How much does Kansas rangeland burning contribute to ambient O_3 and $PM_{2.5}$?

- Analysis of data from 2001 to 2016

Dr. Zifei Liu

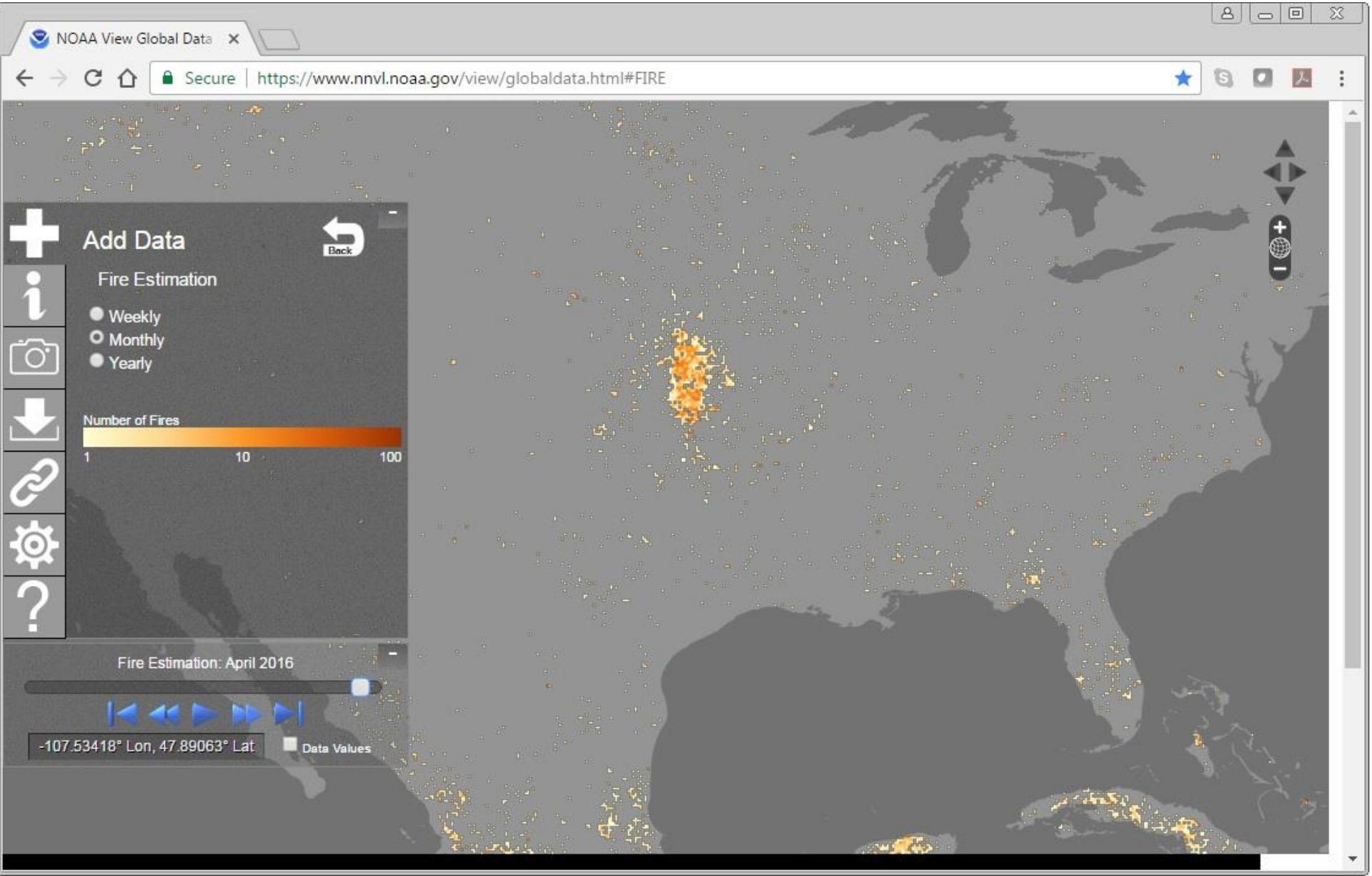
zifeiliu@ksu.edu

Rangeland burning smoke management
and air quality workshop
April 3rd, 2017

K·STATE Research and Extension | Biological and Agricultural Engineering

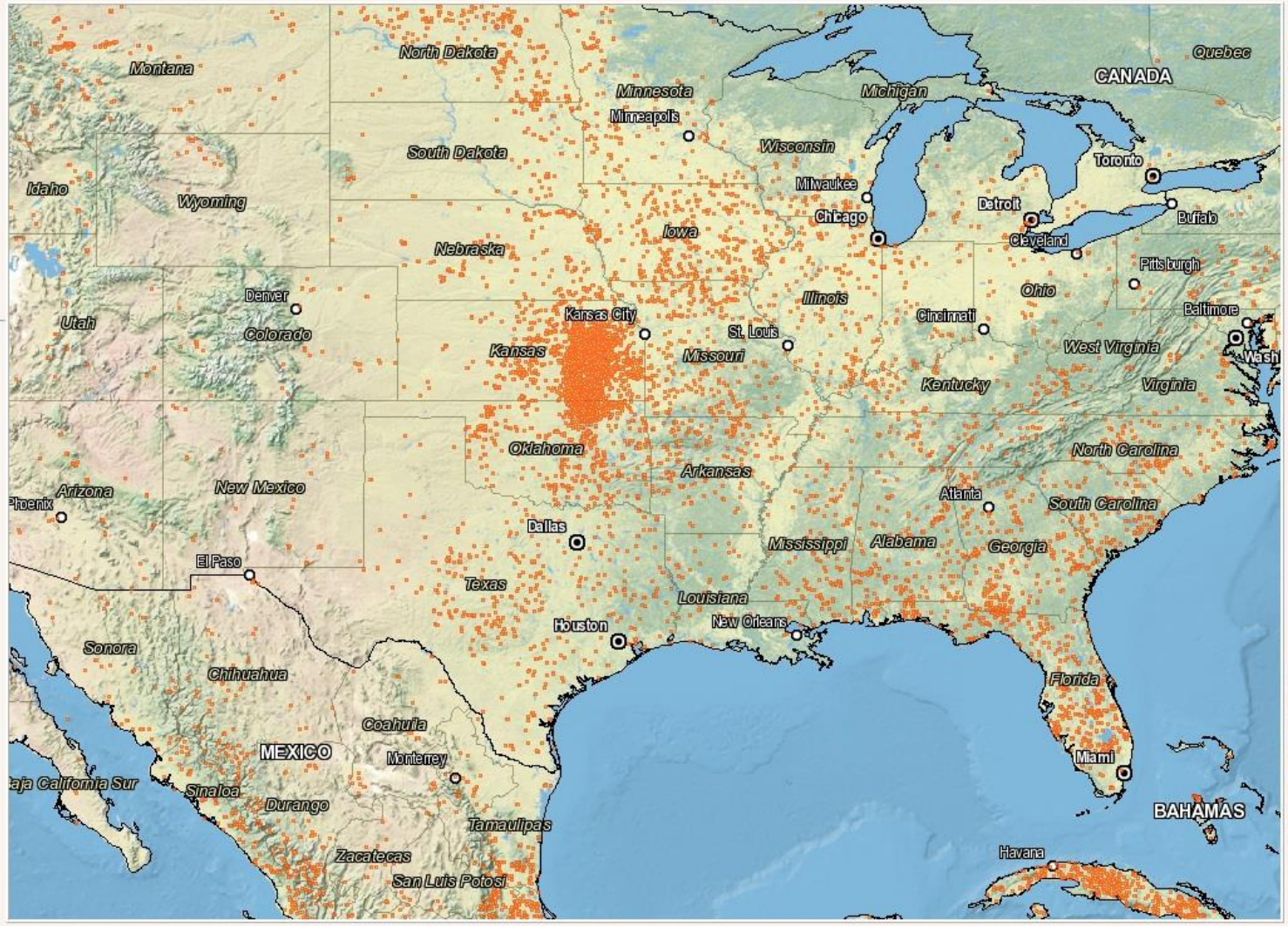
Knowledge for Life

Satellite fires



FIRMS Web Fire Mapper

https://firms.modaps.eosdis.nasa.gov/firemap/



Bookmark current view

Fires

Select fires to display using the following choices.

Data source:
MODIS NRT C6

Satellite source:
Aqua & Terra

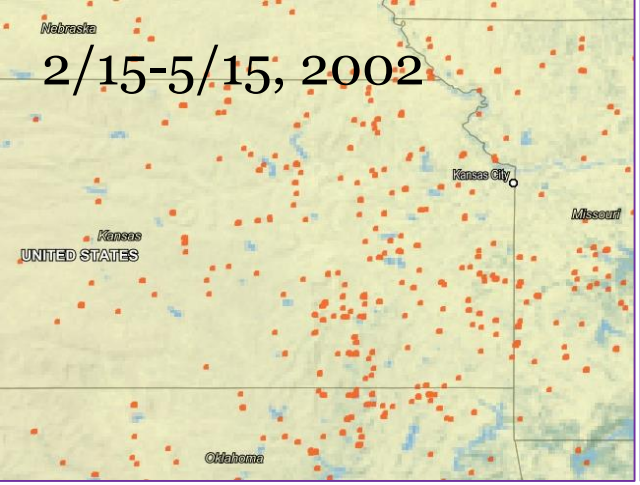
Time period:
- Past 24 hours
- Past 48 hours
- Past 72 hours
- Past 7 days

Custom
Start: 2016-04-01
End: 2016-05-01
Update

Viewing the Fire Aggregate Grid?
Toggle Fire Aggregates Legend

Note: Cloud cover may obscure active fire detections.

Regions
Background Images
Layers
MODIS Burned Area
Activity Log
Links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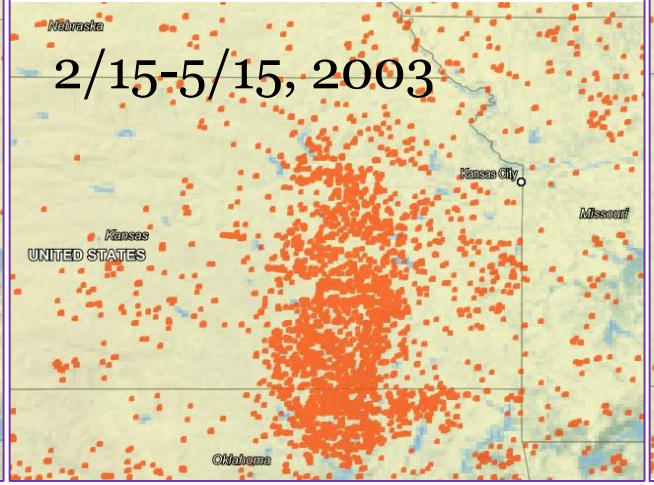
Nebraska
Kansas City
Missouri
Kansas
UNITED STATES
Oklahoma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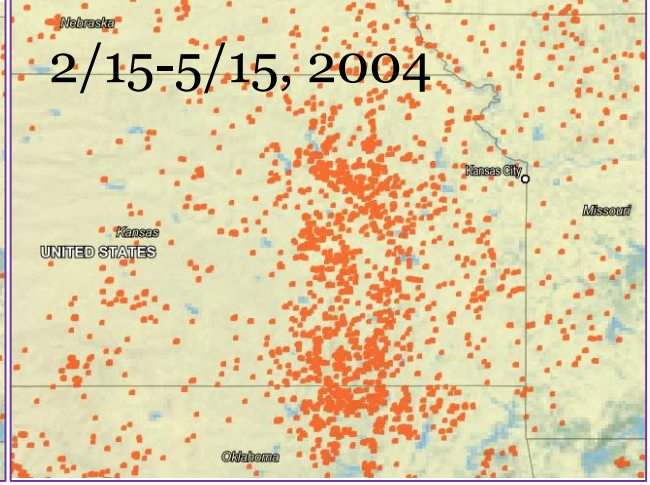
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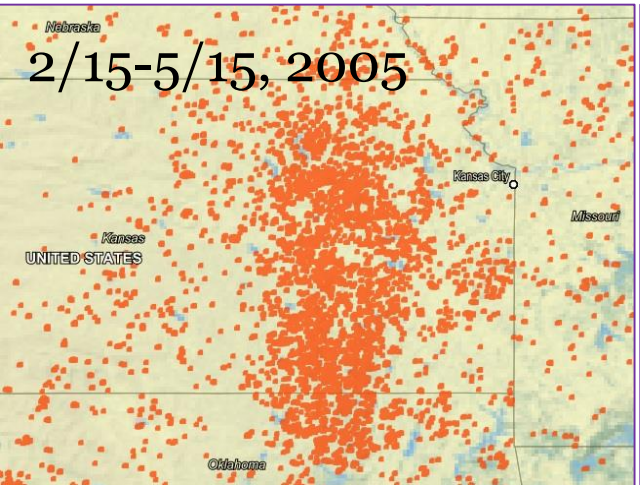
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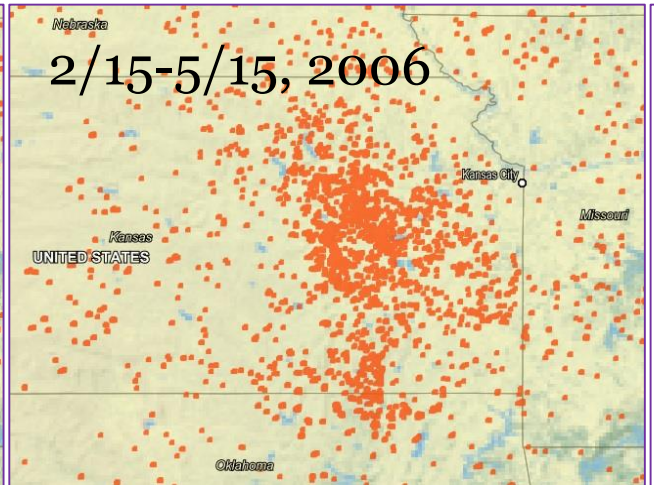
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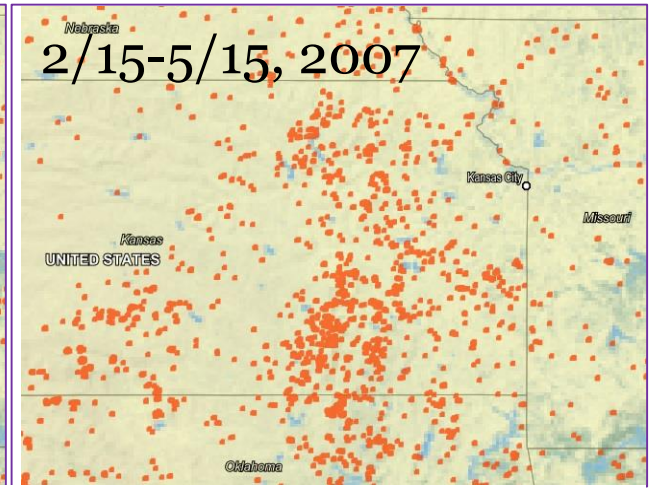
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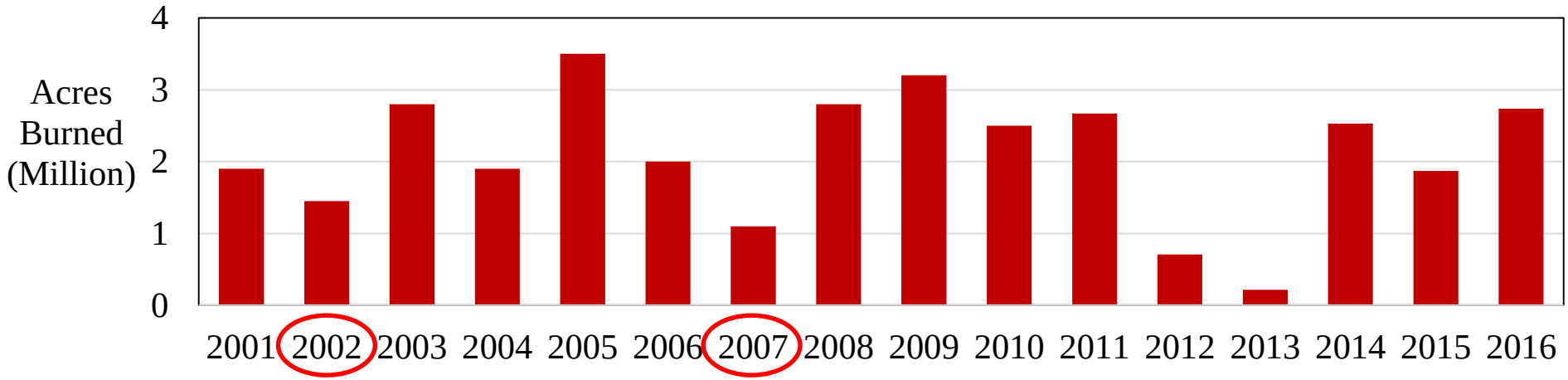
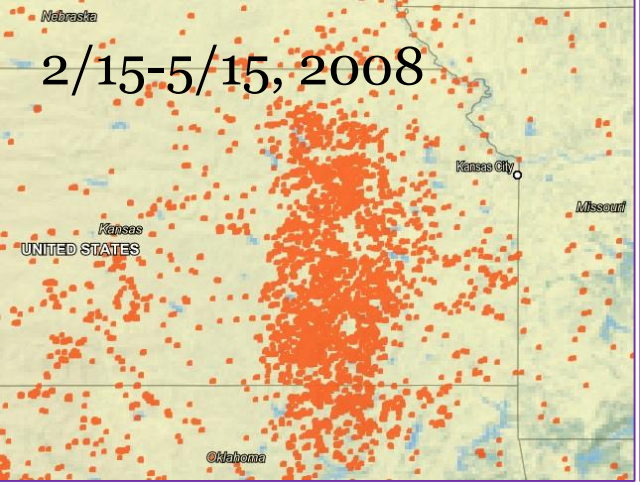

Acres Burned (Million)
4
3
2
1
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016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Kansas
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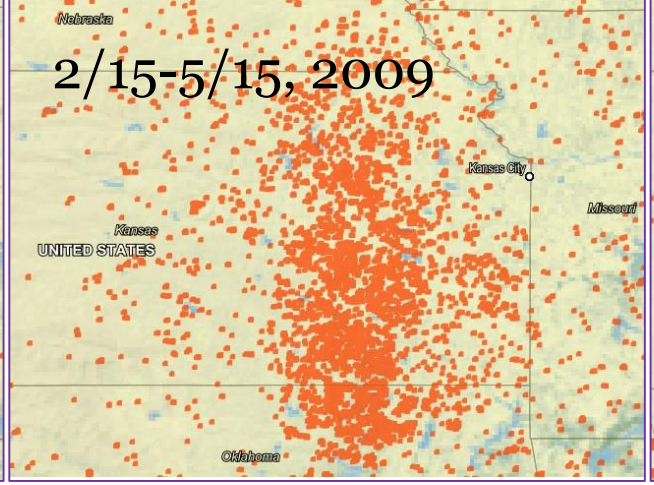
Oklahoma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Kansas
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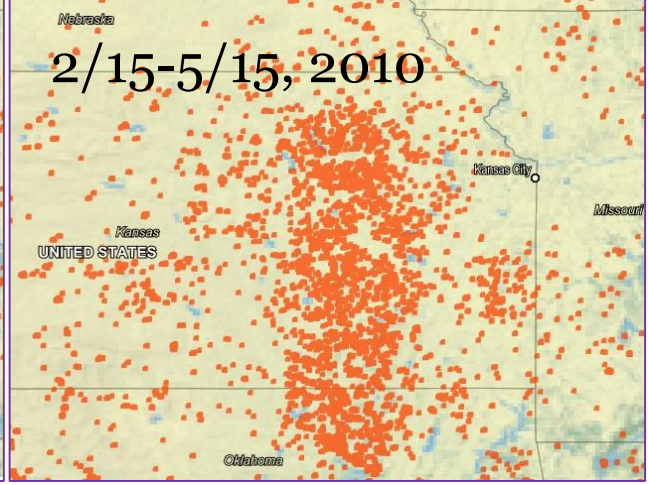
Oklahoma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Missouri
Kansas
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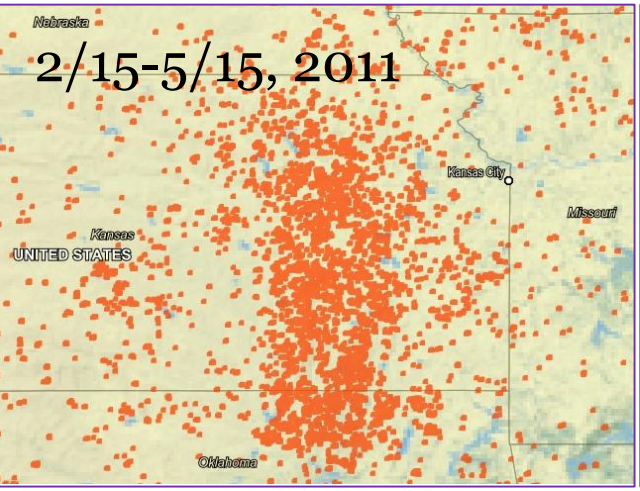
Oklahoma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Missouri
Kansas
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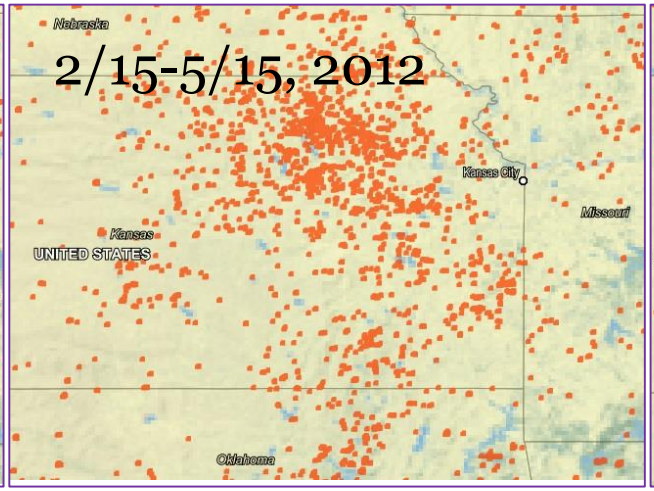
Oklahoma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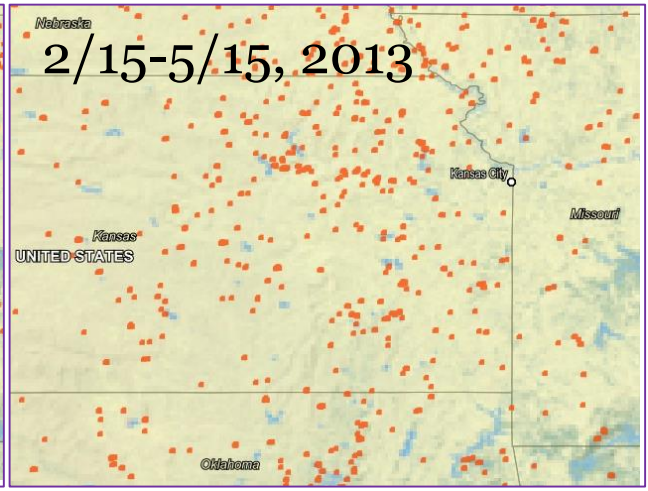
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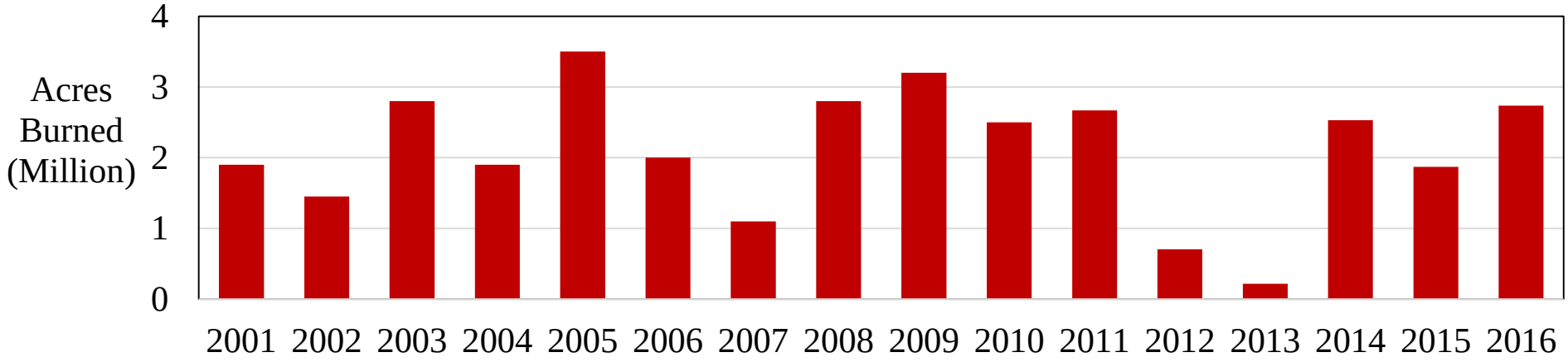
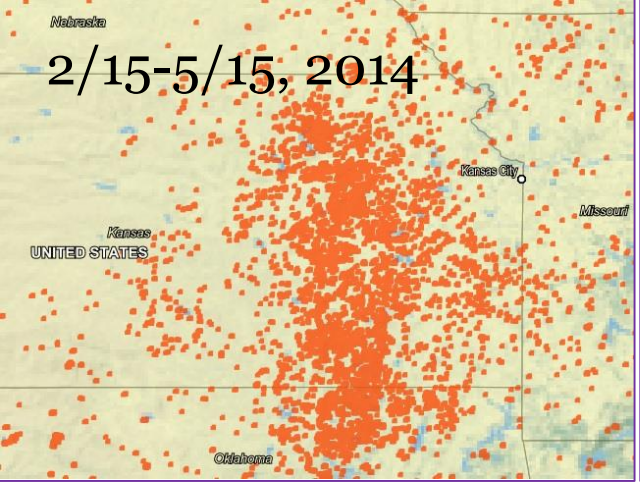
Kansas City
Missouri
Kansas
UNITED STATES
Oklahoma


