Impact of Prescribed burning In the Flint Hills Region

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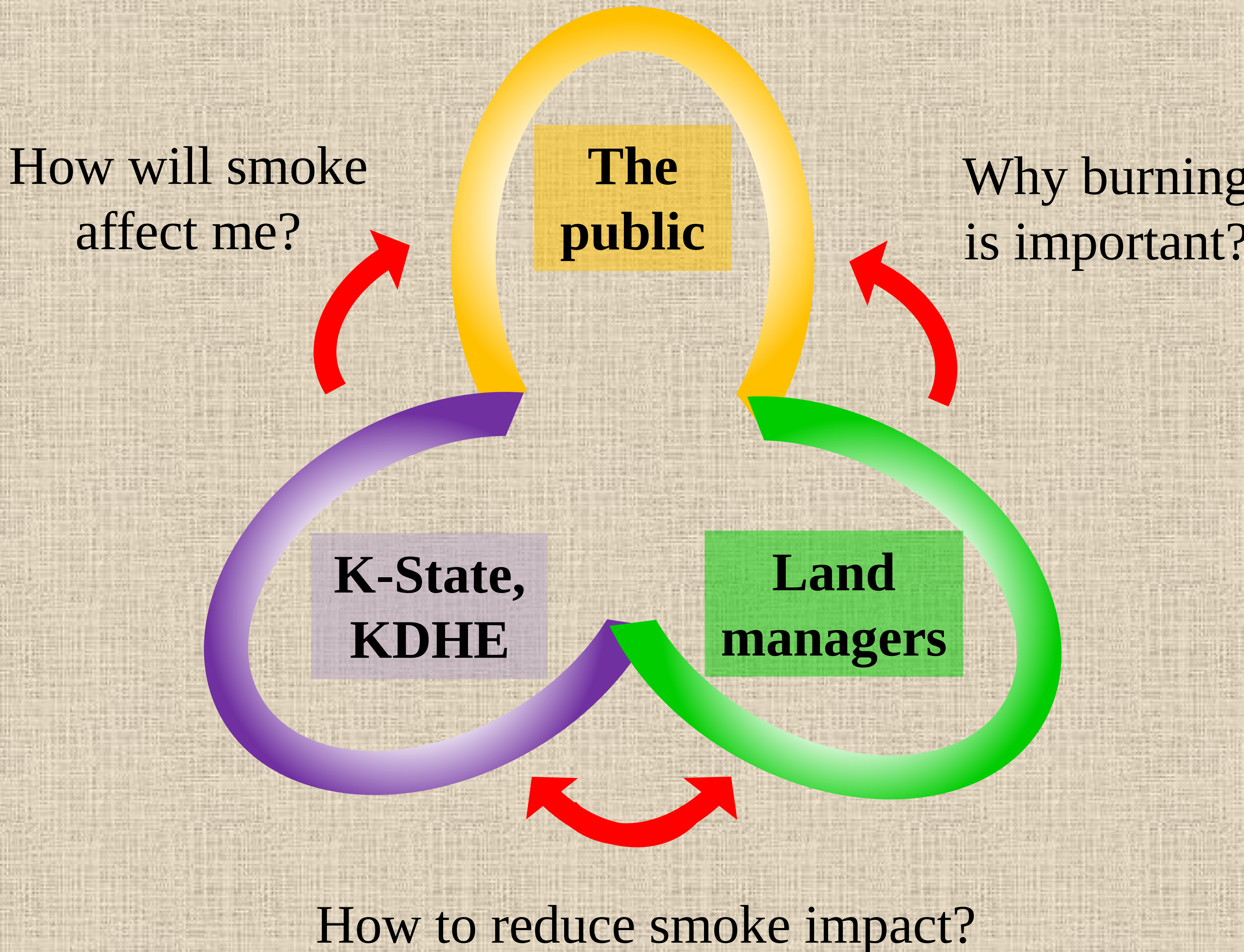
May 10th, 2018

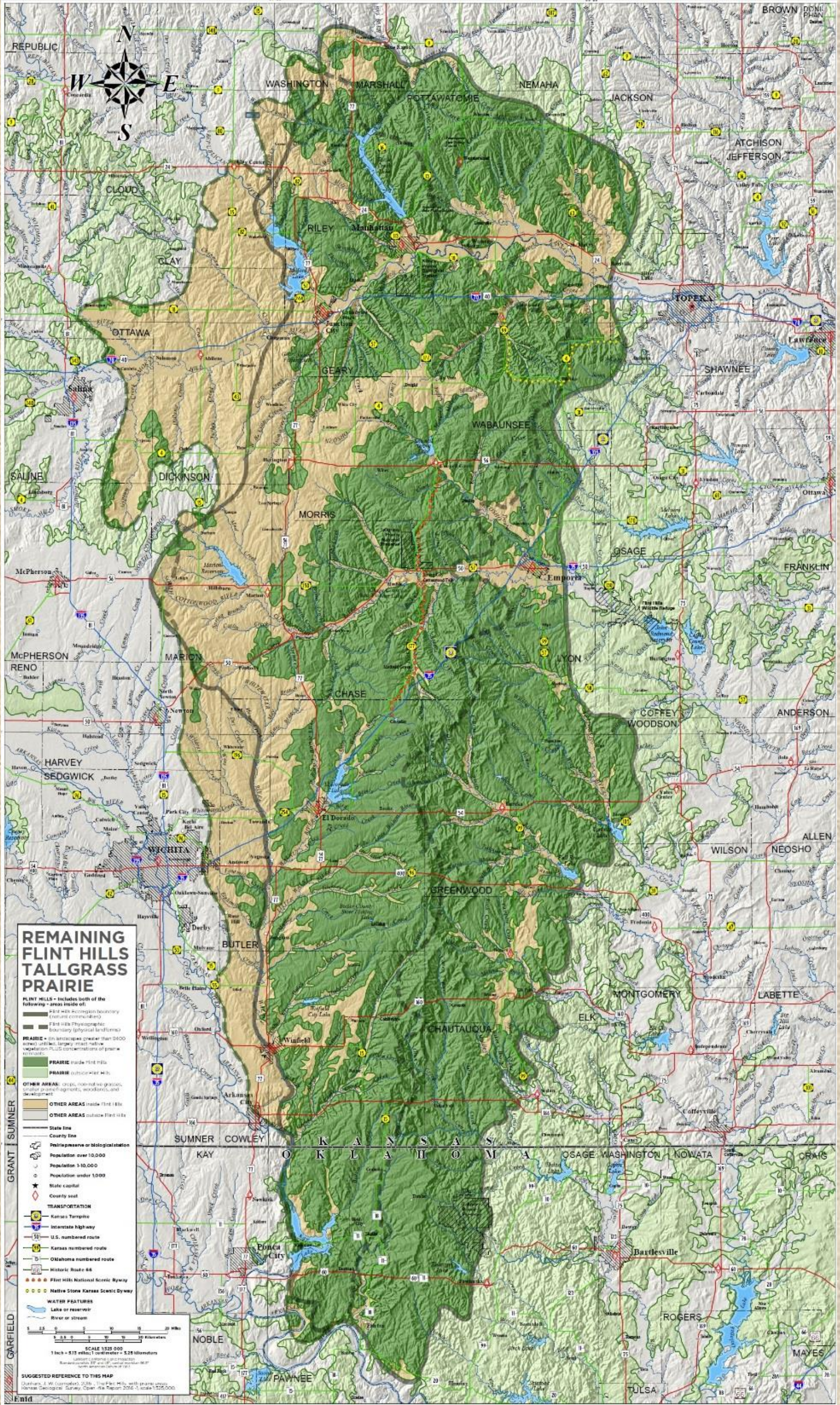

The public
How will smoke affect me?
Why burning is important?
K-State, KDHE
Land managers
How to reduce smoke impact?

April 16, 2018

Outline

- The impact of smoke
- The ozone story
- Why do we burn? When is the best time to burn?
- Monitoring smoke using drone

The impact of smoke



Largest remaining intact tallgrass prairie

7 million acres of rangeland

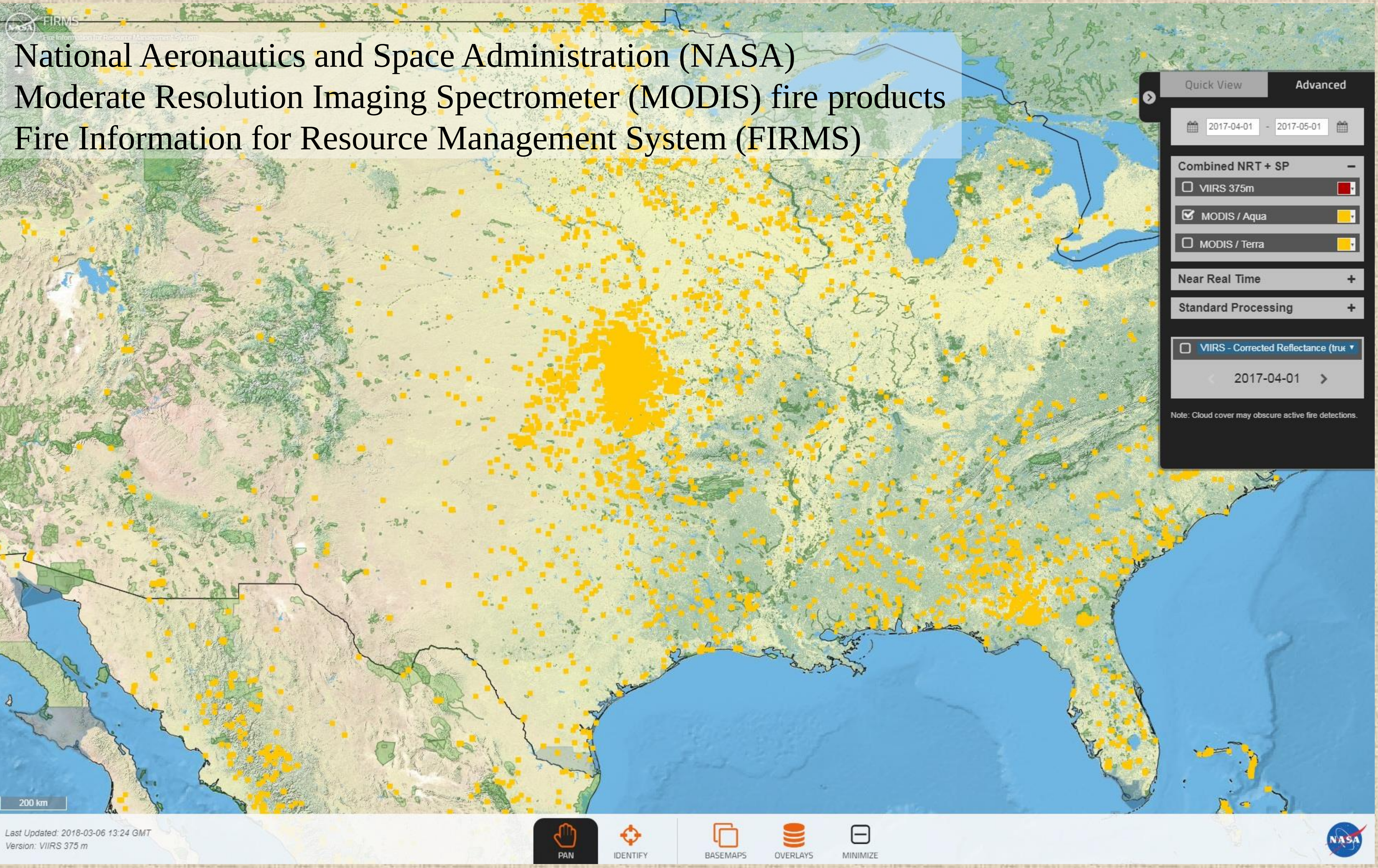
Approximately 1/3 of the rangeland are burned each year

21 counties in Kansas and Oklahoma

Source: Kansas Geological Survey
Open-file Report 2016-1
Flint Hills Discovery Center Foundation

Satellite fires, 4/1 to 5/1, 2017

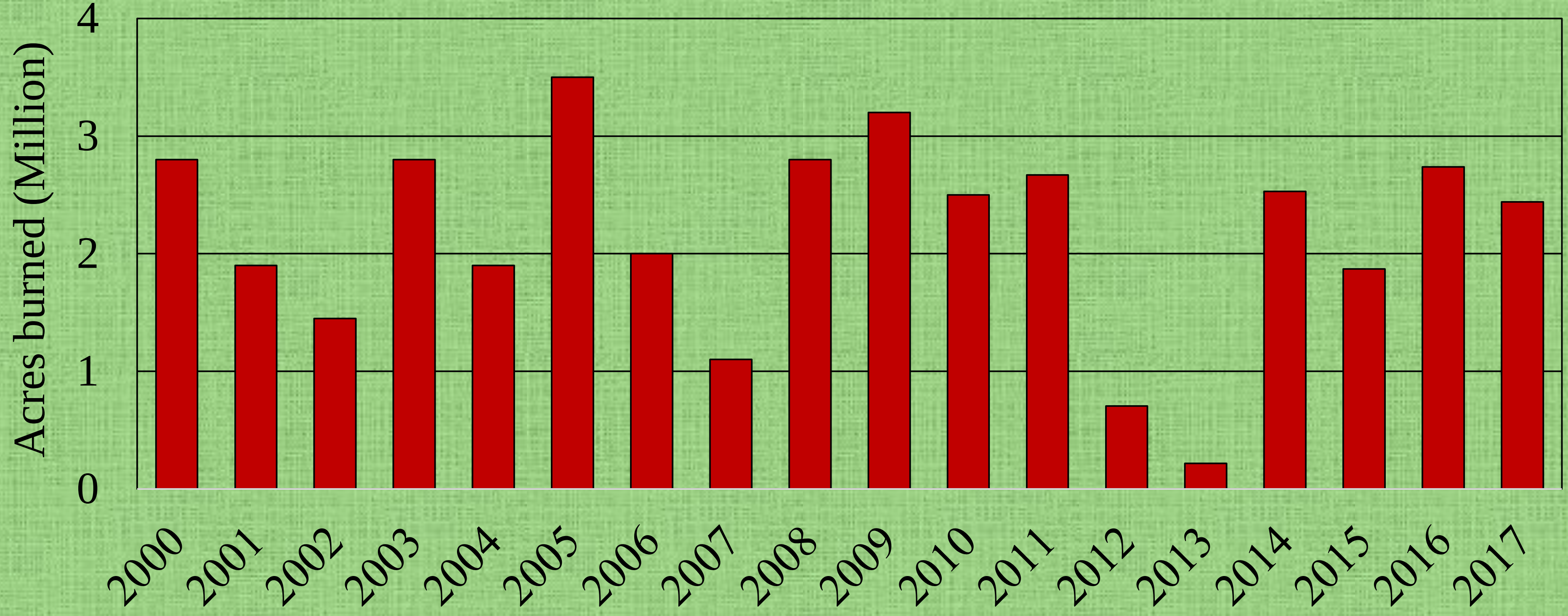
National Aeronautics and Space Administration (NASA)
Moderate Resolution Imaging Spectrometer (MODIS) fire products
Fire Information for Resource Management System (FIRMS)



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

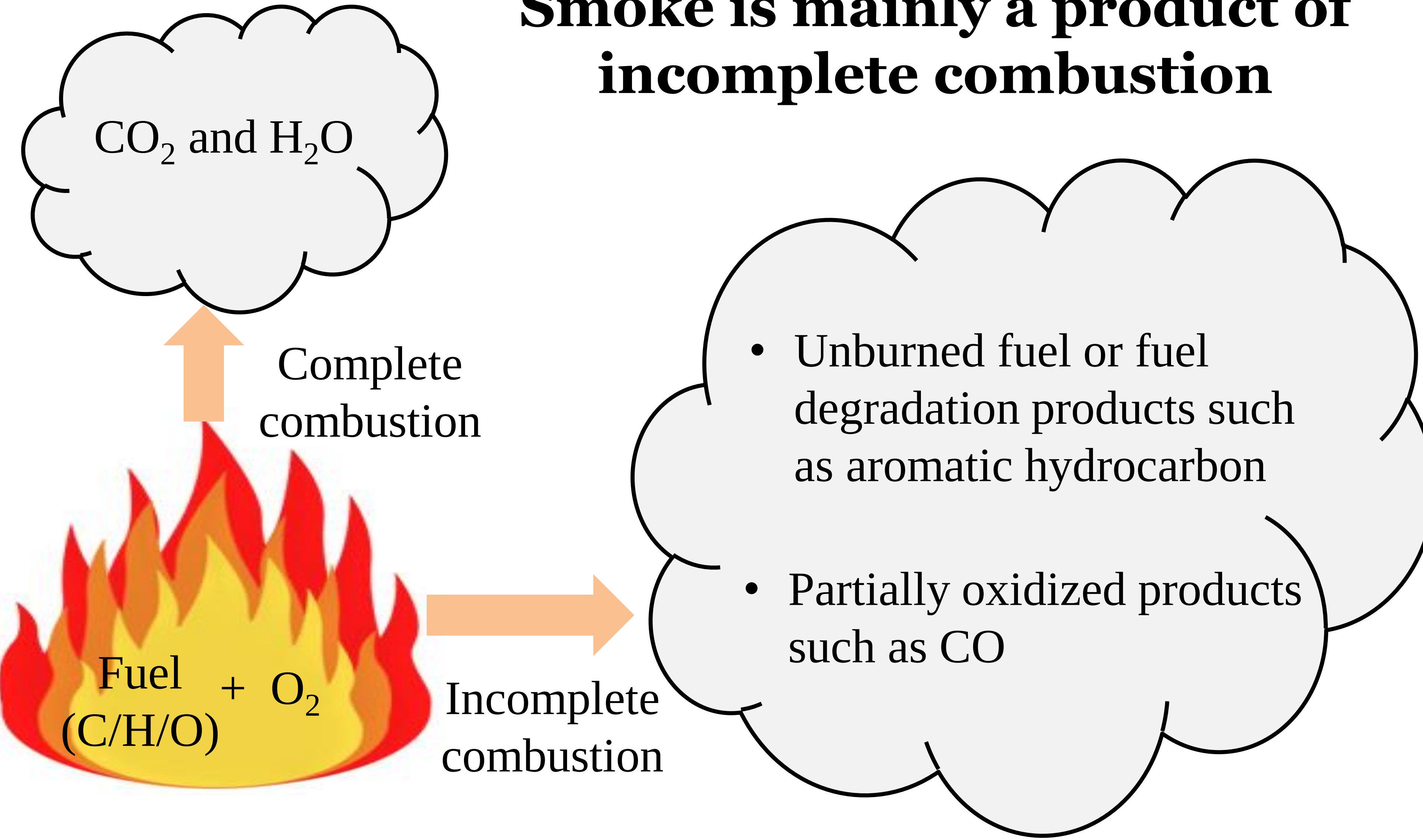
Acres burned

Average: 2.1 Million acres
Median: 2.5 Million acres

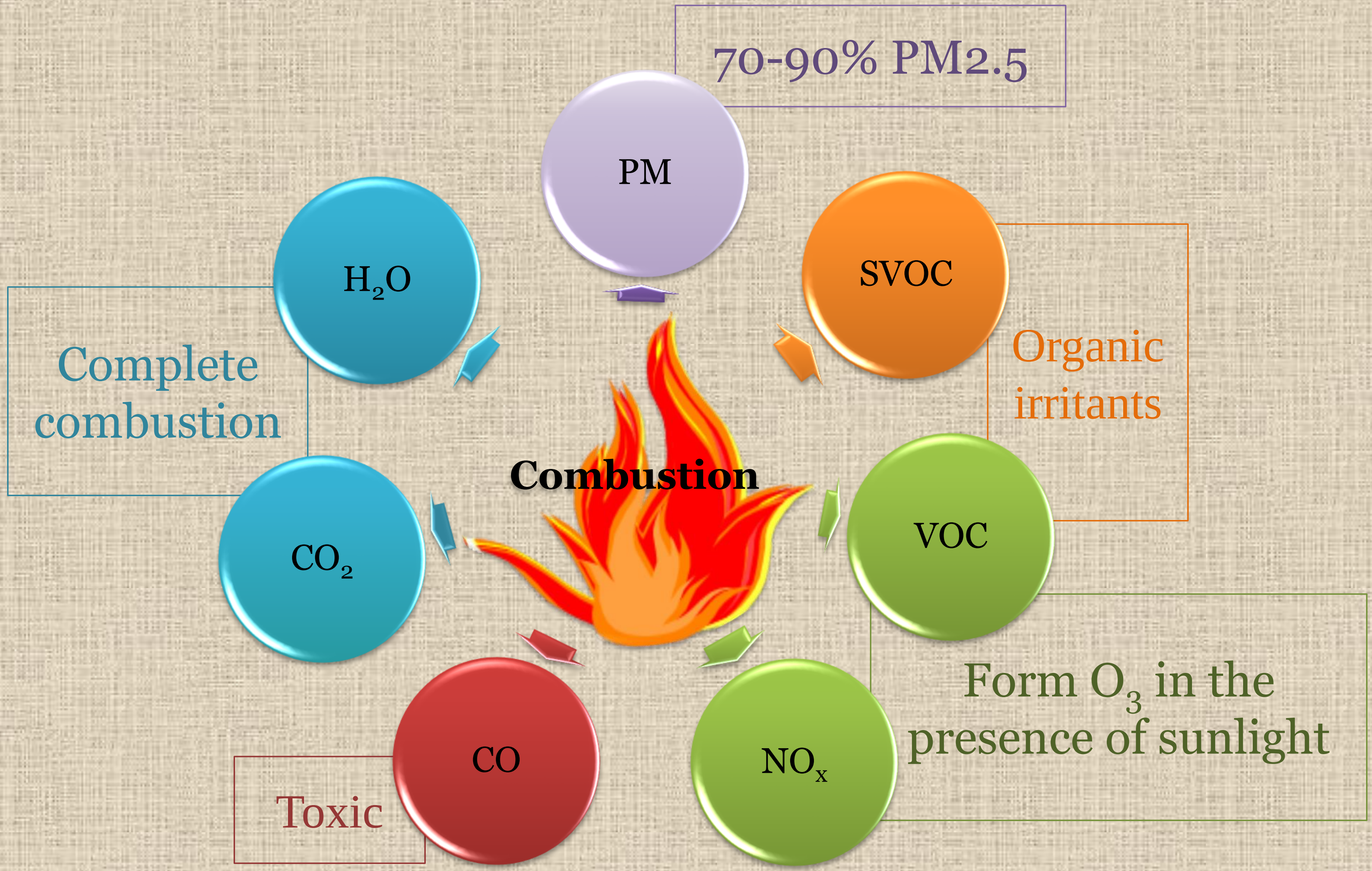


(Mohler and Goodin, 2012)

