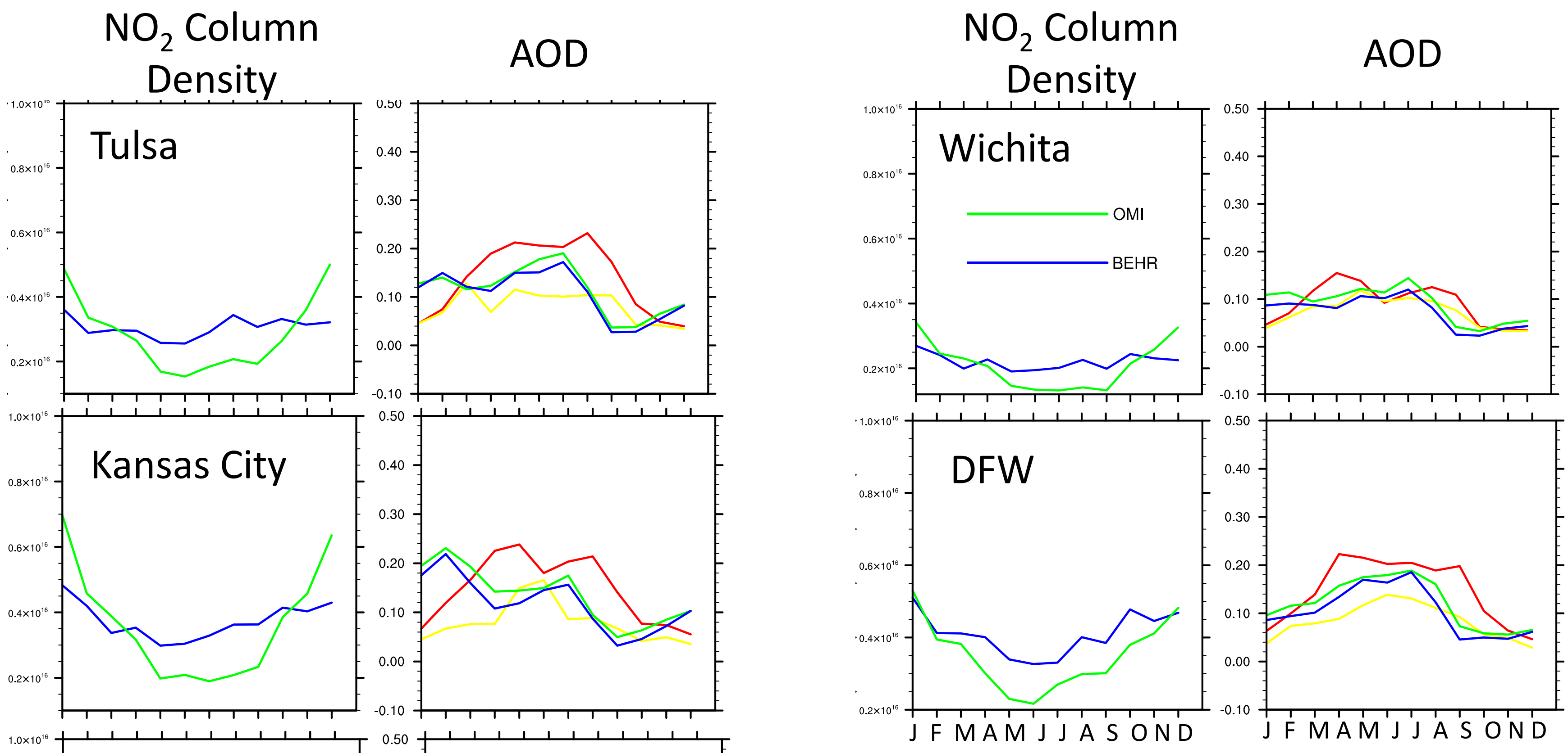
- **Gas Phase (CO, O_3, NO_x)**
- **Aerosol Phase ($PM_{2.5}$, PM_{10})**

