Developing strategies for smoke management under new US ozone and PM standards

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Rangeland burning smoke management and air quality workshop
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K·STATE Research and Extension | Biological and Agricultural Engineering

Knowledge for Life

The goal

- Keep pasture burning, maintain the Flint Hills ecosystem and related economy.
- Burn in a manner that minimize adverse environmental and social effects.

(Photo credit: Judy Crowell)

Specific objectives

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

NAAQS: National Ambient Air Quality Standards

Consequences of nonattainment

- State Implementation Plan (SIP) preparation
  - enhanced emissions inventory ($)
  - photochemical modeling ($)
  - planning ($)
- Transportation conformity. Potential for loss of highway funds and restrictions on how highway funds can be spent ($)
- Economic development curtailed ($)

One opportunity to receive an exemption

2007 Exceptional Events Rule (EER): Monitoring data can be excluded from non-attainment designations if exceedance is due to an Exceptional Event (EE).

- Natural events
- High wind events
- Natural disasters and associated clean-up activities
- Stratospheric ozone intrusion
- Volcanic & seismic activities
- Wildland fires

Could prescribed burning be qualified as Exceptional Events (EE)?

EPA approval of exceedances for prescribed fires used for resource management purposes is contingent upon

- Basic smoke management practices (BSMP) are being employed, or
- The state having a Smoke Management Program (SMP).

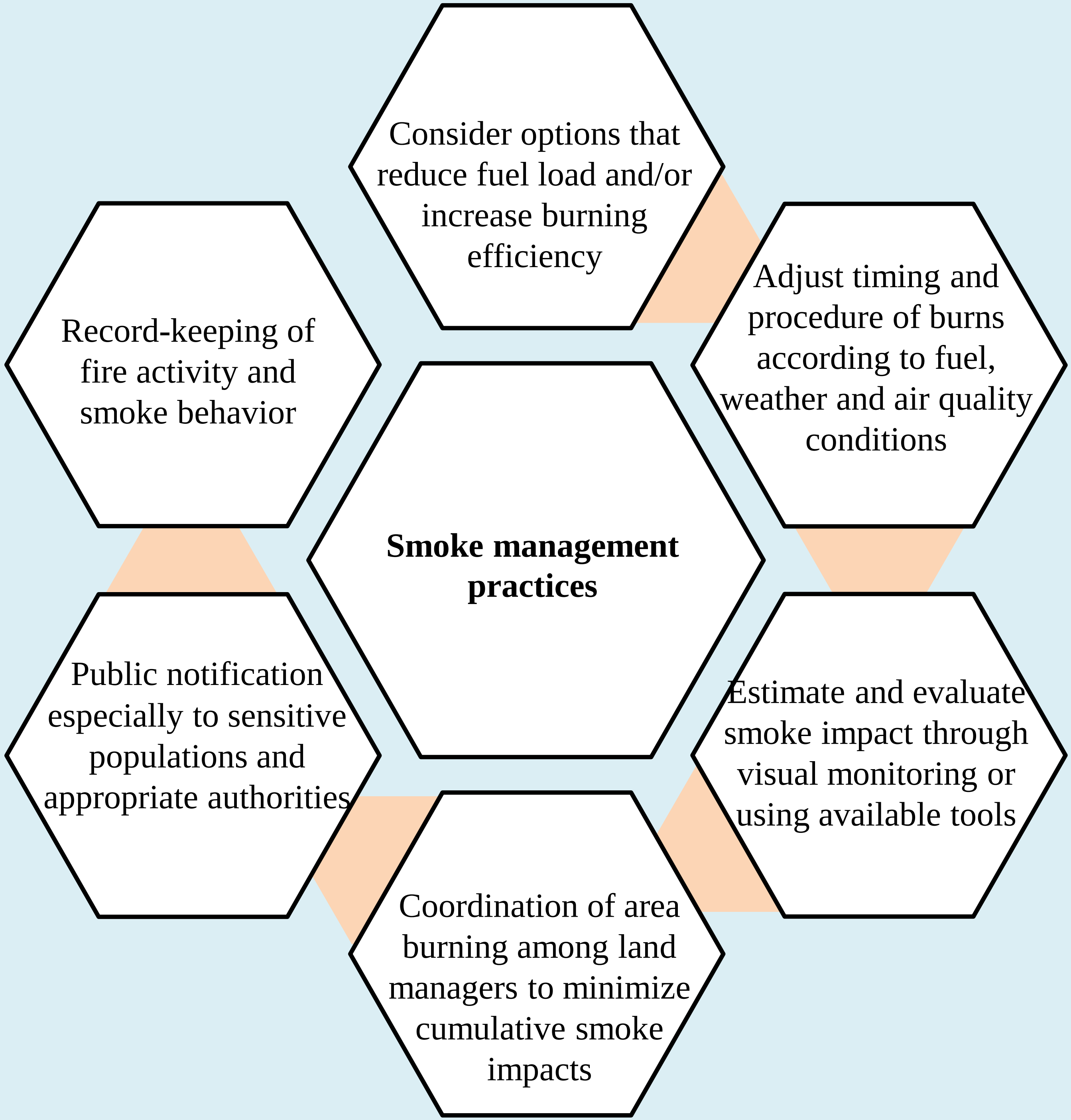
Documentation is Key!

- In order to be considered for EE, technical evidence must be submitted to EPA as a demonstration package, which must include analyses showing that no NAAQS exceedance would have occurred "but for" the EE.

- A quantitative assessment of air quality with and without fire is required, which is a difficult task, especially for O_3.

Basic smoke management practices (BSMP) in the EER

- Steps that will **minimize air pollutant emissions** during and after the burn,
- Evaluate dispersion conditions to **minimize exposure** of sensitive populations,
- Actions to **notify populations and authorities** at sensitive receptors and contingency actions during the fire to reduce exposure of people at such receptors,
- Identify steps taken to **monitor the effects** of the fire on air quality, and
- **Identify procedures** to ensure that burners are using basic smoke management practices.