Acres Burned (Million)
0
1
2
3
4
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016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Kansas
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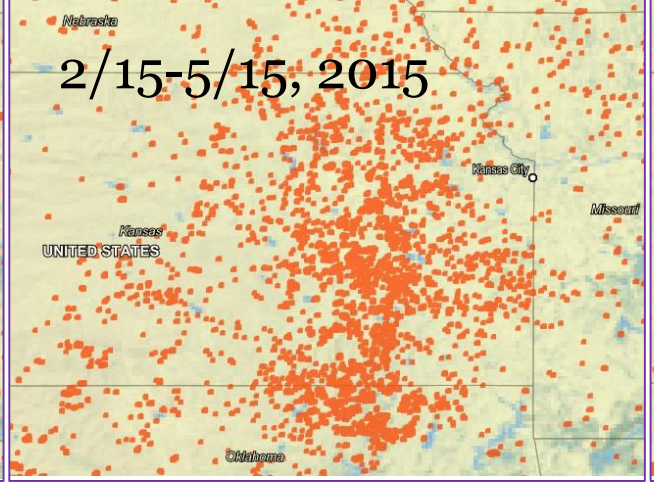
Oklahoma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Missouri
Kansas
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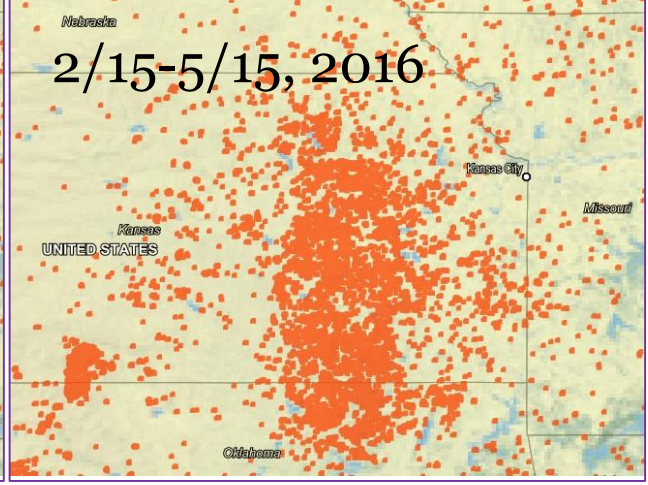
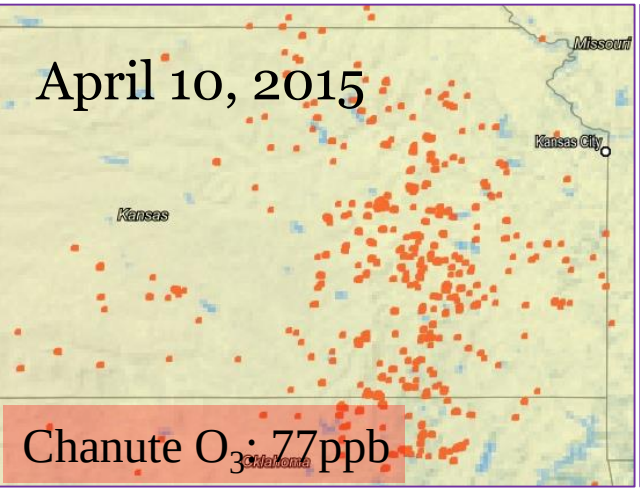
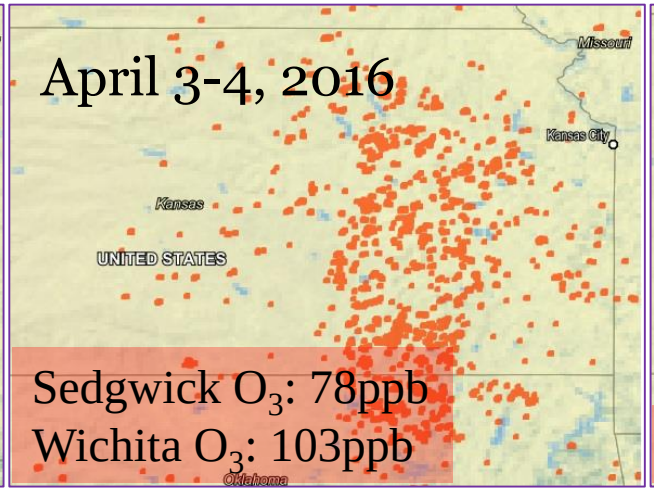
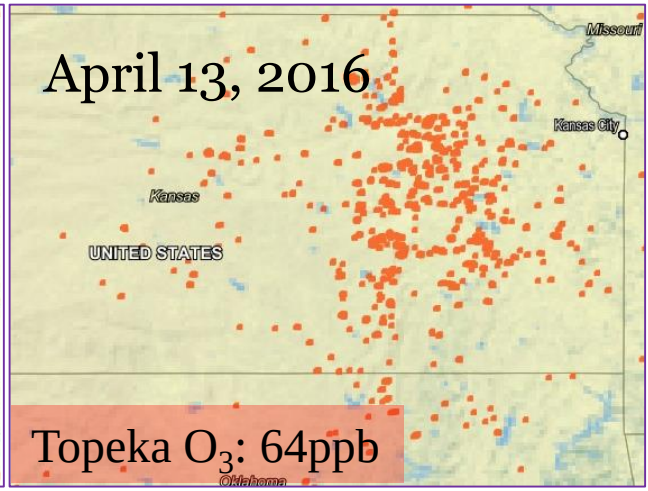
Oklahoma


2/15-5/15, 2016
Nebraska
Kansas City
Missouri
Kansas
UNITED STATES
Oklahoma


April 10, 2015
Missouri
Kansas City
Kansas
Chanute O_3: 77ppb
Oklahoma


April 3-4, 2016
Missouri
Kansas City
Kansas
UNITED STATES
Sedgwick O_3: 78ppb
Wichita O_3: 103ppb
Oklahoma


April 13, 2016
Missouri
Kansas City
Kansas
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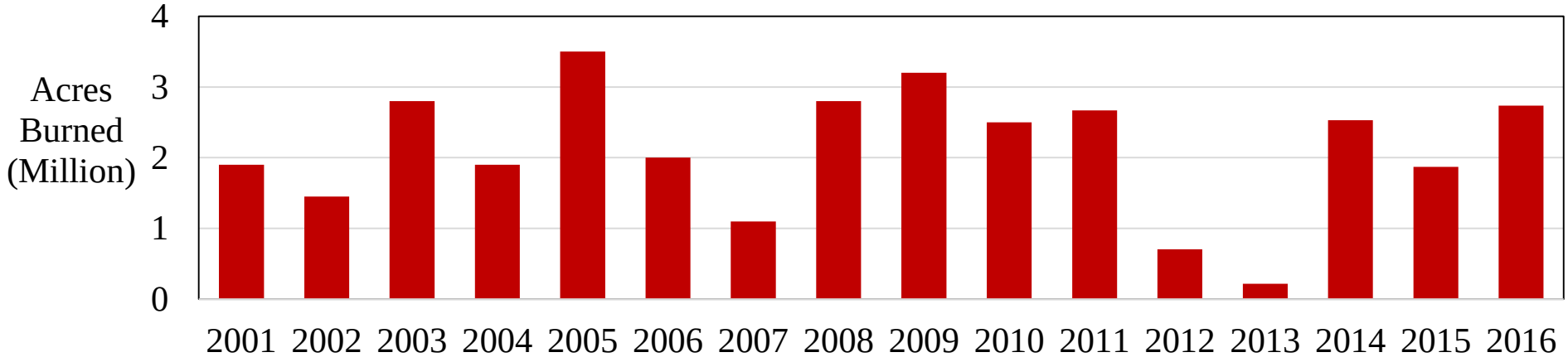
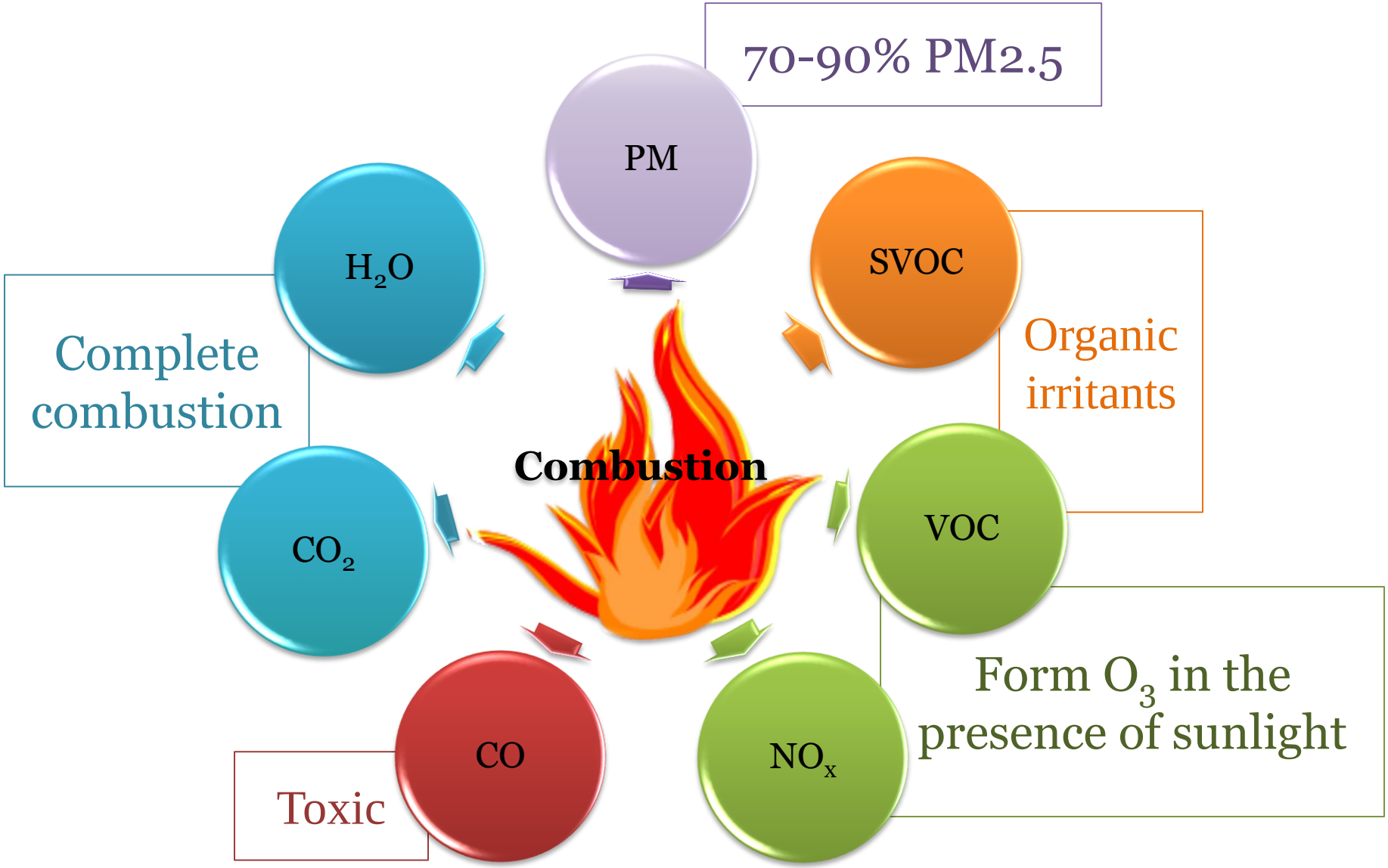
Topeka O_3: 64ppb
Oklahoma


Acres Burned (Million)
0
1
2
3
4
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016

Smoke and air quality



Air pollutants	Observed concentrations in literature		Standards
	At the fires	At downwind communities	
$PM_{2.5}$	148-6865 μg/m^3	63-400 μg/m^3	[a]35 μg/m^3
Acrolein	0.018-0.071ppm	0.009 ppm	[c]0.1 ppm
Formaldehyde	0.03-0.47 ppm	0.02-0.047 ppm	[c]0.016 ppm
Isocyanic acid	-	600 ppb	-
PAHs	-	-	[d]200 μg/m^3
BaP	0.10-0.16 μg/m^3	0.007 μg/m^3	-
Acenaphthene	0.57-1.53 μg/m^3	0.83-0.89 μg/m^3	-
Naphthalene	0-3.27 μg/m^3	0-3.53 μg/m^3	-
Phenanthrene	0.38 μg/m^3	-	-
CO	1-140 ppm	1-6 ppm	[b]9 ppm
O_3	-	Up by 50 ppb	[b]70 ppb

a. NAAQS 24-hr standards; b. NAAQS 8-hr standards;
c. NIOSH 8-hr exposure limits; d. OSHA 8-hr exposure limits

Regulations

- Clean Air Act (CAA)
- National Ambient Air Quality Standards (NAAQS)
- Six criteria air pollutants
  - Particulate Matter (PM)
  - Ozone (O_3)
  - Nitrogen Dioxide (NO_2)
  - Sulfur Dioxide (SO_2)
  - Carbon Monoxide (CO)
  - Lead (Pb)
- Five year review cycle
- Nonattainment area
- State Implementation Plan (SIP)

http://www.epa.gov/ttn/naaqs/

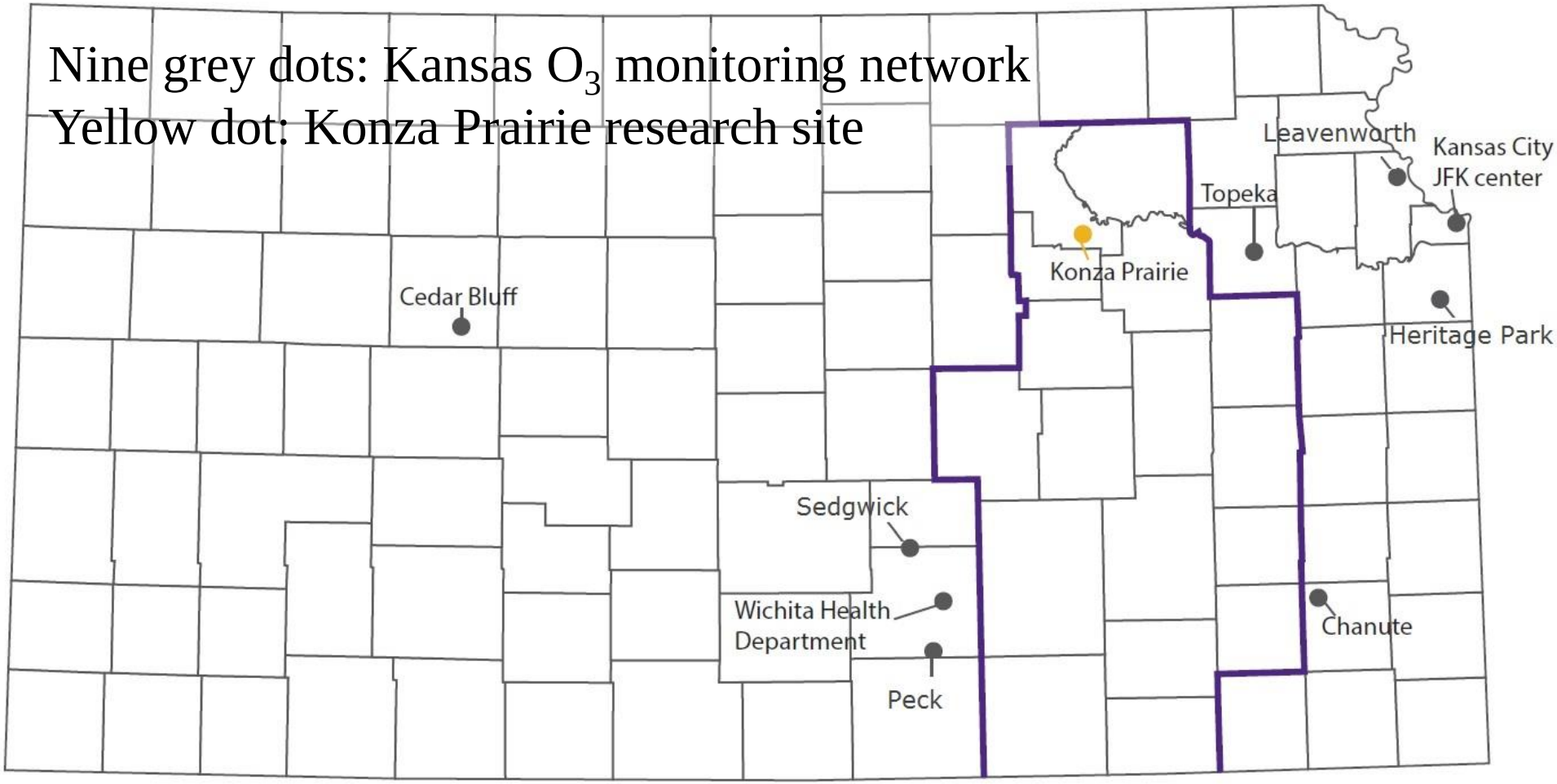
Evolution of O_3 standards

	8-hour	1-hour
1979		120ppb
1997	80ppb	
2008	75ppb	
2015	70ppb	

Evolution of PM standards

		Annual	24-hour
1971	TSP	75 μg/m^3	260 μg/m^3
1987	PM_{10}	50 μg/m^3	150 μg/m^3
1997	$PM_{2.5}$	15 μg/m^3	65 μg/m^3
2006	$PM_{2.5}$	15 μg/m^3	35 μg/m^3
2012	$PM_{2.5}$	Primary 12 μg/m^3 Secondary 15 μg/m^3	35 μg/m^3

Kansas O_3 monitoring sites

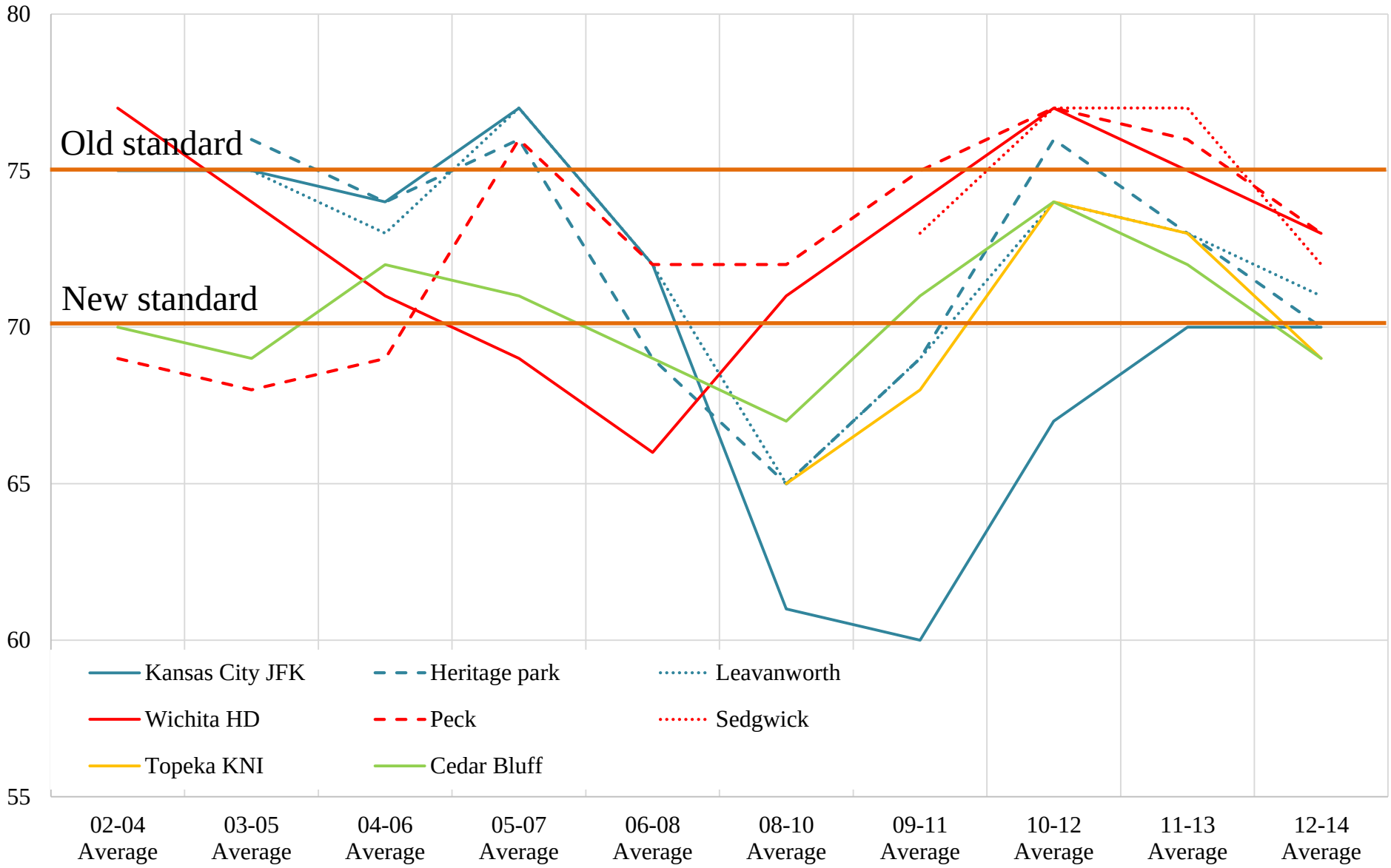


Purple lines: perimeter of the Flint Hills region

- Design value
  - a statistic of air pollutant concentrations.
  - used to compare with air quality standards and to designate nonattainment areas.