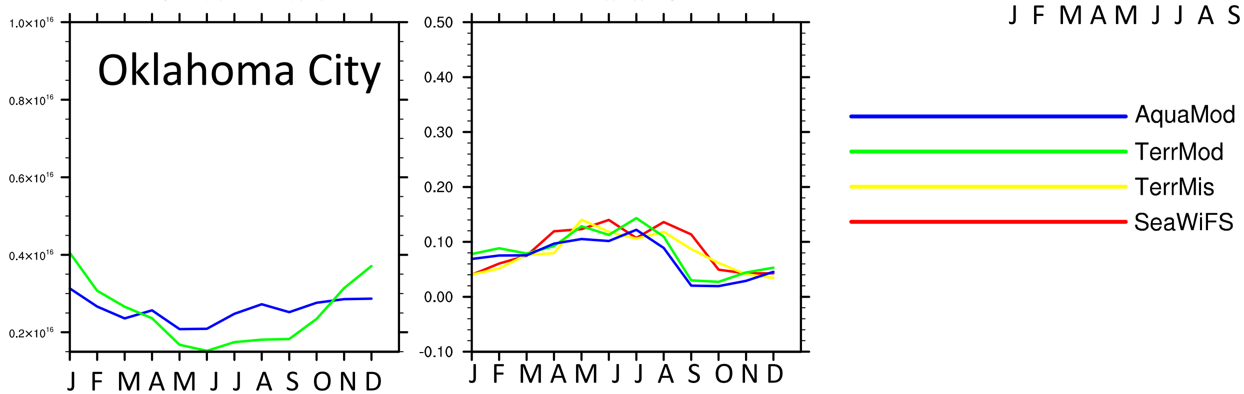


Project perspectives

1. Do urban pollutants (aerosols) contribute to the heat island effects?
2. Does atmospheric composition alter precipitation and extreme events? (aerosol indirect effect)

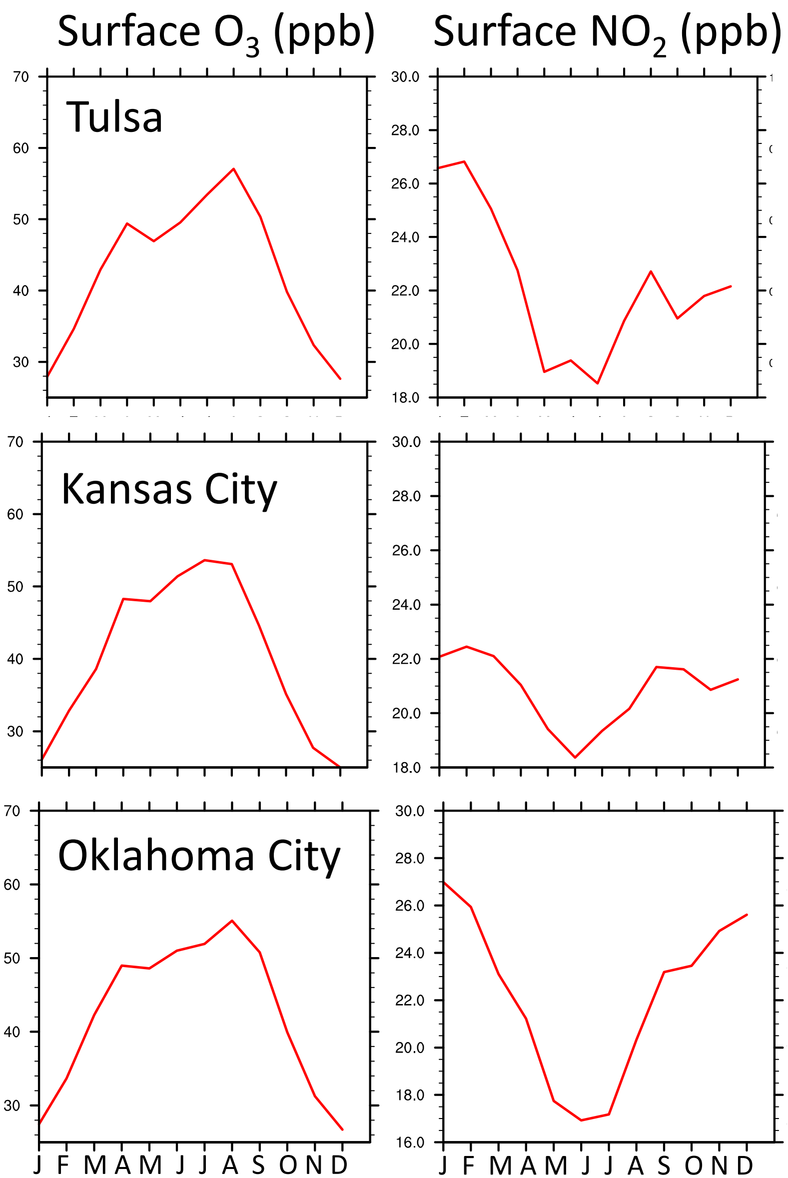
Findings from observations: Satellite-Derived