Smoke is mainly a product of incomplete combustion

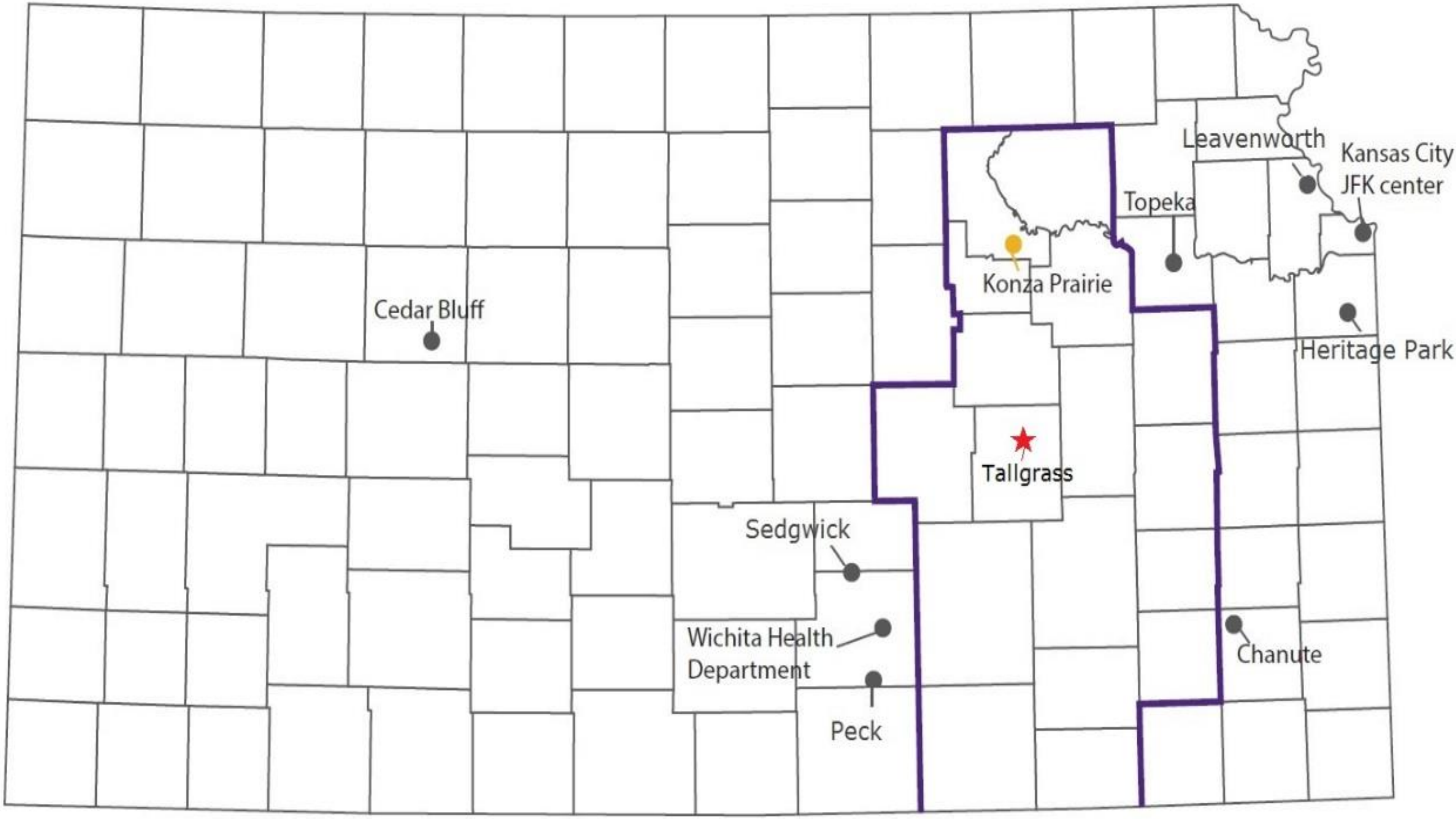


Smoke and air quality



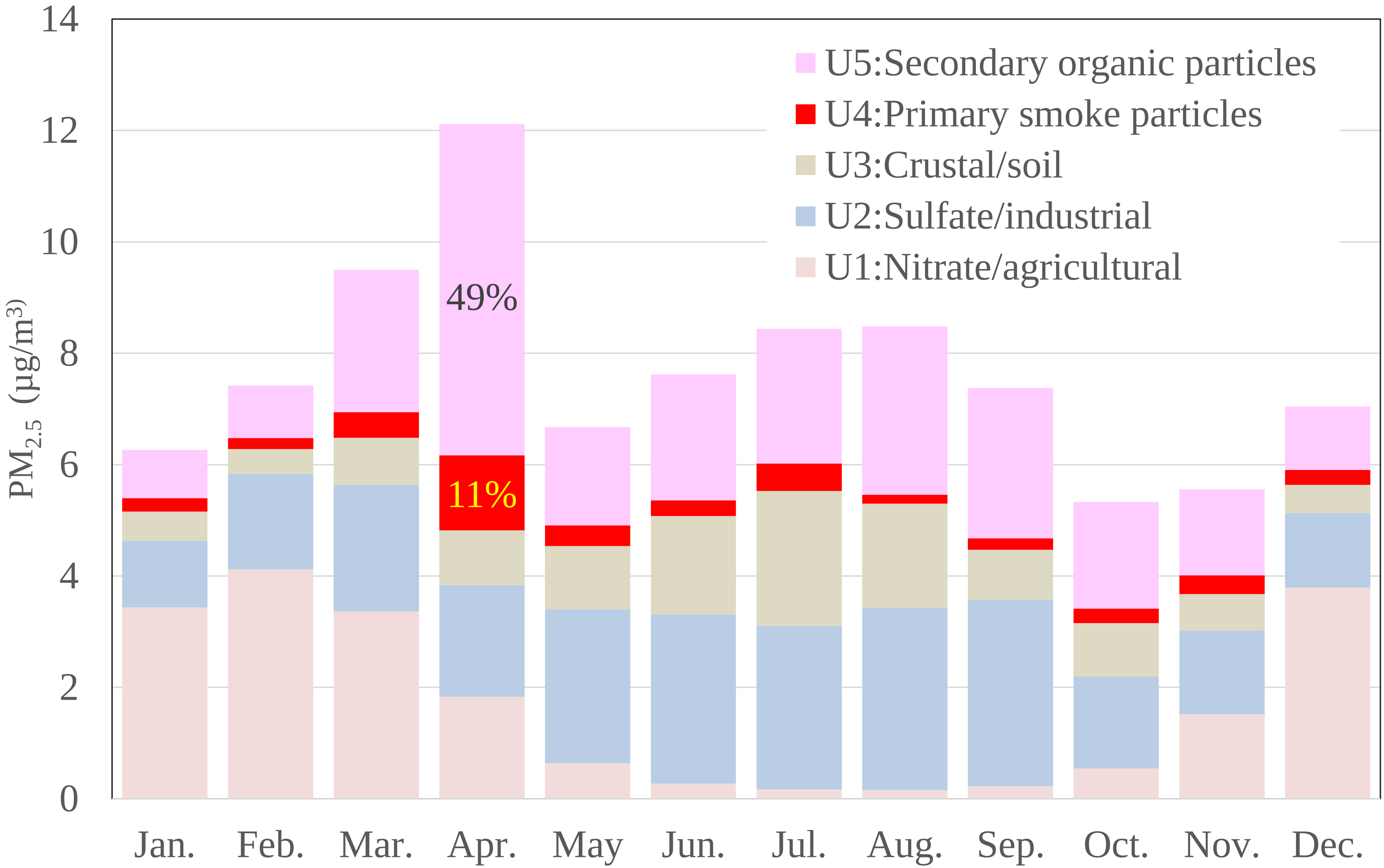
Air pollutants	**Observed concentrations in literature**		NAAQS 24-hr standards
	At the fires	At downwind communities	
$PM_{2.5}$	148-6865 μg/m^3	63-400 μg/m^3	35 μg/m^3

The Tallgrass monitoring site



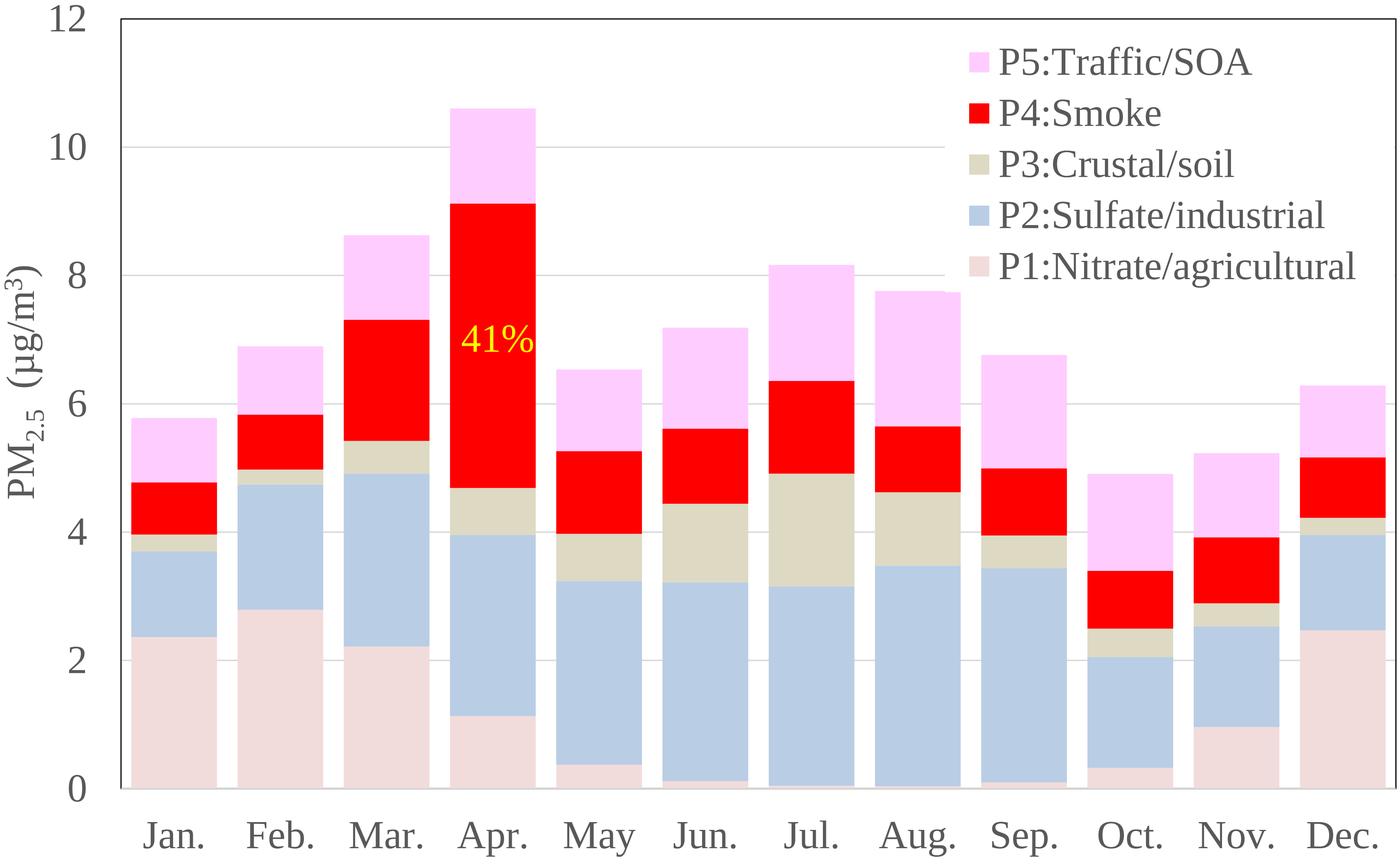
Five $PM_{2.5}$ source categories at the Tallgrass site

(Results from Unmix receptor modeling)

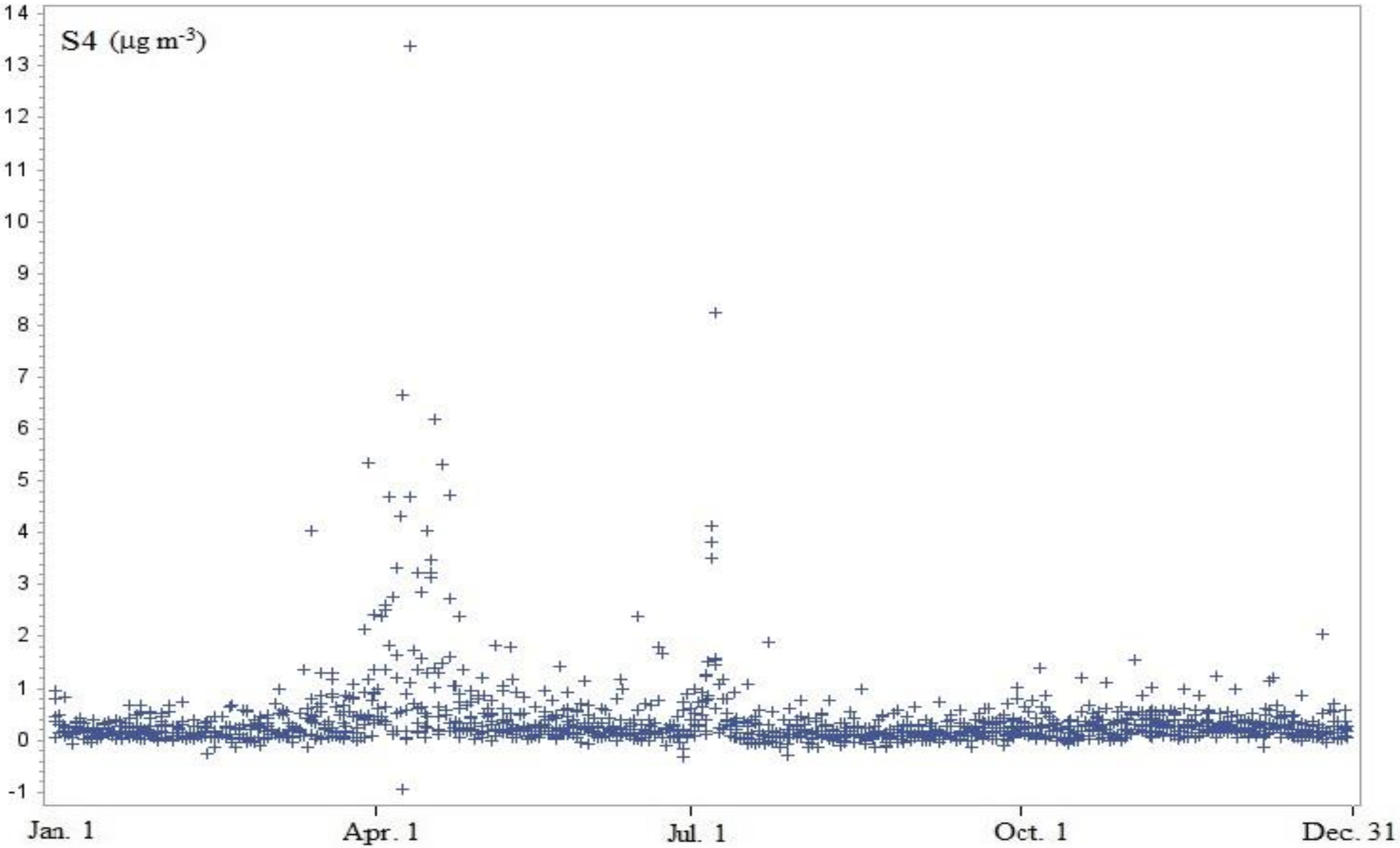


Five $PM_{2.5}$ source categories at the Tallgrass site

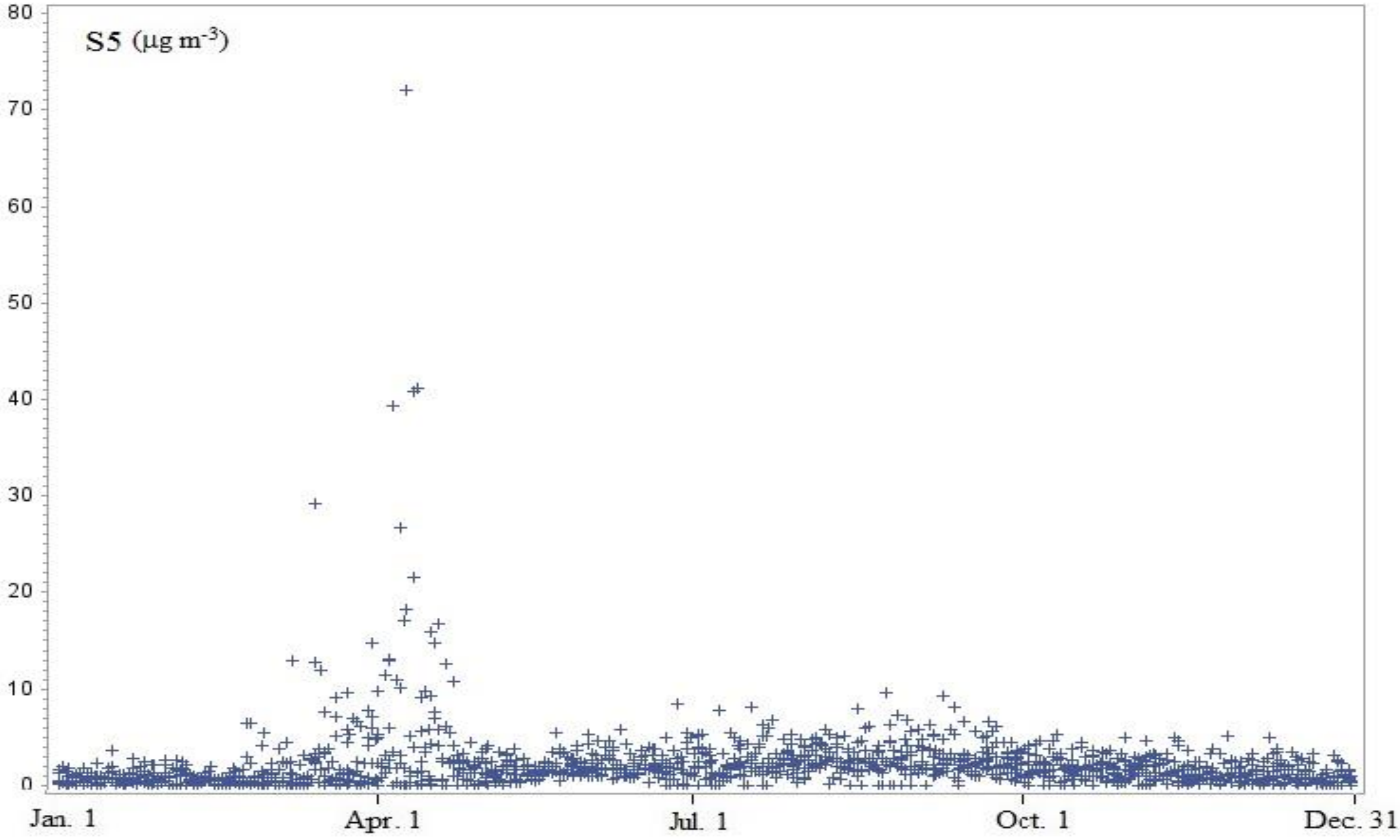
(Results from PMF receptor modeling)



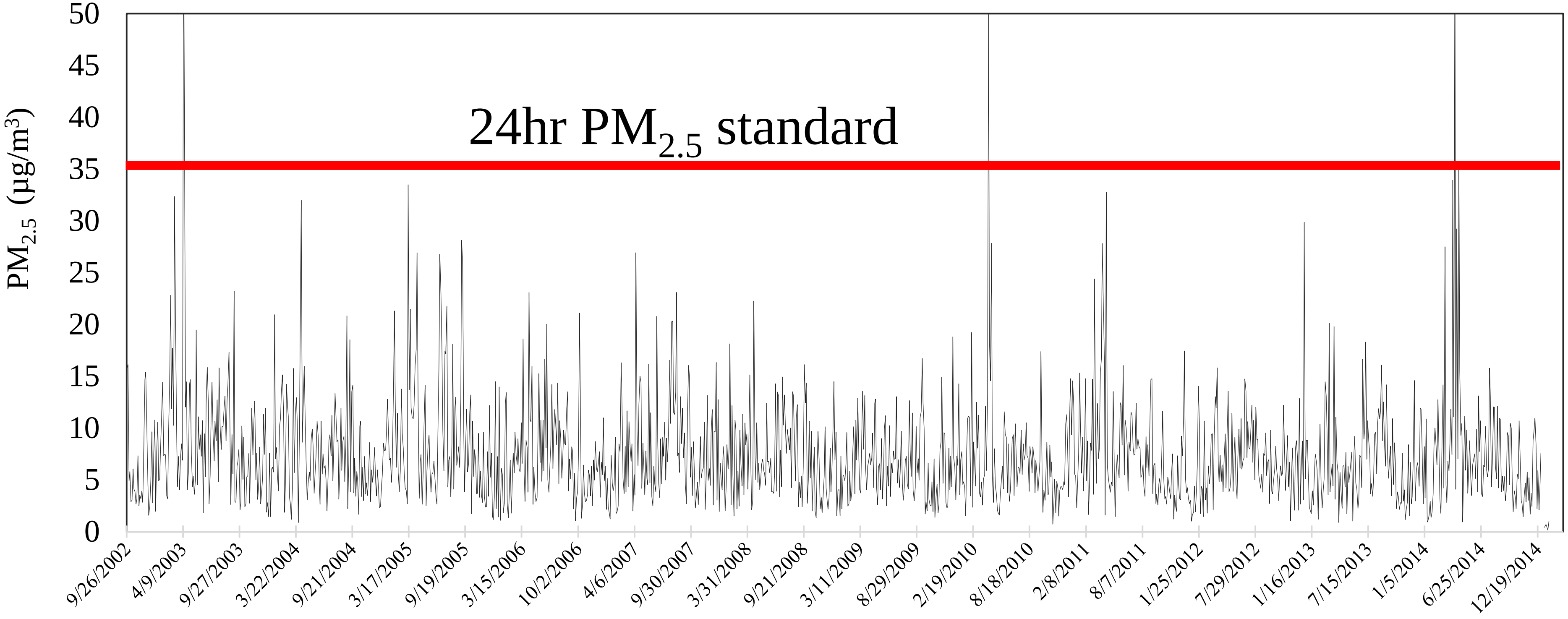
U4-Primary smoke particles



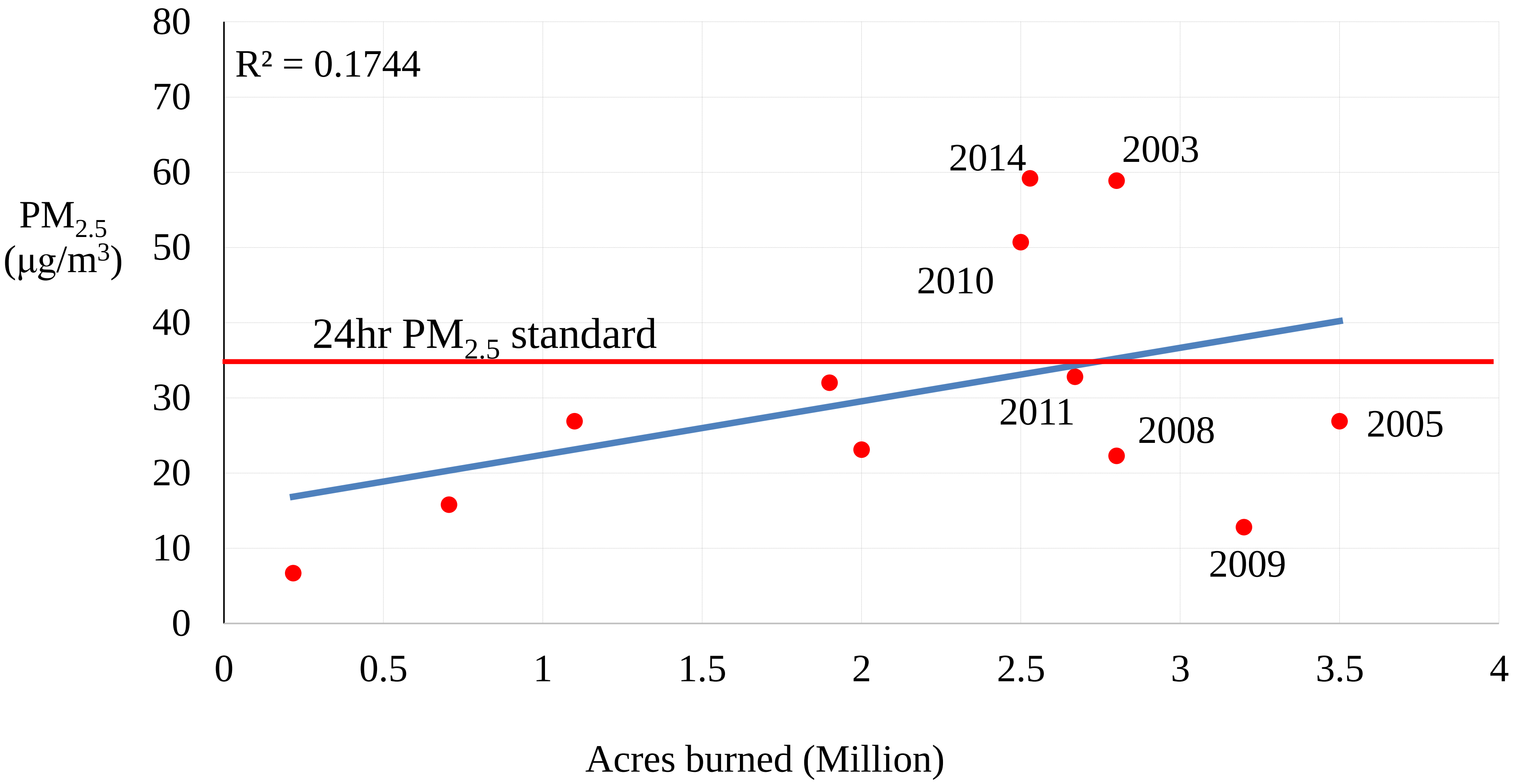
U5-Secondary organic particles



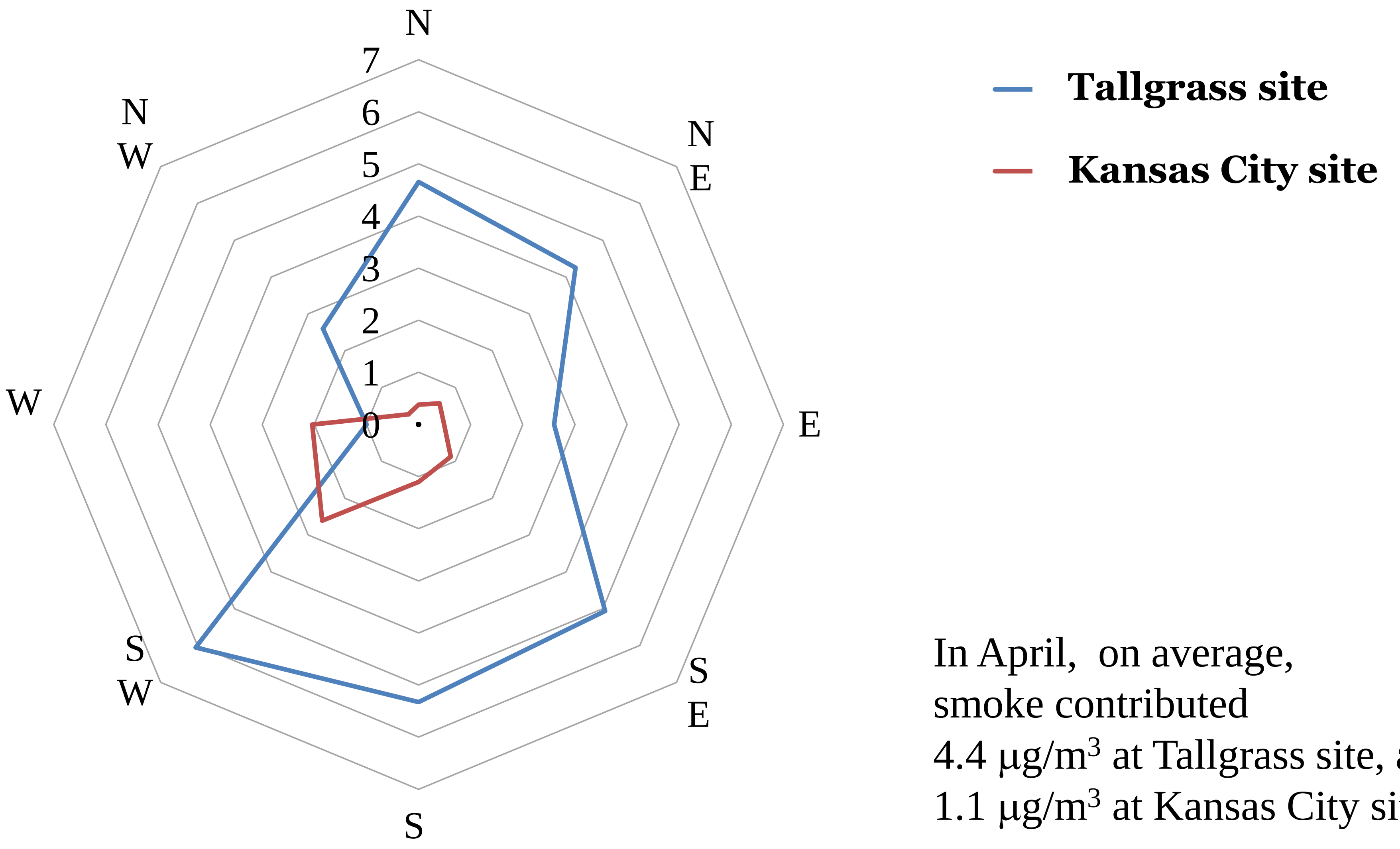
Daily $PM_{2.5}$ at the Tallgrass site



Highest daily $PM_{2.5}$ in April vs. acres burned (Tallgrass site, 2002-2014)