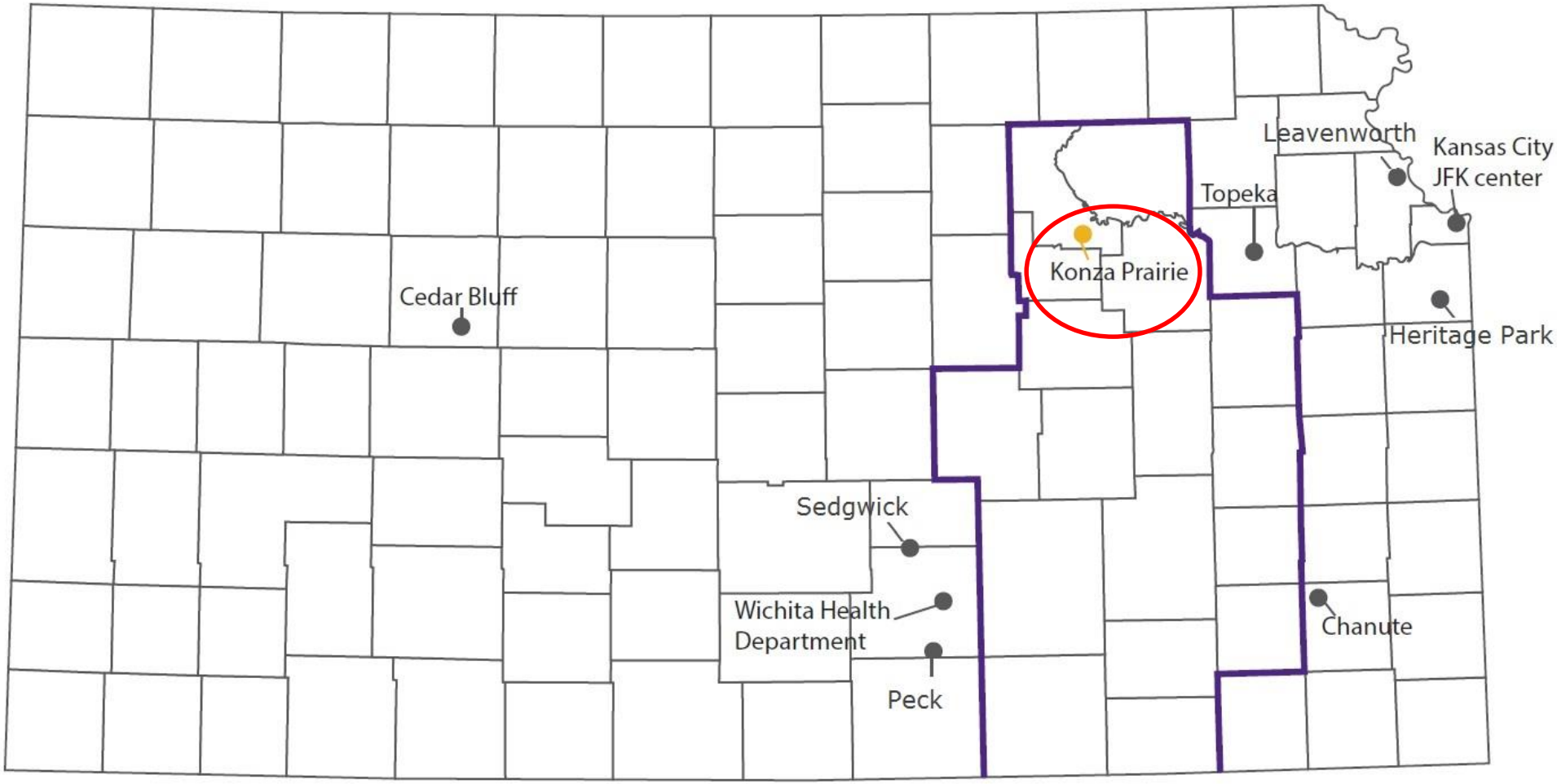
- The design value of O_3
  - the annual fourth-highest daily max 8-hour concentration, averaged over 3 years.

Kansas 8hr O_3 design values (ppb)



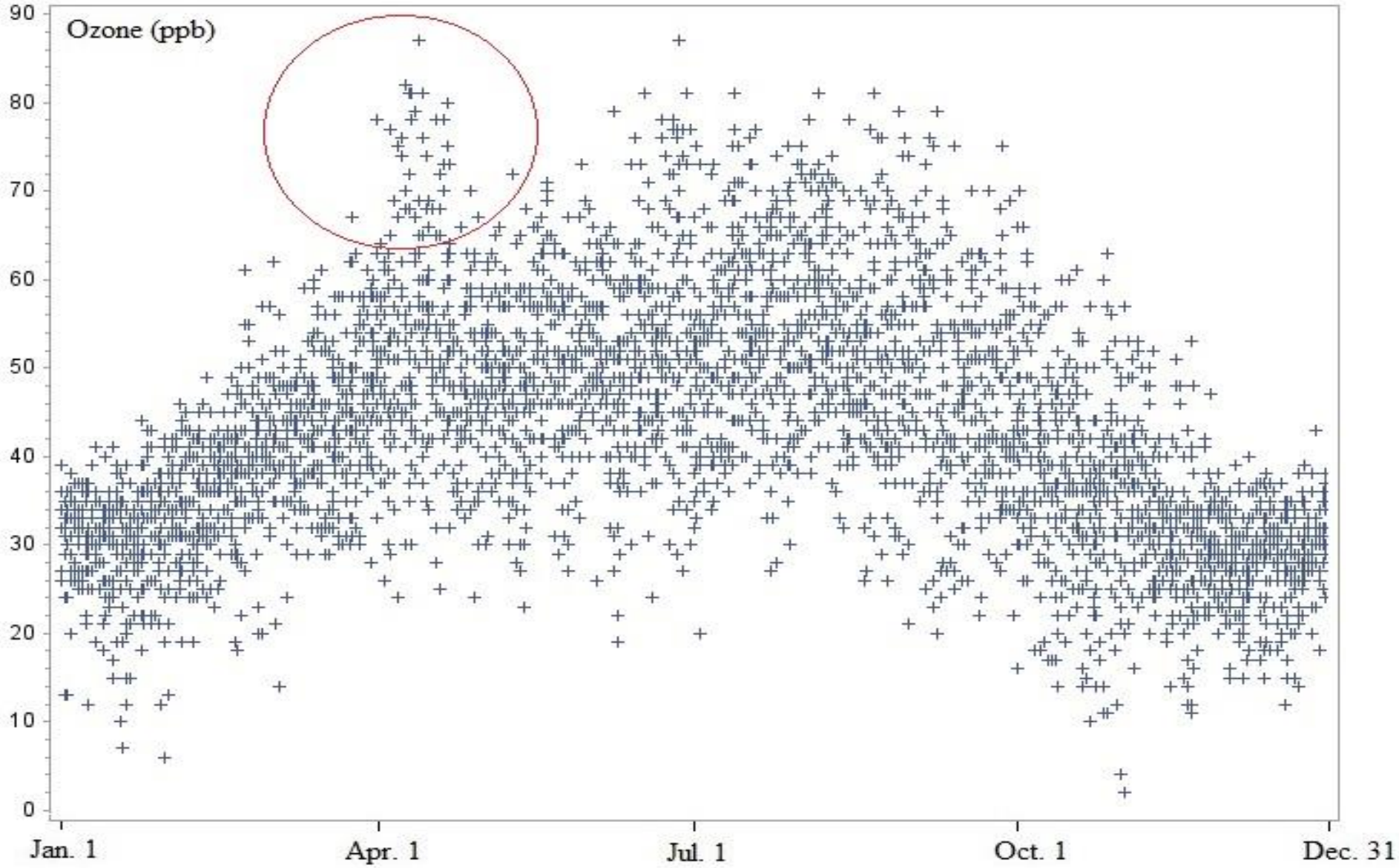
(Data from KDHE, 2010 and 2015. 5-Year Ambient Air Monitoring Network Assessment)

O_3 at the Konza Prairie research monitoring site (2002-2013)

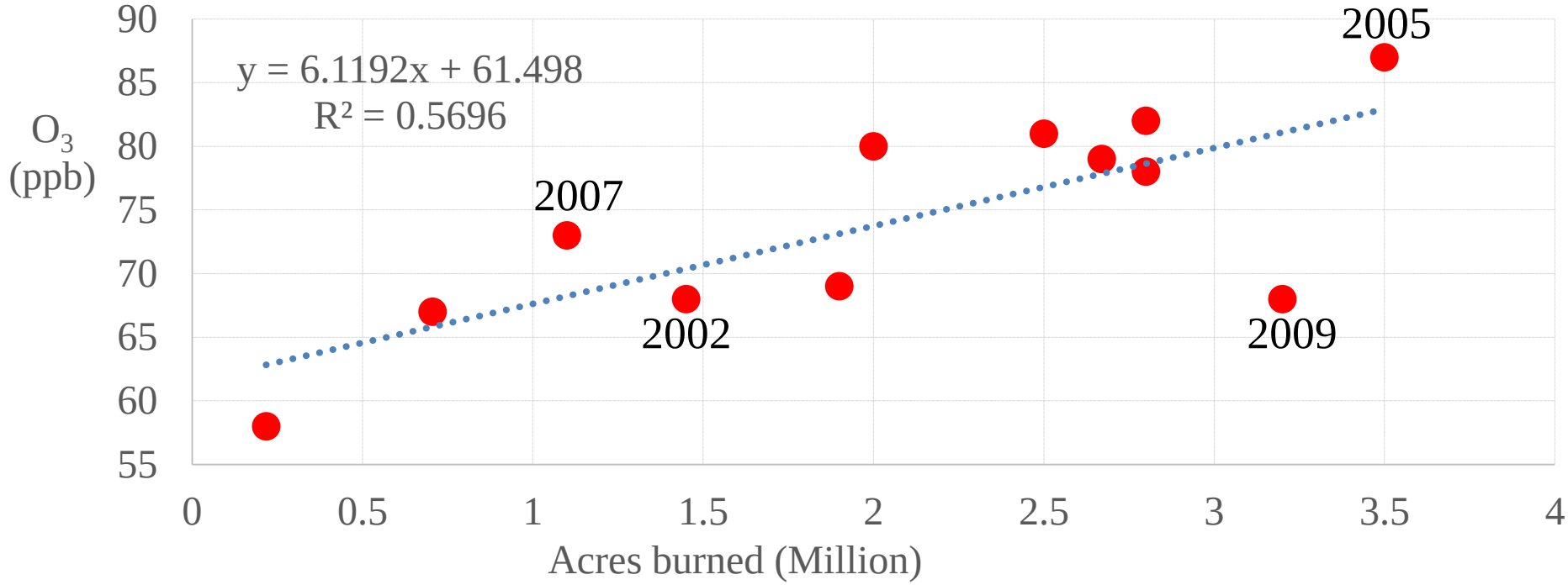


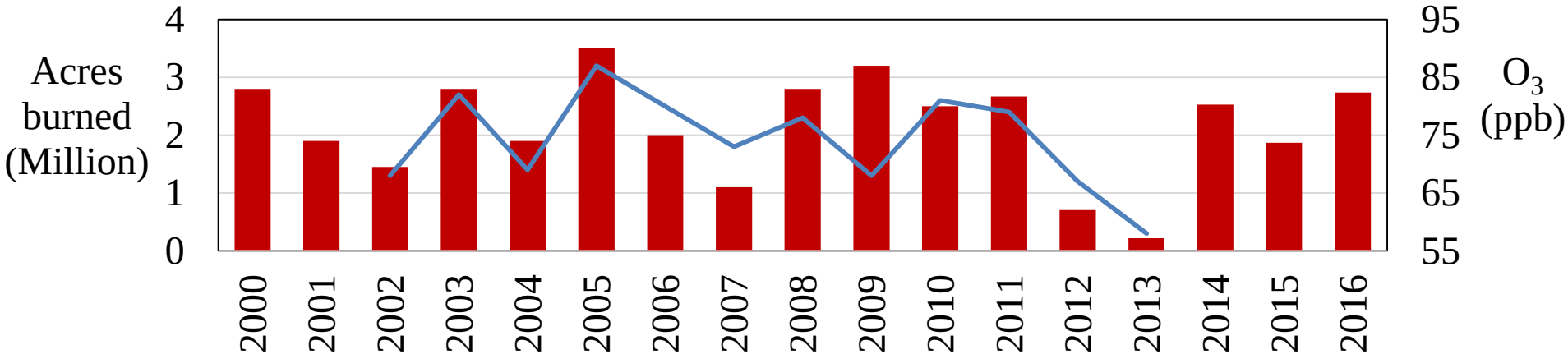
Clean Air Status and Trends Network (CASTNET)

Daily max 8hr O_3 at the Konza Prairie site (2002-2013)

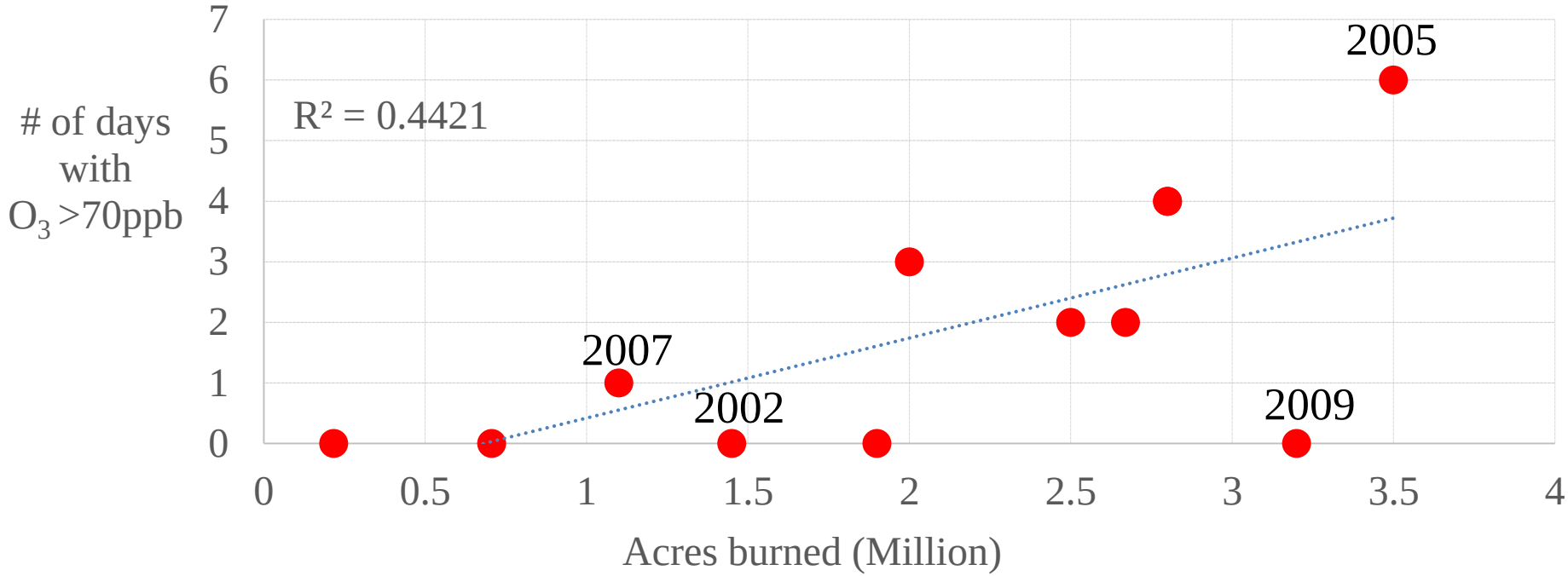


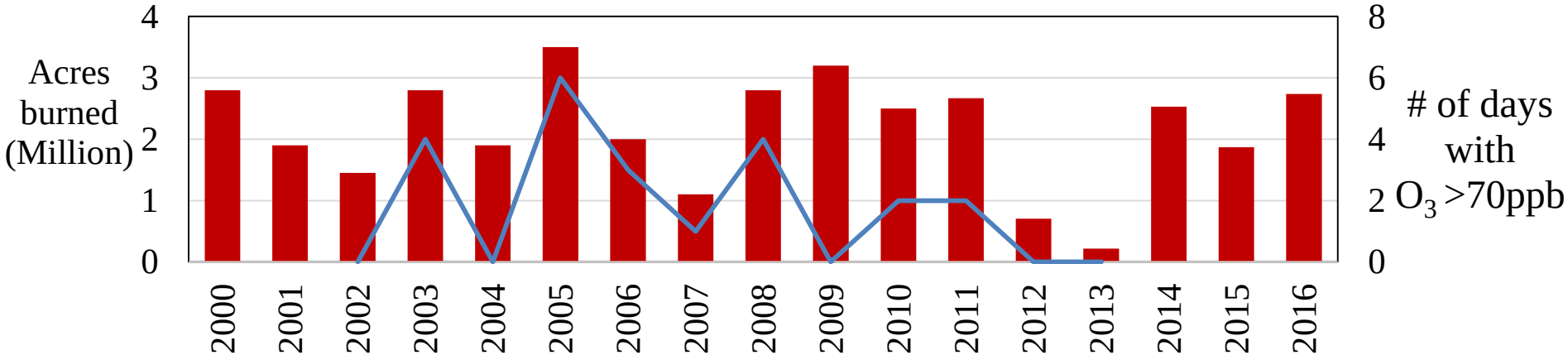
Highest 8hr O_3 in April vs. acres burned (Konza Prairie site)





Number of days with 8hr O_3 >70ppb in April vs. acres burned (Konza Prairie site)

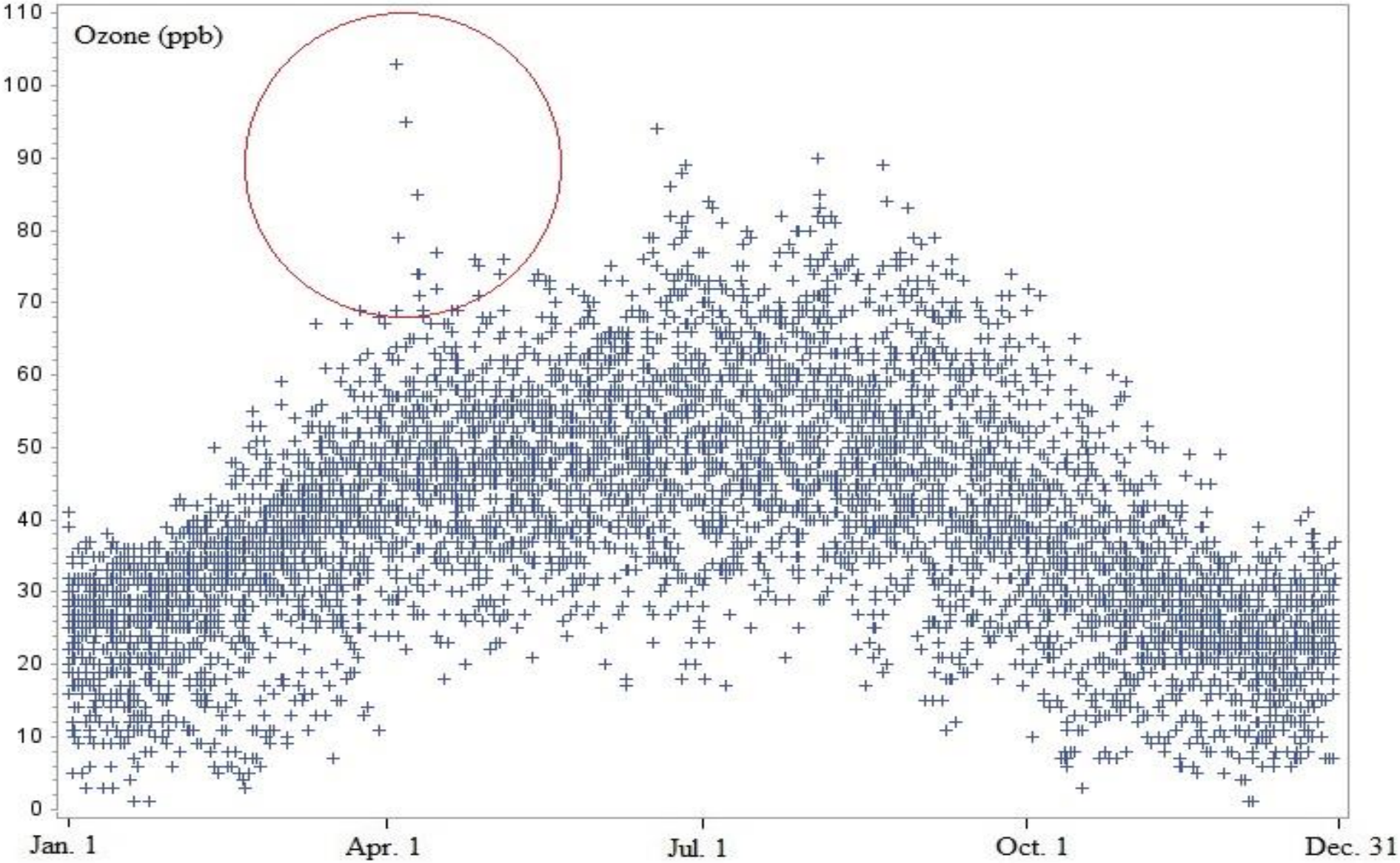




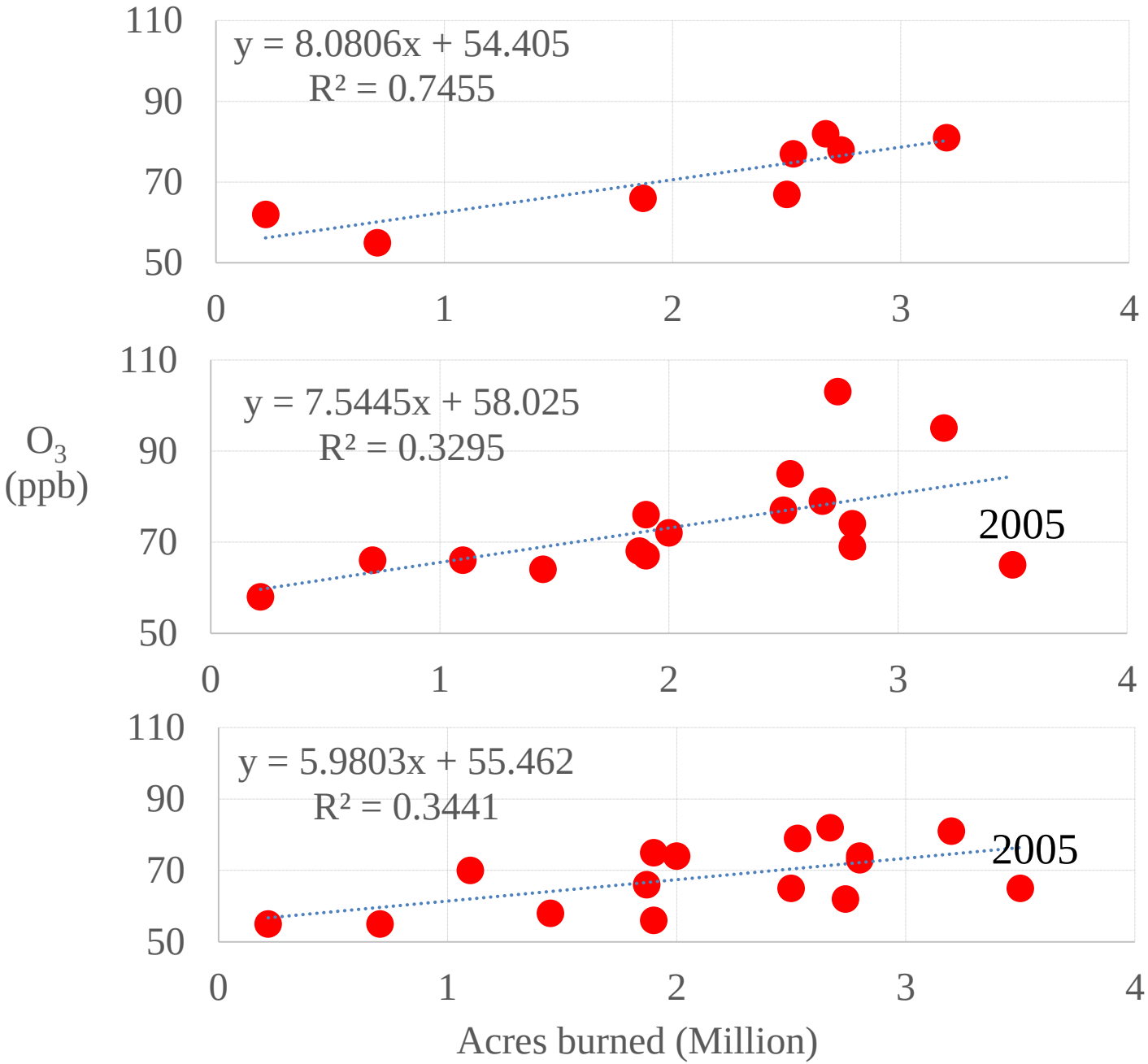
8hr O_3 at the Konza Prairie site (2002-2013)

- O_3>70ppb occurred in all years when acres burned ≥ 2 million (except 2009).
- O_3>70ppb did not occur for all years when acres burned < 1 million.