Smoke management practices
Consider options that reduce fuel load and/or increase burning efficiency
Adjust timing and procedure of burns according to fuel, weather and air quality conditions
Estimate and evaluate smoke impact through visual monitoring or using available tools
Coordination of area burning among land managers to minimize cumulative smoke impacts
Public notification especially to sensitive populations and appropriate authorities
Record-keeping of fire activity and smoke behavior

Flint Hills smoke management plan (SMP)

- Recommended practices to reduce the air quality impacts of prescribed range burning, and tools (website) to assist land managers and local fire officials in making burning decisions.
  - www.ksfire.org with a modeling tool to predict plume movement and other burn resources
- A data collection pilot program with goal to develop a reporting system.
  - Use of a burn checklist

History of the Flint Hills SMP

2003 episode: KDHE and agricultural interests took an initial voluntary educational approach to address the air quality issue.

2009 episode: EPA denied KDHE's request to flag 2009 O_3 exceedance data due to lack of SMP

2010 episode: Formal Flint Hills Advisory Committee was formed; A subcommittee was tasked to write SMP; KDHE adopts SMP in late December 2010; Implementation of the plan is proceeding.

2011 episode: Exceptional event was granted for exceedance of NAAQS

Minimize smoke production

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

Not all smoke is equal

Reduce impact of smoke

- Timing of burns
  - To allow for adequate smoke dispersion
  - To avoid current or forecasted poor air quality conditions

Same smoke, but less impact

Recommended weather conditions for burning in the SMP

<table>
<tr><td>Relative humidity: 30-55%</td><td>Reduced smoke production</td></tr>
<tr><td>Mixing height: >1,800feet (548m)</td><td rowspan="3">Adequate smoke dispersion</td></tr>
<tr><td>Transport winds: 8-20 mph (3.6-8.9m/s)</td></tr>
<tr><td>Preferred start/stop times: 10 am to 6 pm</td></tr>
<tr><td>Cloud cover: 30 to 50%</td><td>Reduced ozone production</td></tr>
</table>

2001-2016

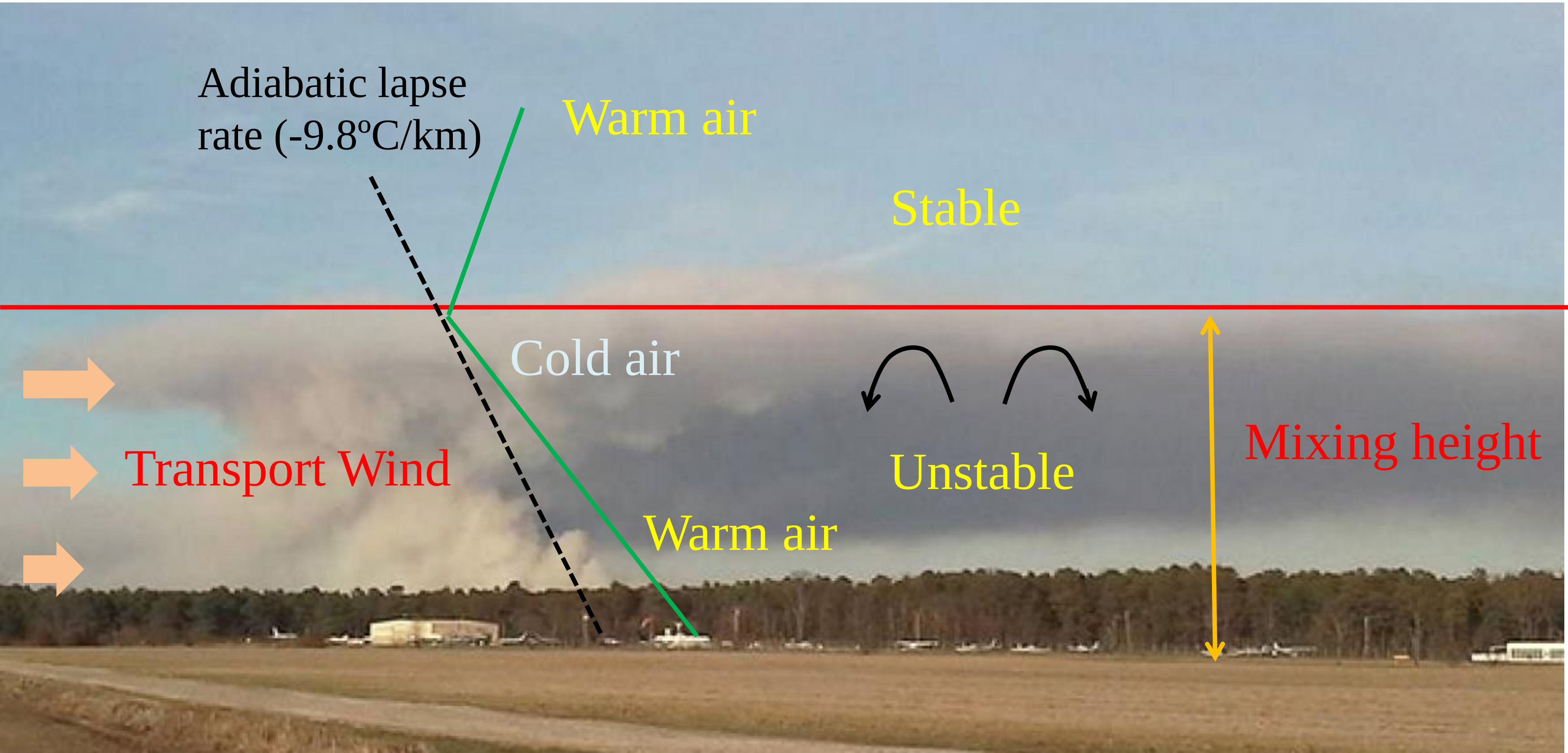
	Average of days with O_3>70ppb in April (47 days in total)	April average
Daily Max 8hr O_3	77±5 ppb	43.9-53.2 ppb
O_3 on the previous day	60±11 ppb	-
Daily maximum air temperature	24.5±4.5 ºC	20.7±5.5 ºC
T_{max}-T_{min}	16.6±5.3 ºC	12.3±5.0 ºC
Solar radiation	738±279 Langley	607±304 Langley
Relative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