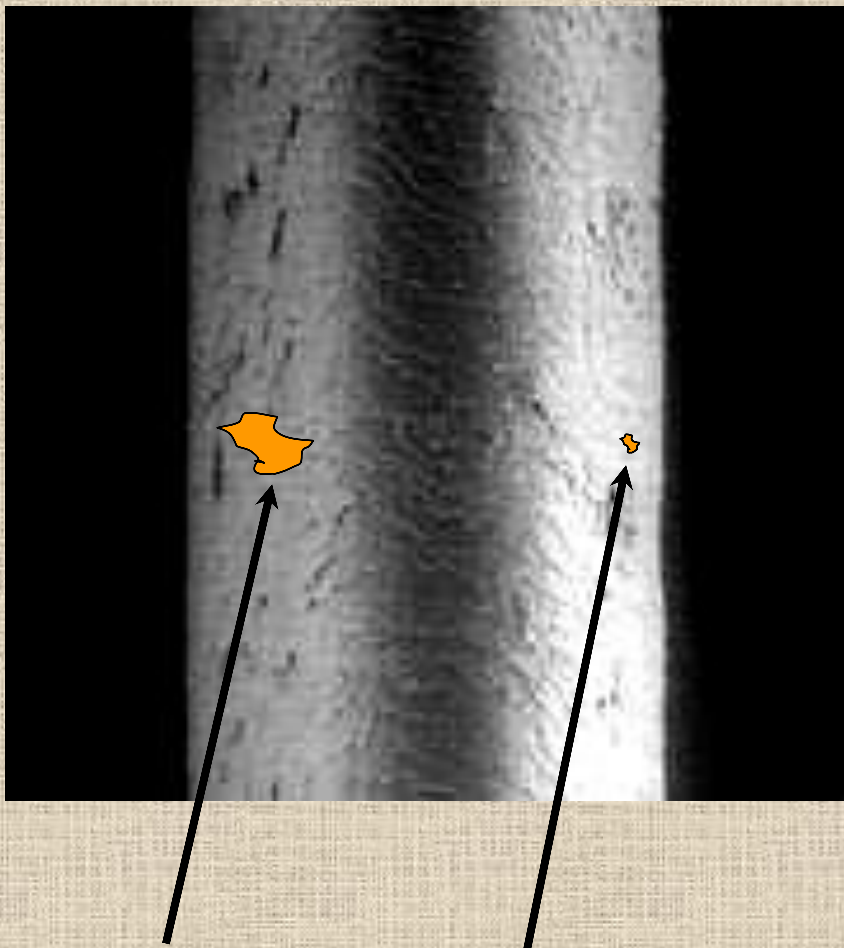


Smoke $PM_{2.5}$ at the Tallgrass site and the Kansas City site in April (in μg/m³)



In April, on average, smoke contributed 4.4 μg/m³ at Tallgrass site, and 1.1 μg/m³ at Kansas City site.

Human hair (50-70μm)



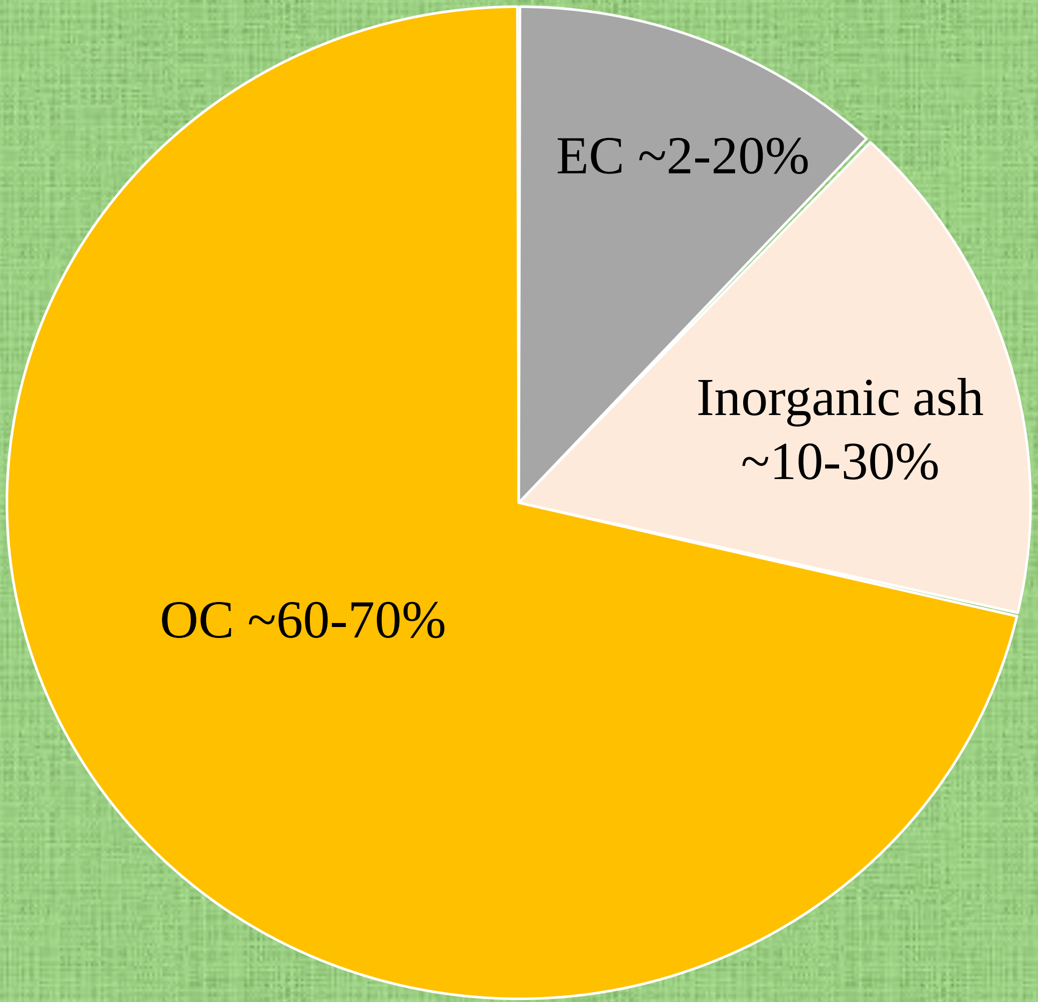
PM10
(10μm)

$PM_{2.5}$
(2.5μm)

- Can reach deeper into human respiration system

- Size near the wavelength of visible light (0.4-0.7μm) can efficiently scatter light and reduce visibility.

Composition of smoke PM



Smoke PM could be more damaging to human health than normal urban particles.

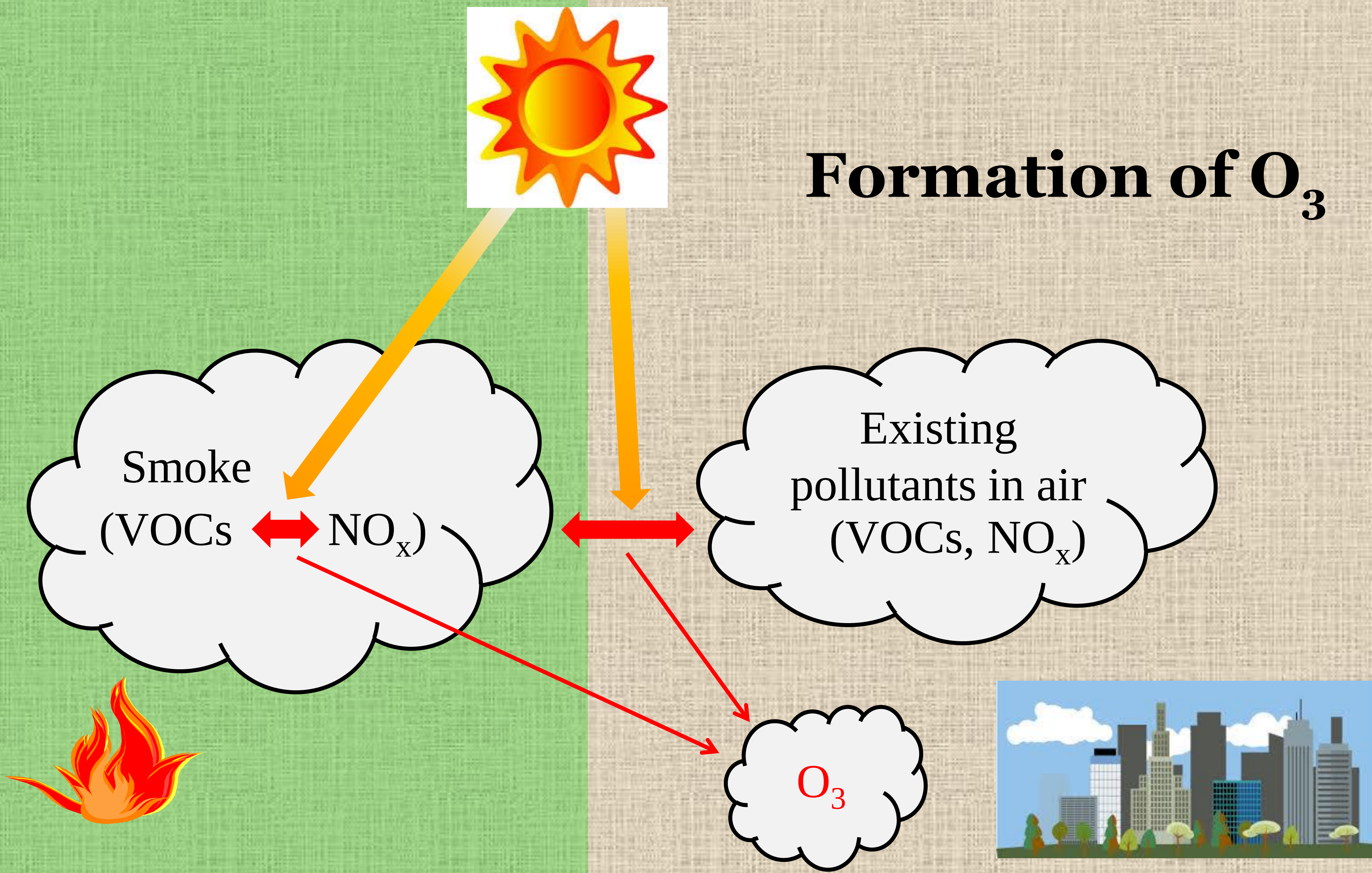
	Observed VOC/SVOC in literature		NIOSH or OSHA 8-hr exposure limits
	At the fires	At downwind communities	
Acrolein	0.018-0.071ppm	0.009 ppm	0.1 ppm
Formaldehyde	0.03-0.47 ppm	0.02-0.047 ppm	0.016 ppm
Isocyanic acid	-	600 ppb	-
PAHs	-	-	200 μg/m^3
• BaP	0.10-0.16 μg/m^3	0.007 μg/m^3	-
• Acenaphthene	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	-	-

Air pollutants	Observed mixing ratios in literature		NAAQS 8-hr standards
	At the fires	At downwind communities	
CO	1-140 ppm	1-6 ppm	9 ppm

Air pollutants	Observed mixing ratios in literature		NAAQS 8-hr standards
	At the fires	At downwind communities	
O_3	-	Up by 50 ppb	70 ppb

- Strong oxidant that damages cells lining the respiratory system
- Cough
- Sore or scratchy throat
- Pain with deep breath, or chest pain
- Fatigue
- Aggravation of lung diseases

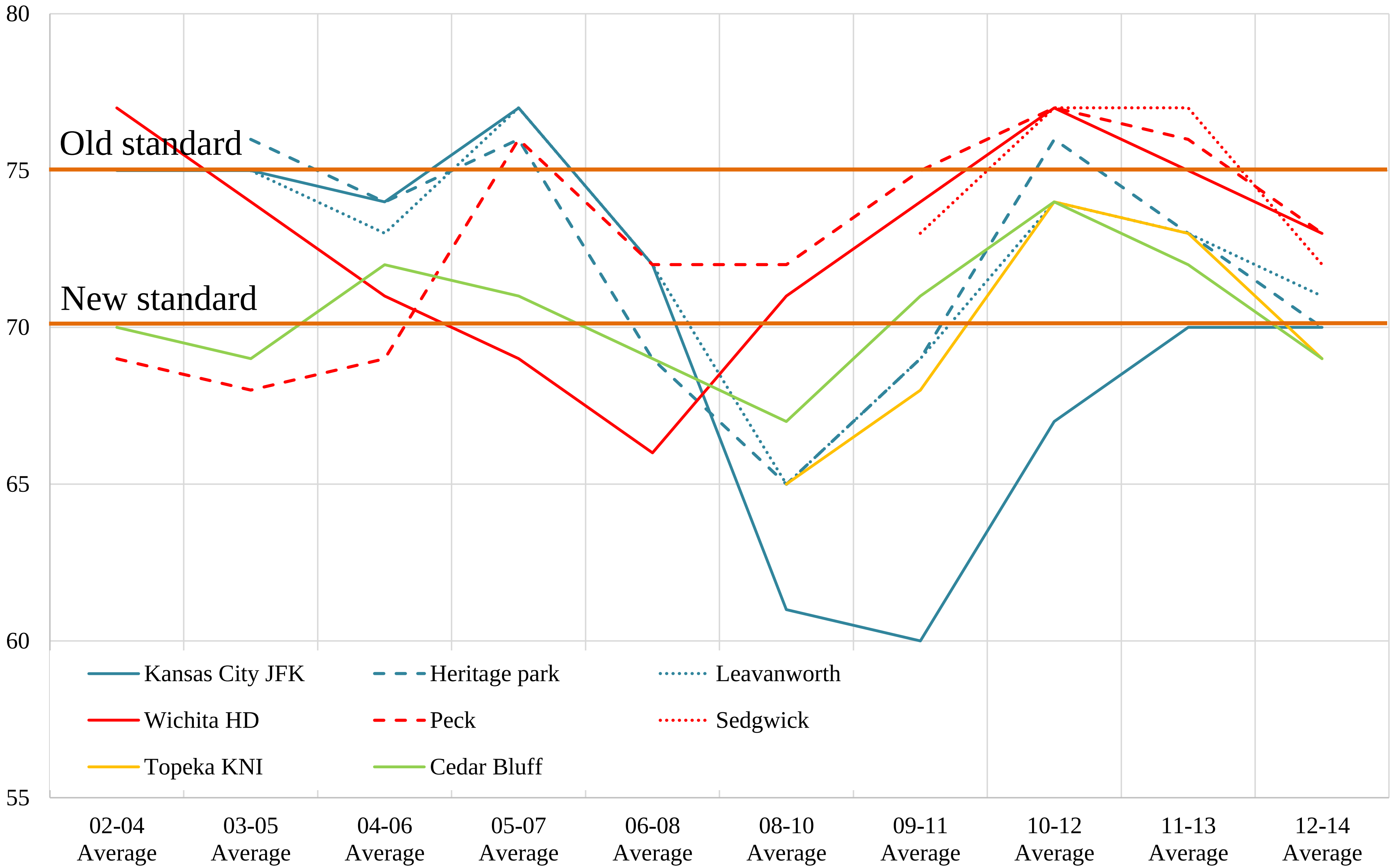
Formation of O_3



Evolution of O_3 standards

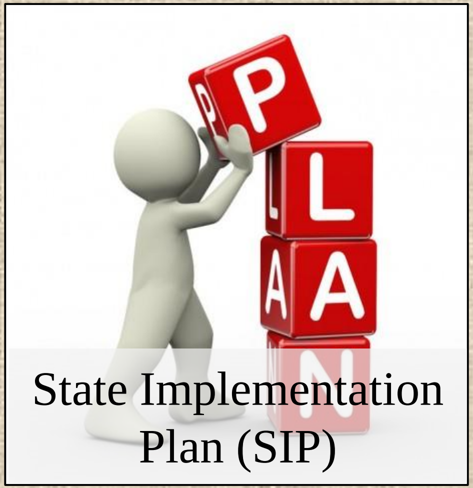
	8-hour	1-hour
1979		120ppb
1997	80ppb	
2008	75ppb	
2015	70ppb	

Kansas 8hr O_3 design values (ppb)

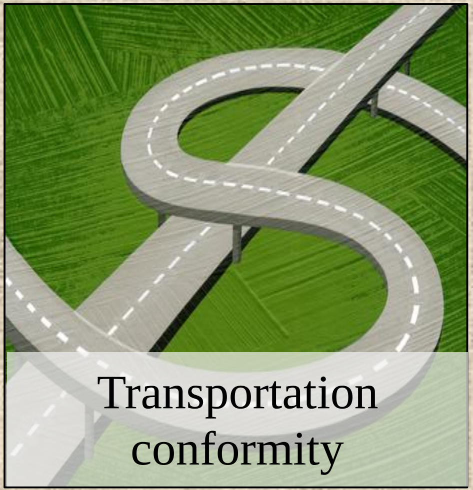


(Data from KDHE, 2010 and 2015. 5-Year Ambient Air Monitoring Network Assessment)

Consequences of nonattainment



State Implementation Plan (SIP)



Transportation conformity

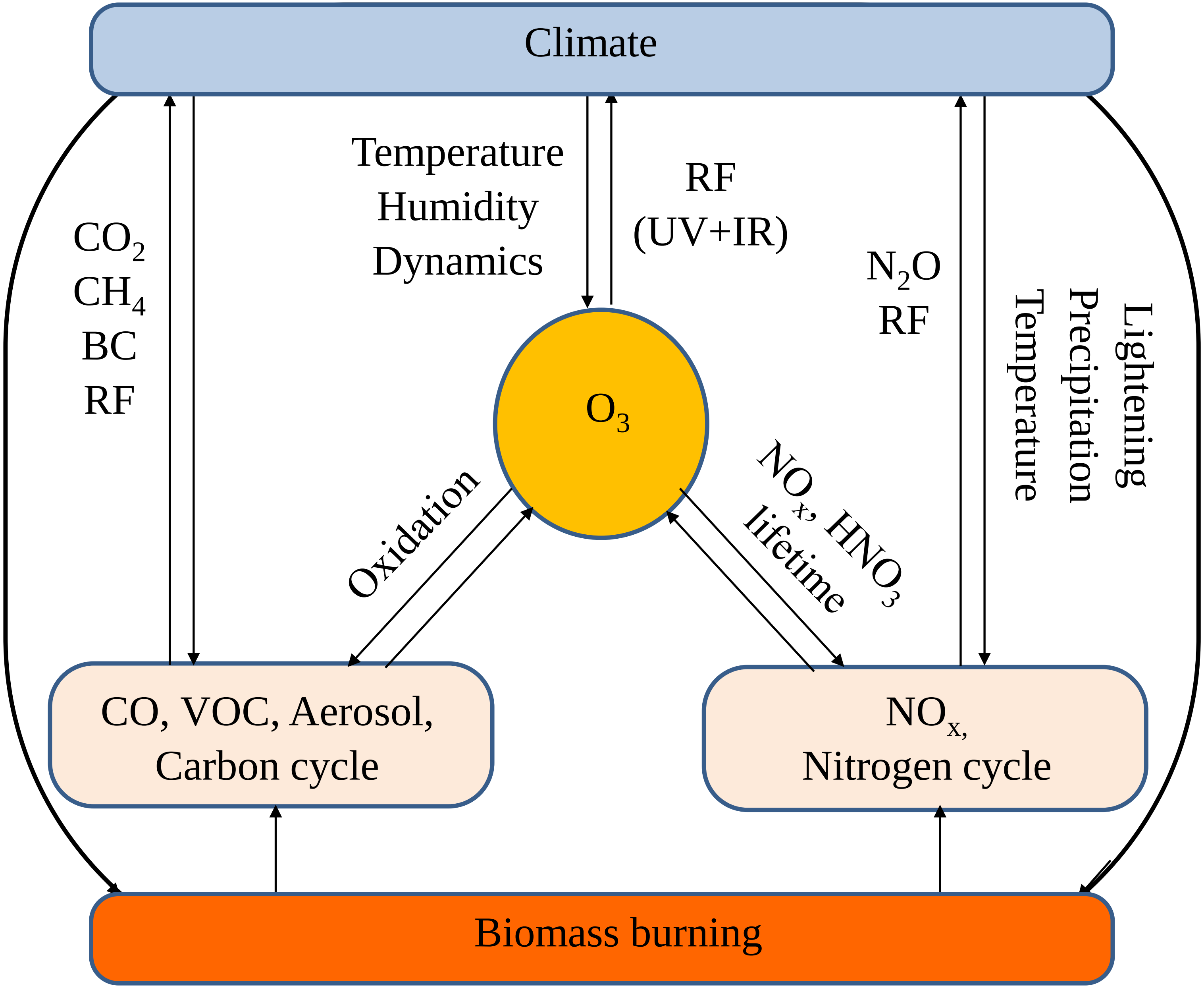
Contingency measures

- Enhanced emissions inventory
- Photochemical modeling
- Economic development curtailed

- Potential for loss of highway funds and restrictions on how highway funds can be spent.