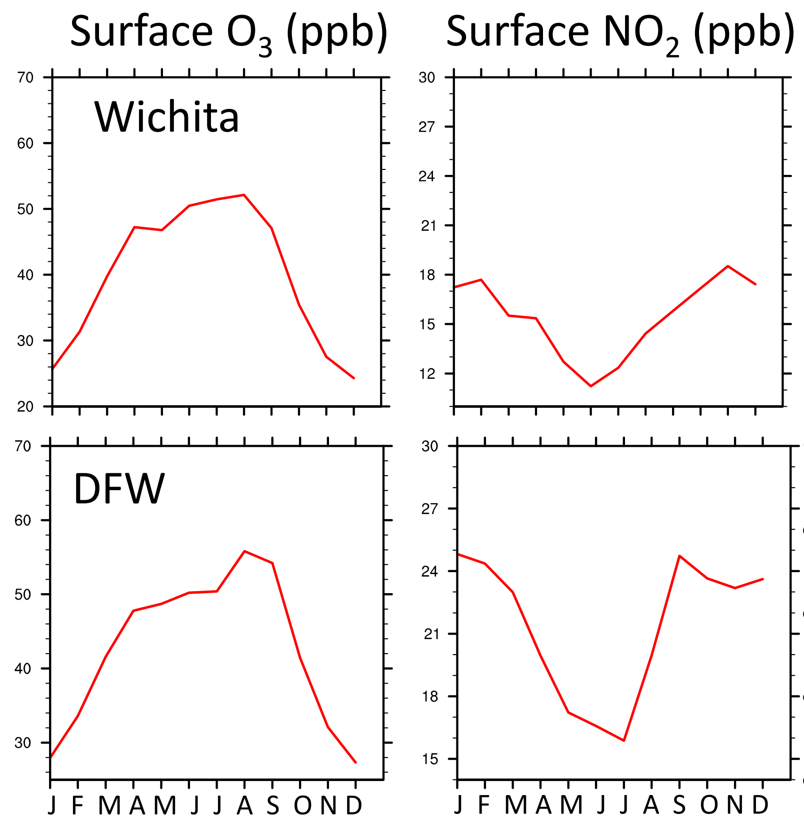




Seasonal snowfall affects satellite retrievals, seen especially in NO_2 column density and AOD