Daily max 8hr O_3 at the Wichita Health Department site (2001-2016)



Highest 8hr O_3 in April vs. acres burned at the three sites around Wichita

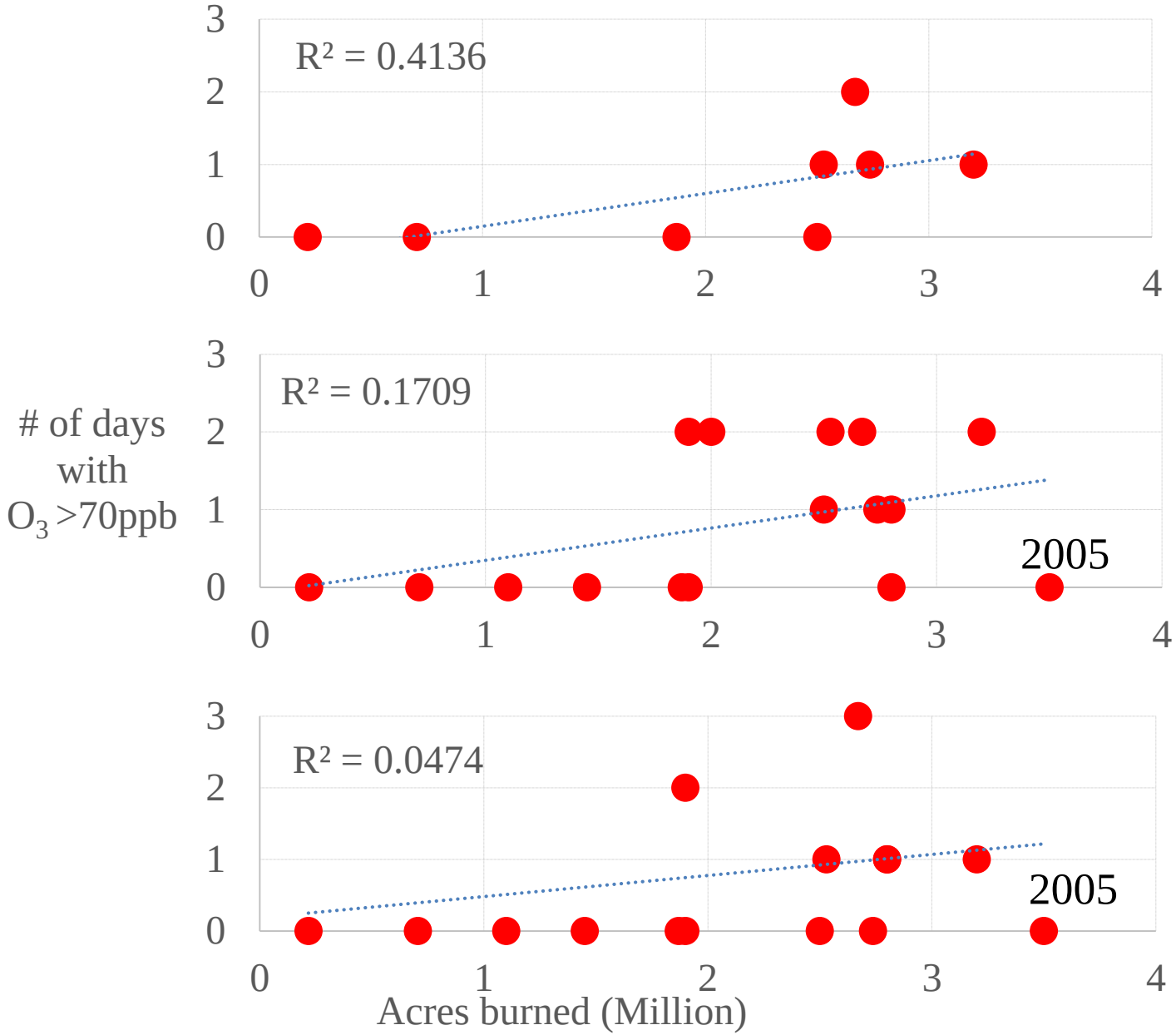


Sedgwick site (2009-2016)

Wichita Health Department site (2001-2016)

Peck site (2001-2016)

Number of days with 8hr O_3 >70ppb in April vs. acres burned at the three sites around Wichita

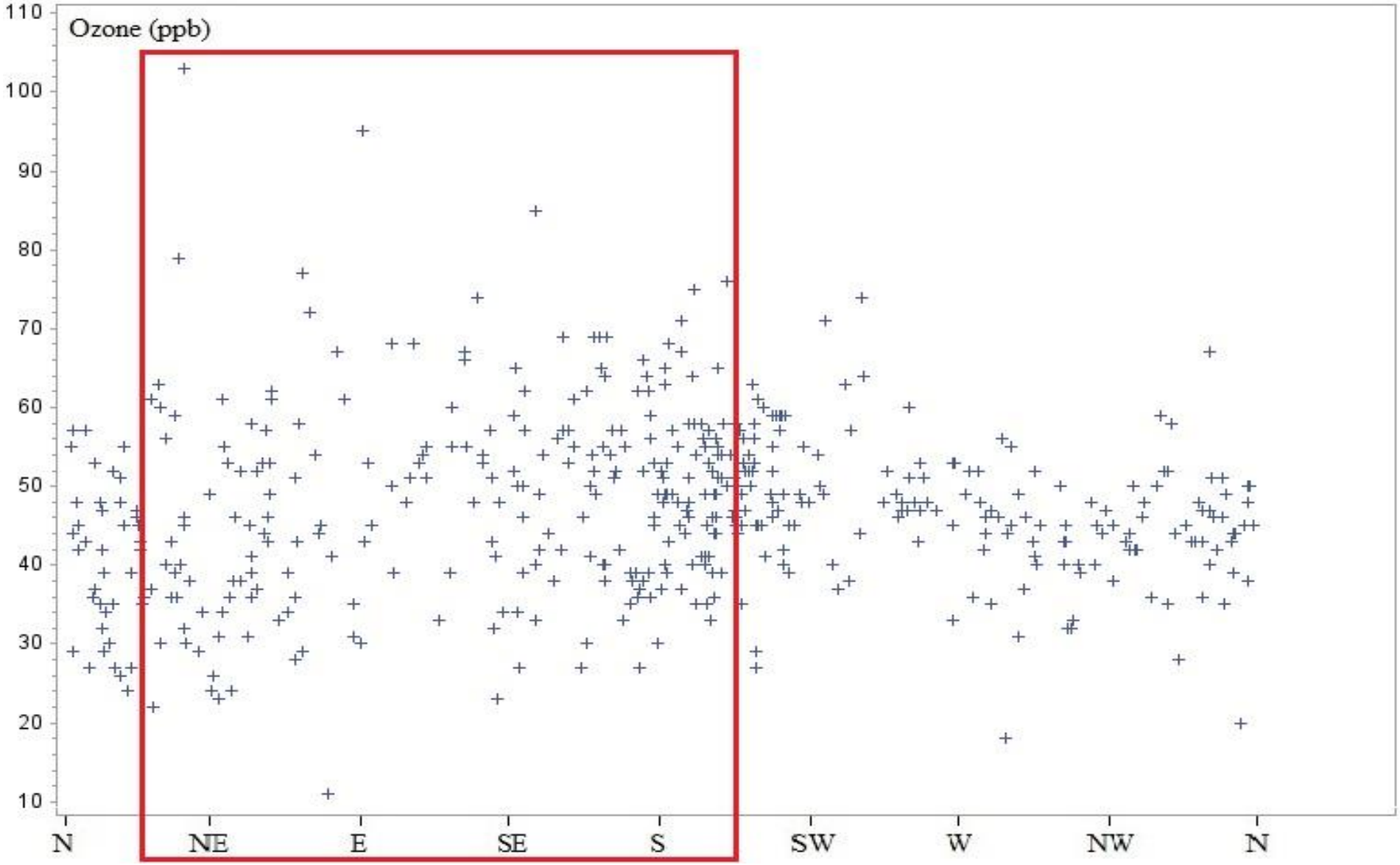


Sedgwick site (2009-2016)

Wichita Health Department site (2001-2016)

Peck site (2001-2016)

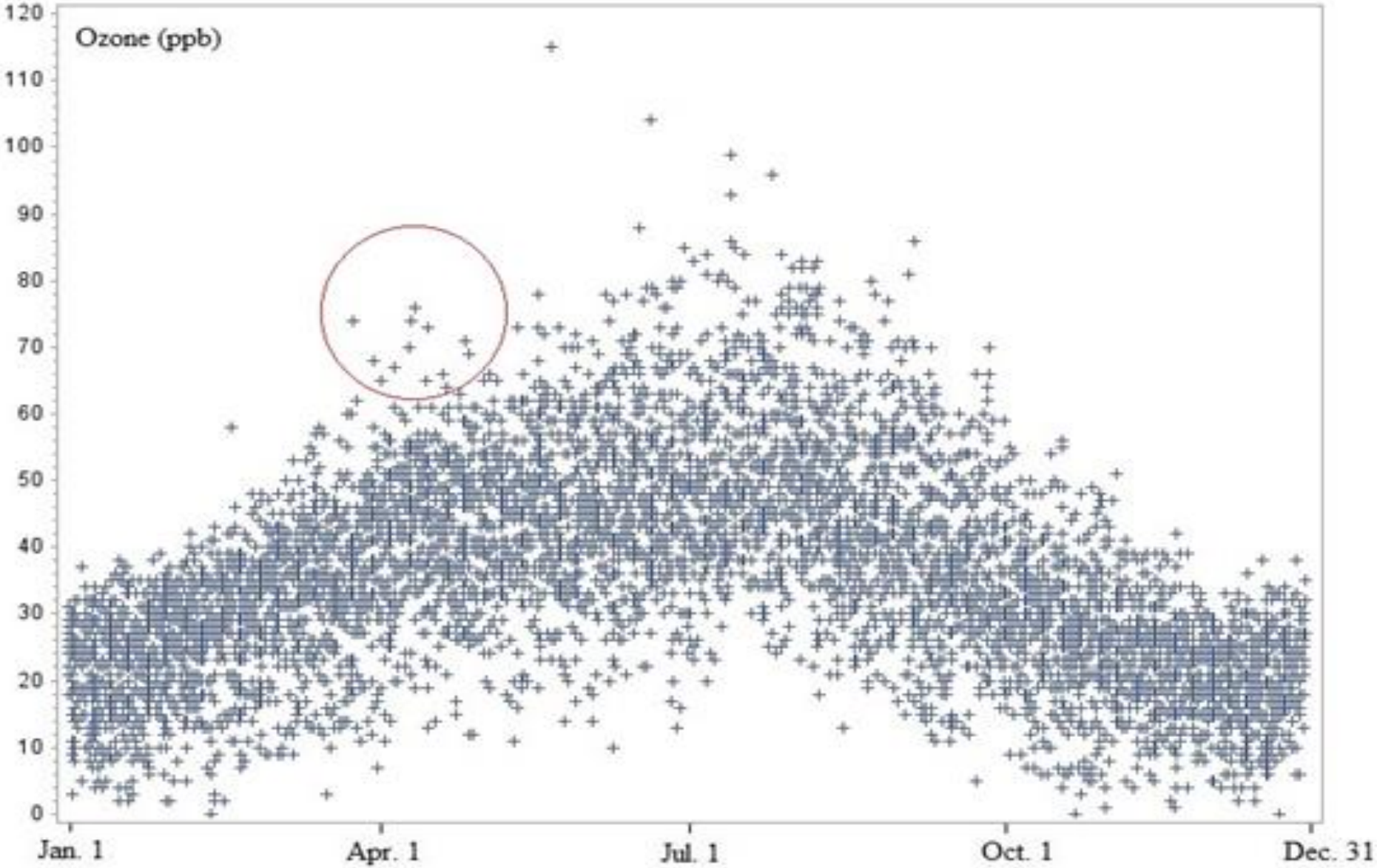
Daily max 8hr O_3 in April at the Wichita Health Department site (2001-2016)



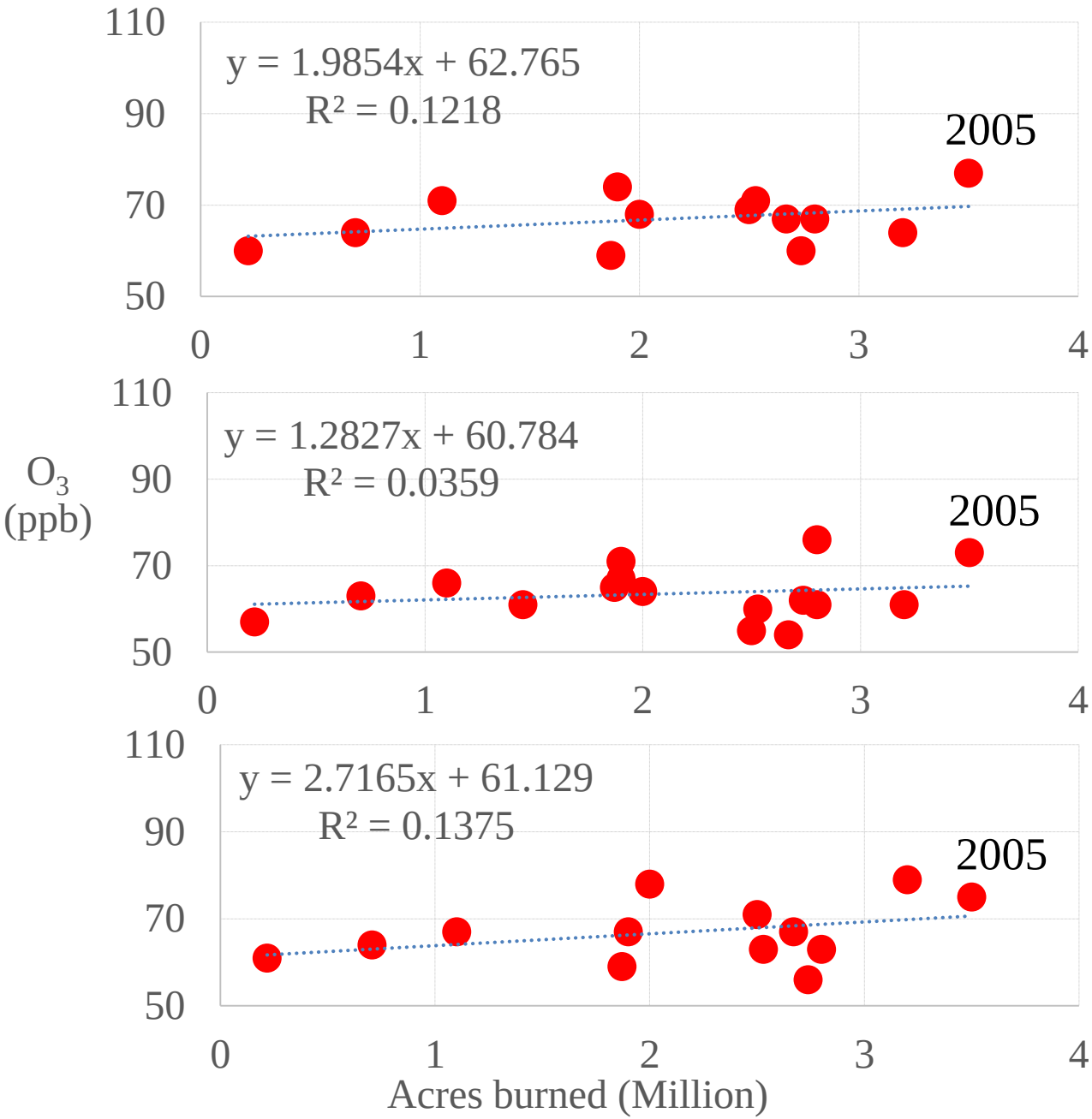
8hr O_3 at the three sites around Wichita (2001-2016)

- When acres burned ≥ 1.9 million, O_3>70ppb may occur.
- When acres burned < 1.9 million, O_3>70ppb did not occur.

Daily max 8hr O_3 at the Kansas City JFK site (2001-2016)



Highest 8hr O_3 in April vs. acres burned at the three sites around Kansas City

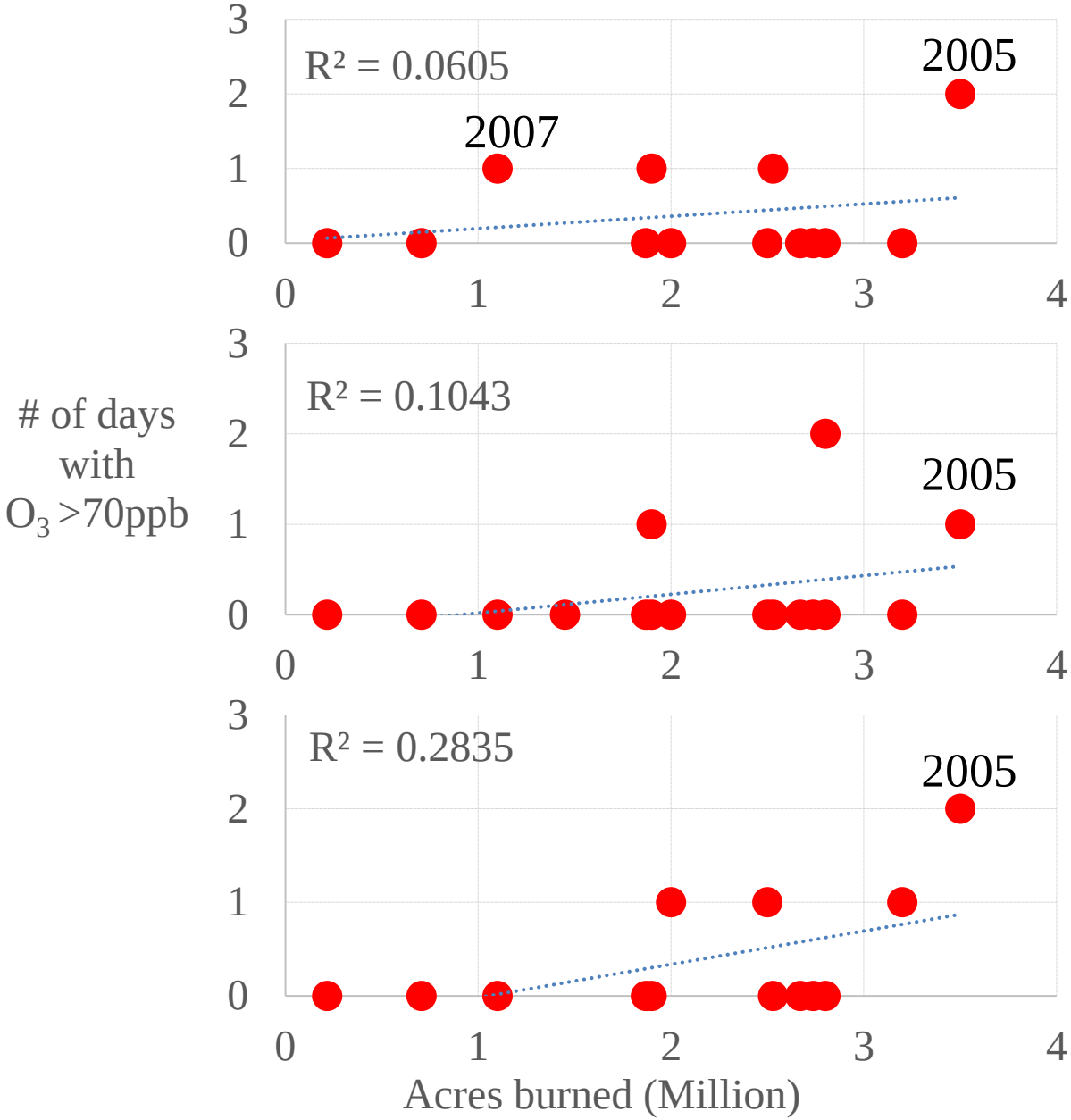


Leavenworth site (2004-2016)

Kansas City JFK site (2001-2016)

Heritage Park site (2004-2016)

Number of days with 8hr O_3 >70ppb in April vs. acres burned at the three sites around Kansas City

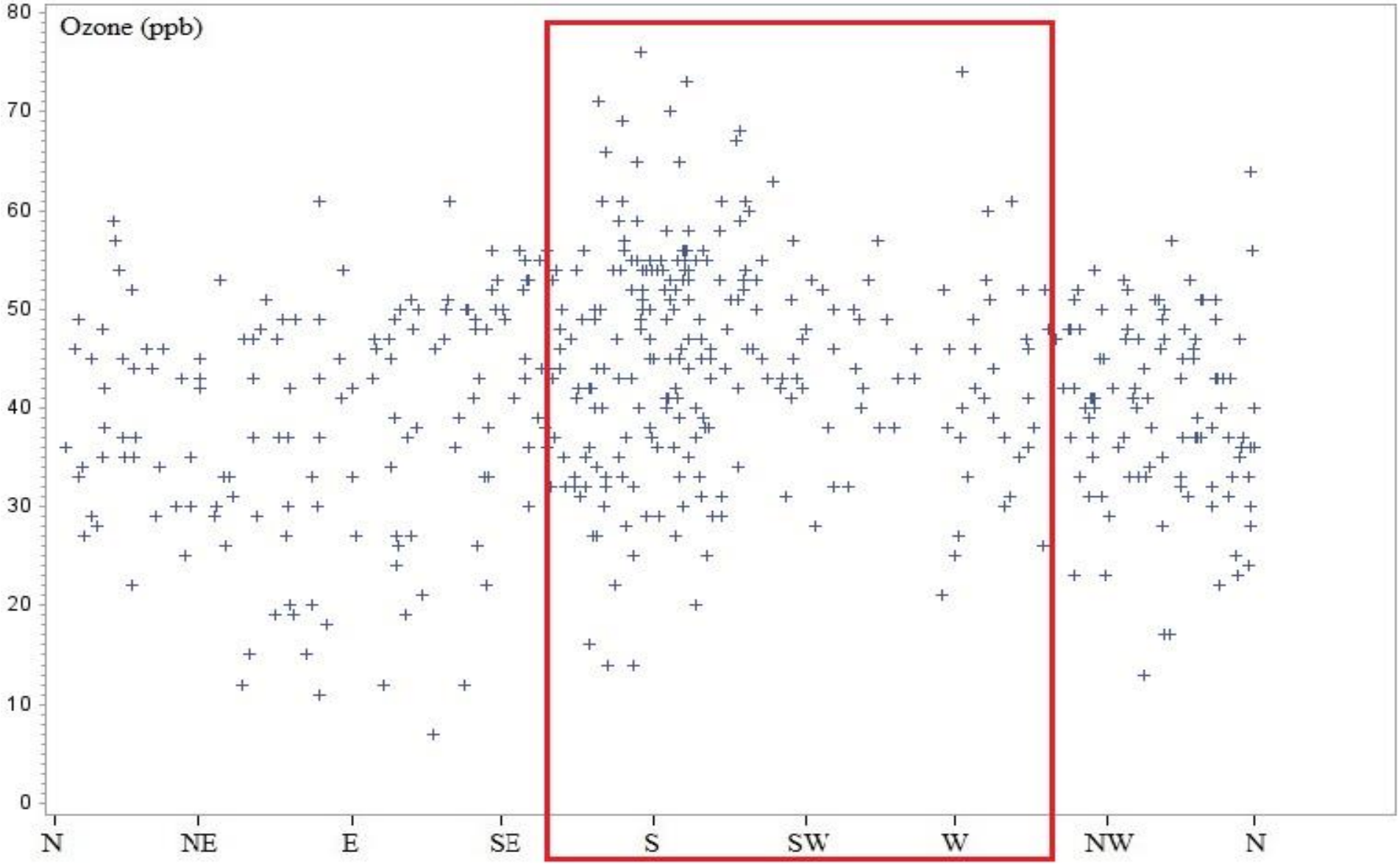


Leavenworth site (2004-2016)

Kansas City JFK site (2001-2016)

Heritage Park site (2004-2016)