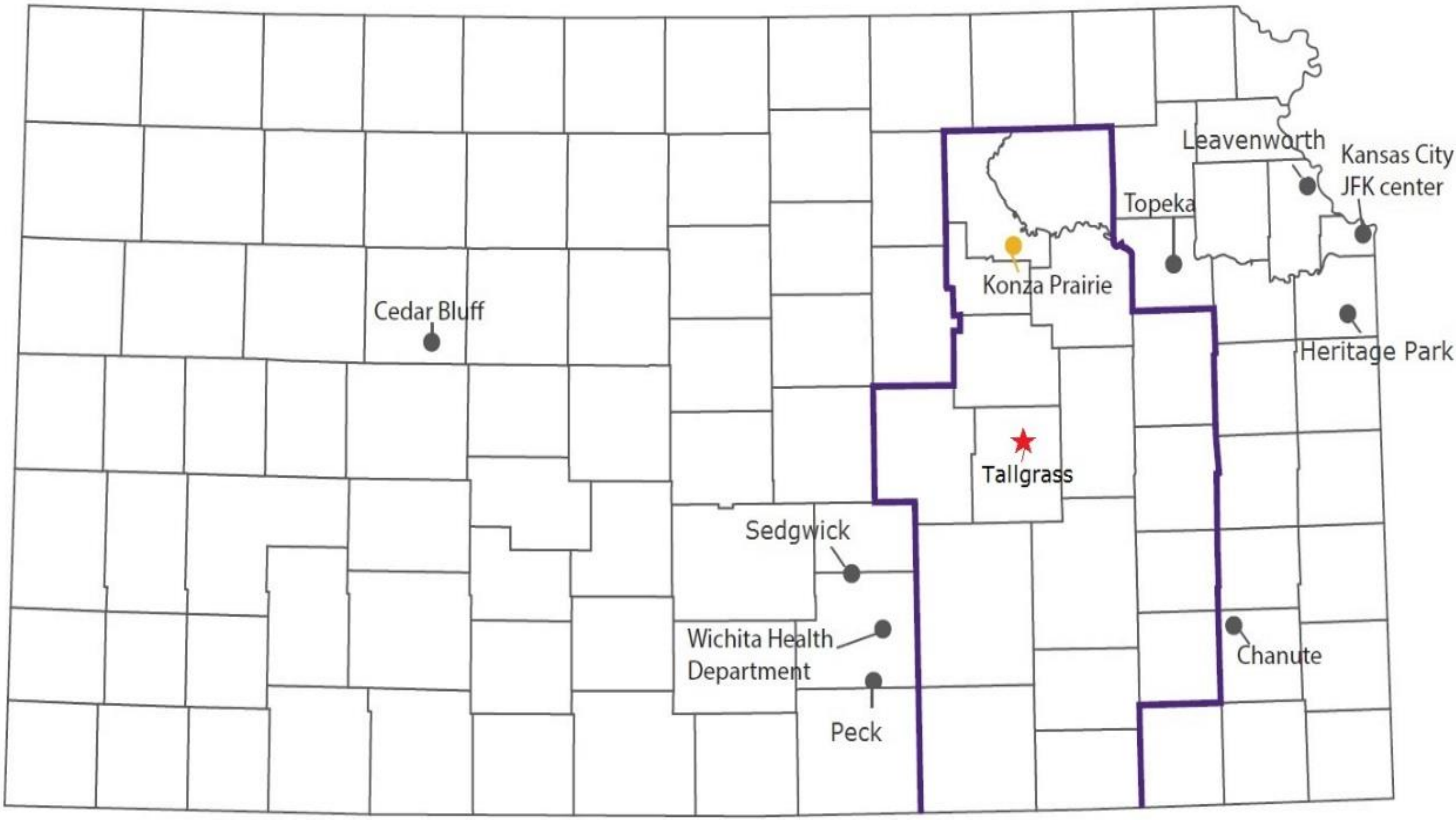
- Expanded burning restrictions

The O_3 story

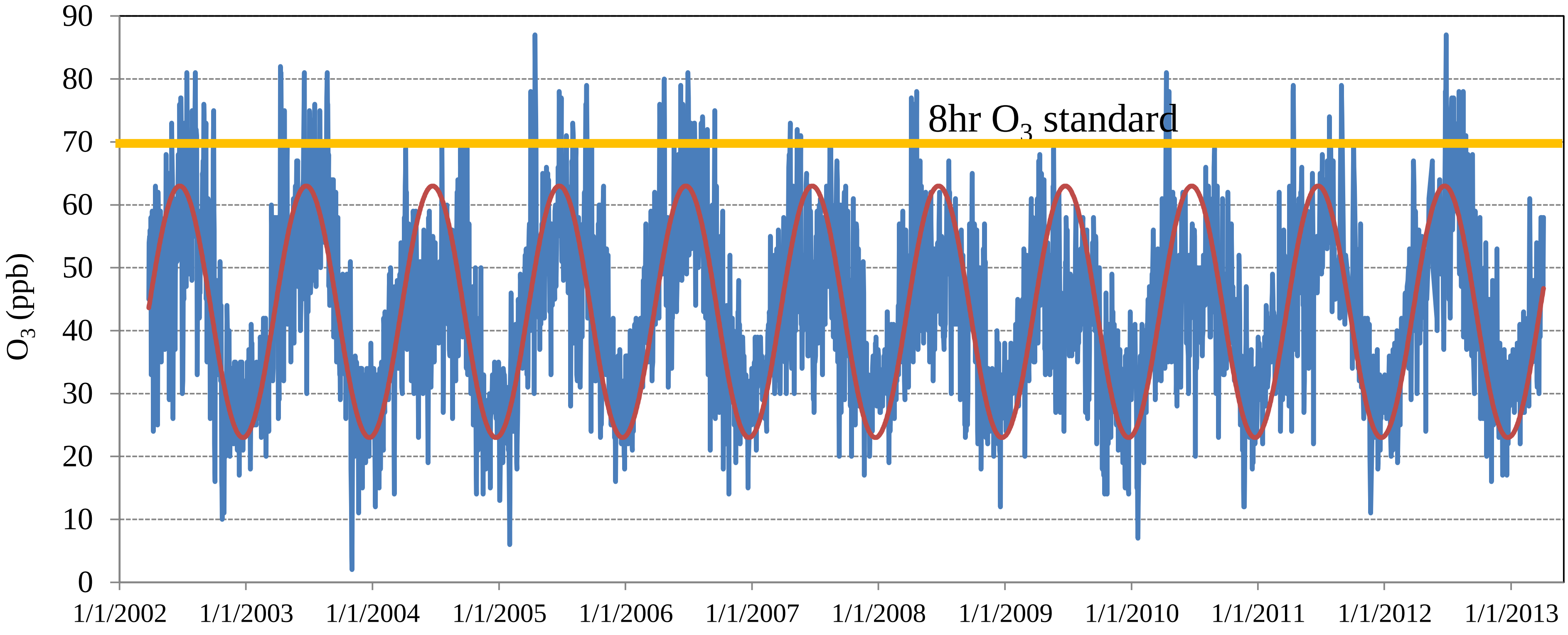


Interaction of fire, atmospheric composition and climate in the earth system
(RF: radiative forcing)

Nine O_3 monitoring sites



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



O_3 regression models

R^2=0.66 to 0.76

$$O_3(d) = c_1 + c_2 \sin\left(\frac{2\pi(d+283)}{365}\right)$$

$+c_3$ [O_3 on the previous day]

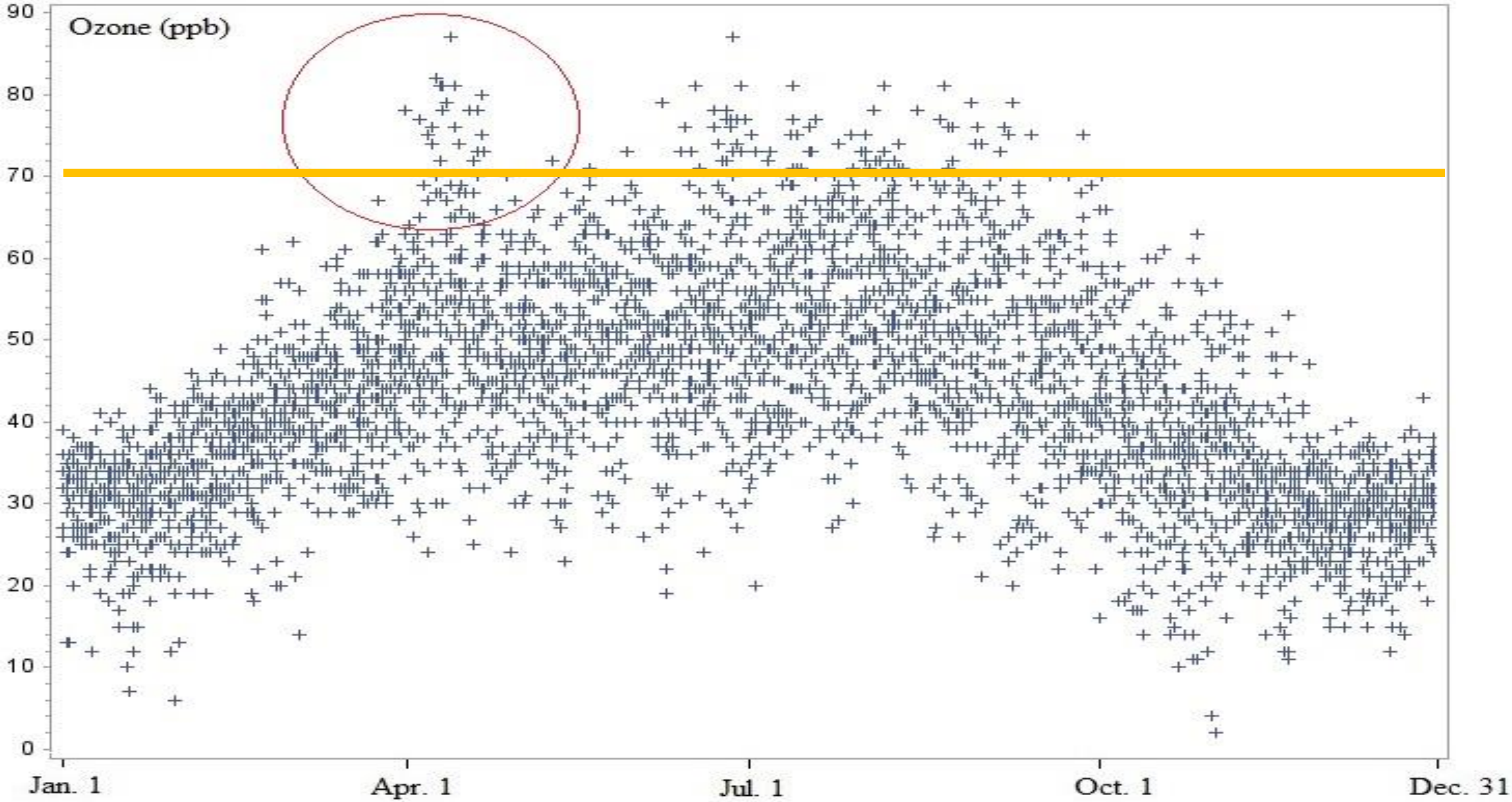
$+c_4$ [Air temperature]

$+c_5$ [Solar radiation]

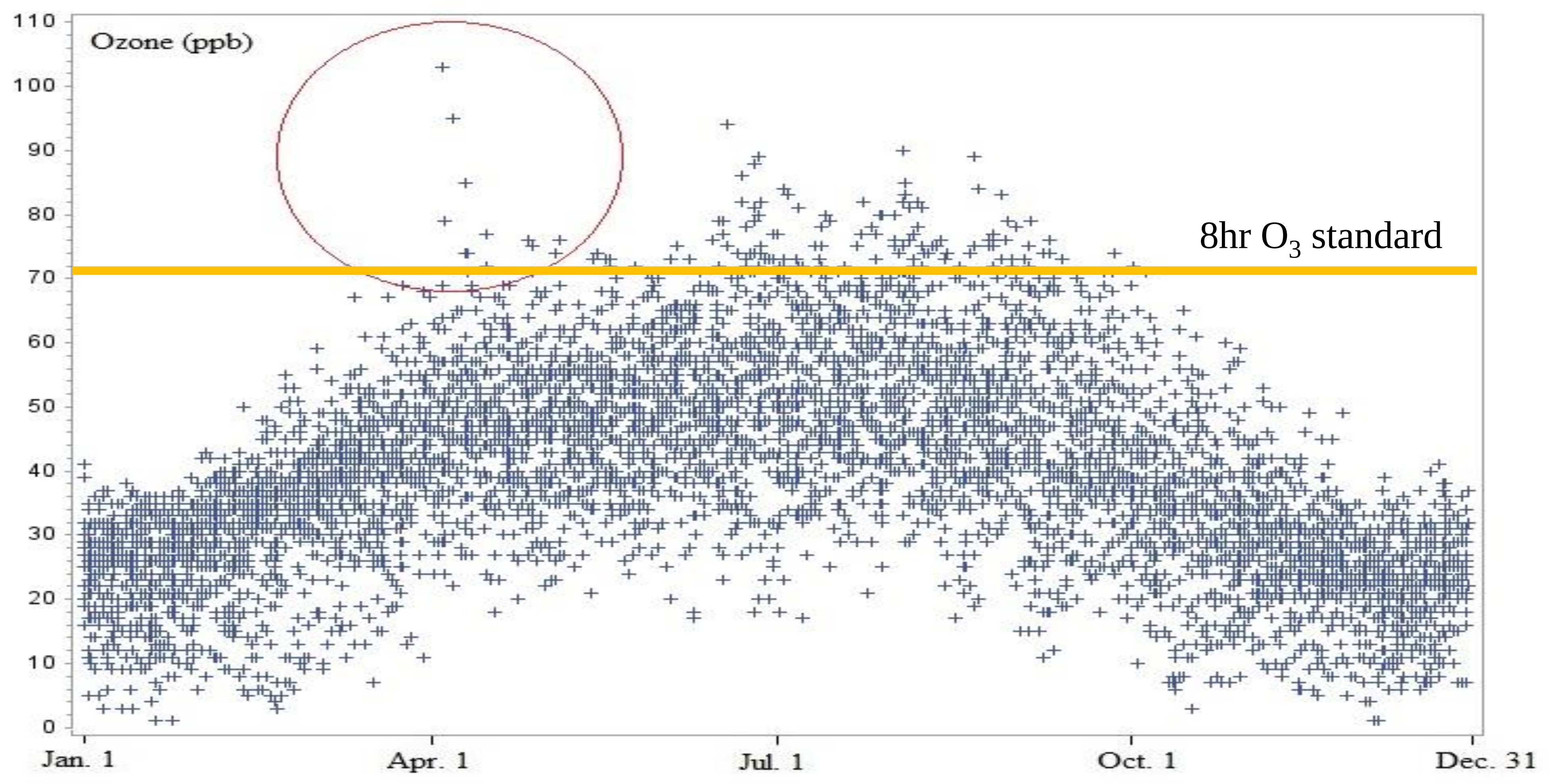
$-c_6$ [Relative humidity]

$-c_7$ [Wind speed]

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

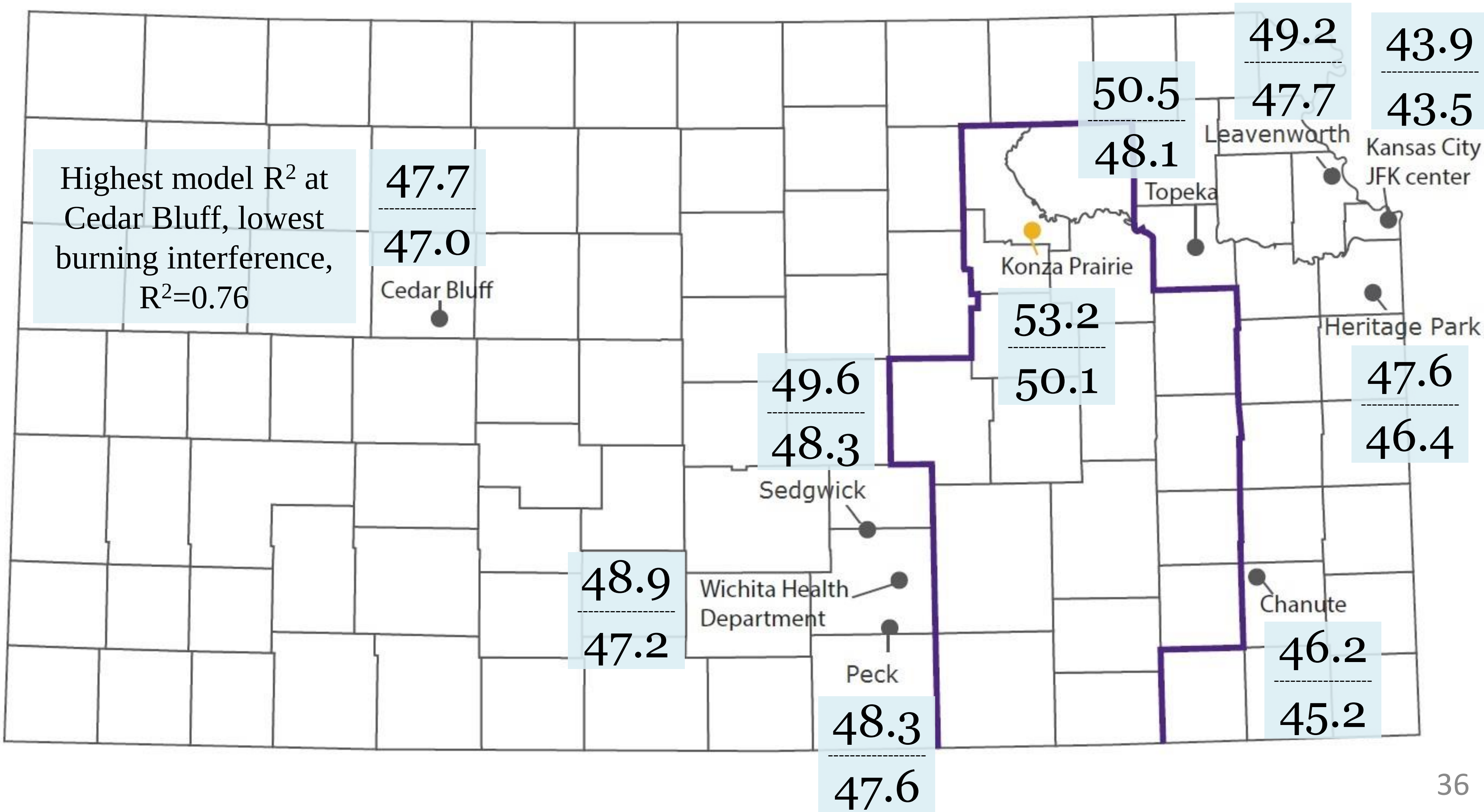


Daily max 8hr O_3 at the Wichita Health Department site (2001-2016)



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)

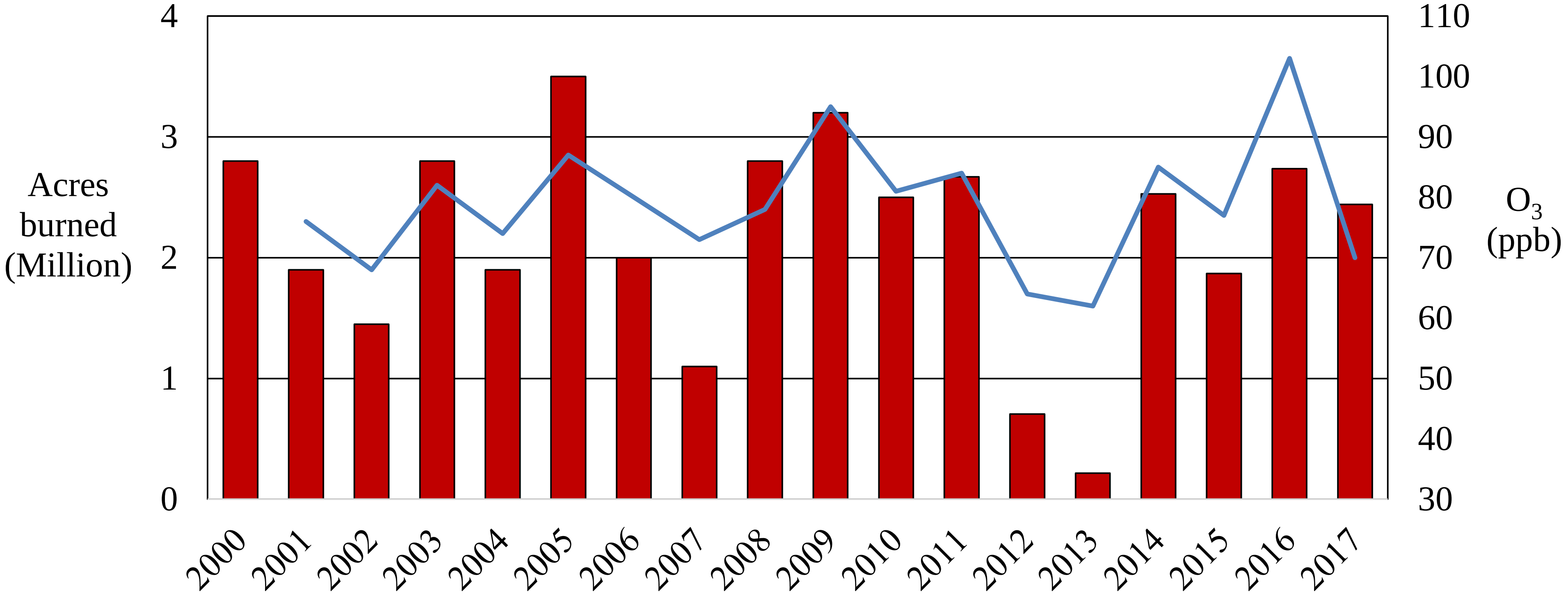
Konza Prairie site	3.1 ppb
Topeka site	2.4 ppb
Three Wichita sites	0.7, 1.3, 1.7 ppb
Three Kansas City sites	0.4, 1.2, 1.5 ppb
Cedar Bluff site	0.7 ppb

2001-2016

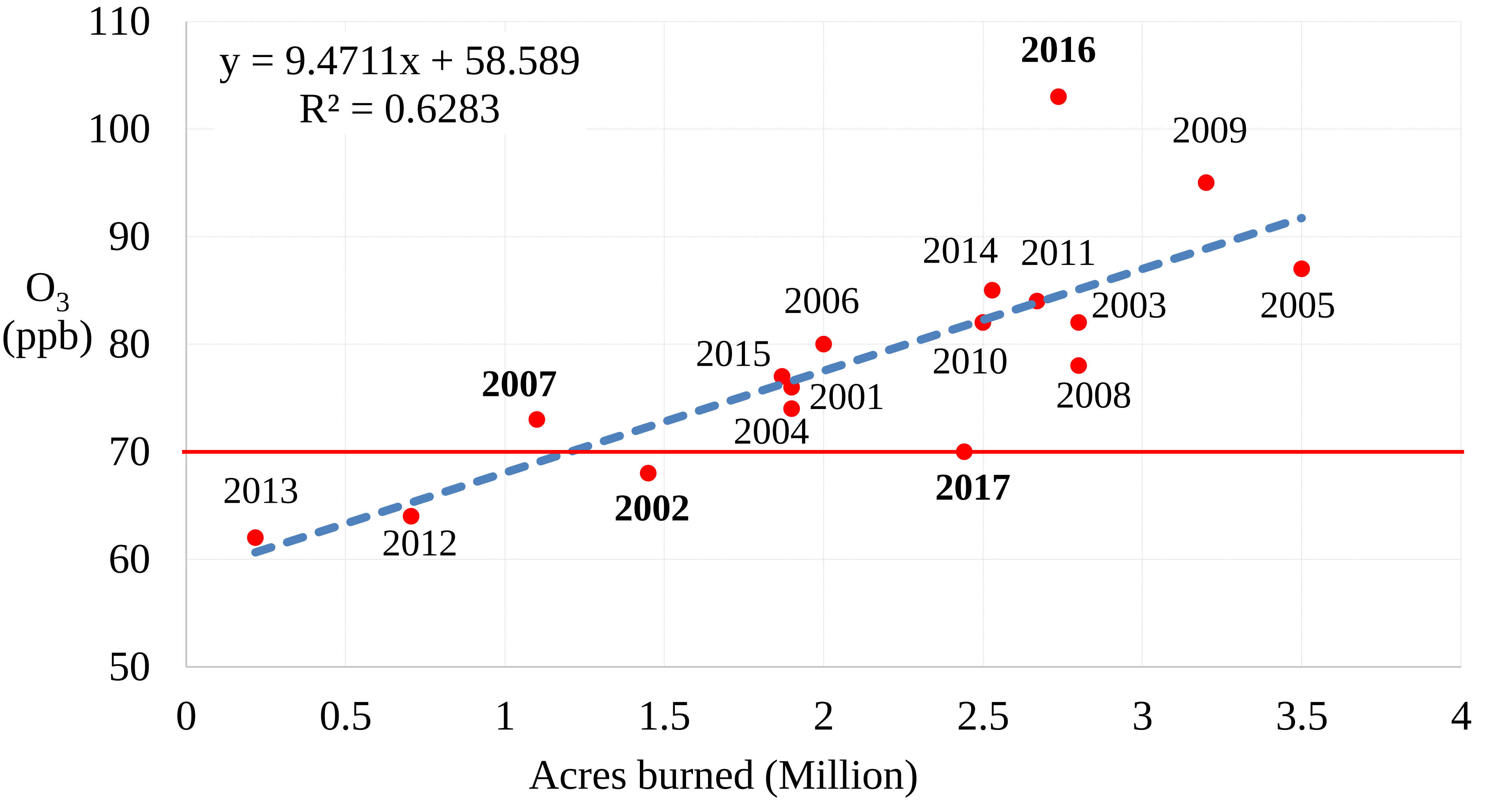
	Average of days with O_3>70ppb in April (47 days in total)	April average
Daily Max 8hr O_3	77±5 ppb	43.9-53.2 ppb
O_3 on the previous day	60±11 ppb	-
Daily maximum air temperature	24.5±4.5 ºC	20.7±5.5 ºC
T_{max}-T_{min}	16.6±5.3 ºC	12.3±5.0 ºC
Solar radiation	738±279 Langley	607±304 Langley
Relative 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