Findings from observations:
EPA Ground-Based Observations





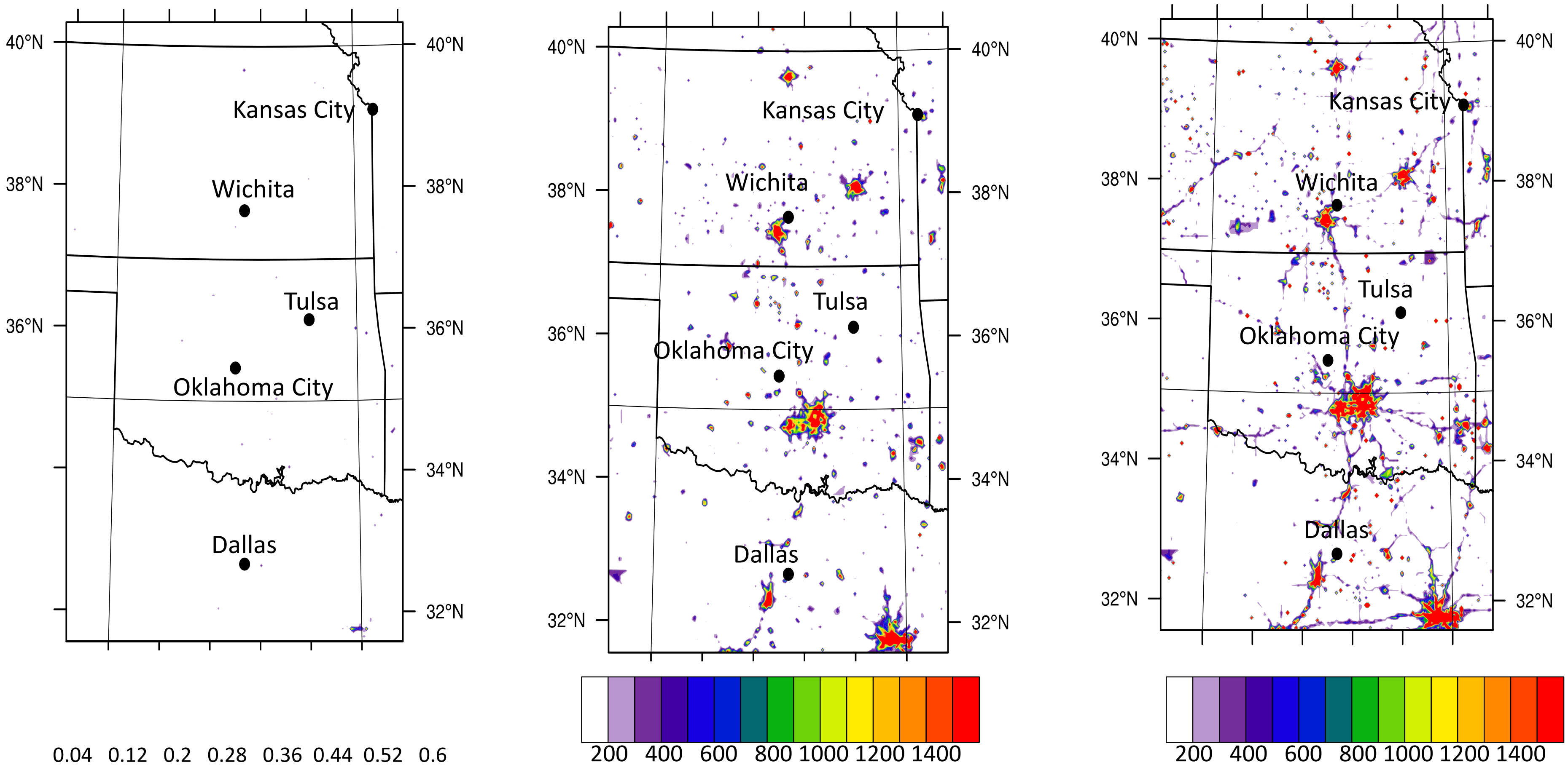
Midwestern cities experience low to moderate levels of pollution, with DFW being the only urban area with non-attainment problems in our study.