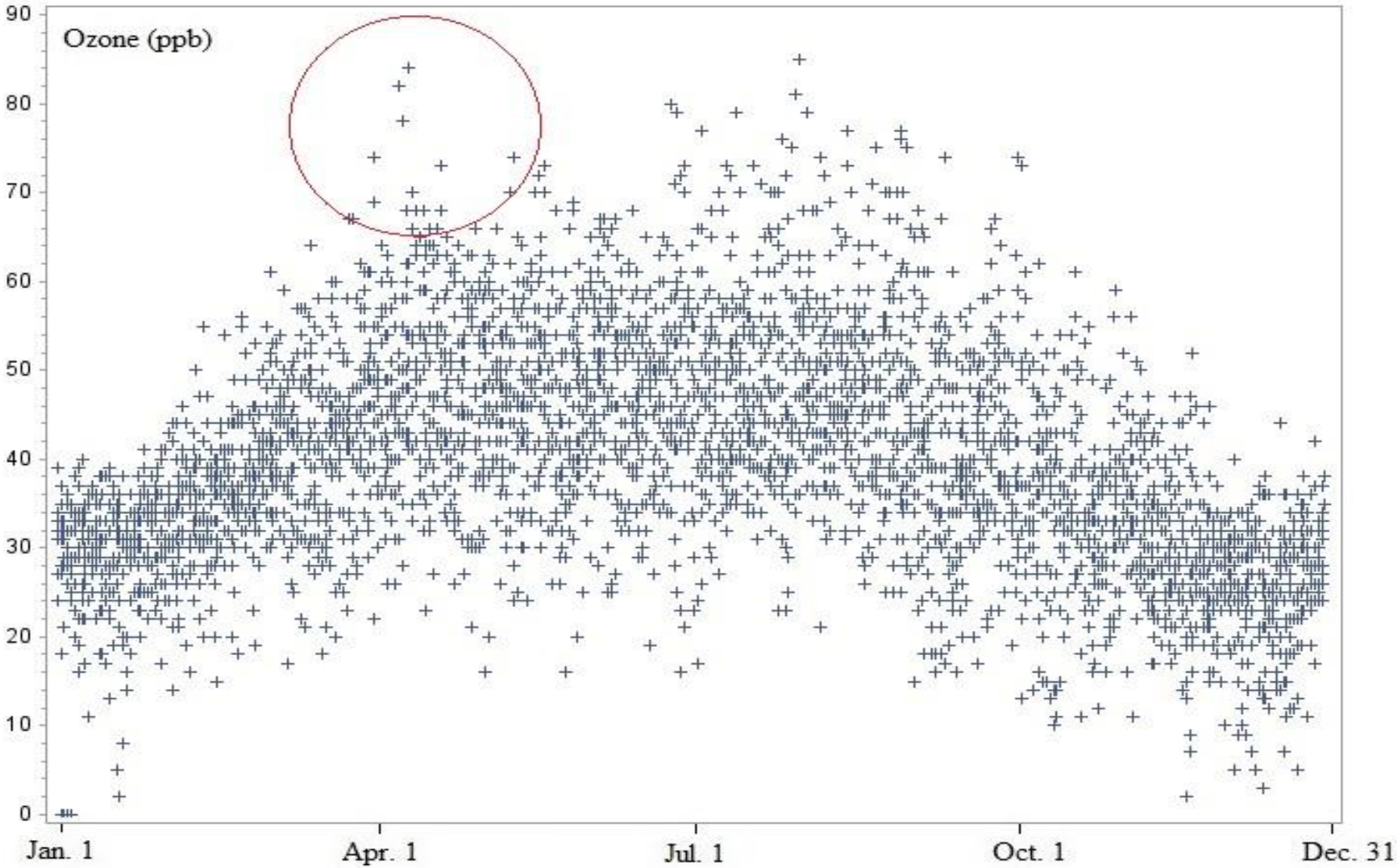
Daily max 8hr O_3 in April the Kansas City JFK site (2001-2016)



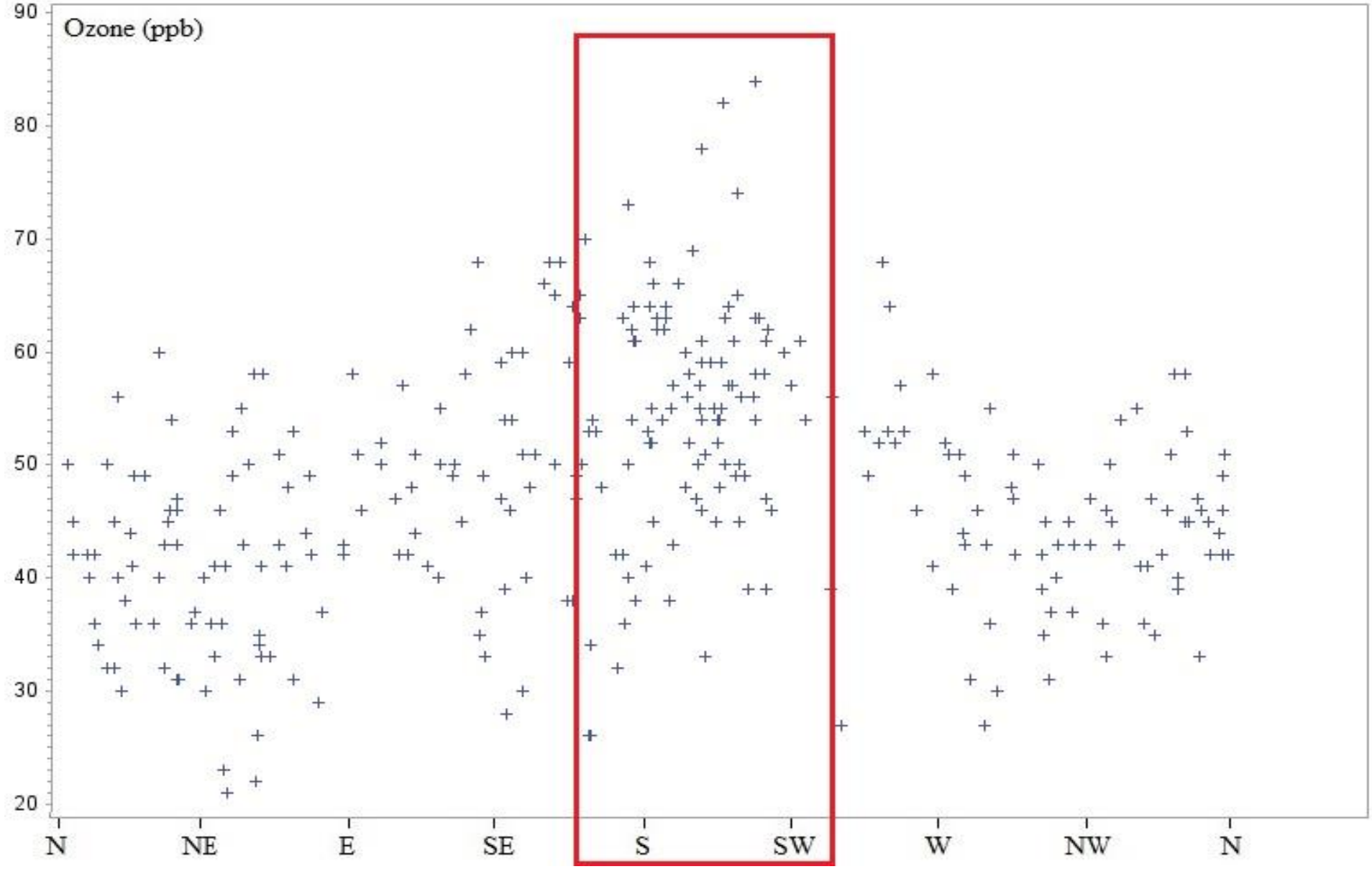
8hr O_3 at the three sites around Kansas City (2001-2016)

- When acres burned ≥ 1.9 million, O_3>70ppb may occur (with less chance than the Wichita sites).
- When acres burned < 1.9 million, O_3>70ppb did not occur (with only one exception at the Leavenworth site).

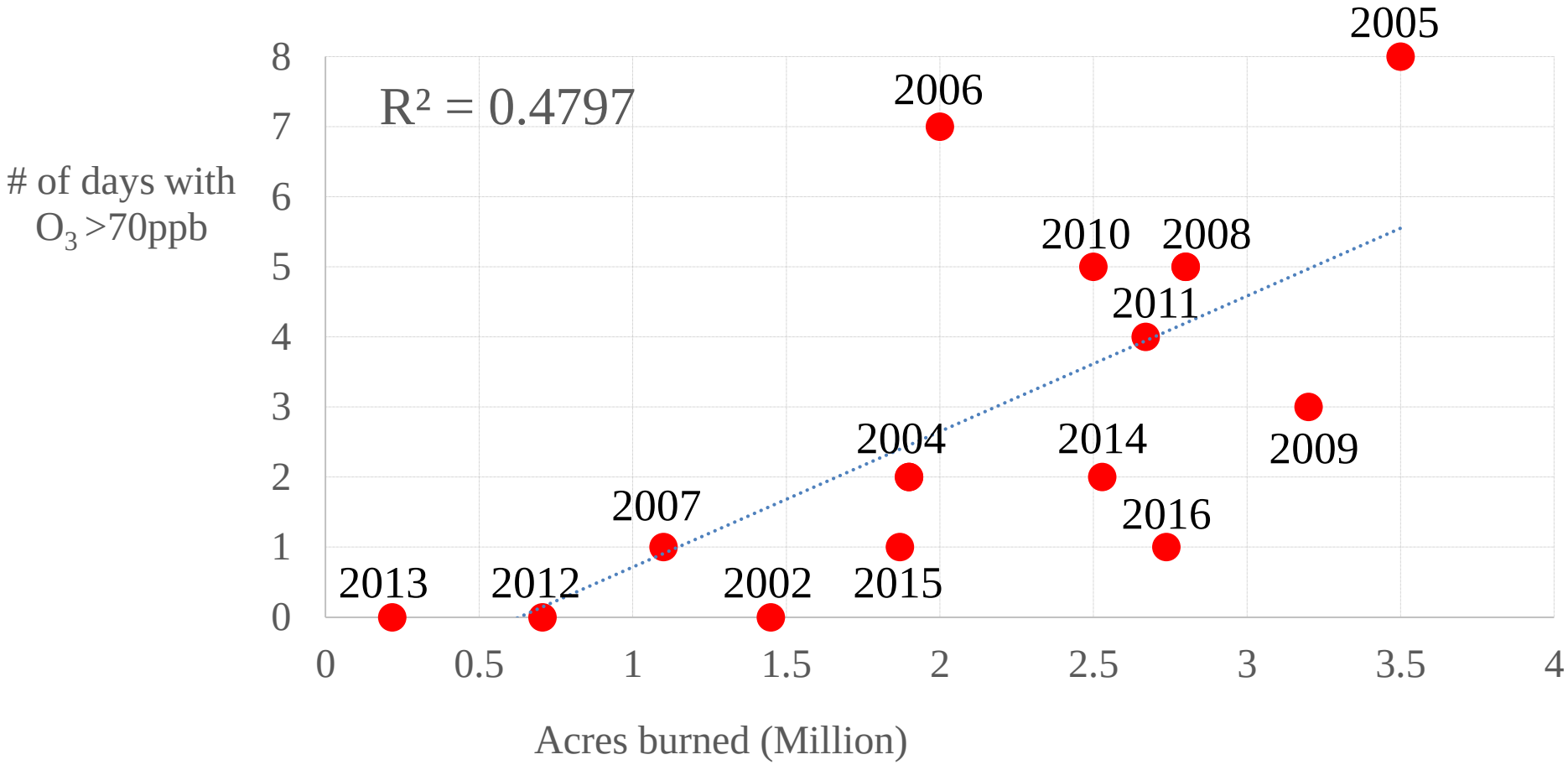
Daily max 8hr O_3 at the Topeka site (2006-2016)



Daily max 8hr O_3 in April at the Topeka site (2006-2016)



Number of days with 8hr O_3 >70ppb in April vs. acres burned at all the ten sites

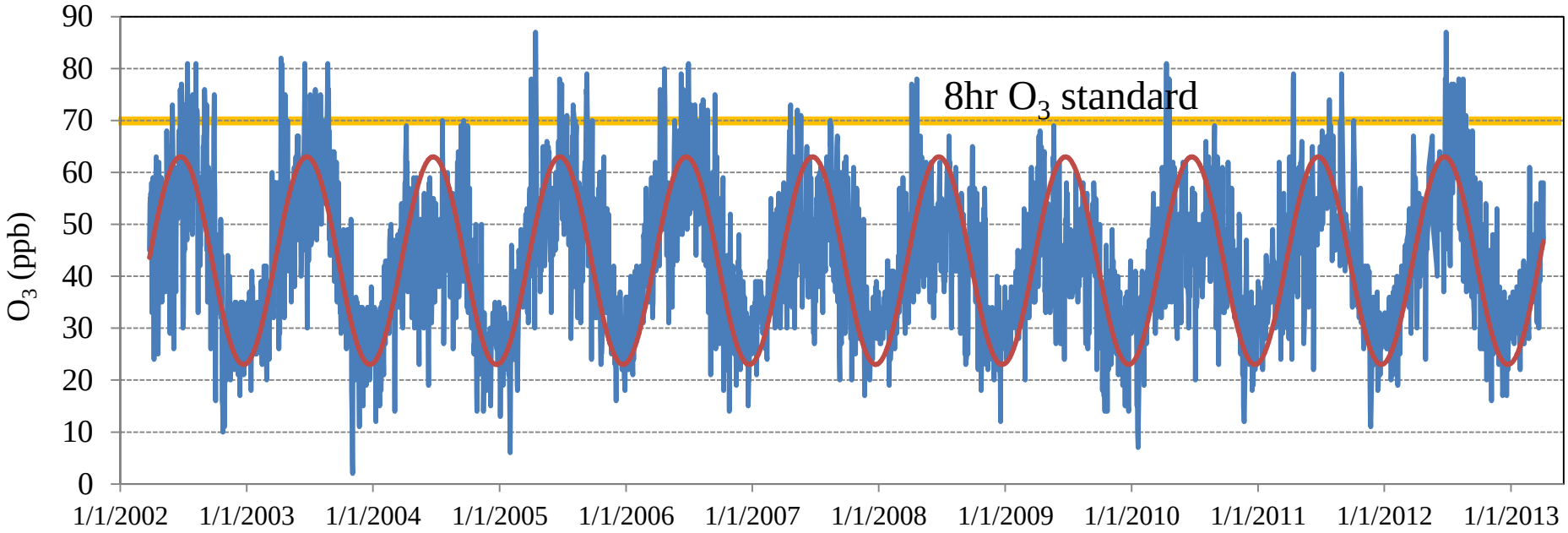


- When acres burned ≥ 1.9 million, O_3>70ppb occurred at least at one of the 10 sites.
- When acres burned < 1.1 million, O_3>70ppb did not occur.

Factors that affect ambient O_3

- Seasonal cycle
- O_3 on the previous day
- Air temperature
- Solar radiation
- Relative humidity
- Wind speed

Daily max 8hr O_3 at the Konza Praire site



O_3 on non-rainy days

$$O_3(d) = 30.5 + 4.75\sin\left(\frac{2\pi(d+284)}{365}\right)$$

$$+0.47O_3(d)_0$$ ← O_3 on the previous day

$$+0.17T_{max}$$ ← Daily max air temperature

$$+0.13(T_{max}-T_{min})$$ ← Air heated by solar radiation

$$-15.6RH$$

$$-0.57V$$

$$R^2=0.71$$

O_3 on rainy days

$$O_3(d) = 37.5 + 4.40 \sin\left(\frac{2\pi(d+284)}{365}\right)$$

$$+0.44O_3(d)_0$$ ← O_3 on the previous day

$$+0.15T_{max}$$ ← Daily max air temperature

$$+0.29(T_{max}-T_{min})$$ ← Air heated by solar radiation

$$-25.5RH$$

$$-0.64V$$

$R^2=0.68$

8hr O_3 at the Konza Prairie site (2002-2013)

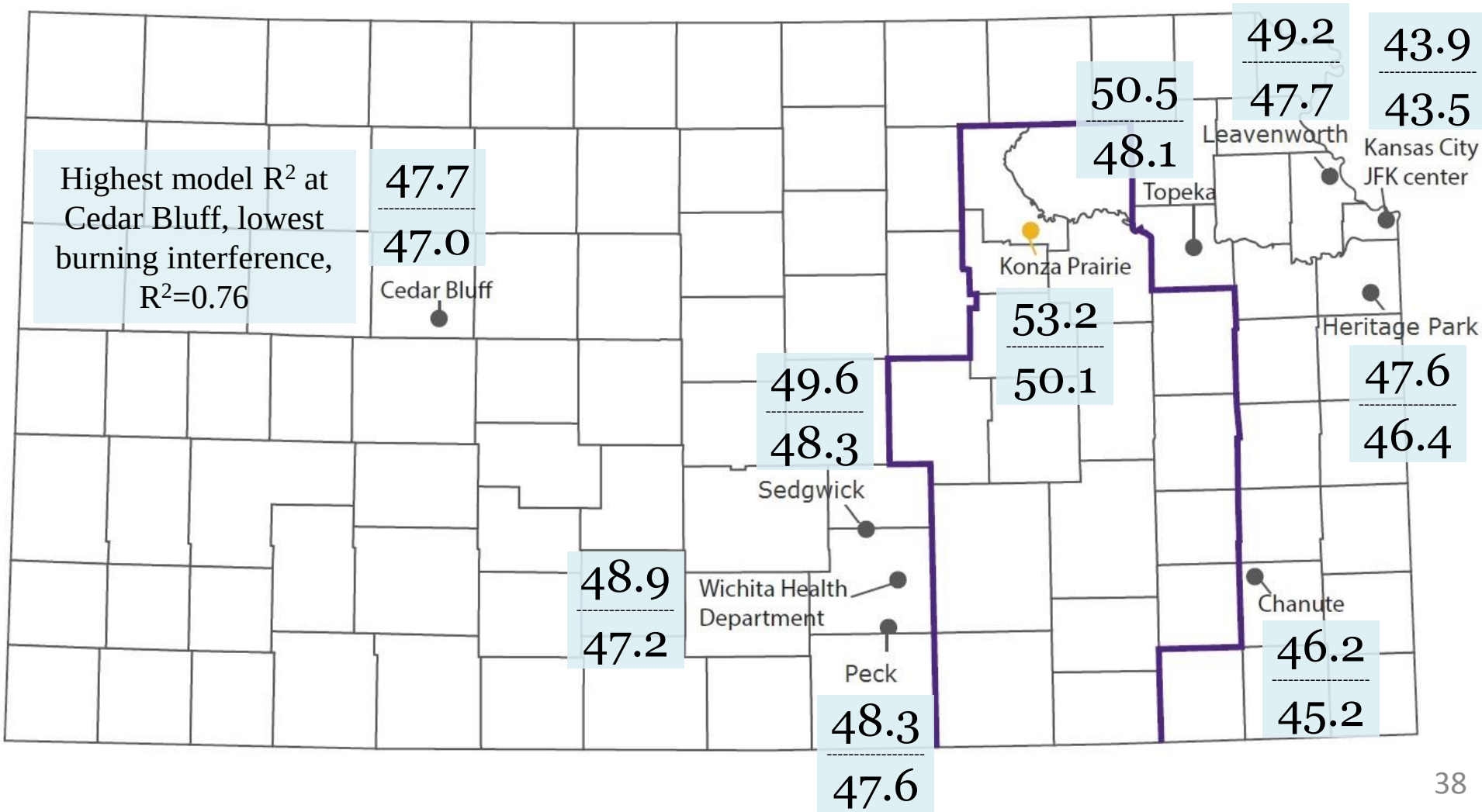
	Annual average	April average (rainy days)	April average (non-rainy days)
Measured O_3 (ppb)	43.0	48.3	53.2
Modeled O_3 (ppb)	43.0	47.5	50.1
Residual (ppb)	0	0.8	3.1

Likely due to burning

Multi-year average O_3 at different sites (non-rainy days in April)

Measured O_3 (ppb)

Modeled O_3 (ppb)



Average O_3 model residuals in April (non-rainy days) (Likely due to burning)

Konza Prairie site	3.1 ppb
Topeka site	2.4 ppb
Three Wichita sites	0.7, 1.3, 1.7 ppb
Three Kansas City sites	0.4, 1.2, 1.5 ppb
Cedar Bluff site	0.7 ppb

2001-2016

	Average of days with O_3>70ppb in April (47 days in total)	April average
Daily Max 8hr O_3	77±5 ppb	43.9-53.2 ppb
O_3 on the previous day	60±11 ppb	-
Daily maximum air temperature	24.5±4.5 ºC	20.7±5.5 ºC
T_{max}-T_{min}	16.6±5.3 ºC	12.3±5.0 ºC
Solar radiation	738±279 Langley	607±304 Langley
Relative humidity	54±10 %	67±14 %
Wind speed	3.4±1.8 m/s	4.1±2.0 m/s
O_3 model residuals	21±9 ppb	-

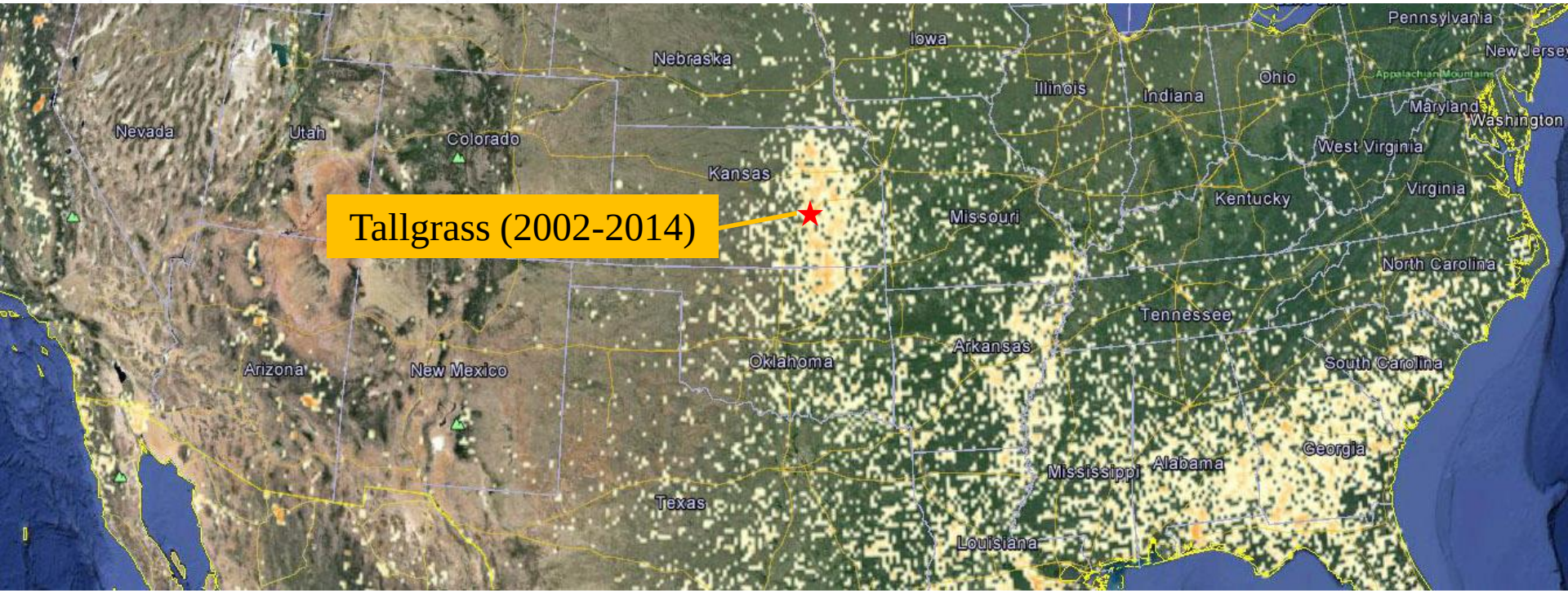
Likely due to burning

$PM_{2.5}$ from smoke

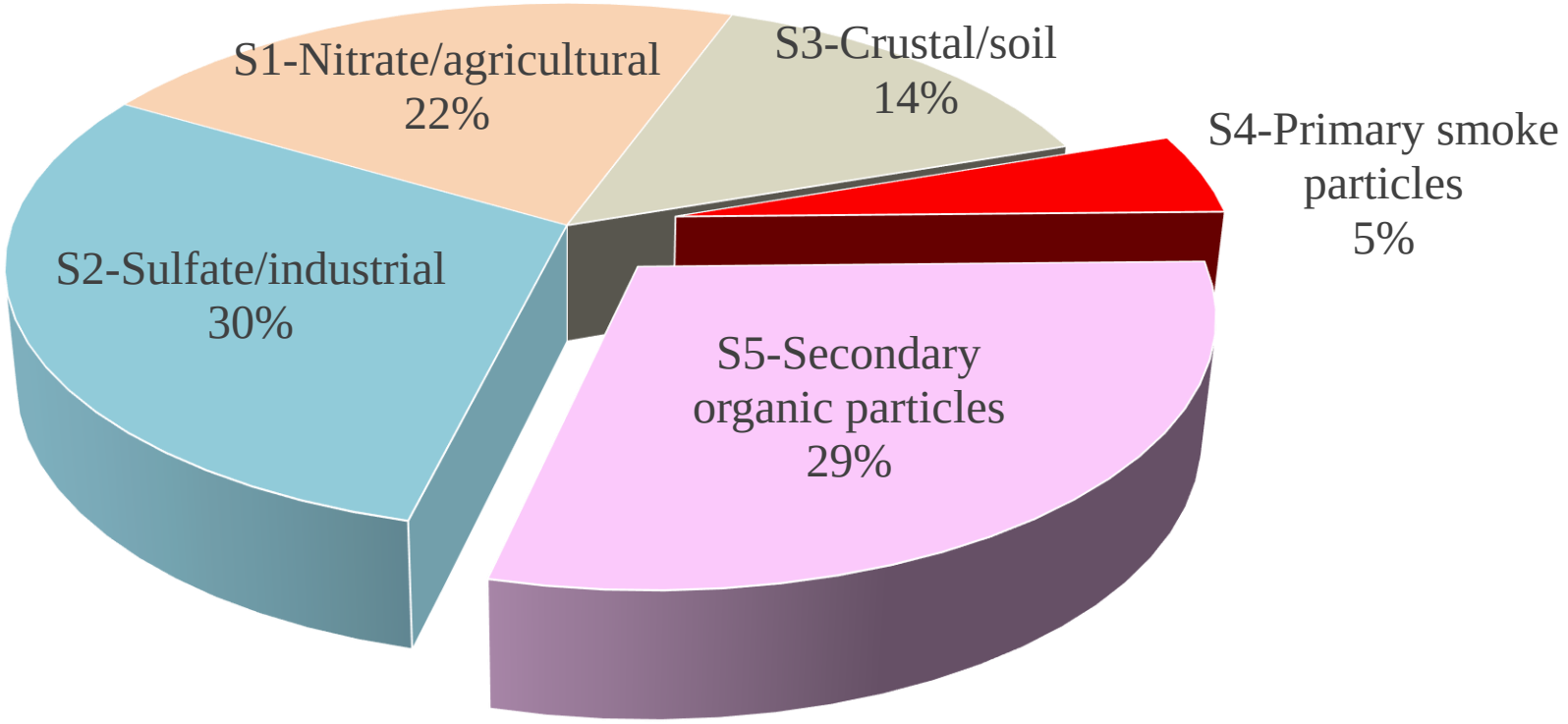
- ~70 to 90% of smoke particles is $PM_{2.5.}$
- Include primary particles and secondary organic particles that are formed through gas-to-particle conversion processes.
- Acts as a vehicle to carry adsorbed hazardous compounds into the respiratory tract.
- Could have greater health impact than normal urban particles.