Acres burned vs. highest 8hr O_3 in April

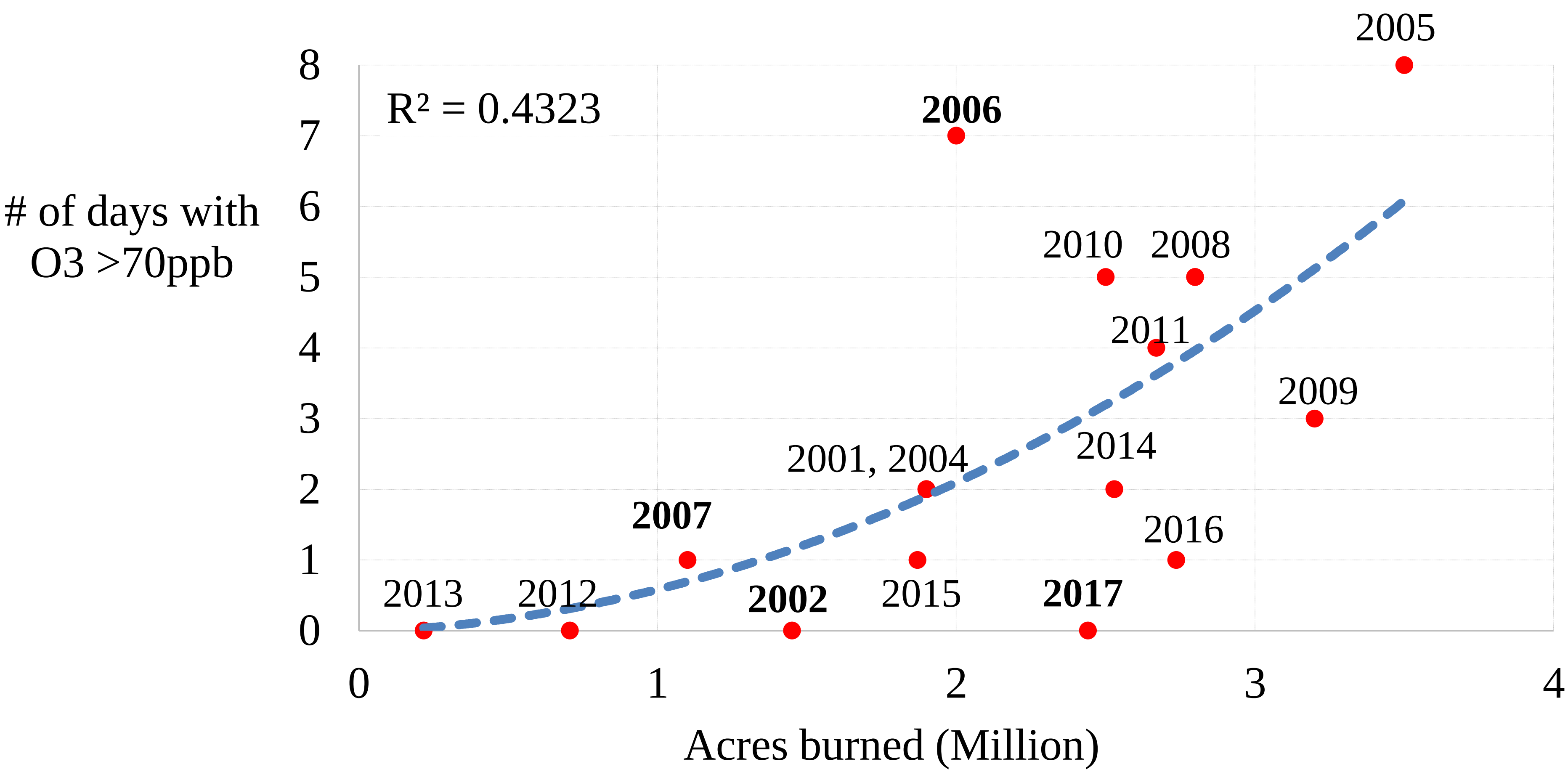


Acres burned vs. highest 8hr O_3 in April



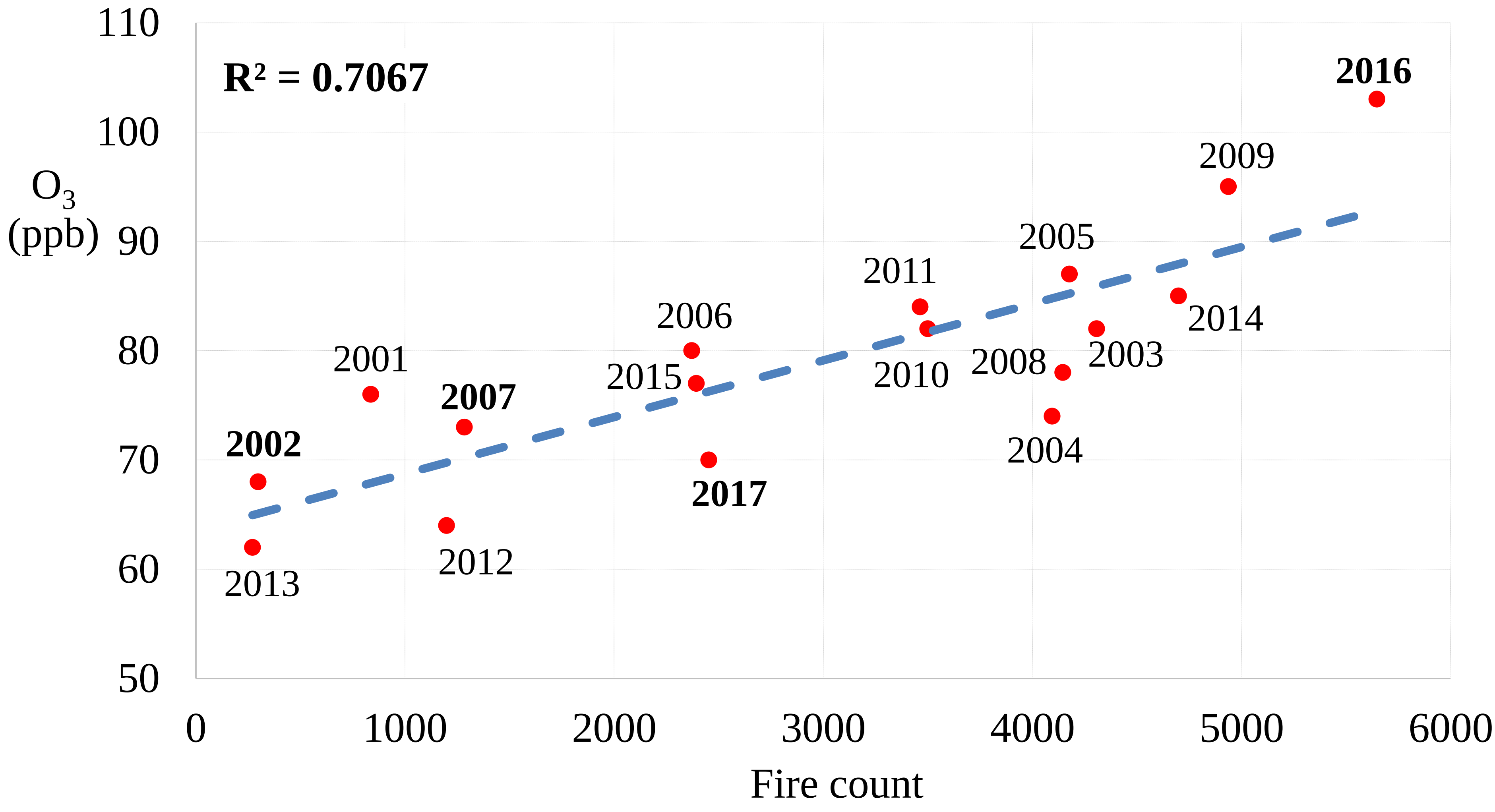
For every one million increase of burn acres, the highest 8-hour O_3 mixing ratios increased around 9 ppb.

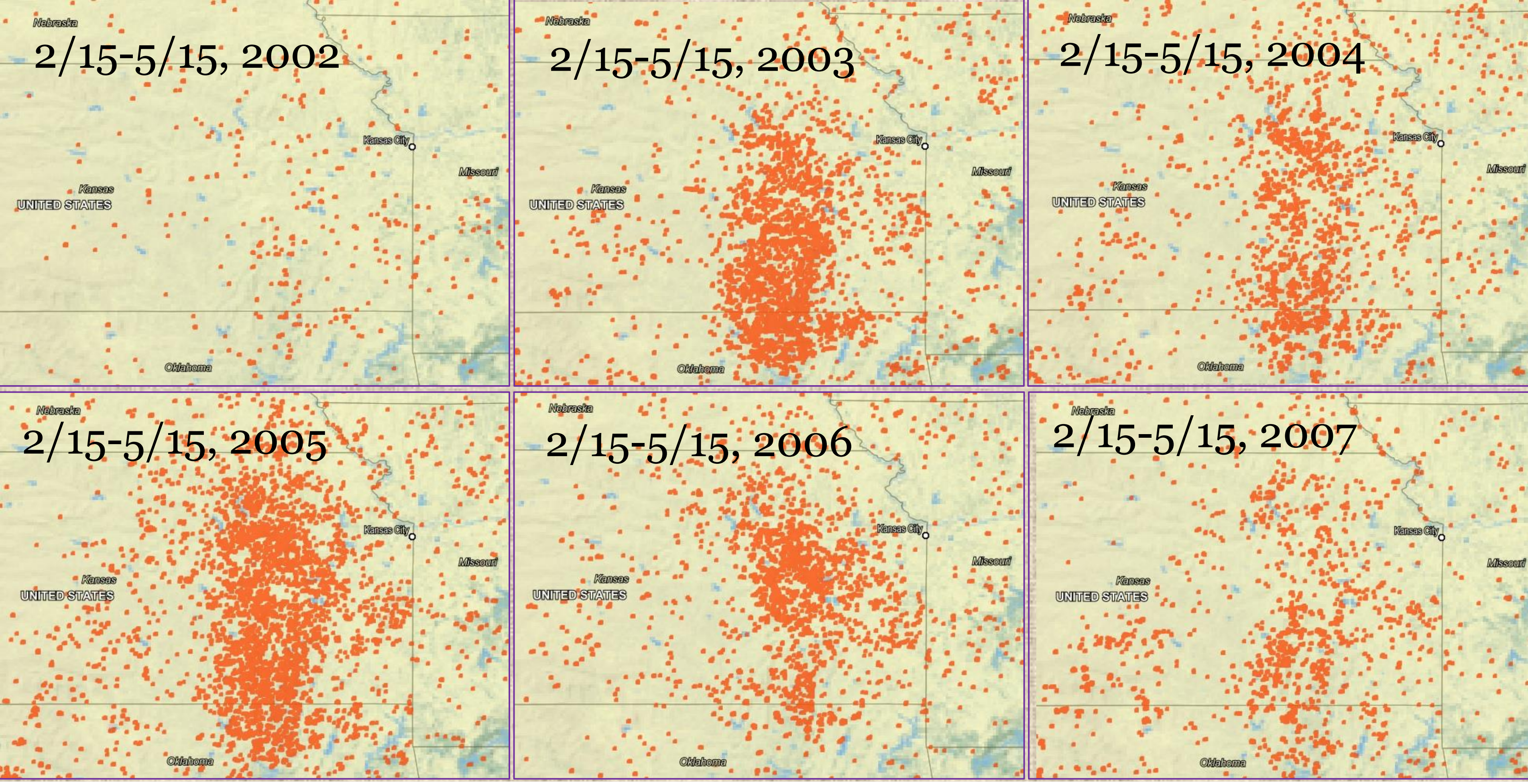
Acres burned vs. # of days with 8hr O_3 >70ppb in April

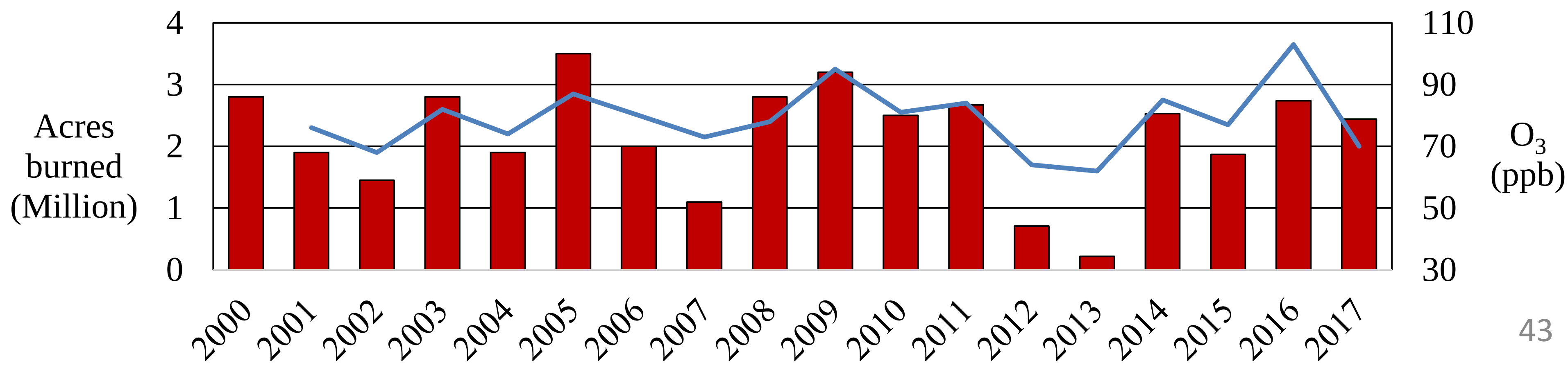


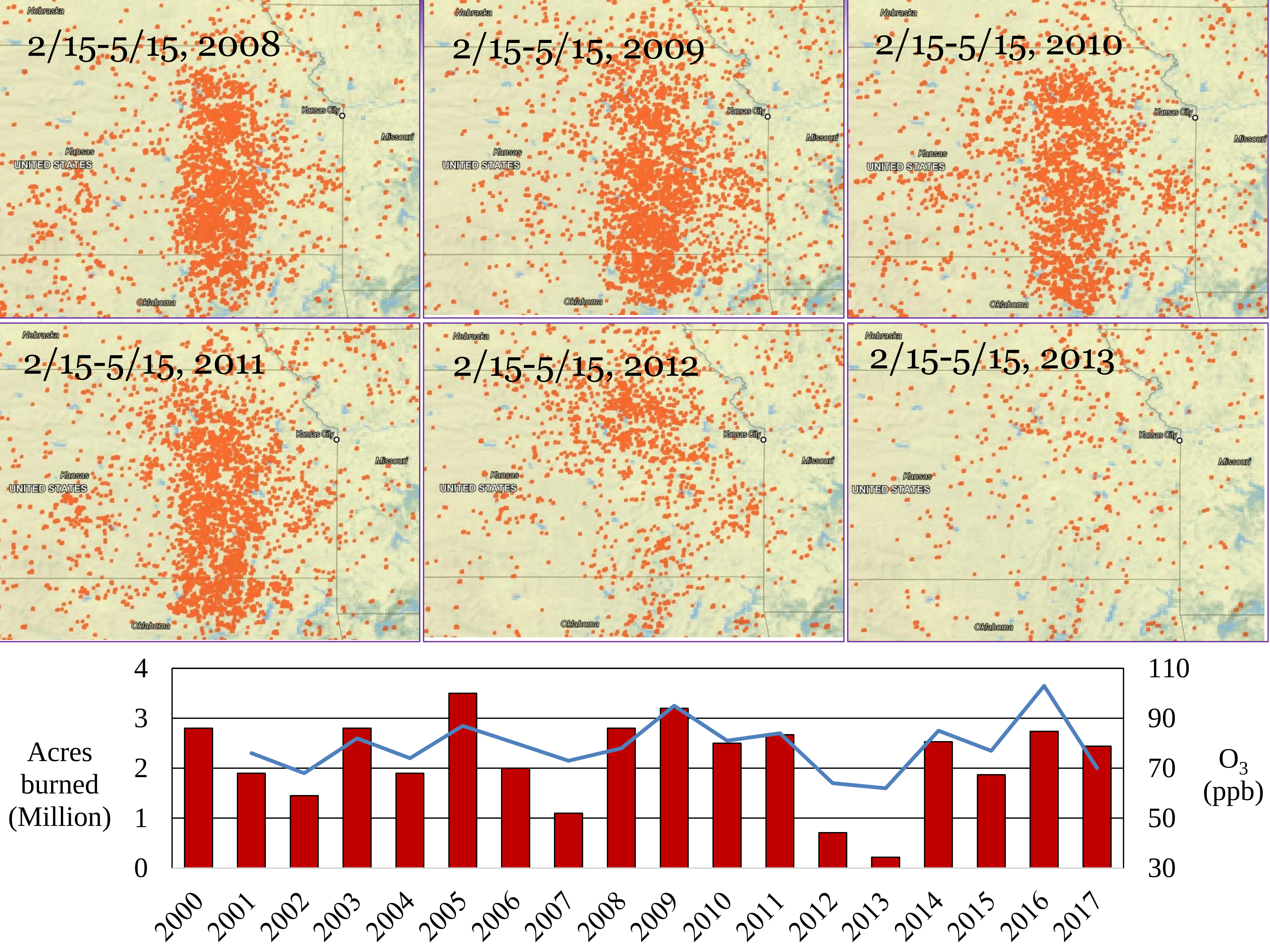
When the acres burned were larger than or equal to 1.9 million, O_3>70 ppb occurred in April at least at one of the ten monitoring sites.

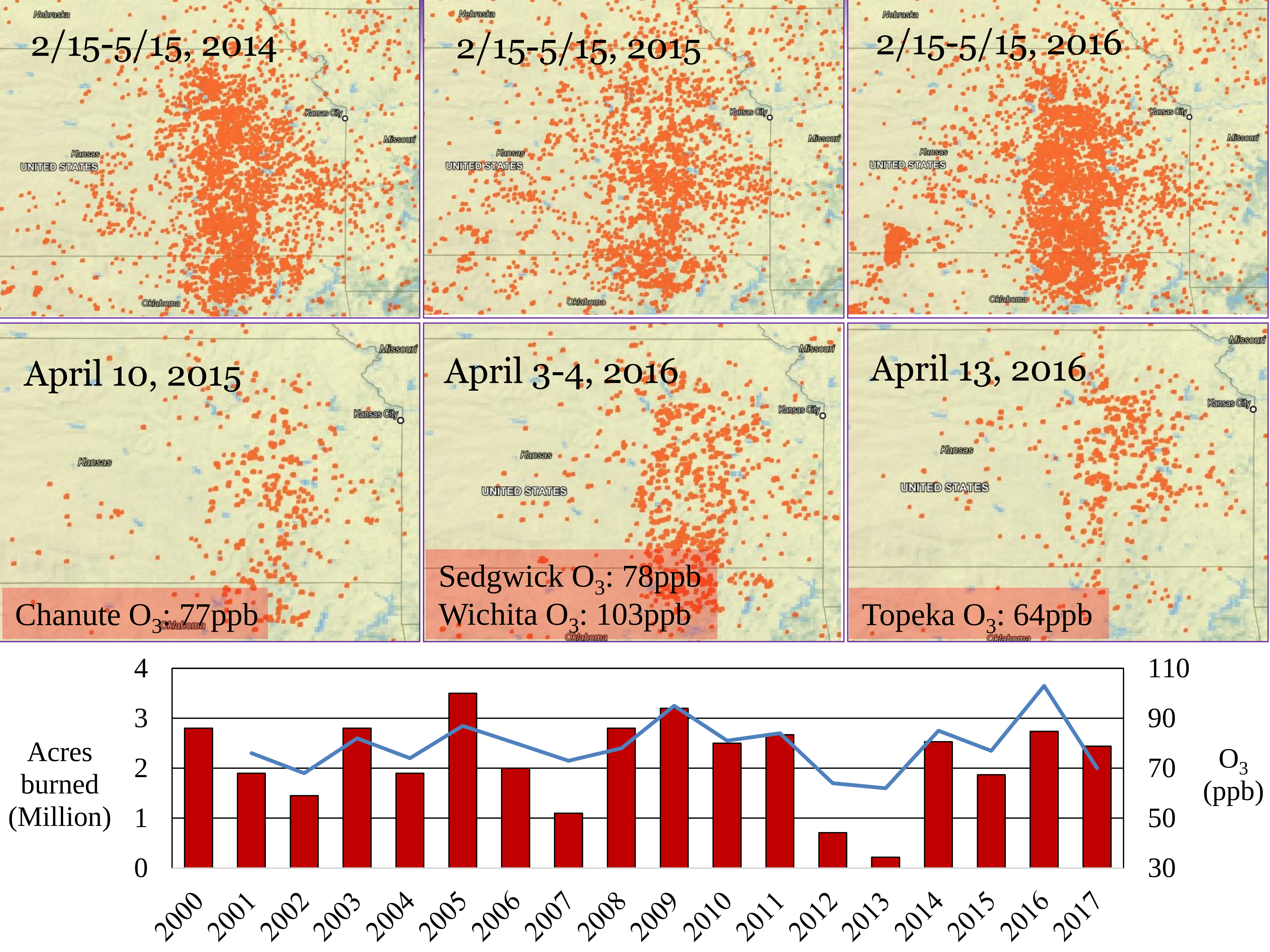
Fire count vs. highest 8hr O_3 in April



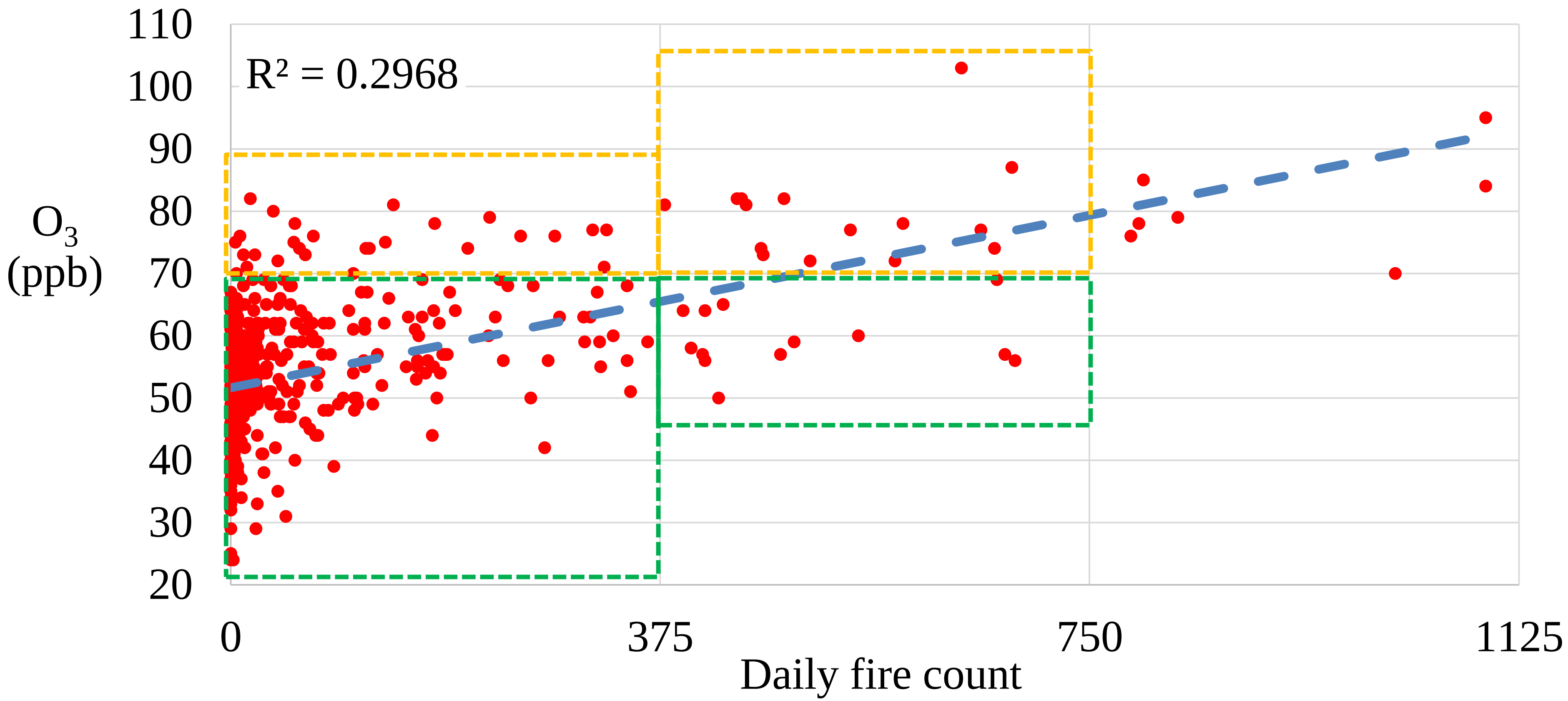

2/15-5/15, 2002
2/15-5/15, 2003
2/15-5/15, 2004
2/15-5/15, 2005
2/15-5/15, 2006
2/15-5/15, 2007
Nebraska
Kansas City
Missouri
Kansas
UNITED STATES
Oklahoma


Acres burned (Million)
0
1
2
3
4
O_3 (ppb)
30
50
70
90
110
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