WRF/Chem Emissions

ENGINEERING

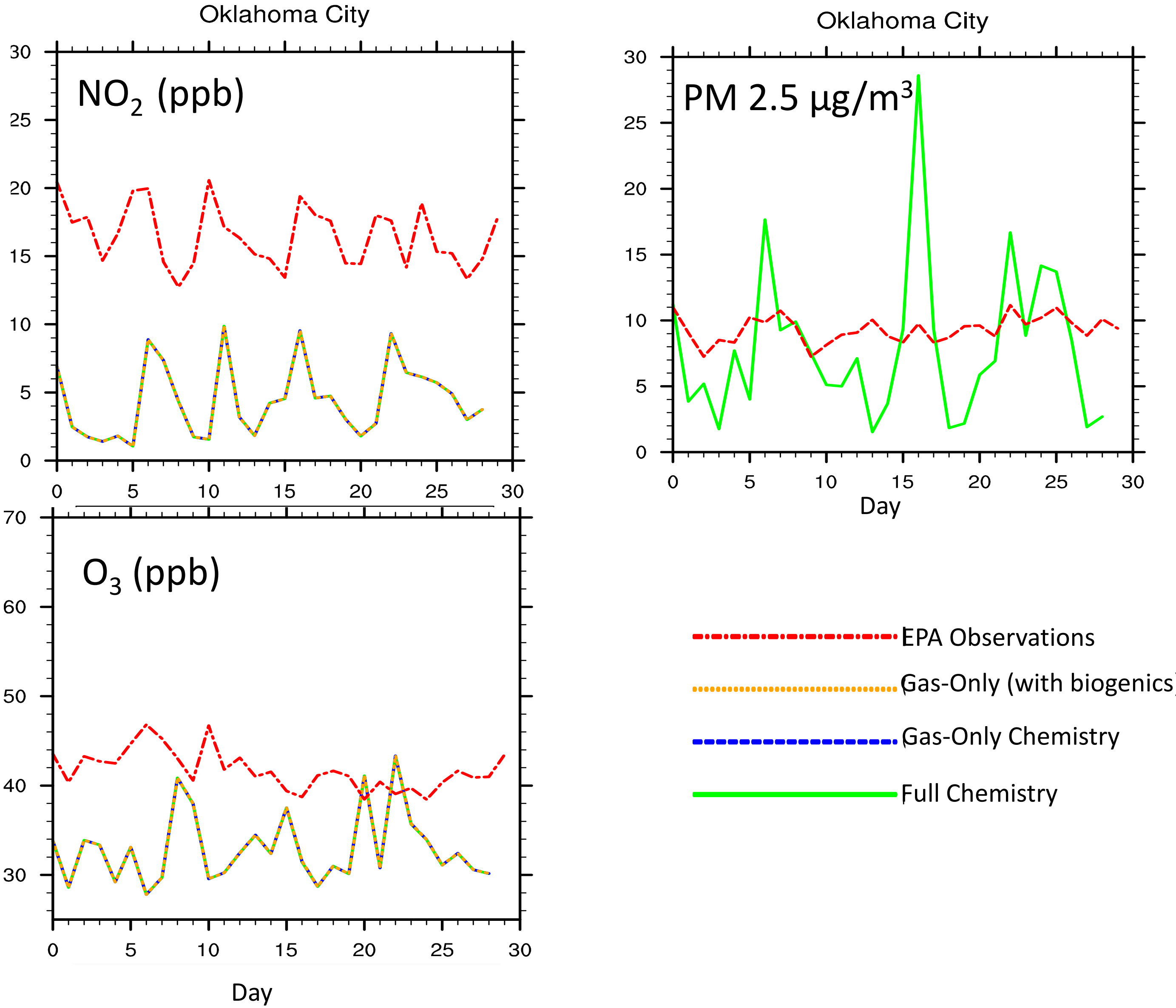
Molecules $hr^{-1}\ km^{-2}$

Isoprene | Anthropogenic VOCs | Anthropogenic NO_x



NOx emissions indicate that our emissions are not located correctly in the model domain