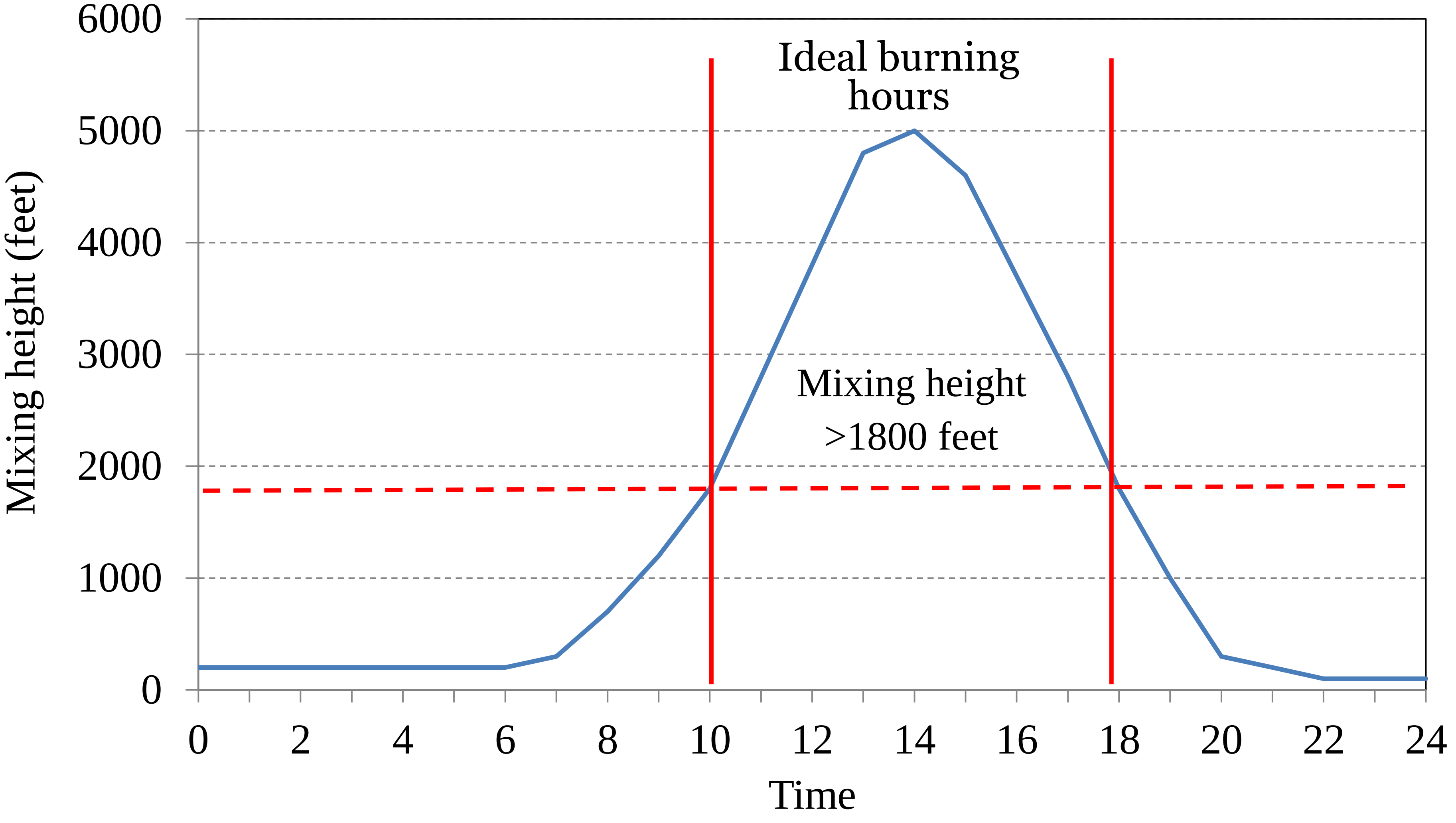
Mixing height

The height above the ground through which the air is under turbulent mixing. The height at which smoke stops rising.

Transport Wind

The average wind speed throughout the depth of the mixed layer.




6000
5000
4000
3000
2000
1000
0
Mixing height (feet)
Ideal burning hours
Mixing height
>1800 feet
0
2
4
6
8
10
12
14
16
18
20
22
24
Time

The National Weather Service (NWS) offer forecasts of **mixing height** and **transport winds** in their fire weather forecasts.

Topeka:
http://www.weather.gov/forecasts/wfo/sectors/topFireDay.php

Wichita:
http://www.weather.gov/forecasts/wfo/sectors/ictFireDay.php

Smoke screening

- Avoid unfavorable wind directions.
- Avoid current or forecasted poor air quality conditions. Especially, avoid high O_3 day.

↓

Smoke modeling

Types of air quality modeling

- Dispersion modeling
  - Simulate physical transportation
  - Does not work for O_3
- Photochemical modeling
  - Simulate both chemical and physical processes
  - May work for O_3
- Receptor modeling

Dispersion modeling tool on www.ksfire.org

- Where your individual plume will go?
- Maximum contribution to major cities based on cumulative impact from fires that could be ignited within 48 hours

Kansas Flint Hills
SMOKE MANAGEMENT

Smoke Management

Kansas Flint Hills Smoke Management

www.ksfire.org

Kansas Flint Hills Smoke Management
1000 SW Jackson
Suite 310
Topeka, KS 66612-1366

(785) 296-1551

Contact us

Kansas Flint Hills Smoke Management

Welcome to the Kansas Flint Hills Smoke Management Website. This site provides a single location for land managers conducting prescribed burns in the Flint Hills to obtain information and access tools to assist them in making burn decisions.

This website supports the Flint Hills Smoke Management Plan, which was developed in an attempt to balance the need for prescribed fire in the Flint Hills with the need for clean air in downwind communities.