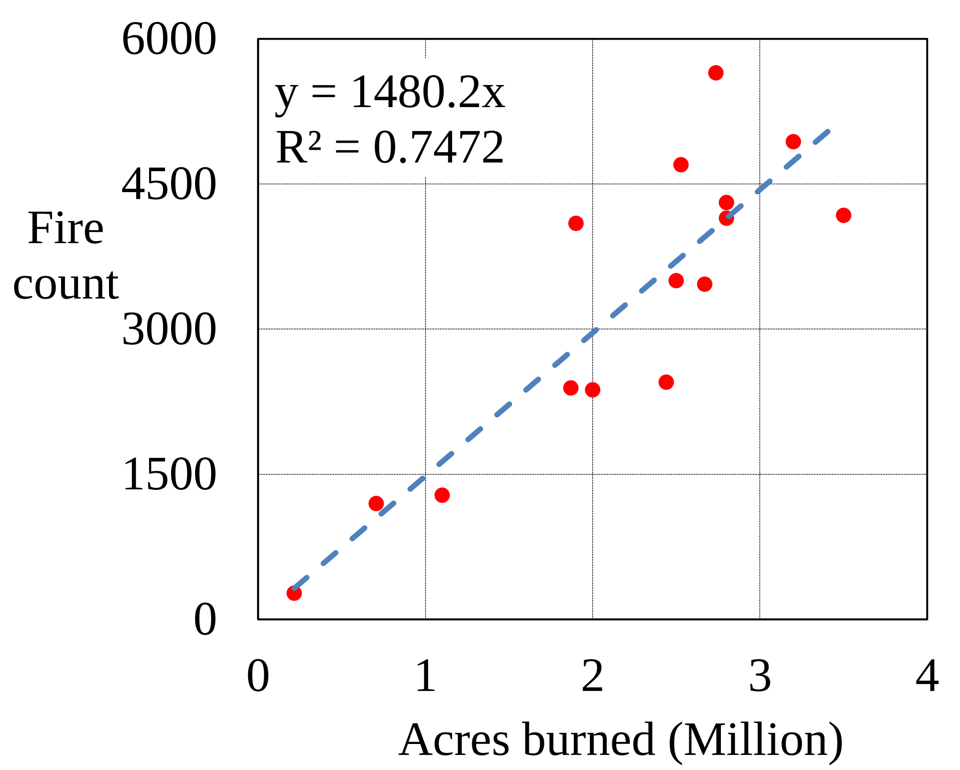

2/15-5/15, 2008
2/15-5/15, 2009
2/15-5/15, 2010
2/15-5/15, 2011
2/15-5/15, 2012
2/15-5/15, 2013
Nebraska
Kansas City
Missouri
Kansas
UNITED STATES
Oklahoma
Acres burned (Million)
0
1
2
3
4
O3 (ppb)
30
50
70
90
110
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017


2/15-5/15, 2014
2/15-5/15, 2015
2/15-5/15, 2016
Nebraska
Kansas City
Missouri
Kansas
UNITED STATES
Oklahoma
April 10, 2015
Chanute O_3: 77ppb
April 3-4, 2016
Sedgwick O_3: 78ppb
Wichita O_3: 103ppb
April 13, 2016
Topeka O_3: 64ppb
Acres burned (Million)
0
1
2
3
4
O_3 (ppb)
30
50
70
90
110
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017

Daily fire count vs. highest 8hr O_3 in April



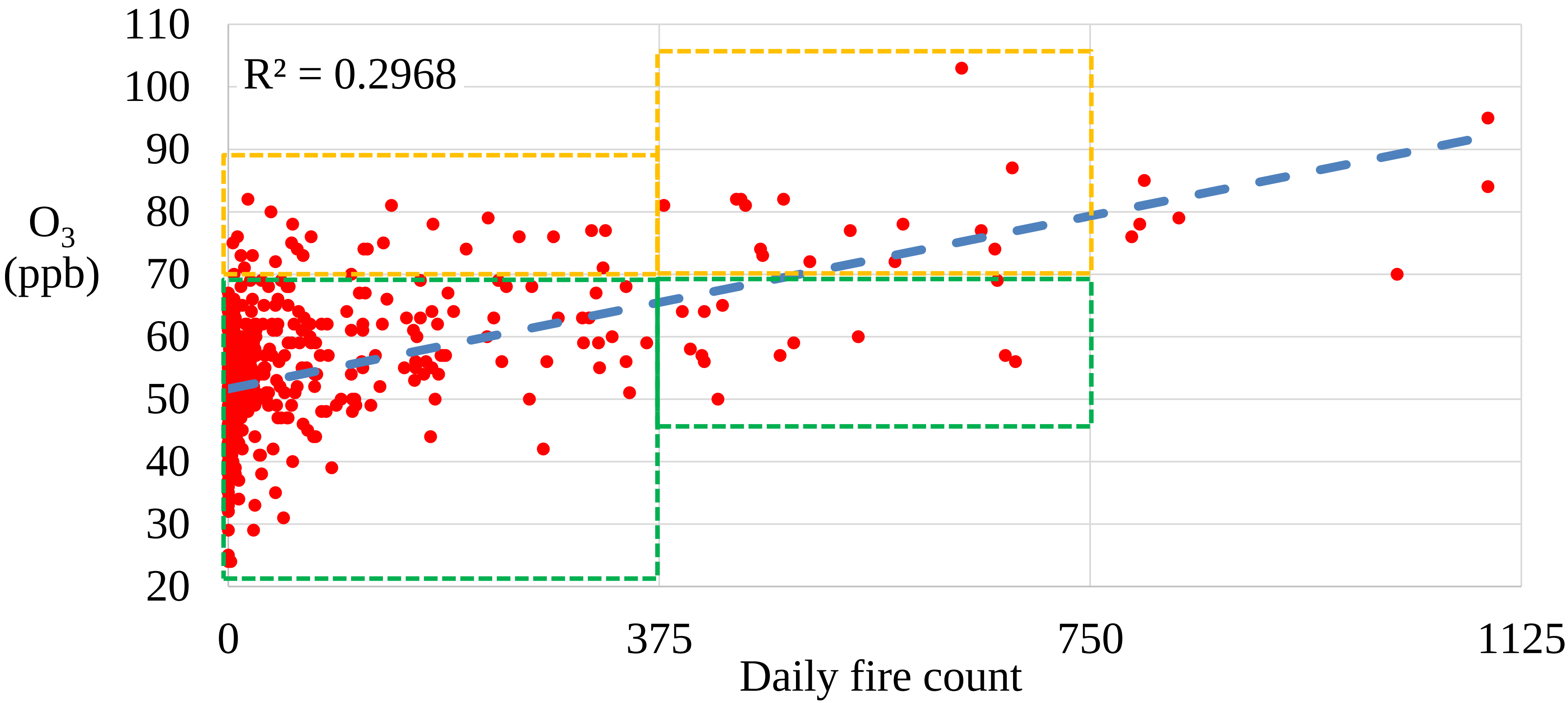
- When daily fire count >750, O_3>70 ppb occurred in all the 7 days.
- When daily fire count is between 375 to 750, O_3>70 ppb occurred in 15 out of 27 days (56%).
- When daily fire count is between 1 to 375, O_3>70 ppb occurred in 27 out of 347 days (8%).
- When daily fire count is 0, O_3>70 ppb did not occur.



1500 fire count
≈ 1 million acres burned

- When daily burned acres >0.5M, O_3>70 ppb is most likely to occur.
- When daily burned acres is between 0.25M to 0.5M, the chance of O_3>70 ppb is 56%.
- When daily burned acres <0.25M, the chance of O_3>70 ppb is 8%.
- When there is no burning, O_3>70 ppb is not likely to occur.

Daily fire count vs. highest 8hr O_3 in April



- When daily burned acres >0.5M, O_3>70 ppb is most likely to occur.
- When daily burned acres is between 0.25M to 0.5M, the chance of O_3>70 ppb is 56%.
- When daily burned acres <0.25M, the chance of O_3>70 ppb is 8%.
- When there is no burning, O_3>70 ppb is not likely to occur.

When daily fire count is between 375 to 750, or daily burned acres is between 0.25M to 0.5M

	Average (7 days)	April average
Daily maximum air temperature	22.5±5.0 ºC	20.7±5.5 ºC
Solar radiation	638±218 Langley	607±304 Langley
Relative humidity	51±6 %	67±14 %
Wind speed	2.0±0.7 m/s	4.1±2.0 m/s

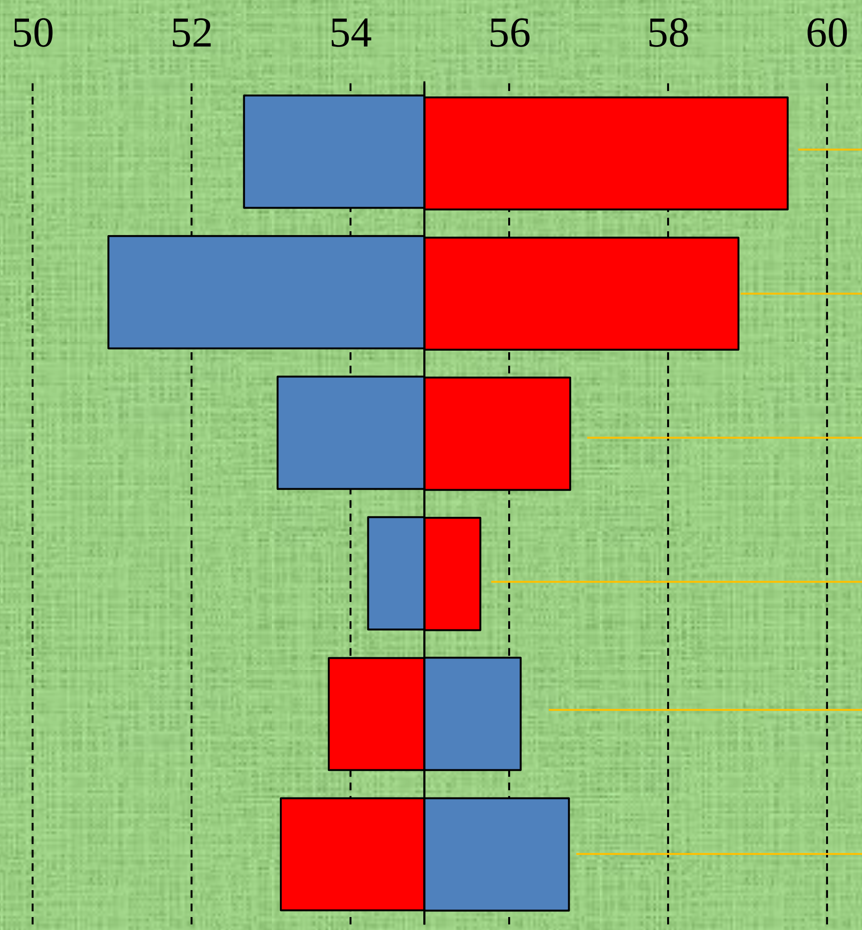
When daily fire count >750, or daily burned acres >0.5M

	Average of days with O_3>70ppb (15 days)	Average of days with O_3<70ppb (12 days)	April average
Daily maximum air temperature	24.4±5.4 ºC	19.2±4.1 ºC	20.7±5.5 ºC
Solar radiation	697±244 Langley	596±98 Langley	607±304 Langley
Relative humidity	54±10 %	54±12 %	67±14 %
Wind speed	2.4±1.1 m/s	2.9±1.2 m/s	4.1±2.0 m/s

When daily fire count is between 1 and 375, or daily burned acres < 0.25M

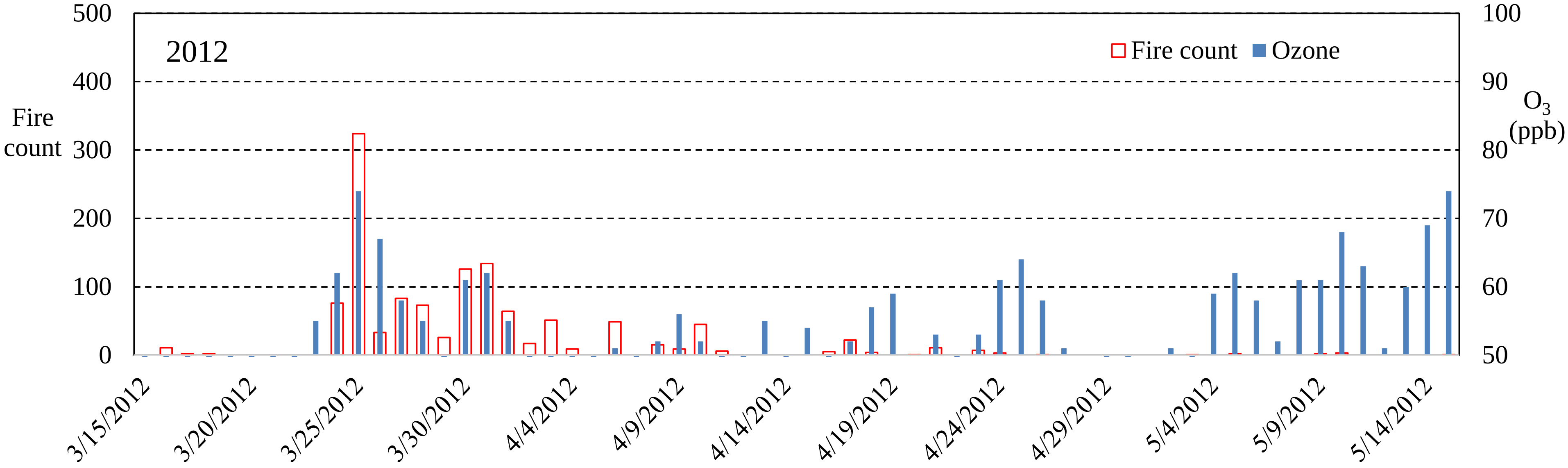
	Average of days with O_3>70ppb (27 days)	Average of days with O_3<70ppb (320 days)	April average
Daily maximum air temperature	24.8±3.8 ºC	20.4±6.5 ºC	20.7±5.5 ºC
Solar radiation	705±268 Langley	610±283 Langley	607±304 Langley
Relative humidity	58±11 %	62±13 %	67±14 %
Wind speed	4.0±1.9 m/s	4.2±2.0 m/s	4.1±2.0 m/s

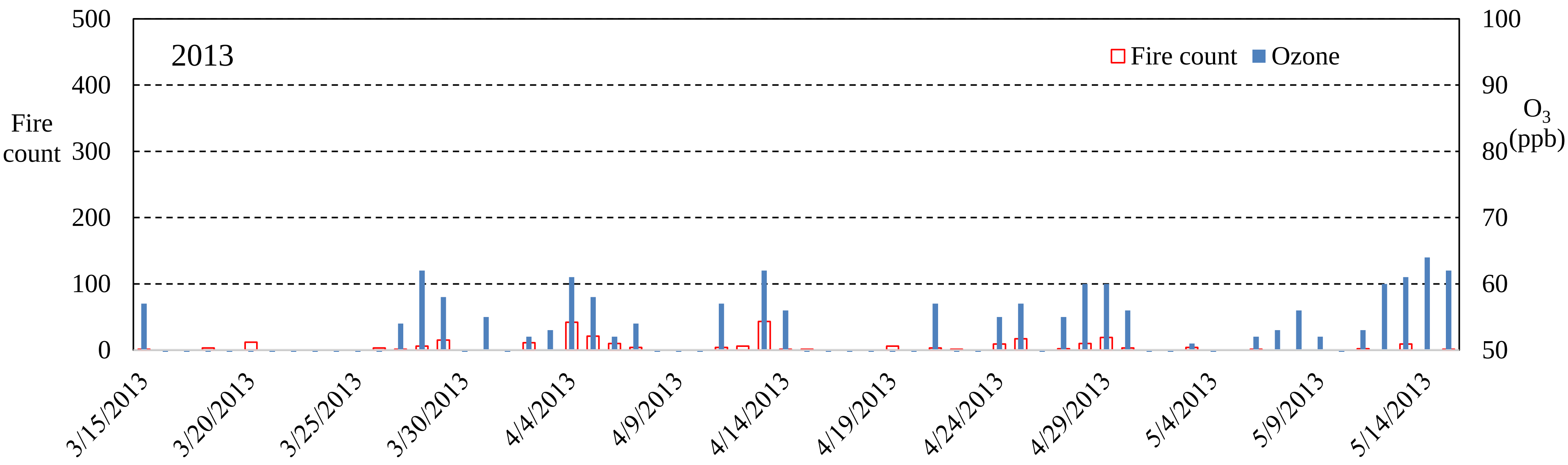
Modeling O_3 (ppb) in April R^2=0.55



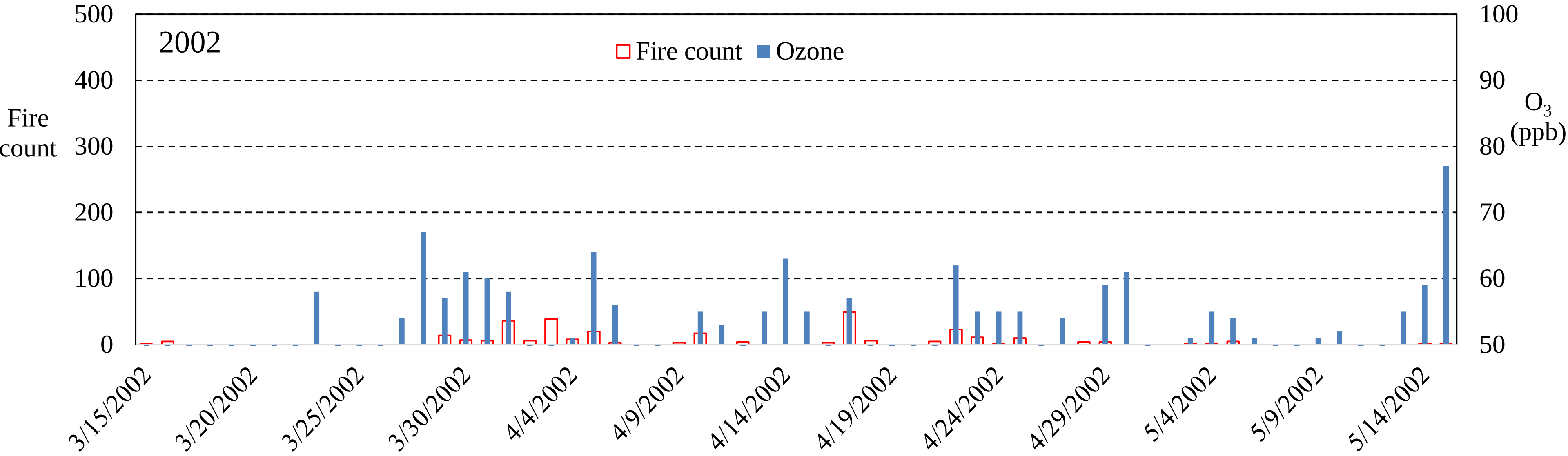
	April average
Fire count	82±166
O_3 on the previous day	55±11 ppb
Daily maximum air temperature	20.7±5.5 ºC
Solar radiation	607±304 Langley
Wind speed	4.1±2.0 m/s
Relative humidity	67±14 %

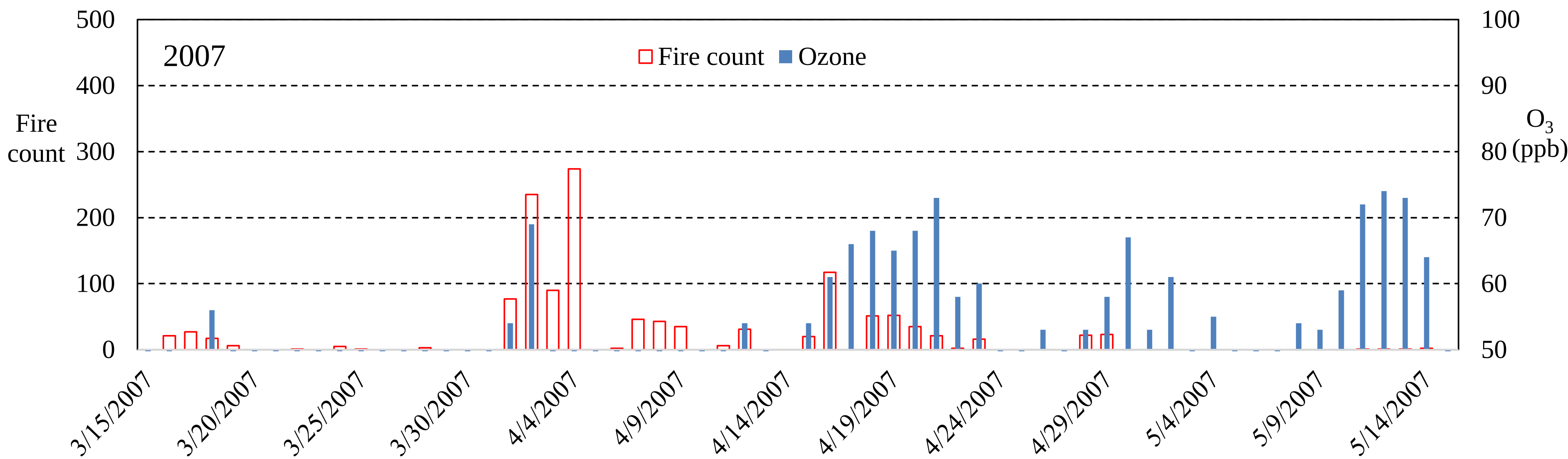
When seasonal burned acres is <1.5 million



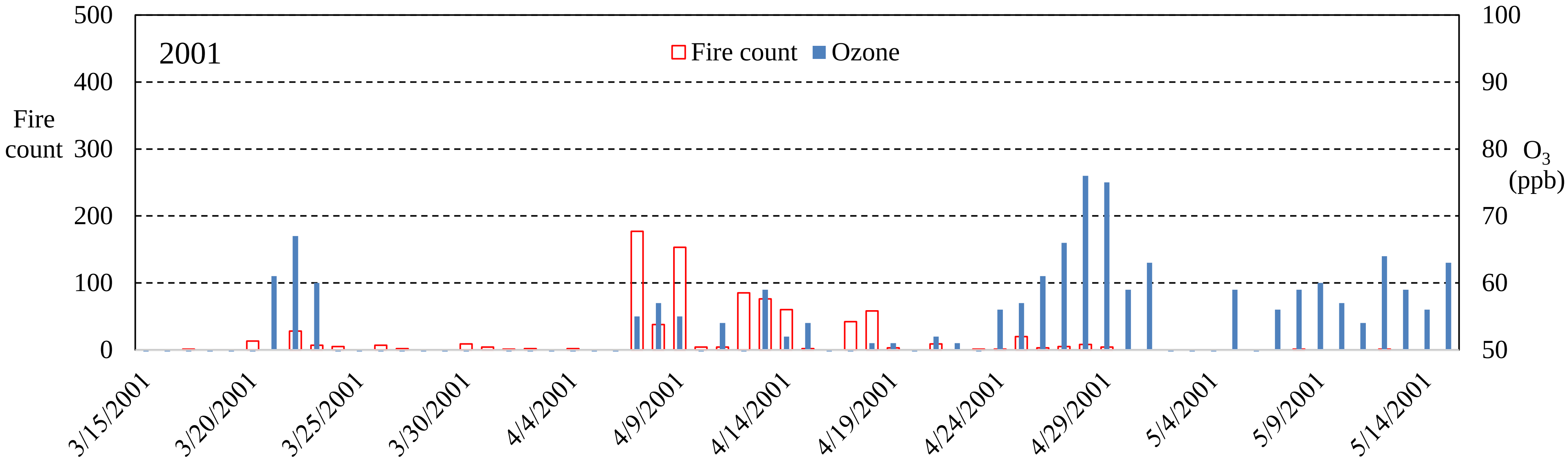


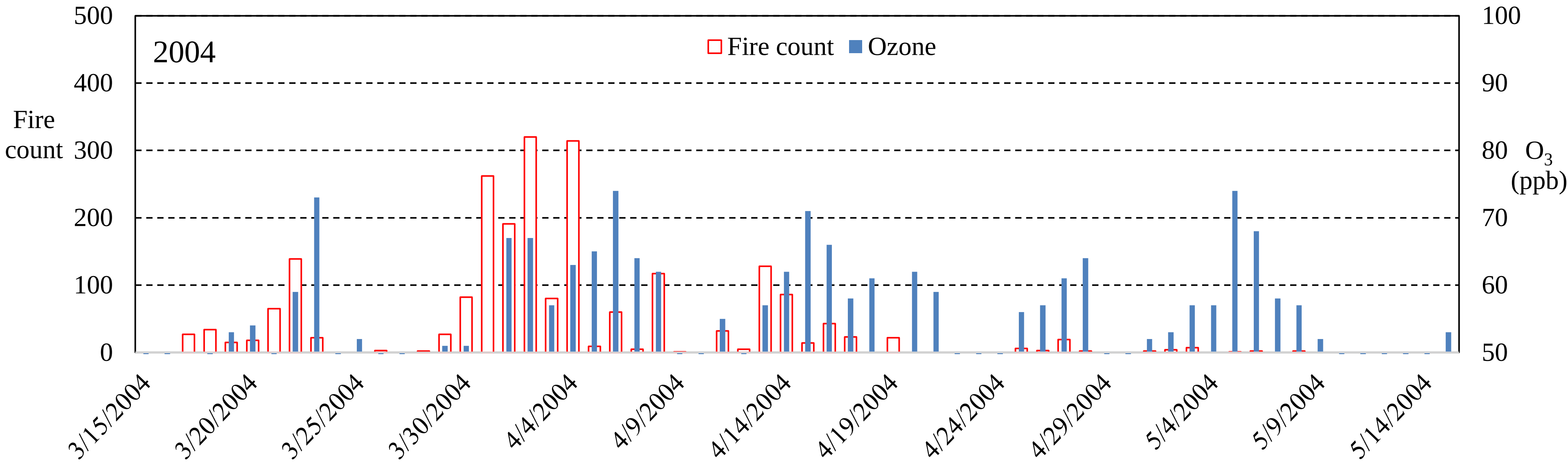
When seasonal burned acres is <1.5 million