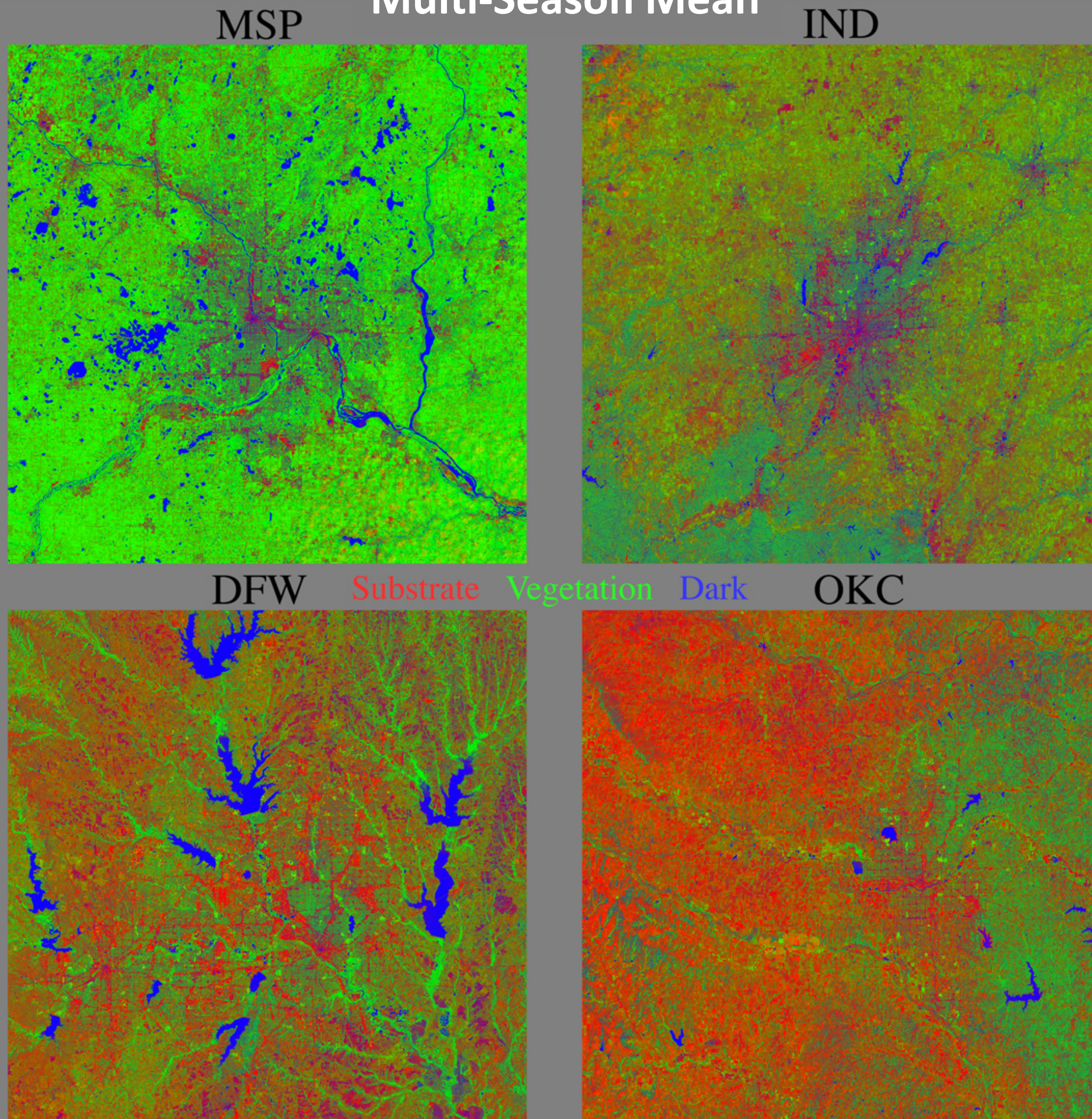
Model Evaluation: Chemistry (OKC)



- NO_2 and O_3 low for all cities
- NO_2 trends captured, but magnitude is off, indicating an emissions issue
- $P(O_3)$ is a function of NO_x and VOC emissions
- PM 2.5 doesn't really match – could be related to precipitation