At A Glance

2016 Air Quality Health Advisory Alert

2015 Flint Hills Acres Burned

April Burning Restrictions (Regulations)

April Burning Restrictions (FAQ)

Kansas Smoke Management Plan - KDHE

Fire Management Practices to Improve Air Quality (PDF)

County Burn Permit Information

Current Burn Bans- Contact your local Emergency Manager

Fire Management Practices to Reduce the Impacts of Smoke (PDF)

About | Cumulative Fire Impacts | Your Fire Impacts

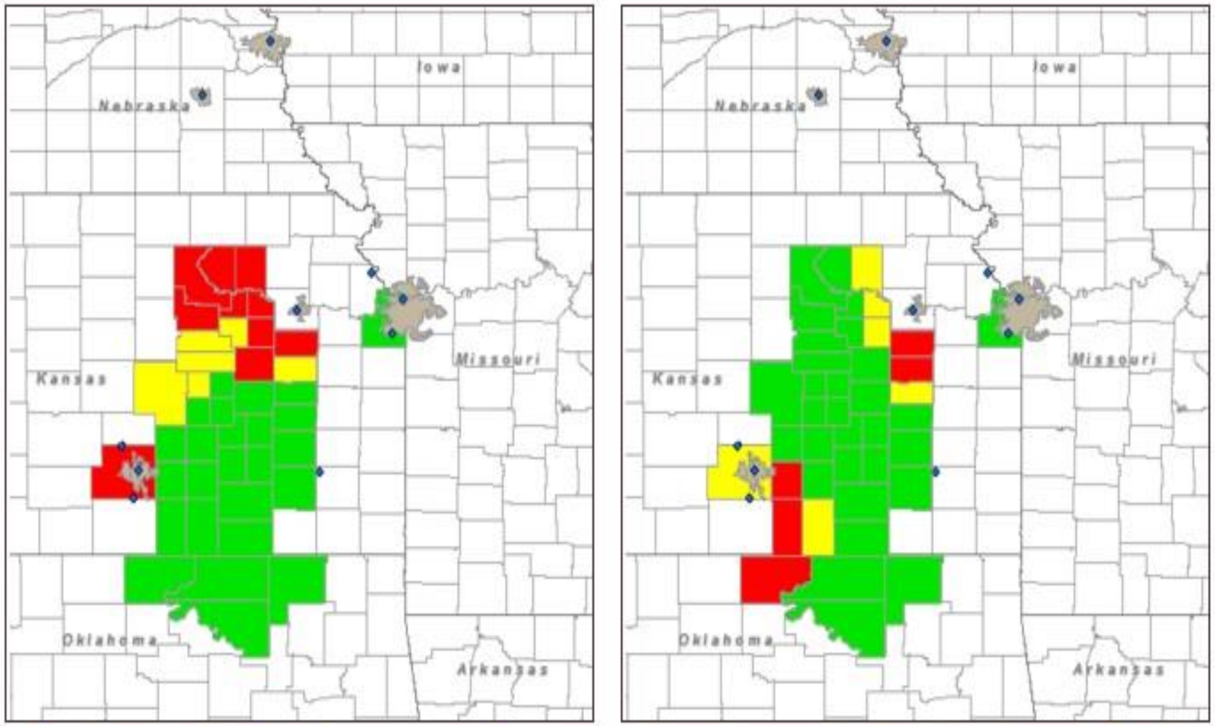
Fire impact predictions only available from March 1, 2016 through May 1, 2016.
Forecasts are updated daily at 1:00 p.m. CDT.

View as: **Map** | Table

Potential Contribution to Major Cities for Fires Ignited On

March 27, 2016 | **March 28, 2016**

Maximum Contribution Potential within 48 hours



Small Contribution · Medium Contribution · Large Contribution · Data Unavailable · Metropolitan Area · Monitor

Forecast Discussion

Sunday, March 27: As surface high pressure moves across Kansas, northwesterly winds will weaken and gradually shift to southwesterly, reducing smoke dispersion and transporting smoke from potential fires in the northern Flint Hills into Topeka and Kansas City. In addition, smoke from potential fires in the western portion of Sedgwick County will be carried into Wichita.

Monday, March 28: Moderate southerly winds will transport smoke from potential fires in the eastern Flint Hills into Topeka. Furthermore, smoke from potential fires in the northern Flint Hills will be carried into Lincoln and Omaha, and smoke from fires in the southwestern Flint Hills will be transported into Wichita.

