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

Dr. Zifei Liu
zifeiliu@ksu.edu

Rangeland burning smoke management and air quality workshop
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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.
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

Smoke management practices
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 O₃ 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
<table>
<thead>
<tr>
<th>Recommended weather conditions for burning in the SMP</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative humidity: 30-55%</td>
<td>Reduced smoke production</td>
</tr>
<tr>
<td>Mixing height: &gt;1,800 feet (548m)</td>
<td>Adequate smoke dispersion</td>
</tr>
<tr>
<td>Transport winds: 8-20 mph (3.6-8.9m/s)</td>
<td></td>
</tr>
<tr>
<td>Preferred start/stop times: 10 am to 6 pm</td>
<td></td>
</tr>
<tr>
<td>Cloud cover: 30 to 50%</td>
<td>Reduced ozone production</td>
</tr>
<tr>
<td></td>
<td>Average of days with $O_3 &gt; 70$ ppb in April (47 days in total)</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>---------------------------------------------------------------</td>
</tr>
<tr>
<td>Daily Max 8hr $O_3$</td>
<td>$77\pm 5$ ppb</td>
</tr>
<tr>
<td>$O_3$ on the previous day</td>
<td>$60\pm 11$ ppb</td>
</tr>
<tr>
<td>Daily maximum air temperature</td>
<td>$24.5\pm 4.5$ °C</td>
</tr>
<tr>
<td>$T_{\text{max}}-T_{\text{min}}$</td>
<td>$16.6\pm 5.3$ °C</td>
</tr>
<tr>
<td>Solar radiation</td>
<td>$738\pm 279$ Langley</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>$54\pm 10$ %</td>
</tr>
<tr>
<td>Wind speed</td>
<td>$3.4\pm 1.8$ m/s</td>
</tr>
<tr>
<td>$O_3$ model residuals</td>
<td>$21\pm 9$ ppb</td>
</tr>
</tbody>
</table>
**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.
Mixing height (feet)

Time

Ideal burning hours

Mixing height >1800 feet
The National Weather Service (NWS) offer forecasts of **mixing height** and **transport winds** in their fire weather forecasts.

**Topeka:**


**Wichita:**

Smoke screening

• Avoid unfavorable wind directions.

• Avoid current or forecasted poor air quality conditions. Especially, avoid high O₃ day.
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
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.
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.
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

Emissions = A \times FL \times \beta \times EF

- A is burned area, ha;
- FL is fuel load, kg DM/ha;
- \beta 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.

<table>
<thead>
<tr>
<th>Air pollutants</th>
<th>Emission factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM$_{2.5}$</td>
<td>5 - 9 g/kg DM</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>2 - 4 g/kg DM</td>
</tr>
<tr>
<td>VOCs</td>
<td>Up to 1.4 g/kg DM</td>
</tr>
</tbody>
</table>

(Ward, 1990; Andreae and Merlet, 2001; Butler and Mulholland, 2004; Urbanski et al., 2009)
**PM$_{2.5}$ emission**

**Prescribed burn vs. cars**

\[ \text{Burned area: 1 ha} \]

Assuming 4000 kg DM/ha fuel load.

\[ \approx 28 \text{ kg PM}_2.5 \]

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

\[ 4,000,000 \text{ car miles} \]
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

\[ PM_{2.5}, O_3, VOC, NO_x, CO, CO_2, OC/EC \ldots \]
Receptor modeling

Quantify source contributions to receptor concentrations

Mathematical procedures

PM$_{2.5}$ speciation data

Receptor

Source

Smoke
Three IMPROVE sites that provide PM$_{2.5}$ speciation data

IMPROVE: Interagency Monitoring of Protected Visual Environments

- Cedar Bluff (2002-2014)
- Sac and Fox (2002-2011)
- Tallgrass (2002-2014)
Two CSN sites that provide PM$_{2.5}$ speciation data

CSN: Chemical Speciation Network

Health Department at Wichita (2001-2015)

JFK center at Kansas City (2001-2015)
Statistical modeling

Meteorological variables

Regression

O₃

Regression

Fire activities (Satellite data)

Forecasted meteorological data

Statistical O₃ models

Forecast O₃ without fires

Planned fires

Forecast O₃ with planned fires
Simulate $O_3$ with and without fire input at the Konza Prairie site (non-rainy days in April)

<table>
<thead>
<tr>
<th>Model without input from fire activities</th>
<th>$R^2$</th>
<th>Average model residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_3(d) = 30.5 + 4.75 \sin \left( \frac{2\pi(d+284)}{365} \right) + 0.47O_3(d)<em>0 + 0.17T</em>{max} + 0.13(T_{max} - T_{min}) - 15.6RH - 0.57V$</td>
<td>0.71</td>
<td>3.1 ppb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model with input from S2 and S5</th>
<th>$R^2$</th>
<th>Average model residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_3(d) = 34.7 + 5.57 \sin \left( \frac{2\pi(d+284)}{365} \right) + 0.36O_3(d)<em>0 + 0.11T</em>{max} + 0.22(T_{max} - T_{min}) - 17.4RH - 0.61V + 0.30S2 + 0.27S5 + 0.097S2 \times S5$</td>
<td>0.73</td>
<td>0.9 ppb</td>
</tr>
</tbody>
</table>
Improving statistical O₃ 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

General public, downwind communities

How will smoke affect me?

Why burning is Important?

How to reduce smoke impact?

Record and report smoke data to assist research and management

KDHE
K-State

Land manager, burn boss
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/