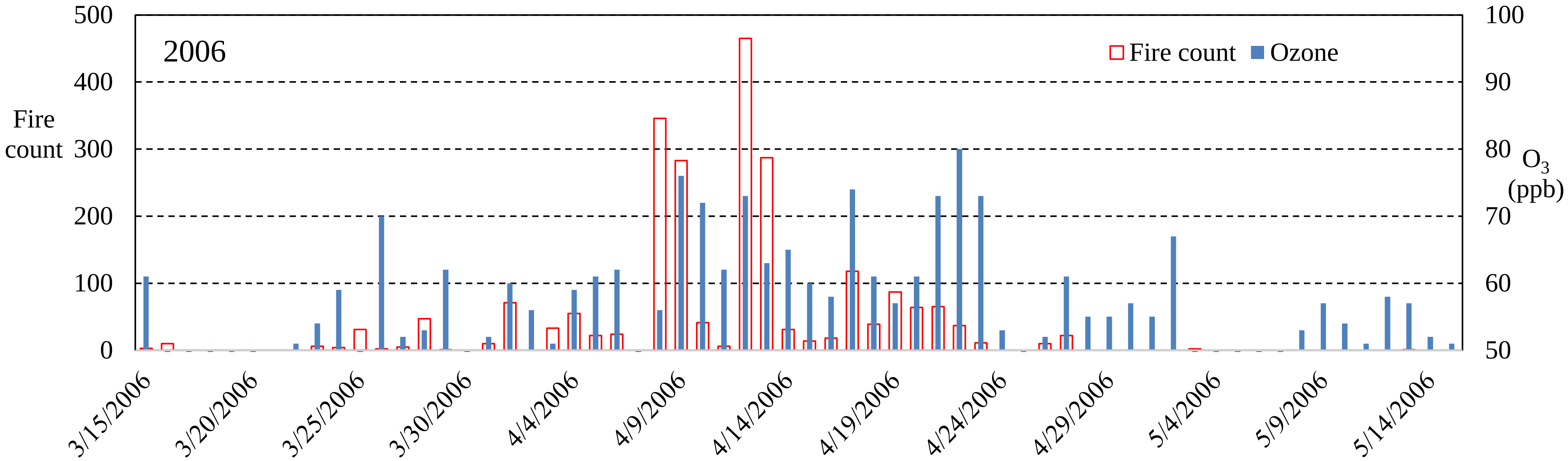


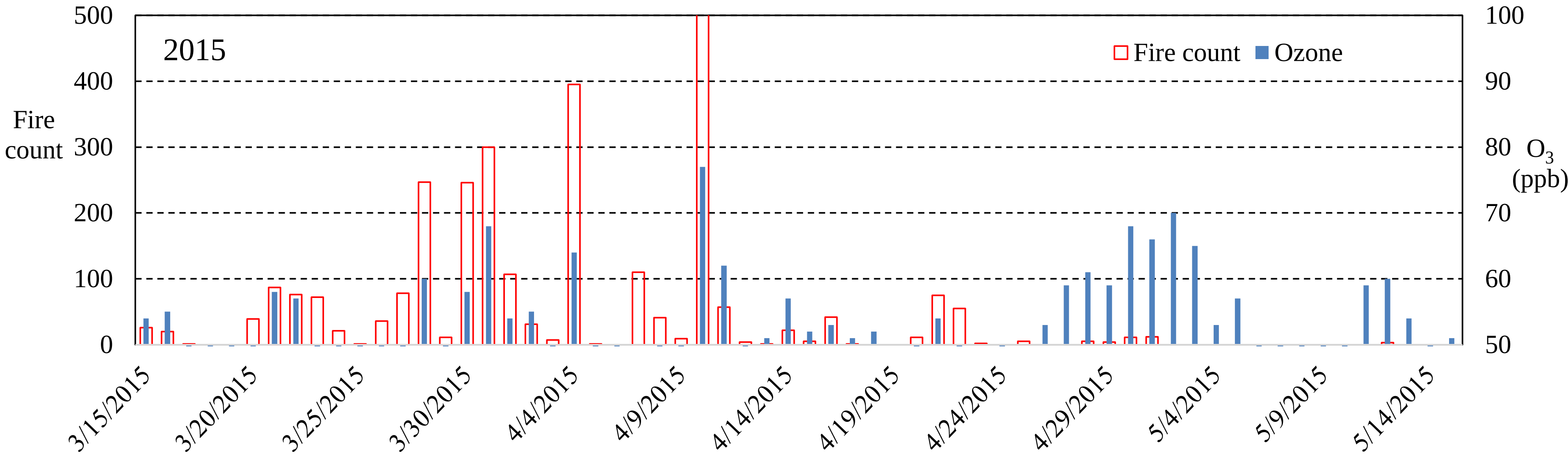
When seasonal burned acres is between 1.5 and 2.5 million



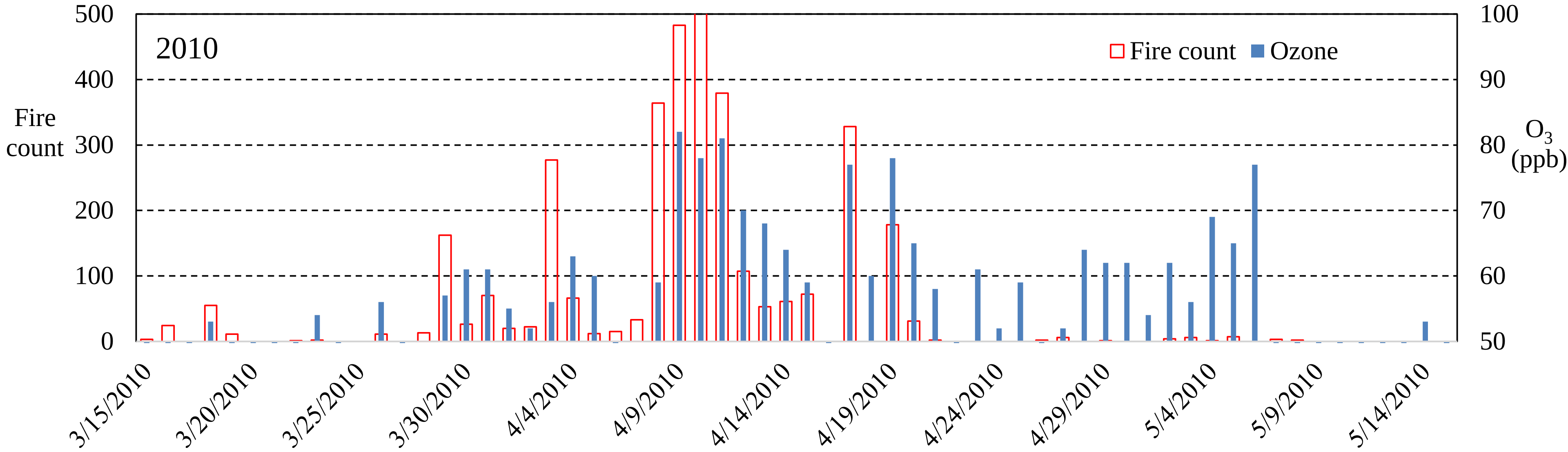


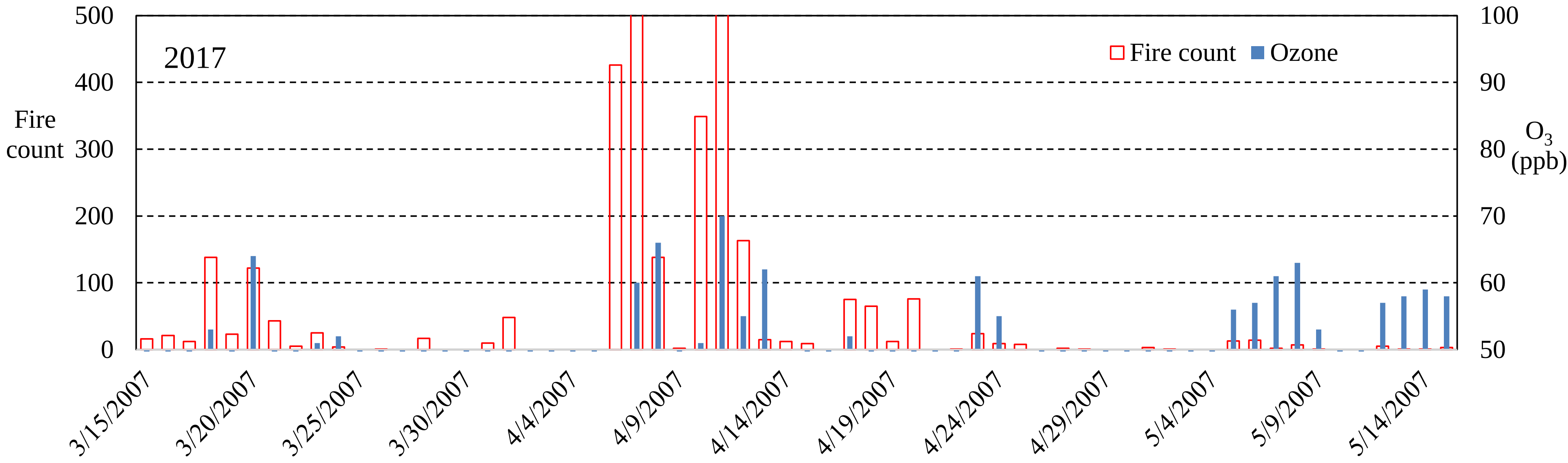
When seasonal burned acres is between 1.5 and 2.5 million



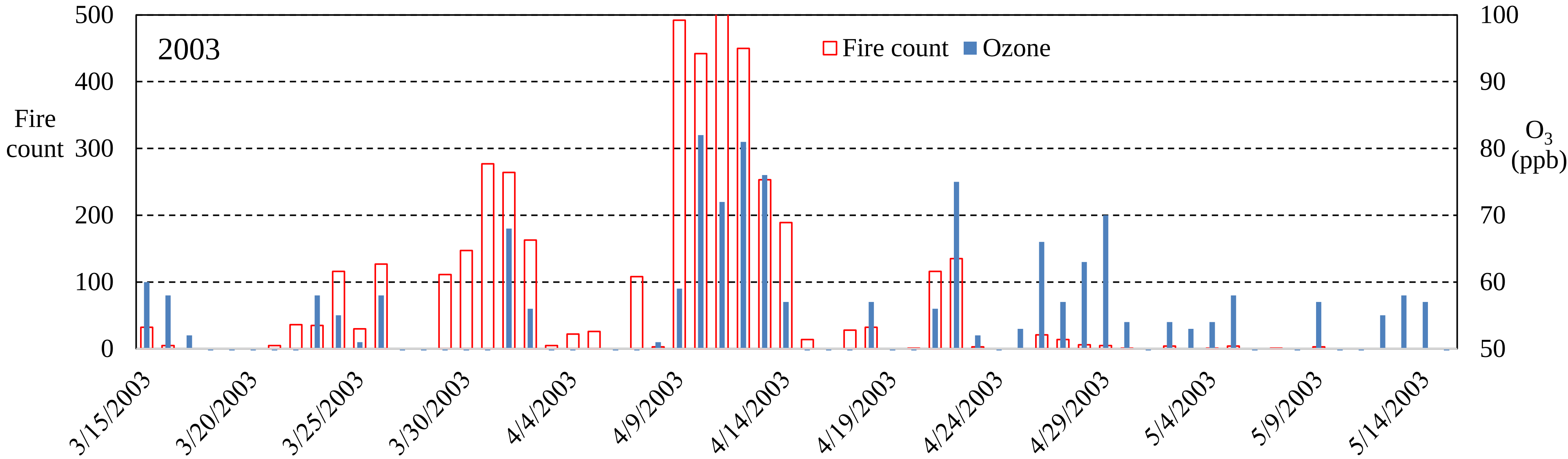


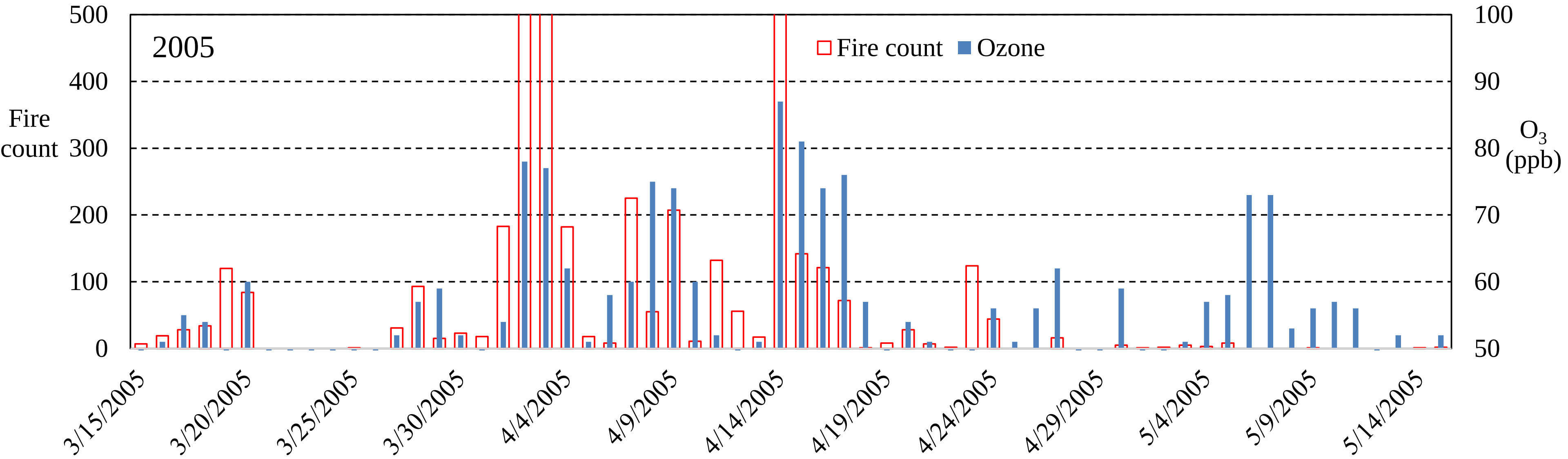
When seasonal burned acres is between 1.5 and 2.5 million