Extended Forecast

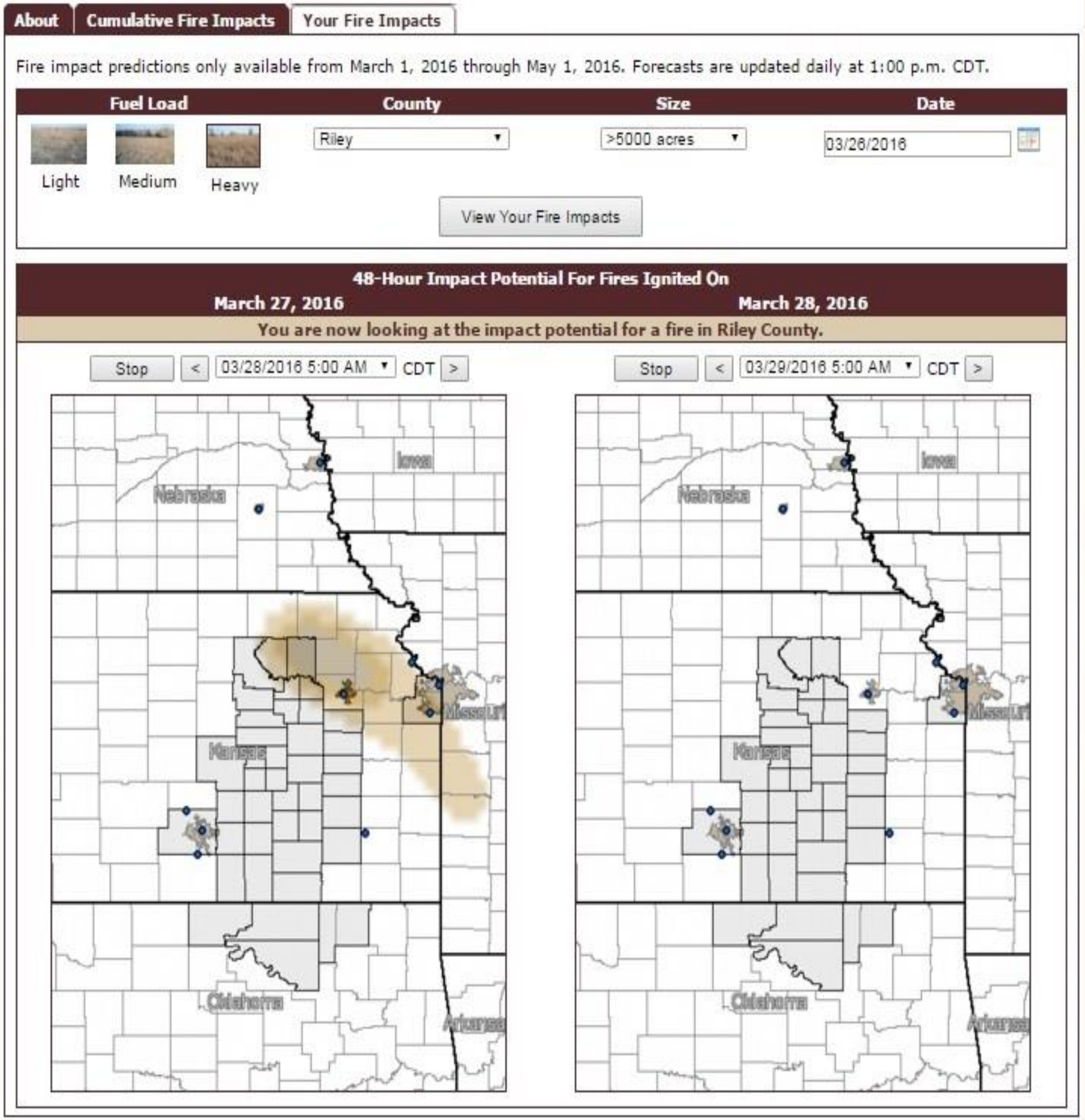
This forecast is for air quality impacts only.

March 29, 2016: Worsening conditions for burning are expected.
March 30, 2016: Improving conditions for burning are expected.
March 31, 2016: Improving conditions for burning are expected.
April 1, 2016: Worsening conditions for burning are expected.

Model 1
Cumulative impact

Estimate maximum contribution by county to major cities based on cumulative impact from fires that could be ignited within the next 48 hours

Forecast discussion



Model 2
Individual plume

Provide hourly individual plume movement and concentration to assess a burn

Photochemical modeling

Input of emission and meteorological data are typically specified at hourly intervals for each computational cell in the modeling domain.

Advanced smoke modeling need accurate smoke emission data

$$\text{Emissions} = A \times FL \times \beta \times EF$$

- A is burned area, ha;
- FL is fuel load, kg DM/ha;
- β is burn efficiency (fraction of biomass consumed), %;
- EF is emission factor, g/kg DM.

Existing emission factors
(Reliability and accuracy are not satisfying)

The amount of a smoke component generated per unit mass of fuel burned.

Air pollutants	Emission factor
$PM_{2.5}$	5 - 9 g/kg DM
NO_x	2 - 4 g/kg DM
VOCs	Up to 1.4 g/kg DM

(Ward, 1990; Andreae and Merlet, 2001; Butler and Mulholland, 2004; Urbanski et al., 2009)

$PM_{2.5}$ emission
Prescribed burn vs. cars

~28 kg $PM_{2.5}$

Burned area: 1 ha

Assuming 4000 kg DM/ha fuel load.

≈

~28 kg $PM_{2.5}$

4,000,000 car miles

Based on $PM_{2.5}$ emission factor for 2014 model gasoline passenger cars: 0.007g/mile (Cai et al., 2013)