$PM_{2.5}$ speciation data at the Tallgrass IMPROVE site

IMPROVE: Interagency Monitoring of Protected Visual Environments

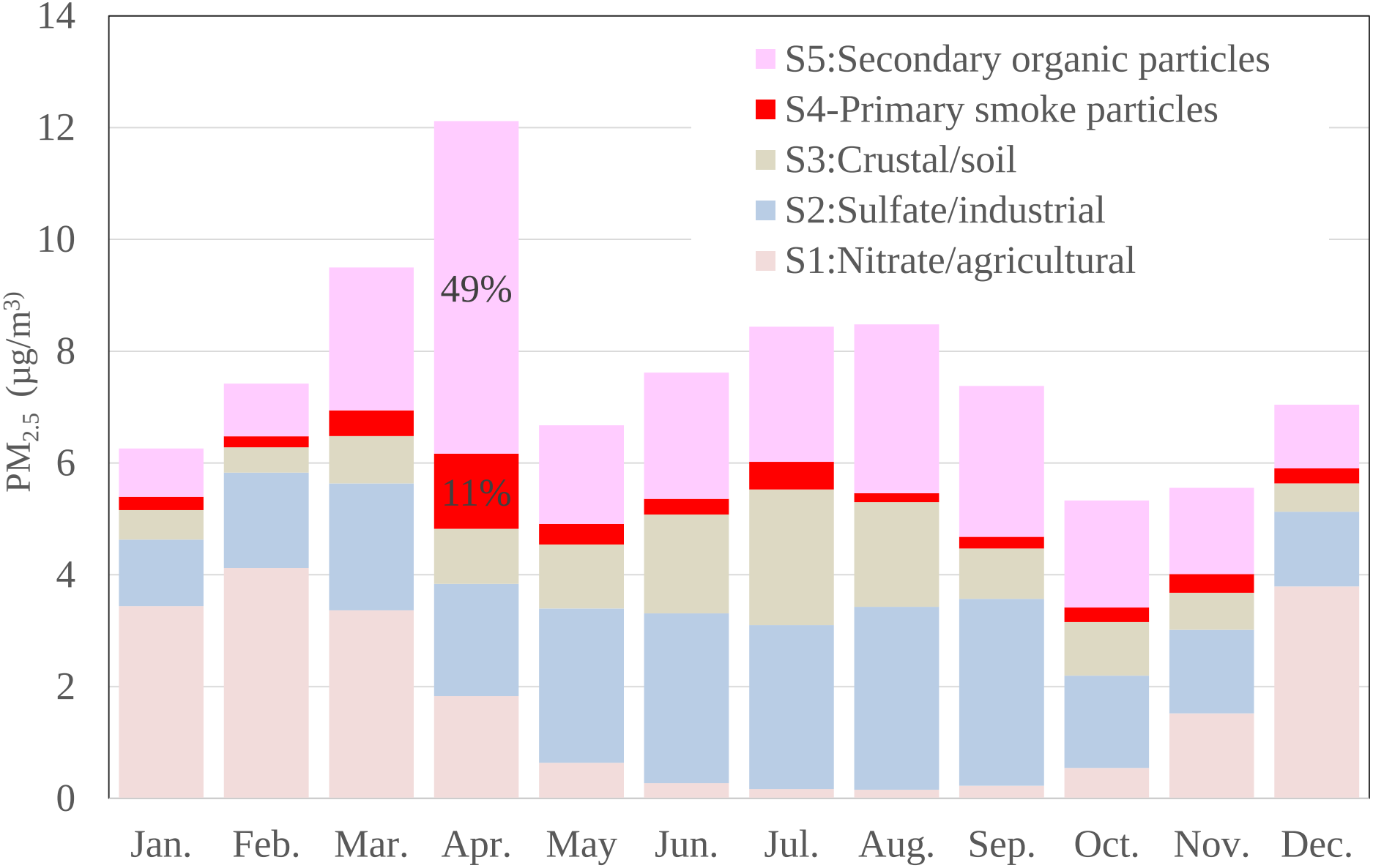


Annual average contributions to $PM_{2.5}$ from the five source categories at the Tallgrass site

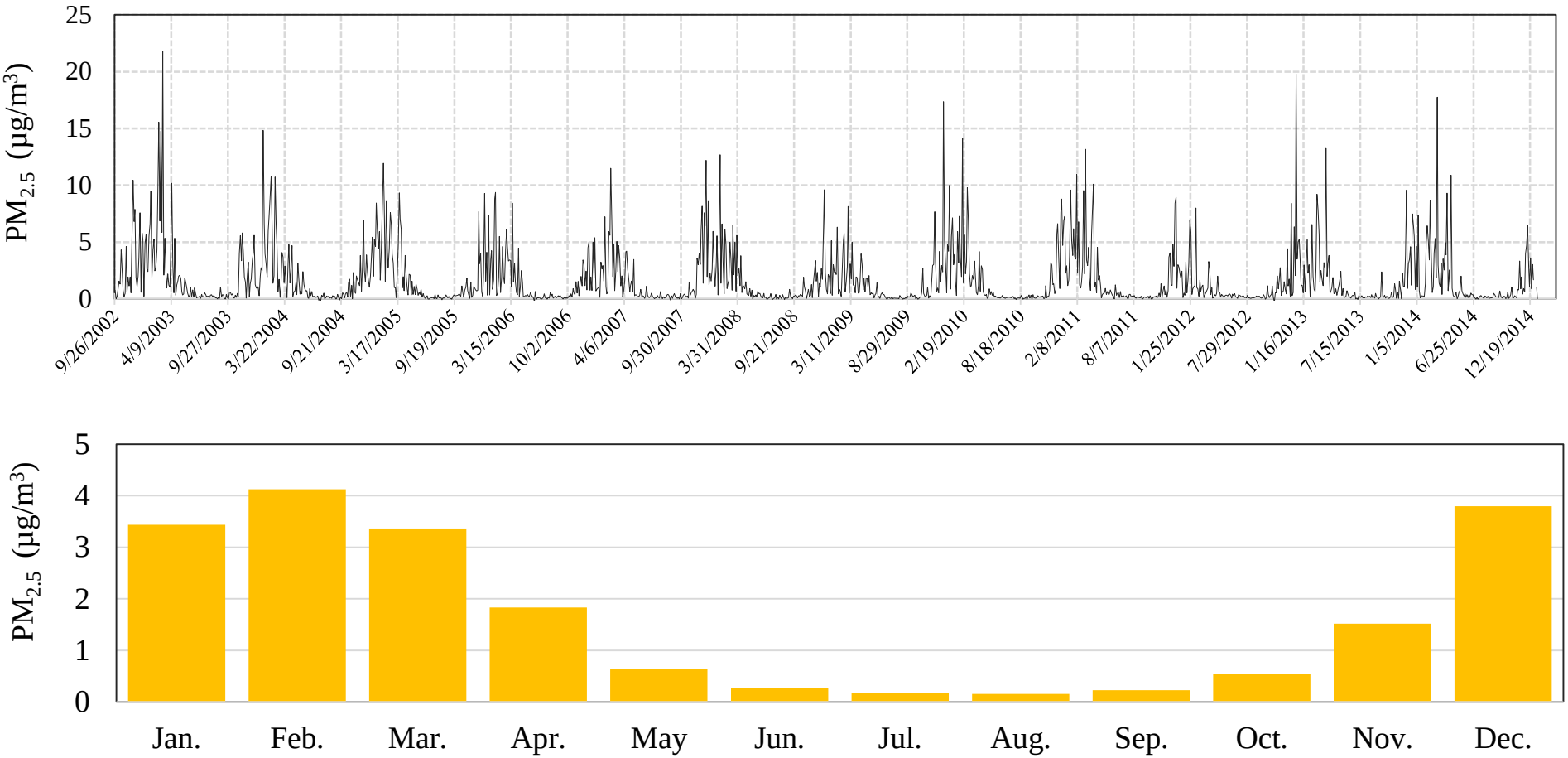


Results of receptor modeling

Monthly variation of $PM_{2.5}$ contributions from the five source categories at the Tallgrass site

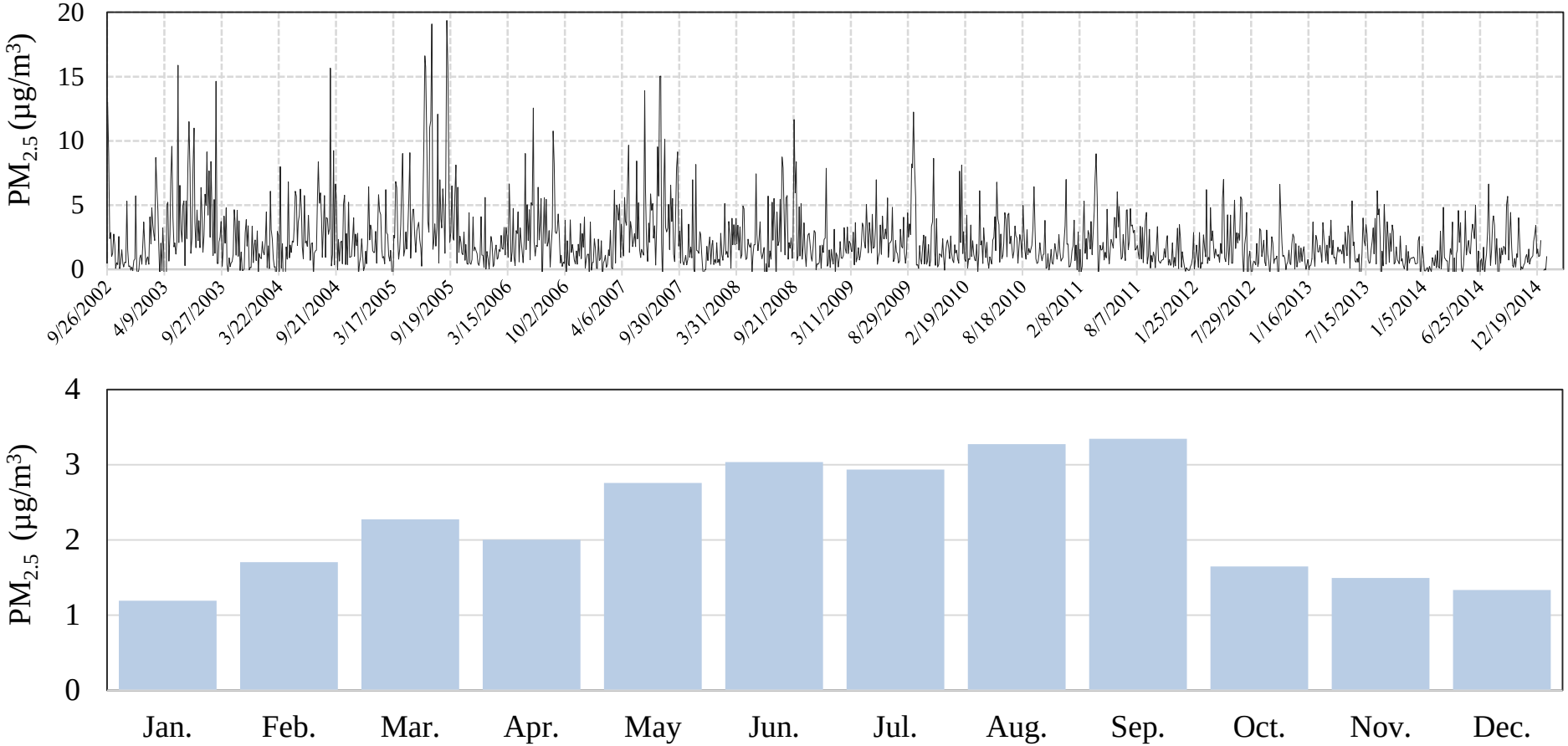


S1: Nitrate/Agricultural

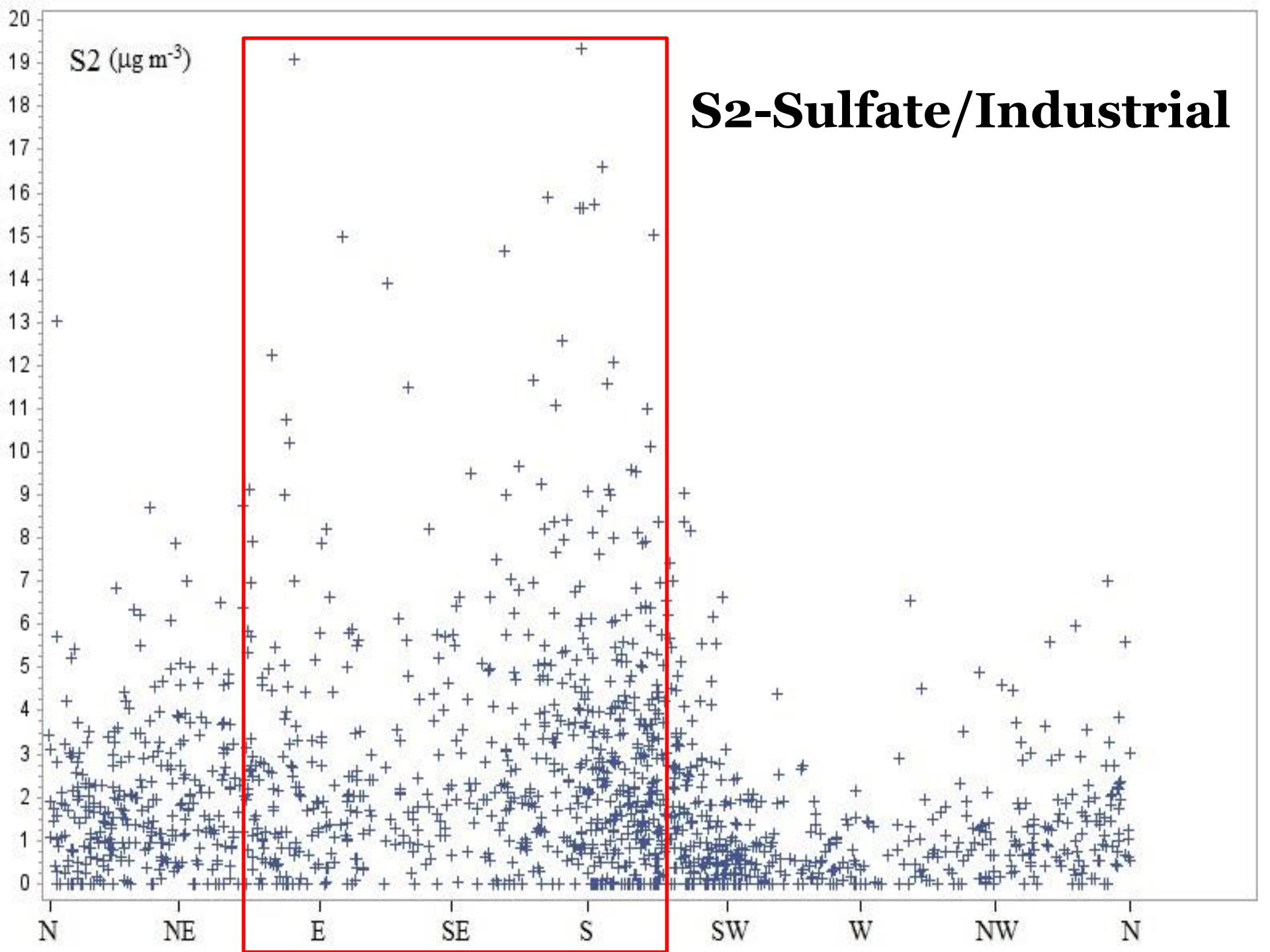


- Featured with high nitrate associated with NH_3 emissions.
- High in winter and low in summer.
- Can be modeled using meteorological predictors.

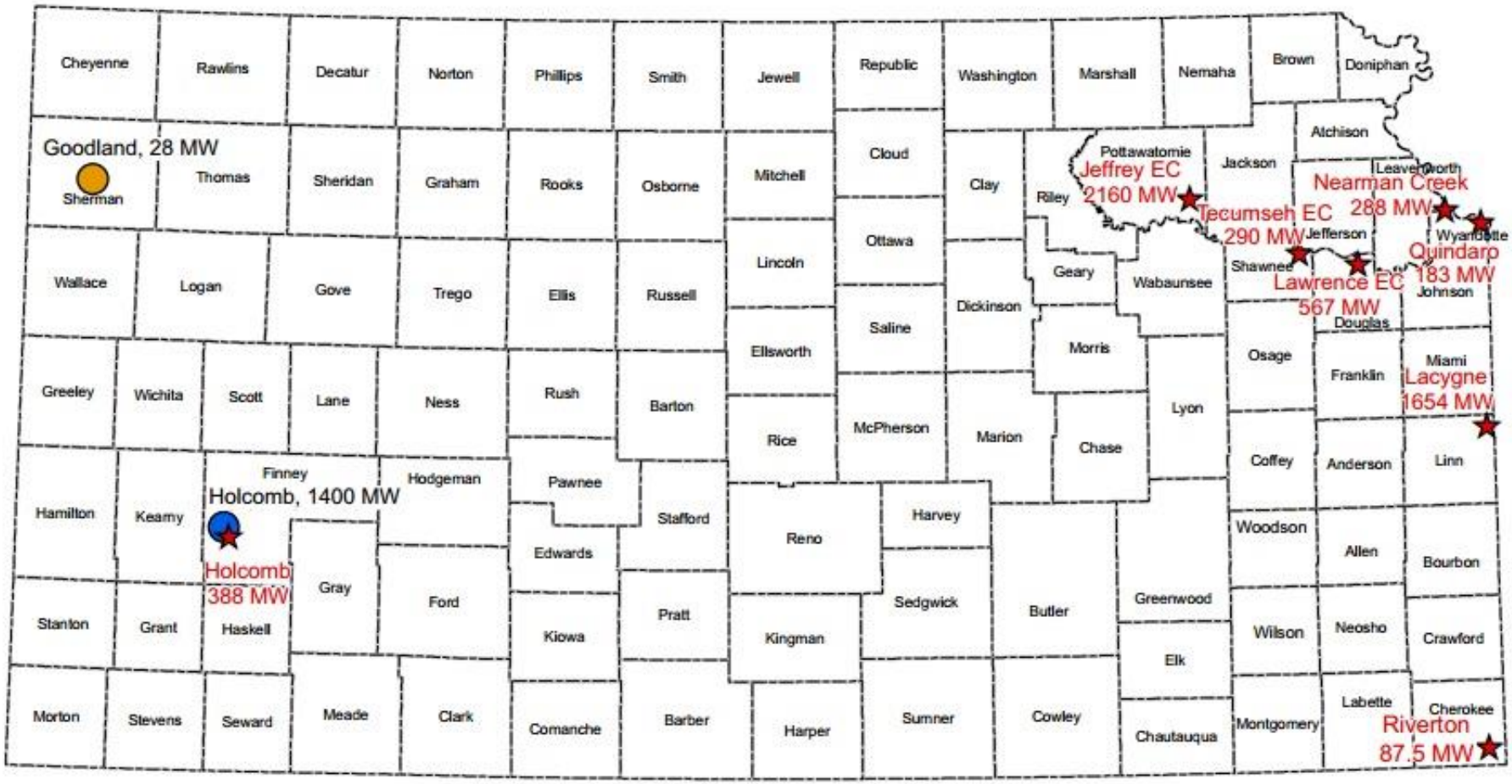
S2-Sulfate/Industrial



- Featured with high sulfate associated with SO_2 emissions.
- Decreasing trend reflected regulation effects.
- High in summer due to photochemistry effect and presence of oxidants on secondary sulfate formation.