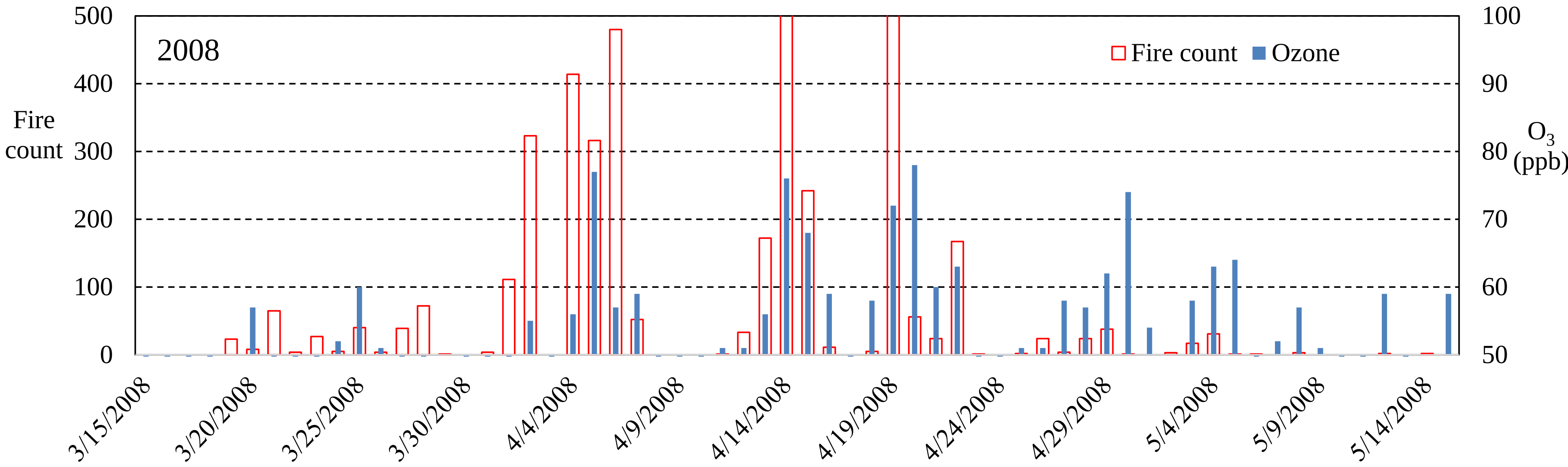


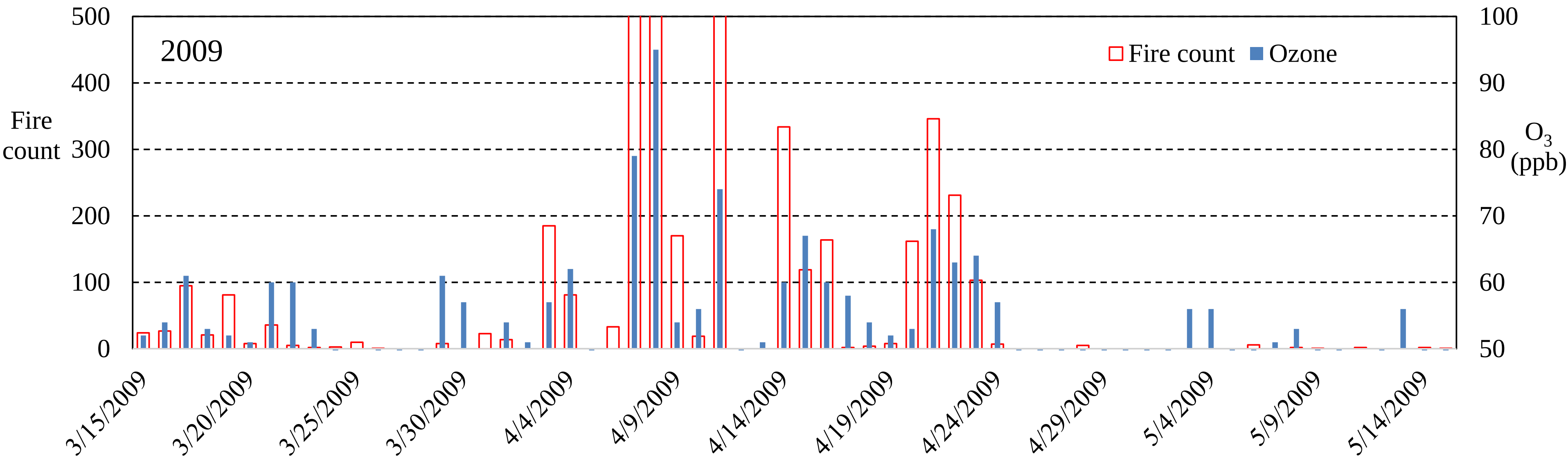
When seasonal burned acres >2.5 million



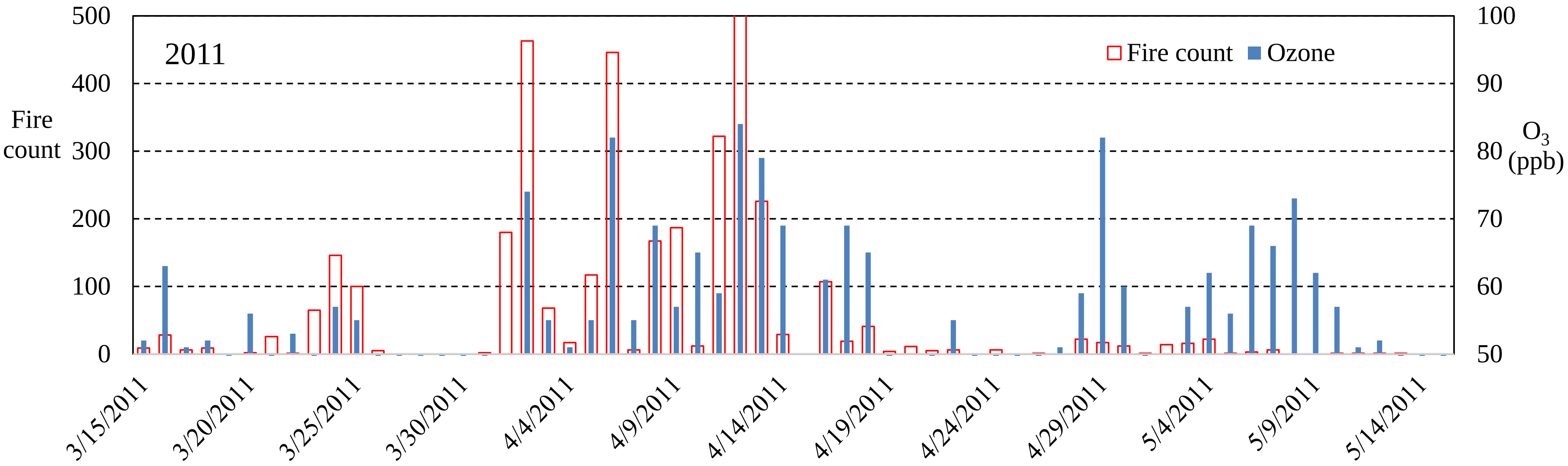


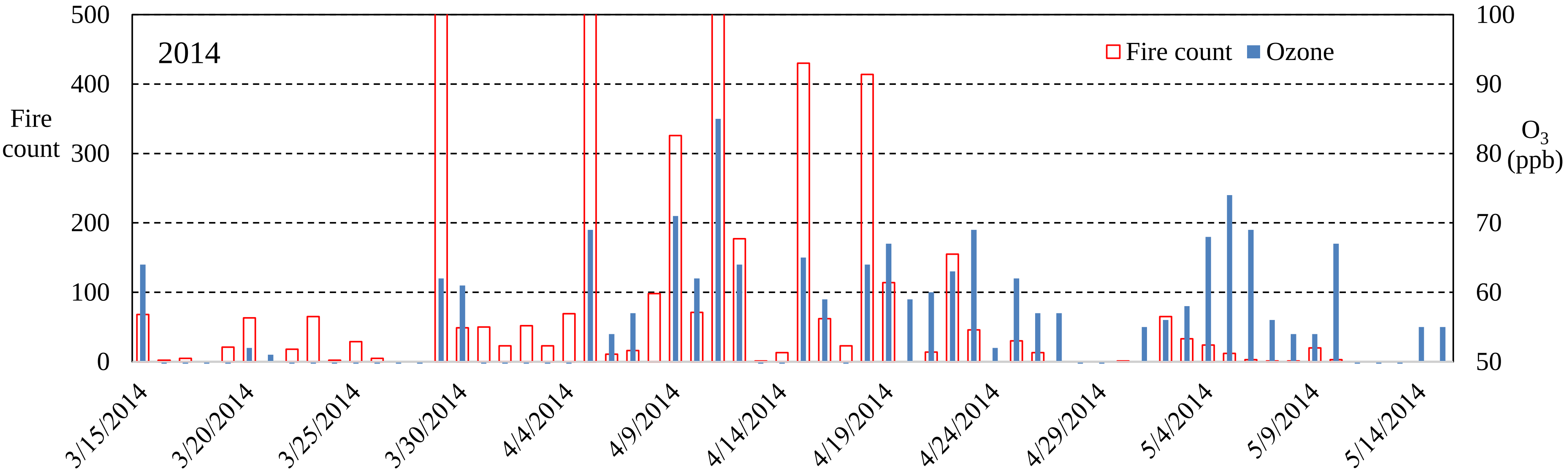
When seasonal burned acres >2.5 million



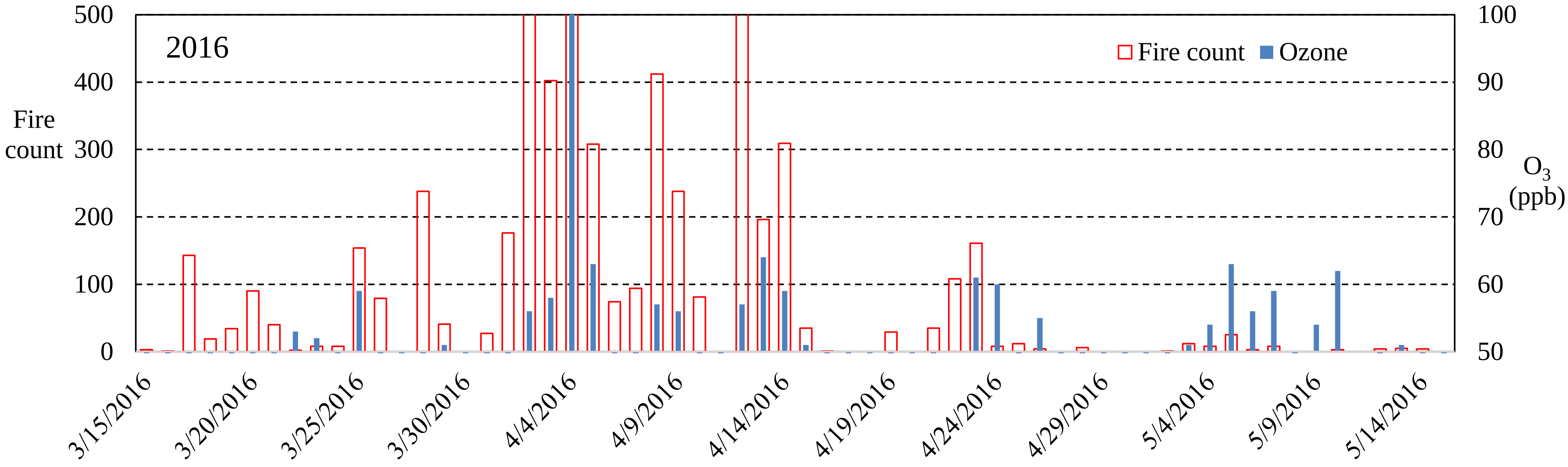


When seasonal burned acres >2.5 million

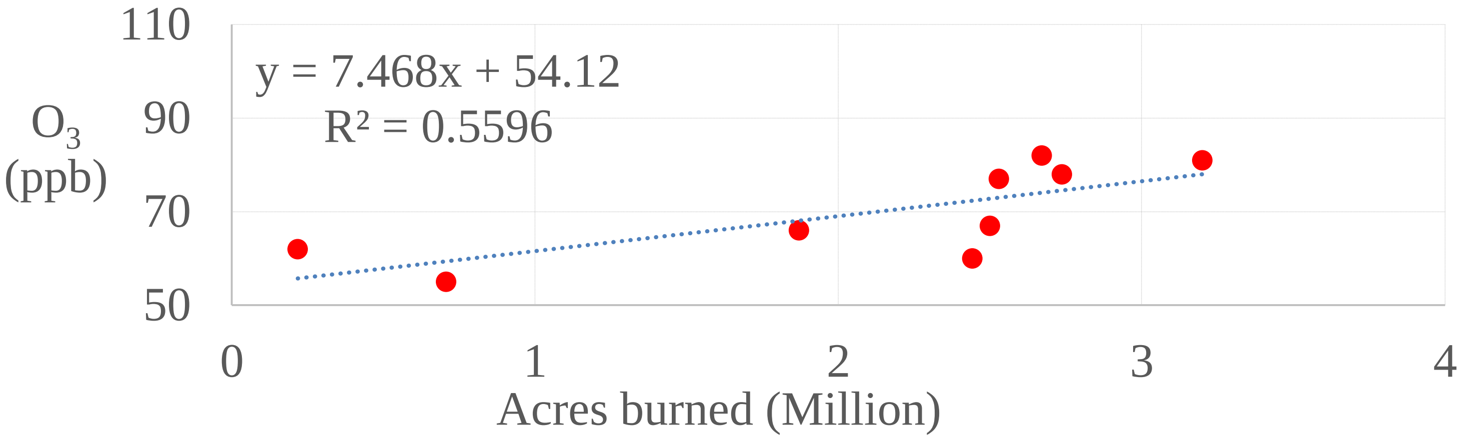




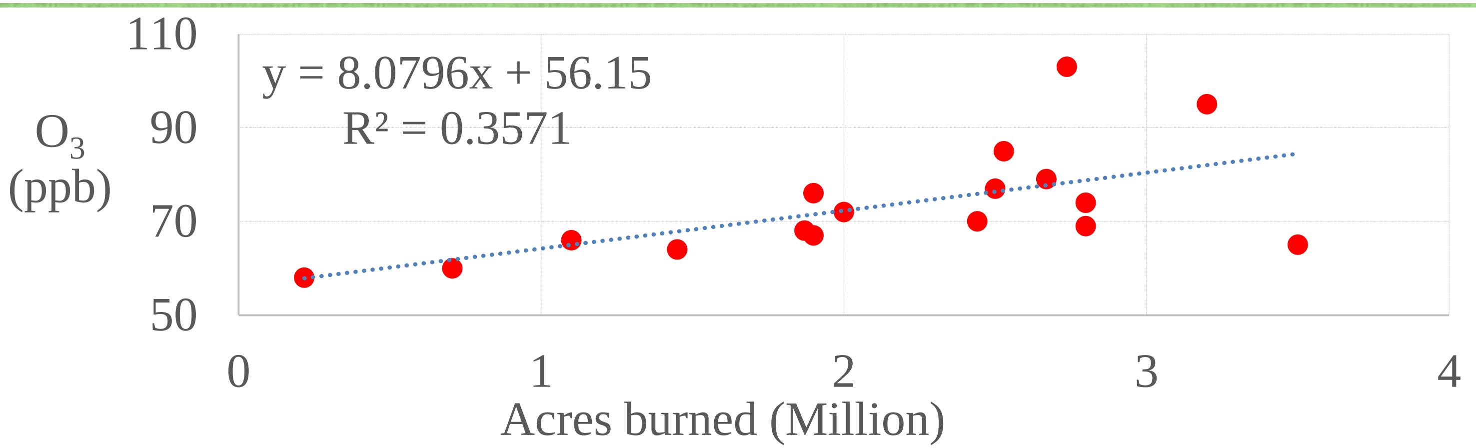
When seasonal burned acres >2.5 million



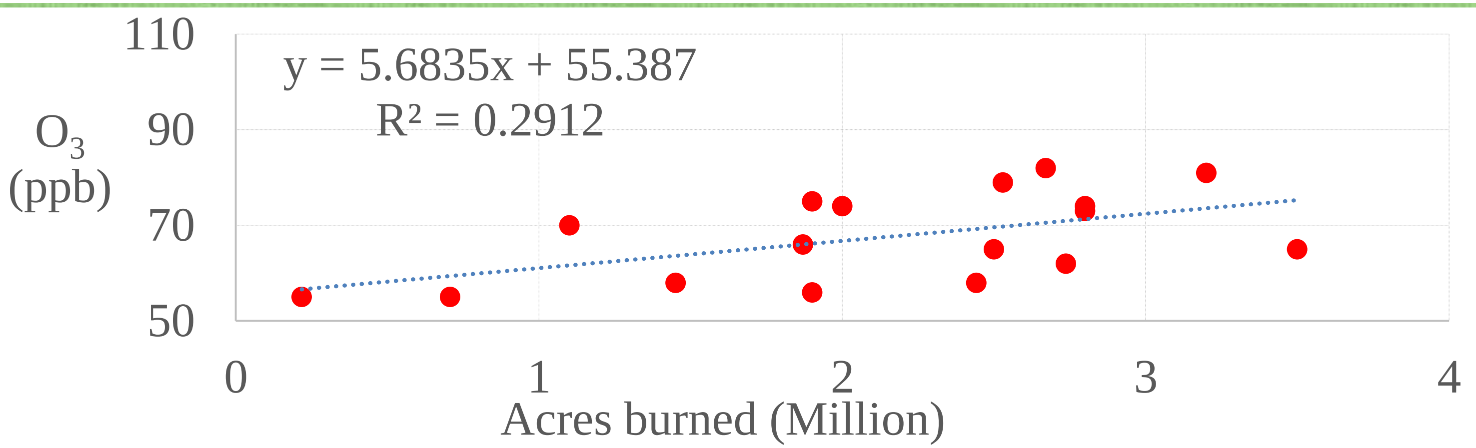
Highest 8hr O_3 in April vs. acres burned at the three sites around Wichita



Sedgwick site (2009-2017)

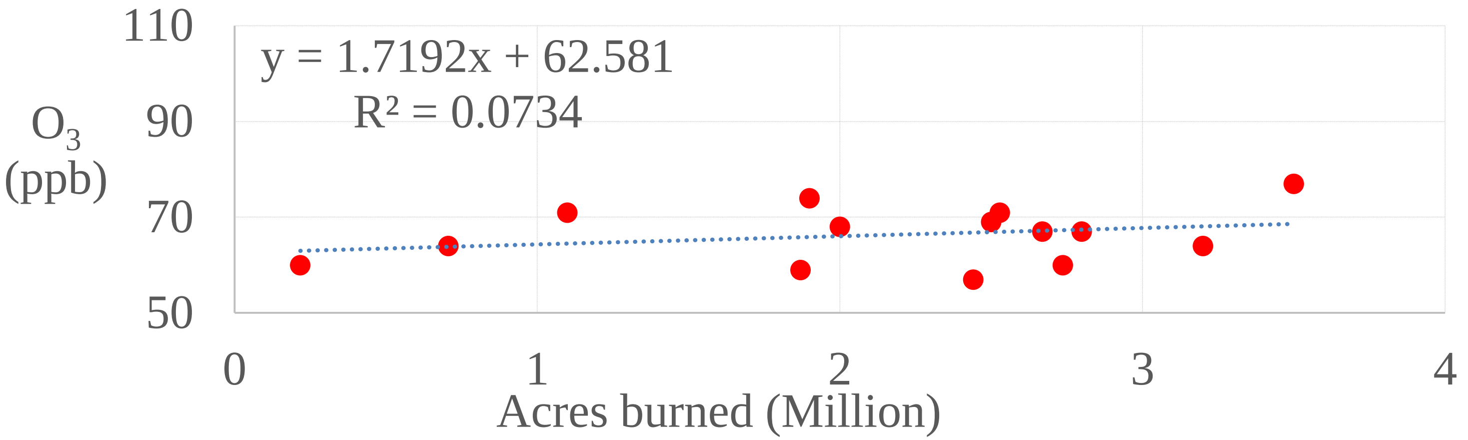


Wichita Health Department site (2001-2017)

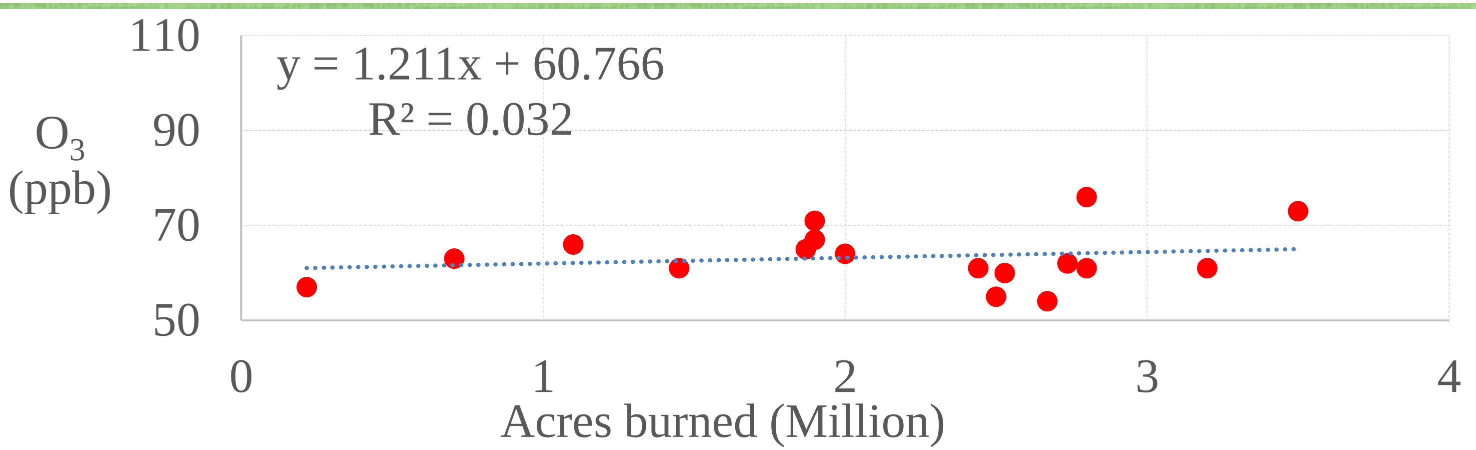


Peck site (2001-2017)

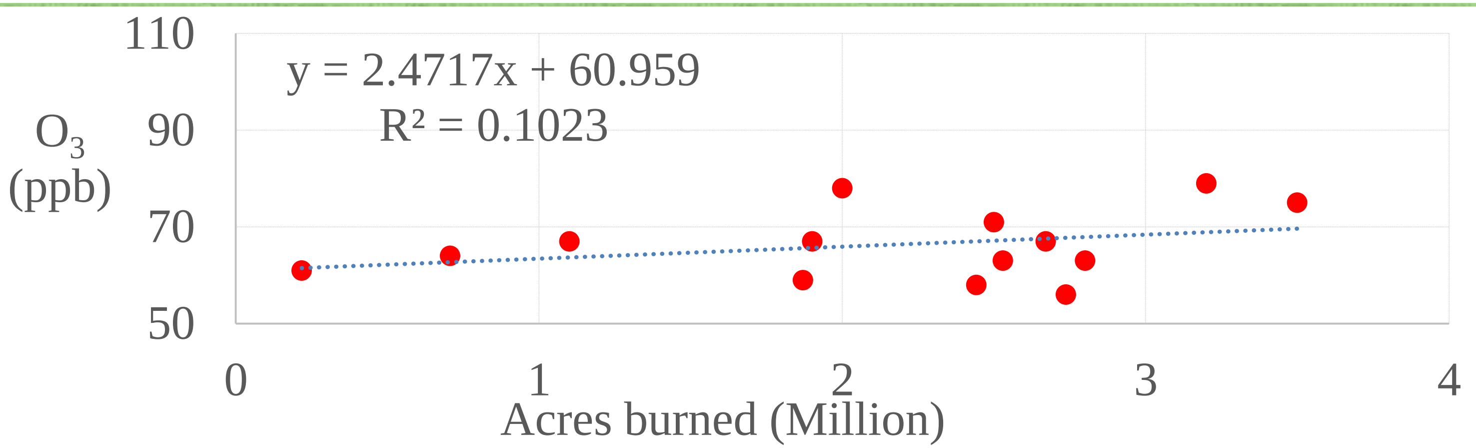
Highest 8hr O_3 in April vs. acres burned at the three sites around Kansas City



Leavenworth site (2004-2017)



Kansas City JFK site (2001-2017)



Heritage Park site (2004-2017)

O_3 levels in April before and after the Flint Hills Smoke Management Plan (SMP) (based on measurements from the nine regulatory monitoring sites in Kansas)

Acres burned (Million)	Before the SMP was implemented			After the SMP was implemented		
	Year	# of days with 8hr O_3>70 ppb	Highest 8hr O_3	Year	# of days with 8hr O_3>70 ppb	Highest 8hr O_3
<1.9	2002 2007	0 1	64 73	2012 2013	0 0	64 62
1.9-2.0	2001 2004 2006	2 2 4	76 74 78	2015	1	77
2.4-2.5	2010	3	82	2014 2017	2 0	85 70
2.7-2.8	2003 2008 2011	2 1 4	76 74 84	2016	1	103
3.2-3.5	2005 2009	3 3	77 95			

Why do we burn?
When is the best time to burn?

Timing of burns

Management objectives

Fire safety

- Forage production
- Plant species composition
- Soil moisture
- Cattle weight gain

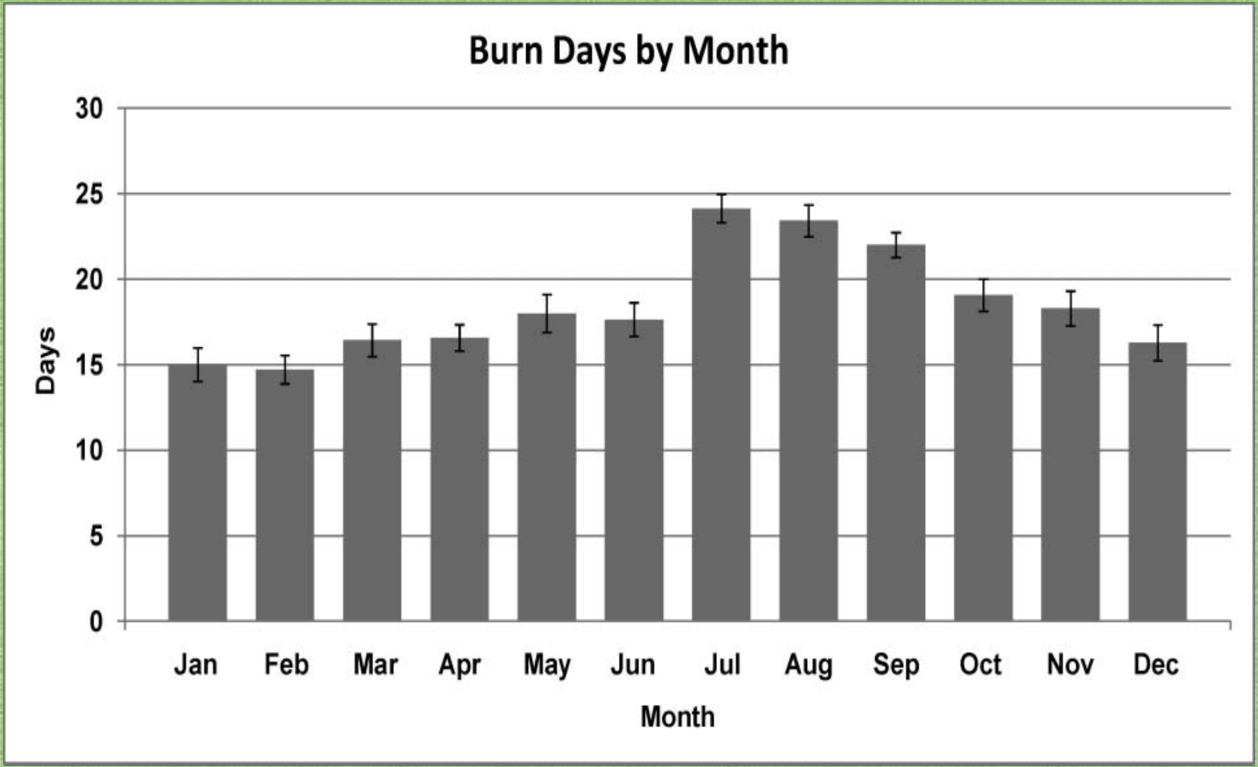
- Relative humidity
- Wind speed
- Wind direction
- Continuous burn window

Does burning have to be restricted to a narrow window in April?

• Forage production	(McMurphy and Anderson, 1963; Owensby and Anderson, 1967); little statistical basis
• Plant composition	Burn earlier in the spring increases cool-season grasses and has little impact on warm-season grasses
• Woody species	No scientific data indicated April burning is superior; frequent burning is most important
• Soil moisture	Much of the data are equivocal
• Animal performance	Only one problematic study (Anderson et al., 1970); potentially misleading

(Towne and Craine, 2016)

How many days are actually available to conduct prescribed burns?



Burn day

- 8am to 6pm
- T=1.7 to 43.3ºC
- RH=25 to 80%
- V=1.07 to 4.02 m/s
- No rain
- 3-hour continuous burn window

Based on Oklahoma Mesonet hourly weather data *(Weir, 2011)*

Burning outside the traditional burn season?

- A 20-year study that looks at the consequences of burning Flint Hills prairie at different times of the year.
- It finds that burning outside of the current late spring time frame has no measurable negative consequences for the prairie and, in fact, may have multiple benefits.

(Towne and Craine, 2014)

Burning outside the traditional burn season?

- Although early studies considered any increase in cool-season grasses as undesirable, that response could actually be beneficial.

  (Towne and Craine, 2016)

- A mix of fire seasons, may be necessary to maintain prairie diversity.

  (USDA, 2009)

- Most land management objectives can be achieved with growing-season burns.

  (Weir et al., 2011)

The goal

- Keep prescribed burning, but burn in a manner that minimize adverse environmental and social effects.

Objectives

- To avoid exceedances of the NAAQS.
- To receive an exemption/flag in the event of an exceedance of the NAAQS (Exceptional Event).

NAAQS: National Ambient Air Quality Standards

Two strategies

Reduce smoke production

- Frequency of burns
- Managing fuel load and fuel moistures
- Ignition and burn technique
- Reduce smoldering

Reduce impact of smoke

- Timing of burns
  - Allow for adequate smoke dispersion
  - Minimize exposure of sensitive populations
  - Avoid high O_3 day

Timing of burns

Smoke modeling tools

Management objectives

Smoke dispersion

Fire safety

Sensitive populations

Avoid high O_3

?

Monitoring smoke using drone

Objectives of the test

- Define sampling packages and standard operating procedures that can be used on unmanned aircraft systems (UAS) for the collection of smoke emission and meteorological data.
- Collect smoke emissions data to develop smoke emission factors that best represent the Flint Hills fires and compare to the current FCCS fuelbed#131 to determine if the current defaults are representative.
- Collect black carbon and thermal image data to ground-verify the models NASA have created from MODIS and VHRRS satellite data.

The sampling packages

Drone: K-State Polytech DJI S1000 multi-rotor (8 rotors) aircraft

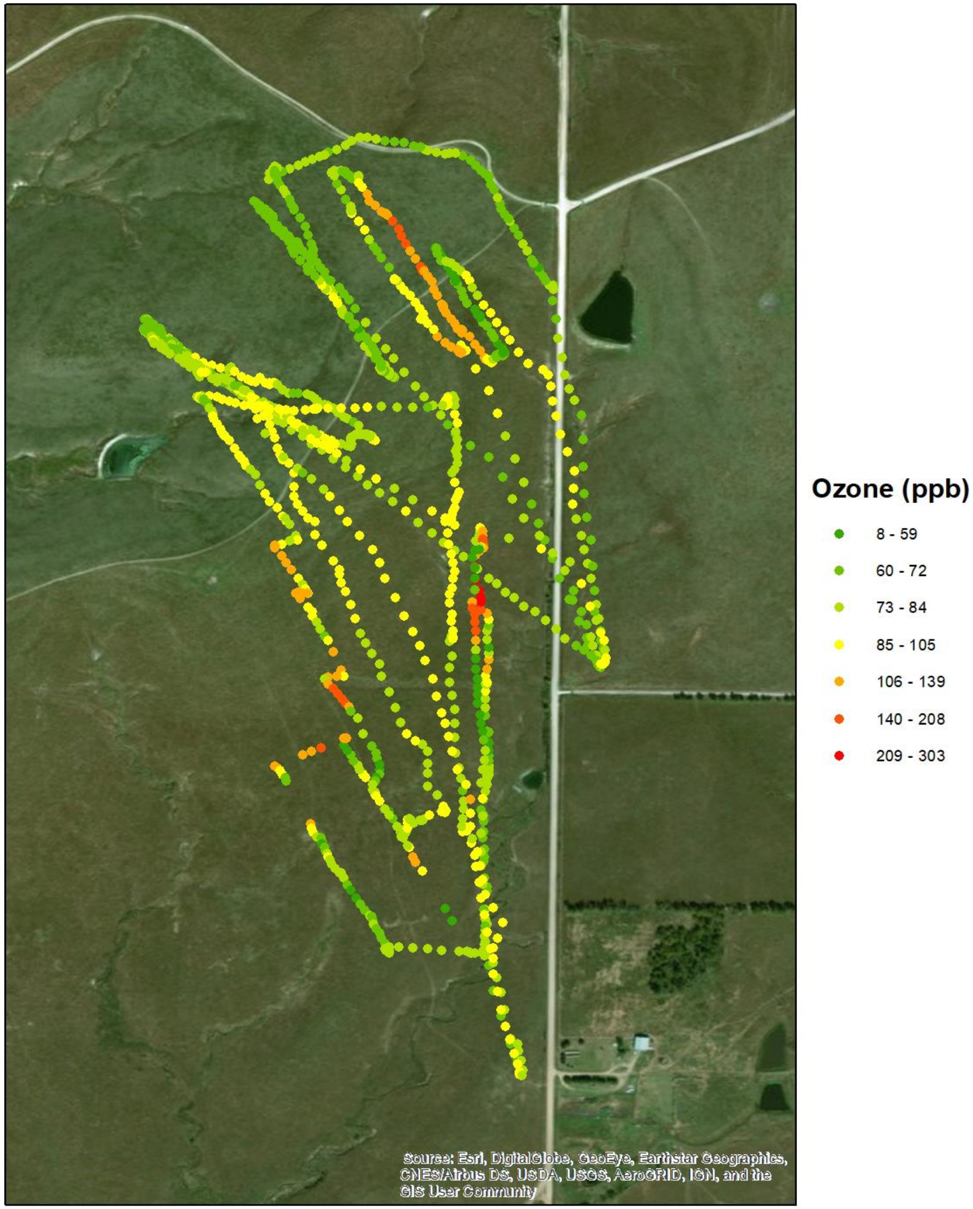
Drone#1: Continuous measurements
O_3: POM, 2B Tech.;
$PM_{2.5}$: MIE pDR-1500, Thermo Sci.

Drone#2: Integrated measurements
Sampling bags for $NO/NO_x/NO_2$, CO/CO_2, and VOCs
PM: Air-O-Cell impactor

Drone#3: MA200 black carbon monitor; Thermal sensor

Around 180 acres burned for the test
on April 16, 2018

April 16, 2018



Preliminary results