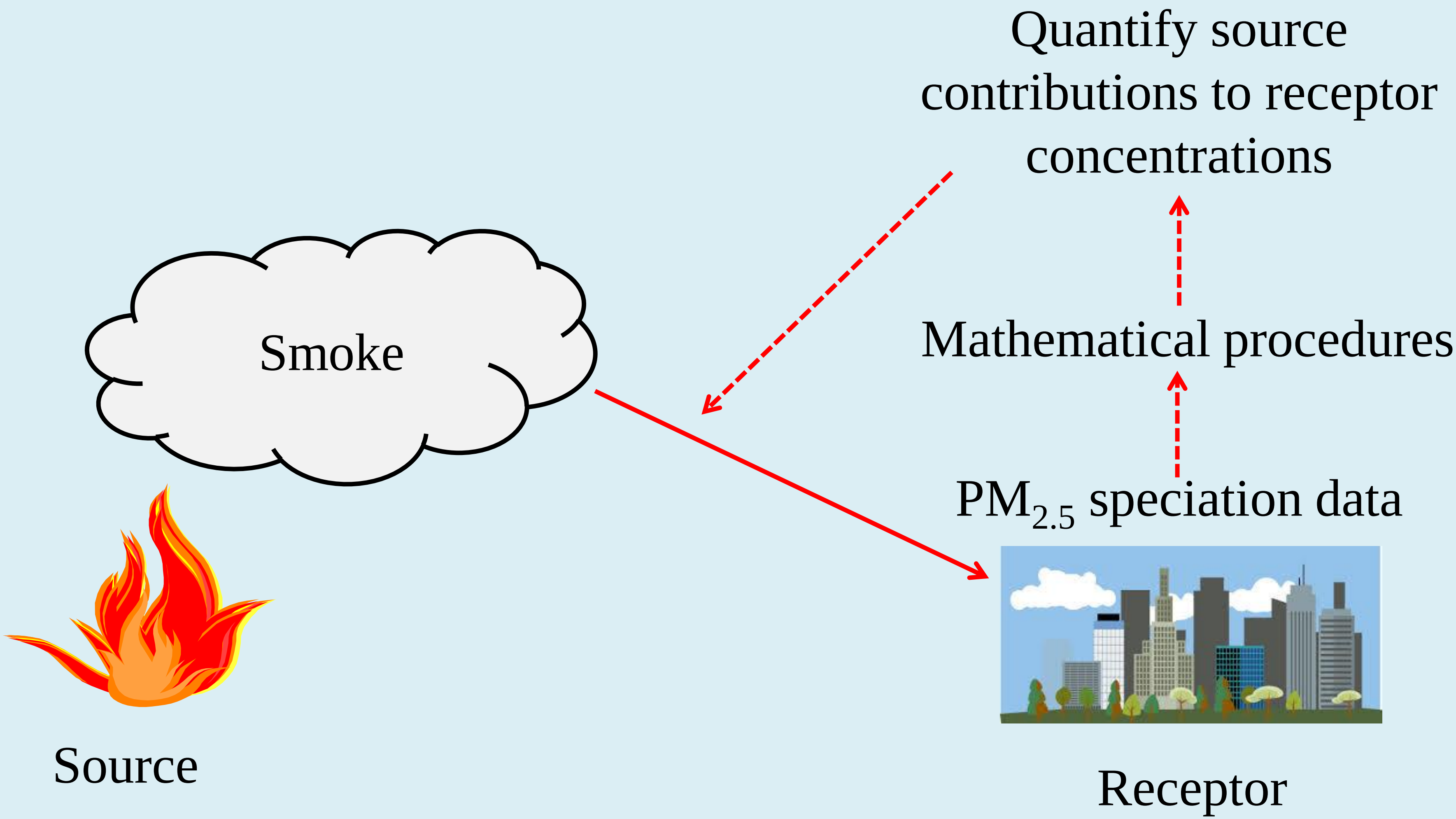
Obtaining reliable emission factors

- Lab measurement: smoke chamber
  - May not represent the real field situation

- Field measurement:
  - Dynamic environment
  - Use drone or aircraft, or ground-based
  - Fresh smoke and aged smoke
  - Continuous and integrated measurement

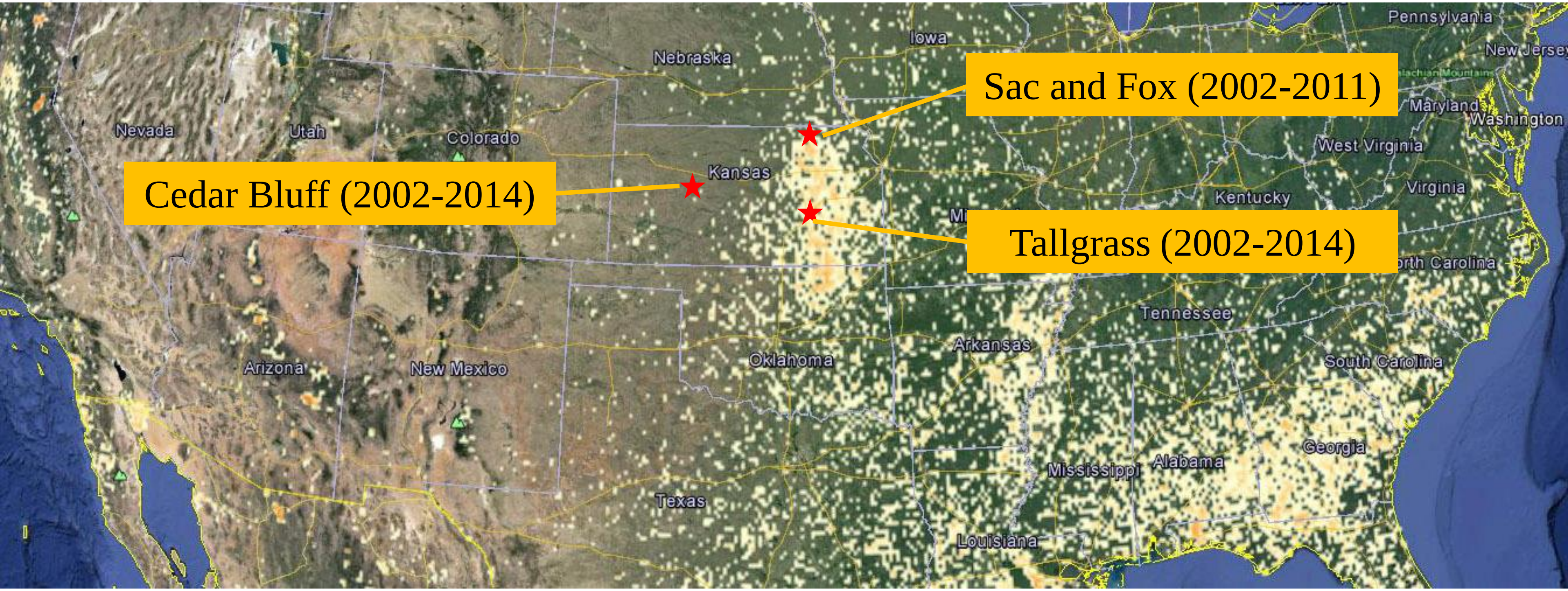
$PM_{2.5}$, O_3, VOC, NO_x, CO, CO_2, OC/EC ...