S2 (μg m-3)
S2-Sulfate/Industrial
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
N
NE
E
SE
S
SW
W
NW
N

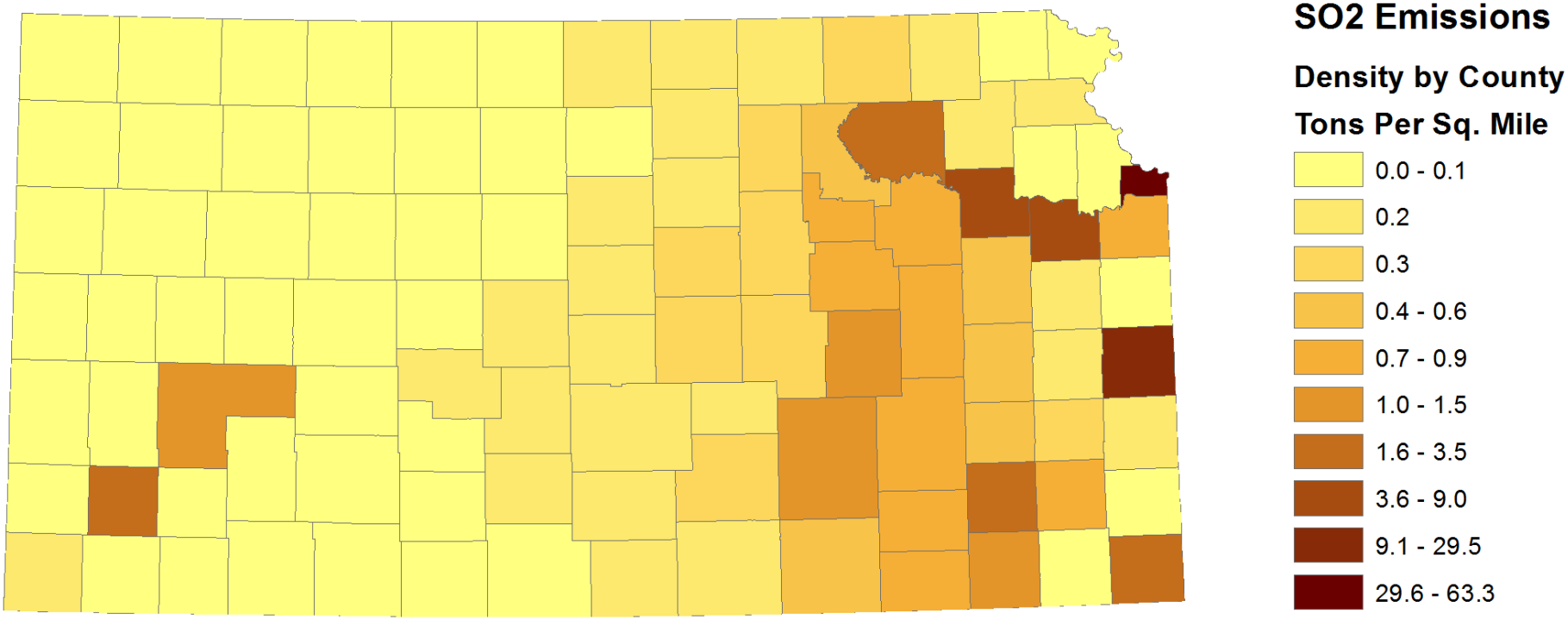
Proposed and Existing Coal-fired Power Plants in Kansas, 2007



Sources: Based on data from the 2006 Federal Energy Regulatory Commission (FERC) Form 1: http://www.ferc.gov/docs-filing/eforms/form-1/viewer-instruct.asp; Quindaro and Nearman Creek data acquired through communication with the Kansas City Board of Public Utilities (KCBPU) (January 2008)

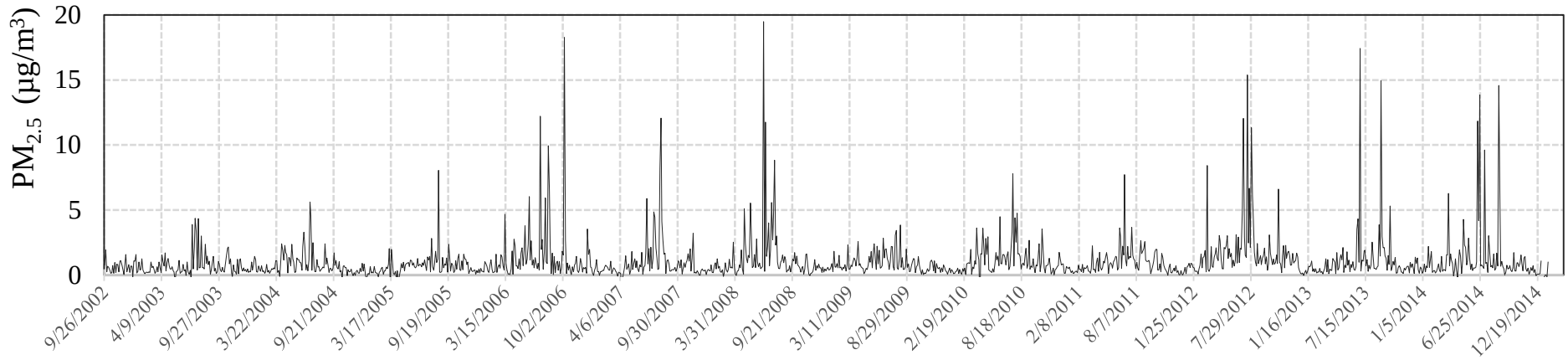
Kansas Energy Chart Book, Chapter 3

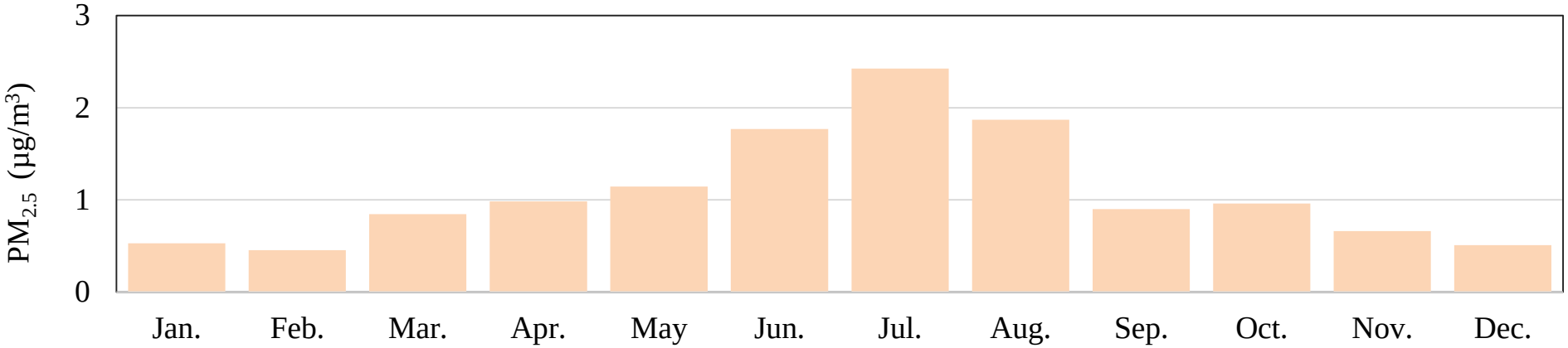
2011 Kansas Emissions Inventory - SO2



(from KDHE, 2015. 5-Year Ambient Air Monitoring Network Assessment)

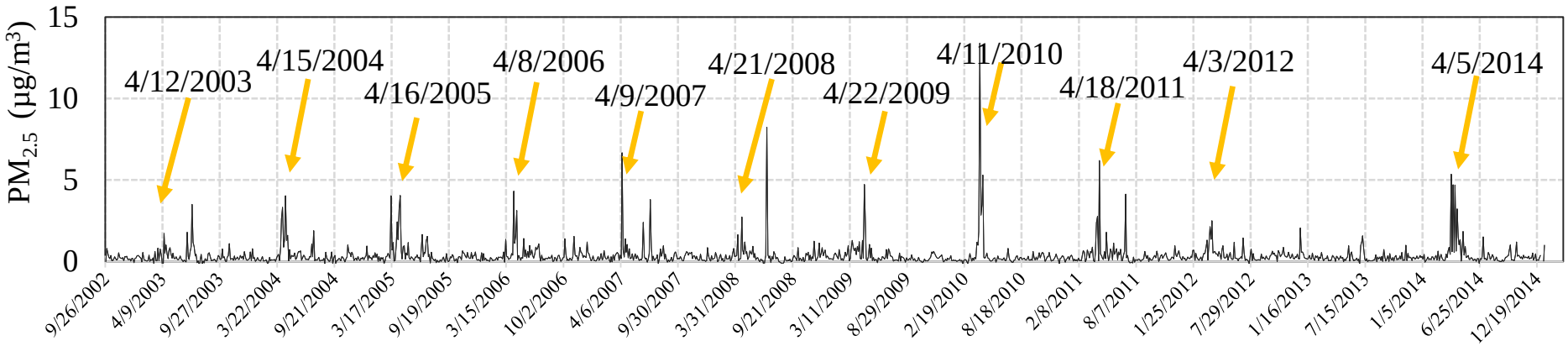
S3-Crustal/Soil

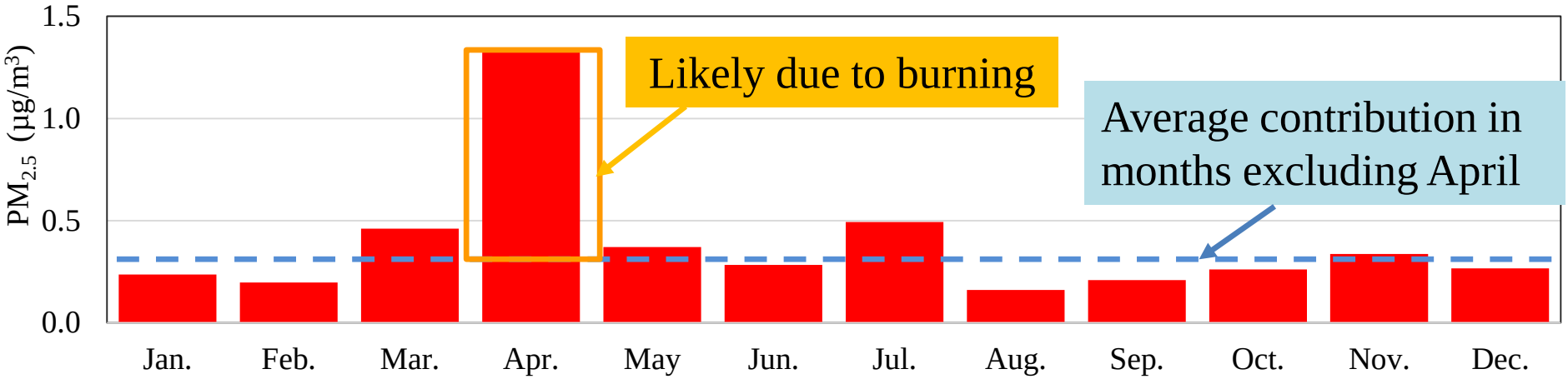




- Identified by soil elements (Si, Fe, Al, …).
- Spikes were observed on windy days.

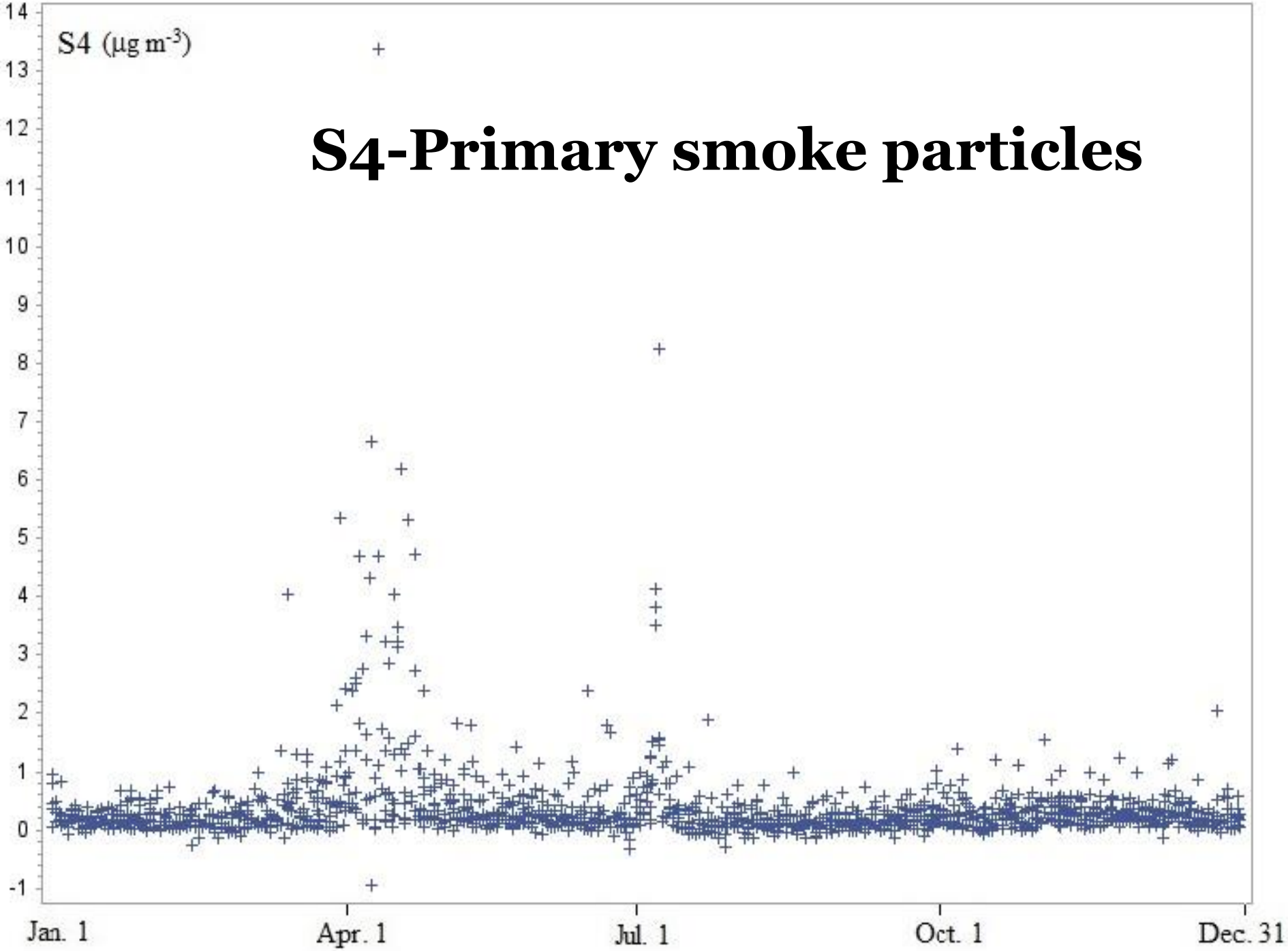
S4-Primary smoke particles



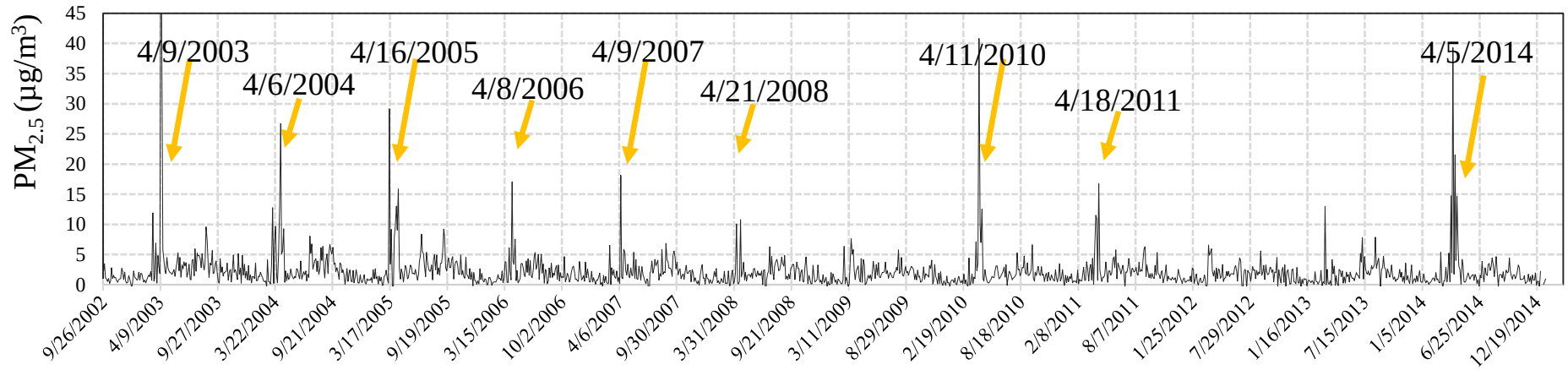


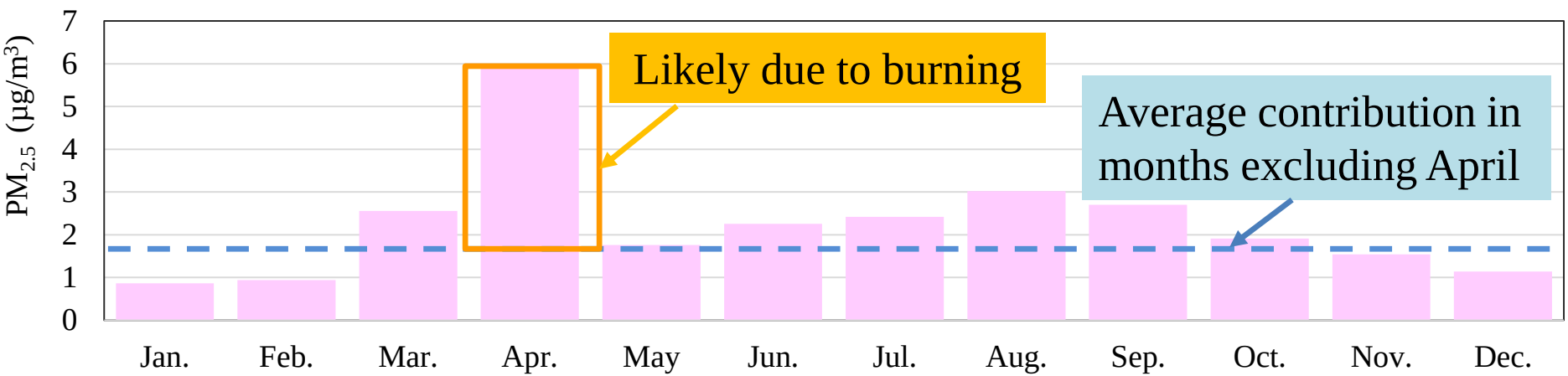
- Characterized mainly by non-soil potassium.
- Spikes were consistently observed in April.

S4-Primary smoke particles



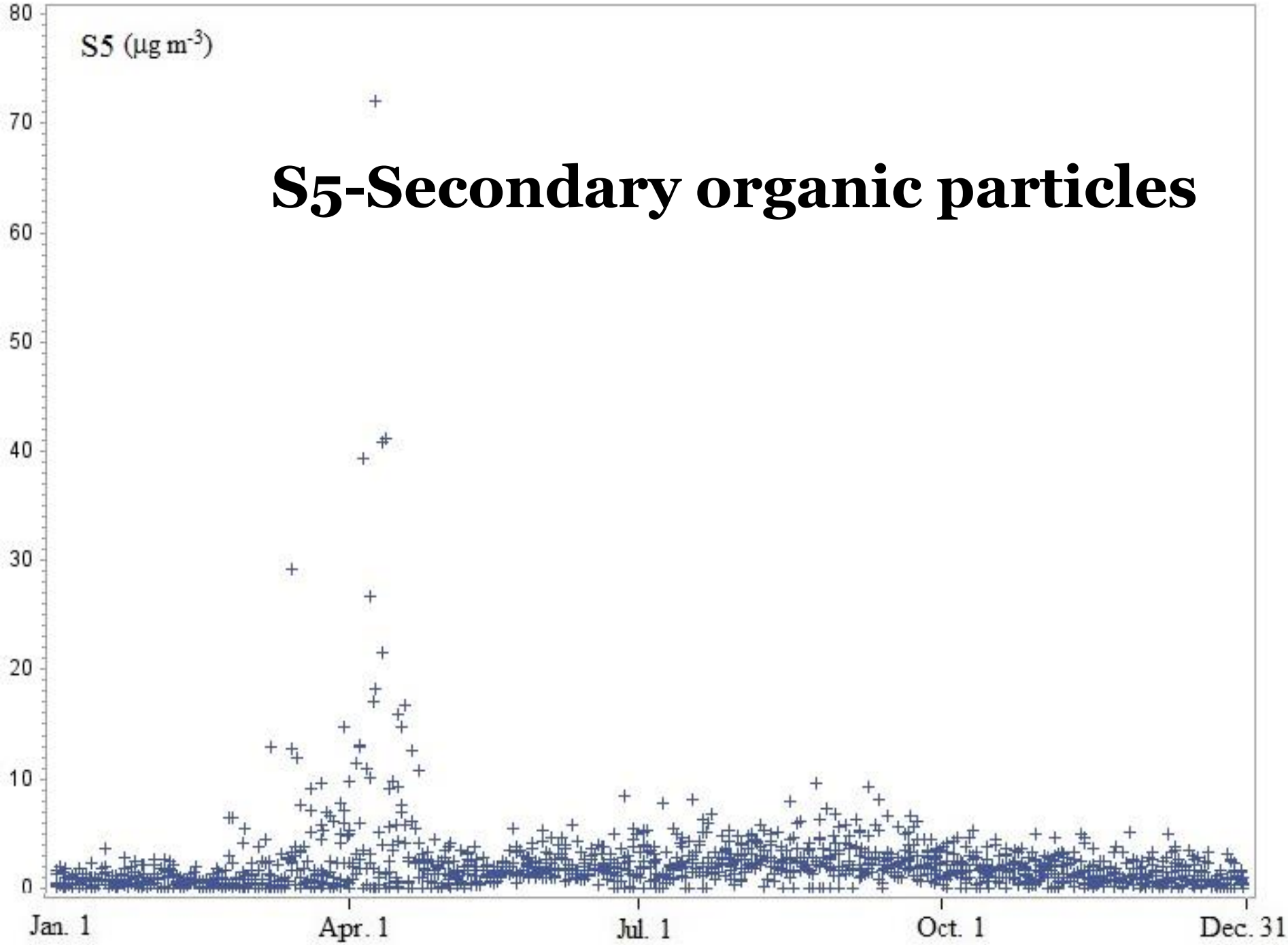
S5-Secondary organic particles





Identified by large OC/EC ratio.

S5 correlated with S4 with Pearson correlation coefficient of 0.49.

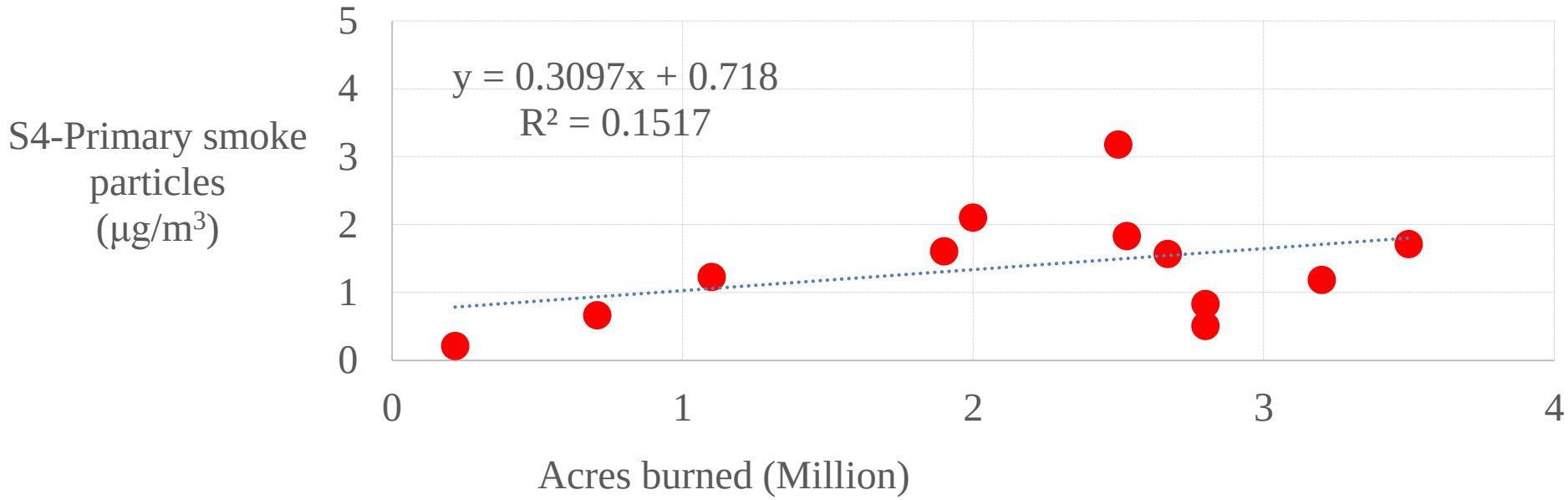


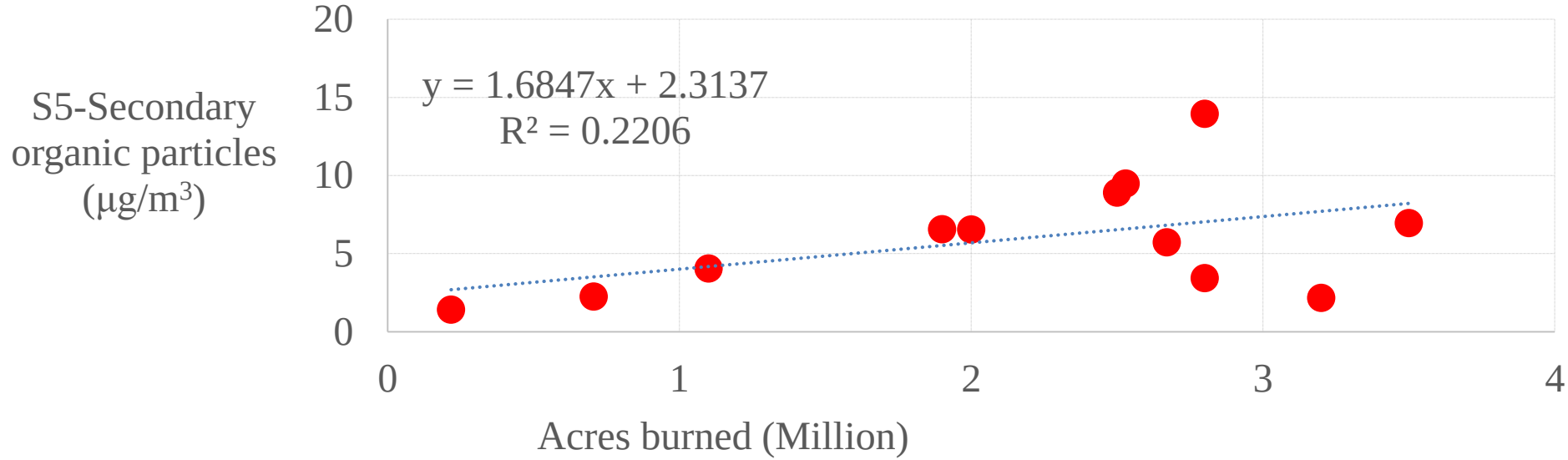
S5-Secondary organic particles

Importance of secondary organic particles

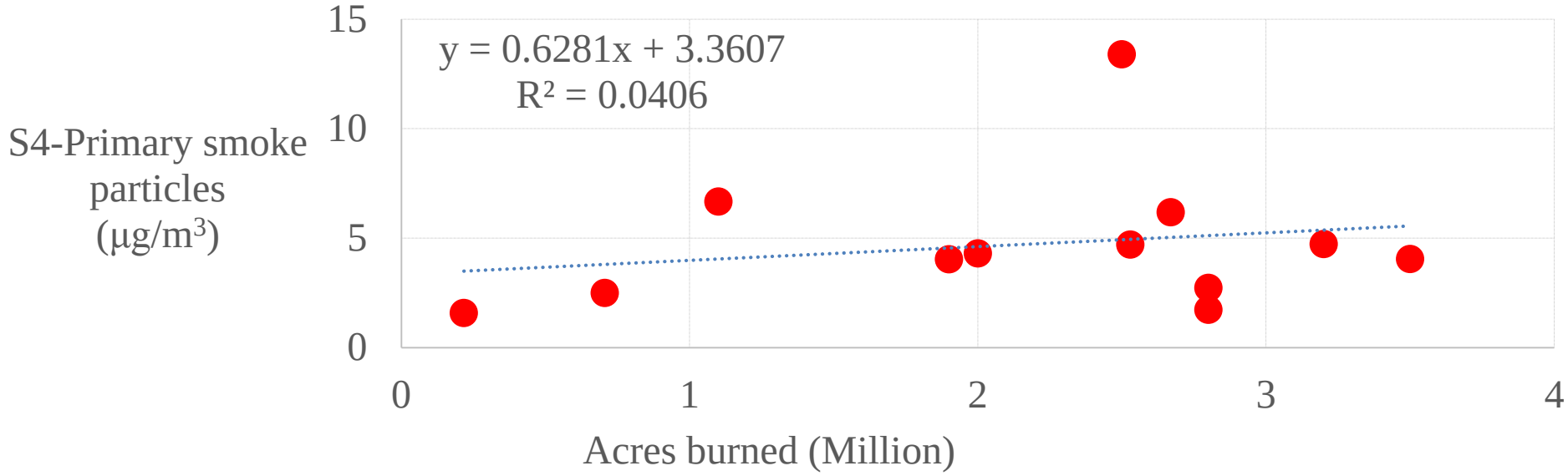
$$\text{Mass of secondary organic particles from burning} \approx 4 \times \text{Mass of primary smoke particles}$$