COLUMBIA UNIVERSITY
IN THE CITY OF NEW YORK

Multi-Season Mean

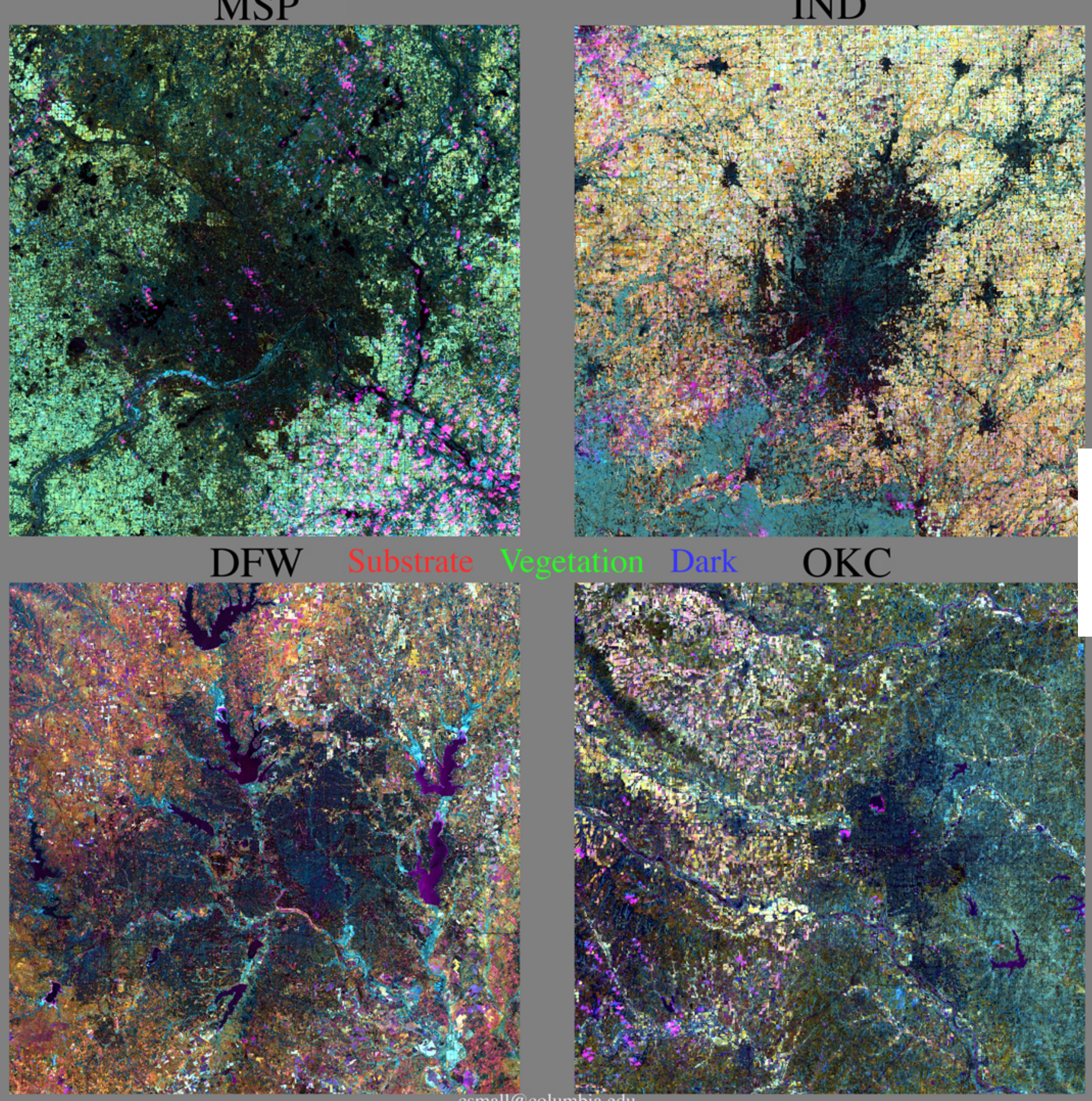


R=Substrate
G=Vegetation
B=Dark

csmall@columbia.edu

Columbia University in the City of New York

Multi-Season Stdev



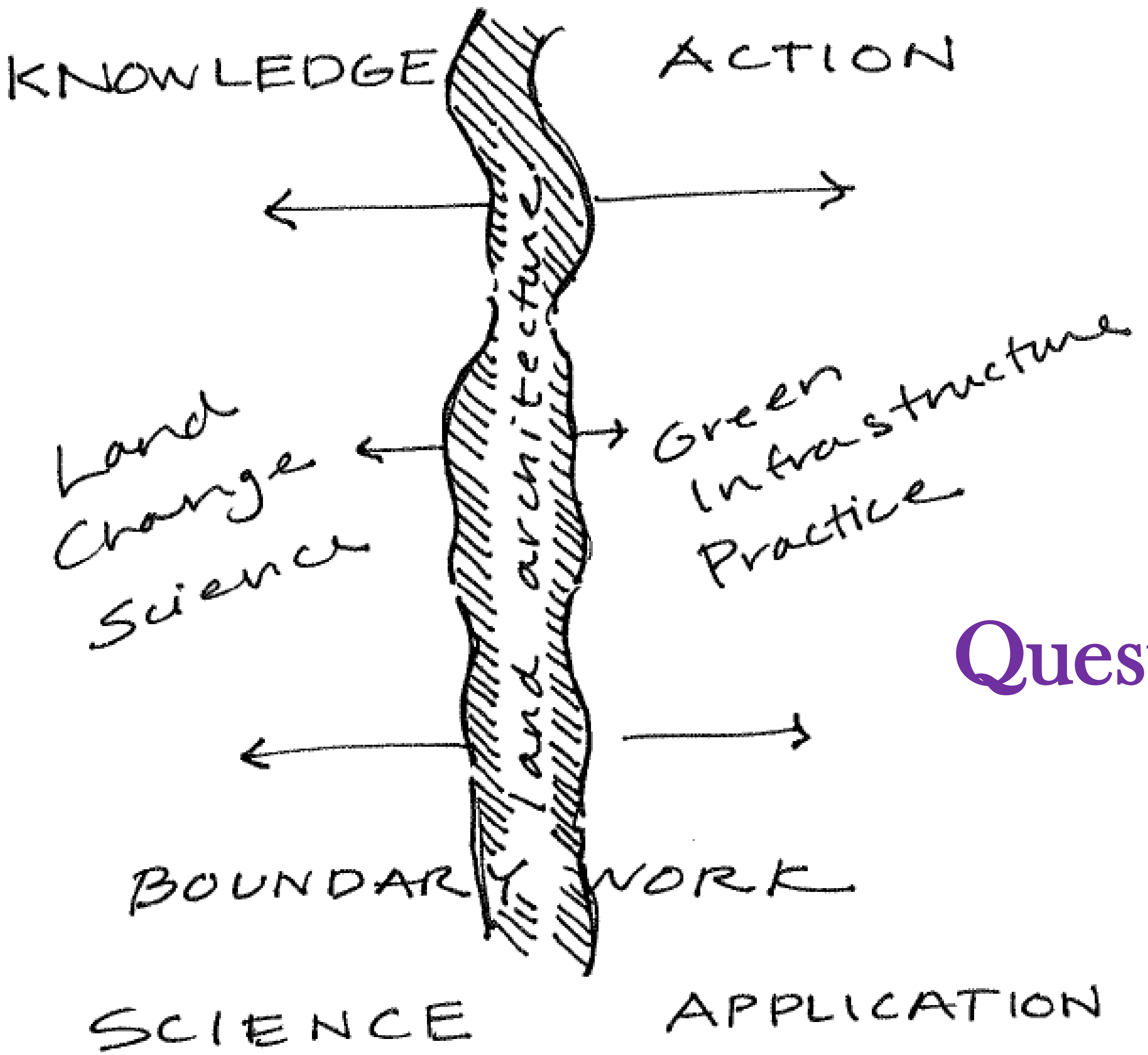
R=Substrate
G=Vegetation
B=Dark

(Photos: Laura Musacchio)

LAND ARCHITECTURE

Land architecture is defined as “the collective design of stakeholders with different land-use goals” and addresses “tradeoffs within and between the human and environmental subsystems of land systems in terms of the kind, magnitude, and pattern of land uses and covers” (Turner 2010, 170).

A conceptual diagram of boundary work for *land change science* and *green infrastructure practice* and the role of *land architecture* as a bridging concept (Figure by Laura Musacchio).



Questions?