Receptor modeling



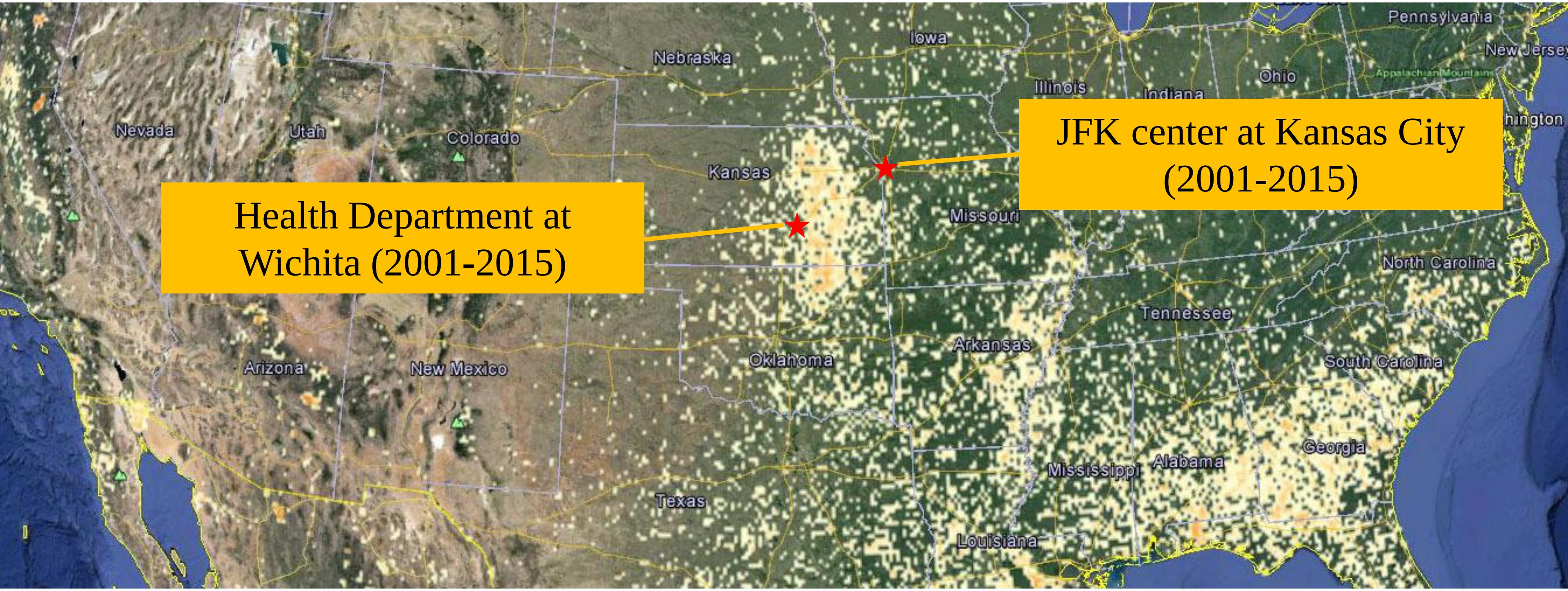
Three IMPROVE sites that provide $PM_{2.5}$ speciation data