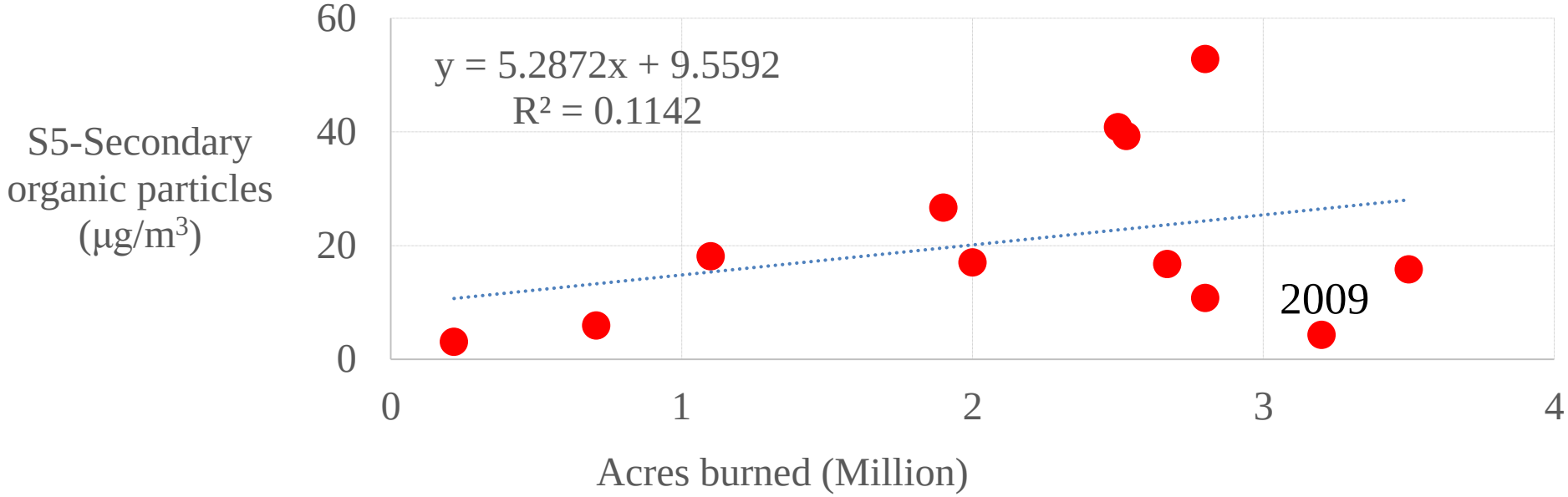
Average S4 and S5 in April vs. acres burned (Tallgrass site)



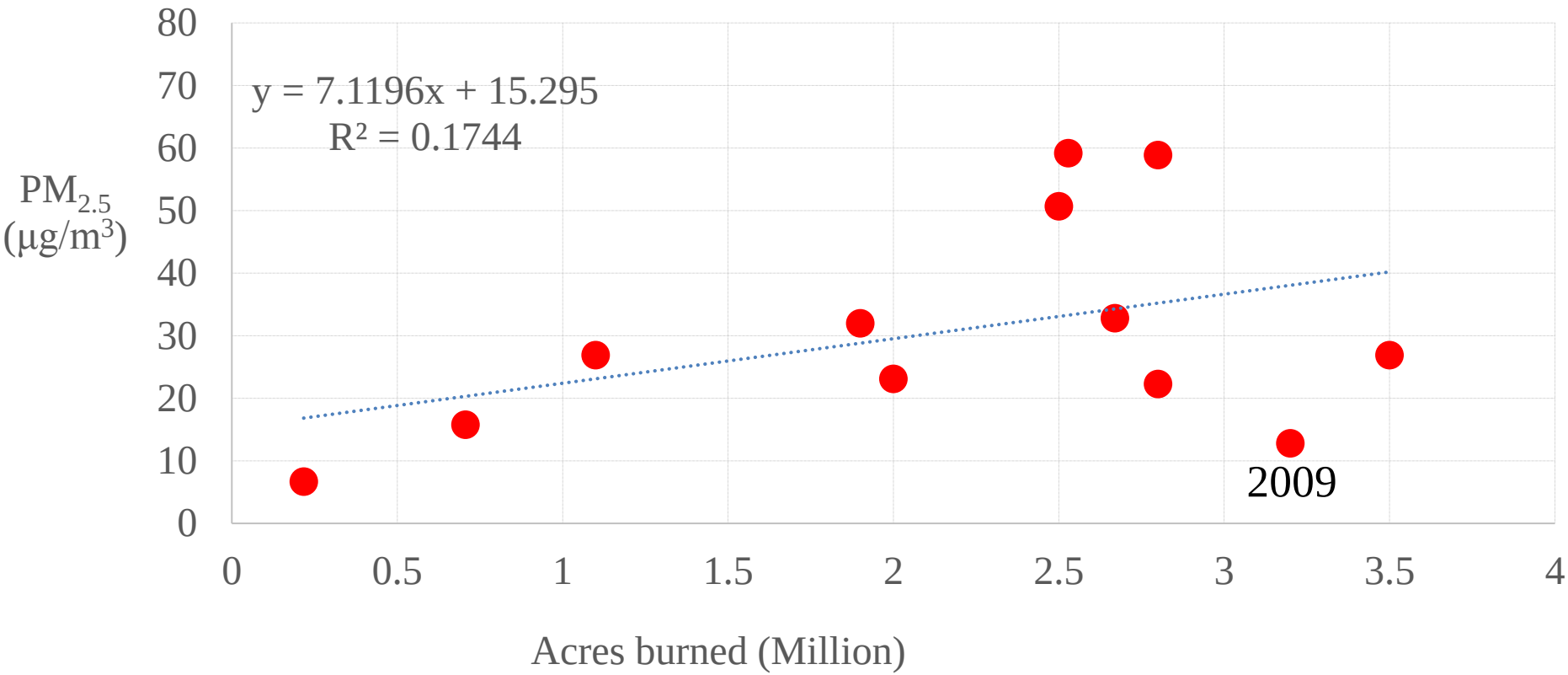


Highest S4 and S5 in April vs. acres burned (Tallgrass site)





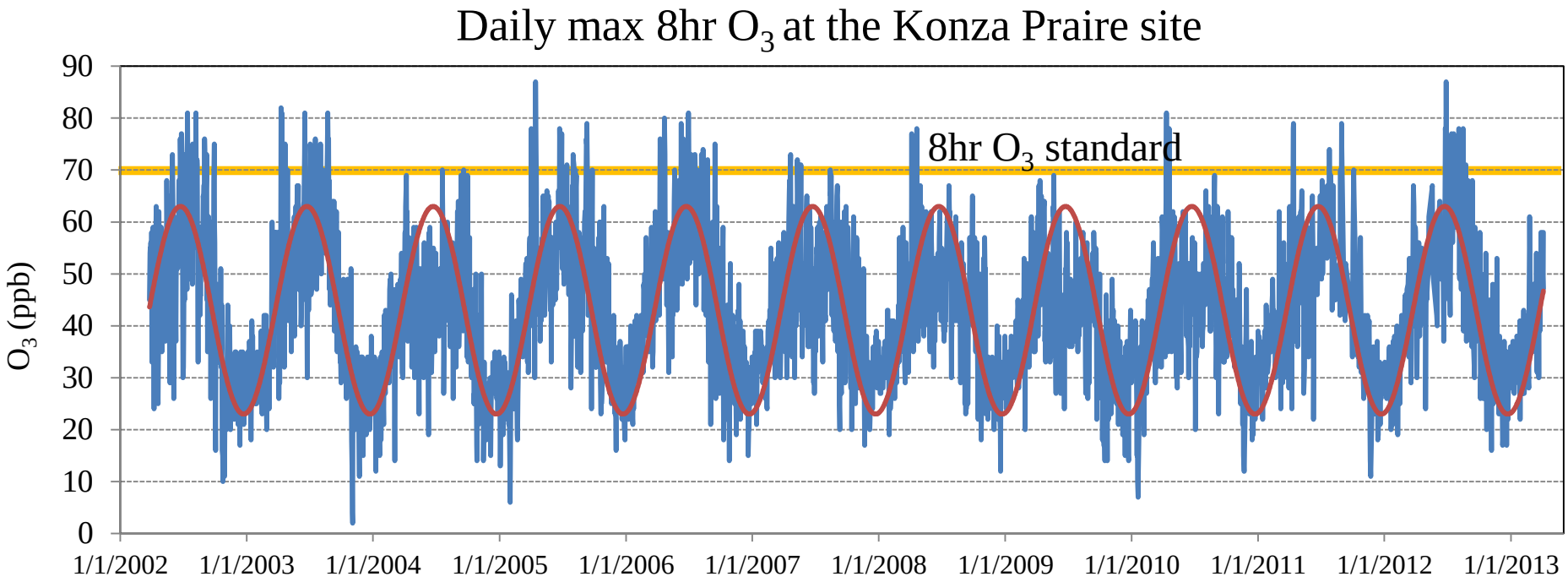
Highest PM2.5 in April vs. acres burned (Tallgrass site)

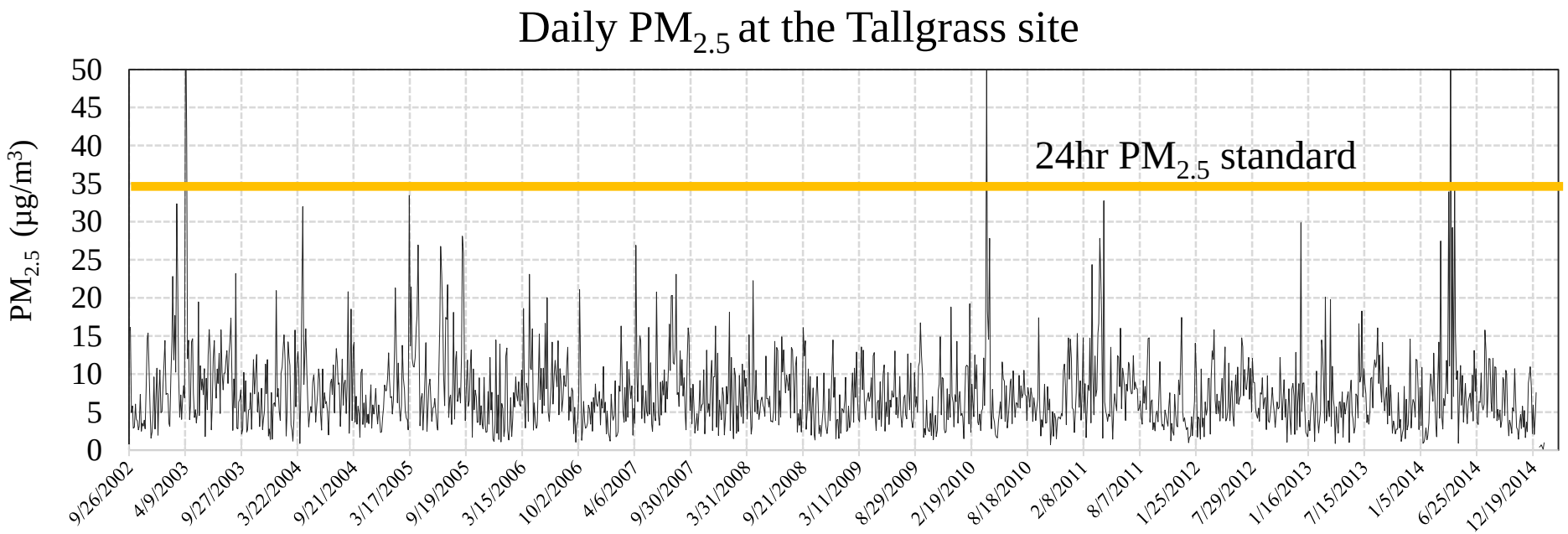


- When acres burned ≥ 2.5 million, $PM_{2.5}$>35µg/m^3 may occur.
- When acres burned < 2.5 million, $PM_{2.5}$>35µg/m^3 did not occur.

O_3 and $PM_{2.5}$

- O_3 and $PM_{2.5}$ controls are traditionally considered separately because their high pollution periods are not concurrent on seasonal timescales
  - O_3 usually peaking in summer and $PM_{2.5}$ often peaking in winter.
  - Higher temperature and lower RH promote O_3 formation but cause volatilization of nitrate aerosols.


Daily max 8hr O_3 at the Konza Praire site
8hr O_3 standard
O_3 (ppb)
90
80
70
60
50
40
30
20
10
0
1/1/2002
1/1/2003
1/1/2004
1/1/2005
1/1/2006
1/1/2007
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013


Daily $PM_{2.5}$ at the Tallgrass site
24hr $PM_{2.5}$ standard
$PM_{2.5}$ (µg/m^3)
50
45
40
35
30
25
20
15
10
5
0
9/26/2002
4/9/2003
9/27/2003
3/22/2004
9/21/2004
3/17/2005
9/19/2005
3/15/2006
10/2/2006
4/6/2007
9/30/2007
3/31/2008
9/21/2008
3/11/2009
8/29/2009
2/19/2010
8/18/2010
2/8/2011
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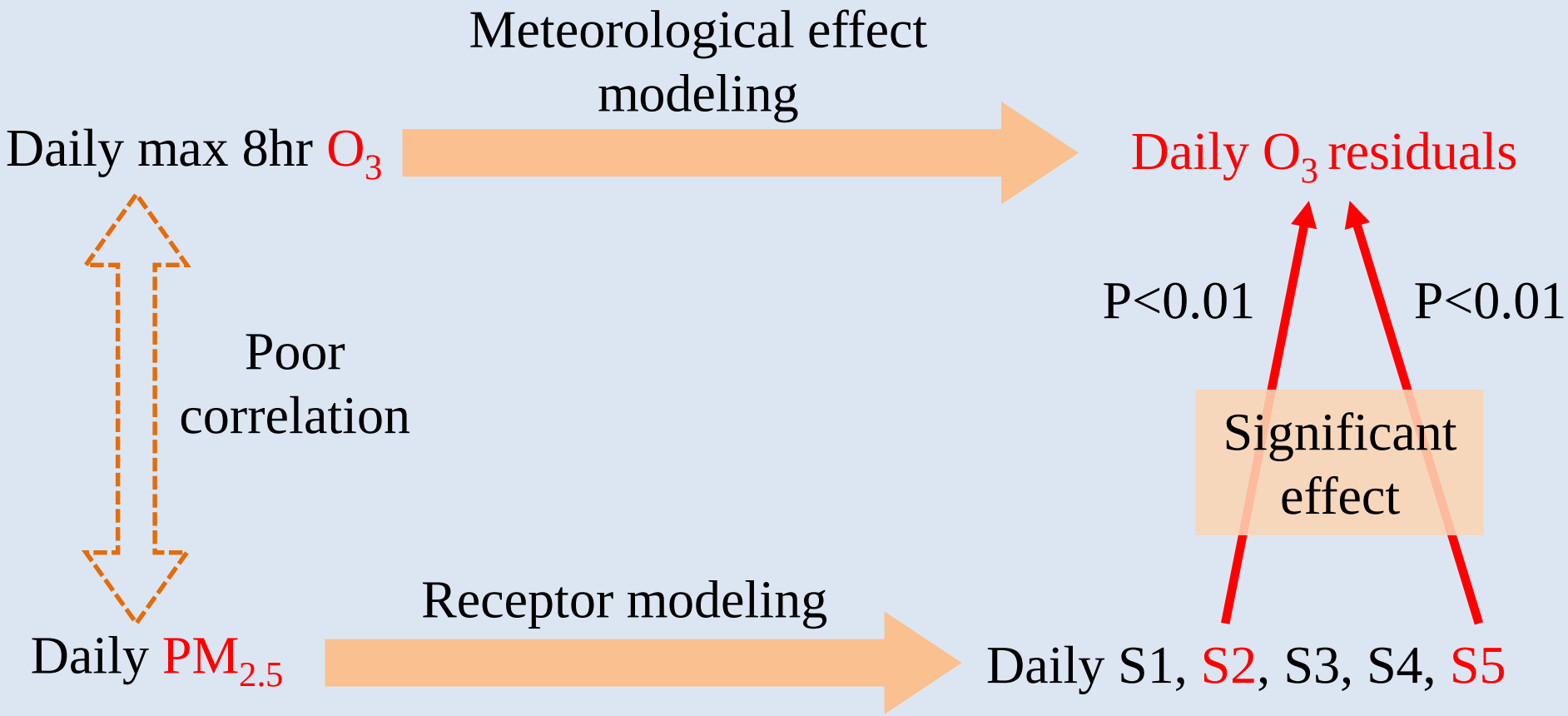
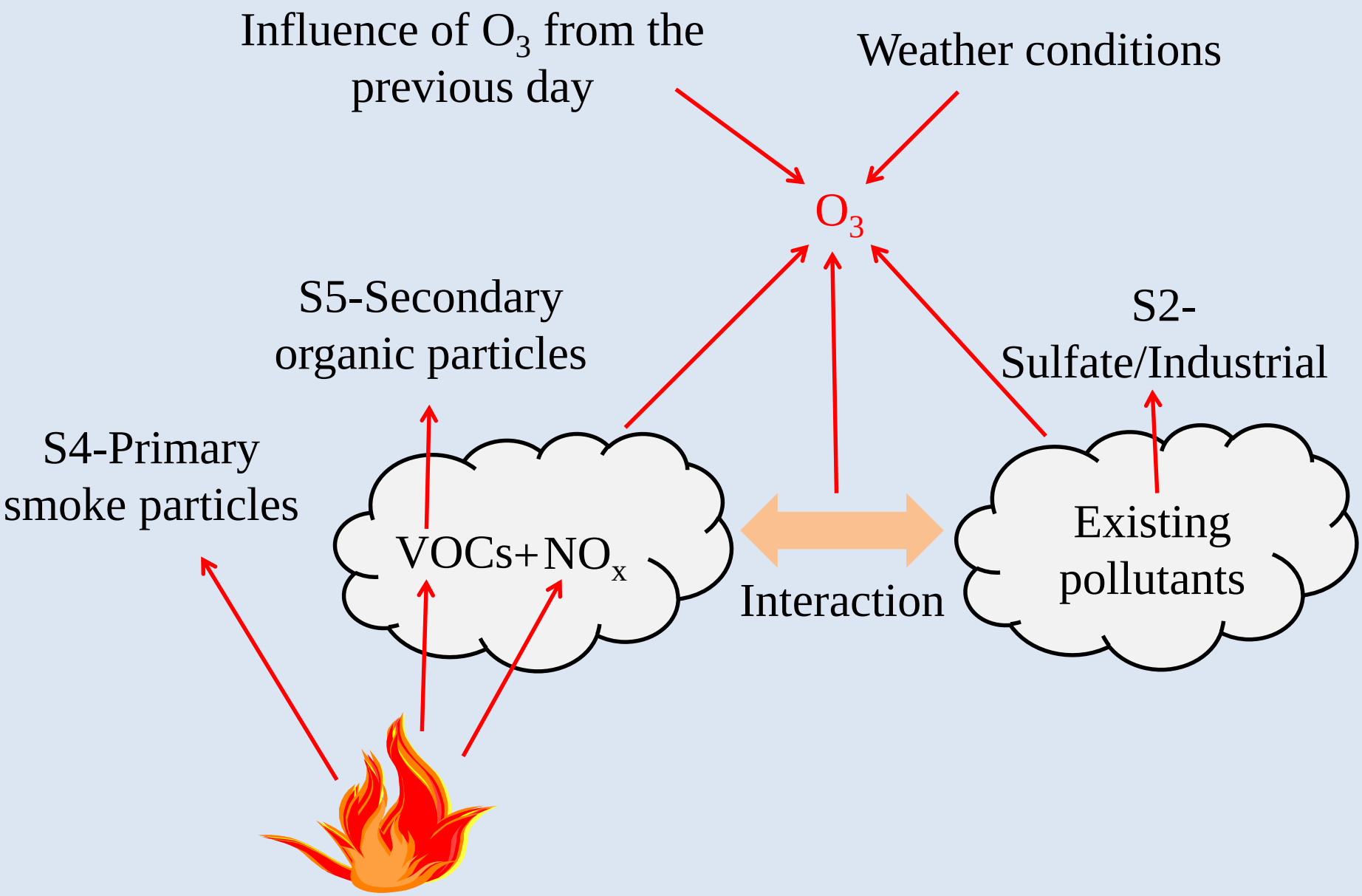
7/15/2013
1/5/2014
6/25/2014
12/19/2014


Meteorological effect modeling
Daily max 8hr O_3
Daily O_3 residuals
P<0.01
P<0.01
Poor correlation
Significant effect
Receptor modeling
Daily $PM_{2.5}$
Daily S1, S2, S3, S4, S5


Influence of O_3 from the previous day
Weather conditions
O_3
S5-Secondary organic particles
S2-Sulfate/Industrial
S4-Primary smoke particles
VOCs+NO_x
Interaction
Existing pollutants