<u>IMPROVE: Interagency Monitoring of Protected Visual Environments</u>

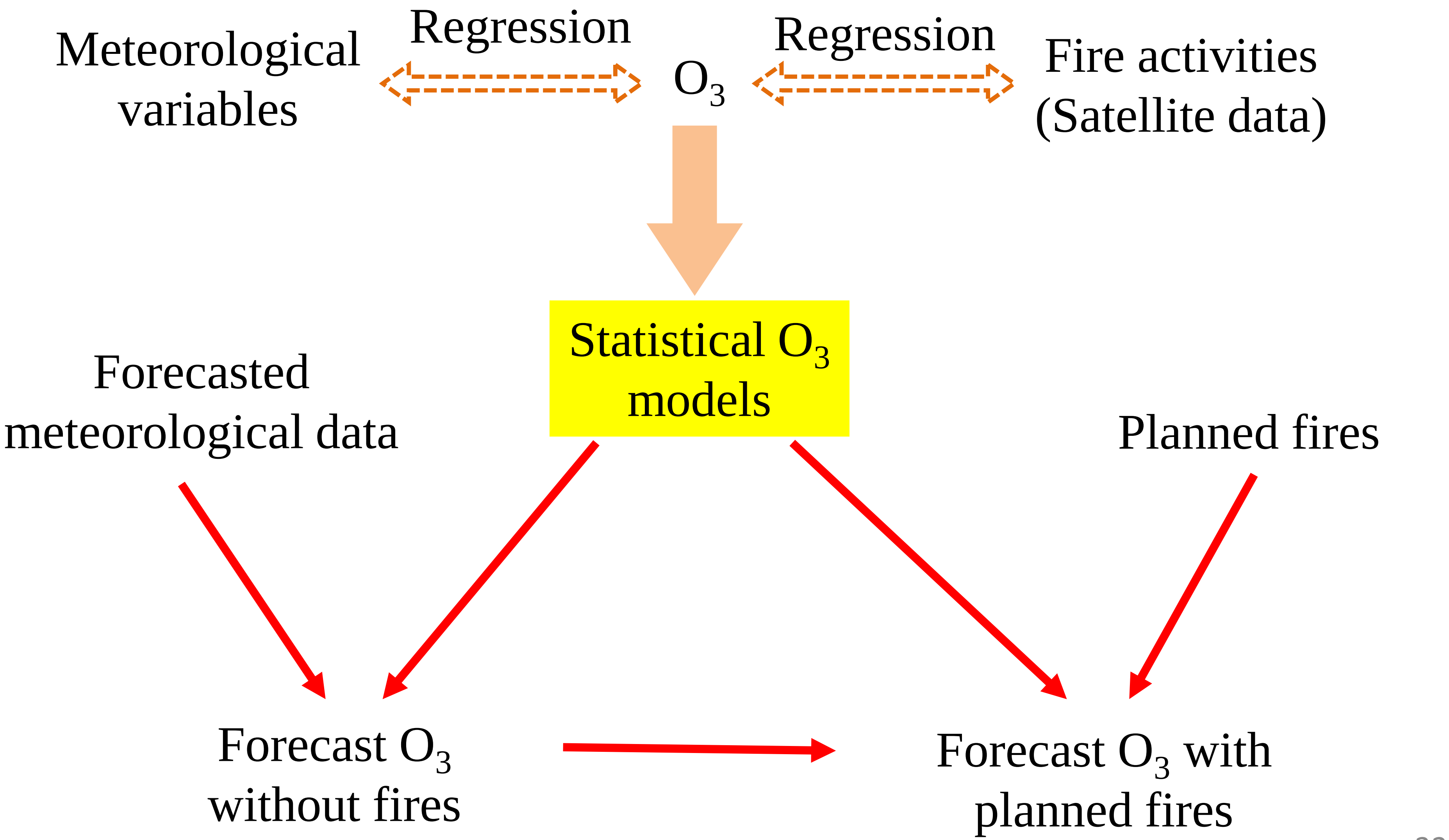


Two CSN sites that provide $PM_{2.5}$ speciation data

CSN: Chemical Speciation Network



Statistical modeling



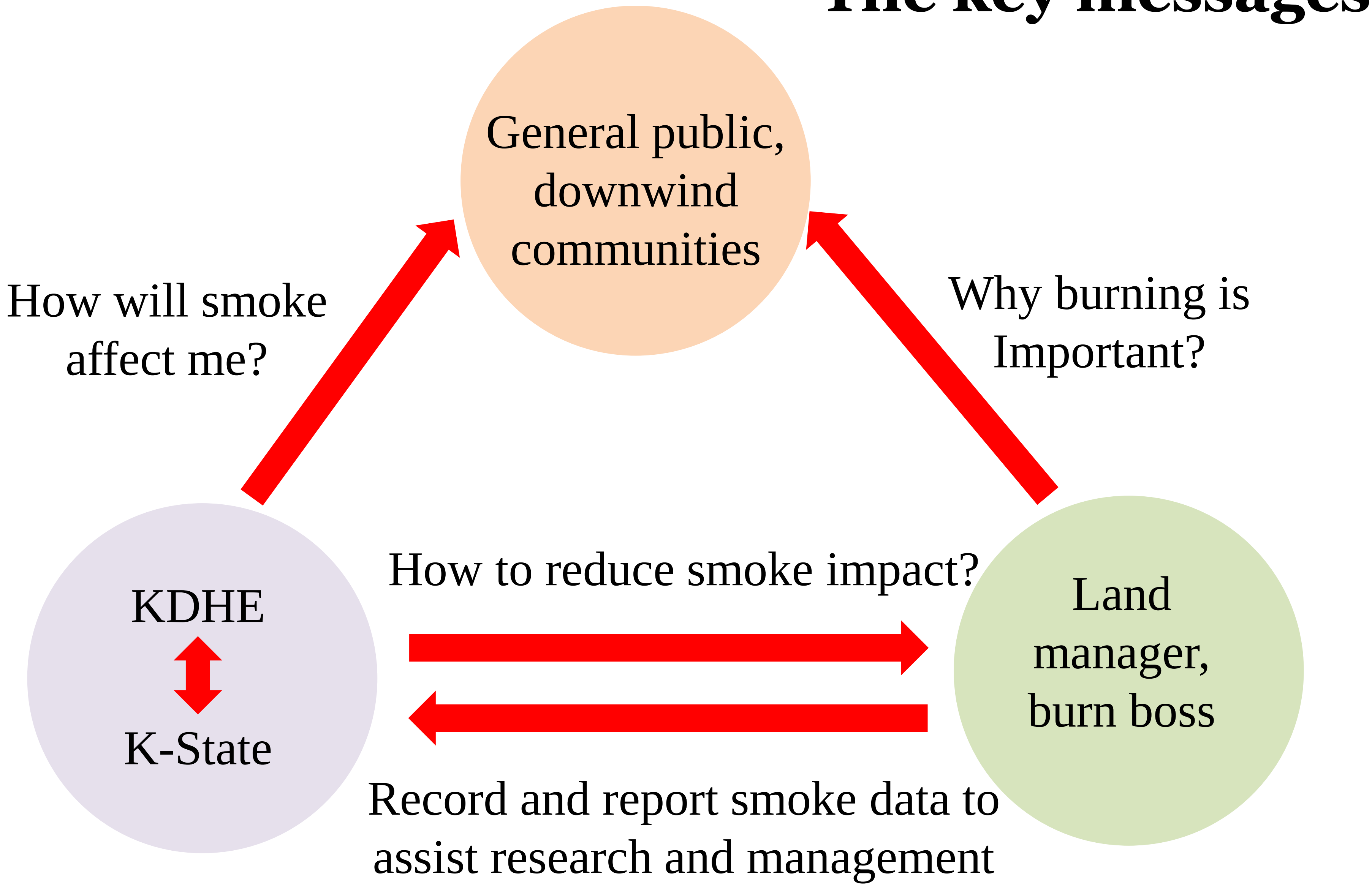
Simulate O_3 with and without fire input at the Konza Praire site (non-rainy days in April)

	R^2	Average model residual
Model without input from fire activities $O_3(d) = 30.5 + 4.75\sin\left(\frac{2\pi(d+284)}{365}\right) + 0.47O_3(d)_0 + 0.17T_{max} + 0.13(T_{max} - T_{min}) - 15.6RH - 0.57V$	0.71	3.1 ppb
Model with input from S2 and S5 $O_3(d) = 34.7 + 5.57\sin\left(\frac{2\pi(d+284)}{365}\right) + 0.36O_3(d)_0 + 0.11T_{max} + 0.22(T_{max} - T_{min}) - 17.4RH - 0.61V + 0.30S2 + 0.27S5 + 0.097S2 \times S5$	0.73	0.9 ppb

Improving statistical O_3 models

- Use more relevant meteorological data
  - Add air stability/mixing height, vapor pressure instead of RH, …
- Use more advanced statistical methods
  - Machine learning with random forest algorithm, …
- Use high quality/resolution fire data
  - Daily burn area rather than seasonal or monthly composites
- Stratify data by seasons or meteorological variables, such as wind direction to improve regression performance

The key messages



Summary of tools/resources for smoke management

- The smoke modeling tool on www.ksfire.org for smoke screening
- Recommended weather conditions for burning in the SMP
- Fire weather forecasts provided by www.weather.gov/forecasts
- Air quality information provided by KDHE and NOAA websites
- Data collection pilot program and the Fire Management Practice Checklist
- FIRMS web fire mapper at https://firms.modaps.eosdis.nasa.gov/firemap/